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Decadal scale stability of sorted bedforms, German Bight, southeastern North Sea

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Abstract

Complex, large-scale sorted bedforms have been investigated in the southeastern North Sea. We present a unique time series of sidescan sonar and multibeam backscatter data spanning 26 years (1977–2003). In the storm-dominated study area, sorted bedforms surrounded by fine sand plains, are widespread. Although, wave and current shear stresses indicate a frequent remobilisation of fine sediment and an episodic remobilisation of coarse sediment, it appears that existing patterns have remained essentially stable over a period of 26 years. Moreover, we observe the birth of new sorted bedforms. The observed patterns are interpreted as the product of a feedback-related sorting process consistent with a recent explanation of sorted bedform formation.

The observed sorted bedforms tend to be oriented perpendicular to the ambient tidal currents, indicating the importance of tidal flows in their shaping. Moreover, they are dominantly symmetric in cross-section, i.e. the boundaries between coarse and fine sediment are sharp. This finding is consistent with a reversing tidal current of almost equal strength during ebb and flood. Similar to subaqueous dunes, sorted bedforms might therefore be subdivided into symmetric and asymmetric types, depending on hydrodynamic forcing. However, the newly emerging sorted bedforms are asymmetric, with an orientation independent of tidal current flow but perpendicular to the direction from which the highest storm waves approach the study area. We thus conclude that extreme storm events may play a major role in the generation of sorted bedforms, whereas the quasi-continuous tidal currents form and maintain their final shape.

Keywords: Inner shelf; Sorted bedforms; Rippled scour depressions; Backscatter; Shear stress; North Sea; German Bight

1. Introduction

The inner continental shelf (as defined by Wright, 1995) can be characterised as a realm where the seabed is frequently agitated by tidal flows and storm-driven waves and currents. While subaqueous dunes and sand ridges are characteristic for sand-rich, tide-dominated environments, so-called rippled scour depressions (Cacchione et al., 1984) or sorted bedforms (Murray and Thieler, 2004), are ubiquitous where sand supply and tidal energy are low. Such bedforms have recently received increasing awareness. The term "rippled scour depression" (RSD) was first coined by Cacchione et al. (1984) to

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describe "channellike depressions of low, negative relief […], containing large sand ripples and transecting the inner shelf generally normal to the bathymetric contours". The term was subsequently more broadly applied to ubiquitous surficial sedimentary features of inner continental shelf environments on sediment-starved margins (see review in Murray and Thieler, 2004). Such features have slight topographic depressions on the order of 1 m and are composed of coarse-to-very coarse sand, gravel and/or shell hash that is arranged into large wave-generated ripples, with wavelengths on the order of a metre. They are typically 100–200 m wide, and extend hundreds to thousands of metres in the cross-shore direction (Murray and Thieler, 2004).

Cacchione et al. (1984) observed RSDs with sharp contacts between fine and coarse sediment and a coarse sediment domain centred in the topographic depression on the inner continental shelf off central California. They attributed the generation of RSDs to storm-generated downwelling flows parallel to the long (cross-shore) axis of the RSDs. In contrast to the results of Cacchione et al. (1984), a closer examination of similar bedforms off Wrightsville Beach, North Carolina (USA) revealed a distinct asymmetry: the coarse sediment domain is not centred on the bathymetric low, but instead occupies the bathymetric low and one flank, while the other flank is covered by finer sediments (Thieler et al., 2001). As the northern edges of the coarse sediment domains are sharp, while the southern edges appear "wispy", Thieler et al. (2001) and Murray and Thieler (2004) speculated that southward shore-parallel currents perpendicular to the axis of the bedforms were responsible for these observed patterns. This view of asymmetric bedforms as transverse rather than longitudinal is shared by several researchers (Goff et al., 2005; Gutierrez et al., 2005). Because the observed bedforms are not simple depressions and the term RSD is associated with cross-shelf flows, Murray and Thieler (2004) proposed the more neutral term "sorted bedform". On the other hand, Goff et al. (2005) pointed out that not all authors reported on the asymmetry of sorted bedforms (e.g. Cacchione et al., 1984; Green et al., 2004). They concluded that two distinct classes of bedforms might be lumped together, distinguished by their asymmetry.

Murray and Thieler (2004) developed a model that explains the formation and maintenance of sorted bedforms. They suggested that wave motions interacting with large roughness elements (large wave-ripples), present on coarse sediment domains, generate near-bed turbulence that is greatly enhanced relative to that in fine sediment domains. This turbulence enhances entrainment and inhibits settling of fine material in an area dominated by coarse sediment. Thus, a feedback tending to produce accumulations of fine material separated by patches of coarse sediments is constituted. Direct field measurements performed on the inner shelf off Tairua Beach, New Zealand (Green et al., 2004), show that under high waves, the suspended-sediment load, originating from the surrounding fine sediment domain, will be high, but turbulence will also be more energetic on the coarse sediment domain, thus more effectively inhibiting deposition. Under low waves, deposition may be less inhibited on coarse sediment domains, but the suspended-sediment load arriving from the surrounding fine sand domain will also be also lower. Consequently, the fine sand deposition rate on coarse sediment domains will be small, even though conditions are more favourable for settling.

The model of Murray and Thieler (2004) predicts spatial stability of sorted bedform patterns, which was observed at time-scales of months to a few years on the inner shelves of off Tairua Beach (Hume et al., 2003) and the German Bight (Werner, 2004). On the other hand, Murray and Thieler (2004) and Goff et al. (2005) observed shifts of the boundary between coarse and fine sediment domains on the order of tens of metres within months to a few years. In the case of Wrightsville Beach, such changes are attributable to storm events, such as hurricane Bonnie (Murray and Thieler, 2004).

Although a general agreement concerning the mechanism responsible for maintaining sorted bedforms exists among researchers, there are still several open questions concerning their generation and long-term temporal stability and their relation to the ambient flow regime. Currently, more questions are raised than answered (Goff et al., 2005). To contribute to this discussion, we investigate temporal changes of sorted bedform patterns on the inner shelf of the German Bight. To our knowledge, investigations of temporal changes of surficial sediment distribution patterns cover several months to a few years at most (e.g. Thieler et al., 1995; Thieler et al., 2001). Here, we present a unique time series of backscatter data covering 26 years between 1977 (Werner, 2004) and 2003. We also investigate the relationships between sorted bedform orientation and ambient inner shelf flow