Genesis of dune fields under unidirectional wind with sand input flux control: an experimental approach

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Introduction: Earth deserts show a rich variety of dune shapes from transverse to barchan, including star and linear dunes, depending on the history of wind regimes (strength and variability) and sand availability [1]. In desert, exposed to one wind direction, dunes perpendicular to the wind direction are found to be transverse or barchan, only sand availability plays a major role on their formation and evolution. However, the evolution time scale of such structures (about several years) limits our investigation of their morphogenesis and morphodynamics. We use here, a laboratory experiment able to considerably reduce space and time scales by reproducing millimeter to centimeter subaqueous dunes, and allowing the control of environmental parameters such as the wind regime (multi-winds, unidirectional wind, [2,3]) and recently, amount of sediment. This set up allows us to characterize more precisely the different modes of dune formation and long-term evolution, and to constrain the physics behind the morphogenesis and dynamics of dunes fields. Indeed, the formation, evolution and transition between the different dune morphologies are better understood and quantified thanks to a new experimental setting constitued by a remote continuous source of sediment (closer to what happens in sand desert): a sand distributor that enables a fine control of the input sand flux. In unimodal wind condition, we will monitor and quantify the transition between stable transverse dunes to barchan's field by modifying the sand supply.

Methods: Our experimental setup allows reproducing subaqueous dunes by controlling environmental parameters, the wind regime (number of winds, frequency, strength…). It consists of a water tank with inside, a disk covered by sand over a plate. The quick translatation moving of the plate (with a speed greater thatn the transport threshold) in one direction triggers a unidirectional wind on the opposite direction of its motion. Then, the plate goes back on it initial position by a slow motion able to prevent grain motion. This movement of roundtrip is called a period. If needed, the rotating disk can reproduce the different direction of the wind to reproduce more complex dunes by multi-winds. The sand bed evolution is followed by a camera top setting and the topography of features is retrieved by a scanner (laser sheet) that acquired profiles at given time points. This set up has already been used successfully by Hersen [2] and Reffet [3], where they studied formation and evolution of barchan, transverse and longitudinal dunes.

Here, in the aim to improve the constraint and the characterization of the transition between transverse and barchan dune fields by the control of input flux sediment, we set a sand distributor able to continuously feed our system in sand. By a translation movement and the rotation of an endless screw, the sand distributor can deposit a sand line just at the entrance of the disk.

We are now able to control the input mass flow of sand per unit length, Qin (mm2/T), and thus to precisely explore different input sand flux by modifying only the frequency of the sand line deposition on the disk (fig. 1). We ran the sand distributor experiment between 0.01 (low) and 0.82 mm2/T (to high sand supply, greater than the saturation flux of our experiment).

Results: We observed three dune morphology domains (Fig. 2):

1. For a low sand availability: the stable "barchans dune fields" domain: The sand line gets the time to decay into barchans before the deposit of the following line. In final, by feeding constantly the system, we observed the formation of a stable field of barchans.

2. For an intermediate sand availability: a transverse dune is created where barchans are continuously ejected. More collisions are counted compared to the low sediment availability morphology domain and superimposed patterns are observed on the transverse dune. The transverse is initially quite flat, and gets bigger over time and input sand flux to tends to a final mature shape. This second regime is defined as the "barchanoïd ridge" domain.

3. For a high sand availability, no more ejections of barchans are observed and a big transverse dune is present with an abrupt avalanche face. This domain is called "the transverse dune stable" domain.

A summary of results is shown with the "phase diagram" in figure 3. This latter contains a description of the three morphologies domains and a 3D scan analysis for domains 2 and 3. The plot corresponds to an estimation of the time necessary to reach a certain value of sand ejected per unit area from the front of the transverse dune, function of imposed experimental Qin. This time is normalized by the period of the sand line deposition of the sand distributor (T_{dist}). It demon

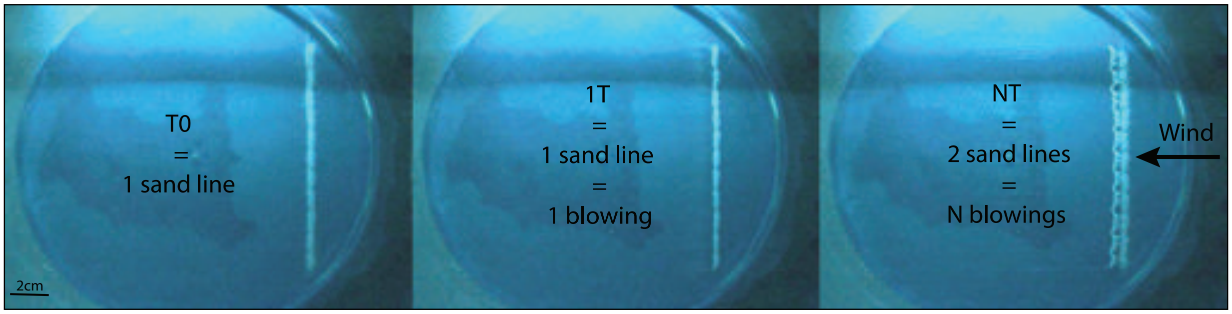

Figure 1: Principle of sand deposit on the disk by the sand distributor after one and n periods of the tray

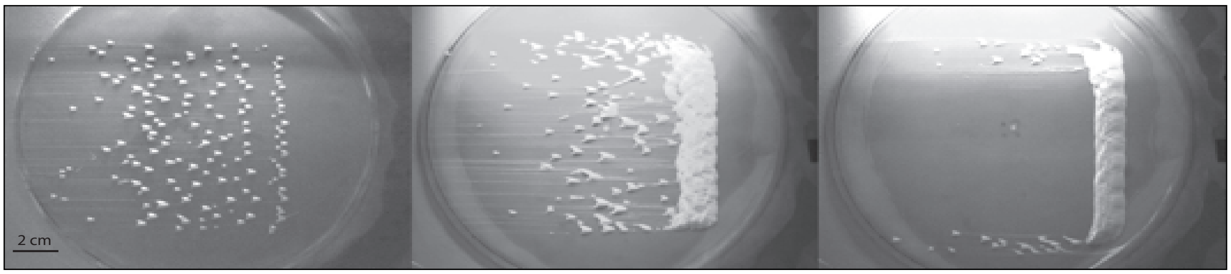

Figure 2: Dune field morphologies under unidirectional wind depending on sand supply – Right to left: low sand availability (Qin 0.017mm^2/T, barchans fields), medium availability (Qin 0.11mm^2/T, barchnoid ridge), high sand availability (Qin 0.24mm^2/T, transverse dune)

strates that the time necessary to reach a certain value of sand ejected gets bigger with the increasing of input sand. It reflects the fact that, as we feed our dune field with more and more sand, we counter the destabilization of the deposited sand line into barchans and allow it to grow in size and aspect ratio, to a point that it finally forms a mature transverse dune with an abrupt avalanche face that traps the sand. At this moment, the big transverse dune does not eject barchans any more.
Moreover, barchnoid ridge seems the most common morphology on earth desert. This morphology is often found along the beach's coasts, area that offers a linear source of sediment [5], very close to our experimental conditions. We thus related this experimental study with a terristrial area (The Maroc south coast) that presents the same condition and the same different type of dunes morphologies due to local difference in availability of sediments.

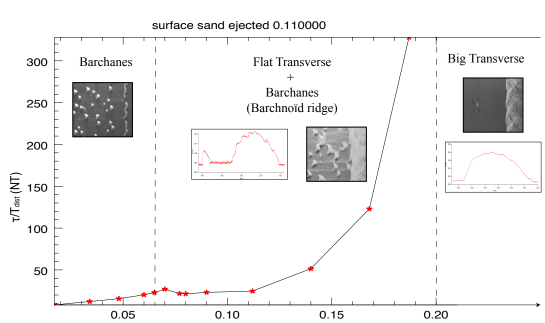

Figure 3: Time necessary to reach a certain value of surface sand ejected over Qin

Conclusion: The running of a set of experiments under an unidirectional wind, and the control of the input sand flux revealed the formation of three morphological domains for dune fields: barchan dune field, barchnoid ridge and a big transverse dune. It appears in presence of a sand input flux, the dunes can growth and spread over time by stability. Inspired by analytical model of [4] about the physic processes of the growth and migration of a dune fields, we would like in a near future to improve our physic understanding of the behavior of dune morphologies and their respective migration speeds in the three domains of stability identified. Also, the next step will be to perform experiments under bimodal wind conditions in order to better constrain the formation mode of linear dunes, depending only on the input sand flux [6]. These kind of studies can farther help us to explain more precisely in different wind history and sand supply, these patterns state that should emerge and, by applying the relevant scale law, to apply this laboratory work to terrestrial and planetary (Venus, Mars and Titan) desert dynamics.

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