TEMPORALLY DYNAMIC, SPATIALLY STATIC, COBBLE BEDFORMS IN REVERSING SUBTIDAL CURRENTS

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ABSTRACT: Flow-transverse cobble bedforms are exposed at extreme low-water Spring tides on an inter-tidal bedrock shelf in the macro-tidal Severn Estuary, UK. Near-bed flow velocities during Spring tides can exceed 1.5ms^{-1}, with water depths varying from zero to in excess of 10m. The bedform geometry tends to be weakly asymmetric; orientated down-estuary with the ebb current. Bedload transport and hydrodynamic data have been measured during both flood and ebb over the crests. The bulk hydraulic data are supplemented by particle tracer studies and laser-scanning of bed configurations between tides. The results of this study explain the interactions between flow characteristics, bedform mechanics, and sedimentological processes of coarse estuarine sediments.

1. INTRODUCTION

Dunes are one of the bedforms commonly found in many rivers as well as tidal and marine environments (Allen, 1984). The existence of dunes effects flow resistance primarily through hydraulic form roughness (Carling et al., 2006; Wilbers, 2004). The size of dunes is considered with repect of the height and length and a wide range of sizes has been reported (Wilbers, 2004). The form resistance produced by dunes initiates turbulence in downstream which in turn is related to dune development, especially size and shape. Apart from effects on flow resistance, dunes are responsible for channel depth limitations. All of these effects are significant in several aspects, such as the design of engineering structures, dredging strategies and storm tide prediction. Moreover, the changes in bedform morphology and the internal structures are useful in the process of interpreting ancient sedimentary assemblages which is believed to be of tidal origin (Carling et al., 2006).

Several studies have described and observed physical characteristics and processes of dunes, both in fluvial and marine environments (e.g. Allen et al., 1994; Kostaschuk and Best, 2005; Choi and Jo, 2015). Only a few researchers have studied and explained the processes of fine-gravel dune formation, such as Dyer (1971), Dinehart (1992a, 1992b), Carling (1996), Carling et al. (2006), Williams et al. (2006). However, coarse-gravel dunes, as well as cobble dunes, are not well researched. There are no studies focused on intertidal dunes developed in coarse gravels. Therefore, this study will address the hydrodynamics, dunes dynamics, and sedimentary structure of coarse gravel (cobble) dunes.

The main goal of this research is to understand the behaviour of subaqueous dunes developed in coarse gravel which are found in the intertidal zone of River Severn, United Kingdom (Figure 1). The specific objectives of the study are: (a) to observe cobble dune movements by comparing the data of dune positions and shape measured in the field site, (b) to collect quantitative flow data and investigate flow hydrodynamics which will provide bulk flow parameters, (c) to examine the interaction between flow hydrodynamics, sediment transport and morphology of cobble dunes to gain an understanding of flow interacts with the bedform, and (d) to study both external and internal structure of dunes developed in coarse sediments.

2. STUDY SITE

Hill Flats, located at approximately 51° 40.45′N: 2° 33.24′W (Carling et al. 2006), is in an intertidal zone in the Severn Estuary, landward of the Bristol Channel (Allen & Fulford 1996; Uncles 2010). The site is on the left bank of the estuary in Southwest Britain and consists of a rock platform 3 km long and 650 m wide approximately and lies in a north-east to south-west direction. The surface of this location is uneven with varied elevation, from c. 0 Ordnance Datum to a few meters above. The highest elevation is towards the landward where there is an artificial sea bank along the shoreline of the Severn. The elevation declines seaward, which elevation is varied by the sea bank, salt marsh, small near-vertical marsh cliffs, mudflats and finally the bedrock platform. The lowest area of Hill Flats extends toward the river in the north-west direction (Allen & Fulford 1996; Carling et al. 2006).

3. METHODOLOGY

In order to understand the processes of dune development, the key factors having effects on dune dynamics were investigated. Data used in this study are derived from fieldwork during the lowest spring tides from February 2012 to September 2015. A repeated footwork survey with dGPS and Total Station provides the locations of the dune crestlines in planform and the distance between each dune through time. A series of dune survey data were overlaid and used to compute migration rates and planform changes through time. Vertical cross-sectional profiles detail dune form in section. For flow conditions, up to three Valeport electromagnetic current meters, model 808, were deployed in the vertical to collect flow data across the dune field. The data consisted of local water depth, velocity profile, flow direction, shear stress, bed roughness, and wind-wave climate. Bedload and suspended load transport rates and grain size variations were also determined using field data to provide detail of the sediment transport environment. Impact sensors recorded bedload intensity and duration. Moreover, coarse-gravel particle tracer studies and terrestrial laser-scanning (Leica P20) of bed configurations between tides were also completed to supplement the sediment transport and morphological data.

4. PRELIMINARY RESULTS

The dunes migrate slightly up or down estuary with each flood or ebb tide respectively during Spring tides. During Neap tides the dunes are mainly immobile. When exposed, the bedform geometry tends to be locally symmetric or more generally asymmetric; orientated down estuary with the ebb current. During Spring tides, impact plate and trap data record vigorous bedload transport of gravel (including large cobbles) during both flood and ebb over the crests and yet, despite this temporal dynamism, the bedforms remain spatially static over long time-periods or show weak down-estuary migration. Stasis implies that the tidal bedload transport vectors are essentially in balance.

Near-bed flow velocities during Spring tides can exceed 1.5ms^{-1}, with water depths varying from zero to in excess of 10m. Near-bed shear stress and bed roughness values vary systematically with the Spring-tide current speeds and the predicted grain-size of the bed load using the Shields criterion is in accord with observed coarser grain-sizes in transport. Coarse gravel is transported in apparently equal quantities on both flood and ebb tides. The particle tracer studies showed that tracers placed on the bedrock troughs between dunes rapidly congregated in the bedforms, whereas tracers placed on the bedform crests tended to remain there indefinitely. Laser scanning at low water showed localized erosion on the up-estuary sides and deposition in the down-estuary sides. The high-energy environment, with effectively *in situ* sorting results in two forms of armouring. (1) Pronounced steep imbrication of platy-cobbles occurs on the steep up-estuary sides of dunes and probably is disrupted during flood tides leading to rapid reworking during flood tides of the toe deposits facing up-estuary. The steep down-estuary sides usually lack distinct imbrication and gravels appear readily entrainable. (2) In contrast, some crest and leeside locations have been stable for prolonged periods such that closely-fitted fabrics result; these portions of the bedforms are static and effectively are 'armour-plated'. Ebb-tide deposits of finer, ephemeral sandy-units also occur over gravel on the down estuary side of the bedforms. Sandy-units (although not observed at low tide) presumably also are deposited on the up estuary side during flooding tides but these deposits are destroyed by ebb flows.

5. CONCLUSIONS

During neap tides the bedforms are not exposed, and sediment is calculated to be of limited mobility. Geometry measurement of dunes shows that the dunes tend to be asymmetric and ebb orientated. Bedload transport of gravels and coarser grains occurs over the dunes during both flood and ebb tides. However, the dunes rarely show significant changes over several tidal cycles. Although there is temporal dynamism existing in the process, the dunes remain spatially static over long periods or have weak down-estuary migration implying a near balance in bedload transport in flood and ebb tides. The hydrodynamic data, delimited by estimates of the threshold of motion, and integrated over either flood or ebb tides, explain the apparent stability of the bedforms. The high-energy environment results in two forms of armouring. The two forms of armouring in this high-energy environment reflect the presence of a static core to dunes below the crests and more dynamic lee-sides consisting of different components of sediment. The relationship of sediment transport processes and the stratification of the bedforms (as yet undefined) is to be considered further.

6. ACKNOWLEDGMENT

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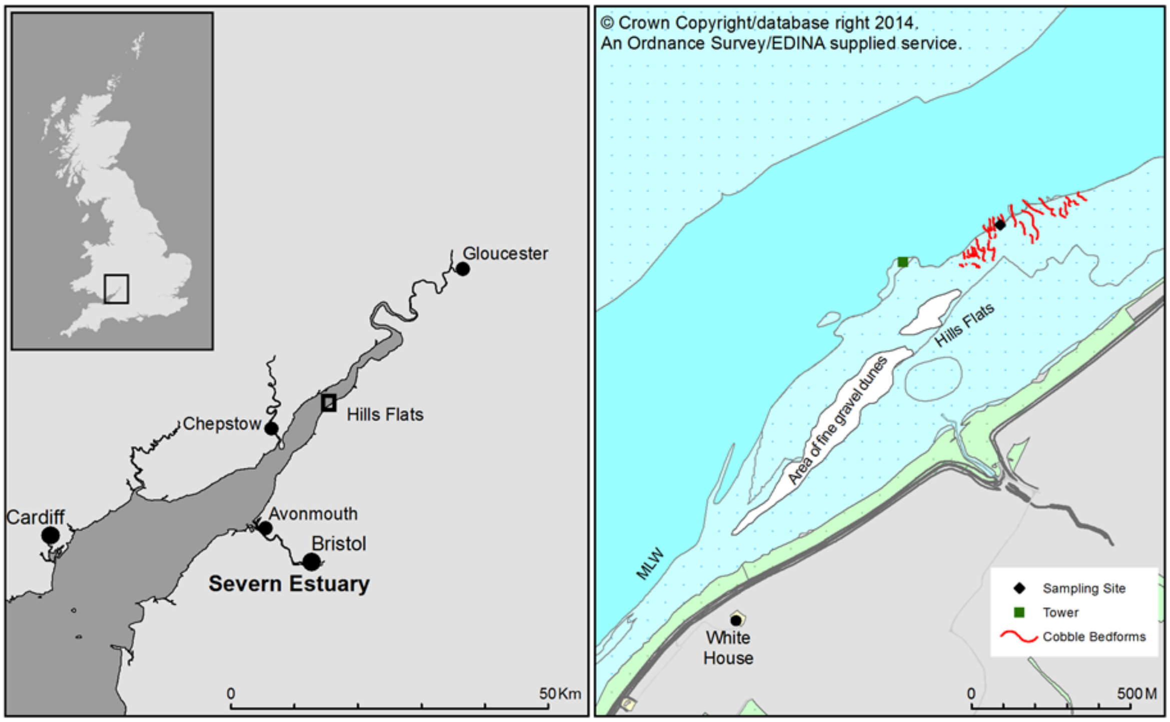

Figure 1. Location of study site, Hill Flats, Severn Estuary, UK.