Available online at www.sciencedirect.com
ScienceDirect
Sedimentary Geology 202 (2007) 281 – 296
Sedimentary Geology
www.elsevier.com/locate/sedgeo

Influence of superimposed bedforms and flow unsteadiness on formation of cross strata in dunes and unit bars

A.J.H. Reesink *, J.S. Bridge

Department of Geological Sciences, Binghamton University, P.O. Box 6000, Binghamton, NY 13902-6000, USA

Abstract

Formation of angle-of-repose cross strata on the lee side of dunes and unit bars is dependent on three main grain-sorting mechanisms: (1) presorting of sediment that arrives at the lee side of the bedform, related to superimposed bedforms and longer-term variations in water flow and sediment transport; (2) sorting due to differential deposition of sediment on the lee side and associated grain flows, and; (3) movement of sediment on the lee side by the water currents in the lee side flow-separation zone. Although most emphasis has been put on mechanism (2), recent field and experimental studies of the dynamics of sandy and gravelly dunes and unit bars show that mechanism (1) is at least as important.

Bedforms superimposed on the backs of dunes and unit bars are ubiquitous, and are composed of size sorted sediment. These superimposed bedforms travel faster than the host bedform and overtake it. If the overtaking bedform has a relatively large height, the lee side of the host bedform becomes reduced in slope and decelerates as the superimposed bedforms overtakes. This results in a "reactivation surface" that is commonly lined with relatively fine-grained sediment. However, if an overtaking superimposed bedforms has a relatively small height (e.g., a ripple or bedload sheet), the lee side of the host bedform remains at the angle-of-repose. The sediment within the overtaking bedform forms a relatively thick cross stratum on the lee side of the host bedform. Arrival of the trough of the next superimposed bedform at the crest of the host bedform results in deposition of a relatively thin stratum. The thickness of the cross stratum couplet formed in this way is related to the height and length of the superimposed bedform and the height of the host bedform, which are related to flow depth and dimensionless bed shear stress on the back of the host bedform. The grain size of the sediment in the superimposed bedforms varies with their height, and this is reflected in the grain size of successive cross strata. The formation of cross-stratified open-framework gravel is associated with size sorting of sand and gravel in superimposed bedforms, and further size sorting associated with flow-separation on the lee side of large host bedforms.

Keywords: Cross-stratification; Cross strata; Dunes; Unit bars; Superimposition; Bedforms; Flow unsteadiness

1. Introduction

Cross-stratification formed by dunes and unit bars is the most common sedimentary structure in river-channel deposits, and is common in many other depositional environments. Ancient cross-stratified deposits are widely used to interpret conditions of flow and sediment transport, such as water depth, flow velocity magnitude and direction during deposition (review in Bridge, 2003). Cross-strata are defined primarily by spatial variation in grain size, which in turn affects spatial variation in permeability, and the movement of fluids through cross-stratified deposits. Grain size sorting in cross strata is determined by three main factors (Fig. 1): (1) presorted sediment that arrives at the brink point, related to

* Corresponding author.
E-mail address: areesin1@binghamton.edu (A.J.H. Reesink).

0037-0738/$ - see front matter. Published by Elsevier B.V.
doi:10.1016/j.sedgeo.2007.02.005

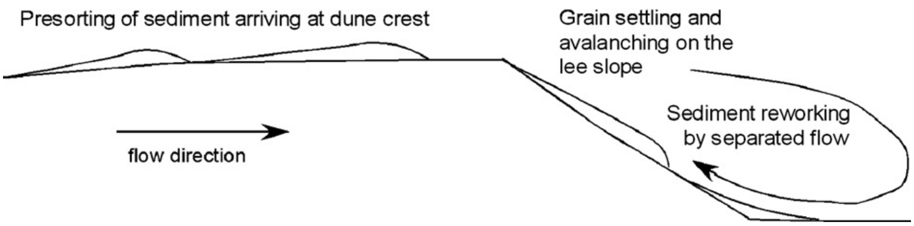

Fig. 1. Controls on the grain size sorting in cross strata formed by dunes.

superimposed bedforms and longer-term unsteadiness in water flow and sediment transport; (2) sorting due to differential deposition of sediment on the lee slope and associated grain flows, and; (3) movement of sediment on the lee side by water currents in the lee side flow-separation zone. Factor (2) is commonly taken as dominant. However, recent experimental and field studies indicate that the role of bedform superimposition (e.g., ripples or bedload sheets on dunes; ripples or dunes on unit bars) in the formation of cross-stratification is much more important than commonly appreciated.

This paper will start with a short outline of our understanding of the formation of cross strata, identify gaps in our knowledge, and address the common misconception that grain flows cause the formation of most, if not all, cross-stratification. Then, new experimental and field data will be presented that demonstrate the importance of presorting of sediment, specifically superimposition of bedforms, in determining the grain size sorting in cross strata. Finally, further research on this topic is suggested in order to allow for more accurate prediction of spatial variation in porosity and permeability (of concern to hydrogeologists and petroleum geologists), and to improve quantitative interpretation of ancient flow and sediment transport conditions.

2. Controls on the grain size sorting in cross strata formed by dunes and unit bars

2.1. Presorting of sediment due to superimposed bedforms and longer-term unsteadiness in water flow and sediment transport

2.1.1. Long-term flow unsteadiness

Changes in the rate and grain size of sediment supply to the crests of bedforms may be related to relatively long-term flow unsteadiness associated with weather-related floods, bank-slumps, and cyclical variations in discharge such as caused by snowmelt and freezing in cold regions, or tides. The grain size of bedload is expected to decrease as flow stage and bed shear stress decrease (review in Bridge, 2003). It has been suggested that relatively coarse-grained cross strata are deposited at high flow stage, and that fine-grained cross strata are deposited at low flow stage (Smith, 1972, 1974; Steel and Thompson, 1983; Smith, 1985). Alternations of sandy cross strata and muddy drapes in tidal dunes (called tidal bundles: Fig. 2) are generally taken to be formed by alternating periods of tidal current flow and tidal slack water (e.g. Visser, 1980; Allen, 1982; Nio et al., 1983). Systematic variation in the thickness of tidal

Fig. 2. Tidal bundles in an excavation in the Oosterschelde (courtesy of Dr. Van den Berg). Height is approximately 2 m.