AGGREGATE LEVY SUSTAINABILITY FUND
MARINE AGGREGATE AND THE HISTORIC ENVIRONMENT

SEABED PREHISTORY:
GAUGING THE EFFECTS OF MARINE AGGREGATE DREDGING

ROUND 2
FINAL REPORT

VOLUME II: ARUN

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Ref. 57422.32

February 2008

SEABED PREHISTORY R2

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Ref. 57422.32

Summary

This study forms Volume II of the 'Seabed Prehistory: Gauging the Effects of Marine Aggregate Dredging - Final Report' commissioned by English Heritage (EH) and undertaken by Wessex Archaeology (WA). It was funded through Round 2 of the Aggregate Levy Sustainability Fund (ALSF) distributed by the Department for Environment, Food and Rural Affairs (DEFRA). The 'Final Report' comprises of eight volumes based on previous reports accomplished by WA for either EH or the Mineral Industry Research Organisation (MIRO), as part of Round 1 or Round 2 of the ALSF project 'Seabed Prehistory'.

In 2003, WA was commissioned by MIRO to undertake the research project 'Seabed Prehistory – Gauging the Effects of Marine Aggregate Dredging'. The 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 Aggregate Levy Sustainability Fund (ALSF). It was administered by MIRO on behalf of the former Office of the Deputy Prime Minister (ODPM), now Department for Communities and Local Government (DCLG).

The study area for this assessment was chosen as a result of prospecting within the Owers Bank area following consultation with representatives from the marine aggregate industry. It is in the Palaeo-Arun area approximately 18km south of Littlehampton, off the coast of West Sussex in the English Channel. Survey work took place from 1st to 18th July 2003 and 27th to 29th September 2003. Twenty vibrocores, 108 seabed grab samples and 245km of seismic survey data were collected over a 3.5km by 1km area, but primarily in a central 1km² around a buried palaeochannel feature.

The conclusions of the survey methodology assessment include:

- Shallow seismic data can provide a sufficient understanding of the subsurface geological structure as to allow features such as palaeochannels to be interpreted and modelled in 3D if the correct seismic source is used. Seismic surveys can help archaeologists to understand the palaeogeography of an area and can be used to guide further work such as vibrocore surveys. However, the seismic data must be collected at a line spacing appropriate for delineating features of interest.

- Bathymetric data, which maps seabed topography, is not an appropriate tool for assessing, identifying or studying submerged prehistoric landsurfaces and their associated archaeological deposits. It provides models of the modern seabed rather than any evidence of relic palaeogeographies or buried stratigraphy.

However, it is critical for providing a vertical reference frame for the interpretation of the shallow seismic data.

- Geoarchaeological core logging and descriptions provide significant additional information to geological logs and photographs. They provide sedimentary evidence of the depositional processes involved, as well as descriptions of the sediment types.

- Geoarchaeological assessment in offshore circumstances through archaeological access to vibrocores is possible and productive. However, archaeological input into the vibrocore survey locations is considered central to the success of environmental reconstruction and the development of palaeogeographic models.

- Grab sampling survey methodology can be applied for archaeological purposes. The process has retrieved possible artefacts from the upper layers of the seabed. Consequently, it can be an effective tool for indicating the presence of near-surface or eroding archaeological deposits, which would be both significant and fragile, and particularly at further risk from the impacts of dredging. Further work needs to be done to confirm this.

- The trialed grab sampling method could be easily implemented and is complementary to the benthic (marine ecological) survey already undertaken as part of the EIA process. It has proven to be a cost effective method of undertaking empirical evaluation for archaeological assessment.

The palaeogeographic assessment of the study area, using the geophysical and geotechnical data, demonstrated:

- the post-transgressive survival of fine-grained sediments, which could potentially contain archaeological deposits, in offshore locations;

- the dynamism of the geomorphological processes and the size of the sediment regimes at work in this area during the Late Palaeolithic and Mesolithic periods;

- significant evidence of plant migration that appears to relate to the 'gap' in the environmental record between northern Europe and southern England. It also provides valuable insight into the environment of early Mesolithic peoples;

- the fact that current terrestrial analogues for stratigraphic formation are not necessarily appropriate to offshore stratigraphy and that there is a consequent need for further research and the development of new geomorphological models.

The study highlighted the importance of the combination of geophysical and geotechnical sources for palaeogeographic evaluation. Geophysical models informed the strategy for environmental sampling and analysis, and the results could be used to refine the geophysical models. It became clear that integrated use of these sources is central to the development of more reliable palaeogeographic characterisations. Moreover, this work demonstrated how these palaeogeographies could be reconstructed, and how they may have been inhabited, and thus provided a more supportable assessment of the potential for archaeological impacts to arise from aggregate extraction.

Radiocarbon dating confirmed a late Devensian to early Holocene date for the pollen sequences analysed from the cores. These dates were in accordance with the recorded vegetational sequences. The OSL dates, on the other hand, proved to be flawed.

Significant further research potential was recognised in the survey dataset, and as a result of the project conclusions. This potential included:

- The analysis suggested that the environmental data have significant further potential for studying the palaeovegetation of southern Britain during the early Holocene with special reference to floral migration from glacial refugia and to the habitat of early Mesolithic communities. There would also be considerable value in comparing this information with other offshore, English palaeochannel sequences from the Sussex Ouse and Sandown Bay area adjacent to the Isle of Wight.

- The project's geophysical dataset included in excess of 250km of seismic data acquired over a 3.5km^2 study area. The acquired data was of high quality and there was scope for further geophysical processing of the data to allow interpretation of smaller features. There is an apparently older, lower palaeochannel feature, which could be pursued through additional survey lines.

- Additional fieldwork would also be valuable to further interpretation. Deeper cores would clarify features at the base of the palaeochannel, and it would be beneficial to try and establish the point at which the identified episodes of sedimentation began. Many of the potential features indicated by the geophysics, including the base of the palaeochannel being studied and the earlier, deeper, palaeochannel were beyond the reach of vibrocores.

An active engagement with the developing study of prehistoric submerged deposits and its related management issues was integral to the 'Seabed Prehistory' Round 1 project. This involved a formal and informal consultation process with the Project Steering Group, individual researchers in related Quaternary archaeological and science fields and researchers working on other methodologically-focused ALSF funded projects. Both the project methodology and conclusions have been presented to a wider audience of people from industry and regulatory bodies as well as members of the research community through a series of conference and seminar papers, public talks and posters. This process continued with the circulation of a first Draft Technical Advice Note for industry. Meanwhile, the second and updated version has been submitted, and the publication of project conclusions in academic journals is being prepared.

SEABED PREHISTORY R2

FINAL REPORT

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Acknowledgements

This project was commissioned by the Mineral Industry Research Organisation (MIRO) acting for the former Office of the Deputy Prime Minister (ODPM), now Department for Communities and Local Government (DCLG). The assistance provided by Derren Cresswell, the project manager for MIRO, is gratefully acknowledged.

Dr Justin Dix and Dr Alex Bastos at the Southampton Oceanography Centre (now National Oceanography centre) carried out the processing and interpretation of the seismic data using Promax and Geoframe. Dr Alex Bastos also conducted a geological interpretation of the vibrocores.

The analyses of the pollen, diatoms and foraminifera were conducted by Dr Rob Scaife, Dr Nigel Cameron and Dr Annette Kreiser respectively. Plant macrofossil identification was carried out by Dr Chris Stevens of Wessex Archaeology (WA). Radiocarbon dating analysis was conducted by the Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences, New Zealand. The Optical Stimulated Luminescence (OSL) dating was carried out by Richard Bailey at University of Oxford (now Royal Holloway College, University of London).

Richard Cooke and Angela Proctor from Emu Ltd collected the geophysical data.

For their help and advice with archaeological, geological and environmental discussions we would like to thank Dr Justin Dix, Dr Rob Hosfield, Dr Antony Long, Dr Martin Bates, Dr Rob Scaife, Jon Parr and Kieran Westley. For their help in selecting a study area and providing an insight into the operations of the marine dredging industry we would like to thank Mark Russell, Dr Andrew Bellamy and Dr Ian Selby.

We would also like to thank the steering group then composed of Dr Ian Selby, Dr Andrew Bellamy, Mark Russell, Dr Gustav Milne, Dr Bryony Coles, Simon Thorpe, Veryan Heal and Matt Tanner for their comments on the project as it progressed.

The geophysical work for this project was supervised and conducted for WA by Dr Paul Baggaley. Jesse Ransley supervised and conducted the geotechnical work for WA with the aid of Steve Legg and Nick Plunkett. Dr Mike Allen supervised the geoarchaeological investigations for WA. This project was managed for WA by Stuart Leather. Additional input on many aspects of this project was given by Dr Antony Firth, Head of the Coastal and Marine Section at WA.

Jesse Ransley, Dr Paul Baggaley, Steve Legg and Jack Russell compiled this report and it was edited by Stuart Leather and Dr Dietlind Paddenberg. Figures were compiled by Karen Nichols and Kitty Brandon.

SEABED PREHISTORY R2

FINAL REPORT

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Table of Contents

Figures

Tables

SEABED PREHISTORY R2

FINAL REPORT

VOLUME II: ARUN

Ref. 57422.32

1. INTRODUCTION

1.1. PROJECT BACKGROUND

1.1.1. In 2005, Wessex Archaeology (WA) was commissioned by English Heritage (EH) to compile the final synthesis of the research project 'Seabed Prehistory – Gauging the Effects of Marine Aggregate Dredging'. The project synthesis was funded through Round 2 of the Aggregate Levy Sustainability Fund (ALSF) distributed by the Department for Environment, Food and Rural Affairs (DEFRA) (see **Volume I**).

1.1.2. Round 1 of the 'Seabed Prehistory' project was undertaken between 2003 and 2004 as part of the Sustainable Land Won and Marine Dredged Aggregate Minerals Programme (SAMP), funded by Round 1 of the Aggregate Levy Sustainability Fund (ALSF) and administered by Minerals Industry Research Organisation (MIRO) on behalf of the former Office of the Deputy Prime Minister (ODPM), now Department for Communities and Local Government (DCLG).

1.1.3. The project was extended to Round 2 in order to assess the application of the Round 1 methodologies to aggregate dredging zones with different geoarchaeological characteristics. Round 2 comprised different components, each component funded through either EH or MIRO, under the ALSF funding for Round 2. Each component was an independent stand alone project, resulting in the eight volumes of this report. **Table II.1** provides an overview of all volumes of 'Seabed Prehistory: Gauging the Effects of Marine Aggregate Dredging - Final Report', **Volumes I-VIII** (Wessex Archaeology 2007a).

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 II.1: Overview of the volume structure of this report.

1.1.4. This report is **Volume II** in the series and sets out the Round 1 investigations into the Arun area. It is an updated version of a previous 'Seabed Prehistory' project report for MIRO (Wessex Archaeology 2004).

1.2. THE STUDY AREA

1.2.1. Following consultation with representatives from the marine aggregate industry, preliminary prospecting took place in the area of the Palaeo-Arun River within the Owers Bank region of the English Channel, *c.* 18km south of Littlehampton in Sussex. The prospecting stage of the survey involved collecting six lines of sub-bottom profiling data using a boomer seismic source. A total of 41km of survey data were collected during this stage of the project. This data was gathered along six long survey lines shown in green on **Figure II.1**.

1.2.2. The study area was chosen after studying the data from these survey lines and identifying a large palaeochannel. This palaeochannel was thought to be the same feature studied by Bellamy (1995). 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 potential. Therefore, this palaeochannel became the focus of our investigation into the area. The study area was adjacent to an existing licensed marine aggregate extraction area on the Owers Bank (see **Figure II.1**), emphasising the relevance of this form of investigation to the marine aggregate industry.

1.2.3. The palaeochannel feature was targeted for the study because these features are intimately related both to the presence of aggregate resources and to the potential presence and survival of archaeological material. These areas are very suitable for testing methodology because they represent challenging and varied geomorphology (see **Volumes IV-VIII**). They also have the best potential for the survival of organic material which is ideal for palaeoenvironmental reconstruction.

1.2.4. The baseline geology of the study area is Bracklesham Beds which are Tertiary deposits of clays, and from geophysical perspective the lowest visible reflector (Hamblin *et al.* 1992). Seabed depth of the study area is between 25-35m below CD (Admiralty Chart 1652). There is a seabed depression to the south-west of the study area and higher bathymetry towards the aggregate area in the north-east of the study area. The depression was initially identified as a potential relict valley feature relating to the Palaeo-Arun River.

1.2.5. The coordinates of the 3.5km x 1km Arun study area (British National Grid) are given in **Table II.2**.

Easting	Northing
512947	86094
513736	85463
511530	82750
510742	83387

Table II.2: Coordinates of the 3.5km x 1km Arun study area (British National Grid projection).

1.2.6. **Table II.3** gives the coordinates of a 1km x 1km core study area (British National Grid) within the general study area described above (see **Section 2.2.14**):

Easting	Northing
512329	85292
513099	84647
512433	83903
511710	84553

Table II.3: Coordinates of the 1km x 1km Arun study area (British National Grid projection).

2. SURVEY METHODOLOGIES

2.1. OVERVIEW

2.1.1. Equipment of the same or comparable specification to that utilised by the marine aggregate industry was used for the assessment throughout the data collection phase of this study. The methodologies that were assessed included both the fieldwork methods of geophysical and geotechnical data acquisition, that is the shallow sub-bottom profiling, vibrocoring and seabed grab sampling, and the processing and analysis of these geophysical and geotechnical survey data. Various survey strategies and processing specifications, as well as methods of data analysis, were compared and discussed.

2.1.2. All horizontal datums in this report are given in Ordnance Survey Great Britain (OSGB 36) projection, and all vertical datums are given in Ordnance Datum (OD) Newlyn.

2.2. GEOPHYSICAL SURVEY

Seismic Source Trials

2.2.1. 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 of this stage of the survey was to allow a comparison of the data produced using these different seismic sources in order to determine which source gave the optimum data for this study.

2.2.2. 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 will give the deepest penetration into the seabed but with the lowest resolution between vertical layers. The pinger seismic source has a high frequency signal (approximately 5 kHz) and so gives less penetration into the geology but with a higher vertical resolution. The chirp seismic source sweeps from a low frequency to a high frequency (approximately 3 to 8 kHz) and therefore provides a combination of reasonable penetration into the seabed with high vertical resolution.

2.2.3. All three of these sub-bottom profile systems used a single channel receiver to detect the signals reflected from the seabed and deeper layers. These seismic sources are directional, i.e. with the energy focused vertically downwards, in order to give strong reflections and high quality data.

2.2.4. This stage of the study showed that the boomer seismic source gave the deepest penetration (approximately 30m) into the geology of the study area with sufficient resolution to determine a full interpretation of the palaeochannel feature. Examples of data from the boomer and pinger seismic source trials, over the palaeochannel, are shown in **Figure II.2**. These data example clearly shows that the pinger seismic source was not able to penetrate to the base of the channel feature of interest to this study. 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.

2.2.5. 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. This finding was in agreement with the experience of other geophysicists operating in this area, for whom the boomer source has been the industry standard sub-bottom profiling tool. This applies to both engineering surveys and for marine aggregate prospecting, evaluation and monitoring surveys.

Survey Strategy

2.2.6. 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. In practice this means using a line spacing of 100–500m (Bellamy 1998:38). The marine aggregate industry would generally not consider surveying at a tighter line spacing than this as it would not be cost effective except in special circumstances. At 500m line spacing the general geology can be determined, however, smaller palaeogeographic features of interest in reconstructing palaeolandscapes may be missed.

2.2.7. The sub-bottom data would be collected and stored as paper records with navigation fix marks taken at regular intervals, every 50m for example, to allow the data to be positioned. Data between these fix marks may be approximately positioned by interpolating between the nearest two fix marks. From these paper records the base layer of the aggregate would be digitised and an isopach map produced, showing the thickness of the resource over the proposed licensing area.

2.2.8. Bathymetric data would also be collected over the proposed marine aggregate extraction area. This data would normally be repeatedly collected over the area during the extraction of the aggregate to allow volume calculations to be made of the amount of aggregate remaining and also to calibrate the geophysical results.

2.2.9. However the survey strategy for this project was significantly different from that often used for marine aggregate exploration. For this project sub-bottom profiling data was collected and stored as paper records to allow the data to be reviewed during collection as done during conventional marine aggregate geophysical investigations. However, the seismic data for this project was also collected and stored digitally. This was because a major aim of the project was to process the seismic data using different software packages. Moreover, while paper records required fixed gain and filter settings, digital records would allow a more thorough interpretation by the application of different gain and filter settings to the data.

2.2.10. The navigation data for this survey was recorded digitally as part of the files containing the sub-bottom data. The navigation data was updated every second, which at a survey speed of 4 knots was effectively a position every 2m on the seafloor. Corrected navigation files could then be calculated during processing to interpolate between these known positions. This corrected navigation file would then provide a position for every shot point in the seismic survey and the depth data.

2.2.11. Bathymetric data was recorded throughout all stages of surveying described in this section of the report. This data was acquired using a single beam echosounder and the data was stored digitally to be processed at a later stage using tidal information from a tide gauge deployed to the north of the study area.

Fieldwork

2.2.12. The geophysical survey was conducted aboard the survey vessel *Emu Surveyor* between 1st and 18th July 2003. The data acquisition was conducted by Emu Ltd under the supervision of WA staff.

2.2.13. The acquisition of seismic data was split into two phases, each using a separate survey pattern. The aim was to constrain the position of the palaeochannel during the first phase and then survey over the palaeochannel at a tight line spacing in the second phase. Both survey grids established at this time are shown in **Figure II.3**.

2.2.14. The survey grid for the first phase had survey lines 3.5km long, orientated north-east to south-west, at a 50m line spacing. Cross lines were 1km long, orientated north-west to south-east and at a line spacing of 500m. The aim of this phase of the survey was to collect data in order to confirm the position and orientation of the palaeochannel feature identified during the seismic source trials. These survey lines are shown in black on **Figure II.3**.

2.2.15. Once this survey had been completed and the position of the palaeochannel had been delineated the second phase of surveying could be implemented. This involved surveying a 1km block that encompassed the palaeochannel feature in this area. This 1km block had survey lines 1km long, orientated both north-east to south-west and north-west to south-east at a 10m line spacing in both directions. These survey lines are shown in green on **Figure II.3**.

2.2.16. The aim of collecting sub-bottom data at this tight line spacing was to allow the data to be processed at various line spacings and allow comparisons to be made between the interpretations from a 50m survey grid and a 200m survey grid for example. Any features of particular interest could also be processed at a 10m line spacing. This process would allow conclusions to be made about the effect of line spacings on the archaeological interpretation of study areas.

2.2.17. A total of 257.5km of seismic data were collected over the study area of 3.5km^2. The seismic data set acquired was generally of high quality due to good weather and calm sea states during the survey period. Surveying on a 10m grid required the boat to stay within 5m of the survey line, which was difficult due to the effect of tides in the area. Only one day of survey time was lost due to bad weather and so there was time to resurvey any lines that had deviated too much from the planned survey lines or were of poor data quality for some other reason.

Data Processing

2.2.18. The single beam echosounder data was processed by Emu Ltd and corrected for tides using data from the tide gauge deployed north of the study area. This processed data was presented to WA as an x, y, z text file for interpretation.

2.2.19. The processing of the digital seismic data was undertaken using two different approaches. One involved processing the data using Coda Geosurvey software, which is a standard package for processing and interpreting single channel seismic data. The second method involved processing the data using Promax and Geoframe software packages which are normally used for interpreting multi-channel seismic data collected for oil and gas prospecting surveys.

Seismic Interpretation using Promax and Geoframe Software

2.2.20. A digital copy of all the sub-bottom profile data was given to Dr Justin Dix and Dr Alex Bastos at the Southampton Oceanographic Centre (now National Oceanographic Centre) to process using Promax and Geoframe software.

2.2.21. Promax and Geoframe are complementary software packages for processing and interpreting seismic data. They are normally used for seismic data collected during oil and gas surveys and have been developed specifically for interpreting surfaces in three dimensions over large study areas. 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.

2.2.22. 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.

2.2.23. The processed seismic data set was then interpreted using Geoframe software. This software package allows the user to interpret the data by identifying and selecting boundaries between layers. If a boundary has been selected across an entire line of data then the position of this boundary will be shown on any intersecting lines when they are reviewed for interpretation. This very important feature allows the person conducting the interpretation to easily check that their interpretation is consistent between all the lines of data being studied.

2.2.24. A detailed description of the data processing using these software packages is included in **Appendix I**. The results of this work were passed back to WA for comparison with the data processed by WA using Coda Geosurvey software and for further interpretation.

Seismic Interpretation using Coda Geosurvey Software

2.2.25. A digital copy of all the sub-bottom profile data was retained by WA for processing using the Coda Geosurvey software.

2.2.26. Coda Geosurvey is a software package designed for the acquisition and processing of sub-bottom profile 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 allows an interpretation to be applied to a line of data by identifying and selecting boundaries between layers.

Comparison of Seismic Interpretation Systems

2.2.27. Coda Geosurvey does not show the position of any boundary already identified on any intersecting lines. This is because Coda Geosurvey treats every survey line as an individual data file. By contrast, Geoframe treats all the data from the survey as a collection of shot points. Therefore Geoframe recognises where shot points are in the same position at the intersection of two survey lines and can illustrate the relative interpretations which have been applied at these points.

2.2.28. This difference between Geoframe and Coda Geosurvey in the ability to observe the interpretation already applied to intersecting lines of data means that it is more difficult to apply an internally consistent interpretation across all the lines of data when using Coda Geosurvey.

Interpretation Scheme

2.2.29. An identical interpretation scheme was used for both processing systems. This scheme involved picking the two main reflectors visible in the data. These layers were the base of the channel infill reflector and the top of the bedrock reflector as illustrated in **Figure II.4**. The term 'top of the bedrock'/'bedrock surface' is used to describe the deepest reflector that can be traced across the entire study area.

2.2.30. The seismic data was collected and interpreted with two-way travel time (TWTT) along the z-axis, not depth. This can be seen on **Figure II.2** where the horizontal scale lines on the seismic data are in units of milliseconds. 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 was estimated to be 1600m/sec which is a standard estimate for shallow, unconsolidated sediments of the type being studied in this survey (Sheriff and Geldart 1983; Telford *et al.* 1990).

2.2.31. After all the seismic data had been interpreted the position of the boundaries could be exported in the form of x, y, z text files, where z was now the calculated depths not the TWTT.

2.2.32. An x, y, z text file was output from both Coda Geosurvey and Geoframe for the bedrock and base of channel infill layers at 50m, 100m and 200m line spacings.

Comparison of Interpretation Schemes

2.2.33. Another major difference between Geoframe and Coda Geosurvey became apparent at this stage of processing in the amount of data they exported to these text files. Coda Geosurvey creates an x, y, z position for every point along the boundary that has been specifically tagged during the interpretation; i.e. an x, y, z point for every click of the mouse along the boundary. However, Geoframe interpolates between the points selected during the interpretation and creates an x, y, z point for every shot point in the data. 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. The result of this was that the x, y, z text files from Geoframe typically contained ten times as many points as the x, y, z text files produced by Coda Geosurvey. Therefore the interpretation exported from Geoframe had a better horizontal resolution than the interpretation exported from Coda Geosurvey.

Visualisation of the Seismic Interpretations

2.2.34. The next stage of the project was to study the interpreted data sets and to assess them in terms of examining the effect of using different line spacings and to allow comparisons between Coda Geosurvey and Geoframe interpretations made at the same line spacings.

2.2.35. In order to achieve this the x, y, z text files were imported into the Fledermaus software package and made into surfaces representing the reflectors which had been interpreted as the top of the bedrock and the base of the channel infill.

2.2.36. Fledermaus is a 3D-visualisation and analysis software package. This software can create 3D solid surfaces for any set of data containing points with an x, y and z value. These surfaces are made by gridding the data and interpolating between the data points before shading the surface with a user selected colour file so that the colours represent the relative heights over the surface. This 3D surface can then be explored and visualised 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 profiles across these surfaces to be made to show some of the vertical information.

2.2.37. 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.

2.2.38. However, 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.

2.2.39. A total of 12 surfaces were made from the output of the seismic interpretation. These correspond to six surfaces representing the top of the bedrock and six surfaces representing the base of the channel infill. These two sets of six surfaces have been made from using the interpretations from both Coda Geosurvey and Geoframe and studying them at 50m, 100m and 200m line spacings.

2.2.40. The cell size for the surfaces was dependent upon the line spacing. Surfaces made from data at a 50m line spacing had a cell size of 15m, at a 100m line spacing a cell size of 25m was used and at a 200m line spacing a cell size of 50m was applied. These cell sizes and a weighting of 3 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.

2.2.41. An example of one of the surfaces is shown in **Figure II.5**. The figure shows the same surface in plan view, at an oblique angle looking towards the east and also a north-south profile over the surface. This figure conveys the idea of working with 3D surfaces but demonstrates that for discussion purposes figures showing the 3D surfaces will be clearest in plan view with associated profiles.

2.2.42. The discussion and geoarchaeological analysis of the surfaces representing the top of the bedrock surface and base of the channel infill takes place in **Section 3**.

2.2.43. In addition to making surfaces for the two layers interpreted from the seismic data, Fledermaus was also used to produce a bathymetric surface of the study area from the single beam echosounder data. This data was gridded at a cell size of 5m with a weighting of 3. The resulting surface is shown in plan view in **Figure II.6**. This choice of gridding parameters has left some holes in the data from the larger study area where the line spacing was 50m. These holes could have been covered by using a higher weighting value but this would adversely smooth the central area where the line spacing was 10m.

2.2.44. This figure illustrates that the bathymetric surface of the study area was a wide valley landform with raised areas shown in red and yellow at approximately 22-25m below OD. In between these two high areas the seafloor drops by up to 15m forming the base of the valley feature at over 37m below OD. This deepest part of the study area is shown in purple and has an east to west trend. Immediately to the north of this feature are two more or less rounded patches and one linear patch of raised seafloor at approximately 26-29m below OD. These three raised features also have an east to west trend and effectively divide the bathymetry of the study area into two regions with the seafloor to the north being approximately 3m higher than the seafloor to the south.

2.2.45. **Figure II.7** shows the bathymetry surface, the base of the channel infill surface and the top of the bedrock surface. These three surfaces are located vertically above each other in 3D. For illustration purposes the three surfaces are shown here separately, in plan view, with a single profile over each surface. The x and y coordinates of the end of these profiles were the same for all three surfaces and so highlight how the morphology over an area changes with depth.

2.2.46. Study of the seismic data in conjunction with this bathymetric surface reveals that the infilled channel which was the target of this project is to the north of the three central raised features. The palaeochannel is not delineated by the modern day bathymetry surface and can only be detected by the use of sub-bottom profiling. Further to this it is immediately obvious from the seismic data that the three raised features in the centre of the study area are in fact gravel deposits (**Figures II.6-7**).

2.3. GEOTECHNICAL SURVEY

Vibrocoring

2.3.1. Borehole or sediment core surveys are an established archaeological evaluation and investigation technique on terrestrial sites. Archaeological involvement in designing such a survey and direct access to the cores (primary data over geological log descriptions and photographs) is an accepted methodology with a proven value in terrestrial circumstances. Borehole data, i.e. both core log descriptions and analysed core samples, are a central source for the growing discipline of geoarchaeology. Geoarchaeology, rather than focus solely on anthropogenic deposits, is used 'to establish dated sequences of environmental change and suggest possible major influences on the environmental record', either human or geomorphological, or the interaction between the two (French 2003:4). Given that the potential of this kind of core data has been demonstrated in terrestrial, and even intertidal, conditions, the focus of the project's methodological investigation is its application in offshore locations.

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

2.3.3. Geoarchaeological core log descriptions, sampling of the cores and analysis of pollen, diatom and foraminifera within the sediment, as well as dating appropriate samples, should help define probable features, and identify any relationships between them.

2.3.4. 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 to provide an offshore, sea level index point.

Sampling Strategy

2.3.5. A judgement-led sampling strategy was developed, drawing on the geophysical data in order to address several specific questions. The survey was designed to:

- investigate the quality of core data that can be retrieved from the seabed to establish how to integrate geoarchaeological objectives with industry standard methods of vibrocore investigations;

- demonstrate the value of this kind of geoarchaeological assessment for reconstructing and assessing submerged prehistoric landscapes;

- assess the most ‘productive’ locations, which will be an important factor in establishing viable guidelines surrounding the nature and number of cores within a marine aggregate vibrocore survey to assess the archaeological potential.

2.3.6. Locations were chosen through initial interpretation of the sub-bottom profiling data in order to calibrate the geophysical data and to confirm the presence of an infilled palaeochannel (**Figure II.8**). Additionally, cores were targeted on various geomorphological features in order to support palaeogeomorphological modelling, to assess the depositional environments and to construct a chronology for the area (**Figure II.9**).

- Two core locations targeted the infill sediments of the palaeochannel feature, one along the calibration line (**VC1-2**) and a second *c.* 600m to the north-west (**VC17-18**). These cores were positioned to investigate the phase of channel infill, sediment deposition, the relative chronology of this period, its depositional environment and any potential evidence of marine influence and even transgression.

- Cores were also located within the wider valley landform to characterise and date the earlier depositional environment (**VC3-4** and **VC7-8**).

- Several cores were located on the edge of the palaeochannel to investigate the period of fluvial incision or excavation phase when the channel was formed, the relationship between incision and infilling and any evidence of marine influence (**VC5-6**, **VC9-10**, **VC 11-12**, **VC13-14** and **VC15-16**). These locations were also most likely to yield channel-edge peat deposits for radiocarbon dating and environmental assessment (**Figure II.8**).

- One core was positioned in the centre of a gravel deposit on the edge of the palaeochannel (**VC19-20**), potentially a ‘bar’ feature or an earlier, remnant gravel ‘terrace’. This was in order to establish whether it was of marine or fluvial origin and to further clarify the internal structure of the deposit.

- Finally, strong, bright reflectors, interpreted as peat horizons, on the edge of the wider palaeovalley landform, were targeted to investigate the chronological relationship between this sedimentary environment, the sediments from this landform and the smaller palaeochannel (**VC3-4**).

2.3.7. Where possible, these cores were positioned to form a transect across the palaeochannel in order to establish a concentrated vibrocoring strategy.

2.3.8. It was intended that both radiocarbon dating and OSL (Optically Stimulated Luminescence) dating methods would be used where appropriate to date the sedimentary units within the cores. Radiocarbon dating can only be used when organic material is present in the sediment and is most effectively used to date peat, which only forms under specific conditions. OSL dating can be used on sands or sandy sediments where no organic material is present. However, the OSL dating process requires samples that have not been exposed to light. Therefore two vibrocores were taken from each location, so that the first core could be opened, assessed and appropriate sediments for OSL dating identified whilst the second core could be preserved in the dark for OSL dating. As a result, twenty vibrocores were collected from ten locations.

Fieldwork

2.3.9. On 27th to 28th September 2003, a 6m hydraulic vibrocorer was used to acquire the twenty vibrocores. Each core was cut into 1m lengths, capped and labelled and taken back to WA for comprehensive logging. In contrast to standard vibrocore survey methodology, the cores were not opened so that visual descriptions could be made on site; instead they were packed for a subsequent, more comprehensive logging process. The second cores from each location were recovered using black vibrocore liners and kept separately in a darkened container to prevent exposure to light (**Figures II.10-11**). A comprehensive, technical methodology and notes are included in **Appendix II**.

2.3.10. The ten locations required different levels of positional accuracy, since they were targeting features of different scales (**Table II.4**). All 20 cores were taken within the level of positional accuracy specified for each location.

Vibrocore	Location (British National Grid)		Depth (OD)	Required accuracy (to target position in m)
	Easting (m)	Northing (m)		
VC1	512991	84551	-33.33m	1m
VC2	512992	84552	-33.33m	
VC3	511901	83217	-32.04m	1m
VC4	511901	83217	-32.04m	
VC5	512930	84774	-33.30m	1m
VC6	512928	84772	-33.30m	
VC7	512617	84091	-36.02m	1m
VC8	512618	84094	-35.97m	
VC9	512472	84860	-29.69m	<5m
VC10	512472	84854	-29.63m	
VC11	512327	84673	-27.03m	<5m
VC12	512325	84670	-27.08m	
VC13	511948	84831	-30.38m	<5m
VC14	511945	84831	-30.38m	
VC15	512782	84827	-31.82m	<5m
VC16	512782	84828	-31.81m	
VC17	512389	84751	-29.07m	5-10m

Vibrocore	Location (British National Grid)		Depth (OD)	Required accuracy (to target position in m)
	Easting (m)	Northing (m)		
VC18	512397	84751	-29.16m	
VC19	512285	84619	-26.27m	10-15m
VC20	512288	84620	-26.26m	

Table II.4: Vibrocore location and depth data.

Processing and Analysis

2.3.11. The detailed core logging took place at WA's environmental facility from the 30th September onwards. For the first part of the analysis one set of the cores were split open to allow core descriptions to be recorded and photographed. From this a detailed log was produced for each core that was then used for the initial interpretation of the sedimentary stratigraphy and for planning the sampling programme.

2.3.12. The core log descriptions identified individual sedimentary units and recorded the structure, colour, texture and lithology of the sediments, describing any inclusions and the nature of the boundaries between the units. This detail was used to make initial interpretations of each unit. The core log descriptions are sedimentological and pedological and can highlight evidence of the depositional processes of the sedimentary environment. Features such as flood or tidal couplets, peat horizons, gleyed clays and characteristic fluvial or tidal sequences of sedimentary units provide evidence of the nature and relative speed of depositional processes and their environments, as well as providing material for pollen, diatom and foraminifera assessment and identifying samples suitable for dating (**Figures II.12-13**).

2.3.13. The core logs were used to create schematic diagrams of vibrocore sections through the study area. These were used, along with initial interpretations of the geophysical data, to identify key depositional sequences/environments and to formulate a sampling strategy to interrogate these sequences. Peat horizons were identified for radiocarbon dating and appropriate samples for OSL dating were pinpointed so that together they would provide a sequential chronology. The sampling was focused in particular on two different depositional phases, the channel infill (**VC1** and **VC17**) and the sedimentary deposits from the edge of the wider palaeovalley landform (**VC3**). The sampling also addressed the environments within which the peat horizons had formed (**VC13** and **VC7**) and was designed to investigate the relationship between these features (**Figures II.14-15**).

Environmental Sampling

2.3.14. Samples were sent to Dr Rob Scaife for pollen assessment and analysis, to Dr Nigel Cameron for diatom assessment and analysis and to Dr Annette Kreiser for foraminiferal assessment and analysis, as shown in **Table II.5** and in **Figures II.14-15**.

Vibrocore	Pollen and diatom samples (depth in m below OD)	Foraminifera samples (depth in m below OD)
VC17	29.47, 30.07, 30.67, 31.27, 31.87, 32.47, 33.07	29.47, 30.07, 30.67, 31.27, 31.87, 32.47, 33.07
VC1	33.73, 34.33, 34.93, 35.53, 36.13, 36.73, 37.33, 37.93, 38.53	33.73, 34.33, 34.93, 35.53, 36.13, 36.73, 37.33, 37.93, 38.53
VC13	33.58	-
VC3	32.44, 32.86, 33.44, 34.04, 34.44, 34.52, 34.64, 35.04, 35.64, 36.64	32.44, 32.86, 33.44, 34.04, 34.44, 34.52, 34.64, 35.04, 35.64, 36.64
VC7	38.58	-
VC19	-	26.79
Total	28	27

Table II.5: Pollen, diatom and foraminifera assessment and analysis samples.

2.3.15. Environmental analysis of sediment samples took place at two different levels: the standard assessment; and further analysis of particular samples. Assessment broadly characterised the depositional environments, whilst full analysis answered specific questions. Assessment identified the presence of various pollen species, diatoms, or foraminifera, whilst analysis provided, for example, a pollen diagram for each sequence and enabled the investigation of particular questions identified through the assessment process.

2.3.16. The presence, variety and quantity of pollen species can identify the vegetation and nature of the depositional environment (i.e. saltmarsh species would suggest a different environment to a woodland assemblage), and can also be characteristic of particular prehistoric periods. The presence of both diatoms and foraminifera within the sediment relates to the salinity of the depositional environment. Diatoms can provide evidence of the size of water bodies, their salinity and the warmth of the water, whilst foraminifera can identify where the sediment was within a saltmarsh zone, illustrating, for example, how far from the sea that sediment was deposited. Each type of analysis is appropriate to particular sediment samples; samples from the gravel deposit (**VC19**), for example, were only assessed for foraminifera since pollen and diatoms are less likely to survive in the gravels. A combined programme of pollen, diatom and foraminifera assessments can provide evidence of the palaeovegetation and the nature of the environmental conditions prevalent at the time. It could identify, for example, the nature of a fluvial environment, potentially suggesting details such as that it was within the tidal reach with a constant but low freshwater discharge.

2.3.17. Concurrent with this, four peat samples were taken for radiocarbon dating and submitted to the Rafter Radiocarbon Laboratory at the Institute of Geological and Nuclear Sciences in New Zealand. Seven sections of the duplicate cores were sent to Dr Steven Stokes at Oxford University so that appropriate samples could be extracted for OSL dating, as shown in **Table II.6** and in **Figures II.14-15**.

Vibrocore	Radiocarbon samples (depth in m below OD)	OSL dating samples (approximate depth in m below OD)
VC17	-	-
VC18	-	29.61, 32.16
VC1	-	-
VC2	-	34.83, 35.43, 38.73

Vibrocore	Radiocarbon samples (depth in m below OD)	OSL dating samples (approximate depth in m below OD)
VC13 VC14	33.58	-
	-	32.13
VC3 VC4	32.88, 34.48	-
	-	36.44
VC7	38.58	-
Total	4	7

Table II.6: Radiocarbon and OSL dating samples.

2.3.18. OSL dates represent the date of sediment deposition; the process dates the 'luminescence signal' of the purified quartz fraction of sandy sediments (Stokes *et al.* 2003). However, in tidal or sub-tidal depositional environments, the luminescence signal might not necessarily have been 'zeroed' definitively, which can affect the range of resolution that an OSL date would represent. The combination of dating techniques was intended to create a more reliable chronology for the different geomorphological features and their associated depositional environments, in order to define the relationships between these features. It should also provide a timescale for the last phases of palaeochannel infill deposition.

2.3.19. The level of sampling originally undertaken means there is potential for more comprehensive analysis of the pollen, diatom or foraminifera within the sedimentary units and more detailed and complex environmental reconstruction. Further sampling and subsequent analysis could be undertaken since both the sampled and remaining core have been preserved.

Grab Sampling

2.3.20. Seabed grab sampling surveys are used by the aggregate industry solely as part of benthic surveys undertaken in preparation for the marine ecological assessment element of an EIA. As such, they are untested as an archaeological evaluation technique.

2.3.21. Consequently, this part of the study was aimed at assessing the archaeological application of this survey method. Specifically, it hoped to establish:

- whether it is a viable methodology for locating any 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 clarifying if any correlation between artefact distribution and buried relict palaeogeographies or archaeological deposits exists.

2.3.22. One of the key issues that have to be addressed if artefacts are located is the question of context. Any material from the upper layers of the seabed is likely to have been reworked from their original context. The semi-mobile, upper strata of the seabed that will be sampled during the survey are subject to marine sediment transportation processes. Fishing and other shipping activities within the study area are also likely to contribute to sediment transport and mixing. Consequently, assessment of seabed grab sampling as an archaeological evaluation method involves addressing this issue in relation to the potential interpretations/conclusions that can be made from this kind of material.

2.3.23. The only published account of a study during which archaeological material was retrieved through seabed grab sampling used a clamshell grab, a large, $0.5m^3$ grab sampler generally used in research surveys (Fedje and Josenhans 2000). In contrast to this, aggregate-related, marine ecological assessment surveys generally use the 'Hamon grab' to take benthic samples from coarse substrates, as recommended by the ODPM's 'Guidelines for the conduct of benthic studies' (2002). These suggest that 'whilst a wide variety of sampling methods are available … the Hamon grab is the recommended tool for sampling the benthic macro-infauna from coarse substrata' (ODPM 2002:21-22). This study used, therefore, a Hamon grab; specifically, the smaller of the two types of Hamon grab which is the most versatile and cost-effective piece of equipment, providing a conventional surface sample unit of $0.1m^2$ and a sample size of up to 15 litres.

Data Acquisition

2.3.24. Despite the successful recovery of a stone artefact off the British Columbian coast by Fedje and Josenhans in 1999, seabed grab sampling remains an unproven archaeological evaluation method (Fedje and Josenhans 2000). Consequently, in contrast to the approach taken with the vibrocore survey, a systematic sampling strategy was adopted in order to determine the efficiency of the technique as a potential archaeological tool. The $1km^2$ study area was divided into a grid of $100m^2$ squares. The central point of each square was the designated sample position, giving a total of 100 grab targets (**Figure II.16**). This gridded sampling strategy was designed to test if there was any discernible correlation between the location of any artefacts, or absences of artefacts, and the geoarchaeological features identified in the seabed below.

2.3.25. The Hamon grab penetrates the uppermost 0.2 to 0.3m of the seabed, providing a 'mixed' sediment sample. This is not considered to be a methodological disadvantage given that the source, the uppermost, reworked marine sediment layer of the seabed is a mixed layer unlikely to contain *in situ* material.

2.3.26. The exact depth and position of each sample was recorded. Positional accuracy was restricted to within 15m of the target location. Where inadequate sample size, less than 8-10 litres, occurred additional 'hits' (grabs) were made in the target sample 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 a combined sample coordinate was established.

2.3.27. Once an adequate sample had been collected it was initially processed aboard the survey vessel by washing through a 1mm sieve; effectively eliminating clay and silt sized particles from the residue. Sample size was often in the region of 10 litres before on-board processing. 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 and to provide targets for additional grabs in areas of interest if the original sites were completed within the fieldwork period.

2.3.28. On 27th to 29th September 2003, a total of 156 grabs, averaging approximately ten hits per hour, were taken (**Figure II.17**; see **Appendix II** for additional fieldwork notes). From these, 108 samples, some of them combined, were collected. The initial visual examination on board the vessel identified four flints of potential anthropogenic origin: G44, G44b, G49 and G70 (**Figure II.18**). This represented a ratio of one flint for every 27 samples. Two bird bones (cormorant-sized, darkened by its deposition environment) were retrieved from G24 and G54, whilst a large fossil tooth of the fish S*ynodontaspis* was noted at G75. Initial field observations also determined the presence of small pieces of slag and/or clinker-like material in a number of the samples from across the study area. Very occasionally, a sample appeared to contain elements of peat or decaying organic remains within 'humic' clay. Where a large amount of this material was present within the sample it was retained as a whole sample and processed accordingly in the laboratory. Erratics were rarely identified.

Processing

2.3.29. Standard artefactual sieving practice was established for processing the 108 survey samples (**Figure II.17**). The wet-sieve processing of samples 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 area, a 4mm sieve was also used, as terrestrial usage of the 4mm sieve has shown potential good retrieval whilst limiting smaller fraction losses. However, difficulties in positively determining anthropogenic material below 2-3mm, combined with the overall paucity of observed artefacts from the larger mesh sizes, suggested further analysis of the finest material would have been neither archaeologically productive nor cost-effective.

2.3.30. Sorting of the sieve residues generally began with the 10mm residue, which could be sorted accurately in a wet state. The 4mm residue was dried before sorting began. The 1mm sieve residue was discarded without further processing.

2.3.31. The sieving and sample analysis process attempted to extract all potentially archaeological artefacts from within both the 10mm and the 4mm sieves and establish a basic distribution, although for the purposes of this study it was only material of specifically prehistoric, archaeological potential that was of interest.

3. RESULTS

3.1. GEOPHYSICAL DATA

3.1.1. The amount and the quality of the seismic data collected over the study area (see **Section 2.2.18**) provided an excellent opportunity to study this area of seafloor in greater detail than would normally be possible in the course of seabed assessment.

The resolution allowed a few small-scale (less than 50m) features to be identified that would otherwise have been missed.

3.1.2. The following data examples are taken from the entire seismic data set. **Figure II.19** shows a line of seismic data collected during the prospecting stage of surveying. From a preliminary review of this line of data it was possible to determine that the study area covered a wide valley landform, approximately 2.5–3km wide, with the axis of the valley orientated north-west to south-east. The palaeochannel feature, which was the focus of the later stages of surveying, is situated towards the eastern edge of this wide valley landform. **Figures II.19** to **II.25** all show seismic sections discussed in this stage of the report and have the same amount of vertical exaggeration.

3.1.3. The higher topography in the north-east corner of the study area was known to be an active dredging area. The effect of the dredging, i.e. 'dredging scars', can be seen in the seismic data for this area (**Figure II.20)**. This dredging activity extended up to the edge of the palaeochannel in part of the study area.

3.1.4. The higher topography in the south-east corner of the study area was interpreted as a bedrock feature, which has probably been covered by a veneer of modern seafloor sediments. On the sloping valley side of this high land was an area of bright reflectors, which were interpreted as being peat horizons (**Figure II.21)**. The presence of peat was later confirmed during the vibrocoring stage of this project (see **Section 3.2**).

3.1.5. The study area was apparently at the head of this valley landform which, from bathymetry charts, appears to continue towards the south-east.

3.1.6. During the initial review of the seismic data it was assumed that the palaeochannel feature would have been flowing from east to west, i.e. away from the Quaternary landmass towards the palaeocoastline. This would mean that the palaeochannel feature was entering the wider valley landform in the region covered by the study area.

3.1.7. The wide valley landform contained a sediment filled palaeochannel at the centre of the study area. A typical example of a seismic profile over the palaeochannel is shown in **Figure II.22**. This palaeochannel was orientated east to west, approximately 200 – 300 m wide and ranged from 14m to 18m deep. It can be seen from the seafloor above the palaeochannel that this feature has little or no bathymetric expression. The channel infill deposit was interpreted as being a fine-grained unit composed of sand/silt. On the southern bank of the palaeochannel was a unit interpreted as being a coarse-grained gravel deposit. The dimensions of the gravel deposit vary along the length of the channel.

3.1.8. The seismic characteristics of the coarse-grained gravel unit can be seen in **Figure II.22**. The unit had a set of discontinuous, steeply dipping, low amplitude reflectors, the architecture of which implies a lateral accretion of sediment. These gravels must have been deposited in a high-energy environment because a large amount of energy would be required to transport sedimentary particles of this size.

3.1.9. **Figure II.22** also shows that the seismic characteristics of the channel infill deposit are a series of continuous, sub-horizontal, high amplitude reflectors. These fine-grained sand and silt deposits will have been laid down when the channel was in a low energy environment, which allowed these small sedimentary particles to drop out of suspension.

3.1.10. **Figure II.22** also shows the relationship between these two seismic units. The fine-grained sand and silts onlap the gravel deposit and were therefore deposited at a later stage.

3.1.11. The bedrock underlying the palaeochannel can be seen beneath the fine-grained channel infill and at a higher level on either side of the palaeochannel, indicating that the channel is incised in the bedrock. This bedrock reflector had a low amplitude underneath the coarse-grained gravel deposit because most of the acoustic energy propagating through gravels was attenuated before it reached the bedrock. Throughout most of the study area the top of this bedrock unit is a fairly linear, constant, high amplitude reflector.

3.1.12. The depth to the top of the bedrock unit, below the seafloor, was generally greater to the south of the palaeochannel than it was to the north of it. This implies that the bedrock was dipping towards the southwest, a fact that was confirmed from the baseline geological information for the region and could also be seen from the bedrock reflectors identified during the prospecting stage of this project.

3.1.13. The features of the bedrock, fine-grained and coarse-grained units described so far can be observed in virtually all the seismic lines over the palaeochannel.

3.1.14. However, there were a number of features that can only be seen on selected seismic lines. These were:

- A thick succession of the coarse-grained gravel unit situated on top of a depression in the bedrock at the edge of the palaeochannel. An example of a seismic profile over this feature is shown in **Figure II.23**.

- A small palaeochannel feature cut into the bedrock underneath the main palaeochannel being studied. An example of a seismic profile over this feature is shown in **Figure II.24**.

- A coarse-grained deposit at the base of the main palaeochannel that is overlain by the fine-grained channel infill. The relationship of this unit to the steeply dipping, coarse-grained gravel unit on the south bank of the palaeochannel was unclear on all the seismic profiles it was observed. This unit was at too great a depth in the palaeochannel to be reached by the vibrocoring. An example of a seismic profile over this feature is shown in **Figure II.25**.

3.2. GEOTECHNICAL DATA

Vibrocores

3.2.1. The vibrocore logs are listed in **Appendix II**. Palaeoenvironmental assessments and analyses such as pollen, diatom and foraminifera analyses are included in **Appendix III**. The results of the ^{14}C and OSL dating are presented in **Appendix IV**.

3.2.2. Vibrocores **VC3** and **VC7** are located within the wider valley landform (**Figure II.14**). **VC3** penetrated the upper 5.31 metres of an approximately 20 metres sequence of valley infill sediments. Sand (with interbedded silt and clay) is overlain by peats and clays. The lowest peat deposit is dated to 9333±45 BP (8740-8440 cal. BC, NZA-19296) at 34.48m below OD. The upper peat is dated to 9131±45 BP (8530-8260 cal. BC, NZA-19298) at 32.86m below OD and is overlain by sand and gravel. **VC7** contained clays with interbedded sand. Peat (containing *Phragmites* sp.) formation was noted at 38.62m below OD and has been radiocarbon dated to 9629±50 BP (9220-8880 cal. BC, NZA-19297).

3.2.3. Peat deposition and interbedded sands, silts and clays are seen in **VC13** on the northern edge of the palaeochannel. The level (33.49m below OD) and date (9155±50 BP (8530-8260 cal. BC, NZA-19299)) of this peat are similar to the upper peat deposit recorded in **VC3**. Peat was also recorded in **VC5** at 33.87m below OD within the northern wider valley landform (**Figure II.14**).

3.2.4. **VC19** was positioned in the centre of a gravel deposit on the edge of the palaeochannel, potentially a 'bar' feature or an earlier, remnant gravel 'terrace' (**Figure II.15**). This was in order to establish whether it was of marine or fluvial origin and to try to further clarify the internal structure of the deposit. **VC19** penetrated 2.7 metres of gravel. The gravel was stratified with slightly differing gravels with varying quantities of sand matrix. Marine shell was noted within the gravels.

3.2.5. The first period of deposition within the palaeochannel is a gravel deposit overlying the bedrock ledge and covering valley infill sediments which may be the same as those observed within **VC7**. The deposit appears to show lateral accretion on seismic profiles and is of uncertain origin. Peat occurring underneath this gravel deposit is possibly the same as peat in **VC7** which is dated to 9629±50 BP (9220-8880 cal. BC, NZA-19297). At this date or later, it is unlikely that the necessary gradient for deposition of gravel within a low lying fluvial system is present. The deposit described from **VC9** also contains marine shell. The gravel deposit is therefore more likely to have resulted from marine influences. The most likely explanation for its formation is that an offshore supply of gravel has been reworked by tidal currents and possibly longshore drift into the palaeovalley and palaeochannel. Winnowing of the sediment by fluvial processes would remove finer grained material.

3.2.6. Channel infill deposits are seen in vibrocores **VC1**, **VC9**, **VC11** and **VC17** (**Figure II.15)**. These are up to 20 metres thick and comprise interbedded silts, sands and clays. Vibrocores did not penetrate the lower 15 metres of this sequence. The seismic profiles show that the base and middle part of this sequence contain fine-grained sediments indistinguishable with those sediments occurring at the top of the sequence. This type of deposition can be rapid and represents estuarine, intertidal and nearshore deposition probably induced by rising sea level.

3.2.7. Several cores (**VC5**, **VC9**, **VC11**, **VC13** and **VC15**) were located on the edge of the palaeochannel. These cores predominantly contained sands, silts and clays indicative of alluvial sedimentation. Peat deposits were recorded in **VC5** (32.69m below OD) and **VC13** (33.62m below OD) (**Figures II.14-15**).

3.2.8. Gravel and sand up to 0.3 metres thick was observed at the top of most of the vibrocores. Marine shell fragments were noted to be common within this deposit. 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).

3.2.9. The sediments and stratigraphy recovered from the vibrocores relating to the palaeovalley and paleochannel appear to represent the offshore continuation of the Palaeo-Arun River and the formation of early Mesolithic terrestrial deposits within its valley floor. An earlier palaeochannel seen in seismic profile (**Figure II.24**) and the cutting of and earliest deposition within the palaeovalley point towards earlier fluvial activity within the study area. Bellamy (1998) studied the same palaeovalley at a wider scale and lower resolution with results showing deposits relating to more than one glacial cycle are represented. The erosion of the palaeovalley in to Tertiary bedrock to *c.* 50m below OD during a period of lowered sea level is difficult to date. The oldest dated peat within the palaeovalley dates to 9629±50 BP (9220-8880 cal. BC, NZA-19297).

3.2.10. The cutting of the palaeovalley feature and its subsequent infilling represent a sedimentary hiatus. It is unclear from the sediments in the vibrocores whether the cutting of and earliest phase of sedimentation within the palaeovalley relates to earlier glacial and interglacial periods. Relative dating obtained by pollen analysis of the lowest sediment unit in **VC3** suggests a possibility that ‘the sediment unit may be of Devensian or late Devensian age, or possibly, a pre- temperate stage of an earlier interglacial cycle’ (Scaife 2004b, **Appendix III**).

3.2.11. Valley infill sediments above this unit are dominated by terrestrial sediments dating to the 9^{th} millennium cal. BC. Peats silts and clays appear to represent a flat, low lying terrestrial landscape subject to seasonal and/or tidal flooding.

3.2.12. Cutting of the palaeochannel and channel infill appear to have occurred after this phase of sedimentation within the palaeovalley. The initial phase of deposition within the palaeochannel represented by the gravel deposit is probably indicative of marine process. The onshore migration of a gravel deposit into the palaeochannel and palaeovalley is the most likely explanation.

3.2.13. Further peat deposition and laminated silts clays and sands are seen within the palaeovalley and on the northern edge of the palaeochannel, presumably whilst the channel was an active water course. It is this period which is a likely period of occupation of the area and which is shown in the digital ‘Arun Visualisation’ (Internet Archaeology, forthcoming).

3.2.14. Marine submergence during the Holocene transgression is represented by (rapid) sedimentation within the palaeochannel unconformably overlain by a transgressive deposit of gravel and sand. During this period it is possible that erosion by wave action has truncated the uppermost sediments of valley and channel infills and valley edges. Alltogether, the sequence seen in the vibrocores appears to represent one cycle of sea level rise during the Holocene period.

Grab Samples

3.2.15. Of the 108 samples collected, only 15 samples provided no results. Slag, clinker and flint were all retrieved. Slag and clinker were both readily identifiable; the flints, however, being relatively small, were harder to categorically define. Non-diagnostic fired clay of unknown function and date also occurred.

3.2.16. Apart from the presence of two bird bones, only fossilised bones were encountered. These generally belonged to the fish *Synodontaspis*, a shark-variant probably dating to the Eocene (*c.* 56-34 million years ago; Melville and Freshney 1982), with only a small proportion belonging to other species of a similar date. The two bird bones are from a cormorant-sized bird. They are darkly coloured due to the waterlogged deposition environment and are not necessarily of antiquity. Complete results for the grab sampling are included in the grab sampling survey technical notes included in **Appendix II**.

3.2.17. 119 flints were retrieved from 50 of the 108 samples. 22 came from the 10mm fraction, 4 of which were identified aboard the survey vessel, and 97 from the 4mm fraction (**Figure II.18**). The flints are all relatively small, averaging 10mm to 16mm and weighing 1g or less.

3.2.18. Of the 22 flints coming from the larger mesh 12 have elements indicative of human activity (from G7, G10, G44, G44b, G49, G58, G61b, G70, G76 & G92b). They vary in size from 10mm to 24mm maximum length and weigh 1g or less.

3.2.19. Five of the identified flints have cortex visible, generally on one side of the flint (dorsal). Cortex is the outer surface of a piece of flint and so its presence on these five flakes indicates that these may be primary or secondary flakes from the initial stages of shaping a flint tool. None of these flints appear to be of a diagnostic type. One has minor blade-like characteristics (G61b), another looks like a squat shaped secondary flake (G10), a third like a possible piercer (G92b), whilst the other nine can be categorised as flakes. The flints come from nine different locations (**Figure II.26**). Samples G44, which includes G44b, and G76 both contain more than one possibility of archaeologically-derived flint within this size category.

3.2.20. Some 13 of the 97 flints collected from the 4mm sieve show a potential anthropogenic origin (from G2, G14, G31, G37, G44, G49, G49b, G54b, G82, G85, G96). They vary in size from 6mm to 16mm and weigh less than 1g each. Only one of these grab locations provided more than one example within its size category (G85). 11 of these flints have cortex present (dorsal surface). Again none of these are of a diagnostic type (although one from G31 looks like a pseudo-microlith), and generally represent flakes and ‘chips’.

3.2.21. The problems of distinguishing the origins of these flints, establishing an anthropogenic origin rather than mechanical weathering, are compounded by a lack of diversity amongst the assemblage. Smaller elements of the assemblage are difficult to distinguish from potentially natural processes. Bulbs are often in 'unusual' positions, making a positive identification of anthropogenic origin difficult. The majority of the flints extracted from the sample appear to come from small flint 'pebbles' rather than from nodules of flint. Indeed the projected parent flint sizes are small enough to question whether they would be utilised for any purpose that might explain the small 'flakes' encountered. Flake platforms are less evident on many examples, and there is no indication of platform preparation, which might be expected to be present if Mesolithic or Palaeolithic cultural debris is to be inferred. A lack of supporting flake scars from previous removals also points towards a non-anthropogenic origin. Very few of the flints have any form of an arris, which may have suggested an anthropogenic origin.

3.2.22. The general lack of observable methodological approach to many of these removals also makes it appear less likely that the majority of these flints have an anthropogenic origin. The presence of starch fractures on some surfaces is suggestive of at least some natural flaking processes in operation. This information is set against the sure knowledge that gravel (most of which is smooth and rolled) is present in the area. Any gravel movement (deposition, re-deposition, scouring and transport) is likely to produce stone on stone contacts, so that the chances of small chips and 'flakes' being released increases proportionate to the number of contacts, weight of contacting objects, and the speed at which contact occurs.

3.2.23. Consequently, the struck flints were defined as highly probably, probably, possibly or improbably of human origin (see **Appendix II**). Only three of the 119 struck flints identified are considered to be of highly probable anthropogenic origin (see table below and **Figures II.18** and **II.26**); four others have probable anthropogenic elements to them, the rest are assessed as possible or improbable.

3.2.24. By far the most common find types encountered within the processed samples consist of slag, categorised on the basis of its vitreous nature, and lighter, airier clinker-like material (which includes many elements initially identified as burnt stone-like material, as well as coal). Almost all of these can be accounted for by shipping activities, especially post-industrial activities; they are possibly residues from firing chambers fuelling shipping.

3.2.25. Two grab positions (G21 and G83) produced examples of fired clay. These are non-diagnostic, of unknown date and function. Some instances of peat remains were identified from 21 samples. This material appears to consist of a grey clay matrix within which small, flattened particles of *Phragmites* stem and rhizome were present. None of this material appeared to be part of an *in situ* deposit. 70 or so fossil teeth of the fish *Synodontaspis* were recovered from a number of samples whose distribution is scattered across the study area. A similar number of fossil fish bones, including vertebrae, were also recovered, generally from the same samples as the teeth.

3.2.26. All this material was non-diagnostic, palaeontological, modern or undatable. Consequently, none of this material was considered to be archaeologically significant. Flints that are of archaeological interest are listed in **Table II.7**.

Grab No.	Number of struck flints	Potential for an anthropogenic origin			
		Highly probable	Probable	Possible	Improbable
10	1	-	1	-	-
31	1	-	1	-	-
44	2	1	-	1	-
44b	2	1	-	1	-
49	6	1	-	2	3
61b	1	-	1	-	-
92b	1	-	1	-	-
2, 7, 14, 37, 58, 70, 76, 82, 85, 96, 49b, 54b	33	-	-	15	18
4, 19, 22, 23, 25, 26, 28, 30, 38, 39, 40, 41, 52, 53, 54, 56, 57, 60, 66, 67, 75, 78, 79, 83, 87, 90, 93, 94, 95, 98, 65b	72	-	-	-	72
Total	119	3	4	18	94

Table II.7: Number of struck flints within grab samples and their potential for an anthropogenic origin.

3.2.27. Of the 15 samples that provided no results, the majority occur within and towards the outer edge of the buried palaeochannel. The broad distribution of these 'blanks', interspersed with samples containing pertinent material, appears to imply that simple erosional distribution associated with the palaeochannel alone cannot be implied.

3.2.28. The flints located during the survey were all similarly sized and weighted. No flints with a potential archaeological origin greater than 25mm in length were collected from the study area. Similarly, no potential anthropogenically-derived flints weighing more than 1g were retrieved from any sample in the collection. The presence of similarly sized and weighted remains can be explained by some sort of 'surface' re-deposition, perhaps a water-sorted deposition pattern. As such a pattern appearing over a square kilometre may also be an indication of wider and further reaching post-transgression marine processes.

3.2.29. The lack of diagnostic elements within the flint assemblage makes it very difficult to conclusively distinguish between anthropogenic processes and mechanical fractures. It is likely that both aspects are represented within the assemblage. A fuller discussion of the nature of the flint assemblage is included in **Appendix II**.

3.2.30. In summary, the broad distribution pattern of these flints across the study area and the similarity of size and weight of the flints encountered suggest that no correlation between the find distribution and the submerged archaeology of the 1km^2 study area is discernible (**Figure II.26**).

4. METHODOLOGICAL ASSESSMENT

4.1. GEOPHYSICAL SURVEY

Surface Modelling using Fledermaus

4.1.1. From the 200km of seismic data collected in the central survey grid shown in **Figure II.3**, a total of 42 1km lines were selected for interpreting using Coda Geosurvey and Promax and Geoframe software. These lines effectively composed a 50m x 50m survey grid over the area and were interpreted to locate the top of the bedrock unit and the base of the channel infill unit. These two layers were used to create surfaces in Fledermaus software to enable the visualisation of the palaeogeomorphology as described above (see **Section 3.1**).

4.1.2. Subsequently, 22 1km lines were selected which composed a 100m x 100m survey grid over the central study area and the process described above was repeated. These 22 lines were a sub-set of the lines used for the 50m x 50m grid, no further interpretation of seismic data occurred between the creation of these two sets of surfaces.

4.1.3. Finally, 12 1km lines were selected which composed a 200m x 200m survey grid over the central study area. Again these 12 lines were a sub-set of the lines used for the 50m x 50m grid, no further interpretation of seismic data occurred between the creation of these two sets of surfaces. An example of the line spacings for these three grids is shown in **Figure II.27.**

4.1.4. The main differences between the Coda Geosurvey and Promax and Geoframe software packages were described above and are summarised here:

- Geoframe allows the user to see the position of the interpretation applied to intersecting seismic lines. This makes it is easier to interpret a layer which is internally consistent throughout the data set. Coda Geosurvey does not have this functionality.

- Geoframe exports an x, y, z position for every shot point along the seismic line. 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.

4.1.5. **Table II.8.** shows the number of x, y, z points produced by the two seismic interpretation software packages, for each of the survey grid patterns studied and used in the making of each of the six surfaces representing the top of the bedrock surface.

	50m x 50m	100m x 100m	200m x 200m
Coda Geosurvey	8,788	4,412	2,302
Geoframe	70,794	37,166	20,470

Table II.8: Number of x, y, z points produced by the two seismic interpretation software packages – top of the bedrock surface.

4.1.6. The number of x, y, z points produced by the two seismic interpretation software packages, for each of the survey grid patterns studied and used in the making of each of the six models representing the base of the channel infill surface, are shown in **Table II.9**.

	50m x 50m	100m x 100m	200m x 200m
Coda Geosurvey	2,478	1,250	630
Geoframe	29,766	15,260	8,334

Table II.9: Number of x, y, z points produced by the two seismic interpretation software packages – base of the channel infill surface.

4.1.7. These differences between the seismic interpretation software packages and the number of x, y, z points that they have produced result in different surfaces being made in Fledermaus for any two comparable surfaces.

4.1.8. In addition to the differences between the two software packages it is also important to consider that the interpretations were conducted by two different geophysicists using different software packages. As geophysical interpretations require some subjective decisions it is probable that they will have applied slightly different interpretations to certain sections of the data, a fact which will also result in differences between any two comparable surfaces.

4.1.9. 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, i.e. using a 15m cell size for a 50m survey grid.

Interpretation of the Top of Bedrock Surface

4.1.10. The surfaces produced by Fledermaus of the interpretation of the top of the bedrock reflector using Coda Geosurvey and Geoframe software packages for the 50m x 50m grid are shown in **Figure II.28**. These two surfaces were made using a 15m cell size and a weighting of 3. This figure also shows two profiles over each of these surfaces but with large vertical exaggerations.

4.1.11. The two top of bedrock surfaces in **Figure II.28** are broadly similar, showing a channel orientated east to west, which is slightly deepening towards the west. Within the channel is a bedrock ledge protruding from the southern bank and narrowing the channel at this point. The profiles over the channel show that it is 200m to 300m wide and up to 18m deep. The two surfaces also show that the bedrock to the north of the channel is up to 4m higher than the bedrock to the south of the channel.

4.1.12. There were a number of differences between the surfaces produced by the two seismic interpretation packages. These were:

- The bedrock surface produced from the Geoframe interpretation contained two linear depressions in the southern section of the study area, which were not seen in the surface produced from the Coda Geosurvey interpretation;
- The profiles over the surfaces show that the southern bank of the channel was steeper in the Geoframe interpretation than in the Coda Geosurvey interpretation;
- The bedrock ledge protruding into the channel was better defined in the Geoframe interpretation than in the Coda Geosurvey interpretation;
- The bedrock surface on the banks of the channel shown in the profiles was more undulating in the Coda Geosurvey interpretation than in the Geoframe interpretation.

4.1.13. Despite these differences the two surfaces produced from the two seismic interpretations show the same main characteristics.

4.1.14. The surfaces produced by Fledermaus of the interpretation of the top of the bedrock reflector using Coda Geosurvey and Geoframe software packages for the 100m x 100m grid are shown in **Figure II.29**. These two surfaces were made using a 25m cell size and a weighting of 3. This figure also shows two profiles over each of these surfaces but with large vertical exaggerations.

4.1.15. There are now 12 holes in the surface produced from the Coda Geosurvey data. These holes appeared because there was not an even distribution of data points in the x, y, z text file produced by Coda Geosurvey in order to ensure that there was a data point in each cell for the gridding process. However, the interpretation from Geoframe has produced enough points so that there are no holes in this surface.

4.1.16. The surfaces and profiles made using the data from the 100m x 100m survey grid in **Figure II.29** are essentially smoothed or low-pass filtered versions of the surfaces and profiles from the 50m x 50m survey grid shown in **Figure II.28.** This is because they have been made with approximately half the number of x, y, z points as the surfaces in the 50m x 50m grid illustrated in **Figure II.28**.

4.1.17. The two surfaces in **Figure II.29** show the same features as seen in the surfaces shown in **Figure II.28**, which was discussed above. These are a channel feature orientated east to west, with a bedrock ledge protruding into it, and bedrock features such as the general deepening of the bedrock towards the south of the study area.

4.1.18. The differences between the surfaces produced from Geoframe and Coda Geosurvey are the same for the data from the 100m x 100m survey grid as they were for the data from the 50m x 50m survey grid and are described in **Section 4.1.12**.

4.1.19. The profiles in **Figure II.29** show that the channel was approximately the same width and depth as the channel seen in the profiles in **Figure II.28**. However, profile 1 over the surface from the Coda Geosurvey interpretation and profile 1 over the surface from the Geoframe interpretation now show a pronounced difference in the morphology of the bedrock ledge.

4.1.20. The surfaces produced by Fledermaus after the interpretation of the top of the bedrock reflector using Coda Geosurvey and Geoframe software packages for the 200m x 200m grid are shown in **Figure II.30**. These two surfaces were made using a 50m cell size and a weighting of 3. This figure also shows two profiles over each of these surfaces but with large vertical exaggerations.

4.1.21. The surfaces and profiles made using the data from the 200m x 200m survey grid in **Figure II.30** show a larger amount of smoothing or filtering than the images shown in **Figure II.29**. However, the surfaces and profiles in **Figure II.30** still show the same basic morphology as could be identified in **Figure II.28** with the channel orientated east to west and the bedrock deepening to the south of the study area. This was despite these surfaces having been made from approximately a quarter of the x, y, z points used for the surfaces shown in **Figure II.28**.

4.1.22. The profiles in **Figure II.30** now show least difference between the profiles over the Geoframe surface and the profiles over the Coda Geosurvey surface. The Geoframe surface still has a steeper south bank to the channel than the Coda Geosurvey surface but this is less pronounced than in **Figures II.28** and **II.29**.

Interpretation of the Base of Channel Infill Surface

4.1.23. The surfaces produced by Fledermaus after the interpretation of the base of the channel infill reflector using Coda Geosurvey and Geoframe software packages for the 50m x 50m grid are shown in **Figure II.31**. These two surfaces were made using a 15m cell size and a weighting of 3. This figure also shows two profiles over each of these surfaces but with large vertical exaggerations.

4.1.24. The two base of channel infill surfaces are broadly similar, showing a channel orientated east to west and deepening to the west. The profiles over these two surfaces show that the channel was 200m to 300m wide and up to 18m deep. There is a constriction in the channel, which narrows to approximately 100m.

4.1.25. There were a number of differences between the surfaces produced by the two seismic interpretation packages. In particular, the application of the Geoframe software resulted in:

- A smoother edge to the base of the channel infill;
- A more constant height difference between the two banks of the palaeochannel.

4.1.26. Despite these differences the two surfaces produced from the Geoframe and Coda Geosurvey interpretations show the same main characteristics.

4.1.27. The surfaces produced by Fledermaus of the interpretation of the base of the channel infill reflector using Coda Geosurvey and Geoframe software packages for the 100m x 100m grid are shown in **Figure II.32**. These two surfaces were made using a 25m cell size and a weighting of 3. This figure also shows two profiles over each of these surfaces but with large vertical exaggerations.

4.1.28. The surfaces and profiles made using the data from the 100m x 100m survey grid in **Figure II.31** are essentially smoothed or low pass filtered versions of the surfaces and profiles from the 50m x 50m survey grid shown in **Figure II.31**. This is because they have been made with approximately half the number of x, y, z points as the surfaces in **Figure II.31**.

4.1.29. The two surfaces in **Figure II.32** show the same features as seen in the surfaces shown in **Figure II.31**, which were discussed above in **Section 4.1.24.**

4.1.30. The differences between the surfaces produced from Geoframe and Coda Geosurvey are the same for the data from the 100m x 100m survey grid as they were for the data from the 50m x 50m survey grid and described above in **Section 4.1.25**.

4.1.31. The surfaces produced by Fledermaus of the interpretation of the base of channel infill reflector using Coda Geosurvey and Geoframe software packages for the 200m x 200m grid are shown in **Figure II.33**. These two surfaces were made using a 50m cell size and a weighting of 3. This figure also shows two profiles over each of these surfaces but with large vertical exaggerations.

4.1.32. The surfaces and profiles made using the data from the 200m x 200m survey grid in **Figure II.33** show a larger amount of smoothing or filtering than the images shown in **Figure II.32**. However, the surfaces and profiles in **Figure II.33** still show the same basic morphology as could be identified in **Figure II.31** with the channel orientated east to west and the bedrock deepening to the south of the study area. This was despite these surfaces having been made from approximately a quarter of the x, y, z points used for the surfaces shown in **Figure II.31**.

4.1.33. The profiles in **Figure II.33** now show least difference between the profiles over the Geoframe surface and the profiles over the Coda Geosurvey surface.

Summary

4.1.34. The section has examined the use of data from three survey grids with different line spacings and the use of two different seismic interpretation software packages.

4.1.35. The Geoframe software produced a more consistent interpretation across the study area and more points in Fledermaus than the interpretation from Coda Geosurvey. This has resulted in higher quality surfaces being produced from the Geoframe interpretations with features being clearly defined.

4.1.36. However, the basic morphology of the surfaces produced from the Geoframe and Coda Geosurvey interpretations were generally similar. Both interpretations produced surfaces with the following features;

- A bedrock surface with a channel 200-300m wide and orientated east to west;
- A channel up to 18m deep with depth increasing towards the west;

- A bedrock ledge protruding into the channel from the south bank;
- Bedrock dipping towards the south across the study area;
- A volume between the top of the bedrock and the base of the channel infill which the seismic data showed to be occupied by a coarse-grained gravel unit.

4.1.37. The clearly defined features produced by the Geoframe interpretation did result in easily interpretable models in Fledermaus. However, the models produced by the Coda Geosurvey interpretation did show the same features and were less expensive to produce. The price difference adds up to several ten thousand pounds.

4.1.38. The appearance of the features listed in **Section 4.1.36**, from both the Geoframe and Coda Geosurvey interpretations, became increasingly smoothed as the line spacing of the three different survey grids increased. This was because the number of x, y, z points being produced decreased as the line spacing increased. However all three survey grids produced models in which the main features could be identified, although the 50m x 50m survey grid produced the clearest models as it contained the most information.

4.1.39. The bedrock ledge in the channel was a significant feature of the size that could possibly be important in recreating the palaeolandscape for an archaeological assessment. Therefore a qualitative way of examining the effectiveness of the different survey grids and the two seismic interpretation packages was to study the appearance of this feature in all six bedrock models.

4.1.40. The bedrock ledge can be identified in the surfaces produced from both the Coda Geosurvey and Geoframe interpretations using data from the 50m x 50m survey grid and the 100m x 100m survey grid (**Figures II.28** and **II.29**). However, the surfaces produced by both the Coda Geosurvey and Geoframe interpretations from the 200m x 200m survey grid do not show this feature as a ledge (**Figure II.30**). In plan view and in profile both of these surfaces show a gently sloping channel bank surface.

4.1.41. Therefore both Geoframe and Coda Geosurvey have produced useable interpretations from the 50m x 50m and 100m x 100m survey grids with all the key features visible. However, the loss of information in the 200m x 200m survey grid means that the interpretation of the study area would be affected at this line spacing.

Interpretation of the Top of the Bedrock from a Linear Survey Pattern

4.1.42. The surfaces discussed so far were produced from the interpretation of seismic data collected over a survey grid with 50m, 100m or 200m line spacing. However, the majority of geophysical surveys conducted for the purpose of investigating marine aggregate deposits will not be surveyed on a grid pattern but as a series of parallel survey lines. To examine the affect of using such a survey pattern on the interpretations already produced, one set of data was re-examined.

4.1.43. To simulate the data collected from investigating a marine aggregate deposit the data from the 100m x 100m survey grid, interpreted using the Coda Geosurvey software, were separated into two sets of lines depending on their orientation. One set of lines was orientated north-west to south-east, the other set was orientated north-east to south-west. The x, y, z points from the interpretation of the seismic data were the same as used in the models discussed above and shown in **Figure II.29**.

4.1.44. Each of these two data sets now represented a survey of parallel lines at 100m line spacing. The x, y, z points were then used to make a surface in Fledermaus as described above, with a 30m cell size and a weighting of 3. This was a larger cell size than was used for the 100m x 100m survey grid because there were now half the number of data points in each model compared to the survey grid, therefore the larger cell size was required to avoid leaving too many holes in the surface.

4.1.45. A surface for the top of the bedrock reflector produced from each of these two data sets is shown in **Figures II.34-35**. The figures show the models in plan view, with the data points and two profiles over the surfaces.

4.1.46. The figures show that both of these linear survey patterns have produced similar surfaces to that produced by the 100m x 100m survey grid. The palaeochannel with the bedrock ledge and the dip in the bedrock towards the south of the study area can still be identified. However, the need to increase the cell size of the models from the linear survey patterns had the result that these models have a lower spatial resolution than the grid survey pattern. Also the linear survey patterns resulted in the edges of the palaeochannel being angular compared with the linear edges of the palaeochannel shown from the grid survey pattern.

4.1.47. Although surveying on a linear pattern will enable an interpretation of a site comparable with surveying on a grid pattern at the same line spacing, the extra data collected during the grid survey will produce a more defined palaeogeomorphology. However, creating models such as those discussed here are only half of the interpretation process, and the seismic sections would be studied for information on how the geological units were deposited as discussed in **Section 3**. Therefore, surveying on a grid pattern will provide more seismic data than a linear pattern and may allow a more complicated depositional sequence to be understood and smaller features to be identified. However, what has not been examined here is the interpretation of a survey using a linear survey pattern with widely spaced cross lines. This type of survey pattern would obviously be an improvement on a linear survey pattern but it is likely that some features would still be poorly defined.

4.2. GEOTECHNICAL SURVEY

Vibrocore-Methodology

4.2.1. Overall the vibrocoring proved a very effective methodology, confirming the potential of applying geoarchaeological approaches to an already established aggregate industry survey method. Each element of the methodology provided additional information, which would not ordinarily be acquired from the information within vibrocore survey reports. The double coring method to obtain samples suitable for optical dating was, in particular, very effective and easily implementable.

4.2.2. To enable double coring of appropriate locations and archaeologically productive positioning of cores, the processed seismic data was used to establish a project sampling strategy.

4.2.3. The bright, strong reflectors interpreted initially as probable peat horizons at the edge of the wider valley form (e.g. **Figures II.8** and **II.21**), were proved by **VC3** to be peat horizons. Their estimated depth at the fix mark on the seismic line, which was used as the vibrocore target, was 34.90m below OD and 36.10m below OD respectively. The actual depths identified in **VC3** were 32.80m below OD and 34.40m below OD. Although the actual depths proved to be higher than those interpolated from the seismic data, the distance between the two horizons is constant, *c.*1.9m of sediment. The apparent offset can be accounted for due to the errors associated with selecting a depth in seismic data of this type. These errors come from incorrect assumptions being made about the velocity of the seismic energy through the water and geological layers. The initial interpretation should therefore be considered successful.

4.2.4. All ten core locations were subject to core logging, which were used to generate an initial schematic deposit model. Three of the ten locations were then sampled systematically across the whole sediment sequence, providing samples for environmental analysis. Five cores were sampled for dating, only three of which contained appropriate sediments for optical dating.

4.2.5. The most productive combination of locations proved to be dispersed across the geomorphological features. Results sufficient for environmental reconstruction and development of a chronology could be obtained from four of the locations, one through the channel fill, one in the channel edge sediments, one in the wider palaeovalley sediments and one in the gravel deposit. Supplementary cores provided further information, but beyond the level considered necessary to evaluate the archaeological potential of the area. Only a small proportion of the number of vibrocores already acquired during the course of aggregate resource assessment survey would therefore be required for geoarchaeological assessment and sampling, if their location, logging and sampling were undertaken archaeologically.

4.2.6. The required accuracy of the vibrocoring, the acceptable margin of error from the target location, was dependent upon the size of the target feature. These ranged from less than 5m to 10-15m. This is more rigorous than the accuracy generally required for vibrocore surveys designed for the broad scale assessment of aggregate resources.

4.2.7. Archaeological input into the coring locations is central to the methodology. Core location decisions, particularly which locations would benefit from double coring and which target accuracy is required for individual locations, need access to seismic data. However, currently geophysical and vibrocore surveys are completed prior to archaeological consultation. Archaeological advice would need to be sought earlier in the data acquisition process in order to implement this methodology.

4.2.8. Timetabling factors are also an important consideration in the processing of the cores themselves. Geoarchaeological core descriptions need to be generated to inform the sampling strategy, before palaeoenvironmental assessment and dating can be undertaken. Each of the dating methods takes three to four months to process. Initial palaeoenvironmental assessment of pollen, diatoms or foraminifera takes between one and three months, but can be produced in less time if there are urgent circumstances. This timescale should fit into the lengthier process of producing the various elements of an EIA for a production licence application, but facilitating an earlier involvement of the archaeological impact assessment process will become an important consideration.

4.2.9. Full palaeoenvironmental analysis of samples, with associated additional costs, could be considered as appropriate mitigation in cases where submerged palaeogeographic stratigraphy, without significant archaeological deposits, were threatened. Full analysis provides a much higher resolution of interpretation, during which specific geoarchaeological questions can be framed and pursued, using the initial assessment to inform the process. Full analysis has proportionally higher costs involved than an initial assessment, however, it could be pursued using the initial samples and no further fieldwork would be required. Furthermore, the additional geoarchaeological information gained from full analysis can be considered comparable to the additional archaeological information gained from excavation. The idea is drawn from work in the Somerset Levels, where there are similar complications in mitigating against impacts on entire landscapes (Firth 2000). The accumulation and publication of such data for submerged remnant landscapes would be of national importance.

Conclusions

4.2.10. Geoarchaeological core logging and descriptions provide significant additional information to geological logs and photographs. Geoarchaeological core logs provide sedimentary evidence of the depositional processes involved, as well as descriptions of the sediment types usually logged in geological cores.

4.2.11. Geoarchaeological assessment in offshore circumstances through archaeological access to vibrocores is possible and productive. The importance of the development of an appropriate method for retrieving samples for optical dating should not be underestimated, since providing evidence with which to develop a chronology for an assessment area is a significant step forward. Equally, the value of environmental data to palaeogeographic reconstruction, providing dynamic environmental parameters through which to assess likely human presence, is important.

4.2.12. Archaeological advice should be sought early in the aggregate resource assessment process, so that a small number of vibrocores can be recovered specifically for archaeological purposes and where appropriate double-coring can be undertaken to facilitate the dating of the stratigraphy. Archaeological input into the vibrocore survey locations and access to vibrocores for geoarchaeological assessment and sampling is considered central to the success of environmental reconstruction and the development of palaeogeographic models.

Seabed Grab Sampling-Methodology

4.2.13. This survey method has never previously been systematically tested as an archaeological evaluation tool. Our small-scale trial has produced possible prehistoric human artefacts, struck flints of possible human origin, establishing that the methodology has potential to recover archaeological material suitable for evaluation. Of the 108 grabs made, 50% contained struck flint and approximately 25% of grabs contained flints of potentially human origin, three of which are considered to be prehistoric human artefacts.

4.2.14. The grab samples also contained loose pieces of peat, the result of coastal or sub-aerial depositional environments, which are of geoarchaeological interest. Furthermore, the method recovered other anthropogenic material, which, though not related to the assessment of the potential for prehistoric landsurfaces and their archaeology, could be useful for other areas of archaeological assessment. Our samples contained significant amounts of slag and clinker material, which was considered to be modern, and demonstrate the capacity for recovery of maritime or ship debris, concentrations of which could potentially highlight unknown vessels or cargo dumps on the seabed.

4.2.15. The methodology trialed closely parallels the benthic survey process that is already undertaken as part of the production of an EIA. Not only was the grab sampling method equivalent, but the post-fieldwork sample processing also compliments the benthic analysis process. Both methods process the samples using wet-sieving to specified fractions, which are then analysed. Moreover, the 'by-product' of benthic analysis, the non-benthic lithic, shell and organic residue, is precisely the part of the grab sample sought for archaeological analysis.

4.2.16. As a result of this corresponding methodology, a separate archaeological grab sampling survey might not be required, if archaeologists were given access to the non-benthic fraction of the benthic grabs. Establishing a standard sub-sampling programme for archaeological analysis would be easily implementable, but given the cost effectiveness of this evaluation method, it is recommended that archaeological analysis of all samples should be undertaken. Also, placing an archaeologist onboard the grab sampling vessel proved an effective methodology; all three of the flints defined as prehistoric artefacts, with the appropriate degree of certainty, were identified by the archaeologist during the grab sampling itself. Having an archaeologist onboard the survey vessel would allow any particularly unusual finds to be pursued further. So that if any significant material was recovered the survey could be targeted to potentially important locations at this initial stage, negating the need for a subsequent, second visit to further investigate locations of high potential.

4.2.17. In terms of both cost effectiveness and practical implementability this methodology has been proven successful.

Interpretation

4.2.18. The grab sampling survey results for the study area showed no correlation between seabed surface artefact distribution and the buried palaeofeatures. Although we are confident the methodology would have identified any eroding archaeological deposit present, it is not unexpected that there is no correlation given the scale of the survey. At this scale of resolution, only 108 grabs over 1km^2, any direct correlation between surface finds and sealed stratigraphy would have been suspicious.

4.2.19. The finds, peat and other material are dispersed across the 1km^2 site. This is likely to be the result of the relative mobility of the upper substrates of the seabed, which are subject to sediment transportation processes, although it is possible the lack of correlation is the result of early, now ceased, site formation processes. Moreover, on a larger scale broader patterns may be discernible. At a lower resolution with a larger dataset potential associations of assemblages with particular types of buried palaeogeography could be tested, or the relationship between the seabed environment and artefact distribution could be investigated.

4.2.20. There were also particular factors involved in interpreting the artefacts themselves. The material has been subject to the full range of marine processes. Two factors in particular affected the interpretation of the project assemblage:

- significant and currently unquantifiable levels of post-depositional breakage and alteration due to attrition and exposure to marine process;

- the small size of the individual artefacts, the largest being between 10-20mm in length and the majority being less than 10mm long.

4.2.21. These factors combined made the artefacts largely undiagnostic and meant the assemblage could not be identified with one culture, industry, or period. However, elsewhere, fishermen have collected stone handaxes and other diagnostic artefacts; Michael White of the Isle of Wight has a notable collection of flint artefacts from a wide date range, recovered from the Solent and catalogued by WA (Wessex Archaeology 2003/2004). The undiagnostic nature of the artefacts recovered from the paleo Arun may yet prove to be a characteristic of the sample.

4.2.22. However, the assemblage cannot simply be interpreted as a terrestrial flint scatter assemblage might be. Transgression events are likely to have reworked original depositional assemblages and the relative mobility of upper marine sediments will have to a lesser or greater extent further redistributed any assemblages. Standard terrestrial frameworks of analysis are therefore compromised. The size of artefacts in this assemblage might, for example, only represent the lithic debitage/debris element of one or more larger cultural assemblages, i.e. the production chippings without the stone artefact.

4.2.23. The impacts of the relative mobility of the upper seabed on artefact distribution and assemblages have not yet been investigated. The closest analogue from terrestrial archaeology is the impacts produced by tillage on ploughzone assemblages. Surface distributions have been shown in several studies to ‘represent only a sample of the total ploughzone population and to fluctuate in content and spatial configuration between tillage events’ creating similar problems for interpretation (Boismier 1997:1; Ammerman and Feldman 1978; Odell and Cowan 1987; Dunnell 1988). Boismier’s work addressed this issue as a series of tractable questions using simulation models and real world analysis ‘to develop a more comprehensive understanding of the movement of portable artefacts in the ploughzone’ (1997:7). Boismier asserted ‘the problem is thus not so much one of determining whether tillage-induced change has occurred in surface artefact distribution, but rather the identification of the degree of change in assemblage composition and spatial configuration’ (1997:239). This idea along with the three dimensional aspect of the displacement of artefacts and the cumulative effect of an undefined number of events correspond well with the circumstances of the upper seabed strata. Ploughzone distribution should not however be treated as a direct analogy, since ploughzone work relates to bounded field areas and the displacement processes involved are very different. Individual transgression events or episodes of trawling and fishing activity may have formed the surface seabed assemblage, but the marine processes acting on the assemblage are constant, dynamic and variable. However, in the case of near-surface or newly eroding sites, sites which have been largely preserved in the stratigraphy beneath the upper, marine strata, there may be more directly comparable circumstances, since such sites may not have been reworked by transgression events and would have had marine processes acting upon them for a more limited period.

4.2.24. Boismier's work concludes that the potential survival of 'behavioural information in ploughzone surface distribution … is better conceptualised as occurring along a continuum ranging from minimal to complete loss of pattern, depending upon the number of tillage events over time' (1997:238). He quantifies this change, describing the impacts on behavioural information as 'initial', 'intermediate' and 'terminal'. The last term represents something of a pessimistic analogue for the marine context, which has a fairly continuous, unquantified displacement process. However, the difference in scale between Boismier's study, which focuses on particular fields, and even our small study area of $1km^2$, suggests that a broader resolution might still provide cultural information on a local and regional rather than individual site scale. Most importantly, work in the ploughzone offers analogues of ways to address the problem of artefact distribution, rather than direct models of the processes involved. Equally, this work demonstrates that 'it is important to realise that ploughzone [or seabed surface] artefact distributions are, in themselves, signatures of tillage [or marine process] –induced change' (Boismier 1997:239).

4.2.25. At this stage of the project, interpretation was a question of what the material is made to stand for. Whilst it was clear these finds do not simply populate the reconstructed palaeolandscape, it also became apparent that there was still a significant amount of information that could be drawn from these finds if they were treated appropriately. Additionally, they represented a new data set for future research into all these issues. Further discussion of this subject is included in **Volume VIII** of this report.

Conclusions

4.2.26. Grab sampling survey methodology can be applied for archaeological purposes. The process has retrieved possible artefacts from the upper layers of the seabed. It will also be an effective tool for establishing the presence of near-surface or eroding archaeological deposits, which would be both significant and fragile, and particularly at further risk from the impacts of dredging.

4.2.27. This methodology could be easily implemented and is complementary to the benthic survey, which would already be undertaken as part of the EIA process. This has proven to be cost effective method of undertaking empirical evaluation for archaeological assessment.

4.2.28. This was the first time this technique had been tested and should therefore be treated as a preliminary methodological study. 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.

4.2.29. One of the questions to be addressed is whether negative results can be reliably established as well. Even though it was initially thought that the absence of archaeology can be concluded from the absence of finds in grab samples, this depends on various factors such as the density of the grab sampling grid, and needs to be compared to matchable terrestrial investigations. These issues will be further discussed in **Volume VIII** of this report.

4.2.30. At this stage, it was recommended that an archaeologist be placed onboard the vessel undertaking the benthic grab sampling survey and that the grab samples taken are made available for archaeological analysis after they have been processed for benthic analysis.

4.2.31. It was also recommended that the results of all such archaeological analysis are collated to form a larger dataset that would facilitate a better understanding of the relationship between seabed surface, artefact distribution and buried palaeogeography and underpin further research hypotheses. These finds should also 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.

4.2.32. Finally, it was recommended that further strategic research be undertaken, particularly addressing questions concerning patterns of artefact distribution across larger areas of seabed and regional assemblages.

5. DISCUSSION AND CONCLUSIONS

5.1. PALAEOGEOMORPHOLOGICAL MODELLING

Introduction

5.1.1. There are a number of possible scenarios that could explain the details seen in the seismic data and the morphologies apparent from the surface modelling described in the previous sections. Three such scenarios are briefly described here focusing on the depositional environment of the gravel deposit within the palaeochannel. Understanding this feature is considered key to understanding the geological processes at work within the area and therefore its archaeological potential.

Scenario 1: Fluvial Gravel Deposit

5.1.2. This scenario begins with the river channel cutting down into the bedrock to create the palaeochannel feature identified in the seismic data and bedrock models. A bedrock ledge in the palaeochannel has not been eroded for reasons that are not known. However the interpretation from the 50m x 50m survey grid with the Geoframe software shows a number of deeper sections within the palaeochannel and a series of ripple and pool sections may have existed in this channel.

5.1.3. Large gravel deposits have built up on the southern bank of the palaeochannel, especially on top of the bedrock ledge. These gravel deposits show evidence of lateral accretion in the seismic sections, which implies that they have been deposited in the inside bend of a meander in the river. However the models show the palaeochannel feature to be a relatively straight feature across the study area.

5.1.4. As sea level has risen, a succession of fine-grained sediments has been deposited in the channel, onlapping the gravel unit and thus implying that they were driven by marine transgression.

5.1.5. This scenario requires a very high-energy river in order to transport the gravels that were up to 20cm in size. This river would have to be high above sea level in order to produce the hydrodynamic gradient necessary to create a sufficiently high-energy environment to transport these large gravels. Then sea level would have to rise significantly in order to change the environment of the river at this point in the channel to being low-energy, to allow the fine-grained sediments to be deposited.

5.1.6. The gravel deposits in this scenario may be expected to show some evidence of sorting with fine gravels on top of coarse gravels. Also there would be no marine shells in the section apart from recent shell fragments at the top of the section.

5.1.7. This river would have been too far south of any glaciers in Britain to have been a glacial outwash channel. However, the climate at the time may have allowed permafrost to affect the area and there may have been a large seasonal discharge down the channel (Bellamy 1998). However, it is thought unlikely that even seasonal discharges would have been able to move gravels of the size seen in the vibrocore taken through the gravel deposit. Also, there was a lack of sorting within the gravel implying that they were laid down randomly and quickly, the opposite of what is normally found within fluvial deposits. In addition to this, a number of marine shell fragments were found within the gravels which is further evidence that this was probably not a fluvial deposit.

Scenario 2: Coastal Gravel Deposit

5.1.8. As above, this scenario begins with a river channel cutting down into the bedrock to form the palaeochannel feature while leaving the bedrock ledge for unknown reasons. However, there has been little sedimentation of fluvial deposits within the channel. The section of the river channel in the study area was close to the shoreline.

5.1.9. A supply of gravels existed offshore or on the beach further along the coastline from the river. Subsequent tidal action reworked these gravels, moving them along the coast, over the beach and some of the gravels may have been washed over into the channel. This occurred repeatedly, producing the lateral accretion seen in the gravels and explains why the gravels were only deposited on the southern bank of the palaeochannel. The river was not of a sufficient size to contain a high enough volume of water to significantly rework the gravel deposit but may have washed out the fine-grained material within the gravels leaving only a coarse-grained deposit.

5.1.10. Subsequently, as a result of an episode of marine transgression, the channel was infilled with sub tidal fine-grained sediments which onlap the gravel unit.

5.1.11. The advantage of this explanation is that it does not require a high energy, fluvial system or major relative sea level rise. Also the gravel unit produced by this scenario would not be sorted and may contain a number of marine shell fragments that had been deposited at the same time as the gravels.

Scenario 3: Marine Re-Working of the Gravel Deposit

5.1.12. As before, this scenario begins with a river channel cutting down into the bedrock to form the palaeochannel feature while leaving the bedrock ledge for unknown reasons. However there has been little sedimentation of fluvial deposits within the channel and as sea level rises quickly there was a low sediment input rate and therefore the channel was not completely filled during the transgression.

5.1.13. A supply of gravels existed offshore and was re-worked and transported across the area by marine currents. Some of these gravels were deposited in the depression created by the channel. This would require repeated movement of gravels into the depression to create the lateral accretion architecture seen in the seismic data.

5.1.14. The input of gravels into the channel then ceased and fine-grained sediments were deposited over the area producing the unit which onlaps the gravels. However, this would have deposited fine-grained sediments across the entire study area which would then have to be removed from the area to the south of the gravel deposit at a later stage.

5.1.15. Alternatively the fine-grained sediment may not have been deposited until a marine regression and subsequent transgression happened which post-dates the emplacement of the marine gravel deposit. This requires an extra stage of sea level change compared to the other two scenarios described and assumes that the rejuvenated river was not energetic enough to erode the gravel deposit. In this scenario the fine-grained channel infill was produced during a marine transgression as described in the previous scenario.

5.1.16. This scenario would not produce any sorting within the gravel deposit but it would correlate with the marine shells or shell fragments found within the gravels.

5.2. PALAEOENVIRONMENTAL ASSESSMENT

Introduction

5.2.1. The initial assessment of the vibrocore samples from the palaeochannel sequences and the upper part of the wider palaeovalley form sequence (as discussed in **Section 3** and highlighted in **Figure II.15**) all produced Boreal pollen assemblages (Scaife 2004a, **Appendix III**). These contained a strong woodland component with fewer herbs, dominated by pine, oak, elm and hazel. They also indicated the presence of saline brackish water or marine conditions in the locale.

5.2.2. This relative uniformity of the vegetational assemblage suggested all the depositional environments were broadly contemporary. However, significant fluctuations in proportions of species in the various cores implied significant changes in vegetation and environment. For example, there was a discernible difference in the pollen and foraminifera assemblage of the lower part of **VC3**. The pollen assemblage in **VC3** generally represented low and limited herbaceous diversity, dominated by arboreal and shrub elements, however, grasses were ‘extremely important’ in the lower part of the core (Scaife 2004a, **Appendix III**). The foraminifera in particular suggested a range of environments from marine brackish near the base to salt marsh in the upper sediments.

5.2.3. As a result, fuller analysis of samples from **VC3** (wider valley edge deposits), **VC1**, **VC17** and **VC13** (palaeochannel) and from the peat horizon in **VC7** (wider valley floor deposits) was undertaken. A pollen analysis report with pollen diagrams for each of the sampled vibrocore sequences, a diatom analysis report with diatom diagrams and a foraminifera analysis report were produced by Dr Rob Scaife, Dr Nigel Cameron and Dr Annette Kreiser (Scaife 2004b; Cameron 2004; Kreiser 2004). The results of these reports are discussed below and the complete reports are included in **Appendix III**.

Palaeochannel (VC1, VC17, VC13 and VC19)

5.2.4. **VC1** and **VC17** have similar pollen assemblages, and similarly low total amounts of pollen, which reflect the fact they are from the upper palaeochannel fills and comprise sand and laminated silts. There is a relative homogeneity of the assemblage across the 5m+ of sediments that is indicative of rapid deposition.

5.2.5. The assemblage itself falls into two distinct categories. The extra-site vegetation, from drier areas within the river catchment, suggests a predominantly wooded landscape throughout the period of sedimentation. The composition of tree pollen present suggests a Boreal age. The on-site habitat is indicated by pollen from grasses and aquatic fen or flood plain species. There are two habitats suggested, wet fen with rooting adjacent to slow flowing open water, and possible salt marsh and mud flat vegetation. This second element of vegetation, when combined with marine or brackish water influences suggested by the diatoms and foraminifera, is indicative of either local salt marsh or periodic saline ingress (spring tides and tidal surges).

5.2.6. **Figure II.36** shows the pollen diagram for **VC13**. This sequence demonstrates vegetational changes typical of the early Holocene establishment of woodland after the close of the Devensian glacial, indicating an early Mesolithic to Mesolithic age. Scaife suggests this profile falls within the period from *c.* 10,000 to *c.* 8000 years BP (9,600 – 6,800 cal. BC, 2004b, **Appendix III**). 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.

5.2.7. The foraminifera evidence from **VC13** indicates 'an environment which experienced large and frequent variations in salinity' (Kreiser 2004:4, **Appendix III**). There are periods of saltmarsh species and estuarine species, with an overall increase in marine influence towards the top of the sequence. This suggests that the peats in this sequence were potentially formed in saltmarsh conditions rather than fenland. These channel edge peats are also in themselves evidence of wetland conditions.

5.2.8. Significantly, **VC13** does not appear to represent sedimentation pre-dating the palaeochannel, but instead appears to be made up of channel edge deposits related to the palaeochannel.

5.2.9. No foraminifera were found in the gravel core sample during analysis (**VC19**, *c.* 26.80m below OD), although marine shell fragments, less than 5mm in length, were identified within the gravel matrix.

Wider Valley Floor (VC7)

5.2.10. This sequence spans 20cm of sedimentation around the peat horizon in **VC7**. It is markedly different from the other sequences analysed. It appears to pre-date the other sequences and it is possible that this organic unit is of Devensian age. Grasses are most important within the assemblage, which overall is indicative of an open habitat on-site with open standing or slow flowing water, with duckweed and white water lily. The small amount of birch, pine, oak and hazel pollen may suggest airborne transport from long distance sources or over-representation of herbs (grasses) 'which have suppressed the relative values of tree and shrub taxa' (Scaife 2004b, **Appendix III**).

5.2.11. The foraminifera analysis shows a slight indication of marginal marine environment, but 'in the absence of other indicators of brackish or marine conditions, it is possible that the fragments may have been re-worked from other deposits' (Kreiser 2004:4, **Appendix III**).

Wider Valley Edge (VC3)

5.2.12. It had been considered that there was a temporal change at *c.* 36m below OD, where there is a sedimentological change, however the pollen analysis suggests there is a temporal hiatus at *c.* 34.50m below OD (see **Figure II.37**, **VC3** pollen diagram). It appears the lower sediments, pollen biozones **VC3:1** and **VC3:2**, are of an earlier age, potentially the early Mesolithic, with Preboreal and early Boreal vegetation. The upper sediments, pollen biozones **VC3:3**, **VC3:4** and **VC3:5**, are later with Boreal vegetation characteristic of the middle Mesolithic.

5.2.13. The pollen assemblage of this earlier phase is dominated by birch and pine woodland. There are also substantial numbers of herbs, including grasses, reeds, sedges, water plantain and marsh fern, water lilies, water milfoil and cysts of freshwater algal *Pediastrum*. This indicates that 'birch and pine woodland dominated with a wetland (on-site) freshwater and reed swamp habitat' (Scaife 2004b, **Appendix III**). It is small numbers of juniper and possibly dwarf birch pollen that, combined with this, suggest a Preboreal or early Boreal environment. There are also sporadic occurrences of oak and hazel pollen that suggest long distance sources prior to their eventual establishment during the later phases of sedimentation in the upper part of the sequence and in the palaeochannel sequences.

5.2.14. Subsequently, there was a cessation of sedimentation or a phase of erosion, evidenced by a marked change of the vegetation in the following phase (see below). This hiatus is characterised by a peak in the amount of pollen (**Figure II.37**) which is probably due to an increased humic matter at the interface between the two environmental phases. This is indicative of a stabilised land surface which developed on the earlier floodplain. 'The interface at *c.* 2.5m [*c.* -34.50mOD] would have been the surface on which hunting and foraging Mesolithic communities are likely to have occupied for exploitation of this low lying wetland habitat' (Scaife 2004b, **Appendix III**).

5.2.15. This hiatus marks a change in vegetation and habitat and represents the start of sedimentation ‘which may be contemporaneous with the fills of the palaeochannel’ (Scaife 2004b, **Appendix III**). The pollen assemblage of the later phase moves from birch and oak to elm, oak and hazel with pine. At the interface, there are high values of grasses, ‘maybe from the development of fen’ (Scaife 2004b, **Appendix III**). There is some saline/brackish influence and Scaife suggests the later phase of sedimentation was most likely due to an increasingly wet environment caused by rising relative sea level and resulting overbank sediment deposition.

5.2.16. The foraminifera analysis suggests a correlating increase in marine influence at the top of the sequence and a parallel change in the foraminifera at approximately 34.50m below OD. The lower part of the sequence is indicative of brackish mudflat sedimentation with some marine input, including ‘the presence of species associated with estuary mouth sediments’ (Kreiser 2004, **Appendix III**). There is also developing indications of vegetated saltmarsh in the vicinity through time. At *c.* 34.50m below OD, there is a parallel key change in the foraminifera assemblage, which becomes entirely comprised of vegetated saltmarsh species. The assemblage is subsequently fairly barren, until the uppermost sample, which contains abundant foraminifera indicative of an encroaching marine environment.

5.3. CHRONOLOGY

5.3.1. There are substantial differences in age across the five core pollen profiles. However, it was clear from the pollen assessment that all these pollen sequences were attributable to late Devensian and early Holocene environmental development.

5.3.2. The palaeochannel fill pollen assemblage suggests early Holocene, Boreal environments, which are generally dated to 8,500-8,000 years BP (7,500 - 6,800 cal. BC). However, given the southern geographical location of this site, it is possible that these sequential vegetation changes may have occurred earlier than in areas to the north (Scaife 2004b, **Appendix III**). The channel edge deposits are broadly dated to the period between 10,000 and 8,000 years BP (9,600 – 6,800 cal. BC). The upper sediments of **VC3** are largely contemporaneous with this, whilst the lower sediments pre-date it. The earlier **VC3** sediments are potentially very early Holocene, from an interstadial phase within the Devensian cold stage or boreal (pre-temperate) phase from an earlier interglacial (such as Ipswichian stage 5e). However, a very early Holocene date is considered most plausible.

5.3.3. It was hoped that this model could be further clarified with successful optical dating results from the lower sands. However, comparing these dates with the radiocarbon dates from peat horizons in the same or parallel cores shows some inconsistency. Even taking into consideration the potential deviations of both sets of dates (**VC1-2**; **VC3-4**; **VC13-14**; **VC17-18**), they do not fit together (**Figure II.14-15** and **Appendix IV**):

5.3.4. The sample from **VC13-14** dated by OSL to 15.22±1.4 ka is dated several thousand years older than the peat horizon positioned stratigraphally earlier (dated to 9,155±50 BP/ 8,530 – 8,260 cal. BC, NZA-19299). Comparing the radiocarbon and OSL dates it would appear that the OSL dates are consistently older than the radiocarbon dates. Further dating and investigation would be required to address this disparity.

5.3.5. Given the apparent inconsistencies between the OSL and radiocarbon dates, it is considered that the radiocarbon dates, which agree with the palaeoenvironmental data, are likely to be better indicators of depositional ages. Crucially, all but the sample from **VC4**, have clear Boreal pollen assemblages and all the OSL dates are significantly too early (Late Devensian) to support such an assemblage. Further inestigation is needed to resolve the OSL dating issue and will be essential for further planning and recommendations towards industry's best practice guidelines (e.g. **Volume VIII** of this report).

5.3.6. Scaife suggests a sequence of events based upon the environmental data (2004b, **Appendix III**). It begins with the deposition of the wider valley floor sediments, **VC7**, and possibly the lower sediments of the wider valley edge, **VC3**. Channel edge deposition, **VC13**, then occurs. This has a characteristic developing Boreal woodland sequence, towards the end of which parallels with the upper sediments sequence at the wider valley edge, **VC3**, and the upper palaeochannel fills, **VC1** and **VC17**, suggest contemporaneous deposition. This last phase of sedimentation is characteristic of the middle and late Boreal.

5.3.7. 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. Scaife suggests that 'sediment load carried from the higher terrestrial zone into the low lying rivers of the Channel were met by rising sea levels and ponding back of the fluvial systems', which would have created a sedimentary regime 'conducive to such rapid sediment formation' (2004a, **Appendix III**). This suggests a dynamic but comparatively short chronology for the stratigraphic sequence.

5.3.8. The geoarchaeological core log descriptions highlight what appear to be either flood couplets or subtidal rhythmites, patterns of deposition produced by spring tides or tidal surges, in the palaeochannel fill deposits (**VC1** and **VC17)**. However, the rate of the channel fill sedimentation is difficult to specifically define, since it has an overall homogeneity, which could represent between tens and hundreds of years of sedimentation. This is a significant sedimentary deposit, on average 20m deep with an estimated volume of 5.5 million m^3 within our $1km^2$ study area alone. However, it is still possible for this level of sedimentation to occur over a very short space of time, especially in subtidal conditions. For example, an 8m subtidal sedimentary deposit was formed in Southampton Water in approximately thirty years (Wessex Archaeology 1998). It would potentially be possible to further clarify the rate of deposition if these features prove to be tidal rhythmites. Tidal rhythmite sequences can possibly be interpreted more precisely, by interrogating the individual rhythmites and quantifying the accumulative seasonal tides, in a similar manner to counting tree rings, to produce a high resolution estimate of the rate of deposition (Long pers. comm.).

5.3.9. 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).

5.3.10. The overall chronology is based upon dates for the development of particular habitats drawn from the south coast of Britain, and the site's southerly offshore position 'may have resulted in earlier arrival dates than for the mainland' (Scaife 2004b, **Appendix III**). The radiocarbon dating results support the interpretations outlined above. These are included in **Appendix IV** and, where appropriate, on **Figures II.14-15 and II.36-37**.

5.4. ARCHAEOLOGICAL POTENTIAL

Introduction

5.4.1. The geophysical models were used to inform the initial interpretation required to develop the environmental sampling and analysis strategy. This becomes a reciprocal process as environmental data analysis helps to inform the development of the geophysical model. For example, **VC13** was originally considered to be deposits from the 'bedrock' into which the palaeochannel was incised. Subsequent environmental analysis indicated that these were channel edge deposits associated with the palaeochannel and of a broadly similar depositional period (**Figure II.15**), and the incision edge of the channel was not located by the vibrocores.

5.4.2. The integration of sedimentological and pedological information with further pollen, diatom or foraminifera assessment and analysis was also important. The original hypothesis of a temporal interface at *c.* 36m below OD in the wider valley edge deposits, **VC3**, based upon sedimentological changes, proved to be unfounded since there was no significant environmental change at this point (**Figure II.37**).

5.4.3. Clearly, the combination of these sources, geophysical, sedimentological and environmental, is the most effective approach.

5.4.4. Boreal vegetation migrated from northern Europe into southern England by *c.* 9,500-10,000BP (8,800 - 9,600 cal. BC) as a result of the ameliorating climate and is indicative of an early Holocene rather than Late Devensian environment. The process of the floral migration from glacial refugia, the rate and nature of the migration, is somewhat masked by the gap in the environmental record for the now submerged English Channel and southern North Sea deposits. Not only does this affect the relative dating potential of the environmental data, but it highlights the importance of the data acquired by this project.

Upper Palaeolithic and Mesolithic Potential

5.4.5. This area has potential for primary Upper Palaeolithic and Mesolithic archaeological deposits, as well as derived artefacts such as the three possible flint artefacts retrieved during the grab sampling.

5.4.6. The initial fluvial environment would have been ideally suited to Upper Palaeolithic and Mesolithic hunting and foraging exploitation and there is, consequently, high potential for human inhabitation of the area. Within an area of generally low relief, the relative high ground within the valley, the larger and lower, wide valley to the west and the coast would have made the area topographically attractive. Valleys were often routeways for faunal species as well as for humans and the area would have been resource rich. The area would have been subject to a changing vegetational environment just prior to, or during, this period and the combination of either saltmarsh or fenland near to a palaeochannel would have provided a degree of useful environmental diversity.

5.4.7. Relative sea level change was, however, rapid during this period and with generally low gradients in the wider channel plain, large areas would have been inundated at rates that may have affected human activity. Marine transgression would have fitted into human timescales, if not of the individual, then of the social group. Accordingly, this would have been a dynamic environment to negotiate. Floral migration is also likely to have had significant cultural effects; sites examined for pollen have demonstrated these early Holocene vegetation changes. They show initial colonisation by birch and pine followed by hazel, oak and elm, all of which are characteristic of the early Holocene, Mesolithic period. Any consequent effects would have been visible in the material record as it was deposited and may still be discernible today.

5.4.8. Despite the unknown cultural effects of marine transgression, exploitation of coastal zones is likely to have continued (as is evidenced by Baltic sites where early and late Mesolithic sites appear above and below current sea level; e.g. Lübke and Terberger (2002)). The area would have become a prime coastal location. It would have been an estuarine bay, potentially forming a nodal point between the coastal environment and the river routeway inland.

5.4.9. As well as fishing and the exploitation of other coastal food resources, combined with nearby Boreal environment resources, the coastal gravel deposit itself may have been an attractive resource to Mesolithic groups. Even when they do not represent the highest quality lithic source, estuarine or coastal gravels were sometimes used, since they were readily accessible resources. There is evidence of this type of opportunistic activity at Langstone Harbour in the Solent (Allen and Gardiner 2000). If the coastal zone was seasonally or periodically occupied, there is potential for primary context material to be deposited among the coastal gravel deposit.

5.4.10. The inundation itself would have affected any Mesolithic groups in the local area. The estuarine environment described above would have migrated upstream. Consequently, there would still have been Boreal vegetation in the locale and there may have been human activity in close proximity. There might even have been coastal fishing activity and maritime traffic in the area. There is ample evidence of Mesolithic vessels and developed inshore fishing techniques from other Northern European locations.

Lower and Middle Palaeolithic Potential

5.4.11. The potential for pre-Devensian, Lower and Middle Palaeolithic, archaeological material within this particular area would appear to be low, especially in the stratigraphic levels that would be affected by gravel extraction. The potential source of Lower or Middle Palaeolithic archaeological material within the impactable zone is the gravel deposit, within which there is also potential for derived Lower or Middle Palaeolithic artefacts to be found. If the origin of the gravels was appropriate, if they were originally fluvially deposited before they were reworked into the current gravel deposit, then they may have included derived Lower and Middle Palaeolithic artefacts.

5.5. Conclusions

5.5.1. The geophysical and geotechnical data clearly demonstrate the post-transgressive survival of fine-grain sediments, which could potentially contain archaeological deposits, in offshore locations. Moreover, it demonstrates the dynamism of the geomorphological processes and the size of the sediment regimes at work in this area during the Late Palaeolithic and Mesolithic periods.

5.5.2. The environmental evidence for this area contains significant evidence of plant migration that appears to relate to the 'gap' in the environmental record between northern Europe and southern England. Scaife suggested that this data could provide nationally important data on eustatic change and floral migration into Britain at the close of the Devensian (**Appendix III**). The data also provide valuable insight into the environment of early Mesolithic peoples.

5.5.3. This work highlights the importance of the combination of geophysical and geotechnical sources for palaeogeographic evaluation. Geophysical models inform the strategy for environmental sampling and analysis, and the results can be used to refine the geophysical models. Integrated use of these sources is central to the development of more reliable palaeogeographic characterisations. Moreover, this work demonstrates how these palaeogeographies can be reconstructed, and how they may have been inhabited, and thus provide a more supportable assessment of the potential for archaeological impacts to arise from aggregate extraction.

5.5.4. Finally, this work also highlights the fact that current terrestrial analogues for stratigraphic formation are not necessarily appropriate to offshore stratigraphy and that there is a consequent need for further research and the development of new geomorphological models.

5.6. Recommendations for Future Work

5.6.1. The analysis suggested that the environmental data have significant further potential for studying the palaeovegetation of southern Britain during the early Holocene with special reference to floral migration from glacial refugia and to the habitat of early Mesolithic communities. There would also be considerable value in comparing the palaeoenvironmental information with other offshore, English palaeochannel sequences from the Sussex Ouse and Sandown Bay area adjacent to the Isle of Wight.

5.6.2. Additional fieldwork would also be valuable to further interpretation. Deeper cores would clarify features at the base of the palaeochannel, and it would be beneficial to try and establish the point at which the identified episodes of sedimentation began. In contrast to the rest of the sequence, grasses dominate the lowest sample in the channel edge sequence, at *c.* 34.58m below OD in **VC13**. Deeper sampling could establish, for example, whether this represents a different and earlier habitat or a brief increase in the proportion of grass pollen in the overall assemblage (**Figure II.36**). Significantly deeper cores would be particularly important; **Figure II.15** illustrates the comparative shallowness of the sediments that have been sampled so far. Many of the potential features indicated by the geophysics, including the lower, earlier palaeochannel (**Figure II.24**), are currently beyond the reach of vibrocores.

5.6.3. The project's geophysical dataset was large and of high quality and there is scope for further geophysical processing of the data to allow interpretation of smaller features. The apparent older, lower palaeochannel feature shown in **Figure II.24** could be pursued through further analysis of adjacent survey lines.

5.6.4. Methodological recommendations about best practice were made based upon productivity for the purposes of archaeological assessment of a given area balanced against cost effectiveness. A number of further research questions were identified during the palaeogeographic modelling solely about the study area, and a vast raft of questions about seabed stratigraphic architecture, remnant palaeogeomorphologies, chronologies and localised effects of sea level change, that could all be productively pursued with further geophysical and geotechnical research.

5.6.5. However, there is a difference between defining the most appropriate methods for an archaeological assessment for the purposes of an EIA and the vast potential of this type of dataset. A recommended best practice summary of the methodological guidelines for industry was presented as a Draft Technical Advice Note in 2004, and an updated version of this has been submitted (Wessex Archaeology 2007b).

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ONLINE RESOURCES

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http://www.communities.gov.uk/index.asp?id=1145523

Wessex Archaeology 2003/2004:

http://www.english-heritage.org.uk/server/show/ConWebDoc.5671

APPENDIX I: GEOPHYSICAL SURVEY REPORT

Wessex Archaeology Seismic Data – Methods of Processing and Interpretation

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Introduction

A total of approximate 250 km of seismic data (boomer source) was collected by Wessex Archaeology to assess the impact of spatial sampling on seismic data interpretation. The seismic data cover: a) a regional 3.5 x 1 km block area where a 100m line spacing survey was undertaken (lines running NW-SE); b) a 1 x 1 km block area, where a 10m line spacing survey, in both direction, was conducted; and c) a 7km long calibration line.

The dataset was treated in two different phases. A first phase comprised the processing and interpretation of the 1 x 1 km block area using 50m survey line spacing. The objective of this first phase was to produce a more regional overview of the palaeo-channel and the associated deposits. Based on this preliminary interpretation, a specific deposit was selected and a more detailed investigation was conducted using the 10m line spacing interval.

A general description of the processing and interpretation methods applied in both phases is presented initially. Then, each phase is described in detail, including the specific processing flow and interpretation techniques applied.

Processing of Boomer Data

Seismic data were originally recorded in a CODA system. In order to load the seismic data into standard seismic processing software, the CODA files were converted to a SEGY file, which would also contain the navigation information, including the layback corrections. Data processing was then undertaken using a industry seismic processing package, PROMAX.

The first phase in the processing sequence consisted of creating a database to calculate the Common Depth Point (CDP) and assign a coordinate to each CDP and transfer to trace headers. Subsequently, the datasets were processed applying different sequences of conventional algorithms. The objective of seismic data processing is to increase the signal-noise ratio (SNR) and improve the vertical resolution of the seismic trace. In order to achieve a balance between vertical resolution and SNR, different processing algorithms were tested, including different deconvolution operations, and a final decision was made based upon the defined targets for the final interpretation.

Within the processing phase, tidal corrections were applied using the Hand Static tool in Promax. Tidal level data were provided by EMU and were already in relation to O.D. Datum. Elevations in meters were converted to time in milliseconds using 1500m/s, as an average speed of sound in sea water.

Seismic Interpretation

Physical surfaces that cause seismic reflections are primarily bedding surfaces and unconformities with velocity-density contrasts (or impedance contrasts; impedance is the product of the density and seismic velocity of a medium). The recognition and investigation of bedding (or cross bedding) surfaces are fundamental for the interpretation of sedimentary deposits. Bedding surfaces are an important indicator of depositional environments, sedimentary processes and palaeo-hydrodynamic conditions (Rubin, 1987).

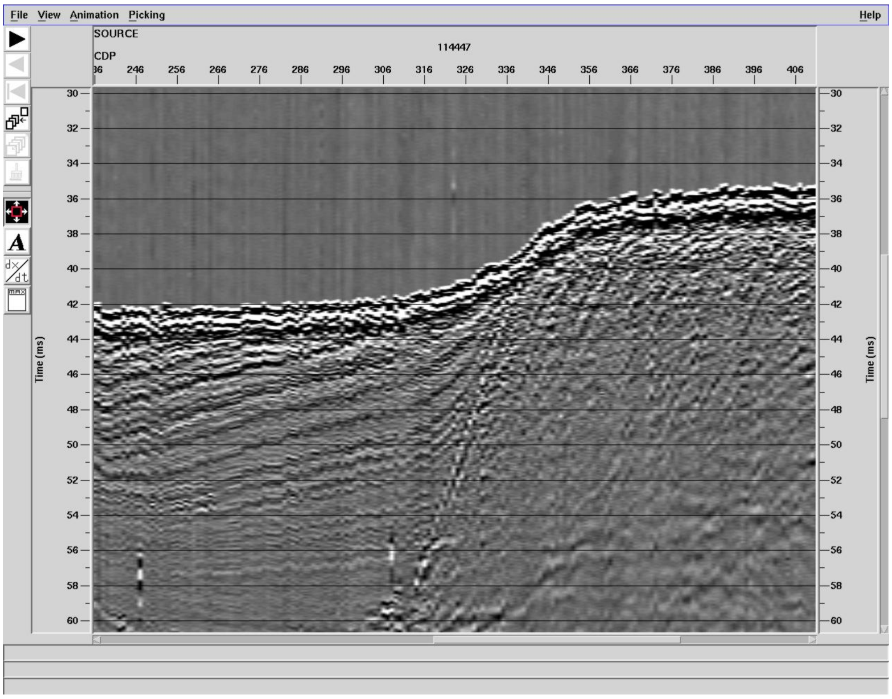
Seismic sections were interpreted based upon internal seismic reflection patterns and the external shape of seismic facies. Initially, sequence boundaries and distinct seismic units were recognised in each seismic section, separately. Subsequently, a standard industry seismic interpretation package, GEOFRAME (Geoquest-Schlumberger), was used as an interpretation tool to trace the recognised boundary surfaces within the sedimentary sequence. These surfaces included a major boundary surface represented by the erosive bedrock surface and the possible transgressive surface. The seabed reflector was also digitised.

The second step in the interpretation phase consisted of producing contour maps of the digitised reflectors and also isopach maps (maps of unit thickness). All the data related to the digitised reflectors were, eventually, exported in ASCII files (x, y and z in ms) and subsequently converted to depth. A standard software package, SURFER, was then used to produce a standard final presentation of contour maps and 3D diagrams.

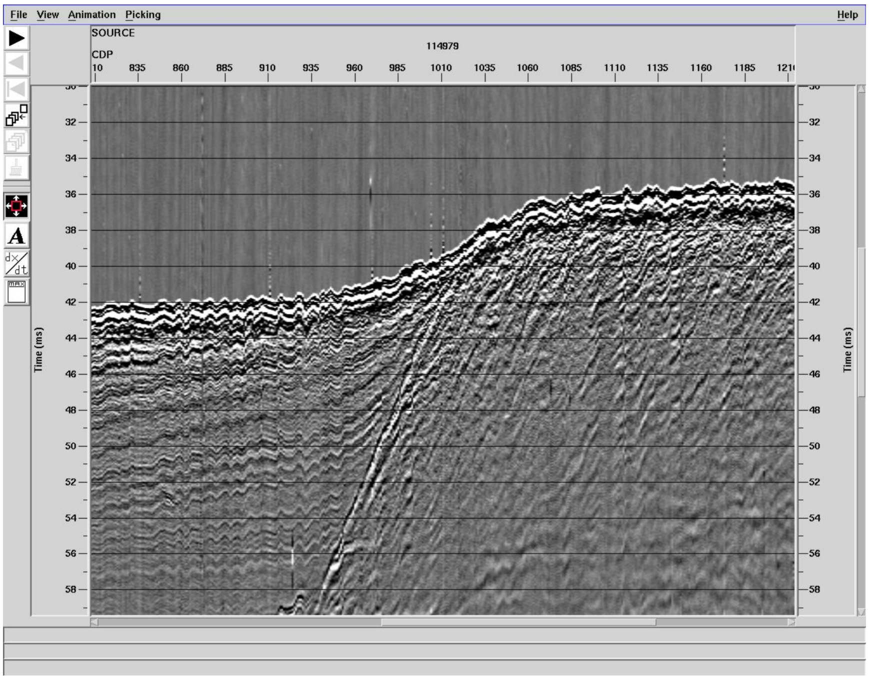
1x1 km Block – 50m survey line spacing

Processing

A total of 42 seismic lines were processed during this first phase. A CDP database was created using a CDP interval of 1.5 m (Figure 1a). Despite the survey being undertaken using a 4Hz frequency (which should allow a CDP interval of 0.5m), the equipment was not triggering in a constant interval. Therefore, it was necessary to use a larger CDP interval to overcome this and create a correct CDP database. The consequence of using a larger CDP interval is that a decrease in horizontal resolution may occur (Figure 1a vs Figure 1b). However, considering the spatial scale of this first phase, this loss in resolution was not significant.



A)



B)

Figure 1a and 1b: Comparison of boomer data binned at 1.5 m CDP and 0.5 m CDP respectively.

With the CDP database created, an interactive spectral analysis was carried out to define the filtering parameters. A Band-Pass Filter was initially applied to remove noise frequencies outside the range of the reflected arrivals. Subsequently, a decision was taken to keep processing at minimum. Hence the following processing flow was applied in this first phase:

Trace dc Removal	Remove the bias dc or offset from the input traces
Bandpass Filter	Parameters: Ormsby Filter – Frequencies: 0-750-6000-10000
Normal Moveout Correction	Applies NMO from a velocity field
CDP/Ensemble Stack	Vertically stacks input ensembles of traces
Hand Static	Tidal correction
Stolt F-K Migration	Seismic migration – CDP interval :1.5m

Interpretation

Three reflectors were digitised from the 42 seismic lines: a) a major boundary surface, representing the bedrock surface; b) a reflector representing what has been interpreted as the initial transgressive surface; and c) the seabed reflector. Subsequently, the unit thickness was calculated to the sedimentary envelop between the transgressive surface and the bedrock, and between the bedrock and the seabed (Figure 2).

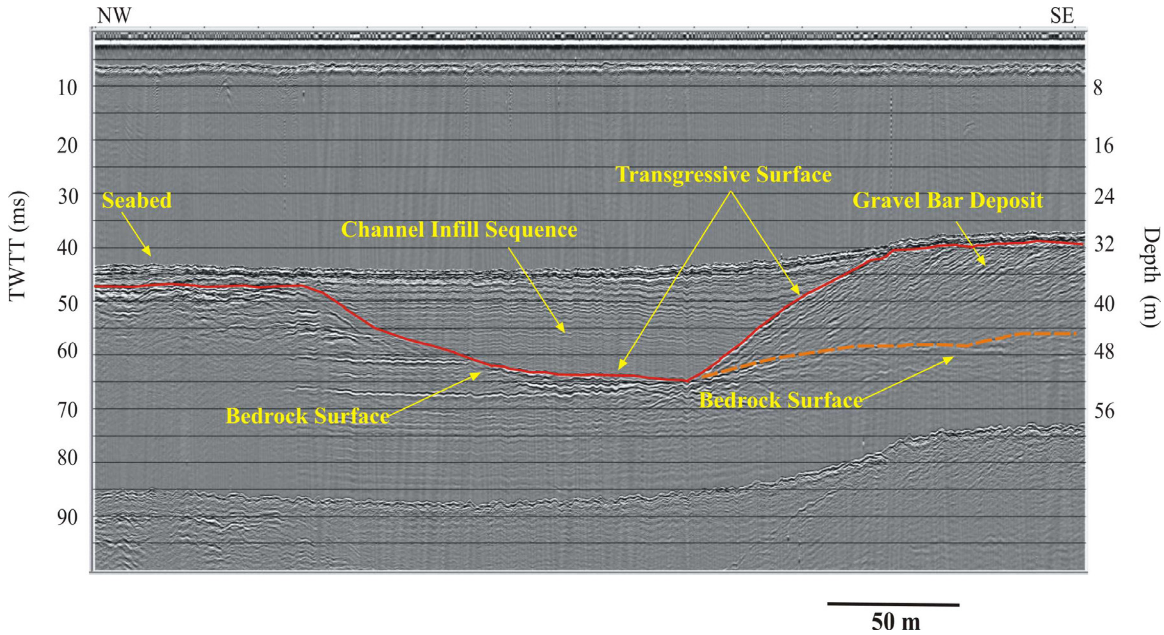


Figure 2: Interpreted Boomer section of the palaeo-channel and gravel deposit. The seismic section shows the bedrock horizon, transgressive surface and the seabed.

One of the objectives of this phase was to test the effect of different survey line spacing in the final result and how it could compromise the final palaeo-environmental interpretation of the study area. Hence, three scenarios were tested and contour maps of the three reflectors were produced. The scenarios considered three different line spacing: 50m, 100m, and 200m (Figure 3). Grid plots were generated using SURFER and the standard kriging method was applied to generate the grid files. Instead of using only one original file with the 50m line spacing data and just change the grid spacing in the software, it was decided that it would be more accurate to actually use three different files. Therefore, the 100m and 200m grid files were generated from files that only contained data abstracted from 22 and 12 lines, respectively.

Subsequently, these grids were used to create contour plots for bathymetry (Figure 4), bedrock surface (Figure 5), transgressive surface (Figure 6) and ultimately isopach maps of total sediment thickness (bedrock – seabed: Figure 7); and pre-transgressive unit thickness (bedrock – transgressive surface: Figure 8).

Steps in Processing and Interpretation

SEGY IN (loading into PROMAX) → Create CDP Geometry (CDP calculation) → Assign Geometry → Process Flow → SEGY OUT → Load data into GEOFRAME → Picking Reflectors in Geoframe → Contour maps in Geoframe → Export ASCII file (reflectors)→ Contour plots in SURFER.

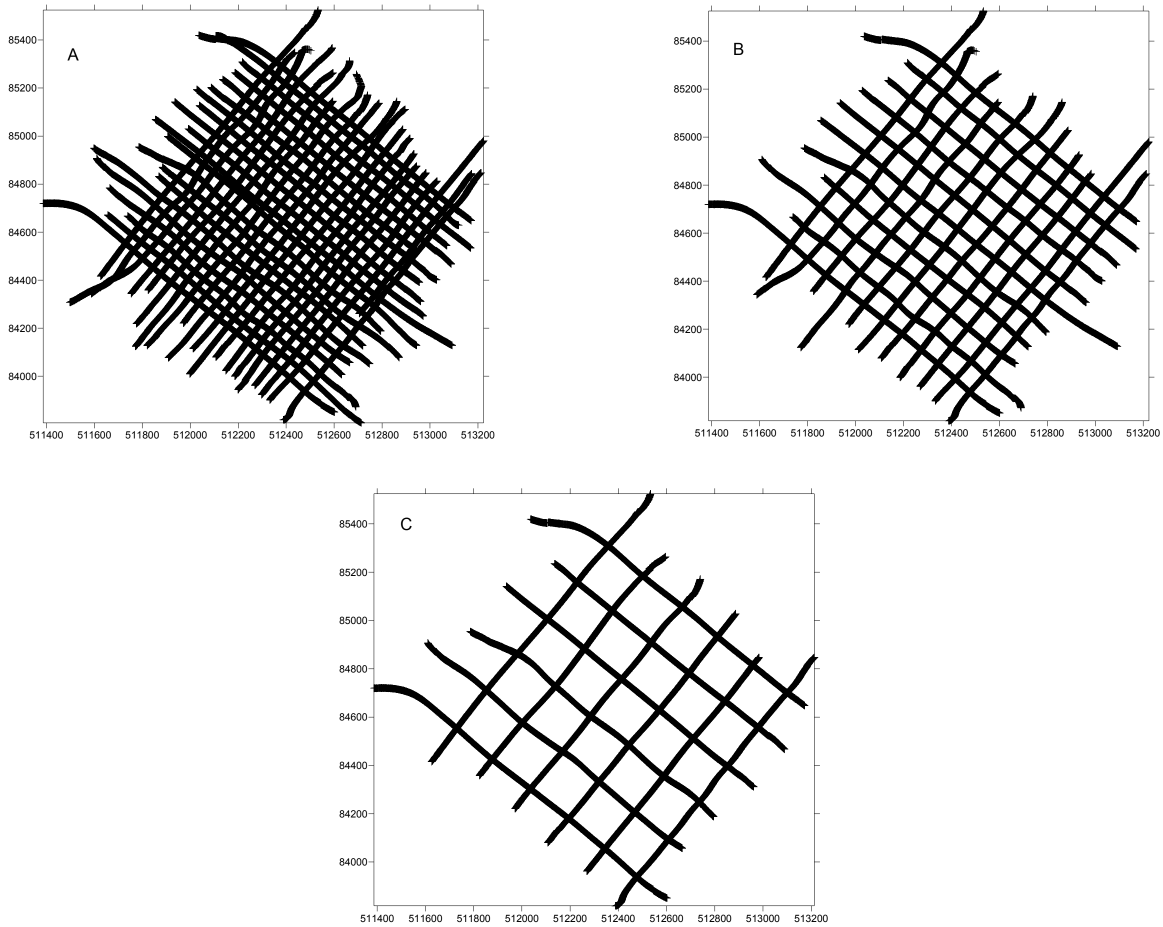


Figure 3: Spatial resolution of the three selected datasets based on line spacing: A) 50m; B) 100m; and C) 200m.

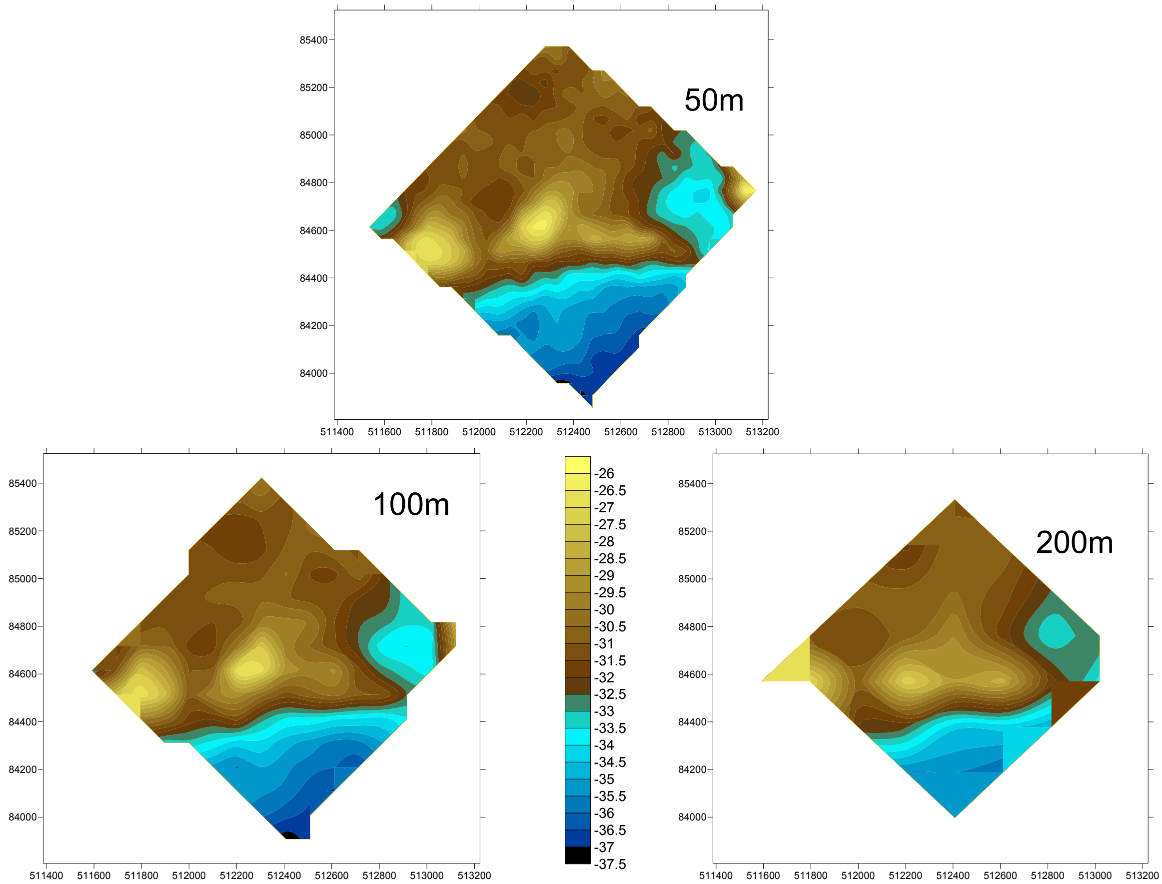


Figure 4: Bathymetry based on line spacing: A) 50m; B) 100m; and C) 200m.

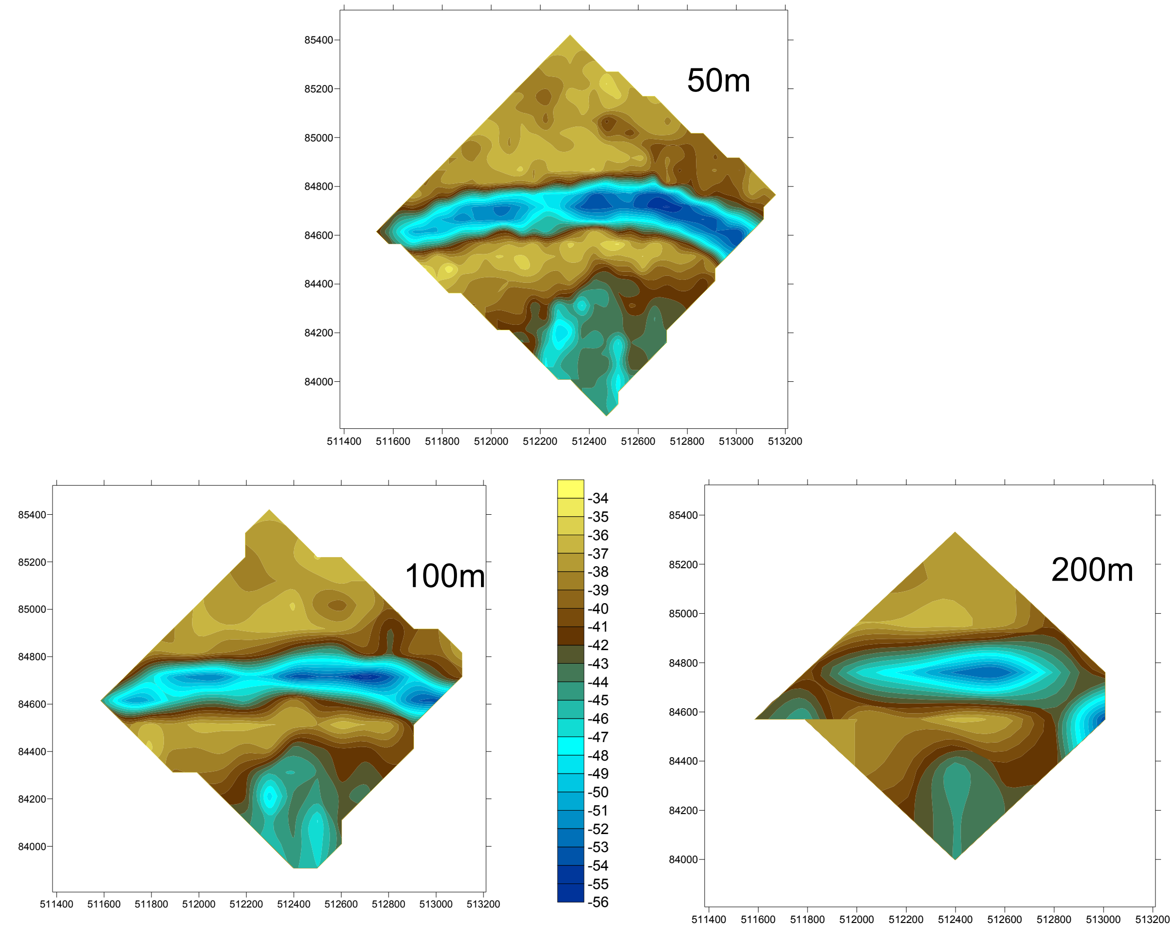


Figure 5: Bedrock surface based on line spacing: A) 50m; B) 100m; and C) 200m.

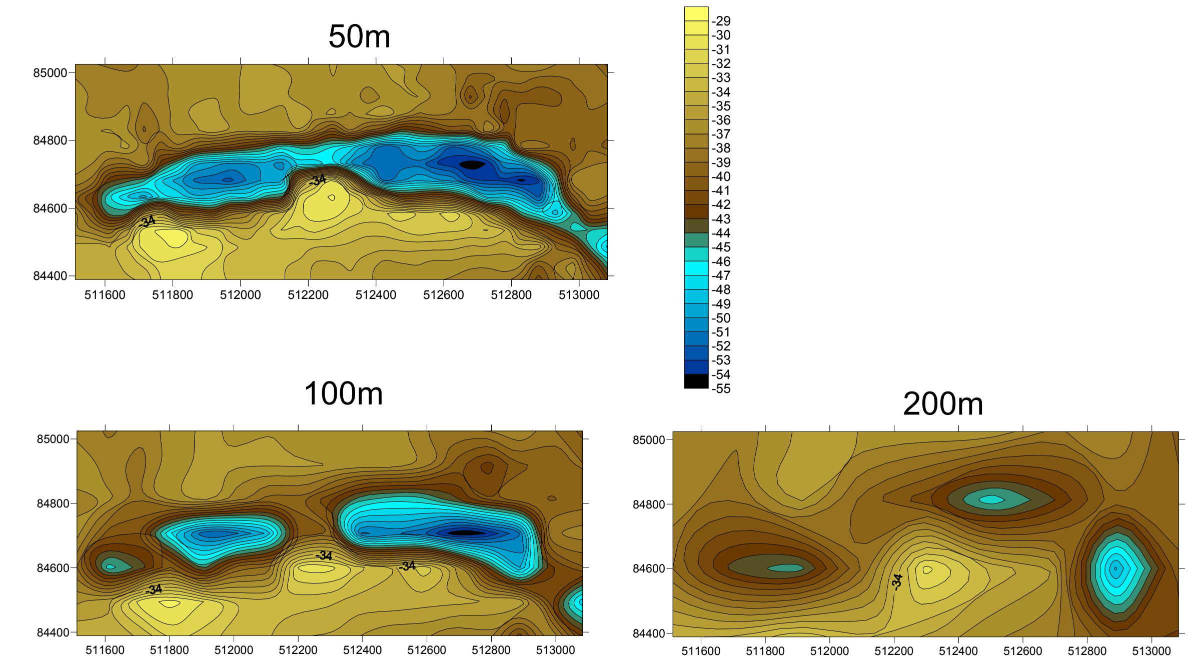


Figure 6: Transgressive surface based on line spacing: A) 50m; B) 100m; and C) 200m.

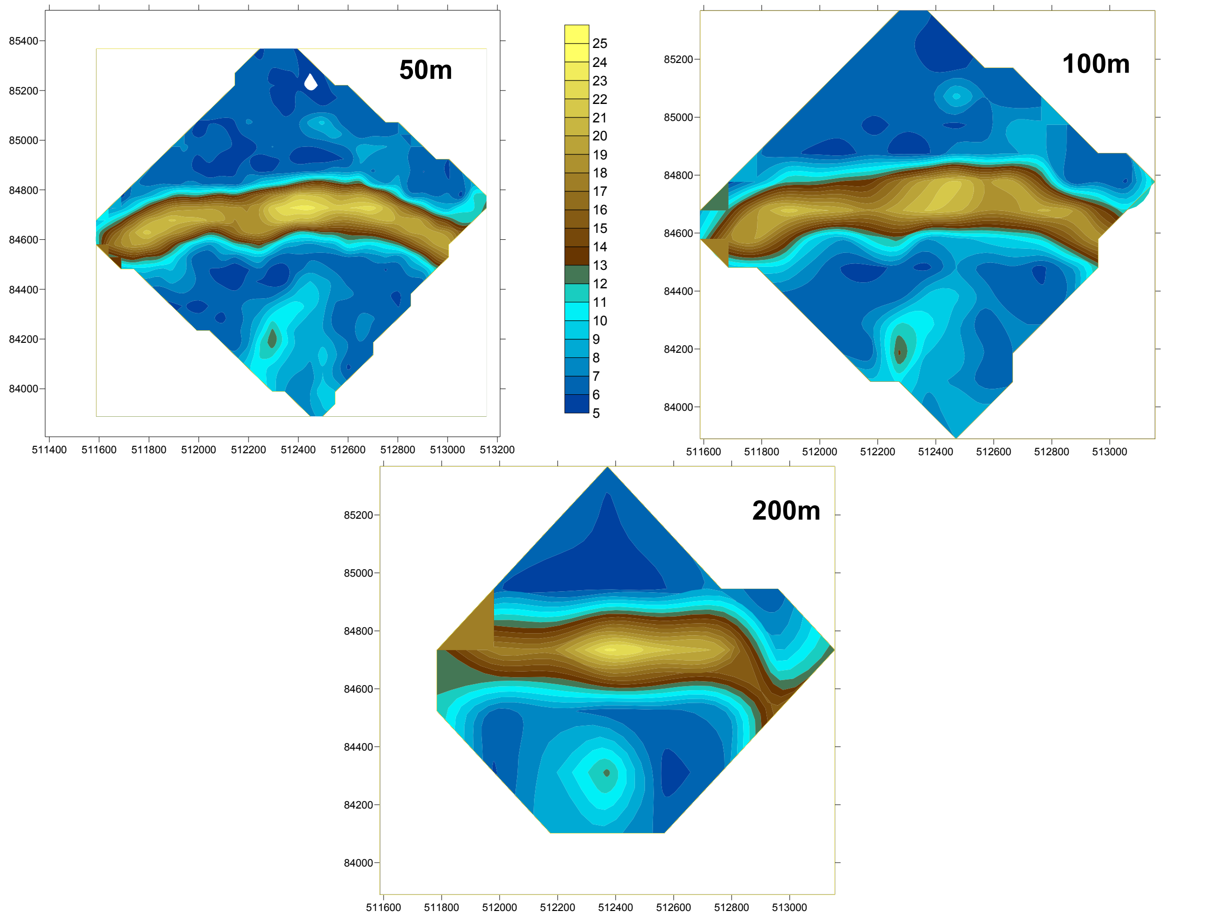


Figure 7: Isopach of total sediment thickness on line spacing: A) 50m; B) 100m; and C) 200m.

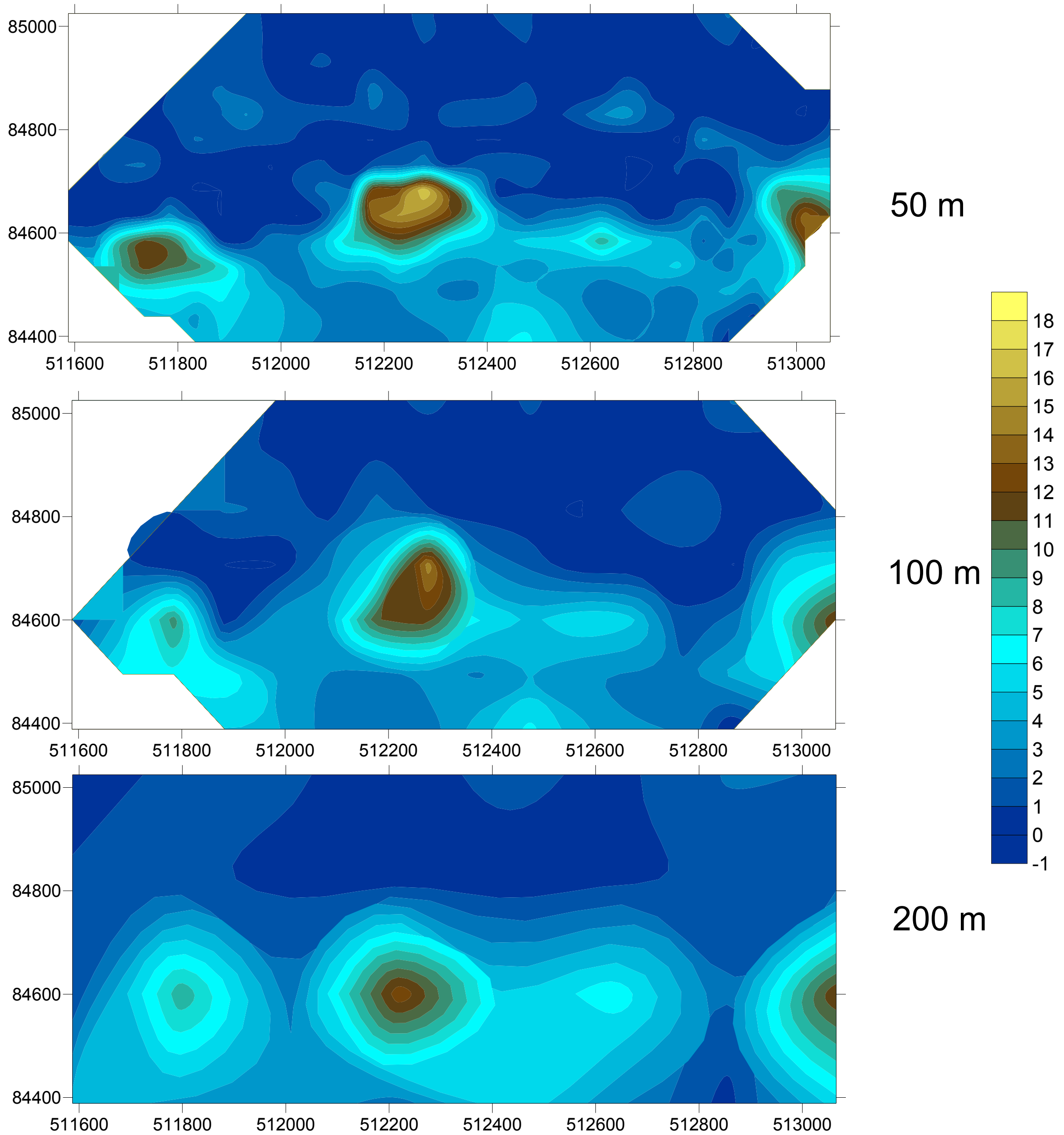


Figure 8: Isopach of pre-transgressive unit thickness based on line spacing: A) 50m; B) 100m; and C) 200m.

750x750m block – 10m survey line spacing

Based on the interpretation from the results of the first phase, a specific deposit was selected to be investigated in more detailed, using a 10m line spacing dataset. The deposit is characterised by inclined reflectors (~10°) that downlap on to the base of the palaeo-channel (Figure 9). The core taken from this site has revealed that the deposit consist of fine to medium gravel (granules and pebbles) with a small sand content. A block of 750x750 m was selected (Figure 10), which comprised a total of 142 lines (Figure 12).

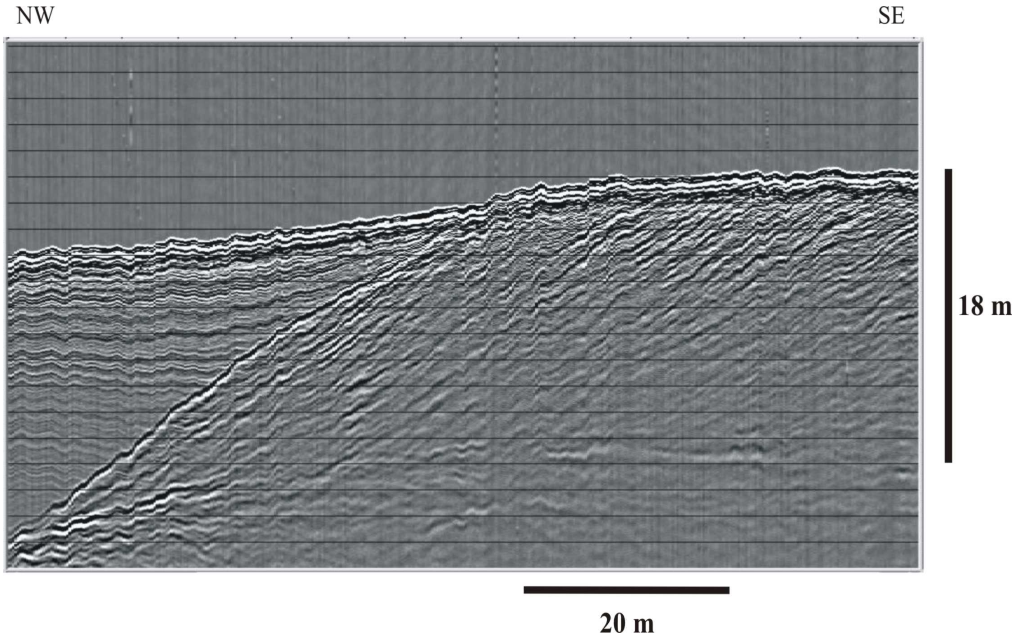


Figure 9: Seismic section showing downlapping of the internal reflectors from the small scale sedimentary unit studied.

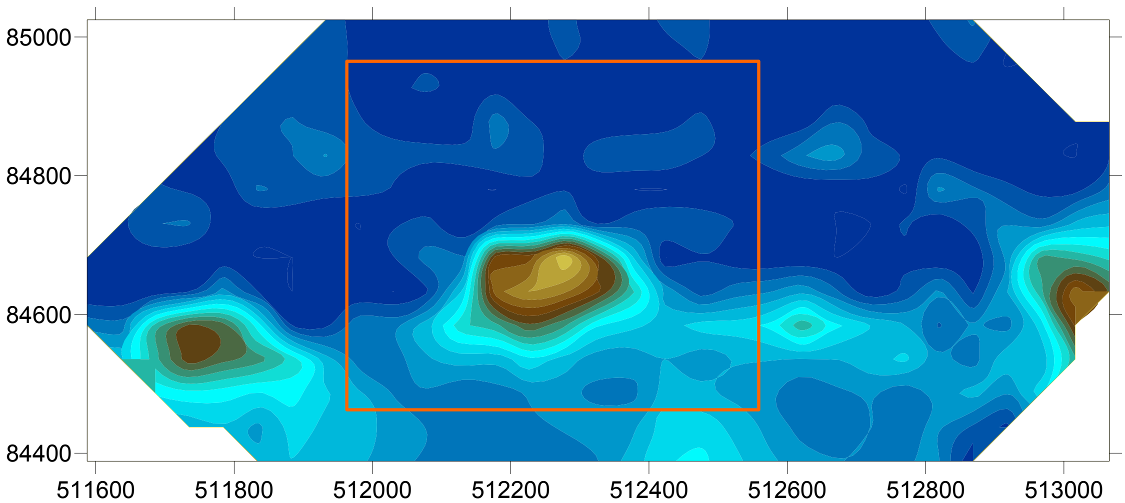


Figure 10: Rectangle defines the area investigated using 10m survey line spacing.

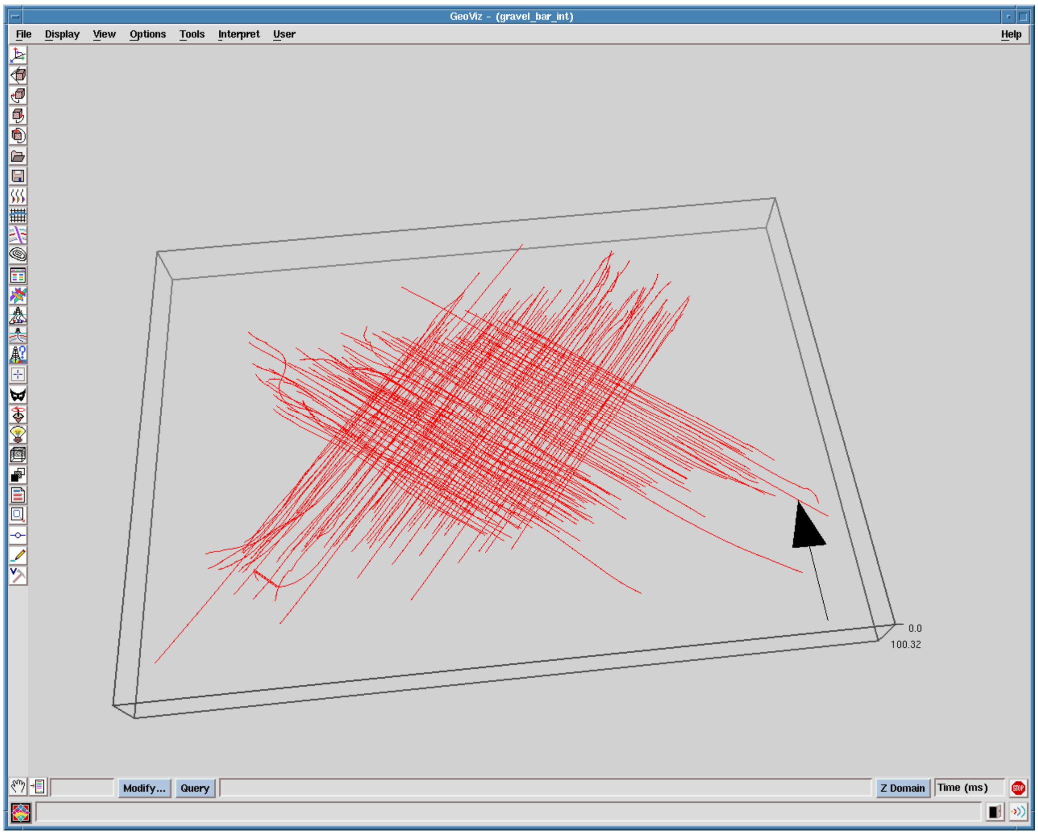


Figure 11: 10 m line spaced tracklines for the small scale sedimentary unit studied.

Processing

A CDP database was again created for the 142 lines. In this case, because a much more detailed investigation was to be carried out, it was decided to use a CDP interval of 0.5m. Because the acquisition system was not triggering in regular interval, the shot points could be more than 0.5 m apart, which would result in a “missing” CDP or no trace for that interval. In order to overcome this, further processing was required. This included the use of two Promax algorithms: a) Pad Traces, which ensure that a trace exists for every interval of the header word; and b) Infill data, which fill missing data intervals or muted traces by predicting from the inverse transform of surrounding traces.

After assigning the CDP geometry to the trace headers, a processing flow was defined and applied to the dataset. The following processing flow was used:

Trace dc Removal	Remove the bias dc or offset from the input traces
Bandpass Filter	Parameters: Ormsby Filter – Frequencies: 0-750-6000-10000
Normal Moveout Correction	Applies NMO from a velocity field
CDP/Ensemble Stack	Vertically stacks input ensembles of traces
Pad Traces	Include a trace for every interval
Infill Data	Fill missing data
F-X Deconvolution	Enhance lateral continuity of reflectors
F-K Filter	Remove dipping noise events
Dynamic S/N Filtering	Enhance lateral coherency of data

AGC	Automatic Gain Control
Hand Static	Tidal correction
Stolt F-K Migration	Seismic migration – CDP interval :0.5m

Interpretation

Two reflectors were digitised using GEOFRAME: a) the potential transgressive surface; and b) the major boundary surface characterised by the bedrock surface. An isopach map between these two surfaces is still to be calculated and produced. The contour map of the transgressive surface defined the morphology of the deposit and its spatial relation to the palaeo-channel (Figure 12a and b).

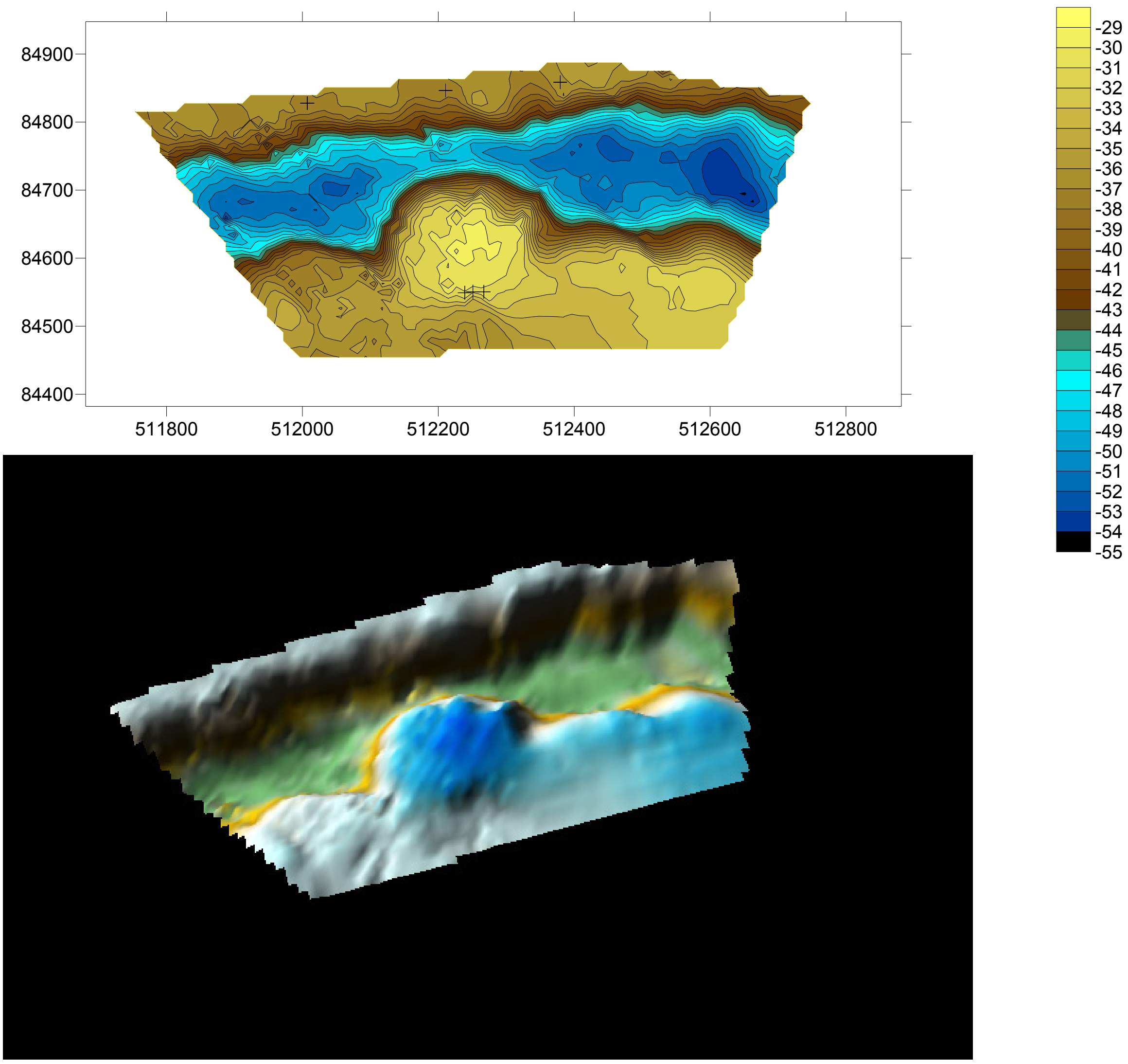
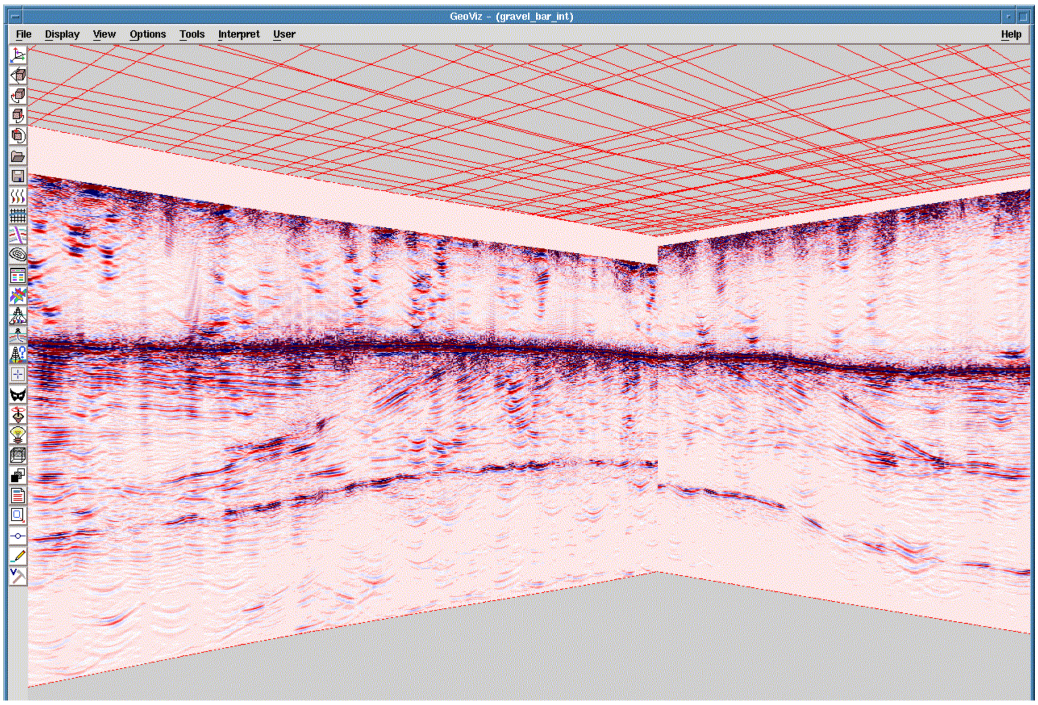


Figure 12: Contour map of the transgressive surface reflector using the 10m line spacing dataset. Below is a 3D diagram of the contour plot.

In order to investigate the geometry of the gravel deposit and the lateral continuity of the inclined reflectors (clinoforms), a visualisation package was used. GEOVIZ, which is a module of GEOFRAME and it is used to provide 3D data visualisation. In Geoviz, a number of cross-lines are plotted on the screen, allowing the interpreter to visualise the data in 3D perspective (Figures 13 and 14). The cross-lines observed in Geoviz revealed that the deposit has a fan shape towards the channel.



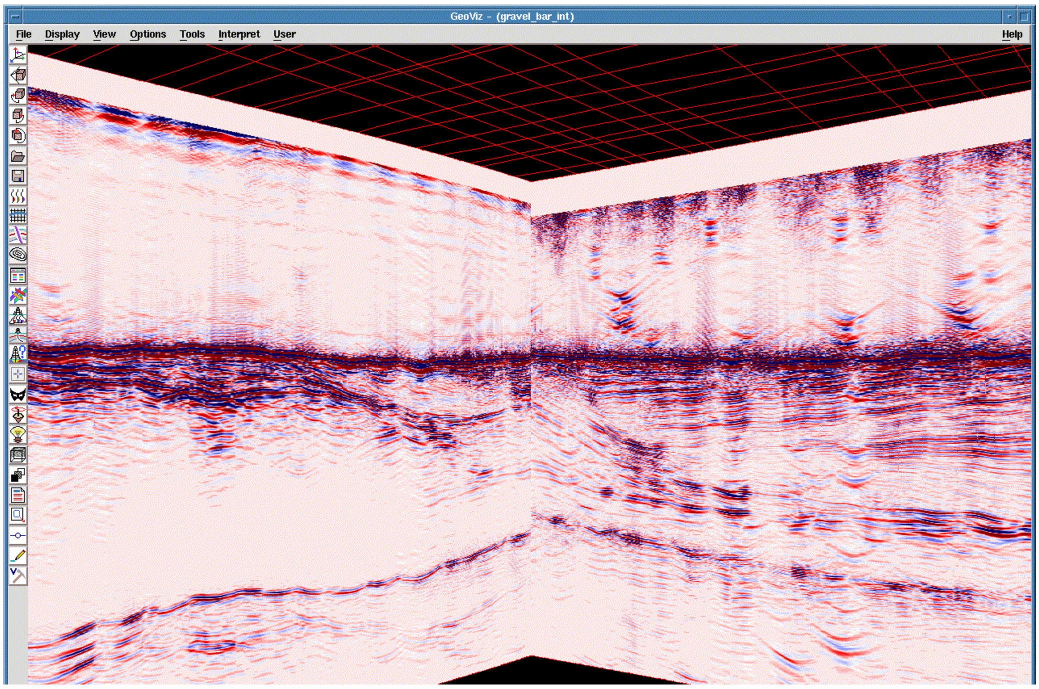


Figure 13 and 14: Visualisation of different cross-lines using GEOVIZ.

Steps in Processing and Interpretation

SEGY IN (loading into PROMAX) → Create CDP Geometry (CDP calculation) → Assign Geometry → Process Flow → SEGY OUT → Load data into GEOFRAME → Picking Reflectors in Geoframe → Contour maps in Geoframe → GEOVIZ (3D visualisation) →Export ASCII file (reflectors)→ Contour plots in SURFER.

Calibration Line – Chirp

The 7km long calibration line was surveyed using a Chirp II seismic source. The uncorrelated data were collected using a standard chirp sweep, 2 - 8 kHz, 32 ms linear sweep at 4 pulses per second. Post-processing of Chirp II data was undertaken using Promax. The first phase in the processing sequence consisted of integrating navigational data to (SEG-Y) trace headers. Subsequently, the chirp data were correlated with the correct sweep wavelet. A simple processing flow was applied subsequently.

Chirp Processing Flow

1) Band-Pass Filter;
2) True Amplitude Recovery;
3) Automatic Gain Control;
4) Trace Math Transform (Reflection Strength);
5) Trace Mixing.

APPENDIX II: GEOTECHNICAL SURVEY LOGS, FIELDWORK NOTES AND LANKELMA VIBROCORE SURVEY REPORT

VIBROCORE LOGS AND FIELDWORK NOTES

VC 1

Depth below seabed (m)	Depth below OD (m)	Description
0.00-0.39	33.33-33.72	0-24 Gravel, medium rounded stones, in coarse sand yellow/brown matrix, with shells, gradual boundary 24-39 Sandy/silty clay loam, coarse sand with shells, small gravel, mixed with layer above – contamination/mixing, abrupt boundary
0.39-0.42	33.72-33.75	Silty clay, with sand [1mm] interleaved very rare, Gley 1 4/1, mainly clay, stone free, flood couplets?, abrupt boundary
0.42-0.61	33.75-33.94	Sand with little bits of very occasional of black organic stain/smear, Gley 1 4/1, stone free, sharp boundary
0.61-0.85	33.94-34.18	Silty clay with 1-2mm sand laminations/bands interleaved, Gley 1 4/1, flood couplets?, abrupt boundary
0.85-1.00	34.18-34.33	Sand, Gley 1 4/1, stone free, with black organic smear/stain (no visible lamination or interleaving), abrupt boundary
1.00-1.42	34.33-34.75	Sand and silty clay interleaved, dark greenish grey, flood couplets? 100-117 Sand with very occasional silty clay [1mm] bands, Gley 1 4/1, flood couplets?, abrupt boundary 117-142 Silty clay with sand [1-2mm], Gley 1 4/1, flood couplets?, abrupt boundary
1.42-1.73	34.75-35.06	Sand, Gley 1 4/1, abrupt boundary
1.73-2.42	35.06-35.75	Laminae, silty clay and sand, dark greenish grey, flood couplets? 173-192 Silty clay c.3mm with sand c.1-2mm interleaved, Gley1 4/1, flood couplets?, abrupt boundary 192-218 Sand with small amount of silty clay interleaved, Gley 1 4/1, with black organic smears/stains (rare) , flood couplets?, abrupt boundary 218-223 Sand [1-2cm] with silty clay [1-2mm] interleaved, Gley 1 4/1, flood couplets?, abrupt boundary 223-242 Silty clay [0.5-1cm] with sand [1-2mm] interleaved, Gley 1 4/1, flood couplets?, sharp boundary
2.42-2.77	35.75-36.10	Sand, Gley 1 4/1, stone free, but rare organic inclusions, sharp boundary
2.77-2.87	36.10-36.20	277-280 Silty clay with organic inclusions, abrupt boundary 280-287 Silty clay [0.5-1cm]and sand [1-4mm] interleaved, Gley 1 4/1, flood couplets, abrupt boundary
2.87-3.43	36.20-36.76	287-291 Clay, Gley 1 4/1, stone free, sharp boundary 291-297 Sand, Gley 1 4/1, stone free, sharp boundary 297-298 Clay Gley 1 4/1with organic black stains/smears, sharp boundary 298-343 Sand, Gley 1 4/1, with first organic smears from 335, abrupt boundary
3.43-3.64	36.76-36.97	Silty clay mainly with sand laminae 2mm-0.5cm, Gley 1 4/1 with black organic smears/stains, flood couplets?, abrupt boundary
3.64-3.95	36.97-37.28	Sand, Gley 1 4/1, with black organic smear/stain at 382, sharp boundary
3.95-4.00	37.28-37.33	Silty clay with sand interleaved, Gley 1 4/1, flood couplets, abrupt boundary
4.00-4.90	37.33-38.23	400-474 Muddy sand, Gley 1 3/1, no defined layers, massive, stone free, with black organic smear/stain occasional, sharp boundary > 456 0.75cm clay band 474-490 Sand with silty clay [0.5cm] interleaved, Gley 1 4/1, black organic smear/stains, flood couplets?, abrupt boundary
4.90-5.09	38.23-38.42	Sand, Gley 1 4/1, abrupt boundary
5.09-5.28	38.42-38.61	509-519 Muddy sand, Gley 1 4/1, with very rare interleaved inclusions of clay [5mm thick] which not all way across the core, abrupt boundary 519-528 Silty clay [1-5mm] and sand [4-10mm] laminae, Gley 1 4/1, flood couplets?, abrupt boundary

Depth below seabed (m)	Depth below OD (m)	Description
5.28-5.65	38.61-38.98	Sand with clay band mid unit, dark greenish grey, no organic 528-542 Sand, Gley 1 4/1, sharp boundary 542-548 Clay band, Gley 1 4/1, sharp boundary 548-565 Sand, Gley 1 4/1

VC 3

Depth below seabed (m)	Depth below OD (m)	Description
0.00-0.21	32.04-32.25	0-15 Gravel, small to medium rounded stones, in yellow/brown coarse sand matrix, with shell fragments, abrupt boundary 15-21 Sandy clay loam, Gley 1 4/1, with coarse sand/shell fragments – 1to2mm, no structure, abrupt boundary
0.21-0.78	32.25-32.82	Clay, dark greenish grey, massive, stone free, phrag/organic lower part unit 21-41 Clay, Gley 1 4/1, massive, stone free, abrupt boundary >36 centre of intrusion of black coarse sand (very small gravel) mineral not organic 5cm diameter 41-78 Clay, Gley 1 4/1 (3/1?), massive, stone free, occasional phragmites (not black), some pretty complete, and with darker black organic smears/inclusions, unit darker towards bottom, but sharp boundary which is unusually inclined > 45-54 very frequent phragmites
0.78-0.84/ 0.82-0.84	32.82-32.88/ 32.86-32.88	[height difference = due to incline across core, this is very clear and doesn't look like product of coring etc] Peat, dark brown, stone free, laminated?, abrupt boundary [not inclined at all].
0.84-2.29	32.88-34.33	Clay, dark greenish grey, massive, stone free, becomes platy then massive and lighter coloured lower part of unit 84-90 Clay, Gley 1 3/1, massive, stone free, with dark organic streaks/smears, clear boundary 90-123 Clay – as above, but platy, plus organics include bits of phrag (not black), clear boundary > 100-118 slightly sandy 123-229 Clay, Gley 1 5/1, massive, stone free, very occasional bits of phragmites and black streaks/smears, >from 200 no organics, abrupt boundary
2.29-2.46	34.33-34.50	229-233 Organic, top 1cm – 10yr 4/2, 3cm below = shade darker, no stones, no visible plant bits, spongy, but does not look laminated, has visible white mineral(?) grains, abrupt boundary 233-240 Clay, Gley 1 3/1, massive, stone free, visible phrag bits very occasional (not black), clear boundary 240-246 Peat, dark brown, laminated, 2-4mm bits of phrag?/plant still visible, bark towards bottom of unit and top 2cm = greyer, abrupt boundary

Depth below seabed (m)	Depth below OD (m)	Description
2.46-4.03	34.50-36.07	Clay with coarse silts and fine sands, stone free, dark greenish grey 246-280 Clay, Gley 1 4/1, massive, stone free, occasional phragmites and black organic stains/smears, gradual boundary 280-317 Clay, Gley 1 3/1, massive but becomes platy from approx. 290, stone free, abrupt boundary > 283-284, 286-287 laminae of sands interleaved > 274 1cm sand lens > 287 1cm sandy clay loam lens > 290 –317 larger phrag pieces 317-319 Sand, fine, lens, abrupt boundary 319-331 Clay, [coarse silt?], Gley 1 4/1, Phragmites pieces visible, slightly platy?, abrupt boundary 331-341 Sandy clay loam, Gley 1 4/1, possible 4mm sand interleaved, abrupt boundary 341-344 Sand, fine, lens, Gley 1 4/1, abrupt boundary 344-367 Silty clay, Gley 1 4/1, [1-2cm bands], interleaved with 1.5cm sand bands, abrupt boundary, flood couplets? > 360/361 Phragmites lens/band across core > 362 1/2cm brownier sand band 367-372 Silty Clay, Gley 1 4/1, massive, stone free, abrupt boundary 372-380 Sand with Silty clay interleaved [2-4mm], Gley 1 4/1, sharp boundary > 380 organic phragmites lens across core 380-387 Silty clay with sand [1-2mm] interleaved, Gley 1 4/1, abrupt boundary 387-392 Sand with few silty clay interleaved [1mm], Gley 1 4/1, abrupt boundary 392-397 very fine 1-2mm interleaving of both silty clay and sand, Gley 1 4/1, abrupt boundary 397-403 Clay, Gley 1 4/1, with phragmites pieces, abrupt boundary
4.03-5.31	36.07-37.35	Sand, dark greenish grey, laminae of clay only for upper third of unit 403-477 Sand, fine, Gley 1 4/1, with infrequent organics, but clear 'laminations' – sort of layering in sand, clear boundary > 468 1cm silty clay lens > 474 0.5cm silty clay lens > 477 interleaved 1mm silty clay (clear boundary) 477-531 Sand, Gley 1 4/1, massive, stone free >495 and 496 Two 2mm by 3mm clay intrusions

VC 5

Depth below seabed (m)	Depth below OD (m)	Description
0.00-0.15	33.30-33.45	0-9 Gravel, rounded medium stones, with shells – in dark yellow/brown sand matrix, abrupt boundary 9-15 Sandy clay, dark greenish grey - Gley 1 4/1, mod stony with small stones, abrupt boundary
0.15-0.63	33.45-33.93	Clay, greenish grey - Gley 1 5/1, massive, stone free, with very occasional inclusions of (phragmites) organics, sharp boundary
0.63-0.65	33.93-33.95	Peat, dark brown, smelly, laminated?, with visible bits of phragmites, stone free, sharp boundary
0.65-1.10	33.95-34.40	Different to above peat: Clay, dark greenish grey, massive, phrag/organics 65-90 Silty clay loam, very dark greenish grey – Gley 1 3/1, massive, stone free, occasional inclusions of organic (phragmites?) – this is the darker 'stripy' bits, sharp boundary 90-110 As above but Gley 1 4/1 with very occasional organic inclusions – less than above – diffuse boundary

Depth below seabed (m)	Depth below OD (m)	Description
1.10-4.53	34.40-37.83	Clay, dark greenish grey, platy, phrag/organics 110-210 As above but platy structure, especially between 130-160, phragmites is now occasional, gradual boundary >195 lens/layer of organic phragmites (not black) cut right across core 210-320 As above but less platy, diffuse boundary >216 lens of organic – phragmites (not black) – across core 320-453 As above but more platy, abrupt boundary >390-400 as above but with much more phragmites, abrupt boundary

VC 7

Depth below seabed (m)	Depth below OD (m)	Description
0.00-0.41	36.02-36.43	0-23 Gravel, small-large, rounded stones, in yellow/brown coarse sand matrix, with shells, abrupt boundary 23-29 Gravel, small rounded stones, shell fragments, in mix of coarse sand and clay as matrix, Gley 1 4/1, clear boundary 29-41 Sandy clay, Gley 1 4/1, with moderately stony very small rounded stones, coarser material with shell fragments, abrupt boundary > 38 1cm black oozy inclusion sandy coarse organic
0.41-1.20	36.43-37.22	Sandy Clay loam, dark greenish grey, organics/phrag, slightly platy lower part of unit 41-60 Sandy Clay, Gley 1 3/1, massive, stone free, organic? Black smears/stains, gradual boundary 60-120 less sandy, still Gley 1 3/1, with black smears/stains but also with phragmites inclusions, massive but becomes slightly coarser and slightly platy towards boundary, clear boundary > 77-80 longitudinal phragmites inclusions running parallel to each other
1.20-2.45	37.22-38.47	Clay, dark greenish grey, organic/phrag, slightly platy to lower part of unit 120-245 Clay, Gley 1 3/1, massive stone free, with black organic smears/stains but no visible phrag, abrupt boundary 173-190 As above but m. phrag pieces (large chunks) 190-245 as above but less frequent phrag and becomes slightly platy from 215/220, abrupt boundary >224-241 darker band, Gley 1 2.5/1
2.45-2.60	38.47-38.62	Organic clay, brown becoming greyer in lower part of unit 245-250 darker 10yr 3/1, organic clay 250-260 lighter/greyer, very laminated, slightly spongy feel, proto-peat?, phragmites still visible clearly at 252, from 255 clayier, less laminated, greyer Gley 1 2.5/1
2.60-4.90	38.62-40.92	Clay, Gley 1 3/1, massive becoming very slightly platy, stone free, with black organic smears/stains, very occasional phragmites visible, clear boundary
4.90-5.25	40.92-41.27	Fine sandy clay loam, Gley 1 3/1, coarser than above >515 wood chunks present

VC 9

Depth below seabed (m)	Depth below OD (m)	Description
0.00-0.37	29.69-30.06	0-15 Gravel, medium, rounded stones, in yellow/brown sand matrix, with shells, abrupt boundary 15-37 Silty clay, greenish grey – Gley 1 5/1, with small rounded stones/gravel, moderately stony, very wet/squidgy, no structure, abrupt boundary

Depth below seabed (m)	Depth below OD (m)	Description
0.37-0.91	30.06-30.60	Silty clay, greenish grey, becomes sandy mid unit, massive, stone free 37-44 Silty clay with 1mm or less sand laminae, greenish grey – Gley 1 5/1, massive, stone free, sharp boundary 44-55 Silty clay loam (very fine sand?) - Gley 1 5/1, very small shell/gravel inclusions, abrupt boundary 55-70 Fine sandy loam, with fine clay laminae - Gley 1 5/1, massive, stone free, clear boundary 70-91 Silty clay, with fine sand laminae - Gley1 5/1, massive, stone free, clear boundary
0.91-1.11	30.60-30.80	Fine sand - Gley 1 5/1, stone free, abrupt boundary
1.11-2.15	30.80-31.84	Laminae, silty clay and sand, greenish grey, flood couplets? 111-144 Silty clay and sand interleaved - Gley 1 5/1, 1-2mm, stone free, flood couplets, abrupt boundary 144-173 Sand with very occasional 1-2mm silty clay - Gley 1 5/1, stone free, abrupt boundary, 173-215 Silty clay interleaved with sand 1-30mm - Gley 1 5/1, stone free, flood couplets, clear boundary
2.15-2.58	31.84-32.27	Sand - Gley 1 5/1, stone free, diffuse boundary
2.58-3.68	32.27-33.37	Laminae, silty clay and sand, greenish grey, flood couplets? 258-289 Gley 1 5/1 silty clay interleaved with sand 1-30mm (as 173-215), stone free, flood couplets, abrupt boundary 289-368 Gley 1 5/1 sand interleaved with silty clay 2-8mm, stone free, flood couplets, abrupt boundary
3.68-3.81	33.37-33.50	Sand - Gley 1 5/1, stone free, abrupt boundary
3.81-4.35	33.50-34.04	Silty clay interleaved with sand 1-2mm - Gley 1 5/1, flood couplets, sharp boundary
4.35-6.00	34.04-35.69	Clay, dark greenish grey - Gley 1 4/1, platy, occasional phragmites (black bits of phrag. too), stone free > 540-550 colour becomes yellower/browner

VC 11

Depth below seabed (m)	Depth below OD (m)	Description
0.00-0.09	27.03-27.12	Sand, dark greenish grey – Gley 1 4/1, stone free, sharp boundary
0.09-0.22	27.12-27.25	Gravel, medium, rounded stones, in Gley 1 4/1 sand matrix (with one massive pebble!), sharp boundary
0.22-0.32	27.25-27.35	22-28 Silty clay - Gley 1 4/1, interleaved with sand 1-2mm, stone free, flood couplets 28-32 As above but sand layers 2-4mm, flood couplets, abrupt boundary
0.32-0.75	27.35-27.78	Sand - Gley 1 4/1, stone free, sharp boundary
0.75-0.81	27.78-27.84	Gravel, very small to medium rounded stones, in sand – Gley1 4/1 – matrix, sharp boundary
0.81-1.12	27.84-28.15	Silty clay - Gley 1 4/1 - interleaved with sand 1-4mm, (Stone free) , flood couplets, abrupt boundary
1.12-1.25	28.15-28.28	Sand, Gley 1 4/1, very wet, sharp boundary
1.25-1.35	28.28-28.38	Gravel, medium rounded stones, in and sand matrix – Gley 1 4/1, sharp boundary
1.35-1.53	28.38-28.56	Silty clay interleaved with sand 1-4mm – Gley 1 4/1, (stone free) , flood couplets, abrupt boundary
1.53-1.59	28.56-28.62	Sand, Gley 1 4/1, stone free, abrupt boundary
1.59-1.71	28.62-28.74	Gravel, medium rounded stones, in sand matrix – Gley 1 4/1, abrupt boundary
1.71-1.72	28.74-28.75	Silty clay with 1mm sand interleaved – Gley 1 4/1, flood couplets?, abrupt boundary
1.72-1.85	28.75-28.88	Sand – Gley 1 4/1, abrupt boundary
1.85-2.00	28.88-29.03	Gravel, medium rounded stones, in sand matrix – Gley 1 3/1, sharp boundary

Depth below seabed (m)	Depth below OD (m)	Description
2.00-2.24	29.03-29.27	Gravel, medium to large rounded stones, in yellow/brown coarse sand matrix, abrupt boundary
2.24-2.40	29.27-29.43	Gravel, small rounded stones, in sand matrix – Gley 1 4/1, diffuse boundary
2.40-2.97	29.43-30.00	Gravel, medium rounded stones, in sand matrix – Gley 1 3/1 and 2.5/1 towards bottom, darkening is mineral not organic, abrupt boundary
2.97-3.40	30.00-30.43	Gravel, medium rounded stones, with shells in coarse yellow/brown sand matrix, coarser sand to base of unit, abrupt boundary
3.40-3.84	30.43-30.87	Gravel, medium rounded stones, in dark greenish grey sand matrix 340-366 Gravel, medium rounded stones, in sand matrix – Gley 1 4/1, sharp boundary 366-376 Gravel, medium rounded stones, in sand matrix – Gley 1 2.5/1, mineral not organic black, abrupt boundary 376-384 Gravel, medium rounded stones, in sand matrix – Gley 1 4/1, abrupt boundary
3.84-3.94	30.87-30.97	Gravel, small to medium rounded stones

VC 13

Depth below seabed (m)	Depth below OD (m)	Description
0.00-0.19	30.38-30.57	Gravel, small-medium rounded, in coarse yellow/brown sand matrix, with shell fragments, Also has a bit of clay mixed in with the sand towards bottom of unit, Gley 1 4/1, abrupt boundary
0.19-0.25	30.57-30.63	Clay, Gley 1 4/1, massive, stone free, with phragmites pieces visible but no black organic smears/stains, abrupt boundary
0.25-0.31	30.63-30.69	Clay, Gley 1 4/1, with shell fragments and very small stones inclusions – moderately stony, abrupt boundary
0.31-0.34	30.69-30.72	Clay, Gley 1 5/1, massive, stone free, lighter colour, abrupt boundary
0.34-1.74	30.72-32.12	Clay, dark greenish grey, massive, sandy mid-unit, organic/phrag 34-93 Clay, Gley 1 4/1, stone free, black organic smears/stains, Phragmites pieces visible, more black organics, lamination towards boundary?, abrupt boundary > 53-60 fine sand interleaved occasionally (1mm) > 54 woody inclusions, still brown, across core, 1-5mm think > 70-88 phragmites root? Running longitudinally – single piece > 70, 80, 88 and 95 = 1cm sand lens 93-100 Sandy clay loam, Gley 1 4/1, with black organic stains, and phrag roots? through, abrupt boundary 100-174 Clay, Gley 1 4/1, massive with very occasional sand lenses, stone free, less black stains, more whole phrag pieces, abrupt boundary > 110, 155, 158 = 1cm sand lens >139-144, 168-170, 162-165 = sand lens > 114-122 reed/root longitudinal > 141-149 two roots/reed longitudinal > 162-173 Phrag pieces
1.74-2.06	32.12-32.44	Sand and clay bands/laminae, dark greenish grey, organic stain-no phrag 174-179 Sand, fine, Gley 1 3/1, abrupt boundary 179-195 Clay, Gley 1 3/1, with sand [3-5mm] interleaved, black organic smears but no phrag visible, stone free, abrupt boundary > 89-93 big sand band 195-206 Sand, fine, Gley 1 3/1, massive, little black smears [1cm by 1mm only], abrupt boundary >195-198 organic inclusions, brown, small pieces (5 total)

Depth below seabed (m)	Depth below OD (m)	Description
2.06-2.55	32.44-32.93	Clay, dark greenish grey, with rare sand laminae, massive, organic/phrag 206-225 Clay, Gley 1 4/1, massive, stone free, abrupt boundary > 221-226 phragmites root/reed longitudinal 225-255 Clay, Gley 1 4/1, with sand lenses/laminae [1-2mm] but very few – particularly 226-228 and 238-240, few black organic smears/stains, clear boundary > 28-232 prob root/reed > 252-257 prob root/reed
2.55-3.20	32.93-33.58	Clay, Gley 1 3/1, slightly platy, with black organic stains and some visible phrag pieces, abrupt boundary > 280-299 phrag reed/root
3.20-3.24	33.58-33.62	Organic Clay, 10yr 3/1 to 2.5/1, peat?, not looking laminated, stone free, abrupt boundary
3.24-3.61	33.62-33.99	Clay, dark greenish grey – darkens mid unit, slightly platy, organic/phrag 324-350 As 255-320 350-352 As above but Gley 1 2.5/1 352-361 Back to Gley 1 3/1, whole phrag pieces are more frequent, darker streaks/stains
3.61-3.64	33.99-34.02	Organic layer, Gley 1 3/1 to 2.5/1, phrag/wood pieces, brown, sharp boundary > 363 5mm clay laminae Gley 1 4/1 – proto-peat?
3.64-3.67	34.02-34.05	Clay, Gley 1 5/1, massive, stone free, abrupt boundary
3.67-5.51	34.05-35.89	Clay, dark greenish grey, slightly platy becomes massive mid-unit, organic/phrag 367-420 As 255-320, Clay, Gley 1 3/1, slightly platy, with black stains and phrag pieces, clear boundary 420-551 Clay, Gley 1 4/1, massive with occasional sand interleaved, stone free, very occasional black smears/stains, > 500-520, 536-539 fine sand lens interleaved (less than 0.5cm) > 512-551 slightly platy again

VC 15

Depth below seabed (m)	Depth below OD (m)	Description
0.00-0.09	31.82-31.91	Gravel, medium rounded stones, in yellow/brown sand matrix, with shells included, abrupt boundary
0.09-0.15	31.91-31.97	Silty clay, Gley 1 4/1, massive, stone free, abrupt boundary
0.15-0.20	31.97-32.02	Gravel, medium rounded stones, with shells, in yellow/brown sand matrix, sharp boundary
0.20-1.70	32.02-34.52	Clay, silty, dark greenish grey, massive, stone free, organic/phrag 20-28 Silty clay, Gley 1 3/1, massive, stone free, with organic bands (including two 1cm bands)and smears (which is why it's darker), clear boundary 28-100 Clay, silty, Gley 1 5/1, massive, stone free, very occasional organic inclusions, abrupt boundary 100-128 Clay, silty, Gley 1 3/1, massive, stone free, occasional organic, which is why darker than above, visible phragmites running through, clear boundary 128-170 Clay, Gley 1 4/1, massive, stone free, with very occasional phrag bits and organic smears, sharp boundary > 259 phragmites 'lens' right across core (1/2mm only)
2.70-3.40	34.52-35.22	Clay, Gley 1 4/1, [thin-medium] platy, stone free, no visible phragmites, gradual boundary
3.40-3.80	35.22-35.62	Clay with sand interleaved, Gley 1 4/1, becomes sand with clay interleaved towards bottom of unit (all laminae 1-3mm), gradual boundary
3.80-4.65	35.62-36.47	Sand, Gley 1 4/1, stone free, > 390 ½cm of less than 1mm interleaved clays > 408-413 1mm bands > 421 ½cm of less than 1mm interleaved clays

VC 17

Depth below seabed (m)	Depth below OD (m)	Description
0.00-0.10	29.07-29.17	Lost – presume surface marine gravel as seen on all cores
0.10-0.15	29.17-29.22	Sandy Clay loam, Gley 1 4/1, small to medium rounded stones, abrupt boundary
0.15-0.34	29.22-29.41	Clay, Gley 1 4/1, massive, stone free, abrupt boundary
0.34-0.42	29.41-29.49	Silty clay interleaved with sands [1-2mm], Gley 1 4/1, stone free, flood couplets?, sharp boundary
0.42-0.72	29.49-29.79	Sand and silty clay bands, dark greenish grey, massive, no organic etc 42-47 Sand, fine, Gley 1 4/1, stone free, sharp boundary 47-48.5 Silty Clay, Gley 1 4/1, stone free, sharp boundary 48.5-49.5 Sand, Gley 1 4/1, stone free, sharp boundary 49.5-51 Silty Clay, Gley 1 4/1, stone free, sharp boundary 51-63 Sand, Gley 1 4/1, stone free, sharp boundary 63-67 Silty Clay, Gley 1 4/1, stone free, sharp boundary 67-72 Sand, fine, Gley 1 4/1, stone free, sharp boundary
0.72-0.76	29.79-29.83	Silty clay and fine sand interleaved [approx.4mm bands], Gley 1 4/1, stone free, flood couplets, abrupt boundary
0.76-1.09	29.83-30.16	Sand and silty clay bands, dark greenish grey, massive, no organics 76-81 Sand, fine, Gley 1 4/1, stone free, abrupt boundary 81-85 Silty clay, Gley 1 4/1, stone free, abrupt boundary 85-88 Sand, Gley 1 4/1, stone free, abrupt boundary 88-109 Clay, Gley 1 4/1, stone free, sharp boundary
1.09-1.28	30.16-30.35	Silty Clay, with fine sand interleaved [sand=1mm and less frequent than clay], Gley 1 4/1, stone free, flood couplets?, abrupt boundary
1.28-1.79	30.35-30.86	Sand and silty clay bands, dark greenish grey, massive, no organics 128-154 Sand, Gley 1 4/1, abrupt boundary > 136 1cm clay band 154-159 Silty Clay, Gley 1 4/1, abrupt boundary 159-165 Sand, Gley 1 4/1, abrupt boundary 165-168 Silty Clay, Gley 1 4/1, sharp boundary 168-174 Sand, Gley 1 4/1, abrupt boundary 174-175 Silty Clay, Gley 1 4/1, abrupt boundary 175-179 Sand, Gley 1 4/1, abrupt boundary
1.79-2.17	30.86-31.24	Silty clay and fine sand interleaved, flood couplets?, dark greenish grey 179-184 Silty clay interleaved with sand, Gley 1 4/1, flood couplets?, abrupt boundary 184-186 Sand, Gley 1 4/1, stone free, sharp boundary 186-217 Silty clay with sand interleaved, Gley 1 3/1, abrupt boundary
2.17-2.47	31.24-31.54	Sand, Gley 1 4/1, sharp boundary > 231 1cm clay band > 242 1cm clay band
2.47-3.00	31.54-32.07	Fine sand and silty clay interleaved, dark greenish grey, flood couplets? 247-255 Sand and silty clay interleaved equally, Gley 1 4/1, flood couplets?, abrupt boundary 255-263 Silty clay with sand [1mm] interleaved, Gley 1 4/1, abrupt boundary 263-274 Sand with clay interleaved [1mm], Gley 1 4/1, abrupt boundary 274-278 Clay, Gley 1 4/1, massive, stone free, abrupt boundary 278-289 Silty Clay with interleaved with sand [1-2mm], Gley 1 4/1, flood couplets, sharp boundary 289-292 Sand, Gley 1 4/1, sharp boundary 292-300 Sand with clay interleaved, Gley 1 4/1, sharp boundary
3.00-3.43	32.07-32.50	Sand, Gley 1 4/1, sharp boundary

Depth below seabed (m)	Depth below OD (m)	Description
3.43-4.40	32.50-33.47	Silty clay with sand laminae, dark greenish grey, no organics 343-363 Silty clay with sand interleaved [2-10mm], Gley 1 4/1, finer towards bottom, abrupt boundary 363-370 Silty clay, Gley 1 4/1, abrupt boundary 370-406 Sand with occasional 1-5mm silty clay bands, Gley 1 4/1, abrupt boundary 406-415 Silty clay and sand interleaved [1-2mm], equal bands, Gley 1 4/1, flood couplets, abrupt boundary 415-440 Silty clay [4-6mm] with 1mm sand bands, Gley 1 4/1, abrupt boundary
4.40-4.45	33.47-33.52	Sand, Gley 1 4/1

VC 19

Depth below seabed (m)	Depth below OD (m)	Description
0.00-0.50	26.27-26.77	Gravel, medium to large at top down to small at bottom of unit rounded stones, in yellow/brown coarse sand matrix (10%?), abrupt boundary
0.50-0.60	26.77-26.87	Gravel/Sand, very small-small rounded stones, in yellow/brown coarse sand matrix (60%?), clear boundary
0.60-0.90	26.87-27.17	Gravel, small rounded stones, with a very little yellow/brown coarse sand as matrix at upper boundary but mainly CLEAN GRAVEL, rounded small-medium, at bottom, abrupt boundary
0.90-1.30	27.17-27.57	Gravel, medium-large rounded stones, in very little yellow/brown coarse sand matrix (10%), abrupt boundary
1.30-1.70	27.57-27.97	Gravel, medium rounded, in darker yellow/brown coarse sand matrix (c.10%), abrupt boundary
1.70-2.63	27.97-28.90	Gravel , medium at top graduating down to medium-large toward bottom, rounded, in yellow brown coarse sand matrix (c.10%), abrupt boundary
2.63-2.70	28.90-28.97	Gravel, medium rounded, in darker coarse yellow/brown sand matrix (c.10%)

Vibrocoring: Additional Fieldwork Technical Notes

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On 27th to 28th September 2003 a vibrocore survey was carried out by Andrews Survey Ltd on behalf of Lankelma Seacore Offshore (LSO) within the larger 3.5km by 1km study area (see attached LSO Owers Bank Vibrocore Survey Report). The work was managed by Emu Ltd on behalf of Wessex Archaeology and representatives from both organisations were onboard the survey vessel throughout the fieldwork. The 48.8m survey vessel, Goosander, was used to deploy a 6m hydraulic vibrocorer.

The survey specifications required two cores from each location. A minimum depth of 3m was specified for a successful core, and a maximum of two attempts at each core was required. All the vibrocores achieved 6m penetration into the seabed, and the majority of cores achieved 4-6m recovery, with only the gravel cores falling significantly short of the target 3m at between 1.80m and 2.70m.

Two cores were specified for each location. The second core was taken using a black vibrocore liner, (a standard clear liner spray-painted black), to prevent light penetrating the recovered sediments and resetting the luminescence 'signal', thus preserving the potential for optical dating of the sediments. These cores, once sectioned and labelled, were stored separately.

The ten target vibrocore positions were given varying degrees of required accuracy, within acceptable margins of error, which ranged from less than 1m to 10-15m. These were determined by the size of the target geophysical feature. All of these acceptable margins of error are considerably smaller than those required for assessing aggregate resources. Current industry standard acceptable margins of error range from 30 to 50m.

Each required level of accuracy was achieved as including those within 1m of the target position. It should be noted that this did not require the survey vessel to anchor, all positioning was achieved using the vessel's thrusters and boosters, as is standard practice for survey subcontractors to the aggregate industry. This level of positional accuracy is, therefore, achievable within current industry methodology.

The position of the cores is taken from the top of the crane arm of the vibrocorer, and does not therefore record the cores actual location on the seabed; a difference can be created by the drag from currents etc. This can be solved by the use of two or more acoustic beacons on the vibrocore frame itself. However, this is expensive and given the level of inaccuracy this is not considered a disadvantage.

The OD heights of the top of the vibrocores were not included in the LSO report and had to be determined subsequently from the seabed bathymetry data collected during the geophysical survey work. Recording and reporting OD heights must, therefore, be recognised as part of the original survey specifications.

Despite the 6m seabed penetration, recovery was generally significantly less. This may be due to material being lost during the recovery process or due to sediment compaction as a result of the corer vibrating during the penetration. There appeared to be limited loss of sediments during recovery, only one ‘catcher’, the valve of spring steel fingers inside the cutting shoe at the end of the vibrocorer (see LSO report), was lost; and the upper part of the liners remained clean, suggesting there had been no sediment slippage from the upper part of the liner. Moreover, compaction appears to have occurred to a greater degree in the less compact, bigger sediments, i.e. the gravels had much poorer recovery (**VC19-20**) than the clays in the channel edge deposits (**VC13-14**), for example.

GRAB SAMPLE FINDS AND FIELDWORK NOTES

Grab No.	BNG Eastings	BNG Northings	Finds								
			Seabed Depth (m)	Slag	Clinker	Iron	Burnt Stone	Peat	Bone	CBM	Flint
1	512855	84804	30		Y						
2	512962	84750	35	Y	Y						Y
3	513017	84684	35	Y	Y						
4	512890	84665	35	Y	Y						Y
5	512808	84719	35								
6	512732	84787	30								
7	512800	84868	29	Y	Y	Y					Y
8	512714	84926	33	Y	Y						
9	512668	84853	27								
10	512642	84994	27		Y						Y
11	512567	84910	32	Y	Y						
12	512495	84965	27								
13	512568	85051	27	Y							
14	512522	84835	27	Y							Y
15	512593	84778	28		Y						
16	512516	84693	27	Y							
17	512686	84710	33	Y	Y						
18	512447	84113	32	Y			Slate				
19	512520	84059	32	Y	Y						Y
20	512450	83970	32	Y	Y						
21	512517	84205	31	Y	Y						
22	512583	84135	33	Y	Y						Y
23	512574	84268	32	Y	Y			Y			Y
24	512660	84209	32	Y	Y		Slate	Y	Y		
25	512624	84342	32	Y	Y						Y
26	512721	84281	32	Y	Y						Y
27	512692	84427	33		Y						
28	512771	84360	32		Y						Y
29	512755	84497	32	Y	Y						
30	512844	84441	32	Y	Y	Y					Y
31	512813	84586	33	Y	Y					Y	Y
32	512898	84513	32	Y	Y						

Grab No.	BNG Eastings	BNG Northings	Finds								
			Seabed Depth (m)	Slag	Clinker	Iron	Burnt Stone	Peat	Bone	CBM	Flint
33	512952	84599	34	Y	Y						
34	512480	84614	31	Y							
35	512432	84264	32	Y	Y						
36	512491	84325	32	Y	Y						
37	512478	84487	33	Y	Y						Y
38	512551	84411	33	Y	Y			Y			Y
39	512532	84559	30								Y
40	512610	84497	32	Y	Y						Y
41	512674	84568	29								Y
42	512607	84640	33								
43	512741	84651	33	Y							
44	512383	84671	26								Y
45	512151	84872	33		Y			Y			
46	512425	85041	27	Y							
47	512489	85122	27	Y	Y						
48	512422	85186	27		Y						
49	512339	85115	27								Y
50	512331	85246	27	Y	Y			Y			
51	512263	85176	27	Y							
52	512201	85091	28	Y	Y						Y
53	512286	85029	27		Y						Y
54	512142	85013	27	Y	Y				Y		Y
55	512217	84936	27		Y						
56	512086	84925	27	Y				Y			Y
57	512016	84862	27	Y	Y						Y
58	512091	84795	28	Y							Y
59	511951	84769	28								
60	512018	84706	28	Y							Y
61	512169	84725	28								
62	512257	84670	23	Y							
63	512309	84746	27	Y							
64	512298	84881	28		Y						
65	512236	84807	27								
66	512372	84828	26	Y							Y

Grab No.	BNG Eastings	BNG Northings	Finds								
			Seabed Depth (m)	Slag	Clinker	Iron	Burnt Stone	Peat	Bone	CBM	Flint
67	512359	84975	31								Y
68	512440	84904	31	Y							
69	512438	84756	28								
70	511761	84548	28								Y
71	511827	84625	24	Y							
72	511891	84704	28								
73	511833	84485	30								
74	511903	84562	28								
75	511988	84499	32	Y	Y						Y
76	511904	84424	31								Y
77	512050	84440	32	Y	Y						
78	511995	84347	32	Y	Y						Y
79	512137	84359	32								Y
80	512064	84290	33	Y	Y						
81	512209	84297	32	Y	Y						
82	512148	84223	32		Y						Y
83	512285	84242	32		Y					Y	Y
84	512219	84164	32	Y	Y						
85	512362	84181	31	Y							Y
86	512300	84103	32								
87	512380	84039	32	Y	Y						Y
88	511971	84650	26								
89	512048	84564	28	Y	Y						
90	512112	84648	27								Y
91	512112	84521	30	Y							
92	512178	84592	29					Y			Y
93	512323	84601	29		Y						Y
94	512397	84534	32	Y	Y						Y
95	512259	84526	29	Y	Y						Y
96	512221	84440	32	Y	Y	Y				Y	Y
97	512330	84463	31	Y				Y			
98	512268	84387	32	Y	Y	Y					Y
99	512353	84316	32	Y	Y			Y			
100	512412	84406	33	Y	Y						

Grab No.	**BNG Eastings**	**BNG Northings**	**Finds**								
			Seabed Depth (m)	**Slag**	**Clinker**	**Iron**	**Burnt Stone**	**Peat**	**Bone**	**CBM**	**Flint**
3b	513013	84680	35	Y	Y						
44b	512393	84683	26	Y							Y
49b	512345	85095	27	Y							Y
54b	512145	85016	28								Y
61b	512180	84736	27		Y						Y
65b	512241	84804	27								Y
65c	512250	84807	27								
92b	512186	84588	23	Y						Y	

Grab Sampling: Additional Fieldwork Technical Notes

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Between 27th and 29th September 2003 a seabed grab sampling survey was carried out by Emu Ltd on behalf of Wessex Archaeology. The survey utilised a Hamon grab installed onto a trawler vessel, the *Arie Dirk*. A Wessex Archaeology representative monitored the grab sampling throughout the process. The grab samples were then transferred to Wessex Archaeology's premises at Salisbury for further processing.

Each grab position was accurately plotted and assigned a unique reference point number. This identification number was recorded as a 'Site Number' (generated by EMU Ltd) in order to provide location mapping of the sampling sites. Where successive grab attempts were made at the same site the same site number was retained, since successive grabs were sometimes necessarily combined so as to provide adequate sample size.

A Leica MX412 Professional DGPS was used to provide accurate positions for the grab as it retrieved a sample from the seabed. Accuracy was restricted to within 15m of the eastings and/or the northings of the target position. There are many factors affecting the accuracies including the skill of the skipper, sea conditions and weather, and grab effectiveness. Sea swell, for example, caused the grab to lift periodically from the seabed at the moment of sample retrieval occasioning additional hits and increasing consequent discard potentials.

Seabed depth within the study area varies between 23m and 35m. An echo sounder was utilised to establish the depth from which a sample had been retrieved.

The grab was perceived as penetrating only the uppermost 0.2-0.3m of seabed, providing a 'mixed' sediment sample for processing purposes. Stratigraphic details are thus not generally represented within the fieldwork notes, except for basic level observations on board the survey vessel. Such observations might include the presence of marine sand over silty clay, but without layer depth determinations being possible.

Initial samples obtained by the grab suggested that the instrument was too light to consistently provide an effective sample in the study area. Extra weight was added to the grab to compensate, with successful grabs resulting from the additional weight. Where coarser aggregates were present even this did not always preclude additional hits. Inadequate sample size was generally the factor that determined a sample would be discarded.

All information was recorded, even for those samples discarded due to poor sample size or incorrect positioning. Where inadequate sample size occurred additional 'hits' (grabs) were made in the sample site vicinity so that a representative sample could be obtained. If a subsequent hit provided an appropriate amount of material earlier hits were discarded; otherwise the samples were combined and a combined sample coordinate was established. The data from discarded samples is incorporated within the overall sampling data table above (Grab Sample Finds). Where additional hits were considered to be necessary the site number was modified by a letter after the number (e.g. G65, G65b or G65c), rather than providing an additional number sequence greater than 100 for identification purposes.

Both laboratory sieving and sorting processes were relatively quick and easy because the finest size fractions had already been largely removed from the sample onboard the survey vessel. The comparatively large mesh sizes also improve processing rates. Sorting of sample residues was similarly efficient because of the amount of immediately discardable material from process observations (mostly gravel and shell).

No count or weight of component of the slag or clinker was made, as these were deemed most likely to have a modern origin. Only their sample positions were recorded. A total of 81 samples contained this material, thereof were 67 samples within the 10mm fraction and 54 samples within the 4mm fraction.

Two positions (G21 and G83) produced examples of fired clay. They have a pale grey to pale greyish brown, slightly micaceous fabric with rare inclusions of shell (these appear to be 'intrusive' probably deriving from the marine shell deposition environment). There appears to be an element of form (some curvature) to the fired clay, but it is not clear what purpose it held. The inside of the curve (on those examples showing form) has an orange-brown to dark orange-brown discolouration penetrating the surface of the fabric to a depth of between 0.5mm and 1mm. These examples are non-diagnostic, of unknown date and function.

Some instances of peat remains were identified from 21 samples. Four come from the 4mm fraction; nine were present in the 10mm fraction and a further 12 samples noted during onboard assessment contained peat-like material. All samples from the 4mm fraction containing peat had the same material in the coarser sieve. This material appears to consist of a grey clay matrix within which small, flattened particles of Phragmites stem and root were present. None of this material appeared to be part of an *in situ* deposit. It is likely that it represents peat development prior to full inundation of the sediment stratigraphy. The spread of this material may be due to seabed disturbances and erosion, complementing other evidences of similar processes.

During the sample processing 70 or so fossil teeth of the fish Synodontaspis were recovered from a number of samples whose distribution is scattered across the study area. Multiple examples were recovered from single samples. These are likely to derive from the Barton Clays, or similar such deposits, giving an Upper Eocene date for their marine deposition. Most of these teeth are sharp with little evidence of rolling present. A similar number of fossil fish bones, including vertebrae, were also recovered, generally from the same samples as the teeth. Numbers are relative rather than absolute as their small size means some may have passed through the 4mm sieve.

The three flints showing the greatest anthropogenic potential (G44, G44b and G49) were assessed on the presence of bulb, striking platform, and the overall nature of the flint.

Another four flints (G10, G31, G61b and G92b) contain elements which appear to have a possible function, or which have elements that are not easily ascribed to natural processes alone. One (G61b) has minor blade-like characteristics whilst another looks like a squat secondary (G10), a third like a possible piercer (G92b) and a fourth (from the 4mm residue of G31) a pseudo-microlith.

The 18 remaining examples are small flakes and chips that could be anthropogenic in origin, but lack sufficient indicators to be conclusively diagnosed (a problem with many of the flints from this assemblage).

All other flints collected from the samples are sufficiently small, with misplaced bulbs, absent striking platforms, thermal fractures and cortical elements which are suggestive of mechanical, rather than anthropogenic, processes. As none of the other flints have sufficient elements to enable them to be separated from flints derived from mechanical processes there is no reason to accept them as archaeological.

It should be noted that if these flints had been retrieved from a known terrestrial site many of them would not necessarily have been rejected. Their rejection in these circumstances is an indication of the probability of natural process at work within the assemblage deposition sequence.

APPENDIX III: PALAEOENVIRONMENTAL ASSESSMENT AND ANALYSIS REPORTS

ASSESSMENT: POLLEN AND DIATOMS

Seabed Prehistory (Arun Offshore): Potential for Pollen and Diatom Analysis in Palaeo-environmental Reconstruction

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1.) Introduction

As part of the Wessex Archaeology research project on South Coast submerged palaeochannels, vibro-cores have been obtained from areas of the English Channel south of the River Arun, Sussex. These are thought to be of Holocene but in places possibly Ipswichian age. These organic and mineral sediments at a depth of greater than –15mOD clearly have potential for studying (1.) the early Holocene (post-glacial) marine transgression which occurred with diminution of the polar ice-sheets and periglacial permafrost zone (2.) the palaeo-vegetation of southern Britain during the early Holocene with special reference to floral migration from glacial refugia and to the habitat of the early Mesolithic (Maglemosian) communities. A total of 28 sub-samples taken from 5 vibro-cores have been examined for their sub-fossil pollen and diatom content. This report examines the results of this preliminary study of the palaeo-environmental potential of the sequences.

2.) Sub-fossil Pollen and Spores Content

2.a.) Introduction: A total of 28 samples have been examined for pollen and spores to (a.) ascertain if pollen and diatoms are present in the sediments, to (b.) provide preliminary information on the palaeo-vegetation during the period of sediment deposition (c.) to suggest a time-span over which the sediments accumulated and (d.) to detail whether the profiles offer potential for a more detailed palaeoenvironmental reconstruction. Core details and sample depths for pollen and diatom analysis is given in table 1. Pollen and spores have been extracted from profiles VC1, VC3, VC7, VC13 and VC17. Of the 28 samples 27 would contain sufficient pollen to enable pollen counts to be made. Only the sample from core VC1 at 1.60m was devoid of microfossils.

2.b.) Results of preliminary analysis: Preliminary examination of these pollen samples in general shows a strong woodland component with general fewer herbs. Overall, the dominant tree and shrub taxa include Pinus (pine), Quercus (oak) Ulmus (elm) and Corylus avellana type (hazel). However, there appear to be significant fluctuations in the numbers of these taxa in the various parts of the different cores implying significant changes in vegetation and environment. Also present in lesser numbers are Betula (birch), Alnus (alder) and Salix (willow). The herbaceous diversity appears to be low in all of the samples which is not surprising in view of the importance of the arboreal and shrub elements. However, in some samples Poaceae are extremely important as for example in the basal levels of VC3 and to a lesser extent in the lower part of VC1. Other herb taxa noted include Chenopodiaceae (goosefoots and oraches which may have implications for salinity reconstruction), Filipendula ulmaria (meadowsweet) and various Asteraceae types (daisy family) including Artemisia. Few marsh/aquatic taxa were observed but include Cyperaceae (sedges in core VC1) with Typha angustifolia/Sparganium type (bur reed and reed mace), Potamogeton (pond weed) and Alisma type (water plantain). Spores were observed in all samples and include monolete Dryopteris type (from typical ferns), Pteridium aquilinum (bracken) and Polypodium vulgare (common polypody). There appear to be very significant numbers of derived pre-Quaternary palynomorphs especially in cores VC1 and VC17. This is not surprising given the minerogenic character of the sediments.

Within the specific cores there appear to be variations which would be highlighted in pollen diagrams. For example, it appears that there is a major difference in VC3 below and above a depth of 2.54m. Below shows a predominance of grasses (Poaceae) and above there are substantial numbers of trees and shrubs (especially hazel and pine). This clearly needs to be examined in detail.

2.c.) Suggested age of the sequences: The apparent importance of trees and shrub pollen in these profiles would suggest that in spite of the depth OD, we are in general dealing with Holocene and not late (Devensian) glacial sediments which would be herb dominated. Note, however, the lowest levels of borehole VC3 may be an exception to this. Correspondingly, the absence of any numbers of thermophiles such as alder, lime, ash and holly for example, suggests that the assemblages are of early Holocene date. That is, Flandrian chronozone I, the pre-Boreal and Boreal periods of *c.* 10,000 to 7,000 BP (9,600 to 5,800 cal. BC). The observed pine (esp. VC3) and hazel pollen especially in all cores is also commensurate with the Boreal pine hazel period (Godwin's pollen zone VI).

2.d.) Importance of the pollen sequences: Given the geographical position of this site and their suggested age, there is very substantial potential for providing valuable information on the background environment of the Mesolithic cultures prior to positive glacio-eustatic changes and importantly to establish the dates of migration of the tree flora into southern England after the close of the last cold stage. There is a paucity of data relating to both of these aspects. Existing data has come from similar palaeo-channels along the south coast off-shore of Sussex the River Ouse (Dix, Long and Scaife unpublished pollen, radiocarbon dates and sea floor bathymetry). Early Holocene channel fills have also been studied to the East of the Isle of Wight in similar depths of water and showing similar early Holocene, oak, and hazel dominated vegetation (Scaife unpublished). Bellamy (1995) has also produced a detailed survey of palaeochannels within this region. Further to the East, studies associated with the Channel Tunnel have provided significant information on the late-glacial and early Holocene flora which would provide a significant comparison.

2.e.) The need for additional analysis: From the above, it is clear that these cores provide a rare chance to examine the sea-bed environment and history of the Channel prior to submergence. Further analysis could provide nationally important data on eustatic change and floral migration into Britain at the close of the Devensian. Thus, it is suggested that a significant number of pollen samples should be fully examined to provide pollen diagrams. This should be carried out in relation to radiocarbon dating and diatom analysis to establish the periods of brackish water or marine inundation. Samples for which pollen analysis is suggested are listed in table 2.

3.) Diatom Content of the Arun Palaeo-channel Cores

3.a.) Introduction: All of the (28) samples analysed for pollen and spores content have also been examined for diatoms. If present, diatoms might be expected to provide a useful indication of the freshwater and/or saline status of the environment in which the sediments were deposited. Preparation/concentration of diatom frustules used digestion of humic/organic material using Hydrogen Peroxide. Samples were dried on microscope cover-slips and mounted on microscope slide using Naphrax mounting medium. Examination was carried out at high power x400 and x1000 using a biological microscope.

3.b.) Results of preliminary diatom analysis: Of the 28 samples examined, the majority contained at least some diatoms. Scanning of all of the prepared slides showed that of the 28 samples only 3 failed to have any frustules present. However in some cases some slides the diatoms were sparse and degraded (fractured). However, some samples were especially rich as for example samples from VC3 at 0.4m, 2.0m and 2.4m and especially the single sample from VC13 at 3.20m. The relative abundance's of diatom frustules is given in table 2 ranging from occasional/sporadic (~) to most abundant (*****).

Although detailed identification of the diatom assemblages has not been carried out, examination of the samples showed clearly the presence of some taxa which are diagnostic indicators of saline brackish water or marine conditions. This is especially important to any future palaeoenvironmental study of these cores since it will provide a key to whether sedimentation has been sea level forced and to qualify radiocarbon dated sea-level change index points.

Taxa noted include *Diploneis didyma, Nitzschia navicularis, Nitzschia* spp. *Paralia sulcat*a, *Actinoptychus senarius, Surirella* spp., *Pinnularia* spp., *Navicula* spp., *Raphoneis* sp. *Epithemium* sp., *Gyrosigma*, *Stauroneis* spp., *Achnanthes* sp. *Synedra* sp. Centrales were especially abundant in some samples.

3.c.) The need for additional analysis: As noted above, diatoms are an essential tool for examining the depositional circumstances of certain sediment types. This is especially applicable to those which are thought to be deposited under saline influences. Here, a more detailed analysis will be required to confirm that stratigraphical changes observed were caused by positive rise in relative sea level (RSL). This study coupled with radiocarbon dating will provide useful sea level change index points of which there is only one published date relating to this period (to my knowledge).

4.) Conclusions

Preliminary pollen and diatom studies have proven extremely successful with preservation of these microfossils in almost all of the samples processed. Examination of the material suggests that the sediments filling these palaeo-channels are of early Holocene age (Flandrian Chronozone I) rather than late Devensian cold stage. They exhibit early Holocene vegetation changes relating to the migration and expansion of the principal tree and shrub taxa from their glacial refugia and their passage onto the coast of England prior to later submergence of the Channel. However, diatoms which are present in most of the samples, also show that brackish water/marine influences were also starting to play an important role in the depositional environment. The sediment fills of these channels are very substantial and appeared to accrue over a relatively short time-span for their thickness. It seems plausible that sediment load carried from the higher terrestrial zone into the low lying rivers of the Channel were met by rising sea levels and ponding back of the fluvial systems. This would have created a sedimentary regime conducive to such rapid sediment formation. Because of the rarity and importance of these sequences, substantial work is recommended. This should take the form of full pollen analysis, diatoms studies where appropriate and radiocarbon dating to produce a detailed chronostratigraphic framework which can be correlated with other (albeit sparse) palaeo-environmental analyses.

5.) Strategy and Cost of Additional Analysis

5.a.) Pollen: Table 2 highlights those samples which should be analysed in order to produce both pollen and diatom data and diagrams which would have credibility. Samples already prepared and examined are at a *very* broad interval. Should a final report go to publication and be reviewed I would be extremely surprised if comments on such a broad sampling interval were not made. Thus, a total of 71 samples for pollen analysis have been suggested. At present 27 of these have already been prepared and examined. This would therefore require preparation of 44 samples. Being somewhat difficult material this would take 3 days at minimum. Ideally pollen counts of a minimum of 300-400 grains per sample would be acceptable especially as the overall taxonomic diversity is low. Pollen is, however, variably preserved and being pragmatic, counts of as many grains as is feasible/necessary should be obtained. This should provide acceptable scientific data to enable a report to scientific publication standards to be produced.

5.b.) Diatoms: Table 2 highlights those samples which are felt should provide an insight into the depositional environment of the palaeo-channels with particular reference to salinity changes. It is recognised by the writer that as with pollen there is a substantial number; especially given time constraints. As with pollen, however, to obtain sound scientific results of first class publication standards, such an analysis is required. However, if full diatom counts cannot be achieved within the time framework or costs are prohibitive, then examination of these levels by a diatom specialist should be undertaken and relative proportions of the principal and diagnostic taxa should be detailed. This would provide the necessary indications of phases of marine/brackish water influences.

5.c.) Integration: To maximise the value of the palaeo-environmental analyses detailed above and also the studies of foraminifera and stratigraphy/sediments the following is required (i.) sufficient radiocarbon dates should be obtained to establish a vegetation chronology (ii.) accuracy of O.D heights should be ascertained (iii.) all ecofactual data should be made available during the for specialists involved to ultimately provide an integrated study.

References

Bellamy, A.G. 1995 'Extension of British landmass: evidence from shelf sediment bodies in the English Channel'. pp.47-62 in Preece, R.C. ***Island Britain: A Quaternary Perspective***. Geological Society Special Publication No. 96.

Table 1

Core	Depth (cm)	Pollen Presence	Diatom Presence	Abundance	Habitat
VC1					
	40	*	*	*	?
	100	*			
	160				
	220	*	*	~	B
	280	*	*	~	?
	340	*	*	**	B
	400	*	*	**	B
	460	*	*	~	?B
	520	*	*	**	?B
VC3					
	40	*	*	***	B
	82	*	*	*	B
	140	*	*	**	B
	200	*	*	****	?F/B
	240	*	*	****	B
	244	*			
	260	*	*	**	B
	300	*	*	*	F/B
	360	*	*	***	?F/B
	460	*	*	*	?
VC7					
	256	*	*	**	?F/B
VC13					
	320	*	*	*****	?F/B
VC17					
	40	*	*	*	B
	100	*	*	**	B
	160	*	*	~	B
	220	*	*	~	?B
	280	*	*	**	B
	340	*	*	**	?B
	400	*	*	*	?B

Table 2

Core	Depth (cm)	Pollen	Diatoms
VC1	40	**	?
	80	*	
	100	**	?
	120	*	
	140	*	?
	160	**	
	180	*	?
	200	*	
	220	**	?
	240	*	
	260	*	
	280	**	*
	300	*	*
	340	**	*
	400	**	*
	440	*	*
	460	**	
	480	*	
	500	*	*
	520	**	*
VC3	40	**	*
	60	*	*
	82	**	
	100	*	*
	120	*	
	140	**	*
	160	*	*
	180	*	*
	200	**	*
	220	*	*
	240	**	*
	244	**	
	260	**	*
	280	*	*
	300	**	*
	320	*	
	340	*	*
	360	**	
	380	*	*
	400	*	
	420	*	*
	440	*	*
	460	**	*
VC7	240	*	*
	250	*	*
	256	**	

Core	Depth (cm)	Pollen	Diatoms
	260	*	*
VC13	320	**	
VC17	20	*	*
VC17	40	**	
	60	*	*
	80	*	
	100	**	*
	140	*	*
	160	**	
	180	*	*
	200	*	
	220	**	*
	240	*	
	260	*	*
	280	**	
	300	*	*
	320	*	
	340	**	*
	360	*	
	380	*	*
	400	**	

ASSESSMENT: FORAMINIFERA

Preliminary Assessment of forams in cores from the Seabed in Prehistory project -53146.

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Samples assessed

A total of 21 samples were assessed (see summary edited into core description tables).These were from the following cores:

VC1: 40, 160, 280, 400, 520
VC17: 40, 160, 280, 400
VC3: 40, 82, 140, 200, 240, 244, 260, 300, 360, 460
VC19: 52
VC13: 320

Results

Core VC3 contains forams typical of a range of environments from marine-brackish near the base at 460 to mid-high salt marsh at 244. Preservation is patchy and seems particularly poor between 82 and 244.

Cores VC17 and **VC1** contain very similar assemblages. They are dominated by brackish species with a significant, though variable marine component. The initial impression is that the proportion of sand in the sample correlates with the proportion of marine taxa, though this has not been established. The concentration and preservation of the forams is good and all samples would be suitable for full analysis.

Core VC13. Just one sample, 320, analysed. This sample contains 7 poorly preserved specimens of one brackish species.

No forams were found in sample 52 from **VC19**.

Further analysis

Core **VC3** is interesting from the foram viewpoint with the range of environments it suggests, particularly from 360 up to 244. Suggestions for further samples, if available: **60, 100, 248, 280, 320, 340**. Contiguous sampling between key levels e.g. below 244 may also be useful.

The two channel infill cores **VC17** and **VC1** are broadly similar in the nature of their assemblages although they presumably represent different timescales within the channel fill.

Pollen and diatom data may indicate particular areas of interest which would benefit from further foram analysis. Otherwise, suggested further samples are those already received but not yet analysed: **VC17: 100, 220, 340. VC1: 100, 220, 340, 460.**

Only one sample from VC13 was examined and was found to have only a few poorly preserved forams. However, if the pollen, diatom and radiocarbon data throw up interesting features in this core, foram analysis may be useful. Possible samples adjacent to pollen/diatom samples at these levels: **VC13 20, 60, 100, 140, 180 220, 260, 300, 340, 360.**

Foram analysis in other cores may be useful depending on the time available for work completion and funds.

Costs of further analyses

For the preparation and full analysis of the samples listed above:
23 samples@ £60.00 £1380.00

For the further analysis of suitable samples already prepared:
14 samples @£30.00 £420.00

Total £1800.00

Costs to date

For the preparation and rapid assessment of 21 samples:

21 samples @ £30.00 £630.00

Timescale for the work.

Current work commitments mean I will not be able to complete the work outlined above until the end of February at the earliest. Ideally I would prefer to have longer to consider the data before submitting a report. If further samples, e.g. contiguous samples from VC3 or samples from other cores are also suggested for analysis, then obviously I would be looking at completing the work sometime in March. Alternatively, it may be thought preferable to concentrate analysis on VC3 rather than analysing VC13.

Annette Kreiser
14th January 2004

Seabed Prehistory (Arun Offshore): Pollen Analysis. The early Holocene Vegetation and Changing Habitats of the English Channel Sea-floor

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1.) Introduction

As part of the Wessex Archaeology research project on South Coast submerged palaeochannels, vibro-cores have been obtained from areas of the English Channel south of the River Arun, Sussex where submerged palaeochannels have been identified and surveyed (Bellamy 1994). These cores provide a rare chance to examine the sea-bed environment and history of the Channel prior to submergence and are thought to be of Holocene but in places possibly Ipswichian age (last interglacial stage 5e). Samples have been examined for sub-fossil pollen and spores to provide information on the aspects of the palaeo-environmental development of the English Channel. These organic and mineral sediments at a depth of greater than –15m.OD clearly have potential for studying the following aspects of the biological and geomorphological evolution of the English Channel prior to separation of Britain from the European land-mass.

i.) To study the palaeo-vegetation during the period of sediment deposition with special reference to floral migration from glacial refugia and to the habitat of the early Mesolithic (Maglemosian) human communities.

(ii.) To suggest a time-span over which the sediments accumulated.

(iii.) The early Holocene (post-glacial) marine transgression which occurred with diminution of the polar ice-sheets and periglacial permafrost zone.

This paper examines the results of this study of the palynological analysis of these borehole/core sequences.

2.) Pollen Procedures

Samples of 2ml volume were processed using standard techniques for the extraction of the sub-fossil pollen and spores (Moore and Webb 1978; Moore *et al.* 1991). Micromesh sieving (10u) was also used to aid with removal of the clay fraction in the mineral sediments. The absolute pollen numbers/frequencies in the samples were calculated using added exotics to known volumes of sample (Stockmarr 1971). The sub-fossil pollen and spores were identified and counted using an Olympus biological research microscope fitted with Leitz optics. A pollen sum of up to 400 grains of dry land taxa per level was counted for each level where possible. Additionally, all extant spores and pollen of marsh taxa (largely Cyperaceae), fern spores and miscellaneous pre-Quaternary palynomorphs were also counted for each of the samples analysed. Total pollen counts are, therefore substantially greater. Pollen diagrams have been plotted using Tilia and Tilia Graph (figures 1 and 2). Percentages have been calculated as follows:

Sum = % total dry land pollen (tdlp).
Marsh/aquatic = % tdlp + sum of marsh/aquatics.
Spores = % tdlp + sum of spores.
Misc. = % tdlp + sum of misc. taxa.

Taxonomy, in general, follows that of Moore and Webb (1978) modified according to Bennett *et al.* (1994) for pollen types and Stace (1992) for plant descriptions. These procedures were carried out in the Palaeoecology Laboratory of the Department of Geography, University of Southampton.

3.) Sub-fossil Pollen and Spores Content

Core details and sample depths for pollen and diatom analysis are given by Dr. M.J. Allen in Tables 1 and 2 above. Pollen and spores have been extracted from profiles VC1, VC3, VC7, VC13 and VC17. After an initial assessment of the pollen content and potential for environmental palaeo-reconstruction was made (Scaife 2004a), additional samples and pollen counts from all but VC17 have been carried out. Less detail has been obtained from VC17, which replicates part of VC1. This, however, acts as a useful comparison to VC1. The palynological characteristics of these profiles are detailed below. From these data, it has been possible to suggest the ages of the sediments (prior to absolute dating), the depositional environment and to reconstruct the vegetation and environment.

3.i.) Profile VC1 (figure 1)

Although of substantial thickness, this 5.0 metre profile spans only the upper part of a deep, sediment filled palaeochannel from which two cores were obtained (see VC17 below). The sediment fills comprise predominantly sand and (often laminated) silts with humic staining. This is reflected in the absolute pollen frequencies which are relatively small and range from 1500 grains/ml to 45,000 grains/ml. Given the thickness of these sediments, the pollen displays a remarkable degree of homogeneity throughout the profile with only one pollen assemblage zone recognised. The profile has however, been divided into three pollen assemblage sub-zone. The overall characteristics of the sequence are as follows.

Trees and Shrubs: These are dominant with 80-95% of total pollen in all but one level. *Corylus avellana* type (hazel; to 80% at 2.0m) is dominant with *Quercus* (oak; to 48% at 5.20m) and *Ulmus* (elm to 38% at 2.40m). Also present are *Betula* (birch) becomes more important from 3.00m (to 28%), *Pinus* (pine; to 18% at 60cm) and *Alnus* (alder; 5%). There are sporadic occurrences of *Juniperus* (juniper), *Fraxinus* (ash), *Tilia* (lime/lindens) and shrubs including *Salix* (willow), *Sorbus/Crataegus* type (rowan/hawthorn) and *Prunus* type (blackthorn and wild apple).

Herbs: The herb diversity is small with only Poaceae (grasses; to 10% except for a single peak of 59% at 3.60m) and Chenopodiaceae (goosefoots and oraches; av. 10%) the only consistent taxa. Large Poaceae (e.g. *Glyceria fluitans*) is present. Of the sporadic occurrences of other herb taxa, *Plantago maritima* is noted at 3.60m.

Aquatic and Fen taxa: Percentage values are small but consistent. These include marginals, Cyperaceae (sedges), *Typha latifolia* (greater reed-mace), *Typha angustifolia/Sparganium* type (bur reed and lesser reed-mace). Aquatic megaphytes include *Potamogeton* type (pond weed), *Myriophyllum spicatum* (water milfoil) and *Nymphaea* (white water lily).

Spores of ferns: These occur only sporadically with *Pteridium aquilinum* (bracken), monolete *Dryopteris* type (typical ferns) and *Polypodium vulgare* (common polypody). *Thelypteris palustris* is present.

Miscellaneous palynomorphs: There are very substantial numbers of pre-Quaternary pollen and spores of Tertiary and Cretaceous age. These are derived from erosion of the bedrock. Hystrichospheres have a minor peak at *c*. 4.50m. The cysts of algal *Pediastrum* occur sporadically throughout.

Notes on pollen zones/sub-zones: Whilst there are no major pollen assemblage zones, some variation in the pollen spectra are apparent. These are itemised as follows.

(a.) Tree pollen assemblages are broadly consistent but, however, there is an expansion of *Betula* above 3.0m and *Ulmus* above 4.0m.

(b.) *Salix* (willow) is markedly under represented in pollen spectra and as such, a small increase in occurrences between 3.60 and 2.10m may be significant.

(c.) Within the herbs, Poaceae are more important from 5.0m to 2.50m.

(d.) There are generally greater numbers of Hystrichospheres and derived palynomorphs at *c.* 4.50m.

3.i.a.) The inferred vegetation

The 5.5m of sediments described here represents the upper-most section of the principal palaeochannel which is incised into material of the broader floodplain. These channel fills will, therefore, post date the lower sediments sequences of profiles VC3 and VC7. They may, however, correlate with the upper zones/levels (e.g. VC3:3 to VC3:5). Profile VC17 (3.ii. below) is directly comparable coming from the same channel fill.

Interpretation of the data (and other profile described below) falls into two distinct categories. First, is that pollen which is derived from the drier interfluves within the catchment area. Here, the pollen suggests a predominantly wooded landscape throughout the time-span represented by the sediment accumulation. Second, is the autochthonous component (on-site) where pollen, especially the grasses and aquatic and fen/flood plain taxa (see above), clearly relate to the depositional habitat. Taphonomy of pollen in such alluvial sediments is, however, complex with pollen input coming from a range of sources in addition to the more usual airborne vector (Burrin and Scaife 1984; Scaife and Burrin 1993). Here, the depositional habitat may be further complicated by the possibility of brackish water ingress. The very substantial numbers of pre-Quaternary palynomorphs relate to this fluvial erosion of the Cretaceous and Tertiary bedrock and possibly earlier Holocene sediments.

The extra-site vegetation and environment: Oak (*Quercus*), elm (*Ulmus*) and hazel (*Corylus avellana*) are the dominant taxa. The latter is consistent throughout whilst, oak is more important in the lower levels (*c.* 5.0m) where a peak occurs. Elm becomes progressively more important to become co-dominant with oak. Birch (*Betula*) and *Pinus* (pine) are present. However, compared with other profiles discussed their values/percentages are relatively small. Furthermore, these are anemophilous and generally over represented in pollen spectra compared to oak and elm (Andersen 1970, 1973). It is, however, noted that there are peaks of birch from 3.0m upwards which may be due to changing sedimentary factors or due to landscape disturbance and regenerative colonisation. Alder (*Alnus*) is consistently present in small values. This taxon is massively over represented in pollen spectra when growing on-site (Janssen 1969) and values here are, at first site, not significant. However, because of the geographical position of this site and the suggested Boreal age of these sediments, this provides a useful indication of its progressive migration into the region. The pollen is either long distance transported (prior to arrival on site) or fluvially transported from areas of growth. This similarly applies to ash (*Fraxinus*) and lime (*Tilia*) which although occur only sporadically, are poorly represented in pollen spectra and may thus indicate early records of these trees.

The on-site habitat: The herb flora is sparse compared with the dominance of the woodland taxa discussed above. Where these occur they suggest two habitats. First, aquatic and fen taxa including grasses, sedges water millfoil, white water lily, pond weed (or arrow grass), reed-mace are indicative of wet fen with rooting marginals adjacent to slow flowing open water. Clearly, however, there is the possibility that pollen from this habitat may have also have been fluvially transported from upstream. Second, is the possible halophytic/salt marsh and mud flat vegetation element which includes Chenopodiaceae (goosefoots, oraches and glassworts) and sea plantain (*Plantago maritima*) and possibly sea aster. Marine/brackish water influences have been evidenced by diatoms and foraminifera and along with the pollen data suggests either local salt marsh or periodic (spring tides and tidal surges) saline ingress.

The age of the sediments: Pollen is not now regarded as an accurate dating method having been superceded by absolute techniques including radiocarbon dating and thermoluminescence. Absolute dates from these profiles are awaited and will provide a temporal framework within which the habitats and pollen zones described here will be placed. However, because of the now generally understood changes which have taken place since the close of the last cold stage at *c.* 10,000 BP (9,600 cal. BC) it is possible to provide initial suggestions as to the temporal span of the cores. As expected given the depths O.D of all the profiles described are referable to the late-Devensian and early Holocene (Flandrian chronozone I). VC:1 has a dominance of oak, elm and hazel with relatively small numbers of birch and pine. When compared with radiocarbon dated terrestrial sequences from southern England, this suggests that VC1 is early Holocene, Boreal, Flandrian chronozone Ib to possibly early Flandrian Ic. That is, at *c.* 8500-8000 BP (7,500 to 6,800 cal. BC). However, given the southern geographical position of this site, it is possible that these sequential vegetation changes may have occurred earlier than in areas to the north.

3.ii.) Profile VC17 (figure 2)

This profile comes from the fills of the main palaeochannel and is thus directly comparable with VC1 above. Consequently, a less detailed study has been made. Absolute pollen frequencies range from 1,500 grains/ml to 18,500 grains/ml. Trees and shrubs are dominant (85-95% of total pollen) with generally few herbs. Small taxonomic diversity compared with VC1 above may be due to the reduced pollen sum.

Trees and shrubs: Quercus (to 50%) is dominant with *Corylus avellana* type (peak to 80%) at 2.20m. *Betula* (6%), *Pinus* (to 18%), *Ulmus* (5%) are also present with sporadic *Juniperus, Fraxinus*, *Alnus* and *Salix*. *Empetrum* is present at 3.40m.

Herbs: These are few with only Chenopodiaceae (9%) and Poaceae (19%) being of note.

Aquatic and Fen: There are only small numbers which comprise *Typha angustifoli*a type, Cyperaceae and *Potamogeton*.

Spores of ferns: These include only small numbers of *Pteridium aquilinum*, *Dryopteris* type, *Polypodium vulgare* and *Equisetum*.

Miscellaneous palynomorphs: As with VC1 there are substantial numbers of derived pre-Quaternary pollen and spores of Tertiary and Cretaceous age. Hystrichospheres and *Pediastrum* are present.

3.ii.a.) The inferred vegetation

As noted in VC1 above, this profile comes from the same fills of the primary palaeo-channel and as such should be comparable. This appears to be the case with dominance of early Holocene (Boreal) oak, elm and hazel woodland on the drier interfluve soils and aquatic, reed swamp and halophytic communities on the floodplain and in the channel. Because the diagram is not analysed at the detail of VC1, direct comparisons are tentative, especially as there is a remarkable degree of homogeneity throughout such a deep sequence. It appears, however, that this 4.0m profile correlates with the top 2.5m of profile VC1. This therefore implies more rapidly accumulating sediment in this profile (i.e. VC17).

3.iii.) Profile VC3 (figure 3)

This profile from the marginal zone of the palaeochannel displays a number of significant changes throughout its depth. Absolute pollen frequencies range from 6000 grains/ml. to 240,000 grains/ml. Five local pollen assemblage zones have been recognised in the 5.0m of sediment. These are characterised from the base of the profile upwards.

VC3: 1 5.20m. to 3.10m. Betula-Pinus-Poaceae (9 levels). This zone is characterised by high herb values and importance of *Betula* and *Pinus*. Trees are dominated by the latter with *Betula* (to 27%) and *Pinus* (to 40%). Also present are small numbers of small *Betula* grains which are tentatively identified as *Betula nana* (dwarf birch). There are also sporadic occurrences of *Juniperus*, *Quercus*, *Alnus* and *Corylus avellana* type and *Salix*. Herbs are dominated by Poaceae (to 90% at 5.0m) with sporadic occurrences of a moderately diverse range of herbs. Marsh and aquatic types are represented by Cyperaceae (to 20%), *Typha angustifolia* type (to 5%). Aquatic megaphytes include *Potamogeton* type, *Nymphaea, Myriophyllum spicatum* and *M. alterniflorum*. Spores include *Dryopteris* type. Algal *Pediastrum* (to 14%) and Pre-Quaternary palynomorphs (12%) are most important in this and zone VC2.

VC3: 2 3.10m to 2.50m. Pinus (3 levels). This zone has been delimited by a peak of *Pinus* to maximum values (to 85%). *Betula* declines from VC1 (to 10%). *Betula nana*, *Juniperus* and *Salix* occur in small numbers. There is a minor expansion of *Corylus avellana* prior to a marked expansion in the VC3 above. Herbs remain dominated by Poaceae but with some reduction (to 20%). Marsh and aquatics remain dominated by Cyperaceae (10%) and *Typha* *angustifolia* type (5%). There are greater numbers of *Pediastrum* and Pre-Quaternary palynomorphs.

VC3: 3 2.50m to 1.30m. Corylus avellana type (8 levels). Absolute pollen frequencies attain high values in two samples at the basal interface of this zone (to 240,00 grains/ml.). *Corylus avellana* type expands to high values (*c*. 65%). *Quercus* and *Ulmus* expand in this zone. *Quercus* (to 20%) has a peak at 2.44m.) prior to the expansion of *Ulmus*. *Betula* declines to small values (to <2%) while pine to 20% declines in response to *Corylus avellana* expansion (statistical/within sum?). Herbs are less in important than in zone VC1 and VC2. Poaceae, however, remains dominant with a peak at 2.40m. to 2.48m. at the interface of zone VC2/VC3. This may be regarded as a transitional local pollen assemblage sub-zone. Marsh and aquatic types and spores remain as VC:2 but with reduced values.

VC3: 4 1.30m to 0.75m Pinus (4 levels). *Pinus* peaks to 60%. *Corylus avellana* type is reduced to *c*. 15%. There is also a small peak of *Betula* (10%). Herbs are dominated by Poaceae (to 40%) with peaks of aquatic/marsh taxa including Cyperaceae (12%) and *Typha angustifolia* type (6%) and spores including *Dryopteris* type (10%), *Pediastrum* (15%) and pre-Quaternary palynomorphs (20%).

VC3: 5 0.75m to 0.20m. *Pinus* values of the preceding zone decline to av. 15% while *Corylus avellana* type attains levels of VC3 (*c.* 50%). *Quercus* increases to 12% at the top of the profile. *Ulmus* becomes more important (to 6%). Poaceae is the dominant herb (30%) although herbaceous diversity is low. Cyperaceae and *Typha angustifolia* remain at previous levels.

3.iii.a.) The inferred vegetation
This profile is located on the edge of the main floodplain into which the principal palaeochannel was cut (profiles VC1 and VC17). There is, therefore, the potential for older sediments than those which fill the palaeochannel described above. This appears to be the case and the profile has a complex biostratigraphy which has been sub-divided into 5 pollen assemblage biozones. It is thought that biozones VC3:1 and VC2 represent the sediments of the broader floodplain, pre-dating the fills of the palaeochannel. A significant change at 2.50m in this profile (VC3) represents the start of sedimentation on the floodplain which may be contemporaneous with the fills of the palaeochannel. Thus, there are two broad time periods (and thus environments) represented. It has been considered that the profile is continuous but all indications are that there is temporal hiatus at *c.* 2.55m.

The earlier phase (biozones VC3:1 and VC3:2) is dominated by birch and pine woodland, the latter which become increasingly important. There are also substantial numbers of herbs which are dominated by grasses and fen herb taxa (reed mace, bur reed, sedges, water plantain and marsh fern) and aquatic megaphytes (white water lily and water millfoil) and cysts of freshwater algal *Pediastrum*. Thus, it appears that the habitat was birch and pine dominated with a wetland (on-site) freshwater and reed swamp habitat. Small numbers of other tree and shrub taxa are also of significance. Sporadic occurrences of oak and hazel are from long distance/extra regional sources prior to their establishment and importance seen in profile VC1 and VC17 and in biozones VC:3-5 here. There are also small numbers of juniper and possibly dwarf birch pollen which along with the birch pine dominance indicate that the environment was a pre-boreal or early Boreal environment. In terms of age, this may be one of the following possibilities (i.) very early Holocene (ii.) a interstadial phase within the Devensian cold stage or (iii.) a boreal (pre-temperate) phase from an earlier interglacial

(Ipswichian stage 5e.). The former (i.) seems most plausible and it is hoped that thermo-luminescence date will clarify this.

The later phase (pollen biozones VC3:3-5) show a marked change in vegetation and habitat from one of birch and oak to one of elm, oak and hazel with pine. The latter shows a phase of increasing importance within this otherwise deciduous habitat (biozone VC3:4) prior to a return to oak and hazel dominance. The interface between the earlier phase noted and biozone 3 is also marked by a marked peak in total absolute pollen frequencies in organic sediments. It is possible that this represents an old land surface developed on the earlier floodplain with high a.p.f. values coming from the increased humic matter. This later incursion of sedimentation most likely occurred due to increasing wetness caused by positive eustatic changes and resulting overbank sediment deposition. It is noted that grasses also attain high values at this interface and may be from development of fen (cf. *Phragmites australis*). There are only small numbers of Chenopodiaceae but these along with *Plantago maritima* suggest at least some saline/brackish influences.

In conclusion, it appears that the lower pollen biozones VC3:1 and VC3:2 are of earlier (pre-boreal and early boreal) age prior to a cessation of sedimentation or phase of sediment erosion. The environment of this phase was dominated by birch and pine woodland. Subsequently, there was hiatus of unknown time-span after which, sediment accretion started again, possibly driven by increasing relative sea level. Pollen suggests that the environment was one of oak, elm and hazel dominance although pine was also present and was able to regain importance for a period prior re-establishment of deciduous woodland. This later sequence has vegetation which is characteristic of the early Holocene, Boreal period Flandrian chronozone Ib-Ic. Throughout these biozones, there is evidence for grass sedge fen and open, ?slow flowing water and ephemeral brackish water incursion. It can be noted that the interface at *c.* 2.5m would have been the surface on which hunting and foraging Mesolithic communities are likely to have occupied for exploitation of this low lying wetland habitat.

3.iv.) Profile VC7 (figure 4)

This profile spans an organic clay unit at a depth of between 2.40 and 2.60m within the 5.25m sequence of sediments which rest on the wider palaeo-valley floor (? floodplain). Four samples have been analysed which are herb dominated with only small numbers of trees and shrubs. Absolute pollen frequencies are relatively high throughout with up to 357,000 grains/ml present. The principal palynological characteristics of the profile are as follows.

Trees and shrubs: Values are small. *Betula* (increasing to 6%), *Pinus* (single peak to 16%) and small numbers of *Betula cf. nana, Juniperus, Quercus* and *Corylus avellana* type.

Herbs: Herbs are dominant although taxonomic diversity is low. Poaceae are important (to 90% total pollen). Marsh and aquatic taxa are present with Cyperaceae (5% at 2.40m.) with occasional *Nymphaea, Alisma plantago-aquatica* type, *Lemna* (duckweed) and *Typha angustifolia/Sparganium* type.

Spores: There are only small numbers of spores with occasional occurrences of *Pteridium aquilinum*, monolete *Dryopteris* type and *Sphagnum* (bog moss).

3.iv.a.) The inferred vegetation

This profile contrasts markedly with the other profiles discussed here. Herbs are dominant with few trees with the latter comprising only small numbers of birch, pine, oak and hazel. These are all anemophilous and are most probably derived from extra regional sources via long distance airborne transport. Grasses are most important and with general small numbers and absence of other herb pollen taxa suggests an open habitat at least on-site. As with the other profiles there is evidence that the on-site communities were grass/sedge fen with other rooting marginal plants and areas of open standing or slow flowing water with aquatic megaphytes (e.g. duckweed and white water lily). It should be noted that this preponderance of herbs (grasses) may represent over-representation of these taxa which have suppressed the relative values of tree and shrub taxa.

Age of the profile: Although radiocarbon dates are awaited, it is possible that this organic unit is of Devensian age.

3.v.) Profile VC13 (figure 5)

Profile VC13 comes from the eastern edge of the primary palaeo-channel. Pollen analysis has been carried out on the 5.40m of silty sand, silts and organic clays. Absolute pollen frequencies range from 19,000 grains/ml to 67,000 grains/ml. with the exception of a single extremely rich sample at 1.40m to 584k grains/ml.

VC13: 1. 5.40m. to 4.40m. Betula- Pinus-Poaceae (3 levels). This zone is defined by the highest values of *Pinus, Betula* and Poaceae. Trees and shrubs are dominated by the former with *Pinus* (to 60%) and *Betula* (*c.* 14%) with sporadic/occasional occurrences of *Picea* (spruce), *Corylus avellana*, *Viburnum* (wayfaring tree) and *Salix*. Herbs are dominated by Poaceae which attain highest values in the basal level (79%) along with Cyperaceae (sedges; to 18%).

VC13: 2. 4.40m to 2.0m. Pinus-Quercus-Corylus avellana-Poaceae. (10 levels.) This zone and sub-zones is/are defined by the incoming of tree/shrub taxa throughout this zone. *Betula* and *Pinus* remain important but with reduced percentage. *Quercus* expands to a peak at 3.64-3.60m (to 26%) after which it declines progressively. *Ulmus* expands from *c.* 3.20m. Shrubs are dominated by *Corylus avellana* type which expands from the base of the zone to *c.* 50% along with *Quercus* after which it similarly declines to smaller values. Herbs are dominated by Poaceae (peak to 60%) with occasional peaks of Chenopodiaceae (20% at 3.40m.) and a more regular occurrence of Artemisia type. Aquatic and fen taxa include Cyperaceae (to 10% in the lower half of the zone) with *Typha angustifolia/Sparganium* type in the upper half of the zone (to 10%). Spores include a minor peak of *Dryopteris* type (at 3.20 – 3.24m.). Algal *Pediastrum* is present throughout in small numbers.

VC13: 3. 2.0m. to 0.75. Pinus. (3 levels.). Characterised by an expansion to maximum values of *Pinus* (to 80% at 1.40m.) *Betula* (5%) and *Pinus* (10%) remain but with slightly reduced values. *Ulmus* and *Quercus* start to expand in the upper part of the zone (8% and 10%, respectively). Herbs are dominated by Poaceae (30%). Marsh/fen taxa show an expansion of Cyperaceae (10%) with *Typha angustifolia/Sparganium* type. Spores of ferns and miscellaneous palynomorphs remain unchanged from preceding zone VC13:2.

VC13: 4. 0.75m to 0.20m. (2 levels). This uppermost zone is defined by increasing *Quercus* and *Pinus* and reduced numbers of *Corylus avellana* type. Trees are dominated by *Quercus* (increasing to 25%) and *Pinus* (20%). Herbs are dominated by Poaceae (to 35%). Also present are aster type (<2%). Marsh/fen taxa comprise Cyperaceae (12%) and *Typha angustifolia* type (to 5%). *Pediastrum* and pre-Quaternary palynomorphs remain unchanged.

3.v.a.) The inferred vegetation

Three pollen assemblage zones have been recognised which demonstrate vegetation changes which are typical of the early Holocene (Flandrian chronozone 1) establishment of woodland after the close of the Devensian glacial. Pollen biozone VC13:1 shows greater numbers of herbs (including grasses and Saxifragaceae) and birch woodland in the basal levels followed by expansion to dominance of pine. Subsequently, in biozone VC13:2, elm, oak and hazel become dominant ousting the earlier pioneer communities. It is noted that here, that hazel precedes oak which precedes elm expansion. Pine remained in the landscape but at subordinate levels. In biozone VC13:3, hazel becomes increasingly important and dominant. This is a feature of the Boreal period for which many explanations have been discussed (see Smith 1970). Subsequently and as expected, oak and elm start to regain importance.

Throughout this sequence, grasses remain important and probably come from a range of plant communities but largely from the on-site habitats which were grass-sedge reed swamp/fen and open water aquatic (nb. fluvial transport from upstream may be involved). Chenopodiaceae from 3.40m. is probably indicative of increasing saline. Brackish water incursion (see Cameron – diatom analysis).

Age of the profile: The sequence of vegetation succession could be related to the early Holocene, pre-Boreal and Boreal migration and expansion of woodland at the close of the Devensian cold stage at *c.* 10,000 BP (*c.* 9,600 cal. BC). The upper part of the profile does not contain thermophiles such as lime and lindens which arrived towards the end of Flandrian chronozone I (i.e. prior to *c.* 7,000 BP (*c.* 6,000 cal. BC)). Thus, it is suggested that this profile falls within the period from *c.* 10,000 to 8,000 yrs BP (*c.* 9,600 – 6,800 cal. BC).

4. Summary and Conclusions

Sub-fossil pollen and spores contained within the sediments essentially reflect the vegetation growing at the time of sediment deposition. These data, apart from revealing the character of vegetation and development through time, may also be used as proxy information for studying other environmental aspects such as climate and eustatic change (i.e. changes in relative sea level) and data presented here will also be integrated into studies of eustatic change, development of the fluvial system and changing palaeogeography.

Pollen analysis of the five core profiles has demonstrated that there are substantial differences in age and depositional habitats present. However, it is clear that all of the sequences are attributable to late-Devensian and early Holocene environmental development. That is, possibly the late glacial stadial. and Flandrian chronozone I (pre-Boreal and Boreal periods). This sedimentation occurred in response to and prior to rapid eustatic change at the close of the last cold stage and before final marine inundation. Stratigraphically, the sediment fills of the main palaeochannel cut into an existing floodplain and as such, sediments will therefore post date the basal alluvial sediments. This gives a suggested sequence of events and contained environmental data which is summarised as follows:

Profile VC7 and the basal levels of VC13 contain greater numbers of herbs (esp. grasses) which may be attributable to the latter part of the last (Devensian) cold stage. These suggest an open herbaceous environment with possibly only occasional birch and pine trees.

Profile VC13 contains a typical sequence of vegetation changes which represents the migration and seral succession of the principal tree and shrub taxa into the region during Flandrian chronozone Ia and Ib. Oak, elm and hazel as dominants which out-compete earlier pioneer birch and pine. Hazel becomes especially dominant as typical Boreal hazel woodland and is seen in profiles VC3, VC1 and VC17.

Profile VC3 has a lower sediment unit (*c.* 5.0m to 2.50m) which contains pollen assemblage dominated by birch and pine but with possible evidence of dwarf birch, juniper, crowberry, cf. gentians (and other herbs) which may indicate an earlier age. Absolute dates are awaited since and it is possible that this sediment unit may be of Devensian or late-Devensian age, or possibly, a pre-temperate stage of an earlier interglacial cycle. The age of this unit (biozones VC3:1 and VC3:2) is therefore not clear at present.

Profiles VC1 and VC17 come from the upper section of the main palaeochannel and are thus of later date. These may correlate with the upper levels of profiles VC3 and VC13. This is based on the importance of oak, elm and hazel woodland and smaller values of pine which are characteristic of the middle and late Boreal period (Flandrian chronozone Ib-Ic.).

Comments made regarding the age and inter-relationship of these columns are based solely on the sequences of events established for the terrestrial zone. It should be noted that the southern geographical and topographical position of the site may have resulted in earlier arrival dates than for the mainland.

It is also noteworthy that the sediment thickness' are great and especially in the case of the channel fill, suggest that sediments accumulated rapidly. This is clearly associated with the interaction of rising relative (to land) sea levels and the River (proto) Arun fluvial system.

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Diatom analysis of core samples from the Wessex Archaeology 'Seabed Prehistory'-Project (53146)

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Introduction

Wessex Archaeology is conducting a research project into the buried seabed stratigraphy off the Sussex coast. A series of channels has been recorded, and cored, off the Sussex coastline of the River Arun. Assessments (e.g. Kreiser 2004, Scaife 2004) suggest that there is a sequence of sediment that relates to a terrestrial landscape of the pre-Boreal and Boreal periods through which a river ran. This river was subject to tidal ingression (biological indicators of brackish water). Sedimentation seems to have been rapid with relatively little environmental change recorded over long sediment sequences and this observation concurs with a high rate of ice melting and rapidly rising sea levels. This environmental archaeological project is concerned with the continuing analysis of this landscape. Specifically, to define the nature and development of the buried landscape and its relevance to possible past human communities (M.J. Allen *pers. comm.*).

The dipping geology has created a wide, sloping palaeo-valley at about 25 m below present sea level. There is a hard rock edge at the west of the valley and fluvio-terrestrial sediments cover its surface. A well-defined channel with a gravel edge cuts into the palaeo-valley. This palaeochannel contains minerogenic sediments with flood or tidal couplets that may be contemporary with the valley floor sediments. The eastern edge of the channel has organic deposits that may be either water-lain from the channel or deposits through which the channel has cut. A number of thin (few cm) organic lenses occur that seem to represent brackish conditions and may contain *Phragmites*. These occur in the valley edge, valley floor and channel edge deposits (M.J. Allen *pers. comm.*).

A number of cores, that were taken using a vibro-corer, are being examined. VC17 and VC1 represent a discrete palaeochannel with flood or tidal couplets. These cores have recently been identified from bathymetric data as being roughly contemporary (M.J. Allen pers. comm.). For this reason only the five samples from VC1 have been scanned although four samples from VC17 have also been prepared for scanning. VC13 contains sediments related to the channel edge and deposits through which the channel cut. VC3 contains surface sediment from the palaeovalley that may be contemporary with the channel infill (upper core) and sediment through which the channel is cut. The thin, organic lenses possibly containing *Phragmites* are recovered in VC13, VC7 and VC3 (M.J. Allen *pers. comm.*).

The purpose of carrying out diatom analysis on these sediments is primarily to investigate the nature of the aquatic environment and in particular the salinity regime. A combination of scanning, assessment and analysis is used to define the broad character and development of the environment, and to report on changes in the salinity and local environment. A list of prioritised samples for diatom analysis has been selected on the basis of assessment and other background data (M.J. Allen, unpublished data). These samples selected for diatom evaluation, omitting the four samples from VC17, are listed in Appendix 1.

Methods

Diatom preparation followed standard techniques: the oxidation of organic sediment, removal of carbonate and clay, concentration of diatom valves and washing with distilled water. Further details of sediment preparation methods can be found at the web site of the Department of Geography UCL: (http://www.geog.ucl.ac.uk/~jhope/lab/sedi.htm). Two coverslips, each of a different concentration of the cleaned solution, were prepared from each sample and fixed in a mountant of a suitable refractive index for diatom microscopy (Naphrax). Counts were made under phase contrast illumination at a magnification of x1000. As a result of the limited amount of time available to carry out diatom scanning and analysis a combination of the two techniques was used. The aim was to provide the greatest coverage of samples and best representation of the assemblages. For the samples that were scanned a low sum count has been made (see Appendix 1) of approximately 50 valves. This provides an objective, quantitative estimate of spp. abundances, rather than a qualitative listing of relative abundance and is better suited to comparison between samples, not least because species histograms can be presented for comparison. However, it should be stressed that these counts are of necessity low sum counts and therefore subject to greater variability than full counts would be. Where full analysis is required in the project design, where possible counting has been carried out (except where preservation and time constraints limited the total diatom sum). However, the overall result has been to provide a good overview of the diatom stratigraphy.

Several diatom floras and taxonomic publications were consulted to assist with diatom identification, including Hendey (1964), Hustedt (1930-1966), Krammer & Lange-Bertalot (1986-1991). Diatom species' salinity preferences were classified using the halobian groups of Hustedt (1953, 1957: 199), these are summarised below:

1. Polyhalobian: >30 g l^{-1}

2. Mesohalobian: 0.2-30 g l^{-1}

3. Oligohalobian - Halophilous: optimum in slightly brackish water

4. Oligohalobian - Indifferent: optimum in freshwater but tolerant of slightly brackish water

5. Halophobous: exclusively freshwater

6. Unknown: taxa of unknown salinity preference.

Diatom data were entered into the Amphora database at ECRC, UCL and data manipulation and plotting carried out using a number of programs (Tran, Tilia, Tiliagraph, TiliagraphView), Diatom halobian groups are indicated in Figures 1-4. Subdivisions of group 3 above, the oligohalobous halophilous diatoms, are not shown. In Hustedt's original publications the halophilous diatoms are split into three groups (mesohalobous to halophilous; halophilous; halophilous to oligohalobous indifferent), but these are aggregated here to clarify the appearance and interpretation of the diatom diagrams. The principal sources used for diatom ecological data are Hustedt (1957) and Denys (1992).

Results and Discussion

A total of 33 samples were scanned or analysed (Appendix 1) and 131 diatom taxa were recognised (Appendix 2). These data are archived on the Amphora database at ECRC, UCL (http://amphora.geog.ucl.ac.uk/).

VC1 (Figure 1)

Five samples were scanned from VC1. Diatom sums are in the range 52 to 54 valves per sample except where preservation was poor, at 1.60 m depth were a count of only 13 valves was possible and the percentage figure is therefore unreliable (see Appendix 1). However, for the purposes of comparison a percentage histogram is presented (Figure 1). The marine planktonic species *Paralia sulcata* is dominant in all five samples where it comprises from 35% to 63% of the diatom assemblage. The other dominant diatoms are also marine taxa and include *Cymatosira belgica* and *Rhaphoneis* spp. along with the marine-brackish planktonic diatom *Thalassiosira decipiens*. Marine-brackish (polyhalobous to mesohalobous) diatoms increase in abundance at 4.00 and 2.80 m and appear to indicate a slight decrease in the input of tidal-transported diatoms. *Paralia sulcata* is also the most common diatom at 1.60 m although only 3 valves were counted in the slide. Despite the poor preservation of diatoms at 1.60 m this level coincides with an abrupt change in the lithostratigraphy of the sequence and apparent decrease in salinity which is also suggested by the declining abundances of *Paralia sulcata* and *Rhaphoneis minutissima* over the three underlying samples. At the same time there is a consistent increase in the number of non-planktonic, brackish, halophilous and freshwater diatoms e.g. *Navicula cincta, Achnanthes delicatula* and *Cocconeis placentula* var. *euglypta*. Given the low sum counts and poor quality of preservation at 1.60 m (which itself is likely to be of significance in indicating environmental change) these results should not be over-interpreted. However, the diatom sequence of VC1 shows a consistent pattern of marine dominance with an apparent phase of decreasing input of marine diatoms in the middle part of the sequence and a return to the dominance of marine diatoms at the top of the core (0.40 m).

VC3 (Figure 2)

Except at the base of this sequence (4.60 m), where poor preservation allowed a diatom count of only 28 valves, the diatom percentages shown on Figure 2 may be considered to be an adequate representation of the diatom assemblages present. Full diatom analysis was carried out as requested on the samples from 2.20-3.20 m with diatom sums of 218-233 valves. As a result of poorer preservation, a sum of 160 valves was counted at 320 cm and no count was possible for 2.44 m where diatoms appeared to be more or less absent. The absence of diatoms from the sample at 2.44 m is consistent with the presence of peat.

In addition to the extremely low concentration of diatoms at the base of the VC7 sequence, the poor quality of preservation is reflected by the dominance of undifferentiated pennate diatom remains (11 valves, equivalent to 40% of the assemblage). Aside from these undifferentiated diatom remains, a mixture of freshwater (*Fragilaria pinnata*) brackish (*Achnanthes delicatula*), marine-brackish (*Navicula flannatica*) and marine (*Paralia sulcata*) species is present in the basal level. This sample is from sand containing laminations. The diatom assemblages of the overlying samples from 3.60 m to 2.60 m are composed of a mixture of marine, brackish and freshwater species. These samples show a slight but consistent increase in polyhalobous diatoms e.g. *Paralia sulcata* (increasing from 7% at 3.60 m to 24% at 2.60 m). At the same time mesohalobous taxa like *Navicula perminuta* decline (from a maximum of over 13% to 1% or less) and the cumulative percentage of brackish water taxa (mesohalobous and mesohalobous to halophilous) also declines. Although the proportion of oligohalobous indifferent (freshwater) diatoms remains high these consistent trends in the salinity groups suggest increasing deposition of marine planktonic diatoms whilst what may be the autochthonous non-planktonic flora declines as a result of increasing salinity. There is a notable peak in abundance of the halophilous species *Navicula cincta* (17%) at 2.80 m.

At 2.40 m and 2.20 m the populations of marine diatoms decline significantly with *Paralia sulcata* absent at 2.20 m and the cumulative abundance of polyhalobous taxa less than 10% at this level. A number of non-planktonic, benthic and attached, brackish and halophilous diatoms become dominant. These changes are consistent with the shift to more organic sediments with peat and *Phragmites* remains. At 2.40 m the dominant diatoms are benthic (mud surface) species such as *Diploneis ovalis* (16*%), Nitzschia navicularis* (9%) and *Diploneis smithii* (7%). The attached, halophile *Rhoicosphaenia curvata* (10%) is co-dominant whilst *Paralia* has declined to 7% at 2.40 m. It is interesting to note that the freshwater (oligohalobous indifferent) component of diatoms becomes less abundant at 2.40 m than in the underlying sediments. Freshwater diatoms then recover at 2.20 m where *Fragilaria pinnata* (15%) is dominant along with the brackish water *Navicula phyllepta* (13%) and a small, finely striated but indeterminate *Hantzschia* sp. (*Hantzschia* sp. 1) of unknown salinity preference.

As a result of the poor conditions for diatom preservation there is a relatively high proportion of diatoms determined only to generic level (e.g. *Navicula* sp.) at 2.00 m. Freshwater taxa then increase to a maximum of over 40% at 1.40 m where the non-planktonic diatoms *Amphora pediculus* (13%) and *Fragiliaria pinnata* (11%) are dominant. In the overlying levels at the top of the sequence (0.82 m and 0.40 m) *Paralia sulcata* and other marine taxa such as *Cymatosira belgica* and *Rhaphoneis surirella* increase in abundance whilst the estuarine planktonic diatom *Cyclotella striata* also reaches a maximum (8% at 0.82 m). Freshwater diatoms decline to less than 20% of the overall flora. It is interesting to note the peaks in the abundance of the aerophilous taxa *Hantzschia amphioxys* and *Nitzschia recta* at 0.82 m consistent with inwash of terrestrial, or bank deposits or drying-out of the sediments (the latter is less likely as the assemblage is reasonably well preserved).

The diatom sequence of VC3 represents a mixture of diatom habitats and salinity conditions often within the same sample. Overall a record of consistent contact with tidal water is presented with the exception of the *Phragmites*-peat unit at 2.20 and 2.40 m where the low percentages of marine diatoms might be accounted for by sediment mixing. Although there are significant variations within the sequence the overall record is consistent with increasing sea levels leading up to the present marine environment. However, the fluctuations of diatom populations within this general picture show that there were a number of changes superimposed on the long-term change. These would be best interpreted in conjunction with other stratigraphic analyses and radiocarbon dating.

VC7 (Figure 3)

Three samples were scanned from VC7 with diatom sums ranging from 53-62 valves. The outline percentage diagram therefore provides an adequate picture of the diatom assemblages in this sequence. It is consistent with the revised schematic cross-section (M.J. Allen *pers. comm.*) showing that VC7 cuts fluvio-terrestrial sediments in the palaeovalley that these three samples are dominated by non-planktonic freshwater or halophilous species (*c.* 40-60% of the total assemblages). In particular attached species such as *Cocconeis placentula* (and varieties) and *Rhoicosphaenia curvata* are common. These may reflect the growth of aquatic macrophytes in shallow water. The common occurrence of *Fragilaria pinnata* also reflects diatom growth in shallow water and this species becomes dominant in the top sample where it comprises 50% of the assemblage. Exceptionally a planktonic halophilous species is present *(Actinocyclus normanii* and variety) but the remainder of the species are attached or benthic. Polyhalobous and mesohalobous diatoms represent tidal input with a maximum of 17% *Paralia sulcata* at 2.50 m. However, compared for example with the VC1 main palaeochannel record, percentages of marine and full estuarine taxa are relatively low in this organic part of the VC7 sequence, which contains *Phragmites* remains. The upper part of the VC7 sequence was not investigated for diatoms.

VC13 (Figure 4)

Ten samples were examined from VC13. Diatom counts with sums in the range 159-163 valves were made on the three basal samples whilst scans with counts in the range 55-67 valves were made on the remaining samples. The outline diatom diagram can therefore be considered to be an adequate overall picture of the main diatom assemblage changes occurring in the sequence.

From 3.60 cm to 2.60 m at the base of the core there are more organic sediments with some *Phragmites* remains. Here there are maximum percentages of freshwater, oligohalobous indifferent taxa. In particular *Fragilaria pinnata* is common. Although this species has its optimum in freshwater it does have a broad salinity tolerance and could grow along with the diverse halophilous and mesohalobous diatoms that were also recorded in these levels. It is notable here that the most common marine taxa are *Paralia sulcata* and *Cymatosira belgica* (*Rhaphoneis surirella* is also common but not at its maximum abundance) whilst *Rhaphoneis* spp. and in particular *Rhaphoneis minutissima* increase in the overlying sediment where the freshwater species decline and overall polyhalobous percentages increase. Thus, from 2.60 m to 1.80 m depth polyhalobous percentages increase, driven mainly by these *Rhaphoneis* spp., at the same time the oligohalobous indifferent component and *Fragilaria pinnata* in particular declines. The shift from a marine component dominated by the planktonic Paralia to domination by benthic (e.g. species that inhabit marine mud and sand flats) at the same time as the decline in freshwater diatoms (and indeed mesohalobes) suggests that there was a real increase in marine influence.

Following this phase, in the overlying sediments from 1.40 m to the top at 0.20 m depth, there is an overall decline of *Rhaphoneis minutissima* and *Rhaphoneis surirella* whilst *Paralia sulcata* recovers to over 30% of the total. At the same time other halophilous (*Actinocyclus* *normanii* 11%; *Navicula cincta* 5%) and freshwater taxa (*Fragilaria brevistriata* 7%) increase in abundance. This indicates that there was a decrease in the autochthonous marine (benthic) component and replacement by halophiles, salt tolerant freshwater diatoms and allochthonous marine plankton. The lithostratigraphy at the top also shows an increase in organic and *Phragmites* remains.

Conclusions

Diatom scanning with low sum counts and analysis with moderately high sum counts has been carried out for 33 samples. Diatom percentage sequences are plotted for four cores VC1, VC3, VC7 and VC13.

The diatom assemblages of each core have been used to outline the possible habitat and salinity changes that may have led to formation of these diatom assemblages.

There is an overall picture of continuous marine contact, with the exception of a peat horizon in VC3 where the small marine component could be accounted for by sediment mixing processes.

However, despite the continuous contemporary or post-burial input of marine diatoms, more subtle variations within the marine assemblage and in the proportions of mesohalobous, halophilous and freshwater diatoms show the changing salinity and habitat conditions.

Possible environmental changes are outlined in the Discussion and Results section above, but further analysis of these results will require comparison with other data (e.g. other biostratigraphy, dating, regional sea-level evidence).

Acknowledgements

Thanks to Mike Allen for providing details of the cores, stratigraphy, assessment reports and subsamples for diatom preparation and analysis.

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Appendix 1. Seabed in Prehistory (5346), samples analysed for diatoms

SAMPLE	CORE	COUNT	LABEL	TOP	BOTTOM (cm)
SBPH05	VC1	52	VC1040	40	41
SBPH06	VC1	13	VC1160	160	161
SBPH07	VC1	54	VC1280	280	281
SBPH08	VC1	54	VC1400	400	401
SBPH09	VC1	54	VC1520	520	521
SBPH10	VC3	62	VC3040	40	41
SBPH11	VC3	53	VC3082	82	83
SBPH12	VC3	55	VC3140	140	141
SBPH13	VC3	59	VC3180	180	181
SBPH14	VC3	55	VC3200	200	201
SBPH15	VC3	232	VC3220	220	221
SBPH16	VC3	233	VC3240	240	241
SBPH18	VC3	226	VC3248	248	249
SBPH19	VC3	223	VC3260	260	261
SBPH20	VC3	227	VC3280	280	281
SBPH21	VC3	218	VC3300	300	301
SBPH22	VC3	160	VC3320	320	321
SBPH23	VC3	53	VC3340	340	341
SBPH24	VC3	60	VC3360	360	361
SBPH25	VC3	28	VC3460	460	461
SBPH26	VC7	62	VC7240	240	241
SBPH27	VC7	53	VC7250	250	251
SBPH28	VC7	54	VC7260	260	261
SBPH29	VC13	55	VC13020	20	21
SBPH30	VC13	60	VC13060	60	61
SBPH31	VC13	56	VC13100	100	101
SBPH32	VC13	60	VC13140	140	141
SBPH33	VC13	62	VC13180	180	181
SBPH34	VC13	64	VC13220	220	221
SBPH35	VC13	67	VC13260	260	261
SBPH36	VC13	159	VC13300	300	301
SBPH37	VC13	160	VC13320	320	321
SBPH38	VC13	163	VC13360	360	361

Appendix 2. Seabed in Prehistory (5346), Diatcodes from Amphora database (ECRC, UCL) and full taxon names and authorities.

CODE	TAXON
AC058B	Achnanthes brevipes brevipes Ag. 1824
AC006A	Achnanthes clevei clevei Grun. in Cleve & Grun. 1880
AC023A	Achnanthes conspicua conspicua A. Mayer 1919
AC016A	Achnanthes delicatula Kutz.
AC001B	Achnanthes lanceolata rostrata (Ostr.) Hust. 1911
AC013A	Achnanthes minutissima minutissima Kutz. 1833
AC9999	Achnanthes sp.
AC147A	Achnanthes submarina Hustedt 1956
AT001A	Actinocyclus normanii normanii (Greg. ex Grev.) Hust. ex VanLand. 1967
AY005A	Actinoptychus undulatus (J.W. Bail.) Ralfs in Pritch. 1861
AP002A	Amphipleura rutilans (Trentepohl ex Roth) Cleve 1894
AM011A	Amphora libyca Ehr.
AM001A	Amphora ovalis ovalis (Kutz.) Kutz. 1844
AM012A	Amphora pediculus (Kutz.) Grun.
AM9999	Amphora sp.
AU9999	Aulacoseira sp.
BA001A	Bacillaria paradoxa Gmelin in Linnaeus 1788
BI004A	Biddulphia aurita (Lyngb.) Breb. 1838
BI9999	Biddulphia sp.
CA002A	Caloneis bacillum bacillum (Grun.) Cleve 1894
CA046A	Caloneis westii (W. Sm.) Hendey 1964
CP013A	Campylodiscus echeneis Ehrenb. 1840
CG002A	Campylosira cymbelliformis (A. Schmidt) Grun. ex Van Heurck 1885
CTE01A	Catenula adhaerens (Mereschk.) Mereschk. 1903
UN9995	Centric undif.
CO010A	Cocconeis disculus (Schum.) Cleve 1896
CO001B	Cocconeis placentula euglypta (Ehrenb.) Grun. 1884
CO007A	Cocconeis scutellum scutellum Ehrenb. 1838
CO9999	Cocconeis sp.
CS9999	Coscinodiscus sp.
CC001A	Cyclostephanos dubius (Fricke in A. Schmidt) Round 1982
CY006A	Cyclotella kuetzingiana kuetzingiana Thwaites 1848
CY002A	Cyclotella pseudostelligera Hust. 1939
CY9999	Cyclotella sp.
CY015A	Cyclotella striata striata (Kutz.) Grun. in Cleve & Grun. 1880
CL002A	Cymatopleura elliptica elliptica (Breb. ex Kutz.) W. Sm. 1851
CT001A	Cymatosira belgica Grun. in Van Heurck 1881
CM9999	Cymbella sp.
DE001A	Denticula tenuis tenuis Kutz. 1844
DM004B	Dimeregramma minor nanum (Greg.) Van Heurck 1885
DP016A	Diploneis aestuari Hust. 1939
DP030A	Diploneis didyma (Ehrenb.) Cleve 1894
DP001A	Diploneis ovalis (Hilse) Cleve 1894
DP005A	Diploneis smithii smithii (Breb. ex W. Sm.) Cleve 1894
DP9999	Diploneis sp.
EP007A	Epithemia adnata adnata (Kutz.) Rabenh. 1853
EP001A	Epithemia sorex sorex Kutz. 1844
EP9999	Epithemia sp.
FR006A	Fragilaria brevistriata brevistriata Grun. in Van Heurck 1885
FR002B	Fragilaria construens binodis (Ehrenb.) Grun. 1862
FR002A	Fragilaria construens construens (Ehrenb.) Grun. 1862
FR002C	Fragilaria construens venter (Ehrenb.) Grun. in Van Heurck 1881
FR001A	Fragilaria pinnata pinnata Ehrenb. 1843
FR9999	Fragilaria sp.
GO9999	Gomphonema sp.
GR9999	Grammatophora sp.
GY9999	Gyrosigma sp.
HA001A	Hantzschia amphioxys amphioxys (Ehrenb.) Grun. 1877
MA9999	Mastogloia sp.
ME015A	Melosira varians Ag. 1827
NA051A	Navicula cari cari Ehrenb. 1836
NA021A	Navicula cincta (Ehrenb.) Ralfs in Pritch. 1861
NA067A	Navicula crucicula crucicula (W. Sm.) Donk. 1871
NA060A	Navicula digito-radiata digito-radiata (Greg.) Ralfs in Pritch. 1861
NA060D	Navicula digito-radiata minima Cleve-Euler 1953
NA363B	Navicula flanatica flanatica Grun. 1860
NA023A	Navicula gregaria Donk. 1861
NA004A	Navicula hungarica Grun. 1860
NA009A	Navicula lanceolata (Agardh) Kutz.
NA025A	Navicula mutica mutica Kutz. 1844
NA565A	Navicula perminuta Grun. in Van Heurck 1880

Appendix 2. continued

NA036A Navicula perpusilla (Kutz.) Grun. 1860
NA058A Navicula phyllepta Kutz. 1844
NA052A Navicula pusilla W. Sm. 1853
NA010A Navicula pygmaea Kutz. 1849
NA008A Navicula rhynchocephala rhyncocephala Kutz. 1844
NA035A Navicula salinarum salinarum Grun. in Cleve & Grun. 1880
NA028A Navicula scutelloides W. Sm. ex Greg. 1856
NA005A Navicula seminulum Grun. 1860
NA080A Navicula slesvicensis Grun. in Van Heurck 1880
NA9999 Navicula sp.
NI014A Nitzschia amphibia amphibia Grun. 1862
NI104A Nitzschia granulata Grun. 1880
NI007A Nitzschia hungarica Grun. 1862
NI127A Nitzschia levidensis (W. Sm.) Grun. in Van Heurck 1881
NI022A Nitzschia navicularis (Breb. ex Kutz.) Grun. in Cleve & Grun. 1880
NI005A Nitzschia perminuta (Grun. in Van Heurck) M. Perag. 1903
NI004A Nitzschia punctata punctata (W. Sm.) Grun. 1878
NI025A Nitzschia recta Hantzsch ex Rabenh. 1861
NI006A Nitzschia sigma sigma (Kutz.) W. Sm. 1853
NI9999 Nitzschia sp.
NI029A Nitzschia terrestris (J.B. Petersen) Hust. 1934
NI013B Nitzschia tryblionella debilis A. Mayer 1913
OP001A Opephora martyi Herib. 1902
PA001A Paralia sulcata sulcata (Ehrenb.) Cleve 1873
UN9994 Pennate undif.
PI9999 Pinnularia sp.
PR011A Plagiogramma van-heurckii Grun. in Van Heurck 1881
POI08A Podosira stelligera (J.W. Bail.) Mann 1907
PSP01A Pseudopodosira westii (W. Sm.) Sheshukova-Poretzskaya in Sheshukova-Poretzskaya & Gleser 1964
RA002A Rhaphoneis amphiceros (Ehrenb.) Ehrenb. 1844
RA007A Rhaphoneis minutissima Hust. 1939
RA9999 Rhaphoneis sp.
RA001A Rhaphoneis surirella (Ehrenb.) Grun. in Van Heurck 1881
RC001A Rhoicosphenia curvata (Kutz.) Grun. 1860
RH001A Rhopalodia gibba gibba (Ehrenb.) O. Mull. 1895
RH003A Rhopalodia gibberula gibberula (Ehrenb.) O. Mull. 1895
SC004A Scoliopleura tumida tumida (Breb. ex Kutz.) Rabenh. 1864
SA9999 Stauroneis sp.
ST9999 Stephanodiscus sp.
SU002A Surirella ovata ovata Kutz. 1844
SU9999 Surirella sp.
SY004A Synedra parasitica parasitica (W. Sm.) Hust. 1930
SY008A Synedra pulchella pulchella Ralfs ex Kutz. 1844
SY9999 Synedra sp.
SY015A Synedra tabulata (Ag.) Kutz. 1844
SY001A Synedra ulna ulna (Nitzsch) Ehrenb. 1836
ZZZ996 Temporary sp. 4
ZZZ816 Temporary sp181
ZZZ815 Temporary sp182
ZZZ814 Temporary sp183
ZZZ812 Temporary sp185
ZZZ811 Temporary sp186
ZZZ810 Temporary sp187
ZZZ801 Temporary sp196
ZZZ800 Temporary sp197
TL001A Thalassionema nitzschioides (Grun.) Grun. ex Hustedt 1932
TH001A Thalassiosira decipiens (Grun.) E. Jorg. 1905
TH9999 Thalassiosira sp.
TY001A Trachyneis aspera aspera (Ehrenb.) Cleve 1894
UN9998 Unknown naviculaceae

ANALYSIS: FORAMINIFERA

Analysis of samples from the Seabed in Prehistory project (53146), for foraminifera

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Introduction

A series of cores has been taken to investigate the seabed stratigraphy off the Sussex coastline level with the River Arun. Investigation of the seabed has revealed what appears to be a palaeo-channel within a wider palaeo-valley. Foraminiferal analysis has been carried out on the following sequences: the palaeo-channel (cores VC1 and VC17), the palaeo-valley edge (VC3), the palaeo-valley floor (VC7) and the palaeo-channel edge (VC13). The aim of these analyses is to provide further information on the nature of the palaeoenvironments cored and on the salinity of any marginal marine environments identified.

Methods

Wet sediment from each sample was wet sieved through 500μ, 125μ and 63μ mesh sieves. Any foraminifera retained on the 125μ sieve were picked out at 30 - 40 x magnification under transmitted and incident light using a Brunel BMZ zoom stereo microscope. Where possible, a minimum of 100 tests were identified (where the total count exceeded this number) and an assessment of the relative proportions of the species made. The 63μ fraction was also examined for the presence of juveniles although it is generally not possible to confidently identify juvenile tests to species level. Identification follows Murray, 1973 & Murray, 1979 and interpretation of their ecology follows Murray, 1991 and Haslett *et al.* 1997.

Results

Cores VC1 and VC17 - The palaeo-channel

Analysis of these cores is summarised in Tables 1 and 2. Benthic foraminifera are abundant and generally well preserved in both cores. In core VC1 the assemblages comprise a mix of brackish and marine genera. Brackish forams form 37% of the assemblage at 5.20 m depth, increasing to 68% at 1.60cm. The dominant species; *Ammonia beccarii* (and the variety *limnetes*)and *Haynesina germanica*, both tolerate large fluctuations in salinity and exposure and *Haynesina germanica* in particular, is typical of mudflat and saltmarsh environments. There are also fragments of agglutinated mid-high marsh species in the 63μ fraction. The marine benthic forams identified are generally found in fully marine subtidal sediments although some species (such as *Elphidium oceanensis* and *Nonion depressulus*) are sufficiently tolerant of fluctuating salinity to be found living in estuary mouth sediment. The *Cibicides* species present in significant proportions in VC1/160, VC1/400 and VC1/520 are marine species which live attached to firm substrates such as shells, and gravel.

In core VC17 the species identified are largely those also found in VC1. However, the composition of the assemblages is clearly different. Brackish species are more abundant in VC17. The brackish component is stable throughout the core, forming between 75% and 82% of the assemblage. Although there are small fluctuations in species proportions between the samples analysed there appears to be no significant change up the core. As in core VC1, the 63µ fraction of the 0.40m sample in VC17 also contains fragments of mid-high marsh species.

Core VC3 - The palaeo-valley edge

Foraminiferal analysis of this core is summarised in Table 3. The concentration of tests is variable and is particularly low between 0.82m and 2.48m although only two levels, 2.20m and 2.40m, contain no forams at all. The foram data can be used to divide the core into three zones. The lowest zone, from 3.20m down to the lowest sample analysed at 4.60m is typified by mixed brackish-marine assemblages similar to those seen in core VC1. Brackish species; *Ammonia beccarii* and *Haynesina germanica* dominate but there are also significant numbers of marine forams contributing 24 - 51% of the assemblage. Forams associated with estuary mouth sediments, such as *Nonion depressulus* and *Elphidium oceanensis* are also frequent.

The middle zone; 2.44-3.20m, is generally less diverse and is dominated by brackish forams, in particular *Ammonia beccarii* v. *limnetes*. This foram (along with *Ammonia beccarii*) can tolerate diurnal variation in salinity of 0-35 $^{0}/_{00}$ (Murray, 1979) and is associated with estuarine mudflats and lagoons. The presence of the agglutinated mid-high saltmarsh taxa *Jadammina macrescens* and *Haplophragmoides wilberti* in sample 2.44m and to a lesser extent in 2.80m, suggests proximity to a vegetated marsh surface. Calcareous forms such as *Ammonia beccarii* may also have been present originally at 2.44m, but may have been subsequently lost through dissolution.

Its is not possible to say whether the barren levels at 2.40m and 2.20m originally contained forams which failed to be preserved or never contained forams.Above the barren levels, forams are sparse up to and including 0.82m. In addition to the brackish adult tests found, samples 1.40m, 1.80m and 2.00m include small forms of marine taxa. These are commonly found on marshes bordering the Severn Estuary at present and are thought to be transported onto the marshes with the incoming tide particularly during storms (Haslett *et al.* 1997). There is no evidence that they can live long in brackish conditions. The topmost level, 0.40m, has a good concentration of predominantly brackish forams with a few adult marine tests.

Core VC7 - The palaeo-valley floor

The results from VC7 are summarised in Table 4. Samples 2.40m, 2.50m and 2.56m do not contain forams. Sample 2.60m contains just one fragment of an agglutinated mid-high marsh species. In addition, fragments of these species were found in the 63µ fraction.

Core VC13 - The palaeo-channel edge

Analysis of core VC13 is summarised in Table 5. Forams are generally abundant throughout the core, with the exception of level 3.20m, and the assemblages are largely dominated by the brackish species *Ammonia beccarii* and *Ammonia beccarii* v. *limnetes.* In the samples 3.20m

– 5.00m, these two taxa have been lumped together due to a high proportion of damaged tests which makes it difficult to reliably distinguish between the two.

From 2.60m down to 5.00m the assemblages are composed almost entirely of *A. beccarii*, pointing to an environment experiencing large fluctuations in salinity but with no indication of the exact nature of this environment. However, levels 3.40m and 3.60m have 20 tests and 51 tests of *Haplophragmoides wilberti* respectively suggesting a nearby vegetated saltmarsh.

Above 2.60m *A. beccarii* still dominates the assemblages but in levels 2.20m, 1.80m and 1.40m a few marine forams appear suggesting a small increase in input from marine sources. At 1.00m the assemblage returns to 100% *A. beccarii* and above this at 0.60m, marine forams comprise 20% of the assemblage. This is largely *Elphidium oceanensis*, a foram which, though usually described as marine, has also been found to tolerate reduced salinity in estuary mouth sediments.

The assemblage at 0.20m is something of an anomaly compared with the rest of the core. Brackish forams (*A. beccarii*) contribute just 19% of the total. One striking aspect of this assemblage is the abundance of coarse, thick-walled marine tests, such as *A. beccarii* v. *batavus*. Its predominance here could be due in part to winnowing by currents removing smaller, lighter tests. Alternatively this 0.20m sample may represent a mix of older, fine-grained estuarine sediment and more recent marine sediment.

Discussion

The species composition of British nearshore and brackish foraminifera has remained unchanged since the Anglian glaciation so the foram data cannot contribute to core chronology over the probable timescale of the cores. However, the abundance and generally good preservation of the forams has allowed the following palaeoenvironmental interpretations.

The palaeo-channel

Foram analysis of cores VC1 and VC17 suggests brackish, mudflat environments for both cores. However, the foram content of the two cores differs sufficiently to suggest that the cores are separated in time and/or space. In VC1 there is a significant input of forams from nearshore marine habitats. The marine genus *Cibicides* is known to live attached to firm substrates (e.g. gravel) in areas experiencing strong tidal currents (Murray, 1991) so has clearly been transported to the finer-grained, muddy sediments sampled in this core. The environment suggested by the foram data therefore is a brackish, low marsh or mudflat surface receiving regular input of material from a nearby subtidal marine environment. There is an indication that the marine influence reduces slightly above 400cm but this is not marked. In core VC17 the marine influence is not quite as great suggesting the sediment accumulated on a slightly higher marsh surface. However, apart from the mid-high marsh foram fragments found in the 40cm sample, there is no foraminiferal evidence for a vegetated marsh surface.

The palaeo-valley edge

Core VC3 appears to contain three zones of brackish salt-marsh sedimentation. The lowest zone from 4.60m up to 3.20m suggests a brackish mudflat environment with a degree of marine input. Of particular significance here is the presence of species associated with estuary mouth sediments; *Nonion depressulus* and *Elphidium oceanensis*, which may be autochthonous.

Above 3.20m up to 2.48m the assemblages are restricted to one species, *Ammonia beccarii*. This euryhaline foram can be found in any brackish habitat and will even tolerate hypersaline lagoon conditions so it is difficult to specify the nature of the palaeoenvironment from the foram data alone. However, the presence of the mid-high marsh species *Jadammina macrescens* at 2.80m indicates there is vegetated saltmarsh in the vicinity. The lack of marine species also indicates a decrease in marine sources of sediment. The key change in the sequence comes at 2.44m where the assemblage comprises entirely mid-high marsh species indicating the development of vegetated saltmarsh.

Above the barren levels at 2.40m and 2.20m, the sparse foram assemblages extending from 2.00m up to 0.82m must be interpreted with caution. It is possible part of the original assemblage has dissolved but those forams present suggest a brackish mudflat source for the sediment. There is some marine input in the form of small marine forams, probably transported in on high tides, particularly during storms, as found in the Severn Estuary at present (Haslett *et al.* 1997). The abundant forams in topmost sample indicate an increasing marine influence at the top of the sequence.

The palaeo-valley floor

The only indication of a marginal marine environment are a few fragments of high-mid marsh forams in VC7/2.60m. In the absence of other indicators of brackish or marine conditions, it is possible that the fragments may have been re-worked from other deposits.

The palaeo-channel edge

The interpretation of Core VC13 is slightly restricted by the predominance of the euryhaline species *Ammonia beccarii* and its variant *A. beccarii* v. *limnetes* throughout the core (apart from the topmost sample) though it is clear the sequence represents an environment which experienced large and frequent variations in salinity. There are however, additional taxa which can aid paleoenvironmental reconstruction. Moving from the base of the core up the sequence, the presence of *Haplophragmoides wilberti* at 3.60m and 3.40m indicates nearby saltmarsh vegetation. At 2.20m and above, marine species tolerant of estuary mouth conditions start to appear and increase up the core indicating an increasing marine influence. There is an interruption in this trend at 100cm where the assemblage briefly reverts back to 100% *A. beccarii* . Above this point the marine influence continues, although it seems likely that the topmost, marine-dominated assemblage at 0.20m is the product of winnowing by currents and/or mixing with recent, fully marine sediment.

Conclusions

The general abundance and good preservation of foraminifera in all the cores, (with the exception of core VC7 and possibly the upper levels of VC3) has allowed confident reconstruction of the marginal marine environments contained in the sequences from the palaeo-channel fill (VC1, VC17), the palaeo-channel edge (VC13) and the palaeo-valley edge (VC3).

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* In all of the following tables, ‘Ecology’ refers to a literature-derived classification for the individual species and should not be taken as an inferred habitat for a particular sample.

Table 1. Summary of foraminiferal analysis of sediments from core VC1

Core name and sample depth in cm	Tests ≥125µ $10cm^{-3}$ wet sediment	Species present and total in sample (or % where total ≥100 tests in 10 cm^3).		*Ecology	Forams <125µ present
VC1/40	175		%		yes (inc. fragments of marsh sp.)
		Haynesina germanica	39	Brackish, mid/low marsh-mudflat	
		Ammonia beccarii v. *limnetes*	14	Brackish-marine	
		Ammonia beccarii	4	Brackish-marine	
		Elphidium williamsoni	1	Brackish, mid/low	
		Nonion depressulus	1	marsh	
		Elphidium earlandi	2	Estuary mouth/marine	
		Elphidium oceanensis	1	Estuary mouth/marine	
		A. beccarii v. *batavus*	9	Estuary mouth/marine	
		Cibicides lobatulus	4	marine	
		Quinqueloculina sp.	12	marine	
		Elphidium gerthi	9	marine	
		Cibicides sp.	2	marine	
		Unknown	2	marine	
		Sample total:	105	Brackish component: 58%	
VC1/160	496		%		yes
		Haynesina germanica	40	Brackish, mid/low marsh-mudflat	
		Ammonia beccarii v. *limnetes*	10	Brackish-marine	
		Ammonia beccarii	16	Brackish-marine	
		Elphidium williamsoni	2	Brackish, mid/low	
		Nonion depressulus	2	marsh	
		Elphidium earlandi	1	Estuary mouth/marine	
		Elphidium oceanensis	3	Estuary mouth/marine	
		Cibicides lobatulus	18	Estuary mouth/marine	
		Quinqueloculina sp.	7	marine	
		Elphidium incertum.	1	marine	
		Unknown	1	marine	
		Sample total:	298	Brackish component: 68%	
VC1/280	301		%		yes
		Haynesina germanica	40	Brackish, mid/low marsh-mudflat	
		Ammonia beccarii v. *limnetes*	15	Brackish-marine	
		Ammonia beccarii	10	Brackish-marine	
		Elphidium williamsoni	1	Brackish, mid/low	
		Elphidium earlandi	2	marsh	
		Elphidium oceanensis	8	Estuary mouth/marine	
		A. beccarii v. *batavus*	1	Estuary mouth/marine	
		Cibicides lobatulus	7	marine	
		Quinqueloculina sp.	9	marine	
		Elphidium gerthi	1	marine	
		Lagena sp.	3	marine	

Core name and sample depth in cm	Tests ≥125μ $10cm^{-3}$ wet sediment	Species present and total in sample (or % where total ≥100 tests in 10 cm^3).		*Ecology	Forams <125μ present
		Unknown	3	marine	
		Sample total:	181	Brackish component: 66%	
VC1/400	295		%		yes
		Haynesina germanica	28	Brackish, mid/low marsh-mudflat	
		Ammonia beccarii v. *limnetes*	5	Brackish-marine	
		Ammonia beccarii	21	Brackish-marine	
		Nonion depressulus	3	Estuary mouth/marine	
		Elphidium oceanensis	2	Estuary mouth/marine	
		A. beccarii v. *batavus*	3	marine	
		Cibicides sp.	16	marine	
		Quinqueloculina sp.	16	marine	
		Elphidium gerthi	1	marine	
		Elphidium sp.	2	marine	
		Spirillina sp.	1	marine	
		Unknown	2		
		Sample total:	236	Brackish component: 54%	
VC1/520	334		%		yes
		Haynesina germanica	25	Brackish, mid/low marsh-mudflat	
		Ammonia beccarii v. *limnetes*	2	Brackish-marine	
		Ammonia beccarii	10	Brackish-marine	
		Nonion depressulus	7	Estuary mouth/marine	
		Elphidium oceanensis	1	Estuary mouth/marine	
		Quinqueloculina sp.	17	Estuary mouth/marine	
		Elphidium gerthi	5	marine	
		Elphidium earlandi	2	marine	
		Cibicides lobatulus	1	marine	
		Cibicides sp.	23	marine	
		Rosalina anomala	1	marine	
		Rosalina williamsoni	1	marine	
		Unknown	5		
		Sample total:	234	Brackish component: 37%	

Table 2. Summary of foraminiferal analysis of sediments from core VC17

Core name and sample depth in cm	Tests ≥125µ 10cm^{-3} wet sediment	Species present and total in sample (or % where total ≥100 tests in 10 cm^3).		*Ecology	Forams <125µ present
VC17/40	166		%		yes
		Haynesina germanica	34	Brackish, mid/low	(inc.
				marsh-mudflat	fragments
		Ammonia beccarii v. *limnetes*	36	Brackish-marine	of marsh
		Ammonia beccarii	3	Brackish-marine	sp.)
		Elphidium williamsoni	2	Brackish, mid/low	
		Nonion depressulus	2	marsh	
		Elphidium earlandi	5	Estuary mouth/marine	
		A. beccarii v. *batavus*	4	Estuary mouth/marine	
		Cibicides lobatulus	4	marine	
		Quinqueloculina sp.	4	marine	
		Elphidium gerthi	5	marine	
		Bolivina pseudoplicata	1	marine	
				marine	
		Sample total:	100	Brackish component:	
				75%	
VC17/160	421		%		yes
		Haynesina germanica	40	Brackish, mid/low	
				marsh-mudflat	
		Ammonia beccarii v. *limnetes*	24	Brackish-marine	
		Ammonia beccarii	5	Brackish-marine	
		Elphidium williamsoni	10	Brackish, mid/low	
		Elphidium oceanensis	5	marsh	
		Cibicides sp.	3	Estuary mouth/marine	
		Quinqueloculina sp.	8	marine	
		Elphidium sp.	4	marine	
		Lagena sp.	1	marine	
		Sample total:	337	marine	
				Brackish component:	
				79%	
VC17/280	193		%		yes
		Haynesina germanica	48	Brackish, mid/low	
				marsh-mudflat	
		Ammonia beccarii v. *limnetes*	22	Brackish-marine	
		Ammonia beccarii	7	Brackish-marine	
		Elphidium williamsoni	1	Brackish, mid/low	
		Nonion depressulus	2	marsh	
		E. oceanensis	2	Estuary mouth/marine	
		Elphidium earlandi	3	Estuary mouth/marine	
		Quinqueloculina sp.	4	Estuary mouth/marine	
		Elphidium gerthi	6	marine	
		Lagena sp.	4		
		Unknown	1	marine	

Core name and sample depth in cm	Tests ≥125µ $10cm^{-3}$ wet sediment	Species present and total in sample (or % where total ≥100 tests in 10 cm^3).		*Ecology	Forams <125µ present
		Sample total:	116	marine Brackish component: 78%	
VC17/340	830	 *Haynesina germanica* *Ammonia beccarii* v. *limnetes* *Ammonia beccarii* *Elphidium williamsoni* *Haplophragmoides wilberti* *Elphidium oceanensis* *Quinqueloculina sp.* *Elphidium gerthi* *Cibicides lobatulus* *Lagena sp.* Unknown Sample total:	% 39 26 14 1 2 1 8 5 1 1 2 498	 Brackish, mid/low marsh-mudflat Brackish-marine Brackish-marine Brackish, mid/low marsh Brackish, high-mid marsh Estuary mouth/marine marine marine marine marine marine Brackish component: 82%	yes
VC17/400	283	 *Haynesina germanica* *Ammonia beccarii* v. *limnetes* *Ammonia beccarii* *Elphidium williamsoni* *Nonion depressulus* *Elphidium oceanensis* *Elphidium earlandi* *Quinqueloculina sp.* *Elphidium gerthi* *Cibicides lobatulus* *Cibicides sp.* Unknown Sample total:	% 46 23 3 7 1 3 1 8 2 3 1 2 170	 Brackish, mid/low marsh-mudflat Brackish-marine Brackish-marine Brackish, mid/low marsh Estuary mouth/marine Estuary mouth/marine Estuary mouth/marine marine marine marine marine Brackish component: 79%	yes

Table 3. Summary of foraminiferal analysis of sediments from core VC3

Core name and sample depth in cm	**Tests ≥125□ 10cm^{-3} wet sediment**	**Species present and total in sample (or % where total ≥100 tests in 10 cm^3).**		***Ecology**	**Forams <125□ present**
VC3/40	318	 *Haynesina germanica* *Ammonia beccarii v. limnetes* *Ammonia beccarii* *Elphidium oceanensis* *A. beccarii v. batavus* *Cibicides lobatulus* *Cibicides sp.* Sample total:	% 1 78 17 1 1 1 1 287	 Brackish, mid/low marsh-mudflat Brackish-marine Brackish-marine Estuary mouth/marine marine marine marine Brackish component: 96%	yes
VC3/82	1	*Haynesina germanica* Sample total:	1 1	Brackish, mid/low marsh-mudflat	yes
VC3/140	9	*Ammonia beccarii* Sample total:	7 7	Brackish-marine	yes (+marine taxa)
VC3/180	8	*Haynesina germanica* *Ammonia beccarii v. limnetes* *Elphidium earlandi* Sample total:	1 6 1 8	Brackish, mid/low marsh-mudflat Brackish-marine Estuary mouth/marine	yes (+marine taxa)
VC3/200	3	*Haynesina germanica* *Ammonia beccarii* Sample total:	1 1 2	Brackish, mid/low marsh-mudflat Brackish-marine	yes (+marine taxa)
VC3/220	0				no
VC3/240	0				no
VC3/244	59	*Jadammina macrescens* *Haplophragmoides wilberti* *Agglutinated marsh sp.* Sample total:	9 46 4 59	Brackish, high-mid marsh Brackish, high-mid marsh	yes
VC3/248	678	 *Ammonia beccarii v. limnetes* *Ammonia beccarii* Sample total:	% 90 10 407	 Brackish-marine Brackish-marine Brackish component: 100%	yes
VC3/260	597	 *Ammonia beccarii v. limnetes* *Ammonia beccarii* Sample total:	% 92 8 418	 Brackish-marine Brackish-marine Brackish component:	yes

Core name and sample depth in cm	**Tests ≥125□ 10cm^{-3} wet sediment**	**Species present and total in sample (or % where total ≥100 tests in 10 cm^3).**		***Ecology**	**Forams <125□ present**
				100%	
VC3/280	82	*Jadammina macrescens* *Ammonia beccarii v. limnetes* Sample total:	4 78 82	Brackish, high-mid marsh Brackish-marine Brackish component: 100%	yes
VC3/300	14	*Haynesina germanica* *Ammonia beccarii* Unknown Sample total:	2 4 1 7	Brackish, mid/low marsh-mudflat Brackish-marine	no
VC3/320	58	*Haynesina germanica* *Ammonia beccarii v. limnetes* *Ammonia beccarii* *Elphidium williamsoni* *Nonion depressulus* *Elphidium oceanensi* *Elphidium earlandi* *Elphidium margaritaceum* *Cibicides sp.* Unknown Sample total:	3 22 1 1 11 2 2 1 2 1 46	Brackish, mid/low marsh-mudflat Brackish-marine Brackish-marine Brackish, mid/low marsh Estuary mouth/marine Estuary mouth/marine Estuary mouth/marine marine marine Brackish component: 59%	yes
VC3/340	218	 *Haynesina germanica* *Ammonia beccarii v. limnetes* *Ammonia beccarii* *Elphidium williamsoni* *Nonion depressulus* *Elphidium oceanensi* *Elphidium gerthi* *Cibicides sp.* *Elphidium margaritaceum* *Gavelinopsis praegeri* Unknown Sample total:	% 29 41 2 4 7 4 1 3 7 1 1 174	 Brackish, mid/low marsh-mudflat Brackish-marine Brackish-marine Brackish, mid/low marsh Estuary mouth/marine Estuary mouth/marine marine marine marine marine Brackish component: 76%	yes
VC3/360	464	 *Haynesina germanica* *Ammonia beccarii* *Elphidium williamsoni*	% 20 25 4	 Brackish, mid/low marsh-mudflat Brackish-marine Brackish, mid/low	yes

Core name and sample depth in cm	Tests ≥125□ 10cm^{-3} wet sediment	Species present and total in sample (or % where total ≥100 tests in 10 cm^3).		*Ecology	Forams <125□ present
		Nonion depressulus	15	marsh	
		Elphidium oceanensis	12	Estuary mouth/marine	
		Quinqueloculina sp.	3	Estuary mouth/marine	
		Elphidium gerthi	6	marine	
		Elphidium margaritaceum	5	marine	
		Cibicides sp.	4	marine	
		Elphidium sp.	3	marine	
		Rosalina williamsoni	2	marine	
		Gavelinopsis praegeri	1	marine	
				marine	
		Sample total:	371		
				Brackish component: 49%	
VC3/460	785		%		yes
		Haynesina germanica	34	Brackish, mid/low marsh-mudflat	
		Ammonia beccarii	23	Brackish-marine	
		Nonion depressulus	5	Estuary mouth/marine	
		Elphidium oceanensis	2	Estuary mouth/marine	
		Quinqueloculina sp.	2	marine	
		Elphidium gerthi	11	marine	
		Elphidium margaritaceum	2	marine	
		Cibicides lobatulus	4	marine	
		Cibicides sp.	8	marine	
		Gavelinopsis praegeri	2	marine	
		Elphidium sp.	2	marine	
		Bolivina sp.	1	marine	
		Brizalina sp.	1	marine	
		Unknown	3		
		Sample total:	628	Brackish component: 57%	

Table 4. Summary of foraminiferal analysis of sediments from core VC 7

Core name and sample depth in cm	Tests ≥125□ 10cm^{-3} wet sediment	Species present and total in sample (or % where total ≥100 tests in 10 cm^3).		*Ecology	Forams <125□ present
VC7/240	0				no
VC7/250	0				no
VC7/256	0				no
VC7/260	1	Fragment of agglutinated salt-marsh species	1	Brackish, high-mid marsh	yes (fragments of marsh sp.)

Table 5. Summary of foraminiferal analysis of sediments from VC13

Core name and sample depth in cm	Tests ≥125µ $10cm^{-3}$ wet sediment	Species present and total in sample (or % where total ≥100 tests in 10 cm^3).		*Ecology	Forams <125µ present
VC13/20	104	*Ammonia. beccarii* *Ammonia. beccarii* v. *batavus* *Elphidium earlandi* *Elphidium sp.* *Elphidium macellum* *Quinqueloculina sp.* Unknown Sample total:	10 31 1 1 1 6 2 52	Brackish-marine Marine Estuary mouth/marine Marine Marine Marine Brackish component: 19%	yes
VC13/60	273	 *Jadammina macrescens* *Ammonia beccarii* v. *limnetes* *Ammonia beccarii* *Elphidium oceanensis* *Rosalina sp.* Sample total:	% 4 71 5 19 1 164	 Brackish, high-mid marsh Brackish-marine Brackish-marine Estuary mouth/marine Marine Brackish component: 80%	yes
VC13/100	454	 *Ammonia beccarii* v. *limnetes* *Ammonia beccarii* Sample total:	% 97 3 227	 Brackish-marine Brackish-marine Brackish component: 100%	yes
VC13/140	226	 *Ammonia beccarii* v. *limnetes* *Ammonia beccarii* *Elphidium earlandi* *Elphidium oceanensis* *Elphidium margaritaceum* *Spirillina vivipara* Unknown Sample total:	% 87 1 7 2 1 1 2 136	 Brackish-marine Brackish-marine Estuary mouth/marine Estuary mouth/marine Marine Marine Brackish component: 88%	yes
VC13/180	130	*Haynesina germanica* *Ammonia beccarii* v. *limnetes* *Ammonia beccarii* *Elphidium earlandi* *Elphidium oceanensis* *Brizalina* Unknown	3 65 1 6 1 1 1	Brackish, mid/low marsh-mudflat Brackish-marine Brackish-marine Estuary mouth/Marine Estuary mouth/Marine Marine	yes

Core name and sample depth in cm	Tests ≥125µ 10cm-3 wet sediment	Species present and total in sample (or % where total ≥100 tests in 10 cm3).		*Ecology	Forams <125µ present
		Sample total:	78	Brackish component: 89%	
VC13/220	283	*Ammonia beccarii* v. *limnetes* *Ammonia beccarii* *Elphidium earlandi* *Elphidium oceanensis* Sample total:	% 85 13 1 1 170	 Brackish-marine Brackish-marine Estuary mouth/Marine Estuary mouth/Marine Brackish component: 98%	yes
VC13/260	1123	*Ammonia beccarii* v. *limnetes* *Ammonia beccarii* Sample total:	% 79 21 674	 Brackish-marine Brackish-marine	yes (inc. agglutinated marsh sp)
VC13/300	328	*Ammonia beccarii* v. *limnetes* *Ammonia beccarii* *Haplophragmoides wilberti* Sample total:	% 96 3 1 197	 Brackish-marine Brackish-marine Brackish, high-mid marsh	yes
VC13/320	15	*Ammonia beccarii* agg. Sample total:	9 9	Brackish-marine	yes
VC13/340	120	*Ammonia beccarii* agg. *Haplophragmoides wilberti* Sample total:	52 20 72	Brackish-marine Brackish, high-mid marsh	yes
VC13/360	112	*Haplophragmoides wilberti* *Ammonia beccarii* agg. Sample total:	51 5 56	Brackish, high-mid marsh Brackish-marine	yes
VC13/420	988	*Ammonia beccarii* agg. Sample total:	% 100 593	 Brackish-marine	yes
VC13/500	540	*Ammonia beccarii* agg. Sample total:	% 100 324	 Brackish-marine	yes

APPENDIX IV: RADIOCARBON (^{14}C) AND OPTICALLY STIMULATED LUMINESCENCE (OSL) DATING

RADIOCARBON (^{14}C) DATING

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A series of four samples of peat were submitted for AMS radiocarbon dating at Rafter Radiocarbon Laboratory, Institute of Geological & Nuclear Sciences, New Zealand. In each case short-lived plant remains were extracted and dated. All radiocarbon results have been calibrated with the atmospheric data presented by Stuiver *et al.* (1998) and performed on OxCal ver 3.9 (Bronk Ramsey 1995; 2001) and are expressed at the 95% confidence level with the end points rounded outwards to 10 years following the form recommended by Mook (1986).

The chronological significance of the results in relation to the sediment and palaeo-environmental sequences is discussed in the report. The results come from three cores and indicate that the peat horizons within them all belong to early 10th millennium BP, i.e. late ninth/early tenth millenium cal. BC; the Boreal climatic phase. Furthermore, the results from the upper sample in **VC3** and that from **VC13** are statistically indistinguishable and when combined these pass χ^2 test (T'=1; T'(5%)=3.8; ν=1; Ward and Wilson 1978). Failure of this test would indicate that the samples must be of different age.

Bore-hole	*Depth below OD (m)*	*Material*	*Lab no*	*Result no*	*δC^{13} ‰*	*Result BP*	*Cal. BC*
VC3	32.86	Plant material	R28440/3	NZA-19298	-26.16	9131±45	8530-8260
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
VC13	33.58	Plant material	R28440/4	NZA-19299	-25.99	9155±50	8530-8260

Table 1. Radiocarbon results from Arun project

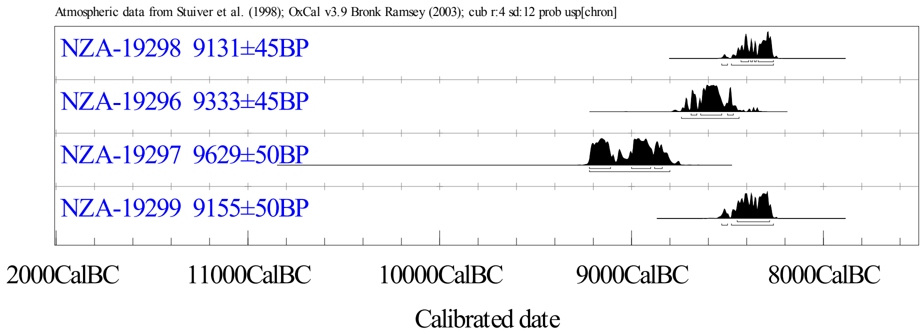

Figure 1. Radiocarbon probability distribution of the four results

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OPTICALLY STIMULATED LUMINESCENCE (OSL) SUBMISSION AND DATING

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Core No	Context	Section No	Sand lens	Preferred 20cm
VC2 = VC1	Channel infill	2	145-170	150-170
VC2 = VC1	Channel infill	6	530-570	540-560
VC2 = VC1	Flood couplets	3	180-240	210-230
VC4 = VC3	Wider terrace edge	5	400-500	440-460
VC14 = VC13	Valley floor next to channel	2	170-200	175-195
VC18 = VC17	Channel infill	1	40-70	45-65
VC18 = VC17	Channel infill	4	300-340	310-330

A summary of the results is provided in Table 1; full analysis is provided in Table 2.

Core	Age (ka)	Error (ka)
VC2 = VC1	22.4	2.0
VC2 = VC1	16.5	1.0
VC2 = VC1	15.2	1.4
VC4 = VC3	17.8	1.8
VC14 = VC13	20.5	1.7
VC18 = VC17	16.2	1.1
VC18 = VC17	18.5	1.3

Table 1: OSL Dating result summary

Table 2: OSL Dating Results

Sample number Age (ka) error (ka)	VC2 3/6 223-228 **22.4** **2.0**	VC18 53-58cm **16.5** **1.0**	VC14 2/6 1-2 **15.2** **1.4**	VC2 2/6 158-162 **17.8** **1.8**	VC2 6/6 549-554 **20.5** **1.7**	VC18 4/6 313-318 **16.2** **1.1**	VC4 447-452 **18.5** **1.3**
De (Gy)	22.24	20.82	18.58	21.65	19.32	19.83	17.84
uncertainty	0.94	0.22	1.30	1.60	0.94	0.42	0.53
Grain size							
Min. grain size (µm)	90	90	90	90	90	90	90
Max grain size (µm)	125	125	125	125	125	125	125
Measured concentrations							
standard fractional error							
% K	1.129	1.143	1.227	1.255	1.021	1.283	0.955
error (%K)	0.086	0.014	0.015	0.077	0.043	0.038	0.019
Th (ppm)	3.761	8.449	6.370	5.827	3.985	6.078	4.519
error (ppm)	0.013	0.020	0.028	0.006	0.027	0.050	0.030
U (ppm)	1.166	1.730	1.701	1.688	1.178	1.600	1.443
error (ppm)	0.024	0.011	0.009	0.003	0.012	0.012	0.021
Cosmic dose calculations							
Depth (m)	20.000	20.000	20.000	20.000	20.000	20.000	20.000
error (m)	10.000	10.000	10.000	10.000	10.000	10.000	10.000
Average overburden density (g.cm^3)	1.000	1.000	1.000	1.000	1.000	1.000	1.000
error (g.cm^3)	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Latitude (deg.), north positive	50	50	50	50	50	50	50
Longditude (deg.), east positive	0	0	0	0	0	0	0
Altitude (m above sea-level))	0	0	0	0	0	0	0
Geomagnetic latitude	52.8	52.8	52.8	52.8	52.8	52.8	52.8
Dc (µGy/ka), 55N G.lat, 0 km Alt.	0.064	0.064	0.064	0.064	0.064	0.064	0.064
error	0.033	0.033	0.033	0.033	0.033	0.033	0.033
Cosmic dose rate (µGy/ka)	0.064	0.064	0.064	0.064	0.064	0.064	0.064
error	0.033	0.033	0.033	0.033	0.033	0.033	0.033

Moisture content							
Moisture (water / wet sediment)	0.400	0.400	0.400	0.400	0.400	0.400	0.400
error	0.040	0.040	0.040	0.040	0.040	0.040	0.040
Total dose rate, Gy/ka	**0.99**	**1.26**	**1.22**	**1.21**	**0.94**	**1.23**	**0.96**
error	**0.08**	**0.07**	**0.07**	**0.08**	**0.06**	**0.08**	**0.06**
% error	**7.97**	**5.83**	**5.98**	**6.92**	**6.86**	**6.23**	**6.33**
AGE (ka)	**22.44**	**16.50**	**15.22**	**17.85**	**20.51**	**16.17**	**18.51**
error	**2.02**	**0.98**	**1.40**	**1.81**	**1.73**	**1.06**	**1.30**
% error	9.02	5.93	9.19	10.12	8.41	6.58	6.99

Sample number Laboratory code	**S1 X0001**	**S1 X0001**	**S1 X0001**	**S1 X0001**	**S1 X0001**	**S1 X0001**	**S1 X0001**
Average beta-attenuation							
standard fractional error	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Natural U	0.900	0.900	0.900	0.900	0.900	0.900	0.900
error	0.045	0.045	0.045	0.045	0.045	0.045	0.045
Th-232	0.852	0.852	0.852	0.852	0.852	0.852	0.852
error	0.043	0.043	0.043	0.043	0.043	0.043	0.043
K-40	0.962	0.962	0.962	0.962	0.962	0.962	0.962
error	0.048	0.048	0.048	0.048	0.048	0.048	0.048
Dose rate conversion (μGy/a)							
standard fractional error	0.050	0.050	0.050	0.050	0.050	0.050	0.050
U (ppm)							
Beta	0.146	0.146	0.146	0.146	0.146	0.146	0.146
error	0.007	0.007	0.007	0.007	0.007	0.007	0.007
Gamma	0.113	0.113	0.113	0.113	0.113	0.113	0.113
error	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Th (ppm)							
Beta	0.027	0.027	0.027	0.027	0.027	0.027	0.027
error	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Gamma	0.048	0.048	0.048	0.048	0.048	0.048	0.048
error	0.002	0.002	0.002	0.002	0.002	0.002	0.002

K (%)							
Beta	0.782	0.782	0.782	0.782	0.782	0.782	0.782
error	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Gamma	0.243	0.243	0.243	0.243	0.243	0.243	0.243
error	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Moisture							
F	0.816	0.816	0.816	0.816	0.816	0.816	0.816
error	0.058	0.058	0.058	0.058	0.058	0.058	0.058
W	0.816	0.816	0.816	0.816	0.816	0.816	0.816
error	0.058	0.058	0.058	0.058	0.058	0.058	0.058
WF	0.667	0.667	0.667	0.667	0.667	0.667	0.667
error	0.067	0.067	0.067	0.067	0.067	0.067	0.067
Age uncertainties							
dDR/K	0.548	0.548	0.548	0.548	0.548	0.548	0.548
dDR/dC(B, K)	0.592	0.600	0.644	0.659	0.536	0.673	0.501
dDR/dA(K)	0.482	0.488	0.523	0.535	0.436	0.547	0.407
dDR/dTh	0.040	0.040	0.040	0.040	0.040	0.040	0.040
dDR/dC(B, Th)	1.747	3.925	2.959	2.707	1.851	2.823	2.099
dDR/dA(Th)	0.056	0.126	0.095	0.087	0.059	0.091	0.067
dDR/dU	0.136	0.136	0.136	0.136	0.136	0.136	0.136
dDR/dC(B, U)	0.491	0.491	0.491	0.491	0.491	0.491	0.491
dDR/dA(U)	0.093	0.138	0.135	0.134	0.094	0.127	0.115
dDR/dW	-0.507	-0.653	-0.632	-0.628	-0.480	-0.635	-0.491
dDR/dF	-0.507	-0.653	-0.632	-0.628	-0.480	-0.635	-0.491
dDR/C(G, K)	0.641	0.649	0.697	0.713	0.580	0.729	0.543
dDR/C(G, Th)	2.137	4.801	3.619	3.311	2.264	3.453	2.568
dDR/dC(G, U)	0.663	0.983	0.966	0.959	0.669	0.909	0.820
dDR/dCosmic	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Dage/dDe	1.009	0.793	0.819	0.824	1.061	0.815	1.038
Dage/dDR	-22.642	-13.077	-12.461	-14.710	-21.763	-13.188	-19.219

Total Gamma	0.595	0.700	0.706	0.710	0.554	0.718	0.553
Total Beta	0.333	0.498	0.451	0.439	0.325	0.444	0.347
Cosmic	0.064	0.064	0.064	0.064	0.064	0.064	0.064
Total	0.991	1.262	1.221	1.213	0.942	1.226	0.963