YARDANGS AND DUNES OF IRAN'S LUT DESERT REVEAL WINDS ON PLANETARY SURFACES.

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Introduction: Winds on planetary surfaces act to create constructional landforms, such as sand dunes, and destructional landforms, such as yardangs, or wind-carved ridges. These landforms can reveal details about the action of wind on the surface, such as wind strength and direction, erodibility of the substrate, and requirements for winds and eroding agents to do work on the landscape [1]. Such relationships are especially valuable on planetary surfaces outside Earth, where direct measurement of wind, and an understanding of material properties, are patchy or nonexistent.

We use the ERA-Interim Project integration of weather station measurements and wind models in the Lut desert of Iran, with accompanying field studies, to better understand how winds interact with the surface. Our results can be extended to planets with significant atmospheres, such as Mars, Venus and Titan, where we have observed dunes and yardangs to exist.

Yardangs and dunes in Iran's Lut desert: Yardangs are created by winds stripping away erodible surface materials, generally lakebed clays or soft volcanic ash. They are long, narrow, parallel ridges having steep slopes, streamlined shapes and blunt upwind margins [2,3,4]. They are found in a variety of locales on Earth [1] and perhaps Venus [5], Mars [6,7] and Titan [8]. Dunes are ubiquitous on all of these bodies as well and have been used to determine wind directions that feed into climate models [e.g. 9]. However, determining wind direction from dunes is not always straightforward [10], especially for linear dunes, which are common on Titan [11,12,13].

The Lut desert of Iran is contained in a relatively low, hyperarid valley and contains perhaps the largest continuous field of yardangs on Earth, being more than 100 km long. Field studies of the yardangs reveal they are composed of lakebed clays, which show evidence of modification by wind and water (Fig 1). They have fine-grained, sandy corridors, sometimes with high sand volumes, and a gravel lag is present in most locations with particles ranging up to 0.5 cm in diameter. The sands and gravels, also present at other yardang locations observed by the authors in the field, likely play the role of eroding agent on the yardangs.

East of the yardang field is a large sand dune field, with sands likely derived from valley-bounding alluvial fans and materials moving southward through the yardang corridors. (Fig. 2).

A study of the winds affecting the yardangs and dunes of the Lut desert will help us understand required conditions on other planetary surfaces.

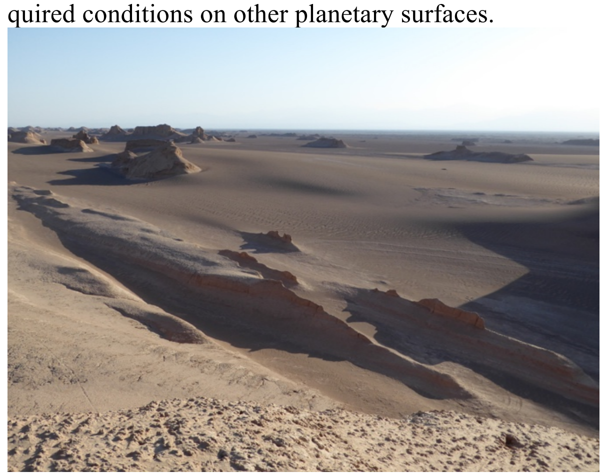

Fig. 1. Yardangs in Iran viewed in the field. Low in the saltation layer, wind fluting is evident.

The ERA-Interim Project for Winds on Earth and in the Lut: Integrating wind data obtained on Earth's surface over time with models for atmospheric circulation has produced the ERA-Interim Project wind model [14]. This has significantly improved resolution over other models and is enabling an understanding of wind directions in all locations on Earth [14]. We observe the results for the ERA-Interim wind model in the Lut desert from 1 Jan 1979 to 31 Dec 2013 at 6 month intervals, visible as colored roses in Fig. 2. Winds can be used to find sand flux directions, using the method described in [15], the green roses in Fig. 2.

In the Lut desert, wind directions clearly line up with the yardang orientations. There is even a subtle bend in the yardang azimuths, in which they range from SSE to nearly S by the southern end of the yardang field, and this is also seen in the wind orientations in the central two roses, (1510 and 1618; Fig. 2). Winds in the NE corner of the yardang field are more disparate in azimuth, and the yardangs in this location, our field site in Oct 2016, are fairly short and discontinuous, perhaps disrupted by different winds (Fig. 1).

The sand flux orientations derived from the winds in the dune fields also correlate well with the orientations of dune crestlines. In the central western portion of the dune field, dune crests trend ENE (Fig. 2). Sand fluxes here have two directions, one dominantly ESE and the other minor to the N. Given the high sediment volumes in this dune field, this alignment fits well with the bed instability mode described in [15], in which dunes grow perpendicular to the maximum gross bedform-normal transport, in this case to the SSE. Furthermore, winds in the far NW of the dunes (1511) show more disparity, perhaps a result of the mountain nearby that has significant relief. This has resulted in disrupted dune forms there. Observations of isolated linear dunes south of the main field are consistent with the fingering mode of dune growth, which results in dune elongation [15]. In this case, dunes elongate in the direction of the resultant sand flux [16,17].

Discussion. Yardangs in Iran appear to have formed by winds blowing directly down their long axes along the direction of the resultant sand flux, as revealed by the ERA-Interim model and by field observations of wind fluting along the yardangs. This means we may expect that yardangs on the planetary surfaces of Mars, Titan and Venus may also form along the resultant sand flux direction, helping establish wind directions in those locations. Dunes in the Lut desert have morphological and wind characteristics consistent with the bed instability and fingering modes of [13,14], further strengthening these models for wind requirements on dune formation and evolution on planetary surfaces. Overall, our observations of effects of wind in Iran are consistent all along the sediment transport pathway, allowing us to quantitatively reconstruct possible scenarios for the development of yardangs and dunefields according to the local climatic conditions. Studies of Iran's Lut desert have great potential for revealing more aspects of wind-dominated landscapes common on Titan [8,11], Venus and Mars, where we lack surface wind information.

References: [1] Goudie A.S. (2007) *Geography Compass 1*, 65-81. [2] Cooke R., Warren A. and Goudie A.S. (1993) *Desert geomorphology*, UCL Press. [3] Goudie A.S. (1999) in *Aeolian Env., Seds Landforms*, 167-180. [4] Mainguet M. (1972) *Le modele des gres*, Paris. [5] Greeley R. (1999) *Tech Rep*, ASU. [6] Ward A.W. (1979) *Jour Geophys Res 84*, 8147-8166. [7] Zimbelman J. et al. (2010) *Icarus 205*, 198-210. [8] Paillou P. et al. (2016). *Icarus* 270, 211-221. [9] Tokano, T. (2008) Icarus 194, 243–262. [10] Lancaster (1995), The Geomorphology of Desert Dunes. [11] Lorenz R. et al. (2006) *Science 312*, 724-727. [12] Lucas et al. (2014). GRL 10.1002/2014GL060971 [13] Charnay et al. (2015) NatGeo. [14] Dee, D.P. et al. (2001). Q.J.R. Meteorological Society, 137:553–597. [15] Courrech du Pont S., C. Narteau, X. Gao (2014). Geology, 42, 743-746. [16] Gao et al. (2015). Scientific Reports, 5, 14677. [17] Lucas et al. (2015). Geology, 43, 1027-1030.

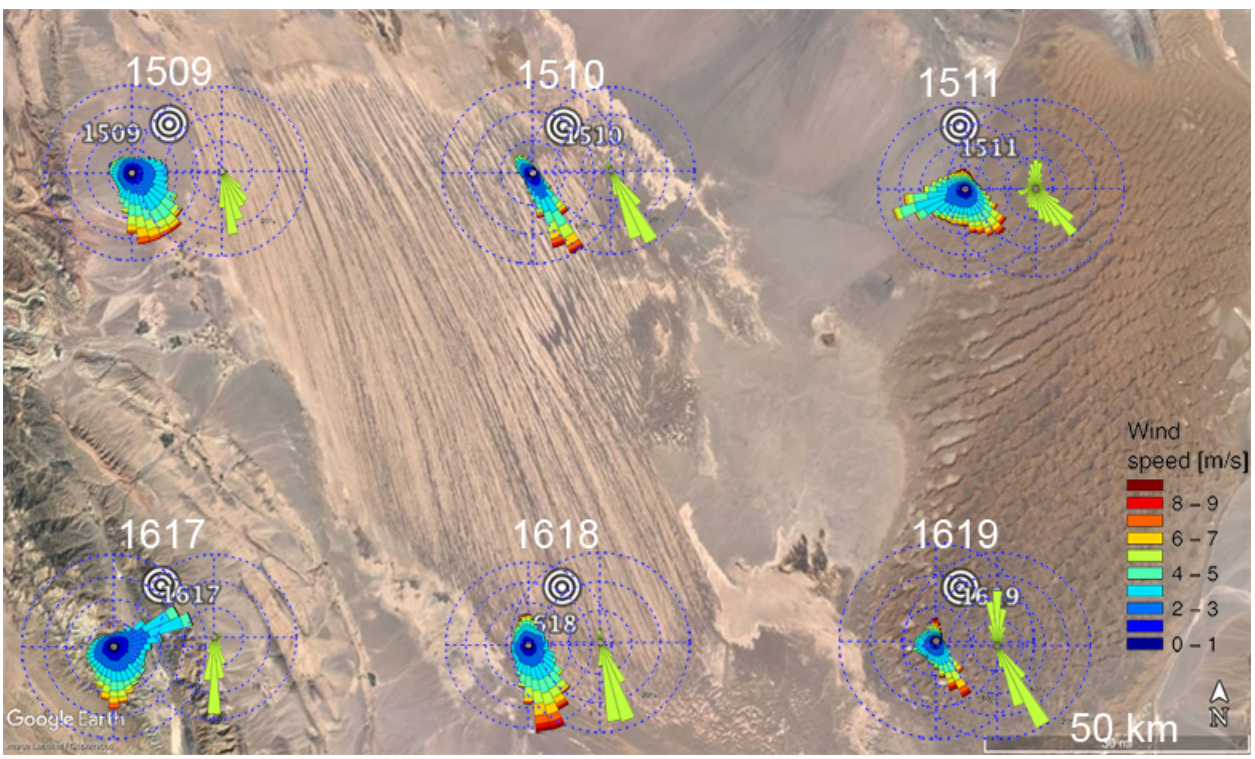

Fig. 2. Image of the Lut Desert yardangs (left, light colored clays) and dunes (right, red colored). Winds (multicolored roses, left) and sand flux (green roses, right) for each location in the ERA-Interim Project are overlain.