WHAT IS THE ULTIMATE FATE OF TITAN'S DUNE SANDS?

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Introduction: Titan's vast sand seas are composed of organic materials arranged in linear dunes [1, 2]. The dunes have been identified by Cassini spacecraft infrared and radar remote sensing instruments [3]. The infrared dark and radar-dark dunes are confined to the equatorial zone, while immediately poleward are the radar-dark but infrared bright (at 0.93 μm) mid-latitude plains. The apparent west to east surface transport directions diverge poleward from the equator and converge in the midlatitude regions at roughly latitude 35 degrees in the midlatitude plains [4,5]. This suggests that ISS dark dune materials should be transported in the average direction eastward following the linear dune crests from the equatorial zone and deposited in the mid-latitude plains [5]. Yet ISS dark materials are not observed in the mid-latitude deposition belts. Why? Where do the dune materials go?

We have begun mapping and examining the characteristics of Titan's dune terrains and also the terrains in immediate contact with dunes in order to constrain the deposits of Titan dune materials.

Dune/Plains boundary: Fig 1 shows an annotated ISS image of the contact of linear dunes of the E Belet/W Shangri-La Sand Sea with mid-latitude Caladan Planitia. At location **1** in the figure, infrared-dark E Belet dunes oriented SW-NE terminate at infrared bright plains. At location **2**, Aura Undae is composed of infrared-dark dunes that are either sourced in Aura Undae or result from Shangri-La dune sands transported across location 1. Location **3** is a large area of featureless infrared-bright undifferentiated plains of Caladan Planitia. Analysis of Cassini VIMS data suggest that this southern section of Caladan Planitia has a more dune-like spectral response compared to northern areas of Caladan Planitia, interpreted as small amounts of dune materials being mixed in this area [6]. Downwind, near **4**, the thin infrared-dark lanes of Tlaloc Virgae are interpreted as being transported sands that are focused by small hummocky and mountainous topographic obstacles [7]. Afekan Crater is immediately W of **5**, and the locally elevated rim and ejecta blanket causes dune sand material to deposit around and upwind of the crater, but lack of downwind deposits suggests the sands disperse or are removed so that by **6** infrared dark materials are no longer observed. A regional embayment of Shangri-La at **6** may be due to a locally elevated area at **8** pushing

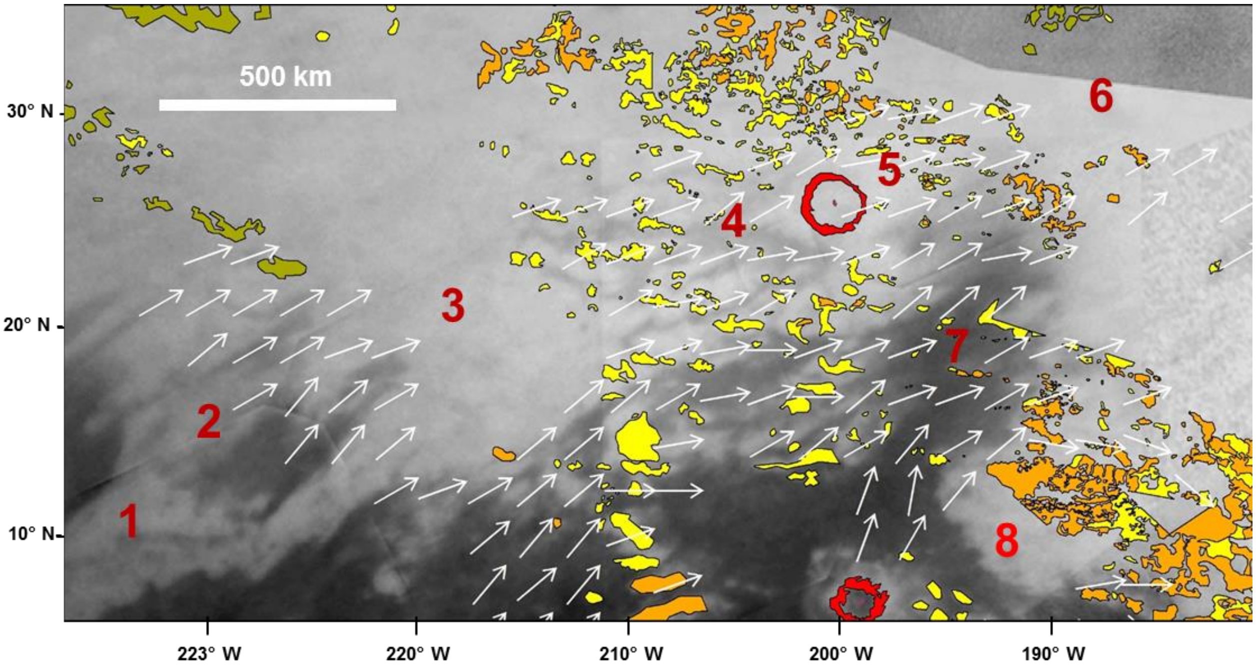

Fig 1. Infrared (0.93 μm) image of the Shagri-La, Aura Undae, Caladan Plantia and Tlaloc Virgae features. Red outlines are crater terrin units, orange and yellow are hummocky mountainous terrain units respectively. Numbers refereed in text. Transport vectors from Malaska et al., 2016 are indicated with white arrows. The dark area at upper right (immeditately above "6") is a mosaic artifact.

additional infrared-dark dune sand material northeastward. The interpreted features in the Fig. 1 area are all consistent with dune sand material being transported across the infrared bright terrain. However, a lack of a deposit downstream from 6 suggests that the materials are either destroyed or modified so that large linear dunes or infrared dark materials are not observed at higher latitudes.

Possible fates of dune materials: A detailed SAR image of the contact between Aura Undae and Caladan Planitia and is shown in Fig. 2. The dunes are seen to extend into and terminate in Caladan Planita. The linear dunes indicated by white arrows break up into a series of linear dunes that bend (likely due to a local wind field induced by topography) and eventually thin and terminate in Caladan Planitia.

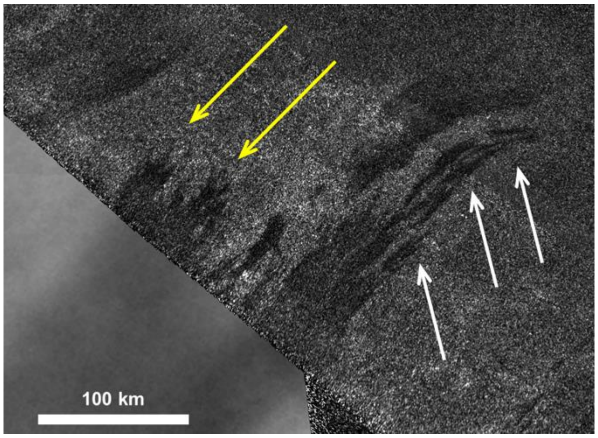

Fig 2. SAR and infrared image of NE (downwind) edge of Aura Undae where it contacts with Caladan Planitia. Yellow arrows show abrupt termination of dunes, white arrows show thinning and break up of dunes with eventual termination. Scene is just to east of label "2" in Fig. 1.

Likely reasons for the termination of the dune materials and lack of extension into the plains include:

Interception by fluvial channels: On Earth, dune fields are terminated in locations where rivers and channels intercept sediments and prevent downwind transport. We do not observe channels and rivers in the undifferentiated plains. Although these could be subresolution, channels and rivers should collect to larger channels, but these are not observed [7]. Since we observe dune materials traversing the plains from spectral analysis and are concentrated in Tlaloc Virgae, this suggests dunes are not fully prevented, but could be attenuated by subresolution channels in the plains.

Termination due to changing wind direction. On Earth the Namib Sand Sea is terminated by a changing wind regime tht creates star dunes at the edges of the dune field. This effectively traps the sediments in the Namib Sand Sea. On Titan, there is no evidence of terminal star dunes, although these may be below the resolution limit of Cassini SAR (200 m per pixel). However, the parallel alignment of wind-aligned features across the entire region suggests a consistent wind pattern beyond the sand sea that extends into and across the plains area [5].

Attenuation due to humid plains. If there is as shallow liquid table in the plains, wetting could trap migrating dune sediments and prevent the formation of dunes, or prevent them from growing larger (Le Gall et al. 2011; Rodriguez et al. 2014). The spacing of dunes near higher latitudes is consistent with a decreasing sand supply. However, if the dune sediments are being trapped in the plains, a mechanism would need to be invoked that would make the trapped sediments brighter in infrared wavelengths, consistent with the observations.

Physical destruction of dune materials due to friability. The exact makeup of the dune materials is unknown. It is possible that the dune grains are friable and could physically or chemically (via dissolution) break down as they proceed in the longtrack position. This process occurs for terrestrial sand grains composed of gypsum[8]. Following breakdown, the grains are composed of fine dusts which may no longer form dune sands. Another mechanism would be required to cause the dusts to become infrared bright.

Subresolution dunes. The dune sand materials could still exist, but break up into sub-resolution barchan dunes that traverse the landscape. This explains the lack of linear dunes, but does not explain the infrared brightness. An IR modifying process would be required as well.

Chemical modification of dune materials. This may be accelerated by entering higher latitude areas where rainfall is thought to be more abundant[9]. Leaching and partial dissolution of the surface of dune materials may change their cohesivity and infrared reflective properties, possibly due to leaching or efflorescence.

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References: [1] Lorenz et al. (2006) *Science 312*, 724-727. [2] Radebaugh et al. (2008) *Icarus 194*, 690-703. [3] Rodriguez et al. (2013) *Icarus 230*, 168-179. [4] Lorenz and Radebaugh (2009) *GRL 36*, L03202. [5] Malaska et al. (2016) *Icarus 270*, 183-196. [6] Lopes et al. (2016*) Icarus 270*, 168-182. [7] Malaska et al. (2016) *Icarus 270*, 130-161. [8] Jerolmack et al. (2011) *JGR Earth Surface 116*, F02003. [9] Moore et al. (2014) *JGR Planets 119*, 2060-2077.