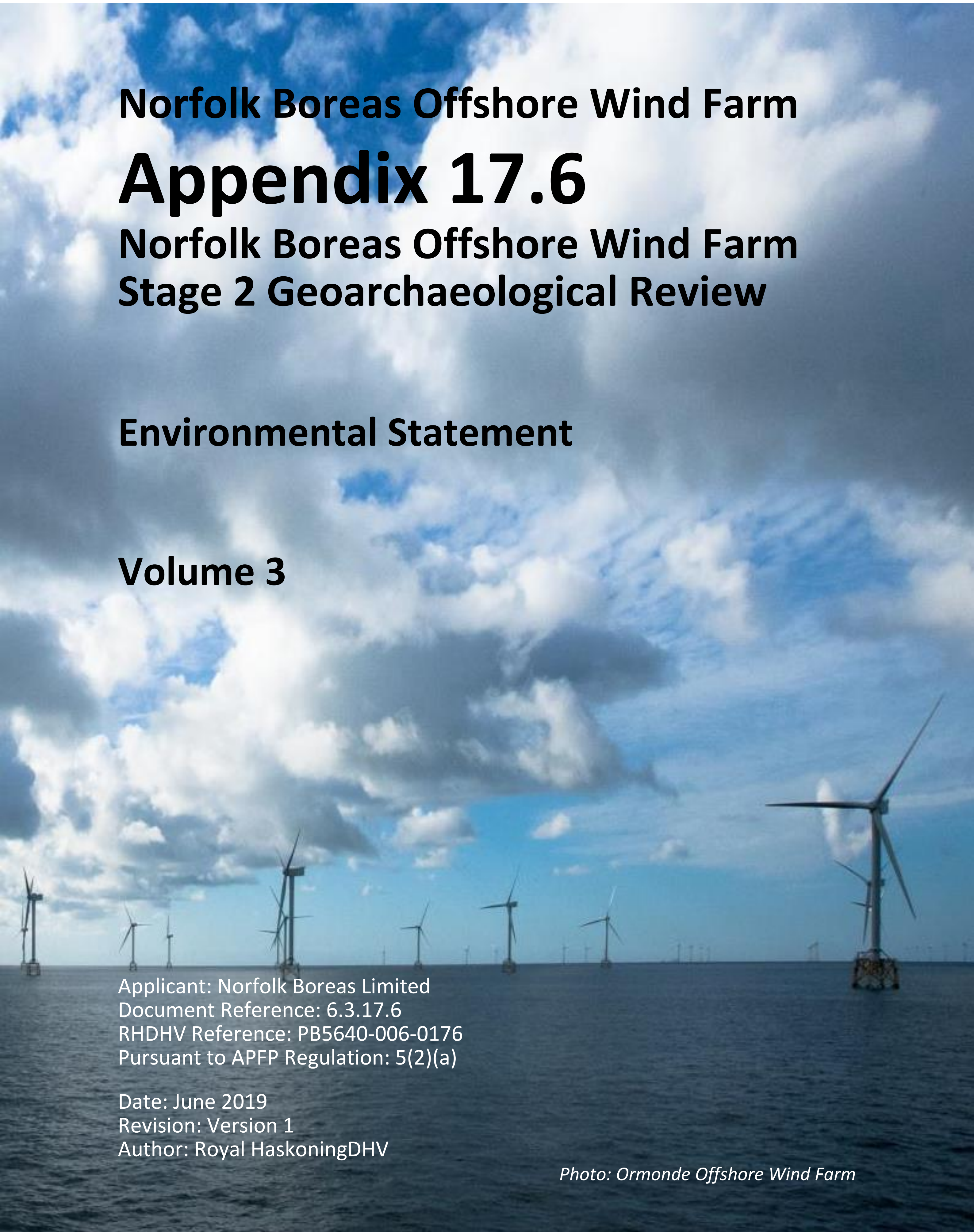


Norfolk Boreas Offshore Wind Farm

Appendix 17.6

Norfolk Boreas Offshore Wind Farm Stage 2 Geoarchaeological Review

Environmental Statement

Volume 3

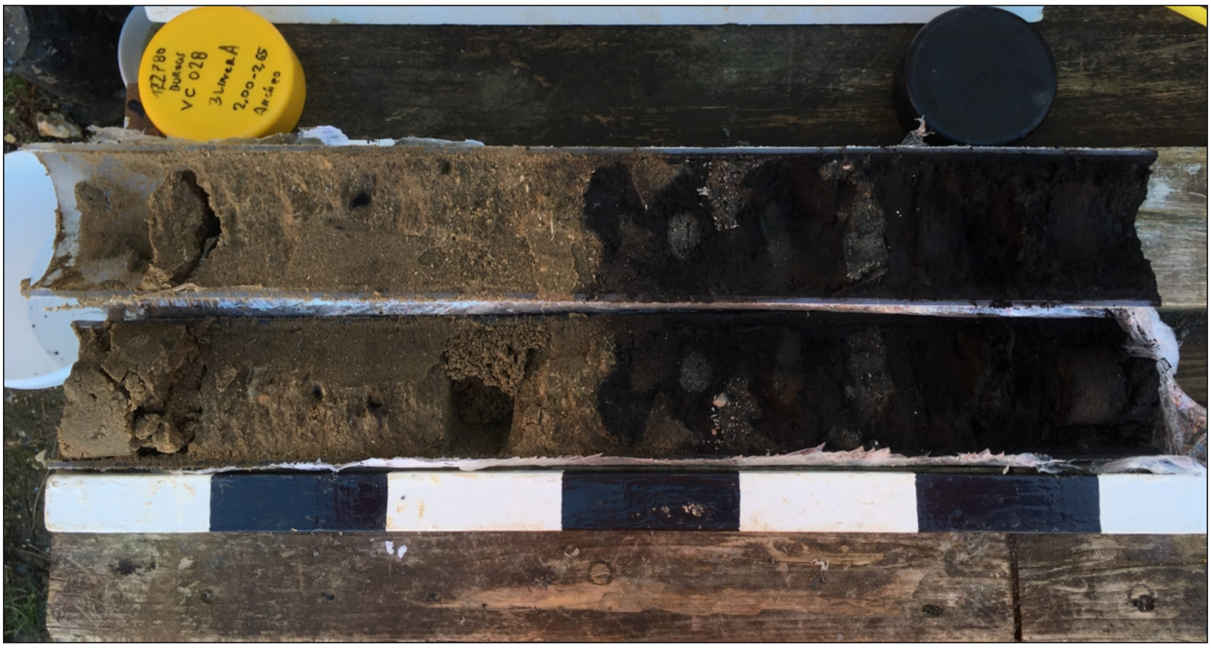
Applicant: Norfolk Boreas Limited
Document Reference: 6.3.17.6
RHDHV Reference: PB5640-006-0176
Pursuant to APFP Regulation: 5(2)(a)

Date: June 2019
Revision: Version 1
Author: Royal HaskoningDHV

Photo: Ormonde Offshore Wind Farm

Norfolk Boreas Offshore Wind Farm

Stage 2 Geoarchaeological Review



Ref: 117120.02
April 2018

wessex archaeology

Document Information

Document title	Norfolk Boreas Offshore Wind Farm Stage 2 Geoarchaeological Recording and Deposit Modelling
Document subtitle	
Document reference	117120.02
Client name	Royal Haskoning DHV
Address	2 Abbey Gardens Great College St Westminster London SW1P 3NL
Site location	Southern North Sea
County	n/a
National grid reference	n/a
Statutory designations	
Planning authority	
Planning reference	
Museum name	
Museum accession code	
WA project name	Same as document title
WA project code	117120
Date of fieldwork	n/a
Fieldwork directed by	n/a
Project management by	David Norcott
Document compiled by	Claire Mellett
Contributions from	Alex Brown and David Howell
Graphics by	Nancy Dixon

Quality Assurance

Version & issue date		Status	Author	Approved by
V1		E	CLM	DRN [redacted]
V2	10/04/2018	E	CLM	DRN [redacted]
V3	17/04/2018	E	CLM	DRN [redacted]

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Summary

Wessex Archaeology was commissioned by Royal HaskoningDHV to undertake Stage 2 geoarchaeological recording and deposit modelling of geotechnical logs in support of the proposed of Norfolk Boreas Offshore Wind Farm hereby referred to as the Norfolk Boreas site. The Stage 2 work forms part of ongoing investigations in advance of the proposed wind farm development, located in the southern North Sea, approximately 72 km northeast of Great Yarmouth.

Five vibrocores (**VC016**, **VC028**, **VC032**, **VC039** and **VC047**) were identified as having high geoarchaeological potential during a Stage 1 review (Wessex Archaeology 2018). Descriptions of these high priority vibrocores, along with all vibrocore geotechnical logs, were used as a basis to construct a deposit model for the Norfolk Boreas site.

An outline stratigraphic model for the site includes five key stratigraphic units. Lower to Middle Pleistocene deposits of the Yarmouth Roads Formation (**Unit 1**), and Ipswichian to early Devensian sediments relating to Lower Brown Bank/Eem Formation (**Unit 2**) were not recovered in the vibrocores as these units are located deep in the stratigraphy beyond the maximum depth of vibrocore penetration (6 m).

Early Weichselian sandy clays and sandy silts related to Upper Brown Bank (**Unit 3**) were the oldest deposits recovered in vibrocores (**VC016** and **VC047**). These sediments are interpreted to represent deposition in a shallow, potentially brackish, lagoon. The deposit model suggests the upper surface of these deposits gently dips towards the south. Maximum thickness of these deposits is unknown as vibrocores terminated within this unit. Upper Brown Bank deposits are of geoarchaeological interest as the lagoon may have provided suitable habitats for human settlement along its shores/margins. It is uncertain whether the lagoon sediments formed during the early Devensian, or over a longer period into the late Devensian. Uncertainty around the age of Upper Brown Bank, and changes in depositional environment which may include periods of drying out, provide a basis for Stage 3 recommendations.

Holocene pre-transgression deposits (**Unit 4**) were recovered in three vibrocores (**VC028**, **VC032** and **VC039**) characterised by peat (**Subunit 4b**) and over/underlying minerogenic sediments (**Subunits 4a** and **4c**). These deposits represent a semi-terrestrial landscape and are considered to date the early Holocene prior to flooding of the North Sea. Peat deposits have high potential to preserve material for radiocarbon dating and palaeoenvironmental analyses and are therefore recommended for Stage 3 assessment. The deposit model suggests peat deposits may be preferentially preserved where they are overlain by large seabed sand banks.

Post-transgression seabed sediments (**Unit 1**) represent final marine inundation of the site.

Stage 3 palaeoenvironmental analysis is recommended on all five high priority vibrocores (**VC016**, **VC028**, **VC032**, **VC039** and **VC047**), focussing on Upper Brown Bank (**Unit 3**) and pre-transgression (**Unit 4**) deposits of greatest geoarchaeological interest.

Recommended Stage 3 works comprise Optical Stimulated Luminescence (OSL) dating and associated palaeoenevironmental analysis (foraminifera, ostracod and diatom) of Upper Brown Bank which will provide a chronological framework to test questions about the age and persistence of this lagoon during Marine Isotope Stage (MIS) 3/2, which is poorly understood but a key period for Homo neanderthalensis and modern humans in NW Europe. Stage 3 works will also include radiocarbon dating and palaeoenvironmental analysis (pollen, foraminifera, ostracod and diatom) of Holocene pre-transgression deposits (**Unit 4**) to establish past landscape and environmental change, particularly in relation to rising sea levels.

Acknowledgements

This work was commissioned by Royal HaskoningDHV on behalf of Vattenfall. The report was compiled by Claire Mellett and illustrations were drafted by Nancy Dixon. The report was reviewed by Alex Brown and Dave Norcott. The project was managed on behalf of Wessex Archaeology by Daniel Atkinson and Louise Tizzard.

Norfolk Boreas Offshore Wind Farm

Stage 2 Geoarchaeological recording and deposit modelling

1 INTRODUCTION

1.1 Project background

1.1.1 Wessex Archaeology (WA) have been commissioned by Royal HaskoningDHV on behalf of Vattenfall to undertake Stage 2 geoarchaeological recording and deposit modelling of geotechnical survey data from the Norfolk Boreas Offshore Wind Farm, hereby referred to as the Norfolk Boreas site.

1.1.2 The Norfolk Boreas site is located approximately 72 km (39 nautical miles) northeast of Great Yarmouth within the southern North Sea. The proposed location of the windfarm is significant as it occupies an area with known nationally and internationally important archaeological and geoarchaeological records from the last one million years (Bicket and Tizzard 2015). The region preserves Pleistocene and Holocene landforms and sediments formed during periods of lower than present-day sea level, when this part of the southern North Sea basin was a landscape suitable for human occupation.

1.1.3 A geotechnical survey campaign was undertaken in October 2017 during which a total of 61 vibrocores were recovered from 50 locations reaching depths of up to 6 m below sea floor (mbsf). These vibrocores provided a continuous record of the deposits within ~6 m of the seabed. Preliminary geotechnical logs and associated test results were subsequently provided to WA for a Stage 1 geoarchaeological review.

1.1.4 The Stage 1 geoarchaeological review identified deposits of potential archaeological interest in thirteen vibrocores, the remaining 48 vibrocores were not recommended for further works as they were assigned low priority archaeological status (Wessex Archaeology 2018).

1.1.5 Five ofthe vibrocores of interest (**VC016**, **VC028**, **VC032**, **VC039** and **VC047**) were assigned high priority status due to the presence of organic material and thick sequences of fine grained deposits. These vibrocores were not split or subsampled for geotechnical testing and were delivered to WA for Stage 2 geoarchaeological recording.

1.1.6 Eight vibrocores (**VC003**, **VC005**, **VC005a**, **VC010**, **VC013a**, **VC024**, **VC029** and **VC033**) were assigned medium priority status and were opened under supervision of a suitably trainined geoarchaeologist at Fugro House, Wallingford (31st October - 1st November 2017). No deposits of geoarchaeological significance were noted during the monitoring of these medium priority vibrocores and no further work was recommended.

1.1.7 This report summarises the results of geoarchaeological recording of five high priority geotechnical vibrocores and presents an outline deposit model for the Norfolk Boreas site. It also presents recommendations for further Stage 3 geoarchaeological sub sampling and assessment.

1.2 Scope of document

1.2.1 To help frame geoarchaeological investigations of this nature, WA has developed a five-stage approach, encompassing different levels of investigation appropriate to the results obtained, accompanied by formal reporting of the results at the level achieved. The stages are summarised below (**Table 1**).

Table 1 Staged approach to geoarchaeological investigations

Stage	Method	Description
1	Review	A desk-based archaeological review of the borehole, vibrocore and CPT logs generated by geotechnical contractors. Aims to establish the likely presence of horizons of archaeological interest and broadly characterise them, as a basis for deciding whether and what Stage 2 archaeological recording is required. The Stage 1 report will state the scale of Stage 2 work proposed**.**
2	Geoarchaeological Recording and deposit modelling	Archaeological recording of selected retained or new core samples will be undertaken. This will entail the splitting of the cores, with each core being cleaned and recorded. The Stage 2 report will state the results of the archaeological recording and will indicate whether any Stage 3 work is warranted.
3	Sampling and Assessment	Dependent upon the results of Stage 2, sub-sampling and palaeoenvironmental assessment (pollen, diatoms and foraminifera) may be required. Subsamples will be taken if required. Assessment will comprise laboratory analysis of the samples to a level sufficient to enable the value of the palaeoenvironmental material surviving within the cores to be identified. Subsamples will also be taken and/or retained at this stage in case scientific dating is required during Stage 4. Some scientific dating (e.g. radiocarbon or Optically Stimulated Luminescence (OSL)) may be undertaken at this stage to provide chronological context. The Stage 3 report will set out the results of each laboratory assessment together with an outline of the archaeological implications of the combined results, and will indicate whether any Stage 4 work is warranted.
4	Analysis and Dating	Full analysis of pollen, diatoms and/or foraminifera assessed during Stage 3 will be undertaken. Typically, Stage 4 will be supported by scientific dating (e.g. radiocarbon or OSL) of suitable subsamples. Stage 4 will result in an account of the successive environments within the coring area, a model of environmental change over time, and an outline of the archaeological implications of the analysis.
5	Final Report	If required Stage 5 will comprise the production of a final report of the results of the previous phases of work for publication in an appropriate journal. This report will be compiled after the final phase of archaeological work, whichever phase that is.

2 GEOARCHAEOLOGICAL BACKGROUND

2.1.1 The Norfolk Boreas site is located in an area characterised by Pleistocene and Holocene sediments (Cameron *et al.* 1992), comprising clays, silts, sands and gravels with occasional organic-rich deposits (peats), overlain by recent unconsolidated marine shelly sands.

2.1.2 The Pleistocene geological history of the North Sea basin is dominated by repeated glacial/interglacial cycles, resulting in rising and falling sea levels and deposition of terrestrial, marine and glacially-derived sediments. The Norfolk Boreas site, and southern North Sea in general, is known to contain an important sedimentary archive including material dating from the earliest occupation of North Western Europe (Parfitt *et al.* 2010) up to more recent post-glacial reoccupation of Britain (Waddington 2015).

2.1.3 Only one glacial episode is thought to have directly affected the area. This was during the Anglian period (MIS 12, 480-423 ka) when ice extended into the southernmost North Sea (**Figure 2**). During subsequent glacial episodes, ice sheets terminated further north so did not directly affect the region. However, indirect affects resulting from changing sea levels and cold periglacial conditions will have influenced the site. The exact southern extent of the Anglian glaciation is debatable. However, bathymetric data suggests part of the Anglian ice sheet may have extended as far south as offshore from Felixstowe (Emu 2009), and Dix and Sturt (2011) argue for an Anglian glacial origin for over-deepened valleys (tunnel valleys) identified within the Outer Thames estuary.

2.1.4 Potential superficial deposits of geoarchaeological significance likely to be encountered within the Norfolk Boreas site area include the Brown Bank Formation, tentatively dating from the late Ipswichian interglacial to early Devensian glaciation (Limpenny *et al.* 2011).

2.1.5 The Brown Bank Formation includes deposits of silty sand, sandy silt and sandy silty clay, which is in places up to 20 m thick. The sandy silty clay deposits are here termed the Upper Brown Bank, to distinguish them from the underlying deposits of silty sand and sandy silt that characterise both the Lower Brown Bank (Lower Devensian) and underlying Eem Formation (Ipswichian) (Limpenny *et al.* 2011; Bicket and Tizzard 2015).

2.1.6 The Brown Bank Formation is present as a blanket deposit across the general area, and is interpreted to represent a shallow lagoon environment, comprising clayey silty sands (Cameron *et al.*1992; Limpenny *et al.* 2011). It remains unclear whether the Upper Brown Bank Formation was also deposited in the late Ipswichian, during a short period in the early Devensian, or over a much longer period extending into the late Devensian, perhaps punctuated by hiatuses in sediment accumulation (Tizzard *et al.* 2015). The date of the Brown Bank Formation therefore has significant implications both for our understanding of the palaeogeographic development of the North Sea as well as the likelihood of encountering Palaeolithic archaeology.

2.1.7 In places across the southern North Sea a sequence of early Holocene pre- marine transgression deposits is mapped overlying Pleistocene sediments. The Holocene sediments include organic-rich peats along with more minerogenic fluvial and alluvial sediments, most often infilling channels (Limpenny *et al.* 2011; Tappin *et al.* 2011; Tizzard *et al.* 2015; Gearey *et al.* 2017; Brown *et al.,* forthcoming), but also preserved on the Brown Bank Formation or overlying periglacial aeolian sediment. The peats are of high geoarchaeological potential, preserving a range of palaeoenvironmental remains and material suitable for radiocarbon dating.

2.1.8 Pleistocene and early Holocene sediments are capped by post-transgression marine sands. The progressive inundation of the North Sea occurred over an extended time scale, with particularly rapid sea-level rise during the early Holocene (11,500-7000 cal. BP), and with fully marine conditions occurring by around 6000 cal. BP (Sturt *et al.,* 2013).

2.1.9 Previous geophysical and geotechnical assessments of the East Anglia One Offshore Project Area (Wessex Archaeology 2010a, 2010b), and Cameron et al. (1992) have been used as a basis to outline the expected stratigraphy and deposits across the Norfolk Boreas site (**Table 2**). Note, the stratigraphic scheme presented here is based on interpretations of shallow geophysics and thus doesn't capture deeper, older deposits that are beyond the period of archaeological interest. A comparison between the stratigraphic scheme presented here and one developed by Fugro for geotechnical purposes is presented in Appendix 1. Both schemes are considered alongside the British Geological Survey lithostratigraphic framework for UK continental shelf deposits (Stoker *et al.* 2011).

Table 2 Geological units expected to be present within the Norfolk Boreas site based on previous geophysical and geoarchaeological assessments (Wessex Archaeology 2010a; 2010b) and Cameron *et al.* (1992).

Unit No	Unit Name (age)	Geophysical Characteristics[1]	Sediment Type[2]	Archaeological Potential
5	Holocene Seabed Sediments (post-transgression MIS 1)	Generally observed as a veneer or thickening into large sand wave and bank features. Boundary between seabed sediments and underlying units not always discernible.	Gravelly sand with shell fragments, sand waves and ripples indicate sediment is potentially mobile.	Low archaeological potential in areas of mobile sediments; basal contact may cover old land surfaces. Mobile sediment could cover wreck sites.
4	Holocene Sediments (pre-transgression MIS 2 - 1)	Small shallow infilled channels with either seismically transparent fill, or fill characterised by sub-parallel internal reflectors.	Unknown, but possibly fluvial, intertidal or littoral deposits.	Shallow infilled depressions or channels have potential for *in situ* or derived artefacts if deposited during occupation. Preserved organic material of interest to palaeoenvironmental studies.
3	Upper Brown Bank (Lower Devensian MIS 5d - 3)	Observed as a blanket deposit across the whole area, generally acoustically transparent or characterised by relatively poorly defined sub-horizontal layered reflectors.	Clayey silty sand and sandy silty clay infilling channels or hollows and deposited in an intertidal/lagoon environment.	*In situ* Lower Palaeolithic artefacts may be protected; Middle Palaeolithic *in situ* and derived artefacts may be associated particularly with channel edges dependent on the age of the fill; palaeoenvironmental information; basal contact may cover old land surfaces.
2	Lower Brown Bank/Eem Formation (Ipswichian or Lower Devensian MIS 5e - 5d)	Observed within large topographically controlled depressions. Characterised by low relief basal and either an acoustically transparent or well-layered fill.	Silty sand and sandy silt, possible intertidal or shallow marine deposits.	*In situ* Lower Palaeolithic artefacts may be protected; Middle Palaeolithic *in situ* and derived artefacts may be associated particularly with channel edges dependent on the age of the fill; palaeoenvironmental information; basal contact may cover old land surfaces.
1	Yarmouth Roads Formation (Lower to Middle Pleistocene MIS >13)	Thick unit either seismically chaotic or containing numerous areas of well-defined cross cutting channel complexes characterised by layered sub-parallel internal reflectors. Top of unit generally a well-defined regional erosion surface.	Silty sand with occasional shell fragments with occasional layers of clay. Generally becoming silty with depth. Sediments deposited as part of delta complex.	Possibility of *in situ* finds in later part of formation if not eroded. Contemporaneous with terrestrial Cromer Forest Bed Formation (Pakefield and Happisburgh). Has been found to contain plant debris, wood and peat in some areas of possible palaeoenvironmental importance. Potential

				greatest where associated with river valleys.

[1] Based on geophysics interpretations at borehole locations (Wessex Archaeology 2010a)
[2] Based on borehole geotechnical logs and Cameron *et al.* (1992)

3 AIMS AND OBJECTIVES

3.1.1 The principle aims of the Stage 2 geoarchaeological recording and deposit modelling are as follows:

- Undertake geoarchaeological recording of five high priority vibrocores identified during the Stage 1 geoarchaeological review;
- Interpret the probable environments represented;
- Model the distribution and depth of deposits across the site using a representative selection of vibrocores, considering all available geotechnical data;
- Determine the importance of the deposits, with regard to their archaeological and palaeoenvironmental potential;
- Make recommendations for dating and palaeoenvironmental assessment as appropriate, with reference to key research questions and regional/national period specific and maritime research agendas.

3.1.2 This report summarises the results of a review of retained geotechnical samples from five vibrocore locations and makes recommendations for further Stage 3 geoarchaeological works. It also presents an outline shallow (<6 mbsf) deposit model for the Norfolk Boreas site.

4 METHODOLOGY

4.1 Geoarchaeological recording of vibrocores

4.1.1 A total of five vibrocores previously identified as having high geoarchaeological potential during Stage 1 works (Wessex Archaeology 2018), were subject to Stage 2 geoarchaeological recording. During the Stage 1 review, only vibrocore sections comprising deposits of interest were requested, a full list of sample details is given in **Appendix 1**.

4.1.2 The vibrocores were split and recorded at WA, Salisbury, between 31st January and 7th February 2018. Core liners were split lengthways and immediately described by a suitably trained geoarchaeologist following Hodgson (1997) and COWRIE (2011), to include information such as:

- *Depth*
- *Texture*
- *Composition*
- *Colour*
- *Inclusions*

- *Structure (bedding etc.)*
- *Contacts between deposits*

4.1.3 Interpretations were made regarding the probable depositional environments and formation processes of the sampled deposits. This data is presented in **Appendix 2**.

4.2 Deposit modelling

4.2.1 Due to the large distance between vibrocores (2-5 km), two-dimensional section diagrams showing key stratigraphic units were considered the most appropriate method of deposit modelling (**Figures 3-6**) after COWRIE (2011).

4.2.2 Four cross sections have been created; two run broadly north to south (Transect 3 and Transect 4) and two run broadly southwest to northeast (Transect 1 and Transect 2) (**Figure 1**). The location of the cross sections was determined using geotechnical data, they were designed to capture the spatial variability in deposits across the site, and to include vibrocores subject to Stage 2 geoarchaeological recording.

5 RESULTS

5.1 Introduction

5.1.1 The results of the Stage 2 geoarchaeological recording are discussed below, with full vibrocore descriptions presented in **Appendix 2**. The results are considered alongside all available geotechnical data, including cone penetrometer tests (CPT), in order to aid description and interpretation.

5.1.2 All vibrocores lie within the Norfolk Boreas site. Every attempt has been made to assign the deposits to the outline stratigraphy presented in **Table 2**. However, finer, centimetre scale variations in deposits were identified during Stage 2 geoarchaeological recording and a refined stratigraphy for the uppermost deposits across the Norfolk Boreas site has been developed as outlined in **Table 3**. This refined stratigraphy is based on geoarchaeological recording of vibrocores only as the Stage 2 geoarchaeological works have been undertaken

5.1.3 Any uncertainty as to the date and/or taphonomy of deposits serves as an opportunity to propose further works, detailed in **section 8,** as part of the recommendations for Stage 3 assessment.

5.1.1 These Stage 2 geoarchaeological works were undertaken prior to completion of an assessment of palaeolandscape features using geophysical data that has been acquired across the Norfolk Boreas site. Therefore, all interpretations and results presented here are based on geotechnical and geoarchaeological information only. Given resolution differences between geophysical data (meter scale) and vibrocore assessments (sub-centimetre scale), interpretations are potentially subject to change pending Stage 3 works and integration of geophysical and geoarchaeological data.

5.2 Stratigraphy

5.2.1 An outline stratigraphy, based on previous geophysical and geotechnical surveys, and published literature (e.g. Cameron *et al*. 1992; Stoker *et al*. 2011), was developed for the site (**Table 2**). Due to the shallow target penetration of vibrocores (maximum 6 mbsf), deeper stratigraphic units including Yarmouth Roads Formation (**Unit 1**) and Lower Brown Bank/Eem Formation (**Unit 2**) were not recovered in vibrocores.

5.2.2 Stage 2 geoarchaeological recording targeted deposits considered to be of archaeological interest, principally peat deposits (**Unit 4**) (**VC016**, **VC028 VC032** and **VC039**) and sediments relating to the Upper Brown Bank (**Unit 3**) (**VC016** and **VC047**). The results of the Stage 2 geoarchaeological recording (**Appendix 3**) are used to refine the stratigraphy of the site (**Table 3**) and provide a basis to construct an initial deposit model.

5.2.3 While every attempt was made to correlate deposits to the outline stratigraphic scheme developed for the Norfolk Boreas site (**Table 2**), in certain instances it was possible to resolve the stratigraphy further allowing Units to be subdivided into subunits (e.g. **Unit 4**). However, there were also cases where ambiguity made it difficult to define the stratigraphic context (e.g. undifferentiated). This uncertainty in taphonomy provides a basis for further Stage 3 works.

Table 3 Deposits identified from vibrocores during Stage 2 geoarchaeological recording

Unit No	Unit Name (see Table 2)	Description	Depositional Environment
5	Holocene seabed sediments (post-transgression MIS 1)	Medium to coarse sand with frequent shell fragments	Marine – present day seabed sediments. A transgressive lag deposit may define the lower boundary
4c	Holocene (pre-transgression MIS 2-1)	Coarsening upwards sequence of structureless clay overlain by laminated silt with evidence of crossbedding and organic laminations	Represents initial flooding of the peat land surface followed by deposition in a shallow water intertidal environment
4b	Holocene (pre-transgression MIS 2-1)	Peat ranging from strongly to weakly decomposed with plant fragments (reeds) roots and wood preserved	Terrestrial – coastal peatland likely brackish reed peat, potentially becoming woodier
4a	Holocene (pre-transgression MIS 2-1)	Fining upwards sequence of sand with silt laminations and plant/root fragments overlain by laminated to organic silt with roots and plant fragments	Precedes development of the overlying peat, likely a coastal plain with potential channels (fluvial/tidal)
Undifferent-iated	Holocene pre-transgression or Upper Brown Bank	Interbedded sand and silty clay with shell fragments and silt laminations (occasionally organic)	Undetermined. Laminations could indicate a fluvial or intertidal environment. May have been deposited in Holocene channels or may be a sandier sub unit of Upper Brown Bank
3	Upper Brown Bank (MIS 5d-3)	Silty clay and clayey silt with closely spaced fine laminations. May be sandy in places or comprise sand partings/laminations.	Shallow water lagoon to intertidal.
2	Lower Brown Bank (MIS 5e-5d)	Not recovered in vibrocores	
1	Yarmouth Roads (Lower to Middle Pleistocene MIS >13)	Not recovered in vibrocores	

Upper Brown Bank (Unit 3)

5.2.4 The oldest sediments recovered in the vibrocores were sequences of interbedded clayey silt and silty clay interpreted to be Upper Brown Bank. These were recovered in **VC016** (1.60-5.75 m) and **VC047** (2.41-5.30 m). The maximum thickness of this unit cannot be determined using vibrocores alone as they terminate at shallow depths within these deposits. However, variations in the distribution and thickness of these deposits across the Norfolk Boreas site will be assessed as part of ongoing geophysical works.

5.2.5 In **VC047** the deposits are typically finely laminated with occasional organic silt laminations or fine sand partings. In **VC016**, the sediments appear bedded and there are discrete beds (<5 cm thick) of laminated silt within the clay. Wavy and lenticular sedimentary structures were observed in **VC016**, possibly indicating currents and bioturbation.

5.2.6 Based on the retained vibrocores assessed, these sediments are interpreted to have been deposited in a shallow water environment, possibly a lagoon, influenced by tidal regime or other currents. Bioturbation has been recorded elsewhere in the Brown Bank Formation (Cameron *et al.* 1990) supporting the proposed interpretation of these sediments as Upper Brown Bank.

Undifferentiated Unit (Upper Brown Bank or Holocene)

5.2.7 Overlying Upper Brown Bank deposits, a silty fine to medium sand with occasional shell fragments and black mottles was observed in **VC016** (1.37 m thick). In **VC047**, Upper Brown Bank is overlain by a silty clay with shell fragments (0.89 m thick). These deposits are not typical of Upper Brown Bank based on previous descriptions of this unit.

5.2.8 It is difficult to determine the depositional environment of the sediments in **VC016** and **VC047** based on Stage 2 geoarchaeological recording only. The presence of reworked shell may suggest deposition in a marine to coastal environment. However, these could equally be coastal to marine deposits that were later reworked by fluvial or periglacial aeolian (wind blown) (e.g. Twente Formation; Cameron *et al*. 1992) processes. The presence of finer grained clay and silt may indicate a shallow water setting and shows similarities to Upper Brown Bank. Uncertainty surrounding the age and taphonomy of these deposits is used as a basis to propose further Stage 3 works.

5.2.9 At this stage of the assessment, these deposits have been classified as undifferentiated as their depositional history and age is unknown. Based on the site stratigraphy, they may relate to Upper Brown Bank or Holocene pre-transgression sediments, although they could potentially be associated with a previously unrecorded unit such as Twente Formation.

Holocene (Unit 4a, 4b and 4c)

5.2.10 Vibrocores **VC028**, **VC032** and **VC039** comprise deposits interpreted to be early Holocene in age dating to a time when the southern North Sea was subaerially exposed prior to sea-level transgression (**Unit 4**). As geoarchaeological recording allows characterisation of deposits at a sub-centimetre scale, it was possible to subdivide **Unit 4** into three subunits (**4a**, **4b** and **4c**; **Table 3**). Note, due to their limited thickness, it would not be possible to resolve these subunits on geophysical data.

5.2.11 Stratigraphically, the oldest of these deposits is **Subunit 4a** which is present in **VC028**, **VC032** and **VC037**. **Subunit 4a** is characterised by a lower fine sand deposit with occasional plant fragments and organic silt laminations, and in **VC028** and **VC032**, this sand is overlain by a thin (2-5 cm) deposit comprising laminated silt. Fine roots extending from the overlying sediments are observed within the uppermost 5 cm of **Subunit 4a.**

5.2.12 **Subunit 4b** overlies **Subunit 4a** in all three vibrocores and comprises a peat deposit. The peat is relatively thin ranging in thickness from 0.17 m in **VC039** to 0.33 m in **VC028**. The peat varies from strongly decomposed where no obvious plant fragments are observed, to weakly decomposed where abundant reeds, and occasional seeds and wood fragments are preserved.

5.2.13 The lowermost peat deposit comprises frequent reeds (**VC039** and **VC032**). This reed peat is overlain by a more amorphous peat, which in turn is overlain by a more fibrous peat in **VC032** suggesting different stages of peatland development are captured within these deposits. The peat deposit in **VC028** is sandier and includes shelly sand intraclasts potentially indicating reworking.

5.2.14 In **VC032**, the peat (**Subunit 4b**) is overlain by **Subunit 4c** which is a 0.26 m thick deposit of clay that gradually coarsens upwards to a silt deposit that comprises closely spaced fine laminations showing cross bedding structures indicative of deposition in a tidal environment. Occasional laminations comprising fibrous organic silt are observed.

5.2.15 In **VC028** and **VC039**, the top of the peat is bounded by an erosion surface that is overlain by shelly sands interpreted to be marine.

5.2.16 Upper Brown Bank (Unit 3) and early Holocene pre- transgressive deposits (Unit 4) are not present within a single core and their stratigraphic relationship is based on understanding of regional stratigraphy.

Holocene seabed sediments (Unit 5)

5.2.17 The uppermost deposit recorded in all five vibrocores is a medium to coarse sand that comprises frequent shell fragments. This deposit is interpreted as marine and represents present-day seabed sediments. The lower boundary of this deposit is typically sharp and comprises high proportions of shell, some of which are in-tact whole bivalves. This boundary is likely the transgressive surface that formed as sea level flooded the former landscape.

5.2.18 The presence of seabed sediments indicates that deposits of archaeological interest, at least at these five vibrocore locations, are buried at depths between 0.60 and 4.70 mbsf and are not exposed at the seabed.

5.3 Deposit modelling

5.3.1 Four broadly linear two-dimensional cross sections have been created providing an outline model of the stratigraphy and depositional environments present within the Norfolk Boreas site (**Figures 3-6**).

Transect 1

5.3.2 Transect 1 comprises seven vibrocores, including **VC029** and **VC047** which have been subject to Stage 2 geoarchaeological recording (**Figure 3**). Transect 1 shows representative stratigraphy of the northern sector of the site and runs SW-NE broadly parallel to the northern boundary of the Norfolk Boreas site (**Figure 1**).

5.3.3 Upper Brown Bank (**Unit 3**) sediments were penetrated in **VC029**, **VC041** and **VC047** with the upper surface occupying elevations between approximately -35 and -37 mLAT. Upper Brown Bank was not penetrated in **VC043** or **VC044** despite these vibrocores penetrating below -37 mLAT which is the maximum depth Upper Brown Bank was observed along this transect. This may suggest Upper Brown Bank occurs at lower elevations at these locations.

5.3.4 In **VC047**, Upper Brown Bank is overlain by an undifferentiated deposit. As this vibrocore lies in the most north-eastern corner of the site, it is not possible to establish if this is an isolated deposit or a more widespread feature.

5.3.5 Holocene seabed sediments dominate the stratigraphy of Transect 1 and they are present in all seven vibrocores ranging in thickness from 1.52 m in **VC047** to 5.9 m in **VC042**. In **VC040**, **VC043**, **VC044** and **VC045**, Holocene post-transgression (**Unit 5**) sediments are the only stratigraphic unit penetrated. At these locations a large sediment bank formed by modern seabed processes can be seen on bathymetric data. The sediment bank may provide protection to earlier deposits.

Transect 2

5.3.6 Transect 2 comprises eight vibrocores, from seven locations as **VC013** and **VC013a** were both recovered at the same location. The transect and runs from SW-NE across the southern sector of the site (**Figure 1** and **Figure 4**). This transect was constructed from interpreted vibrocore logs only so does not include any locations subject to Stage 2 geoarchaeological recording.

5.3.7 Upper Brown Bank (**Unit 3**) is present in **VC013**, **VC013A**, **VC010** and **VC08** where its upper surface occupies an elevation between approximately -38 and -42 mLAT which is deeper than in the northern sector (see Transect 1). Upper Brown Bank is overlain by Holocene post-transgression (**Unit 5**) sediments that were deposited in a marine setting. The thickest sequences of **Unit 5** (**VC012**, **VC011** and **VC09**) appear to be associated with sediment banks present across the site making it difficult to reach the underlying early Holocene and Pleistocene sediments with a 6 m vibrocore.

Transect 3

5.3.8 Transect 3 runs from north to south through the centre of the Norfolk Boreas site and comprises nine vibrocores from seven locations (duplicate cores taken at **VC019/VC019a** and **VC05/VC05a**), including two that have been subject to Stage 2 geoarchaeological recording (**VC039** and **VC032**) (**Figure 5**).

5.3.9 Upper Brown Bank (**Unit 3**) dominates the stratigraphy of this transect and is present in seven of the nine vibrocores. The upper surface of Upper Brown Bank appears to dip gently towards the south from approximately -39 mLAT at **VC033** in the north, to -43 mLAT at **VC05** in the south.

5.3.10 In **VC039** and **VC032** Upper Brown Bank is absent but sequences of peat and associated minerogenic deposits interpreted as early Holocene pre-transgressive (**Unit 4**) sediments are preserved. These deposits occupy a higher elevation (approx. -36 mLAT) than the Upper Brown Bank deposits below. However, it is unknown if they originally formed on higher ground, or if they were more widespread blanket deposits that were later eroded.

5.3.11 Holocene post-transgression seabed sediments (**Unit 5**) are preserved in all vibrocores. They are thickest in the north (>3 m) where they form a large sediment bank, and they thin to the south. Notably, the Holocene pre-transgression deposits (**Unit 4**), which are of the greatest archaeological interest, are preserved below thicker sequences of seabed sediments associated with sediment banks (**VC039** and **VC032**). This would imply these present-day seabed features play a key role in preserving deposits of geoarchaeological significance.

Transect 4

5.3.12 Transect 4 runs from north to south along the western margin of the Norfolk Boreas site and comprises five vibrocores. This cross section shows all stratigraphic units identified from vibrocore geotechnical logs (**Figure 6**).

5.3.13 Upper Brown Bank (**Unit 3**) is present in four of the five vibrocores and again exhibits a trend that suggests it occupies higher elevations in the north (approx. -35 mLAT) and dips gently to the south (approx. -40 mLAT).

5.3.14 At **VC016**, an isolated deposit of unknown age and depositional environment, here classified as Undifferentiated (**Table 3**), is present. This undifferentiated deposit is overlain by a thin veneer (0.23 m) of seabed sediments. It is not known at this stage if this is a widespread deposit that has been reworked elsewhere, or if it is an isolated feature associated with local topography such as a channel or hollow.

5.3.15 Holocene pre-transgression peat and associated minerogenic sediments (**Unit 4**) have been recovered in **VC028**. This early Holocene appears to occupy higher elevations (approx. -34 mLAT) than the Upper Brown Bank suggesting it formed on topographic highs. However, this may be an artefact caused by later phases of erosion whereby peats at lower elevations have been removed. Again, it appears the peat is preserved at this location due to the presence of an overlying sediment bank that has protected this deposit from present-day seabed currents.

5.3.16 Holocene post-transgression seabed sediments overly the early Holocene and Pleistocene stratigraphy along this transect. These deposits are thickest where they are associated with sediment banks on the modern-day seabed.

6 DISCUSSION

6.1.1 Initial Stage 1 assessment of vibrocores (Wessex Archaeology 2017) has been followed by detailed Stage 2 geoarchaeological recording of five vibrocores which supported the development of an outline deposit model for the Norfolk Boreas site.

6.1.2 The Stage 2 assessment has revealed an extensive, and in places complex, sequence of Pleistocene and Holocene deposits across the Norfolk Boreas site. These deposits have been divided into five broad stratigraphic units (**Table 3**) and three subunits which together characterise the stratigraphy of the site.

6.1.3 While the stratigraphic model comprises units dating back to the early Pleistocene (Yarmouth Roads [**Unit 1**]) and early Late Pleistocene (Lower Brown Bank/Eem Formation [**Unit 2**]), these were not recovered in vibrocores due to the shallow depth of penetration.

6.1.4 The oldest deposit recovered in vibrocores is interpreted as Upper Brown Bank dating to the Early/Middle Devensian (MIS 5d-MIS 3), potentially extending into the Late Devensian (Limpenny *et al.* 2011). The greatest recovery of this unit was 4.15 m in **VC016**. Its full extent was not penetrated due to the shallow target penetration depth of vibrocores but this deposit has the potential to reach thickness of up to 20 m.

6.1.5 Subtle variations in the proportion of sand, silt and clay within the Upper Brown Bank deposits, and the thickness of laminations/beds suggest a variable depositional environment. In both **VC016** and **VC047** there is evidence of reworking at discrete depths (3.18-3.68 mbsf 4.00-4.56 mbsf, respectively). Laminations which were initially sub-horizontal appear vertical and distorted. It is unknow if this deformation occurred during coring or is the result of environmental processes such as sediment slumping or subaerial exposure.

6.1.6 The complexity in the Upper Brown Bank has been taken to suggest a multi-period, multiphase unit of deposition, rather than necessarily a single continuous deposition of lagoon sediment. The Upper Brown Bank is of potential archaeological significance as low-lying wetlands and lagoon shores may have presented opportunities for exploitation with settlement on areas of high ground.

6.1.7 Upper Brown Bank is overlain in **VC016** (1.37 m) and **VC047** (0.89 m) by a deposit whose age and depositional environment is undetermined. At this stage, this sediment may be related to Upper Brown Bank or pre-transgression Holocene units. Further Stage 3 works are required to establish the nature and stratigraphy of this deposit.

6.1.8 Pleistocene sediments are overlain by deposits of Holocene age, comprising pre-transgression terrestrial-coastal deposits (**Unit 4**) and post-transgression seabed sediments (**Unit 5**).

6.1.9 Unit 4 has been subdivided into three subunits; **4a**, **4b** and **4c**. Together these are interpreted to represent an initial semi-terrestrial environment (**Subunit 4a**) upon which peat developed and matured (**Subunit 4b**) before it was inundated by early Holocene sea-level rise (**Subunit 4c**). It is likely these peats developed near to the coast but the geometry of the palaeolandscape is unknown. This can potentially be addressed using geophysical data.

6.1.10 Relative to metres below Lowest Astronomical Tide (mLAT) the peat occurs between 33.32 and 36.02 mLAT. The difference in altitudinal height of the peat may reflect differential lateral and vertical auto-compaction of a contemporaneous blanket peat deposit, or isolated pockets of peat formation under the background of fluctuating but rising post-glacial sea levels. These peat deposits are likely to date prior to the final inundation of the southern North Sea basin which occurred between 8000-7000 cal. BP.

6.1.11 Seabed sediments are present across the site in varying thicknesses relating to the presence or absence of sediment banks and sand waves. These sediments mark final submergence of the formerly terrestrial southern North Sea landscape and the prevalence of fully marine conditions.

7 RECOMMENDATIONS

7.1 Introduction

7.1.1 Based on the results of the geoarchaeological recording and deposit modelling of geotechnical samples, a series of recommendations are made for further targeted geoarchaeological assessment, itemised below and in **Table 4**.

7.1.2 The selection of samples for Stage 3 assessment is based on the geoarchaeological significance of the deposits preserved, the suitability of sediments for the palaeoenvironmental and dating techniques available, and the research questions proposed.

7.1.3 During Stage 2 assessment, deposits of highest geoarchaeological significance from which samples have been retained include early Holocene pre-transgression peats and associated over/underlying minerogenic deposits (**Subunits 4a**, **4b** and **4c**), Upper Brown Bank (**Unit 3**) and an undifferentiated deposit that is potentially Upper Brown Bank or early Holocene in age, both are periods of archaeological interest.

Table 4 Recommendations for Stage 3 palaeoenvironmental assessment and scientific dating

Vibrocore	Assessment

	^{14}C	OSL	Plant Macrofossil	Pollen	Foraminifera/ Ostracod	Diatoms
VC016	-	2	-	-	10	10
VC028	1	-	1	5	8	8
VC032	2	-	2	6	8	8
VC039	1		1	3	6	6
VC047	-	2	-	-	10	10
Total	**4**	**4**	**4**	**14**	**42**	**42**

7.2 Upper Brown Bank (Unit 3)

7.2.1 Further stage 3 assessment is recommended on Upper Brown Bank deposits from **VC016** and **VC047**. OSL dating is proposed on two samples from each vibrocore location to provide a chronological context for the Upper Brown Bank across the Norfolk Boreas site.

7.2.2 It remains unclear if Upper Brown Bank was deposited over a short period of time during the early Devensian, or whether it represents longer term deposition, potentially punctuated by periods of exposure and drying out. By dating Upper Brown Bank deposits at the Norfolk Boreas site and comparing them with published dates elsewhere in the southern North Sea, this question can be addressed.

7.2.3 In support of OSL dating, it is recommended palaeoenvironmental analyses are undertaken on Upper Brown Bank sediments to provide further insight into environmental conditions within the lagoon which can feed into palaeogeographic reconstructions.

7.2.4 The recovery of interlaminated sandy clays indicative of deposition in shallow water, possibly a brackish intertidal environment, makes assessment of foraminifera, ostracod and diatoms the most suitable proxy techniques as these have high preservation potential.

7.2.5 Palaeoenvironmental assessment of Upper Brown Bank also provides a fundamental control for comparison with foraminifera, ostracod and diatom assessment of overlying sediments of uncertain date and taphonomy (see **section 8.3**).

7.2.6 It is not proposed to undertake pollen analysis on Upper Brown Bank as the Devensian date of these sediments covers a time when the environment would have been a cold tundra landscape with little in the way of substantial pollen-producing vegetation.

7.2.7 Upper Brown Bank is a deposit of archaeological interest as it represents a shallow water lagoon environment which may have provided a suitable habitat for human settlement and occupation along its margins and shores. There is also potential the lagoon dried out intermittently which has implications for the archaeological potential of the deposits. Therefore, understanding the palaeogeographic development of this lagoon in the context of the northwest European archaeological record is key.

7.3 Undifferentiated (Upper Brown Bank or Holocene)

7.3.1 The age and depositional history of silty sand and silty clay deposits overlying Upper Brown Bank in **VC016** and **VC047**, is unknown. This uncertainty forms the premise for Stage 3 works on these undifferentiated deposits.

7.3.2 Due to the fine grained and clastic nature of these sediments, it is recommended that foraminifera, ostracod and diatom assessments are undertaken to help determine depositional history and palaeoenvironment.

7.4 Holocene (Unit 4)

7.4.1 Further Stage 3 assessment is recommended on vibrocores **VC028**, **VC032** and **VC039** focussing on the peat and over/underlying minerogenic deposits. These sediments have the highest geoarchaeological potential both in terms of radiocarbon dating and the preservation of palaeoenvironmental material.

7.4.2 It is unknown at this stage if the peat deposits from **VC028**, **VC032** and **VC039** are part of the same blanket deposit, or if they formed independently in isolated locations. There is also evidence in **VC032** to suggest initial peat development was dominated by reeds which were subsequently replaced by more woodland vegetation.

7.4.3 Minerogenic sand and silt deposits comprising plant fragments and roots underlie the peat in all three vibrocores. In **VC032**, overlying clay and silt deposits are interpreted to represent flooding of the peat as sea-levels rose during the early Holocene. These sequences when interpreted together can provide valuable information on sea-level and climate change, and the potential impact this would have had on human communities in the southern North Sea during the early Holocene.

7.4.4 Targeted pollen and plant macrofossil analysis, along with radiocarbon dating is recommended on the peat deposits. Foraminifera, ostracod and diatom assessment are recommended on minerogenic sediments over/underlying the peat deposits.

7.5 Research questions

7.5.1 A series of research questions are proposed which will underpin the recommendations for Stage 3 assessment, taking into account regional research framework (Medlycott 2011) and the national maritime research framework (Ransley *et al.* 2013).

7.5.2 Specific research questions include:

- What palaeoenvironments are represented by the deposits preserved across the site? How do these change through time?
- What is the age of peat deposits? Do they represent a contemporary phase of peat formation across the site or separate phases of peat formation within environmental niches?
- What is the age of Upper Brown Bank Formation? Did it form relatively quickly in the early Devensian or accumulate as a more gradual deposit over a longer period of time?
- What do the results mean for palaeolandscape development and palaeogeographic evolution of the southern North Sea, and what is the archaeological significance of this?

7.6 Palaeoenvironmental assessment methods

7.6.1 Palaeoenvironmental assessment will involve a suite of complementary techniques, comprising, pollen, macrofossils, diatom, foraminifera and ostracods, supported by OSL and radiocarbon dating of suitable deposits (**Table 4**). Multiple techniques are typically assessed in accordance with Historic England guidelines on good practice in environmental archaeology (Historic England 2011) and geoarchaeology (Historic England, 2015), providing a comprehensive understanding of the depositional and environmental context of the sediments.

Pollen analysis

7.6.2 Pollen is one of the principal techniques used in environmental archaeology to investigate past vegetation environments and the impact of human communities on the landscape, the latter often evident as distinct phases of woodland clearance or specific land-use strategies (e.g., cereal cultivation, creation of pastures or meadows). Pollen is best preserved in waterlogged organic and oxygen-free sediment, such as peat, where the pollen grains are most representative of the surrounding vegetation at the time of deposition. Marine/riverine sediments are not ideal for pollen assessment as the grains may be transported over long distances or suspended in the water column for significant periods of time.

Radiocarbon dating

7.6.3 Radiocarbon dating is an established technique used for determining the date of a range of organic materials. AMS (Accelerator Mass Spectrometry) dating of slices of peat, or of short-lived material (seeds, twigs) recovered from the peat, will provide a secure chronological context for these deposits and the palaeoenvironmental assessment recommended on select boreholes. Where thick peats are present AMS dates from the top and base of the peat are recommended, where as one date will suffice for thin and relatively short-lived peats.

Diatoms, foraminifera and ostracods

7.6.4 Diatoms (unicellular algae), foraminifera (marine protozoa) and ostracods (bivalve Crustacea) occur in a wide range of marine and semi-terrestrial environments (e.g. saltmarsh) and provide important comparative indicators on past coastal and riverine change. Assessment of sediments at transitions can help to distinguish evidence for sea-level, coastal and riverine change, including, the influence of storm/high tide events on semi-terrestrial environments (perhaps visible as fine organic/mineral banding in sediments).

Optical Stimulated Luminescence dating

7.6.5 OSL dating is an established technique for establishing the depositional age of sediments that or too old or lack organic material to be dated using conventional radiocarbon methods. OSL can be applied to a range of depositional environments including, alluvial, fluvial, glacial, coastal and shallow marine. The age range extends from decades to 300,000 years and is therefore applicable to sediments of Upper Brown Bank age. A comprehensive review of the applications of OSL in archaeology is presented in Duller (2008).

REFERENCES

Bicket, A, Tizzard, L 2015 A review of the submerged prehistory and palaeolandscapes of the British Isles, *Proceedings of the Geologists' Association* 126, 643-663

Brown, A, Russel, J, Scaife, R, Tizzard, L, Whittaker, J, Wyles, F, forthcoming Late-glacial / early Holocene palaeoenvironments in the southern North Sea Basin: new data from the Dudgeon offshore wind Farm *Journal of Quaternary Science*

Cameron, T D J, Crosby, A, Balson, P S, Jeffery, D H, Lott, G K, Bulat, J, Harrison, D J 1992 *The Geology of the Southern North Sea.* London, British Geological Survey United Kingdom Offshore Regional Report HMSO

COWRIE 2011 *Offshore Geotechnical Investigations and Historic Environment Analysis: Guidance for the Renewable Energy Sector*. Oxford, COWRIE Ltd, published report ref GEOARCH-09

Dix, J, Sturt, F, 2011 *The relic palaeolandscapes of the Thames Estuary*. MALSF unpublished report.

Duller, G A T 2008 *Luminescence dating: guidelines on using luminescence dating in archaeology*. English Heritage. https://content.historicengland.org.uk/images-books/publications/luminescence-dating/luminescencedating/

EMU Ltd. 2009 *The Outer Thames Estuary Regional Environmental Characterisation*. London, GB ALSF/MEPF (DEFRA)

English Heritage 2011 *A guide to the theory and practice of methods, from sampling and recovery to post-excavation, 2nd edition*. https://content.historicengland.org.uk/images-books/publications/environmentalarchaeology-2nd/environmental-archaeology-2nd.pdf/

Fugro 2017 *Norfolk Boreas Offshore Wind Farm Geophysical Site Investigation: Report 1 of 3 Volume 2 of 2 Interpretive Site Investigation Report*, unpublished report ref: GEO59-R1-2(01)

Historic England, (2015). Geoarchaeology: using Earth Sciences to understand the archaeological record. https://historicengland.org.uk/imagesbooks/publications/geoarchaeology-earth-sciences-to-understand-archaeologicalrecord/

Gearey, B R, Hopla, E-J, Boomer, I, Smith, D, Marshall, P, Fitch, S, Griffiths, S, Tappin, D R 2017. Multi-proxy palaeoecoological approaches to submerged landscapes: a case study from 'Doggerland' in the southern North Sea, in M Williams, T Hill, I Boomer and I P Wilkinson (eds.) *The archaeological and forensic applications of microfossils: a deeper understanding of human history*. London, The Micropalaeontological Society, Special Publications Geological Society 35-53

Hodgson, J M, 1997 *Soil Survey Field Handbook*, Harpenden, Soil Survey Technical Monograph No. 5

Limpenny, S E, Barrio Froján, C, Cotterill, C, Foster-Smith, R L, Pearce, B, Tizzard, L, Limpenny, D L, Long, D, Walmsley, S, Kirby, S, Baker, K, Meadows, W J, Rees, J, Hill, J, Wilson, C, Leivers, M, Churchley, S, Russell, J, Birchenough, A C, Green, S L, Law, R J 2011 *The East Coast Regional Environmental Characterisation*. MEPF

Medlycott, M, 2011 Research and archaeology revisited: a revised framework for the East of England. *East Anglian Archaeology* 24.

Parfitt, S A, Ashton, N M, Lewis, S G, Abel, R L, Coope, G R, Field, M H, Gale, R, Hoare, P G, Larkin, N R, Lewis, M D, Karloukovski, V, Maher, B A, Peglar, S M, Preece, R C, Whittaker, J E, Stringer, C B, 2010 Early Pleistocene human occupation at the edge of the boreal zone in northwest Europe. *Nature*, 466 (7303), 229–33

Ransley, J, Sturt, F, Dix, J, Adams, J, Blue, L, 2013 *People and the sea: a maritime archaeological research agenda for England*. York, Council for British Archaeology Research Report 171

Stoker, M S, Balson, P S, Long, D, Tappin, D R 2011 *An overview of the lithostratigraphical framework for the Quaternary deposits on the United Kingdom continental shelf*, British Geological Survey Research Report RR/11/03

Sturt, F, Garrow, D, and Bradley, S, 2013 New models of North West European Holocene palaeogeography and inundation. *Journal of Archaeological Science* 40, 3963- 3976

Tappin, D R, Pearce, B, Fitch, S, Dove, D, Gearey, B, Hill, J M, Chambers, C, Bates, R, Pinnion, J, Diaz Doce, D, Green, M, Gallyot, J, Georgiou, L, Brutto, D, Marzialetti, S, Hopla, E, Ramsay, E, Fielding, H 2011 *The Humber Regional Environmental Characterisation*. British Geological Survey Open Report OR/10/54.

Tizzard, L, Bicket, A, De Loecker, D 2015 *Seabed Prehistory. Investigating the Palaeogeography and Early Middle Palaeolithic Archaeology in the Southern North Sea*. Wessex Archaeology Monogr. 35.

Waddington C 2015 Mesolithic re-colonisation of Britain following on the drowning of North Sea landscapes in N Ashton, C Harris (eds) *No Stone Unturned. Papers in Honour of Roger Jacobi.* London, Lithic Studies Society,221-232

Wessex Archaeology 2010a *East Anglia Offshore Wind Project. Assessment of Archaeological potential of Quaternary Deposits for Geotechnical Sampling*. Salisbury, unpublished report ref 74540.04.

Wessex Archaeology 2010b *East Anglia Offshore Wind Project. Proposed selection of geotechnical samples for archaeological potential*. Salisbury, unpublished report ref 74540.05

Wessex Archaeology 2018 *Norfolk Boreas Offshore Wind Farm: Stage 1 Geoarchaeological Review*. Salisbury, unpublished report ref 117120.01

APPENDICES

Appendix 1

WA Lithostratigraphy					Fugro Soil Stratigraphy[3]		BGS Lithostratigraphy[4]
Unit No	**Unit Name (age)**	**Geophysical Characteristics[1]**	**Sediment Type[2]**	**Archaeological Potential**	**Soil Unit**	**Soil Unit Name**	**Formation**
5	Holocene Seabed Sediments (post-transgression MIS 1)	Generally observed as a veneer or thickening into large sand wave and bank features. Boundary between seabed sediments and underlying units not always discernible.	Gravelly sand with shell fragments, sand waves and ripples indicate sediment is potentially mobile.	Low archaeological potential in areas of mobile sediments; basal contact may cover old land surfaces. Mobile sediment could cover wreck sites.	A1	Bligh Bank	Southern Bight Formation
4	Holocene Sediments (pre-transgression MIS 2-1)	Small shallow infilled channels with either seismically transparent fill, or fill characterised by sub-parallel internal reflectors.	Unknown, but possibly fluvial, intertidal or littoral deposits.	Shallow infilled depressions or channels have potential for *in situ* or derived artefacts if deposited during occupation. Preserved organic material of interest to palaeoenvironmental studies.	A2	Elbow	Elbow Formation
-	Twente (Upper Devensian MIS 2)	Not identified in shallow geophysical data	Not identified in geotechnical logs	Thin layer of aeolian periglacial sand deposited when the southern North Sea was a glaciated terrestrial landscape. Potential to contain *in-situ* and derived archaeological and palaeoenvironmental material.	B	Twente	Twente Formation
3	Upper Brown Bank (Lower Devensian MIS 5d-3)	Observed as a blanket deposit across the whole area, generally acoustically transparent or characterised by relatively poorly defined sub-horizontal layered reflectors.	Clayey silty sand and sandy silty clay infilling channels or hollows and deposited in an intertidal/lagoon environment.	*In situ* Lower Palaeolithic artefacts may be protected; Middle Palaeolithic *in situ* and derived artefacts may be associated particularly with channel edges dependent on the age of the fill; palaeoenvironmental information; basal contact may cover old land surfaces.	C	Brown Bank	Brown Bank Formation
2	Lower Brown Bank/Eem Formation (Ipswichian or Lower Devensian MIS 5e - 5d)	Observed within large topographically controlled depressions. Characterised by low relief basal and either an acoustically transparent or well-layered fill.	Silty sand and sandy silt, possible intertidal or shallow marine deposits.	*In situ* Lower Palaeolithic artefacts may be protected; Middle Palaeolithic *in situ* and derived artefacts may be associated particularly with channel edges dependent on the age of the fill; palaeoenvironmental information; basal contact may cover old land surfaces.	C	Brown Bank	Brown Bank Formation and Eem Formation

WA Lithostratigraphy					**Fugro Soil Stratigraphy[3]**		**BGS Lithostratigraphy[4]**
Unit No	**Unit Name (age)**	**Geophysical Characteristics[1]**	**Sediment Type[2]**	**Archaeological Potential**	**Soil Unit**	**Soil Unit Name**	**Formation**
-	Swarte Bank (Anglian MIS 12)	Not identified in shallow geophysical data	Not identified in geotechnical logs	Low archaeological potential as associated with glacial processes	D	Swarte Bank	Swarte Bank Formation
1	Yarmouth Roads Formation (Lower to Middle Pleistocene MIS >13)	Thick unit either seismically chaotic or containing numerous areas of well-defined cross cutting channel complexes characterised by layered sub-parallel internal reflectors. Top of unit generally a well-defined regional erosion surface.	Silty sand with occasional shell fragments with occasional layers of clay. Generally becoming silty with depth. Sediments deposited as part of delta complex.	Possibility of *in situ* finds in later part of formation if not eroded. Contemporaneous with terrestrial Cromer Forest Bed Formation (Pakefield and Happisburgh). Has been found to contain plant debris, wood and peat in some areas of possible palaeoenvironmental importance. Potential greatest where associated with river valleys.	E	Yarmouth Roads	Yarmouth Road Formation
-	Winterton Shoal/Smith's Knoll (Lower Pleistocene)	Not identified in shallow geophysical data	Not identified in geotechnical logs	Pre-date earliest occupation; of no archaeological interest.	F	Winterton Shoal/Smith's Knoll	Winterton Shoal Formation and Smith's Knoll Formation

[1] Based on geophysics interpretations at borehole locations (Wessex Archaeology 2010a)
[2] Based on borehole geotechnical logs and Cameron *et al.* (1992)
[3] Fugro (2017)
[4] Stoker et al. (2011)

Appendix 2

VC	Sample type	Section depth	Section made available?[1]	Section subject to Stage 2 recording?	Comments
VC016	Unsplit continuous core	0.00-1.00 m	Yes	Yes	n/a
	Unsplit continuous core	1.00-2.00 m	Yes	Yes	
	Unsplit continuous core	2.00-3.00 m	Yes	Yes	
	Unsplit continuous core	3.00-4.00 m	Yes	Yes	
	Unsplit continuous core	4.00-5.00 m	Yes	Yes	
	Unsplit continuous core	5.00-5.75 m	Yes	Yes	
VC028	Unsplit continuous core	2.00-2.65 m	Yes	Yes	The uppermost 2 m of core comprised marine sands so were not requested for Stage 2 geoarchaeological recording
	Unsplit continuous core	2.65-3.10 m	Yes	Yes	
VC032	Unsplit continuous core	3.00-4.00 m	Yes	Yes	The uppermost 3 m of core comprised marine sands so were not requested for Stage 2 geoarchaeological recording
	Unsplit continuous core	4.00-5.00 m	Yes	Yes	
VC039	Unsplit continuous core	2.00-3.00 m	Yes	Yes	The uppermost 2 m of core comprised marine sands so were not requested for Stage 2 geoarchaeological recording
	Unsplit continuous core	3.00-3.75 m	Yes	Yes	
VC047	Unsplit continuous core	0.00-1.00 m	Yes	Yes	n/a
	Unsplit continuous core	1.00-2.00 m	Yes	Yes	
	Unsplit continuous core	2.00-3.00 m	Yes	Yes	
	Unsplit continuous core	3.00-4.00 m	Yes	Yes	
	Unsplit continuous core	4.00-5.00 m	Yes	Yes	
	Unsplit continuous core	5.00-5.30 m	Yes	Yes	

[1] Section provided by geotechnical contractor. Note these sections were available at time of Stage 2 recording but these sections may have subsequently been destroyed or disturbed through geotechnical testing.

Appendix 3

BH/VC	Section/sample (mbsf)	Depth (mbsf)		Description	Depositional Environment	Geological Unit	Litho-stratigraphic Unit
		From	To				
VC16	0.00-1.00	0.00	0.16	Olive brown 2.5Y 4/3 medium to coarse SAND with frequent shell fragments including some intact bivalves. Gradual lower boundary.	Marine	Holocene post-transgression	Unit 5
		0.16	0.23	Dark grey (2.5Y 4/1 medium SAND with dark grey mottles and occasional shell fragments. Gradual lower boundary.	Marine		
		0.23	0.63	Very dark greenish grey GLEY1 3/1 silty fine to medium SAND with occasional black mottles and shell fragments of granule to pebble size. Gradual lower boundary.	Shallow marine, coastal, intertidal or fluvial	Holocene pre-transgression or Upper Brown Bank	Undifferentiated
		0.63	0.70	Very dark greenish grey GLEY1 3/1 silty clayey fine to medium SAND with occasional black mottles and shell fragments of granule to pebble size. Gradual lower boundary.			
		0.70	1.00	Very dark greenish grey GLEY1 3/1 fine silty SAND with very closely spaced fine laminations of silt and organic silt. Rare shell fragments and grey mottles.			
	1.00-2.00	1.00	1.60	Very dark greenish grey GLEY1 3/1 silty fine SAND with rare shell fragments and occasional darker brown mottles of fibrous organic material. Gradual lower boundary.			
		1.60	2.00	Very dark greenish grey GLEY1 3/1 slightly sandy SILT with occasional dark grey mottles and very closely spaced fine laminations. Rare organic silt laminations.	Lagoonal to intertidal	Upper Brown Bank	Unit 3
	2.00-3.00	2.00	3.00	Very dark bluish grey GLEY2 3/1 very clayey SILT. Closely spaced very fine laminations of silt and fine sand. Sandier at top becoming more clayey after 2.40 mbsf.			
	3.00-4.00	3.00	3.18	Greenish black GLEY2 2.5/1 slightly clayey sandy SILT. Very fine closely spaced laminations with rare shell fragments. Occasional organic sand partings and rare plant fragments (roots).			
		3.18	3.68	Greenish black GLEY2 2.5/1 slightly clayey slightly sandy SILT with sub-horizontal laminations. Some evidence of vertical faults in deposit that formed post deposition. Sharp lower boundary.			
		3.68	4.00	Greenish black GLEY2 2.5/1 slightly clayey slightly sandy SILT with vertical laminations. Deposit appears reworked/deformed.			

BH/VC	Section/sample (mbsf)	Depth (mbsf)		Description	Depositional Environment	Geological Unit	Litho-stratigraphic Unit
		From	To				
VC016	4.00-5.00	4.00	5.00	Bluish black GLEY2 2.5/1 to very dark greenish grey GLEY1 3/1 interbedded very clayey SILT and very silty CLAY. Silt beds comprise very closely spaced fine laminations of fine sand. Discrete beds (<3 cm thick) of black organic sand present at 4.40 and 4.59 mbsf. Deposit becomes more silty towards the base. Possible wavy bedding observed with evidence of bioturbation.	Lagoonal to intertidal	Upper Brown Bank	Unit 3
	5.00-5.75	5.00	5.75	Bluish black GLEY2 2.5/1 slightly sandy silty CLAY with rare shell fragments. Clay comprises discrete beds of very fine closely spaced silt and very fine sand laminations with rare organic silt laminations. Beds are widely spaced (>5 cm). Possible evidence of burrowing.			

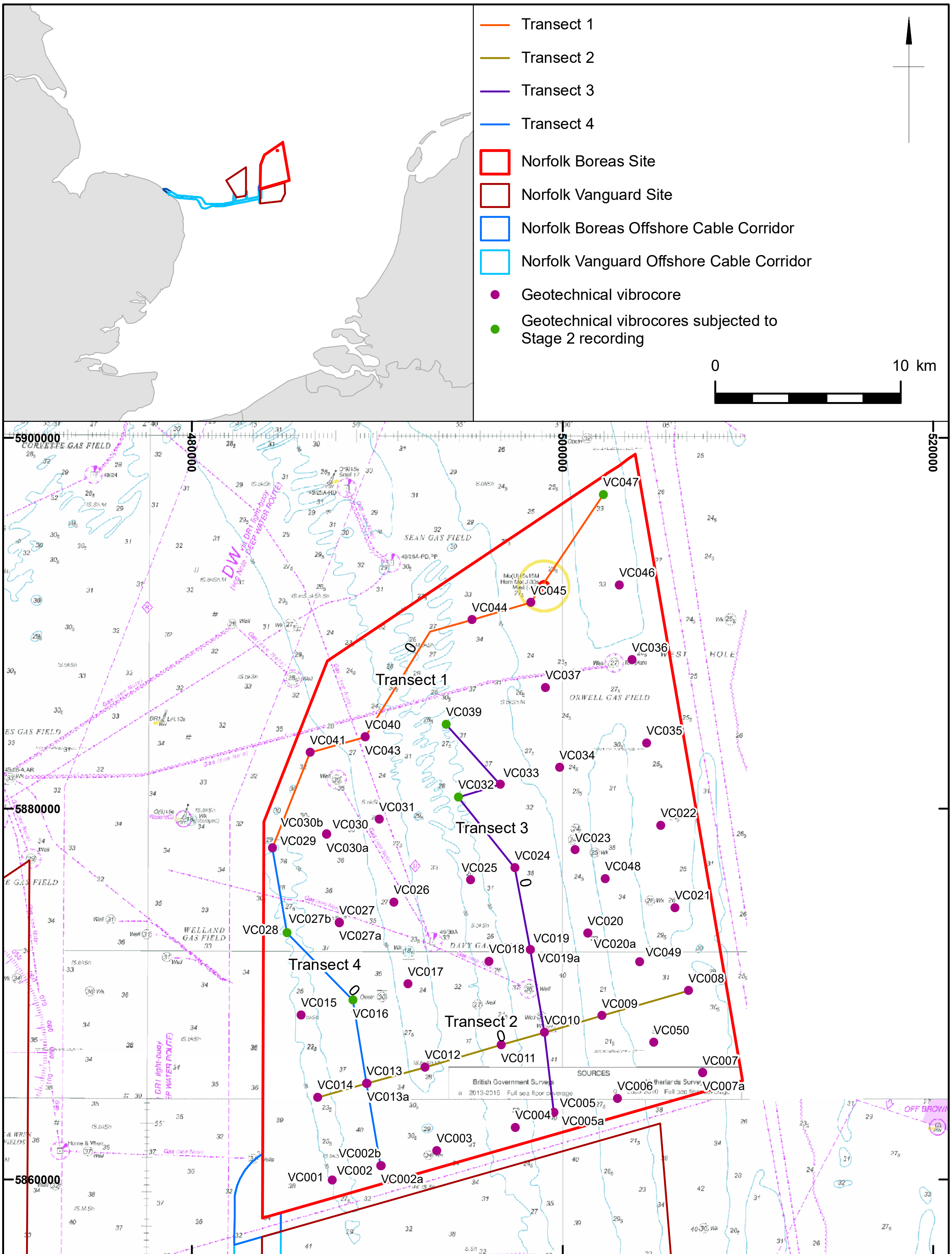
BH/VC	Section/sample (mbsf)	Depth (mbsf)		Description	Depositional Environment	Geological Unit	Litho-stratigraphic Unit
		From	**To**				
VC28	2.00-2.65	2.00	2.32	Olive brown 2.5Y 4/4 medium to coarse SAND with frequent shell fragments including some intact whole bivalves and rare black organic mottles. Sharp lower boundary.	Marine	Holocene post-transgression	Unit 5
		2.32	2.48	Black 10YR 2/1 dense/compact PEAT. Very strongly decomposed amorphous. Occasional inclusions/beds of dark grey 2.5Y 4/1 shelly medium sand at 2.38, 2.40, 2.43 and 2.48 mbsf. Gradual lower boundary.	Terrestrial. Sand intraclasts/beds appear reworked into the peat indicating possible higher energy events.	Holocene pre-transgression	Unit 4b
		2.48	2.65	Black 10YR 2/1 dense/compacted PEAT. Moderately decomposed. Appears laminated/bedded with occasional wood fragments becoming sandy near the base. Sharp lower boundary.	Terrestrial		
	2.65-3.10	2.65	2.67				
		2.67	2.72	Very dark greyish brown 2.5Y 3/2 very sandy SILT with very closely spaced fine laminations and rare plant fragments. Sharp lower boundary.	Coastal, estuarine, intertidal, alluvial or fluvial	Holocene pre-transgression	Unit 4a
		2.72	3.10	Bluish grey GLEY2 5/1 fine SAND with no apparent structure and occasional orange brown mottles. Between 2.72 and 2.87 mbsf evidence of fine roots extending down from the overlying silt.			

BH/VC	Section/sample (mbsf)	Depth (mbsf)		Description	Depositional Environment	Geological Unit	Litho-stratigraphic Unit
		From	**To**				
VC32	3.00-4.00	3.00	3.38	Dark grey 5Y 4/1 well sorted medium SAND with frequent shell fragments of granule to pebble size. Gradual lower boundary.	Marine	Holocene post-transgression	Unit 5
		3.38	3.51	Dark greyish brown 10YR 4/2 silty fine SAND with frequent intact shells of granule size. Becomes siltier at base. Gradual lower boundary.			
		3.51	3.54	Dark greyish brown 10YR 4/2 broken SHELL in a silty matrix. Shells are intact bivalves.	Shallow marine to littoral, possibly ravinement surface		
		3.54	3.67	Very dark greyish brown 10YR 3/2 SILT with very closely spaced fine laminations of fibrous organic material. Shows evidence of cross bedding. Frequent intact shells of granule size. Gradual lower boundary.	Intertidal	Holocene pre-transgression	Unit 4c
		3.67	3.80	Dark greyish brown 10YR 3/2 silty CLAY with occasional shell fragments. No apparent structure. Sharp lower boundary.			
		3.80	3.85	Very dark brown fibrous PEAT with frequent roots, leaves and seeds (bog weed) preserved. Weakly decomposed. Gradual lower boundary.	Terrestrial	Holocene pre-transgression	Unit 4b
		3.85	4.00	Very dark brown 2.5YR 2.5/2 dense/compact PEAT almost completely decomposed with some lighter brown mottling.			
	4.00-4.65	4.00	4.12	Black 10YR 2/1 dense/compact PEAT. Moderately decomposed with frequent reeds. Gradual lower boundary.			
		4.12	4.14	Dark greyish brown 10YR 4/2 organic sandy SILT with frequent plant fragments. Sharp lower boundary.	Coastal, estuarine, intertidal, alluvial or fluvial	Holocene pre-transgression	Unit 4a
		4.14	4.40	Dark grey GLEY1 4/N becoming dark greenish grey GLEY1 4/1 fine SAND with occasional plant fragments (reeds?). Gradual lower boundary.			
		4.40	4.59	Greenish grey GLEY1 5/1 fine SAND with closely spaced fine organic silt laminations and occasional mottles around roots/leaves			
		4.59	4.65	No recovery			

BH/VC	Section/sample (mbsf)	Depth (mbsf)		Description	Depositional Environment	Geological Unit	Litho-stratigraphic Unit
		From	To				
VC39	2.00-3.00	2.00	2.47	Grey 2.5Y 5/1 fine SAND with occasional shell fragments of granule to pebble size some intact bivalves preserved and occasional black minerogenic fragments. Gradual lower boundary.	Marine	Holocene post-transgression	Unit 5
		2.47	2.93	Grey 2.5Y 5/1 clayey silty fine SAND with frequent shell fragments. Sharp lower boundary.			
		2.93	3.00	Very dark brown 10YR 2/2 compact/dense PEAT very strongly decomposed with rare wood fragments and possible reeds preserved.	Terrestrial	Holocene pre-transgression	Unit 4b
	3.00-3.75	3.00	3.10	Black 10YR 2/1 compact/dense PEAT very strongly decomposed with possible laminations of reeds preserved. Gradual lower boundary.		Holocene pre-transgression	
		3.10	3.29	Dark greenish brown 10YR 4/2 silty fine SAND slightly organic with occasional root and plant fragments including seeds (bog weed). Rare shell fragments and lighter brown mottling.	Coastal, estuarine, intertidal, alluvial or fluvial	Holocene pre-transgression	Unit 4a
		3.29	3.67	Dark grey 10YR 4/1 fine to medium well sorted SAND with occasional plant fragments and dark brown mottles and shell fragments of granule size.		Holocene pre-transgression	

BH/VC	Section/sample (mbsf)	Depth (mbsf)		Description	Depositional Environment	Geological Unit	Litho-stratigraphic Unit
		From	To				
VC47	0.00-1.00	0.00	0.10	No recovery			
		0.10	0.32	Light olive brown 2.5Y 5/4 slightly silty fine SAND with occasional shell fragments and dark brown mottles. Gradual lower boundary.	Marine	Holocene post-transgression	Unit 5
		0.32	1.00	Greyish brown 2.5Y 5/2 silty fine SAND with frequent shell fragments.			
	1.00-2.00	1.00	1.10	Greyish brown 2.5Y 5/2 silty fine SAND with occasional shell fragments. Gradual lower boundary.			
		1.10	1.18	Light brownish grey 2.5Y 6/2 fine to coarse SAND with frequent shell fragments. Gradual lower boundary.			

BH/VC	Section/sample (mbsf)	Depth (mbsf)		Description	Depositional Environment	Geological Unit	Litho-stratigraphic Unit
		From	To				
VC47	1.00-2.00	1.18	1.52	Very dark greenish grey GLEY1 3/1 silty fine SAND with occasional shell fragments. Gradual lower boundary.	Marine	Holocene post-transgression	Unit 5
		1.52	2.00	Dark greenish grey GLEY1 4/1 slightly silty CLAY with occasional dark greenish grey fine sand lenses that comprise frequent shell fragments	Shallow marine, coastal, intertidal or fluvial	Holocene pre-transgression or Upper Brown Bank	Undifferentiated
	2.00-3.00	2.00	2.19	Dark greenish grey GLEY1 4/1 slightly silty CLAY. Appears structureless. Gradual lower boundary.			
		2.19	2.41	Dark greenish grey GLEY2 4/1 silty fine SAND with frequent shell fragments. No obvious structure. Sharp lower boundary.			
		2.41	3.00	Dark greenish grey GLEY2 3/1 very silty CLAY with very closely spaced fine laminations and occasional dark grey fine sand partings.	Lagoonal to intertidal	Upper Brown Bank	Unit 3
	3.00-4.00	3.00	4.00	Very dark greenish grey GLEY2 3/1 very silty CLAY. Very fine closely spaced laminations. Occasional dark grey mottles.			
	4.00-5.00	4.00	4.56	Very dark greenish grey GLEY2 3/1 very silty CLAY. Very fine closely spaced laminations. Occasional dark grey mottles. A vertical fault structure runs through the core. Gradual lower boundary.			
		4.56	4.70	Very dark greenish grey GLEY2 3/1 sandy silty CLAY. Very fine closely spaced laminations. Occasional dark grey mottles. Gradual lower boundary.			
		4.70	5.00	Very dark greenish grey GLEY2 3/1 silty CLAY. Very fine closely spaced laminations. Occasional dark grey mottles.			
	5.00-5.30	5.00	5.30	Very dark bluish black GLEY2 3/1 very silty slightly sandy CLAY with very fine closely spaced laminations.			



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Coordinate system:
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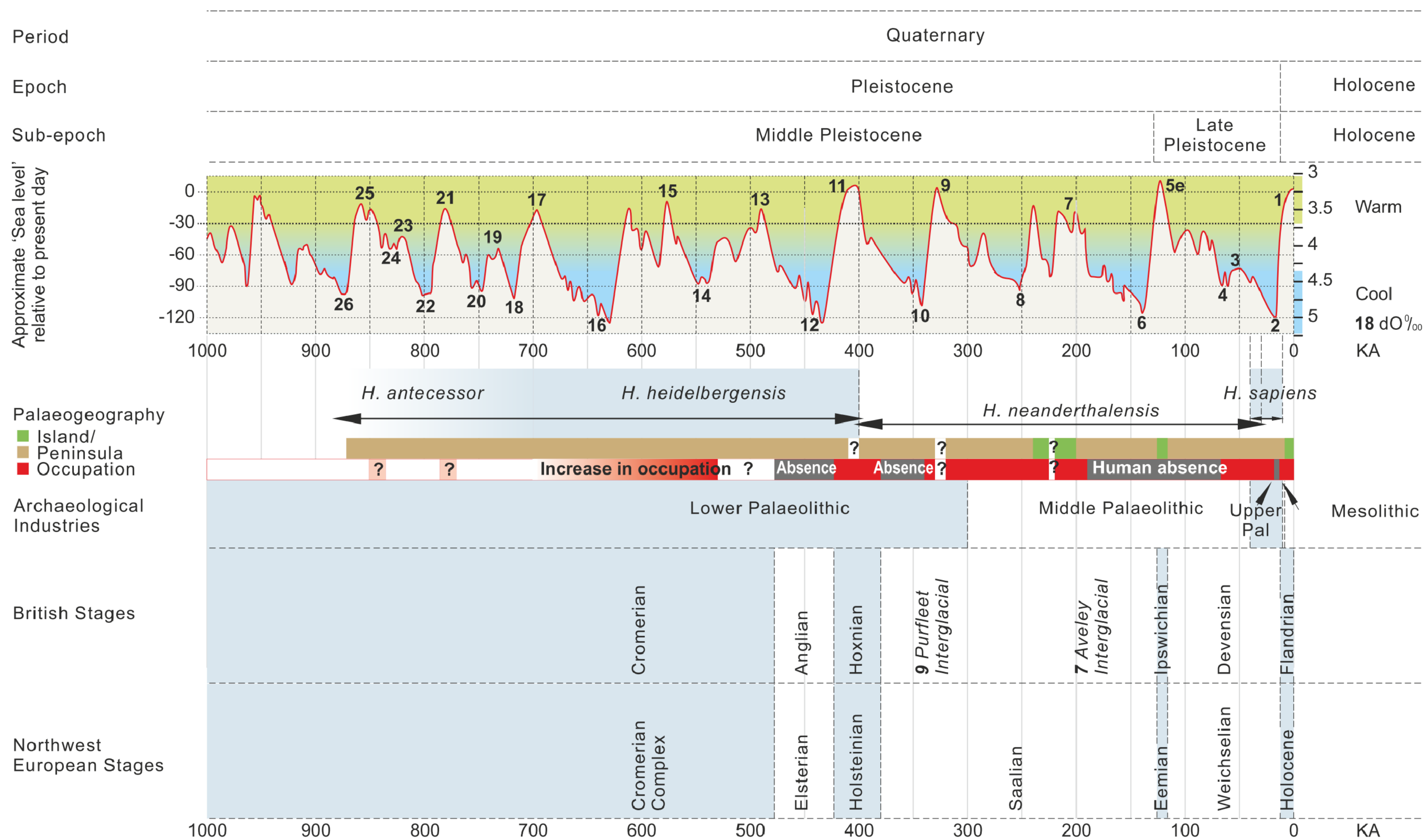
Site location

Figure 1



The figure presents information derived from several references: the global sea-level curve is from Lisiecki and Raymo (2005) and Jelgersma (1979). Details on the geology and archaeology were provided by Dix and Westley (2004); Funnel (1995); Gibbard and van Kolfschoten (2004); Kukla et al. (2002); Lee et al. (2006); Lowe and Walker (1997) and Wymer (1999).

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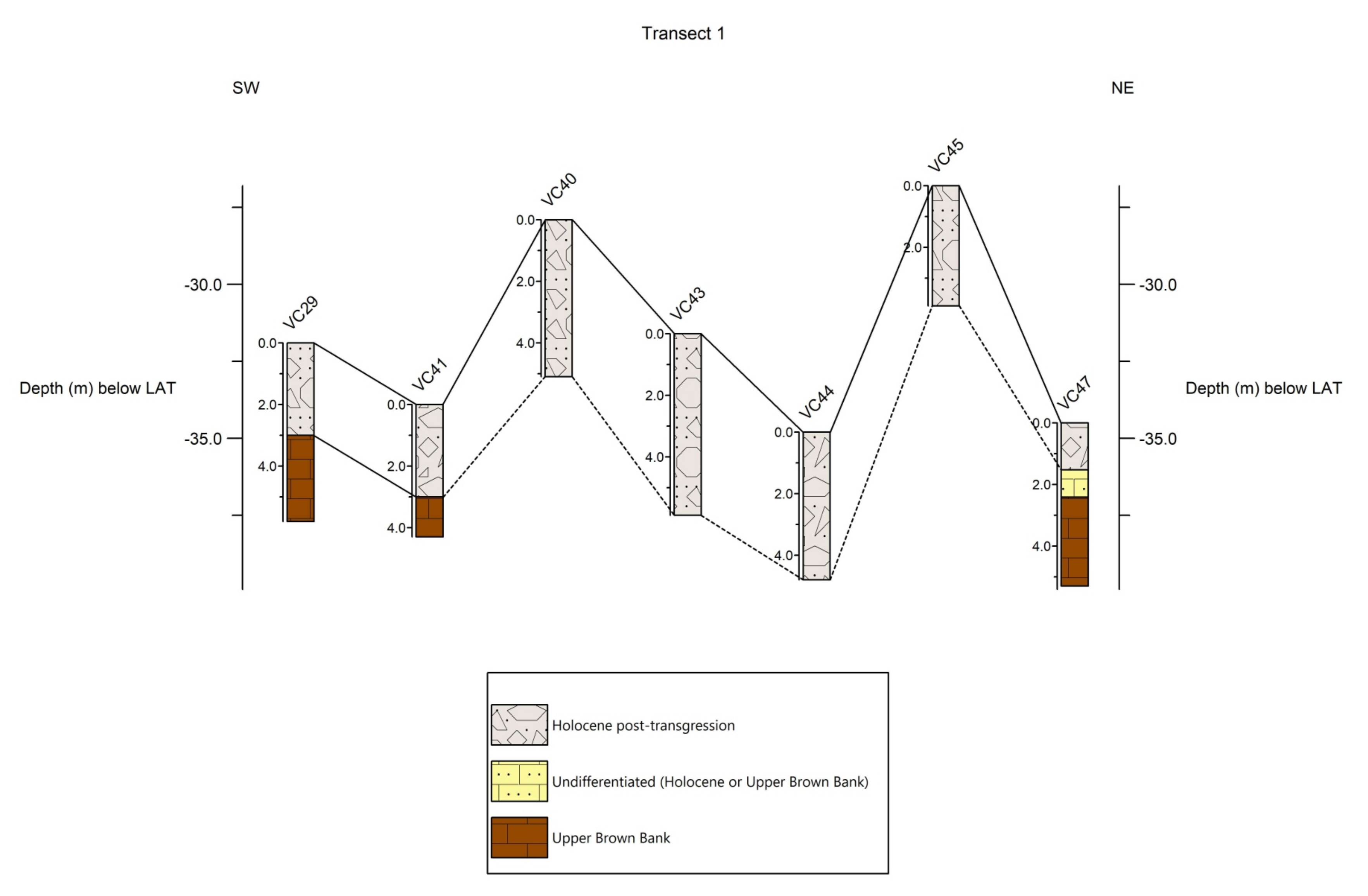
Chronostratigraphic timeline for the last 1 million years

Figure 2



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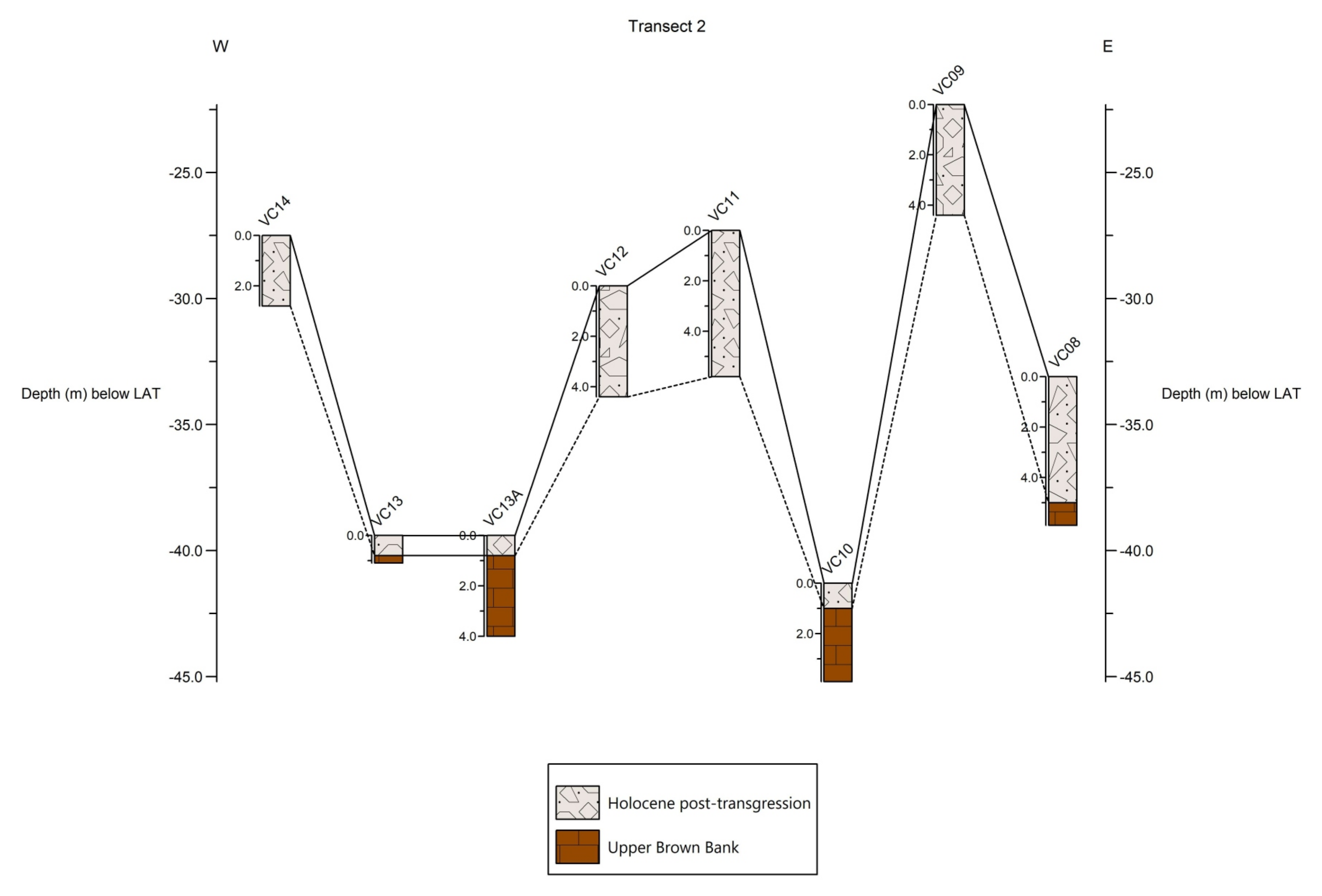
Transect 1

Figure 3



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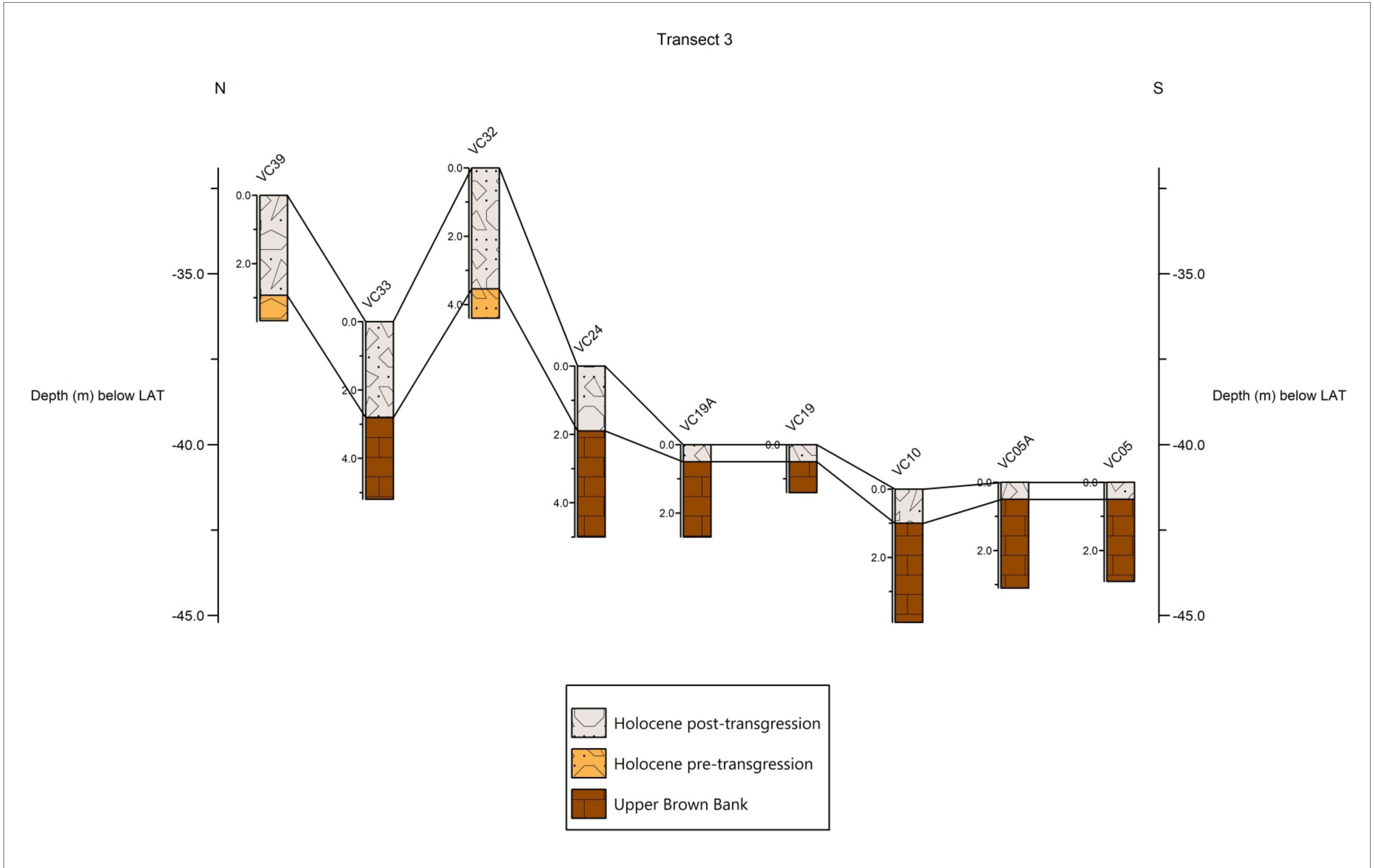
Transect 1

Figure 4



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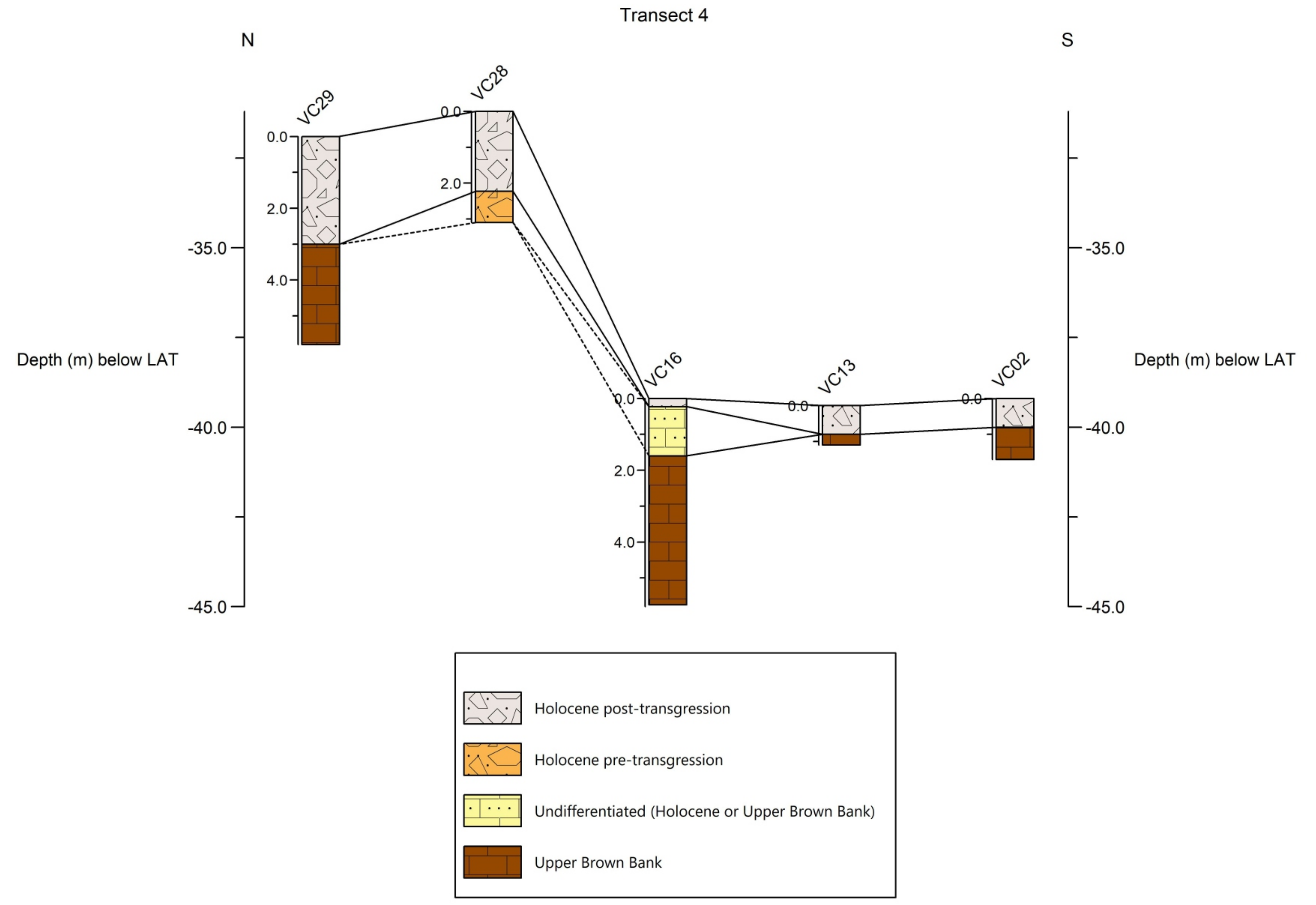
Transect 2

Figure 5



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Transect 3

Figure 6

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