COEXISTENCE OF TWO DUNE GROWTH MECHANISMS IN A LANDSCAPE SCALE EXPERIMENT

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Introduction: New evidences on Earth [1-3], Mars [4] and Titan [5,6] indicate that sand availability does not control only dune shape but also the dune growth mechanism. Assuming an unrestricted, infinite sand supply, periodic dune patterns grow in height with an alignment for which the normal-to-crest component of transport is maximum [7]. In zones of low sand availability, dunes elongate in the direction of the resultant sand flux at the crest under the combined effects of reversing winds. As a consequence, dunes with different shapes, orientations and dynamics can coexist under the same multidirectional wind regime. They can be identified, classified and studied according to elementary dune types [8] and theoretical models predicting orientation, wavelength as well as migration and elongating rates [1, 9-12]. Nevertheless, models have yet to be validated by observations on the synchronous emergence and growth of the two different types of dunes in a natural aeolian environment. Hence, we performed a new type of landscape-scale experiments taking advantage of a unique experimental site at the south-eastern edge of the Gobi desert in China [11]. Here, we present the results obtained from October 2013 to November 2017, a period during which incipient bedforms grow in height by more than two orders of magnitude.

Method: The main objective of the landscape-scale experiments is to characterize and analyze the development of dunes under natural wind action using controlled initial and boundary conditions [11]. This is an original concept in geomorphology particularly well suited to validate and quantify the physical processes involved in landscape dynamics. Given the extreme conditions encountered in arid deserts and the time scales associated with dune formation, these in-situ experiments must combine high-resolution and long-term measurements, including topography and climate variables. These challenges are being met in the Tengger Desert (Inner Mongolia, China) thanks to a Franco-Chinese collaboration.

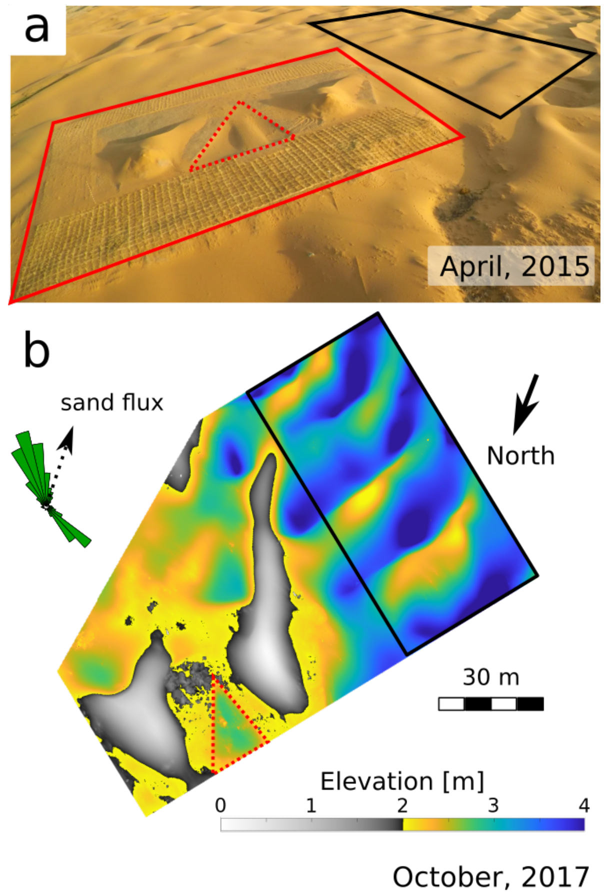

Figure 1: The elongating dune and the sand-bed experiments: (a) Aerial view of the experimental site on April 25, 2015; (b) Surface elevation on October 27, 2017. Inset shows the sand flux rose derived from the local wind data. The dashed arrow indicates the resultant flux direction on a flat sand bed. High resolution topographic surveys reveal the synchronous development of dunes according to the two dune growth mechanisms. In the sand-bed experiment (black rectangle), periodic oblique dunes grow and migrate southeastward [8]. In the elongating dune experiment (red zone), asymmetric barchans and eventually *longitudinal linear dunes extend from the initial sand piles (gray bedforms in (b)).*

Two experiments with different conditions of sand availability were conducted in parallel. In the elongating dune experiment, two conical sand piles 2.5 and 3 m high were deposited on a gravel bed surrounded by straw checkerboard (red zone in Fig. 1a). In the flat sand bed experiment, preexisting dunes were also leveled to start with a planar rectangular area of bare sand 100 m long and 75 m wide (black zone in Fig. 1a). Using our local reference system and a terrestrial laser scanner, regular high-resolution topographic surveys (>10^3 points per m^2) are used to investigate dune growth.

Results: In the sand bed experiment, the residual topography after flattening has a mean height of a few centimeters, which remains almost constant over the six first months. Then, a periodic dune pattern with a characteristic wavelength of 15 m emerges and grows in amplitude at a rate of approximately 0.6 m yr^{-1}. These two distinct phases have been analyzed in more details to investigate the linear and non-linear phases of the flat sand bed instability [12]. Most importantly for our present purpose, the periodic dunes may be classified as obliques dunes with a angle of 33° between their crests and the resultant sand flux. They migrate southeastward at a rate of 2.5 m yr^{-1} despite frequent crest reversals associated with the local bimodal wind regime (see inset in Fig. 1b).

The two sand piles are subject to the same wind regime, but show more changes in shape due to their relatively small size. In fact, they adopt quickly the classical crescentic shape of barchans associated with the current wind. Output sand fluxes along the horns reinforce this short term memory effect and we must regularly add sediment on the top of the sand piles to compensate for these losses. In addition, as the resultant flux on a flat sand bed is southward, the sand losses of the dune to the northeast feed the dune to the southwest. As a result, it increases in size more rapidly and eventually reaches the critical size for elongation [8]. Then, the arm located downwind of the resultant sand flux start to elongate on the gravel bed. Its width and height decrease linearly according to the distance from the initial sand pile, confirming that its morphodynamics is primarily controlled by wind reversals and a constant outflux along the direction of elongation [8,13]. Ultimately, it forms a longitudinal linear dune with an angle of 15° between the crest and the resultant sand flux. It elongates of 10 m from October 2016 to November 2017.

Concluding remarks: The landscape-scale experiments conducted over more than four years in the Tengger desert reveal the formation and the development of two different types of dunes depending on the conditions of sand availability. A periodic pattern of oblique dunes developing on a thick layer of sand coexists with a longitudinal linear dune elongating on a gravel bed. Considering incipient dune growth, this is the first experimental evidence for the simultaneous expression of the two different dune growth mechanism under natural wind action.

Our observations also also show that it is difficult to differentiate between the two types of dunes in the field. Indeed, both of them have a low aspect ratio and their relative orientation is often less than 25°. In addition, defects in zones of high sand availability tend to align with the fingering modes, while superimposed bedforms on the flanks of elongating dunes are likely to develop in the bed instability mode. It explains why the coexistence of the two modes of dune orientation have not been systematically documented in the past during field investigations by geographers or geomorphologists. This is not the case using remote sensing data and high-resolution topographic surveys. Planetologists will therefore have a major role to play in developing a modern understanding of active dune fields.

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References: [1] Courrech du Pont et al. (2014) Geology, *42*, 743-746. [2] Gao et al. (2015) Scientific Reports (2015) 5, 14677. [3] Lucas et al. (2015) Geology, 43, 1030. [4] Fernandez-Cascales et al. (2018) EPSL, 489, 241-250. [5] Lucas et al. (2014) GRL, 41, 60971. [6] Lucas et al. (2019) JGR-Planets, 129, 5965. [7] Rubin and Hunter (1987) Science, 237, 276–278. [8] Rozier et al. (2019) GRL, 46, 14521-14530. [9] Gadal et al. (2019) J. Fluid Mech., 862, 490–516. [10] Gadal et al. (2020) Geology, 48, 10.1130/G46987.1. [11] Ping et al. (2014) Nature Geoscience, 7, 99-103. [12] Lü et al. (2021) Proc. Nat. Acad. of Sciences USA, 18 , e2024105118. [13] Gao et al. (2021) JGR-Earth Surface, 126, e2020JF005913.