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Coastal evolution in south-west England, United Kingdom: An enhanced reconstruction using geophysical surveys

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Abstract

The coastline of south Devon, south-west England, is believed to be subsiding faster than any area in the United Kingdom (UK). Current estimates are based however on very limited Holocene relative sea level (RSL) and lithostratigraphic data. There is, therefore, an urgent need for more information to improve our understanding of coastal evolution in the region. Sediment coring from Slapton Sands and Blackpool Sands in south-east Devon provides material for interpreting land- and sea-level changes. Further stratigraphic mapping was carried out using 2D Electrical Resistivity Tomography (ERT) of the near-surface. This method of geophysical survey, ground-truthed with borehole data, has rarely been used for palaeoenvironmental reconstruction but provided useful results here. Models of Holocene coastline evolution, based on those from the Eastern USA, show that sea level in Start Bay was ~17 m below present RSL ca. 9000 cal. yr BP. A barrier–lagoon system was forced landward by seas rising at ~5 m/ka across substrates comprised of weathered slate and shale. Thick deposits of minerogenic fines (~10 m at Slapton Sands) were identified in cores and mapped using the ERT survey method. Barrier-lagoons became choked by sediment when RSL was ~5 m below present at ca. 4400 cal. yr BP and reached their current configuration during the late Holocene. ERT results show that the Slapton Sands modern-day barrier complex is a uniform ~9 m thick for a longshore distance of at least 1.5 km.

Keywords: Holocene; relative sea-level change; lithostratigraphy; coastal evolution; Electrical Resistivity Tomography; barrier–lagoon system

1. Introduction

Few coastal lithostratigraphic studies have been published from south-west England in comparison to the rest of the United Kingdom (Waller and Long, 2003). This is extraordinary given Shennan and Horton's (2002) estimate that the region's coast is the fastest subsiding shoreline in the UK. In addition, the region was also peripheral to the British Ice Sheet at the Last Glacial Maximum (Peltier, 1998) and is therefore a favourable location for the testing of geophysical models (Lambeck, 1995, 1997; Peltier et al., 2002) and forebulge theory (Wingfield, 1995). Holocene sea-level index points (SLIPs) are scarce (Heyworth and Kidson, 1982; Haslett et al., 1997; Waller and Long,

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2003) and few models based on coastal sedimentary surveys exist to explain coastline evolution in the region (Massey, 2004; Chadwick et al., 2005).

Back-barrier sediments along the Channel coast of south-west England contain valuable information about its post-glacial land- and sea-level recovery history (Carr and Blackley, 1973, 1974; Healy, 1993, 1995; Edwards, 2001). A few lithostratigraphic studies from south-east Devon (Fig. 1) have contributed to the regional geological archive (Clarke, 1970; Hails, 1975a,b; Morey, 1976, 1983a,b) but it is clear that there is a lack of high-quality, well-constrained data from the region. For example, Shennan and Horton's (2002) estimate of land subsidence for south Devon (1.23 ± 0.18 mm yr^{-1}) is based on only 5 index points from sediments poorly linked to the reference tide level (Haslett et al., 1997, 1998). There is a need, therefore, for coring projects and other subsurface surveys that provide insight into the nature of south Devon's palaeoenvironments (Massey, 2004) both to improve our local understanding of coastline evolution, and on a larger scale to understand sea-level change and its drivers (Waller and Long, 2003).

Back-barrier sediments may contain fossils indicative of former intertidal environments from which the height of SLIPs can be quantified (Massey et al., 2006a). Suitable material for radiocarbon dating can also be obtained from lithofacies identified in cores thus providing temporal constraints on coastline positions (Heyworth and Kidson, 1982). However, coring in itself is a limited method of data collection for improving our understanding of coastline changes (Massey et al., 2006c). Geophysical surveys, on the other hand, allow greater geographic coverage and should, when coupled with ground-truth data from cores, identify valuable sequences without the need for further extensive, expensive, and time-consuming coring. Electrical resistivity surveying began about 100 yr ago for prospecting purposes in Sweden (Petersson, 1907; Bergström, 1913) and a little later in the USA (Schlumberger, 1920), and there are now several methods available to the surveyor (Dahlin, 2001). For example, 2D Electrical Resistivity Tomography (ERT) of the near-surface is one such method that has been used to good effect in engineering and environmental projects but, until recently (Massey, 2004; Massey et al., 2006c; this project), not in the field of coastline evolution.

The direct current (DC) resistivity field method is based on measuring the potentials between a pair of electrodes while transmitting DC between another electrode pair (Overmeeren and van Ritsema, 1988; Robinson and Coruh, 1988; Dahlin, 2001). Typically, for operational reasons, a low (<10 Hz) frequency alternating current (AC) is substituted for DC. Depth of penetration along the survey run is proportional to electrode spacing in homogenous strata (Bernstone and Dahlin, 1996) thus varying the electrode spacing will provide more or less detail about subsurface stratigraphy (Gish and Rooney, 1925). An interpretation of the field data (the apparent resistivity is the measured quantity of the field survey) (Johansen, 1977) provides a physical model after which the resulting physical parameters can be interpreted geologically (Dahlin, 2001). Two-dimensional electrical resistivity imaging or tomography (ERT) of subsurface sediments is ideally suited to complex surveys (Griffiths and Barker, 1993; Dahlin and Loke, 1998) because it employs computer-controlled multi-electrode data acquisition systems to make significant time-savings during fieldwork. Nonetheless, back-barrier marshes remain challenging environments for any type of resistivity survey method because of the complex interaction of three primary factors: porosity, water saturation, and pore fluid salinity, which together control the measured resistivities (Hallenburg, 1984). Subsurface mapping projects involving the use of ERT must therefore be verified via ground-truth data from cores strategically located along the surveyed profile, to interpret the physical parameters of the resistivity model.

The aim of this paper is, through the provision of additional resistivity survey data from Slapton Sands and Blackpool Sands (Massey et al., 2006c), to further evaluate our understanding of the method for research into coastal evolution. Index points obtained from cores used in the ground-truthing method also provide insight into local Holocene sea-level changes. Finally, models of coastal change, based on those of Kraft and Chrzastowski (1985) originally developed along the eastern seaboard of the USA, are used to further elucidate the Holocene barrier–lagoon history of south-east Devon.

2. Regional setting and study sites

The rias, or drowned river valleys, of south Devon's submerging coastline were fronted by gravel barriers during the early to middle Holocene (Hails, 1975a,b; Morey, 1976; Waller and Long, 2003). Lithofacies and their fossil contents indicative of former barrier–lagoon systems can be found at several sites (Clarke, 1970; Massey, 2004; Chadwick et al., 2005). The back-barrier sediments should ideally record distinctly different electrical resistivities (Massey et al., 2006c) for differing lithofacies. Two coastal back-barrier systems selected here (Fig. 1) comprise variable thicknesses of minerogenic-peat, fines and gravel sediments overlying a hard substrate (Fig. 2). The underlying solid geology is