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Implications of dune pattern analysis for Titan's surface history

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ABSTRACT

Analysis of large-scale morphological parameters can reveal the reaction of dunes to changes in atmospheric and sedimentary conditions. Over 7000 dune width and 7000 dune spacing measurements were obtained for linear dunes in regions across Saturn's moon Titan from images T21, T23, T28, T44 and T48 collected by the Synthetic Aperture RADAR (SAR) aboard the Cassini spacecraft in order to reconstruct the aeolian surface history of Titan. Dunes in the five study areas are all linear in form, with a mean width of 1.3 km and mean crest spacing of 2.7 km, similar to dunes in the African Saharan and Namib deserts on Earth. At the resolution of Cassini SAR, the dunes have the morphology of large linear dunes, and they lack evidence for features of compound or complex dunes. The large size, spacing and uniform morphology are all indicators that Titan's dunes are mature features, in that they have grown toward a steady state for a long period of time. Dune width decreases to the north, perhaps from increased sediment stabilization caused by a net transport of moisture from south to north, or from increased maturity in dunes to the south. Cumulative probability plots of dune parameters measured at different locations across Titan indicate there is a single population of intermediate-to-large-sized dunes on Titan. This suggests that, unlike analogous dunes in the Namib and Agneitir Sand Seas, dune-forming conditions that generated the current set of dunes were stable and active long enough to erase any evidence of past conditions.

1. Introduction

Linear dunes are the most abundant type of dune by area on Earth and Saturn's moon Titan (Bullard et al., 1995; Lorenz et al., 2006; Radebaugh et al., 2008; Le Gall et al., 2011). They form a major part of the sediment transport system, represent the results of atmospheric and surface processes, and are sensitive to changes in both (Lancaster, 1995; Warren and Allison, 1998). A detailed geomorphologic study of these features can reveal important relationships and processes and illuminate the evolutionary history of the surface. Here we analyze dune width and crest spacing in select regions across Titan to identify variations with location and to reveal details of dune-forming processes on Titan on regional and global scales.

1.1. Dunes on Titan from Cassini SAR

The Cassini–Huygens mission has revealed Titan to have a varied and complex surface. Among other Earth-like features such as river channels (Lorenz et al., 2008), lakes (Stofan et al., 2007) and mountains (Radebaugh et al., 2007), the surface of Titan is covered by vast fields of sand dunes (Lorenz et al., 2006; Radebaugh et al., 2008).

Dune sands on Titan are organic in composition and fine in size. Photochemical reactions in Titan's atmosphere produce complex organics that fall out of the atmosphere and accumulate on the water ice-rich crust (Soderblom et al., 2007). The materials are then perhaps solidified into a sedimentary layer, then eroded by methane rainfall and surface flow into particles of varying sizes, including sand-sized (Lorenz et al., 2006). Eventually, the particles are worked by near-surface winds, with velocities >1 m/s to saltate such particles in Titan's conditions (Lorenz et al., 2006), into large fields of sand dunes (Lorenz et al., 2006; Barnes et al., 2008; Radebaugh et al., 2008). Thick sands are dark to the Synthetic Aperture RADAR instrument (SAR) on the Cassini spacecraft, indicating they are smooth or absorbing at the Cassini SAR wavelength (2.17 cm), and are dark in the visible and near-infrared spectrum, as seen by the Cassini Visual and Infrared Mapping Spectrometer (VIMS) and Imaging Science Subsystems (ISS) instruments (Barnes et al., 2008).

Dunes are abundant on Titan's surface, covering close to 13% of the total surface area, based on SAR observations (350 m resolution, about 35% global coverage to date) and VIMS and ISS analyses (global coverage but lower resolution) (Le Gall et al., 2011; Rodriguez et al., 2014), and found within a belt ±30° latitude of the equator (Lorenz et al., 2006; Radebaugh et al., 2008; Lorenz and Radebaugh et al., 2009; Le Gall et al., 2011). No permanent lakes or seas or large topographic obstacles (with the exception of the Xanadu landmass) are present to disrupt global wind patterns or dune formation (Lorenz and Radebaugh, 2009).

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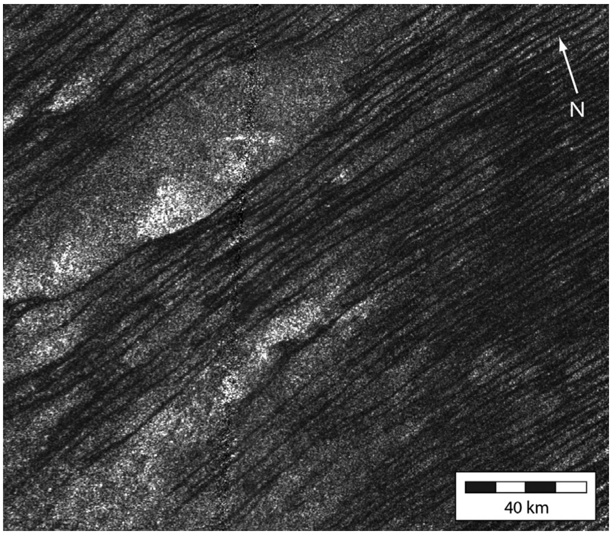

Fig. 1. Example of Titan's linear dunes from Cassini SAR swath T21 centered at about 10.4°N, 279°W. Like similar terrestrial linear dunes, Titan's dunes are slightly sinuous and generally parallel but do not appear to host superimposed or flanking dunes.

The vast majority of Titan's dunes are linear in form and oriented nearly parallel to the equator (Barnes et al., 2008; Lorenz and Radebaugh, 2009). They are up to several km in width and spacing, are up to 180 m high (Barnes et al., 2008; Neish et al., 2010) and can be more than 100 km long (Fig. 1; Lancaster, 2006; Lorenz et al., 2006; Radebaugh et al., 2008). Titan's dunes have been active in the recent geological past, as evidenced by the fact that few, if any, other morphological features overlie dunes at Cassini SAR resolutions. In addition, the interdune area in many of the dune fields is clearly distinguishable by VIMS. This means the substrate is exposed and kept clear of any dune sediments that may have blown or flowed, by mass wasting, into the interdune areas by active winds (Barnes et al., 2008).

Despite the differences in gravity, atmospheric density and sand grain composition on Titan and Earth, the size, morphology, and behavior of Titan's dunes around obstacles are similar to large linear dunes on Earth. Therefore, processes attributed to the evolution of terrestrial linear dunes are applied to dunes on Titan (Lorenz et al., 2006; Radebaugh et al., 2008, 2010; Le Gall et al., 2011).

2. Parametric analysis of Titan dune width and spacing

2.1. Dune morphometric study

Titan's dune widths and crest spacings were measured in five Cassini SAR swath images, T21, T23, T28, T44, and T48 (Fig. 2). These image regions were chosen because they all span a range of latitudes and cross the equator, enabling changes with latitude to be readily observed, they have easily identified dunes and interdunes (unlike the more challenging T8 Belet region, for example) and they are located across many different Titan longitudes. Measurements were made using the USGS ISIS program at regular 5 km intervals along dune long axes. Since most dunes on Titan are many times longer than 5 km, this spacing provides an adequate sampling to capture significant variations along each dune. Tests using smaller measurement intervals of 1.8 and 0.8 km did not yield significantly different results than those obtained using the 5 km interval. Dune widths were measured perpendicular to the long axis and taken to be the width of the SAR-dark streaks, which are interpreted as dunes (Fig. 3). Interdune spacing was obtained in similar fashion except the widths of the SAR-light areas between the dark streaks were measured. Since dune crests are not commonly visible in the SAR images the crest-to-crest spacing, a common measurement in terrestrial dune analysis (Breed and Grow, 1979; Lancaster, 1989, 1995; Ewing et al., 2006) was approximated. This was accomplished by pairing the average dune width

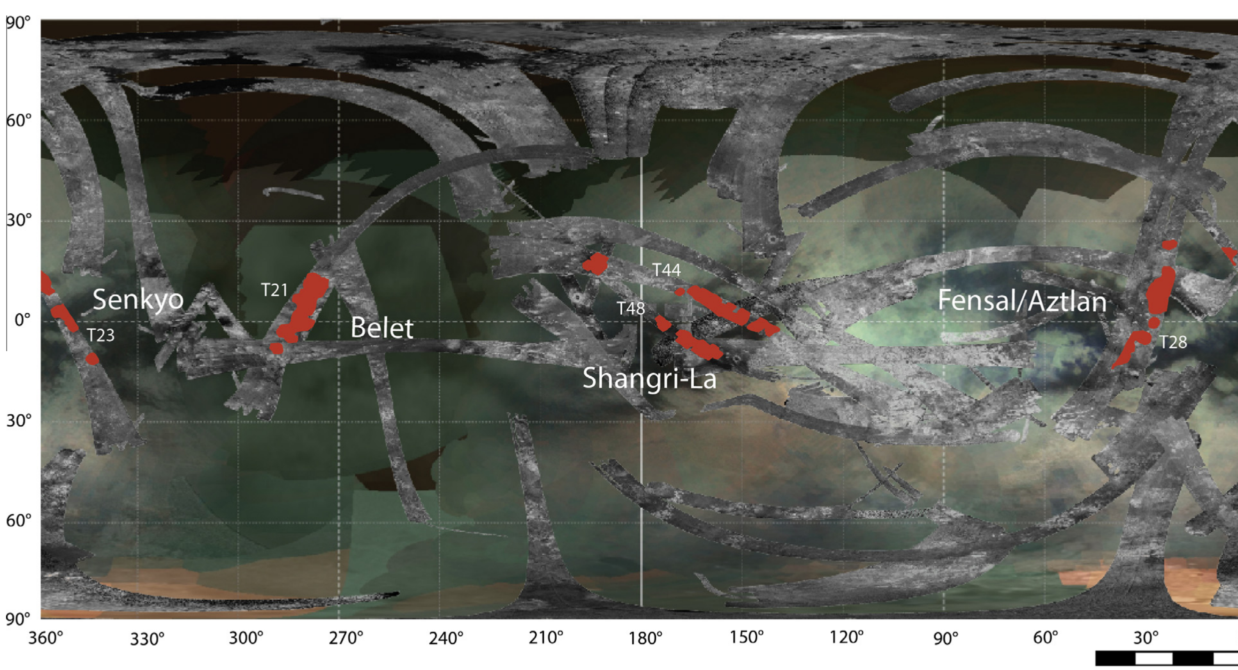

Fig. 2. The approximate location of each measurement made in this study (in proportionately large symbols, and thus overlapping) is marked in red on a global mosaic of 36 of Cassini's SAR swaths, shown as grayscale strips, on a Cassini VIMS/ISS basemap. The five swaths sampled for this study are labeled, as are the major sand seas on Titan. The red points roughly outline the dune fields observed in these swaths. Swaths vary in width from 150 km to nearly 400 km. SAR coverage across Titan's equatorial latitudes at the time of writing is approximately 35%.