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MARINE AGGREGATE AND THE HISTORIC ENVIRONMENT

SEABED PREHISTORY: GAUGING THE EFFECTS OF MARINE AGGREGATE DREDGING

ROUND 2
FINAL REPORT

VOLUME VIII: RESULTS AND CONCLUSIONS

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Summary

This report is Volume VIII of the Final Report of the project 'Seabed Prehistory: Gauging the Effects of Marine Aggregate Dredging'. This phase of the project was commissioned by English Heritage and undertaken by Wessex Archaeology (WA). The project was funded through the Aggregate Levy Sustainability Fund (ALSF) and distributed by the Department for the Environment, Food and Rural Affairs (DEFRA).

The Final Report comprises eight volumes. Volume II to VII are based on reports from different phases of the project commissioned through either English Heritage or the Mineral Industry Research Organisation (MIRO) as part of Round 1 or Round 2 of the ALSF.

This volume is the project synthesis and it aims to compare and contrast the methods and results from the study areas of both the English Heritage and MIRO administered projects, and to draw final conclusions.

The 'Seabed Prehistory' project focused on the small scale and high resolution analysis of five different study areas either in the North Sea (Humber, Great Yarmouth, Happisburgh and Pakefield) or the English Channel (Arun, Eastern English Channel). All study areas are located close to or within licensed marine aggregate dredging areas, apart from the Happisburgh and Pakefield study area which is related to terrestrial aggregate deposits. The specific geoarchaeological characteristics of each study area are outlined below:

- The Arun study area focussed on a palaeovalley of the Palaeo-Arun River. This river system is a tributary to the main trunk stream of the English Channel;
- The Great Yarmouth study area focussed on a part of the palaeoriver Yare. The area investigated formed part of a wide shallow palaeovalley;
- The Eastern English Channel study area formed part of a major branched palaeoriver system, which was part of or close to the English Channel trunk scheme;
- The geomorphological characteristics of the Humber area were that of a coastal palaeoenvironment, which was in contrast to the riverine palaeoenvironments of the Arun, Great Yarmouth and Eastern English Channel study areas;
- The Happisburgh and Pakefield Exposures project was inspired by the current research on the palaeoriver systems in East Anglia which extend into the southern North Sea basin. The principal aim of the study was to trace sediments of known archaeological potential onshore into the offshore marine environment.

The survey methodologies included:

- Geophysical surveys comprising of a bathymetric survey to establish water depths and seabed morphology across the study area, a sidescan sonar survey to record the seabed sediments, and further highlight the seabed morphology and a shallow seismic survey to identify individual sub-seabed geological horizons that were then modelled across the survey area;
- Vibrocore surveys conducted to calibrate the geophysical survey data, in terms of matching sediments to geophysical horizons and to provide detailed stratigraphy of the area as well as to provide environmental samples for assessment, analysis and dating. This information was then used to deduce relative chronologies of sediment deposition and identify evidence from past landscapes;
- Grab sampling surveys undertaken within selected study areas for artefact recovery and in order to locate any exposed fine grained deposits and/or prehistoric remains within the upper sediment layers of the seabed.

The methodological results are summarised below:

Geophysical survey methodologies were assessed at each study area for evaluating prehistoric seabed deposits. Survey design, acquisition and recording methods were evaluated and developed taking into consideration industry standards and methods.

At each of the five geophysical survey areas, the survey design, both line specification and choice of area, was dependent on the scale of the features to be resolved. Based on the results of the project it was found that surveys undertaken with a line spacing of no more than 100m with crosslines situated up to twice the principle line spacing provided a quality dataset for archaeological interpretation.

Accurate positioning of the vessel and equipment is an essential requirement for a survey. The repeatability of position information is crucial for the corroboration of geophysical data with the geotechnical data, and for the implementation of archaeological mitigation measures.

Bathymetry data were collected during each survey. Bathymetric data not only provided information on water depth and the morphology of the seabed, but also provided a vertical reference datum that can be used to accurately position geophysical horizons from shallow seismic data. Knowing the absolute level of horizons is the first stage in establishing the general chronological context of archaeological features. Throughout the surveys bathymetric data were successfully acquired using a single-beam echosounder.

Sub-bottom profilers are used to investigate the sub-surface geology. In order to establish the most appropriate seismic source to identify sedimentary horizons sub-seabed, numerous seismic sources were trialled during the project. On the basis of this project, the boomer system was shown to produce the best compromise between penetration in the seabed geology and the resolution of geological horizons. Alternative sources, such as pinger and chirp, achieved better resolution of fine-grained (silt and clay) deposits specifically within the first five metres of the seabed, but did not achieve sufficient penetration in the coarse-grained (sand and gravel) deposits targeted for aggregate dredging. As such, it is considered that the boomer is the most versatile source for archaeological purposes.

Digital dual-frequency sidescan sonar systems are already widely used in the marine aggregate industry and are successful in producing data for archaeological purposes. This was confirmed by the surveys conducted as part of this project. Digital acquisition of the geophysical data (sidescan sonar and sub-bottom profiler) allowed post-survey processing with gain and filter settings optimised to enable in-depth geophysical interpretation.

The interpretation of the geophysical data illustrated their usefulness as a tool for conducting the initial palaeogeographic evaluation of an area. Although important palaeosurfaces can be identified on the geophysical data, in order to fully reconstruct the palaeogeographic model of the area ground-truthing of the geophysics data is required in the form of vibrocores, grab sampling and subsequent environmental and dating analyses of these data.

Based on the initial geophysical data interpretation a judgement-led vibrocoring sampling strategy was developed within the study areas. On the basis of the sedimentary unit descriptions and the comparison of the core logs, major sedimentary units were ascribed principal phases which were then correlated with the sedimentary units described within the seismic interpretation. Profiles created by the phasing were integrated with the seismic data enabling comments on their palaeoenvironmental and geoarchaeological significance to be made.

Geoarchaeological core log descriptions, sampling of the cores and analysis of pollen, diatoms, ostracods, foraminifera, molluscs and waterlogged plants within the sediment, as well as dating appropriate samples, helped define prehistoric seabed deposits and identified any relationships between them. ^{14}C (radiocarbon) and OSL (optically stimulated luminescence) samples were taken from relevant deposits in order to provide chronological information.

During the project the vibrocore survey data provided: calibration of the geophysical data; a relative chronology for the area identifying the relationship between palaeogeographical features; a measure of the absolute timescales involved in the depositional processes (through OSL and ^{14}C dating of appropriate samples); evidence for the environmental reconstruction of the depositional environments; evidence of marine transgression.

Grab sampling surveys have been conducted in the Arun, Eastern English Channel and Humber study areas. These have demonstrated that grab sampling survey methodology can be applied for archaeological purposes. The Arun grabbing survey specifically has retrieved possible artefacts and possible anthropogenic charcoal from the upper layers of the seabed.

Apart from possible artefact retrieval the other advantage of grab sampling surveys lies in the possibility to establish a record of the upper and exposed seabed sediments, which are particularly at risk from the impacts of dredging. These sediments cannot be documented by geophysical analyses, because sub-bottom profiling techniques are not able to record the upper decimetres of the seabed, and sidescan sonar surveys only provide an indication of the surface sediment type. Vibrocore locations will be based on the results of the sub-bottom profiler survey, thus targeting *buried* fine-grained and organic layers. The difference in sediments recordable by grab sampling on one hand and vibrocoring and geophysics on the other hand was verified by radiocarbon dates for the Arun study area which confirmed the difference in age and the presence of a clear stratigraphic sequence.

No evidence of surviving prehistoric deposits was recovered from the Eastern English Channel or the Humber grab samples. However, the sieved grab samples represent a very small fraction of the total deposits within the study areas and as such a lack of prehistoric archaeological material within the samples does not mean that it does not exist within the areas surveyed.

For a better understanding of the results of underwater grab sampling surveys, an assessment of similarities between terrestrial sampling techniques and the grab sampling methodology undertaken as part of the 'Seabed Prehistory' project has been made. Appropriate marine site examples have been included in the discussion. Issues that need to be considered to execute successful grab sampling surveys are: site size, character and condition. These will impact upon the survey design, specifically the size of the area to be sampled, the grid density and the sample size.

In order to ensure an adequate coverage of the area to be investigated by grab sampling, it is recommended to enlarge the sampling scale in terms of study area, grid density and sample size.

With regard to sample size, a cost effective approach would be to apply archaeological analysis to the one ton grab samples that are taken within aggregate dredging areas for grain size and sediment/clast analyses. A visual scan of the sediment could be conducted onboard the vessel, making big scale laboratory processing redundant. By investigating an estimated number of ten samples per day, the amount of sampled sediment could be considerably increased compared to Hamon grab samples, thus increasing the chances to discover archaeological material of any kind. The practicalities of this suggested methodology would have to be investigated to enable the aims of both archaeologists and industry to be satisfied.

With regard to maritime contexts, it would be neither productive nor cost effective to imply an overall high sampling fraction without taking into consideration specific site conditions. The palaeogeographic reconstruction of a study area would have to be balanced against appropriate predictive site models before the application of an especially dense sampling grid would be justifiable and most probably prove successful.

The size of the grab sampling survey area would have to be determined according to the specific site circumstances and the scale of the palaeolandscape features to be investigated. However, the informative results of the Arun Additional Grabbing survey showed that the size should be related to the wider palaeogeographic features in the region.

The geoarchaeological results are summarised in the following:

At any location in the North Sea and English Channel, reworked material from the Palaeolithic and Mesolithic may be present. Those sediments identified during this project as containing, or potentially containing significant prehistoric archaeological material are summarised below. As the earliest known occupation of north-west Europe is presently thought to have begun *c.* 700,000 years ago (Parfitt *et al.* 2006), only deposits identified as this age or later are discussed as having archaeological potential.

- The Arun survey area is dominated by a valley containing fluvial sands and gravels probably dating to the Devensian (OIS 5d to 2) periods. These deposits may contain Upper Palaeolithic and Mesolithic archaeological remains. Above this level, Holocene peats, silts and clays dating to the early Mesolithic period were recovered.

- Oak (*Quercus* sp.) heartwood charcoal and *Phragmites* recovered by grab sampling stratified within a peat deposit is a dated potential indication of human habitation in the Arun area during the early Mesolithic. The *Phragmites* were dated to 8,200-7,740 cal. BC (SUERC-12007) and the charcoal is dated to 8,230-7,960 cal. BC (NZA-26303). The charcoal could however have been formed by natural causes although it is considered more likely to have been produced as a result of deliberate burning. This peat is presently exposed on the seabed. Other, earlier Mesolithic peat deposits were identified by geotechnical and geophysical survey and these may also contain archaeological material.

- Estuarine silts and clays dating to the early Mesolithic deposited at a similar time to the peats were extensive at the Arun site. These sediments, whilst containing a wealth of environmental material, are also known to preserve ephemeral archaeological remains such as human footprints. These types of deposits can also seal and preserve archaeological material.

- Possible flint chips were recovered from the marine "lag" deposit covering the site although these were mostly indistinguishable from flint chips produced by mechanical fracture.

- The Eastern English Channel study area would have formed part of the same channel river system of which the Arun palaeovalley was a tributary. OSL dates and sedimentary data suggest that a marine lag deposit dating to the Wolstonian (OIS 7, 6) or Ipswichian (OIS 5e) is the earliest deposit on the site. This deposit also shows evidence of sub-aerial exposure which dating suggests probably occurred during the late middle Palaeolithic, Devensian (?OIS 5b) period. The deposit itself may contain reworked Palaeolithic material, however, as a landsurface *in situ* archaeological material may be present.

- A large palaeovalley cut into this deposit showed evidence of deposition from the (Devensian OIS 2) to the Holocene (OIS 1) early Mesolithic period. One small remnant palaeovalley predating this (OIS 5e to OIS 2) filled with a ?fluvial gravel deposit may contain derived or *in situ* Palaeolithic material. Within the main large palaeovalley a sequence of cut and filled channel sediments were identified by geophysical survey. Sediments towards the top of the sequence contained environmental remains relating to slow moving freshwater and estuarine rivers in this area during the Upper Palaeolithic and Early Mesolithic periods. Freshwater is an essential resource and the identification of these types of freshwater deposits could indicate potential areas suitable for habitation (and potential deposition of in situ remains). No artefactual evidence of prehistoric archaeological interest was however found in the Eastern English Channel area. This is not however to say that it does not exist.

- The Happisburgh and Pakefield areas contained two major sedimentary units inferred from the geophysical, geotechnical and environmental data to be recent seabed sediments overlying sediments predating the earliest occupation of NW Europe. The archaeological potential of the areas is therefore low although the potential presence of reworked material in the recent sediments is noted.

- The Great Yarmouth area presents probably the most complete chronological and sedimentary sequence of any of the survey areas. However, the dating of this area is complicated. The earliest deposition in the area is shallow marine sands and gravels dated by OSL dating to the Cromerian Complex period (OIS 16-14). These deposits are noted to be within the range of human occupation of Britain.

- Above these shallow marine sands and gravels, freshwater gravels, sand and silt dating from the Wolstonian (OIS 9, 8, 7 and 6) to Ipswichian (OIS 5e) periods contained charcoal which is a possible indication of occupation of the area. Charcoal can be formed by natural causes (e.g. lightning) or may be a direct indication of habitation if it is the result of material burnt as fuel in hearths. If this is indeed evidence of occupation and if the OSL dating is correct then this would be highly significant, because occupation during the Ipswichian has not been proven in the British Isles.
- Overlying these sediments estuarine silts and clays deposited during the Ipswichian (OIS 5e) show evidence of subsequent exposure as a land surface (gleying and roots). OSL dating suggests this occurred during the Devensian (OIS 2) corresponding to the late Upper Palaeolithic. This deposit is in areas exposed on the seabed.
- The Humber area contained glacial deposits dating to the Devensian (OIS 2) and marine sands and gravels dating to the Holocene sea level rise (late Mesolithic). The possibility of reworked artefacts in these deposits is noted although unproven in this study.

Demand for marine aggregates will increasingly remove Pleistocene sediments from the seabed and any related prehistoric archaeology with it. To fully understand where these sites and artefacts might occur and the effects of aggregate dredging upon them, consideration must be given to a wide range of archaeological and scientific data regarding chronology, sea levels, environment etc. Study of any artefacts in conjunction with relevant archaeological scientific studies generated in part by the prospection for marine aggregates and associated surveys will help further inform the public, industry and archaeologists about the effects of marine aggregate dredging on prehistoric archaeology.

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This report was written by John Russell, Louise Tizzard and Dr Dietlind Paddenberg. The project was managed for WA by Stuart Leather. Dr Antony Firth, Head of Coastal and Marine, and Steve Webster, Senior Project Manager, provided internal guidance, advice and quality assurance throughout the project.

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1. INTRODUCTION

1.1. PROJECT BACKGROUND

1.1.1. This report is **Volume VIII** of the Final Report of the project ‘Seabed Prehistory: Gauging the Effects of Marine Aggregate Dredging’. This phase of the project was commissioned by English Heritage (EH) and undertaken by Wessex Archaeology (WA). The project was funded through the Aggregate Levy Sustainability Fund (ALSF) and distributed by the Department for the Environment, Food and Rural Affairs (DEFRA).

1.1.2. The Final Report comprises eight volumes. **Volume II** to **VII** are based on reports from different phases of the project commissioned through either EH or the Mineral Industry Research Organisation (MIRO) as part of Round 1 or Round 2 of the ALSF.

1.1.3. Round 1 of the ‘Seabed Prehistory’ project was undertaken between 2003 and 2004 and was part of the Sustainable Land Won and Marine Dredged Aggregate Minerals Programme (SAMP), funded by Round 1 of the ALSF and administered by MIRO on behalf of the former Office of the Deputy Prime Minister (ODPM), now Department for Communities and Local Government (DCLG).

1.1.4. The extension of the ‘Seabed Prehistory’ project to Round 2 in 2005 aimed to assess the application of the Round 1 methodologies to aggregate dredging zones with different geoarchaeological characteristics. Round 2 comprised different project components, each component funded through either EH or the MIRO. Each component was an independent stand alone project.

1.1.5. The final Project Synthesis aimed to compare and contrast the methods and results from the study areas of both the English Heritage and MIRO administered projects (**Table VIII.1**).

Administering body	Study Area / Project
MIRO	Arun
English Heritage	Arun (Additional Grabbing + Visualisation)
English Heritage	Great Yarmouth
MIRO	Eastern English Channel
MIRO	Humber
English Heritage	Happisburgh and Pakefield Exposures
English Heritage	Project Synthesis

Table VIII.1: Components of the Seabed Prehistory project.

1.1.6. The Project Synthesis focuses on the overall project objectives stated in **Volume I** and summarised below:

- to better understand the extent and character of prehistoric seabed deposits;
- to develop new methodologies for assessing and evaluating prehistoric seabed deposits in the course of license applications;
- to guide industry, regulators and public towards better understanding, conservation and appreciation of prehistoric seabed deposits implicated by marine aggregate dredging.

1.1.7. **Table VIII.2** provides an overview of the Project Synthesis 'Seabed Prehistory: Gauging the Effects of Marine Aggregate Dredging. Final Report, Volumes I-VIII' (Wessex Archaeology 2007).

Volume	Title
I	Introduction
II	Arun
III	Arun Additional Grabbing
IV	Great Yarmouth
V	Eastern English Channel
VI	Humber
VII	Happisburgh and Pakefield Exposures
VIII	**Results and Conclusions**

Table VIII.2: Overview of the volume structure of this report.

1.1.8. **Volume I** provides an overview of the project's background, aims and objectives and the baseline environment with regard to marine geoarchaeology and submerged prehistoric landscapes, as well as summaries of **Volumes II** to **VIII**. **Volumes II** to **VII** are updated versions of previous 'Seabed Prehistory' project reports for either EH or MIRO. This report is **Volume VIII** in the series and sets out the project's comparative results and conclusions in terms of methodological and geoarchaeological objectives as described in the following.

1.1.9. The comparative analysis of the survey methodologies comprises three separate discussions:

- The fieldwork implementation and data quality of the geophysical survey are compared between areas and the merits of the different geophysical processing and interpretation techniques are evaluated (**Section 2**);
- The merits of the vibrocore methodology are evaluated between the areas, in terms of the scale of palaeogeographic features and the calibration of the geophysical data related to the number of vibrocores taken. The depth of penetration of the cores is assessed compared to feature depth, and alternative coring options are explored (**Section 3**);
- The data from the grab sampling surveys are compared to test the association between the presence of prehistoric artefacts on the seabed and palaeogeographic features (**Section 4**).

1.1.10. The comparative analysis of the geoarchaeological results comprises – in a chronological order – discussions on the extent and character of the prehistoric seabed deposits of each area in terms of their sediment architecture and the interpretations of the depositional processes that formed this architecture. From this comparison comments are made on the archaeological potential of each area and the relative importance of the palaeogeographic features and interpreted landscapes (**Section 6.1-3**).

1.1.11. The project improved archaeologists and developers understanding of the varying archaeological contexts in which aggregates are found. It developed geophysical and geotechnical survey methodologies for the assessment of prehistoric archaeology within proposed aggregate dredging areas, and contributed to research into prehistoric archaeology. It reduced the impacts of dredging activities on the marine cultural resource by enabling the compilation of better-informed Environmental Assessments in the course of aggregate licensing (**Section 6.4**).

1.2. THE STUDY AREAS AND THEIR CHARACTERISTICS

1.2.1. All study areas are located either in the English Channel or the southern North Sea off the English coast, close to or within licensed aggregate dredging areas. The locations of all study areas are given **Figure VIII.1**.

1.2.2. The Arun area (**Volumes II-III**) in the English Channel *c.* 18km off Littlehampton, Sussex, was chosen because palaeolandscape features of potential archaeological interest such as palaeochannels had been recorded there by industry (Bellamy 1995), and because it was adjacent to an existing licensed marine aggregate extraction area on the Owers Bank, emphasising the relevance of this form of investigation to the marine aggregate industry. The actual study area of 3.5 x 1km was chosen after a large palaeochannel had been identified from prospective geophysical survey lines (**Figure VIII.2**). It was approximately 20m deep and 300m wide and was likely to have been a major geographic feature in the palaeolandsurface, implying a high archaeological and palaeoenvironmental potential. Seabed depth of the study area was 25 to 35 metres, including a seabed depression to the south-west and higher bathymetry towards the aggregate area in the north-east of the study area. The depression was identified as a potential relict valley feature relating to the Palaeo-Arun river. Having been a tributary river to the main trunk stream of the English Channel defines the specific geomorphological characteristic of this study area.

1.2.3. The Great Yarmouth area (**Volume IV**) in the North Sea *c.* 10km off Great Yarmouth, Norfolk, was chosen because previous work in this area highlighted peat and clay deposits close to the seabed occurring as part of a fine-grained sediment unit closely associated with the aggregate deposits within dredging area 254 in 30 to 35 metres water depth. These sediments were considered to be infill deposits within the Yare palaeovalley (Bellamy 1998; Wessex Archaeology 2002). According to onshore analogies, they were interpreted as being deposited in a nearshore/tidal, flat/marshland environment during the Holocene (Arthurton *et al.* 1994). Terrestrial archaeological finds had been documented along the course of the Palaeo-Yare (Wymer 1997). The actual study area was chosen based on prospective geophysical data and following consultation with representatives from the marine aggregate industry. It comprised 800 x 800m and was situated in the south-western corner of dredging area 254 (**Figure VIII.3**). In contrast to the trunk river systems or tributaries of the other study areas, the Palaeo-Yare was a single main river situated in an especially wide and shallow palaeovalley. The Great Yarmouth study area also provided the opportunity to assess the ability of shallow seismic equipment to locate an archaeologically important layer in the near seabed sediments.

1.2.4. The Eastern English Channel area (**Volume V**) *c.* 30km offshore south-west of Beachy Head, West Sussex, was chosen after a new dredging area had been licensed that would to be the focus of industrial activity for the next 15 to 20 years. The actual study area was selected after reviewing geophysical data collected by the British Geological Survey (BGS) as part of their ALSF project 'Eastern English Channel Large-scale Seabed Habitat Map'. After processing this data 14 palaeochannels were identified running through the region. Following consultation with the BGS, WA selected an area over one of these channels between the licensed aggregate areas 464 West and 464 East for further investigation (**Figure VIII.4**). It was evident that within the palaeovalley there were multiple phases of infill showing that this area was likely to have deposits relating to various stages of prehistory. The study area had also been mapped as part of a larger palaeovalley system which originated from the rivers now situated in northern France (Hamblin et al. 1992:79 figure 62). In the Eastern English Channel study area, it was possible to investigate parts of a major branched palaeoriver system, which is now the English Channel trunk stream, in 50 to 55 metres depth.

1.2.5. The Humber study (**Volume VI**) focused on an area south of the Humber Estuary, *c.* 16km off the Lincolnshire coast, close to the active dredging areas 197 and 106 (**Figure VIII.5**). Throughout the Pleistocene the area had been severely affected by repeated periods of glaciation which completely re-modelled the landscape, with the older river course destroyed or buried and an entirely new landscape formed beneath the ice by glacial and fluvioglacial erosion and deposition (Carr *et al*. 2006). In this area the remnants of the last major ice sheet advance are represented in the form of a sub-glacial till called Bolders Bank Formation (Cameron *et al.* 1992). As the Bolders Bank Formation represents the erosion of a former landsurface there was little potential for pre-Devensian archaeological artefacts to remain *in situ*, however, derived artefacts transported by the ice sheet possibly survived. Within the channels carved out by the meltwater sands and gravels would have been deposited. By the end of the Dimlington Stadial at around 13,500 years BP (*c.* 14,100 cal BC) no ice would have remained over the area and a periglacial landscape would have prevailed (Coles 1998). The actual study area was targeting a completely infilled depression located in a dredging area (Bellamy 1998: figure 4). The infill sediments comprised coarse-grained sediments and on-lapping fine-grained sediments which potentially contained archaeological deposits *in situ.* The specific geomorphological characteristic of the Humber area was that it represented a coastal palaeoenvironment in 13 to 33 metres water depth, as opposed to the riverine palaeoenvironments of the Arun, Great Yarmouth and Eastern English Channel studies.

1.2.6. The Happisburgh and Pakefield Exposures project (**Volume VII**) was inspired by the current research on the palaeoriver systems in East Anglia which extend into the southern North Sea basin (e.g. Rose *et al.* 2001; 2002) and which are dredged for aggregates in their terrestrial parts. The principal aim of the study was to trace sediments of known archaeological potential onshore into the offshore marine environment. Finds of flint artefacts within these onshore sediments, mostly within the Cromer Forest-bed, demonstrated that human occupation of north-west Europe started about 200,000 years earlier than hitherto thought, *c.* 700,000 years ago. The Cromer Forest-bed Formation is a pre-glacial deposit of Cromerian Complex age comprising primarily organic detritus muds and sands laid down within channels and on the floodplains of rivers. The newly found artefacts were associated with the Ancaster and Bytham River deposits at Happisburgh and Pakefield respectively (Parfitt *et al*. 2005). Consequently, the survey comprised two main study areas focussing on the near-shore deposits at Pakefield and Happisburgh. Furthermore, a series of geophysical investigation lines off the coasts of Suffolk and Norfolk was undertaken, to attempt to locate the edges of any channels that may be part of the Bytham or Ancaster palaeoriver systems (**Figure VIII.6**).

1.3. Survey Methodologies Overview

1.3.1. The geophysical survey methodologies generally comprised a bathymetric survey to establish water depths and seabed morphology across the study area, a sidescan survey to record the seabed sediments and further highlight the seabed morphology and a shallow seismic survey to identify individual sub-seabed horizons that were then modelled.

1.3.2. Based on the geophysical data interpretation vibrocore locations were proposed within the study areas. The aims of the vibrocore surveys were to calibrate the geophysical data with regard to stratigraphy, to help provide a relative chronology for the area, i.e. to identify the relationship between palaeogeographic features, to provide an absolute timescale of the depositional processes through appropriate dating techniques, and to provide evidence for the environmental reconstruction of the depositional environments.

1.3.3. Grab sampling surveys were undertaken within selected study areas in order to locate any exposed fine grained deposits and/or prehistoric remains within the upper sediment layers of the seabed.

2. GEOPHYSICAL SURVEYS

2.1. Introduction

2.1.1. One of the principal aims of the 'Seabed Prehistory' project concerns the testing and development of methodologies for assessing and evaluating prehistoric seabed deposits. This aim is addressed by testing the archaeological application of geophysical data acquisition, recording, processing and interpretation methods that are suitable for adoption by the industry in the course of license applications.

2.1.2. The specific aims of this section are to compare and contrast the practical application of integrated survey methodologies employed in the five study areas; to compare and contrast the acquired data in terms of quality, resolution and applicability; to draw conclusions and to make recommendations to industry and regulators based on current methodologies employed by industry for the licence application process, and the findings of this project.

2.1.3. Between July 2003 and July 2006 five geophysical surveys were undertaken in areas around the south and east coast of the UK. In the case of the Arun, Eastern English

Channel and Great Yarmouth surveys WA commissioned external survey companies to acquire the data; for the Happisburgh and Pakefield, and Humber surveys the geophysical data acquisition was conducted by WA (**Table VIII.3**).

Study area	Survey company	Dates	Equipment
Arun	Emu Ltd	01/07/03 – 18/07/03	Echo-sounder and sub-bottom profiler
Eastern English Channel	Gardline Environmental Ltd	14/10/05 – 24/10/05	Echo-sounder, sub-bottom profiler, sidescan sonar.
Great Yarmouth	Titan Environmental Surveys	30/08/05 – 19/10/05	Echo-sounder, sub-bottom profiler, sidescan sonar.
Happisburgh and Pakefield	Wessex Archaeology	01/06/06 – 06/06/06	Echo-sounder, sub-bottom profiler, sidescan sonar.
Humber	Wessex Archaeology	07/06/06 – 13/06/06	Echo-sounder, sub-bottom profiler, sidescan sonar.

Table VIII.3: Details of the geophysical surveys and companies involved in the Seabed prehistory project.

2.1.4. An integrated survey methodology was employed at each study area. This comprised the acquisition of bathymetry, sub-bottom profiler and sidescan sonar data in all areas except for the Arun study area where sidescan sonar was omitted. Prior to the initial Round 1 survey, there was uncertainty regarding the usefulness of sidescan sonar data when assessing palaeogeography of an area. However, it became apparent during the Arun survey that the sidscan sonar data may have provided useful detail pertaining to the geomorphology of the area and the sediments composition of the uppermost sediment unit. As such, the acquisition of sidescan sonar data was included in subsequent survey designs. The usefulness of these data is discussed further in **Volume VIII, Section 2.6.**

2.1.5. At each site a series of investigation/prospection lines were acquired to assess the area for palaeogeographic features of archaeological interest prior to the main survey. Once complete, a survey grid was designed to best assess the archaeological feature of interest.

2.2. SURVEY DESIGN

2.2.1. In the course of the licence application process a number of different geophysical surveys are undertaken. At the prospection stage wide area surveys will be carried out initially to identify a potential resource. After prospection a survey will be undertaken for licence applications. This survey will provide further information on the extent and character of the resource, and may also be used by different scientific disciplines as part of the assessment process. Additional surveys may be commissioned to further refine the extent and character of the resource and meet the requirements of the assessment process.

2.2.2. The current survey strategy used by the marine aggregate industry is to acquire sub-bottom profiling data at a line-spacing suitable to determine the geology of the area. This usually means using a line spacing of 100 – 500m (Bellamy 1998), with a small number of tie-in lines acquired at 90 degrees to the preferential line direction (generally referred to as ‘cross-lines’).

2.2.3. Each survey area requires an individual survey design. Each design needs to take into account the size of the feature of archaeological interest and the choice of a suitable line-spacing in order to provide a high enough resolution to delineate and interpret the feature of interest. The cost of the survey in terms of acquisition and processing time also needs to be taken into account.

2.2.4. For the majority of the study areas initial prospection lines were run in order to best locate features of interest and design the survey grid accordingly. During the Happisburgh and Pakefield survey a series of investigation lines were run (**Volume VII, Section 2.2**). The difference between these lines was that prospection lines were used to identify a specific palaeogeographic feature on which the survey would be directly based. The investigation lines were acquired to provide contextual geological data of the region. This aided in the processing of the high resolution survey areas at Happisburgh and Pakefield by highlighting the geological and geophysical characteristics of the area as a whole.

2.2.5. In order to establish the best line spacing to use an assessment of survey strategy was undertaken for the Arun (**Volume II**) and Humber (**Volume VI**) study areas. The study was conducted during the Arun survey in order to assess best methodological practice which would influence the survey design of the Round 2 projects. The assessment in the Humber study area was conducted to re-assess this methodology in a different geological setting to ensure that the methodology was still applicable.

2.2.6. The Arun study involved an investigation into the use of linear- or grid-based surveys processed at varying line spacings (50 x 50m, 100 x 100m and 200 x 200m) to establish which method provided the detail required to identify and interpret submerged landscapes. The interpreted surface data was input into visualisation software (I.V.S. Fledermaus software package) and gridded into a surface using the methodology described in detail in **Section 2.7**.

2.2.7. An assessment of the modelling of different line-spacings (50 x 50m, 100 x 100m and 200 x 200m) concluded that models at 200 x 200m spacing produced less resolute data and affected the quality of the interpretation. The 50 x 50m grid is the most resolute and therefore this dataset is most likely to identify small palaeogeographic features.

2.2.8. At present the majority of geophysical surveys conducted for the purpose of investigation marine aggregate deposits will be surveys as a series of parallel survey lines with only occasional tie-in cross-lines. To examine the affect of using a parallel survey design one of the datasets was re-examined. Two surface images were produced and compared. The first was composed of the interpretation from main lines only; the second surface was composed of the interpretation from the main lines and cross lines.

2.2.9. This study concluded that a grid-based survey methodology provided the better surface. Although similar geomorphic features were observed on both the grid-based and linear-based datasets, the increased data collected during a grid-based survey resulted in a higher resolution dataset producing a more defined palaeogeomorphology interpretation.

2.2.10. A further study was conducted at the Humber study area. Specifically, this was an assessment to test whether the results from the Arun line spacing study still held in a different geological, geomorphological and archaeological setting. Lines were acquired at 50m line spacing with cross lines acquired at 100m line spacing. In order to assess whether using a smaller line-spacing would improve the interpretation a small sub-area was selected to the south of the survey area and data were acquired at a decreased (25m) line-spacing.

2.2.11. Using the same methodology as the Arun survey, the assessment showed that using 25 x 100m grid line spacing improved the resolution of the interpretation. However, there is no evidence in the Humber dataset to suggest that in the small sample area chosen features observed in the smaller grid dataset are not observed in the large grid dataset. This indicates that using a grid size of 50 x 100m will provide a useable dataset for interpretation of data with all key features visible.

2.2.12. The data resolution could be further improved by decreasing the distance between the lines on the east – west orientated lines (e.g. 50 x 50m grid). However, the Round 1 project concluded that a grid of 100 x 100m will produce an adequate dataset for palaeogeographic interpretation, and as such a smaller grid of 50 x 100m was deemed suitable.

2.2.13. The Arun study area comprised a $1km^2$ central study area and based on the results of the line-spacing study described above was interpreted at a grid line-spacing of 50m. The results of the Arun survey influenced the survey design of the subsequent Round 2 surveys.

2.2.14. The Eastern English Channel study area comprised a $1km^2$ area over a palaeochannel feature with sub-bottom profiling lines acquired at 50m line spacing orientated south-west to north-east and 100m line spacing for cross-lines (orientated north-west to south-east). The palaeochannel of interest in the study area was thought to be orientated north-west to south-east (Wright 2004). The principal aim of the survey was to delineate the edges off the channel and its infill. Therefore, by acquiring data across the width of the channel at a tighter line spacing (50m) the edges of the channel could be delineated at a high resolution. The cross-lines were acquired along the length of the channel providing tie-in data at a wider line spacing (100m). Due to time limits during the survey a third of the cross-lines could not be run. However, the lines that were run covered the edges of the palaeochannel area and it is considered that the loss of this data was not detrimental to the interpretation of the channel feature. Sidescan sonar data was collected at 50m line-spacing on lines orientated south-west to north-east.

2.2.15. For the Great Yarmouth study area data were acquired within a 0.8 x 0.8km area providing a detailed look at sediments lying within the Palaeo-Yare river. The geophysical data were collected at 50m x 100m line spacing.

2.2.16. Unlike the Arun, Eastern English Channel and Great Yarmouth surveys where the feature of interest was known prior to study, the Humber study area was designed solely on the basis of prospection lines acquired prior to the survey. Based on this data and the locations of adjacent aggregate areas, an area of seabed covering 6 x

1.2km, orientated north-west to south-east, was surveyed. The long lines were collected a 50m line spacing and the shorter cross-lines were acquired at 100m line spacing.

2.2.17. The survey designs at Happisburgh and Pakefield were very different compared to the other surveys. The aim of the Happisburgh and Pakefield surveys was to trace sediments observed onshore into the offshore environment as opposed to investigating close to aggregate dredging areas. Water depth, tides and obstruction features such as sandbanks and groynes all had an effect on the survey design.

2.2.18. The area surveyed near-shore Pakefield was approximately 3.4km^2 in size (2.6km long and 1.3km wide) comprising 11 survey lines with a line spacing of approximately 100m. This line spacing was used in order to achieve adequate coverage of the area in the limited time available. The lines closest to shore had to be surveyed at high-tide in order to limit the chances of grounding the vessel or towed equipment. All lines were orientated south-west to north-east parallel to the coastline. No lines were run perpendicular to the shoreline because of the shallow water (<5m) and the risk of grounding the towed equipment.

2.2.19. At Happisburgh the survey comprised four long lines running parallel to the coast between Waxham and Happisburgh. A focused survey comprising four additional lines was conducted directly off the coast from Happisburgh. The study area was limited to the north by a guard vessel protecting a newly trenched exposed pipeline (no vessels towing equipment were allowed near the area) and limited to the west by the steeply sloping beach profile and the presence of groynes. Although the survey was conducted at high tide the exact location of the groynes could not be sighted and the risk to the towing equipment and vessel was considered high. For these reasons no lines were run perpendicular to the coast at Happisburgh or in nearshore waters. The depths for the Happisburgh survey were not less than 10m.

2.3. POSITIONING

2.3.1. Accurate positioning of the vessel and equipment is an essential requirement for a survey. The repeatability of position information is crucial for the corroboration of geophysical data with the geotechnical data, and for the implementation of archaeological mitigation measures.

2.3.2. Global Positioning Systems (GPS) are satellite navigation systems which provide accurate, worldwide, continuous three-dimensional position fixing (latitude, longitude and altitude). The position calculated by a GPS receiver uses the current time, the position of the satellite and the travel time of the received signal. The position accuracy is primarily dependent on the satellite position and signal delay. The general accuracy of the system is between 3 and 5m. Differential GPS (DGPS) is an enhancement to GPS improving the base accuracy by using a network of fixed ground based reference stations that broadcast corrections between the positions indicated by the satellite systems and the position of the reference station. GPS positions are all referenced to World Geodetic System 84 (WGS84) datum. If positions are recorded in a different datum, further corrections need to be applied.

Acquisition

2.3.3. Vessel positioning was supplied by DGPS system and recorded in latitude, longitude and WGS84 datum during the surveys. Positional corrections were received from terrestrial base stations (IALA Trinity House DGPS network) for all study areas except the Eastern English Channel study area where corrections were received via satellite subscription (C-Nav). The geodetic coordinates were then projected in order to show a 2-D representation of the curved surface of the earth for use in GIS (geographical information system) and for charting purposes. Details are provided in **Table VIII.4**

Study area	DGPS Receiver	Data logging	Coordinate projection system	Coordinate projection datum
Arun	Leica MX412	Every 1 second	OSGB 36	Airy 1830
Eastern English Channel	C-Nav	Every 1 second	Universal transverse Mercator (UTM) Zone 31	WGS 84
Great Yarmouth	Trimble DMS Pro	Every 5 metres	Universal transverse Mercator (UTM) Zone 31	WGS 84
Happisburgh and Pakefield	Leica MX412	Every 1 second	Universal transverse Mercator (UTM) Zone 31	WGS 84
Humber	Leica MX412	Every 1 second	Universal transverse Mercator (UTM) Zone 31	WGS 84

Table VIII.4: Details of the positioning systems and projections used in the geophysical surveys.

2.3.4. Offsets from the DGPS receiver antennae on the vessel to the echosounder and the towing points of the towfish (sub-bottom profiler and sidescan sonar) were measured enabling their positions to be logged in the raw data files or to be applied during the processing stage.

2.3.5. Through position checks conducted at each survey site the accuracy of the vessel position was estimated to be within 1m. The positioning of the towfish was estimated based on the vessel position, offset between the towpoint and vessel antenna, and length of cable paid out to the towfish. However, in the case of the Eastern English Channel sidescan sonar survey an ultra short baseline (USBL) tracking system was used. Issues regarding positioning of towed equipment are discussed in the following sections relating to sub-bottom profiler (**Section 2.5**) and sidescan sonar (**Section 2.6**) surveys.

2.4. BATHYMETRY

2.4.1. Bathymetry data were collected during each survey. Bathymetric data not only provide information on water depth and the morphology of the seabed, but also provide a vertical reference datum that can be used to accurately position geophysical horizons from shallow seismic data. Knowing the absolute level of horizons is the first stage in establishing the general chronological context of archaeological features.

2.4.2. Bathymetric data are collected using an echosounder of which there are two types: a single-beam echosounder and a multibeam echosounder. A single-beam echosounder consists of a transducer which is attached to a pole over the side of the vessel in a fixed position. The transducer emits an acoustic pulse directed downwards to the seabed and then records the time it takes for the signal to be returned. This time is then converted to a depth measurement using the speed of sound in water value. The single-beam echosounder gathers point depths in a line beneath the survey vessel as the vessel progresses along the acquisition line.

2.4.3. The multibeam echosounder, however, ensonifies the seabed in the form of a swath beneath and to either side of the survey vessel deriving continuous and well positioned spot heights for many thousands of points on the seabed as the vessel moves forward. As such, the multibeam sonar data produces a dataset with many more data points compared to the single-beam echosounder covering the same area. One of the main disadvantages of using the multibeam echosounder is the cost. It is at least 40 times more expensive to run and process the data compared to single-beam data.

Acquisition

2.4.4. Throughout the surveys bathymetric data was acquired using a single-beam echosounder. The principal aim of the bathymetry data in the 'Seabed Prehistory' project was to provide a precise vertical reference datum for the sub-bottom profiler data. This was accomplished by acquiring single-beam echosounder and sub-bottom profiler data simultaneously along each line. The single-beam echosounder data were also processed into a DEM (digital elevation model) surface in order to ascertain the seabed morphology of the area. Although using the multibeam echo-sounder may have provided a more detailed image of the seabed morphology (due to the increased number of data points within a given area), taking the cost and processing time of the multibeam data into account, it was not considered necessary for this project. The single-beam echosounder was used successfully throughout the surveys.

2.4.5. There are three main issues concerning the acquisition of good quality depth data. These are the positioning of the echosounder transducer head, both horizontally and vertically; the compensation for the effect of vessel motion on the data; and the accurate value of speed of sound through the water.

2.4.6. The horizontal offsets of the transducer head from the GPS vessel antenna position were calculated and input into the echosounder processing unit. The transducer draught (vertical offset) was measured and entered into the echosounder to obtain depths relative to the sea-surface.

2.4.7. The motion of the vessel impacts the data; as the vessel moves through the water the time taken for a signal to travel from the transducer to the seabed and to return will vary even in areas of a flat seabed. As such, compensation of these vessel movements needs to be taken into account.

2.4.8. Consequently, in each survey a motion sensor was rigidly mounted above the transducer to measure the vertical displacement (heave) and attitude (roll/pitch) of the vessel. These correction data were interfaced with the echosounder in order to provide a corrected water depth.

2.4.9. As mentioned above the speed of sound in water is required for the calculation of water depth. The speed of sound in seawater is approximately 1500m/s but varies dependent on environmental conditions such as pressure (water depth), temperature and salinity. As such, the speed of sound in water needs to be calculated for the period of the survey. This can be achieved using the bar-check method or measured using a conductivity, temperature, depth (CTD) profiler.

2.4.10. The bar-check method involves suspending a metal plate or bar at known various depths below the echosounder transducer and calibrating the transducer depth reading with the known depth of the plate. These signals are then used to adjust the speed of sound input and transducer draught into the echosounder.

2.4.11. Alternatively, a CTD profiler can be used. The CTD profiler is a probe lowered over the side of the vessel which records the temperature and conductivity reading at set intervals as it is lowered and raised through the water column. From the results an average speed of sound can be calculated and input into the echosounder.

2.4.12. The bar-check method was used for all surveys with the exception of the Eastern English Channel survey. Due to the large size of vessel used during the survey it was not convenient to conduct a bar-check. As such, the transducer draught was surveyed prior to the survey and the speed of sound was attained using a CTD profiler.

2.4.13. Throughout the surveys the accuracy of the draught and velocity offsets were checked regularly. The corrected bathymetric data were recorded digitally and on the echosounder paper trace, and interfaced with the navigation data.

Data Processing Methodology

2.4.14. The bathymetric data is exported from the echosounder in ascii format for processing. Processing involves tidally reducing the depth data to a known vertical reference datum, and editing the data removing any navigation jumps or depth points which are not consistent with the seabed morphology. These may include depth points from detritus or marine life in the water column. All depth references for each of the surveys were reduced to Ordnance Datum (OD) Newlyn.

2.4.15. The data is tidally reduced using tides acquired using one of three methods; by deployment of a tide gauge for the duration of the survey (Arun, Happisburgh and Pakefield, and Humber); derived from GPS observations during the survey (Great Yarmouth); or using predicted tides (Eastern English Channel). These tide curves are then adjusted to account for the time difference between the tidal observation at the coast and the location of the survey area. These tidal data are then applied to the observed water depths to produce a corrected bathymetric dataset.

2.4.16. By referencing the depth to Ordnance Datum (OD) direct comparisons to onshore depths, topography and context of find positions can be made. This is important where the altitude of a river estuary has been measured on land but is being traced offshore (e.g. the Arun), or where artefacts have been found in a particular horizon onshore and are being traced offshore (e.g. Happisburgh and Pakefield).

2.4.17. There are, however, limitations in relating offshore sites to a land-based datum due to the extrapolation of these theoretical surfaces beyond their intrinsic limits. However, a common datum is required to assess relationships between sediments and by implication evidence of landscapes in different areas.

2.4.18. Once the data had been reduced to OD the data were then input into a visualisation package in order to create a DEM (digital elevation model) for analysis and interpretation (see **Section 2.7)**.

2.5. SUB-BOTTOM PROFILER

2.5.1. Sub-bottom profilers are used to investigate the seabed geology. A seismic source is towed behind a survey vessel and is triggered at a fixed firing rate. The source emits acoustic energy which travels through the water column and the sub-seabed geology. The energy is reflected as it travels through layers of different density. The reflected energy is detected by a hydrophone streamer towed in the vicinity of the source. The outputs of the individual hydrophone elements are summed and fed to a single channel processor unit and are recorded digitally.

2.5.2. The effectiveness of a sub-bottom profiling system is determined by a combination of penetration, vertical and horizontal position accuracy, and resolution of the data. Penetration is a function of power and frequency of the source, and is affected by sediment composition, weather and water depth. Typical penetration values for compacted sediments are between 5 and 10m, and between 50 and 100m in clays (depending on frequency: the lower the frequency, the deeper the penetration).

2.5.3. The vertical resolution is a measure of the ability to identify individual, closely-spaced reflectors and is determined by the pulse length. The maximum resolution possible is approximately one quarter of the wavelength of the pulse. The size of the wavelength can be determined by dividing the seismic velocity by the frequency of the system.

Comparison of Seismic Sources

2.5.4. Within the 'Seabed Prehistory' surveys three seismic sources were used to acquire data: boomer, pinger and chirp. The three seismic sources have different characteristics and therefore produce different data sets over the same study areas. The boomer seismic source has a low frequency signal (approximately 1 kHz) that gives the deepest penetration into the seabed but with the lowest resolution between vertical layers. The pinger seismic source has a high frequency signal (approximately 2.5 - 5 kHz) and so gives less penetration into the sub-seabed geology but with a better vertical resolution between layers. The chirp seismic source sweeps from a low frequency to a high frequency (approximately 2 to 12 kHz) and therefore provides a combination of reasonable penetration into the seabed with high vertical resolution. However, the effectiveness of the chirp is dependent on sediment type.

2.5.5. Details on which system was used for each survey, frequency used and vertical resolution of the system are provided in **Table VIII.5**. Examples of the equipment used are shown in **Figure VIII.**7.

Profiling type	System	Frequency	Towing depth	Optimum vertical resolution	Study area
Surface-tow boomer	Applied Acoustic Engineering AA200	1 kHz	Sea surface	40cm	Arun, Great Yarmouth, Happisburgh and Pakefield, Humber
Sub-tow boomer	EdgeTech 240	1 kHz	Just below sea surface	40cm	Eastern English Channel
Pinger	Probe 5000 pinger	3.5 kHz	Sea surface	10cm	Great Yarmouth
Chirp	EdgeTech 3100P with SB-216S tow vehicle	2 – 12 kHz	2-5m above seabed	8cm	Happisburgh and Pakefield

Table VIII.5: Details of the sub-bottom profiler systems used in the geophysical surveys.

2.5.6. For the surface-tow boomer, pinger and the sub-tow boomer the seismic signal was received via an external hydrophone streamer. The streamers consist of individual hydrophone elements located within neutrally buoyant kerosene filled tubing. The tubing is specially designed to minimise turbulent noise through the water. An EdgeTech 265 hydrophone was used with the surface-tow boomer and pinger, and a Benthos 1510P was used with the sub-tow boomer.

2.5.7. The EdgeTech 265 uses eight hydrophone elements evenly spaced in a 3.8 meter active section with a current summing amplifier located just forward of the active section. The Benthos 1510P uses ten AQ4 hydrophone elements evenly spaced in a 2.7 meter active section with a current summing amplifier located just forward of the active section. The chirp has a series of line array receivers mounted within the towfish body. Whether external or internal hydrophone, the received signal is sent through a processor unit and is recorded digitally. In addition to this the data was printed to hardcopy during acquisition, which allowed numerous lines to be easily reviewed and compared.

2.5.8. The positioning of the towfish during the survey is imperative to acquiring a good quality dataset. The positioning was established by calculating the layback of the towfish taking into account the distance of the towfish behind the vessel, the height of the towfish above the seabed, and the offsets from the GPS vessel positioning antenna and the sub-bottom profiler towpoint on the vessel. Where there is an offset between the seismic source and receiver (i.e. where there is an external hydrophone) the data signal received is positioned half the distance between the source and receiver. The accuracy of the position of the data was ascertained by comparing the same feature on a survey line and the cross-line acquired at 90 degrees.

2.5.9. The choice of seismic source is dependent on the purpose for which the data is to be used, the geology of the area, depth sub-seabed of the features of interest and the size of the features of interest. As part of the methodology for the Arun study area a 3.5km survey line containing the palaeochannel feature was surveyed using three different seismic sources; a boomer, a pinger and a chirp. The aim was to allow a comparison of the data produced using these different seismic sources in order to determine which source gave the optimum results.

2.5.10. The comparison showed that the boomer seismic source gave the deepest penetration into the geology of the study area with sufficient resolution to determine a full interpretation of the geoarchaeological features. Examples of data from the boomer and pinger seismic source trials, over the palaeochannel, are shown in **Figure VIII.8**. These data examples clearly show that the pinger seismic source was not able to penetrate to the base of the feature. The chirp seismic source was also not able to achieve the same data quality as the boomer seismic source, because it was unable to penetrate the surface gravels in the study area. The combination of penetration and resolution produced by the boomer source, in this geological setting, resulted in this source being used for the next stage of the survey. The choice of the boomer source concurs with industry findings. The boomer source has been used as the industry standard sub-bottom profiling tool for both engineering surveys and for marine aggregate prospecting, evaluation and monitoring surveys.

2.5.11. At the Eastern English Channel study area palaeogeographic features were expected at a depth of around 40m sub-seabed (Wright 2004). Based on the results of the Arun seismic source trial, the boomer source was selected as it was considered that the other sources would not necessarily penetrate the sediments to a suitable depth (**Figure VIII.9)**.

2.5.12. The feature under scrutiny at the Great Yarmouth site was very different to the Arun and Eastern English Channel sites. Rather than investigating the limits of a large palaeovalley, the Great Yarmouth site was a focussed survey investigating a small section within the Palaeo-Yare valley. Within the area a thin unit of fine-grained sediments including peat were expected less than two metres beneath the seabed (Bellamy 1998; Wessex Archaeology 2002).

2.5.13. Initially, data were collected using a boomer source. However, due to the relatively low frequency signal and consequent low signal resolution the data did not characterise the peat layer to the degree anticipated in the near surface sediments. As such, only survey lines in one direction (as opposed to a grid) were run with this seismic source.

2.5.14. In order to achieve better vertical resolution in the upper metres and on the basis of discussions with Dr. Andrew Bellamy (UMA Ltd.) on his previous experience in the area, the pinger source was considered to be more appropriate. Pinger data were collected throughout the site. The pinger profiler seismic source has a higher frequency than the boomer source; although it provides less penetration sub-seabed, the data has a higher vertical resolution in the upper layers.

2.5.15. **Figure VIII.10** illustrates the difference in vertical resolution and quality of the two sources. On the boomer data reflections can be observed to a depth of 10m below seabed compared to approximately 6m on the pinger data.

2.5.16. The pinger profiler data was generally of poorer quality compared to the boomer data, partly due to poor weather and sea state conditions and partly due to the pinger source being attached to the surface-tow catamaran where the data is likely to be more affected by the sea state than if it was towed at depth. On the pinger data it is difficult to discern any sediment structure in the first metre immediately below the seabed as it was obscured by the strength of the seabed return signal.

2.5.17. Due to the differences in resolution each dataset highlighted specific features. The fine-grained sediment unit was clearly observed on the pinger data as areas with no reflections; this was more difficult to discern on the boomer data. However, the boomer data highlighted the general stratigraphy with more resolution than the pinger data.

2.5.18. At the three sites discussed above, the surveys were specifically targeted around known features of interest. In the case of the Humber site the archaeological potential of the area was unknown. It was expected that any surviving sediments overlying the glacial till would be post-transgression sediments, however, there was a possibility of the survival of fluvio-glacial sediments in the area. The boomer was the chosen source for this survey as it provided the best compromise between identifying sub-surface reflections to an adequate depth and the vertical resolution of the data. Seismic reflections were observed greater than 10m below the seabed (**Figure VIII.11**).

2.5.19. The aforementioned surveys were conducted in or within the vicinity of aggregate dredging areas. As such it was known that the sediments in the area would likely contain coarse sands and gravels. The chirp seismic source was not considered to be an appropriate survey method because it would not have been able to achieve the same data quality as the boomer seismic source due to its generally poor penetration in gravelly sediments (less than 6m).

2.5.20. The surveys at Happisburgh and Pakefield were conducted in areas were sands, clays and some gravels were expected. Based on previous work at Pakefield (Parfitt *et al.* 2005) it was perceived that interpretation within the top two metres would prove critical in tracing the onshore deposits offshore. The chirp system generally produces a smaller seabed pulse compared to the boomer system. As such, less data is masked beneath the seabed pulse on chirp data, providing resolute data within the first two metres of the seabed. Also, due to the higher frequency settings the chirp provides more resolute data compared to the boomer source (**Figure VIII.12**). Hence, the chirp was considered the best option for these surveys. For the investigation lines in deeper water the surface-tow boomer system was used. The aim of the investigation lines was to provide an overview of the general geology of the area and the boomer was chosen as it provides data to a greater penetration sub-seabed than the chirp system, providing data to a greater depth, albeit at a lower resolution.

2.5.21. Data quality further affects the interpretation of the data. A corruption of data quality may lead to the misinterpretation of geophysical horizons of archaeological interest.

2.5.22. Various issues affect data quality and these include: the loss of transmission signal due to increasing water depth; the obscuring of data due to the seabed multiple; and weather effects. The seabed multiple occurs when the signal is transmitted to the seabed but rather than reflecting directly to the receiver, is reflected from the sea surface to the seabed and then to the receiver, creating a multiple image of the seabed. The surveys were conducted in relatively shallow water (less than 70m) and as such loss of the transmission signal was not a problem during the surveys. The seabed multiple was observed on all the datasets but did not obscure the interpretation of the data except at the Pakefield site. At Pakefield the seabed multiple was observed within 5m of the seabed in places, and reflections were obscured in an area to the east of the survey area resulting in a gap in the interpretation.

2.5.23. Weather effects are most likely to compromise the data. A certain amount of noise caused by adverse weather conditions and sea states can be filtered from the data in the post-processing stage. However, at each site surveying operations were suspended when the effect of vessel motion due to the sea conditions compromised the data quality to the extent that horizons of archaeological interest could not be resolved.

Data Processing and Interpretation

2.5.24. Seismic reflections observed on sub-bottom profiling data are caused by an impedance contrast (a product of the density and seismic velocity of a medium) between geological surfaces. The reflections correspond to the boundaries between different sedimentary units. These data are fundamental for the interpretation of sedimentary units and provide detail of the depositional environment, formation processes and likely hydrodynamic conditions at the time of deposition.

2.5.25. The seismic data were collected in industry standard format (SEG-Y or CODA format) and interpreted with two-way travel time (TWTT) along the z-axis, not depth. Therefore to convert the TWTT to the interpreted boundaries into depths the velocity of seismic waves through the geology must be known or estimated. For this project the velocity of the seismic waves through the sub-surface geology was estimated to be 1600m/s which is a standard estimate for shallow, unconsolidated sediments of the type being studied (Sheriff and Geldart 1983; Telford *et al.* 1990).

2.5.26. After all the seismic data had been interpreted and depths of sub-seabed boundaries calculated, the interpretation was exported in the form of x, y, z (easting, northing, depth) text files.

2.5.27. There are numerous software packages on the market that can be used to interpret sub-bottom profiler data. In the Round 1 project two products were trialled: Coda GeoSurvey software, and the combination of Promax and Geoframe software. The aim was to assess the difference in the interpretation of data using a standard package for processing and interpreting single-channel seismic data (Coda Geosurvey) and a software package normally used for interpreting multi-channel seismic data collected for oil and gas prospecting surveys (Promax and Geoframe). Full details of this analysis are provided in **Volume II** of this report.

2.5.28. Processing and interpretation of the data using Coda Geosurvey was carried out by WA; Promax and Geoframe were used by Dr Justin Dix and Dr Alex Bastos at the National Oceanographic Centre (formally Southampton Oceanographic Centre).

2.5.29. Coda Geosurvey is a software package designed for the acquisition and processing of shallow seismic sub-bottom profiler data. This software allows the data to be replayed one line at a time with user selected filters and gain settings in order to optimise the appearance of the data for interpretation. Coda Geosurvey then enables an interpretation to be applied to a line of data by identifying and selecting boundaries between layers.

2.5.30. Promax and Geoframe are complementary software packages for processing and interpreting seismic data. This software is very sophisticated, expensive and time consuming, and would not normally be used for interpreting single-channel seismic data collected during studies over marine aggregate areas.

2.5.31. Promax software was used to process all the seismic data in one batch, applying the basic stages of processing such as filters, gains and tidal corrections etc. The processed seismic data set was then interpreted using Geoframe software. Similar to Coda Geosurvey, this software package allows the user to interpret the data by identifying and selecting boundaries between layers.

2.5.32. The comparison between the two software packages was conducted along with the line spacing analysis (**Section 2.2**). An identical interpretation scheme was used for both processing systems. This scheme involved picking the two main reflectors visible in the data. Once the reflectors had been interpreted the positions of the boundaries were exported as x, y, z text files. The interpretation was exported at 50m, 100m and 200m line spacings. These data were then modelled into surfaces and features were compared. The methods of the modelling of surfaces are described in **Section 2.7**.

2.5.33. One significant difference between the two software packages is that Geoframe exports an x, y, z position for every shot point along the seismic line. The shot point refers to the position halfway between the triggered source and the hydrophone receiver and is calculated during the processing stage based on analysis of the sample rate of the boomer system. Coda Geosurvey only exports an x, y, z position for every point which the user has selected using the mouse. The result was an order of magnitude difference between the number of x, y, z points produced by Geoframe compared with Coda Geosurvey. Therefore, Geoframe produces interpretations with a higher horizontal resolution than Coda Geosurvey.

2.5.34. The Geoframe software produced a more consistent and resolute interpretation across the study area than the interpretation from Coda Geosurvey. This has resulted in higher quality surfaces being produced from the Geoframe interpretations with features being clearly defined. However, the basic morphology of the surfaces produced from the Geoframe and Coda Geosurvey interpretations were generally similar with no significant differences in the interpretation. When modelled using a 3D-visualisation software (see **Section 2.7**), the interpretation from both software packages showed the same features. However, the interpretations from the Coda Geosurvey software were less expensive to produce. The price difference between the two packages adds up to several ten thousand pounds.

2.5.35. Based on this study it was considered that the industry standard Coda Geosurvey software was the most appropriate system to use. The Coda system was then used for processing and interpretation of all subsequent Round 2 surveys.

2.5.36. Processing methodologies varied between study areas and also between lines within each site. Each data line was adjusted using filters to achieve best quality data for interpretation. The effects of the main filtering processes are shown in **Figure 13** and are described briefly below. Types of filters used included bandpass filters to remove the extreme high and low frequency signals from the data (**Figure 13b**) and a zap filter to remove noise from the water column (**Figure 13c**); the time varying gain is the measure of the increase in signal amplitude and increases the signal of the reflector and therefore highlights certain reflections within the image (**Figure 13d**). Trace mixing can be applied to the data to enhance the lateral continuity of horizontal features by averaging a specified number of traces (individual received signals) along the line (**Figure 13e**). Furthermore, swell filtering can be applied in order to minimise the effects caused by the motion of the receiving unit (**Figure 13f**). However, it should be noted that although the effect of swell can be minimised, excessive noise in the data caused by adverse sea-state can not be fully removed.

2.5.37. During the survey data was quality controlled with basic filters applied and surveying operations were suspended if the effect of vessel motion due to the sea conditions compromised the data quality to the extent that horizons of archaeological interest could not be resolved.

2.5.38. The layback and offsets from the towfish were added to the data at the processing stage to enable accurate positioning of the interpretation.

2.5.39. Once processed, the main bedding boundaries and unconformities were interpreted and tagged. The seismic nature of the units was assessed and an interpretation made concerning their sedimentary nature based on the different composition and density of the sedimentary units (Telford *et al.* 1990). For example, a seismically transparent layer is likely to represent fine-grained sediments, whereas an acoustically complex unit indicates coarse-grained sediments (**Figure 14a**). Structures within the sediment units such as evidence of prograding sediments (**Figure 14b**), onlapping sediments (**Figure 15a**) and cut and fill deposits (**Figure 15b**), also aid in the interpretation of depositional environments. Sediment architecture and interpretation with regard to submerged landscapes are discussed in more detail in **Section 6.2.**

2.5.40. The interpreted boundary layer data points were then exported as x, y, z data and where subsequently imported into 3D-visualisation software in order to interpret the lateral extent, morphology and interaction of the surface layers.

2.5.41. The seismic data interpretation, along with the sidescan sonar and bathymetric data were used to design a suitable geotechnical survey. The vibrocores allowed calibration of the identified geophysical horizons and provided samples for environmental analysis and dating. Design and implementation of the geotechnical survey is discussed in detail in **Sections 4** and **5.**

2.6. SIDESCAN SONAR

2.6.1. A sidescan sonar system consists of transducers on either side of a towfish which emit pulses of acoustic energy in the direction perpendicular to travel. The acoustic energy is reflected from the seafloor to the transducers and the strength of the returned pulses recorded via a workstation onboard the vessel. The strength of the reflections is dependent on the properties of the seafloor material; different sediment types produce different strength signals. This results in an acoustic image of the seabed relief and indicates the character of the seabed sediments. Areas where no acoustic energy is reflected are also displayed in the form of shadows. Shadows form behind objects protruding from the seabed or within seabed depressions.

2.6.2. Sidescan sonar data is collected at specific frequencies and ranges. The sound frequencies used are generally between 100kHz (low frequency) to 500kHz (high frequency). The range refers to the maximum distance (in metres) from the towfish that the sonar will display. Higher frequencies yield better resolution, but are generally less effective at greater ranges due to signal attenuation.

Acquisition

2.6.3. A sidescan sonar survey was carried out at all survey sites with the exception of the Arun study area. Two survey systems were used; the details are provided in **Table VIII.6.**

Study area	Towfish	Low frequency and range	High frequency and range	Positioning	Recording system
Arun	-	-	-	-	-
Eastern English Channel	Klein 3000 digital towfish	125 kHz at 75m range	445 kHz at 75m range	Nautronix ATSII USBL tracking system	SonarPro software
Great Yarmouth	Klein 3000 digital towfish	125 kHz at 75m range	445 kHz at 75m range	Calculated from layback	SonarPro software
Happisburgh and Pakefield	Edgetech 4200-FS digital towfish	120 kHz at 150m range	410 kHz at 75m range	Calculated from layback	Coda Geosurvey software
Humber	Edgetech 4200-FS digital towfish	120 kHz at 150m range	410 kHz at 75m range	Calculated from layback	Coda Geosurvey software

Table VIII.6: Details of the sidescan sonar systems used in the geophysical surveys.

2.6.4. Digital dual frequency systems are widely used in the marine aggregate industry for both prospecting and seabed sediment mapping. Both the Klein 3000 towfish and the EdgeTech 4200-FS towfish (**Figure 16**) are digital systems and were used to establish seabed sediment types in the survey areas.

2.6.5. The digital systems collect data at both high and low frequencies and produced high quality images suitable for archaeological purposes. The Klein 3000 towfish acquires both high and low frequencies at a single range, whereas the EdgeTech 4200-FS allows different range settings to be applied to the different frequencies. This allows high frequency data to be acquired at a short range resulting in a higher resolution dataset, whilst simultaneously recording low frequency, long range data. **Figure 17** shows the difference in resolution of the same features at both high and low frequencies, at short and long ranges.

2.6.6. The data quality was optimised by adjusting the height of the fish above the seabed by changing the length of the tow-cable to account for changes in water depth and vessel speed. The optimum height of the fish above the seabed is generally one tenth of the range. For example, for the Great Yarmouth and Eastern English Channel surveys the range used was 75m, therefore the optimum height for the fish would be approximately 7.5m above the seabed. For the EdgeTech towfish, data were collected with a range setting of 150m for the low frequency and 75m for the high frequency. As such, the towfish was positioned at a height ensuring that data were acquired to the full range setting at both frequencies, rather than being towed at a specific optimum height.

2.6.7. The positioning of the towfish during the survey is imperative to acquiring a good quality dataset. The position of the towfish can be calculated using offset and layback values or by mounting an acoustic positioning beacon to the fish from which a position can be attained. For shallow water operations the towfish layback can be calculated fairly accurately, however as the water depth increases and more cable is paid out this becomes more complex.

2.6.8. For the Great Yarmouth, Humber, and Happisburgh and Pakefield surveys the water depths were shallow (<30m water depth) with a maximum cable out of around 40m. Layback was estimated using the known distance from the vessel positioning antenna and the length of cable paid out behind the vessel. The layback was adjusted during the post-processing phase of the survey by identifying a distinct target on two data lines run in opposite directions; if the estimated layback was correct the feature on the two data lines would appear in the exact same position, if not the layback value was adjusted until accurate positioning of the target was achieved.

2.6.9. The Eastern English Channel survey was conducted in water depths of between 41 and 77m. Due to the depth of the water, up to 200m of cable was paid out. In order to accurately monitor the position of the towfish an ultra short baseline (USBL) tracking system was used which determined a range and bearing to the towfish from a known point on the vessel. The system was calibrated prior to the survey and any corrections were taken into account when calculating the final position of the towfish.

2.6.10. As well as the positioning of the towfish it is important to know the towfish orientation. If the fish is crabbing through the water due to strong water currents and not flying straight behind the vessel, accurate positioning of seabed features can be difficult. The accuracy of the data can be improved by processing the data using its known heading. Both the Klein 3000 and the Edgetech 4200 towfish have an inbuilt compass allowing the heading to be recorded throughout the survey.

2.6.11. During each survey it was ensured that the sidescan sonar range setting was chosen taking the line spacing into account. At each site at least 200% coverage of the seabed was attained. For example, at the Great Yarmouth study area a line spacing of 50m was used with a sidescan sonar range of 75m.

2.6.12. The data were collected digitally on a workstation either using Klein SonarPro software in *.xtf format for data acquired from the Klein towfish and using Coda Geosurvey software in coda format for data acquired from the EdgeTech towfish. The data were stored on hard disk as date/time referenced files for post-processing, interpretation and the production of sonar mosaics.

2.6.13. The sidescan sonar data were primarily acquired to assess sediment types across the survey area. Any sediment changes over the areas were noted and compared to the sub-bottom profiling data to assess the thickness of the uppermost layers. In the case of the Great Yarmouth survey a unit of fine-grained sediments possibly containing peat was identified close to the seabed surface. Based on the sub-bottom profiler data only, it was unclear whether this layer occurred at the seabed or whether there was a veneer of sediments overlying the fine-grained sediment. The sidescan sonar data indicated a covering of coarse-grained sediment over the entire survey area, suggesting a layer overlying the unit of interest. This was subsequently proven by the vibrocore data. This example serves to highlight how sidescan and sub-bottom profiling data can be used in conjunction to improve the interpretation of an area. The sidescan sonar data was also used with the bathymetry data to interpret any morphological features within the study areas.

2.6.14. Additionally, the sidescan sonar data were also used to inform the design of the vibrocore and grab sampling surveys to ensure that there was no debris, outcropping geology or other hazards in the planned sample locations.

2.6.15. Although sidescan sonar data does not provide detail on the sub-strata, the data contributes to the interpretation of both morphological features from the bathymetric data and also the uppermost unit of the sub-bottom profiler data which, depending on thickness, can be obscured by the seabed pulse. The acquisition of sidescan sonar data at the Round 2 survey sites have shown that it is an essential part of an integrated geophysical survey.

2.6.16. Data quality is important to ensure that the data is fit for interpretation purposes. Data quality can be affected by propeller noise of passing vessels; ships wake, either the survey vessel or other passing vessels; increased ambient noise caused by weather effects; fish in the water column; density changes in the water column; and towfish instability. During each survey any data adversely affected by these effects were re-run.

Sidescan Sonar Processing and Visualisation

2.6.17. The sidescan sonar data were acquired in a standard digital survey format (*.xtf format). The data were then processed using Coda Geosurvey software at WA. Coda Geosurvey is an acquisition and interpretation software package that allows sidescan sonar data to be re-played, processed and then merged to form a mosaic image of the surveyed area.

2.6.18. The software allows image enhancement by altering the colour definition of the image and improvement by altering time-varying gain (TVG) settings (gain is a measure of the increase in signal amplitude). Once processed sediment boundaries and seabed anomalies can be interpreted on-screen and the tags exported in x, y, z format.

2.6.19. Once the individual lines were processed they were joined together using the mosaicing package to produce a single georeferenced sidescan sonar image of each study area. This image could then be viewed in conjunction with other data sets. The package enables the lines to be layered in any order, allowing the ship-track artefact to be hidden from the mosaic, thereby ensuring the best quality image possible. The mosaic package also allows the fish layback to be adjusted in order to improve the accuracy of the positioning of anomalies and boundaries.

2.6.20. The advantage of using a digital towfish with an inbuilt compass is that it enables the navigation track to be smoothed according to the actual heading of the towfish rather than the heading of the vessel. Processing the data using the ships heading assumes that the towfish is positioned directly behind the vessel and orientated in the same direction as the vessel. However, this is not always the case, for example, the towfish orientation may be affected by strong currents causing the fish to crab along the navigation track. Processing the data using the fish-heading values will take these factors into account providing a more accurate position of the data.

2.7. VISUALISATION OF SURFACE LAYERS

2.7.1. In order to view the interpreted surface point data, representing the seabed or sub-seabed horizons, the data were input into a 3D-visualisation package which allowed the points to be gridded and viewed as a continuous surface. For the 'Seabed Prehistory' project the I.V.S Fledermaus 3D-visualisation and analysis software package was used.

2.7.2. This software can create a digital elevation model (DEM) represented by 3D surfaces for any set of data containing points with an x, y and z value. These surfaces are made by dividing the area into a grid based in a nominal cell size. The data is then interpolated and a depth value is assigned to each cell, before shading the surface with a user selected colour file so that the colours represent the relative heights over the surface. Several tools are provided within this software to interrogate the 3D surface in conjunction with other relevant geo-referenced data sets. As these surfaces are best studied in 3D, it can be difficult to get all the information they display onto a flat image; therefore Fledermaus allows cross-section profiles across these surfaces to be made to show selected vertical information.

2.7.3. A cell size and weighting must be selected when gridding a data set. The chosen cell-size is the minimum value that can be used to ensure that data can be assigned to each cell. This value will vary depending on the line spacing used and the distance between data points. The resulting surface will be made up of rectangles corresponding to the cell size. The heights between neighbouring cells will be averaged over the number of adjacent cells corresponding to the weighting value. The weighting value affects the smoothing of the data. The higher the weighting value used, the smoother the data will appear. If there is a large number of closely spaced x, y, z points then small cell sizes can be used and a surface containing a high resolution of horizontal spatial detail can be produced.

2.7.4. In data sets with relatively large gaps between the data points, a large cell size must be used to prevent holes appearing in the surface. Any gaps in the data, which leave empty cells in the gridding process, will result in holes being left in the surfaces produced, i.e. holes will appear where there is not an even distribution of data points in order to ensure that a data point exists in each cell for the gridding process. Alternatively the weighting could be increased instead of the cell size but this would effectively smooth the data and reduce the vertical resolution.

2.7.5. The cell size for the surfaces was dependent upon the line spacing. The cell sizes and weightings were chosen through a process of trial and error after examining the data in order to give surfaces with the best possible level of detail while at the same time giving the fewest holes in the surface as possible.

2.7.6. All the surfaces produced in Fledermaus for this study contained digital artefacts (i.e. ridges representing features that are not real) allowing the direction of the survey lines to be seen in the modelled data. This was a result of selecting a cell size which was smaller than the line spacing of the survey grid.

2.7.7. Perhaps most importantly with regard to submerged landscape interpretation, Fledermaus allows the depths of sub-surface horizons to be directly referenced to depth below OD seabed values. Referencing the marine data to the same datum (OD) as terrestrial data enables the sub-surface horizons to be directly associated with terrestrial deposits, and marine deposits from different areas.

2.8. CONCLUSIONS

2.8.1. In general the survey design, both line specification and choice of area, is dependent on the purpose of the survey and the scale of the features to be resolved. Larger features such as palaeochannels may be observed with quite large line-spacings, however, organic horizons that may be used to sample for environmental conditions and dating may occur at varying scales and therefore a smaller line spacing would be required. As it is not feasible to conduct every survey at a small line spacing, such as 10m, a compromise needs to be made.

2.8.2. Based on the results of the 'Seabed Prehistory' project it was found that surveys undertaken with a line spacing of no more than 100m with crosslines situated up to twice the principle line spacing provided a quality dataset for interpretation. This spacing should ensure the determination of features greater than 100m, depending on their orientation. While a 50 x 50m grid pattern would improve the resolution and therefore clarity of geoarchaeological interpretation, this may not be regarded as cost-effective.

2.8.3. In order to successfully position the data for interpretation purposes it was considered that the accuracy of the positioning system (vessel position) should be better than 2m and the position of the geophysical survey equipment should be resolved to better than 5m.

2.8.4. Based on the results of the project it is considered that the bathymetry data should be referenced to a vertical reference datum either through tidal observations or through GNSS surveying techniques, rather than using predicted tides.

2.8.5. On the basis of this project, alternative systems, such as pinger and chirp, have achieved better resolution of fine-grained (silt and clay) deposits specifically within the first five metres of the seabed, but do not achieve sufficient penetration in the coarse-grained (sand and gravel) deposits targeted for aggregate dredging.

2.8.6. In general, boomer systems are likely to produce the best compromise between penetration in the seabed geology and the resolution of geological horizons. As such, it is considered that the boomer is the most versatile source for archaeological purposes.

2.8.7. Processing of the data allowed the interpretation to be made based on the best image possible. As such, it is recommended that sub-bottom profiler data should be acquired digitally to allow post-survey processing with gain and filter settings optimised to enable in-depth geophysical interpretation.

2.8.8. Based on the above discussion certain conclusions can be made regarding the use of sidescan sonar systems when investigating the seabed prehistory of an area:

- Digital dual frequency systems are already widely used in the marine aggregate industry and are successful in producing data for archaeological purposes;
- The range used needs to be set to ensure full coverage of the site. The range setting used is dependent on the survey line spacings used. Seabed coverage of 200% allows seabed targets or sediment boundaries to be observed on at least two data lines acquired in opposite directions. This allows the positioning accuracy to be checked and improved during post-processing of the data;
- In areas of deeper water where there is a lot of cable out and strong- and cross-currents may occur a tracking device on the towfish may be required to ensure accurate positioning of the data;
- To ensure data quality, surveying operations should be suspended if the effect of the sea conditions compromises the data quality either due to noise effects on the data or excessive instability of the towfish.

2.8.9. Using a digital sidescan sonar fish, preferably with an inbuilt compass, allows processing of the data to be carried out. This enables the production of better images for interpretation purposes and allows the positioning accuracy of the data to be assessed and adjusted.

2.8.10. The surveys have highlighted that geophysical data is a useful tool for conducting the initial palaeogeographic evaluation of an area. Although important palaeosurfaces can be identified on the geophysical data, in order to fully reconstruct the palaeogeographic model of the area ground-truthing of the geophysics data is required in the form of vibrocores, grab sampling and subsequent environmental and dating analyses of these data.

3. VIBROCORING

3.1. INTRODUCTION

3.1.1. The geophysical survey data provides a model of the seabed stratigraphy and potential remnant geomorphological features, and the aim of vibrocoring is to investigate the formation and modification of that morphology by hydrological regimes, transgression, regression, and potentially, human action.

3.1.2. Geoarchaeological core log descriptions, sampling of the cores and analysis of pollen, diatoms, ostracods, foraminifera, molluscs and waterlogged plants within the sediment, as well as dating appropriate samples, should help define prehistoric seabed deposits and identify any relationships between them.

3.1.3. Specifically, the analysis of appropriate vibrocores can characterise the depositional environments of the sedimentary units identified by the geophysical data. This can further inform the geophysical model of the palaeogeographical features and aid the reconstruction of various remnant prehistoric landscapes. Vibrocore survey data should provide:

- calibration of the geophysical data;
- a relative chronology for the area identifying the relationship between palaeogeographical features;
- a measure of the absolute timescales involved in the depositional processes (through optical and radiocarbon dating of appropriate samples);
- evidence for the environmental reconstruction of the depositional environments;
- evidence of marine transgression.

3.2. SAMPLING STRATEGY

3.2.1. A judgement-led sampling strategy was developed, based on the initial geophysical data interpretation. A coordinate and recovery depth based upon the geophysical data was generated in order to investigate key stratigraphic sequences. Based on the geophysical unit in question a location radius was suggested in order to ensure the relevant unit or structure was sampled.

3.3. ACQUISITION

3.3.1. Between September 2003 and July 2006 five vibrocoring surveys were undertaken. In each case, WA contracted an external survey company to carry out these surveys. Details of the surveys and companies involved are provided in **Table VIII.7**.

Study area	Survey company	Dates	Core barrel length	Number of core locations	Number of cores
Arun	Lankelma Seacore Offshore/ Emu Ltd	27/09/03 – 28/09/03	6m	10	20
Eastern English Channel	Gardline Environmental Ltd	14/10/05 – 24/10/05	6m	8	16
Great Yarmouth	Gardline Environmental Ltd	23/07/06 – 24/07/06	5m	8	17
Happisburgh and Pakefield	Gardline Environmental Ltd	19/07/06	5m	3	5

Humber	Gardline Environmental Ltd	22/07/06 – 22/07/06	5m	8	16

Table VIII.7: Details of the vibrocoring surveys.

3.3.2. For each survey a high powered vibrocore unit (**Figure VIII.18**) was used with either a 5m or 6m core barrel. The length of the core barrel is the maximum achievable penetration into the seabed and therefore the maximum length of sediment core that can be obtained.

3.3.3. Generally, at each core location two cores were acquired. The first was acquired using a standard Perspex core barrel liner for sedimentological and environmental analysis. The second core was specifically acquired for optically stimulated luminescence (OSL) dating. These were recovered using black vibrocore liners and kept separately in a darkened container to prevent exposure to light. The process of OSL dating assesses the age of sandy sediments when they were last exposed to light, therefore any exposure of the cored sub-seabed sediments would contaminate the sediments and dating analyses would not then be possible.

3.3.4. Each core was cut into 1m lengths (**Figure VIII.18**) for ease of transport from the vessel to WA. Each core section was capped and labelled and taken back to WA for comprehensive logging and analysis. At each core location the date, time, position and corrected water depth was recorded by the survey company and provided to WA.

3.3.5. All positional data were generated during the surveys by the commissioned companies. In all cases DGPS (differential global positioning system) data were used. This provided vessel positioning to an accuracy of 1m.

3.3.6. In order to accurately position the core sample the offset distance from the vessel DGPS antennae to the vibrocore deployment point was measured and incorporated into the positioning data. DGPS positions were recorded in geodetic coordinates (WGS 84 datum) during the surveys. The geodetic coordinates were then projected to British National Grid (OSGB 36 datum) for the Arun survey and UTM zone 31 (WGS 84 datum) for the rest of the surveys.

3.3.7. Accurate water depths for each sample were acquired using a single-beam echo-sounder. The depths were later tidally reduced to Ordnance Datum (OD) Newlyn using local tide data (**Section 2.4**).

3.4. Processing and Interpretation

3.4.1. The vibrocores were split longitudinally and a paper and photographic record made (**Figure VIII.19**). Basic sedimentary characteristics were recorded including depositional structure as well as texture, colour and stoniness (cf. Hodgson 1976).

3.4.2. From the descriptions a sedimentary log was plotted for each core. The logs were then compared in terms of their vertical distribution throughout the study area. This was achieved by plotting the cores in sections referenced to OD.

3.4.3. On the basis of the descriptions and the comparison of the core logs, major sedimentary units were ascribed principal phases. These were numbered and correlated with the sedimentary units described within the seismic interpretation. Profiles created by the phasing were integrated with the seismic data enabling comments on their palaeoenvironmental and geoarchaeological significance to be made.

3.4.4. Sediments recovered included peat, clay, silt, sand and gravel (**Figure VIII.19**). Terrestrial environments were directly inferred from peat (Arun; **Volumes II** and **III**), gleyed clay (Great Yarmouth; **Volume IV**) and sub-aerially exposed gravels (Eastern English Channel; **Volume V**). These terrestrial sediments can be seen in (**Figure VIII.19**).

3.4.5. Fluvial and glaciofluvial environments were inferred from sediments recorded in the Eastern English Channel (**Volume V, Section 3.1-3.2**), Great Yarmouth (**Volume IV, Section 3.1-3.2)** and Humber study areas (**Volume VI, Section 3.1-3.2**). Glacial till was recorded in the Humber study area (**Figure VIII.19).**

3.5. GEOPHYSICAL AND GEOTECHNICAL DATA COMPARISON

3.5.1. Once the vibrocores have been logged and interpreted the data is used to inform the geophysical interpretation. The sub-bottom profiler data enables the structure and general composition of sedimentary units to be interpreted. However, combined with the sedimentary data and results of the environmental analysis, questions concerning the stratigraphy and depositional environments of the sediment units can be answered.

3.5.2. The depths of the geophysical unit boundaries and the measured depths of the sediments boundaries in the vibrocores within the target area vary slightly. There are numerous potential causes of these discrepancies. It may be due to the vertical resolution of the seismic data. The vertical resolution of the boomer data is approximately 0.4m (**Section 2.5**). Sedimentary layers thinner than 0.4m are unlikely to be distinguishable on the data. Also, an average speed of sound velocity of 1600 m/s through the sediments has been used, and slight variations in the seismic velocity of the sediment will result in subtle depth changes that may be apparent when comparing the depths of boundaries to the sediment boundaries observed in the vibrocore. Discrepancies can also be due to the distance from the core location to seismic data, and the undulating nature of the boundaries over short distances.

3.5.3. Similarities in sediment type can also cause discrepancies between the sub-bottom profiler data and the vibrocore data. An obvious horizon within the geophysical data can be represented only by gradual changes within the vibrocores. Equally, obvious sedimentary changes within the vibrocores may not cause strong reflection on the geophysical data. This was highlighted in the Humber study area (**Volume VI**). As such geophysical and geotechnical data need to be treated as two halves of one dataset.

3.6. ENVIRONMENTAL ASSESSMENT AND ANALYSIS

3.6.1. By comparing the geoarchaeological and geophysical results the major sedimentary units apparent within the cores were investigated by sampling. Type of sample,

sample size, sample location and sample numbers chosen for assessment are based upon considering the following factors:

- sediment type;
- research questions;
- preservational factors.

3.6.2. Due to the size of the vibrocores (*c.* 10cm diameter), only a limited amount of sediment from each horizon is available for sampling. Therefore the smaller and more abundant a particular type of environmental remain is, the more likely it is to be encountered within a particular sedimentary horizon. Pollen, diatoms, foraminifera and ostracods are all small (generally less than 1mm diameter) and may be very abundant within relatively small amounts of sediment. Sediment samples for pollen usually comprise *c.* 4cm^3 and those for foraminifera and ostracods comprise 10cm^3. Samples taken for molluscs and waterlogged plant remains were approximately 500cm^3 in size. Processing of samples is dependent upon sediment type and a range of techniques is often employed.

3.6.3. Samples are assessed for presence and preservation of environmental remains. This assessment informs the potential of the sediments and environmental remains they contain to elucidate the environmental, chronological and archaeological significance of the deposits.

3.6.4. Analysis of environmental remains is based upon the results of the assessment of samples. Assessment and analysis of pollen, diatom, foraminifera, ostracod, mollusc and waterlogged plant samples were undertaken involving specialist processing and identification. Those samples and sequences of sediments deemed environmentally and archaeologically significant are then subjected to analyses. **Table VIII.8** shows the types of and numbers of assessed and analysed samples undertaken at the different locations.

Study area	Pollen	Diatoms	Forams	Ostracods	Molluscs	Water-logged
Arun	48	33	48			
Eastern English Channel	10	10	12	12		
Great Yarmouth	35	8	32	32	4	4
Happisburgh and Pakefield	20	10	7	7		
Humber	10	10	14	14		

Table VIII.8: Details of types of and numbers of assessed and analysed environmental samples undertaken at the different survey areas.

3.6.5. Pollen samples were taken at each area. The presence of different types of trees, shrubs, grasses and ferns can be inferred from the pollen and spores preserved within a sediment. These pollen data can be used not only to identify the vegetation type but also the nature of the depositional environment. Relative chronological (biostratigraphic) information can also be inferred for the Pleistocene period due to the successive colonisation of certain plants from and to glacial refugia. For example, the presence of *Najas Minor* at the Great Yarmouth study area is an indicative species of the Ipswichian (OIS 5e) or earlier (**Volume IV, Section 4.2**). Pollen samples were also used for the detection of microcharcoal (**Volume IV**).

3.6.6. Diatom samples were taken at each area. Diatoms are siliceous unicellular green algae which are often preserved in great numbers within waterlain deposits. Many diatoms are particular to water bodies with specific levels of salinity, dissolved oxygen and pH and types of sediment and vegetation. As such, diatoms provide evidence of the size of water bodies, their salinity and water temperature of the of the waterlain deposits, further enhancing the evidence for the depositional environment.

3.6.7. Foraminifera samples were taken at each area. Foraminifera are microscopic unicellular protists which inhabit marine and brackish waters. The hard part named the test (or shell) is often readily preserved within sediments. Within estuarine, salt marsh and shallow marine areas they are often highly indicative of elevation within the tidal frame and salinity. Some foraminifera are of biostratigraphic value within the Pleistocene.

3.6.8. Ostracods samples were taken from Great Yarmouth (**Volume IV**), Eastern English Channel (**Volume V**), Humber (**Volume VI**) and Pakefield (**Volume VII**) vibrocores. Ostracods are a sub-class of crustaceans which inhabit virtually every aquatic environment. The body is enclosed by a calcified carapace which is preserved within sediments. Ostracods can inform upon the salinity, water movement, sediment type, water depth and temperature of a depositional environment. Ostracods are useful biostratigraphic indicators within the Pleistocene.

3.6.9. Molluscs were assessed and analysed from the Great Yarmouth vibrocores (**Volume IV**). Molluscs are soft bodied invertebrates with a hard external calcareous shell which preserves well within sediments. Molluscs inhabit marine, brackish, freshwater and terrestrial environments and are particular to salinity, temperature and vegetation types. Molluscs can be of biostratigraphic value. Molluscan material was ^{14}C radiocarbon dated (**Section 3.7**.2).

3.6.10. Waterlogged plant material was assessed from the Great Yarmouth vibrocores (**Volume IV**). Within waterlain sediments plant material is often preserved and can inform upon local aquatic environments and vegetation. Plant material was ^{14}C radiocarbon dated (**Section 3.7**.2).

3.7. DATING

3.7.1. ^{14}C (radiocarbon) and OSL (optically stimulated luminescence) samples were taken of relevant deposits in order to provide chronological information. **Table VIII.9** outlines the numbers of ^{14}C and OSL dates taken at each of the different areas.

Study area	**^{14}C**	**OSL**
Arun	4	7
Arun Additional Grabbing	2	0
Eastern English Channel	3	6

Study area	^{14}C	OSL
Great Yarmouth	7	8
Happisburgh and Pakefield	0	0
Humber	3	6

Table VIII.9: Numbers of samples dated using ^{14}C and Optically Simulated Luminescence (OSL) techniques at the different survey areas.

3.7.2. Stasis horizons containing vegetative organic matter (peat) suitable for ^{14}C dating were only encountered on the Arun site. Where present short lived plant remains such as *Phragmites* reed stems were chosen for dating. Charcoal was dated from within a peat deposit in the Arun Additional Grabbing survey (**Volume III**). Plant material was ^{14}C dated at Arun (**Volumes II** and **III**) and Great Yarmouth (**Volume IV**). Mollusc shells were common in many of the deposits and unworn specimens were chosen as the next most suitable material for ^{14}C dating where suitable vegetative plant material was not available. Molluscan material was ^{14}C dated from the Great Yarmouth (**Volume IV**), Eastern English Channel (**Volume V**) and Humber (**Volume VI**) vibrocores.

3.7.3. ^{14}C dating in this project has covered a time span from the Devensian (49,500±3,000 BP (NZA-27095), Great Yarmouth, **Volume IV**) to Holocene (5,605±35 BP/ 4,150 – 3,970 cal. BC (SUERC-12316), Humber, **Volume VI**) periods. One sample from Great Yarmouth (**Volume IV**) was beyond the limits of radiocarbon dating.

3.7.4. OSL dates were chosen from suitable sandy horizons on the basis of the geophysical data interpretation and the core logging. As the OSL sample was obtained from a different core, exact sedimentary horizons were difficult to target. In some cases where more than one core was logged from the same location, markedly different sediments were recorded. To overcome this problem sedimentary logs were provided with the OSL samples and if the OSL samples when taken did not match the sedimentary descriptions the samples were rejected.

3.7.5. OSL dating in this project has provided dates from the Cromerian Complex (577.2±65.4 ka, Great Yarmouth, **Volume IV**) to the Holocene (5.6±0.5 ka, Humber, **Volume VI**) periods.

3.8. CONCLUSIONS

3.8.1. Vibrocoring can be used effectively as an archaeological tool, groundtruthing geophysical data and providing detailed sedimentary information. The vibrocores can also be sub-sampled for environmental remains and material for absolute dating. The dates obtained and information on sea level and the environments present when the deposits were forming can be used to predict the nature of the archaeological resource.

3.8.2. In one core in the Great Yarmouth area (**VC1**; **Volume IV**; **Figure VIII.19)**, small amounts of charcoal were recovered at three levels potentially dating from the Wolstonian (OIS 9, 8, 7 and 6) and Ipswichian (OIS 5e) periods. This highlights the potential for vibrocores to recover archaeological material. In the 1980's a flint tool was recovered in a core from the Viking Bank in the North Sea (Long *et al.* 1986). Clearly the chance of recovering artefactual evidence from vibrocores is very slim due to their size. However targeting potential archaeologically interesting layers after geophysical, sedimentological, environmental and chronological data has been considered with reference to relevant site predictive models might be productive (**Section 6.3**). Small samples from cores can be used for detecting microcharcoal (**Volume IV**). This method could be employed in order to search for more deeply buried archaeological sites not accessible by grab sampling or diving.

4. GRAB SAMPLING

4.1. COMPARATIVE METHODOLOGICAL ASSESSMENT

Introduction

4.1.1. Seabed grab sampling surveys are undertaken by the aggregate industry as part of benthic studies in preparation for the marine ecological assessment element of an EIA. This methodology had not previously been tested as a tool for archaeological evaluation.

4.1.2. Consequently, the aim of this study was to establish:

- whether it is a viable methodology for locating prehistoric remains within the upper marine sediment layers of the seabed;
- whether it is a useful/productive methodology for evaluating the potential archaeological resource by highlighting if any correlation between artefact distribution and buried relict palaeogeographies or archaeological deposits exists.

4.1.3. Grab sample surveys were conducted in the Arun study area (Round 1 and Round 2), in the Eastern English Channel study area and in the Humber study area (both Round 2) (**Figure VIII.1**). All surveys were carried out on behalf of WA by survey contractors. **Table VIII.10** provides an overview of the study areas, survey contractors and dates and the relevant report volumes in which detailed results can be found.

Study area	Survey date	Survey Company	Report volume
Arun	27/09/03-29/09/03	Emu Ltd	II
Arun Additional Grabbing	26/03/05-09/06/05	Titan Surveys Ltd.	III
Eastern English Channel	22/09/05-24/09/05	Gardline Environemntal Ltd.	V
Humber	20/07/06-22/07/06	Gardline Surveys Ltd.	VI

Table VIII.10: Details of the grab sample surveys.

Equipment

4.1.4. Aggregate-related, marine ecological assessment surveys use the ‘Hamon grab’ to take benthic samples from coarse substrates (ODPM 2002). Grab sampling does not preserve stratigraphic context of unconsolidated sediments. However, as observed during the Arun additional gabbing survey (**Volume III**) some stratigraphic information was inferred from sample of peat.

4.1.5. The Hamon grab used penetrates the uppermost 0.1 to 0.3m of the seabed, providing a 'mixed' sediment sample. The grab provides a conventional surface sample unit of $0.1m^2$ and a sample size of up to 10 litres. Grab deployment and recovery were achieved by using an A-frame and winch onboard the vessels (**Figure VIII.20**).

4.1.6. All positional data were generated during the surveys by the commissioned companies. In all cases DGPS (differential global positioning system) data were used receiving corrections from terrestrial base stations (Arun, Arun Additional Grabbing and Humber surveys) or via satellite subscription (Eastern English Channel survey). These corrections provided vessel positioning to an accuracy of 1m. To accurately position the Hamon grab the offset distance from the vessel DGPS antennae to the grab deployment point was measured and incorporated into the positioning data. Accurate water depths for each sample were acquired using a single-beam echo-sounder.

Survey Design

4.1.7. A gridded sampling strategy was adopted in order to achieve a systematic distribution of samples. Therefore, all 'Seabed Prehistory' grab sample survey areas were divided into grids of $100m^2$ squares. The central point of each square was the designated sample position, giving for example 100 grab targets for a $1km^2$ survey area (**Figure VIII.21**).

4.1.8. The systematic strategy would allow an appraisal of the efficacy of the sampling method as an investigative archaeological technique. The systematic strategy would also assess any discernible correlation between the locations of artefacts, or absence of artefacts and the geoarchaeological features which were identified by geophysical and vibrocoring techniques.

4.1.9. The Arun grabbing survey covered the central Arun study area of $1km^2$, resulting in 100 grab targets. During the Arun Additional Grabbing project this area was extended to a further four 1km x 1km squares (C, E, F and H), within an overall area measuring 2km x 4km, inclusive of the area (labelled G) sampled previously (**Figure VIII.21**). The intent of the square distribution was to cover the width of the palaeovalley (E, F, G, H) and to follow the palaeochannel upstream (C) (**Figure VIII.21**). The original sampling cell size of 100 metres was also applied in the additional squares, resulting in another 400 grab targets.

4.1.10. The locations of the Eastern English Channel grab samples were selected during the geophysical survey to include the edge of the palaeochannel (**Figure VIII.21**). The grid covered a total area of 0.5 x 2km, resulting in 100 grab sample targets. The Humber grabbing area covered a total of 1km x 1km and was chosen because of the variety of sedimentary units discernible in this area in an initial geophysical assessment, and because this area was free of mobile sand banks. Samples were taken at 100 metres centres which resulted in 100 grab sample targets (**Figure VIII.21**).

4.1.11. **Table VIII.11** provides an overview of the size of all grab sample survey areas and the number of grab sample targets per study area.

Study area	Size of grab sample survey area	Number of grab sample targets
Arun	1km x 1km	100
Arun Additional Grabbing	2km x 4km (including 1km^2 sampled previously)	400 (500 including previous sample targets)
Eastern English Channel	0.5km x 2km	100
Humber	1km x 1km	100

Table VIII.11: Details of the size of grab sample areas and numbers of samples obtained at each survey area.

Methodology

4.1.12. At each sampling site the survey vessel was manoeuvred onto station with the aid of the navigation system, which included a helmsman's monitor displaying the target site.

4.1.13. DGPS positions were recorded in WGS84 datum in geodetic coordinates (latitude, longitude) during the surveys. The position tolerance at each location varied according to the conditions. The geodetic coordinates were then projected to British National Grid (OSGB36 datum) for the Arun and Arun Additional Grabbing surveys and UTM zone 31 (WGS84 datum) for the Eastern English Channel and the Humber surveys. The water depths were later tidally reduced to Ordnance Datum (OD) Newlyn using local tide data (**Section 2.4).**

4.1.14. A single grab sample of between eight and ten litres was acquired. The site number, date, time, water depth and position of each sample were recorded.

4.1.15. Where inadequate sample size, which comprised a volume return of less than eight litres, occurred additional samples ('hits') were taken in the same target position, so that a representative sample could be obtained. If a subsequent hit provided an appropriate amount of material earlier hits were discarded, or the samples were combined and the coordinates of each of the hits averaged to give a single coordinate for the actual target location. Up to three attempts were made to recover a valid sample at any one location.

Processing

4.1.16. The general onboard processing methodology comprised the washing of each sample through a 1mm sieve, effectively eliminating clay and silt sized particles from the residue. Material less than 1mm diameter was discarded. A brief examination of the sieve residue was made prior to the sample being stored for laboratory processing. This was undertaken primarily to locate any larger or immediately identifiable artefacts. If samples proved to be abundant with material of archaeological interest additional grab locations were planned in these locations. The sieved and washed residue from each sample was transferred to a labelled plastic storage container along with the sample identification tag. Samples containing blocks (and large quantities) of fine-grained sediments including peat, silt and clay were transferred to the sample bucket with minimal or no onboard wet sieving.

4.1.17. The Humber grab samples were not washed onboard, but put into labelled plastic tubs for storage and transportation to WA's environmental premises at Salisbury.

This adaptation of the project methodology was due to logistical constraints which did not allow for an archaeologist to be present during the fieldwork. This provided an opportunity to establish whether solely laboratory sample processing was an effective method.

4.1.18. The bucketed samples were transported to WA's environmental section, where standard artefactual sieving practise was established for processing the grab samples. The wet-sieve processing was conducted through a nest of sieves of mesh sizes 9.6mm (classed as 10mm for processing purposes), 4mm and 1mm. The 10mm sieve is generally considered to be a standard mesh size for artefact retrieval from the sampling process. However, since Palaeolithic or Mesolithic material may have been encountered within the sample areas, a 4mm sieve, which is accepted as an appropriate mesh size for retaining microlithic elements and for lithic debitage retrieval, was also used. The use of the 4mm sieve for samples from terrestrial contexts has shown good retrieval of archaeological material, whilst limiting smaller fraction losses.

4.1.19. The sieving and analysis process of the Round 1 Arun grab samples attempted to extract all prehistoric artefacts from within both the 10mm and the 4mm sieves. Difficulties in positively determining anthropogenic material below 2-3mm, combined with the overall paucity of observed artefacts from the larger mesh sizes, suggested that further analysis of the finest material would have been neither archaeologically productive nor cost-effective. The 1mm sieve residue was therefore discarded without further processing.

4.1.20. However, in Round 2 after the results of the Arun Additional Grabbing survey the 1-4mm as well as the 10mm and 4-10mm residues were all visually scanned for archaeological material, in order to make allowance for fragmented charcoal residues and tiny environmental remains. Archaeological finds from all surveys, including flint, bone, slag, clinker, glass, burnt stone and ceramic building material (CBM), as well as environmental remains and fossil finds, were retained for further analysis. The less than 1mm residues (of those samples not already washed onboard) were discarded.

4.1.21. In the case of the Arun Additional Grabbing survey, the sample processing strategy was reconsidered for samples containing large amounts or blocks of sediment (peat) that appeared to show intact sedimentary architecture. Samples containing peat and fine-grained sediments (containing environmental material) were processed in the above manner and sub-samples were taken for environmental analysis. The sub-samples were also scanned for archaeological material before storage.

4.1.22. Pollen and diatom samples as well as foraminifera/ostracod samples were taken from the centre of uncontaminated blocks of peat in order to establish likely depositional conditions and environments (**Section 3.6**). Sample sizes of approximately $4cm^3$ and $10cm^3$ respectively were taken, labelled and kept in cold storage. Furthermore, radiocarbon samples were taken from the centre of uncontaminated blocks of peat. Where possible stem remnants were taken and stored in cold storage for radiocarbon submission. Two litre mollusc samples were also taken. In each case the sediment was wet sieved through a nest of sieves of the sizes 10mm, 4mm, 1mm, 500µm and 250µm. After scanning the residues for archaeological material they were dried and kept for further analysis. One litre sub-samples were processed by flotation for the retrieval of plant macrofossils and invertebrate remains. The samples were soaked in hot water for 24 hours to disaggregate the sediment. The samples were then sieved to 500μm using standard flotation practices. The residue was scanned for archaeological material and then stored in Industrial Methylated Spirit (IMS) for future analysis. Wood and charcoal retrieved from the samples were kept for further analysis.

4.1.23. Organic material, and in particular peat, pertinent to investigating seabed prehistory was not found in any of the grab samples during the eastern English Channel and Humber grab sampling surveys. As such, no palaeoenvironmental sampling was carried out.

Taxonomy

4.1.24. The general taxonomy of recovered flints was established during the Round 1 Arun study (**Volume II, Section 3.2**). The struck flints were defined as highly probable, probable, possible or improbable in terms of human origin (**Table VIII.12; Volume III, Appendix IV)**. The flints showing the greatest anthropogenic potential were assessed on the presence of bulb, striking platform, and the overall nature of the flint. Flints classified as probable artefacts contained elements which appeared to have a possible function, or which had elements that are not easily ascribed to natural processes alone, such as minor blade-like characteristics or resemblances to secondary flakes, piercers and pseudo-microliths. Examples classed as possible flint artefacts included small flakes and chips that could be anthropogenic in origin, but lacked sufficient indicators to be conclusively diagnosed. Improbable artefacts comprised sufficiently small (microlithic?) flints with misplaced bulbs, absent striking platforms, thermal fractures and cortical elements which were suggestive of mechanical, rather than anthropogenic, processes.

Level	Criteria
Highly Probable	Recognisable tool or debitage type Obvious platform & bulb, preparation, regular anthropogenic dorsal scars
Probable	Obvious platform & bulb, irregular dorsal scars
Possible	Obvious bulb, irregular/no dorsal scars
Improbable	Unusually placed bulb, no dorsal scars

Table VIII.12: Criteria for determining potential anthropogenesis of struck flint.

4.1.25. Apart from possible prehistoric lithic artefacts, environmental remains and other finds were recorded in order to establish the character and nature, of the upper seabed sediments. This information also informed other factors such as sediment mobility. Definition of environmental remains followed EH guidelines (English Heritage 2002) and comprised of plant material (reeds, hazelnut and wood including charcoal) and animal remains (molluscs, beetles and bones) as well as fossils such as fish teeth and fossilised bird bones.

4.1.26. Other finds included slag, clinker, coal, burnt stone, ceramic building material (CBM) and glass. Slag residues, categorised on the basis of its vitreous nature, and the lighter, airier clinker-like material as well as coal and burnt stone can predominantly be accounted for by industrial shipping activities; they are possibly residues from firing chambers fuelling ship's engines. Apart from these probably modern materials, other finds were either non-diagnostic or undatable.

4.1.27. Furthermore, the presence, size and condition of erratics was recorded, as well as general sediment characteristics such as gravel, sand, silt, clay, peat and shell contents.

Results

4.1.28. The Round 1 Arun grab samples yielded a total of 119 struck flints, three of which were classified as highly probable, four as probable, 18 as possible and 94 as improbable artefacts. In the Round 2 Arun Additional Grabbing survey a total of 668 struck flints were identified. Of these, 12 were described as highly probable flint artefacts, with a further ten probable, 19 possible and 627 improbable artefacts (**Figure VIII.22**). In the other two areas that were studied, Eastern English Channel and the Humber, no struck flints were identified.

4.1.29. However, other finds were retrieved from all study areas. These generally included slag, clinker and coal. Additionally, the Arun and Arun Additional Grabbing samples yielded corroded iron residues, burnt stone, ceramic building material (CBM) and glass.

4.1.30. Faunal remains were also recovered from all survey areas. Within the Eastern English Channel samples these were restricted to fossils, whereas the Humber samples contained fossils and recent animal bones of fish and mammals. However, the Arun and Arun Additional Grabbing samples proved to be more productive, resulting in the recovery of animal bones (birds, fish and others such as the rib of a medium mammal and an amphibian (frog or toad) pelvis), fossils, plant and wood remains including hazelnuts, reed stems and roots, beetle (Coleopteran) wing cases and some freshwater and terrestrial molluscs. The variety of finds per study area is summarised in **Table VIII.13**.

Study area	Fossils	Animal bones (birds/ fish/ mammals)	Beetles	Terrestrial and freshwater Molluscs	Plant and wood remains	Charcoal
Arun (Round 1-2)	X	X	X	X	X	X
Humber	X	X				
Eastern English Channel	X					

Table VIII.13: Details of finds from the grab sampling surveys.

4.1.31. Within the overall Arun sampling area, peat was recovered from *c.* 50 samples. The charcoal, most of the reed stems and roots, and beetle remains were extracted from lumps of peat or silt and clay. Approximately a third of these c. 50 samples contained more than 70% of peat (**Volume III, Section 3.3.3**, **Volume II, Appendix II**). Peat was not recovered from the Humber or the Eastern English Channel grab samples, even though the Eastern English Channel grab samples did contained low quantities of silt in some cases.

4.1.32. Two samples from the Arun Additional Grabbing grabs were submitted for radiocarbon (^{14}C) dating. One reed stem (*Phragmites* sp.) gave a result of 8,815±40 BP/ 8,200-7,740 cal. BC (SUERC-12007). The oak heartwood charcoal recovered from peat in the same sample gave a result of 8,893±30 BP/8,230-7,960 cal. BC (NZA-26303) (**Figure VIII.23**.

4.1.33. The Eastern English Channel grab samples were dominated by gravelly sand with a high shell content, whereas the Humber grab samples consisted of sand and gravel in varying proportions which contained marine shells as well. Within the Arun area, most samples were also dominated by high proportions of gravel and sand with a high shell content, apart from the peaty sediments in *c.* 1/10 of the samples as described above.

Discussion

4.1.34. One of the key issues that had to be addressed if artefacts were located was the question of context, i.e. were the artefacts recovered from the sedimentary layer where they were first deposited by the person that last used or disposed of them. The presumption at the project inception was that any archaeological material from the upper layers of the seabed was likely to have been reworked from its original context and was therefore derived. The 'semi-mobile, upper strata of the seabed' (**Volume II, Section 2.3.23**) that were sampled during the surveys were potentially subject to marine sediment transportation processes. Disturbance of the seabed surface can also be caused by marine industrial activity such as commercial fishing or aggregate extraction. Consequently, assessment of seabed grab sampling as an archaeological evaluation method involved addressing these issues in relation to the potential interpretations/conclusions that could be made from this kind of material.

4.1.35. The grab sampling survey results for the Round 1 Arun study area showed no correlation between seabed surface artefact distribution and the buried palaeofeatures. The finds, peat and other material were dispersed across the 1km² site. Although this was probably due to the scale of resolution of about 100 grabs over 1km² (**Sections 4.2-3**), this was originally also considered to be the result of the 'relative mobility of the upper substrates of the seabed'. However, it was acknowledged that the 'lack of correlation might be the result of early, now ceased, site formation processes' (**Volume II, Section 4.2.19**).

4.1.36. This hypothesis was supported by the investigation into the sediments on site during the Round 2 Arun Additional Grabbing survey (**Volume III**). The gravels found in the grab samples were encrusted by serpulids, bryozoans and crustaceans, which indicates sediment that is not presently mobile. This evidence is consistent with the general description of gravels in the area, which are thought to constitute a lag (i.e. not mobile) deposit formed as a transgressive beach during rising sea levels (Hamblin *et al.* 1992), probably during the Mesolithic period. Later winnowing of material through tide and current processes has probably only removed some of the finer sediments (**Volume III, Section 4.4**).

4.1.37. On completion of the Round 1 Arun grabbing survey, it was stated that 'broader patterns of artefact distribution may be discernible on a larger scale' (**Volume II, Section 4.2.19**). This view was reinforced by the results from the processing of the

Arun Additional Grabbing samples. The spatial distribution of the grab samples containing peat matched those peat deposits identified by geotechnical and geophysical survey. No peat was recovered in area E, underlining the geophysical interpretation of this region as an area where bedrock approaches the seabed surface (**Figure VIII.23**).

4.1.38. Furthermore, highly probable and probable struck flint appears to correlate with the wider valley edges of the Palaeo-Arun. Of particular note is the highly probable and probable struck flint recovered in the vicinity of the charcoal as shown in **Figure VIII.23**. However, interpretation of the spatial distribution of the struck flint (presence/absence of flint recovered rather than abundance) must take into account the difficulty in ascribing an anthropogenic origin or date to the flint assemblage.

4.1.39. Two factors in particular affected the interpretation of the Round 1 Arun flint assemblage. First, significant and currently unquantifiable levels of post-depositional breakage and alteration probably occurred due to attrition and exposure to marine processes. Second, the size of the individual artefacts is small, the largest being between 10-20mm in length and the majority being less than 10mm long. These factors combined made the artefacts largely undiagnostic and therefore the assemblage could not be associated with one culture, industry, or period.

4.1.40. The methodology of flint analysis from the Round 1 Arun survey (**Volume II**) was applied to the Round 2 Arun Additional Grabbing assemblage for comparative purposes. The possibility that the struck flint was generated by mechanical fracture was again supported by the absence of larger material such as tools, cores and diagnostic debitage. These types of flint artefacts are more commonly found (re-deposited) within gravel deposits. The assemblage as a whole was dominated by primary chips and flakes with linear and crushed platforms symptomatic of mechanical fracture.

4.1.41. Where samples were recovered containing high proportions of peat it was considered likely that these sediments were exposed on the seabed. However, the possibility that these samples represented a collection of parts of large deposits of reworked or rafted peat cannot be ruled out (**Volume III, Section 4.4**). The samples containing peat were retrieved from within the Palaeo-Arun valley where early Mesolithic peat deposits were identified by geophysical and geotechnical surveys as described in **Sections 2** and **3** (this volume).

4.1.42. In some of the vibrocores taken in the Round 1 Arun study the top 0.15 metres recovered showed up to three different deposits. These deposits, if not consolidated (e.g. peat, **Figure VIII.22**), were mixed by the retrieval of the grab. The retrieval of sediment and finds from such a mixed sample precluded informative stratigraphic relationships to be identified and therefore the context of finds retrieved could not be deduced. However, in some cases where lumps of peat were recovered, it was possible to generate a basic stratigraphy and the vertical alignment of the sediment could be determined by the position of the intrusive boring mollusc *Pholas dactylus* within the sediment. The sediments could also be separated, thus any finds could be attributed to a dateable and (roughly) stratified deposit.

4.1.43. Peat is generally an indicator of a former land surface within a former wetland environment. Freshwater and terrestrial environments were also attested to by the large numbers of environmental indicators which were found within the grab samples e.g. freshwater and terrestrial molluscs. These molluscs were mostly found in gravel and sand deposits and are probably derived from fluvial outwash.

4.1.44. In addition, an amphibian (frog or toad) pelvis fragment was recovered and is highly likely to have originally been deposited in a terrestrial or freshwater context. A medium mammal rib fragment was also recovered and is also likely to have been reworked from a non-marine context. The possibility that these bones have a more modern provenance could not be ruled out. The lack of bone relating to marine fish and mammals in both Arun grab sampling surveys was noted and considered to be a result of either bottom detritus feeders or a depositional environment not conducive to the preservation of bone. However, two seabird bones were recovered and were considered most likely although not necessarily to have a modern origin.

4.1.45. Charcoal found within a block of peat was considered to be a possible indication of human occupation of the area. The possibility of its formation by natural causes (lightning/forest fire) was noted but considered unlikely, 'since the only likely mechanism for the wood of a mature deciduous tree to be fully charred in this wetland landscape is deliberate anthropogenic burning e.g. for use as fuel in hearths' (C. Chisham, see **Volume III**, **Appendix III**). The fact that the charcoal was unabraded refuted any suggestion of significant reworking.

4.1.46. It was demonstrated that the charcoal could be contemporary with peat recovered from the same sample. The oak (*Quercus* sp.) heartwood charcoal dated to 8,893±30 BP/ 8,230-7,960 cal. BC (NZA-26303) and reed (*Phragmites* sp.) dated to 8,815±40 BP/ 8,200-7,740 cal. BC (SUERC-12007). The charcoal does not date a burning event and the potential age of oak heartwood introduces an error of up to around 500 years (**Volume II**, **Appendix III**). This error is not present in the *Phragmites* reed as it only lives for one year. This meant that the peat and charcoal could possibly be considered contemporary even if the charcoal date were up to 500 years older than the *Phragmites* reed date.

4.1.47. Comparison of these results with the Arun Round 1 dated peats (**Appendix I**) demonstrated that the dated peats recovered from the Round 1 vibrocores are older than the peat recovered from the Round 2 grab sample. This was as expected as elevation of the seabed at the grab sampling location was higher than the elevations of the peat deposits within the vibrocores. The closest peat in elevation and date is from vibrocore **VC3** at 32.86m below OD, dating to 9,131±45 BP/ 8,530-8,260 cal. BC (NZA-19298). The fact that the peat dates are proportional to their elevation (the oldest is the deepest) suggests that peat deposition is probably very closely linked to sea level rise and time in this area (**Figure VIII.24; Section 6.3**).

4.1.48. In contrast to the Arun evidence, no indicators of surviving prehistoric deposits were recovered from the Eastern English Channel or the Humber grab samples. The deposit from which the Eastern English Channel grab samples derived is homogenous ranging in thickness from 0.5 to 5m. This means any underlying deposits would not have been affected by the Hamon grab. Radiocarbon dating of the grab sampled deposit suggested that it formed during the early Mesolithic period

(8,442±35 BP/7,320 – 6,860 cal. BC (NZA-23787). Foraminifera recovered from the samples indicate a marine depositional environment. It is likely that the deposit rapidly accumulated as a result of rising sea level during the early Mesolithic period. Any prehistoric material within this deposit has probably been reworked from its original context. However, the sieved grab samples represent a very small fraction of the total deposit within the study area and as such a lack of prehistoric archaeological material within the samples does not mean that it does not exist within this deposit.

4.1.49. In the Humber area the potential for *in situ* prehistoric archaeological remains is also low. According to the vibrocore assessment, this is due to the deposits either being glacial or shallow marine in origin. There is however potential for reworked Palaeolithic and Mesolithic archaeological material to be present in deposits of clay, sand and gravel within the study area (**Volume VI, Section 6.3.2**). No artefacts of prehistoric origin were recovered from the grab samples.

4.1.50. A large numbers of fossils have been recovered from all study areas. They are evenly distributed across the grab sampling areas. The fossils within the Arun and Eastern English Channel study areas are probably derived from the (Eocene) Barton beds. Sharks teeth, bones and large benthic foraminifera are common in the Lower Barton Bed or Highcliff Member (Melville and Freshney 1982). Fossils were deliberately collected by humans throughout prehistory, mainly to produce jewellery, amulets or ceremonial burial layouts (Oakley 1965a-b). The most common fossils recovered during the Humber survey, for example, were crinoids containing significant numbers of *Pentacrinites*, and occasional gastropods were recorded as well. These species in particular as well as shark teeth have been used for bead production by prehistoric peoples (Oakley 1965a:16; 1965b:122-123). However, no fossils that were identified were thought to have been altered by peoples in the past.

4.1.51. Modern materials recovered from all study areas such as slag, clinker, coal, fired clay (CBM) and glass are most likely to have been results of shipping activity. The coal is possibly reworked by natural processes; however it is more likely to represent modern waste material discarded with the slag and clinker from ships engines. No concentrations indicative of dumps of modern material were observed.

Conclusions

4.1.52. The finds from the Arun grab sampling have provided possible evidence of human occupation of the Palaeo-Arun area. The charcoal recovered from a lump of peat is unlikely to have been produced by natural causes (**Volume III**, **Appendix III**). Flint recovered from the Round 1 and Round 2 grab sampling surveys is also arguably of anthropogenic origin although in many cases it is difficult to distinguish from flint produced by mechanical or natural processes.

4.1.53. The distribution of the Arun flint assemblages appeared to correlate with the hypothesis set out in **Volume III**, **Section 1.1** '*All struck flint is associated with broader palaeogeographic landforms'*. The inference being that the material may have been deposited during the post glacial period. The large sample spacing (100 metres) however precluded identification of small concentrations of struck flint.

4.1.54. The oak charcoal is a possible indication of occupation of the Arun area in the latter part of the early Mesolithic period. The palaeoenvironmental analysis of samples retrieved from vibrocores in the area confirmed that terrestrial environments existed in this area since the last glaciation and up until the early Mesolithic period. The large amount of peat (and the grey silts and clays) recovered from the grab samples showed that deposits relating to the Palaeo-Arun and containing stratified material of potential archaeological interest are being exposed on the seabed.

4.1.55. No evidence of surviving prehistoric deposits was recovered from the Eastern English Channel or the Humber grab samples. However, the sieved grab samples represent a very small fraction of the total deposits within the study areas and as such a lack of prehistoric archaeological material within the samples does not mean that it does not exist within the areas surveyed.

4.2. SAMPLING THEORY

Terrestrial versus Maritime

4.2.1. This section aims to assess similarities between terrestrial and maritime survey techniques. A number of experimental field surveys as well as computer simulations and desk based assessments have been conducted and published for terrestrial evaluation techniques (Hey and Lacey 2001; Clark and Schofield 1991; Schofield 1991; Schick 1987; Petraglia and Nash 1987; McManamon 1984; Schiffer *et al.* 1978; Thomas 1975).

4.2.2. However, comparable studies do not exist for the marine environment. Between terrestrial sampling techniques and the grab sampling methodology undertaken as part of the 'Seabed Prehistory' project analogies of site size, density and condition have been made to assess the effectiveness of this methodology in identifying/locating prehistoric *in situ* and derived sites. Where appropriate marine site examples exist, they have been included in the discussion.

4.2.3. Terrestrial evaluation techniques generally comprise of augering/soil cores, fieldwalking, test pitting/shovel tests and machine trenching. An auger is a device for removing material by means of a rotating hollow half shell drill. In archaeology, augers usually recover a core of less than five centimetres in diameter, whereas soil cores are bigger (about ten centimetres in diameter). In most cases soil cores are obtained by drilling into the medium with a hollow steel tube; a variety of corers exist to sample different media under different conditions.

4.2.4. Fieldwalking includes one or several persons walking around a field in a systematic pattern in order to spot any archaeological remains on the surface. Test pitting or shovel tests comprise a series of test holes of a designated size, depth and density which are usually dug out by a shovel in order to determine whether the soil contains any cultural remains that are not visible on the surface.

4.2.5. Machine trenching involves the cutting of designated trial trenches over a study area by means of a mechanical excavator. It enables the recording of sub-surface soil features on a bigger scale than the other methods.

4.2.6. Within a marine context, the augering/soil cores might be comparable to vibrocoring, fieldwalking might be comparable to diving surveys and test pitting/shovel tests might be comparable to grab sampling. No adequate 'marine machine trenching' strategy has been established to date.

4.2.7. Vibrocoring within the 'Seabed Prehistory' project aimed predominantly at establishing the sedimentary stratigraphy, providing environmental samples for dating and analysis to inform the interpretation of past environments, rather than the discovery of archaeological artefacts (**Section 3.1**). This is in accordance with results from terrestrial investigations which have shown that 'soil cores, which have the narrowest diameter among subsurface probes, appear to be relatively ineffective for the discovery of sites without abundant and widespread features or cultural soil horizons because their small diameter nearly always prevents them from discovering artefacts' (McManamon 1984:269).

4.2.8. In terms of artefact recovery in a terrestrial setting shovel testing has proved to be more effective than augering and soil coring. An experiment comparing augers and shovel tests (25-50cm diameter) conducted as part of the Cape Cod National Seashore Archaeological Survey indicated that augers with diameters of about 10cm were only 67% as effective as shovel tests with 40cm diameters at discovering artefacts within prehistoric site areas. This was so despite the fact that augers outnumbered shovel tests by approximately four to one in this experiment (McManamon 1984:269). Another example was a project in Arkansas were 30% of the sites near the ground surface (up to 20cm deep) were found by shovel testing, whereas techniques such as boring and coring yielded on the average few artefacts and often missed sites (Schiffer *et al.* 1978:7-8).

4.2.9. A recent study investigating the effectiveness of terrestrial evaluation techniques compared fieldwalking to test pitting, and to machine trenching (Hey and Lacey 2001; see also McManamon 1984:229-231). The results of the project showed that for the identification of archaeological sites from the Neolithic to medieval times, machine trenching was the most successful method. However, for Neolithic and Bronze Age terrestrial sites trenching proved to be only a marginally more effective than fieldwalking in the discovery of sites.

4.2.10. This was interpreted as a direct reflection of the problems of finding dispersed remains. Palaeolithic and Mesolithic sites were not included in the study but are most comparable to Neolithic and Bronze Age site remains because of the similarities in the find assemblage (i.e. predominantly lithic artefacts) and the site characteristics (dispersed remains rather than extensive site structures).

4.2.11. The effectiveness of 'underwater fieldwalking', i.e. diving surveys, has been demonstrated by research into submerged prehistoric sites in the Baltic Sea. For example, since underwater research started in the German part of the southern Baltic Sea during the late 1990's, a number of sites has been discovered by diving surveys targeting hypothetical site locations predicted according to a topographic site preference model developed by Danish researchers in the mid 1980's (Fischer 1995:373-376; Lübke 2002). However, these sites were generally located close to the present day coast in a water depth of less than 20 metres and were not subject to tidal impacts. This approach was not considered to be applicable to deep water offshore dredging areas. Targeted diving surveys were considered inappropriate because of the lack of proven predictive site models offshore, and large scale diving activities would be very limited in terms of time and efficiency for technical reasons.

4.2.12. A direct comparison of sample density between grab sampling and terrestrial analogues highlights the difficulties that are involved with the interpretation of grab sampling assemblages. For example, data relating to the sampling and recovery of flint chips and tools have been published for the Mesolithic site at Rock Common, West Sussex (Harding 2000), which is located in geographical proximity to the Arun grabbing areas. At Rock Common, about 52,600 worked flints were recovered from a series of test pits. The volume of these pits is equivalent to approximately 9,500 grab samples. During the Arun Round 1 and Round 2 grabbing surveys 41 flints regarded as possible, probable and highly probable struck flint were recovered from 507 grab samples. This means that on average each 'grab sample' at Rock Common contained 5.54 worked flints, compared to 0.08 worked flints per grab sample within the Arun study area. Furthermore, at Rock Common 19% of the assemblage consisted of recognisable tools or cores, thus highlighting the lack of diagnostic elements within the Arun grab sample assemblage, where only 0.2% comprised possible recognisable tool types.

4.2.13. These numbers highlight the problems that are involved with grab sampling analyses despite the number of successes that were achieved during the application of the method within the 'Seabed Prehistory' project and especially within the Arun study area (**Volume III**). Due to the assumed relative mobility of upper marine seabed sediments, their archaeological investigation was considered to be comparable to ploughzone archaeology in terrestrial contexts (**Volume II, Section 4.2.23**). At a closer look, however, many factors are involved and have to be taken into account, as highlighted in the following.

4.2.14. Survey methods are dependent upon abundance and clustering, obtrusiveness, visibility and accessibility of a study area (Schiffer *et al.* 1978:4-10). It was acknowledged in previous studies that 'archaeological research of any sort that uses survey data from regions where site discovery is difficult must confront and resolve, or at least acknowledge, discovery problems' (McManamon 1984:223). Even though visibility and accessibility differ considerably between terrestrial and maritime contexts it is worth considering the possible parallels in abundance, clustering and possibly obtrusiveness in order to benefit - despite the lack of comparable studies into maritime contexts - from many years of research into ploughzone archaeology.

4.2.15. One study specifically paid tribute to the fact that increasingly large-scale surveys were taking place, entailing the need of survey designs for study areas in excess of 50km² and including survey designs for low density artefact distributions. It was important to emphasize that cost-effectiveness entered into the survey design of these areas (Schiffer *et al.* 1978:1-2). Consequently, it was stated that 'if all sites in a study area are very obtrusive, a low intensity survey, perhaps at 100m intervals, would encounter nearly all sites. On the other hand, if there are mostly small sites and isolated artefacts, inspection would be needed at intervals of no more than a few metres in order to find the majority of surface artefacts. Unfortunately, study areas usually include archaeological materials covering a range of obtrusiveness. Since it is seldom practical to conduct an entire survey at 2m spacing – thus ensuring high discovery probabilities for all phenomena within survey units – compromises in intensity are in order' (Schiffer *et al.* 1978:13). These factors are relevant to investigation in the marine environment. The archaeological study areas defined as part of aggregate dredging licence areas generally cover large areas of seabed compared to conventional terrestrial excavations.

4.2.16. For a better understanding of the results of underwater grab sampling surveys, a closer look at the character of the sites to be encountered on the seabed follows. Issues that need to be considered to execute successful grab sampling surveys are: site size, character and condition. These will impact upon the survey design, specifically the size of the area to be sampled, the grid density and the sample size.

Site Size

4.2.17. First, it is important to be aware of the variations in prehistoric settlement size. Specific figures have been published for Dutch and other continental sites of the Palaeolithic Federmesser group (Arts 1988). Two categories are described on the basis of flint scatter size. First, there are more or less circular scatters covering an area of 4 to 100m². This is the typical size. Another category consists of oval scatters made up of 50,000 to 100,000 flints and covering an area of 2,000 to 25,000m². This size of site is rarely seen. One of the best explored British late Upper Palaeolithic open-air sites is Hengistbury Head in Dorset, situated on a narrow arm of land which projects into the English Channel close to the entrance of the Solent. It was estimated that the Hengistbury Head site (or linked zones of activity) covered an area of some 2,000 to 3,000m² and seemed to belong to the latter group (Barton 1992:200).

4.2.18. Ultimately, of course, the size model employed above provides only a very crude index of the actual dimensions of a site or the extent of site activity. Amongst other things, it does not take into account the potential for migrational shifts caused by repeated visits to the same location, either on a seasonal basis or over much longer periods (Barton 1992:200). For example, the Paris basin sites that are described in the study tend to corroborate the idea of relatively large hunting groups which probably came together on a seasonal rather than a permanent basis (Baffier *et al.* 1982). Accordingly, open air sites like Hengistbury Head fall into this category and have been interpreted as a large aggregation of units that were occupied seasonally during the autumn and spring migrations of horse and reindeer (Barton 1992:200).

4.2.19. In some cases, there are indications of the range of sites to be expected in a certain palaeolandscape setting. For example, with regard to the Mesolithic sites at Hengistbury Head and in its surroundings two types of topographical settings were distinguishable, i.e. high sandy ground and low river edge sites. It seemed likely that sites of the first group on higher sands were associated with a narrower range of activities - and therefore size? - than sites of the lower lying second group. A possible explanation for this evidence was that given that all assemblages were broadly contemporary, it seemed possible that all these findspots could lie within a projected life-time's round of a single hunter-gatherer group (Barton 1992b:260), as similarly observed elsewhere (e.g. Thomas 1975 and **Section 6.3**).

4.2.20. Recent research into submerged Mesolithic and Neolithic sites in the southern Baltic Sea showed that the most substantial site only covered an area of about 250 x 100m, with the main feature, a big storage pit, being 3.5 x 1.8m in size (Lübke 2002:207). The other sites consisted mainly of waste deposits covering areas considerably smaller than 100m². If the same sampling strategy that was applied in the 'Seabed Prehistory' project was applied to the sites discovered in the Baltic they would not necessarily have been detected. This is despite the fact that the site conditions would generally facilitate their discovery by grab sampling, because most of the archaeological features and artefacts outcropped directly on the seabed or were only buried beneath a thin sand layer; in other cases, they appeared directly below a 20cm thick surface layer consisting of gravel with numerous eroded stone artefacts (Lübke 2002:203, 207-208).

Site Character

4.2.21. Artefacts are commonly the most widespread and abundant of site constituents (McManamon 1984:233). Features and cultural deposits do not commonly approach the extended spatial distribution of artefacts and in some cases might not even exist in a site area or large portions of it. The reasons for this is that artefacts are made and used in more activities and are therefore more widely distributed than the other two constituents.

4.2.22. In general, features result from activities that involve the construction, maintenance, and use of facilities such as storage pits, hearths, and structures. Cultural deposits result from relatively large-scale processing or dumping of organic materials. Both of these kinds of general activities are likely also to involve artefacts. In addition, artefacts are also deposited through discard, loss, or abandonment. Furthermore, artefacts, especially lithic ones, are more durable than features or cultural layers, because they are less likely to be destroyed by natural processes or unnatural disruption such as aggregate dredging, than either features or cultural layers. In terms of site location therefore techniques that detect artefacts will be more effective at discovery than those that detect only features or cultural layers (McManamon 1984:233-234).

4.2.23. In a paper combining evidence from a ploughzone experiment west of Salisbury, Wiltshire, with excavated lithic assemblages from southern England, it was stated that 'sites, in the sense of excavated settlements, will produce an enormous range of density variation suggesting that one or two flint artefacts may represent settlement activity to the same extent as 200 flint artefacts from a different area of similar size' (Clark and Schofield 1991:93). In the context of downland Britain, it has been argued that 90% of the sub-surface assemblage would be represented in the ploughsoil at any one time, while others have suggested that between 0.30%, 2.005% and 2.79% of the ploughzone assemblage will be present on the surface.

4.2.24. Clark and Schofield (1991:101-103) provided some site density figures of assemblages characteristic for domestic sites that have been excavated in southern England. The maximum recovery estimates were based on figures suggested by an appropriate experiment (3.5% for flakes and tools, 0.5% for cores) and minimum recovery estimates were based on the figure of 0.3% (after Smith 1985). Accordingly, the numbers of flints visible on the surface varied between a minimum of one to 15 and a maximum of 240 to 2782 according to site. The flint fraction visible with a 15m sample-line-interval (i.e. a 20% sampling strategy) varied between a minimum of 0 to 3 and a maximum of 48 to 557 flints respectively, comprising mostly waste and hardly any tools or cores. However, clear distinctions were apparent between domestic and industrial zones such as flint quarries. At Grime's Graves, for example, figures of up to 1,600,000 items of debitage were listed within the ploughsoil in a single hectare unit, i.e. 160 items per m², resulting in a surface minimum of between 4,800 and 56,000 flints (0.48 to 5.6 flints per m²) in total, and a fraction visible trough line-walking of between 960 and 11,200 flints per hectare (0.096 to 1.12 flints per m²).

4.2.25. In contrast to this, results of surface collections in the upper Meon river valley in south-east Hampshire suggested mean site densities of 13, 16 and 50 flints respectively per hectare (0.0013, 0.0016 and 0.005 flints respectively per m²) (Schofield 1991:119). Average artefact densities of the prehistoric sites discovered by the Cape Cod National Seashore Archaeological Survey added up to about 45 to 50 flints per m². However, data describing typical variations in spatial site distribution suggested that between 12 and 42% of the areas of these sites were devoid of any artefacts. Variations in artefact abundance were also substantial, and the data suggested substantial spatial clumping of lithic artefacts (McManamon 1984:269). However, despite *average* values of 45 to 50 artefacts per m² there was considerable variability in artefact density from one site to the other. In fact, within the project described above the numbers varied between seven and 129 artefacts per m², including all stages in between (McManamon 1984:272 Table 4.15).

4.2.26. Apart from artefacts, biological macrofossils such as charcoal fragments, other charred plant material, including cereal remains and hazel nutshells, as well as bone fragments have also been listed as cultural site indicators. However, the key issues with regard to these indicators are to assess what types of macrofossil are the most informative, and to evaluate what absolute densities of material are likely to indicate a site. Murphy (2004:81) suggested that to address these points at intertidal sites where sediment cover had been stripped from large areas of the prehistoric land by surface erosion, systematic artefact collection, sample excavation and soil sampling could be done. An example was provided by investigations into the Neolithic site of The Stumble in the Blackwater Estuary in Essex. This study showed that cereal remains and burnt bone appeared to be the best indicators of Neolithic sites. Densities of more than 0.5g charcoal/kg of soil were likely to be significant, although dense charcoal deposits unrelated to settlement activity were known to occur elsewhere on the Essex coast. The presence of hazel nutshell and sloe fruitstone did not appear to be a helpful site indicator. However, in seeking to use these data to aid interpretation of palaeosol samples from buried and submerged sites, the author emphasised that they only related 'to one particular site of one period – the Neolithic' (Murphy 2004:86). This is especially important with regard to the cereal remains, as cereals were not cultivated during the earlier Mesolithic and Palaeolithic periods.

4.2.27. In the Baltic, settlements are the most numerous type of submerged archaeological site to date. They are primarily defined by the presence of worked flints. In addition, in Danish waters, Mesolithic settlements along the shore have usually one or more fish traps associated with them which probably makes fish traps the most numerous prehistoric feature within these waters. Furthermore, a number of submerged Stone Age graves have been recorded from the Danish sea floor.

4.2.28. Generally, one or more of the following elements is usually preserved to a varying degree (Fischer 2004:27-28):

- A rubbish dump that may have been submerged at the time of deposition rich in organic remains such as fragments of wickerwork fish weirs, log boats, discarded tools, and in particular a lot of food remains;
- A habitation area with fireplaces, flint knapping workshops, etc.;
- Graves, usually located on the upper parts of the sites.

4.2.29. Danish submerged votive sites are usually confined to areas that are protected from adverse weather conditions such as fjords and narrow straits. At these sites precious artefacts such as Neolithic flint daggers, axes and pottery have been deposited deliberately. Stray finds constitute another richly represented archaeological category from the Danish sea floor. They typically consist of items lost at sea such as bone fish hooks and antler harpoon heads (Fischer 2004:28).

Site Condition

4.2.30. The question of fluvial effects on stone artefacts has only been cursorily examined in the past. In an experiment conducted over four years in Kenya investigating the impact of fluvial processes on cultural deposits 'particularly upon the lithic and faunal materials characteristic of early Palaeolithic sites' 43 sites were set up and monitored. The hypothesis of the research was that the stone artefacts and faunal remains found at early sites had been originally deposited upon landsurfaces which had been inundated periodically by floodwaters and surface washes. The experimental sites were set up and varied in size from one to 100m, comprising mostly 300 to 400 and sometimes up to 5,000 artefacts.

4.2.31. The large proportion of debitage was less than 2cm long. Sites were placed within stream channels (in low water channels or on gravel and pointy bars), on channel banks, on alluvial floodplains some distance from channels, on slopes, and in high-energy and low-energy lake margin situations. It transpired that the least disturbance occurred at low energy lake margins, middle disturbance was related to the floodplain sites, and channels and high energy beaches were most likely to be highly disturbed (Schick 1987:89-95).

4.2.32. A similar experiment was conducted in a one-quarter square mile plot located within the Jemez River floodplain in New Mexico. The floodplain is nearly level but has variable sloping terraces and colluvial hillslopes at its margins. Even though the archaeologists expected that with rapid flows only larger, heavier items would remain where they were deposited, items located within ephemeral streams were not relocated as expected: they were rearranged but were partially buried which protected them from water flow. Correlations between artefact weight and movement were not as expected and initial burial seemed to be an important factor for preservation of sites in fluviatile conditions. Burial tended to protect the transportation process in a streambed. With increased velocity, pieces (both small and large) were not moved, unless the bed underwent incision and the artefacts were undermined (Petraglia and Nash 1987:126-127).

4.2.33. These studies further underline the possible preservation of Palaeolithic and Mesolithic sites which were subject to fluvial processes within and/or close to aggregate dredging areas. In this context it is also necessary to reconsider the initial assumption of mobile upper seabed sediments (**Volume I, Section 4.2.19**). Grab sample analyses in the Arun and Eastern English Channel study areas, for example, indicated the presence of sandy and gravelly surface seabed sediments that were not currently mobile, but constituted lag deposits formed during the Mesolithic (**Section 4.1.38**), thus implying that upper seabed sediments - despite tidal currents and other marine processes - are not always mobile.

4.2.34. Therefore the distribution patterns identified in the Arun study area, as part of the 'Seabed Prehistory' project, may indeed represent patterns of human exploitation in the area if the anthropogenic nature of the artefacts was certain. However, assessments have to be made on a case by case basis as not all areas, for example in the English Channel, are subject to a stable sediment transport regime, but are in fact covered by mobile seabed sediments (Hamblin *et al.* 1992:86).

4.2.35. Similar conditions apply for post-glacial Danish submerged Stone Age sites in the Baltic. Here, an abundance of artefacts is preserved within refuse layers outside the settlements, whereas the habitation surfaces themselves have generally been eroded by marine transgressions and regressions. According to Malm (1995:386) this is due to the following processes:

- During the lifetime of a prehistoric settlement situated immediately above the shore, a large amount of rubbish will be deposited in adjacent reed beds. The rubbish will become ensnared in the reed roots just below sea level and form a refuse layer. At the habitation area itself, waste is deposited from implement production, meals, mislaid and destroyed tools;
- As the sea rises, the settlement is flooded. In the transgression phase, wave action erodes the cultural layer on the habitation surface. The cultural layer is washed out and the implements are dispersed. 'Depending on location and topography, this dispersal could be more or less extensive, just as the deposition of sand can be more or less massive' (Malm 1995:386 fig. 1);
- After continuing sea level rise there is now so much water above the settlement that 'wave action no longer erodes the settlement deposits' (Malm 1995:386 fig. 1). A thin layer of sand is locally deposited, and plants such as eelgrass invade the area and retain the sand.

4.2.36. However, it is still possible to find features within the former habitation areas. One example of an intact fireplace from the Argus site in Denmark consisted of an irregular stone pavement littered with residue from the fire; charred branches forming a star-shaped pattern, lumps of burnt flint, ashes, and small fragments of burnt food remains were discovered. As the dump areas were often located in the shallow water next to the habitation areas, some of the refuse layers in the Baltic have been saturated in oxygen-free water ever since their deposition. In such cases they contain perfectly preserved organic remains such as textiles made of plant fibres, and elaborate wooden artefacts (Fischer 2004:27).

4.3. Summary

Overview

4.3.1. The 'Seabed Prehistory' project has demonstrated that grab sampling survey methodology can be applied for archaeological purposes. The Arun grabbing survey specifically has retrieved possible artefacts and possibly humanly produced charcoal from the upper layers of the seabed.

4.3.2. Apart from possible artefact retrieval the other advantage of grab sampling surveys lies in the possibility to establish a record of the upper and exposed seabed sediments, which are particularly at risk from the impacts of dredging. These sediments cannot be documented by geophysical analyses, because sub-bottom profiling techniques are not able to record the upper decimetres of the seabed, and sidescan sonar surveys only provide an indication of the surface sediment type. Vibrocore locations will be based on the results of the sub-bottom profiler survey, thus targeting *buried* fine-grained and organic layers. Retention of the surface deposits can be an issue within the core because of mixing at the seabed surface. It would only be by pure chance if any exposed fine-grained sediments were discovered by vibrocoring, especially when considering their very limited horizontal coverage.

4.3.3. Therefore, grab sampling surveys in relative terms are an effective method to establish the presence of exposed organic seabed sediments. This was confirmed within the Arun study area. Typically, the uppermost peat layers discovered by geophysical and vibrocoring techniques lay at *c.* 0.65m (**VC5**), 0.80m (**VC3**), 2.50m (**VC7**) and 3.20m (**VC13**) sub-seabed respectively (**Volume II, Appendix II**). The difference in sediments recordable by grab sampling on one hand and vibrocoring and geophysics on the other hand was verified by the radiocarbon dates (derived from grab sample **H54** and vibrocores **VC3, VC5, VC7** and **VC13**) which demonstrated the difference in age between these sediments and the presence of a clear stratigraphic sequence (**Volume III, Appendix V**), as illustrated in **Table VIII.14**.

Grab sample/ core	Depth below OD (m)	Material	Lab no	Result no	δC^{13} ‰	Result BP	cal. BC
H54	*c.* 32.5	Phragmites	-	SUERC-12007	-26.2	8815±40	8200-7740
H54	*c.* 32.5	Oak heartwood charcoal	R-29367	NZA-26303	-24.3	8893±30	8230-7960
VC3	32.86	Plant material	R28440/3	NZA-19298	-26.16	9131±45	8530-8260
VC13	33.58	Plant material	R28440/4	NZA-19299	-25.99	9155±50	8530-8260
VC5	33.94	Plant material	Not dated	-	--	-	-
VC3	34.48	Woody Plant material	R28440/1	NZA-19296	-27	9333±45	8740-8440
VC7	38.59	Phragmites leaves	R28440/2	NZA-19297	-26.39	9629±50	9220-8880

Table VIII.14: Details of the dating of vibrocore and grab samples at the Arun survey area.

4.3.4. However, the level of success of a grab sampling survey does depend on various factors as summarised in the following.

Specifications

4.3.5. It is considered important that a qualified archaeologist is involved during the planning stages of any grab sampling survey in order to facilitate a targeted approach. This implies separate survey/processing stages for geophysical, vibrocoring and grab sampling surveys respectively. The reason for this is that vibrocore locations are most effectively chosen after a preliminary interpretation of the sedimentary architecture has been drafted by processing of the geophysical data (**Section 3.2**), and any decisions with regard to the value and location of grab samples are most effectively taken after the vibrocores have been processed and have provided information with regard to dating, sediment mobility and palaeogeography of the study area. This information will allow the formulation of specific research hypothesis and will enable substantiated decision taking such as in the Arun Additional Grabbing survey (**Volume III, Section 1.1**).

4.3.6. An alternative approach has been trialled during the Eastern English Channel grab sampling survey, where geophysical, vibrocoring and grab sampling survey were undertaken in one survey campaign. Even though this approach is more time- and therefore cost-effective than the staged design favoured above, the results are more subject to chance conditions. For the Eastern English Channel area this resulted in the sampling of the widespread surface deposit of the youngest, in this case a shallow marine Mesolithic unit (**Unit 10**). Vibrocore processing, however, showed that former landsurfaces and Ipswichian or older deposits (**Unit 1**) were exposed on the seabed. If grab sampling survey design would have taken place in a staged approach, these Palaeolithic deposits potentially containing derived artefacts could have been incorporated in the sampling location design. However, despite the less successful character of this approach, it does still provide basic information in cases were severe time constraints apply.

4.3.7. It is recommended that an archaeologist be placed onboard the vessel undertaking the benthic grab sampling survey so that sampling and/or processing strategies can be modified depending upon sediments and/or artefact types that are retrieved. This would specifically apply to organic artefacts (bone, wood, leather etc.) which can be preserved in waterlogged conditions but often need immediate attention to prevent rapid disintegration. Another possible scenario would be the retrieval of artefacts from stratified lumps of deposits, thus strongly indicating the preservation of an archaeological site *in situ*. This might even result in a change of grab sample locations in order to prevent further destruction of exposed archaeological deposits by the grab and in the creation of a preliminary exclusion zone, followed by further investigation depending on the specific situation and after consultation with the relevant parties such as the aggregate industry and English Heritage.

Progress of Research

4.3.8. The Arun Round 1 grab sampling survey was the first opportunity where the technique was tested and it was therefore treated as a preliminary methodological study. On completion, it was acknowledged that 'there is further potential for research across larger areas or at a broader resolution. There is also scope for research to begin to quantify the factors surrounding artefact displacement and the question of archaeological context in the upper layers of the seabed' (**Volume II, Section 4.2.28**). After three more surveys have been completed, the results and conclusions can be summarised as follows:

- Not a broader, but a smaller resolution would be necessary in order to ensure that no major archaeological deposits are being missed, especially in areas where the palaeogeographic reconstruction combined with the applicability of appropriate predictive site models indicates potential survival of prehistoric remains. Predictive site preference modelling based on topographical features has proved to be a successful method for the discovery of post-glacial archaeological remains in the Baltic Sea (Fischer 1995) and in the Atlantic (Bell and Renouf 2003; Bell *et al.* 2006:16) (**Section 6.3**). In order to determine similar probable site locations for the Pleistocene and early Holocene periods in the North Sea and the English Channel, it is fundamental to provide reliable evidence to reconstruct palaeogeographies. The combined approach of geophysical and geotechnical survey techniques can therefore be considered as a crucial step in this process;
- So far, the at least partial survival of potential archaeological contexts in the upper layers of the seabed could be confirmed by the recovery of peat lumps containing stratified deposits. Based on this evidence it is possible that more widespread potential archaeological contexts are preserved as well, similar to Baltic examples where intact Mesolithic and Neolithic cultural layers *in situ* have been discovered in peat deposits directly below the seabed (Lübke 2002);
- The factors surrounding artefact displacement cannot be quantified yet. In order to follow up these questions, a clearly defined archaeological site would be necessary where surroundings could be investigated by extended grab sampling. This would presumably throw further light on comparable find distributions elsewhere, possibly indicating inferences that could be made with regard to site character and importance.

4.3.9. One of the questions to be addressed was whether conclusions from negative results can be drawn. Even though it was initially thought that the absence of archaeology can be concluded from the absence of finds in grab samples, it has become clear that this depends on various factors. The density of the grab sampling grid and the size of the samples combined with the expected site types within the study area have to be taken into consideration.

Recommendations

4.3.10. In order to ensure an adequate coverage of the area to be investigated by grab sampling, it is recommended to enlarge the sampling scale in terms of study area, grid density and sample size. With regard to sample size, a cost effective approach would be to apply archaeological analysis to the one ton grab samples that are taken within aggregate dredging areas for grain size and sediment/clast analyses. On average they recover *c.* 300 litres of sediment from a depth of up to *c.* 0.5m. This sediment is then dispersed onto an adequately sized 5cm mesh onboard the vessel. By the use of an additional smaller mesh, the sediment could simultaneously be scanned for archaeological remains. In order to achieve this within a limited timescale, it is recommended that three to four archaeologists be onboard for processing. The scanned residues would be discarded directly, making big scale laboratory processing redundant. By investigating an estimated number of ten samples per day, the amount of sampled sediment could be considerably increased compared to Hamon grab samples, thus multiplying the chances to discover archaeological material of any kind. The practicalities of this suggested methodology would have to be investigated to enable the aims of both archaeologists and industry to be satisfied.

4.3.11. Furthermore, it was noted during terrestrial research that 'using a high sample fraction may be particularly useful when a site contains prehistoric archaeology' (Hey and Lacey 2001:30; 49). However, with regard to maritime contexts, it would be neither productive nor cost effective to imply an overall high sampling fraction without taking into consideration specific site conditions. The palaeogeographic reconstruction of a study area would have to be balanced against appropriate predictive site models before the application of an especially dense sampling grid would be justifiable and most probably prove successful.

4.3.12. The size of the grab sampling survey area would have to be determined according to the specific site circumstances and the scale of the palaeolandscape features to be investigated. However, the informative results of the Arun Additional Grabbing survey showed that the size should be related to the wider palaeogeographic features in the region.

4.3.13. Finally, it is recommended that the results of all such archaeological analysis are collated to form a larger dataset in order to facilitate a better understanding of the relationship between seabed surface, artefact distribution and buried palaeogeography and underpin further research hypotheses. Finds should be entered into the coastal and marine finds records held by the NMR and local authorities, so that data related to them can be accessed by archaeological researchers.

5. ARCHIVING

5.1. Marine archaeological archives are an important resource. Archaeological archives, both material and documentary, are crucial to our understanding of the past. The archives allow future re-access and re-interpretation with the advent of new research hypotheses. However, although the national significance of the data is acknowledged, currently there is no clear system for the deposition and curation of maritime archaeological archives (IFA MAG 2007).

5.2. The archaeological archive consists of all parts of the archaeological record including the finds and digital records as well as the written, drawn, and photographic documentation (Brown 2006).

5.3. Both digital and material archives were produced from the 'Seabed Prehistory' project. The digital archive can be described as coded information that is translated into a computer into a readable format (Brown 2006). The geophysical dataset forms part of the digital archive. The material archive for the 'Seabed Prehistory' project included materials recovered from scientific sampling from the vibrocores and grab samples. These include environmental samples and archaeological finds.

5.4. For this project the raw geophysical data has been archived in accordance with the archiving guidelines (Brown 2006). That is to say, the data has been stored in conditions that minimise the risks of damage or deterioration to the data, the creation of the digital archive is fully documented and consistent standards have been used throughout regarding terminology, content, format, and file naming. The raw digital data is recorded in an industry standard format i.e. the format in which it was collected, along with any paper records and survey logs relating to the data.

5.5. Finds from the grab samples included potential worked flint, ceramic building material, coal, slag, clinker, burnt stone and glass. All finds were recorded and those to be archived (flint, bone, charcoal and ceramic building material) were archived at WA.

5.6. Once the vibrocores had been logged, samples were taken and sent away for external analysis and archiving (plants and molluscs for ^{14}C radiocarbon analysis, pollen and diatoms). Samples for foraminifera, ostrocods and molluscs were taken from the cores, recorded, and stored dry in suitably labelled glass containers at WA. Waterlogged plant and insect samples were stored in IMS (Industrial Strength Methylated Spirit) solution. The remainder of the vibrocores are stored at WA. Environmental subsamples and ^{14}C radiocarbon dating subsamples were also retrieved from the grab samples and archived in the same manner.

5.7. The entire data archive is currently held at WA. Geophysical and geotechnical data acquired by the aggregate industry is not specifically acquired for archaeological purposes and although it is archived with the company it is not for archaeological purposes. Although it forms a potentially important part of the prehistoric record further study of the geophysical and geotechnical data lies with the discretion of the owner of the data.

6. GEOARCHAEOLOGICAL RESULTS: A COMPARATIVE ANALYSIS

6.1. INTRODUCTION

6.1.1. Through the course of the 'Seabed Prehistory' project numerous depositional environments and different sediments types have been identified. These include fluvial, fluvioglacial, glacial, estuarine and coastal shallow marine/sublittoral environments from the different study areas and all areas contained evidence of changing environments through time. This highlights the complex nature of evolvement of the regions now covered by the North Sea and English Channel from the beginning of the Pleistocene.

6.1.2. The following section aims to collate the geoarchaeological results of the different studies conducted as part of the Round 1 and Round 2 'Seabed Prehistory' project and to compare them in terms of chronology, deposition history, archaeological potential and the implications of the results on marine aggregate dredging.

6.1.3. Within the study areas certain sediment units and horizons are significant in terms of archaeology as they represent parts of former landscapes. Of particular interest are peat layers representing flat, low-lying landscapes, or gravel surfaces which were once parts of landscapes. Also, of importance are fine-grained sediments located at the edges of channels (in estuarine and riverine environments).

6.1.4. Each of the 'Seabed Prehistory' study area focuses on a small detailed area of a larger palaeolandscape. This allows specific details on the structural, sedimentological and environmental aspects of the specific area to be determined, but can not necessarily provide details of the wider landscape. Extrapolating the results of these small study areas to entire landscapes could lead to over- and misinterpretation which the data can not fully support. However, the study of small isolated areas can successfully feed into the wider knowledge of landscapes on a regional scale.

6.2. PALAEOGEOGRAPHIES: DATES AND DEPOSITS

6.2.1. A detailed summary of the deposits observed at each of the study areas provides descriptions of sediments, depositional environments, chronology and palaeogeography of each area. **Figure VIII.24** illustrates dating evidence for each area compared to relative sea-level curves from the Cromerian Complex to Holocene times.

Pakefield (Pre-OIS 17)

6.2.2. Chronologically, the sediments observed at the Pakefield study area are the oldest regarding the Pleistocene palaeogeography of the 'Seabed Prehistory' project.

6.2.3. During the geophysical and geotechnical surveys four sedimentary units were observed. The upper two units were of Holocene marine transgression sediments (**Volume VII**). The two units underlying the Holocene sediments are thought to be associated with the Bytham River. The Bytham River system formed in a catchment area that covered much of the northern parts of the Midlands and Eastern England, and flowed west to east draining towards what is now the North Sea basin. The river system was destroyed by glacial erosion during the Anglian Glaciation (OIS 12) and no expression of the river system remains in the present landscape. However, in parts, the valley sediments were covered and preserved by the Anglian glacial deposits (Rose *et al*. 2001).

6.2.4. The Bytham River was one of the largest in Britain at this time. Pre-Anglian Palaeolithic archaeological artefacts have been found at numerous sites along the river. These include High Lodge and Warren Hill in Norfolk, and Waverley Wood near Coventry in Warwickshire.

6.2.5. The extents of the Bytham River valley have been traced onshore, however, it is not known how far, or in which direction it extends along the now submerged landscapes in the North Sea. The survey area was situated towards the southern edge of the valley where flint artefacts were found in the floodplain and estuarine deposits in the coastal cliff section at Pakefield (Parfitt *et al*. 2005).

6.2.6. The survey area covered a small area ($3.4km^2$), approximately 200m from the coastline (**Figure VIII.6**). The area represents such a small part of the Bytham River valley that it is difficult to state from the geophysics data how the identified sediments fit into the wider valley structure. However, certain interpretations can be made using the results from the vibrocore survey.

6.2.7. The deepest unit is observed throughout the site on the geophysics sub-bottom profiler data. The unit comprises fine- to coarse-grained sands and gravely sands overlain by a layer of clayey silt with thin sandy clay laminations. The gravel fraction of the gravely sands is composed of sub-rounded to rounded flint and quartz.

6.2.8. Foraminifera recovered from this sedimentary unit mainly comprised *Elphidiella hannai* and *Elphidium arcticum*. Both of these taxa are indicative of cold shallow marine and estuarine conditions. *Elphidiella hannai* is of some biostratigraphic value as it is common in the lower Pleistocene in the North Sea basin and not known in the British Isles after the Anglian Glaciation (Funnel 1995).

6.2.9. The sediments, in particular the presence of flint gravel and the foraminifera indicate that these sediments belong to the Norwich Crag Formation observed along the Norfolk and Suffolk coast. The sands and gravels possibly represent a coastal marine deposition along an estuarine-indented coastline with deposition of locally derived sediments including flint (Rose *et al.* 2002). The clayey silt layer is likely to be deposited in a low energy environment such as an estuary. In a cliff section drawn by J.H. Blake for the Geological Survey of England and Wales in 1890, a unit of laminated clays and sands was attributed to the Chillesford-beds (Parfitt *et al.* 2006). The currently named Chillesford Silty Clay Member of the Norwich Crag Formation comprises interbedded silty clay laminations deposited in the low-energy environment of a tidal estuary (Rose *et al.* 2001). The Norwich Crag Formation is of Early Pleistocene age having formed around 2.0 Ma.

6.2.10. Based on the geophysical data, the sediment unit observed at the Happisburgh study site is considered likely to be contemporaneous with the onshore Norwich Crag and Red Crag Formations, which are known to directly underlie the Wroxham Crag Formation (Rose *et al.* 2002:52 Table 1).

6.2.11. In the cliff section at Pakefield, the unit overlying the Norwich Crag Formation is the Wroxham Crag Formation and comprises Early and early Middle Pleistocene marine, estuarine and freshwater sediments (Parfitt *et al*. 2005). Lee *et al.* (2006) characterised this layer, where it crops out in the cliff exposure, in more detail. It is described as two sub-facies of the Wroxham Crag Formation comprising silty sands and gravels overlying silty sands and clayey silts. The base of this unit lies at approximately 5m below OD (Parfitt *et al*. 2005). It was within the upper part of the Wroxham Crag Formation were Parfitt *et al.* (2005) identified worked flint.

6.2.12. Within the Pakefield survey area a sedimentary unit was observed on the geophysics data overlying the Norwich Crag Formation, the base of which is observed at a depth of less than 8m below OD. Similar sediments to those described in the literature were observed in the vibrocores. Based on its stratigraphic nature and comparisons with the onshore literature this sedimentary unit is considered to belong to the Wroxham Crag Formation. The depth of this unit onshore (5m below OD) and the depth at which it is observed on the geophysics survey (8m below OD) indicate that this horizon is sloping to the east. This possibly indicates sloping towards a coastline; however, within the survey area the gradient of this horizon is much shallower.

6.2.13. Pollen analysis from the Wroxham Crag Formation sediments is defined as two distinct zones. Zone 1 is dominated by alder with indicators of a damp fen environment (Osmundaceae and Cyperaceae) surrounded by mainly deciduous (birch and oak) woodland. This is considered to be part of a temperate stage of an interglacial period. Zone 2 is dominated by Pine suggesting a boreal woodland environment which may be of pre-temperate or post temperate zonation (Scaife 2006a). Indicators of marine (dinoflagellates), brackish (*Plantago maritima*) and freshwater (*Pediastrum*) environments are all present in Zone 2 probably indicating a dynamic coastal environment in which the Wroxham Crag sediments were deposited.

6.2.14. The surface of the Wroxham Crag Formation is marked by a marine transgression erosion surface. Away from the coast the Wroxham Crag Formation unit thins as the overlying Holocene sediments thicken, indicating a greater degree of erosion moving away from the coast.

6.2.15. Onshore, it was observed that overlying the Wroxham Crag Formation is the Cromer Forest-bed Formation. Excavations of these Bytham River floodplain deposits have uncovered 32 worked flints, including a simple flaked core, a crudely retouched flake and a quantity of waste flakes (Parfitt *et al.* 2005). Fossils, plant and beetle remains indicate that the floodplain would have provided a resource-rich environment for early humans, along with flint-rich river gravels providing raw materials for tool manufacture (Parfitt *et al.* 2005).

6.2.16. The floodplain deposits containing flint artefacts are the earliest indication of human occupation in Britain. Based on palaeomagnetism, lithostratigraphy and biostratigraphy deposits have been dated as OIS 17 (*c.* 680 ka) at the youngest, and may be as old as OIS 19 (*c.* 750 ka) (Parfitt *et al.* 2005:1011; Lee *et al.* 2006:174-176). The discovery of artefacts at Pakefield demonstrates a longer human occupation of north-west Europe than hitherto thought, pre-dating other evidence by as much as 200,000 years.

6.2.17. Prior to the 'Seabed Pehistory' project surveys, the depth of the floodplain sediments offshore was not known. Although the low levels of terrace aggradations, and long profile and low gradient of the Bytham River (Lee *et al.* 2004; Parfitt *et al.* 2005; Lee *et al.* 2006) indicated that the deposits were likely to be at the level of the seabed offshore of the coastal site, the geophysics data indicate that these sediments have been eroded by glacial or marine erosion processes.

Great Yarmouth (OIS 13 to OIS 2)

6.2.18. Pre-Anglian sediments were also observed in the lower section of the Great Yarmouth study site. However, the palaeogeographic land surfaces of interest are younger and are associated with the development and deposition within the valley of the Yare River.

6.2.19. The Yare River valley was cut after the Anglian Glaciation incised in to the underlying Cromerian Complex deposits and is known to have extended offshore during periods of lowered sea level (Bellamy 1998). The river extends from the Norfolk coast eastwards into what is now submerged beneath the North Sea.

6.2.20. Terrestrial Lower Palaeolithic finds including hand-axes and flakes have been found along the course of the Yare and are generally associated with re-worked fluvial deposits and glacial sediments (Wymer 1997). As such, it is these riverine and glacial sediments that are of particular interest in the Great Yarmouth study area.

6.2.21. The geophysical survey was conducted approximately 10km off the coast of Great Yarmouth. The survey focussed on a small 0.8 x 0.8km area within the limits of the Yare River valley.

6.2.22. The earliest deposits within the study area comprise a seismically low amplitude unit observed throughout the study area. The sedimentary unit comprised poorly sorted sand and gravel (including chalk, flint, mudstone and quartz) and frequent shell fragments. This is interpreted as shallow marine sands and gravels of the Yarmouth Roads Formation which was confirmed by the dating of the vibrocore sediments. OSL dating of the top of this sediment unit (base of the overlying unit) indicates a date of 577.22±65.4 ka. Cameron *et al.* (1992) describes the Yarmouth Roads Formation as comprising sediments deposited as part of a complex delta-top sequence forming part of the Ur-Frisia delta plain consisting of sands with pebbles (including chalk) which is of Cromerian Complex age (478 to 787 ka), i.e. deposited prior to the Anglian Glaciation.

6.2.23. Overlying the Yarmouth Roads Formation is a unit interpreted as coarse-grained sediment deposited in a high energy environment. This unit is observed throughout the study area and is generally up to 5m thick. On the geophysical data no distinct boundary was observed between the top of the Yarmouth Roads Formation and the overlying sediment unit indicating a gradual increase in the coarseness of the sediments.

6.2.24. The vibrocore data suggest that this unit comprises silts, sands and gravels interpreted as fluvial deposition. This is in accordance with the interpretations given by Bellamy (1998) and Arthurton *et al.* (1994). The few ostracods found were also indicative of probable fluvial reworked freshwater environments.

6.2.25. The pollen analysis of this unit contains a grass dominated pollen assemblage indicative of permafrost/soliflucted soils. Temperature amelioration is indicated by pioneer trees and shrubs including birch (*Betula*) into a landscape including areas of marsh and freshwater as demonstrated by the presence of freshwater algal *Pediatsrum.*

6.2.26. This is confirmed by the OSL dating which indicates a Wolstonian (OIS 8, 7 or 6) date for the formation of this unit. The temperature amelioration indicated by the pollen has probably occurred at the end of the Wolstonian (OIS 6) and beginning of the Ipswichian (OIS 5e) period.

6.2.27. It is these Wolstonian sands and gravels that are of interest to the aggregate dredging industry. These sands and gravels are known to occur throughout dredging area 254 and are likely to be observed on a wider scale within the Yare valley.

6.2.28. The dominant bathymetric feature observed within the study area is a discontinuous north-west to south-east orientated mound which is up to three metres higher than the surrounding seabed. The width of this feature varies: to the south, the feature is up to 400m wide; to the north it is less than 100m wide (**Figure VIII.25**). The feature extends beyond the limits of the study area to the south and as such, the true extents of this feature are unknown. The mound is predominantly composed of a unit of fine-grained sediments overlying the coarse-grained sediment unit observed throughout the study area. The fine-grained sediment unit is observed on the geophysics data either overlying the coarse sediment unit as a relatively uniform layer, forming mound structures or infilling channels cut into the underlying gravels. Predominantly the thickness of this unit is less than 2m, thickening to 4m associated with channel infill to the south-east of the study area, and with a mound feature to the north (**Figure VIII.25**).

6.2.29. Although the geophysical data indicate the fine-grained unit as one unit, the geotechnical data indicate three distinctive sub-units associated with different depositional environments (**Figure VIII.26**).

6.2.30. The deepest of these three units was organic clayey silt. The organic content including plant stems was high and gastropods were frequent at the top of the unit. This deposit was interpreted as having been deposited in a slow moving or still, probably freshwater, environment. Aquatic environments are inferred with increasing numbers of aquatic plants including *Myriophyllum verticillatum* and occasional *Nuphar*. The presence of some Chenopodiaceae in this zone might indicate some brackish and/or saline conditions. A low concentration of freshwater diatoms was recovered including *Epithemia adnata* further indicating a freshwater environment. At the base of this sub-unit the ostracod fauna is dominated by *Darwinula stevensoni* indicative of a shallow, slow-moving or still freshwater body. Towards the upper part of this sub-unit the ostracod fauna is dominated by *Pseudocandona sarsi* and *Candona candida* indicative of a small shallow freshwater body which in the broader context of a river valley may in this case be an ox-bow lake.

6.2.31. Pollen indicates birch woodland, and birch bark charcoal recovered is a possible indication of human activity in the area (**Section 6.3.35**). Mare's tail (*Hippurus vulgaris*) is indicative of ponds, lakes and slow streams at this level. Tassel-weed (*Ruppia maritima*) and horned pondweed (*Zannichellia palustris*) were also found and are indicative of shallow lagoons of brackish water.

6.2.32. Evidence of an incursion of saline/brackish water is then observed as the environment changes from freshwater to estuarine deposition. The estuarine sediments comprise silty sand and clayey silt with a high organic content and contain many molluscs including *Ostrea edulis*, *Cardium edule* and hydrobids especially towards the base.

6.2.33. The environmental remains within the estuarine sediment all indicate a marine influence and sea level rise with salt marsh and estuarine foraminifera, ostracods, molluscs, plants and diatoms. At the top of this sub-unit more shallow marine taxa show an increasing marine influence in an alluvial estuarine environment with salt marsh and proximal deciduous forest.

6.2.34. At the top of the estuarine sediments, vibocore data provided evidence of sub-aerial exposure of the estuarine clays. An OSL date of 16±2.3 ka might be indicative of the period (Devensian OIS 2) when this occurred.

6.2.35. The fine-grained sediment unit had previously been tentatively interpreted being analogous to the onshore Holocene Breydon Formation (Bellamy 1998), however, OSL dating (116.7±11.2 ka) suggested that the sequence probably formed some 100,000 years earlier than this during the Ipswichian (OIS 5e) period. Radiocarbon dating indicated that this sediment was deposited *c.* 50,000 BP. Although there is a discrepancy between the OSL and radiocarbon dates, the likely age of these sediments is older than previously thought. The pollen sequence is also similar to East Anglian Ipswichian sites where pine (*Pinus*) and birch (*Betula*) woodland is succeeded by oak (*Quercus*) before the occurrence of hazel (*Corylus*) (Godwin 1975). Sea levels were relatively at or around 30m below OD twice during OIS 5e (Siddall *et al.* 2003).

6.2.36. The successive environments interpreted from the environmental remains recovered from the samples broadly confirmed the sedimentological observations and interpretations of freshwater to estuarine environments. Some indications of increasing salinity were however noted amongst the predominantly freshwater faunas indicative of a freshwater pool, lake or oxbow lake, surrounded by a birch and pine woodland. Brackish tolerant species of molluscs, diatoms and ostracods in the lowest sub-unit suggest sporadic slight increases in salinity. The underlying deposits in this area are predominantly coarser-grained sands and gravels, and therefore in order for a freshwater lake, pool or oxbow lake to develop in this area, a high water table is needed to prevent drainage. This high water table may have been caused by sea level rise which would explain the arrival of mollusc and ostracod species tolerant of slight increases in salinity at the top of the predominantly freshwater unit.

6.2.37. The fine-grained fluvial/estuarine sediment unit is known to occur outside of the study area throughout the western half of dredging area 254 (Bellamy 1998) and it is possible that remnants of these sediments are observed on a much wider scale within the confines of the valley structure.

Humber (OIS 2 to Late Mesolithic)

6.2.38. At the time when the estuarine sediments were exposed to the air (OIS 2) at Great Yarmouth, the environment was very different to the north at the Humber study area. During the Devensian three major phases of glaciation occurred in the North Sea basin, but did not extend southwards as far as the Great Yarmouth study area (**Figure VIII.1**): the Ferder glacial episode in the Early Devensian (OIS 4), the Cape Shore glacial episode during the Mid- to Late-Devensian (OIS 3), and in the Late-Devensian (OIS 2) the Bolders Bank glacial episode (Carr *et al.* 2006). Within the Humber study area only the remnants of this third major ice sheet advance were represented in the form of the Bolders Bank Formation.

6.2.39. Throughout the Humber survey (**Figure VIII.5**) area a thick continuous layer of till interpreted as the Bolders Bank Formation was observed. The Humber study area was larger than the other areas (6 x 1.2km); however, the deposited sediments were consistent throughout the site.

6.2.40. The Bolders Bank Formation is a sub-glacial till and exists as a large lobe that extends 50km offshore from north-east England before spreading out over a large area of the southern North Sea (Cameron *et al.* 1992). The surface of the till was observed on the geophysical data to be heavily modified by small channels and depressions and infilled with sands and gravels. These sediments are interpreted as fluvioglacial sediments deposited in an outwash plain environment developed along the margins of ice sheets where braided rivers form numerous outlets along the ice fronts.

6.2.41. Only a small amount of these fluvioglacial deposits remain due to subsequent reworking and deposition of overlying sands and gravels. Foraminifera, ostracods, sediments and molluscan remains indicate that these are shallow marine/sublittoral sediments. The base of these marine sediments observed throughout the site varies between 17.4 and 26.3m below OD. Comparison of the radiocarbon dates and the depths of the samples relative to sea level curve data for the southern North Sea (Jelgersma 1979; Shennan *et al*. 2002) indicate that a late Mesolithic date would be expected for this type of deposit (**Figure VIII.24**). Deposition would have been associated with the continuing inundation/marine transgression during the late Mesolithic period.

Eastern English Channel (OIS 7 to Late Mesolithic)

6.2.42. Similar aged sediments to the fluvatile and estuarine sediments associated with the Yare River valley were observed at the Eastern English Channel study area. Based on the results of the surveys, the palaeochannel at the Eastern English Channel study area indicates a more complex sequence of deposition and erosion events suggesting a more dynamic river system compared to the Yare River.

6.2.43. The Eastern English Channel study area ($36km^2$) lies approximately 30km offshore south-west of Beachy Head, West Sussex, between the licensed aggregate areas 464 West and 464 East (**Figure VIII.4**). The area is situated along a large palaeovalley system extending throughout the English Channel (**Figure VIII.1**) which originated from the area now occupied by northern France (Wright 2004; Hamblin *et al.* 1992:79 Figure 79).

6.2.44. The Eastern English Channel survey provides a detailed study on a small section of this huge palaeovalley system which, combined with other research, will enable the interpretation of how this complex system developed.

6.2.45. The study area lies within the Hampshire-Dieppe basin. The underlying Cretaceous bedrock (Greensand, Gault Clay and Upper Chalk) is unconformably overlain by Tertiary sediments (Woolwich Beds, London Clay, Wittering, Earnley, Selsey and Barton beds) of the Middle Eocene Barton (or Huntingbridge) formation (Hamblin *et al.* 1992; Wright 2004), into which the palaeovalley system cut during the Pleistocene.

6.2.46. Within the study area the palaeovalley was orientated south-east to north-west, over a distance of approximately 4km and was approximately 1.4 to 2.0km wide. It had a maximum depth of 75m below OD. The central section of the palaeovalley contained a narrower, deeper channel (**Figure VIII.27)**.

6.2.47. The identified feature constitutes a long wide shallow palaeovalley with evidence of several phases of cut and fill events. Ten units were identified on the geophysical data representing phases of accretion and erosion from the first channel incision to the final marine transgression of the area. Due to the complexity of the channel, units have been numbered and are described as such below (**Figure VIII.28**).

6.2.48. Horizons were also identified that have been truncated and cannot be traced in all the seismic profiles. These suggest that certain phases in the development of the valley are not fully represented. It is therefore difficult to reconstruct the continuous development of the valley.

6.2.49. Due to the limited depth of penetration (maximum 6m) of the vibrocores, the geotechnical data can only provide detail on shallow sediment units. However, the data provide valuable information concerning the environmental conditions and dates of sediments leading to an interpretation of the development of the channel.

6.2.50. **Unit 1** is a sheet of gravel on-lapping the truncated bedrock and is visible on either side of the valley forming two separate units (**Unit 1a** and **Unit 1b**) (**Figure VIII.28**). Based on the data it cannot be established whether **Unit 1a** and **Unit 1b** were once part of an extensive sheet of gravel or whether they are two separate units deposited at different times.

6.2.51. **Units 1a** and **1b** are interpreted as being deposited in a high energy fluvial or more probably shallow marine environment. Its compaction indicated possible greater age than the other sedimentary units. Oxidisation of the upper part of this unit was observed in the vibrocore and is indicative of sub-aerial exposure after its deposition. Sub-aerial exposure clearly demonstrates a terrestrial environment, suggesting that this deposit was at some point above sea level.

6.2.52. Dating of the sub-aerially exposed part of **Unit 1** at 41.56m below OD indicated a Devensian (OIS 5c-5a) date for sub-aerial exposure of this unit. This assumes that sunlight was able to penetrate the sediment when the sub-aerial exposure occurred.

6.2.53. **Units 1a** and **1b** appear stratigraphically to be the oldest Pleistocene units identified within the study area and it is probable that they pre-date the formation of the palaeovalley. Molluscan material within this sediment is probably marine in origin. OSL dating at 42.88m below OD indicates that this sediment unit is a shallow sublittoral deposit formed as a result of transgressive or regressive systems in the Ipswichian (OIS 5e) or Wolstonian (OIS 7 or 6) periods. This correlates with relative sea levels proposed by Siddall *et al.* (2003) for the last 470,000 years.

6.2.54. Dating suggests that the formation of the palaeovalley and fluvial systems recorded in this study area are younger than OIS 7/6. This is in agreement with the chronology inferred by the sequence stratigraphic model for the area proposed by Wright (2004) and correlates with the relative sea levels proposed by Siddall *et al.* (2003) for the last 470,000 years (**Figure VIII.24**). However, this disagrees with most theories on the formation of the Pleistocene palaeovalley system in the English Channel which generally point towards a much older date. The mapped palaeovalleys of the English Channel appear to demonstrate that the palaeovalley within this study area is an offshore extension of one of the French rivers, probably the Canche or the Authie (Hamblin *et al.* 1992). It is suggested by Hamblin *et al.* (1992) that the formation of palaeovalleys within the Eastern English Channel began during the Cromerian Complex period (*c.* 787 to 478 ka). Onshore terrace deposits of the River Somme date to approximately 1,100 ka (Antoine *et al.* 2003) and the offshore formation of the Somme and Seine rivers may be earlier than Hamblin *et al.* (1992) suggest. The possibility that events relating to more glacial cycles are not represented in the sedimentary sequence observed cannot be ignored. However, these events might be preserved in the sedimentary record outside the study area within the long profile of the palaeovalley feature.

6.2.55. The base of **Unit 2** represents small scale incisions of **Unit 1** present on the western side of the study area (**Figure VIII.28**). These features are sporadic and represent short-lived events. These units must have formed subsequent to deposition of **Unit 1** and prior to **Unit 3.** Based on OSL dating their formation probably occurred between 176.55±19.98 ka and 21.15±1.53 ka (OIS 7-2).

6.2.56. **Unit 3** defines the base of the palaeovalley at a depth of approximately 60m below OD in the northern section of the study area, and up to a depth of approximately 62m below OD in the southern end of the study area. This reflector shoals on both sides of the palaeovalley with flanks on either side. These have been incised by the overlying **Unit 4** and truncated at the level of current seafloor (**Figure VIII.28)**. The deposit itself is indicative of a high energy (fluvial) environment with evidence of reworking of bedrock material. OSL dating (21.15±1.53 ka) indicates deposition during the Devensian period (OIS 2).

6.2.57. **Unit 4a** is interpreted from the geophysical data as a bank of fluvial gravels resting on the western terrace of **Unit 3** and sloping down into the channel basin of **Unit 4**. The implication of this is that **Unit 4** is a later cut. This cut was then filled to the base of the wider valley. If this deposition has occurred subsequent to the deposition of **Unit 3** then a Devensian date (OIS 2) is suggested. The incision of this part of the channel to *c.* 100m below OD would require significantly lower sea levels than that of today. The Devensian glacial maximum at *c.* 18,000 BP (19,300 cal. BC) is a potential period when sea levels were low enough, up to 120m lower than today for this fluvial incision to have occurred (Siddall *et al.* 2003).

6.2.58. The incision, which formed the deeper palaeovalley that was in-filled by **Unit 4,** has left a pair of bed-cut terraces, which comprise **Unit 3 (Figure VIII.28)**. These vary in width between approximately 300 and 500m, although the eastern terrace is generally wider than the western terrace throughout the study area. The incision that is in-filled by **Unit 4** gradually deepens towards the middle of the channel. In the south of the study area the depth of this palaeochannel increases by up to 5m.

6.2.59. As **Unit 4** developed, the erosion and transportation of heavy coarse material deposited during a period of high energy sedimentation (**Sub-unit 4a**) gave way to the deposition of finer-grained sediments (**Sub-unit 4b**) indicating a period of substantially diminished fluvial flow. The infilling of **Unit 4** became complete when it reached the terraces at the base of **Unit 3** at approximately 63m below OD.

6.2.60. **Unit 5** is interpreted as fine-grained, probably fluvial, infill sediment (10 – 15m thick) of the main palaeovalley that is cut by later channels (**Figure VIII.28)**. Deposition of **Unit 5** is most likely to have occurred during the latter part of the Devensian period. **Units 5**, **6** and **7** represent cut and fill events potentially caused by short term fluctuations of climate and sea level during the Devensian (Hosfield and Chambers 2005).

6.2.61. **Units 6** and **7** are channel infill deposits infilling channels cut into **Unit 5** (**Figure VIII.28**). It is still difficult to ascertain the chronological deposition of these two units as the data do not show a clear stratigraphic relationship between them. The units are located on the western and eastern flanks of the valley respectively. These two channels are interpreted as part of a braided fluvial system.

6.2.62. The base of **Unit 7** indicates a channel incision into the underlying **Unit 5** and the sediments deposited within **Unit 7** indicate subtle environmental changes in deposition.

6.2.63. Evidence from pollen, foraminifera and ostracod samples taken from vibrocore **VC3** are able to throw light on the depositional environments of **Unit 7 (Figure VIII.29)**. Three sub-units were identified. The lowest part of **Sub-unit 7i** at 56.91m below OD produced a foraminiferal assemblage interpreted as an estuary mouth. Above this, the finer grained sequence (**Sub-unit 7ii**) produced non-marine ostracods including *Ilyocypris monstrifica* and *Candona candida* at 56.55m below OD and 56.51m below OD indicative of slow moving or still bodies of freshwater. At 56.44m below OD pollen retrieved is indicative of a depositional environment of a wet herb fen (Scaife 2006b) with no indication of brackish water.

6.2.64. The pollen sample at 56.44m below OD (**Sub-unit 7iii**) is dominated by pine and birch. The presence of pine and birch suggests that this sequence is post- Devensian. The radiocarbon date 9,811±35 BP/9,160 – 8,350 cal. BC (NZA-23789) of **Unit 8**, at 55.13m below OD in vibrocore **VC3**, suggests that **Unit 7** could be older than it, possibly late glacial interstadial (Windermere/Allerød; Zone II)' (Scaife 2006b).

6.2.65. Vibrocore **VC3** shows a transition from estuarine (**Sub-unit 7i**) to freshwater (**Sub-unit 7ii**) and then to marine (**Unit 10**) environments of deposition (**Figure VIII.29**). This would suggest an overall trend of sea level rise with a lowered phase where the freshwater environments are interpreted (**Sub-unit 7ii** - from 56.41m below OD to 56.57m below OD). This is possibly due to a period of cooling temperatures.

6.2.66. The base of **Unit 8** is discontinuous for the majority of the study area, but suggests that this surface formed over a valley at 51m below OD.

6.2.67. In the north of the study area, the nature of the bank is clearly observed. The lens or slope front fill overlays a very course material that progrades down into the centre of the valley becoming a finer sub-parallel bank fill as it ends at the edge of **Unit 4**. Moving southwards through the study area, the base of **Unit 8** splits into two surfaces; the western flank deposit and the eastern flank, which is a substantial bank deposit of fairly fine material. However, the eastern flank was severely eroded, and appears separated from the valley edge.

6.2.68. The base of **Unit 8** represents a cut channel that extends across the valley. This channel was probably cut during a period of lower sea level, possibly during the Loch Lomond stadial. The geophysical signature of **Unit 8** suggests that it is a surface of sand and reworked gravel that has been deposited slowly. The depositional environment is difficult to ascertain but may have been deposited in shallow marine, fluvial or estuarine conditions. No pollen, foraminifera or ostracods were preserved within this unit. Radiocarbon dating indicates an Early Mesolithic time of deposition (9,811±35 BP/9,160 – 8,350 cal. BC (NZA-23789) at 55.13m below OD). Given the taphonomy of the sample, it is likely that the shell represents the maximum age of these sediments.

6.2.69. **Unit 9** is a sequence of faint channel shaped surfaces, probably a system of braiding channels, occurring in the upper centre sections of the study area cutting into **Unit 8 (Figure VIII.28)**. Remnants of these braided channels are intermittently observed in the north of the study area, becoming more prominent towards the southern third of the study area. However, it is likely that the braided channels flowed throughout the area before subsequent erosion and deposition of overlying sediments changed the landscape once more.

6.2.70. To the north of the study area **Unit 9** is characterised by fine-grained sediments. To the south of the area the unit thickens and two facies are identified: a fine-grained sediment on-lapping a coarse-grained unit.

6.2.71. **Unit 9** as interpreted from the geophysical data represents sedimentation within a braided channel system prior to the Holocene transgression. It is stratigraphically positioned between **Unit 8** and **Unit 10** which have maximum ages based on calibrated C14 results of 9,663±35 BP/9,160 – 8,150 cal. BC (NZA-23788) and 8,442±35 BP/7,320 – 6,860 cal. BC (NZA-23787) respectively.

6.2.72. The latest episode of sedimentation is represented by **Unit 10** comprising sands and gravelly sands which are thought likely to represent rapid sedimentation in a shallow marine/littoral environment. This was confirmed by foraminiferal evidence. Foraminifera recovered including Miliolids are indicative of a marine inner shelf environment. The base of **Unit 10** is mostly identified as a continuous surface truncating earlier facies across the valley. Mollusc shell (*Mytilus edulis*) radiocarbon dated from the base of this unit (around 48m below OD) suggests that this deposit formed around 8,442±35 BP (7320 – 6860 cal. BC, NZA-23787).

6.2.73. Sea level index points (SLIPs) are specific sediment units with a known vertical reference that have been dated. They normally comprise *in situ* peat deposits. These points produce a curve of relative sea level against time. Before *c.* 8,000 BP (6,800 cal. BC) there are very few reliable SLIPs (Shennan and Horton 2002). Ongoing research into glacio-eustatic rebound and syntheses of known SLIPs for the Holocene period shows that the sea level curve produced by Jelgersma (1979) appears to be the most accurate for the Eastern English Channel and Southern North Sea (Dix and Westley 2004). If the depths of the radiocarbon samples are adjusted to Mean Sea Level in order to compare their vertical position with Jelgersma's sea level curve the radiocarbon dates for **Unit 8** are approximately 8 to 10m above Jelgersma's projected mean sea level for the period 9,811±35 BP/ 9,160 – 8,350 cal. BC (NZA-23789) to 9,663±35 BP/9,160 – 8,150 cal. BC (NZA-23788). The radiocarbon date 8,442±35 BP/ 7,320 – 6,860 cal. BC (NZA-23787) for **Unit 10** is approximately 10m below the projected mean sea level curve for this date. This comparison confirms the interpretation that **Unit 8** comprises fluvial/estuarine sedimentation above sea level and the interpretation of **Unit 10** as a marine inner shelf deposit.

6.2.74. As described above the section of the palaeovalley studied during the 'Seabed Prehistory' project shows a complex, changing environment within a relatively short passage of time.

Arun (OIS 5d to Late Mesolithic)

6.2.75. The Arun study area is situated to the northwest of the Eastern English Channel study area and focuses on a valley and channel. The Arun palaeovalley was a tributary of the same channel river system of which the palaeovalley identified in the Eastern English Channel study area was a part (**Figure VIII.1**).

6.2.76. The Arun survey area covers a wide valley form 2.5 to 3km wide orientated north-west to south-east. A small palaeochannel is situated towards the eastern edge of this wide valley form. To the south-east of the study area bedrock is observed at the seabed covered by a veneer of modern seabed sediments. This forms part of the head of the valley which continues towards the south-east. The palaeochannel is orientated east to west and is approximately 200 – 300m wide. The channel is incised into the wider valley floor and into the Tertiary bedrock. Along the channel on the southern bank a bedrock ledge is observed protruding into the channel. The depth to the top of the bedrock unit, below the seabed, was generally greater to the south of the palaeochannel than it was to the north of it implying the bedrock was dipping to the south-west.

6.2.77. Three distinct regions are observed within the study area: the wider valley floor; the wider valley edge and the palaeochannel (**Figure VIII.30**). The deposits infilling these features are discussed in chronological order.

6.2.78. The initial cutting of the palaeovalley feature (including the channel) and its subsequent infilling represent a sedimentary hiatus. It is unclear from the sedimentary evidence acquired during this survey during which glacial and interglacial periods the valley was cut. However, relative dating by pollen analysis suggests that the infill sediments are of Devensian or late Devensian age (Scaife 2004), therefore the valley must have formed before or during the Devensian.

6.2.79. Deposition of sediments on the wider valley floor and the lower sediments of the wider valley edge were deposited first. This was followed by channel edge deposition and the upper sediments of the wider valley edge and upper palaeochannel fills. Deposition of sediments associated with the last marine transgression then occured.

6.2.80. On the wider valley floor initial deposition is likely composed of Devensian sands (OIS 5d–2). A small palaeochannel feature was noted cut into the bedrock underneath the main palaeochannel (**Figure VIII.30**) infilled with a coarse-grained deposit. Although not confirmed, it is possibly this was contemporaneous with the deposition of Devensian sands.

6.2.81. On the wider valley floor sediments comprise sand with interbedded silt and clay. Pollen analysis suggests an open habitat with standing or slow flowing water with duckweed and white water lily. Foraminifera analysis suggests a slight indication of brackish estuarine environment.

6.2.82. Peat deposits formed on the wider valley floor are observed. The geophysics identified a discontinuous horizon of peat across the study area and the geotechnical data indicate two peat layers. Environmental analysis of cores in this area suggests that these sediments pre-date the channel in-fill sequence. The peat has been dated to 9,333±45 and 9,131±45 BP/ 8,530 – 8260 and 8740 – 8440cal BC (NZA-19298 and NZA-19296, respectively).

6.2.83. The peat, silts and clays observed within the wider valley appear to represent a flat, low-lying terrestrial landscape subject to seasonal and/or tidal flooding. Further peat layers and laminated silts, clays and sands are seen within the palaeovalley and on the northern edge of the palaeochannel, presumably deposited whilst the channel was an active water course.

6.2.84. The development of the palaeochannel edge represented by an accretionary deposit of coarse-grained gravels probably developed during this time. This coarse-grained gravel unit is observed along the southern bank of the channel. The bank is present along the length of the channel, however its dimensions vary.

6.2.85. The channel infill sediments overlying and on-lapping the channel-edge gravels generally comprised up to 20m of fine-grained sediments and interbedded silts, sands and clays. The change in the grain size of the sediments indicates a likely change in flow regime within the channel; the fine-grained sediment suggests a low-energy environment compared to the deposition of gravel. The sediments were most likely deposited in estuarine, intertidal and nearshore deposition, possibly induced by a rising sea level.

6.2.86. Pollen analysis from the channel infill sediments indicates a wet fen adjacent to slow, flowing open water or salt marsh and mud flat vegetation. Both environments concur with the sedimentological evidence of fine-grained sediments deposited by a low energy water environment. Marine and brackish water influences are suggested by diatoms and foraminifera indicative of local salt marsh and probable tidal flooding.

6.2.87. Along the edge of the palaeochannel the pollen sequence indicates vegetational changes typical of the early Holocene establishment of woodland at the close of the Devensian glacial, indicating an early Mesolithic to Mesolithic age. In addition to the local, developing Boreal woodland, throughout the sequence grasses remain important and an on-site habitat of grass-sedge reed swamp or fen is likely. There is also some pollen evidence of increasing salinity towards the top of the sequence, which may suggest incursions of brackish or marine water.

6.2.88. The sedimentary deposits analysed, especially the palaeochannel fills, are substantial and appear to have accrued over a relatively short period of time given their size. This suggests a dynamic but comparatively short chronology for the stratigraphic sequence. This is possibly due to sediment load carried from the higher terrestrial zone into the low lying river channels met by rising sea levels and stemming the fluvial flow.

6.2.89. There are two Late Devensian and early post-Devensian meltwater 'pulses' identified in the regional sea level curves, one at 14,500 BP (15,500 cal. BC) and one at 10,500 to 11,000 BP (10,500 to 10,900 cal. BC), which may have been the source of this high volume sediment regime for the sand below the peat (Shennan *et al.* 2000).

6.2.90. The uppermost sedimentary unit observed throughout the site comprises sands and gravels with frequent marine shell fragments. The gravel and sand is thought to have formed as transgressive beach and sub-littoral deposits during rising sea levels. Later winnowing by marine currents has possibly removed finer sediment and it has also been proven that this deposit is not presently mobile (Hamblin *et al.* 1992). During the transgression period it is possible that erosion by wave action has truncated the uppermost sediments of valley and channel infills and valley edges.

Comparison

6.2.91. There are difficulties when comparing remnant submerged landscapes with regards to the timing of deposition and spatially, due to their isolated nature. However, certain comparisons can be made.

6.2.92. The channels identified at the Arun and Eastern English Channel study area belong to the large palaeovalley system of the English Channel. Previous studies have associated the channel observed in the Eastern English Channel study area with an offshore extension of either the Canche or Authie River in France. The palaeovalley observed in the Arun site is thought to be an offshore extension of the south coast Arun River. The formation of the regional palaeovalley system is thought to have begun during the Cromerian Complex period (Hamblin *et al*. 1992). However, both the Eastern English Channel and the Arun surveys have indicated later developments within the regional palaeovalley system.

6.2.93. The date of the incision of the Arun valley into the underlying bedrock has not been ascertained during the survey. However, the age of sediment infill is comparable to infill sediments identified within the Eastern English Channel study area (**Figure VIII.24**). In both areas channel in-fill sediments of fluvial, estuarine and shallow marine environment are present indicating rising sea-levels within the areas.

6.2.94. Although the channels at the two sites developed during the same period, deposition was very different. The palaeochannel at the Arun site has two units of sediment fill: coarse-grained gravel deposited at the channel edge overlain by a relatively quickly in-fill deposit of fine-grained sands. Whereas, the channel in the Eastern English Channel study area exhibits numerous phases of cut and fill with both individual and braided channel systems developing then being subsequently eroded or re-worked.

6.2.95. It is difficult to compare the small section of the Yare valley identified at the Great Yarmouth study area to the English Channel palaeovalley. As the Yare River valley edges were not delineated it is not possible to compare their formation. The infill sediments indicate earlier development than the English Channel palaeovalleys. The uppermost sediments observed in the Yare River were deposited as the Eastern English Channel palaeochannel was cut. Evidence of oxidation of sediments indicating exposed landsurfaces during the Devensian were observed at the Eastern English Channel study area (oxidised gravels) and at the Great Yarmouth study site (gleyed clay).

6.2.96. The Humber study area is very different in that it is not associated with a river valley or channel. Any evidence of small channelling associated with a glacial outwash plain has mainly been eroded and heavily re-worked by the marine transgression.

6.3. SEABED PREHISTORY: THE ARCHAEOLOGICAL POTENTIAL

6.3.1. In order to establish the potential archaeology of the study areas, relation to selected known models for locating coastal and submerged prehistoric sites is considered with particular reference to palaeogeographic reconstruction. The specific deposits recovered and their archaeological potential is discussed separately.

Predictive Site Location Models

6.3.2. Danish researchers specifically have made successful use of a topographical model that presupposes a direct connection between Mesolithic coastal settlements and the most suitable contemporary localities for fishing with standing gear (Fischer 1995:373). The model was developed from archaeological and ethnological data acquired from Roskilde and Karrebæk Fjords. In the latter area coastal settlements from the last millennium of the Mesolithic are not submerged, but are easily accessible along the present shore line, which in this area is almost identical to the Late Mesolithic coastline due to the isostatic and eustatic equilibrium within the region.

6.3.3. For several decades it had been known that the Mesolithic settlements in this area tended to be located near the best present day localities for fishery with standing gear. Through interviews with old fishermen who had practised the traditional fjord fishery, the topographical characteristics of the best fishing places were defined. They were situated at the mouth of streams, at places where the fjords narrowed, or on small islands and peninsulas in shallow waters with low-gradient slopes, where there is a higher potential for fish (Fischer 1995:373).

6.3.4. Through the interviews it was also established that until the late 19th century, fishing was carried out with fish traps, i.e. stationary structures in the form of fences woven of branches, combined with traps made of twig baskets (Fischer 1995:374). Gear of this kind is known unchanged far back into the Mesolithic, not only in the Scandinavian, but also in the British record, comprising evidence for wood and stone traps (Salisbury 1991).

6.3.5. Wider investigations revealed that the great majority of coastal settlements from the Mesolithic Ertebølle Culture in Scandinavia were situated immediately by the shore, at places ideal for fishing with traditional stationary gear. It was evident that people there lived directly above their fishing screens, which were located at places where many fish would swim past. The abundant fish bones found in the occupation strata of the sites and measurements of ^{13}C ratios in human and dog bones confirmed that marine food sources played a central role for the inhabitants of these sites. Coastal fishery was undoubtedly the most stable and the most important part of the subsistence base in the Late Mesolithic of South Scandinavia (Fischer 1995:374).

6.3.6. According to the fishermen of Karrebæk Fjord in Denmark, the good sites for fishing with stationary constructions had well defined topographical characteristics. Fischer (1995:374) combined this knowledge with evidence for Ertebølle sites in the original landscape and provided the following set of criteria for topographic Late Mesolithic coastal site locations in South Scandinavia:

- Along a narrow inlet connecting large water surfaces, and with considerable hinterland on both sides. Here the most potential site locations are immediately beside the narrowest spot;
- Along a narrow inlet between a small island and a mainland. Here the most potential site location would be on the mainland side;
- At the tip of a headland. The probability of finding settlement remains is greatest if the headland juts into sheltered water without strong waves;
- At the mouth of a larger stream or river. Here the most potential site location is on relatively flat land.

6.3.7. First trials of this predictive fishing-site location model comprised of ground truthing by diving surveys in water depths of up to 20m and confirmed that the success rate of the model-based predictions was higher than 80%. The sites discovered included features such hearths and tool production waste concentrations. According to the aims of the surveys, most of the sites represented Late Mesolithic habitation immediately by the sea shore. However, Early Mesolithic and Late Palaeolithic settlement traces representing habitation along former rivers and lakes have also been found (Fischer 1995:375).

6.3.8. A similar approach was applied in a Canadian research project (Bell and Renouf 2003; Bell *et al.* 2006:16). Early Maritime Archaic Indian (MAI) sites (8,000 to 5,500 BP/ 6,800 to 4,300 cal. BC) seemed to be absent in Newfoundland, despite the fact that such sites occurred in nearby southern Labrador and that Newfoundland cherts had been found in early MAI sites on the Quebec Atlantic shore, suggesting that early MAI must had at least visited Newfoundland. Bell and Renouf (2003:359) assumed that the absence of early MAI sites in the archaeological record of Newfoundland south of the areas of isostatic uplift and equilibrum could be explained by their submergence in the offshore.

6.3.9. Therefore, the authors synthesised information on late MAI site locations on Newfoundland (Bell and Renouf 2003:366-367). Extrapolating from these late MAI site selection patterns to early MAI site locations, they proposed that early MAI sites were most likely to be found

- in areas that were once coastal;

- in sheltered nearshore rather than exposed offshore locations;
- midway within a deep or bay;
- in a sheltered area such as a cove or the landward side of an island, near a river, stream or pond, with a view in more than one direction;
- near a height of land which could be used as a resource monitoring station;
- near a water source;
- near a route to the interior.

6.3.10. Bell and Renouf (2003:366-367) concluded that 'understanding the changing post-glacial coastline is crucial in regions where prehistoric human occupation was tied to the coast'. In their opinion, the implications of the Newfoundland example 'for other coastal areas characterised by maritime populations are clear: the changing coastal landscape, particularly dramatic in the first half of the Holocene, must be fully appreciated and integrated in the study of post-glacial coastal sites'. Generally, the 'reconstruction of relative sea level history and coastal palaeogeography during all periods of prehistoric occupation has proven extremely useful in understanding site preferences' (Bell and Renouf 2003:350).

6.3.11. The Danish and Canadian research primarily aimed at locating waterside (mostly coastal) rather than inland sites, and consequently the sites discovered comprised mainly coastal sites. However, it seemed that the majority of Stone Age sites on the South Scandinavian sea floor were in fact originally located in the immediate vicinity of large bodies of water – rivers, lakes, and especially the sea. Fischer (2004:27) concluded that 'in those days people apparently preferred to live directly by the waters edge'.

6.3.12. Due to isostatic land rise, late Pleistocene and early Holocene beach lines are now above sea level in certain regions of Norway, Sweden and Scotland, enabling analysis of prehistoric coastal habitation patterns. From investigations into the Norwegian and Swedish evidence it emerged that the sea coast was the focal area of habitation in this region at least as far back as *c.* 10,000 years ago (Fischer 2004:32). Coastal Mesolithic settlements are also known from the western Scottish coast, and isostatic land rise occurred in certain parts of Scotland (e.g. Finlayson 1995; Mithen 1995; Russell *et al.* 1995). Future investigations into settlement patterns might help to define possible site locations for the Scottish part of the North Sea region, where the same archaeological situation may exist below present sea level.

6.3.13. Fischer (2004:34) pointed out that 'the first pioneers of the Scandinavian Peninsula seemingly arrived already well-acquainted with life on coast. We may, therefore, safely assume that coast-adapted societies had existed long before, along the now-submerged sea shores of the North Sea and even further away along western and southern Europe'. This is, for example, confirmed by isotope analyses in the 'Red Lady of Paviland' (*c.* 26,000 BP) from the southern coast of present day Wales which indicated that around 10-15% of this individual's dietary protein derived from the sea (Richards *et al.* 2001). Furthermore, Mesolithic human and dog bones in Denmark (Fischer 2003), Sweden (Lidén *et al.* 2004) and Eastern England (Vale of Pickering) displayed high ^{13}C values, indicating a high proportion of marine food in the daily diet - even though the bones from England, for example, had been found in an inland bog (Clutton-Brock and Noe-Nygaard 1990; Schulting and Richards 2002).

6.3.14. A striking hypothesis is that 'potentially the rather small and simple late Palaeolithic and early Mesolithic sites known from above water in the countries around the North Sea may represent nothing but brief and specialised visits by people who lived on the coast much of the year and there left evidence of a much wider variety of economic and social activities (Fischer 2004:23).

6.3.15. This is confirmed by the Upper Palaeolithic evidence in south-west European regions (Fischer 1996) and especially within the area of the Hamburgian and Ahrensburgian Cultures (c. 12,500-12,000 and c. 10,000 years respectively) in northern Germany. The sites within this region represent seasonal camps specialised in reindeer hunting, and they are typically found at the upper reaches of watercourses connected to the main river Elbe (Fischer 2004:35). A similar pattern emerges for the early Holocene habitation of Norway (Bang-Andersen 2003).

6.3.16. Both the Baltic and the Atlantic site location models focussed on post-glacial, i.e. Late Upper Palaeolithic, Mesolithic and Neolithic sites. Therefore, they could to some extent use the present day seabed bathymetry maps to define possible site locations (Bell *et al.* 2006:16; Fischer 1995:374), as these post glacial habitation sites had not been affected by glacial transgressions and regressions causing the transformation of entire landscapes. In contrast to this, the 'Seabed Prehistory' project also aimed to investigate the potential survival of Lower, Middle and Early Upper Palaeolithic remains underwater.

6.3.17. The application of geophysical and geotechnical methodologies was a crucial step in the process, because this approach allowed the reconstruction of submerged sediment architectures not only of Holocene, but also of Pleistocene age by means of combined bathymetric, sidescan sonar, sub-bottom profiler and vibrocoring techniques. Sub-bottom profiler and vibrocoring data specifically allowed the identification of sub-seabed sediments and enabled the reconstruction of palaeochannels and associated palaeovalleys that are not visible on bathymetric or sidescan sonar data.

6.3.18. These former river courses and their estuaries are of special interest because, similar as in the Baltic record, 'an array of indirect evidence points to the existence of intense habitation along the former coastlines and freshwater systems on the floor of the North Sea' (Fischer 2004:23). At the same time, these areas are primarily subject to marine aggregate dredging which often focuses on fluvial gravels.

6.3.19. In this context it is relevant to note that even though the Danish sites that were initially found by following the fishing site model were mostly located in places where little later erosion or sedimentation had taken place, the model was, at a later stage, also successfully applied to areas covered with more recent sediments of sand and gyttja (i.e. organic silt). This was also achieved 'by means of seismic surveying' (Fischer 2004:31).

6.3.20. It seems therefore possible to apply a similar approach to the North Sea floor and the Eastern English Channel floor. Due to technical restrictions, i.e. mainly the lack of larger vessels, the Danish diving surveys were limited to a water depth of 25m. 'If the technical facilities are provided it should, however, be possible to work in large parts of the North Sea more or less in the same way as we have done on the shallow parts of the Danish sea floor' (Fischer 2004:23). For initial inspection of potential sites that are covered by deep layers of later sediments good results have been obtained on the Danish seafloor with the aid of larger equipment such as industrial sand-pump dredgers and hydraulic digging machines.

6.3.21. As a result, until 2003 approximately 2300 prehistoric sites were recorded from the Danish sea floor. This number was thought to represent only a few percent of what is actually preserved within the national sea territory (Fischer 2004:23). From initial inspections in the adjacent areas of Sweden and Germany the potential for finding submerged sites there appeared equally positive (Larsson 1983; Fischer 1997; Lübke 2002; 2003).

6.3.22. However, one has to be aware that the models outlined above mainly focus on *in situ* archaeological deposits. As Dix and Westley (2004:206) pointed out, 'a large proportion of the submerged evidence will likely take the form of reworked secondary and tertiary contexts. As these have been removed from their point of deposition, this negates traditional predictive modelling approaches that infer or deduce rules governing human choices in site location'. This applies especially for the fluvially and glacially derived material that might be encountered during aggregate dredging. With regard to the 'Seabed Prehistory' projects, the relevant deposits with potential for derived deposits have been outlined in the report volumes and are summarised below (**Section 6.3.32-43**).

6.3.23. Furthermore, both the potential for *in situ* or derived deposits is impacted by the preservation conditions. Hence, with regard to the 'Seabed Prehistory' project, 'this may result in a preservational or context guided approach whereby modelling focuses not just on where past humans would theoretically have located their sites, but on where conditions have meant that this evidence is likely to be preserved, in other words, a 'deposit' rather than 'site' based approach' (Dix and Westley 2004:206).

6.3.24. It has to be tested if the models outlined above are appropriate for much of the potential resource within the 'Seabed Prehistory' project study areas either geomorphologically or 'culturally'. The potential for surviving landsurfaces that might be complete enough to be described as a landscape, from any period earlier than the Mesolithic, is limited and the likelihood of finding enough material to constitute a relict cultural landscape is very low - not least because this idea might have had very little meaning in the Lower and Middle Palaeolithic periods (**Volume I, Section 2.7.2**).

6.3.25. In a comparative assessment of predictive site modelling, Dix and Westley (2004:207) concluded that 'limited predictive models could be constructed for certain localized (i.e. kilometres or less) areas, but only if sufficient geological and sedimentological evidence is available to enable both a secure reconstruction of the palaeolandscape to be undertaken and allow some assessment of the impact of marine processes on the distribution of archaeological material. […] 'Nevertheless, some predictive models should be constructed and tested in the near future […], as these provide new data that enable the construction of a next generation of more accurate models'.

Relevance for the 'Seabed Prehistory' Project Study Areas

6.3.26. At the project design stage the geophysical survey was targeted towards the identification of palaeovalleys and palaeochannels. This was based on the general hypothesis that evidence of prehistoric activity will be found in the proximity of these types of features. This is based on the evidence from the Danish study and the location of a number of prehistoric sites in the UK and France that have been found on the banks of rivers and channels, as well as the work undertaken in Denmark (Champion *et al*. 1984; Roberts and Parfitt 1999; Parfitt *et al*. 2005; Wessex Archaeology 2005a; 2005b). This hypothesis was also adopted as these types of features are relatively apparent in the geophysical data.

6.3.27. This project has not identified any *in situ* archaeological sites and therefore only a comparison between the conditions set out in the model and the conditions of the areas defined by the geophysics, geotechnical and environmental analysis can be undertaken. It should also be noted that the evidence from the project provides a limited snapshot, both spatially and temporally, of palaeogeographies at specific points in prehistory.

6.3.28. The closest parallel to the Arun study area seems to be the site location 'at the mouth of a larger stream or river', i.e. an estuary, with the most potential site location being 'on relatively flat land' (**Section 6.3.6**). This is because marine deposits and environmental remains indicate the proximity of the Arun palaeochannel and palaeovalley system to the contemporary, in this case Mesolithic, coastline (**Volume II, Section 6.1.8-11).** In accordance with this potential correlation, the best evidence for potential survival of prehistoric remains among the 'Seabed Prehistory' project study areas has been found within the Arun area (**Section 4.1.30-35**).

6.3.29. The Great Yarmouth study area represents part of a 2km wide palaeovalley including an island of *c.* 300m length, of Wolstonian (OIS 8, 7 and 6) and Ipswichian (OIS 5e) age and therefore considerably older than the sediments recorded within the Arun study area. The area investigated in the Great Yarmouth study is much too small to determine whether the island situation corresponds with the potential site location 'along a narrow inlet between a small island and a mainland', with the most potential site location being 'on the mainland side' (**Section 6.3.6**). However, if any prehistoric remains were recorded within this palaeogeography, they would be of high significance as the Ipswichian Interglacial is so far characterised by a lack of archaeological records throughout Britain (**Volume I, Section 2.2.11**).

6.3.30. The Eastern English Channel study area provides 'snapshots' of a multi-layered palaeochannel system that does not currently allow the allocation of any site location model, as the area investigated is not big enough to enable exact interpretations of the relationship to features such as inlets, islands, headlands or the coastline. More 'snapshots' of the area would be necessary in order to interpolate between them and subsequently draw a wider-scale picture. However, dating suggests the sediments recorded cover a time span from the Wolstonian (OIS 6) to the Holocene/early Mesolithic (OIS 1) period.

6.3.31. Within the Humber study area, only marine and glacial sediments were recorded probably dating from the Devensian (OIS 2) to Holocene (OIS 1)/late Mesolithic period. This means that the area would have been either covered by ice or inundated at any point during the Upper Palaeolithic or the Mesolithic period. Environmental analyses, however, indicate that the post-glacial coastline was close to the study area, even though the exact distance can not be determined based on the data. If close enough, the area could potentially contain remains of water based activities such as fishtraps. Any search for prehistoric coastal sites would have to focus on areas further inland.

6.3.32. The sediments recorded within the Happisburgh and Pakefield study areas proved to be older than the oldest recorded occupation of Britain, i.e. older than *c.* 700 ka and as such no specific correlations are possible. Despite predominantly stationary seabed sediments in the Arun, Eastern English Channel, Great Yarmouth and Humber study areas, in some areas of the seabed, upper seabed sediments are more mobile and subject to erosion. This applies especially for sites down to a water depth of at least 10m (Fischer 2004:25-27), and therefore to the Happisburgh and Pakefield sites.

6.3.33. The research conducted as part of the Round 1 and Round 2 'Seabed Prehistory' project generated first 'snapshots' of existing sub seabed sedimentary architecture and its related archaeological potential in the southern North Sea and the English Channel. More 'snapshots' are necessary in order to draw a more conclusive picture at a wider scale. The applied methodology, though, has proven to provide relevant basic data. Similar approaches, although at a smaller scale, are currently being undertaken in the Menai Strait between Anglesey and Wales (M. Roberts, pers. comm.) and in the Irish Atlantic (Bell *et al.* 2006).

Archaeological Potential by Site, Sediment, Date and Finds

6.3.34. At any location in the North Sea and English Channel, reworked material from the Palaeolithic and Mesolithic may be present. Those sediments identified during this project as containing, or potentially containing significant prehistoric archaeological material are discussed. As the earliest known occupation of north-west Europe is presently thought to have begun *c.* 700 ka (Parfitt *et al.* 2006), only deposits identified as this age or later are discussed as having archaeological potential.

6.3.35. The Arun study area is dominated by a valley containing fluvial sands and gravels probably dating to the Devensian (OIS 5d to 2) periods (**Figure VIII.30**). These deposits may contain Upper Palaeolithic and Mesolithic archaeological remains. Above this level, Holocene peat, silts and clays dating to the early Mesolithic period were recovered.

6.3.36. Oak (*Quercus* sp.) heartwood charcoal recovered by grab sampling stratified within a peat deposit is a dated potential indication of human habitation in the Arun area during the early Mesolithic. The reed (*Phragmites* sp.) sampled from within the peat dated to 8,815±40 BP (8,200-7,740 cal. BC, SUERC-12007) and the charcoal is dated 8,893±30 BP (8,230-7960 cal. BC, NZA-26303). The charcoal could have been formed by natural causes although it is considered more likely to have been produced as a result of deliberate burning. This peat is presently exposed on the seabed. Other, earlier Mesolithic peat deposits were identified by geotechnical and geophysical survey and these may also contain archaeological material.

6.3.37. Estuarine silts and clays dating to the early Mesolithic deposited at a similar time to the peats were extensive at this site which, whilst containing a wealth of environmental material, is also known to preserve ephemeral archaeological remains such as human footprints (Bell 2000). These types of deposits can also seal and preserve archaeological material.

6.3.38. Possible flint chips (**Figure VIII.22**) were recovered from the marine "lag" deposit covering the site although these were mostly indistinguishable from flint chips produced by mechanical fracture.

6.3.39. The Eastern English Channel would have formed part of the same channel river system of which the Arun palaeovalley was a tributary (**Figure VIII.1**). OSL dates and sedimentary data suggest that a marine lag deposit dating to the Wolstonian (OIS 7, 6) or Ipswichian (OIS 5e) is the earliest deposit on the site. This deposit also shows evidence of sub-aerial exposure which dating suggests probably occurred during the late middle Palaeolithic, Devensian (?OIS 5b) period. The deposit itself may contain reworked Palaeolithic material, however, as a landsurface *in situ* archaeological material may be present on it (**Figure VIII.19** and **VIII.27**).

6.3.40. A large palaeovalley cut into this deposit showed evidence of deposition from the (Devensian OIS 2) to the Holocene (OIS 1) early Mesolithic period (**Figure VIII.27**). One small remnant palaeovalley predating this (OIS 5e to OIS 2) filled with a ?fluvial gravel deposit may contain derived or *in situ* Palaeolithic material. Within the main large palaeovalley a sequence of cut and filled channel sediments were identified by geophysical survey. Sediments towards the top of the sequence contained environmental remains relating to slow moving freshwater and estuarine rivers in this area during the Upper Palaeolithic and Early Mesolithic periods. Freshwater is an essential resource (Mears 2003:56) and the identification of these types of freshwater deposits (**Figure VIII.19**) could indicate potential areas suitable for habitation (and potential deposition of *in situ* remains). No artefactual evidence of prehistoric archaeological interest was however found in the Eastern English Channel area. This is not however to say that it does not exist.

6.3.41. The Happisburgh and Pakefield areas contained two major sedimentary units inferred from the geophysical, geotechnical and environmental data to be recent seabed sediments and sediments predating the earliest occupation of north-west Europe. The archaeological potential of the areas is therefore low although the potential presence of reworked material in the recent sediments is noted.

6.3.42. The Great Yarmouth area presents probably the most complete chronological and sedimentary sequence of any of the study areas. However, the dating of this area is complicated. The earliest deposition in the area is shallow marine sands and gravels dated by OSL dating to the Cromerian Complex period (OIS16-14) (**Figure VIII.24** and **VIII.26**). These deposits are noted to be within the range of human occupation of Britain (Parfitt *et al.* 2006).

6.3.43. Above these shallow marine sands and gravels, freshwater gravels, sand and silt dating from the Wolstonian (OIS 9, 8, 7 and 6) to Ipswichian (OIS 5e) periods were found. Charcoal was contained within these sediments, which is a possible indication of occupation of the area (**Figure VIII.26**). Charcoal can be formed by natural causes (e.g. lightning) or may be a direct indication of habitation if it is the result of material burnt as fuel in hearths. One piece (charred birch bark) was radiocarbon dated to 49,500±3,000 BP (NZA-27095). This is at the limit of radiocarbon dating and is inconsistent with the OSL dates acquired stratigraphically earlier and later than this sample (175.7±22.6 ka at 30.97m below OD and 116.7±11.2 ka at 29.59m below OD). Although the radiocarbon dates indicate a younger date the OSL samples and environmental indicators (pollen sequence and the presence of *Najas Minor*) would suggest the charcoal dates from the Ipswichian (OIS5e) period. If these pieces are evidence of habitation from Ipswichian deposits this would be highly significant as this period is at present thought to be one of non-occupation of the British Isles (Wymer 1999).

6.3.44. Above this level estuarine silts and clays deposited during the Ipswichian (OIS 5e) show evidence of subsequent exposure as a landsurface (gleying and roots). OSL dating suggests this occurred during the Devensian (OIS 2) corresponding to the late Upper Palaeolithic. This deposit is in areas exposed on the seabed.

6.3.45. The Humber area contained glacial deposits dating to the Devensian (OIS 2) and marine sands and gravels dating to the Holocene sea level rise (late Mesolithic). The possibility of reworked artefacts in these deposits is noted although unproven in this study.

6.4. GAUGING THE EFFECTS OF MARINE AGGREGATE DREDGING

6.4.1. Marine aggregate dredging involves the extraction of sand and gravel from the seabed around the British Isles, supplying demand for raw materials by the UK construction industry, beach replenishment and land fill projects. Aggregates are usually dredged from areas in 18-30m water depth (Cameron *et al.* 1992) although deeper operations in water depths of around 50m, such as licensed extraction areas in the Eastern English Channel are now more common.

6.4.2. In 1996, 20 million tonnes of gravel and sand aggregate was estimated to have been extracted from the seabed around the British Isles (Bellamy 1998). This resource, like the archaeological, is finite. The resource is extracted to depths of around five metres (Bellamy 1998). Broadly speaking therefore archaeological sites and artefacts will be affected by marine aggregate dredging if they are in or near an aggregate extraction area and within five metres of the seabed.

6.4.3. The effects of marine aggregate dredging on archaeology is inextricably linked to sediments. Sediments recovered during the 'Seabed Prehistory' project include peat, clay, silt, sand and gravel. These deposits relate to shallow marine, estuarine, fluvial, glacial and terrestrial environments. All of these environments could have formed parts of inhabited landscapes during the Pleistocene. It is of course the sands and gravels which are targeted as aggregate resources and it is upon these types of sediment which the effects of marine aggregate dredging on archaeology will be most significant. Previous studies specifically addressing marine aggregate dredging and archaeology include Wenban-Smith (2002) and Firth (2004).

6.4.4. Gravels and sands identified in the North Sea and English Channel are thought to have been formed by marine and fluvial processes during the Pleistocene period (Cameron *et al.* 1992). It is considered that these are the archaeological resources most likely to be affected by marine aggregate dredging. Marine sands and gravels can contain *in situ* archaeological remains. This is exemplified by the finds at Boxgrove (Roberts and Parfitt 1999). Offshore aggregate resources around the British Isles are however more commonly related to former river courses: "longer term future of the gravel dredging industry lies in the exploitation of thicker but highly irregular and/or localised Pleistocene fluvial sands and gravels" (Bellamy 1998). **Figure VIII.1** demonstrates the correlation between river valleys and aggregate extraction areas. Terrestrial analogues suggest that these are often the places in which (particularly Palaeolithic) archaeology is found (Wymer 1999).

6.4.5. Those sands and gravels of fluvial derivation are potential sources of archaeological artefacts. It is important to note that "we find human implements in river-*bed* deposits, while their makers certainly lived on the *banks*" (Cornwall 1958:23). This highlights that the archaeology within these deposits is most likely to be represented by derived material.

6.4.6. Marine aggregate deposits may have also been an attractive resource in the Palaeolithic and Mesolithic period. Coastal and fluvial areas are known *foci* of Palaeolithic and Mesolithic archaeology. Aggregate areas containing gravel and sand would have been relatively well drained compared to areas dominated by finer grained sediments especially within the context of rising sea levels. Flint contained within marine aggregate deposits may also have attracted Palaeolithic and Mesolithic communities in order to obtain the raw materials for the manufacture of stone tools.

6.4.7. Areas containing fine grained deposits (peat, silt clay and sand) relating to submerged terrestrial landscapes are more likely to contain *in situ* archaeological remains. This is due to the fact that lower energy environments (evidenced by the deposition of small particles) are less likely to disturb any archaeology which they might contain. These deposits are not generally thought to be at risk from marine aggregate dredging as they are not of economic interest and are avoided even within licensed dredging areas (Bellamy 1998). However, Wenban-Smith (2002) points out that fine-grained silts and clays may well be present within or on marine aggregate deposits as discrete layers undetectable by prospective surveys. This situation applies to the Mesolithic where sea level rise has caused deposition of fine grained material within submerged river valleys – peat, silt and clay on top of Devensian and earlier sands and gravels (e.g. Arun). This is also applicable to the Palaeolithic as evidenced by the fine grained material in the Great Yarmouth area sealing a fluvial deposit of sands and gravels. Fine laminae of silt and clay were also recovered within Wolstonian fluvial deposits in this area.

6.4.8. Fine-grained deposits could be affected by marine aggregate dredging if the deposit is near an aggregate dredging area. In the case of Arun (**Figure VIII.23**) deposits identified as stratified peat, silts and clays containing potential indications of habitation of the area during the Mesolithic are within a few hundred metres of a licensed dredging area. In addition to this, fine grained deposits could be affected by the removal of gravels and sands which seal and protect them.

6.4.9. Retrieval of prehistoric material during the processing of marine aggregates is one way in which artefacts can be recovered from marine aggregate deposits. Recent work by WA and the British Marine Aggregate Producers Association (BMAPA) raising awareness of archaeology and marine aggregate extraction has produced finds including a worked flint from an aggregate extraction area in the North Sea.

6.4.10. Demand for marine aggregates will increasingly remove Pleistocene sediments from the seabed and any related prehistoric archaeology with it. To fully understand where these sites and artefacts might occur and the effects of aggregate dredging upon them, consideration must be given to a wide range of archaeological and scientific data regarding chronology, sea levels, environment etc. Study of any artefacts in conjunction with relevant archaeological scientific studies generated in part by the prospection for marine aggregates and associated surveys will help further inform the public, industry and archaeologists about the effects of marine aggregate dredging on prehistoric archaeology.

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