

Bridging the gap: a terrestrial view of shallow marine sequences and the importance of the transition zone

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Abstract

The shallow shelf area around the coast of the UK contains an important record of maritime and, potentially prehistoric archaeology. Increasingly this area is the focus of anthropogenic activity such as gravel extraction and cable laying in advance of which it is increasingly common practice to investigate the archaeological potential of the sequences/regions. Well structured approaches have been developed for the investigation of maritime wrecks and the latest Prehistoric remains, however the Palaeolithic archaeological potential of these regions is less clear. This is partly due to the depth of burial of archaeological material and the rather more fragmentary nature of the sequences present. Where consideration of the Palaeolithic archaeology has been undertaken, models and presumptions derived from terrestrial situations have been extrapolated across the near shore zone, where often there is no data, and into the maritime area. Within the maritime area these models have been used to interpret seismic data and scarce offshore core data for making regional reconstructions. Here we consider some of the issues in reconstruction and highlight the difficulty in extrapolating between terrestrial and maritime situations without careful investigation in the transition zone. In particular we argue that rather than assuming similarities between patterns of landscape evolution between the on- and off-systems we should anticipate dissimilarity of patterns, missing sequences and different landscape formation processes particularly in those areas of the shallow shelf area formerly occupied by drainage basins during sea level low-stands.

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1. Introduction

Many of the most important buried/preserved landscapes in the UK today are those presently submerged along our coast line. These include both relatively recent landscapes associated with the last marine transgression (Coles, 1998; Momber, 2000) in the earlier part of the Holocene and elements of much older landscapes associated with a large number of Pleistocene sea level transgressions and regressions over at least the last 0.5 million years (e.g. Bridgland et al., 1993; Bellamy, 1995; Bridgland, 2002; Fitch et al., 2005). With these significant changes in sea level many sites occupied on the shelf

during terrestrial phases have become flooded. In some cases evidence of occupation is preserved close to the modern sea bed or beneath subsequent layers of sediment. However, in other situations the remains may have been removed during marine transgression (Dix et al., 2004) or indeed during the subsequent sea level fall.

Despite a long history of archaeological practice in maritime studies it is only relatively recently that attention has turned to examining the Prehistoric potential of those areas of the continental shelf exposed during periods of lowered sea level (Coles, 1998; Flemming, 1998; Dix et al., 2004). However, recent developments in marine survey technology and new methods for modelling the (sub)sea floor together with a recognition that activities such as aggregate extraction from the sea bed may impact on deposits of high archaeological

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potential, mean that consideration is now being given to these relatively inaccessible areas (Wenban-Smith, 2002).

The primary focus of many studies of the shelf has often been for later Prehistoric archaeology, i.e. the Mesolithic to Bronze Age periods (Flemming, 1998; Momber, 2000). In these cases the archaeological remains exist at or close to the surface of sedimentary sequences preserved beneath the sea bed. Thus the remains are relatively easily mapped and the associated landscapes close to the bathymetric profile of the off-shore. It is considerably less common for archaeologists to target the shelf specifically for Palaeolithic archaeology although interest in these deposits is now growing (Wenban-Smith, 2002). Older Palaeolithic artefacts (if present) are likely to be more deeply buried than those associated with the last marine transgression. Furthermore they are usually associated with complex sequences and terraces of fluvial sediments that are typically discontinuous on the sea floor. In order to interpret these sequences it is therefore common practice to adopt models and ideas based on study of better-understood terrestrial sites (archaeological and geological) to the off-shore region by attempting to reconstruct landscape models and associated assemblages of archaeological material from different periods. Whilst this is not ideal, until significant quantities of archaeological material have been identified and excavated in the marine zone, archaeological interpretations of sequences in the off-shore zone can only be driven by such on-shore derived concepts. The practice described above is often adopted but rarely debated in the context of maritime archaeology. However, to be valid it is important to be certain that the features of the maritime geological and geomorphological record reflect those of the terrestrial record from which our knowledge of Palaeolithic archaeology has been derived. This can only be done by understanding the full context from present day land to off-shore sites through extrapolation over the land–marine transition zone.

The archaeological significance of the transition zone has been highlighted by English Heritage in their document “Taking to the Water” (Roberts and Trow, 2002). This recognizes that national evaluation studies to characterize poorly recorded or little understood elements of the maritime cultural landscape are necessary in connection with studies designed to improve understanding of drowned coastal landscapes and palaeoenvironments. Such transitional landscapes have tremendous potential for the preservation of archaeological evidence pertaining to the exploitation of coastal and marine resources.

In this paper we seek to open debate on some of the assumptions that underpin our interpretation of shallow marine situations. In particular we focus on issues related to the presence of sediments suitable for preserving (Palaeolithic) archaeological remains. We suggest that maritime archaeology is presently at a crossroads. Current projects to map sea floor archaeological potential are limited by the difficulty in creating frameworks comparable to those in the terrestrial region. This is because independent chronostratigraphic or biostratigraphic frameworks that have been erected for the on-shore area do not exist presently for the offshore area and therefore direct correlations with terrestrial situations have been assumed rather than

empirically demonstrated. Correlations may be attained either by extensive off-shore drilling, sample recovery and analysis, or by attempting to demonstrate links via the transition zone. We question the simplistic approaches to interpreting and correlating geological sequences in the shallow marine zone based solely on the extrapolation of on-shore terrestrial systems into the shelf area principally because continuity between terrestrial and maritime areas through the transition zone cannot often be demonstrated. For example it is now widely accepted that during sea level low stand phases fluvial systems extended across the exposed shelves around the UK. These systems have been mapped in a number of situations such as the Thames estuary (Bridgland et al., 1993; Bridgland, 2002). However, within the northern sector of the English Channel direct continuity between on-shore and off-shore fluvial systems remains to be demonstrated despite attempts to derive predictions from their study in the off-shore zone. We highlight these problems by considering recent evidence regarding the complexity of sequences in the Sussex/Solent Coastal Corridor and adjacent marine contexts (Fig. 1).

2. Major fluvial systems and terraces as markers from the transition zone to off-shore (transverse systems)

The presence of fluvial systems on the shelf area is well documented through seismic profiles obtained as part of aggregate extraction investigations for many rivers including the Thames (Bridgland et al., 1993; Bridgland, 2002) and the Channel area (Bellamy, 1995; Antoine et al., 2003) (Fig. 2). Where sequences have been documented off-shore attempts have been made to integrate this evidence within the broad on-shore framework of climate change from interglacial to glacial periods (Bellamy, 1995). However, direct physical links between on-shore and off-shore terrace sequences have rarely been demonstrated and considerable caution is therefore required when attempting to place off-shore sequences within local terrestrial stratigraphic frameworks prior to determining the archaeological potential.

When considering the correlation of fluvial deposits from terrestrial to shallow marine situations it is necessary to first consider the assumptions behind interpretation of systems and sequences in relation to river terrace sequences, sea level change and developing frameworks. Two fundamentally different approaches to the investigation of sequences have been developed for terrestrial and marine records. For NW Europe the conceptual model of Bridgland (1994, 1995, 2000, 2006) is one that often underlies our perception of terraces in terrestrial situations and this has also been applied to off-shore terrace sequences (Bridgland et al., 1993; Bridgland, 2002). Within the maritime province sequence stratigraphic interpretation has been the basis for interpreting the seismic sub-bottom data (Vail et al., 1977a–c).

2.1. Limitations of terrestrial conceptual models

For terrestrial situations Bridgland (2000, 2006) identifies six phases of terrace formation over a full glacial–interglacial

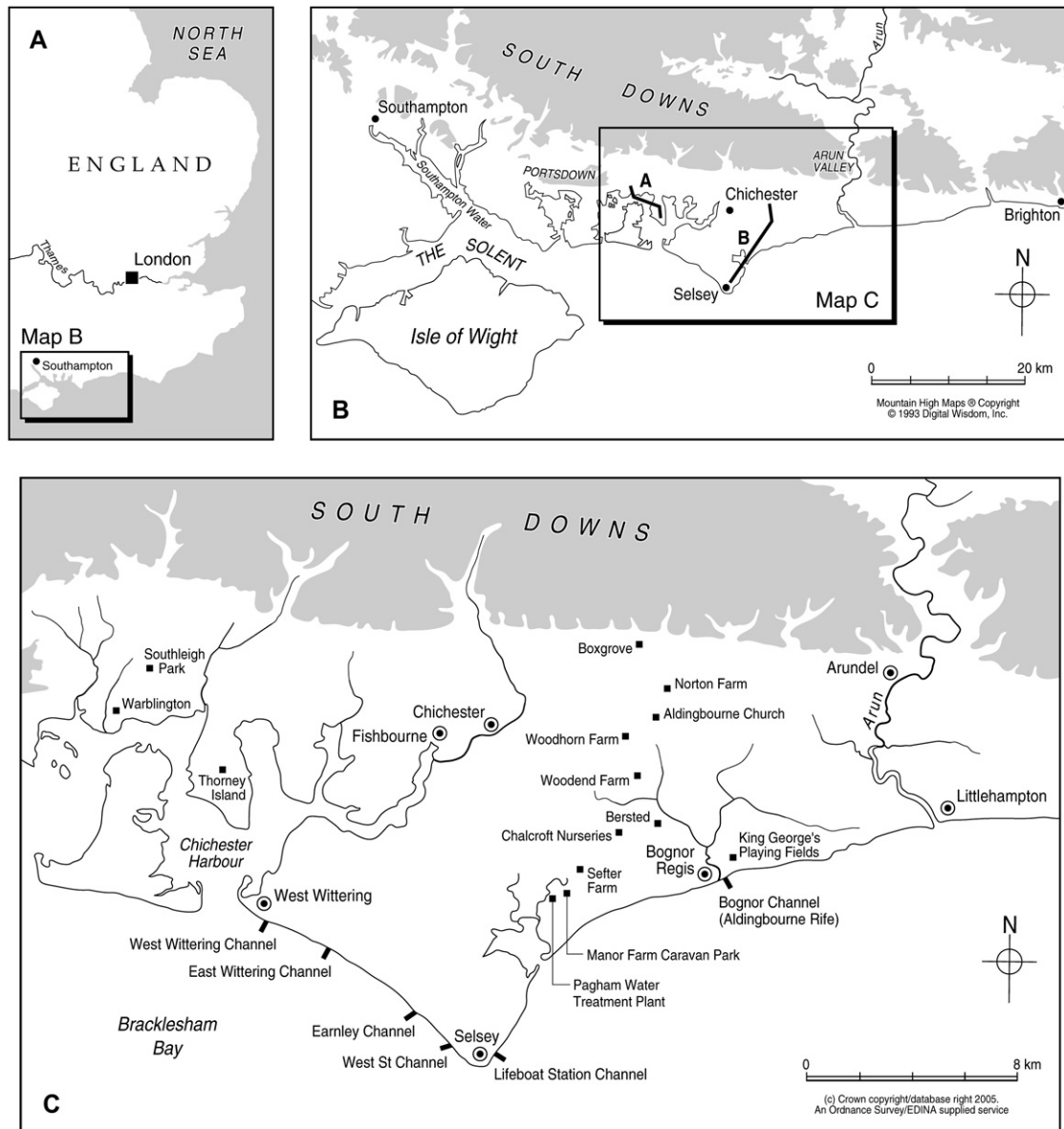


Fig. 1. (A) Channel coast of the Sussex Solent Coastal Corridor. (B) West Sussex Coastal Plain and the location of transects A and B (Fig. 7). (C) Detailed site location plan for the Chichester/Selsey area.

cycle, using observations and mammalian biostratigraphy from the Lower Thames Valley as a type model. This model suggests that terrace separation occurs as the land surface progressively uplifts, for example due to erosional isostasy or tectonics (Maddy, 1997; Bridgland, 2000, 2006; Westaway et al., 2006), and that terrace formation is a result of climatic fluctuation over a glacial–interglacial cycle. Bridgland (2000, 2006) suggests that incision occurs as a result of both warming and cooling, but in many cases only the warming-related incision is significant enough to create a new terrace, with cooling-related incision merely truncating previous cold and temperate stage deposits. The assumptions are made that: (a) coarse-grained deposition is limited to cold stages; (b) there is sufficient downcutting between depositional episodes that individual sediment bodies can be distinguished and (c) successive terrace fragments

can be linked downstream by applying a single longitudinal gradient.

Except in a few special situations (e.g. Bridgland, 2003), terrace deposits at different altitudes have very similar clast-lithological properties. Therefore, in the absence of any biostratigraphical control (as in many river systems, e.g. Allen and Gibbard, 1993; Antoine et al., 2003), tracing successive phases of fluvial deposition is usually based on altitudinal variations along long profiles. However, there are problems with seeking to reconstruct successive phases of river activity on the basis of altitude. First, the extent of downcutting between different phases may vary both from event to event, and spatially within the river system (e.g. where bedrock varies along the rivers length), particularly if the river has a form marked by occasional deep scouring at the base of channel systems. Second,

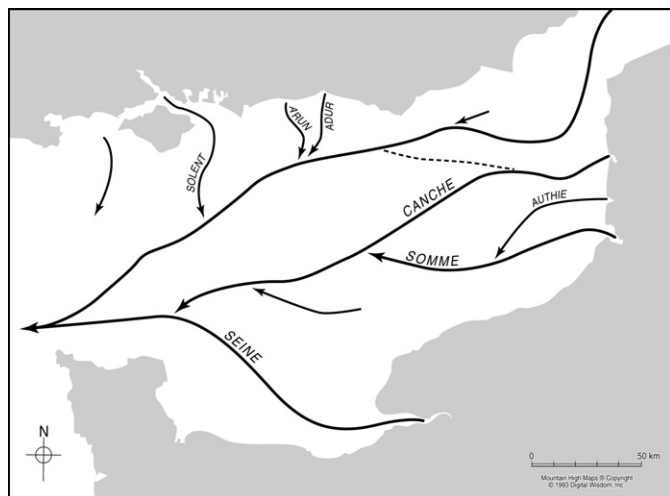


Fig. 2. Reconstructed sea level low stand palaeogeography of major river systems in the English Channel/Manche area.

the time periods over which individual terraces form appear to be quite long (in some cases up to 100,000 years). Over such time periods it is unlikely that the gradient of stream flow would remain constant throughout the period of deposition, particularly if ice-sheet accumulation and associated sea-level change in previous cold stages were as complex as that suggested for the last cold stage (e.g. Boulton et al., 1991). Furthermore, the proposed tectonic control on terrace separation (e.g. Bridgland, 2000; Westaway et al., 2006) may not operate smoothly, possibly causing further discontinuities in the sequence and changes in gradient. Finally, for those portions of the river extending across shallow shelf areas it should be remembered that the shallow marine zone will have undergone repeated loading and unloading by marine waters throughout the Pleistocene. This cyclical pattern will have further modified the influence of tectonic control on uplift.

Another weakness of the Bridgland model is that while it can accommodate some evidence for estuarine conditions within the sequences it does not really account for the complexities of the lower estuarine reaches of rivers and the impact of significant transgressions on sequence generation. For example, Holocene sequences in the lower Thames form a wedge thickening from 2 m at Tower Bridge to 35 m thick near Canvey Island (Marsland, 1986; Bates and Whittaker, 2004). In the vicinity of Grays the Holocene deposits rest on Pleistocene sediments of more than one age (i.e. the East Tilbury Marshes Gravel and the Shepperton Gravel (Fig. 36 in Gibbard, 1994)). This is due to the higher downstream gradient of the gravel bodies and terrace surfaces than the Holocene estuarine alluvium resulting in the burial of relatively older, higher terraces beneath the floodplain in a downstream direction. Any preservation of such sediment sequences during subsequent phases of lowered sea level would potentially lead to unreliable correlations based on included biological materials. Thus, directly extrapolating models developed predominantly for freshwater/terrestrial stretches of the river may be inappropriate for the estuarine reaches of the river where large estuarine channels are known, as in eastern Essex (Roe, 1999) and the

Medway marshes (Lake, 1977; Bates, 1999; Bates et al., unpublished).

The importance of gradient to correlation is clearly seen in the eastern Solent system. Gravels on the eastern side of Southampton Water and the lower part of the Test Valley (Fig. 3) have been mapped on-shore by Edwards and Freshney (1987). They recognised up to eleven terrace levels at various heights trending north-west/south-east up the Test Valley between Romsey and Portsmouth (Figs. 3 and 4). Using the terrace attributions of Edwards and Freshney (1987) the base of terraces 3–5 can be seen to fall only very gently downstream, in contrast to terrace 1 deposits which have a much steeper gradient (Fig. 4), as previously recognised by Everard (1954a). Although these appear to show roughly uniform gradients, the correlation of individual terrace fragments is dependent on the gradients used. Indeed Westaway et al. (2006) suggest a new nomenclature based on different gradients. In addition it should be noted that there is some overlap in altitude of deposits associated with different terraces at terrace edges, because terrace deposits seem to thicken at transitions (Dr Ian West, personal communication, 2003). These problems are exacerbated when correlating deposits across the transition zone, for several reasons. Marine transgression over submerged parts of the river sequence may cause alteration, with emplacement of younger marine deposits over terrace levels or erosion of terrace surfaces and adjoining bedrock valley sides/interfluvial terrains during cutting of the ‘wave cut platform’. In all cases this will lead to changes in sequence altitude.

2.2. Limitations of marine conceptual models

For the maritime region sequence stratigraphic approaches using seismic data have been used to understand sequences preserved beneath the sea floor. This approach recognises that the succession of rocks is cyclic (in some ways similar to the succession recognised in the terrace record from areas subject to uplift) and is composed of genetically related stratal units (sequences and systems tracts) (Posamentier et al., 1988). In particular the approach subdivides and interprets the sedimentary record using a framework of surfaces collected from outcrop and borehole data linked through 2D and 3D seismics. The appropriateness of the approach to the mapping and interpretation of sequences of Quaternary age in the shallow marine zone is based in part on the assumption that systems tracts are products of relative sea level change. This may in part be true depending on the relative proximity of the river to the ocean in each case. The sequence stratigraphy approach provides techniques for chronostratigraphic interpretation of seismic lines giving the ability to age-date seismic strata in previously unexplored basins together with more accurate facies identification in unknown strata.

Sequence stratigraphic analysis has a number of general concepts that can be applied globally. Fundamental is the concept of relative sea level change that is controlled by eustasy, subsidence, tectonics and sediment supply rate. The relative sea level change can be identified in a geological sequence and on seismic records by a particular geometrical relationship

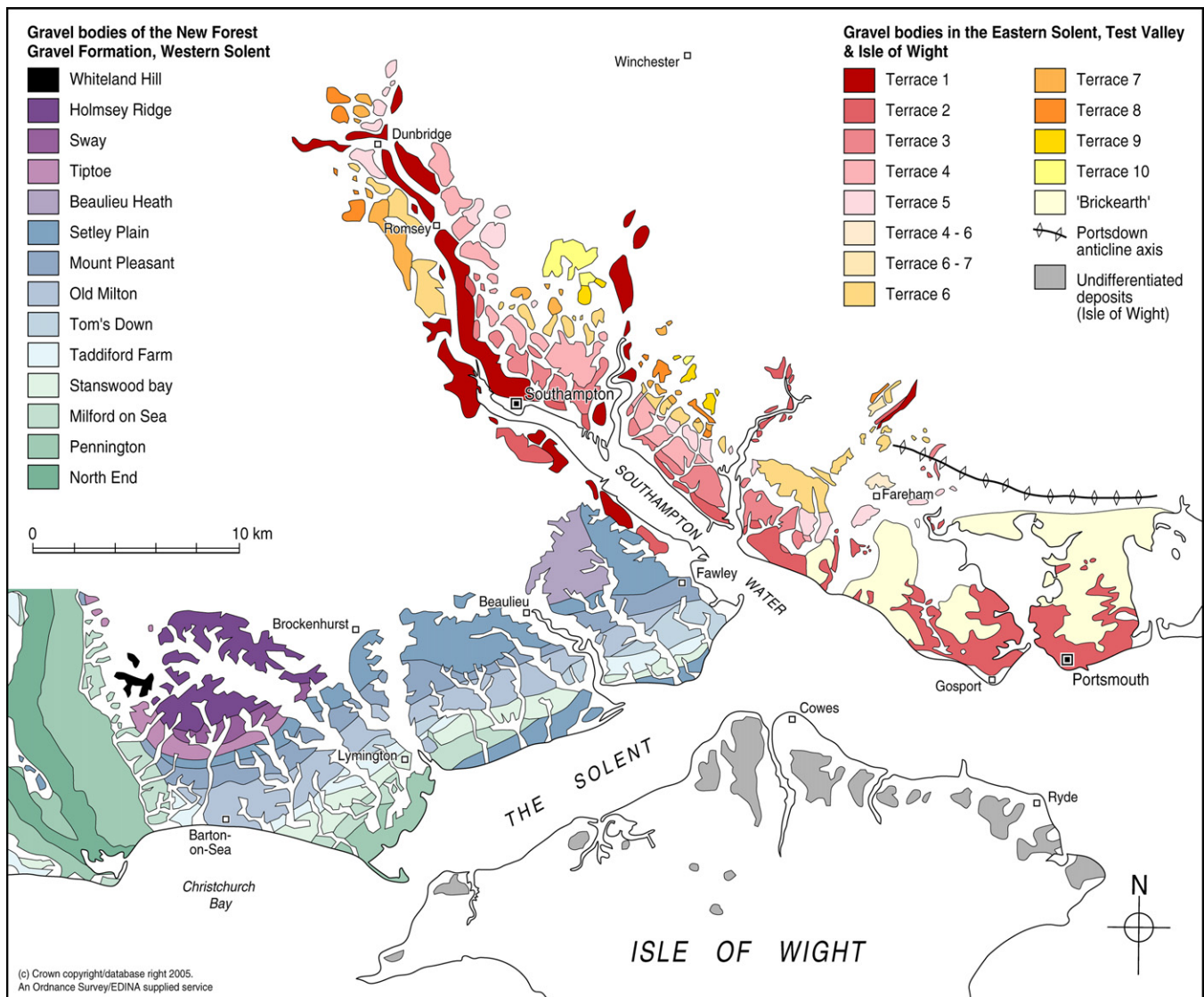


Fig. 3. Distribution of gravel bodies around Southampton Water and western end of West Sussex Coastal Plain (modified from Allen and Gibbard, 1993 and Edwards and Freshney, 1987).

of units related to changes in sedimentation pattern. These geometrical relationships are believed to be similar on a global basis and thus once recognised they can be used as a technique (or key) for correlation. At the heart of stratigraphic sequence analysis is the identification of depositional units in terms of laminae, beds, parasequences and sequences bounded by unconformity surfaces or sequence boundaries. Within the Channel region Lericolais et al. (2003) discuss the application of sequence stratigraphy to the deposits associated with the 'Channel River'. They describe the necessity to adapt the approach to include a consideration of additional phenomena such as glacio-isostatic changes in order to determine the relative importance of a variety of geomorphological processes that determine the behaviour of the river. In using stratigraphic sequences to reconstruct palaeolandscapes it is important to consider the large temporal span that transgressive surfaces can represent across individual systems. While a transgressive surface may be preserved from current day offshore to current

day onshore, at any point in time the onshore habitable space that corresponds to that surface may be very different. Thus making a series of palaeolandscapes reconstructions along the transgressive surface for different time periods is difficult to achieve when viewed from a purely sequence stratigraphy point of view. Foremost in the archaeologist mind must be the question of what has been preserved and what lost of the sequence?

2.3. Comparison of the two approaches

Comparing and linking these two disparate approaches to the understanding of sequence development in the terrestrial and shallow marine zone requires careful consideration and a number of key points need to be addressed in future work:

1. The nature of the evidence being used to reconstruct these systems (terrestrial and marine) differs significantly. In the

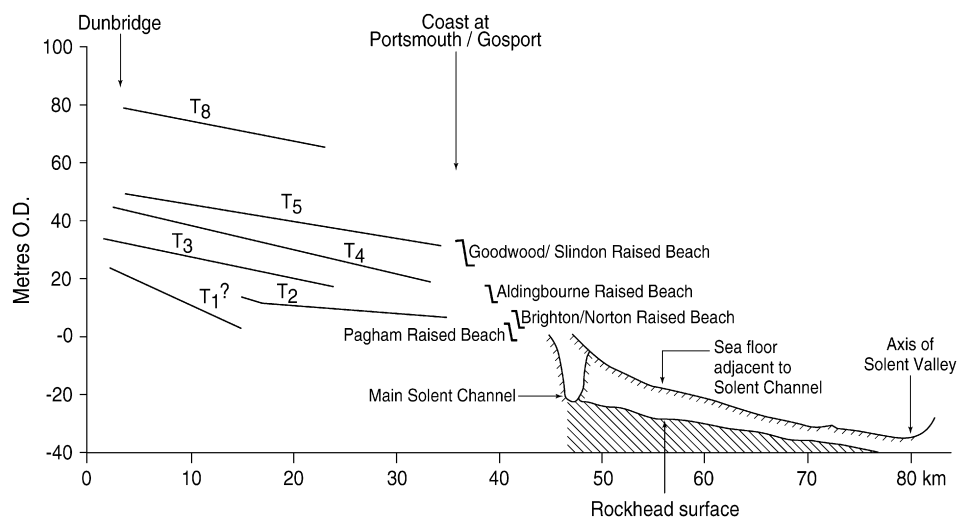


Fig. 4. Longitudinal profile of selected terraces in the Eastern Solent (modified from Dyer, 1975; Bates et al., 2004; Westaway et al., 2006) showing the sea floor and rockhead surface for the off-shore Solent system and altitudinal range of selected raised beaches of the West Sussex Coastal Plain.

terrestrial situation, borehole records describe the nature of the sediments at that point in space but are widely spaced due to sampling restrictions (costs etc). In the marine situation, bathymetric reconstructions and seismic profiles can provide continuous information on sediment body geometry but data on the precise nature of the sediment types is usually only by inference. Consequently it is difficult to integrate information from these two situations.

- Difficulties of collecting data in shallow-water areas means there is often a geographical gap within the transition zone for which no data exists.
- Recognition of “patterns” in stratigraphic records within the onshore and offshore areas differs and is based on very different parameters.
- Rarely is it possible in the terrestrial situation to recognise and adequately model the 3-D distribution of the terrace sequences; usually long profiles along terraces are coupled with detailed investigations and analysis of key sites linked to the surface morphology and mapped distribution of units.
- Within marine situations although 3-D investigation through seismic sections is the norm adequate investigation of the nature of those sequences is typically based on limited ground truth and a heavy reliance on models developed from the sequence stratigraphic approach.
- The driving mechanisms for sequence development differ between the land and marine approaches to sequence investigation. Terrace formation in the terrestrial sector (as envisaged by Bridgland) is driven by climate cycling developing against a background of regional tectonic uplift. By contrast sequence formation in the marine sector (as envisaged from a sequence stratigraphic perspective) is viewed as a product of base level change, in this case sea level change manifest as a series of transgressive surfaces.

The eastern Solent sequence provides a good example of the difficulties involved in such correlation. No systematic mapping of terrace deposits has been published from within

Southampton Water, although the base of the Pleistocene deposits has been mapped (Dyer, 1975; West, 1980). Edwards and Freshney (1987) recognised three submerged terrace levels, cut into by a further channel infilled with Holocene sediments. These interpretations are based on descriptions by Everard (1954b) of gravel terraces at 1.5 and 2.5 m below OD and by Hodson and West (1972) of a gravel-filled channel at Fawley with a base 21 m below OD. However, it is not clear how they envisaged these three terrace levels correlating along Southampton Water. In addition, although Edwards and Freshney (1987) suggest that terrace 1 is correlated with one of these submerged terraces, they do not suggest which. Finally, a seismic cross-section from the Solent below Calshot Spit shows two channel fills at similar elevation and a channel cut into this infilled with Holocene sediments (Dyer, 1975). This does not resemble terrace sequences predicted by Bridgland’s model and it is hard to see how it correlates with the terrace sequences proposed upstream.

3. Near-shore systems (lateral systems)

Beyond the confines of the major transverse river valleys uplifted coastlines offer useful illustrations of the range of different environments of deposition and associated sediment types that may occur in close proximity to the coastal zone, and may potentially exist in the offshore region between major lines of drainage. The West Sussex Coastal Plain (Figs. 1 and 5) is a useful area for investigating these elements and has been the focus of ongoing investigation over the last 25 years. Some of the results of these investigations are discussed here.

Pleistocene deposits of the West Sussex Coastal Plain were first described in detail by Prestwich (1859). By the early 20th century it was recognised that a series of high sea-level events were preserved in the area (Palmer and Cooke, 1923; Fowler, 1932; Calkin, 1934). Today we recognise that at least 4 altitudinally (and, by implication, chronologically) discrete beaches are present in the area (Bates et al., 1997, 2003). These include the

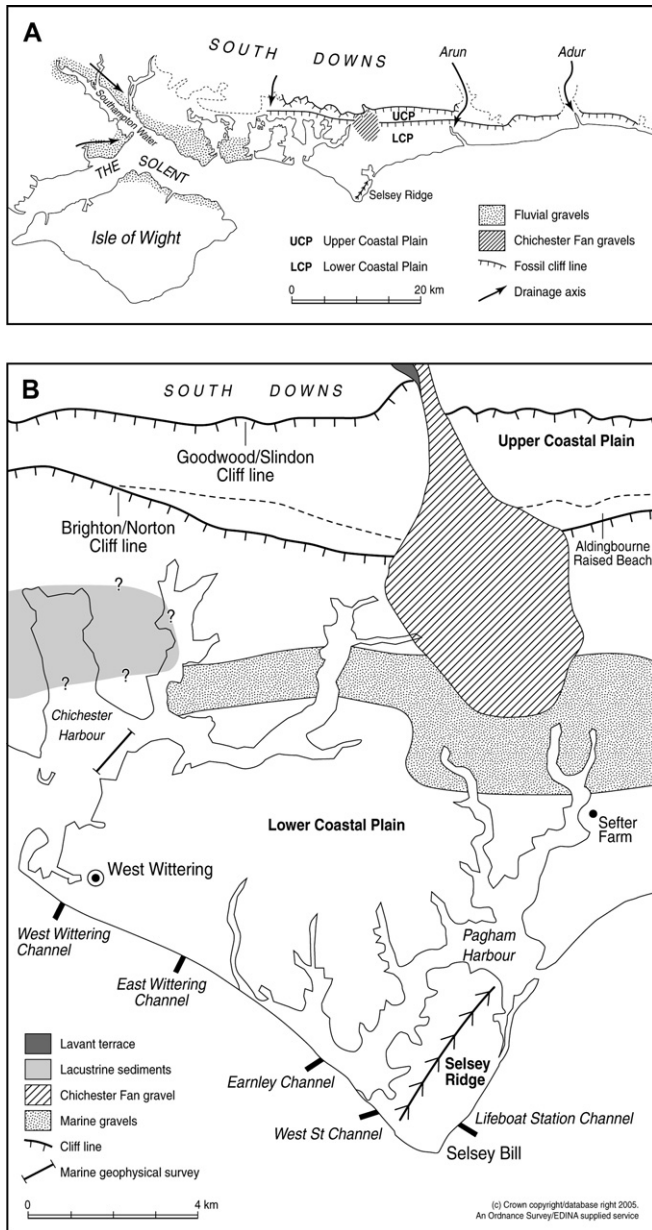


Fig. 5. (A) Sussex Solent Coastal Corridor showing main Pleistocene geomorphological elements. (B) Selsey/Chichester area showing main features of the Pleistocene significance.

major sand and gravel body at heights above 30 m (100 feet) OD referred to as the Goodwood–Slindon or ‘100 foot’ Raised Beach (Bates et al., 1997, 2003) (Figs. 1 and 5). A lower series of sands and gravels between 5 m and 9 m OD on the Lower Coastal Plain, typified by deposits at Norton Farm (Bates et al., 2000), also exists throughout the area (Brighton/Norton Raised Beach). Additional beaches exist at heights of between 16 and 20 m OD (Aldingbourne Raised Beach) and below 5 m OD (Pagham Raised Beach) (Figs. 6 and 7). These deposits form spreads of sand and gravels trending broadly parallel to the northern margin of the coastal plain and are typically overlain by cold climate coarse flint gravels and overlying finer, often decalcified, silt units (brickearths) (Fig. 7). Other cold stage

sediments include the Chichester Fan Gravels and bedded silts and coarser chalk gravels (Figs. 6 and 7).

To the east of the complex central plain area around Chichester the Arun Valley has a complex sedimentary sequence that has been partially controlled by changing bedrock geology (Fig. 8). Up to 6 terraces have been mapped immediately inland of the South Downs where the river cuts through the soft bedrock sequences of the Weald. Here relatively unrestricted lateral movement of the river, coupled with tectonic uplift, has allowed extensive terraces to form. Where the river cuts through the South Downs, greater resistance to erosion causes the river channel to become restricted. Only 4 terraces are preserved through the Chalk gap although a number of bedrock flats also exist that probably indicate former base levels for fluvial erosion (Bull, 1932, 1936; Kirkaldy and Bull, 1940; Woodcock, 1981). Finally, as the river emerges onto the coastal plain, all evidence of terraces disappears as the river traverses the soft Tertiary clays and silts prior to re-crossing the Chalk and finally traversing Tertiary clays and silts beyond the modern coast line (Fig. 8).

The absence of terraces within the coastal plain area is unsurprising since marine erosion during transgressive episodes in the Pleistocene probably truncated former expanses of river gravels within the region. For example Arun Terrace 4 sediments occur immediately above the cliffline of the Brighton–Norton Beach to the east of the Arun, apparently truncated by marine erosion of the coastal platform and landward movement of the cliff system during one or more high sea level stands. This will be exacerbated by long term tectonic uplift which brings sequences previously below wave base and the erosion envelope into the zone of destruction. Thus the uplift responsible for terrace formation in the first place is also responsible for the trimming of the terrace deposits in the area of marine transgression across the coastal plain.

A final type of deposit recognised on the WSCP are channels exposed beneath the beach on the foreshore that are filled with sediments containing biological remains of Quaternary age. These have been known since at least the late 19th century (Reid, 1892; Heron-Allen, 1911; Palmer and Cooke, 1923; West and Sparks, 1960; West et al., 1984). They are thought to be cut into the bedrock at around 0 m OD to varying depths. Because of changes to coastal defence structures these deposits have rarely been seen since the 1960s and are consequently little understood. However, they are considered to be very important in understanding the evolution of the Sussex/Hampshire landscapes over the last 0.5 million years (Preece et al., 1990; Bates et al., 1997). Recently, these deposits have been re-examined and samples recovered for dating (Bates et al., 2004). An example is the channel at West Wittering (Fig. 9). Geophysical and borehole study (Fig. 9B) has revealed the complexity of the channel fills (Fig. 10). Combining the data from both the boreholes and the geophysical surveys a double channel structure was noted (Fig. 10) where channel I is filled with sandy clays while channel II is filled with gravels. Both channels are capped by clay-silts. Gravels and clay-silts overlie the sequence. This evidence, coupled with that provided by the contained microfossils, suggests that both the

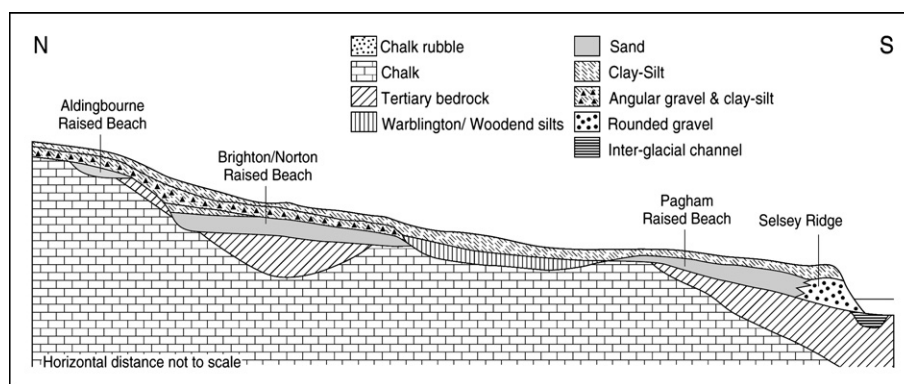


Fig. 6. Schematic profile through the Lower Coastal Plain in Chichester area.

sandy-clays filling channel I and the clay-silts sealing both channels I and II belong to a temperate interglacial. They may well represent elements of the sequence previously reported by Reid (1892). Interestingly a channel complex with similar characteristics has also recently been identified below low tide levels within the complex of tidal channels comprising Chichester Harbour (Fig. 9C).

Presently a number of different channels have been identified along the West Sussex coast in which deposits of different ages are present (Bates et al., unpublished). These include both Pleistocene examples such as those at West Wittering, West Street Selsey (Figs. 9 and 10) and Holocene channels such as that at Bognor Regis (Bates et al., 2005) (Fig. 10). The presence of a number of different channels with complex sedimentary

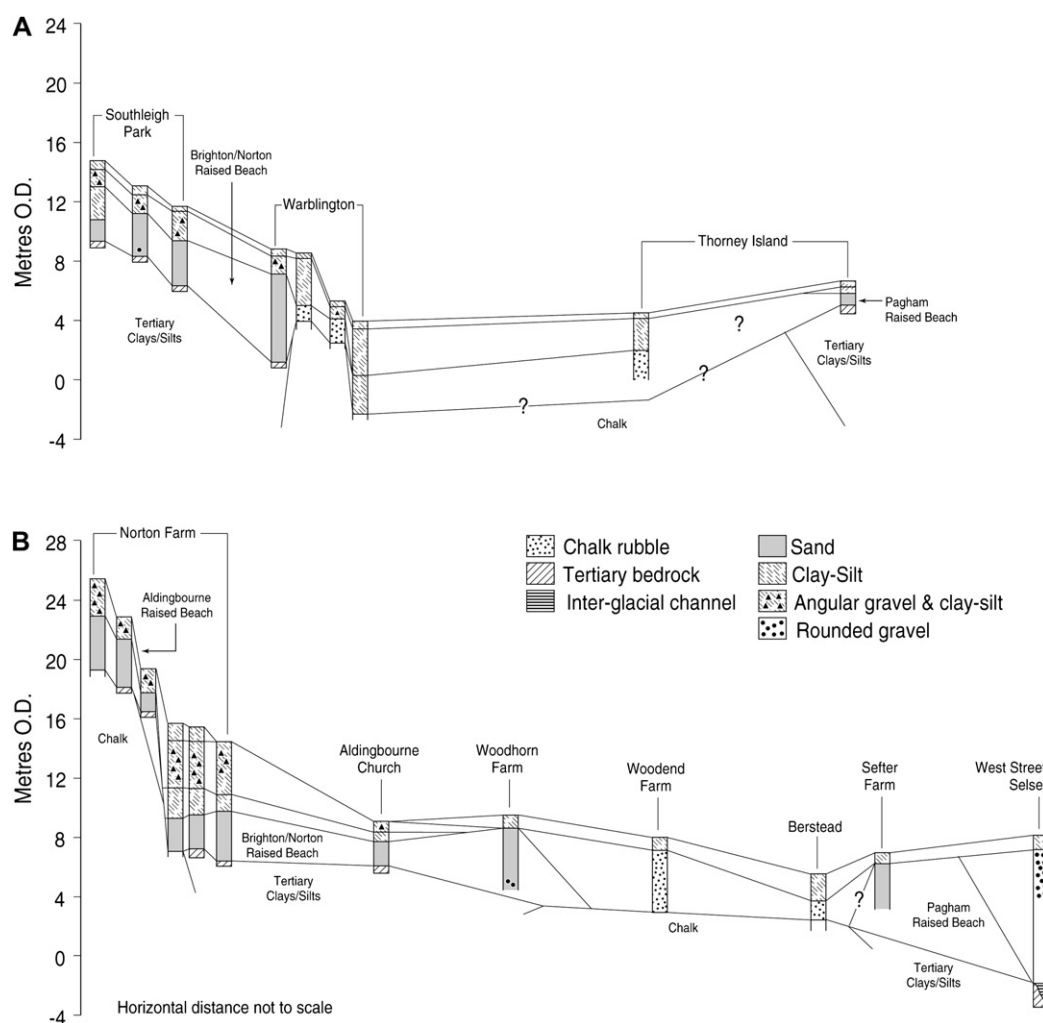


Fig. 7. Stratigraphic profiles constructed from boreholes and test pits. (A) Southleigh—Warblington—Thorney Island. (B) Norton Farm—Colworth—North Bersted.

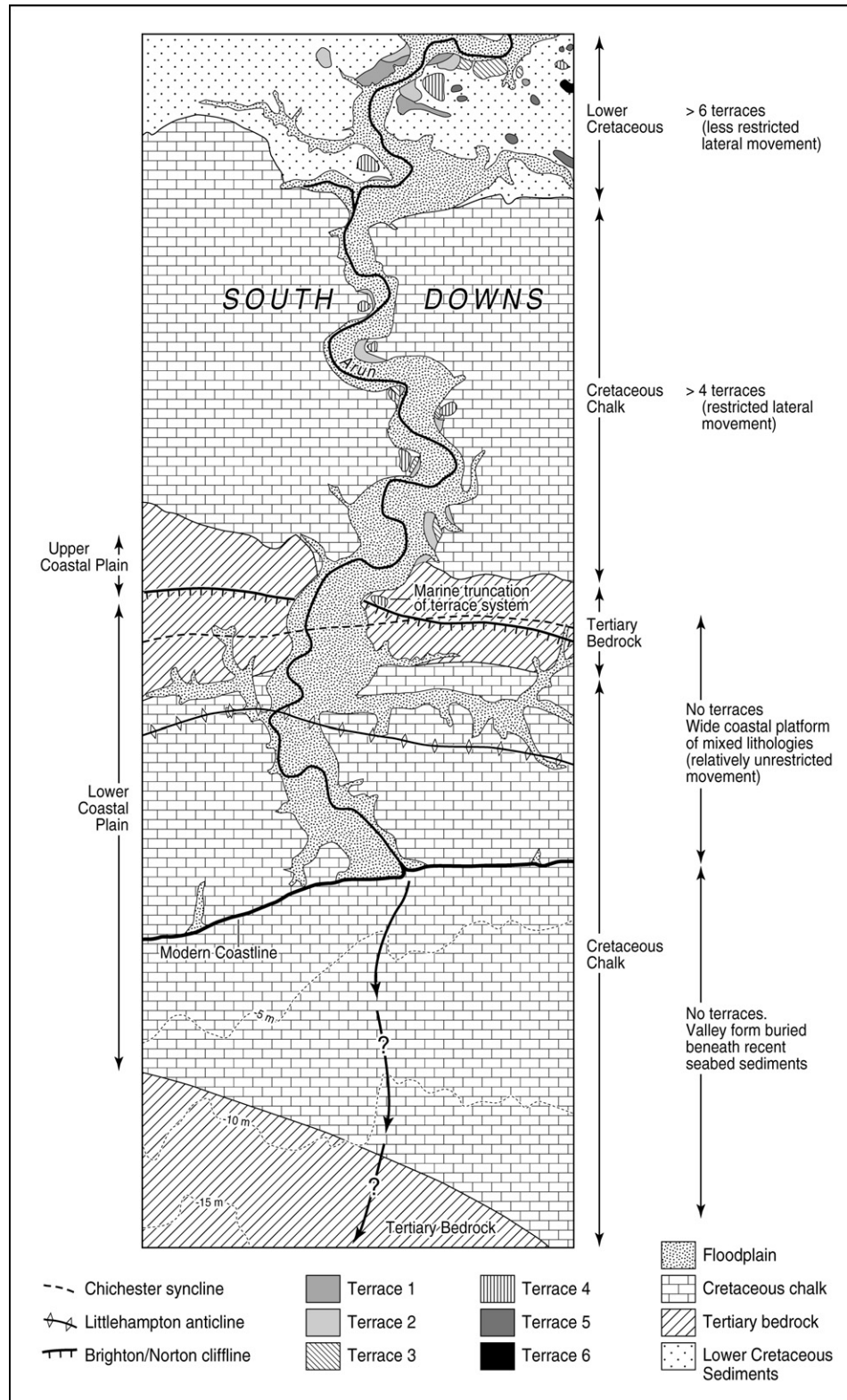


Fig. 8. Distribution of Pleistocene sediments of the river Arun and associated bedrock geologies from the Weald to off-shore.

architectures within the near-shore zone (i.e. between -3 m and $+10$ m OD) reflects a continuum from dry land to sub-tidal situations that mirrors not only current changes in local geomorphology but also ancient lateral variability in geomorphology and consequently sedimentology. At present direct

correlations between on-shore and transition zone sequences can be demonstrated through the West Wittering site (Fig. 9) while sediments (lacustrine deposits at Warblington/north Thorney) associated with cold climate (sea level low stand) periods can be traced into sub-alluvium contexts to the north of

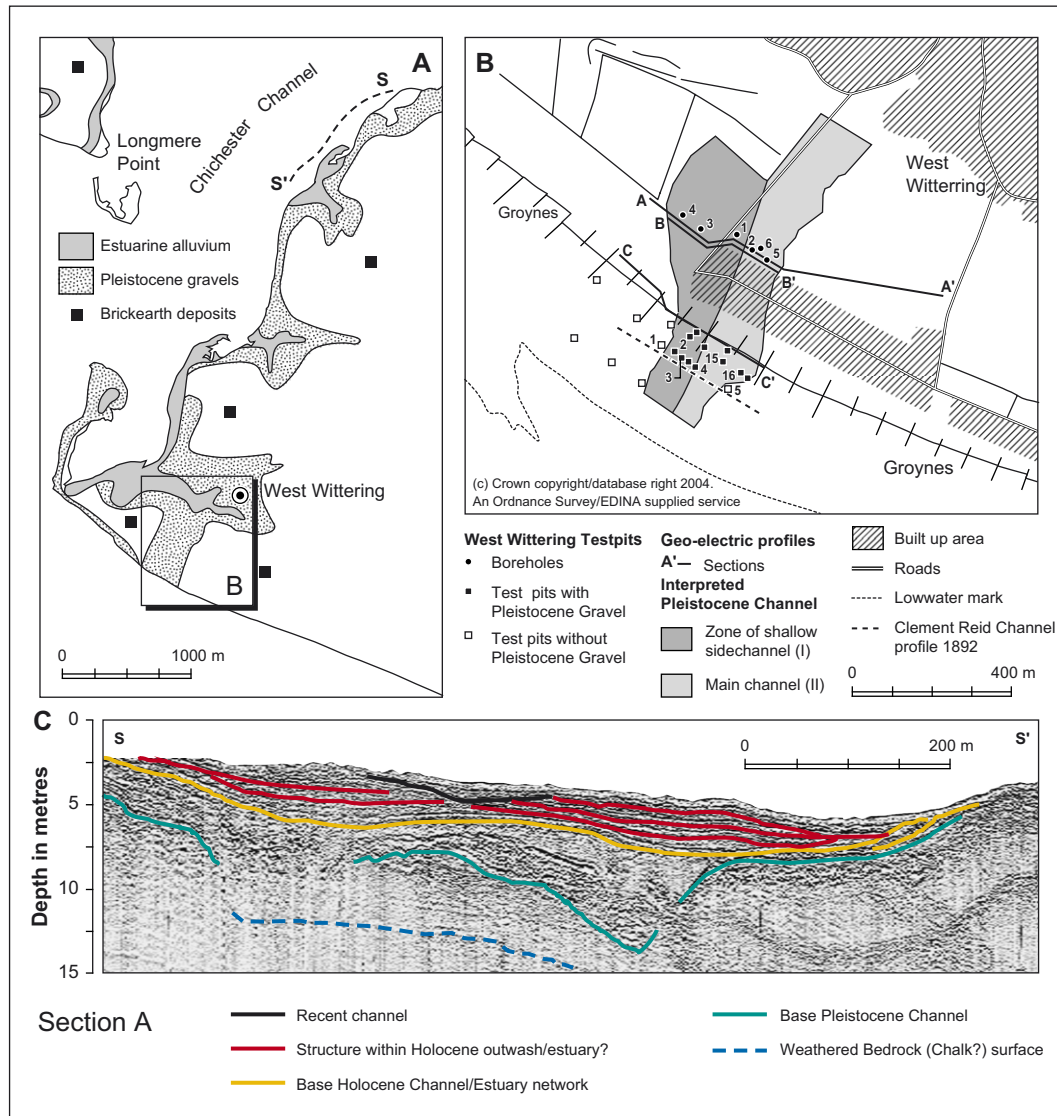


Fig. 9. (A) Superficial geology (modified from BGS mapping) for the West Wittering/Chichester Channel area showing location of study sites. (B) Detailed site location plan for West Wittering. (C) Seismic section through channel beneath Chichester Harbour (line A–A', in (A)).

Thorney Island (Fig. 7). Seaward continuity of other features such as the channels around Selsey cannot be demonstrated at present. However the fact that these channels (of a wide variety of ages) occur at similar datums to each other (Fig. 11) all attest to the local complexity of sequences.

4. Correlating sequences across the transition zone; the Sussex/Solent Corridor example

The study area defined by the Solent system to the west and the Arun system to the east is of considerable interest to the aggregate industry both within terrestrial areas of the Sussex Solent Coastal Corridor and the off-shore region. For this reason it is necessary to understand the sedimentary sequences both on and off-shore and how they correlate. However, interpreting the sequences across the transition zone is complex and controlled by a number of key factors:

1. *Bedrock geology.* The bedrock geology forms a broad west to east distributed system of Chalk and Tertiary sediments beneath the superficial sediments of the coastal plain (Fig. 5) and the shallow shelf areas north of the Northern Palaeovalley. Sequences of deposits are distributed either parallel to the strike of these deposits (coastal sediments) or transverse to the strike (fluvial sediments). Evidence from the Arun system would suggest that formation and preservation of terraces across these bedrock geologies will therefore vary.
2. *Palaeogeography.* To the west the Solent river system entered the Channel waters via the eastern end of the Isle of Wight until at least the end of the last interglacial (Bates et al., 2003) creating a major valley system/estuary during sea level high stands in the vicinity of the Isle of Wight/Portsmouth Gap. The presence of this river system led to the deposition of gravels and sands in cold stages and less well

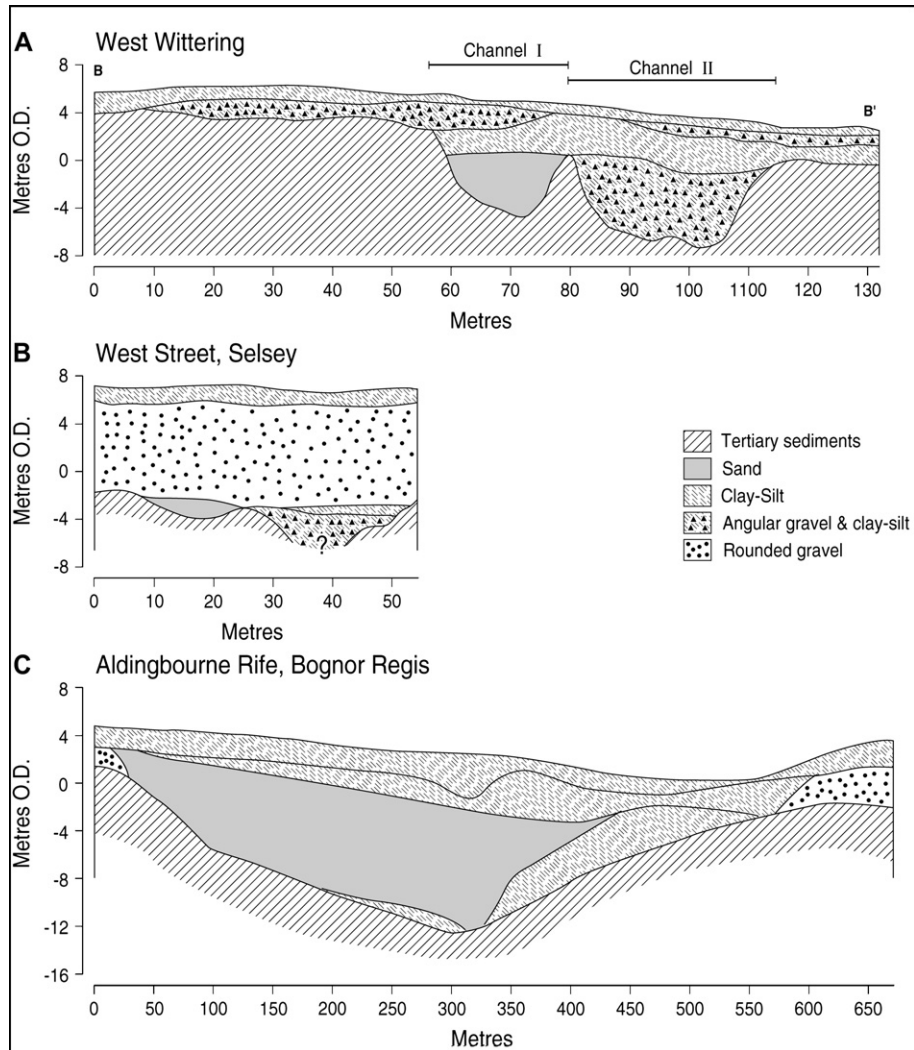


Fig. 10. Comparison between channels along coast between West Wittering and the Arun Valley. (A) West Wittering channel. (B) West Street, Selsey channel. (C) Aldingbourne Rife channel at Bognor Regis.

preserved finer grained silts and clays in temperate stages as linear bodies of material parallel to the main drainage axis (Everard, 1954a; Allen and Gibbard, 1993; Velegrakis et al., 1999; Bates et al., 2003). To the east open shorelines existed through much of the later Middle and Upper Pleistocene depositing sands and gravels parallel to the coast line on

high stand coastal platforms that were cut at repetitively lower levels. This pattern of estuary and open coast would have influenced patterns of coastal erosion during transgression and following stabilisation of the high sea level. The result would have been truncation, over-riding and mixing of the fluvial deposits and older marine deposits to the east,

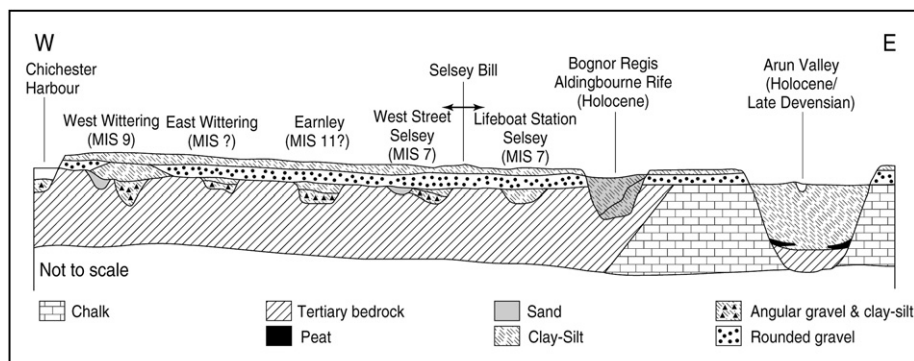


Fig. 11. Schematic illustration of channels along West Wittering–Littlehampton coast.

near the shore platform. In contrast, there would have been relatively lower erosion to the west in the Solent estuary.

3. *Uplift*. Quaternary uplift in the region is now well established (Preece et al., 1990; Westaway et al., 2006) and has supplied the driving mechanism for the creation and preservation of both terraces in the Solent and coastal platforms and associated beaches of the West Sussex Coastal Plain. Uplift of the marine platforms will have resulted in the creation of new platforms at lower elevations around the coast in areas of open coast lines and the removal of deposits associated with older events particularly on emergent valley sides cut into and through the coastal plain.
4. *Fluvial processes*. Bridgland has argued that terrestrial rivers are primarily influenced by climatic oscillations (coupled with tectonic uplift) to produce terraces. However, it is commonly accepted that within the context of the shelf area during low stands fluvial processes were influenced by base levels defined by sea level. The boundary where sea-level becomes an important factor determining river behaviour will have varied over time with changing sea levels. Numerical modelling of fluvial erosion and deposition on the continental shelf has shown that the precise nature of sealevel fluctuations during these periods has a strong influence on sediment redistribution and channel development (Fagherazzi et al., 2004).

The evidence that would therefore be available to construct regional frameworks between the on-shore and off-shore is therefore complex and likely to vary laterally along the coast. For example within the eastern Solent an extensive sequence of terraces (Figs. 3 and 4) plunge seawards at a variety of different gradients. Off-shore fragments of possibly equivalent gravel aggradations and terraces have been identified but critically the transition zone sequences have only been examined in superficial detail. Comparison of terraces reconstructed in the terrestrial zone (Fig. 4) with the bathymetry of the present sea floor clearly indicates that if terrace gradients continued at similar values across the shallow transition zone then only the most recent terraces would intersect with the channel or sea floor. Terrace 3 and all older terraces are projected to occur at elevations above that of the contemporary sea floor. This implies one of the following:

1. These terraces once extended across the shelf area. However marine erosion (probably associated with the creation of raised beaches, Fig. 5) has removed the valley tops/sea floor on which they were deposited. In this case most of the contemporaneous sequences likely to contain Palaeolithic archaeological remains will have been removed and/or reworked.
2. The terrace gradients steepen significantly in the transition zone to allow them to intersect with the sea floor and be preserved beneath the sea floor in the valley systems. In this case without significant investment in drill cores and dating programs for the off-shore region we cannot be certain of the correlation of units or the archaeological significance of any sequences preserved in the off-shore.
3. Patterns of sedimentation associated with deposition of fluvial sediments in the shelf area are very different to those in fully terrestrial situations. In this case considerable additional investigation needs to be undertaken to define these sedimentation patterns and resultant stratigraphic architecture.

It remains a strong probability that elements of all these factors may need to be considered in any interpretation of the sequences. Furthermore Lericolais et al. (2003) suggest that processes acting on sequence development in the Channel are influenced by the differences in degree of sea level fall. They argue that if sea level does not fall below -70 m OD little incision will occur. However if sea level drops below -70 m OD the longitudinal profile is imbalanced and the river will incise towards base level. Thus processes operating on the river within the upper shelf region may vary both within and between cold periods.

Similar problems also exist with the interpretation of the Arun sequence. Although no long profiles exist for the Arun terraces it is clear that there is little continuity between terrace remnants on-shore and off-shore because of marine erosion of fluvial deposits, e.g. terrace 4 (Bates, 2001). Variability in bedrock geology coupled with the relatively unrestricted nature of the coastal plain topography has probably resulted in truncation of fluvial sequences in the near-shore zone. In contrast further off-shore the transgression was less destructive because terraces and fluvial stratigraphy are preserved (Gupta et al., 2004). This may be due to rather more rapid rises in sea levels during late glacial and early interglacial phases. When maximum interglacial sea levels coincided with a phase of relatively prolonged stability in coastal position, bedrock erosion and the removal of overlying fluvial sediments will have occurred. In this case it is questionable whether any but the most recent sequences of fluvial aggradation are preserved in the vicinity of the Arun palaeovalley. Indeed Gupta et al. (2004) appear to suggest a single terrace is present in the flooded part of the valley system.

In addition to problems projecting fluvial terrace deposits off-shore, sequences in the zones between major drainage basins may potentially be composed of an even more complex, mosaic of local environments. Across the Lower Coastal Plain in West Sussex, marine sediments are spatially and stratigraphically interspersed with terrestrial and freshwater sediments. In places some of these units (i.e. the marine sands of the Brighton/Norton Raised Beach or the cold climate deposits traced from Warblington to Colworth, Fig. 7) are large, laterally mappable deposits. However, elsewhere the sequences may be relatively localised and restricted to shallow incisions into bedrock (e.g. the channels present around the Selsey coast, Fig. 11). The evidence from these sequences suggests that a wide range of ages of deposits may be represented in a small geographical area within narrow elevations either side of OD. It is possible that similar situations may also occur within the shallow subtidal zone off-shore of Selsey Bill (Fig. 2).

A final problem when dealing with these off-shore sequences is the possibility that the environments and associated conditions that existed in the exposed shelf areas during sea level low stand cold phases and the early parts of interglacials

when sea level was relatively low have no equivalents in locations that have always been within terrestrial contexts. Currently minimal palaeoenvironmental data is available for these off-shore areas with the exception of information from the early part of the Holocene in the off-shore Arun area investigated by Wessex Archaeology (Wessex Archaeology, 2004). However, it is possible that conditions during the Holocene differed significantly from those within the current terrestrial zone. Additionally it is clear that the major river systems draining across much of the channel floor would have been substantial. Marine geophysical evidence (Bourillet et al., 2003) indicates that many of the bedforms associated with these rivers were of a scale unknown in on-shore systems. This would imply rivers operating in different modes and with water depths/flow velocities far in excess of those upstream. Between river systems the development of soils and weathered regolith will have experienced very different histories and their suitability for immediate colonisation by plants will require thought. Consequently landscape evolution (including plant and animal occupation as well as human) may be unlike that in our present terrestrial situations which would have been the upper catchment areas for the major rivers of the channel area.

5. Implications for Palaeolithic archaeology

Although there is little or no evidence for Palaeolithic archaeological remains in the offshore area of the Arun or Solent systems if present, archaeological remains would occur as re-worked material within the river gravels, as *in situ* material within finer grained units associated with the fluvial sediments or in association with the myriad of deposits similar to those identified beneath the Sussex Coastal Plain between the river systems. With the exception of the very well preserved sequences associated with the Goodwood/Slindon Raised Beach at Boxgrove (Roberts and Parfitt, 1999) other sites within the coastal plain have produced little archaeological material (Bates et al., 2004). In contrast within the eastern part of the Solent the nature and distribution of Palaeolithic artefacts have recently been reviewed by Bates et al. (2004) and artefacts were noted throughout terraces 1–6. Consequently evidence, in places patchy, for hominin activity might be expected in the offshore region. However, on the basis of the projection of the terrace morphology into the offshore region (see above) only evidence associated with terraces 1 and 2 is likely to exist within the offshore equivalents of the Solent system.

Other factors to be taken into account are the nature of the conditions prevalent within the offshore region during periods of lowered sea levels. Cold stage occupation of the landscape surrounding the Channel is documented at sites in both England and the continent. Occupation at the Boxgrove site continued from the interglacial into the cold stage ascribed to MIS 12 (Roberts and Parfitt, 1999) while interstadial occupation of the La Cotte de St. Brelade site in Jersey occurred during MIS 6 (Callow and Cornford, 1986). Further cold stage activity has been documented at Harnham near Salisbury in MIS 8 (Bates et al., unpublished). The only site presently documented beneath modern sea level (by implication occupied during a phase

of lowered sea level, i.e. a cooler period) is at La Mondree, Fermanville (Scuavee and Verague, 1988). However, despite the presence of hominins within the region during cold stages it should be remembered that at present little is known of the nature of the landscapes associated with these river valleys on the shelf and the associated interfluvial areas. In many cases, with the higher rates of spring runoff and the extended nature of the drainage basins of many of the rivers traversing the shelf during the period of lowered sea level, significant barriers to movements may have developed making blocks of land between rivers landscape cul-de-sacs (Fig. 2). These barriers to movement, and their possible influence in restricting large mammal movements within these terrain blocks, may have lowered the potential resource distribution within the lower reaches of the rivers thereby making them less attractive for hominin occupation. Furthermore the paucity of data regarding the nature of the vegetation within these zones requires consideration. Poor soil development, coupled with a significantly enhanced salt content, may have inhibited rapid colonisation of these regions by vegetation thereby further reducing their attractiveness to hominins.

In conclusion despite the known presence of hominins adjacent to the Channel floor two factors need to be remembered when ascertaining the Palaeolithic potential for the offshore:

1. *Occupation*. Did hominins actually occupy the shelf? If vegetation patterns and associated resource distribution (large mammals) were significantly influenced by the regional history of sea level rise and fall conditions suitable for Palaeolithic hominin activity might be limited. Furthermore barriers to movement created by the patterns of fluvial activity may also have reduced the attractiveness of the area to early hominins. Evidence for occupation remains to be demonstrated in the Sussex/Solent region.
2. *Preservation potential*. Are the processes leading to sequence formation and modification suitable for preserving records (if present) extending through the Pleistocene (i.e. are there sediments present dating to the periods of occupation?). In the case of the Sussex/Solent corridor this looks extremely unlikely but remains to be proven.

6. Conclusions

Evidence from the area of the Sussex Solent Coastal Corridor illustrates the difficulties in correlating fluvial sediments across the transition zone (of the Solent and Arun systems), it also demonstrates the complexity of sequences in the near-shore zone that makes any off-shore predictions highly speculative. In particular it suggests that simple correlation between on- and off-shore sequences should be treated with a great deal of caution. Furthermore although models such as Bridgland's terrace model (Bridgland, 2000) form the basis for our understanding of the on-shore stratigraphic sequences such models may require modification prior to application in off-shore regions.

It is now widely recognised that local palaeogeographies and palaeogeographic change are very important in defining patterns of sedimentation and development of sequences across

short distances; a point well illustrated here by the identification of the complex, laterally diverse sequences in the near-shore zone of the West Sussex Coastal Plain. However, other factors also impact the Pleistocene record, including those associated with sequence preservation. Particularly the prevailing marine conditions and patterns of transgression and regression are of considerable significance to formation and preservation of local stratigraphy here. This is likely to result in different histories of sequence formation and preservation even between systems separated by only short distances on the shelf area. Consequently it is possible that each system will contain a unique sedimentary record and generalisations between systems cannot be assumed. Thus despite the small distances involved (about 40 km east to west) and the apparent similarity of sediments within the Arun and Solent systems it is possible that the sediments preserved in these systems had different modes of deposition, ages and differing preservational potential. Consequently their archaeological potential may be very different. Strategies for investigation and mitigation therefore need to be closely tied to individual areas and the application of generic models to sequence generation only attempted with caution.

Finally the basis for assigning regional correlations to submerged sedimentary sequences should therefore both demonstrate the relationship between sequences through the transition zone and clarify the nature of the deposits in the off-shore systems. Only by achieving this will it be possible to determine the archaeological potential of offshore deposits and therefore aid developing strategies for investigation and mitigation for those areas under threat of extraction. Areas such as the West Sussex Coastal Plain and its offshore extension are important regions as they can address key issues of importance not only to the archaeologist but the wider fields of sedimentology and sequence stratigraphy. In particular this is an ideal situation in which to address questions regarding how and to what degree nearshore marine system tracts can be directly linked to fluvial systems influenced by terrestrial variables. Furthermore, questions regarding variations in rate and direction of sea level change that are expressed in the architecture of the fluvial systems can also be examined.

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References

- Allen, L.G., Gibbard, P.L., 1993. Pleistocene evolution of the Solent river of southern England. *Quaternary Science Reviews* 12, 503–528.
- Antoine, P., Coutard, J.-P., Gibbard, Ph., Hallegouet, B., Lautridou, J.-P., Ozouf, J.-C., 2003. The Pleistocene rivers of the English Channel region. *Journal of Quaternary Science* 18, 227–243.
- Bates, M.R., 1999. A geoarchaeological assessment of a borehole from the Kingsnorth Power Station site, Hoo St. Werburgh, Rochester-upon-Medway. Unpublished report. S. Bates and M.R. Bates, Lampeter.
- Bates, M.R., 2001. The Meeting of the Waters: raised beaches and river gravels of the Sussex Coastal Plain/Hampshire Basin. In: Wenban-Smith, F.F., Hosfield, R. (Eds.), *Palaeolithic Archaeology of the Solent River*. Lithic Studies Society Occasional Paper 7. Lithic Studies Society, London, pp. 27–45.
- Bates, M.R., Parfitt, S.A., Roberts, M.B., 1997. The chronology, palaeogeography and archaeological significance of the marine Quaternary record of the West Sussex Coastal Plain, Southern England. *Quaternary Science Reviews* 16, 1227–1252.
- Bates, M.R., Bates, C.R., Gibbard, P.L., Macphail, R.I., Owen, F.J., Parfitt, S.A., Preece, R.C., Roberts, M.B., Robinson, J.E., Whittaker, J.E., Wilkinson, K.E., 2000. Late Middle Pleistocene deposits at Norton Farm on the West Sussex coastal plain, southern England. *Journal of Quaternary Science* 15, 61–89.
- Bates, M.R., Keen, D.H., Lautridou, J.-P., 2003. Pleistocene marine and periglacial deposits of the English Channel. *Journal of Quaternary Science* 18, 319–337.
- Bates, M.R., Wenban-Smith, F.F., Briant, R.M., Marshall, G., 2004. Palaeolithic archaeology of the Sussex/Hampshire coastal corridor, project number 3279. Unpublished report for English Heritage. University of Wales, Lampeter.
- Bates, M.R., Whittaker, K., 2004. Landscape evolution in the Lower Thames Valley: implications for the archaeology of the earlier Holocene period. In: Cotton, J., Field, D. (Eds.), *Towards a New Stone Age. Aspects of the Neolithic in South-East England*. CBA Research Report Series RR 137. Council for British Archaeology, York, pp. 50–70.
- Bates, M.R., Jones, S., Keen, D.H., Walker, M.J.C., Whittaker, J.J., 2005. Palaeoenvironmental investigations at the Butlins Hotel Site, Bognor, West Sussex. Unpublished report. University of Wales, Lampeter.
- Bellamy, A.G., 1995. Extension of the British landmass: evidence from shelf sediment bodies in the English Channel. In: Preece, R.C. (Ed.), *Island Britain: a Quaternary Perspective*, pp. 47–62. Geological Society Special Publication No. 96.
- Boulton, G.S., Peacock, J.D., Sutherland, D.G., 1991. Quaternary. In: Craig, G.Y. (Ed.), *The Geology of Scotland*, third ed. Geological Society, London, pp. 503–542.
- Bourillet, J.-F., Reynaud, J.-Y., Baltzer, A., Zaragosi, S., 2003. The ‘Fleuve Manche’: the submarine sedimentary features from the outer shelf to the deep-sea fans. *Journal of Quaternary Science* 18, 261–282.
- Bridgland, D.R., 1994. The Quaternary of the Thames. In: *Geological Conservation Review Series 7*. Chapman and Hall, London.
- Bridgland, D.R., 1995. The Quaternary sequence of the eastern Thames basin: problems of correlation. In: Bridgland, D.R., Allen, P., Haggart, B.A. (Eds.), *The Quaternary of the Lower Reaches of the Thames*. Quaternary Research Association, Durham, UK, pp. 35–52. Field Guide.
- Bridgland, D.R., 2000. River terrace systems in north-west Europe: an archive of environmental change, uplift and early human occupation. *Quaternary Science Reviews* 19, 1293–1303.
- Bridgland, D.R., 2002. Fluvial deposition on periodically emergent shelves in the Quaternary: example records for the shelf around Britain. *Quaternary International* 92, 25–34.
- Bridgland, D.R., 2003. The evolution of the River Medway, S.E. England, in the context of Quaternary palaeoclimate and the Palaeolithic occupation of NW Europe. *Proceedings of the Geologists Association* 114, 23–48.
- Bridgland, D.R., 2006. The Middle and Upper Pleistocene sequence in the Lower Thames: a record of Milankovitch climatic fluctuation and early

- human occupation of southern Britain. *Proceedings of the Geologists Association* 117, 281–306.
- Bridgland, D.R., D'Olier, B., Gibbard, P.L., Roe, H.M., 1993. Correlation of the terrace deposits between the Lower Thames, eastern Essex and the submerged off-shore continuation of the Thames-Medway valley. *Proceedings of the Geologists Association* 104, 51–57.
- Bull, A.J., 1932. Notes on the geomorphology of the Arun Gap. *Proceedings of the Geologists Association* 43, 274–276.
- Bull, A.J., 1936. Studies in the geomorphology of the South Downs. Eastbourne to the Arun Gap. *Proceedings of the Geologists Association* 47, 99–129.
- Calkin, J.B., 1934. Implements from the higher raised beaches of Sussex. *Proceedings of the Prehistoric Society of East Anglia* 7, 333–347.
- Callow, P., Cornford, J.M., 1986. *La Cotte de St Brelade* (Jersey) 1961–1978: Excavations by C.B.M. McBurney. Geobooks, Norwich, UK.
- Coles, B.J., 1998. Doggerland: a speculative survey. *Proceedings of the Prehistoric Society* 64, 45–81.
- Dix, J., Quinn, R., Westley, R., 2004. A re-assessment of the archaeological potential of continental shelves. <<http://www.arch.soton.ac.uk/Research/Aggregates/shelve-report.htm>> (accessed October 2005).
- Dyer, K.R., 1975. The buried channels of the 'Solent River', southern England. *Proceedings of the Geologists Association* 86, 239–246.
- Edwards, R.A., Freshney, E.C., 1987. *Geology of the country around Southampton*. Memoir for 1:50,000 Geological Sheet 315 (England and Wales). HMSO, London.
- Everard, C.E., 1954a. The Solent River: a Geomorphological Study. *Transactions of the Institute of British Geographers* 20, 41–58.
- Everard, C.E., 1954b. Submerged gravel and peat in Southampton Water. *Papers and Proceedings of the Hampshire Field Club* 18, 263–285.
- Fagherazzi, S., Howard, A.D., Wiberg, P.L., 2004. Modeling fluvial erosion and deposition on continental shelves during sea level cycles. *Journal of Geophysical Research* 109, F3 (2003JF000091).
- Fitch, S., Thomson, K., Gaffney, V., 2005. Late Pleistocene and Holocene depositional systems and the palaeogeography of the Dogger Bank, North Sea. *Quaternary Research* 64, 185–196.
- Flemming, N.C., 1998. Archaeological evidence for vertical movement on the continental shelf during the Palaeolithic, Neolithic and Bronze Age periods. In: Stewart, I., Vita-Finzi, C. (Eds.), *Coastal Tectonics*, pp. 129–146. Geological Society of London Special Publications 146.
- Fowler, R., 1932. The "One Hundred Foot" raised beach between Arundel and Chichester, Sussex. *Quarterly Journal of the Geological Society of London* 88, 84–99.
- Gibbard, P.L., 1994. *Pleistocene History of the Lower Thames Valley*. Cambridge University Press, Cambridge, 229 pp.
- Gupta, S., Collier, J., Palmer-Felgate, A., Dickinson, J., Bushe, K., Humber, S., 2004. *Submerged Palaeo-Arun River: Reconstruction of Prehistoric Landscapes and Evaluation of Archaeological Resource Potential* (2 volumes). Imperial College, London.
- Heron-Allen, E., 1911. *Selsey Bill: Historic and Prehistoric*. Duckworth and Co, London.
- Hodson, F., West, I.M., 1972. Holocene deposits of Fawley, Hampshire, and the development of Southampton Water. *Proceedings of the Geologists Association* 83, 421–441.
- Kirkaldy, J.F., Bull, A.J., 1940. The geomorphology of the rivers of the Southern Weald. *Proceedings of the Geologists Association* 51, 115–150.
- Lake, R.D., 1977. Buried channel deposits in the south-east Essex area; their bearing on Pleistocene palaeogeography. *Report of the Institute of Geological Science*, No. 77/21, 13 pp.
- Lericola, G., Auffret, J.-P., Bourillet, J.-F., 2003. The Quaternary Channel River: seismic stratigraphy of its palaeo-valleys and deeps. *Journal of Quaternary Science* 18, 245–260.
- Maddy, D., 1997. Uplift-driven valley incision and river terrace formation in southern England. *Journal of Quaternary Science* 12, 539–545.
- Marsland, A., 1986. The floodplain deposits of the lower Thames. *Quarterly Journal of Engineering Geology* 19, 223–247.
- Momber, G., 2000. Drowned and deserted: a submerged prehistoric landscape in the Solent, England. *International Journal of Nautical Archaeology* 29, 86–99.
- Palmer, L.S., Cooke, J.H., 1923. The Pleistocene deposits of the Portsmouth district and their relation to Early Man. *Proceedings of the Geologists Association* 34, 253–282.
- Posamentier, H.W., Jervey, M.T., Vail, P.R., 1988. Eustatic controls on clastic deposition I – Conceptual frameworks. In: Wilgus, C.K., Hastings, B.S., Kendall, C.G.S.C., Posamentier, H.W., Ross, C.A., Van Wagoner, J.C. (Eds.), *Sea-Level Changes: An Integrated Approach*, pp. 109–124. Special Publications of the Society of Economic Paleontology and Mineralogy 42.
- Preece, R.C., Scourse, J.D., Houghton, S.D., Knudsen, K.L., Penny, D.N., 1990. The Pleistocene sea-level and neotectonic history of the eastern Solent, Southern England. *Philosophical Transactions of the Royal Society of London B* 328, 425–477.
- Prestwich, J., 1859. On the westward extension of the old raised beach of Brighton and on the extent of the sea-bed of the same period. *Quarterly Journal of the Geological Society of London* 15, 215–221.
- Reid, C., 1892. The Pleistocene deposits of the Sussex Coast and their equivalents in other districts. *Quarterly Journal of the Geological Society of London* 43, 344–361.
- Roberts, M.B., Parfitt, S.A., 1999. Boxgrove. A Middle Pleistocene Hominid Site at Earham Quarry, Boxgrove, West Sussex. English Heritage, London. English Heritage Archaeological Report 17.
- Roberts, P., Trow, S., 2002. Taking to the water: English Heritage's initial policy for the management of maritime archaeology in England. English Heritage, London.
- Roe, H.M., 1999. Late Middle Pleistocene sea-level change in the southern North Sea: the record from eastern Essex, UK. *Quaternary International* 55, 115–128.
- Scuvey, F., Verague, J., 1988. *Le gisement sous-marin du Paléolithique moyen de l'Anse de la Mondrée à Fermanville (Manche)*. C.E.H.P.-Littus, 121 pp.
- Vail, P.R., Mitchum Jr., R.M., Todd, R.G., Widmier, J.M., Thompson III, S., Sangree, J.B., Bubb, J.N., Hatleid, W.G., 1977a. Seismic stratigraphy and global changes in sea level. In: Payton, C.E. (Ed.), *Seismic Stratigraphy – Applications to Hydrocarbon Exploration*. Memoir of the American Association of Petroleum Geologists, 26, pp. 49–62. Tulsa, OK.
- Vail, P.R., Mitchum, R.M., Thompson III, S., 1977b. Seismic stratigraphy and global changes of sea-level, part 3: relative changes of sea level from coastal onlap. In: Payton, C.E. (Ed.), *Seismic Stratigraphy – Applications to Hydrocarbon Exploration*. Memoir of the American Association of Petroleum Geologists, 26, pp. 63–82. Tulsa, OK.
- Vail, P.R., Mitchum, R.M., Thompson III, S., 1977c. Seismic stratigraphy and global changes of sea-level, part 4: global cycles of relative changes of sea level. In: Payton, C.E. (Ed.), *Seismic Stratigraphy – Applications to Hydrocarbon Exploration*. Memoir of the American Association of Petroleum Geologists, 26, pp. 83–97. Tulsa, OK.
- Velegrakis, A.F., Dix, J.K., Collins, M.B., 1999. Late Quaternary evolution of the upper reaches of the Solent River, Southern England, based upon marine geophysical evidence. *Journal of the Geological Society of London* 156, 73–87.
- Wenban-Smith, F.F., 2002. Marine aggregate dredging and the historic environment: Palaeolithic and Mesolithic archaeology on the seabed. BMAPA and EH, London.
- Wessex Archaeology, 2004. ALSF Seabed Prehistory 2003–2004. http://www.wessexarch.co.uk/projects/marine/alsf/seabed_prehistory/index2003-2004.html.
- West, I.M., 1980. Geology of the Solent estuarine system. In: *The Solent Estuarine System: an Assessment of the Present Knowledge*. NERC Publications Series C22, pp. 6–19.
- West, R.G., Sparks, B.W., 1960. Coastal interglacial deposits of the English Channel. *Philosophical Transactions of the Royal Society of London B* 243, 95–135.
- West, R.G., Devoy, R.J.N., Funnell, B.M., Robinson, J.E., 1984. Pleistocene deposits at Earnley, Bracklesham Bay, Sussex. *Philosophical Transactions of the Royal Society of London B* 306, 137–157.
- Westaway, R.W.C., Bridgland, D.R., White, M., 2006. The Quaternary uplift history of central southern England: evidence from the terraces of the Solent River system and nearby raised beaches. *Quaternary Science Reviews* 25, 2212–2250.
- Woodcock, A., 1981. The Lower and Middle Palaeolithic periods in Sussex. *British Archaeological Reports British Series* 94.