TITAN'S LANDSCAPES EXPLAINED: SMOTHERED, COVERED, AND THIN.

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Introduction: Saturn's moon Titan is a hydrocarbon world with a deep subsurface ocean and thick water ice crust covered in a layer of organic molecules. Water ice is only exposed on 13% of Titan's surface, while the rest of the landscaped is covered in organic materials and shaped by sedimentary processes [1].

Many of the terrains characterized by recent mapping efforts provide insight into the formation and evolution of different landscapes, including the enigmantic Xanadu region: a rugged mountainous landscape that is paradoxically also a basin. Our mapping and detailed analysis of Titan's labyrinth terrains [2] has also enabled an understanding of the complex interplay between Titan's icy substrate and overlying organic blanket.

We present here a conceptual model of how Titan's landscapes formed, and how this model can be extended to include other potential hydrocarbon worlds beyond our solar system.

Titan conceptual surface evolution model: The depth of sediments at any given location on Titan is the balance of airfall deposition, transport of materials in from adjacent locations, and transport out from the region of interest. When outward transport outpaces transport in, the landscape will effectively deflate.

Our mapping provides evidence that wind is the primary transporter of organic materials in the equatorial and mid-latitudes [3]. Windward of most topographic rises at these latitudes we see eolian deposits overlying expected fluvial deposits. Wind deposition follows a global pattern likely set by high altitude winds locally bringing materials down to the surface [4]. The direction is determined by location and atmospheric pattern, but the quantity of material moved is dictated by topographic obstacles. Areas blocked from inbound transport will be sediment-starved, such that winds will carry away materials, resulting in overall landscape deflation. Tectonic structures will create topographic blocks that starve downwind locations. Transport directions [3] and topography [5] are key to predicting Titan's surface appearance.

Titan's landscapes can be explained by three scenarios: areas where organic materials accumulate (smothered Titan), areas where inbound and outbound organic sediments balance (covered Titan) and areas where organics are scarce as they have been transported away to surrounding areas (thin Titan.).

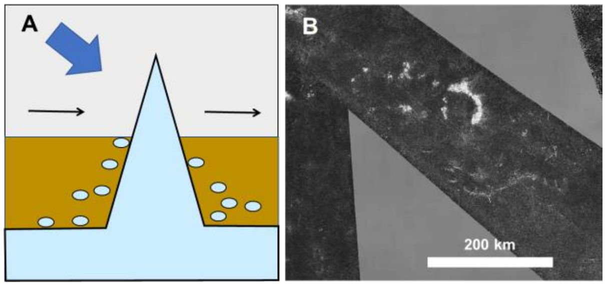

Fig. 1. Smothered Titan scenario. A) side view of an icy mountain, eroded and buried icy cobbles, and brown organic plains. Arrows indicate wind direction. B) SAR of area centered on Titan at 29.8°N, 245°W. A partially filled crater can be seen at image center.

Smothered Titan: These are areas where organic materials accumulate(Fig 1.). Unlithified organic sediments may be porous and thus may not support vallleys or channels. Impact craters are quickly infilled and even buried; due to thick sediment cover they may have different morphologies compared to an icy impact. In dry areas, wind transport is the dominant deposition mechanism.. Subtle variation in topography may be the palimpsests of buried features. Mountains, if expressed, are eroded inselbergs poking up out of the surrounding plain. In areas where induration of deeply buried organic sediments occur, uplift will generate labyrinth terrains, which will be capable of holding channels and valley structures due to said induration. Where induration does not occur, uplifted materials quickly disperse. Dissolution of soluble organic components will create karstic morphologies [6]. The thickness of the plateaux is determined by the orginal thickness of organic materials and amount of uplift. The sediment thickness is estimated to be on the order of 100s m to up to 1 km of organics. Where surfaces intersect the local liquid table, dampened or even surface liquids can appear. In areas without a lot of wind transport, such as Titan's polar latitudes, fluvial and karstic processes dominate material transport.

In the current regime, the smothered Titan scenario is represented by the mid-latitude deposition belts near ~35°N and 35°S [3]. These are vast areas covered by undifferentiated and scalloped plains [7,8], wind streaks [8], and uplifted labyrinths [2,8]. Due to the high organic content, microwave emissivity is relatively high in these regions [9].

Covered Titan: These are areas where organic materials fall and are transported away almost as fast as they are delivered to the surface (Fig. 2). Topographic blocking, as well as fluvial transport moving materials into basins, will dictate where the thickest sediments accumulate. There will be a mix of exposed basement ice near uplifts and organic sediments within basins. Exposed icy area will always contain some amount of organic materials in flux. In areas with wind-mobile materials, linear sand dunes or broad sand sheets will occur. Dunes, mountains, and variable featured plains will dominate. In areas with less sediment mobility, thin plains will dominate. Where cover is thinnest, more craters will be observed. Emissivity values will be highest near dunes, but lowest in icy plains or mountains. [9]

The sand seas of Titan are representative of this scenario. Average organic thickness is on the order of 10's of meters. While the sand seas constitute 17% of Titan's surface area, they only make up <2% of Titan's solid organic volume [10]. The thickest cover is in Belet, then Shangri-La, and the thinnest cover is in NE Shangri-La. The regional crater density parallels this assesment, with the highest density in NE Shangri-La and few craters evident in Belet.

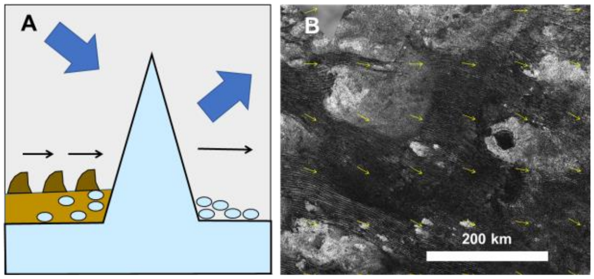

Fig 2. Covered Titan scenario: A) graphic of an icy mountain buried on the windward side by windblown organics. B) SAR image of Titan at 6°N, 152°W. A crater is present to right of image center.

Thin Titan. In these locations, wind transport out of the area dominates (Fig. 3). There will be only a thin coating of organic materials present in deep, protected valleys. Most of the landscape will be exposed basement ice, with an erosional surface resulting from fluvial overland flow. Dendritic drainage networks and evaporite basins will dominate in dryer regions. Evaporite basins and deep protected valleys will be the predominant repositories of solid organic materials. Due to extensive areas of water ice, the microwave emissivity will be low. Craters will remain exposed, but degraded through physical erosion and tectonic processes. This scenario will have the highest crater density.

The thin cover scenario is best illustrated by the enigmatic Xanadu region. In Xanadu, blocking of sediment flux by highlands NE of the region result in stripping of materials across Xanadu, across Hotei regio (an evaporitic basin), and across the icy Xanadu annex. [9].

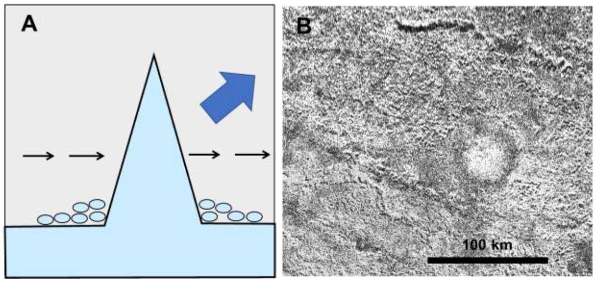

Fig 3. Thin Titan scenario: A) graphic of an icy mountain with limited organic cover. Eroded ice sediments are exposed. B) SAR image of central Xanadu region of Titan at 6°S, 112°W. Crater at image center.

Exoplanet Titan: Titan is representative of other potential hydrocarbon worlds beyond the solar system. The interplay between surface age and organic sediment deposition rates allow us to estimate landscape geomorphologies of such worlds. On planets/moons with even more deposition than Titan, we predict a landscape with muted surface topography except in locations where uplift has generated massive labyrinth plateaux. On surfaces with less organic deposition but similar meteorological processes (including fluvial erosion) we predict a surface resembling the Xanadu region of Titan.

Conclusions: Our conceptual model of Titan attempts to explain it's surface through a combination of organic depositon, deflation, wind transport, topography, and uplift history, along with limited fluvial and karstic processes. We can extend this model to other hydrocarbon worlds to predict exoplanet landscapes.

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