DOES TITAN'S LANDSCAPE BETRAY THE LATE ACQUISITION OF ITS CURRENT ATMOSPHERE?

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Introduction: Titan may have acquired its massive atmosphere relatively recently in solar system history. The sudden appearance of a thick atmosphere may have changed Titan's global topography. This change in global topography may be expressed in the latitudinal distribution of landform types across its surface.

Hypotheses: Hypotheses have been suggested for supplying Titan's methane-rich atmosphere that do not rely on cryovolcanic replenishment. It has been argued that there have been no conclusively identified volcanic features seen on Titan [1], consistent with these theories. The warming sun may have been key to generating Titan's atmosphere over time [2,3,4,5,6]. For instance Titan may have experienced a long Triton-like phase, where Titan's surface was covered by methane and possibly nitrogen ices. Alternatively nitrogen may have been collapsed out of Titan's early atmosphere because ancient methane was photochemically destroyed at a rate faster than it could be supplied to the atmosphere [3]. The surface would have gradually warmed, perhaps in conjunction with irradiation-induced lowering of the surface albedo, as the solar luminosity increased toward the present day, releasing methane, and then large amounts of nitrogen (perhaps suddenly), into the atmosphere [2,5,6]. A simple scenario we consider here would be that Titan was Triton-like until recent geologic time when solar warming rapidly created a thick atmosphere, initially with much more methane than at present, resulting in global fluvial erosion that has over time retreated towards the poles with the removal of methane from the atmosphere [e.g., 5,6] (Fig. 1). The sudden appearance of a thick atmosphere may have changed Titan's global topography.

Model Analysis: Present-day Titan experiences only small (~4 K) pole-to-equator variations, owing to efficient heat transport via the thick atmosphere [7]; these temperature variations would have been much larger (~ 20 K) in the absence of an atmosphere. If Titan's ice shell is conductive, the change in surface temperature associated with the sudden development of an atmosphere would have led to changes in shell thickness. In particular, the poles become warmer, resulting in shell thinning and a reduction in elevation (also inducing compression), while the equator becomes colder, resulting in shell thickening and uplift (inducing extension). Figure 2 shows the predicted change in surface elevation as a result of the change in surface temperature, using the numerical conductive shell thickness model of [8].

Geological Observations: Preliminary mapping of putative basement rock, as manifested by bright, rough, ridges, scarps, crenulated blocks, or aligned massifs, indicates that it mostly appears within 30° of the equator. Hence we deduce that most currently exposed basement erosion is located in the equatorial region. Equatorial ancient Uplands regions on Titan exhibit pronounced "banding" or "crinkling" interpreted to be ridge and valley patterns of fluvially-dissected basement topography. Smooth, dark areas within these uplands units are interpreted to be local sedimentary deposits, often apparently in old craters.

High mid-latitude regions on Titan exhibit dissected sedimentary plains (Fig. 3) at a number of localities. Much of the high mid latitudes are otherwise relatively featureless, consistent with these latitude belts being dominated by plains-forming sediment. The polar regions are mainly dominated by deposits of fluvial and lacustrine sediment (Fig. 4). Polar compression may have formed the isolated massifs seen there, akin to isolated mountains thought to form in compression on Io [9,10].

The development of the thick atmosphere would have resulted in a regional polar strain of order 10^{-4}, but the local strain at isolated mountains could have been of order 10^{-3}. The polar massifs are typically ~100 km wide, so if they are due to faulting then the predicted topography is roughly 100 m (depending on the angle of the fault), which is approximately what is observed. (To accommodate the same strain by folding would require much higher relief.)

We hypothesize that with initially heavy global rainfall, the erosional denudation of the originally elevated equatorial region and the loading of sediment poleward of it would possibly accentuate the further rise of the equator and the sinking of the regions beyond, which might be significant depending on lithospheric rheology. We are investigating whether there are reasonable values for lithospheric rheology that would make loading and denudation significant additional players.

References: [1] Moore, J.M. & Pappalardo R.T. (2011), *Icarus*, *212*, 790-806. [2] McKay, C.P. et al. (1993) *Icarus*, *102*, 88-98. [3] Lorenz, R. et al. (1997) *Science*, *275*, 642-644. [4] Lorenz, R. et al. (2008) *GRL*, *35*, L02206. [5] McKay, C.P. (2010) Titan through time: Titan's Future (abs.) in *Titan Through Time; A Workshop On Titan's Past, Present and Future*, p. 85. [6] Toon. B. et al. (2010), Nitrogen Ocean/Lakes on Early Titan (abs.), *BAAS*, *42*, 1077. [7] Tokano, T. (2005) *Icarus*, *173*, 222-242. [8] Nimmo, F. & Bills B. (2010) *Icarus*, *208*, 896-904. [9] Schenk, P.M. & Bulmer M.H. (1998) *Science*, *279*, 1514. [10] McKinnon, W.B. et al. (2001) *Geology*, *29*, 103-106.

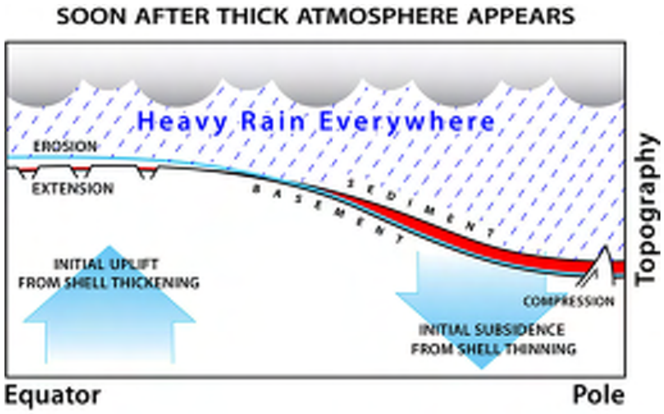

Fig. 1. A simple climate evolution scenario illustrated here postulates that Titan was Triton-like (thin clear atmosphere) until recent geologic time when solar warming (perhaps abetted by a large impact event) rapidly created a thick atmosphere, initially with much more methane than at present, resulting in global fluvial erosion that has over time retreated towards the poles with the removal of methane from the atmosphere. This late atmosphere might also cause the equator to rise and the poles to sink (blue curve). Equatorial erosion and polar sediment sinks might cause futher uplift and subsidence. We are investigating whether there are there reasonable values for lithospheric rheology that would make loading and denudation significant additional players.

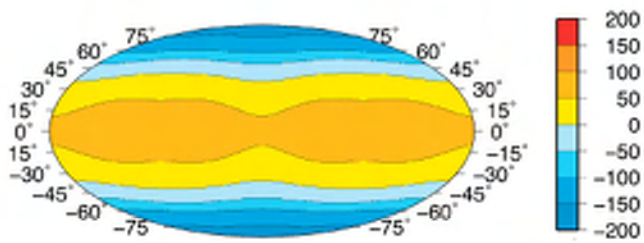

Fig. 2. Change in topography of Titan as a consequence of the change in surface temperature variations due to acquisition of an atmosphere. The poles become warmer, resulting in shell thinning and a reduction in elevation, while the equator becomes colder, resulting in shell thickening and uplift. The minor longitudinal variations arise from the shell thickness variations due to tidal heating (see ref 8 for details on the numerical model employed). Units for scale bar are in meters.

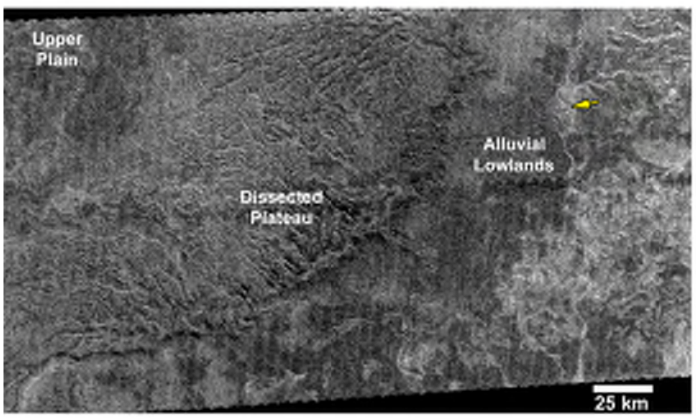

Fig 3. A region representative of the high mid latitudes exhibiting a partially-dissected surface ("dissected plateau"). The dissection is interpreted to be fluvial due to dendritic valleys draining southward. The figure contains two broad radar-dark surfaces. The undissected surface to the left we classify as "radar-dark terrain". It might represent alluvial lowlands or an undissected part of the plateau bordering it to the right. The relatively smooth radar-dark surface that we interpret as being alluvial plains is crossed by several broad, sinuous valleys or channels (arrow) and we classify it as "radar-dark lowlands". Portion of swath T39, ~50°S, 210°W

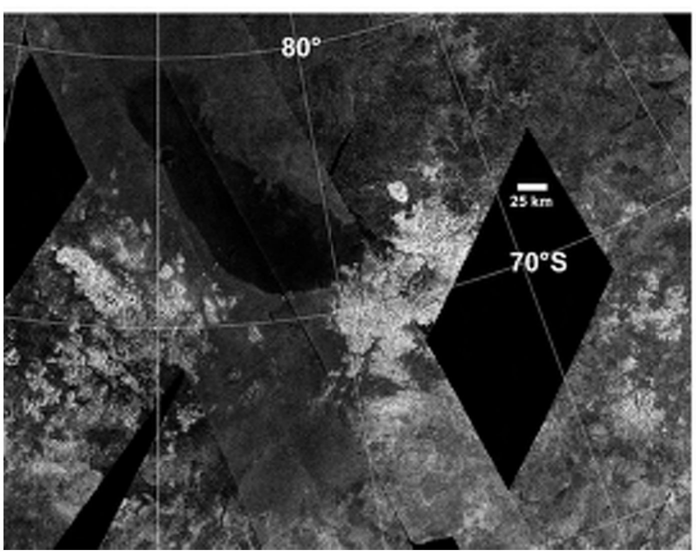

Fig 4. The polar regions are mostly dominated by sediment plains and lakes and their deposits. Polar compression may have formed the isolated massifs seen there akin to isolated mountains thought to form in compression on Io [9, 10]. The development of the thick atmosphere results in a regional polar strain of order 10^{-4}, but the local strain at isolated mountains could be of order 10^{-3}. The polar massifs are typically ~100 km wide, so if they are due to faulting then the predicted topography is roughly 100 m (depending on the angle of the fault), which is approximately what is observed. (To accommodate the same strain by folding would require much higher relief.) Image portion of a USGS *Cassini* Radar SAR base map.