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Evolution of megaripples from a flat bed

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ABSTRACT

Megaripples in Nahal Kasuy in the southern Negev desert of Israel are characterized by a mean wavelength of about 70 cm and by a bimodal distribution of coarse and fine particle sizes, the latter of which is necessary for megaripple formation. The goal of the following work was to explore long-term megaripple evolution and its dependence on wind power and directionality and to study the grain-size distribution by advanced grain-size analysis as a process indicator. Temporal dynamics of wind power such as drift potential (DP) were measured, and samples taken from megaripple crests were analyzed for grain size distribution (GSD) as the megaripple evolved from a flat bed. The GSD was initially unimodal, but it became more bimodal as the ripples grew. At the ripple crest, GSD is sensitive to storms that blow from directions perpendicular to the prevailing winds. These storms can slow the process of ripple recovery as the layer of coarse particles at the crest become finer. After two years the megaripples recovered almost fully, but a series of storms destroyed them and created small ripples in their place. Such complete ripple destruction can occur only when the megaripples are high enough (~5 cm in Nahal Kasuy), i.e., the crest must be above the saltation layer. Thus, periods of megaripple construction are ended by destructive episodes due to strong storms, and the process repeats itself. At the larger scale, the ripple dimensions of different plots may cause them to respond differently to the same storms.

1. Introduction

Aeolian ripples, which form regular patterns on sandy beaches and desert floors, indicate the instability of flat sand surfaces under the wind-induced transport of sand grains. Two different kinds of sand ripple are observed in nature—normal ripples and megaripples (Bagnold, 1941; Sharp, 1963). Their main features are summarized in Table 1. Megaripples from various locations are shown in Fig. 1, together with the grain size distributions (GSDs) of samples taken from the crests.

Megaripples have been described in many places, among them the Kelso Dunes and Coachella Valley sands in Southern California (Sharp, 1963), in the Libyan desert (Bagnold, 1941; El-Baz, 1986), the northern Sinai (Tsoar, 1990), Swakopmund, Namibia, (Fryberger et al., 1992), northeastern Iceland (Mountney and Russell, 2004), the coast of northeastern Brazil (Yizhaq, 2008) and on the Great Sand Dunes National Park and Preserve in south-central Colorado (Zimbelman et al., 2009). Enormous megaripples were documented in Carachi Pampa, Argentina, at a height of 4000 m above mean sea level (Milana, 2009). Composed of volcanic pebbles, these megaripples were formed by the action of extremely strong winds (probably the strongest winds known on Earth, ~400 km/h). Megaripple wavelengths were up to 43 m and their heights were about 2.3 m (Milana, 2009) with a crest maximum grain size of 19 mm.

The physical mechanism responsible for the formation of sand ripples is the action of the wind on loose sand. When wind strength exceeds some threshold, grains displaced by the direct action of the wind are lifted into the air. However, even strong winds cannot keep sand grains suspended indefinitely (they are too heavy), and therefore, they eventually fall to the ground. During their flight, sand grains reach velocities that are approximately equal to that of the wind. Upon impact with the ground surface, the grains impart energy and momentum into the sand and eject other grains. For sufficiently high wind velocities, the bombardment by sand grains accelerated by the wind generates a cascade process, creating an entire population of saltating grains "hopping" on the sand surface. When the saltating, high-energy grains collide with the bed, their impacts eject smaller, lower energy grains, termed reptons (Andreotti, et al, 2004) . The windward slope, characterized by small bumps, is subjected to more impacts than the lee slope. As such, the flux of reptons is higher uphill than downhill, which causes the bumps to increase in size. Size analyses of grains from different parts of the megaripples and from normal ripples showed that a bimodal mixture of grain sizes is needed for megaripple formation and that the coarse particles are more abundant at the crest (Isenberg et al., 2011; Yizhaq et al., 2009).

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Table 1
Main features of normal Aeolian ripples and megaripples.

	Normal ripples	Megaripples
Wavelength (λ)	Up to 30 cm	0.3–43 m
Ripple index (ratio of λ to ripple height, RI)	>15	<15
Time scale	Minutes	Days and years
Sorting	Unimodal distribution of grain sizes (typically 0.100–0.300 mm in diameter)	Bimodal distribution of grain sizes, with coarse grains 0.7–4 mm in diameter
Basic processes	Saltation and reptation (creep) of fine grains	Saltation and reptation of fine grains and creep of coarse grains.

In a recent study (Isenberg et al., 2011), we used a photogrammetric technique to show that megaripples start out as normal ripples and grow due to a rapid coarsening process. Their evolution is a function of wind power and of the variability in wind direction. The final wavelength is not simply correlated to the mean saltation length, but rather, it develops through the interactions between ripples of different sizes (Isenberg et al., 2011; Yizhaq et al., 2009). Larger wavelengths probably reflect longer development times and stronger winds, characteristics common to bedforms in different environments, such as ripples and dunes in rivers, oceans, and deserts (Werner, 1995).

The megaripple system exhibits self-organization, such that spatio-temporally ordered structures emerge spontaneously (Anderson, 1990; Kocurek and Ewing, 2005; Werner, 1995). During

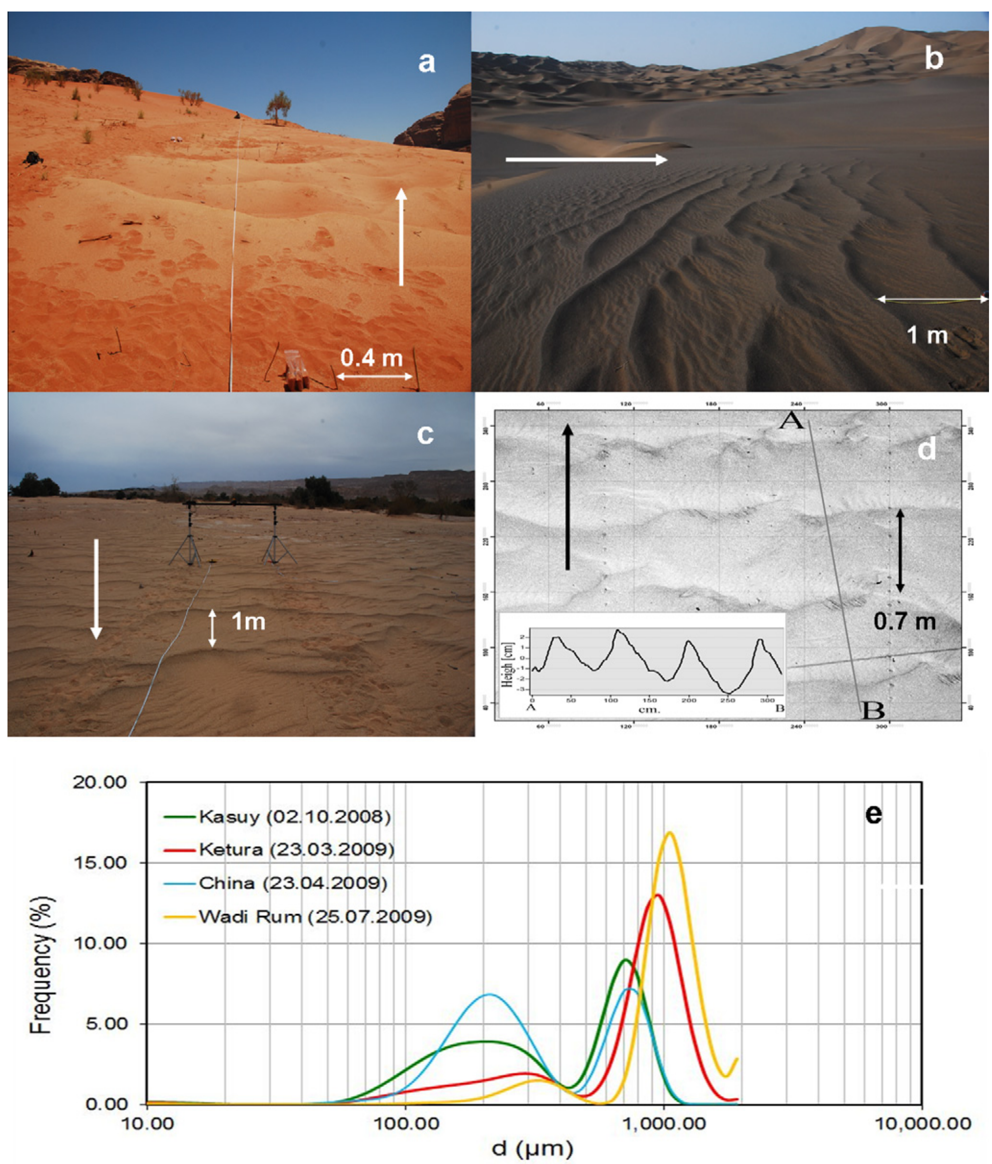

Fig. 1. (a) Megaripples from Wadi Rum in Jordan. (b) Megaripples in the Sanshan Desert, western Xinjiang, China. The average wavelength is about 1 m (the length of the measuring tape in the lower right hand corner of the picture is 1 m). (c) Megaripples in Ketura in the Arava valley, Israel. (d) Megaripples in Nahal Kasuy in Israel and a profile measured using photogrammetry (plot F before flattening). The arrows in images (a) through (d) indicate the prevailing wind direction. (e) Typical bimodal (coarse and fine sand) grain size distribution of samples taken from the crests. Sample dated are shown on the figure.