Establishing Depositional Coastal Landform Development through Particle Characteristics: A Case Study of the Marshland at Budleigh Salterton, Devon

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Abstract:

Understanding the physical processes of the past is fundamental to our current understanding and management of the coastline. Depositional landforms, such as back-barrier marsh, are at particular risk from rising sea levels and therefore need to be managed effectively and sustainably. This study aimed to use particle characteristics to identify the role of coastal barrier progradation and high-magnitude low-frequency events, on the development of the back-barrier marsh at Budleigh Salterton, Devon. Particle characteristics plotted onto the bivariate plot model of Lario *et al.* (2002) revealed that barrier progradation did lead to a decrease in particle size. Following this initial decrease, particle size tended to increase up-core. This study indicates that this is the result of higher energy fluvial activity depositing larger sediments during lateral migration. Further, the plots revealed little evidence that high-magnitude low-frequency events have been significant in the marsh development, however further analysis is recommended.

Keywords:

Coastal Geomorphology; Coastal Barriers; Depositional Environments; Back-Barrier Marshland; Marsh Formation; Particle Size Analysis; Bivariate Plots; High-Energy Events.

Introduction

Budleigh Salterton is a small town located on the Devon coastline at the mouth of the River Otter (Figure 1). Sediment deposition across the mouth of the estuary over time has led to a gravel barrier forming. Behind the barrier an extensive low-lying, back-barrier marshland has developed that serves as an important ecological habitat.

Figure 1: Location Map of the Budleigh Marshland

Coastal Barrier and Back-Barrier Marsh Formation

Coastal barriers are common features of the British coastline with their formation largely relying on the supply of sediment from longshore transport (Goodwin *et al.,* 2006; Petersen *et al.,* 2008), and sufficient depositional space in the form of an open embayment. They can also be formed by an open estuary (Roy *et al.,* 1994), which is known to be the case at Budleigh Salterton Both sediment supply and depositional space are influenced by long-term climatic variability (Brooke *et al.,* 2008).

Marshlands often form in the sheltered conditions behind coastal barriers. Marsh development is influenced by numerous factors. A delicate balance exists between the tidal regime; the wind and wave climate; sediment supply; sea level; and vegetation (Allen, 1990). Coastal barrier progradation will affect most of these factors; ultimately they provide a sheltered environment behind which a back-barrier marsh may form as water turbidity is slowed allowing for fine particle deposition (Packham and Willis, 1997; Nielsen and Nielsen, 2002). More established marshlands typically include a natural drainage system within creeks and levees, and usually have thin layers of clay deposited on the surface (Hanley and La Pierre, 2015).

Both barriers and back-barrier marsh are traditionally considered to be features of low-energy coastlines forming under stable/slow sea level rise (Cundy *et al.,* 2007). However, it is important to note that many other allogenic factors may also play a role in their development, and can be classified as either 'geological' or 'contemporary' processes (Roy, 1984). Of particular importance is the supply of fine sediment for back-barrier marsh formation (French, 2006). Sediment source and transport, for example, not only control the rate of estuary infilling but also influence numerous particle characteristics, such as size and sorting (Pethick, 1992). Tidal range is also of high importance (Hayes, 1979); the generation of tidal currents and the length of slack water settling periods influences both overall marsh morphology (Allen, 1993) and deposit thickness (Klein, 1972).

Depositional Environments & Particle Characteristics

As a consequence of differential physical processes such as erosion, transportation, and deposition, sediment laid down in different depositional environments may possess unique and distinctive particle characteristics (Lario *et al.,* 2002). In particular, particle size can yield important clues to previous environmental conditions at the time of deposition (Friedman, 1979). Understanding these processes and how environments have changed under various physical conditions is fundamental to our current understanding of past environments and how the coastline functions naturally, and therefore the successful management of the coastline. However, Gale and Hoare (1991) have suggested that research into the specific use of particle size in aiding with depositional environmental reconstruction has often presented poor quality results. Because of the perceived limitations particle analysis, although relatively long established, is underdeveloped. However, following technological enhancements and new methodological concepts that have developed in the past few decades, far greater research has now been conducted (Syvitski, 1991; Spencer *et al.*, 1998).

The Particle Characteristics of Back-Barrier Marsh

As discussed above, tidal activity is one of the main influences on the development of back-barrier marsh (Hayes, 1979). UK marshes tend to comprise largely of fine to very fine silts and clays (Allen, 1993). These particles require a combination of factors to be deposited; a low-energy environment is crucial, such as semi-closed/closed basin or a sheltered estuary. These lower energy settings are typical of coastlines with high tidal ranges that allow for the spreading of wave energy across the tidal cycle (Haslett, 2009).

It is also possible that other physical agents and processes, alongside tides, may also have an impact on the sedimentological processes within marshlands. For example, fluvial processes are also likely to affect marsh development, especially given the fact that in the UK many marshlands are found within estuaries. Fluvial processes are typically more powerful and posses more potential energy to transport than tidal processes (Boorman, 2003). Therefore, larger sediments, such as sands or possibly gravels, may be transported and incorporated into marsh deposits where fluvial activity is particularly high (Pethick, 1992).

As well as being able to identify the nature of the depositional agent (for example fluvial, marine, or glacial), it is now possible to suggest the energy conditions at the time of deposition. As discussed, fine back-barrier marsh deposits are traditionally considered to be features of low-energy, tidally dominated coastlines (French, 1997). Storm and more wave-dominated settings on the other hand, are typically considered to be responsible for the deposition of larger coarser sediments (Stumpf, 1983). This is not to say however, that they do not play a role in marsh evolution. It is often the case that the sediments making up the barrier are eroded by storm waves and incorporated into the marsh, as waves overtop the barrier. It can therefore be argued that the presence of these coarser sediments within the marsh would indicate that high-magnitude events have played a role in that marshlands evolution (Lario *et al.,* 2002).

Methods

This study used the bivariate plot model of Lario *et al.* (2002) to create an environmental reconstruction of the low lying marshland at Budleigh Salterton, based on particle characteristics. In particular, the study identified the role of the prograding coastal barrier in the development of the marsh and highlighted the role of high-magnitude low-frequency events.

Data Collection

Particle characteristic data was collected through a series of 3 cores taken with a Gouge Auger corer. Particle samples were then taken from all of the major sedimentological units within each individual core. For each unit one sample was taken from the upper, middle, and lower sections. This ensured that as well as having a spatially representative data set, the results are also temporally representative. This helped to create an accurate environmental reconstruction of the marshland and identify the role of both barrier formation and high-magnitude low-frequency events.

Data Analysis

Due to the fine particle nature of the sediments, a sieve tower was not able to separate the samples collected (Syvitski, 1991). Therefore particle size analysis was completed using a Mastersizer 2000 Laser, which offers a higher resolution analysis and is preferable in terms of time constraints to other methods (Eshel *et al.,* 2004; Kovacs, 2008).

The results of the laser analysis produce a data set in micro-millimetre units that were then converted converted into phi (Φ) bringing the study in line with established methods (Folk and Ward, 1957). Once all data was converted, it was entered into the particle size analysis software GRADISTAT (Blott and Pye, 2001). The software was used to calculate particle characteristic descriptive statistics for each major unit based on the upper, middle, and lower samples taken from each unit. Namely the mean particle size and sorting, based on the standard deviation, was calculated (Folk and Ward, 1957: Friedman, 1979). Further, the grain size distribution was automatically generated for each unit, allowing for the dominant particle classification, for example fine silt or coarse sand, to be identified (Blott and Pye, 2001).

Bivariate plots are a common form of particle characteristic interpretation. As such, numerous studies have developed 'envelopes' allowing for a graphical representation of how different depositional environments are associated with certain particle characteristics (Mason and Folk, 1958; Friedman, 1961; Tanner, 1991; Lario *et al.,* 2002). This study applied the bivariate plot developed by Lario *et al.* (2002), which itself is an adaption of the sediment/particle size analysis of Tanner (1991), and employs the use of the average particle size and sorting (Figure 2). This plot has been chosen due to its specific reference to back-barrier marsh evolution and the inclusion of a channel/storm 'envelope' alongside open and closed basin conditions. Therefore allowing for the representation of channel flow, either fluvial or tidal, and/or high-magnitude low-frequency events.

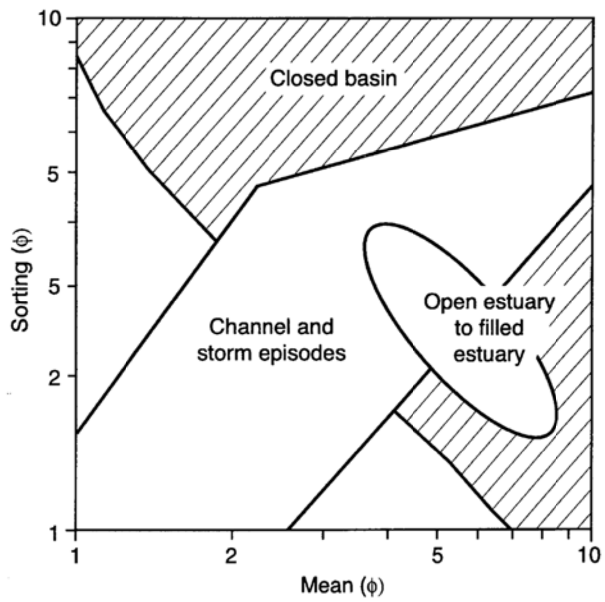

Figure 2: The Bivariate Plot Model of Lario *et al.* (2002)

Results

Figure 3 shows sedimentary logs created for the three cores taken at Budleigh marsh. At the base of cores BS1 and BS3 medium grained sand was present before decreasing in size to fine sand up-core. The base of core BS2 is characterised by fine sand. All three cores then move into a unit of medium silts; in cores BS1 and BS2 this unit is then overlain by finer silts. Following this initial decrease, particle size then steadily increases up-core across all three cores, transitioning into coarse silts at the uppermost unit.

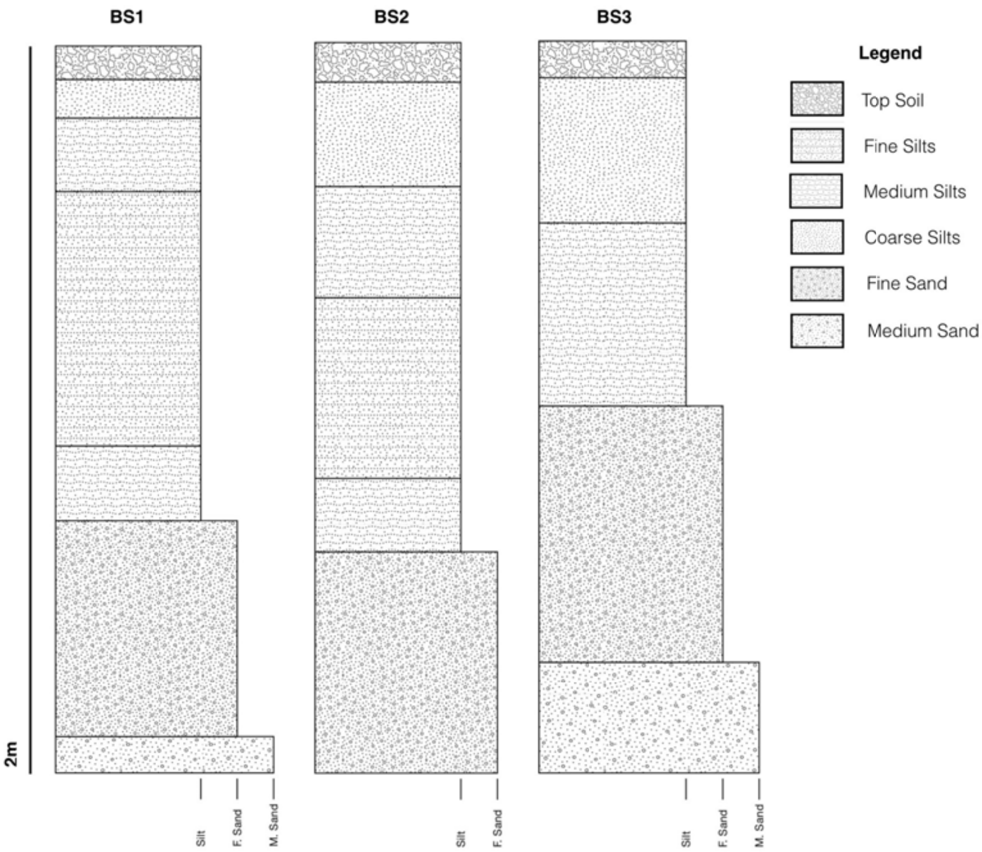

Figure 3: Sediment Logs for Cores BS1, BS2, & BS3

Figures 4 show the bivariate plot of Lario *et al.* (2002) overlain with the results of the samples taken within the cores. Each sample (one from the upper, middle, and lower section from each major layer) is shown on the plot as a series of dots. All of the units are relatively similarly sorted between 2Φ and 3Φ. All samples are also clustered around the open basin/channel to closed basin transitional boundary.

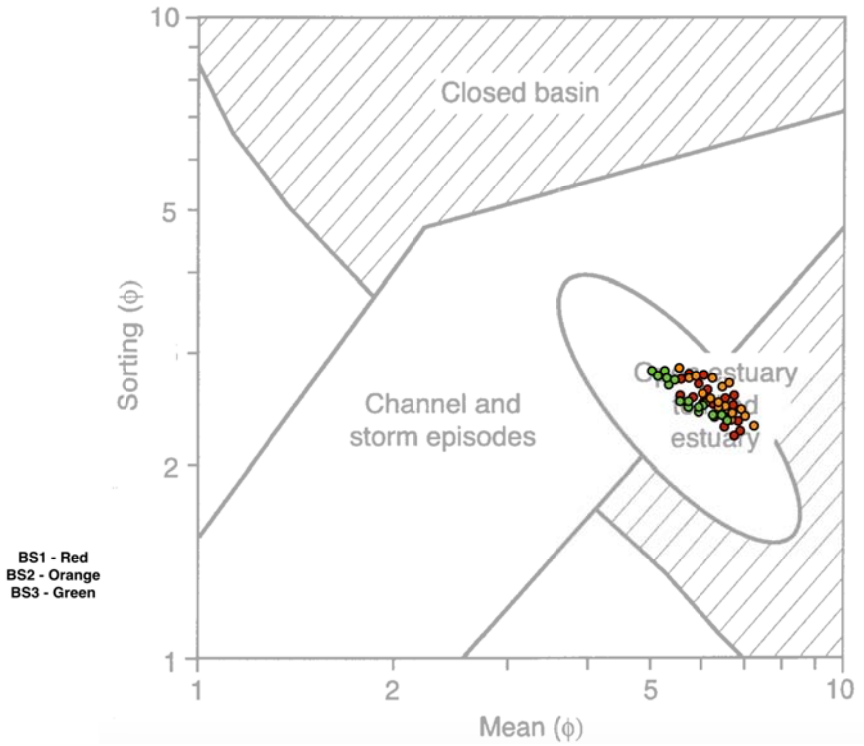

Figure 4: Bivariate Plot for Cores BS1, BS2, & BS3

Discussion

The Role of Barrier Progradation on Back-Barrier Marsh Development

At the 2m depth across all cores sand particles where present, with cores BS1 and BS3 comprising of medium sized sand (Figure 4). The bivariate plot analysis shows that this is indicative of an open estuarine environment that is exposed to open wave/coastal conditions. As such, it can be suggested that these sands were deposited under relatively higher energy conditions prior to barrier progradation (Allen, 1993).

The sediment above the sand units shifts to medium to fine silts, notably in cores BS1 and BS2 (Figure 4). These particle distributions are typically associated with low energy depositional environments (Spencer *et al.*, 1998). It is possible that this new low energy environment was created as the barrier prograded across the mouth of the open estuary, thus creating a more enclosed and shallower estuary. Finer silts tend to settle in these conditions due to protection from high-energy wave conditions; tidal variations at slack water; and the physical process of flocculation (Manning *et al.,* 2010).

Moving up the sequence from the initial change from sands to silt, a gradual increase in particle size can be identified. Generally the fine/medium coarse silts gradually become coarser grained. As such, when the results are overlain on the bivariate plot there is a general trend which shows that the particles move back towards the higher energy settings. There are numerous possible explanations behind this increase in particle size up-core including tidal and fluvial processes involving erosion, transportation, and subsequent deposition. .

Firstly, tides are one of the dominant forces of landform change in the coastal environment as the changing tide generates strong tidal currents. These currents can be enhanced by barrier progradation; as the barrier develops the mouth of the estuary is narrowed, funneling the currents creating higher energy conditions that are capable of transporting larger sediments (French, 1997).

Secondly, fluvial environments are also typically considered to be high-energy agents and are therefore capable of transporting larger sediments (Pethick, 1992). Further, like tidal currents, fluvial energy can be enhanced following the narrowing of the estuary mouth (Haslett, 2009). It is proposed that the fluvial option is more likely given the geography of the Budleigh marshland, as the marsh is located on the mouth of the River Otter. Further, historical maps show the river has regularly meandered laterally across the marshland over the past century. These lateral movements of the river would redistribute existing particles as well as lead to the deposition of coarser material (Andrew and Cooper, 2006). Thus explaining the increase in particle size up-core.

The Role of High-Magnitude Low-Frequency Events

From the bivariate plot analysis (Figure 4) no samples were recorded well within the storm episode envelope. This would initially suggest that there is little evidence that high-magnitude low-frequency events have played a role in the marsh evolution. However, there was evidence of gravels found around core BS3 on the topsoil, although not within the core itself. These gravels had the same characteristics as those comprising the gravel barrier and therefore show that waves occasionally overtop the barrier transporting small volumes of gravel sediment in the process. This indicates that high-energy events do have some influence over the sediment characteristics of the marshland.

Further, Cundy *et al.* (2007) found that marshland can comprise of fine sediment that has been deposited following significant estuary in-wash under high-energy storm conditions. Should this be the case at Budleigh Salterton, essentially any of the fine sediments in the cores from this study could have been deposited under higher energy conditions as suggested by the particle analysis adopted. As such, further study and a highly detailed data analysis is required to identify whether the samples collected are deposits of these higher energy events.

Conclusion

It is clear from the particle size analysis adopted by this study that there is considerable variation in the particle characteristics of the sediment forming the marshland at Budleigh Salterton. All cores indicated that sands were present in the deeper levels of sediment, and moving up-core an initial decrease in sediment size was observed. This study suggests that this decrease can be explained by barrier progradation creating a low-energy environment, allowing for the deposition of finer sediments. However, above these finer particles sediment size typically increases slightly up-core. Numerous physical processes and agents can explain this, including tides and rivers. This study proposes that the larger sediments are fluvial derived that have been deposited following lateral channel migration across the estuary.

Initial results from this study indicate that high-energy events have played little role in the formation of the marshland. This is due to the lack of sediments falling within the channel/storm episode envelope of the bivariate plots adopted. However, more recent studies have suggested that finer sediments can also be deposited during higher energy, less frequent events (Cundy *et al.,* 2007). As such further more detailed research is suggested to determine the energy conditions at the time of deposition for these sediments, and it recommeneded that more samples are collected around the cores that should notable differences in sediment size up-core (BS1 & BS2, Figure 3).

Author Profile

Both Harry West and Paolo Santarpino are undergraduate students studying BSc(hons) Geography and Environmental Management at the University of the West of England, Bristol. This study was completed following their second year of study, and is not linked to any academic assessment.

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