WINDS AND SAND TRANSPORT PATTERNS ON TITAN FROM DUNE INTERACTIONS WITH TOPOGRAPHY.

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Introduction: The tens of thousands of linear dunes organized into dune fields and sand seas on Titan are emerging as a dominant landform [1,2] (covering an estimated 15% of the satellite [3]) and an indicator of perhaps active geological processes on this body. As we continue to study these features for evidence of their origins and evolution, we look to terrestrial, more data-rich examples of dunes for clues to these processes [4]. The most puzzling aspect of current Titan dune studies is the discord between mean wind directions inferred from sand transport indicated by dune/topography interactions (W to E, or westerly [5]), and winds predicted by Global Circulation models and from basic physics of angular momentum conservation (easterly [6]). We discuss several terrestrial dune regions with known wind data that are robust morphological analogues to features observed on Titan in the hopes of more clearly determining wind directions on Titan from dune-topography interactions.

Alternate winds in the Namib: The Namib Sand Sea, located in SW Africa, contains ~100 km^3 sand sourced from the Orange River in the south and confined both topographically and through eolian processes [7]. In the central parts of the sand sea, winds blow during the spring, summer, and fall from the SW and are nearly oppositely directed, northeasterly, during the winter [7]. This leads to a time-averaged transport of sand to the northeast, but at very slow rates, which helps retain the sand in the sand sea [8].

The effect of these bi-directional winds on dune morphology is best observed where dunes interact with topographic obstacles (Fig. 1a). In the southern part of the sand sea, 100 km south of weather stations in the central area, several inselbergs project through the 10 m thick sand base and act to deflect the dune sands in their migration. We apply the wind directions from the central Namib to illustrate possible winds near the southern obstacles to see how winds, dunes, and obstacles interact (Fig 1a). Winds cause the typically straight linear dune forms to wrap around the topographic obstacle. This draping morphology (marked D in Fig. 1a) is best understood in the context of two alternating winds that bring sands up as high as possible onto the obstacle. Northeasterly winds are blocked by the obstacle, causing transverse dunes to form from single-directional southwesterly winds (TD for transverse dunes in Fig. 1a).

Similar features can be found on Titan in the Belet Sand Sea. A rugged, radar-bright, topographic obstacle affects the surrounding dunes (Fig. 1b). Linear dunes are draped onto the flanks of the obstacle (D in Fig. 1b), and disruption to the dune forms near the obstacle may be transverse dunes or other forms below the radar resolution of 300 m (TD? in Fig. 1b) due to wind shadowing. Two widely separated, seasonally alternating winds, with potential orientations drawn in Fig. 1.b, could be responsible for the dune morphologies seen in this region of Titan's Belet sand sea, based on comparisons of dune morphologies here with those in the southern Namib.
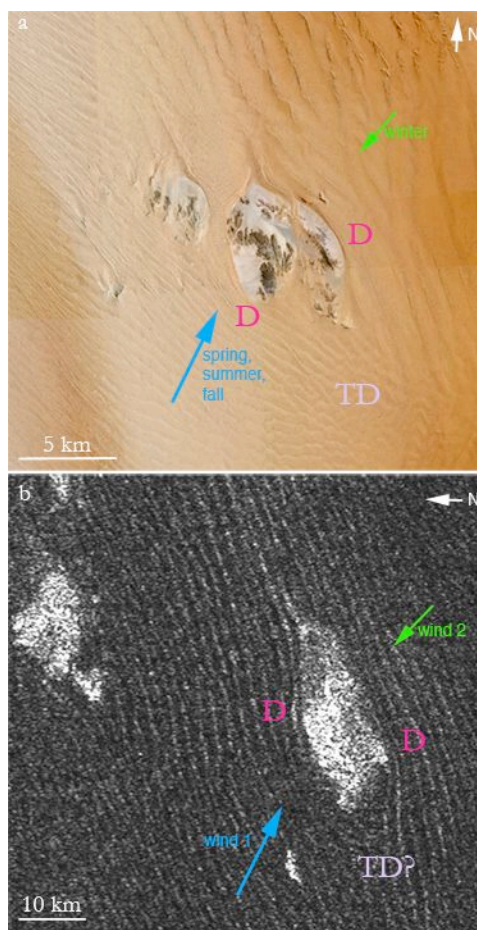

Fig. 1.a. Topographic obstacles in the Namib Sand Sea with arrows corresponding to seasonal wind directions (Lancaster 1995). b. Obstacle in the Belet Sand Sea, Titan, 7S 250W. Possible wind directions illustrated. D indicates draping of dunes onto topographic margins, TD indicates transverse dunes or disrupted forms near the obstacles.

Trade winds in Libya: Dunes in the Saharan desert have a variety of forms, but are dominantly linear and are parallel to sand transport pathways, which, for the Saharan desert, are controlled by trade winds. These winds are clockwise as a result of the Coriolis effect, sweeping in from the north at the eastern edge of the Sahara and out to the Atlantic at the western edge. The winds are a result of the Earth's rotation and latitudinal solar heating, so their broad form should not be sensitive to climatic changes. During dryer, windier Pleistocene conditions, when many linear dunes may have formed, regional trade winds were likely similar to those today. Thus, dune forms in the Sahara may be in equilibrium with current trade wind patterns [9].
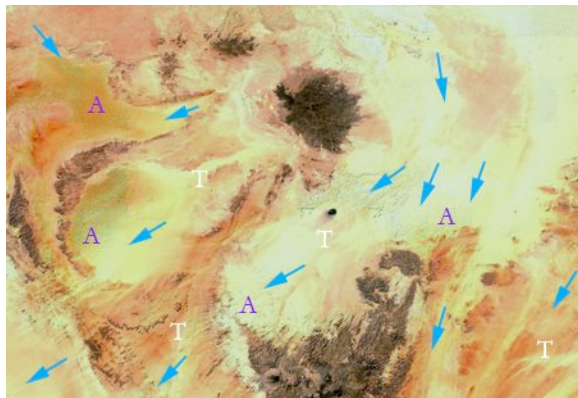

Fig. 2. Sand transport pathways for the Libyan Sahara (from [10]). Sand is yellow. Letters T indicate where transport dominates and A where accumulation is occurring. MODIS image from NASA.

Known current sand transport pathways, correlated with trade wind patterns [10], are shown for the Libyan Sahara in Figure 2. These pathways illustrate the transport of sand from northern mountains and rivers to the central and southern Saharan desert [10]. Unlike in the Namib, there are no opposing winds to confine the sand, and sediment bypassing dominates, occuring mainly over flat regions or through fluvial systems. However, locally, sand collects upwind of topographic obstacles, where winds decrease in strength and saltation is diminished [11]. Once sand begins to collect ahead of obstacles, the process feeds back and leads to upwind migration of the wind velocity minimum [10,11]. Thus, a local sand sink upwind of a topographic obstacle is established. The disruption of wind and collection of sand upwind of obstacles leads to a dearth of sand immediately downwind of obstacles and gradual regeneration of duneforms farther downwind. Results of these processes on landform morphologies – sand-rich vs. sand-sparse areas, obstacle-diverted dunes, and streaks indicating recent sand transport, can be seen clearly in a MODIS regional image (Fig. 2,

marked A for accumulation areas) and ASTER close-up image (Fig. 3.a) [4].

These relationships are also seen on Titan, albeit at lower resolutions. In regions away from sand seas, dunes are clearly separated from interdunes, and sands appear to be primarily undergoing transport (Fig. 3b). Morphological comparisons of these dune regions with those in Libya indicate the sand transport direction and related winds are uniformly from the west to the east.
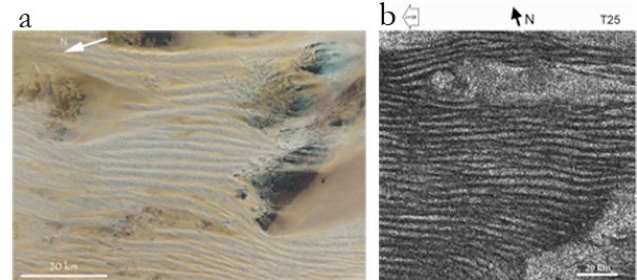

Fig. 3a. Closeup of dune forms in Libya seen in Fig.2. Sand transport is from left to right. 3.b. Similar morphologies in a Cassini radar image of dune forms in T25 region of Titan indicate sand transport direction is to the east (left to right).

Conclusions: Dune-forming winds in the Namib sand sea are widely opposed and alternate seasonally, acting to keep sands thick and to form linear dunes. When these dunes interact with topographic obstacles, their form shows evidence of these alternating winds. Similar forms on Titan indicate winds in sand seas, located mainly near the equator, could be widely separated and seasonally alternating. In the Sahara, where trade winds transport sand and form linear dunes, dune interactions with obstacles show evidence of these trade wind directions. Similar morphologies in regions of Titan poleward of the equator, where sand is more sparse than in sand seas, indicate sediment bypassing is occurring and winds are westerly. These results are correlated with previous studies of wind directions based on dune morphologies [2,5] but are anticorrelated with current GCM model wind directions [6].

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