A STRATIGRAPHY FOR TITAN BASED ON MATERIAL PROPERTIES AND DISTRIBUTIONS.

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Introduction: Although definitive information on the composition on the surface materials of Titan is lacking, equatorial regions have many Earth-like landforms that suggest similar processes shape the surfaces of both bodies [1, 2]. We seek to understand Titan's geologic history through mapping landform geomorphologies and relating them to compositions inferred from *Cassini* imagery. Key landforms at Titan's equatorial regions are linear sand dunes principally of organics [1, 2, 3]. While the overall pattern of sand seas has been established [4], regional relative sand abundance have not yet been mapped. We mapped sand abundances and related those geographically to potential nearby sand sources. We also examined material distributions across the sand seas, sand source regions, highlands, and some impact craters to establish a potential stratigraphy, the first of its kind, for Titan's equatorial regions.

Methods: All mapping was done with the aid of color select tools in GNU Image Manipulation Program (GIMP).

Relative abundances of sand deposits were mapped by correlating the darkest deposits seen in Imaging Science Subsystem (ISS) imagery with the thickest sand deposits. Because ISS-dark regions are also dark in higher resolution Synthetic Aperture Radar (SAR) imagery, it is likely that interdunes within ISS-dark regions have sand-rich interdunes. Moderately dark ISS values within sand seas were mapped as moderate sand abundance. Sand sea boundaries were determined from VIMS-brown units, similar to results by [4].

VIMS-blue and VIMS-purple surfaces [5] at equatorial regions near dunes were also mapped. VIMS-blue materials are thought to consist of water ice with organics, and VIMS-purple has previously been interpreted to be a combination of dunes and VIMS-blue interdunes [4].

Results: The most sand-rich areas (e.g., sand covered interdunes) tend to occupy the eastern regions of sand seas (Fig. 1). Additionally, shapes of upwind (western) sand sea margins often reflect distributions of adjacent upwind VIMS-blue surfaces.

A large E-W trending linear VIMS-blue feature crosses southern Xanadu and follows the NW margin of Aztlan (Fig. 1).

Several impact craters, including Menrva[1] and Sinlap[2] (Fig. 1), have VIMS-bright rims and central peaks, and VIMS-blue crater floors.

Discussion: Eastward displacement of thicker sand deposits relative to the centers of sand seas correlates with the inferred topographic obstructions on the eastern downwind margins the sand seas and the dominant wind direction towards the east [1, 2].

The E-W trending VIMS-blue surface crossing southern Xanadu following the NW boundary of Aztlan has been suggested to be the result of tectonic activity [6]. Recent modelling found that Titan's crust may have significantly thickened ~ 500 million years ago [7]. Such an event may have caused tectonic rifting and exposure of deeper water ice-rich bedrock.

It is likely that VIMS-blue materials are made of organics with some water ice [4]. Experiments involving lab-created tholins and liquid water suggest tholins may be soluble in water [8]. It may be possible that

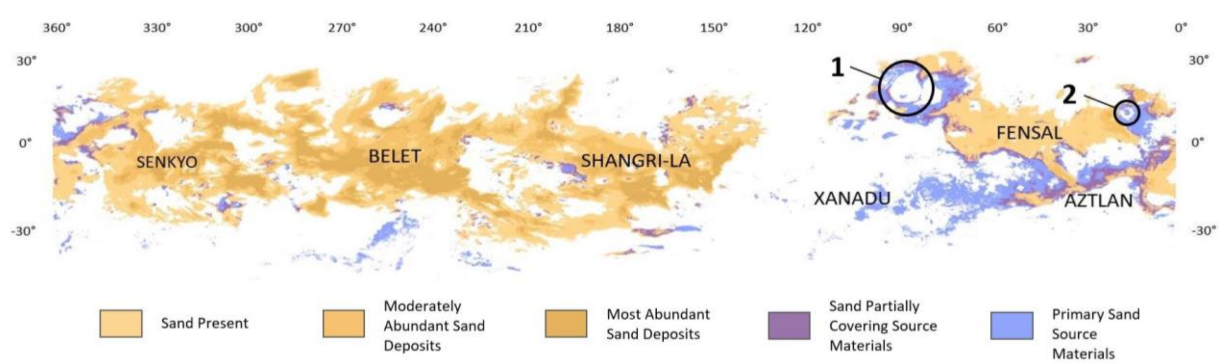

Figure 1. Extent of sand seas (tan), and inferred regions of relatively abundant deposits of sand on Titan (moderate and dark tan). Blue is interpreted to be dominated by source materials for sand. Purple shows overlap between sand and sand source materials. Menrva[1] and Sinlap[2] are also labelled.

VIMS-blue materials were originally created from an early stage magma ocean of water mixing with tholins and freezing. More recent layers of VIMS-blue materials may have also formed from subsequent cryovolcanic lava flows assimilating near-surface organics before freezing. Because VIMS-blue materials appear to be lower stratigraphically and contain water ice [7], they may be relatively dense and compacted.

VIMS-bright materials, which cover much of the equatorial highlands, are spectrally similar to evaporite deposits from liquid bodies of methane [3]. Additionally, VIMS-bright surfaces at temperate latitudes exhibit karst topography in SAR [9]. These observations indicate at least some VIMS-bright materials are methane soluble. Comparisons of VIMS and Huygens imagery suggest that VIMS-bright materials do not persist as clasts far from their origin, implying low mechanical strength. [10, 11] suggested that VIMS-bright materials formed from accumulated tholins. Because VIMS-bright deposits are likely formed from airfall and generally lie higher stratigraphically than VIMS-blue deposits, they are probably more porous and less compacted [10, 11].

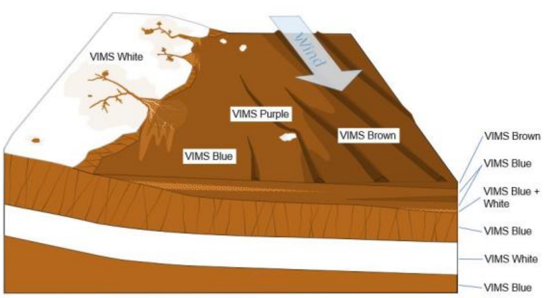

Figure 2. Generalized model of sand production and transportation across the equatorial latitudes of Titan.

VIMS-brown sands have been interpreted as originating from a variety of sources [3, 10]. We argue that the inferred higher porosity, methane solubility, and lower mechanical strength of VIMS-bright compared to VIMS-blue materials make the former an unlikely sand source. Spectral signatures also suggest that VIMS-blue and VIMS-brown surfaces are compositionally more similar to each other than VIMS-bright surfaces. Minor spectral differences have been attributed to differences in clast sizes [12, 13]. Because of VIMS-blue material properties and distribution that correlates with the western margins of sand seas, we suggest that VIMS-brown sand is predominantly sourced from VIMS-blue materials (Fig. 2).

Geologic units observed at weathered impact craters such as Paxsi and Selk, and relatively unweathered craters like Sinlap are puzzling if there are only single layers of deposits. In particular, VIMS-bright materials are exposed on the eroded upturned crater rims as well as in the deeper-derived central peaks, and there are often VIMS-blue materials on the crater floors. This indicates there may be multiple layers of VIMS-blue and VIMS-bright materials at the equatorial regions exposed through cratering, erosion, and tectonism as described above.

We propose the following geologic history for the equatorial latitudes of Titan: Early planetary heating led to a magma ocean of water on Titan early in its development. Tholins from the atmosphere mixed with the ocean and the mixture froze. VIMS-bright tholins subsequently accumulated on the surface by airfall. Large impacts (possibly forming Xanadu as interpreted by [14]), excavated and deposited VIMS-blue materials as ejecta. Later cryovolcanism may have also created VIMS-blue layers. VIMS-bright tholins continued to be deposited, and this process of alternating atmospheric deposition with cryovolcanism, or deep crustal excavation through cratering created alternating layers of VIMS-blue and VIMS-bright within impact craters. Currently, methane precipitates and creates channels. Surface materials are partially dissolved, or eroded and transported to alluvial fans. Wind selectively transports VIMS-brown sand (proposed to be eroded from larger VIMS-blue clasts) and deposits it in downwind adjacent sand seas. Some VIMS-bright clasts may persist within sand seas for a time before disintegrating [15].

Conclusions: The surface history of Titan at the equatorial regions is complex, but can be revealed through Earth-analogue studies and analysis of material properties. With the advent of *Dragonfly*, a distinct understanding of materials and landscapes will clarify this history.

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