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DUNES ON TITAN AT THE BEGINNING OF THE CASSINI SOLSTICE MISSION. J. Radebaugh¹, R. D. Lorenz² and A. Le Gall³, ¹Department of Geological Sciences, Brigham Young University, Provo, UT 84602, jani-rad@byu.edu, ²Johns Hopkins University Applied Physics Laboratory, Laurel, MD, ³Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS-UVSQ), Paris, France.

Introduction: Dunes on Titan, a dominant landform comprising 12-20% of the surface, represent the end product of many surface processes acting in foreign conditions. Winds in a nitrogen-rich atmosphere with Earth-like pressure transport sand that is likely to have been derived from complex organics produced in the atmosphere. These sands then accumulate into large linear dunes in planet-encircling sand seas concentrated near the equator.

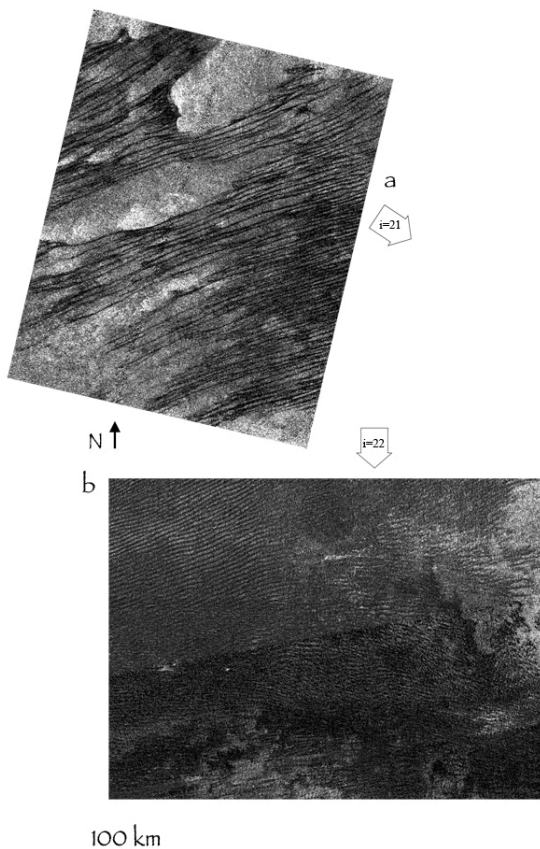


Fig. 1. Dunes on Titan from high latitudes (a) where inter-dune fraction is high, and from low-latitude sand-rich seas.

Dune Morphology and Distribution: Dunes on Titan are found between 30° N and S latitude and nearly encircle the globe at the equator [1,2,3]. They are generally organized into large sand seas, regions of relatively high sand volume. Dunes on Titan generally appear as SAR-dark lines against muted or bright substrate (Fig. 1) because dune sands are absorbing to the SAR signal. The dunes are predominantly linear in form, being parallel over great distances with lengths much greater than widths. Linear dunes comprise an estimated 50% of all dunes on Earth and fill much of

the vast Saharan, South West African, Australian, and Saudi Arabian deserts [4]. From 6000 measurements of dunes across Titan, dunes are 0.7-3.8 km wide with a mean of 1.3 km (SD 0.4), and are spaced 1.6-5 km with a mean of 2.9 km (SD 0.5 km) [5]. These sizes and spacings are comparable to the largest terrestrial linear dune sizes and spacings [6].

Dune Sand Origin and Composition: Given that dune morphologies on Titan are so similar to those of linear dunes on Earth, it is assumed these dunes are formed by saltation of sand-sized particles. Morphologies are not consistent with these features being erosional, rather than depositional forms, such as yardangs, which may be carved out of fine, cohesive sediments. Dunes in general are formed by saltation of a narrow range of particle sizes, given that fine particles are either suspended and removed or remain anchored to the bed, and coarse particles are too large to be lofted or rolled by winds. Dune sands on Titan are likely indeed sand-sized, slightly smaller than for most dunes on Earth at ~0.06 to 0.25 mm [7], this being the optimal size for saltation in Titan's gravity (1/7 Earth) and air density (4x Earth) assuming particle cohesion is similar on the two bodies.

Material compositions on Titan's surface have been difficult to constrain, not least because spectroscopy is hampered by atmospheric absorptions [8]. Titan's dune sands, based on observations and modeling, are thought to be composed of complex hydrocarbons and/or nitriles ultimately derived from atmospheric haze particles [9,10]. Dune sands are dark to visible and near-IR instruments, and their spectra from VIMS are consistent with organics [11,9,12]. In addition, microwave radiometry [13] implies a bulk dielectric constant more consistent with organics than with water ice.

Most dunes on Earth derive their sediments from fluvial and deltaic deposits, ultimately eroded from bedrock, although other sources can include dry lake bed deposits, beaches, and interdunes within the dune regions [14]. It is known that a constant organic 'snow' from Titan's atmosphere must lead to vast deposits of organic solids on Titan's surface [10]. These may form sedimentary layers that become hardened, through sintering or diagenesis via an introduced, organic cement, and then eroded by methane rainfall and channel formation into particulate sands. These sands may be carried by eolian or fluvial processes to sand sinks, either regional topographic lows or wind traps, and then blown into dunes by globe-encircling winds [15].

Another sand source may be lake beds that dry seasonally, exposing sediments to erosion and transport by wind [16,17,18].

Wind Directions: Dunes on Earth and other planets have been used as regional wind indicators, given their direct morphological relationship with dominant winds. Dunes on Titan are classified as linear, based on the commonalities in their morphologies compared with this dune type on Earth [7,19]. Linear dunes can form from at least two different wind conditions, wide unimodal winds, coming from one broad direction and blowing down the dune long axis [e.g., 20], or bimodal winds, wherein at least two strong winds blow from widely separated ($>90^\circ$) directions [e.g., 21]. Controlled experiments and numerical models by Reffet et al. [22] reveal that bimodal winds separated by at least 130° generate longitudinal dune forms, and that sand transport occurs down the dune long axis. It is generally agreed upon that even wide unimodal wind regimes have important seasonal winds from different directions [23], and that the time-averaged vector sum of winds, weighted by strength, in the bimodal wind model is generally down the dune long axis [6]. Thus, it has been assumed that strength-weighted-time-averaged winds are parallel to Titan's dunes and that sand transport occurs in the direction of mean wind flow [15,12,19,2]. Measurements of the long axes of over 16,000 dunes covering $\sim 4\%$ of the surface revealed Titan's dunes are broadly parallel with lines of latitude across the globe, with variations of about 30° on their orientation of 90° from north [2]. The mean direction of wind flow, globally to the east, was determined from the interaction of dunes with topographic obstacles [15,2,19]. This is in agreement with the model by Tokano [24] that allows for fast westerlies near the surface seasonally.

Dune Maturity and Climate: Morphological studies, in the form of pattern analysis of various dune parameters, are starting to yield important results concerning dune field maturity on Earth and other planets [e.g., 25]. The strength in these studies for planetary surfaces is that many characteristics of a region can be determined from spatial analyses alone. If Titan has undergone a recent change in climate or wind direction, for example, superposed forms or variations in overall size would be evidence of this change. At Cassini Radar's resolution of 300 m at best (capable of resolving intermediate to large forms), with the exception of disrupted or cross-cutting forms seen upwind of some obstacles, very few superposed forms are evident in dune fields on Titan. Preliminary studies of dune parameters numerically corroborate this observation [5]. Interdune fraction, the ratio of interdune width to dune spacing, increases toward the north, indicating sand availability is decreased northward, and perhaps dunes are restricted from movement. It is possible

moisture increases toward the north, as indicated by vast lakes and seas at the north pole, and that the liquids help stabilize the dunes [16,26].

The uniformity of dune type across Titan, coupled with emerging pattern analysis results, indicate dunes on Titan may reside in an equilibrium condition that has persisted for a long time. Sand seas are relatively long lived on Earth, as the transport and accumulation of sand can occur over tens of thousands of years in some regions, in many cases episodically [6]. Just how these processes might scale to Titan conditions of lower atmospheric energies and other parameters is the subject of current modeling [e.g., 16].

Dunes are the result of a long sequence of surface evolutionary processes, including atmospheric chemistry, volcanism/tectonism, formation of sedimentary layers, erosion by rainfall, erosion by wave action, fluvial transport, and finally atmospheric dynamical processes. They are relatively ephemeral, and thus highlight current processes. Dunes on Titan can therefore reveal many aspects of past and present processes on the surface of Titan.

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