Contiguous **P**alaeo-**L**andscape **R**econstruction

(Transition Zone Mapping for Marine-Terrestrial Archaeological Continuity)

Final Report

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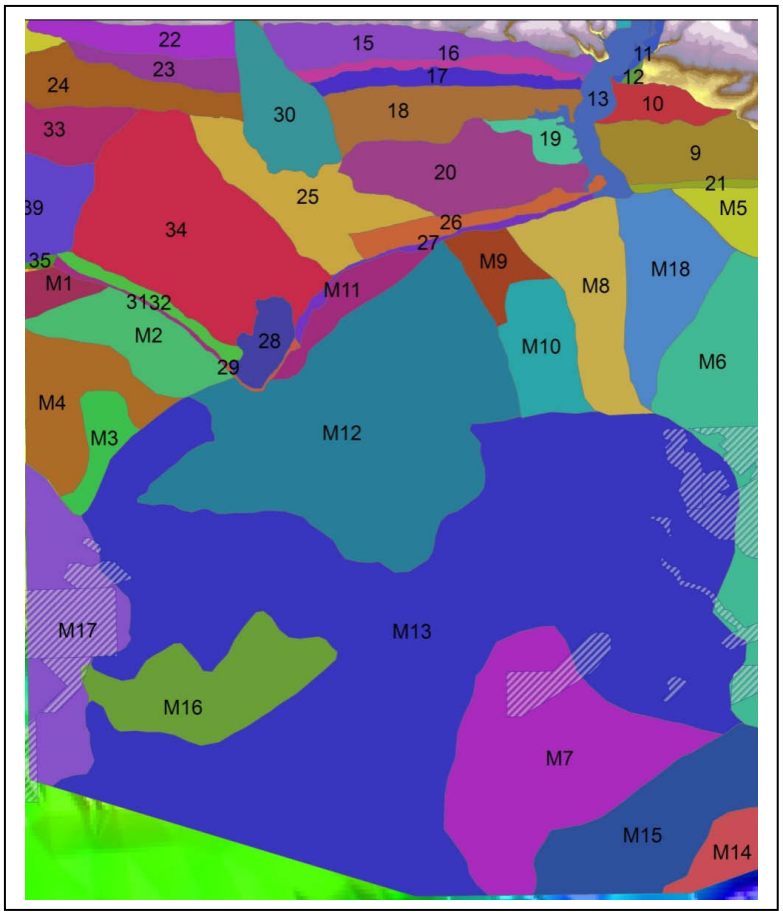

Onshore-offshore Archaeological Zones

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1. Introduction

Despite their radically different present day environmental circumstances, marine and terrestrial archaeological remains provide a seamless physical and intellectual continuum. As a result of coastal change, some originally terrestrial sites are now submerged and some marine sites are now on land; other sites have ambivalent settings, being situated in the inter-tidal zone and enjoying marine and dry land environments sequentially; and others extend from dry land into the sea (Roberts and Trow, 2002). The current shoreline therefore has little context in palaeo-archaeological reconstruction.

The primary objective of this project was to examine the possibility of producing a ***contiguous palaeo-landscape reconstruction*** across the marine to terrestrial boundary therefore enhancing the archaeological continuity across space and through time within an area of landscape previously examined through a series of stand-alone investigations. It is suggested that only by completing this successfully will marine sites that are of present and future concern to aggregate dredging, be fully interpreted with their correct archaeological context. Furthermore, this will importantly ***reduce the regional uncertainty*** associated with the interpretation of marine sites thus allowing marine sites to fully contribute to not only the local palaeo-landscape reconstructions but also the regional and National understanding of their archaeological significance. The project investigated this methodology on an area in the West Sussex coastal corridor between Havant and the Arun Valley.

The aggregate industry maintains extraction sites in both the marine and terrestrial environment. In both of these settings it is necessary that archaeological studies are made as part of the extraction licence. To maximise the information gained from these archaeological studies and furthermore to facilitate future aggregate exploitation it would be economically beneficial to be able to place the investigations within a regional framework. This project shall therefore greatly benefit the aggregate industry by providing a review of best methodologies for accomplishing this.

Developing the capacity to manage aggregate extraction landscapes in the future is at the core of the objectives for the ALSF programme. Specifically, Objective 2 identifies the acquisition of baseline information and characterisation of resources as a priority. This project seeks to address these core objectives by providing baseline information on the archaeological characterisation of a land to marine zone. In completing this project, the University of St Andrews has considered the strategic priorities set out by English Heritage in Implementation Plan for Exploring our Past, EoP98 (1998) and Taking to the Water (Roberts and Trow, 2002), Power of Place: the Future of the Historic Environment (English Heritage, 2000), The Historic Environment: a Force for our Future (DCMS, 2001) and Discovering the Past, Shaping the Future: Research Strategy 2005-2010.

The project undertook the following key stages:

1 **Evaluation of Methodologies for mapping contiguous landscapes –** review of the methods for mapping palaeo-landscapes from the land (including river catchments) to the marine (up to 12 mile territorial waters) environment across the transition zone with no data gaps. This also included a review of the capabilities within UK industry for addressing mapping in this zone

2 **Construction of a 3D palaeo-landscape models –** the construction of a series of full 3D palaeo-landscape models based on existing land and marine data through the transition zone in an area of high archaeological value through to areas that are currently being exploited for aggregate resources

3 **Result dissemination/public outreach –** to provide through dedicated workshops the new methodologies to the aggregate community for adoption within their development programmes. To complete peer-reviewed articles in scientific journals

1.2 Project Background

1.2.1 Land to Marine Continuity

Today our understanding of onshore sites is far in advance of our understanding of offshore sites (e.g. see Bridgland, 2000, 2002). Continuity of fluvial systems across the shelf area is well documented through seismic profiles obtained as part of aggregate extraction investigations for many fluvial systems including the Thames (Bridgland *et al*., 1993; Bridgland, 2002), the Channel area (Bellamy, 1995; Antoine *et al.,* 2003). Where sequences have been documented off-shore attempts have been made to integrate this evidence within the on-shore framework of climate change from interglacial to glacial periods (Bellamy, 1995). However, because the frameworks for interpreting sequences differ between the marine and terrestrial environments (e.g. most workers in terrestrial situations would utilise Bridgland's terrace model (Bridgland, 2000) while those in the maritime zone apply approaches based on sequence stratigraphy (Posamentier and Vail, 1988). Consequently it is only through a continuity of interpretation from the land into the marine environment that we will be able to make a full evaluation of the marine sites and indeed integrate the methodological approaches adopted by both camps. Therefore the investigation of the transition zone (the linking zone marked by the maximum high and low tide limits) sites is an absolute necessity if we are to fully understand, and place these sites within an archaeologically reasonable context derived from a land-based understanding.

Knowledge on offshore prehistoric archaeology is at best scarce. This project will investigate the potential for all prehistoric archaeology (Pleistocene and Holocene – lower/Middle/Upper Palaeolithic and Mesolithic with potentially early Neolithic) in the offshore areas. Key to this project is the combined understanding of land and marine sequences so that an investigation of either will lead to overall increased understanding. Therefore through the development of the methodologies we hope to increase our understanding not only of archaeology in offshore areas but also the depth to which it will be necessary to investigate.

1.2.2 Aggregate Site Position

Aggregate extraction sites are located in the landscape of today both on land and in the marine environment. Because of the isolated nature of many exploitation sites, both onshore and offshore, it is often very difficult to fully assess the significance of archaeology that has been uncovered in an investigation, or indeed to ascertain what the likely potential of the site is in terms of its contained archaeological record in advance of extraction or construction. This is especially true for marine sites where ground truth data is difficult and expensive to obtain. This project aims to develop methods for contextualising marine sites so that they fit within regional contiguous models of palaeo-landscapes from the land through the transition zone to the marine environment. Thus understanding the

links through the transition zone becomes paramount to understanding the offshore, marine archaeology and giving this its full regional significance.

1.2.3 The Coastal Zone – a Transportation Corridor

Many of the most important palaeo-landscapes in the UK today are those associated with both palaeo and recent transportation corridors that are presently submerged along our coast line. These include both relatively recent landscapes associated with the last marine transgression in the earlier Holocene as well as elements of much older landscapes associated with a large number of Pleistocene sea level transgressions and regressions over the last 0.5 million years. With the significant rise in sea level since the last glacial maximum, most of these areas have become flooded however, in many places the evidence of occupation will have been preserved close to the modern sea bed or beneath subsequent layers of sediment. It is vital that palaeo-landscape reconstruction is completed on a wide-area (regional) basis so that the different time elements of the landscape are not confused with different stratigraphic sequences within a landscape.

1.2.4 Archaeological Building blocks

Most previous marine archaeological investigations have focused on seabed or near seabed archaeological remains immediately pre-dating the last marine transgression in the late Pleistocene/early Holocene (i.e. the late Palaeolithic/Mesolithic archaeological archive) rather than remains of more deeply buried Palaeolithic archaeology (assuming its presence) dating to various phases in the Middle and Upper Pleistocene as the former remains are more easily mapped. Palaeolithic remains however will often be more deeply buried than those associated with the last marine transgression and will be associated with elements or building blocks of local stratigraphy and geomorphology that are typically discontinuous on the sea floor. It is the individual building blocks that will contain the Palaeolithic remains both onshore and offshore and thus this project will not only attempt to construct palaeo-landscapes through joined-up land to marine surfaces but will piece together the elements of palaeo systems that are linked together in a hierarchical structure.

1.2.5 Archaeological Potential

As a consequence of refining our understanding of the different archaeological periods likely to be represented by material in the marine zone it is important to recognise that the location of potential archaeological sites within these areas is reliant on being able to carefully reconstruct elements of the contemporary palaeo-landscapes and locate these elements within a stratigraphic framework that may be placed into regional, national and international frameworks for Palaeolithic archaeology and Pleistocene geochronology. Until significant levels of archaeological material have been identified and excavated in the marine zone archaeological interpretations of sequences in the offshore zone can only be driven by concepts derived from onshore where the archaeology shows an association and context within a geomorphological framework. This can only be

done with an understanding of the wide-area context from present day land to offshore sites.

1.2.6 Keyhole Archaeology and Regional Significance

Previous projects such as Seabed Prehistory (EH 3876 MAIN), Submerged Palaeo-Arun and Solent Rivers (EH 3543 MAIN) and direct mapping projects associated with specific aggregate extraction have produced useful results but these are often only seen in isolation as *keyhole* investigations. In order to fully appreciate the significance of their results it is necessary to place them in a *broad regional context*. The importance of a regional approach has been demonstrated by the recent programmes in Regional Environmental Assessments onshore and Marine Landscapes offshore. None of the currently existing programmes however make attempt to link on shore and offshore information through the concepts of true palaeo-landscape environments as they were formed. A contiguous marine to terrestrial model will achieve the following:

- construct a broad regional context for individual (land and marine) aggregate extraction and other archaeological sites
- reduce the uncertainty of individual results from isolated sites
- give greater impact to the findings from isolated studies
- integrate the main geomorphologically separated aggregate extraction areas into regional and ultimately a UK-wide model

1.2.7 Regional Protocol Development

While the methods of this project will initially be applied to a specific test area on the south coast around Chichester, the resultant protocols will be applicable to all of the major aggregate extraction zones around the coast of England, for example the Eastern English Channel, the Humber, The Thames and The Severn. It is suggested that other zones could be tested in collaboration with the EH Maritime team and other groups, for example with the work of Professor Vince Gaffney, University of Birmingham.

1.2.8 Methodologies for Mapping in the Transition Zone

Understanding the offshore is only possible through extrapolation over the land-marine transition zone. This project therefore aims to develop key combinations of methodologies to enable far greater understanding of both onshore and offshore archaeological site settings. This is of direct relevance to maritime archaeology and importantly the aggregate industry that now operates successfully in the coastal waters of the UK.

1.2.9 Management and Conservation Strategies

The project will greatly facilitate developing the capacity to manage aggregate extraction landscapes in the future thus providing much needed support for management and conservation strategies in aggregate extraction areas where a full understanding of the archaeology is not at present possible (particularly for the Palaeolithic period). As a secondary benefit the programme of work will allow

key baseline information to be obtained in an area of challenging environment that is under increasing stress from exploitation of resources, increased leisure activities and erosional impacts from recent rising sea level as a result of climate change.

1.2.10 Archaeological Significance of Transition Zones

The archaeological significance of these transition zones has been recognised by English Heritage in their document Taking to the Water (Roberts and Trow, 2002). This document identifies priorities for future research including (Section 12.5):

- national evaluation studies to characterize poorly recorded or little understood elements of the seamless maritime cultural landscape. Such studies are a proactive way of identifying sites and site types or related activities and industries likely to merit protection and management, including sites and landscapes not currently represented in the record;

- studies designed to improve understanding of drowned coastal landscapes and palaeo-environments. Such landscapes have tremendous potential for the preservation of archaeological evidence of the exploitation of coastal and marine resources and for use in predicting the nature, scale and pace of coastal change.

1.2.11 Relation to ALSF Objectives and other ALSF Projects

Developing the capacity to manage aggregate extraction landscapes in the future is at the core of the objectives for the ALSF programme. Specifically, Objective 2 identifies the acquisition of baseline information and characterisation of resources as a priority. Today the characterisation of the off-shore resource within extraction areas is approached from two opposing perspectives. Firstly, archaeological knowledge based on information from terrestrial sites is used as the basis for estimating off-shore potential. Critically associations between geomorphological situations/sedimentological contexts and contained archaeology are made on the basis of routine associations found in terrestrial situations. This knowledge is projected offshore into a zone in which neither stratigraphic continuity nor similarities in environments of deposition have yet been demonstrated at a level complementary to the scale of archaeological resource/investigation. Secondly, geological knowledge of the offshore is based routinely on interpretations of seismic data occasionally ground truthed by virbro-core samples and contextualised in the seismic stratigraphic framework. This results in an incompatibility in methodologies and, more importantly limitations to our investigations. Consequently this project seeks to address these limitations and aims to provide a methodology to address this on a regional basis and to further capitalise on information from sites both on shore and offshore. Management of archaeological maritime resources requires a wide knowledge of the palaeo-landscapes and an appreciation of the complexities of the Quaternary record that includes key information on past conditions.

In summary, the following key points can be made concerning how national maritime archaeological research goals can be addressed within the ALSF programme:

- Maritime archaeological sites are often difficult to monitor and in highly vulnerable locations that need constant evaluation for long term safe guarding.
- Due to this difficulty and the expense of surveying maritime sites, limited studies will only ever be possible therefore the most information possible must be elicited from any individual site
- The maximum information can only be gained when a site is contexturalised from land to marine within both a regional and a national context.
- Contextualisation is vital for providing important information for the long term management of maritime sites.
- The interpretive potential of any archaeological material depends upon understanding of depositional and post-depositional processes that have affected it.

This project has significant relevance to other previous ALSF projects and a number of current ALSF projects. Specific projects include, Submerged Palaeo-Arun and Solent Rivers: Reconstruction of Prehistoric Landscapes Pt 1 & 2 (ALSF 3545 MAIN); the England's Historic Seascapes Programme (ALSF 3783, 4728, 4729, 4730, 4731, 5254). The test case area within and off-shore of the West Sussex Coastal Corridor (currently under investigation as part of the Palaeolithic Archaeology of the Sussex/Hampshire Coastal Corridor (ALSF 3279 MAIN)) has been identified and selected as it represents a reasonable opportunity to address the key issues highlighted here within the context of an area within which considerable knowledge now exists. Key findings of this project included:

- Sequences were more complex than previously thought across the region
- Both marine deposits from interglacials as well as cold stage deposits from glacial periods were present
- Dating of deposits was more complex than previously considered
- Channels similar to those on the foreshore were known to be present beneath Chichester Harbour

In addition to the links to ALSF projects, direct links exist between specialists in this project and the Heritage Lottery funded project work currently being undertaken in Chichester Harbour by the Chichester Harbour Conservancy.

2. The Transition Zone

The transition zone has been defined as the region near the land-sea boundary where neither land nor marine operations can be carried out without significant modifications (Sheriff, 1994). The zone can include marsh areas, shallow lagoons, the surf zone, beaches, estuaries and mud flats. The transition zone is typically bounded by the limits of low and high tide however, in many circumstances due to the inaccessibility of terrain above and below these limits the zone is extended some distance both onshore and offshore. The term “White Zone” has also been used for this zone and in this context has been derived from the hydrocarbon industry to represent a zone that is not of hydrocarbon licensing. The term white zone is not used further in this study as it also represent areas outwith the current continental shelf licensing areas in deep water. The British Geological Survey have also coined the term “White Ribbon” (Mason et al., 2006) for the zone to include the region spanning the land-sea interface.

The term “coastal zone” could also be applied to this area. Coastal zones have been the focus of both national and international management efforts over the past 30 years with Integrated Coastal Zone Management programmes adopted by bodies such as the World Bank, UN Environment Programmes and more locally the European Union. Coastal zones are defined as the coastal land and foreshore and adjacent sea but also includes a description of the natural environment of the coast “an area of dynamic transition where land and sea interact and which includes both the landwards margin and inshore waters” (figure 2.1).

2.1 Problems in Surveying in the Transition Zone

Surveying within the transition zone is a notoriously difficult proposition. The main impediments to successful surveys can be sub-divided into natural conditions and anthropogenic conditions

2.1.1 Natural Conditions

All marine surveys must cope with extreme natural conditions including tide, wind, wave and current actions. All of these can be particularly severe especially around the coast of the UK where large tidal ranges exist in many estuary settings and the action of wind and wave become amplified in shallow waters. Large tidal ranges mean that there is often a limited working window during which surveys can be accomplished either by boat from the marine approach or by foot from the land approach. Furthermore, areas such as tidal mud flats can not only be difficult to negotiate on foot at low tide but are also extremely dangerous with fast rising tides. The use of specialised survey platforms such as hovercrafts has been suggested for these areas. As the transition zones extend from some metres (rarely tens of meters) below mean sea level to the high water mark a shallow draft vessel is necessary for continuation of marine surveys inshore. The problem with these however is that most shallow draft vessels carry

a relatively small payload and are not seaworthy far offshore thus limiting the continuation of survey in the marine direction.

Additional problems with the deployment of some marine survey types, for example electrical, electromagnetic and radar geophysical methods, are especially sensitive to the presence of the highly conductive salt water. For many techniques, for example airborne and remote sensing (radar and light-based survey methods) the near shore waters are often highly turbid with large suspended sediment loads resulting from shoreline erosion and the transport of sediment material down river systems into the nearshore zone.

2.1.2 Anthropogenic

The transition zone represents a corridor around the coast that is highly utilised by man. Activities within this zone include industrial uses such as commercial fisheries, aggregate extraction, shellfish cultivation and also leisure activities such as fishing, diving, sailing, power boating. The zone is also marked by numerous infrastructure impacts such as the landfall of oil and gas pipelines, telecommunication cables and the outfall for offshore sewerage discharge. The zone has seen historical use for centuries and continued use today as a transportation corridor along which and through which shipping passes. This can restrict the type of activities conducted within the zone and at times prohibit certain activities. Further complications at a number of sites around the UK are restrictions due to military use. In these areas either complete access bans exist or limited access is enforced.

2.1.3 Datum – Ties between Land and Marine Datum

The need for correlation across the transition zone necessitates that a common vertical datum is used. In the UK land topographic data has been acquired by the Ordnance Survey to a datum set as the mean sea level at Newlyn in Cronwall calculated between 1915 and 1921. This point is taken as the reference point for the height data on all Ordnance Survey maps. Marine data however has been acquired by the UK Hydrographic Office using a datum based on Lowest Astronomical Tide (LAT). This is the lowest tide predictable based on all effects of gravity and is therefore the mean lower low water. Thus the UKHO definition of Chart Datum will vary around the UK. Following from the definition of Chart Datum a number of other useful measures are taken such as Mean High Water Springs (used at the coastline definition), Mean Low Water, High Water (or mean sea level). For transition zone studies a seamless vertical datum is required which does not vary over time or location. Unfortunately, there is quite a difference between Chart Datum and Ordnance Datum Newlyn (WGS84) around the UK. For example -2.8m at Torquay, -1.5m at Lowestoft, -6.1m at Barry, +0.6m at Banstaple (see figure 2.2).

A key element to defining a locally seamless combination of marine and land data is establishing an appropriate geoid model through connections at specific onshore tide stations. This has been done by the UKHO and provides an

appropriate surface for data at least to 10km offshore (figure 2.3). The model is under continuous review and refinement. For this project this common datum was used however it appreciated that this might not be the most convenient in other projects, in particular those that are surveying at the far extremes of the current geoid extent.

2.2 General Background

2.2.1 Regional zones within the offshore UK – basis for Palaeo-landscape Reconstruction

A review of the emerging literature regarding the nature of the regional geological setting, geomorphology and sequences present within the eastern and southern shallow marine zones of Britain indicate that three broad areas can be defined (Figure 2.4) within which sets of characteristics can be identified:

1. Subsiding basins in which sequence accumulation occurs through natural superimposition in which the oldest sediments usually occur at the bottom of the basin with younger sediments progressively laid down at higher elevations within the basin. In such cases no fluvial terrace systems are likely to occur and only the most recent evidence is visible in the near bottom zone. This situation occurs in the southern North Sea and such systems do not have on-shore equivalents at the present time.

2. Areas of uplift at the margins of these sedimentary basins in which substantial terrace systems may occur within the valley systems. This situation occurs present in the Thames estuary where forms superficially similar to the terrace systems of the lower Thames have been traced offshore by Bridgland (2002) and Bridgland and D'Olier (1995) (Figure 2.5).

3. Areas in which excavated valley forms can be identified but within which terraces are intermittently present or limited in extent. Valley forms are separated by extensive areas of seabed where a thin veneer of sediment masks bedrock close to the sea bed. This type of situation is illustrated by the Channel/Manche coast of Southern England (Figure 2.6).

Within each identified zone primary sequence formation processes are likely to vary in importance depending on prevailing tectonics and regional to local geomorphology. For example within the subsiding basin of the southern North Sea depositional processes are likely to be operating as the principle mechanism responsible for sequence formation with erosion and depositional factors of local importance only. By contrast within the south coast Channel/Manche scenario erosional factors are likely to be of considerable importance with depositional processes operating at local scale and only of transient nature in many cases. Consequently the stratigraphic architectures of major sediment bodies preserved within these different zones is likely to consist

of very different packages of sediments in which sequence history, complexity of contained artefact taphonomy etc may vary considerably. An additional factor to consider is the nature of the final sequence formation factors immediately prior to inundation. Within the subsiding basin-like features individual channels from the most recent events are likely to be well preserved and have clear internal and external form. By contrast those areas of terrace formation where downcutting and reworking of material plays a significant role may well contain less well defined features that are more difficult to identify and trace through and between systems.

2.2.2 Major fluvial systems and terraces as markers from the transition zone to off-shore palaeo-landscapes

The presence of fluvial systems on the shelf area is well documented (Figure 2.7) through seismic profiles obtained as part of oil and gas exploration, aggregate extraction and infrastructure investigation. For example former courses of the Thames can be traced beneath its modern estuary (Bridgland and D'Olier, 1995) (Figure 2.5). Where such 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 (they are typically assumed) 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) (Figure 2.8) 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). Furthermore it is now clear that an additional facet of the systems now requires investigation, namely that of the estuaries associated with the rising and falling sealevels. In most cases little attention has been focused on the role of estuaries in sequence formation during the Pleistocene. This contrasts with the study of estuaries (at least in the downstream parts of our major river valleys) of Holocene age.

2.2.3 Limitations of terrestrial 3D landscape conceptual models

For terrestrial situations Bridgland (2000, 2006) identifies six (or more) phases of terrace formation over a full glacial-interglacial cycle, using observations and

mammalian biostratigraphy from the Lower Thames Valley as a type model (Figure 2.8). The 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 (Figure 2.5). However, there are problems with seeking to reconstruct successive phases of river activity on the basis of altitude. Firstly, 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. Secondly, 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. For those portions of the river extending across shallow shelf areas 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. Finally it must be remembered that the time intervals available for sequence deposition as well as sequence erosion and downcutting will decrease in a downstream direction during sea level low stands, i.e. it is only during relatively short periods of time that the lowest sea levels were attained. Consequently insufficient time for sequence creation may be encountered in some parts of the system.

In the context of the present project it is the absence of any real consideration of the estuarine wedge of the system that is the major weakness of the Bridgland model. For example within the lower Thames model although brackish

conditions may be accommodated in places in the sequence (e.g. at Purfleet, Schreve *et al*., 2002) no account is really taken of the likely complexities of the lower estuarine reaches of rivers and the impact of significant transgressions on sequence generation. In the study area the sequences revealed at Lepe (where more than 8m of estuarine sediments were encountered) are a good example of such deposits (Figure 2.9). However, the concept of the Pleistocene estuary has received little attention in the literature (at least in the British context) with the exception of the recognition of the estuarine setting of some of the deep channels present in eastern Essex (Roe, 1999, 2001) and at the afore-mentioned site in the Solent (Brown *et al*., 1982). To the authors' knowledge there has been no discussion of the patterns of sequence formation in such contexts. This contrasts with the studies of the Holocene estuaries where considerable discussion has taken place to understand the sequences (e.g. Long *et al*., 2000). For example the time-transgressive nature of the Holocene sequences in the lower Thames (Figure 2.10) are well documented as are the relationships between the Holocene sediment wedge and the underlying unconformity (transgressive surface). In the Thames, sediments form a wedge thickening from 2m at Tower Bridge to 35m 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 (Figure 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*., 2007a).

The Medway Marshes (Figure 2.11) are a case in point in which a complex stratigraphy has developed within the lower reaches of the estuary. Recently, buried Pleistocene sediments lying below more than 5m of Holocene floodplain sediments at elevations between 0m O.D. and -5m O.D. have been located at Allhallows (Bates *et al*., 2007a) (Figure 2.12). These deposits contained ostracods that indicate that for at least part of the infill history estuarine conditions prevailed in the channel (known locally as the Allhallows Channel). These sediments are difficult to ascribe to the conventional stratigraphic framework. Previous work by Bridgland (2003) utilised a model closely related to that conceived for the lower Thames estuary in which a count from the top approach would indicate a declining age with elevation for sequence generation towards and beneath the marsh surface. Using this approach the postulated age for the channel sequences would be the last interglacial (MIS 5e) or the penultimate interglacial (MIS 7). However, contained ostracods as well as an

amino acid geochronology (Penkman pers. comm.. 2007) would indicate an older date and probable correlation with MIS 9 is more likely. If this latter scenario is correct a large, deep channel would be required extending from a depth of -5m up to some 20m O.D. (the estimated elevation of the sediments thought to be broadly contemporary with the channel, the Stoke Gravel of MIS 10-8 age). Subsequent erosion and reduction of the channel sequence and the deposition of gravels across the eroded surface would then account for the presence of gravels of younger age resting at a variety of elevations above that of the Allhallows Channel.

Pertinent evidence can also be gleaned from a study of the emerging picture of the Holocene sediment stack and the patterns of sequence development associated with flooding and sedimentation with Medway estuary (Figure 2.13). Radiocarbon dating (Figure 2.14) indicates that sequence generation within the estuarine wedge does not always appear to conform with the simple patterns of sequence accumulation outlined by workers such as Long *et al.* (2000) for the Thames and other river systems in SE England. While similar patterns to those of Long *et al*. are noted in the inland (southern) parts of the estuary where peats that accumulated around 5000 years ago can now be found at around -3m to -5m O.D. towards the Isle of Grain and the coast sediment accumulation associated with the more marine elements of the estuary appear to happen in different ways. Here the marine parts of the sequences appear to be accreting at significantly lower present elevations (e.g. the onset of marine sedimentation occurred at around 4200 years ago at current depths of around -16m O.D. This evidence suggests that complex time depth relationships exist between the accumulated sediments and phases within the current interglacial and that considerable differences are noted between those parts of the estuary experiencing marine conditions from those only experiencing estuarine conditions.

2.2.4 Limitations of marine 3D landscape 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 tracks 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 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 palaeolandscape 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's mind must be the question of what has been preserved and what lost of the sequence?

2.2.5 Comparison of the two approaches – towards a unified 3D model

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 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.

2. Difficulties of collecting data in shallow-water areas means there is often a geographical gap within the transition zone for which no data exists.

3. Recognition of "patterns" in stratigraphic records within the onshore and offshore areas differs and is based on very different parameters. Indeed it is only beginning to emerge that differences in patterns in stratigraphic record characterise not only the terrestrial freshwater fluvial zone but also the estuarine zone as well.

4. 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.

5. 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.

6. 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.

2.2.6 Reconstructing and tracing Pleistocene landscapes: questions of time and space

2.2.6.1 3D reconstruction models over long (greater than 10k) time periods

Prior to attempting to consider the possibility of correlating sequences across the transition zone and reconstructing 3-D Pleistocene landscapes it is important to consider precisely the nature of the tasks being attempted. Attempts to reconstruct past Pleistocene landscapes are often hampered by fragmentary evidence, incomplete sequences, poor dating control and an absence of material to examine the faunal and floral aspects of the landscapes. Coupled to these problems is the likelihood that Pleistocene landscapes in the UK do not have modern analogues today and therefore a modified 'principle of uniformitarianism' needs to be applied in attempting to reconstruct past landscapes. However, despite these problems, it is frequently the case that authors attempt to provide dramatic illustrations of reconstructed landscapes. For example text books dealing with the Pleistocene or Palaeolithic record common show reconstructed palaeogeographies (see McNabb, 2007) while geologists such as Gibbard (1985,

1994) and Bridgland (1994) have reconstructed the pattern of drainage in southern England associated with the Thames and Medway systems. This has been achieved by mapping the distribution of sands and gravels of these rivers and (in the case of Bridgland) placing them within a chronological framework based on the marine isotope record. These macro scale palaeogeographies (Table 2.1) tend to work well at the scale of the marine isotopes (100k year cycles), where even the relatively coarse temporal framework achieved using dating methods beyond the limit of radiocarbon dating (Walker 2006), can usefully date and correlate sediments. Such frameworks are useful for considering human distribution/dispersal within macro regions and across macro MIS timescales, but less useful for examining intra-site landscapes and human activity at shorter time intervals. In the context of tracing on-shore sequences through the transition zone and into the off-shore it is sequences at this scale that offer the best chance of achieving direct correlations.

2.2.6.2 3D reconstruction models over short (1k-10k)time periods

Tracing other scales of sequences is however, more problematic. Occasionally evidence may be obtained from the lithological archive for geographies at smaller scales and shorter time intervals (Table 2.1). For example the sediments associated with the raised beaches of West Sussex (see below) represent preserved palaeolandscapes at a scale typically of less than 100km and with temporal resolutions probably down to 10,000 years or less. Both these sequences and those representing the larger scales offer the best targets for aggregate extractors due to the large quantities of gravel being sought in order to make their removal cost effective.

2.2.6.3 3D reconstruction models over very short (less than 1k) time periods

Finally, lithological sequences may contain horizons that represent even finer grained temporal intervals (e.g. buried landsurfaces), which preserve high resolution archaeological remains of small scale events of short temporal duration (knapping activity etc.). These situations may often provide important information on human behaviour at a scale ranging from hours to days. These are usually restricted spatially and, because of the short time duration represented, are difficult to correlate with other sites, even nearby sites that are broadly contemporary. Recently excavated sites such as Boxgrove (Roberts & Parfitt 1999), Barnham East Farm (Ashton et al. 1998) and the Southfleet Road elephant site at Swanscombe (Wenban-Smith *et al.* 2005) fall into this category (Table 2.1). Such sequences may be difficult to locate with all but the most intensive of surveys.

2.2.7 The Sussex/Solent system – test case for 3D modelling

Palaeolithic archaeology within the West Sussex area is best known for the important site at Boxgrove (Roberts and Parfitt 1999) (Figure 2.6). However, this site is associated with more extensive marine deposits preserved at the northern end of a major coastal plain preserving sediments representing depositional

systems at a range of scales and varying in date from nearly 500,000 years old to the last 10,000 years (Holocene). These sequences 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). Presently it is also acknowledged that cold stage deposits also form an important element of the sequences present.

The significance of the deposits of the region are:

- A series of raised beaches of different ages have been preserved within the area between Portsdown and Brighton at different elevations in the landscape as a result of regional uplift (Figure 2.15). These beaches can be traced for considerable distances across the landscape (Figure 2.16) and are the basic units for reconstructing regional landscape geographies at the meso scale. These are equivalent to the sequences of fluvial sediments that are often used in palaeogeographic reconstruction.

- The marine deposits are replaced by fluvial sediments of the Solent system at the western end of the region: sediments of the Arun and Adur enter the coastal plain at Arundel and Shoreham (Figures 2.16 and 2.17). These deposits can be potentially traced for some distance across the landscape although changes in bedrock and local geomorphology have made it difficult to trace them for any significant distance (Figure 2.17).

- Extensive, preserved buried landsurfaces are associated with parts of the buried marine sequences. For example both the Goodwood/Slindon and Brighton/Norton Raised beaches have associated sequences of intact buried landsurfaces (Figure 2.18). At Boxgrove relatively large areas (5–50+ ha) of palaeo-landscape are unusually preserved along with undisturbed archaeological and palaeo-environmental remains. These palaeolandscapes occur in very different situations in the present day to those associated with their original formation. At Boxgrove sediments associated with a substantial area of exposed sand flats in the intertidal zone at the base of a chalk cliff are now preserved at c. 40 m above OD beneath up to 5 metres of solifluction gravel at the south side of the line of chalk hills, the South Downs.

- These marine 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) (Figure 2.19). Other cold stage sediments include the Chichester Fan Gravels and bedded silts and coarser chalk gravels (Figure 2.20).

To date the only sequences recognised on land that have been possible to identify beyond the shoreline (within the present marine zone) represent fluvial sediments of the Solent or Arun systems. On shore these sequences have been documented in the Arun Valley which has a complex sedimentary sequence that has been partially controlled by changing bedrock geology (Figure 2.17). 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 recrossing the Chalk and finally traversing Tertiary clays and silts beyond the modern coast line.

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.

At a more local scale 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 & Sparks, 1960; West *et al.*, 1984). They are thought to be cut into the bedrock at around 0m O.D. to varying depths and extend below low tide mark in a number of locations (Figure 2.21). Because of changes to coastal defence structures these deposits have rarely been seen since the 1960's 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 (Figures 2.22 and 2.23). Geophysical and borehole study has revealed the complexity of the channel fills. Combining the data from both the boreholes and the geophysical surveys a double channel structure was noted where channel A is filled with sandy clays while channel B 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 infilling of finer sediments during a temperate interglacial. Presently a number of different channels have been identified along the West Sussex coast in which deposits of different ages are present (Figure 2.21). These include both Pleistocene examples such as those at West Wittering, West Street Selsey and Holocene channels such as that at Bognor Regis (Bates *et al*., 2005) and may form targets for mapping within the offshore zone. The presence of a number of different channels with complex sedimentary architectures within the near-shore zone (i.e. between -3m and +10m O.D.) 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.

2.2.8 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 (Figure 2.24) 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 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

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 sea level 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 (Figures 2.25 and 2.26) 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 (Figure 2.25) 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) 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 -70m O.D. little incision will occur. However if sea level drops below -70m O.D. 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.

While the large scale systems associated with the fluvial systems of the channel floor are perhaps the most obvious target for both the aggregate extraction industry and the archaeologist/geologist attempting to correlate on and off shore sequences other smaller sequences may also be present and offer interesting promise. Sequences preserved within 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 and cold climate deposits occupying depressions on the coastal plain such as that around Warblington (Figure 2.27) are large, laterally mappable deposits (Figure 2.16). However, elsewhere the sequences may be relatively localised and restricted to shallow incisions into bedrock (e.g. the channels present around the Selsey coast – Figure 2.21). 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.

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 early 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 and careful, targeted future investigation. 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. A similar situation has been observed by Gaffney et al (2007) for the southern North Sea where the marine end of large river systems have been mapped but without the continuity onshore into the palaeo-terrestrial environment.

3. Geophysical Methods

3.1 Seismic Methods

Whether for seabed or sub-seabed analysis sonar methods have been extensively used within the transition zone for many decades. However, all of the these systems have been designed to operate in typical shelf depths of tens if not hundreds of metres and consideration needs to be taken when utilizing these systems with the intrinsically shallower depths of the transition zone. It is not within the scope of this report to describe the details of all of these techniques and the reader is referred to the forthcoming EH Marine Geophysics Guidance notes for further details of each system. This section will deal more directly with the specifics of operating these systems in shallow water.

3.1.1. Seabed systems.

A range of systems provide either qualitative and/or quantitative data of both the morphology of the bed and its material composition. The principal techniques used for the acquisition of such data are side scan sonar data and swath bathymetry systems. **Side scan sonars** transmit a fan-shaped acoustic pulse perpendicular to its travel-path with a horizontal beam typically smaller than 1º and vertical beam angles per transducer between 40º and 60º a configuration which produces wide area coverage in a range of water depths. These systems typically utilize pulses with a frequency between 100 kHz (medium range - 100's metres) and 500 kHz (short range - 10's metres), however increasingly higher frequency systems, to in excess of a Megahertz, are now available. The resolution of side scans depends up on the horizontal beam angle, pulse width and the frequency content but most are now typically capable of identifying decimetre scale features even at relative distant ranges (10's – 100's metres) although it is important to recognise that resolution deteriorates toward the outer edge of the insonified area. Even though the majority of the pulse energy is focused in a total vertical beam width of 80°-120° significant energy is still transmitted throughout at least 180° and this unintended affect actually results in wide swaths of data being obtained in even very shallow water depths. All forms of side scan systems are conventionally towed behind the vessel in a hydrodynamically designed towfish and so in the shallow waters of the transition zone care must be taken during deployment and survey to optimize water depth for image quality and safety. Side mounting of systems has been successfully attempted from a number of groups as has deploying the system from a surface towed catamaran. In both cases care should be taken to avoid boat generated noise and wake that can degrade data quality.

New developments in side scan sonar technology include the production of **synthetic aperture sonars** (SAS) whose operation is comparable to that of the aircraft-borne synthetic aperture radar (SAR). The advantage of these system is the ability to obtain high resolution imagery (< 10 cm by 10 cm), which is not range dependant, using relatively low frequencies (< 200 kHz). The improved

resolution, in comparison with the conventional side scan system, comes at the cost of increased computation since the position and motion of the towfish needs to be known exactly and used in the post-processing of the data. Another recent advance is the commercial development of a 'multi-pulse' side scan sonar (e.g. EdgeTech 4300-MPX, EdgeTech 4700-DFX, Klein 5000 Series). A consequence of the narrow beam width of the traditional high-resolution side scan sonars is that the survey speed normally needs to be reduced to 5 knots or less to ensure 100% along track coverage. The 'multi-pulse' side scan system, however, emits several (normally 4 or 5) adjacent parallel beams per side at the same time, allowing 100% coverage and increasing the operating speed to 10 - 16 knots. Both of these new technologies are capable of operating in the shallow waters of the transition zone.

All of these systems provide high resolution qualitative data on the morphology of the seabed and its material properties. However, the ability to image objects is also strongly dictated by the geometry between the sonar head and the target object, with a useful empirical study of this relationship being presented in Quinn et al. (2005). Unfortunately, operating in shallow waters restricts the potential of altering survey geometry in order to optimize imaging quality and so may constrain potential data quality. Although all side scan acquisition and processing software provide options for deriving quantitative data in terms of dimensions and in particular heights of objects, unless allied with independent bathymetric data all of these measurements are derived from simple Pythagorean formula. This approach can provide first or second order magnitude dimensional measurements of height but no more and so quantitative results should be treated accordingly. Similarly, backscatter variability as a proxy indicator of material variation of the seabed is an area of significant current research and is also intimately controlled by overall survey geometry. At present research is focused on the post-acquisition analysis of calibrated datasets, however, there is currently little fundamental work on high frequency (> 100 kHz) scattering and in particular on the significance of insonification angle.

Over the last two decades imaging of the seabed has been increasingly undertaken using swath bathymetry systems. These systems are available in a wide range of frequencies, varying from 12 kHz to 500 kHz, with the highest frequency systems providing centimetric-scale images of the seabed. Swath systems also transmit a fan of ultrasonic sound, broad in the across track direction (typically 120º to 150º) and narrow in the along track direction (between 0.5º and 3º). From the angle and the travel time (i.e. the range) of the returned signal, the position of each echo can be computed and so quantitative data (i.e. depth) of the actual bed is acquired. Depending on how the angle and travel time pairs are determined, two different systems are recognised: beam forming **Multibeam Echo Sounders** and **Interferometric** or phase discrimination **Sonars**.

The **Multibeam Sonar** uses beam forming to determine the depth to the seafloor. The system is made up of two transducer arrays, a transmitting array whose long axis is parallel to the direction of travel and a receiving array perpendicular to that. Each array produces a fan shaped beam which is narrow in the direction of its long axis. The arrays are made up by a number of identical and equally spaced transducer elements, forming a fixed number (e.g. 126, 254 or 512) of transmit and receive beams at different angles (hence the name 'multibeam'). Beam steering the receiving array can be altered so that echoes from a number of directions can be received. Using beam steering, each receiver beam will intersect with the emission beam, resulting in a series of footprints on the seabed along the ensonified area. The echo arrival time of each footprint and the angle of the received beam, corresponding to that footprint, is then used to determine the depth to the seabed. Using this system, the seabed is sampled more densely at small angles than at higher angles. Therefore, the accuracy and resolution will be highest for the inner parts of the swath and will decrease with increasing swath width. Further, the fixed geometry of this system means that in shallow waters the swath width reduces significantly, a typical rule of thumb is that swath width is 6-7 times water depth but with the best surveys operating at between 75%-100% overlap this corresponds to line spacing of only 3-4 x water depth which in shallow water could represent the need for very high density surveys.

Interferometric Sonars consists of two sonar heads on a V-shaped structure. Each sonar consists of one transmitting array and at least two receiving arrays, parallel to each other and parallel to the direction of travel. Similar to side scan sonar, the transmitting transducer arrays produce a single beam that is wide in the vertical direction and narrow in the horizontal direction. The receiving arrays, spaced at carefully chosen fixed distances, will detect the backscattered signal at different arrival times. The travel times provide the range to the echo, while the phase difference measured between the signals at the different receivers determines the angle of arrival. The knowledge of both the range and the angle, allows the exact position of the echo to be calculated. In contrast to the multibeam system, the system will receive thousands of beams with the density of the sounding locations larger for the outer parts of the swath than for the inner parts. The high density of data points is reduced during the post-processing however the final data still retains good quality across track data density and because of the wide angled geometry of the system can continue to acquire wide swaths even in shallow water. As with the side scan systems interferometric systems also suffer from restricted geometry options in shallow water and hence optimal imaging capability.

3.1.2. Sub-seabed systems

As with seabed systems the key issue related to work within the transition zone is the practicality of taking standard techniques and modifying them for operation in shallow waters. In shelf and coastal environments there are four principal devices that are used for high resolution imaging of the immediate sub-seabed: single

frequency controlled waveform sources (pingers and more recently parametric sources); swept frequency controlled waveform sources (Chirp systems) and accelerating water mass sources (boomer systems). In simple terms the pinger and parametric sources provide high vertical resolution data in relatively fine grained sequences (clays, silts and fine sands) and are most typically used in estuarine environments. Chirp technology attempts to moderate the classic trade off between penetration and resolution that have hampered single frequency systems and is potentially capable of providing very high resolution data in a wider range of sediment types. Finally, boomer systems are regarded as the work horse of shelf surveying as they give reliable penetration results in the widest range of grain sizes (including coarse grained gravels) whilst still maintaining viable resolution.

Operation of all of these systems has to counter the following to operate in the shallow waters of the transition zone:

1. Presence of bottom multiples
2. Operating through vessel induced wake
3. Reverberation due to excessive source energy within water column
4. Operating within the nearfield of the source

Intrinsically, the geometry of operating in shallow waters makes bottom multiples occurring within the data window inevitable. At present the majority of techniques for multiple suppression result in significant degradation of any real data associated with the time window of the multiple and a successful software solution is still being sort. New developments in acquisition currently show the most promise through the use of high-frequency multichannel streamer that allows more conventional stacking algorithms developed for lower frequency systems as used by the oil exploration industry to be adapt for use with high frequency data. At present only one of these streamers exists (owned by the University of Southampton) and work on the processing is still in its infancy. Parallel work is being undertaken at a number of institutions where the development of true multi-channel 3D system arrays is being undertaken.

In very shallow waters bubble induced wake can take longer to dissipate and hence the source and receiver can frequently be engulfed by high scattering bubbles thus preventing any reflections of the seabed or sub-surface structures being recorded. This can be mitigated against by reducing speed to a minimum (but inevitably increasing survey time); increasing distance from vessel to source/receiver, however this reduces both manoeuvrability in what are often restricted environments, this affect will be significantly enhanced if a long multi-channel streamer is deployed; or finding alternative sources of propulsion including non-motorised vessels and divers, the latter can provide excellent data but obviously limited coverage.

Similarly, with high energy sources significant reverberation can occur, an effect that can reduce image data quality. This again is an effect that can be difficult to deal with as the only options are to reduce input energy (not always an option with standard controlled waveform systems albeit a common option with boomers) or undertake either Wiener filter or source signature deconvolution during processing to reduce the ringiness of data. These processing options are most effective on data from a well constrained reproducible trace such as the Chirp sweeps.

The final issue to be aware of in the use of sub-bottom systems in the transition zone is that frequently the seabed would occur within the nearfield zone of the pulse. The near field is the region where the differential distances to the different elements of the source are large enough for the phase differences to cause significant constructive and destructive interference. The limited work done on this effect so far suggests that it could play an important role in the data quality retrieved from very shallow water depths but as yet no quantitative empirical tests have been made.

In reality although the issues described above are the subject of increased interest from the academic and commercial sector examples of shallow water surveys do exist and suggest useable data is retrievable from the majority of transition zone water depths (at present demonstrable to be > 2-3 m). However, actual extant data is relatively rare from this environment so any effective investigation of the sub-seabed environment in this part of the transition zone will inevitably require significant new acquisition programs to be undertaken.

3.2 Electrical and Electromagnetic Techniques

Electrical and electromagnetic methods are extensively used in terrestrial archaeological surveys however their use for marine surveying, and in particular for maritime archaeology, is extremely rare. Recent attempts at using these methods have focused on hydrological, sedimentological and engineering studies. For these situations, the variation in electrical resistivity of the sub-surface has been linked to material bulk properties such as pore water salinity, porosity, clay content and even temperature. Early work with marine based electrical and electromagnetic instrumentation in marine settings was mainly for scientific studies of oceanic crust. More recent work has focused on the use of EM for exploration of gas hydrates and most recently a renewed interest from the hydrocarbon industry has seen the development of the technique as a direct hydrocarbon indicator. The use of EM for near surface investigations has been driven by an interest in ground water systems as well as a desire from civil engineering for the remote assessment of material properties.

Over the last 20 years, the development of the inductive conductivity method for near surface investigations has been driven largely by a few institutions in the USA, a few companies and the main manufacturer of electromagnetic

equipment, Geonics Ltd. of Mississauga, Canada. Geonics have developed a range of portable frequency domain electromagnetic geophysical instruments which can measure variations in ground electrical conductivity. The theory and background to this development is given by McNeill (1980) and a review of applications is published by McNeill (1989). Electromagnetic surveys can be subdivided into frequency domain and time domain surveys. Both types of survey are conducted using two coils of wire, one to generate a primary electromagnetic field (the transmitter) and a second coil to measures the electromagnetic field (the receiver). With frequency domain surveys measurements on the receiver coil are made while the transmitter coil is emitting the primary field whereas with time domain survey measurements the primary field is not being transmitted while the receiver is recording. Both have advantages and disadvantages and both have been tried to some extent in the transition zone.

3.2.1 Frequency Domain Electromagnetics

Three instruments, named EM-38, EM-31 and EM-34 have been developed to allow mobile continuous recording of ground conductivity and with different transmitter to receiver coil separations giving differing depths of ground penetration. These instruments are summarised in Table 3.1.

The EM-38 and EM-31 instruments are suitable for one man carry operations but the EM-34 with three large intercoil spacings requires two-man operation. The advantages of the EM-38 and EM-31 is that GPS can be carried simultaneously allowing an integrated rapid recording system of station location and ground conductivity. Conductivity data can be recorded at fast walking pace or towed in a non-metallic trailer behind a survey vehicle.

To date the EM-38 and EM-31 have received minimal interest from the archaeological community and marine applications have been confined mainly to fresh water lakes in North America. Some examples of their use in fresh water situations include an EM-38 installation in an underwater housing for towed operation along the bottom of lake Ontario, Canada adjacent to the entry of the River Humber. Conductivity data were successfully recorded and allowed the mapping of lake bed contamination to be recorded (Geomar, 2007).

Nadeau et al (2003) used both EM-31 and EM-34 instruments in association with continuous seismic reflection methods to delineate glacial deposits beneath the Saint John River at Fredericton, New Brunswick, Canada. The EM-31 unit was deployed in a paddle powered wooden canoe along with a portable DGPS navigation system. Water depth information was already available from a detailed bathymetric map and water conductivity data were also available. The authors presented an approximate method of correcting the electrical conductivity data of the river bed for variable water depths and produced a contour map of bathymetry corrected apparent conductivity. Water depths in the survey area varied from 0 – 6.5 metres. The maximum depth range of EM-31 is given in

Table 3.1 as 6 metres so in the deepest water areas the authors utilised the deeper penetrating EM-34 system. Installed in a two boat system the main EM-34 unit with receiver coil was placed in a non-metallic canoe powered by a small outboard motor. The EM-34 transmitter was placed in an inflatable boat and the inter coil separation controlled by the tow rope length between the two boats. Successful conductivity profiles were obtained using 10 metre and 20 metre transmitter coil to receiver coil separation. Local water conductivity was measured at 10.3 mS/m. Note however that with the average seawater conductivity being significantly greater bathymetric corrections may not be possible.

Van Overmeeren (1989) gives details of the application of the Geonics EM-34 inductive conductivity instruments in the search for sandy creeks containing fresh water within tidal deposits containing saline groundwater. Using the EM-34 with three different intercoil spacings of 10, 20 and 40 metres resistivity maps were constructed for each of these coil spacings which were in vertical mode orientations.

The results of the 10 metre vertically oriented coils shows typical resistivity values converted from measured conductivity over sandy creeks with fresh water values of 30-50 Ohm metres while surrounding tidal deposits with saline water give values in the range 5 - 15 ohm metres. It must be stated that these measurements were taken at ground surface in a delta and not with standing salt water. Van Overmeeren points out that results of EM-34 surveys are difficult to quantitatively interpret particularly in saline areas where the constraints of this instrument, which is designed to operate at low induction numbers, are not satisfied. This limitation is discussed by McNeill (1980).

McDonald et al (1998) carried out similar geophysical surveys to investigate saline intrusion and geological structures beneath areas of tidal coastal wetland in Hampshire, UK. Inductive conductivity measurements using Geonics instrumentation were repeated in order to study time dependent subsurface conductivity changes.

Geonics advise that the application of a standard EM-34 unit may require adjustment to cope with the high conductivities anticipated in surveys in salt water. Geonics offer interesting forward modelling software for inductive conductivity, PC Loop, This is PC based and allows the input of multiplayer thickness and conductivities of a model with a resulting calculation of inductive conductivity at ground surface.

The EM-34 when used in the three intercoil spacings of 10, 20 and 40 metres operates at frequencies of 6400, 1600 and 400 Hz respectively. Recently, Geophex Ltd of North Carolina, USA, has produced a multi-frequency GEM2 electromagnetic instrument operating in the range of 300 Hz to 48KHz. Multiple frequency data is obtained on a continuous profile basis and with an intercoil

spacing of 2 metres it appears to be worthy of investigation to be deployed in the salt water environment in a non-metallic boat.

A further interesting development is reported by Slater (2005) and shows a small shallow water paddleboat equipped with magnetic gradiometer, EM-31 conductivity, DGPS and water quality probe. This multicomponent equipment package was used in geophysical characterisation of contaminated wetlands.

Frequency domain electromagnetic systems (FDEM) are frequently flown in the search for conductive base metal deposits. Although mineral search is the driving force FDEM surveys are becoming increasingly used for other applications, for example, airborne resistivity mapping for sand and gravel deposit detection, sea ice thickness and sea bed bathymetry. Fugro (2007) give examples of this type of mapping in publicity material. The basic system is an eight-metre long 'bird', a fibreglass cylinder towed beneath a helicopter and operating a series of 5 transmitter and receiver coils ranging in frequency from 400 Hz to 56,000 Hz.

The British Geological Survey, in cooperation with the Geological Survey of Finland, operate a similar frequency domain system but with the coils installed on the wing tips of a Twin otter fixed wing aircraft. Most surveys carried out from this type of aircraft have been for geological mapping. A review of the system and its applications are given in Geological Survey of Finland Special Paper No. 39 (2005). However, to date no case history material has been published relevant to discrimination of sediment types or structures beneath a salt water layer in a transition zone.

3.2.3 Time Domain Electromagnetics

Geonics Ltd has also developed time domain electromagnetic systems (TDEM) for geological mapping, mineral ore detection and unexploded ordnance (UXO detection). In the cases of geological mapping and mineral ore detection the basic system, the EM-47, consists of a ground loop of single turned wire circa 40 x 40 metres through which a current is passed using a transmitter which controls the frequency and shape of the transmitted wave. A fixed receiver loop, 1 metre in diameter, is placed in the centre of this transmitter loop and the associated receiver monitors the shape of the voltage decay curve at the receiver coil when the transmitter is switched off. The resultant decay curve can be interpreted in terms of subsurface layering and conductivity using PC software such as TEMIX supplied by Interpex of Colorado, USA. A useful case history of EM-47 application to resistivity mapping of the deposits of a river delta in British Columbia is published by Best et al (2003). Interpretation yielded thickness and resistivity of sediment layers to a depth in excess of 100 metres. Fitterman and Stewart (1986) described with case histories the application of TDEM in hydrological studies.

The use of time domain electromagnetics (or transient electromagnetics) in fresh water situations has been tested by Goldman et al. (1996 and 2004) with a

terrestrial Geonics system adapted for acquiring central loop soundings by floating the transmitter loop and a central loop receiver coil. These tests on the Sea of Galilee were designed to map the occurrence of saline groundwater. Operating in water depths of 10-20m they interpreted resistivity depth profiles consisting of a water layer with resistivity 9.5 – 10.5 Ohm metres overlying lake bed sediments with resistivity values of 2.5 – 4.0 Ohm metres. A further, deeper, sedimentary layer with a resistivity range of 80 – 170 Ohm metres was also detected. The schematic configuration of this system and a photograph of the system operating in the Sea of Galilee are shown in figure 3.1. A similar objective was the focus of a series of investigations reported by Barret et al. (2005) who used an adaptation to the Zonge NanoTEM system to identify point groundwater saline intrusions into the Murray River, South Australia. Both these studies produced a series of 1D conductivity-depth models that were subsequently interpolated to produce pseudo-2D sections. The authors comment that in comparison to land surveys once a floating transmitter loop has been set up on the lake surface it is quite easy to tow it between various recording stations. It should be noted that there could be difficulties in accurately maintaining the location of the receiver coil in the loop centre and also maintaining the integrity of the encircling transmitter loop particularly in areas of wave action. In TDEM operations it is essential that no metal objects are allowed within the transmitter loop so deploying support vessels with outboard motors or major metal fittings cannot be permitted.

Besides the central loop TDEM sounding configuration there is an alternative configuration which is termed ‘off-set sounding’. In this configuration a much smaller transmitter loop, 5 metres in diameter, is connected by wire to a receiver coil which is separated laterally, 10-15 metres from the transmitter coil. The sounding procedure is exactly the same with that of the central loop configuration. However, this off-set sounding method appears to be more applicable in a marine towed configuration. No references were noted concerning TDEM application for geological mapping in the transition zone.

Over the past 15years two groups, the Geological Survey of Canada and Woods Hole Oceanographic Institute have been particularly active in the development of multifrequency EM for marine operations. Multifrequency EM systems consist of a horizontal magnetic dipole source that is dragged along the seafloor together with a number of coaxial receivers. The depth of investigation and resolution of the system is dependant on the source-receiver offsets. For deep water work, the system is optimized for sub-bottom resolution but in shallow water it has proved difficult to compensate for effects due to the water “airwave” and the “water wave”. The EM transmitter in these systems consist of a horizontal magnetic dipole arrangement that can generate harmonic magnetic fields over a range of frequencies (typically in the order of 200Hz to 20kHz). The receivers are tuned to measure the transmitter magnetic field and located at fixed distances from the transmitter. At any given frequency the strength of the magnetic field will decay away from the transmitter as a function of the

conductivity of the seafloor. In high conductivity material the decay is rapid whereas in low conductivity material (high resistivity material) the decay is slow. A full discussion of the propagation of fields within the Earth has been given by Cheesman et al. (1987).

3.2.4 Airborne TDEM methods

Airborne TDEM has been extensively used in the search for subsurface conductive mineral deposits. Generally the requirements are for high electrical power to energise the transmitter coil loop which is located around the survey aircraft. This has involved large two or four-engine survey aircraft, e.g. the Fugro GEOTEM system. Recently lighter helicopter-towed bird TDEM systems have been introduced in mineral surveys but geological mapping is not a priority for such surveys. No references were found to their application over salt water areas.

3.3 Electrical

The majority of electrical resistivity measurements carried out in geophysical surveys on land fall into two categories:
A) Multi-electrode resistivity 'imaging' surveys where a linear array of steel electrodes are inserted into the ground and connected by a multicore cable to a computer-based switching device which allows a resistivity pseudo cross section of the subsurface to be calculated. Typically, 24 or 48 ground electrodes are utilised. This technique is described by Dahlin (1996)

B) The 'Twin Probe' resistivity method which consists of two separate pairs of steel electrodes in ground contact. One pair, the mobile pair, frame mounted usually separated by 0.5 metres and moved as the measuring system across a survey grid whilst the other electrode pair are stationed at a substantial distance from the mobile pair. This technique is the resistivity method of choice of many archaeological geophysicists and is described by Gaffney & Gater (2003).

As previously stated when a highly electrically conductive layer of salt water is introduced above sediments electrical resistivity surveys become extremely difficult due to the problem of transmitting electrical current through this conductive layer into the sediments on the sea bed. Additionally these sediments, depending upon their permeability and porosity will contain salt water and their resistivity values will be sharply reduced from typical values observed from resistivity measurements on land where less conductive fresh water is usually present in the sediments. Typically unsaturated sands and gravels located on land exhibit resistivity values from 500 – 3000 Ohm metres. The presence of fresh water saturating these sediments reduce values to 100-1000 Ohm metres. Substitution of this fresh water by saline sea water with resistivity value of 0.3 ohm metres, reduces values to 1 or 2 Ohm metres. Snyder et al (2002) demonstrated that for situations where the seafloor sediments show resistivities of 3-5 times that of the overlying water, and that the water depth does not exceed half the dipole length, then the measure apparent resistivity will be at

least 50% of the true sub-bottom resistivity. They also showed that the sensitivity to changes in sub-bottom resistivity increases with the source – receiver offset. For their work a dipole-dipole array with potential dipoles separated by 10m each was designed for surveying in water depths of 5-10m. Notwithstanding the difficulties associated with the salt water, resistivity imaging has been successfully applied using two techniques, sea bed emplaced electrodes and surface towed electrodes.

In these two techniques the conventional electrode take-outs of the multi-core connecting cable which in land surveys is connected via jumper cables to steel rod electrodes in the ground are now replaced by graphite, lead or stainless steel pods at each electrode take out on the multicore cable. These pods become the effective electrodes by being in direct contact with sea bed sediments or in contact with salt water when towed at the surface. Sea bed emplaced electrodes and the connecting multicore cable require sinker weights, 2-4 Kg in weight, at each electrode pod to ensure that the electrodes are firmly in electrical contact with the sea bed. This may entail difficult logistics and is confined to shallow water depths. However, it can be used successfully as part of a 'roll-along' mode to extend an imaging line seawards with a falling tide. Clearly placing sea bed electrodes onto the sea bed accurately with suitable weights and ensuring accurate inter-electrode spacing is a difficult and skilled operation. In the above case no roll-along of electrodes was attempted.

A demonstration of the use of electrical resistivity by extending surveys from the shore into the intertidal zone during low water at West Wittering is given in Figure 3.2 where two sections are shown across a channel that runs perpendicular to the coast. Section 1 was acquired onshore away from the saltwater intrusion where fresh water dominated the ground water. The channel is clearly defined by the coarser material within the channel that is cut into low permeability clay of lower electrical resistivity. In section 2 acquired further down the channel out to sea within the intertidal zone the contrast in resistivity between the channel and the surrounding clay has reversed as the coarser channel fill has become saturated with salt water. Note also from this figure that the relative contrast in electrical conductivity (or its inverse resistivity) has also been greatly reduced in the presence of the salt water.

The alternative method of towing electrodes through the sea water is becoming increasingly used in near shore environments and rivers for pipeline surveys and other engineering applications. In this technique the surface area of the electrical 'take outs' on the multicore cable is again enlarged and constructed of either graphite or stainless steel. Each electrical 'take out' electrode is buoyed with a surface float and the multicore connecting cable can be easily towed as a 'resistivity streamer' at the sea surface.

AGI (2002) has produced a short publicity note (Figure 3.3) showing a freshwater lake survey using an 8 electrode resistivity streamer. A photograph shows the

configuration of the 8cm long graphite marine electrode. The resulting resistivity pseudo section in figure 2 shows a detailed resistivity variation from near shore out to a water depth of 24 metres. Subsurface resistivity variations of between 30 to 160 Ohm metres were recorded for the lake bed. Noteworthy is the delineation of resistivity variation within the fresh water column of the lake. This variation is interpreted as 'possibly dependent upon water temperature variation'.

Technos (2004) published both a photograph of a towed electrode streamer and a resistivity pseudo section in a salt water environment (Figure 3.4). Depth variation is from 1 to 4 metres. The resulting resistivity pseudo section shows a resistivity variation of 0.2 to 3.0 Ohm metres at the sea bed.

It is useful to compare the fresh water lake section (figure 3.3) with the salt water section (figure 3.4). Several points are noteworthy:

- The salt water resistivity section (AGI) shows the lack of detail in the sea bed due to the very conductive surface layer of salt water. Delineation of differing sediments and bed rock within the subsurface will be difficult given such a low resistivity range of variation.
- Given the predominant conductive effect of the surface layer of salt water it is important that very detailed bathymetric surveys are carried out along the resistivity profile location.
- Near shore variations in temperature and salinity will affect the resistivity of the surface salt water layer and must be taken into account. This will require temperature and salinity measurements of the salt water column.
- Tidal effects will require monitoring as these will change salt water thickness during data collection.
- Wave conditions may also effect salt water configuration.

Snyder et al (2003) describe a surface resistivity streamer cable with nine take outs at ten metre intervals connected to a combined resistivity/IP receiver and a 600-Watt transmitter. Designed to operate in either fresh or salt water environments as a surface towed resistivity system it acquires both IP and resistivity data in dipole-dipole configuration at conventional spacings from n=1 to n=6. The authors comment that data collection rates are 40 line kilometres of profile data per day have been collected with this system.

There is evidence, but no published information, of a towed resistivity survey carried out along parts of the UK fresh water inland canal network during the early 1990s. The objective was to map resistivity variations in order to detect locations of the canal clay lining where water leakage was occurring. The success or otherwise of this survey was not known.

No references have been noted which detail the possible deployment of a towed or dragged resistivity streamer placed directly onto the sea bed which should provide some mitigation from the somewhat overwhelming surface salt water

layer conductive effect. With care and hopefully a lack of sea bed obstacles a sea bed dragged resistivity streamer is worthy of investigation. All major resistivity manufacturers, ABEM (Sweden), AGI (Texas, USA) and Iris Instruments (France) produce marine profiling resistivity survey packages.

An alternative method of surface resistivity mapping on land is the use of the capacitively coupled resistivity system which is towed at a walking pace across the ground surface. The commercial version of the system is the 'Ohm mapper' manufactured by Geometrics (San Jose, USA). The instrument consists of a transmitter (pod) that electrifies two coaxial cables with an A/C current. The current is coupled to the earth through the capacitance of the cable. A matched receiver (pod) tuned to the transmitter frequency measures the associated voltage on the receiver's dipole cables. The receiver pod then transmits a voltage measurement, normally to the operator's logging console. Subsequent computer processing calculates the apparent resistivity under the towed array. At first sight this method has attractions for sea bed resistivity towing but further investigation shows that the Ohm mapper is most suited to high resistivity regions and good, dry ground contact is important. With a resistivity operating range of circa 3 – 100,000 Ohm meters plus the marine environment the Ohm mapper would appear to be unsuitable to sea bed operations. Further technical information is available in Geometrics (2001).

3.4 Radiometric Methods

Differences in the quantity of gamma rays emanating from a geological surface can be used to map the presence of anomalous radioactivity. A simple scintillometer or a Geiger-Muller instrument can be used to map terrestrial radioactivity by placing the detector instrument on a rock or soil surface and measuring the gamma ray activity in counts per second over a given time period such as 1-2 minutes.

The background radioactivity of various rocks varies due to radioactive content of constituents such as potassium, Thorium and Uranium. Granite rocks usually exhibit a higher concentration of radioactivity than for, example, chalk.

Although a total gamma ray count anomaly map can provide useful information on 'high' and 'low' radioactivity variation. More additional information can be obtained if the total gamma ray count can be analysed to identify the proportions of gamma ray activity relating to the main radioactive element, namely Potassium (K), Thorium (Th) and Uranium (U). The instrument capable of carrying out this discrimination is a gamma ray spectrometer. Both scintillometers and gamma ray spectrometers are used frequently in land and borehole logging for mineral exploration and as an aid to geological mapping.

Airborne radioactivity (radiometric) survey consists of placing large radioactivity sensors (detector crystal slabs) in the aircraft and analysing the output from the

detectors using a spectrometer to measure concentration levels of the radioelements detected. Typically data is displayed with contour maps of total radioactive counts and the three principal radioelements. Further information is given by Nielson et al (1990). Sea surface radiometric surveys will be limited as gamma ray activity is effectively shielded from a detector system by a metre of soil or rock or a layer of water 1-2 metres in depth. In the 1970s the British Geological Survey developed a system which was encased in a tube and could be towed or dragged by a vessel along the sea bed in contact with the sediments. Miller and el (1977) and Bowie and Clayton (1972) describe this instrumentation and the method, however over subsequent years this sea bed spectrometer has been developed and has been used in sea bed surveys around the UK for example, Jones (2001). In this study radiometric surveying is used to map granite outcrops prior to the installation of sea bed fibre optic communications cable. The vessel necessary for this survey was large and the method has yet to be proven in shallow water surveys. Jones (2001) did comment that given the K, TH, and U counts of the sea floor derived from spectral radioactivity measurements it should be possible to classify the sea bed into a range of sediments and rock types.

3.5 Total Field and Gradiometer Magnetics

Total field magnetic surveys are flown using proton, overhauser effects or optically pumped magnetic sensors. Such instrumentation is deployed in hundreds of fixed wing survey aircraft and helicopters and is the ‘first step’ survey in many minerals and hydrocarbon prospecting surveys as well as a standard tool in geological map making. Reeves et al (1997) have reviewed the state of the art in airborne geophysics.

Depending upon survey objectives the airborne platform can be flown from heights, above ground of 70 – 100 metres for mineral surveys and up to several hundred metres for hydrocarbons or regional geological surveys. On a small-scale survey low altitude magnetic surveys have been carried out at ground clearance heights of 20 metres or less using helicopters, crop dusting aircraft and microlite systems.

Magnetic Gradiometry is used much less sparingly and has been the province of larger aircraft with a three magnetic sensor array, a sensor at each wingtip and a third in a tail ‘stinger’ attachment. In this configuration horizontal magnetic gradient is measured. Some research has been carried out into vertical magnetic gradiometry specifically in UXO surveys. Gamey et al (2002) have reported on experimental vertical gradient surveys. No reference has been noted of any publication relating to airborne magnetic surveys over the transition zone or to archaeological surveying.

Recently magnetometers have been installed in unmanned airborne vehicles (UAV) allowing this type of vehicle to carry out autonomous three dimensional

flight patterns for 10 hours at a speed of 75 km/h. Preliminary details are published by Killeen (2004). Fugro, a specialist airborne geophysical company offers an autonomous remote airborne platform entitled 'ranger'.

Both Geometrics Ltd. and Marine Magnetics Ltd. offer a configuration of two sensors in a towed underwater horizontal gradient towed mode whilst Marine Magnetics offer a combined 3-sensor system offering both horizontal and vertical gradiometer measurements. The towed gradient sensors are configured in a similar manner to the single total field sensor described for marine work earlier and thus are also susceptible to inaccuracies in positioning and the difficulties in determining the height of the sensors above the seafloor. Apart from the potential hazard of sensor loss due to underwater obstacles, particularly in shallow water, there is additional difficulty in that during boat turn manoeuvres the sensors typically move with respect to each other causing excessive noise and an increased magnetic anomaly during the turn.

Breiner (1977) produced a table of the approximate magnetic effects of steel ships as measured by a magnetometer tow system. Typically for a 200 ton steel vessel, circa 25 metres in length, with a tow system of 100 metres the magnetic effects of the vessel on the towed sensor is 6nT. With a tow system of 150 metres the magnetic anomaly of the vessel is 1.6 nT. However, should mainly wooden or fibreglass ship structures be encountered then this magnetic effect is rapidly reduced to the smaller signatures resulting from the vessel engines or cargo.

For very shallow surveys, if care is taken it is possible to mount a total field sensor or gradiometer sensor on a wooden or other non-magnetic pole (Stinger) which can protect the sensor in front of the boat prow. Appropriate positioning of portable magnets can be used to compensate for the magnetic effects of the boat's engines and other magnetic material.

Magnetic gradient, and to some extent total magnetic field measurements have not been used extensively to map palaeo-landscapes either for archaeological studies or for geological investigations. This field of application has much potential but requires extensive research.

3.5.1 Shallow Water Surveys

Typically marine magnetics is utilised in the mode of a sensor towed underwater via a cable astern of a survey vessel. This mode allows the magnetic sensor to be sufficiently distant from the survey vessel that any magnetic effect due to the vessel can be ignored.

Generally the sensor is towed at 2-5 metres above the seafloor and 2-10m below the sea surface in shallow water surveys. The towing or dragging of marine magnetometers along the seafloor was tested in the 1970s in the North Sea for mapping the exact location of underwater telephone cables either laid on the sea

bed or buried at shallow depth. The total field magnetic anomaly was of the order of 10-20 nT at a distance of 3-5 metres. The technique has not found great use since mainly due to the hazardous nature of dragging equipment on the seafloor. The majority of surveys are accomplished with towed sensors. For example, Paoletti et al (2005) carried out a towed magnetometer survey for archaeological purposes at the bay of Baia near Naples, Italy using a Geometrics G856 proton precession magnetometer with a sensor towed 20 metres behind a loom fishing boat and Boyce et al (2004) published results of a similarly configured survey at Caesarea Maritima, Israel.

Fenning (1999) reports that in a survey of the bed of the River Thames adjacent to the south bank in London the target to be located was a buried World War II bomb. Given the river traffic and tow difficulty of an underwater survey, an inflatable boat with no engine was equipped with a vertical gradiometer GEM 19G Overhauser unit and a laser ranging prism plus an operator. This boat was towed 20 metres behind a small survey vessel with the inflatable boat being tracked by a laser ranging unit. A map of vertical magnetic gradient anomalies was produced. Similar wooden rafts have been constructed to tow a vertical gradiometer and being remotely winched across a contaminated pond. Real time gradiometer data was telemetered to the shore. Reynolds (2001) gives an account of this application. Gem System(2005) display a 4-sensor gradiometer in a commercial specification sheet. Figure 3.5 shows vertical gradiometer plus a 3 sensor horizontal gradiometer system mounted on a rubber boat powered by a small outboard engine. Survey location is carried out using GPS and DGPS.

Three commercial companies offer marine magnetometers, namely Geometrics of San Jose, California, USA; Marine Magnetics of Richmond Hill, Toronto, Canada and; J W Fishers of East Taunton, Massachusetts, USA.

Land-based archaeogeophysical surveys are frequently carried out on land using the fluxgate gradient magnetometer or gradiometer. Typical instruments are manufactured by Geoscan Ltd or Bartington Instruments Ltd and relevant details are given in Gaffney & Gater (2003). The gradiometer is carried by the field operator in a vertical mode with the operator walking at a constant speed along the lines of a survey grid. Vertical magnetic gradient data is acquired on a constant time basis and thus the operator requires skill and experience in surveying at a constant walking speed in order to obtain data at regularly spaced intervals. Typical noise levels of gradiometers is 0.1 nT and a survey accuracy of circa 1 nT. A study of relevant literature has found no technical references detailing the use of fluxgate gradiometers in the marine environment. The obvious difficulties of this technique are of maintaining a constant survey speed and sensor verticality. Additionally these gradiometers are most effective in detecting magnetic anomalies in the top two metres of the sub-surface. Inserting a layer of several metres of salt water will present a further difficulty.

Reford (2006) has reviewed the usefulness of horizontal gradiometer data and has concluded that

1. Horizontal gradient data improve the accuracy of resolution of the gridded total magnetic field beyond that which can be interpreted from a single magnetometer.

2. Horizontal gradient data can enhance anomalies over small magnetic sources that are located between magnetometer survey lines and also over linear sources that strike obliquely to the survey lines.

The advantages of a small vessel using an on-board magnetic gradiometer system are:

- Ease of manoeuvrability in shallow water
- No tow system
- Gradiometer data do not require correction for diurnal magnetic variation and thus an additional on-land base station magnetometer is not required.
- Cost-effective mobilisation of a small boat from the shore rather than deploying from a harbour or pier.
- Horizontal gradiometer can provide useful additional data.

3.6 Ground Penetrating Radar

The use of ground penetrating radar in terrestrial archaeological geophysics and landscape mapping is widespread, however its practical use in the transition zone and especially in the marine zone is limited. In saltwater and in saline saturated sediment, GPR penetration is limited to a few centimetres. This is mainly a function of the increased conductivity of salt water and also the predominance of clay (usually electrically conductive) material in the sediment in near shore environments. A number of case histories are available showing the influence of saltwater on the transmission of radar frequency energy in the presence of salt water and an example is given in figure 3.6. The abrupt cut-off in GPR penetration can be readily seen as the saline groundwater is encountered. For this reason, no further discussion of this technique is given.

4. UK Survey Capabilities in the Transition Zone

A number of survey companies have experience in working across the transition zone. All of the companies are major service organistions that have extensive experience in both the onshore and offshore survey areas. Many minor companies were contacted during the course of the project however only the major players are discussed in further detail below.

4.1Guardline Marine Sciences:

With a permanent staff of over 250, Guardline Marine Sciences covers a range of marine survey operations from deep water activities associated with oil and gas companies to shallow water, near shore environmental and archaeological investigations. Specifically for archaeological work the company has four divisions to draw upon for expertise, namely Guardline Environmental, Guardline Geosciences, Titan Environmental Surveys and their most recent acquisition, Guardline Lankelma. The company maintains a fleet of survey vessels from the small near shore *Coastal Surveyor, Titan Explorer and Titan Surveyor* to the offshore 70m *Ocean Researcher*. The fleet has a compliment of marine geophysical survey capabilities including sub-bottom profilers, multibeam sonar, sidescan sonar and ground discrimination sonar. For ground truth work the company has a range of sample systems including vibrocorers, cone penetrometers (with from 5-35m penetration) and bottom samplers. Acquisition is supported by a dedicated geotechnical laboratory and onshore processing facilities.

Guardline Lankelma was recently acquired by Guardline Marine Sciences. Lankelma has a long history of providing geotechnical solutions to land and marine situations. The company is one of the foremost suppliers of cone penetrometer surveys in the UK with CPT rigs from small units with hold down weights of 2 tonnes to large rigs with hold down weights of over 20 tonnes. Of particular interest to transition zone surveying are the light weight mobile units and especially its rubber-tracked, light weight crawler rigs that exert very low ground pressure and thus are capable of working on the very soft muds that are typical of many estuary situations around the British coast line. For survey work specifically in the surf zone Lankelma have developed the Neptune CPT unit. This Remotely Operated Vehicle is based on a sub-sea crawler unit initially designed for operation in the North Sea to water depths of up to 2000m. The vehicle consists of a tracked platform and a CPT with an air weight of approximately 4.5 tonnes. In the surf zone 5m of push is typical for a $2cm^2$ piezocone. The Neptune rig is controlled by a strengthened deck umbilical linked to the main survey platform – typically a larger survey vessel or jackup rig. The Neptune can be mobilised from a small landing craft and thereafter driven down the beach into the surf zone. This type of deployment makes the acquisition of high quality CPT in the transition zone a very real probability. Moreover, it is possible to do this with modern positioning allowing horizontal and vertical accuracies of 0.1m and 0.01m respectively. An example of these type of

ROV unit is shown in Figure 4.1 where successful deployment was achieved for an outfall at Woolacombe under difficult acquisition conditions (Gardiner, 2006).

For true marine operations, a series of rigs are available that make use of subsea automated control units powered by subsea power packs. These are typically controlled using acoustic telemetry for greater real-time interaction. The rigs are designed to use both $5cm^2$ and $10cm^2$ piezocones pushed into the ground using an electric powered friction wheel unit. For soft sediments a maximum thrust setting of 20-30kN with the $5cm^2$ unit is appropriate and has the additional benefit of meeting the NEN (Dutch) standards for CPT. The company also has the ability to conduct shear wave seismic cone penetrometer surveys. For these types of surveys the cone head is fitted with shear wave elements that can detect the passage of shear waves generated by a source at the surface. The resultant shear wave velocity profile can sometimes be diagnostic of material type in the subsurface.

Further ground truth data can be collected by grab sampling, gravity coring and vibrocoring. It is the latter that has been used to date in the majority of marine archaeological projects where continuous sequences of sediments are required for analysis and dating.

In addition to the usual geophysical capabilities including seismic and sonar, Lankelma has also developed a towed resistivity system for continuous electrical survey and categorisation of sea floor sediments. The system uses a modified 7 channel Schlumberger array powered by user-variable currents of up to 25A and 48.5V. While these systems have not routinely been tested in the transition zone they demonstrate that it may be possible to measure electrical resistivity offshore in a similar manner to that which it has been done onshore to such great success.

4.3 Pelorus Surveys

Pelorus Surveys is a specialist division of Soil Mechanics. Soil Mechanics is one of the largest geotechnical and geoenvironmental specialists operating in the UK with Pelorus providing hydrographic, geophysical and oceanographic capabilities. Their experience therefore encompasses land, near shore and offshore areas. Specifically, Pelorus has experience in the complete range of land and marine geophysical techniques together with complementary ground truth methods such as vibrocoring. For marine investigations the company operates an 11m Sea Cat survey vessel to MCA CAT2 accreditation. Of particular interest to transition zone operations, the company maintains a suite of bottom drag seismic cables that can easily be deployed in the transition zone for integration with onshore geophysical methods. The company is backed by the Soil Mechanics Geotechnical divisions which represent some of the most well respected engineering services in the UK over the last 30 years. Surveys are carried out with standards as designated by the International Hydrographic Office and the

company complies with Environmental Management Systems under requirements of BS EN ISO 14001:2004.

4.4 Fugro

Fugro is one of the largest service sector companies supplying services to the hydrocarbon, engineering and environmental communities. With over 7000 employees and 200 offices it has a worldwide presence and a diverse experience base. Onshore, near shore and offshore geophysical services are backed up by extensive engineering geotechnical facilities.

Fugro offers tailored near shore surveying using purpose-built survey vessels such as the M/V Fugro Surveyor. This vessel is classified to MCA Class 3 thus enabling operations up to 20miles from a safe haven. The vessel is equipped as follows for

- Single beam and multibeam echo sounder operations for detailed bathymetric charting in support of engineering and construction projects, navigation surveys, resource evaluation and conservancy.
- Side scan sonar surveys for detailed seabed mapping and the location and identification of man-made objects such as debris, shipwrecks, UXOs and sub-sea structures.
- Seismic profiler surveys for the investigation of sub-sea geology.
- Multibeam and Swathe Bathymetry

For ground truth sampling, Fugro maintains an extensive suite of sample systems including cone penetrometer testing (CPT) rigs with both standard deployment and track deployment (Figure 4.2). The later maintain a holddown capacity of 20 tonnes and ideally suited to transition zone work. The cones can be fitted with standard testing capabilities (sleeve friction, cone resistance but also a suite of geophysical capabilities)

Onshore and transition zone geophysics include electrical, seismic, magnetic, radar methods with capabilities that also extend to downhole/crosshole work. For work further into the transition zone/near shore area the company is equipped with marine plant for deployment on either floating or fixed platforms. Floating platforms include the versatile Uniflote pontoons and standard jack-up rigs. Project experience has also include operations where investigations on tidal mud flats have necessitated the support and supply using hovercraft (Figure 4.3).

5. Software Solutions

Palaeo-landscape reconstruction is a three dimensional problem that requires a 3D solution. For the past two decades, the oil and gas industry has addressed the issues surrounding 3D representations with an ever increasing sophistication of both hardware and software solutions. Today it is not only possible to represent 3D information in graphical computer-driven format but it also possible to project this information into a 3D virtual reality for almost complete immersion. This advanced format of data display and manipulation has recently been used for palaeo-landscape reconstruction to great effect by Gaffney et al. (2007). While this level of data processing and interpretation is undoubtedly leading to far greater understanding of palaeo-landscapes and also allowing a dissemination of the information in a way never before possible, the investment in technology is such that it is not available to the vast majority of workers in the field, in particular to the county archaeologist, the development archaeologist and the average academic. However, perhaps of greater significance are not the technical issues of the data manipulation but that of the availability of the raw data resource. The palaeo-landscape reconstructions undertaken by Gaffney et al. (2007) are based on proprietary data held by a number of different organisations (mainly oil and gas companies with some ownership by aggregate extraction companies). Data densities are therefore focused on those areas thought to be potential source areas and hence a major focus is on the deeper offshore parts of the southern North Sea. For other areas data densities are lower and therefore these 3D representations cannot be undertaken. As a consequence of this for this project a decision was therefore taken to investigate a software solution to data processing and interpretation that would be both cost affective and involve a reasonable level of time investment in learning new programmes.

5.1.1 The possible software available

A number of dedicated software packages are available for the representation of sub-surface geological data in three dimensions. Most of these software products have been developed for either the hydrocarbon industry or the mining industry and thus have certain characteristics that are aimed at problems typically encountered in these industries. A particular issue with software developed for the hydrocarbon industry is that of the depth scaling. All oil and gas reservoirs exist at some depth beneath the surface of the Earth and so software packages are built to handle data to very much greater depths than the palaeo-landscapes that archaeologists are interested in typically investigate. As the depth increases to target horizons, the resolution of the data will decrease and so the software is designed to operate optimally for lower resolution data than the archaeologist would typically require. The issues also surround software designed for the mining industry. One industrial sector that does operate in depth and resolution of a similar format to the landscape archaeologist is the hydrology/environmental sector. Programmes designed for this industry offer the best options for the archaeologist. Three sets of programme were investigated in this project as possible working solutions to the landscape

characterisation, namely, GSI3D (BGS), Terrastaion (Terrasciences) and Rockworks (Golden Software).
The following criteria were used to assess each product:

- Ability to handle multi-layers
- Ability to manually pinch out the horizons between boreholes
- Ease of data upload
- Integration with ArcGIS
- Manipulation of data within the programme and outwith the programme in data base format
- Visualisation of data
- Export of data
- Volume of data that the programme could hold and easily use
- Cost

5.1.2 Final Software solution

It was felt important to the project that the final software solution was one that could easily integrate with ArcGIS mapping software as this has become the preferred geographic information handling and display medium for practitioners in both the terrestrial and marine archaeological sector and also the aggregate industry. It was also felt important that links (upload and download) were easily executed between the 3D data display solutions and Microsoft Access data bases as many of the curatorial teams use this format of database for storing regional data. A key element of the programme was how it would handle both stratigraphic and lithological interpretations (Figures 5.1a and 5.1b) where it is necessary to assign different boundaries to the same borehole information based on the geological information. Furthermore, it was very important that the user could manually decide where in space horizons were truncated rather than only allowing the computer programme to define sequence boundaries based on the presence or absence of data.

The final software solution is illustrated in Figure 5.2 and consisted of a combination of ArcGIS (v.9.2), MS Access and Rockworks (v. 2006). Rockworks should prove particularly useful for field archaeologist, curators and other sectors of the industry as it is a relatively cost-effective addition to the standard suite of programmes owned by most investigators.

5.1.3 Test Data

In order to test the software solutions proposed by the combined use of Rockworks, ArcGIS and MSAccess, an area of onshore West Sussex extending into the English Channel to the east of the Isle of White was chosen. This area was of interest as it represents one where extensive onshore and offshore data was thought to be available and the offshore area contained a number of current and proposed aggregate licence blocks. The boundaries to the area are shown in Figure 5.3.

5.1.4 Data Availability and licence issues

The availability of data for onshore, terrestrial archaeological investigation includes information from a wide variety of sources. Some of these sources are freely available however many of them require specific licences for their use, for example, OS map data, OS digital terrain models, BGS bathymetry data, BGS geological data, SeaZone data. These licences are typically granted for not only individual pieces of data but also control the use of this data and its display. Such restrictions are proving to be very problematic as they not only restrict the end user but restrict what can and cannot be shown of the final products and what can be passed on from the end of the project to a third party or the client. The future of much of these type of investigations may well be dictated by these licences and data access which it is recommended are negotiated on a higher government level than on the individual project level.

The following information was included in the project:

- BGS data archive (solid and drift geology together with borehole archive)
- OS current and historical maps
- OS generated Digital Terrain Models
- Engineering projects
- County archaeological data bases
- National Monuments Record
- Specific research projects, e.g. previous EH projects, ALSF projects
- Aggregate site information

The availability of information for offshore investigation is typically orders of magnitude sparser than the onshore side but included the following:

- BGS archive (both seafloor sediments and occasional borehole)
- Local dive sites

- Offshore pipe and cable/communication projects
- Landscape Analysis
- SeaZone bathymetry
- Global topography and bathymetry
- BGS digi250 bathymetry

5.2 Working Maps

5.2.1 Topography and Bathymetry

An analysis of the data available to the project was begun with the construction of a number of topographic and bathymetric maps. Small scale (large area) maps are available for free use from many global data sources. For example, onshore topographic data can be downloaded from the internet in the form of Global terrain models – see for example GTOPO30 for a 30 second resolution (approximately 1km) topographic representation. A higher quality DEM acquired from the Shuttle Radar Topography Mission at 90m resolution is also available for parts of the Globe. Bathymetry data is available for the most of the globe at 1 minute spacing from GEBCO (General Bathymetric Chart of the Oceans from the British Oceanographic Data Centre, Liverpool). SRTM30Plus data used by NASA World Wind attempts to combine both the GTOPO30, the SRTM and the bathymetric data into one unified surface.

Higher resolution topographic data is available for the UK from the Ordnance Survey at 1:10,000 scale with higher resolution data available in specific areas from LiDAR surveys undertaken by the Environmental Agency. The latter are of particular relevance to the transition zone as much of the south and east coasts of England have had this type of data acquisition giving digital terrain models at cm resolution (see Channel Coastal Observatory). The former requires purchase of a licence agreement from the OS after which the data is available for use in any particular project but the licence agreement does not allow the data or any format of the data to be passed on to a third party. This type of licence agreement is common to all mapping data and as discussed previously will seriously impact on the use of the mapping products from any research project. The highest resolution offshore data consistently available for the coast and shelf of the UK is provided by the Hydrographic Office. This data was evaluated for this project through access from SeaZone and also through licence agreement for digital bathymetric data through University agreements with Edina Digimap. The onshore OS topography is shown in Figure 5.4 together with the offshore GEBCO derived bathymetry, and the SeaZone derived bathymetry.

5.2.2 Geology

Figure 5.5 shows the onshore and offshore solid geology derived from the BGS mapping. For continuity across the transition zone, the geological units in both maps have been simplified but a colour representation summary is partially matched in order to show the coastline.

5.2.3 Borehole data

Figure 5.6 shows the extent of boreholes across the onshore and offshore areas. Immediately apparent is the lack of both onshore and offshore information in certain areas. While it is appreciated that this is not necessarily the total number of offshore core locations as it is anticipated that the aggregate companies will have a number of data points associated with their resource evaluation exercises it does represent the average scarcity of data that can be expected in areas around the coast of the UK. Furthermore, when these data had been uploaded it was also apparent how inadequate the information in each core site was in terms of geological and archaeological information.

5.2.4 Mapping Geological Surfaces

Two key surfaces were mapped from the data, namely the combined topography/bathymetry surface and the sediment interface to bedrock surface. Figure 5.7 and 5.9 show the topography/bathymetry derived from OS topography data and Seazone bathymetry data. Figures 5.7, 5.8 and 5.10 show the bedrock surface. The relationship of these two surfaces is illustrated in the isometric illustrations in Figure 5.11. From these two surfaces a calculation of total sediment thickness or sediment isopach can be made. This is shown in Figure 5.12.

5.2.5 Geophysical Data

Sub-bottom profiling

Sub-bottom profiling using sonar techniques in the offshore areas is only accomplished as part of specific site investigations. Typically these are associated with aggregate extraction itself, with pipeline and communication route corridors and with oil and gas installations. Additional data is becoming available over the last few years in support of planning applications for offshore wind farm developments. Because all of these types of information are stored in a variety of locations and most of the data is proprietary and therefore counted as being sensitive it is difficult to access into a project that aims to publicly disseminate the end results. These issues will have to be addressed if future projects aim to make meaningful wide-area (regional) maps.

Seafloor imaging

High resolution seafloor images are also available for small areas within the project. For example data sets gathered in near shore zones to the east of Southampton by the University of Southampton provide sidescan sonar together

with high resolution bathymetry in transition zone areas. All offshore aggregate areas also have both bathymetry, usually acquired with multibeam sonar, and sidescan sonar data either as full coverage maps or as swath corridor surveys. As these data are for specific isolated areas they were not considered in detail in the project.

5.2.6 Geological and Archaeological Cross sections

A major advantage with the use of ArcGIS was its links to the Rockworks programme and data base. Once all the project information had been uploaded to both the MSAccess data base and the ArcGIS data base, the Rockworks programme was linked to the project. This then allows direct, interactive access to boreholes and the automatic generation of both stratigraphic and lithological cross sections from within the ArcGIS mapping view. This ability was used to construct cross sections from onshore West Sussex to offshore and also down the Solent into the test project area. These cross sections are shown in Figure 5.13. The ability to construct these cross sections and usefulness of them is a function of the amount of data that is available within the project, the more data available the greater the utility.

5.2.7 Designating zones

Integrating diverse datasets to derive useful statements on the Palaeolithic resource distribution and potential is most effectively achieved using multi-disciplinary approaches within a geoarchaeological framework. Such an approach, as championed by Karl Butzer (1981), sees past hominid behaviour as inextricably engaged with an (ancient) landscape composed of geological and biological entities. Study of these past traces of human activity can only be achieved (according to Butzer) through a holistic approach embracing different lines of evidence as equal elements in the discipline of palaeogeography. In this study we have adopted such a holistic and inclusive approach to consider the nature of our archaeological resource.

Past work on the terrestrial side of the study area has been undertaken as part of the PASHCC project (Bates *et al*., 2007). This study attempted to consider the nature of the buried Pleistocene sequences, refine their distribution and ascertain their age, palaeoenvironmental significance and contained Palaeolithic archaeology. The main outcome of the project was an integrated GIS drawing on a range of sources. Here we have attempted to extend this approach to the marine (Figure 5.14) although unfortunately significantly less data was available for our investigation especially of the type necessary to fully complete a terrestrial-marine 3D model. Such data as outlined in section 3 would necessitate a new acquisition effort.

Following integration of the different sources of information consideration was given to the development of a meaningful method of presenting the data. This process resulted in the creation of a number of zones within the study area (see

Figure 5.14). The criteria for picking these zones as has been extensively described in section 2, to be based on scientific review of methodologies that transcend either a land-based or wholly marine-based modelling effort. Thus it was necessary to attribute and link concepts detailed in section 2 to this specific case or regional area. The resulting zones were digitised and attribute data appended. The listing of attribute data used for this regional setting is presented in Table 5.1 and is a modification of the attributes recorded in the PASHCC zones (Bates *et al*., 2007) for the terrestrial side and a modification of this for the marine side. It should be noted here that the boundaries between individual zones are by necessity shown as hard boundaries but these have been placed on the basis of the best knowledge available to the authors at the time of writing. Consequently it is likely that boundary position will vary significantly and that sequences, deposits etc that exist in adjacent zones may well extend into other zones. Care should therefore be taken when considering the significance of individual zones and due attention should be taken of those adjacent zones when determining potential significance of sites. The individual attribute criteria based on the available data are discussed in section 5.2.8.

5.2.8 Zone attributes

Table 5.2 illustrates the criteria that were considered in the construction of the final zone map (Figure 5.14) and associated classification (Table 5.1). Critical to the classification is the geomorphological context and topographic situation in relationship to the surficial (Drift) and solid geology. With respect to palaeo-landsurfaces it has been shown that it is not only necessary to evaluate the present topography-bathymetry but also that which is buried and therefore evaluation of sub-surfaces are considered at this stage. A summary of the possible Palaeolithic artefacts and zoological remains is often sparse especially for the marine zones. The intensity of previous investigation will always be patchy depending on commercial interest. However, with special regard to aggregate areas or potential aggregate extraction areas this might prove more abundant than for typical marine zones. The degree of disturbance is a qualitative assessment of both natural and anthropogenic activity in an area. Finally the likely importance and the key research questions result from the evaluation of the objective criteria listed.

6. Conclusions

The primary objective of this project was to examine the possibility of producing a contiguous palaeo-landscape reconstruction across the marine to terrestrial boundary therefore enhancing the archaeological continuity across space and through time within an area of landscape previously examined through a series of stand-alone investigations. The project attempted to do this by undertaking the following key sub-tasks:

1 **Evaluation of Methodologies for mapping contiguous landscapes –** review of the methods for mapping palaeo-landscapes from the land (including river catchments) to the marine (up to 12 mile territorial waters) environment across the transition zone with no data gaps. This also included a review of the capabilities within UK industry for addressing mapping in this zone

2 **Construction of 3D palaeo-landscape models –** the construction of 3D palaeo-landscape models of both land and marine settings with a specific discussion of a of full 3D palaeo-landscape model based on existing land and marine data through the transition zone in an area of high archaeological value through to areas that are currently being exploited for aggregate resources

3 **Result dissemination/public outreach –** to provide through specialised presentation sessions at dedicated workshops the new methodologies to the aggregate, and scientific community at large, for adoption within development programmes. To complete peer-reviewed articles in scientific journals, see for example Bates *et al*., (2007c)

A successful review was undertaken of methodologies remotely mapping across the transition zone together with a review of the major contracting companies and their capabilities to undertake investigations in the transition zone.

The project identified a cost-effective suite of programmes for the storage, analysis and presentation of data across the transition zone. Furthermore, the project demonstrated that not only enhanced 3D understanding could be gained of the zone but that additional significant insight could be gained of both the marine and terrestrial sequences. It was demonstrated that terrestrial to marine continuity is essential to understanding fully both sequences. In particular this is relevant as different parts of the greater landscape are preserved in the two different settings.

A test model was established for the project in the Sussex area (offshore Selsey between the Arun and Chichester). The model was populated with readily available information (both free and commercially available). From the model a number of key horizons were mapped, namely the topography-bathymetry surface and the sediment/bedrock surface. No further subdivision of the

sedimentary sequence was possible for the whole area as the offshore detail was not great enough in either depth or space. For greater utility for the aggregate companies in the future it is suggested that more data is made available from dredging areas for analysis together with the evaluation of further offshore seismic data from oil and gas companies.

Despite the general lack of information, which is quite typical for most offshore areas around the coast of the UK, it was possible to establish key archaeological zones offshore that could be compared to archaeological zones onshore (table 5.1 and 5.2). The establishment of these zones and the continuity across the transition zone is important for contextualising archaeology and for aggregate development. A greater utility to this type of approach could be established in the future by conducting targeted surveys, both geophysical and ground truth, in the transition zone but further testing of this would be necessary before widespread acceptance of the relevance was proved. As no one place holds all the information for the offshore areas of the UK it is suggested that compilation into one place would be of great benefit to the aggregate companies, regulators and academia.

7. References

AGI (1997). Marine bottom resistivity survey, Miami, Florida – a case history. AGI, Austin, Texas, USA. Pp.1

AGI (2002) Lake resistivity survey using towed electrode – A case history. AGI, Austin, Texas, USA. Pp.1

Allen, L.G. and 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. and Ozouf, J.-C. 2003. The Pleistocene rivers of the English Channel region. Journal of Quaternary Science 18 , 227-243.

Antoine, P., Coutard, J.-P., Gibbard, Ph., Hallegouet, B. Lautridou, J.-P. and 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 & 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. 27 – 45. In: Wenban-Smith, F.F. and Hosfield, R. (eds.) Palaeolithic archaeology of the Solent River. Lithic Studies Society Occasional Paper 7. Lithic Studies Society: London.

Bates, M.R. and Whittaker, K. 2004. Landscape evolution in the Lower Thames Valley: implications for the archaeology of the earlier Holocene period. 50 – 70. In: Cotton, J. and 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.

Bates, M.R., Bates, C.R. and Briant, R.M. 2007c Bridging the gap: a terrestrial view of shallow marine sequences and the importance of the transition zone. Journal of Archaeological Science 34, 1537-1551.

Bates, M.R., Bates, C.R. and Wittaker, J.E. 2007a Mixed method approaches to the investigation and mapping of buried Quaternary deposits: examples from Southern England. Archaeological Prospection 14, 104-129.

Bates, M.R., C.R. Bates, P.L. Gibbard, R.I. Macphail, F.J.Owen, S.A.Parfitt, R.C. Preece, M.B.Roberts, J.E. Robinson, J.E. Whittaker and K.E. Wilkinson. 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., Jones, S., Keen, D,H, Walker, M.J.C. and Whittaker, J.J. 2005 Palaeoenvironmental investigations at the Butlins Hotel site, Bognor, West Sussex. Unpublished report. University of Wales, Lampeter: Lampeter.

Bates, M.R., Keen, D.H. and Lautridou, J-P. 2003 Pleistocene marine and periglacial deposits of the English Channel. Journal of Quaternary Science 18, 319 – 337.

Bates, M.R., S.A. Parfitt and 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., Wenban-Smith, F.F., Briant, R. and Bates, C.R. 2007b Curation of the Sussex/Hampshire Coastal Corridor Lower/Middle Palaeolithic Record. ALSF, 3279 ANL. Project Report. Unpublished Report, Department of Archaeology and Anthropology, University of Wales Lampeter.

Bates, M.R., Wenban-Smith, F.F., Briant, R.M. and Marshall, G. 2004. Palaeolithic Archaeology of the Sussex/Hampshire Coastal Corridor, project number 3279. Unpublished report for English Heritage. University of Wales, Lampeter: Lampeter.

Bellamy, A.G. 1995. Extension of the British landmass: evidence from shelf sediment bodies in the English Channel. 47 – 62. In (Preece, R.C., ed.) Island Britain: a Quaternary perspective:. Geological Society Special Publication No. 96.

Bellamy, A.G. 1995. Extension of the British landmass: evidence from shelf sediment bodies in the English Channel. 47 – 62. In (Preece, R.C., ed.) Island Britain: a Quaternary perspective:. Geological Society Special Publication No. 96.

Best, M. E., Gutsell, J. & Clague, J. (2003). Time domain electromagnetic resistivity mapping of a Fjord-Head delta. Journal of Environmental and Engineering geophysics, Vol. 8, no 3, pp. 167-177

Boulton, G.S., Peacock, J.D., and Sutherland, D.G. 1991. Quaternary. 503 – 542. In: Craig, G.Y. (ed) The Geology of Scotland. 3rd edition. Geological Society, London.

Bourillet, J-F., Reynaud, J-Y., Baltzer, A. and Zaragosi, S. 2003 The 'Fleuve Manche': the submarine sedimentary features from the outer shelf to the deep-sea fnas. Journal of Quaternary Science 18, 261 – 282.

Boyce, J. I., Reinhardt, E. G. Raban, A. & Pozza, M. R. (2004) Marine magnetic survey of a submerged Roman Harbour, Caesarea Maritima, Israel. The International journal of Nautical Archaeology, 33: 122-136

Breiner, S. (1977) Magnetic search in the marine environment. MM-TR1, publication by Geometrics Instruments, San Jose, California, USA. 40pp

Bridgland, D.R. 1994. The Quaternary of the Thames. Geological Conservation Review Series 7, Chapman and Hall, London.

Bridgland, D.R. 1995. The Quaternary sequence of the eastern Thames basin: problems of correlation. 35 – 52. In: Bridgland, D.R., Allen, P., Haggart, B.A. (eds) The Quaternary of the Lower Reaches of the Thames. Field Guide. Quaternary Research Association; Durham.

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. 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. and D'Olier, B. 1995 The Pleistocene evolution of the Thames and Rhine drainage systems in the southern North Sea Basin. 27-45. In: Preece, R.C. Island Britain: a Quaternary Perspective. Geological Society of London Special Publication 96.

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., 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., D'Olier, B., Gibbard, P.L. and 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.

Bridgland, D.R., D'Olier, B., Gibbard, P.L. and 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.

Brown, R.C., Gilbertson, D.D., Green, C.P. and Keen, D.H. 1975. Stratigraphy and environmental significance of Pleistocene deposits at Stone, Hampshire. Proceedings of the Geologists' Association 86, 349-363.

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., and Cornford, J.M. 1986 La Cotte de St Brelade (Jersey) 1961-1978: excavations by C.B.M. McBurney. Geobooks: Norwich.

Coles, B.J. 1998. Doggerland: a speculative survey. Proceedings of the Prehistoric Society 64, 45-81.

Culshaw, M. 2005. From concept towards reality: developing the attributed 3D geological model of the shallow subsurface. Quarterly Journal of Engineering Geology and Hydrogeology, Volume 38, Number 3, 2005, pp. 231-284(54)

Dahlin, T. (1996). 2D resistivity surveying for environmental and engineering applications. First Break, Vol 14 No. 7, The Netherlands, 14, pp. 275-282

Dix, J., Quinn, R. and 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.

Doll, W.E., Gamey, T.J. & Holliday, J. S. (2001) Current research into airborne UXO detection. Proceedings of 2001 symposium on the application of geophysics to environmental and engineering problems, expanded abstract.
Doll, W.E., Gamey, T.J., Holliday, J. S. & Lee, J. L. C. (2005) Viability of an airborne electromagnetic system for mapping of shallow buried metals. In Near Surface geophysics, Edited by Dwain Butler, SEG, Tulsa, Oklahoma, pp 653 – 661.
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. and Wiberg, P.L. 2004 Modeling fluvial erosion and deposition on continental shelves during sea level cycles. Journal of Geophysical Research 109, F3, 2003JF000091
Fenning, P. J. (1999) Pers. Comm. Vertical gradiometer instrumentation for a survey on River Thames in central London.
Fitch, S., Thomson, K. and Gaffney, V. 2005 Late Pleistocene and Holocene depositional systems and the palaeogeography of the Dogger Bank, North Sea. Quaternary Research 64, 185 – 196.
Fitterman, D. V & Stewart, M. T. (1996) Transient electromagnetic sounding for groundwater geophysics, vol. 51, SEG, Oklahoma, USA. Pp. 995-1005
Flemming, N.C. 1998. Archaeological evidence for vertical movement on the continental shelf during the Palaeolithic, Neolithic and Bronze Age periods. 129 – 146. In: Stewart, I. and Vita-Finzi, C. (eds.) Coastal tectonics. 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.
Gaffney, C. & Gater, J. (2003). Revealing the buried past – geophysics for archaeology. Tempus publishing, UK. Pp. 192
Gamey, T.J., Doll, W.E., Beard, L. P. & Bell, D. T. (2002) Airborne vertical magnetic gradient for UXO detection. Proceedings of 2002 symposium on application of geophysics to environmental and engineering problems, expanded abstracts p.11
GEM Systems (2007) Four-sensor gradiometer. Publicity brochure, Gem Systems, Richmond Hill, Canada, pp2
Geological Survey of Finland (2005). Aerogeophysics in Findland 1972-2004. Methods, system characterisation and application. Edited by Meri-Liisa Airo.
Geological Survey, Special paper No. 39, Espoo, Finland, pp. 197
Geomar (2007) Inductive Conductivity mapping of Lake bed of Lake Ontario, Canada. Personal Communication.

Geometrics (2001). Ohm-mapper – resistivity mapping. Geometrics, San Jose, California, USA. Pp.4

Gibbard, P.L. 1994. Pleistocene History of the Lower Thames Valley. Cambridge University Press: Cambridge. 229pp.

Goldman, M., Hurwitz, S., Gvirtzman, H., Rabinovich, B. & Rotshtein, Y. (1996) Application of marine time-domain electromagnetic methods in lakes: The sea of Galilee, Israel. The European Journal of Environmental and Engineering Geophysics, vol 1, no. 2, Geophysical Press, Castelnau-le-Lez, France. Pp. 125-139

Gupta, S., Collier, J., Palmer-Felgate, A., Dickinson, J., Bushe, K. and Humber, S. 2004 Submerged Palaeo-Arun River: Reconstruction of Prehistoric landscapes and evaluation of archaeological resource potential. Imperial College: London. 2 vols.

Heron-Allen, E. 1911. Selsey Bill: Historic and Prehistoric. Duckworth and Co: London.

Hodson, F., and West, I.M. 1972. Holocene Deposits of Fawley, Hampshire, and the Development of Southampton Water. Proceedings of the Geologists' Association 83, 421-441.

Jones, A.P., Tucker, M.E. and Hart, J.K (eds.) 1999 The description and analysis of Quaternary stratigraphic field sections. Quaternary Research Association Technical Guide No. 7. Quaternary Research Association: London. 286pp.

Jones, D. J. (2001) Development and application of marine gamma-ray measurements: A review. Journal of environmental radioactivity, 53, Elsevier. Pp. 313-333

Killeen, P. G. (2004) Back in the match – exploration trends and developments 2004, The Northern Miner, Toronto, Canada, pp.9

Kirkaldy, J.F. and A.J. Bull. 1940. The geomorphology of the rivers of the Southern Weald. Proceedings of the Geologists' Association 51, 115 – 150.

Lagerås, P. 2003 Approaches and methods for commissioned archaeology in wetland: experience from the E4 Project in Skåne, Southern Sweden. European Journal of Archaeology 6, 231 – 249.

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. 13pp.

Lericolais, G., Auffret, J-P. and Bourillet, J-F. 2003 The Quaternary Channel River: seismic stratigraphy of its palaeo-valleys and deeps. Journal of Quaternary Science 18, 245 – 260.

Long, A.J., Scaife, R.G. and Edwards, R.J. 2000 Stratigraphic architecture, relative sea-levels, and models of estuary development in southern England: new data from Southampton Water. In: Pye, K. and Allen, J.R.L.(eds.) *Coastal and Estuarine Environments: sedimentology, geomorphology and geoarchaeology*. Geological Society, London, Special Publications, 175, 253

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.

Mason, T., Rainbow, B. and McVey, S. 2006. Colouring the “White Ribbon”. Hydro International, v. 10, No. 4, pp. 19-21.
McDonald, R. J., Russill, N. R. W., Miliorizos,M. & Thomas, J. W. (1998). A geophysical investigation of saline intrusion and geological structure beneath areas of tidal coastal wetland at Langstone Harbour, Hampshire UK. In Robins, N. S. (Ed) Groundwater pollution, aquifer recharge and vulnerability. Geological Society of London, Special Publication, 130, pp 77-94.
McNeill, J. D. (1980) Electromagnetic terrain conductivity measurement at low induction numbers. Technical Note TN-6, Geonics, Mississauga, Ontario, Canada, pp15
McNeill, J. D. (1989) Use of electromagnetics for groundwater studies in Geotechnical and Environmental geophysics. Volume 1. Edited by S. H. Ward, SEG, Oklahoma, USA/ pp. 191-218
Momber, G. 2000. Drowned and deserted: a submerged prehistoric landscape in the Solent, England. International Journal of Nautical Archaeology 29, 86-99.
Nadeau, J. C., Butler,K. E. & Parrott, R. (2003). Application of riverine geophysics for delineation recharge to a river valley aquifer – Fredricton, N. B., Canada
Nielson, D. L., Linpei, C. & Ward, S. H. (1990) Gamma ray spectrometry and radon emanometry. In environmental geophysics, geotechical and environmental geophysics. Vol. 1, pp219-250, SEG, Tulsa, Oklahoma, USA
Palmer, L.S. and J.H. Cooke. 1923. The Pleistocene deposits of the Portsmouth district and their relation to Early Man. Proceedings of the Geologists’ Association 34, 253 - 282.
Paoletti, V. Secomandi, M., Piromallo, M., Giordano, F. Fedi, M. & Rapolla, A. (2005) Magnetic survey at the submerged archaeological site of Baia, Naples, Southern Italy., Archaeological Prospect. 12, 51-59
Posamentier, H. W., and P. R. Vail, 1988, Eustatic controls on clastic deposition II—sequence and systems tract models, *in* C. K. Wilgus, B. S. Hastings C. G. St. C. Kendall, H.W. Posamentier, C. A. Ross, and J. C. Van Wagoner, eds., Sea-level changes: an integrated approach: SEPM Special Publication 42, p. 125–154.
Posamentier, H.W., Jervey, M.T. and Vail, P.R. 1988 Eustatic controls on clastic deposition I – Conceptual frameworks. 109 – 124. In: Wilgus, C.K., Hastings, B.S., Kendall, G.G.S.C., Posamentier, H.W., Ross, C.A. and Van Wagoner, J.C. (eds.) Sea-Level Changes: An Integrated Approach. Special Publications of the Society of Economic Paleontology and Mineraology 42.
Preece, R.C., J.D. Scourse, S.D. Houghton, K.L. Knudsen, and D.N. Penny. 1990. The Pleistocene sea-level and neotectonic history of the eastern Solent, Southern England. Philosophical Transactions of the Royal Society of London B328, 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.
Quinn, R., Dean, M., Lawrence, M., Liscoe, S and Boland, D. 2005. Backscatter responses and resolution considerations in archaeological side-scan sonar

surveys: a control experiment. Journal of Archaeological Science, v. 32, pp. 1252-1264.
Reeves, C. V., Reford, S. W. & Milligan, P. A. (1997) Airborne Geophysics: Old methods, new images. In Proceedings of Exploration 97 Conference edited by A. G. Gubbins pp13-30 Geo F/X division of A. G. Information Systems Ltd, Canada.
Reford, S. (2006) Gradient enhancement of the total magnetic field. The Leading Edge. Vol. 25, No. 1, pp59-66, SEG, Tulsa, USA
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.
Reynolds, J. M. (2001) Multi-method geophysical investigation of an acid tar lagoon, Llwynginion, N. Wales. Abstracts Proceedings or 7th EEGS-ES meeting, University of Birmingham, Sept 7 2001, pp142-143
Roberts and Trow, 2002, Taking to the Water: English Heritage's Initial Policy for the Management of Marine Archaeology in England. English Heritage
Roberts, M.B and S.A. Parfitt. 1999. Boxgrove. A Middle Pleistocene hominid site at Eartham Quarry, Boxgrove, West Sussex. English Heritage Archaeological Report 17. English Heritage: London.
Roberts, P. and 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.
Roe, H.M. 2001 Late Middle Pleistocene biostratigraphy of the Thames valley, England; ne data from eastern Essex. Quaternary Science Reviews 20, 1603-1619.
Schreve, D.C., Bridgland, D.R., Allen, P. Blackford, J.J., Gleed-Owen, C.P., Griffiths, H.I., Keen, D.H. and White, M.J. 2002 Sedimentology, palaeontology and archaeology of late Middle Pleistocene River Tehames terrace deposits at Purfleet, Essex, UK. Quaternary Science Reviews 21, 1423-1464.
Scuvee, F. and Verague, J. 1988 Le gisement sous-marin du Paléolithique moyen de l'Anse de la Mondrée à Fermanville (Manche). C.E.H.P. – Littus. 121pp.
Sheriff, R. (1994) Encyclopaedic dictionary of exploration geophysics. Society of Exploration Geophysics, Tulsa Publications, USA. 3rd Edition 376pp.
Slater, L. (2005). Near Surface and environmental geophysics at Rutgers University, New Jersey, USA. Fast Times, News magazine for near surface geophysical sciences. Environmental and Engineering Geophysical Society, Denver, Colorado, USA. Pg.9.
Snyder, D. D., MacInnes, S. C., Raymond, M. J. & Zonge, K. L. (2003) Continuous Resistivity Profiling In Shallow Marine And Fresh Water Environments. Internal Publication, Zonge Engineering Research

Organization, Tucson, USA. Pp. 10
http://www.zonge.com/PDF_Papers/IP_MarineProfiling.pdf
Technos (2004) Overview of methods in site characterisation for water covered areas. Technos News Feb. 2004., Technos Inc., Miami, Florida, USA. Pp. 8.
Union Railways (North) Ltd 2002 Archaeological boreholes at Thames Crossing. Fieldwork Report. London: Union Railways (North) Ltd.
Vail, P.R., Mitchum, R.M. and Thompson III, S. 1977b Seismic stratigraphy and global changes of sea-level, part 3: relative changes of sea level from coastal onlap. 63 - 82. In: Payton, C.E. (ed.) Seismic Stratigraphy – Applications to Hydrocarbon Exploration. Memoir of the American Association of Petroleum Geologists, Tulsa, 26.
Vail, P.R., Mitchum, R.M. and Thompson III, S. 1977c Seismic stratigraphy and global changes of sea-level, part 4: global cycles of relative changes of sea level. 83 - 97. In: Payton, C.E. (ed.) Seismic Stratigraphy – Applications to Hydrocarbon Exploration. Memoir of the American Association of Petroleum Geologists, Tulsa, 26.
Vail., P.R., Mitchum, R.M., Jr., Todd, R.G., Widmier, J.M., Thompson, S. III, Sangree, J.B., Bubb, J.N. and Hatleid, W.G. 1977a Seismic stratigraphy and global changes in sea level. 49 – 62. In: Payton, C.E. (ed.) Seismic Stratigraphy – Applications to Hydrocarbon Exploration. Memoir of the American Association of Petroleum Geologists, Tulsa, 26.
Van Overmeeren, R.A. (1989) Freshwater bearing sandy creek beds explored by electromagnetic measurements in a mainly saline coastal area of the Netherlands. P. 716-729 In Proceedings of Exploration ’87. Third Decennial Exploration for Minerals and Groundwater. Edited by G. D. Garland, Ontario Geological Survey, Special Volume 3. pp. 960.
Velegrakis, A.F., J.K. Dix and M.B. Collins. 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. 6 – 19. In: The Solent Estuarine System: an assessment of the present knowledge. NERC Publications Series C22.
West, R.G. and B.W. Sparks. 1960. Coastal interglacial deposits of the English Channel. Philosophical Transactions of the Royal Society of London B 243, 95 - 135.
West, R.G., R.J.N. Devoy, B.M. Funnell, and J.E. Robinson. 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. and 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.

8. List of Illustrations and Tables

Table 5.2 Criteria for individual zone characterisation in table 5.1

Figures

Figure 2.1 Schematic diagram of coastal zone (adapted from EU Com(95)511)

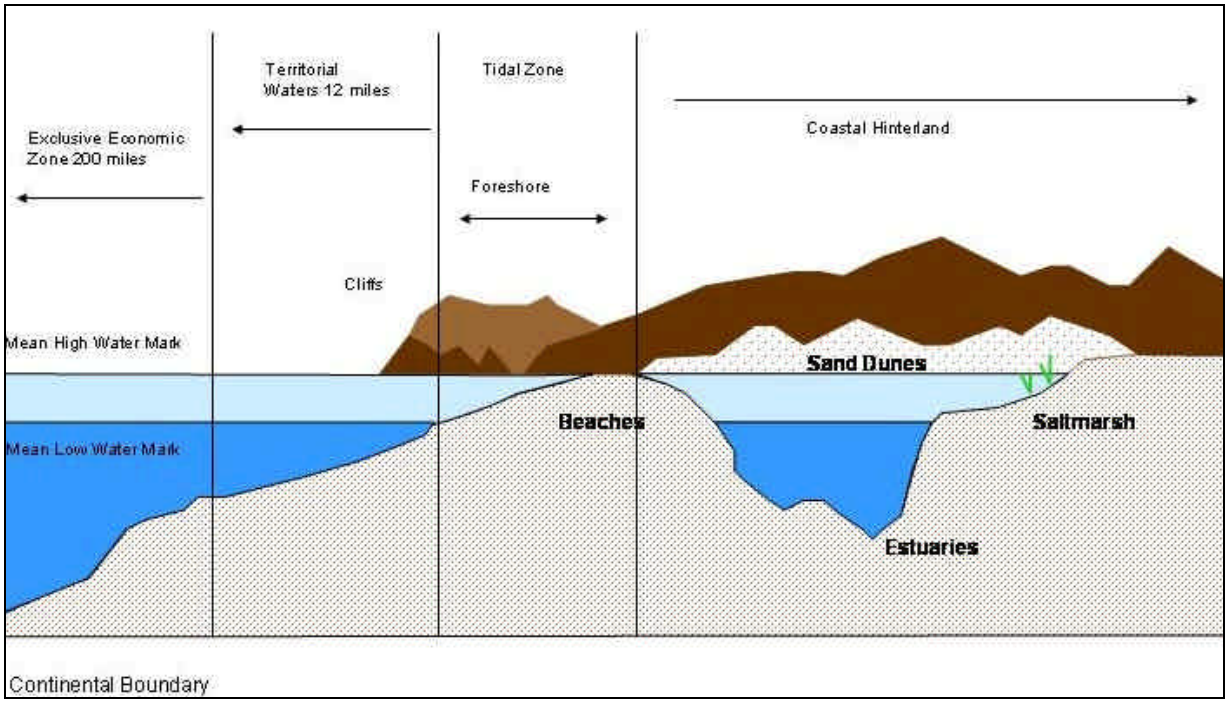


Figure 2.3 Current UKHO geoid model for UK shelf area

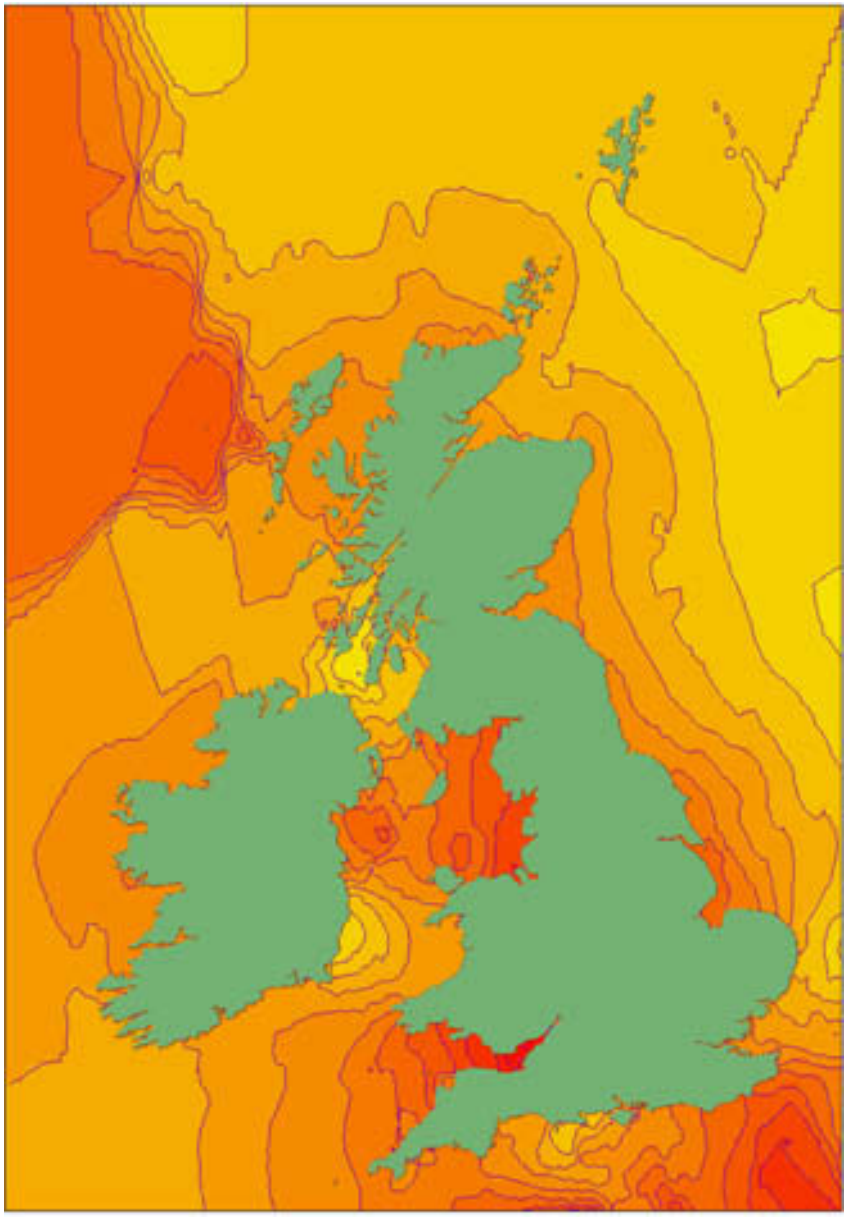


Figure 2.4 Southern England and the coastal waters showing area of subsiding North Sea Basin, region of Thames terraces and southern channel coast

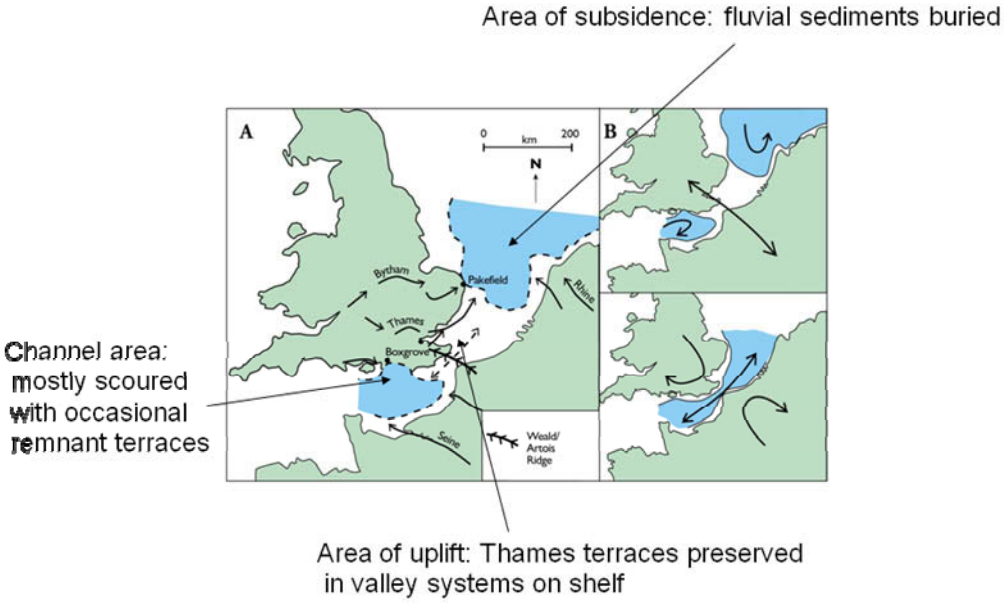


Figure 2.5 Terraces of the Thames beneath the southern North Sea (from Bridgland, 2002)

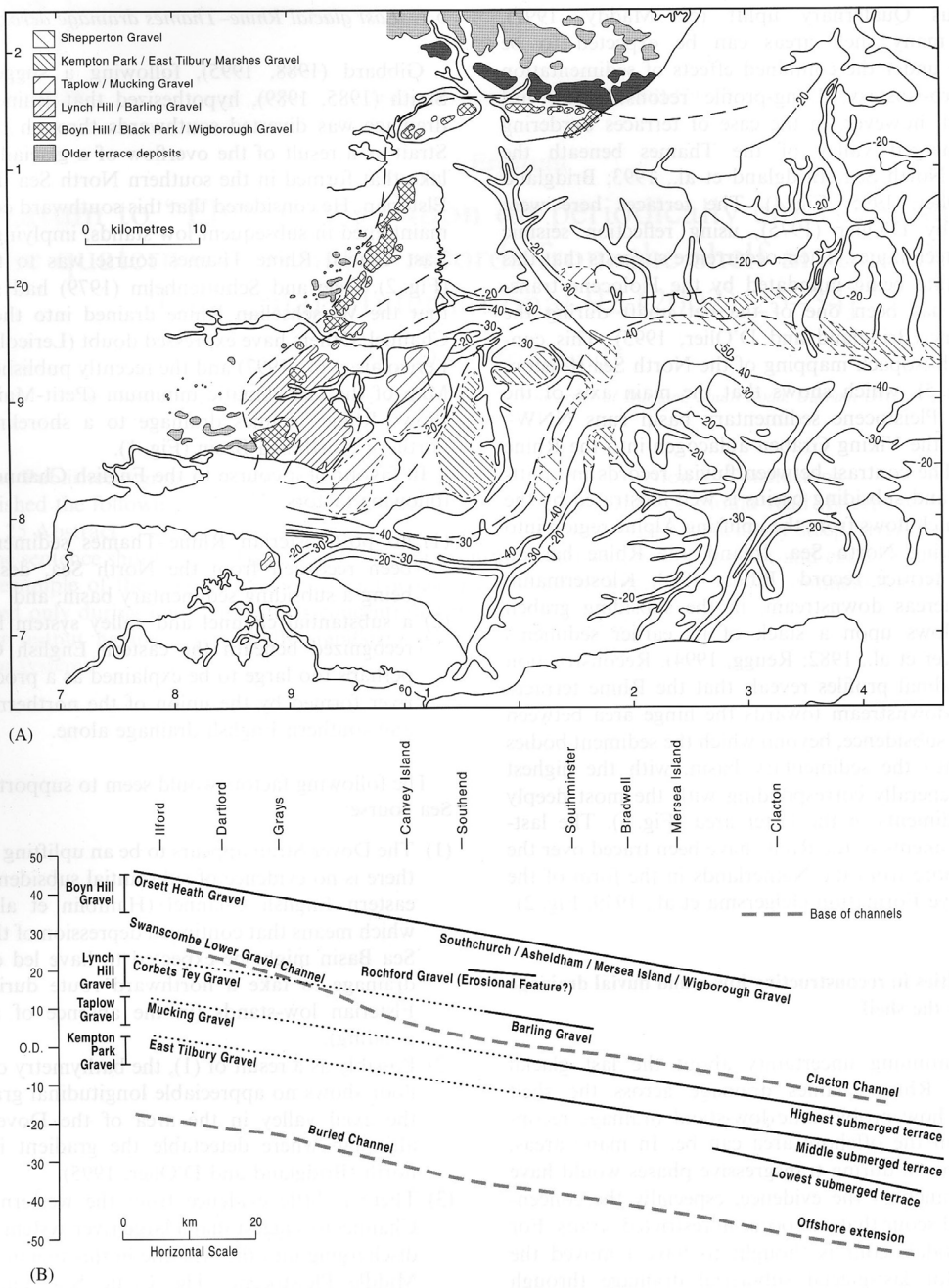


Figure 2.6 Regional geomorphology of the Sussex/Hampshire Coastal Corridor

Figure 2.7 Reconstructed channel river systems (from Bates *et al*., 2007)

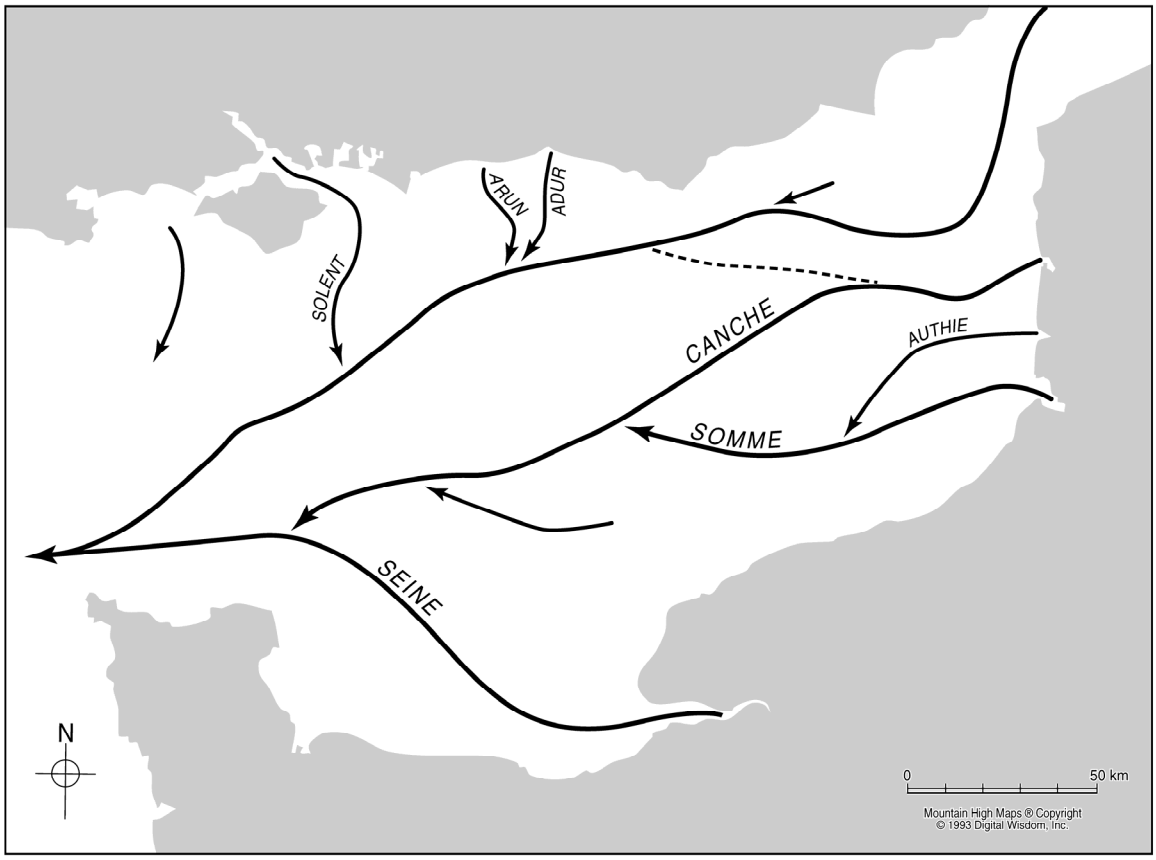


Figure 2.8 Lower Thames terrace model (Bridgland, 2006)

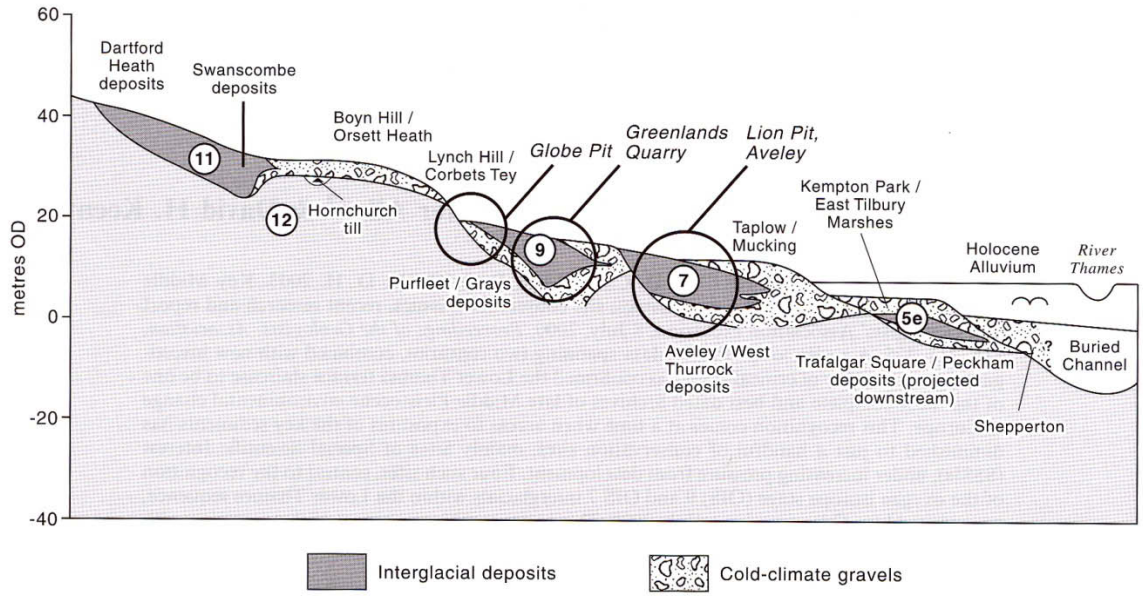


Figure 2.9 Stratigraphic sequences at Stone Point, Lepe

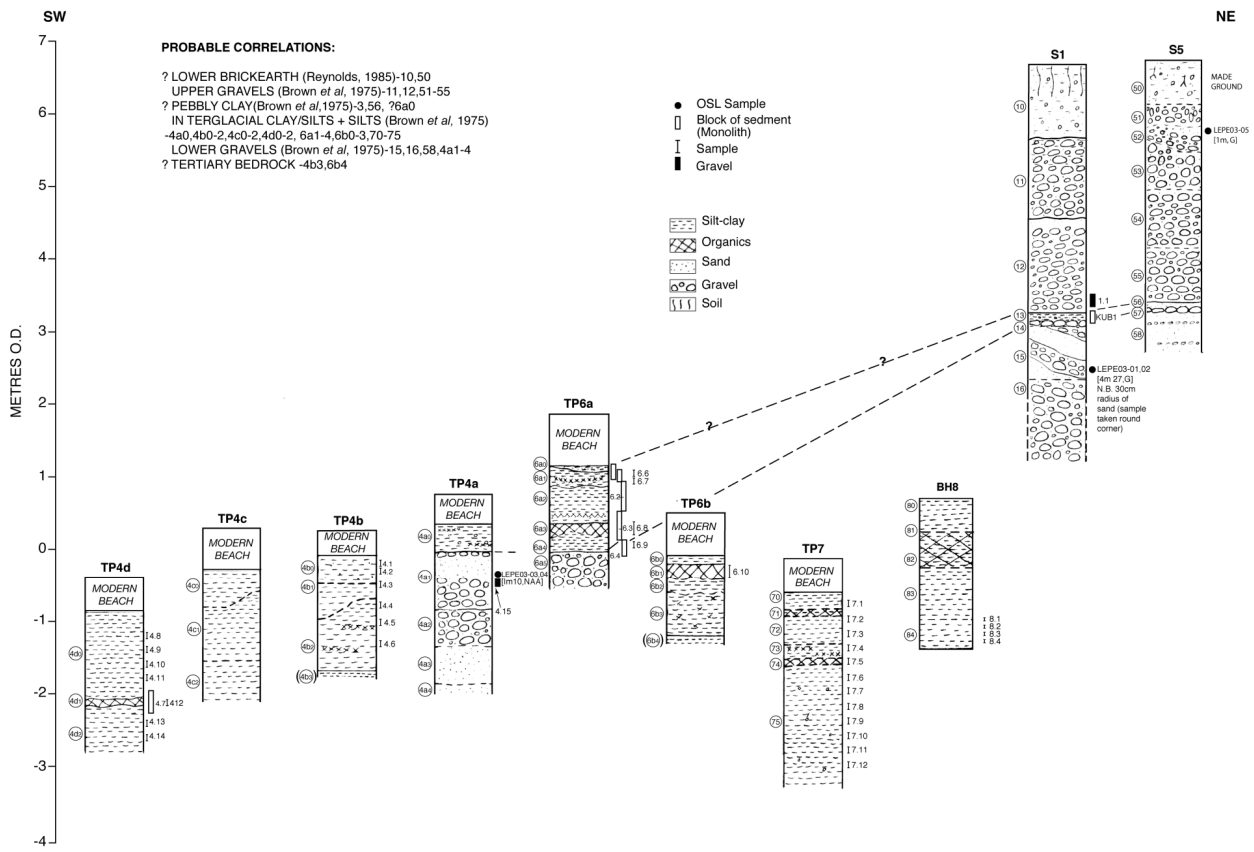
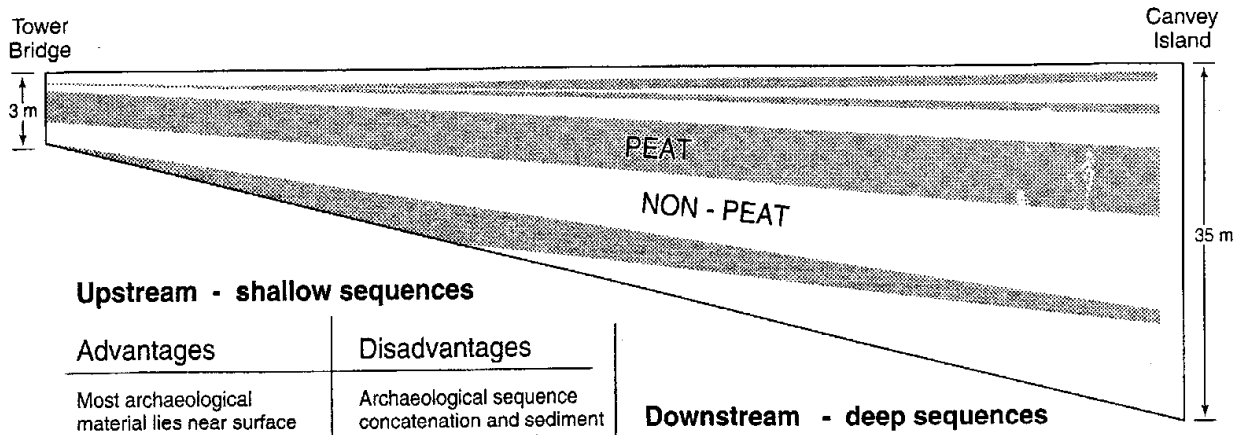


Figure 2.10 Holocene sediment wedge in Lower Thames Valley



Upstream - shallow sequences

Advantages	Disadvantages
Most archaeological material lies near surface	Archaeological sequence concatenation and sediment sequence compression
Archaeological sites visible to conventional survey techniques	Presence of major unconformities in sequence
Relative ease of excavation	Fluctuating water table impact on much of sequence reducing organic preservation potential

Downstream - deep sequences

Advantages	Disadvantages
Good time/depth resolution of sequence	Only most recent archaeological material near surface
Relatively complete sequences with few unconformities	Invisibility of much of the archaeological record to conventional survey techniques
Good organic preservation due to relatively high position of water table	Practical difficulties in excavation due to groundwater, sediment depth and instability of sections

Figure 2.11 Medway Marshes site location plan

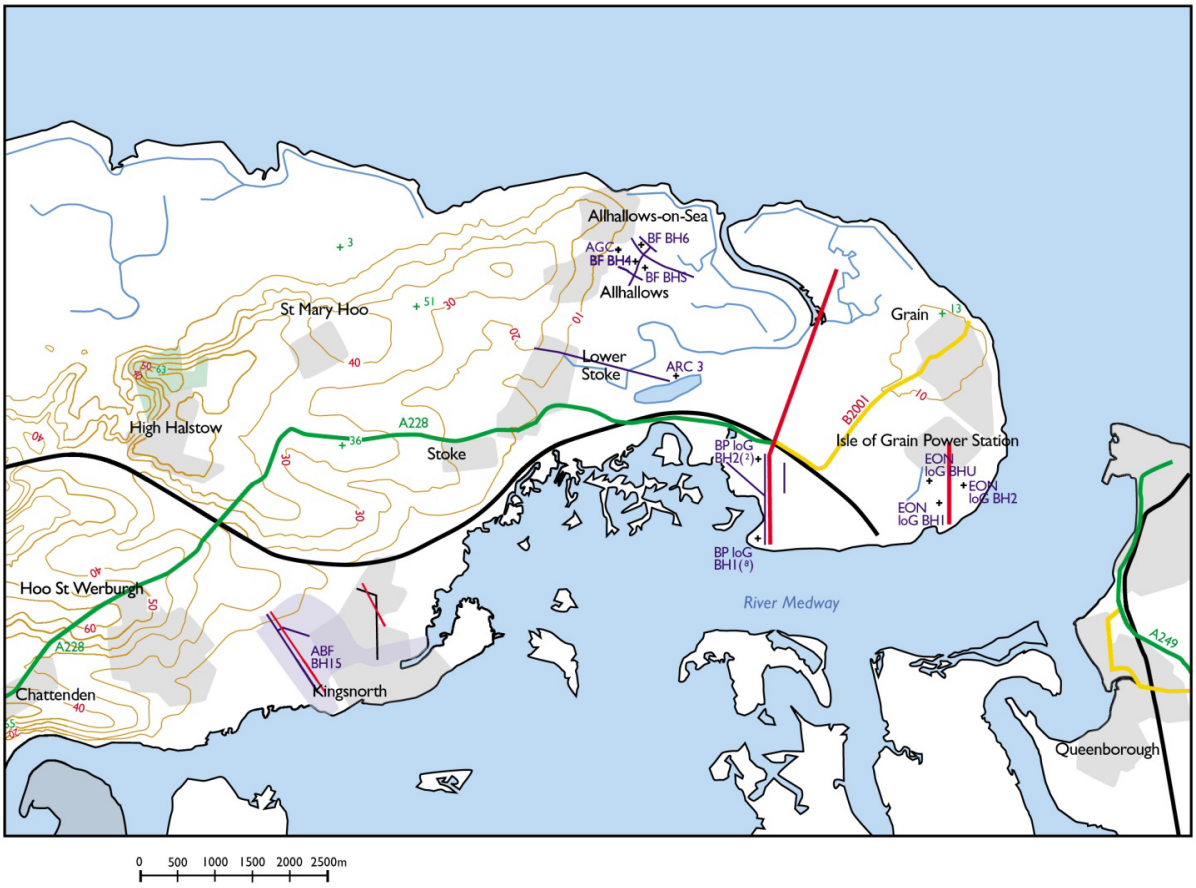


Figure 2.12 Stratigraphic sequences in the Medway Marshes at Allhallows

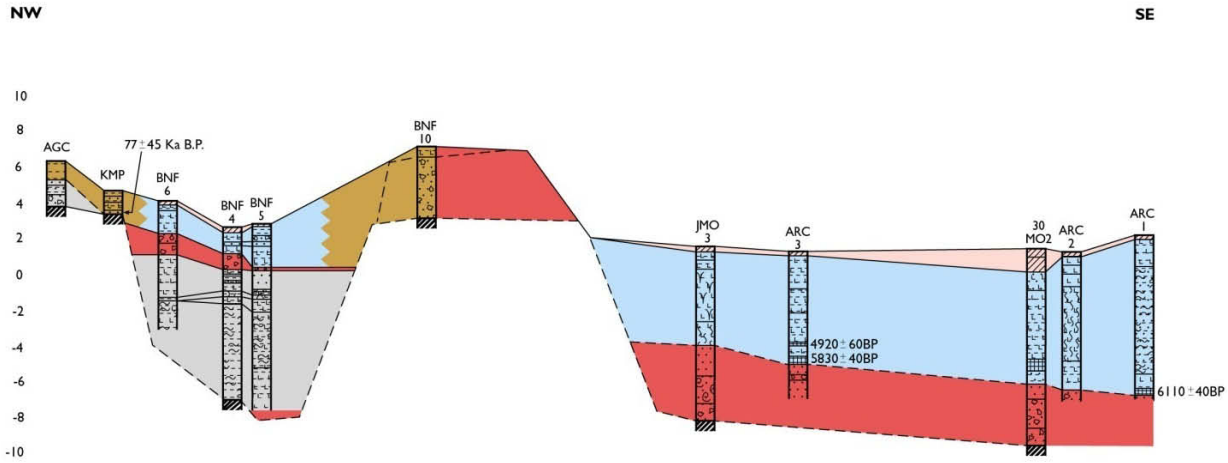


Figure 2.13 Stratigrahpic sequences from the Isle of Grain

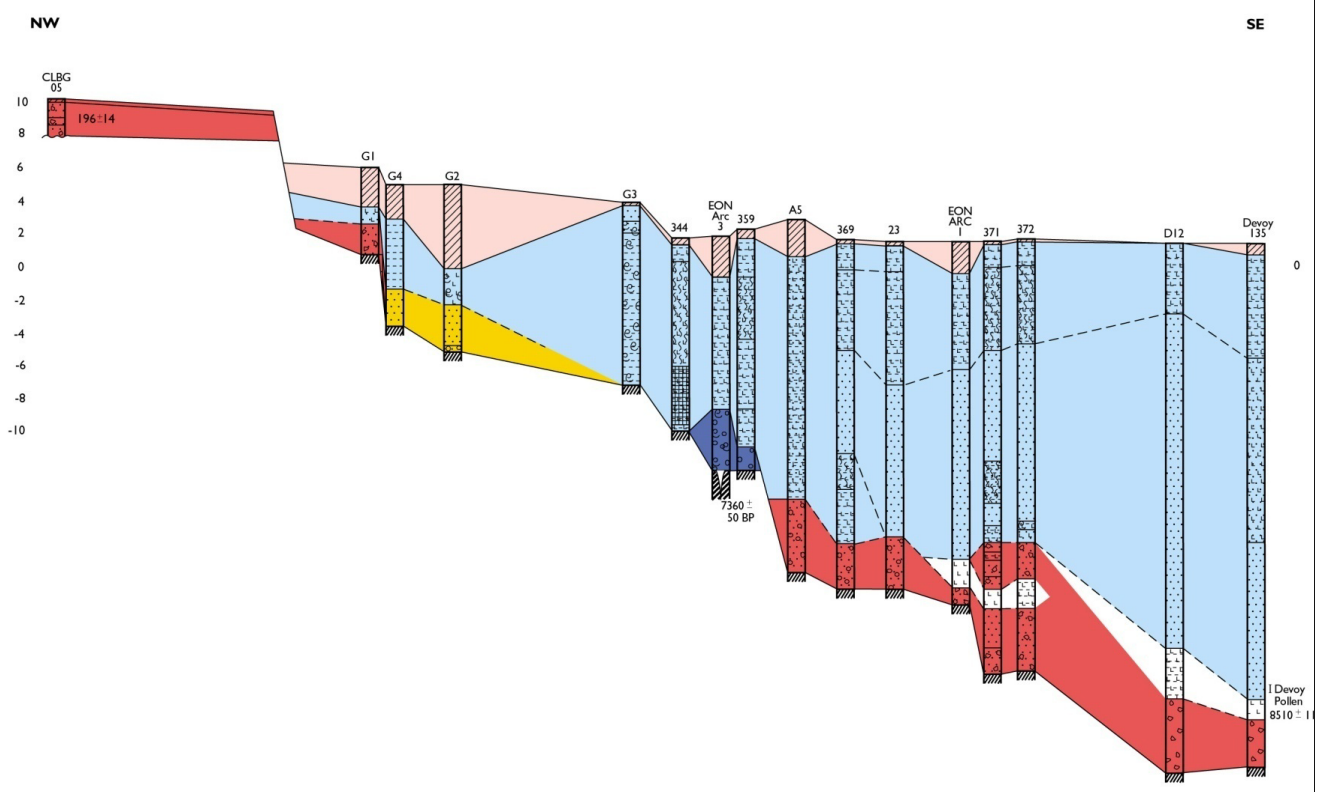


Figure 2.14 Radiocarbon dating evidence from the Medway Marshes

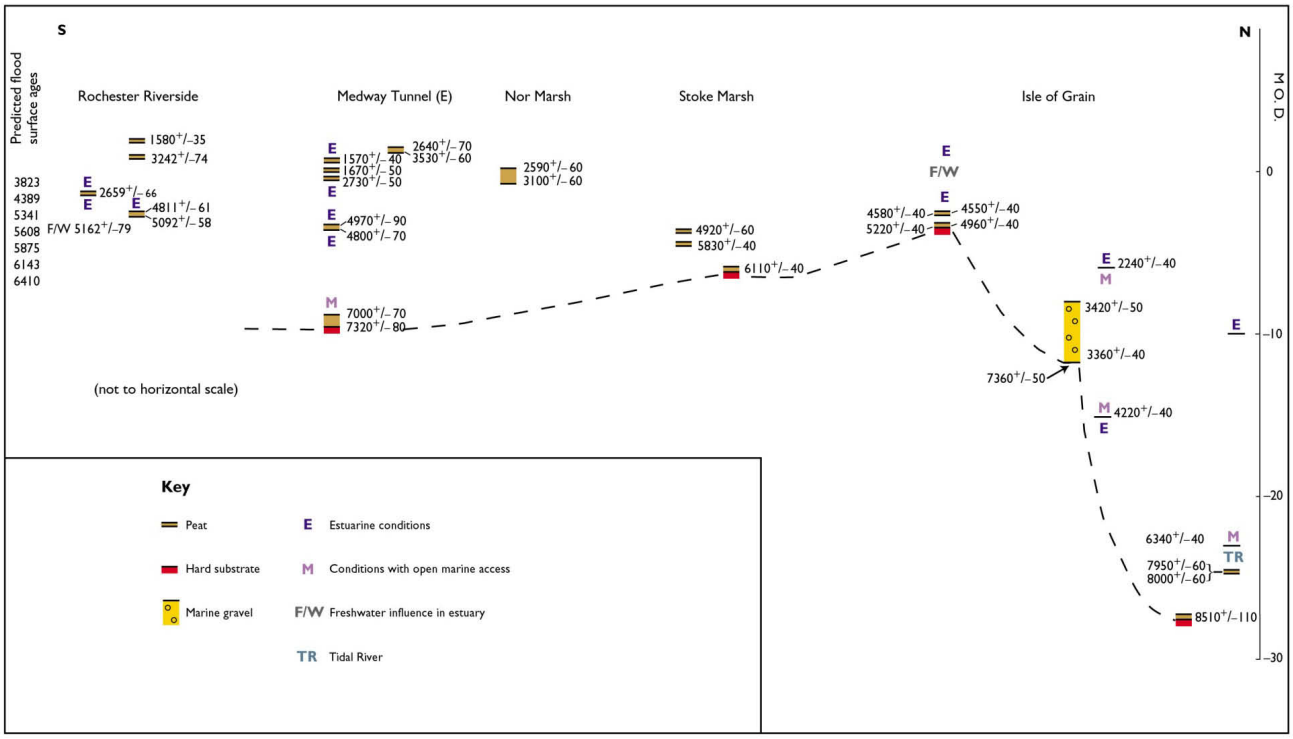


Figure 2.15 Schematic scheme through marine terraces of the West Sussex Coastal Plain

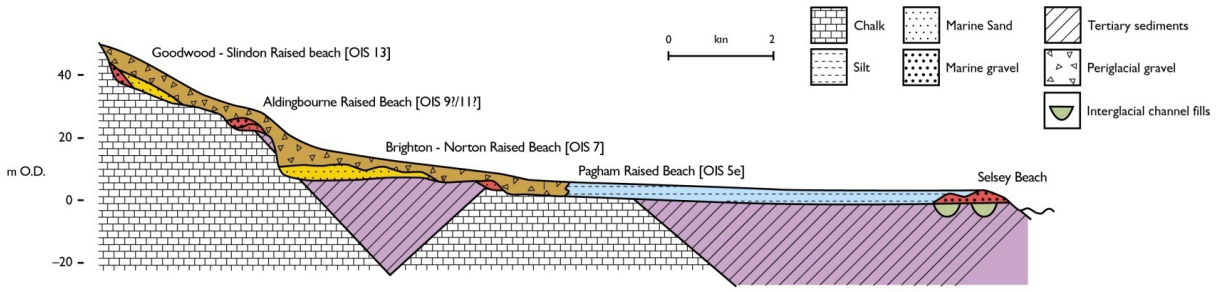


Figure 2.16 Distribution of main marine terraces across the West Sussex Coastal Plain

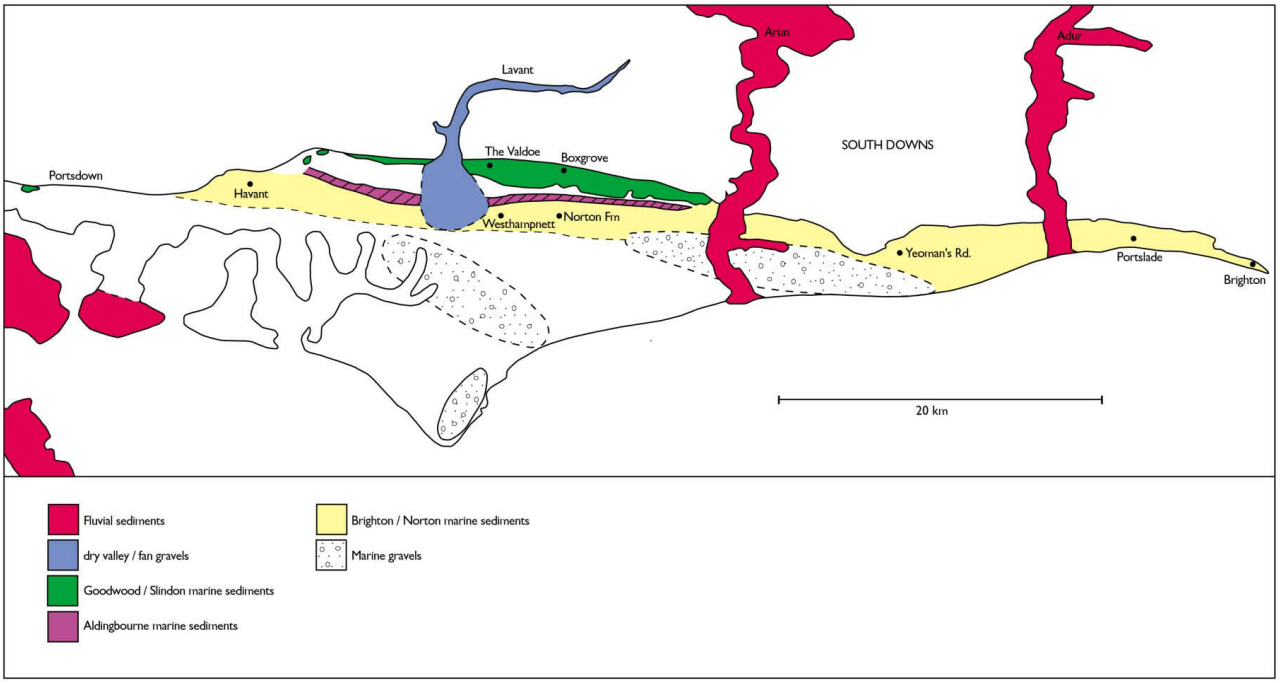


Figure 2.17 River Arun on-shore to off-shore geomorphology

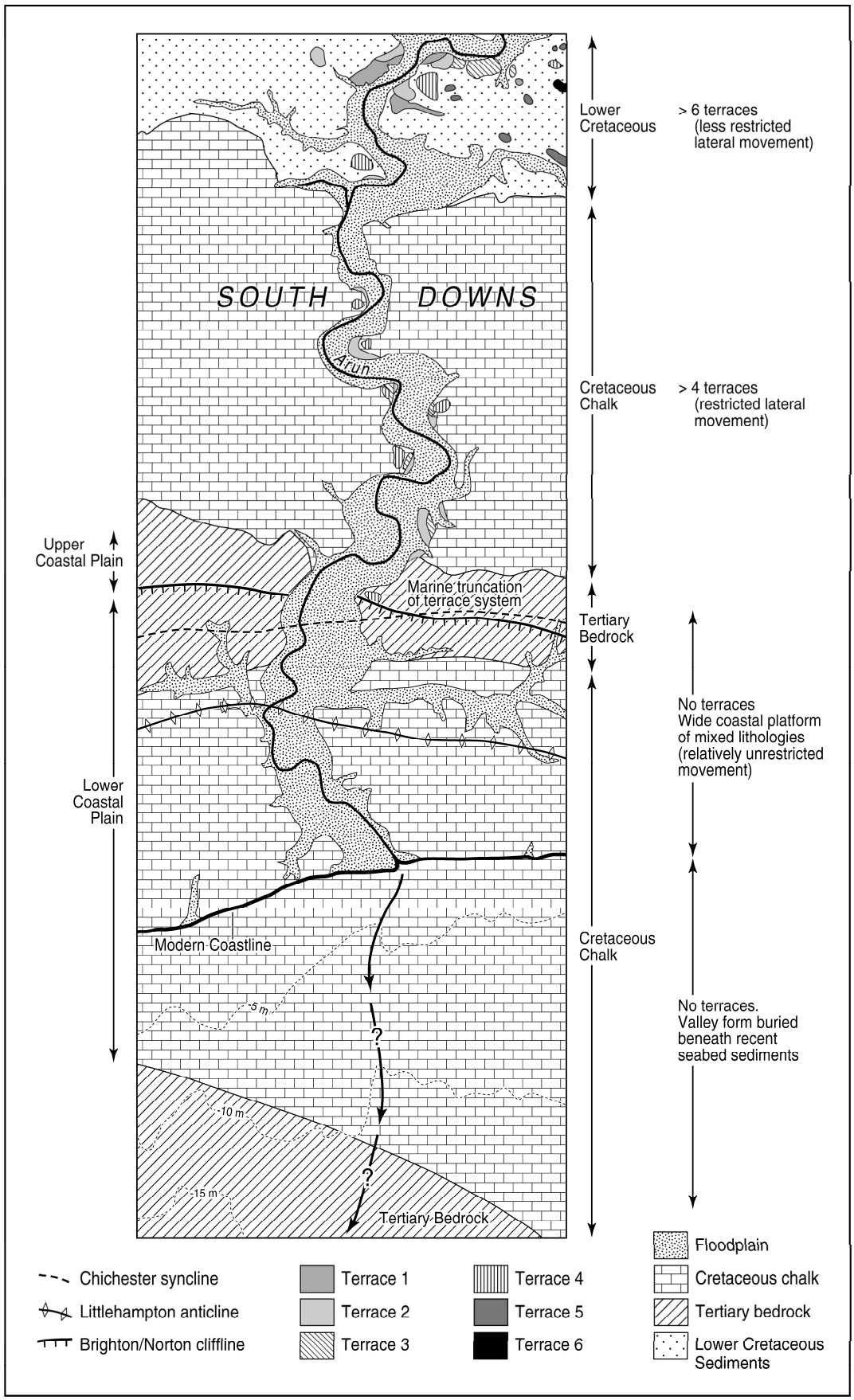


Figure 2.18 Westhampnett East quarry. A: buried landsurface. B: animal bones resting on buried landsurface. C: erosion through buried landsurface

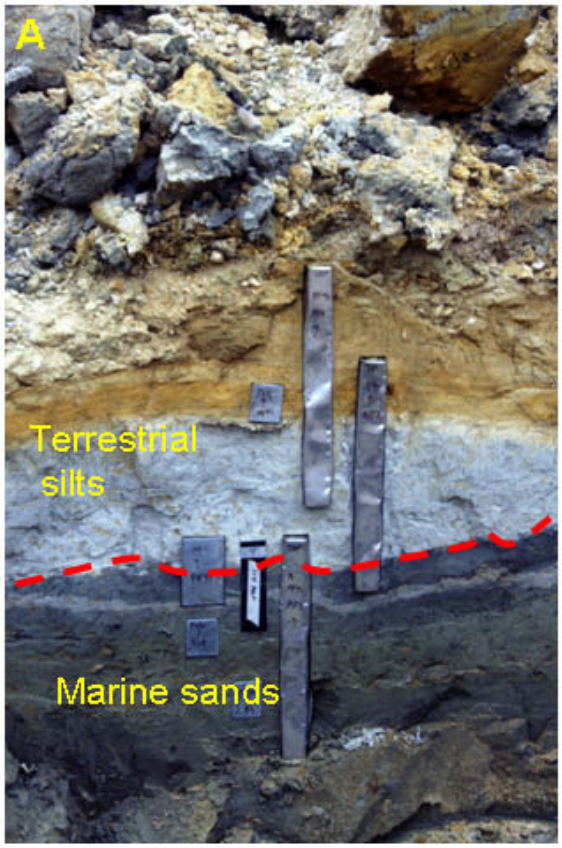


Figure 2.19 Schematic illustration of sediments from the western end of the West Sussex Coastal Plain

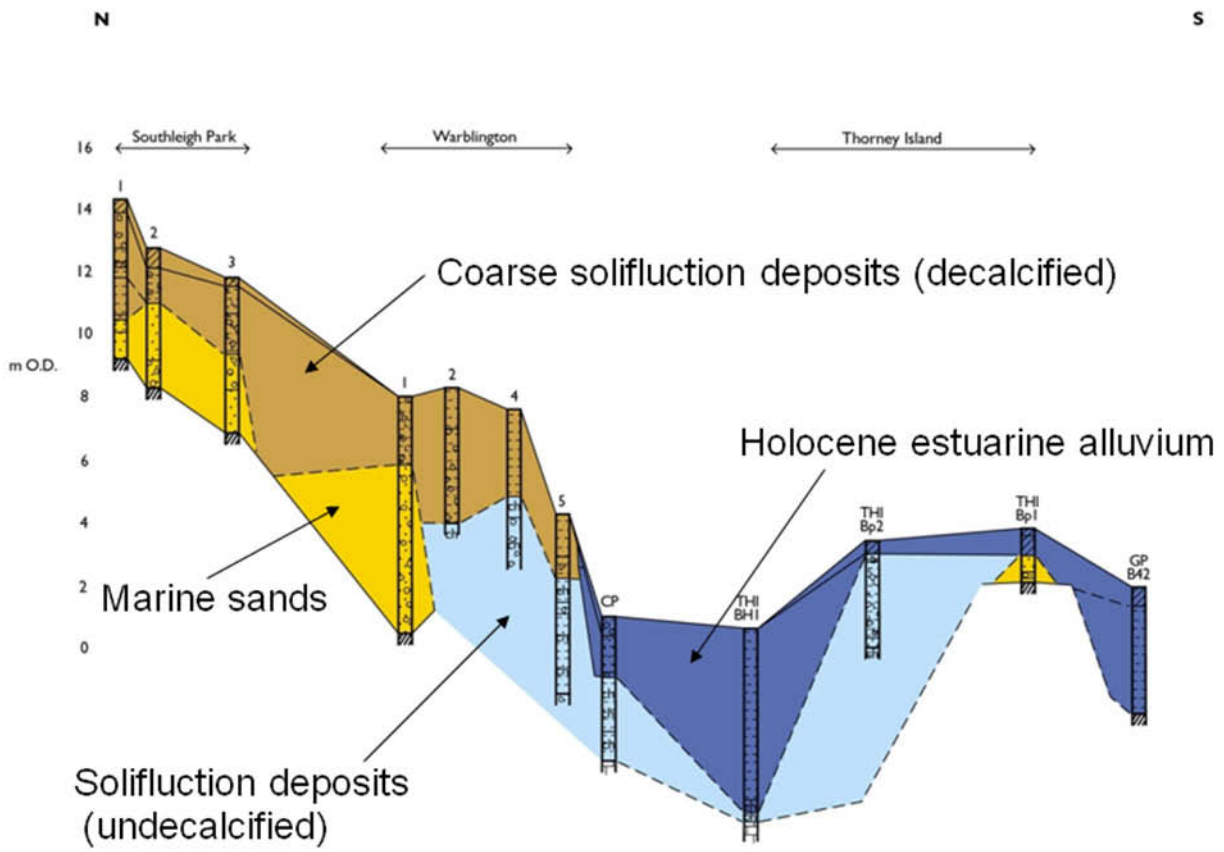


Figure 2.20 Chichester Fan Gravels and Kingsham

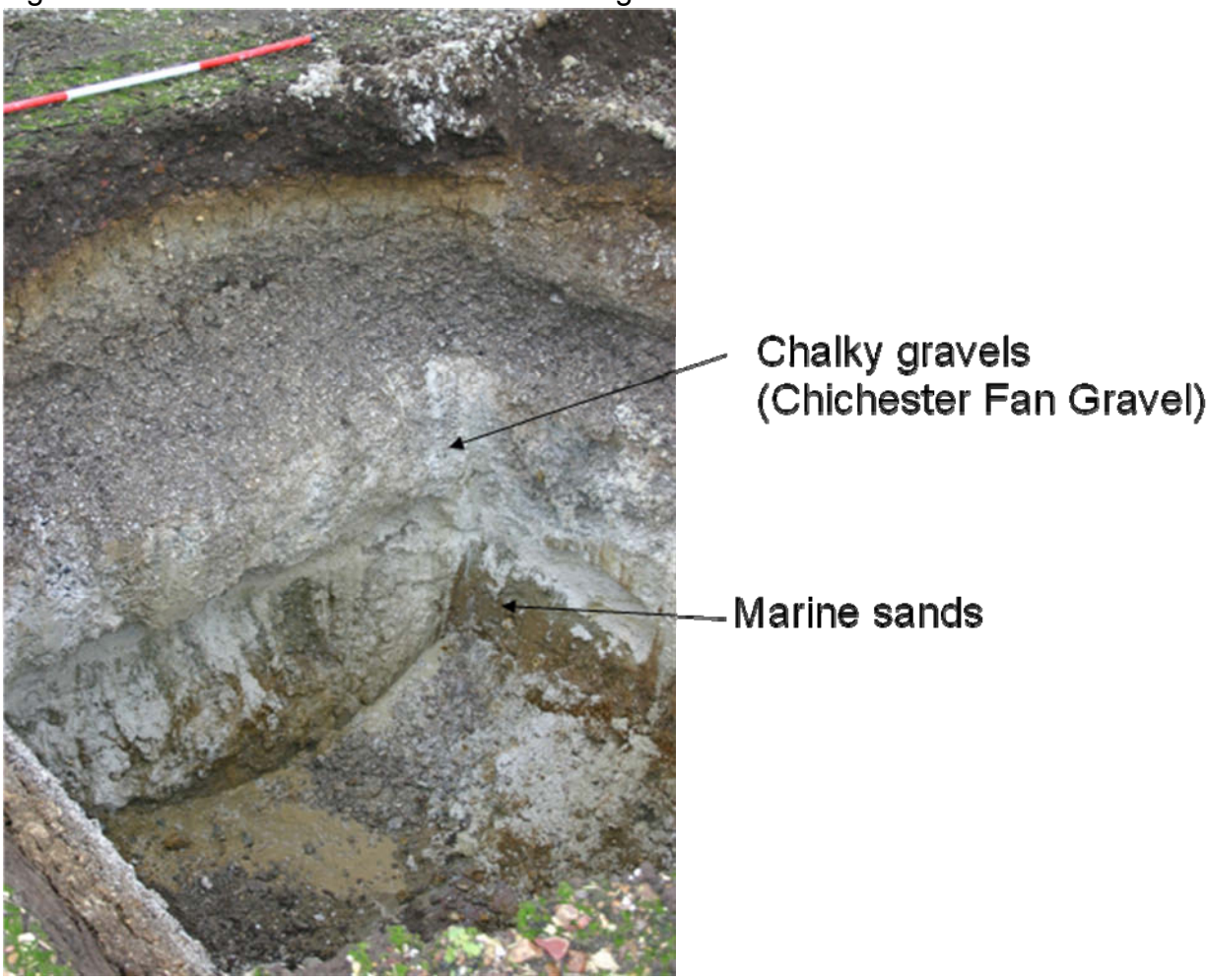


Figure 2.21 Channels of the West Sussex Coastal Plain intertidal area

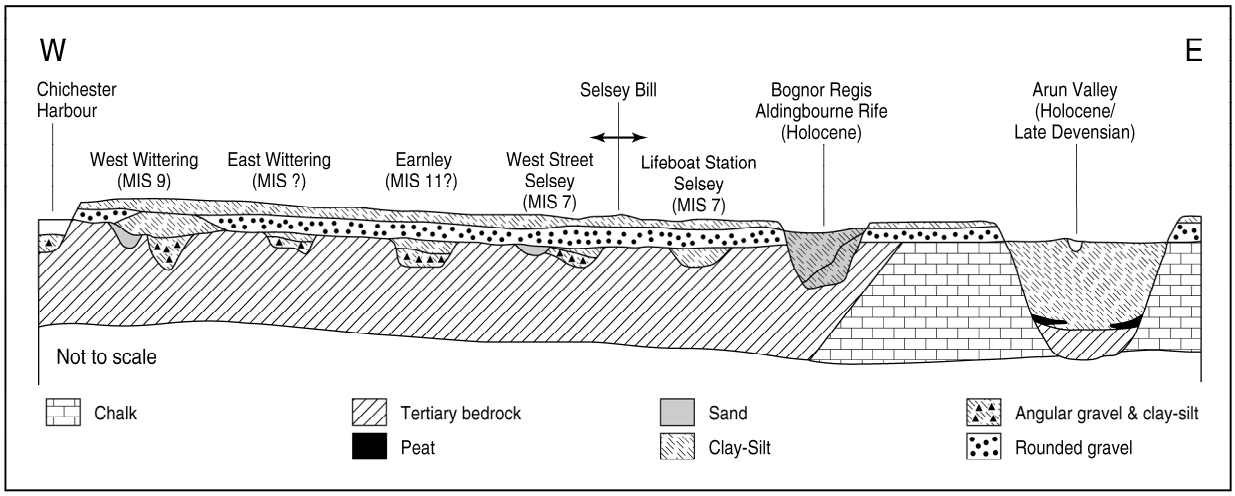


Figure 2.22 West Wittering Channel. A: regional location. B: site location and distribution of investigations. C: Off-shore channel in Chichester Harbour

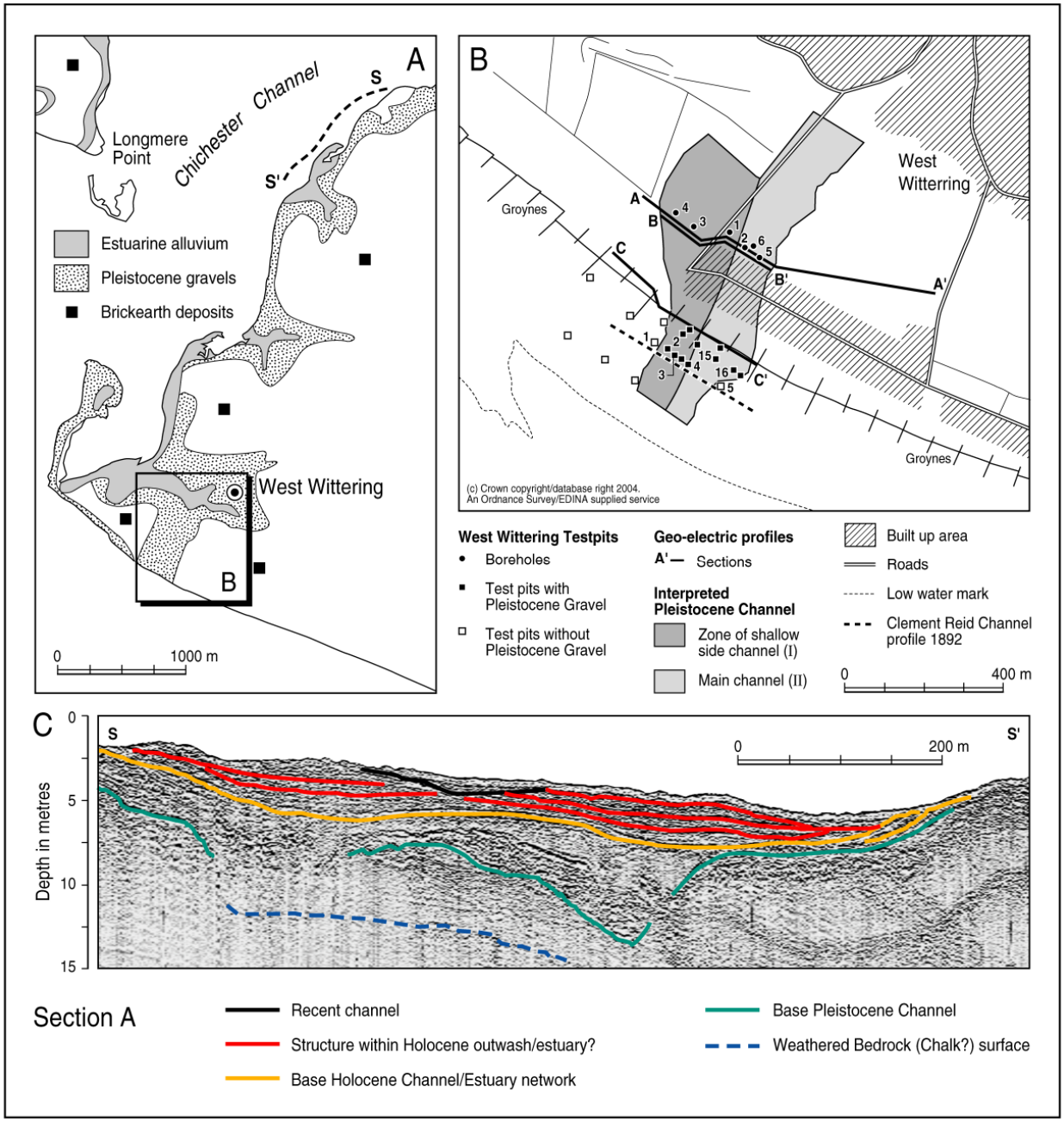


Figure 2.23 Channels of the West Sussex Coastal Plain. A: West Wittering. B: West Street, Selsey. C: Aldingbourne Rife, Bognor Regis

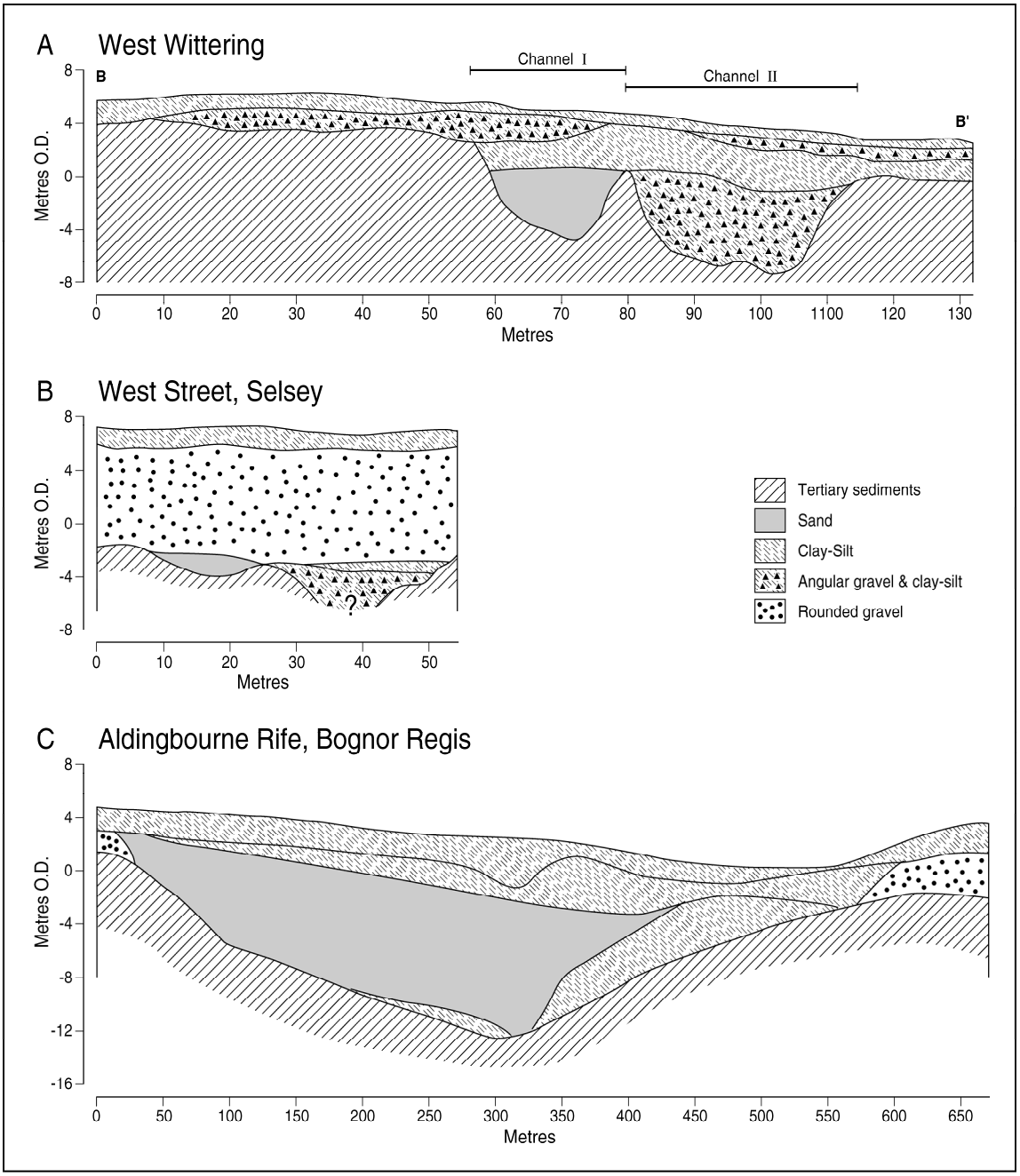


Figure 2.24 Bedrock geology of the study region

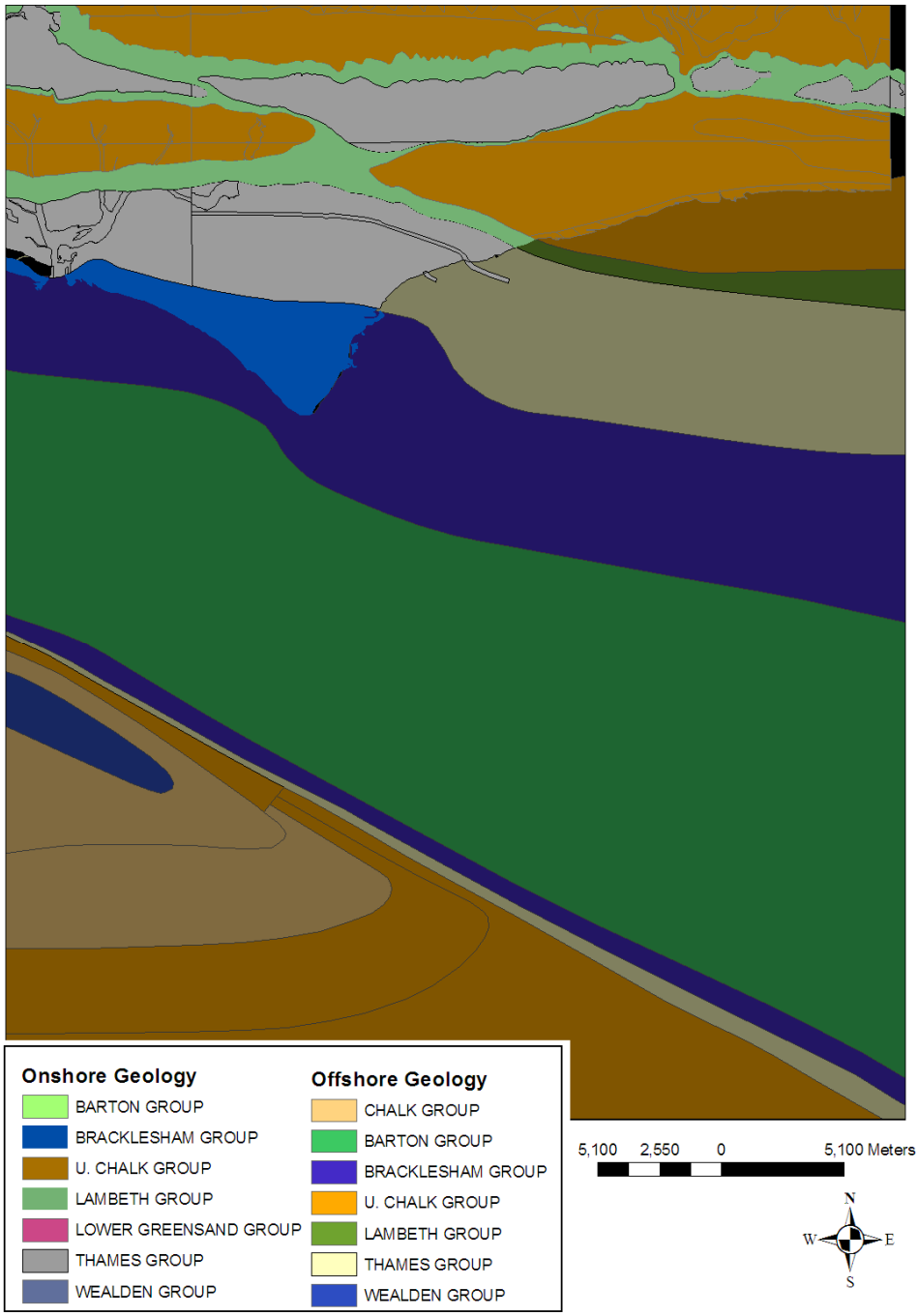


Figure 2.25 Bedrock geology of the study region

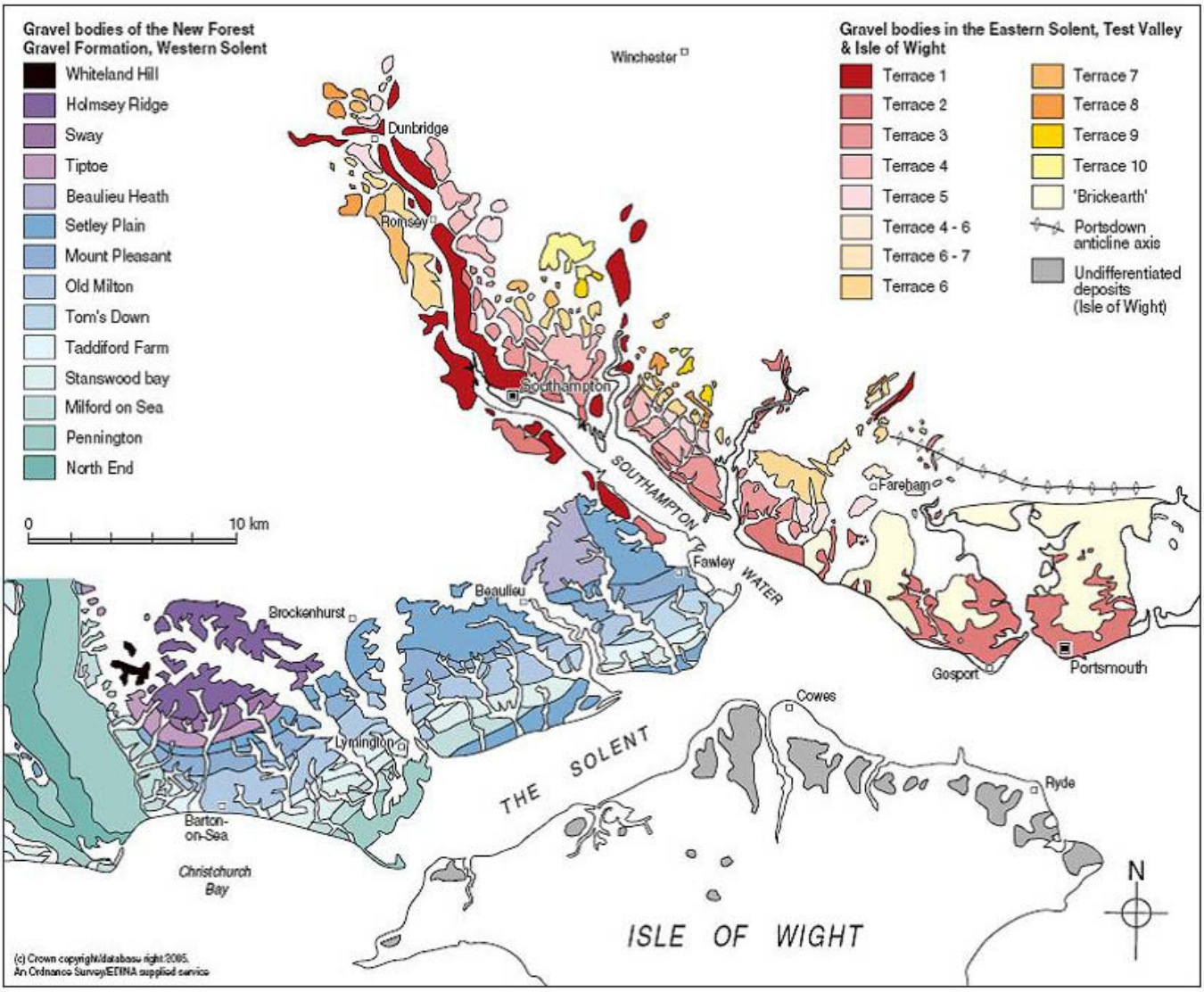


Figure 2.26 Geological map of superficial sediments in the Solent area

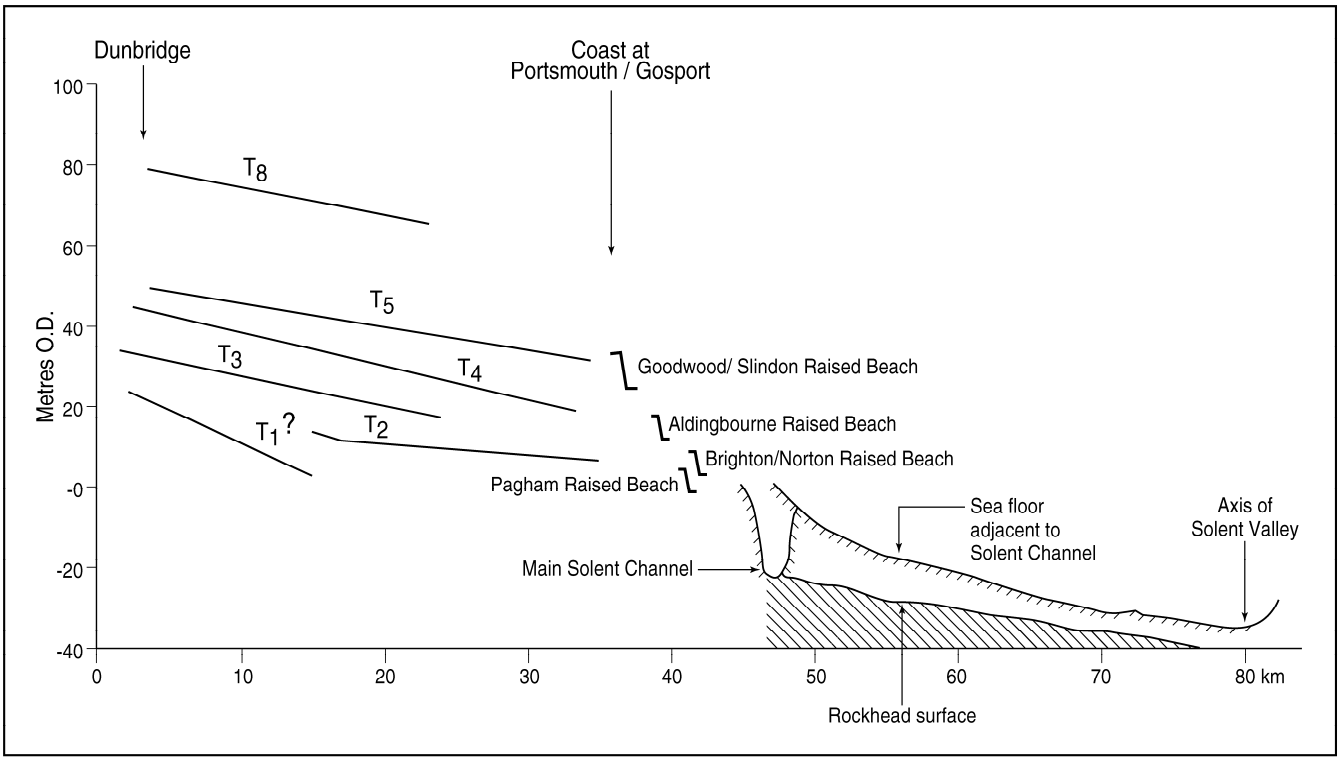


Figure 2.27 Terrace stratigraphies of the eastern Solent

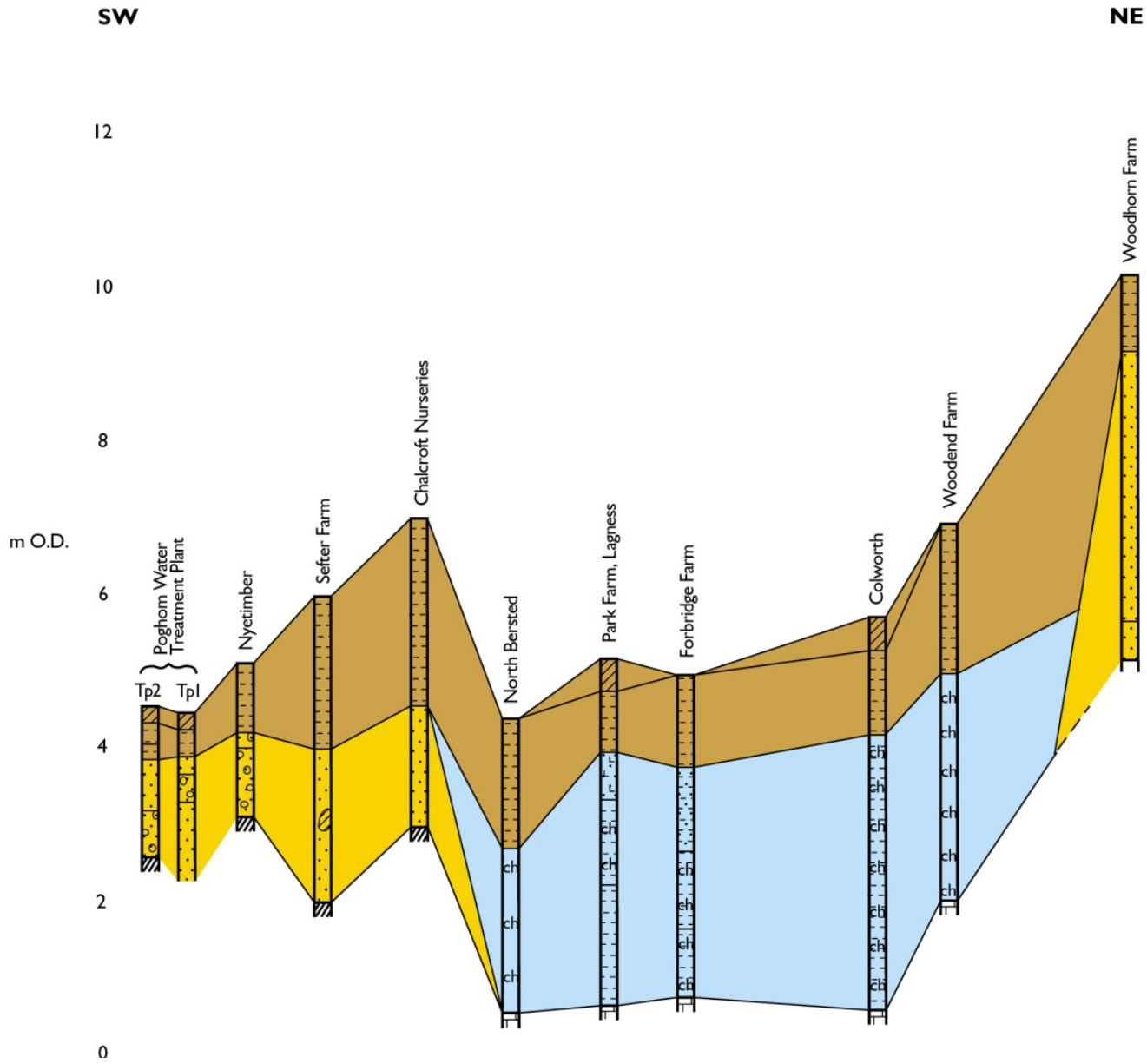


Figure 3.1 Survey in the Sea of Galilee using timedomain geophysics equipment, reproduced from Goldman et al. (1996 and 2004)

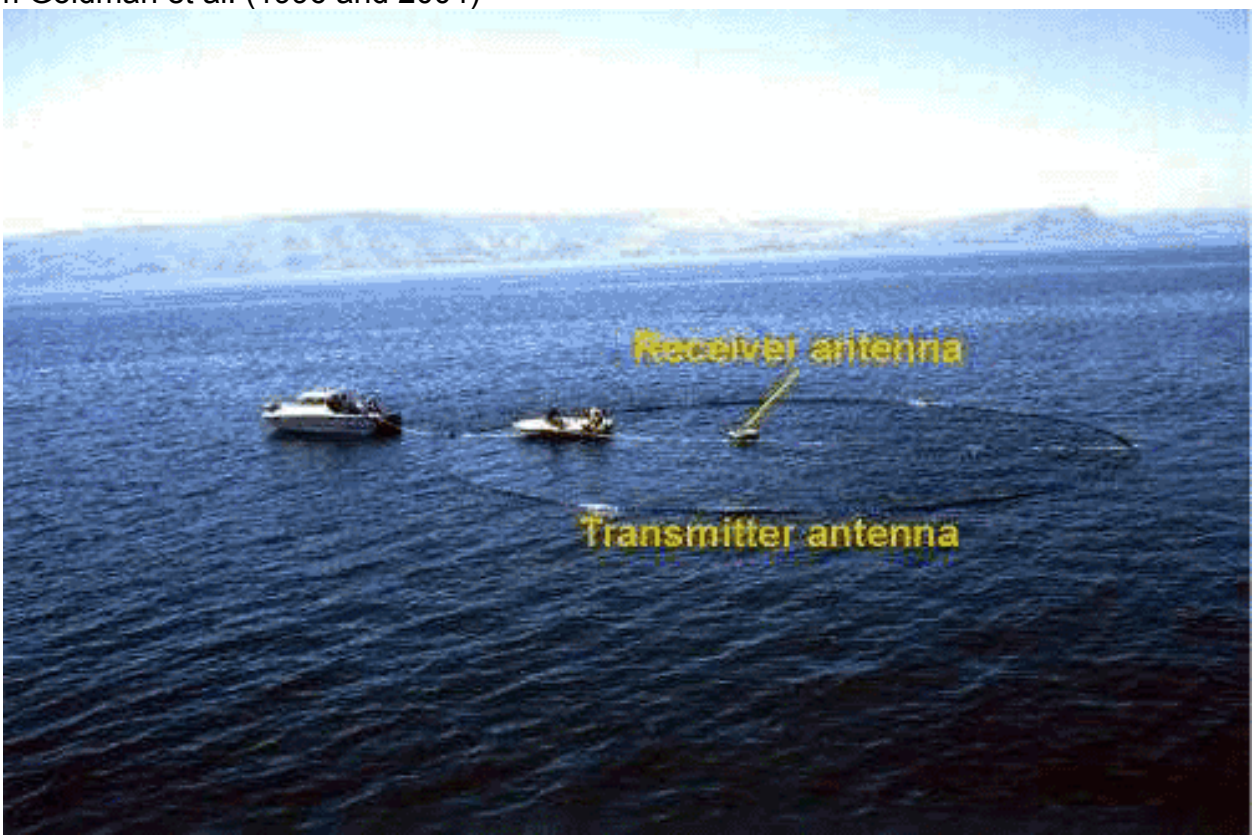


Figure 3.2 Electrical image cross-sections at the shore at Selsey, Sussex. Section 1 shows near shore profile, section 2 shows section across the same channel but further offshore in the transition zone

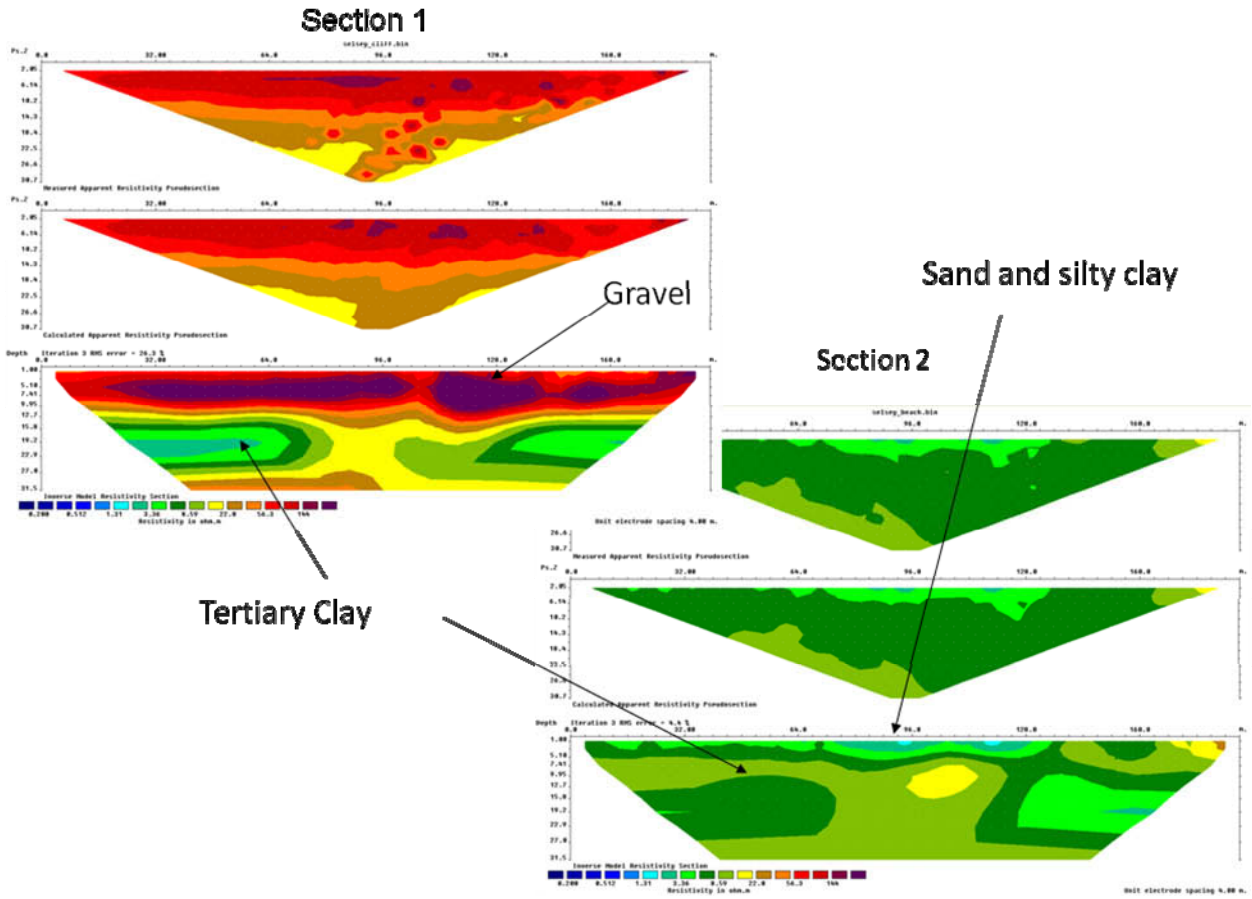


Figure 3.3 Eight channel electrode resistivity streamer (AGI, 2002)

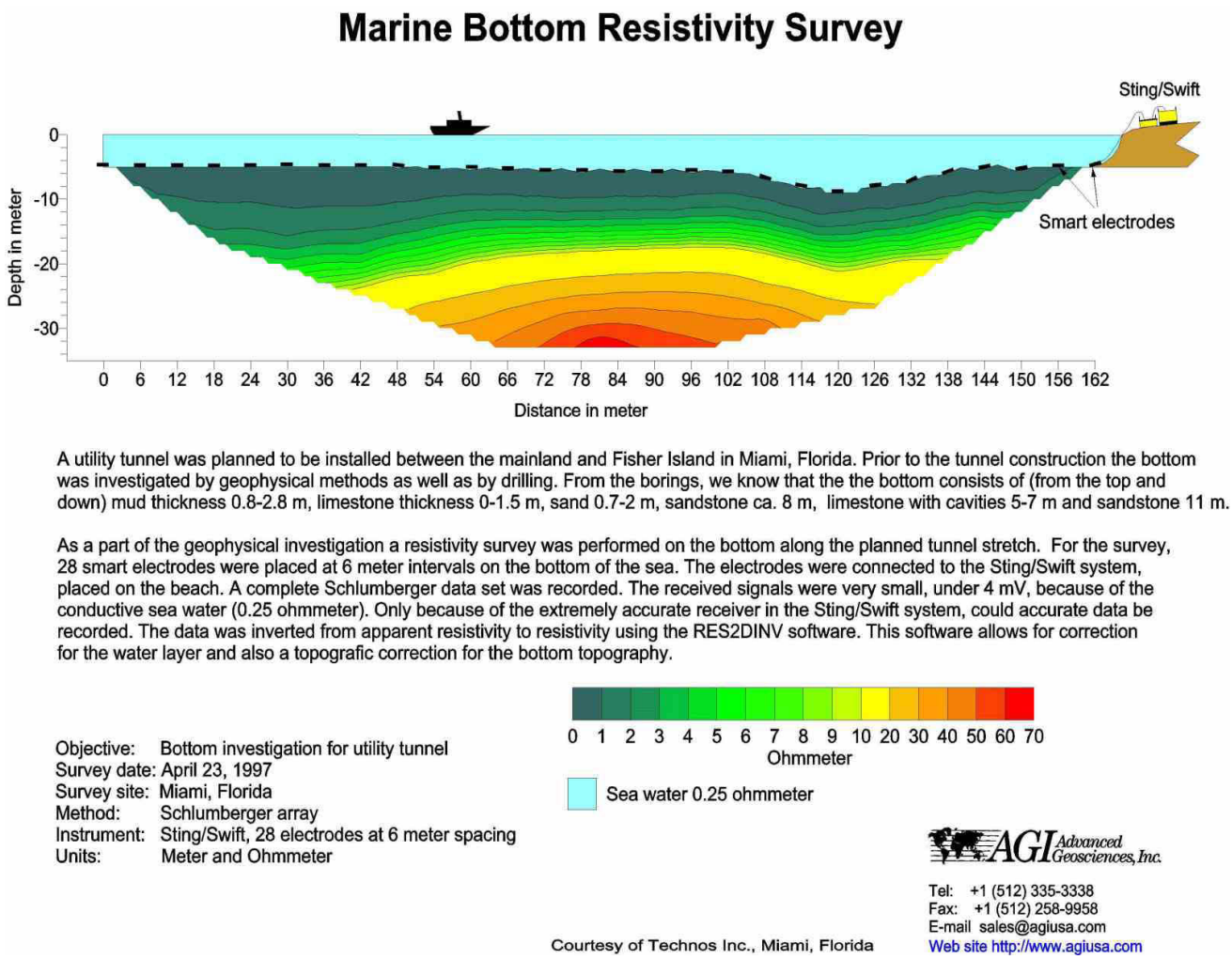


Figure 3.4 Towed electrode streamer and a resistivity pseudo section in a salt water environment (Technos, 2004)

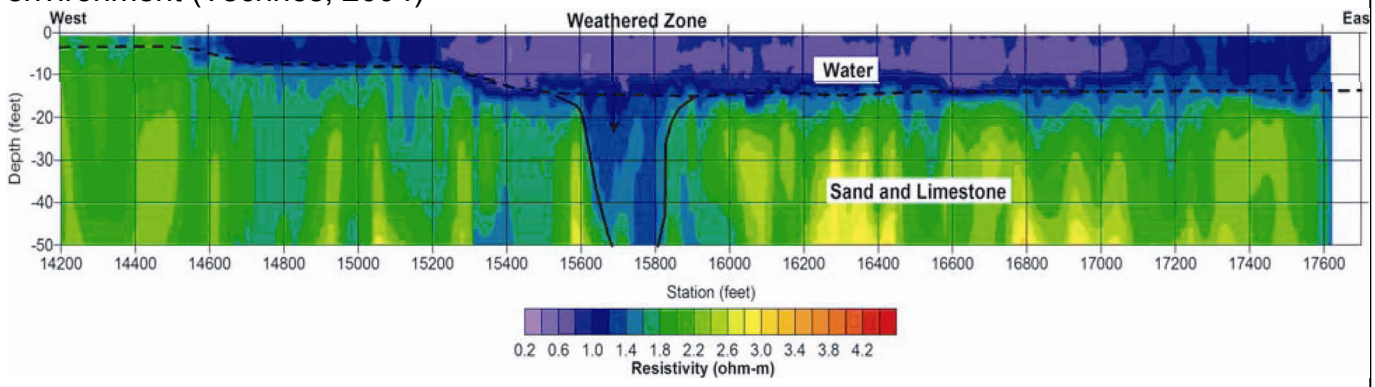


Figure 3.5 Display a Four sensor gradiometer with one vertical sensor and 3 horizontal sensors configured for shallow water survey (Gem System, 2005)

Figure 3.6 GPR record over the transition zone showing lack of penetration in salt water saturated sediments

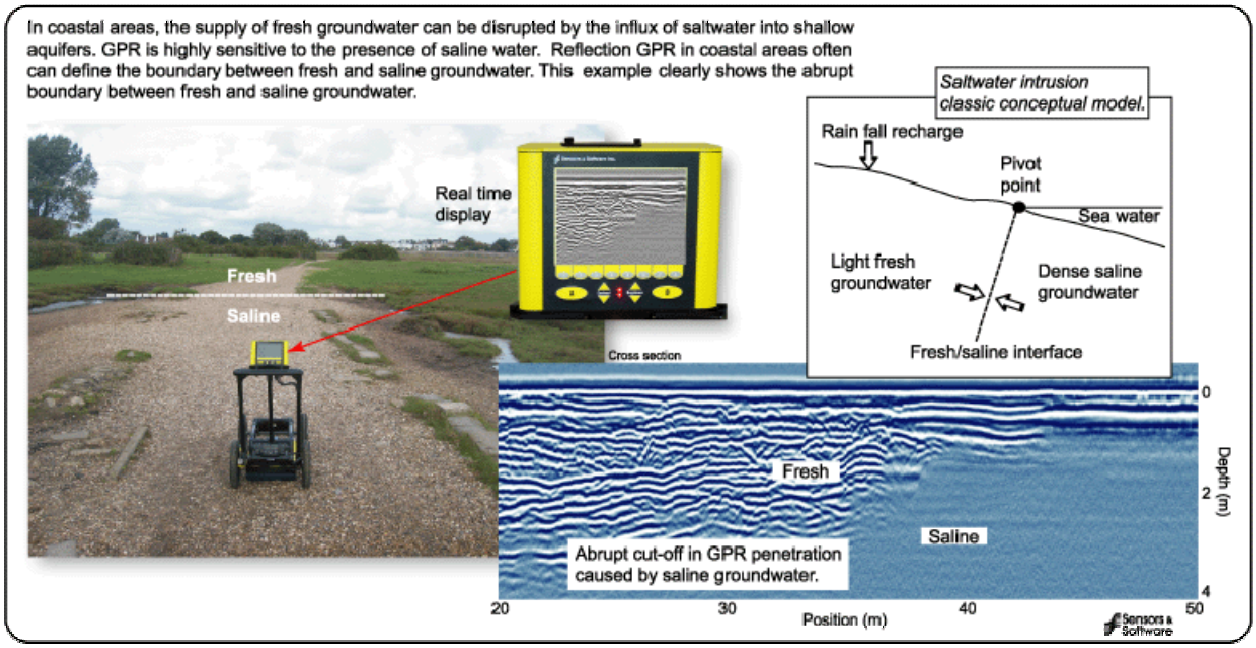


Figure 4.1 Guardline Lankelma ROV mounted CPT vehicle surveying in the surf zone

Figure 4.2 Fugro track mounted rig and CPT on jackup platform

Figure 4.3 Fugro support in the transition zone using hovercraft

Figure 5.1 Illustration of difference in mapping lithology vs. stratigraphy

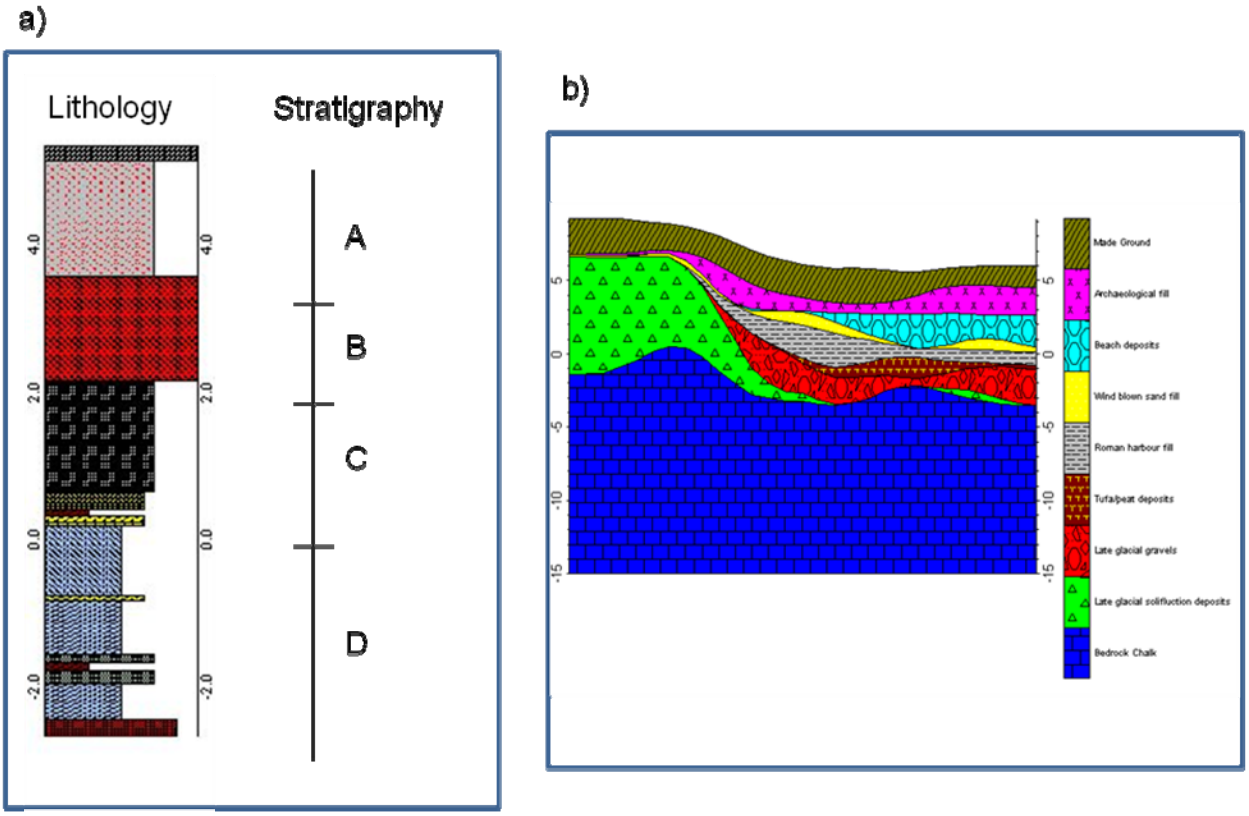


Figure 5.2 Software solution for CPLR project including ArcGIS, Microsoft Access and Rockworks

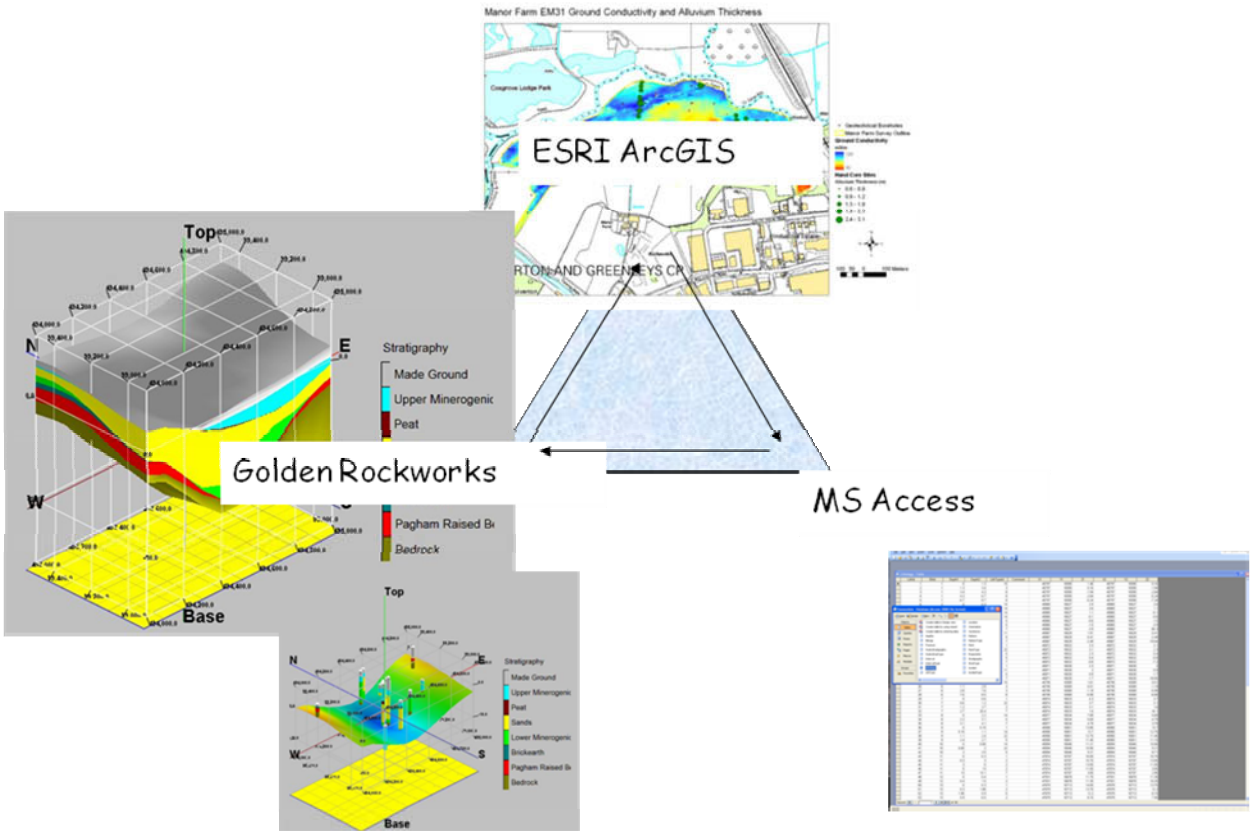


Figure 5.3 Test model area south of Selsey, West Sussex showing offshore aggregate licence areas

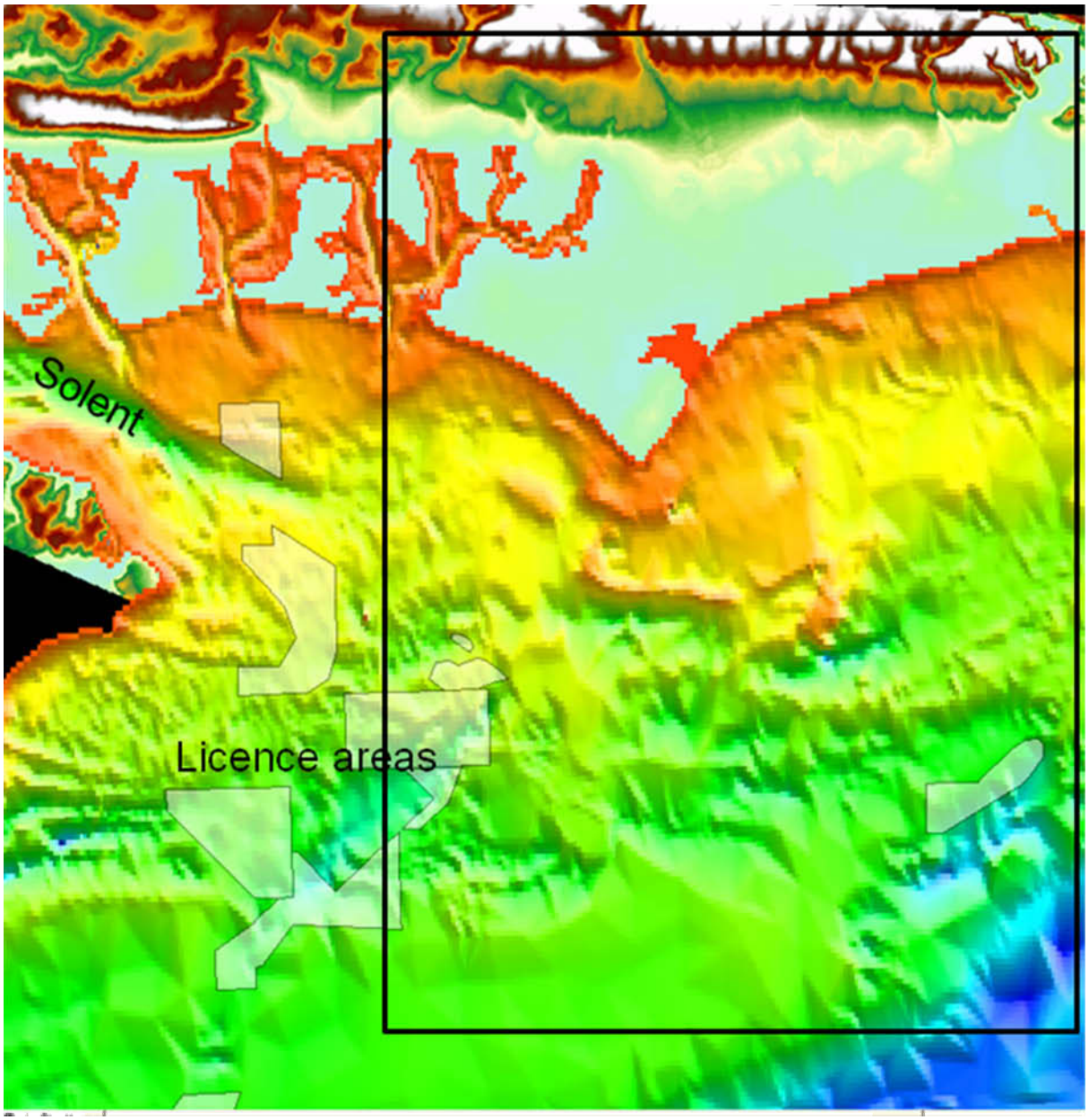


Figure 5.4 Illustration of onshore topography together with Gebco derived offshore bathymetry and Seazone derived offshore bathymetry

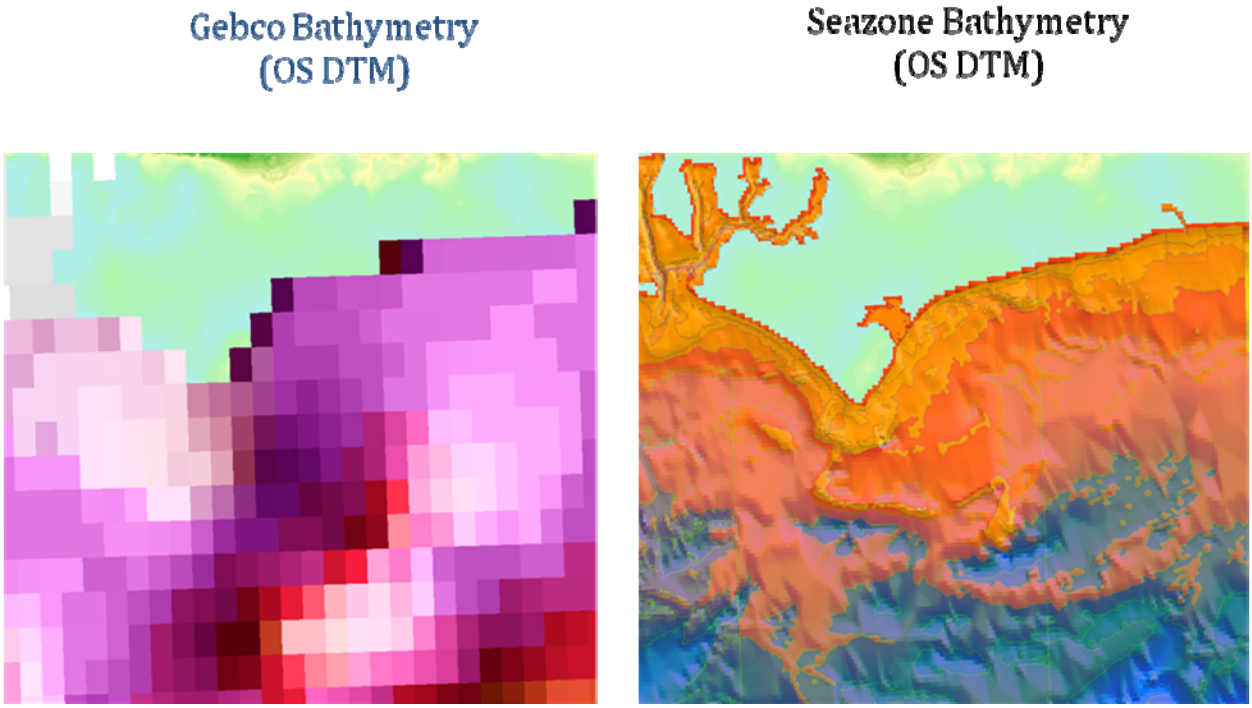


Figure 5.5 Onshore and offshore solid geology derived from BGS mapping

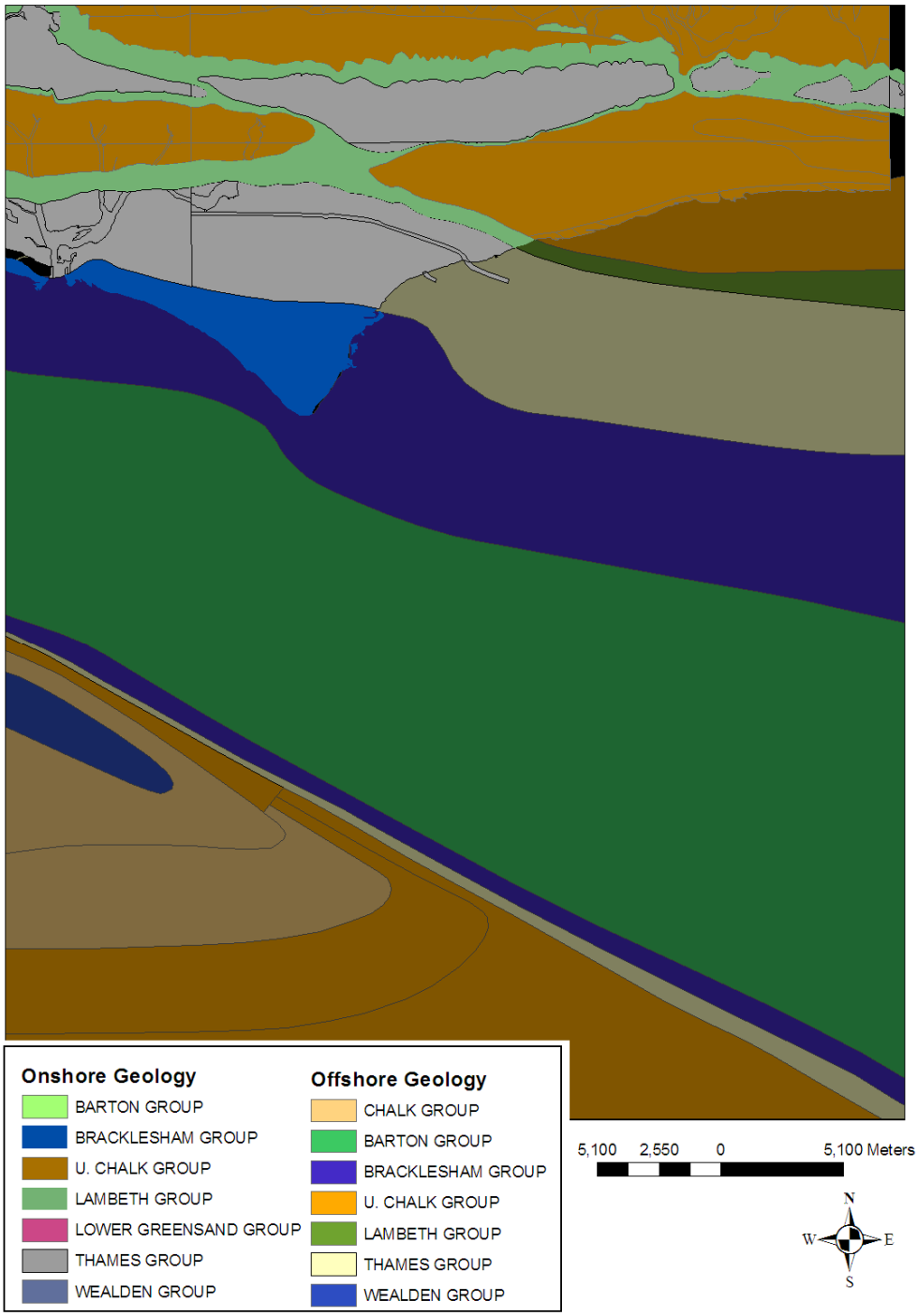


Figure 5.6 Onshore and offshore borehole locations

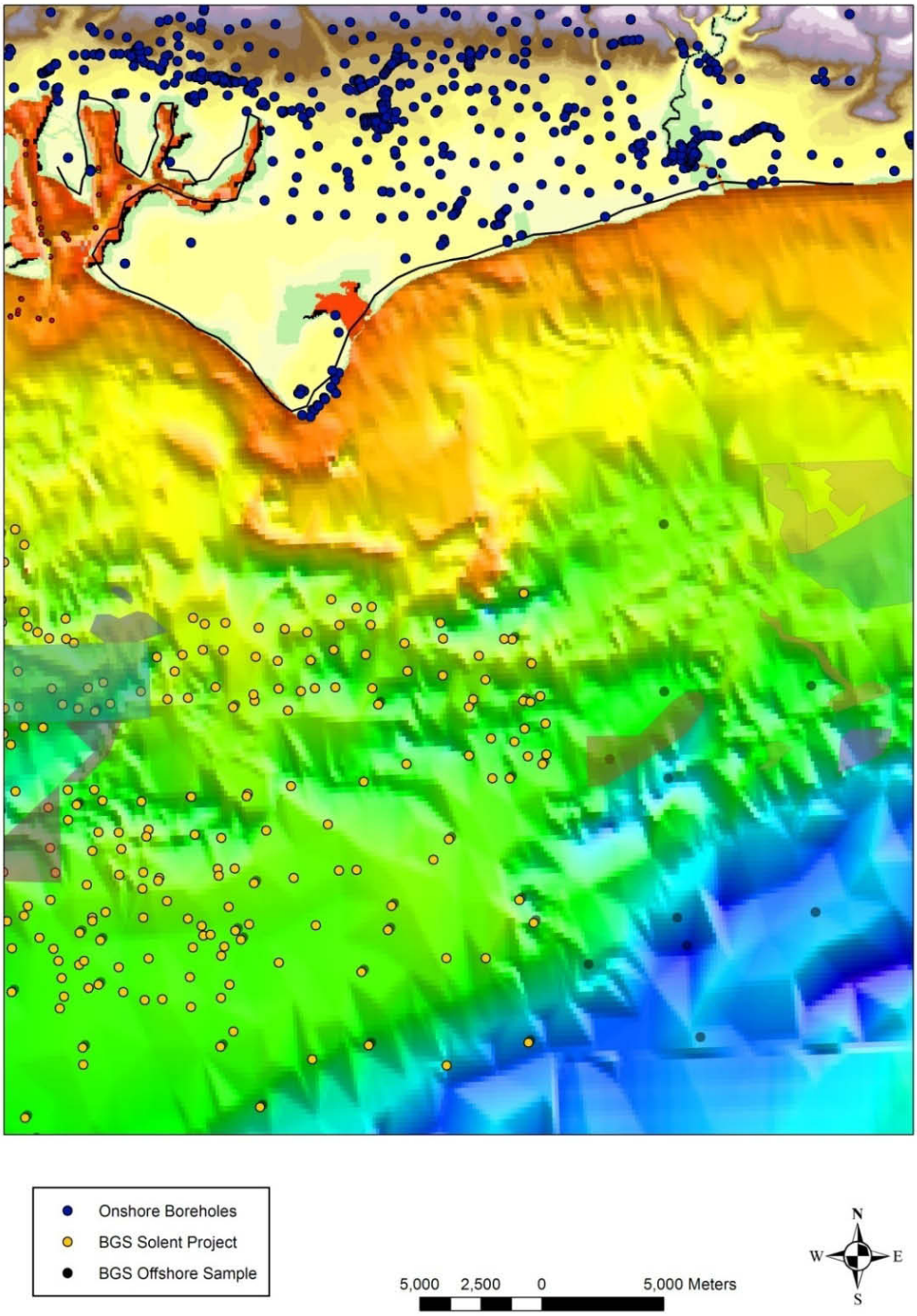


Figure 5.7 Onshore/offshore merged topography/bathymetry and onshore/offshore merged bedrock elevation map

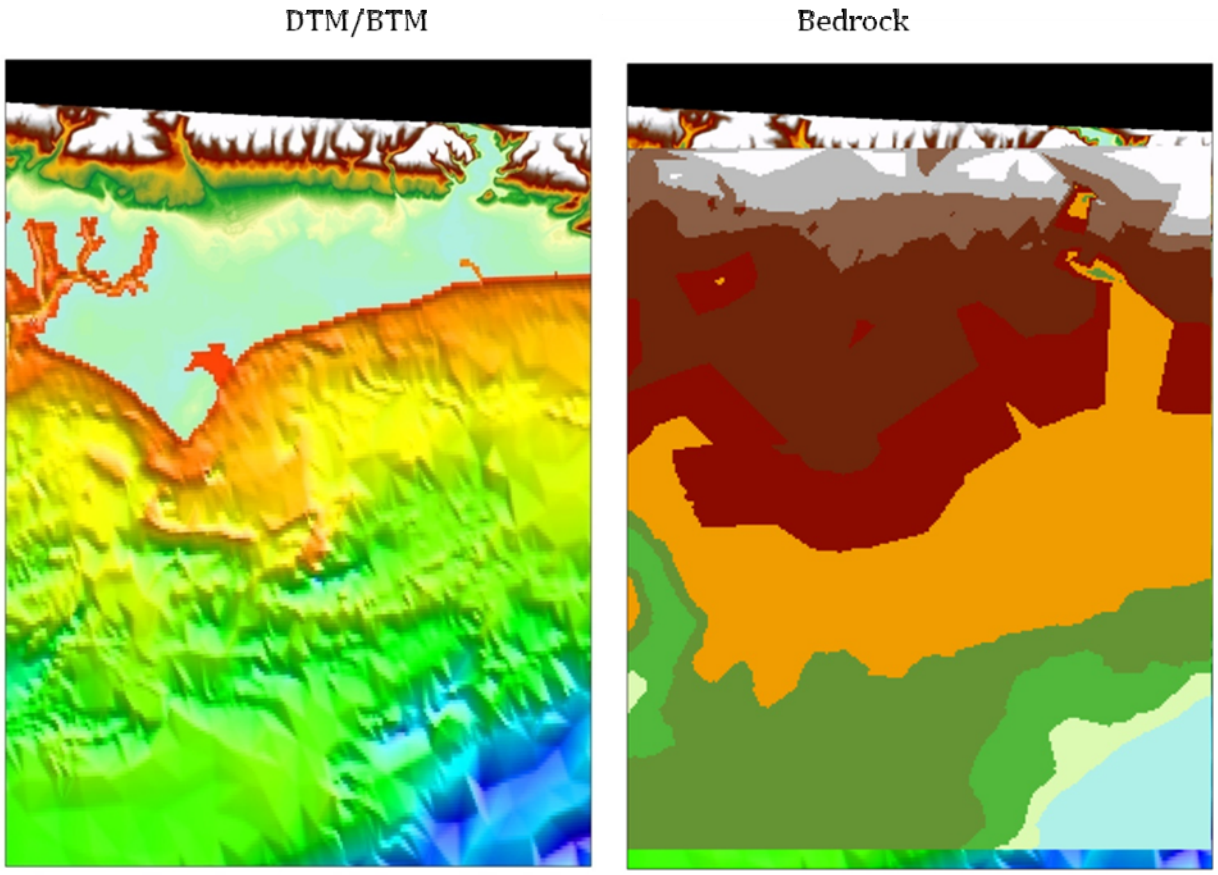


Figure 5.8 Onshore/offshore calculated bedrock elevation map

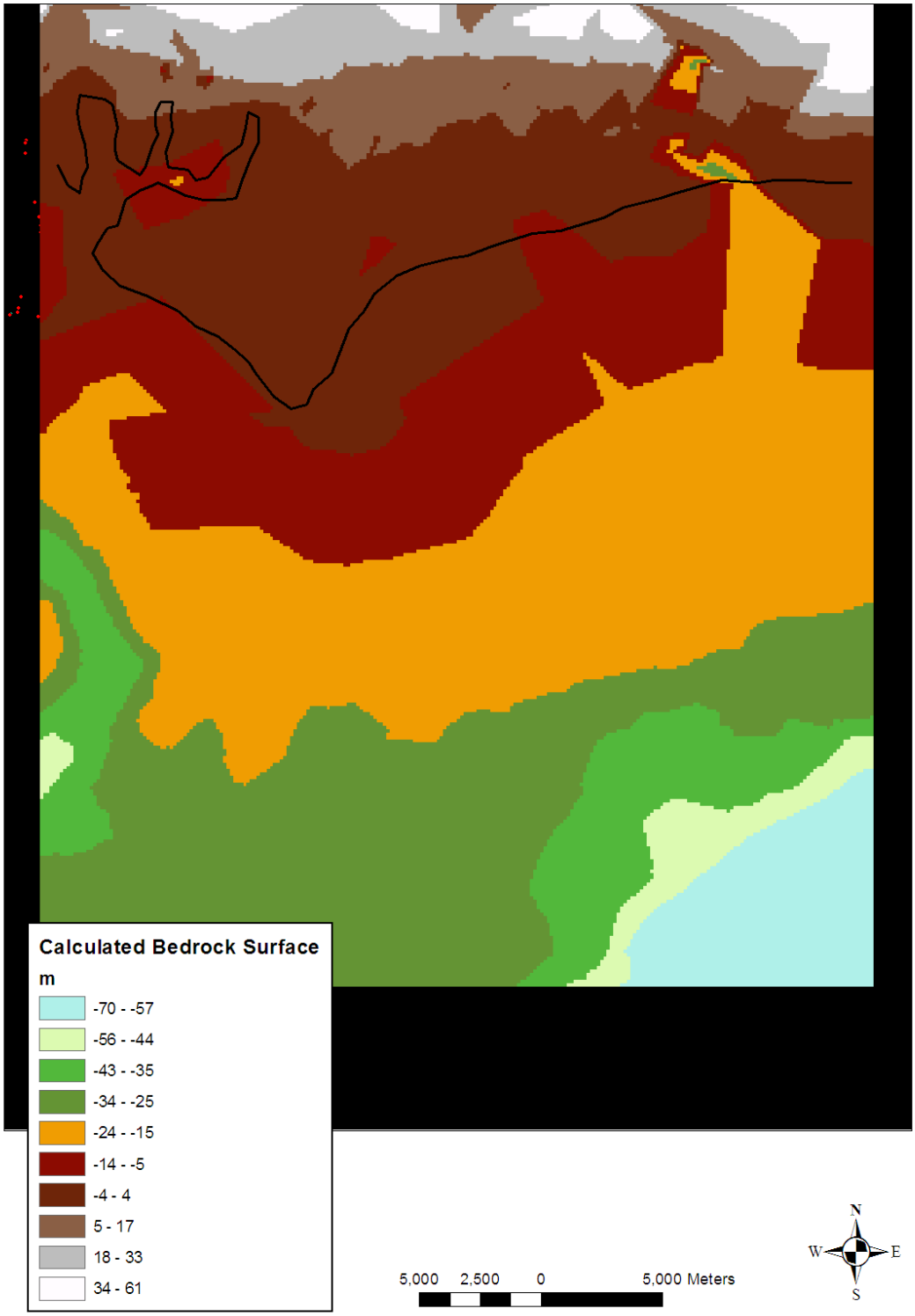


Figure 5.9 Isometric view of onshore/offshore merged topography/bathymetry map

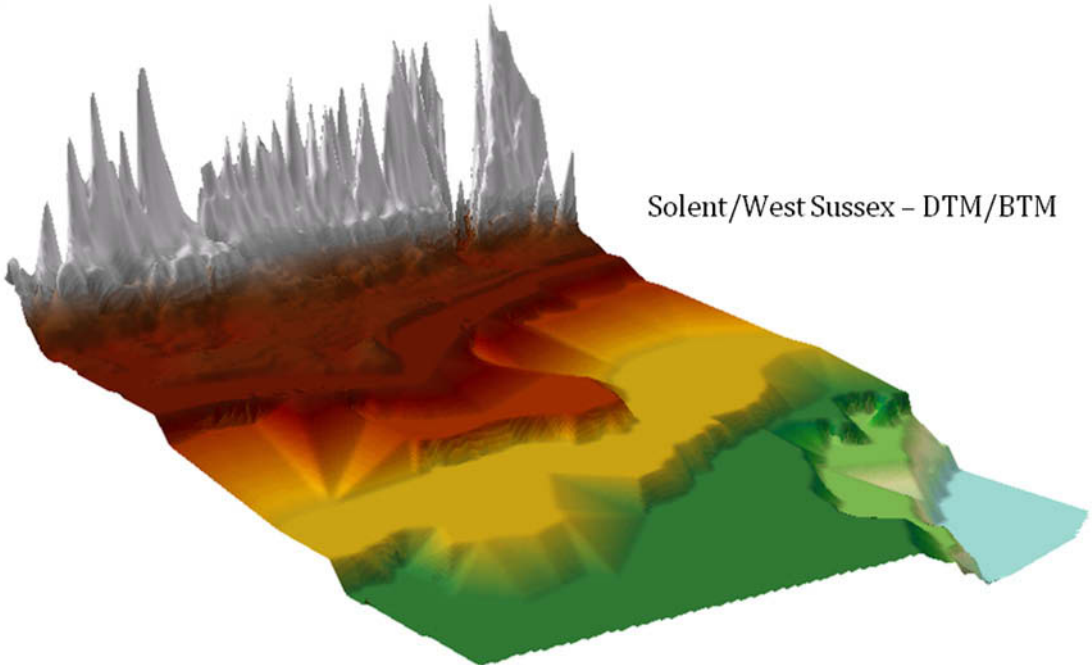


Figure 5.10 Isometric view of onshore/offshore merged bedrock elevation map

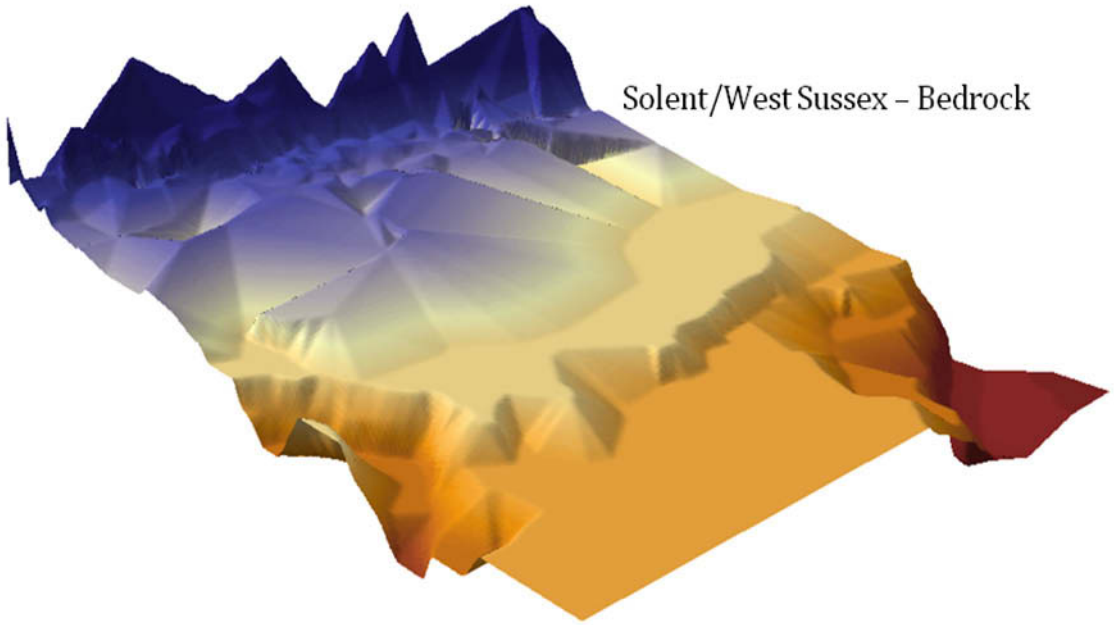


Figure 5.11 Isometric view of onshore/offshore merged topography/bathymetry and merged bedrock elevation maps

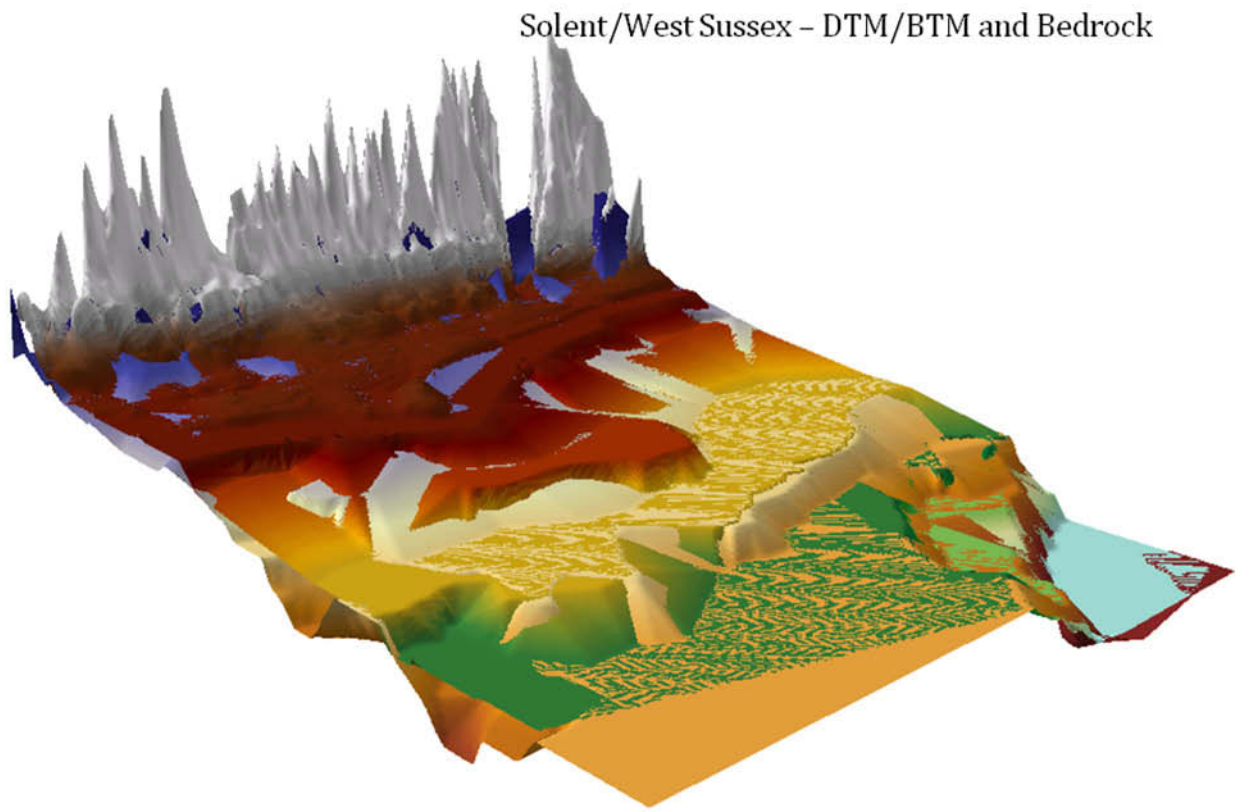


Figure 5.12 Isopach difference map between onshore/offshore merged topography/bathymetry and merged bedrock elevation maps, i.e. total estimated sediment thickness

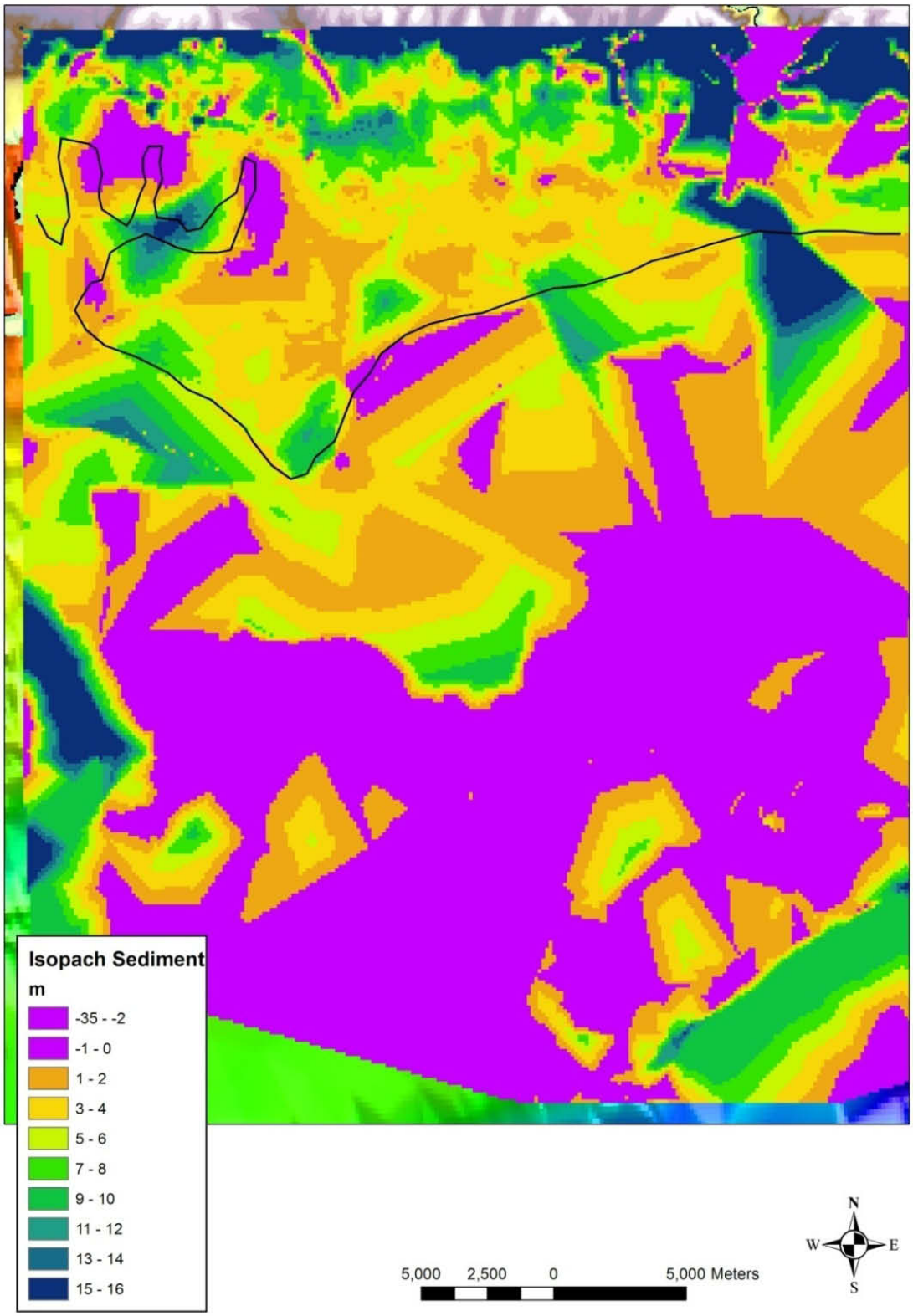


Figure 5.13 Illustration from Rockworks of extracted boreholes over coastal plain to north of Sesely

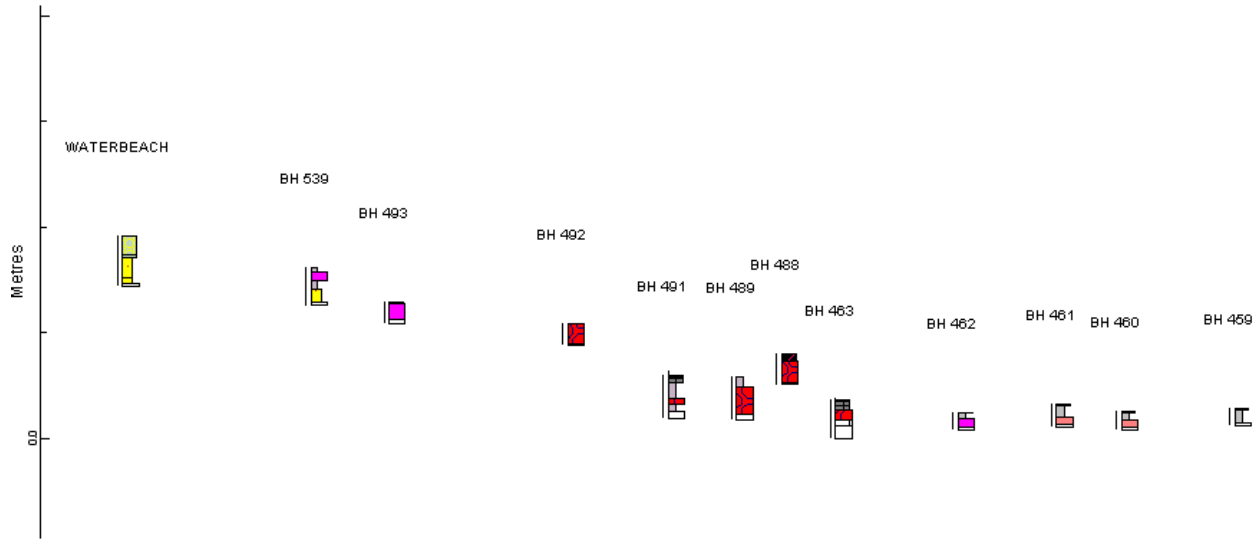
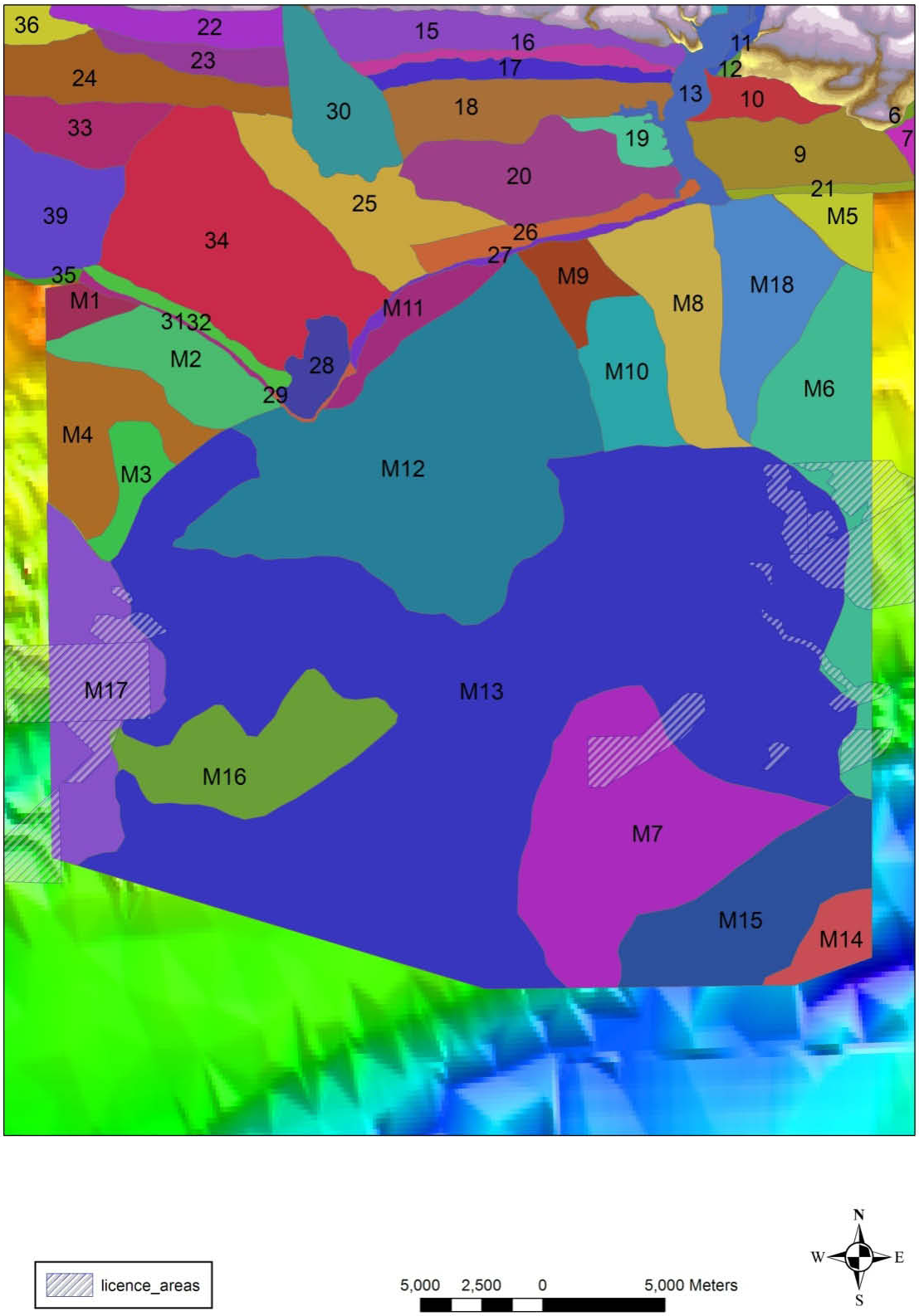


Figure 5.14 Archaeological zone map, onshore from PASCC project, offshore from this project. For description of zone numbers refer to table 5.1



Tables

Table 2.1 Scale and the Palaeolithic resource

	Micro ($<0.5km^2$)	Meso ($0.5-100km^2$)	Macro ($>100km^2$)
Short (0-100 years)	Boxgrove waterhole (Q1/B) Unit 4b activity Unit 4c Harnham	Boxgrove Slindon Silts Boxgrove 5a landsurface	
Medium (100-10000 years)	Swanscombe I (Lower Loam/Lower Gravel	Sussex Raised Beaches Swanscombe II (Middle Gravels	Swanscombe II (Middel Gravels – faunal connections)
Long (>10000 years)		Thames terrace sequences	Channel geography Bytham River

.

Table 3.1 Approximate depth of penetration from Geonics inductive conductivity instruments

Instrument	Intercoil Spacing (m)	Depth of Penetration (m)
EM-38	1.0	1.5
EM-31	3.7	6.0
EM-34	10	15
EM-34	20	30
EM-34	40	60

Table 5.1 Attributes and archaeological onshore and offshore zones

No	Geomorphological context	Bedrock (as mapped by BGS)	Superficial seabed sediments (as mapped by BGS)	Superficial sediments - other	Summary of possible Palaeolithic artefactual and zoological remains	Geological periods	Intensity of investigation (boreholes)	Degree of disturbance	Likely importance/ potential	Key research questions
M1	Mouth of Chichester Harbour drainage system	Bracklesham Group	Sand, gravelly sand	Moderate thickness of sediment	Predominantly derived artefacts (low Palaeolithic potential) with moderate palaeoenvironmental potential	Late Pleistocene to Holocene	None	Moderate	May contain important sequence documenting channel changes through later Pleistocene associated with Chichester Harbour drainage and the Lavant Valley	How persistent has been the location of the Chichester/Lavant channel through this area? What is the climate evidence associated with the sequences? How many different ages of channel fill can be identified here?
M2	Eastern edge of exit from Chichester Harbour along Manhood Peninsula	Bracklesham Group and Barton Group	Sand	Relatively thick sequences of sediments. Buried channel noted within zone filled with unconsolidated sands and gravels (precise location unknown).	Predominantly derived (but moderate Palaeolithic potential) with moderate to high palaeoenvironmental potential	Middle Pleistocene to Holocene	None	Low to moderate	Probably contain extension of channels seen in foreshore of wide range of ages from Middle Pleistocene to Holocene. Likely to be rich in palaeoenvironmental material	Can the interglacial channels of the foreshore be traced seawards? Do they record different parts of the interglacial in different locations? Can they be sampled and dated?
M3	Off-shore extensivon of Chichester Harbour drainage system	Barton Group	Gravelly sand	Thin to no thickness of sediments. No sediments in southern end of Chichester Harbour outfall	Low Palaeolithic and palaeoenvironmental potential	?	None	High	Low importance as sediment thickness looks to be low and therefore minimal preservation	Is this valley form devoid of sediments?

M4	Interfluve between Solent and Chichester Harbour drainage systems	Barton Group and Bracklesham Group	Sand, slightly gravelly sand	Moderate thickness of sediment	Unknown	?	None	Moderate	May contain evidence for sequences building up on interfluve between rivers. Zone represents good vantage point for past populations	What are the nature of the sediments in the interfluve area? What are their ages?
M5	Eastern interfluve of Arun Valley system	Chalk	Slightly gravelly sand	Moderate thickness of sediment	Unknown	?	None	Moderate	May contain evidence for sequences building up on interfluve between rivers. Zone represents good vantage point for past populations	What are the nature of the sediments in the interfluve area? What are their ages?
M6	Main Arun Valley trace	London Clay, Bracklesham Group, Barton Group, Chalk, Lambeth Group	Gravelly sand and sandy gravel	Moderate thickness of sediment	Moderate to low Palaeolithic potential, low to moderate palaeoenvironmental potential	Middle Pleistocene to Holocene	None	Low to moderate	Main Arun Valley known to contain terraces of late Pleistocene age plus Holocene sequences. Good record preserved here	What is the age of the terraces? Do they contain palaeoenvironmental material?
M7	Edge of Northern Palaeovalley (plateau margin)	Barton Group, London Clay, Bracklesham Group	Gravelly sand and sandy gravel	Moderate thickness of sediment with large areas devoid of sediment	Unknown	?	Very low borehole data	?	Possible edge of valley sequences preserved - good vantage points for humans observing activity in main valleys	What is the nature of the sequences and what are their ages?
M8	Interfluve between Aldingbourne and Arun Valleys	London Clay, Chalk	Gravelly sand and slightly gravelly sand	Moderate thickness of sediment	Unknown	?	None	Low to moderate	May contain evidence for sequences building up on interfluve between rivers. Zone represents good vantage point for past populations	What are the nature of the sediments in the interfluve area? What are their ages?

M9	Off-shore extension of Aldingbourne Valley	London Clay, Chalk	Gravelly sand	Relativel thick sequence of sediments. Sediments infilling northern part of Aldingbourne outfall	Low Palaeolithic and moderate palaeoenvironmental potential	Predominantly Holocene (some very late Pleistocene?)	None	Low to moderate	Good sequence preservation in channel of Aldingbourne Rife. May contain sequences spanning earlier parts of Holocene	What age are the sequences and under what conditions were they deposited?
M10	Off-shore extension of Aldingbourne Valley	London Clay, Bracklesham Group	Slightly gravelly sand	Thin to no thickness of sediments. Little sediment in southern end of Aldingbourne outfall.	Low Palaeolithic and palaeoenvironmental potential	? Predominantly Holocene	None	High	Low importance as sediment thickness looks to be low and therefore minimal preservation	Is this valley form devoid of sediments?
M11	Coastal intertidal zone	Bracklesham Group, London Clay	Gravelly sand	Thin to no thickness of sediments	Low Palaeolithic potential, low to moderate palaeoenvironmental potential	?	None	High	Thin sequences preserved close to shore - low likely preservation potential	Are any sequences (?channels) preserved in this area?
M12	Selsey foreland arc	Bracklesham Group, Barton Group, London Clay	Sandy gravel	Moderate to thick sequences of sediments	Unknown	?	None	? Low to moderate	Areas of known historical erosion with moderate sequence thickness. Area likely to be able to address key issues regarding coastal evolution from last interglaical onwards	What age are the sequences and under what conditions were they deposited?
M13	Central plateau surface	Barton Group, Bracklesham Group, Chalk, Lower/Upper Greensand	Gravel	Thin to no thickness of sediments	Low Palaeolithic and palaeoenvironmental potential	?	Moderate borehole data	?High	Unknown due to scarcity of sequences. Too little data to comprehend	Is this area devoid of sediments? Are smaller scale features (containing sediments) present within the area?
M14	Part of Northern Palaeovalley	Barton Group	Sandy gravel	Thin to no thickness of sediments	Low Palaeolithic and palaeoenvironmental potential	?	Very low borehole data	?	Unknown	Is this area devoid of sediments? Are smaller scale features (containing sediments) present within the area?

M15	Margin of Northern Palaeovalley	Barton Group, Bracklesham Group	Sandy gravel	Moderate to thick sequences of sediments	Moderate to low Palaeolithic potential, low to moderate palaeoenvironmental potential	Middle Pleistocene to Holocene	Very low borehole data	Low to moderate	May record depositional events of later Pleistocene date	What age are the sequences and under what conditions were they deposited?
M16	Main Solent Valley system	Barton Group, London Clay, Chalk, Wealden Group	Gravel	Thick sequences of sediments	Moderate to low Palaeolithic potential, low to moderate palaeoenvironmental potential	Middle Pleistocene to Holocene	Very low borehole data	Low to moderate	May record depositional events of later Pleistocene date	What age are the sequences and under what conditions were they deposited?
M17	Edge of Solent valley system (plateau margin)	Barton Group, Bracklesham Group, Chalk, Lower/Upper Greensand, Wealden Group	Sandy gravel and gravelly sand	Moderate thickness of sediments mixed with areas of no sediment	Unknown	?	Moderate borehole data	?	Possible edge of valley sequences preserved - good vantage points for humans observing activity in main valleys	What is the nature of the sequences and what are their ages?
M18	Mouth of Arun system	Chalk, London Clay	Slightly gravelly sand, gravelly sand	Thick sequences of sediments	Low to moderate Palaeolithic potential, moderate palaeoenviornmental potential	Late Pleistocene to Holocene	None	Low to moderate	Likely to contain important Holocene records associated with Arun development	What age are the sequences and under what conditions were they deposited?

Table 5.2 Criteria for individual zone characterisation in table 5.1

Number	**Unique zone number**
Geomorphological context	**Text description of geomorphological context and topographic situation**
Bedrock (as mapped by BGS)	**Text description of bedrock as derived from the BGS mapping**
Superficial sediments (as mapped by BGS)	**Text description of the superficial sediments as derived from the BGS mapping**
Superficial sediments (as mapped/ identified in this project)	**Text description of the superficial sediments as derived from in this project**
Summary of possible Palaeolithic artefactual and zoological remains	**Text description of artefactual and zoological potential based on geoarchaeological criteria**
Geological periods	**Middle Pleistocene** **Late Pleistocene** **Holocene**
Intensity of investigation	**Qualitative descriptions based on data:** **None** **Low** **Moderate** **High**
Degree of disturbance	**Qualitative descriptions based on data:** **Residual** **Always very disturbed** **Sometimes little disturbed** **Usually/always little or undisturbed**
Likely importance/ potential	**Qualitative descriptions based on data** ***(flags up the likelihood of finding important Palaeolithic and/or zoological remains)***
Key research questions	**List in relation to national/regional research questions**