The initiation and evolution of transverse dunes: A literature review

Paul Jarvis

1 Introduction

2 Fluid flow

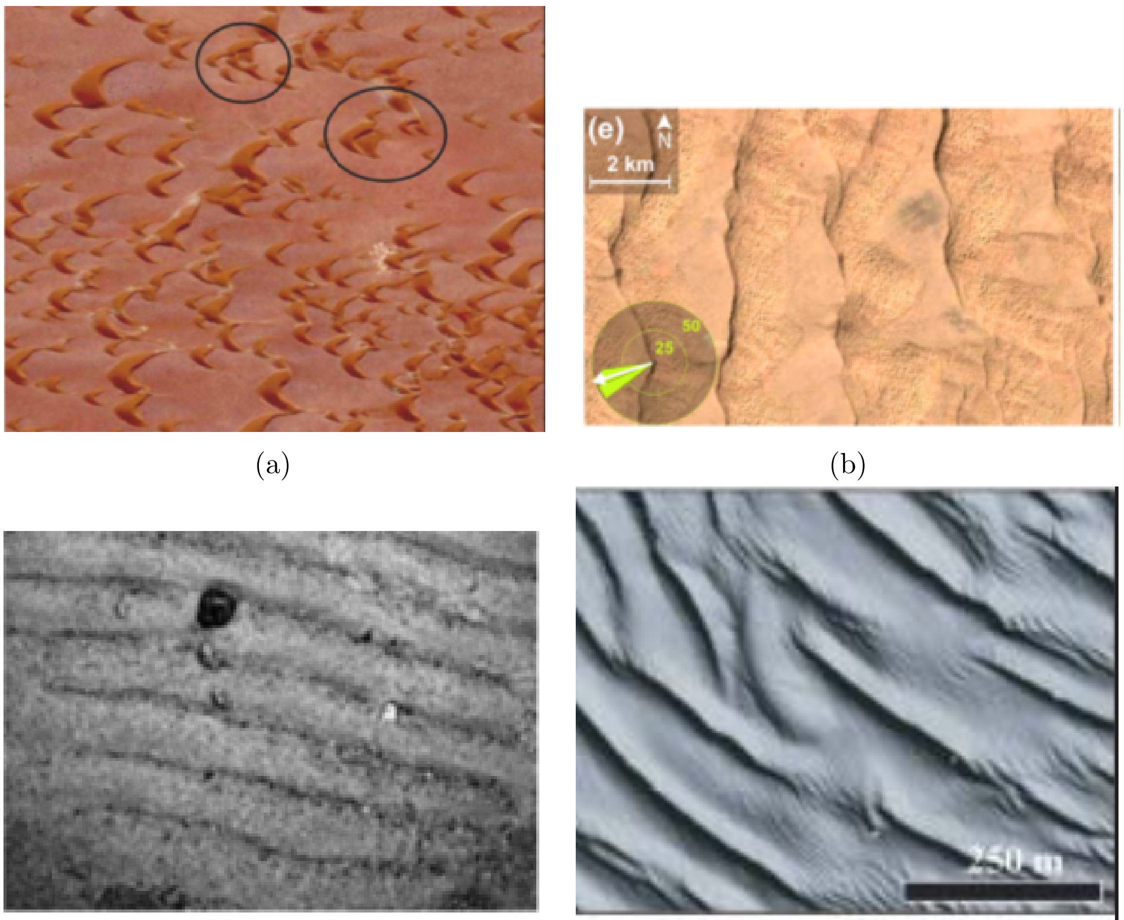
The first consideration when considering sedimentary processes is the driving flow. Although it is possible for sediment transport to occur in laminar flow (Charru and Mouilleron-Arnould, 2002; Charru et al., 2004; Mouilleron et al., 2009), the majority of research into the dynamics of ripples and dunes has considered turbulent conditions (Andreotti et al., 2002; Kroy et al., 2002; Langlois and Valance, 2007; Wierschem et al., 2008; Franklin and Charru, 2011; Charru and Franklin, 2012; Andreotti et al., 2012; Franklin, 2015)

3 Types of sedimentary bedforms

There are a variety of different types of sedimentary bedforms found in nature, with the diversity reflecting the hugely variable conditions under which erosion and sedimentation processes occur. Most generally, there are two types of environment in which bedforms can be found: subaerial; and subaqueous. Subaerial bedforms result from the flow of air over a granular medium, such as a desert, beach or a volcanic ash deposit. Subaqueous bedforms are created by the action of water, and can be found on river-beds, shallow coastel regions, or deeper continental shelves. Within this hierarchy, further variability in shape and size of bedform originates from spatial and temporal variations in flow-speed, flow-depth, particle size, particle density and local topography. Examples of different types of bedforms are shown in figure 1.

4 Modes of sediment transport

In order for an overlying fluid to displace any sediment, it is neccessary for the shear stress exerted on the bed surface to be sufficient to lift a particle up and over its neighbours.



(a) (b)

(c) (d)

Figure 1: Examples of bedforms. a) A field of barchan dunes from Morocco. (Durán et al., 2011). b) Transverse dune field in the East Taklamakan desert, China (Gao et al., 2015). Subaqueous ripples in Zion National Park, USA (Andreotti et al., 2012). d) Large subaqueous dunes in San Francisco Bay, USA (Barnard et al., 2006).

Hence, the lift force provided by the flow must be sufficient to overcome gravity. This balance is quantified through the Shields number

$$\Theta = \frac{\tau}{(\rho_{\mathrm{p}} - \rho_{\mathrm{f}})gd}, \tag{1}$$

where τ is the surface shear stress, ρ_{p} and ρ_{f} are the densities of the particles and fluid respectively, $g = 9.81$ m s^{-2} is the acceleration due to gravity and d is the particle diameter. Hence, there is some critical value of the Shields number at which motion becomes possible.

Broadly, there are three mechanisms describing how sediment can be transported by an overlying fluid (Bagnold, 1941). For Shields numbers just above the threshold for motion, bedload transport (reptation) will occur, whereby particles slide and roll across the surface. With increasing flow velocity, these particles can be lift higher into the flow, and 'hop' across the bed following ballistic trajectores, a process called saltation. Once the size of turbulent fluctuations in the vertical fluid velocity are comparable to the settling velocity of the particles, they can become suspended in the fluid and are transported as suspended load. For the purpose of the rest of this review, all sediment transport can be assumed to occur through reptation or saltation unless otherwise specified.

There is a finite limit to the amount of sediment a given flow can transport. This is quantified through the saturated sediment flux q_{sat} (Bagnold, 1941; Owen, 1964). Therefore, there must also be a lengthscale L_{sat} and/or timescale T_{sat} over which this saturation can be achieved. Expressions for q_{sat} scales depend on the mechanics of transport but a general partial differential equation for the sediment flux q can be given as (Charru et al., 2013)

$$T_{\mathrm{sat}} \frac{\partial q(x,t)}{\partial t} + L_{\mathrm{sat}} \frac{\partial q(x,t)}{\partial x} = q_{\mathrm{sat}} - q(x,t). \tag{2}$$

This equation is valid for a unidirectional flow.

5 Inititation of transverse structures

6 Coarsening

7 Open questions

References

B. Andreotti, P. Claudin, and S. Douady. Selection of dune shapes and velocities Part 1: Dynamics of sand, wind and barchans. *Eur. Phys. J. B*, 28:321–339, 2002.

B. Andreotti, P. Claudin, O. Devauchell, O. Durán, and A. Fourrière. Bedforms in a turbulent stream: ripples, chevrons and antidunes. *J. Fluid Mech.*, 690:94–128, 2012.

R. A. Bagnold. *The physics of blown sand and desert dunes.* Methuen & Co., first edition, 1941.

P. L. Barnard, D. M. Haynes, D. M. Rubin, and R. G. Kvitek. Giant Sand Waves at the Mouth of San Francisco Bay. *Eos*, 87, 2006.

F. Charru and E. M. Franklin. Subaqueous barchan dunes in turbulent shear flow. Part 2. Fluid flow. *J. Fluid Mech.*, 694:131–154, 2012.

F. Charru and H. Mouilleron-Arnould. Instability of a bed of particles sheared by a viscous flow. *J. Fluid Mech.*, 452:303–323, 2002.

F. Charru, H. Mouilleron, and O. Eiff. Erosion and deposition of particles on a bed sheared by a viscous flow. *J. Fluid Mech.*, 519:55–80, 2004.

F. Charru, B. Andreotti, and P. Claudin. Sand Ripples and Dunes. *Annu. Rev. Fluid. Mech.*, 45:469–493, 2013.

O. Durán, V. Schẅammle, P. G. Lind, and H. J. Herrmann. Size distribution and structure of Barchan dune fields. *Nonlin. Processes Geophys.*, 18:455–467, 2011.

E. M. Franklin. Formation of sand ripples under a turbulent liquid flow. *Appl. Math. Model.*, 39:7390–7400, 2015.

E. M. Franklin and F. Charru. Subaqueous barchan dunes in turbulent shear flow. Part 1. Dune motion. *J. Fluid Mech.*, 675:199–222, 2011.

X. Gao, C. Narteau, and O. Rozier. Development and steady states of transverse dunes: A numerical analysis of dune pattern coarsening and giant dunes. *J. Geophys. Res. Earth Surf.*, 120:2200–2219, 2015.

K. Kroy, G. Sauermann, and H. J. Herrmann. Minimal model for aeolian sand dunes. *Phys. Rev. E*, 66, 2002.

V. Langlois and A. Valance. Initiation and evolution of current ripples on a flat sand bed under turbulent water flow. *Eur. Phys. J. E.*, 22:201–208, 2007.

H. Mouilleron, F. Charru, and O. Eiff. Inside the moving layer of a sheared granular bed. *J. Fluid Mech.*, 628:229–239, 2009.

P. R. Owen. Saltation of uniform grains in air. *J. Fluid. Mech.*, 20:225–242, 1964.

A. Wierschem, C. Groh, I. Rehberg, N. Aksel, and C. A. Kruelle. Ripple formation in weakly turbulent flow. *Eur. Phys. J. E*, 25:213–221, 2008.