Multibeam survey of a tidal banner bank: morphology of dunes in eroding partially compacted sands?

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Sand transport simulations often make no allowance for compaction, but even modest compaction significantly increases threshold of movement. Nash Sands, a banner bank in the Bristol Channel, was surveyed in 2002 with multibeam sonar, following a decade of single-beam monitoring. The monitoring data reveal an area that declined by 5-10 m over the prior 11 years and thus where partially compacted sands are likely to have been excavated. In this area, a southerly promontory of the bank retreated by 900 m over the 11 years in the ebb-current direction. Based on dune migration rates, which nearby average 184 m y^{-1}, the 11-year of 900 m retreat is only half that expected. Morphologies of dunes in the multibeam data vary, with some showing superimposed megaripples, indicating mobile surface sand, but other areas lacking such megaripples and having a smoother morphology. We question whether the latter morphology marks less mobile compacted sand.

1. INTRODUCTION

The effect of compaction on sand mobility remains poorly characterized. Modest compaction of a sand surface by pre-stressing it with a current can lead to 27% increase in the shear velocity associated with threshold of motion (Paphitis and Collins, 2005). Monteith and Pender (2005) found that bedload flux decreased with increasing durations of pre-stressing. According to Ockelford and Haynes (2013) resistance to erosion arises because the pre-stressing current causes vertical settlement of particles, which increases hiding effects and grain pivot angles, and because of re-orientation of surface particles. Other indirect evidence would suggest that compaction could lead to greater erosional resistance. Craig (1978) summarizes the results of shear tests on sands under drained conditions. Compacted sands remain incohesive but develop greater shear strengths (friction angles of 35˚ and 45˚ for uniform rounded and angular sand, respectively) compared with loose sand (27˚ and 33˚, respectively). Although seabed erosion by tidal currents does not usually involve shear failure, these results also hint that particles have become more closely packed and resistant to erosion by the mechanisms discussed by Ockelford and Haynes (2013).

We study here Nash Sands, a banner bank in the Bristol Channel, where strong ebb currents (Uncles, 1983) have drawn out the sand from a promontory of the coastline (Figure 1). Banner banks are tidal sand banks emanating from near headlands in the direction of dominant tidal sand transport (e.g., Ferentinos and Collins, 1980; Pingree, 1978). Historical charts reveal that Nash Sands has changed shape and position, movements exposing earlier deposited sand that offer the potential to study how compaction has influenced bedform morphology and migration rates.

2. DATA AND METHODS

Over Nash Sands, multibeam data were collected in late summer 2002 in two phases (the full survey over three days, 16-18 August, and some repeat measurements on 4 September) and single-beam data collected by a local survey company for us in May 2003. Where the different surveys cover the same areas, the two phases of multibeam data show seabed change over ~19 days, while comparison with the single beam show change over 263 days.

The multibeam data were collected with a 101-beam Reson Seabat 8101 240 kHz sonar, with a spatial resolution of around 1 m constrained here by the precision of differential GPS broadcasts from Nash lighthouse. Sounding data were processed by manually removing erroneous soundings using CARIS/HIPS software (such as caused by detections of water-borne noise) and combining with sound velocity and tidal height data from a locally-installed tide gauge before gridding at 1 m resolution. The data are presented as depths relative to Chart Datum (Lowest Astronomical Tide). An overview of these data is shown as a depth-coded colour map with shaded relief in Figure 1, along with two years of the single-beam monitoring data. Figure 2 shows the multibeam data with colours provided by elevation changes in the single beam data. An enlargement of part of the data that declined over that period is shown in Figure 3.

These data were interpreted using methods similar to those described by Schmitt and Mitchell (2014). Sand dunes were identified between successive surveys using their shapes in both cross-section and plan-view (Schmitt and Mitchell, 2014; Schmitt et al., 2007). While migrating, dunes preserved their shapes between the two multibeam surveys and were generally easy to track between the 2002 multibeam and 2003 single-beam surveys except in Nash Passage, where the dunes smoothed out and were too weakly defined for tracking on an annual basis.

Processing of the single-beam monitoring data is summarized by Lewis et al. (2015). Surveys were carried out each year from 1991 to 2002 (excluding 1999-2000) in grid patterns. The data from each survey year were interpolated onto a 20 m x 20 m regular grid using a nearest neighbour scheme. The resulting bathymetry grids for years 1991 and 2002 are shown in the insets to Figure 1. The grids were then differenced to produce elevation changes, which are shown in Figure 2 along with shading from the multibeam data to help in locating morphologic features. Overlain contours in Figure 2 represent the 1991 and 2002 depths as indicated in the lower-left key.

Further data available to us include sediment texture data from a grid of grab samples, which show median grain size (D_{50}) varies from 0.2 to 0.5 mm over East Nash (one sample within the eroded area has 0.5 mm D_{50}). Data from current meter CM2 (Figure 1) collected over one neap-spring cycle show almost rectilinear currents (ellipticity 0.02) with a maximum current of 1 m s^{-1} at 1 m above bottom.

3. OBSERVATIONS

Nash Sands has a curvilinear shape with 'cat back' rounded dunes on its south flank with a sense of asymmetry suggesting ebb dominance (transport to the west). Dune tracking between surveys revealed an average celerity of the dunes along south East Nash of 184 m y^{-1}. The monitoring data show that the crest of the bank advanced southwards and the promontory farther west retreated during this period. In Figure 2, these are shown as areas of accumulation and erosion, respectively. The apparent retreat is 910 m. If this were simply due to dune translation at 184 m y^{-1}, retreat over 11 years would be twice as large.

Within the eroded area (Figure 3), the multibeam sonar data reveal a curious variation in surface texture. Many dunes have typical superimposed megaripples, though here with multiple crest-line orientations, suggestive of varied current directions acting on mobile sand. However, the dunes marked C2, C5 and northerly parts of C6 and C7 have a smoother texture (smaller ripples). These lie at similar elevations to the dunes with superimposed megaripples.

If the dunes migrated perpendicular to their crestlines without changing elevation (i.e., the erosion in Figure 2 were a result of simple retreat of the whole slope), the elevations of the troughs would mark the levels above which the sand has recently been mobile. Projecting these trough levels 'upstream' to where they intersect the modern seabed suggests where (below these levels) the sand has only recently been exposed. A selection of these elevations is marked in Figure 3. The projection 'upstream' of these elevations is shown by the black dots shown. Although some examples have been reported of megaripples changing morphology towards troughs into smaller heights and wavelengths (so this pattern could be unremarkable), there are some changes across this boundary, such as for dune C6, with larger megaripples above the boundary.

Overall, although we cannot claim to have found unequivocal evidence for compaction effects on sand morphology, we find the variations in dune morphology here curious and prompt the question of whether compaction can affect the rate and dynamics of sand transport.

2. CONCLUSIONS

Dunes in an area of Nash Sands that declined by 5-10 m over a decade curiously have either superimposed megaripples or smoother texture with much smaller megaripples. We speculate these differences may reflect varied compaction effects. Further study may provide practical indications for how compaction can be accounted for in transport simulations.

3. ACKNOWLEDGMENT

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4. REFERENCES

Craig, R.F., 1978. Soil Mechanics, 2nd Ed. Van Nostrand Reinhold, New York, 318 pp.

Ferentinos, G. and Collins, M.B., 1980. Effects of shoreline irregularities on a rectilinear tidal current and their significance in sedimentation. J. Sed. Petrol., 50: 1081-1094.

Lewis, M.J., Neill, S.P. and Elliott, A.J., 2015. Interannual variability of two offshore sand banks in a region of extreme tidal range. J. Coastal Res., 31: 265-275.

Monteith, H. and Pender, G., 2005. Flume investigations into the influence of shear stress history on a graded sediment bed. Water Resour. Res., 41: Paper W12401.

Ockelford, A.-M. and Haynes, H., 2013. The impact of stress history on bed structure. Earth Surf. Proc. Land., 38: 717-727.

Paphitis, D. and Collins, M.B., 2005. Sand grain threshold, in relation to bed 'stress history': an experimental study. Sedimentology, 52: 827-838.

Pingree, R.D., 1978. The formation of the shambles and other banks by tidal stirring of the seas. J. the Marine biological Association of U.K., 58: 211-226.

Schmitt, T. and Mitchell, N.C., 2014. Dune-associated sand fluxes at the nearshore termination of a banner sand bank (Helwick Sands, Bristol Channel). Cont. Shelf Res., 76: 64-74.

Schmitt, T., Mitchell, N.C. and Ramsay, A.T.S., 2007. Use of swath bathymetry in the investigation of sand dune geometry and migration around a near shore 'banner' tidal sandbank. In: P.S. Balson and M.B. Collins (Eds.), Coastal and shelf sediment transport, Geol. Soc. Lond., Spec. Pub. 274. pp. 53-64.

Uncles, R.J., 1983. Modelling tidal stress, circulation and mixing in the Bristol Channel as a prerequisite for ecosystem studies. Can. J. Fish. Aqua. Sci., 40 (Suppl. 1): 8-19.

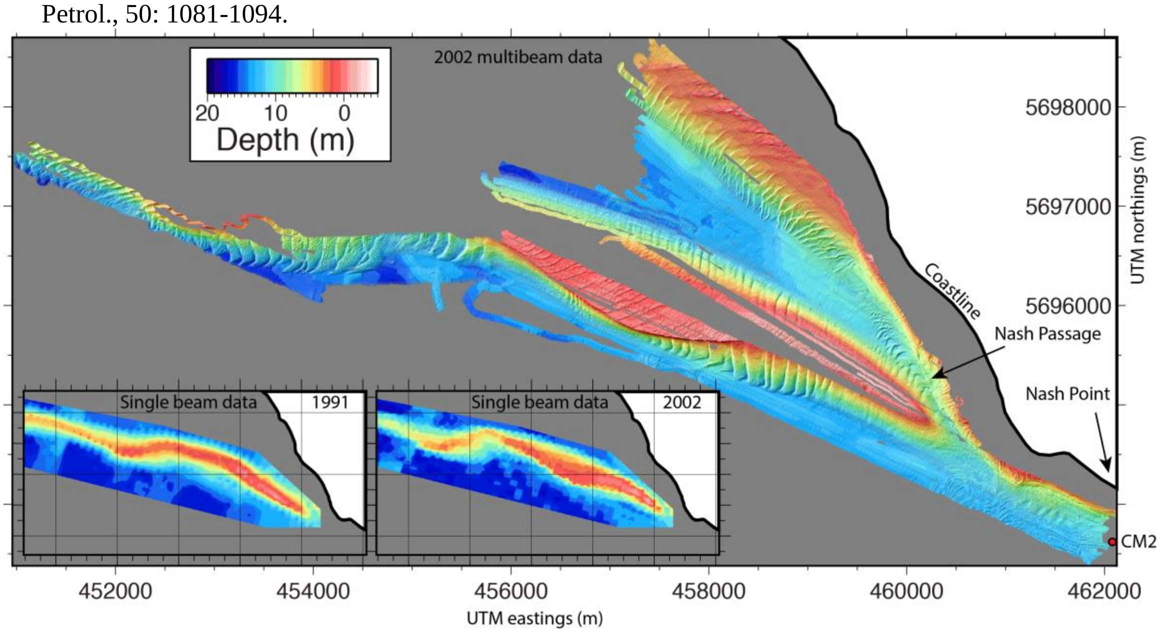

Figure 1. Overview of the multibeam echo-sounder data collected in 2002 over Nash Sands. Coordinates are Universal Transverse Mercator projection metres (zone 30). Lower-left insets show the single-beam data collected in 1991 and 2002 as part of the monitoring efforts (same colour depth scale and extent as the main panel).

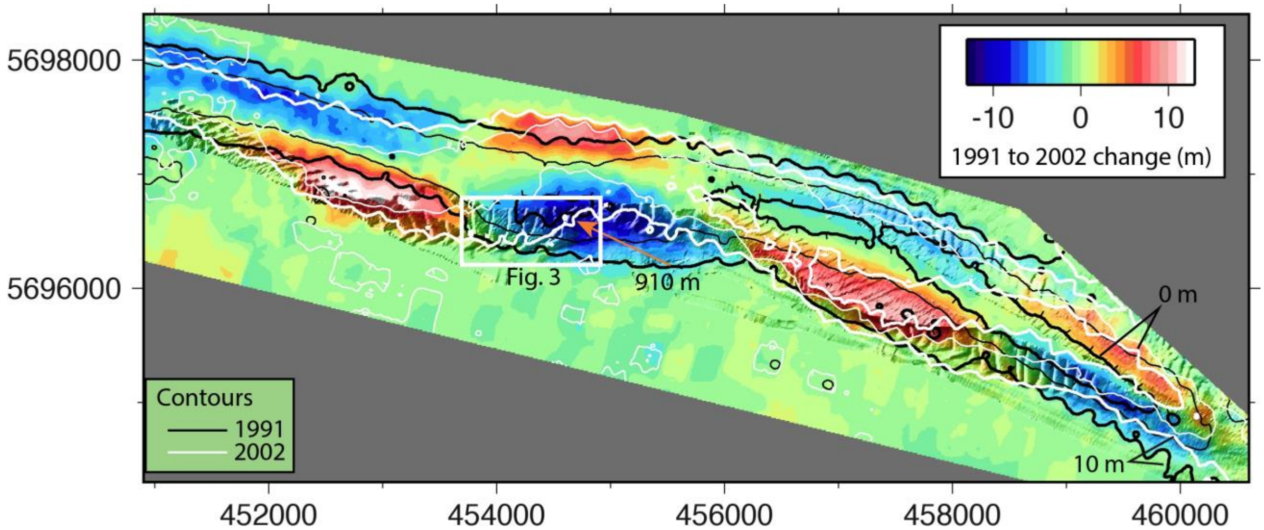

Figure 2. Elevation change over the period 1991 to 2002 from single-beam surveys (colours) with shading from the 2002 multibeam sonar survey. In the colour key, positive values imply deposition, negative values erosion. Also shown are 5-m depth contours of the 1991 and 2002 single-beam surveys (10 m intervals in bold, as annotated lower-right, and tick marks indicating down-direction for the closed contours). Orange arrow in centre marks the 910 m movement in the 10 m depth contour over this period.

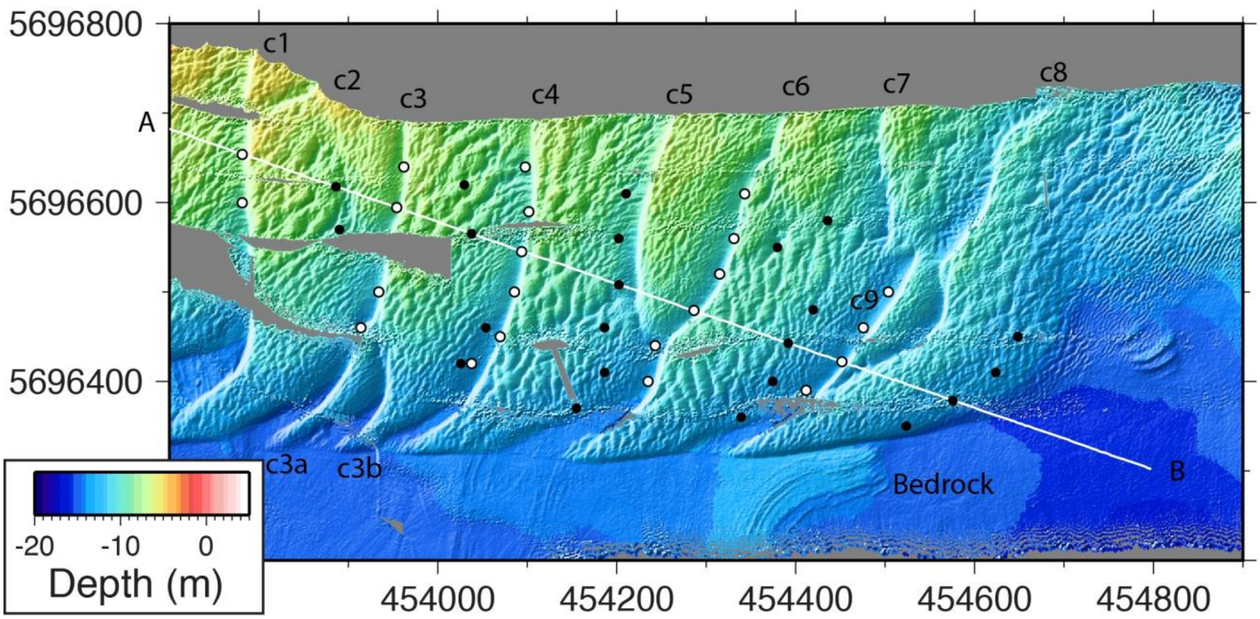

Figure 3. Enlargement of the multibeam data located in Figure 2. Black dots locate where the elevations of minima in toughs (open circles) intersect the surface where projected along the line shown.