SAND DISTRIBUTION, ICE-RICH REGIONS, AND SOURCES OF THE SAND SEAS OF TITAN.

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Introduction: The equatorial regions of Titan are dominated by linear dune fields made of complex organic particles [1, 2]. These dunes have many similarities to terrestrial dunes, such as those found in the Namib Sand Sea [1, 3]. Previous studies of Titan's sand seas included mapping sand sea margins [4, 5, 6, 7], but did not involve mapping relative sand abundances. Mapping sand distributions and abundances would reveal patterns in sediment transport and accumulation, and could show regions affected by obstruction of sand movement. It may also provide additional insights into the history and current forces at work in the region.

It is thought that the organic sands are formed from interactions between solar ultraviolet radiation and atmospheric methane [2]. Over time these complex organics "snow" down, accumulate onto a bedrock surface of water ice and likely lithify, perhaps creating the VIMS-bright terrains interpreted by [7]. A general mode of sand formation is that methane rains onto the surface, collects into rivers that flow across the lithified organics, and erodes them to fine-to-coarse sized clasts that are distributed across floodplains and termini of alluvial fans, along with cobble-sized clasts of water ice [7, 8]. As strong winds blow across the alluvial fans and floodplains, they transport the smaller clasts of lithified complex organics and leave behind the water ice cobbles as a lag deposit [7]. This process creates surfaces dominated by water ice that can be inferred to be regions of sediment flux between sites of erosion on highlands and deposition in the sand seas. Our methods further develop previous mapping of water ice deposits [6, 7] and yield a more complete map.

Using Cassini data, we made correlations across VIMS, SAR, and ISS datasets in order to map interpreted sand abundances of the sand seas and relative abundances of water ice exposed at the surface.

Methods: The extent of abundant sand deposits were inferred by mapping the darkest regions visible in Imaging Science Subsystem (ISS) near-infrared imagery. This interpretation is reasonable because at a wavelength of 938 nm, ISS imagery generally images the surface and near surface. These regions also correlate with patches especially dark in higher resolution Synthetic Aperture RADAR (SAR) imagery, which suggests the presence of sand dunes with sand covering the interdunes. We used sand sea boundaries [6] determined by mapping the extent of sand visible in Visible and Infrared Mapping Spectrometer (VIMS) [4].

VIMS-blue surfaces interpreted to be dominated by the presence of water ice [7] were manually mapped in ArcGIS Pro with the aid of color select tools in GNU Image Manipulation Program (GIMP).

Results: The interpreted extent of abundant sand deposits tend to be in the eastern areas of the sand seas (Fig. 1). Although most of the abundant sand deposits within Belet are in the sand sea's southern region, there is apparent displacement to the east relative to the sand sea's boundaries. Some abundant sand deposits

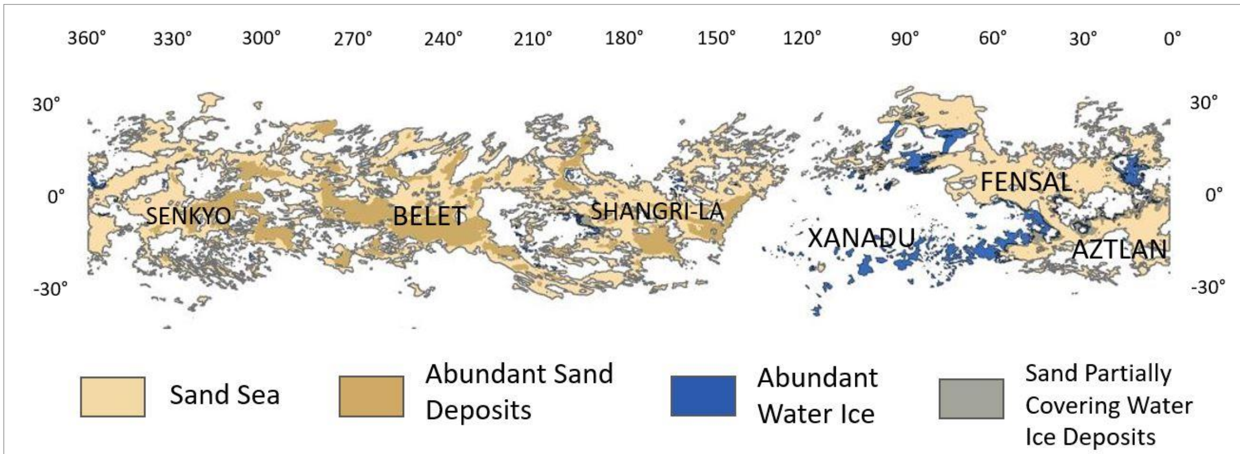

Figure 1. Extent of sand seas (tan) according to [10], and inferred regions of relatively abundant deposits of sand on Titan (dark tan). Blue is interpreted to be dominated by water ice and based on findings of [7]. Gray shows overlap between sand and water ice deposits.

extend across the center of a narrow corridor running from western to eastern Shangri-La and merge with a broad deposit of abundant sand along the eastern boundary of the sand sea.

Exposures interpreted to be dominated by water ice generally occur adjacent to sand seas along their western margins. The Xanadu region is largely covered by white and light blue surfaces in VIMS, but it is also spotted with dark blue, water ice-rich surfaces. Many of these water ice regions are a part of a large E-W trending linear feature that crosses southern Xanadu up to NE Aztlan.

Discussion: It is likely that areas mapped as abundant sand deposits are generally thicker than sand deposits in surrounding areas. Eastward displacement of thicker sand deposits relative to sand sea boundaries may be caused by topographic obstruction on the eastern downwind part of the sand sea, or by a reduction of sediment supply over time [8]. The dominate wind direction across the sand seas is generally west to east.

The thickest sand deposits in eastern Shangri-La are spread along the SE boundary of the sand sea (Fig. 1), suggesting obstructive influences here [9]. The region is adjacent to Xanadu, which is dominantly low in elevation and has a high albedo [10]. Previous computer models suggest that the large size of Xanadu, its low topography, and albedo all contribute to the deflection of sand-bearing wind currents across SE Shangri-La [10, 11]. This deflection of wind currents may account for the obstruction of the migration of sand across SE Shangri-La and accumulation of thick sand deposits there.

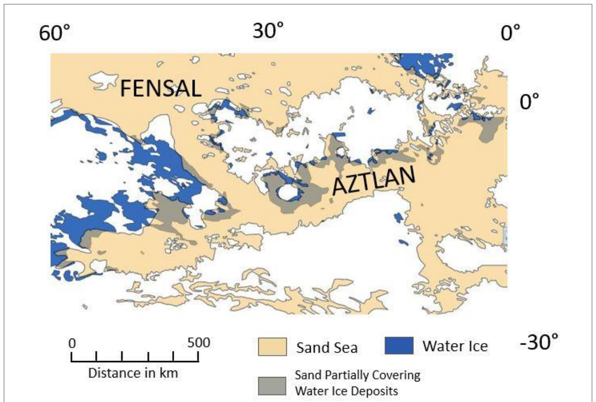

Figure 2. Aztlan and Fensal with surfaces dominated by water ice. Xanadu is to the west.

Few sufficiently dark regions were present in ISS within Fensal and Aztlan to be mapped as abundant sand deposits. This suggests there is generally less sand available here, possibly as a result of the proximity of this terrain to sand-poor Xanadu that lies upwind. It is also possible that landscapes in the eastern equatorial region of Titan are tectonically younger. An E-W trending linear exposure dominated by water ice that crosses southern Xanadu and follows much of the northern boundary of Aztlan has been suggested to be a fault [12]. It is possible that the creation of new landforms here have prevented the existence of a stable cratonic block on which sand seas can develop to maturity [13].

Most areas mapped as being water ice abundant are adjacent to sand seas, and some have shapes that are somewhat similar to adjacent sand seas. An ideal example is the previously mentioned E-W trending exposure of water ice and the sand sea Aztlan (Fig. 2). If sand dune crest directions for linear dunes indicate migration direction, and the water ice abundant exposures are interpreted as being intermediate passageways from VIMS-bright sediment sources to the sand seas, then it would be difficult to conclude that sand has migrated more than 300 km there. Further work needs to be done on evaluating sand migration distances across the surface of Titan.

Conclusions: Dark areas inferred to have abundant (thick) sand deposits are generally located in the eastern parts of the sand seas. We support the results that suggest air currents above the SE margin of Shangri-La were deflected and argue that such a disruption could account for the abrupt SE boundary of the sand sea and its interpreted distribution of sand abundances.

The similar shape of the E-W trending linear exposure dominated by water ice with Aztlan support previous findings [7] that sediment is sourced from VIMS-bright regions, passes across water ice rich surfaces, and is swept up by the wind into sand seas.

Our findings suggest that sand within Aztlan has migrated roughly 300 km. Further research is needed to evaluate the migration distances for other sand seas.

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