AEOLIAN LANDSCAPE DYNAMICS FROM SOURCE TO SINK

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Introduction: Wind-blown sand and dust shapes singular landscapes in arid environments. On Earth, the contributions of aeolian processes to the evolution of continental surfaces and to their mass exchanges with oceans and the atmosphere are still sensitive issues subject to considerable uncertainties. Compared to sediment transport in rivers, this is because wind transport is not associated with a well-identified channel network that directly links sand and dust production (source) to accumulation (sink) areas [1]. It is the same on aeolian-dominated planetary surfaces, such as Mars, despite the negligible role of water in more recent eras. However, linking landscape dynamics to the aeolian sediment routing system becomes essential to quantify the geomorphic controls of aeolian processes on arid landscapes at all scales.

By describing sandflows throughout the Sahara, *Wilson* [2] has established the basis for source-to-sink consideration in aeolian environments. This pioneering work revealed that deflation can be on the same order of magnitude as river erosion. Nevertheless, since most sandflows eventually end up in a river or in the sea, it was impossible to balance the sediment budget on such a continental scale. In this respect, smaller aeolian systems, as closed as possible, seem more appropriate to investigate sediment transport and morphogenic processes according to the local wind regimes. Furthermore, new remote sensing imagery and dating techniques together with more accurate wind data and a deeper understanding of dune dynamics, now provide more observational and theoretical evidences on sandflows. Taking advantage of them, we focus here on southeastern Iran to study the aeolian landforms of the Lut Desert (Fig. 1).

Sandflows and aeolian landforms: The Lut Desert is located in an endorheic watershed with a hyper-arid continental climate. From late winter to early spring, northerly or southerly storm winds prevail, driven by meridional pressure gradients. In summer, diurnal variations in the thermal structure of the basin and the surrounding mountains generate strong north-northwesterly winds during the day and easterly katabatic winds at night.

We analyze the ERA5-Land surface wind data [3] to describe the different wind regimes throughout the Lut Desert. To the Northwest, sandflows are mainly south-southeastwards. Then, they roll up counter-clockwise into a vortex spiral located above the center of the desert. These converging sandflows form an internal aeolian routing system, turning the Lut region into a major sand trap (Fig. 1).

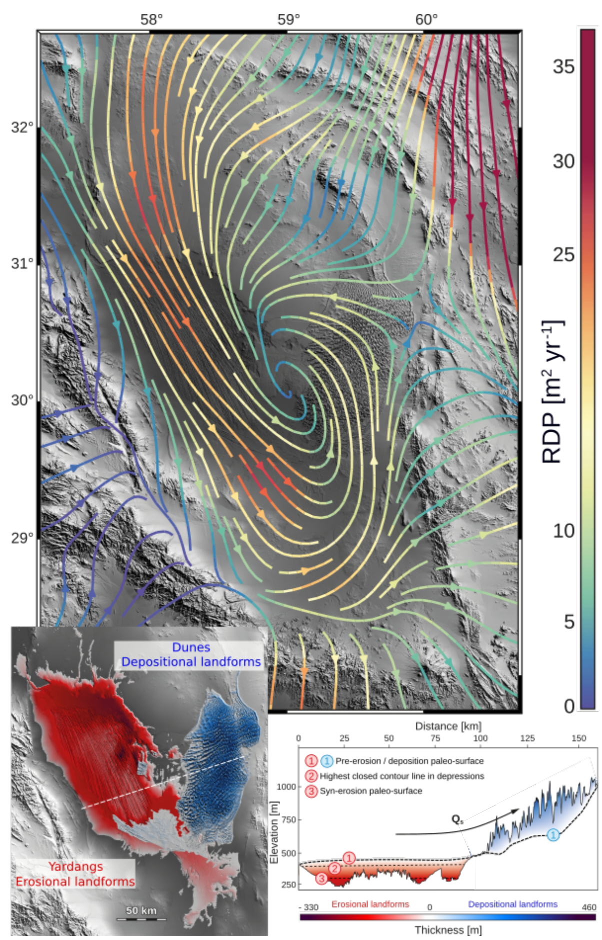

Figure 1: Aeolian Landscape dynamics in the Lut Desert. Sandflows predicted from the ERA5-Land wind data (top). Map and cross-section of the present-day topography and paleosurface reconstructions (bottom). In contrast with fluvial-dominated landscapes, aeolian deposition can occur up the slope, at higher elevation than aeolian erosion.

West of the Lut Desert, different landforms are carved with an NNW-SSE orientation in the continental fined-grained deposits of the sedimentary basin. Among them, the most striking scenery is a field of mega-yardangs reaching heights of more than 80 m. Another one, less obvious but larger, is a closed depression surrounded by a set of smaller hollows. The major depression has a maximum depth of more than 200 m and corresponds to an imbricated endorheic area surrounding the field of mega-yardangs. All these closed erosional features must be of aeolian origin because no other transport agent than the wind could have evacuated the abraded material or the sediments accumulated by other surface processes during their excavation [4].

Within and downwind of the main depression, different dune systems develop. Trains of barchan dunes can locally emerge in the corridors between yardangs. To the southeast, at the mouth of the yardang field, longitudinal dunes and transverse bedforms coexist with a direction of elongation and migration that regularly bend from southeast to east [5-7]. They eventually reach the southern edge of a sand sea that covers the east of the Lut Desert. The central part of this sand sea is dominated by giant transverse dunes migrating toward north-northeast with superimposed bedforms of different sizes and orientation [8].

All areas are exposed to sand-transporting winds of similar strength blowing at different times of the years, so that the cyclonic transport pattern results from a continuous transition from unimodal to more complex wind regimes. This transition is evidenced by the different types of active bedforms along the sandflow paths, from trains of barchan dunes to star dunes through longitudinal and transverse dune patterns [9,10]. Locally, the divergence of sandflows gives short-term erosion and deposition rates of 0.1 mm yr^{-1}. Integrating sandflows perpendicularly to the transport direction downwind of the mega-yardang field and upwind of the sand sea, we estimate output and input discharges of ~0.8 and ~0.4 $x10^6$ $m^3 yr^{-1}$ over the last 40 years [4].

Long-term transport properties: Based on morpho-sedimentary mapping (Fig. 1) and cosmogenic surface dating, we characterize the spatial and chronological organization of the aeolian landforms of the Lut Desert to quantify their combined dynamics over the last million years. All volumetric reconstructions and their time constraints give long-term erosion and deposition rates of the order of 0.1 mm yr^{-1}. From the material excavated from the depressions, we also estimate erosion discharges of ~$0.6x10^6$ $m^3 yr^{-1}$ over the past ~2.35 Myr, and of ~$1.2x10^6$ $m^3 yr^{-1}$ over the last ~109 kyr. From the sand captured in the dune fields, we assess a deposition discharge of ~$0.4x10^6$ $m^3 yr^{-1}$ over the past ~2.35 Myr.

Concluding remarks: We map the modern sandflows of the Lut Desert, along which we evaluate the volume and chronology associated with the excavation of mega-yardangs upwind and the formation of giant dunes downwind. Sediment discharges deduced from long-term erosion and deposition are of the same order of magnitude as short-term and medium-term sand discharges derived from wind data and dune morphodynamics [4]. At the scale of the internal aeolian sediment routing system, we establish an overall sediment budget constrained by the joint development of the erosional and depositional landforms. Given the extent of terrestrial drylands, hot or cold, our quantitative results reveal the full potential of source-to-sink methods to document how aeolian processes drive landscape dynamics and closely link the evolution of continental surfaces to atmospheric circulations. Except for dating, similar studies can also be implemented on other aeolian-dominated planetary surfaces of the solar system. They will translate into new research opportunities, notably to decipher modern and past climatic conditions on Earth, Mars, or Titan from the feedbacks between aerodynamics, granular mechanics, and landscape dynamics.

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