Norfolk Vanguard Offshore Wind Farm

Appendix 17.3

Stage 2 Geoarchaeological Reporting

Environmental Statement

Volume 3 - Appendices

Applicant: Norfolk Vanguard Limited
Document Reference: 6.2.17.3
RHDHV Document Reference: PB4476-005-0173
Pursuant to APFP Regulation: 5(2)(a)

Date: June 2018
Revision: Version 1
Author:

Photo: Kentish Flats Offshore Wind Farm

Environmental Impact Assessment
Environmental Statement

Document Reference: PB4476-005-0173

June 2018

For and on behalf of Norfolk Vanguard Limited

Approved by: Ruari Lean, Rebecca Sherwood

Signed: [redacted]

Date: 8th June 2018

Norfolk Vanguard Offshore Wind Farm

Stage 2 Geoarchaeological Recording

Ref: 112380.03
March 2018

wessexarchaeology

Portway House
Old Sarum Park
Salisbury
Wiltshire
SP4 6EB

www.wessexarch.co.uk

Vanguard Offshore Wind Farm

Stage 2 Geoarchaeological recording and deposit modelling

Prepared for:
Royal HaskoningDHV
Rightwell House
Bretton
Peterborough
PE3 8DW

Prepared by:
Wessex Archaeology
Portway House
Old Sarum
Salisbury
SP4 6EB

www.wessexarch.co.uk

March 2018

Report Ref 112380.03

Quality Assurance

Project Code	112380	**Accession Code**		**Client Ref.**	
Planning Application Ref.		**Ordnance Survey (OS) national grid reference (NGR)**			

Version	Status*	Prepared by	Checked and Approved By	Approver's Signature	Date
v01	E	*Alex Brown*	*DRN*	[redacted]	13/10/17
File:	W:\Projects\112380_Reports\112380_Vanguard_Stage 2				
V02	F	*Alex Brown*	*DRN*	[redacted]	01/11/17
File:	W:\Projects\112380_Reports\112380_Vanguard_Stage 2_v2_Nov2017				
	F	*Alex Brown*	*DRN*	[redacted]	20/02/18
File:	W:\Projects\112380_Reports\Submitted\112380_Vanguard_Stage 2_Feb18				
V03	F	*Alex Brown*	*DRN*	[redacted]	19/03/18
File:	W:\Projects\112380_Reports\Submitted\112380_Vanguard_Stage 2_v3				
V03	F	*Alex Brown/ Claire Mellett*	*DRN*	[redacted]	23/03/18
File:	W:\Projects\112380_Reports\Submitted\112380_Vanguard_Stage 2_v3				

* I = Internal Draft; E = External Draft; F = Final

Vanguard Offshore Wind Farm

Stage 2 Geoarchaeological recording and deposit modelling

Contents

Figures

Tables

Vanguard Offshore Wind Farm

Stage 2 Geoarchaeological recording and deposit modelling

Summary

Wessex Archaeology (WA) have been commissioned by Royal HaskoningDHV to undertake a Stage 2 geoarchaeological recording and deposit modelling of geotechnical logs in support of the proposed Norfolk Vanguard East (NV East) and Norfolk Vanguard West (NV West) Offshore Wind Farm (OWF).

The Stage 2 work forms part of ongoing investigations in advance of the proposed wind farm development, located in the southern North Sea basin, 47 km (NV West) and 89 km (NV East) east of Bacton, north Norfolk, respectively. The proposed offshore cable corridor (OCC) extends from the Norfolk coast near Happisburgh for 90 km to NV West and 100km to NV East.

Twenty-three vibrocore sequences were identified for Stage 2 geoarchaeological recording with very high (**VC074, VC076 VC085**) high (**VC079, VC089, VC095, VC101, VC107 and VC116**) and medium (**VC070, VC075, VC080, VC081, VC084, VC086, VC088, VC092, VC97 VC103, VC104, VC117, VC118** and **VC119**) geoarchaeological potential.

An outline stratigraphic model for the site includes eight key stratigraphic units, comprising Pliocene-Lower Pleistocene (**Unit 1**), Lower-Middle Pleistocene (**Unit 2**) and Anglian (**Unit 3**) deposits of limited geoarchaeological potential. **Unit 4** is either Ipswichian or Lower Devensian date related to the Eem or Lower Brown Bank Formation (**Unit 4**). **Unit 1** to **Unit 4** were too deeply buried to be present in the vibrocores. **Unit 5** corresponds to the Brown Bank Formation, considered to represent a shallow lagoon environment. It is uncertain whether the lagoon sediments formed during the early Devensian, or over a longer period into the late Devensian. It is possible that the lagoon may have dried up, exposing sediment to erosion and wind. **Unit 6** corresponds to the Twente Formation, representing a thin deposit of periglacial windblown sand up to 1m thick tentatively identified in areas across NV West. In places **Unit 5** and **Unit 6** are overlain by Holocene peat and alluvium (**Unit 7**), in cases also preserved in pre-transgression palaeochannels (e.g. **VC074**). Post-transgression marine sands (**Unit 8**) represent the final marine inundation of the site.

Stage 3 palaeoenvironmental assessment is recommended on vibrocores **VC074**, **VC076**, **VC079**, **VC085** and **VC107**, focusing on **Unit 5, 6** and **7** of greatest geoarchaeological potential. Stage 3 work will comprise OSL dating of **Unit 5** in vibrocores **VC079** and **VC107**, in order to determine the depositional history of the Brown Bank Formation and refine our understanding of the archaeological and geoarchaeological potential of this unit. Palaeoenvironmental assessment and radiocarbon dating is recommended on Holocene peat and alluvial sediments (**Unit 7**) in vibrocores **VC074**, **VC076** and **VC085**. The peat and over/underlying minerogenic deposits have the greatest potential for radiocarbon dating and are most likely to preserve the widest range of palaeoenvironmental remains (pollen, diatoms, foraminifera, ostracods), providing data on past landscape and environmental change and evidence for human activity and impact. Limited assessment is also recommended on **Unit 6** to determine whether these deposits represent aeolian sands tentatively recorded across the site.

The geoarchaeological potential of the Vanguard OWF site lies in the deposits of the Upper Brown Bank (**Unit 5**) distributed widely across NV East, NV West the OCC, **Unit 6** (Twente Formation) of possible aeolian origin identified across NV West, and deposits of peat (**Unit 7**) contained within

channels and sealing the Upper Brown Bank and Twente Formation across NV West and parts of the OCC. Overall, the deposits of **Units 5, 6 and 7** contain the greatest archaeological potential to understand the physical development of the landscape, reconstruct patterns of environmental change and investigate evidence for potential human activity and human-environment relationships.

Vanguard Offshore Wind Farm

Stage 2 Geoarchaeological recording and deposit modelling

Acknowledgements

This work was commissioned by Royal HaskoningDHV. The report was compiled by Dr. Alex Brown. Illustrations were prepared by Nancy Dixon. The project was managed on behalf of Wessex Archaeology by Dan Atkinson and David Norcott.

Vanguard 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 to undertake a Stage 2 geoarchaeological recording and deposit modelling of geotechnical logs in support of the proposed Norfolk Vanguard Offshore Wind Farm (**Figure 1**).

1.1.2 Norfolk Vanguard comprises two distinct areas, Norfolk Vanguard West (NV West) and Norfolk Vanguard East (NV East) ("the Offshore Wind Farm (OWF) sites"). An offshore cable corridor joins the OWF sites to the landfall at Happisburgh South.

1.1.3 The Stage 2 work forms part of ongoing investigations in advance of the proposed wind farm development, located in the southern North Sea basin, 47 km (NV West) and 89 km (NV East) east of Bacton, north Norfolk, respectively. The proposed offshore cable corridor extends from the Norfolk coast near Happisburgh for 90 km to NV West and 100km to NV East (**Figure 1**).

1.1.4 The location of the proposed wind farm and cable corridor are of particular prehistoric archaeological interest, located in an area that at the height of the last ice age formed part of a vast habitable plain connecting Britain with the rest of the European continent. This landscape was then progressively drowned by rising post-glacial sea-levels with full marine conditions occurring across the southern North Sea basin by ca. 7000 BP.

1.1.5 An initial Stage 1 geoarchaeological review of vibrocore logs from 65 locations identified twenty-three vibrocore sequences with very high (**VC074, VC076 VC085**) high (**VC079, VC089, VC095, VC101, VC107 and VC116**) and medium (**VC070, VC075, VC080, VC081, VC084, VC086, VC088, VC092, VC97 VC103, VC104, VC117, VC118 and VC119**) geoarchaeological potential (Wessex Archaeology, 2017a). The vibrocore sequences are subjected to Stage 2 geoarchaeological recording, along with deposit modelling of these and other relevant geotechnical records from the site, with recommendations made for Stage 3 palaeoenvironmental assessment where considered appropriate.

1.2 Scope of report

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: Stages of geoarchaeological assessment and recording.

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 geology of the area has been outlined as part of an earlier palaeogeographic assessment of the study area (Wessex Archaeology, 2017b), combining a review of the, geotechnical, geophysical and known geological data. This identified a series of geological units across the broader area, outlined in **Table 2,** and shown in **Figures 2-7**.

2.1.2 The Geological Units identified by Wessex Archaeology are listed against the corresponding units identified by Fugro (2017c). It should be noted that Fugro used deeper digital seismic data which will have aided interpretation of deeper units such as Westkapelle Ground Formation; the Wessex stratigraphic units by comparison were interpreted using shallow

analogue sub-bottom profiler data and as such there was less confidence in interpreting those deeper units identified by Fugro.

2.1.3 Geotechnical investigations, comprising both **CPT** (cone penetrometer tests) and **VC** (vibrocore) operations, were undertaken by Fugro EMU Limited, with onshore laboratory and reporting undertaken by Fugro GeoConsulting Limited (Fugro, 2017a). Wessex Archaeology subsequently undertook an initial geoarchaeological review of geotechnical logs (Wessex Archaeology 2017a) prior to the current report.

2.1.4 Geophysical survey data was acquired in 2012 by Emu Limited (NV East) (Emu Ltd, 2013), and in 2016 by Fugro Survey B. V. (NV West and OCC) (Fugro, 2016, 2017b, 2017c), and subsequently reviewed by Wessex Archaeology as part of a palaeogeographic assessment of geophysical data within the Norfolk Vanguard OWF area (Wessex Archaeology, 2017b).

Table 2: Geological units of geoarchaeological potential identified within the Vanguard region (after Wessex Archaeology, 2017b). Geological units identified by Wessex Archaeology are accompanied by corresponding units identified by Fugro (Fugro, 2017c)

WA Unit	Fugro Unit	Geological Unit	Age	Geoarchaeological potential
8	A1	Holocene seabed sediments	Post-transgression (MIS 1)	Gravelly sand with shell fragments, sand waves and ripples indicate sediment is mobile. Low potential in areas of mobile sediment: basal contact may cover old land surfaces.
7	A2	Holocene sediments	Pre-transgression (MIS 2–1)	Fluvial, estuarine and terrestrial (including peat) deposits. Shallow infilled depressions or channels with potential for preserved organic material of palaeoenvironmental significance.
6	B	Twente Formation	Upper Devensian (MIS 2)	Thin layer of aeolian periglacial sand. Potential to contain in-situ and derived archaeological and palaeoenvironmental material
5	C	Upper Brown Bank Formation	Early/Mid Devensian (MIS 5d–3)	Clayey silty sand infilling channels or hollows and deposited in an intertidal/lagoon environment. Potential for *in-situ* Lower Palaeolithic artefacts. Middle Palaeolithic artefacts may be associated with channel edges dependent on age of infill. Basal contact may cover old land surface
4	C / D	Lower Brown Bank Formation / Eem Formation	Ipswichian or Lower Devensian (MIS 5e–5d)	Silty sand and sandy silt. Possible intertidal or shallow marine deposit. In-situ Lower Palaeolithic artefacts may be protected. Middle Palaeolithic artefacts may be associated with channel edges dependent on age of infill. Basal contact may cover old land surface
3	E	Swarte Bank Formation	Anglian (MIS 12)	Silty sandy clays associated with the Anglian glaciation. Unlikely to contain archaeological material.

2	F	Yarmouth Formation	Lower to Middle Pleistocene (MIS >13)	Silty sand with occasional shell fragments, deposited as part of marine delta complex. Low potential, unlikely to contain archaeology or deposits of palaeoenvironmental significance.
1	I	Westkapelle Ground Formation	Pliocene – Lower Pleistocene (MIS 103-63)	Deltaic silty clays and sands. Pre-date earliest occupation; of no archaeological interest

2.1.5 Where age estimates are available these are expressed in millions of years (MA), thousands of years (Ka), and within the Holocene epoch as years before present (BP). These dates are supplemented, where known, with the comparable Marine Isotope Stage (MIS) where odd numbers indicate an interglacial period and numbers a glacial period.

2.1.6 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.

2.1.7 Only one glacial episode is thought to have affected the southern North Sea during the Anglian period (ca. 480–423ka), although subsequent glacial episodes will have affected the region as a result of changing sea-levels. The exact southern extent of the Anglian glaciation is debated, although bathymetric data suggests part of the Anglian ice sheet may have extended as far south as offshore Felixstowe (Emu, 2009).

2.1.8 Palaeolandscape features are more likely to be preserved off the East Anglian coast as the area has only experienced one glacial advance. Further to the north (north of the North Norfolk coast) similar palaeolandscape features are likely to have been removed during the subsequent Saalian and Devensian glacial advances.

2.1.9 Geophysical and geotechnical data have been used to devise a basic stratigraphy for the study area, comprising eight units covering the Pleistocene and Holocene (**Table 2**). These comprise both terrestrial and fluvial sediments associated with palaeochannels, floodplains, periglacial aeolian deposits, lagoon and lacustrine environments.

2.1.10 **Unit 1** pre-dates the earliest human occupation of Britain and is unlikely to contain archaeological or palaeoenvironmental remains, and is therefore of limited geoarchaeological relevance. **Unit 2** is contemporary with the terrestrial Cromer Forest Bed Formation (> MIS 13) which has produced some of the earliest evidence for the hominin occupation of Britain (Parfitt *et al*. 2010, Ashton *et al*. 2014). **Unit 3** deposits are associated with the Anglian glaciation and therefore unlikely to contain archaeological material. **Unit 3** has not been definitely recognised on geophysical data within the NV OWFs (Fugro 2017c; WA 2017b).

2.1.11 **Unit 4** is of uncertain age, but may contain either the Eem Formation, dating to the Ipswichian, or Lower Brown Bank Formation deposits of Lower Devensian Age (Cameron *et al.* 1992). The Eem Formation is described as shelly and muddy sands representing a shallow marine/intertidal environment, whilst the Upper Brown Bank Formation comprises clayey silts and sands infilling channels and/or hollows, deposited within an intertidal/lagoon environment. **Unit 4** has only been sporadically identified in NV West compared to NV East, and tentatively identified in some areas of the OCC (**Figures 2-4**).

2.1.12 Humans were absent from the area during the development of the Eem and Lower Brown Bank Formations (**Unit 4**), although the geoarchaeological potential of the Upper Brown

Bank Formation (**Unit 5**) is considered to be higher, although variable, dependent on the presence/absence of suitable features. **Unit 5** is present as a blanket deposit across the whole of NV East and NV West, and is interpreted as a shallow lagoon environment, comprising clayey silty sands. The presence of organic material within the sediment has been suggested in places by accumulations of shallow gas revealed during geophysical surveys. A number of internal features have been identified within **Unit 5** that have been interpreted as possible internal erosion surfaces. It is possible that the lagoon may have periodically dried up, exposing previously submerged sediment as dryland and resulting in the observed internal erosion surfaces. **Unit 5** becomes more intermittent along the OCC and is absent from approximately 30km from landfall (**Figure 4**).

2.1.13 The geophysical surveys hint at a complex deposition history for **Unit 5**, suggesting a multi-period, multi-phase unit rather than continuous deposition of lagoon sediment; this has implications for the archaeological potential of the deposits.

2.1.14 The Upper Brown Bank Formation is overlain across NV East by recent post-transgression sea bed sediments (**Unit 8**), varying in thickness from a thin veneer to sand banks up to 15m thick.

2.1.15 Overlying the Upper Brown Bank Formation in some areas is the Twente Formation (**Unit 6**), comprising a thin deposit of sand up to 1m thick and interpreted as a periglacial aeolian (windblown) sand deposit of Upper Devensian age. **Unit 6** has been tentatively identified in vibrocores **VC075**, **VC076** and **VC088** but has not been identified along the OCC (**Figure 2** and **4**). The extent of the Twente Formation shown on **Figure 3** is based on BGS data as it could not be confidently identified on the seismic data (Fugro, 2017b).

2.1.16 **Unit 6** would have formed after the retreat of the Devensian ice sheet, with wind transporting loose sediment southward across the largely unvegetated periglacial landscape. Similar windblown sands (also called coversands) have been found across East Anglia and continental Europe (Crombe *et al.* 2012). In places these form small dune ridges within low-lying wetland landscapes that would have been favourable locations for settlement with potential for recovery of *in situ* archaeological material.

2.1.17 Overlying the Pleistocene sediments is a sequence of early Holocene deposits (**Unit 7** and **Unit 8**). Surveys and coring in this area have identified terrestrial deposits, including peat, which are thought to have been deposited prior to and during the early-mid Holocene marine transgression of the southern North Sea basin. The peat deposits form either on the top of the Upper Brown Bank Formation, on top of windblown sands, or within Holocene channels, all indicated on the geophysical surveys, and in the former two as areas of high amplitude reflectors (**Figure 3**). In the latter case, geophysical surveying identified 12 pre-transgression shallow channel features, some also corresponding with high amplitude features (e.g. channel 75112, **Figure 3**). Some of these cores appear to show a gradual upward transition from saltmarsh to peat (**VC085**), in turn sealed by muds (classified together as **Unit 7**), providing evidence of the progressive inundation of terrestrial landscapes as a result of rising post-glacial sea-levels (Cooper *et al.* 2008). Where peat deposits are preserved on the top of the Upper Brown Bank Formation these may equally indicate peat formation during the Late Devensian. These deposits, and particularly the peat, are of high palaeoenvironmental potential.

2.1.18 The progressive inundation of North Sea palaeolandscapes occurred over an extended time scale, with particularly rapid sea-level rise occurring during the early Holocene (11,500–7000 cal. BP) and fully marine conditions across the North Sea by probably around 6000 cal. BP (Ward *et al.* 2006). Marine sediments deposited since the Holocene transgression typically comprise sands, gravels and muds (**Unit 8**).

3 AIMS AND OBJECTIVES

3.1.1 The principal aims of the Stage 2 geoarchaeological recording of vibrocores are as follows:

- Describe retained vibrocore sequences;
- Undertake deposit modelling of described vibrocores and geotechnical logs;
- Interpret sedimentary sequences and landscape represented by retained vibrocores, geotechnical logs and deposit modelling;
- Make recommendations for further Stage 3 palaeoenvironmental assessment where appropriate, with reference to key research questions and regional/national period specific and maritime research agendas.

4 METHODS

4.1 Geoarchaeological recording of vibrocores

4.1.1 A total of **22** vibrocores were subject to Stage 2 geoarchaeological recording, located across NV West, NV East and the OCC (**Figure 2-4**), a 23rd vibrocore (**VC119**) of medium priority was not present amongst cores sent to Wessex Archaeology. An initial review and monitoring of geotechnical logging identified a series of vibrocores of very high, high, medium and low geoarchaeological priority (Wessex Archaeology, 2017a). Samples of very high and high priority were set aside for Stage 2 recording, whilst those of medium priority were opened under geoarchaeological supervision at the Fugro laboratory in Wallingford and selected samples returned to Wessex Archaeology. The vibrocores and their location are listed below in **Table 3**. The remaining low priority vibrocores were described by a suitably experienced geotechnical engineer and the logs reviewed to ensure no further geoarchaeologically significant sequences were missed.

Table 3: Vibrocores selected for Stage 2 recording. Green = very high priority, orange = high priority, blue = medium priority cores previously recorded and returned to Wessex Archaeology. * = vibrocore not present.

Vibrocore location and priority		
Norfolk Vanguard West	**Norfolk Vanguard East**	**Offshore Cable Corridor**
VC070 (2.7-2.9, 5.7-6 m)	**VC092** (2.7-3 m)	**VC116** (0-6.35 m)
VC074 (0-5.6 m)	**VC095** (0-6.30 m)	**VC117** (1-1.5 m)
VC075 (4.4-4.7 m)	**VC097** (3.7-4.5 m)	**VC118** (0.7-1.5, 3-4, 4.5-5 m)
VC076 (0-4.35 m)	**VC101** (0-6.10 m)	**VC119*** -
VC079 (0-5.25 m)	**VC103** (3-3.5, 4-4.5 m)	
VC080 (2-2.15 m)	**VC104** (2.7-3, 5.7-6 m)	
VC081 (1-2, 2.7-3 m)	**VC107** (0-6.0 m)	

VC084 (3.1-3.2 m)		
VC085 (0-5.85 m)		
VC086 (4.25-4.50 m)		
VC088 (3.25-3.6 m)		
VC089 (0-6.30 m)		

4.1.2 The vibrocores were opened in the Wessex Archaeology laboratory and described by a suitably experienced geoarchaeologist following Hodgson (1997), to include information such as:

- *Depth*
- *Texture*
- *Composition*
- *Colour*
- *Inclusions*
- *Structure (bedding, ped characteristics etc)*
- *Contacts between deposits*

4.1.3 All deposit records were made using the standard Wessex Archaeology recording system. The detailed sediment descriptions and interpretations are tabulated in the **Appendix.**

4.2 Deposit modelling

4.2.1 Deposit modelling was undertaken in addition to Stage 2 geoarchaeological recording of vibrocores. This involved the use of all available vibrocore logs and associated geotechnical records (Fugro, 2017a).

4.2.2 The large distance between vibrocores (between 2.9 and 5.9 km) and localised nature of key deposit within discrete features is not ideally suited to the creation of Digital Elevation Models (DEMs) or thickness plots. Instead a series of linear transects (**Figures 5–7**) have been constructed to provide a representative cross-section illustrating the key stratigraphic units within NV West, NV East and the OCC. Interpretation of stratigraphic units has utilised the Wessex interpreted geophysical data (Wessex Archaeology, 2017b), illustrated on **Figures 2–4**, alongside geotechnical logs (Fugro, 2017a).

4.2.3 The Wessex interpreted geophysical data is used to determine the location of borehole transects in order to capture the full range of stratigraphic units. At this stage full integration of geophysics and geotechnical data through depth conversion has not been undertaken.

5 RESULTS

5.1 Stage 2 recording, assessment and deposit modelling

5.1.1 The Stage 2 geoarchaeological recording results are summarised below, with full vibrocore descriptions presented in the **Appendix**. The acquired vibrocores vary in length, including complete unopened vibrocore sequences (up to 6.3 m), and smaller sections (0.2–0.5 m)

retained followed initial geotechnical logging and geoarchaeological monitoring at the Fugro Laboratory.

5.1.2 The results of the Stage 2 geoarchaeological recording are considered alongside the complete geotechnical dataset (Fugro, 2017a), including both **CPT** (cone penetrometer tests) and **VC** (vibrocore) logs, and Wessex interpreted geophysical data (Wessex Archaeology 2017b) (**Figures 2–4**), aiding the interpretation of palaeolandscape features and depositional processes, and in turn feeding into the identification of research questions and specific recommendations for Stage 3 palaeoenvironmental assessment.

5.1.3 The vibrocores are distributed across NV West (12), NV East (7) and the OCC (3) (**Table 3**). Every attempt has been made to assign deposits to the stratigraphic units detailed in **Table 2**. However, this hasn't been possible in all cases due to the complexity of the site and stratigraphy (comprising a range of topographic features and deposits), the large area covered by the windfarm development and the distance (3–6 km) separating individual vibrocores (**Figure 2-4**).

5.1.4 Any uncertainty as to the date and/or taphonomy of deposits serves as an opportunity to propose further works, detailed in **section 7** as part of the recommendations for Stage 3 assessment.

5.2 Vibrocore assessment

5.2.1 An outline stratigraphy has been devised for the study area comprising eight units (**Table 2**). Of these eight units, **Unit 1** to **Unit 4** are not present within the vibrocores due to the shallow depth of the samples (not exceeding a maximum depth of 6.30 m). **Unit 5,** where present**,** is also only partially represented, typically extending beyond the base of the vibrocores and reaching a maximum thickness of 17.54 m in **CPT095 (Fugro, 2017)**.

5.2.2 Of the units considered to be of geoarchaeological significance, the Stage 2 geoarchaeological recording of vibrocores has targeted **Unit 5** (Upper Brown Bank Formation) and **Unit 7** (Holocene pre-transgression sediments).

5.2.3 **Unit 4** (Eem Formation/Lower Brown Bank Formation) was considered to be too deeply buried to occur in the vibrocores. However, in **VC079**, Holocene post-transgression marine sands (**Unit 8**) are underlain by a very dark grey compact clayey silt, considered to represent the Upper Brown Bank Formation (**Unit 5**). **Unit 5** (0.30-4.55 m) in turn seals a dark grey shelly clayey sand, containing moderately poorly rounded gravels throughout, initially thought to represent Unit 4.

5.2.4 Among the retained vibrocores, similar silty fine to medium shelly sands are present in **VC077** and **VC086**, and in the geotechnical records are present in several other vibrocores (**VC092, VC098-VC100, VC111, VC114**), typically as components of the silty/sandy clay (**Unit 5**). In the geotechnical logs (Fugro, 2017a) the sediment underlying **Unit 5** is represented by a dense sand, instead considered to represent the shallow marine/lagoonal deposits of **Unit 4**. It is most likely therefore that the shelly clayey/silty sands in **VC079** represent a component of **Unit 5** rather than **Unit 4**, reflecting the internal variability and complex depositional history of the Upper Brown Bank Formation.

5.2.5 The Upper Brown Bank Formation (**Unit 5**) has been recorded in a large proportion of the vibrocores of very high (**VC074, VC085, VC089**), high (**VC079, VC095, VC101, VC107, VC116**) and medium priority (**VC070, VC084, VC092, VC097, VC103, VC104**).

5.2.6 **Unit 5** varies in composition within and across vibrocores, typically a very dark grey compact clay to clayey silt (e.g. **VC079**, **VC085**, **VC089** and **VC101**), but with varying components of fine sand (**VC070** and **VC074**), silty sand (**VC084**), clayey sand (**VC079**) sandy clay (**VC095**) and sandy-silt (**VC097** and **VC116**). Laminations are apparent in almost all vibrocores containing **Unit 5**, comprising both fine clay, silt and sand, in addition to occasional silty and sandy organic laminae (**VC086**, **VC103**, **VC107**) shelly inclusions, mottling and iron staining (**VC104**).

5.2.7 The vibrocores only include the upper portions of **Unit 5**, with the unsplit very high and high priority vibrocores containing between 3.2 m (**VC085**) to 5.2 m (**VC107**). Recording of the retained high and medium priority vibrocores (**Appendix**), along with existing CPT and vibrocore logs, (Fugro, 2017) indicate **Unit 5** varies in thickness from as little as 2.57 m (**VC088**) to 17.54 m (**CPT095**), and most often averaging between 5-9 m thick.

5.2.8 Several other vibrocores (**VC076, VC081, VC084, VC086, VC107, VC116**) include deposits of uncertain origin, but that may represent **Unit 5** (**Appendix**)**.**

5.2.9 **VC076** includes a dark grey fine sand (4.0-4.35 m) directly underlying peat, either representing the Upper Brown Bank Formation (**Unit 5**) or possibly periglacial aeolian sands of the Twente Formation (**Unit 6**), both suggested in this area on the basis of geophysical surveys (**Figure 3**). Further bands of sand are recorded in geotechnical borehole logs, including **VC076** (7.05-7.33 m) (Fugro, 2017a). These sandy bands within **Unit 5** could represent distinct phases when parts of the lagoon are hypothesised to have dried out, aerially exposing sediment to aeolian action.

5.2.10 **VC081** includes a short section of dark greenish grey clay (2.7-3.0 m) that may represent the upper section of **Unit 5**, although this is difficult to determine for certain based on the short section of vibrocore available for recording.

5.2.11 **VC084** includes a thin deposit of very dark greenish grey silty sand (3.17-3.20 m), with a clear boundary to the overlying marine sands (**Unit 8**). The grey silty sand may represent **Unit 5**, although a certain identification is hampered by the small section (0.1 m) of vibrocore available for recording.

5.2.12 **VC086** is short section of vibrocore (4.25-4.50 m), comprising a dark greyish brown mottled silty-sand with distinct organic laminations. In this case it is difficult to determine if this represents the eroded upper surface of the Upper Brown Bank Formation (**Unit 5**) or a component of the overlying marine sands (**Unit 8**) that geotechnical logs describe including lamina of black clay and pockets of possible organic material and decomposed plant material.

5.2.13 **VC107** comprises marine sands (**Unit 8**) underlain by a thin black silty-sand (0.52-0.80m), in turn overlying very dark greenish grey silty clay of the Upper Brown Bank Formation (**Unit 5**). There is a very sharp boundary at 0.80 m between **Unit 5** and the overlying unit that may represent an erosional surface within **Unit 5** or boundary with pre-transgression fluvial sediment (**Unit 7**), although no Holocene channels are suggested by the geophysics in this area (**Figure 3**).

5.2.14 **Unit 6** (Twente Formation) is described as thin layer of periglacial aeolian sand (**Table 2**), that although not definitely identified on the geophysical survey has been tentatively identified from geotechnical log descriptions in vibrocores **VC075**, **VC076** and **VC088**.

5.2.15 Stage 2 geoarchaeological recording identified potential aeolian sediment at the base of **VC075,** comprising a thin deposit of very dark grey slightly silty sand (4.67-4.70 m), with

similar dark grey fine sands recorded in **VC076** (4-4.35 m), in both cases sealed by peat (**Unit 7**).

5.2.16 No aeolian sediments were recorded from retained samples of **VC088** (**Appendix**). However, a visual inspection of Fugro vibrocore photographs (Fugro, 2016) includes apparent sand deposits below black organic sediments, similar to **VC075** and **VC076**, and therefore suggestive of potential aeolian deposits.**VC085** also includes a dark grey medium sand (2.61-2.92 m) sealed by organic silty clay, that may also represent aeolian sediments.

5.2.17 **Unit 7** comprise Holocene pre-transgression sediments, including semi-terrestrial peat, fluvial and estuarine deposits. **Unit 7** has been recorded in six vibrocores (**VC074**, **VC075**, **VC076**, **VC080**, **VC085** and **VC088**), and a possible further two vibrocores (**VC081** and **VC116**).

5.2.18 Peat is present in five vibrocores (**VC074**, **VC075**, **VC076**, **VC085** and **VC088**), varying in thickness between 0.35 m (**VC088**) and 0.80m (**VC074**) and composition from dark grey to black clayey peat with sandy bands (**VC074**) to dark brown to black fibrous peats (**VC075** and **VC076**). Fragments of wood and land snails were observed in the **VC074** peat, with plant remains visible in **VC088**.

5.2.19 The peat occurs in one of three main contexts, either resting on Upper Brown Bank Formation (**Unit 5**) or periglacial aeolian sands (**Unit 6**) (**VC075**, **VC076** and possibly **VC085**), or forming part of a sequence of fluvial and estuarine deposits contained within Holocene pre-transgression palaeochannels (**VC074** and **VC085**).

5.2.20 Vibrocore **VC074** targeted a potential Holocene palaeochannel. Here the peat overlies a dark grey fine sand to slightly clayey silty fine sand (1.58-4.75 m) interpreted as channel fill, and including fragments of marine shell. However, the similarity in sediment between **Unit 5** and **Unit 7** makes it very difficult to identify the base of the channel and the interface between the two units.

5.2.21 Smaller retained samples include 0.15 m of organic sands (**VC080**), with organic sand and silts (1.28-1.49 m) underlying marine sands (**Unit 8**) in **VC081**, most probably overlying **Unit 5**. In addition. **VC116** only includes a dark greenish grey slightly sandy-silt with an abrupt boundary with **Unit 5**, although as stated above (**section 5.2.14**) it is uncertain at this stage if these sediments belong to **Unit 7** or **Unit 5**.

5.2.22 Of the 22 vibrocores subjected to stage 2 geoarchaeological recording, 13 retain the uppermost deposits of Holocene post-transgression marine sands (**VC074, VC076, VC079, VC081, VC084, VC085, VC089, VC095, VC101, VC103, VC107, VC116** and **VC118**). The marine sands vary in thickness from a thin veneer 0.3 m thick (**VC079**, **VC089** and **VC116**) to over 3 m (**VC076**, **VC084**, **VC103** and **VC118**), with geotechnical logs recording localised deeper deposits from **VC073** (9.96m), **VC108** (13.6 m) and **VC109** (10.99 m). The sands vary in colour from predominantly yellowish brown to brown, light olive brown, greenish-black, greenish-grey, variably including occasional thin clay lamina, pockets of iron staining, black (possibly organic) staining and marine shell fragments.

5.3 Deposit modelling

5.3.1 Three linear transects have been constructed, providing a representative cross-section illustrating the range of deposits within NV East (**Figure 5**), NV West (**Figure 6**) and the Offshore Cable Corridor (OCC) (**Figure 7**).

Transect NV East

5.3.2 Transect NV East comprises six vibrocores (**VC111**, **VC092**, **VC095**, **VC099**, **VC103** and **VC107**) oriented west-east across the southern section of NV East and the adjoining OCC (**Figure 5**). The vibrocores exhibit a gradual west to east incline in elevation from 38.9 to 34.8 m LAT (Lowest Astronomical Tide). The deposits are broadly similar, comprising post-transgression Holocene marine sands (**Unit 8**) overlying Upper Brown Bank Formation (**Unit 5**).

Transect NV West

5.3.3 Transect NV West comprises five vibrocores (**VC070**, **VC075**, **VC080**, **VC085** and **VC088**) oriented southwest-northeast along the northern margins of NV West (**Figure 6**). The deposits exhibit a general west-east increase in elevation from 40.4 to 32.3 m LAT.

5.3.4 The vibrocores primarily comprise **Unit 8** (post-transgression marine sands) and **Unit 5** (Upper Brown Bank), but with deposits of Holocene peat (**VC075**, **VC085** and **VC088**) and organic sands (**VC080**) (**Unit 7**). The peat is no more than 0.36 m thick, and rests either on top of possible saltmarsh (**VC085**), Upper Brown Bank Formation (**VC080**) or periglacial windblown sands (**Unit 6**) (**VC075**). Two peats are preserved in **VC075** separated by silty-clay, with the peat in **VC085** overlain by clayey-sand. The clayey-sand in **VC085** may represent low energy marine sediment or fluvial deposits relating to a nearby channel suggested by geophysical surveying approximately 300 m to the north.

Transect OCC-NV West

5.3.5 Transect OCC-NV West comprises seven vibrocores (**VC119**, **VC118**, **VC117**, **VC116**, **VC074**, **VC079** and **VC084**) oriented west-east to southwest-northeast along the offshore cable corridor and southern section of NV West (**Figure 7**). The transect covers approximately 30 km, with the vibrocores exhibiting an eastward reduction in elevation along the offshore cable corridor (44.3 to 47.7 m LAT), but rising steeply within NV West (max. 38.5 m LAT).

5.3.6 The deposits within the offshore cable corridor comprise post-transgression marine sands (**Unit 8**) underlain by Upper Brown Bank Formation (**Unit 5**). **Unit 8** is the only deposit recorded in **VC118** and **VC117**, up to 5 m thick, but present in **VC116** as a thin deposit (< 0.5 m) overlying a thin organic sandy silt (**Unit 7**) resting on **Unit 5.**

5.3.7 The deposits within NV West include a deep sequence of peat (0.80 m) and clayey to silty-sand (**Unit 7**) in **VC074** infilling a pre-transgression Holocene palaeochannel.

6 DISCUSSION

6.1.1 Initial Stage 1 assessment of vibrocores (Wessex Archaeology, 2017a) has been followed by a detailed Stage 2 geoarchaeological description of 22 retained vibrocore samples, supported by deposit modelling. Together, these stages of initial assessment and detailed description have revealed an extensive, and in places complex, sequence of Pleistocene and Holocene deposits across the study area. These deposits have been divided into a series of eight units conforming to an outline stratigraphic model for the site (after Wessex Archaeology, 2017b).

6.1.2 The outline stratigraphic model for the site comprises a sequence of deposits extending back to the Pliocene and Lower Pleistocene (**Unit 1**). **Unit 2** (Yarmouth Roads Formation) is contemporary with the deposits of the Cromer Forest Bed (> MIS 13), exposed along the East Anglian coast at sites such Happisburgh and Pakefield, and including archaeological evidence for the earliest hominin occupation of Britain was discovered (Parfitt *et al*. 2010;

Ashton *et al*. 2014). The Cromerian interglacial was followed by the Anglian glaciation, although deposits dating to this period have not been definitively identified within the study area.

6.1.3 **Unit 4**, identified in places across NV East but more sporadically across NV West (**Figures 3 and 4**), are considered to belong either to the Eem Formation, dating to the Ipswichian, or the Lower Brown Bank Formation, dating to the Lower Devensian (Cameron *et al.* 1992). Eem Formation deposits are considered to represent a shallow marine environment, with the Lower Brown Bank interpreted as a lagoon deposit.

6.1.4 **Unit 4** is overlain by **Unit 5** (Upper Brown Bank Formation), extending across NV East and NV West and significant sections of the OCC (**Figures 2-7**). **Unit 5** dates to the Early/Middle Devensian, and may have continued to form into the Late Devensian (Limpenny *et al*. 2011). Internal features identified within the Upper Brown Bank Formation suggest a complex depositional history, including possible relict dunes and erosion surfaces (**Figure 3**) that formed during periods when the lagoon dried up.

6.1.5 Stage 2 geoarchaeological recording of retained high and medium priority vibrocores, alongside existing CPT and vibrocore logs (Fugro, 2017a), indicate that **Unit 5** varies between 3.2 and 17.54 m (averaging between 5-9 m thick), but only the top section of the Upper Brown Bank Formation is preserved within the retained vibrocores (max. 5.2m in **VC107**). **Unit 5** is typically recorded as a compact clay to clayey silt, but includes components of sand, silty and clayey sand, sandy clay and sandy silt, in addition to fine-coarse lamina, organic inclusions and shelly material.

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

6.1.7 **Unit 5** is overlain in some areas by periglacial aeolian sands of the Twente Formation (**Unit 6**), although this unit was only tentatively identified in three vibrocores (**VC075, VC076** and **VC088**), sealed by later Holocene peat deposits.

6.1.8 Pleistocene sediments are overlain by deposits of Holocene age, comprising either pre-transgression semi-terrestrial, fluvial and estuarine deposits (**Unit 7**) or post-transgression seabed sediments (**Unit 8**). **Unit 7** includes peat deposits, representing the partially decayed remains of plants deposited in a waterlogged semi-terrestrial environment.

6.1.9 Peat was identified in five vibrocores (**VC074**, **VC075**, **VC076**, **VC085** and **VC088**), varying in thickness between 0.35 m (**VC088**) and 0.80 m (**VC074**). The peat occurs either directly on the Upper Brown Bank Formation, on top of periglacial aeolian sands, or preserved within Holocene palaeochannels.

6.1.10 Relative to metres below Lowest Astronomical Tide (mLAT) the peat occurs between 36.7-37 m LAT (**VC075**) and 39.28-40.08 m LAT (**VC074**). The difference in altitudinal height of the peat may reflect differential lateral and vertical auto-compaction of a contemporaneous peat unit across NV West, or distinct episodes of peat formation under the background influence 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. Post-transgression seabed sediment (**Unit 8**) blanket the area.

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 palaeoenvironmental assessment is based on the geoarchaeological significance of the recorded units, the presence of organic material (most likely to preserve the widest range of palaeoenvironmental indicators), and the quality of the available samples.

7.1.3 Within the Stage 2 geoarchaeological recording, the deposits of highest geoarchaeological priority comprise **Unit 5** and **Unit 7**, dating to periods when the southern North Sea would have been suitable for occupation. Deposits considered to represent possible periglacial aeolian sands (**Unit 6**) are also recommended for limited further assessment in order to characterise these deposits and refine the outline stratigraphic model for the site.

Table 4: Recommendations for Stage 3 palaeoenvironmental assessment and scientific dating.

Vibrocore	Assessment						
	Pollen	Diatom	Foraminifera / ostracod	Plant macrofossil	14C dating	OSL	Particle size
VC074	8	8	8	2	2	-	-
VC075	-	-	-	-	-	-	3
VC076	5	4	4	2	2	-	3
VC079	-	10	10	-	-	2	-
VC085	5	6	6	2	2	-	-
VC089	-	-	-	-	-	2	-
VC107	-	10	10	-	-	2	-
Total	18	38	38	6	6	6	6

7.2 Upper Brown Bank Formation (Unit 5)

7.2.1 Further Stage 3 assessment is recommended on **Unit 5** deposits vibrocores **VC079, VC089** and **VC107**, focusing on optically stimulated luminescence (OLS) dating of deposits identified as the Upper Brown Bank Formation (**Unit 5**).

7.2.2 The Upper Brown Bank Formation (**Unit 5**) is taken to represent a shallow lagoon deposit. The complexity of the Upper Brown Bank Formation has been taken to suggest a more complex depositional history for this unit, including periods when the lagoon may have periodically dried out, exposing sediments to erosion and wind blow. The lagoon shores and ridges of aeolian sand (**Unit 6**), would have provided potentially suitable locations for human settlement and activity.

7.2.3 It remains unclear, however, whether **Unit 5** was deposited over a short period early in the Devensian, or over a much longer period of time over the course of the early-late Devensian, perhaps punctuated by hiatuses in sediment accumulation. OSL dating of **Unit 5** will

therefore provide an important opportunity to date these deposits and refine our understanding of the geoarchaeological and archaeological potential.

7.2.4 Although none of the vibrocores fully penetrate **Unit 5**, targeted OSL dates will nonetheless determine whether **Unit 5** continued to form over an extended time period later into the Devensian. Both vibrocores **VC079**, **VC089** and **VC107** comprise **Unit 5** overlain by post-transgression Holocene marine sands (**Unit 8**).

7.2.5 OSL dating from three vibrocores is preferable given the extensive area over which the vibrocores are distributed and the observed internal variability and complex formation processes of the Upper Brown Bank Formation.

7.2.6 It is not proposed to undertake pollen analysis on **Unit 5** 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 However, targeted foraminifera, ostracod and diatom assessment is recommended on two vibrocores containing **Unit 5** (**VC079** and **VC107**) in order to derive palaeoenvironmental data to characterise the environmental conditions occurring within the lagoon. **VC079** in particular includes coarser sediment inclusions from 45.35-46.05 m LATm, with distinct laminations present in both cores, that hint at variation in the energy of deposition within the Upper Brown Bank Formation.

7.2.8 Palaeoenvironmental assessment of **Unit 5** also provides a fundamental control for comparison with foraminifera, ostracod and diatom assessment of Holocene alluvium and sediments of uncertain date and taphonomy (**see section 7.4.5**).

7.2.9 In these circumstances, palaeoenvironmental assessment may be able to distinguish between a shallow freshwater lagoon environment (**Unit 5**) and marine, estuarine or even freshwater sediments contained with an early Holocene channel (**Unit 7**), representing a more time and cost-effective solution to OSL dating. OSL dating has only been recommended on **Unit 5** sediments in **VC097, VC089** and **VC107**.

7.3 Periglacial aeolian sands 'Twente Formation' (Unit 6)

7.3.1 Periglacial aeolian sands of the Twente Formation (**Unit 6**) have been tentatively identified in vibrocores **VC075**, **VC076** and **VC088**. Further Stage 3 assessment is recommended on probable aeolian sand from **VC075** and **VC076** in order to characterise this unit and refine the outline stratigraphy for the site (**Table 2**).

7.3.2 Assessment will involve limited particle size analysis to characterise the grain size distribution of the sediment. An aeolian hypothesis will be strengthened if the particle size distribution is unimodal, indicative of a well-sorted, single mode of transport and sediment source, and including a relatively small silt component. By comparison, the sediments are less likely to be aeolian in origin if the particle size distribution is polymodal, suggesting multiple sources and modes of transport.

7.4 Holocene deposits (Unit 7)

7.4.1 Further Stage 3 assessment is recommended on vibrocores **VC074**, **VC076** and **VC085,** focusing on the peat and over/underlying minerogenic deposits. These sediments have the highest geoarchaeological potential in terms of suitable deposits for dating and likely to contain the widest range of well-preserved palaeoenvironmental remains.

7.4.2 The peat in each of the vibrocores formed within a different environmental setting, within a pre-transgression palaeochannel (**VC074**), on possible aeolian sands (**VC076**), and as part of a transition from saltmarsh to peat (**VC085**). The base of the peats also vary slightly in elevation (40.08 to 37.5 m LAT), although this may be a function of post-depositional sediment auto-compaction.

7.4.3 However, palaeoenvironmental assessment and scientific dating is recommended on all three vibrocores to determine whether the organic deposits represent a contemporary phase of peat formation across the site, or form separate phases of peat formation within distinct environmental niches.

7.4.4 Moreover, the peat/alluvial interfaces represent specific marine regressive/transgressive episodes, and are best placed to consider the impact of climate change and sea-level rise on early Holocene landscapes and human communities within the southern North Sea basin.

7.4.5 Targeted foraminifera, ostracod and diatom assessment are also recommended on deposits in **VC074** and **VC085** where the similarity between **Unit 5** and **Unit 7** sediments raises some uncertainly as to where the interface lies between the two units**.**

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:

- Determine the environments represented by the geophysics and geotechnical samples.
- Reconstruct past landscape and environmental change, including sea-level rise, vegetation change, and evidence for human activity impact.
- What is the depositional history of the Brown Bank Formation? Did it form relatively quickly in the early Devensian or accumulate as a more gradual deposit? What implications does this have for the archaeological and geoarchaeological potential of the deposits?
- Do the peats represent a contemporary phase of peat formation across the site, or separate phases of peat formation within discrete environmental niches?

7.6 Palaeoenvironmental assessment methods

7.6.1 Palaeoenvironmental assessment will involve a suite of complementary techniques, comprising pollen, diatom, foraminifera and ostracods, supported by radiocarbon dating of suitable organic deposits (**Table 3**). 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.

Diatoms, foraminifera and ostracods

7.6.3 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 peat-alluvial transitions can help to distinguish evidence for sea-level, coastal and riverine change not immediately apparent in the pollen record, including, the influence of storm/hide tide events on semi-terrestrial environments (perhaps visible as fine organic/mineral banding in sediments).

Particle size analysis

7.6.4 Particle size analysis is a technique that quantifies the size distribution of grains ≤2mm in a soil or sediment. It is a useful technique to help understand the formation processes of deposits. For example, aeolian sands should be moderately well-sorted and contain virtually no silt or gravel.

Radiocarbon dating

7.6.5 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.

Optically Stimulated Luminescence (OSL)

7.6.6 OSL dating is an established technique for dating sediments that are too old to be dated using conventional methods such as radiocarbon dating. The advantage of OSL dating is that the method doesn't require organic material and has a range from around 100 to 300,000 years, and therefore suited to **Unit 5** sediments.

8 REFERENCES

Ashton, N., Lewis, S G., De Groote, I., Duffy, S M., Bates, M., Bates, R., Hoare, P., Lewis, M., Parfitt, S A., Peglar, S., Williams, C., and Stringer, C, (2014). Hominin Footprints from Early Pleistocene Deposits at Happisburgh, UK. In: *PLoS ONE*, 9 (2), e88329.

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

Cooper, W S., Townsend, I H., and Balson, P S, (2008). *A Synthesis of Current Knowledge on the Genesis of the Great Yarmouth and Norfolk Bank Systems*. The Crown Estate.

Crombé, P., Van Strydonck, M., Boudin, M., Van den Brande, T., Derese, C., Vandenberghe, D A G., Van den Haute, P., Court-Picon, M., Verniers, J.,

Gelorini, V., Bos, J A A., Verbruggen, F., Antrop, M., Bats, M., Bourgeois, J., De Reu, J., De Maeyer, P., De Smedt, P., Finke, P A., Van Meirvenne, M., and Zwertvaegher, A, (2012). Absolute Dating (^{14}C and OSL) of the Formation of Coversand Ridges Occupied by Prehistoric Hunter-Gatherers in NW Belgium. *Radiocarbon*, 54(3-4), 715-726.

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

EMU Limited (2013). *East Anglia FOUR Offshore Wind Farm Geophysical Survey Report*. Unpublished Client Report, Ref: 12/J/1/02/2066/1346 FINAL.

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/environmental-archaeology-2nd/environmental-archaeology-2nd.pdf/

Fugro, (2016). *Measure and derived geotechnical parameters and final results. Annex 1 – vibrocore photographs. Norfolk Vanguard Offshore Windfarm Geotechnical investigation report, UK Continental Shelf, North Sea*. GEO50/R2/Rev.1

Fugro, (2017a). *Measured and derived geotechnical parameters and final results. Norfolk Vanguard Offshore Wind Farm Geotechnical investigation report, UK Continental Shelf, North Sea*. GEO50/R2/Rev.2

Fugro (Fugro Survey B.V.) (2017b). *Geophysical investigation report. Volume 1 of 3: Operations & Calibrations. Norfolk Vanguard Offshore Wind Farm*. Unpublished report, ref. GE050-R1.

Fugro (Fugro Survey B.V.) (2017c). *Report 1 of 3: Geophysical Investigation Report. Volume 3 of 3: Geophysical Route Survey. Norfolk Vanguard Offshore Wind Farm*. Unpublished report, ref. GE050-R1.

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

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. and 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., and Stringer, C B, (2010). Early Pleistocene

human occupation at the edge of the boreal zone in northwest Europe. In: *Nature*, 466 (7303), 229–33.

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

Ward, I., Larcombe, P., and Lillie, M, (2006). The dating of Doggerland – Post-Glacial geochronology of the southern North Sea. *Environmental Archaeology* 11, 207-218.

Wessex Archaeology, (2017a). *Vanguard Offshore Wind Farm, Stage 1 geoarchaeological review.* Unpublished Client report, ref: 11480.01.

Wessex Archaeology, (2017b). *Norfolk Vanguard Offshore Wind Farm, marine archaeological technical report*. Unpublished Client report, ref: 112380.02.

9 APPENDIX

9.1 Vibrocore records

Location:		455852.0 E 5864848.7 N	**Vibrocore:**	VC070	**Comments: 112380 Vanguard VC070 (Medium priority)**		
Level (top):		40.4 mLAT	**Drg:**				
Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**		
Mono	mLAT						
2.70-2.90	43.1-43.2	5		Gley 1 N 3 very dark grey clay with fine sand. Occasional flecks of gley 1 N/2.5 black clay. General finning of sand down profile	Upper Brown Bank Formation	Upper Brown bank formation	
2.90-5.70	43.2-46.1	-		GAP – Sections not present			
5.70-6.00	46.1-46.4	5		Gley 1 N3/ very dark grey clay mottled throughout with gley 1 N 2.5 black clay. Also, distinct laminations of slightly organic gley 1 N 2.5 fine sand between 5.68 – 5.76m	Upper Brown Bank Formation		

Location:	464000.9 E 5853015.0 N	**Vibrocore:**	VC074	**Comments: 112380 – Vanguard VC074 (Very High priority)**		
Level (top):	38.5 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
0.00-0.78	38.5-39.28	8		10YR 5/4 yellowish brown medium sand. Fairly homogenous and stone free. Some linear iron staining from 0.65 m to base. Darkening to 10YR 4/1 dark grey at boundary. Gradual boundary.	Marine sands/sea bed	Marine sands
0.78-1.58	39.28-40.08	7		Interleaved layers of 10YR 4/1 dark grey medium sand and 10YR 2/ soft very organic, slightly clayey peat oxidising to 10YR 2/1 black. Interleaving peters out at 0.88m and deposit becomes pure peat. Faintly horizontally laminated throughout with occasional woody fragments. Layer of irregular (3mm-3cm) interleaving of peat and 10YR 5/1 grey fine sand at 1.22-1.42m. Fragment of land snail (cf *Cepaea* sp.) at 1.34m. Sharp boundary.	Peat with sandy inundations due to fluctuations in water level.	Peat with fluctuations in water level
1.58-4.75	40.08-43.25	7		10YR 4/1 dark grey fine sand, slightly clayey, fining down profile to become coarse silt/fine sand. Occasional areas of faint horizontal banding throughout. Irregular patches of 2.5Y 5/2 greyish brown coarse silt between 4.00-4.75m. Marine shell fragment at 2.65m.	Channel fill	Pre-transgression palaeochannel fill
4.75-5.00	43.25-43.5	5		Gley 2 2.5/1 5B bluish black silty fine sand	Upper Brown Bank Formation	Upper Brown Bank Formation
5.00-5.60	43.5-44.1	5		Gley 1 2.5/1 10Y greenish black very fine sand with coarse silt and some clay. Homogenous with no clear horizontal banding visible. Rare marine shell fragments.	Upper Brown Bank Formation	

Location:	458998.4 E 5866965.6 N	**Vibrocore:**	VC075	**Comments: 112380 Vanguard VC075 (Medium priority)**		
Level (top):	32.3 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
4.40-4.45	36.7-36.75	7		10 YR 2/2 very dark brown minerogenic but slightly fibrous peat. Sharp boundary	Minerogenic peat.	Peat with periods of stabilisation and inundation
4.45-4.51	36.75-36.81	7		10 YR 2/2 very dark brown fibrous peat. Oxidises to 10YR 2/1. Sharp boundary	Peat.	
4.51-4.54	36.81-36.84	7		10 YR 3/1 very dark grey silty clay. Some fine rooting from the peat above. Clear boundary.	Salt marsh?	
4.54-4.67	36.84-36.97	7		Very fibrous 10 YR 2/1 black peat. Highly organic. Clear horizon. Compact but with visible plant remains.	Peat.	
4.67-4.70	36.97-37.0	6		10 YR 3/1 very dark grey slightly silty fine sand.	Periglacial aeolian sands	Twente Formation

Location:	458994.6 E 5863171.8 N	**Vibrocore:**	VC076	**Comments: 112380 – Vanguard VC076 (Very High priority)**		
Level (top):	34.0 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
0.00-3.60	34.0-37.6	8		10YR 5/6 yellowish brown medium sand with sparse to moderate small sub-rounded stones and whole and fragmented marine shell. Laminations of Gley 1 2.5/N black slightly organic buttery silty clay at 1.42-1.43m and 1.80-1.81m. Intermittent layers of 2.5Y 2.5/1 black at 0.70-0.90m, 1.50-1.90m and 3.35-3.5m. Clear boundary.	Marine sands with organic patches	Marine sands
3.6-4.00	37.6-38.0	7		10YR 2/1 black soft and slightly minerogenic peat becoming 10YR 2/2 very dark brown fairly fibrous peat. Compact and finely horizontally laminated throughout. Becoming 7.5YR 2.5/2 very dark brown and slightly silty from 3.94 to base. Sharp boundary.	Peat being choked off by marine sand s above.	Peat
4.00-4.35	38.0-38.35	6		5Y 4/1 dark grey fairly fine sand with patches of 2.5Y 4/3 olive brown. Visible rooting from peat above to 2.57m. Fairly compact with no visible horizontal banding.	Periglacial aeolian sands	Twente Formation

Location:	466749.7 E 5853859.1 N	**Vibrocore:**	VC079	**Comments: 112380 – Vanguard VC079 (High Priority)**		
Level (top):	40.8 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
0.00-0.30	40.8-41.1	8		10YR 5/4 yellowish brown medium sand. Fairly homogenous with occasional marine shell fragments throughout. Sharp boundary	Marine sands/sea bed	Marine sands
0.30-4.55	41.1-45.35	5		Gley 1 3/1 10GY very dark grey compact slightly organic clayey silt. Silt is mainly quite coarse, bordering on a fine sand in some places. Homogenous throughout with occasional areas of higher clay content and sparse marine shell fragments. No visible horizontal laminations, appears 'marbled' in areas with more clay. Boundary is gradual and a bit 'mixed up' with Gley 1 2.5/N black silty clay and some 10YR 3/4 dark yellowish brown iron stained silty clay.	Upper Brown Bank Formation	Upper Brown Bank Formation
4.55-5.25	45.35-46.05	5		10YR 3/1 very dark grey fine to medium compact clayey sand with moderate poorly sorted small rounded to sub rounded stones and marine shell throughout. Band of 10YR 3/6 dark yellowish brown medium clayey sand with common poorly sorted small rounded to sub rounded stones and marine shell at 4.58-4.62m. Sand coarsens slightly down profile.	Upper Brown Bank Formation	

Location:		462164.3 E 5869081.7 N	**Vibrocore:**	VC080	**Comments: 112380 Vanguard VC080 (Medium priority)**		
Level (top):		34.9 mLAT	**Drg:**				
Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**		
Mono	mLAT						
2.00-2.06	36.9-36.96	7		10 YR 2/2 very dark brown silt. Sharp boundary	Organic silt.	Possible peat development being choked off by inundation events.	
2.06-2.07	36.96-36.97	7		10 YR 2/1 black slightly organic fine sand. Clear boundary. Some peaty material.	Organic sand with peat		
2.07-2.15	36.97-37.05	7		Mottled mix of 2.5 Y dark greyish brown and 2.5 Y 3/3 dark olive brown fine sand with laminations of 2.5 Y 2.5/1 black slightly organic fine sand.	Organic sand		

Location:		464097.1 E 5865795.0 N	**Vibrocore:**	VC081	**Comments: 112380 Vanguard VC081 (Medium priority)**		
Level (top):		35.8 mLAT	**Drg:**				
Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**		
Mono	mLAT						
1.00-1.28	36.8-37.08	8		10 YR 4/4 dark yellowish brown medium sand with common marine shell fragments. Abrupt boundary	Marine sand/seabed	Marine sands	
1.28-1.49	37.08-37.29	8 or 7?		10 Y 3/1 very dark greenish grey clayey fine to medium sand. Marbled with gley 1 2.5/N, slightly organic silt with fine sand. Occasional marine shell fragments throughout. Band of 10YR 2/1 black, slightly organic clay between 1.41 and 1.45m	Organic sands and silts with possible eroded material redeposited. Not certain of this is part of pre or post-transgression Holocene sediments	Organic sands and silts	
1.49-2.70	37.29-38.5			GAP – sections not present			
2.70-3.00	38.5-38.8	5?		Gley 1 10Y 3/1 very dark greenish grey clay with fine sand. Homogenous.	Upper Brown Bank Formation?	Upper Brown Bank Formation	

Location:	469907.6 E 5855974.2 N	**Vibrocore:**	VC084	**Comments: 112380 Vanguard VC084 (Medium priority)**		
Level (top):	38.5 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
3.10-3.17	41.6-41.67	8		10 YR 4/3 brown coarse sand mottled with Gley 1 3/N very dark grey slightly silty sand. Marine shell fragments throughout. Clear boundary.	Marine sands.	Marine Sands
3.17-3.20	41.67-41.7	5?		Gley 1 3/1 very dark greenish grey slightly silty sand. Compact	Probable Upper Brown Bank Formation	Upper Brown Bank Formation

Location:		465321.2 E 5871195.8 N	**Vibrocore:**	VC085	**Comments: 112380 – Vanguard VC085 (Very High priority)**	
Level (top):		35.4 mLAT	**Drg:**			
Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
0.00-1.00	35.4-36.4	8		2.5Y 5/4 light olive brown medium sand with sparse marine shell (whole and fragmented) throughout. Becoming 2.5Y 4/3 olive brown down profile with occasional linear patches of Gley 1 2.5/2.5 black slightly organic clay.	Marine sands	Marine sands
1.00-1.74	36.4-37.14	7		Gley 1 4/1 5GY dark greenish grey slightly clayey fine to medium sand fining down profile with laminations of 10YR 4/1 dark grey soft slightly silty clay from 1.10-1.43. Occasional marine shell throughout. Very sharp boundary.	Intertidal channel fill	Intertidal channel fill
1.74-2.10	37.14-37.5	7		10YR 2/2 very dark brown soft, crumbly very organic peat oxidising to 10YR 2/1 black. Quite compact with fine horizontal laminations throughout. Rare small woody fragments. Sharp boundary.	Peat.	Peat
2.10-2.61	37.5-38.01	7		7.5YR 3/2 dark brown very organic silty clay, almost a very minerogenic peat becoming very silty down profile and lightening to 2.5Y 4/2 dark greyish brown. Possible evidence of rooting apparent as darker linear patches in the top 15cm. Clear boundary.	Possible salt marsh with peat development.	?Salt marsh
2.61-2.92	38.01-38.32	5		2.5Y 4/1 dark grey medium sand with some fine laminations of 2.5Y 4/1 dark grey clay at 2.68-2.75 otherwise fairly homogenous. Some vertical roots visible indicating rooting from peat above. Sharp boundary	Upper Brown Bank Formation	Upper Brown Bank Formation
2.92-5.37	38.32-40.77			5Y 4/1 dark grey very silty clay becoming coarse silt with depth from 3.62m. Occasional vertical roots visible to 3.80m (?from peat above). Very fine laminations of Gley 1 2.5/N black from 3.80m, becoming predominant from 4m to base. Concentration of marine shell fragments at 3.75-3.85. Sharp boundary.	**?BROWN BANK FORMATION**	Intertidal channel fills **?BROWN BANK FORMATION**

Location:		465321.2 E 5871195.8 N	**Vibrocore:**	VC085	**Comments: 112380 – Vanguard VC085 (Very High priority)**	
Level (top):		35.4 mLAT	**Drg:**			
Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
5.37-5.85	40.77-41.25			Gley 1 4/1 5G dark greenish grey compact plastic silty clay. Faint horizontal laminations of Gley 1 2.5/N black throughout.	**?BROWN BANK FORMATION**	

Location:		469004.4 E 5869009.3 N	**Vibrocore:**	VC086	**Comments: 112380 Vanguard VC086 (Medium priority)**	
Level (top):		36.2 mLAT	**Drg:**			
Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
4.25-4.50	40.45-40.7	5 or 8?		Predominantly 2.5Y 3/2 very dark greyish brown but mottled in places with 2.5Y 4/4 olive brown slightly silty fine sand. Distinct laminations of 2.5Y 2.5/1 black slightly organic sand. Visible plant remains.	Successive short-term stabilisation events. Unsure if this is upper part of Unit 8 or lower part of Unit 5	Top of Upper Brown Bank Formation or base of post-transgression seabed sediments

Location:	468497.9 E 5873319.3 N	**Vibrocore:**	VC088	**Comments: 112380 Vanguard VC088 (Medium priority)**		
Level (top):	34.8 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
3.25-3.45	38.05-38.25	7		10 YR 3/1 very dark grey slightly minerogenic peat. Visible rare plant remains. Mottled with 10 YR 2/1.	Peat being choked off.	Peat being choked off.
3.45-3.60	38.25-38.40	7		10 YR 2/2 very dark brown fibrous peat with common visible plant remains. Oxidises visibly to 10YR 2/1 black.	Peat	

Location:	470432.2 E 5870045.7 N	**Vibrocore:**	VC089	**Comments: 112380 - Vanguard VC089 (Very High priority)**		
Level (top):	37.4 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
0.00-2.26	37.4-39.64	8		10YR 5/4 yellowish brown medium sand. Homogenous with occasional marine shell fragments. Band of siltier grey (Gley 1 4/1 10Y dark greenish grey) sand between 0.6 – 1m. Sharp boundary.	Marine sands/sea bed.	Marine sands
2.26–6.30	39.64-43.7	5		Gley 1 3/N very dark grey compact slightly organic clayey silt. Silt is mainly quite coarse, almost a fine sand in places. Generally homogenous but with horizontal laminations and marbled with more clay throughout. Pronounced change in colour to Gley 1 2.5/N, black, at 5.21m. Still marbled with Gley 1 10Y 3/1, very dark greenish grey. General fining of silt and sand down profile Rare marine shell fragments throughout.	Upper Brown Bank Formation	Upper Brown Bank Formation

Location:		484593.7 E 5848529.7 N	**Vibrocore:**	VC092	**Comments: 112380 Vanguard VC092 (Medium priority)**	
Level (top):		37.2 mLAT	**Drg:**			
Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
2.70-3.00	39.9-40.0	5		Gley 1 N4/1 dark grey clay mottled with bands of gley 1 10Y 4/1 dark greenish grey clay and flecks of gley 1 N 2.5 black. Some iron staining. Becomes sandier down profile.	Upper Brown Bank Formation	Upper Brown Bank Formation

Location:	488002.0 E 5848006.4 N	**Vibrocore:**	VC095	**Comments: 112380 Vanguard VC095 (High priority)**		
Level (top):	34.8 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
0.00-0.70	34.8-35.5	8		10YR 5/4 yellowish brown medium sand. Fairly homogenous with occasional marine shell fragments throughout. Gradual boundary 0.6-0.7m	Marine sands	Marine sands
0.70-1.00	35.5-35.8	8		Gley 1 10Y 2.5/1 greenish black slightly silty sand which is quite coarse with occasional marine shell fragments. Abrupt boundary.		
1.00-1.52	35.8-36.32	8		10YR 4/4 dark yellowish brown medium sand. Compact and sterile. Gradual boundary between 1.42-1.52.		
1.52-1.92	36.32-36.72	8		Gley 1 10Y 3/1 very dark greenish grey compact slightly clayey sand with occasional marine shell fragments. Occasional areas of higher clay content. Sharp boundary.		
1.92-2.00	36.72-36.8	8		10YR 4/1 Dark grey coarse sand with common marine shell fragments. Compact.		
2.00-2.54	36.8-37.34	8		10YR 5/3 Brown medium sand with occasional marine shell fragments and abrupt boundary.		
2.54-3.91	37.34-38.71	5		Gley 2 5B 2.5/1 blueish black silt bordering on fine sand. Horizontal laminations of clay throughout. Very rare marine shell fragments. Abrupt boundary.	Upper Brown Bank Formation	Upper Brown Bank formation
3.91-4.07	38.71-38.87	5		Gley 1 10Y 3/1 Very dark greenish grey very fine sandy clay, homogenous.		
4.07-6.30	38.87-41.1	5		Gley 1 3/N very dark grey clayey with common laminations of fine sandy silt. Rare organic inclusions. Fewer laminations from 6.09		

Location:	492184.3 E 5854650.9 N	**Vibrocore:**	VC097	**Comments: 112380 Vanguard VC097 (Medium priority)**
Level (top):	37.5 mLAT	**Drg:**		

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
3.70-3.97	41.2-41.47	5		Gley 1 10 Y 4/1 dark greenish grey clay. Compact, sterile and homogenous. Sharp boundary.	Intertidal channel fills, mainly low energy events.	
3.97-4.00	41.47-41.5	5		Mottled gley 1 N 2.5 black fine sandy silt and 2.5 Y 5/3 light olive brown very fine sand.	?	
4.00-4.05	41.5-41.55	5		Gley 1 3/N very dark grey, very fine sand. Abrupt boundary.	Intertidal channel fills, mainly low energy events.	
4.05-4.50	41.55-42.0	5		Gley 1 10 Y 3/1 very dark grey clay with laminations (at 45° to profile) and mottling of gley 1 3/N very dark grey fine sand, less pronounced and more sporadic down profile.	Intertidal channel fills, mainly low energy events.	

Location:	495986.7 E 5855742.4 N	**Vibrocore:**	VC101	**Comments: 112380 Vanguard VC 101 (High priority)**		
Level (top):	35.5 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
0.00-0.46	35.5-35.96	8		10YR 4/4 dark yellowish brown medium sand. Homogenous with rare marine shell fragments. Darkening to 10YR 4/2 at gradual boundary	Marine sand/sea bed	Marine sands
0.46-1.00	35.96-36.5	8		Gley 1 10Y 3/1 very dark greenish grey slightly clayey fine to medium sand. Occasional marine shell fragments.		
1.00-1.60	36.5-37.1	8		10YR 5/4 yellowish brown medium sand, soft compaction. Sterile with diffuse boundary.		
1.60-2.82	37.1-37.32	8		Gley 1 10Y 4/1 dark greenish grey medium sand, compact. Amorphous patch of slightly finer 10YR 5/4 clayey sand between 2.05 and 2.3m. Gradual change to gley 2 10BG 4/1 dark greenish grey clayey sand. Slight fining down profile. Clear boundary		
2.82-4.29	37.32-39.79	5		Gley 1 3/3 very dark grey compact clayey silt. Silt is quite coarse bordering on fine sand. Generally homogenous but mottled in places with higher clay content. Horizontal laminations of gley 1 2.5/2.5 black silty clay. Clear boundary.	Upper Brown Bank Formation	Upper Brown Bank Formation
4.29-6.10	39.79-41.6	5		Gley 1 4/5GY dark greenish grey compact clay. Fairly homogenous but with horizontal laminations of gley 1 2.5/2.5 black coarse silty clay between 5.11 and 5.39m.		

Location:	495974.9 E 5847831.4	**Vibrocore:**	VC103	**Comments: 112380 Vanguard VC103 (Medium priority)**		
Level (top):	35.8 mLAT	**Drg:**				
Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
3.00-3.09	38.8-38.89	8		2.5Y 5/2 greyish brown medium sand. Slightly mixed up with silty clay from below. Homogenous. Clear irregular boundary	Marine sands	Marine sands
3.09-3.50	38.89-39.3	5		Horizontal bands of 2.5Y 4/2 dark greyish brown silty clay (with small (<2mm) round mottles of 2.5Y 3/1 very dark grey) and 2.5Y 3/1 very dark grey very fine sand/coarse silt.	Brown bank formation	Brown bank foramtion
3.50-4.00	39.3-39.8	-		GAP	GAP – section not present	
4.00-4.37	39.8-40.17	5		2.5Y 4/1 dark grey silty clay with some very fine sand oxidising to 2.5Y 4/2 dark greyish brown. Fairly regular bands (<3cm) of 5Y 4/2 olive grey slightly silty fine sand. Clear irregular boundary.	Brown bank formation with ?aeolian events on erosion surface.	Brown bank formation with ?aeolian events on erosion surfaces and short periods of stabilisation.
4.37-4.50	40.17-40.3	5		Laminations of 2.5Y 3/1 silty clay (with some very fine sand) and fine sand/coarse silt of the same colour. From 4.43m the laminae become very thin with layers of 7.5YR 2.5/1 black organic silt. Plant remains observed under microscope.	Brown bank formation with ?aeolian events on erosion surface and short periods of stabilisation.	

Location:	499790.2 E 5860769.2 N	**Vibrocore:**	VC104	**Comments: 112380 Vanguard VC104 (Medium priority)**		
Level (top):	40.0 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
2.70-3.00	42.7-43.0	5		2.5 Y 4/2 dark greyish brown compact fine silty clay. Homogenous but with very sporadic iron staining. Thin lens of 2.5Y 7/1 light grey sand at 2.94m	Upper Brown Bank Formation	Upper Brown Bank Formation
3.00-5.70	43.0-45.7	-		GAP – Sections not present		
5.70-6.00	45.7-46.0	5		2.5Y 3/3 dark olive brown clay. Fairly homogenous but there are thin lenses of 2.5 Y 8/4 pale yellow fine sand and 10 YR 3/1 very dark grey slightly organic fine sand between 5.74 and 5.75m	Upper Brown Bank Formation	

Location:	499791.7 E 5848922.3 N	**Vibrocore:**	VC107	**Comments: 112380 – Vanguard VC107 (High priority)**		
Level (top):	36.7 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
0.00-0.52	36.7-37.22	8		2.5Y 4/2 dark greyish brown medium slightly silty sand with patches of 2.5Y 4/3 olive brown. Frequent marine shell throughout. Clear irregular boundary	Marine sands	Marine sands
0.52-0.80	37.22-37.5	5 or 7		5Y 2.5/1 black compact fine silty sand with occasional amorphous patches of Gley 1 2.5/N black soft silty clay. Rare patches of organics. Very sharp boundary.	Uncertain if this unit represents part of the Upper Brown Bank or Holocene pre-transgression sediment	Upper Brown Bank formation or Holocene?
0.80-6.00	37.5-42.7	5		Gley 1 5GY 3/1 very dark greenish grey to Gley 1 5GY 4/1 dark greenish grey compact silty clay. Silt content varies with very fine laminations of coarser silt throughout the sequence. Occasional darker (Gley 1 2.5/N black) laminations of what appears to be slightly more organic coarse silty clay, especially at 3.45-3.50. Some very fine (1mm) laminations of 10YR 2/2 very dark brown at 2.90-2.93. Deposit becomes more clayey and slightly crumbly in appearance when broken from 4m to base.	Brown Bank formation	Upper Brown Bank formation

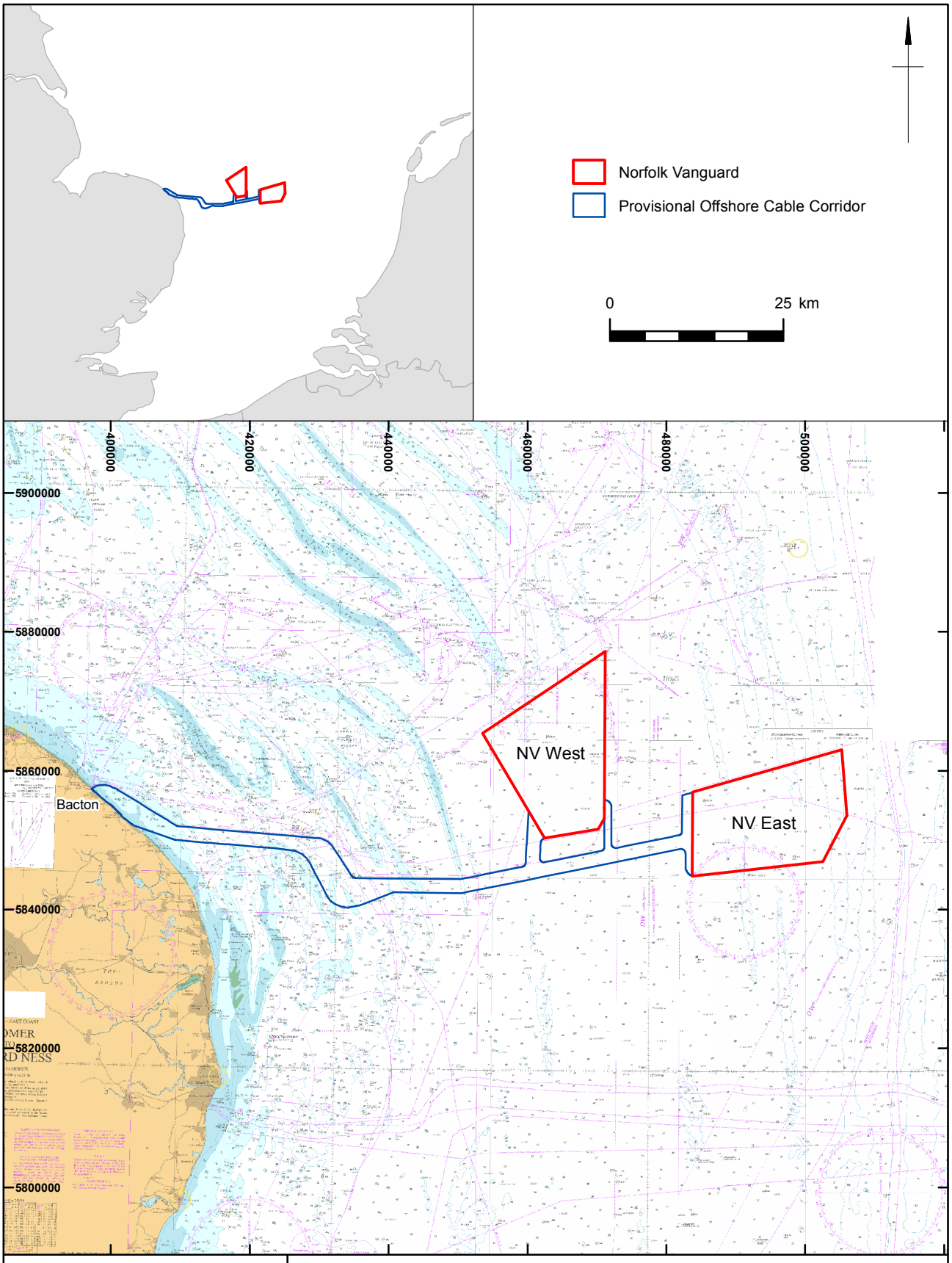
Location:	460846.7 E 5848268.4 N	**Vibrocore:**	VC 116	**Comments: 112380 Vanguard VC116 (high priority)**		
Level (top):	47.7 mLAT	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
0-00-0.25	47.7-47.95	8		2.5Y 4/3 olive brown fine silty sand/. Sharp Boundary	Marine sands	Marine sands
0.25-0.65	47.95-48.25	7		Gley 1 10Y 4/1 dark greenish grey very slightly sandy silt. Sand is fine to medium. Rare marine shell fragments, mainly confined to 0.38-0.40m. Abrupt boundary.	Intertidal channel fills, mainly low energy events	Intertidal channel fills
0.65-1.31	48.25-49.01	5		Gley 1 N 2.5 black, fine slightly organic sandy silt. Occasional marine shell fragments. Slightly higher clay content in places, particularly 0.90-1.11m. Clear boundary.	Upper Brown Bank Formation	Brown Bank Formation
1.31-5.30	49.01-53.0	5		Gley 1 10Y 3/1 very dark greenish grey clay. Clear horizontal laminations. Sterile. Gradual boundary.		
5.60-6.35	53.0-54.05	5		Gley 1 N 2.5 black fine sandy silt. Some horizontal laminations but mottled in places with a higher clay content. General fining down profile.		

Location:	457661.6 E 5844832.9 N	**Vibrocore:**	VC117	**Comments: 112380 Vanguard VC117 (medium priority)**		
Level (top):	46.4	**Drg:**				

Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**	
Mono	mLAT					
1.00-1.32	47.4-47.72	8?		Gley 1 10Y 5/1 greenish grey fine sand, faintly iron stained (2.5Y 4/3 olive brown) in wide bands with occasional thin laminations of Gley 1 10Y 4/1 dark greenish grey slightly silty clay. Thin (3mm) band of 10YR 3/1 very dark grey slightly organic fine sand at 1.16m. Clear boundary.	?Post inundation marine events ?sand dunes or ?redeposited Aeolian sands	?Sand dunes/redeposited Aeolian sands overlying tidal or estuarine deposits with short periods of stabilisation.
1.32-1.43	47.72-47.83	8?		Closely spaced laminations of fine sand and silty clay as above with very thin (<2mm) laminations of 10YR 4/6 dark yellowish brown iron stain and Gley 1 2.5/N black organic sandy silt with visible plant remains. Bands are concentrated between 1.34-1.39m and then become more widely spaced. Sharp boundary	?short stabilisation events as indicated by iron staining and presence of organics.	
1.43-1.50	47.83-47.9	8?		Fairly regular bands (<0.5mm) of 2.5Y 4/2 dark greyish brown clayey silt and 2.5Y 4/3 olive brown fine sand.	?shallow sub tidal or estuarine environment	

Location:			**Mono:**	VC 118	**Comments: 112380 Vanguard VC 118 (Medium priority)**		
Level (top):			**Drg:**				
Depth		**Unit**	**Samples**	**Sediment description**	**Interpretation**		
Mono	mOD						
0.70-3.29				2.5Y 4/3 olive brown fine silty sand with thin laminations of sandy clay of the same colour. Amorphous patches (<8cm) of 2.5Y 3/1 very dark grey ringed in a very thin (<1mm) band of 7.5YR 4/6 strong brown iron stain at 0.75m, 0.92m and 1.38-1.45m. Occasional marine shell. Sharp wavy boundary lined in a thin band of iron stain as described above. **GAP BETWEEN 1.5-3.00** (sections not present)	Marine sands with possible organic patches and iron staining.		Marine sands with fluctuations in water energy.
3.29-4.00				Gley 1 3/N very dark grey fine silty sand with some clay. Horizontal laminations of Gley 1 2.5/N black sandy clay at 3.34-3.41. Becomes sandy clay between 3.62-3.73. Rare marine shell.	Organic marine sands		
4.00-4.50				GAP – section not present	GAP		
4.5-5.00				2.5Y 4/3 olive brown fine silty sand with thin laminations of sandy clay of the same colour. Sandy clay band at 4.60-4.63 and black patches with iron stain band as above at 4.80 and 4.97	Marine sands with possible organic patches and iron staining.		

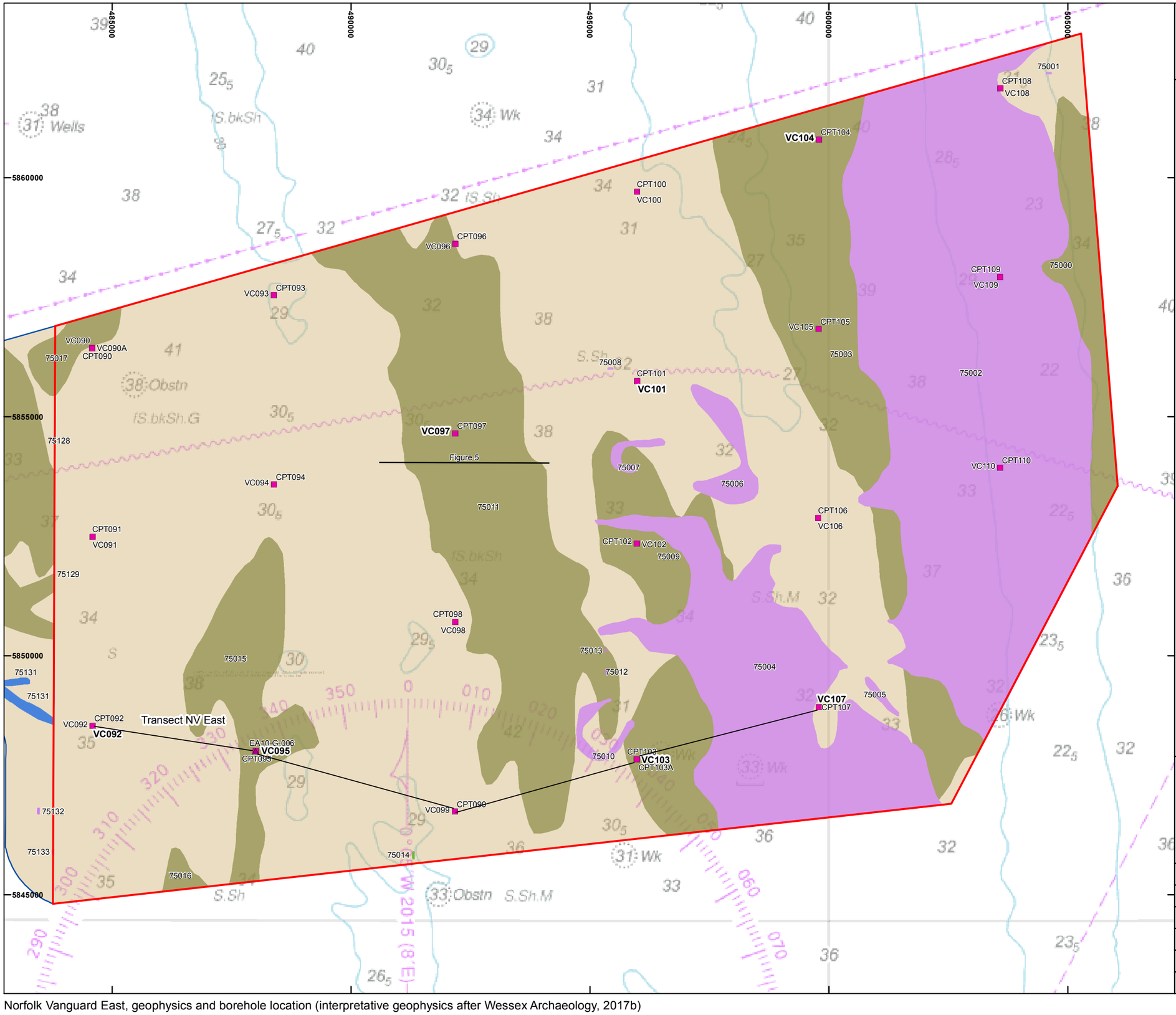


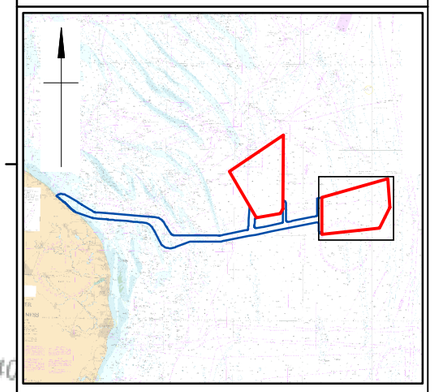
Date:	09/10/2017	Revision Number:	0
Scale:	1:800,000 at A4	Illustrator:	KJF
Path:	W:\Projects\112380\GIS\FigsMXD\Geoarch Stage 2\2017_10_09		

Coordinate system:
ETRS1989 UTM Z31N

Location of Norfolk Vanguard Offshore Wind Farm

Figure 1





Norfolk Vanguard

Provisional Offshore Cable Corridor

Transect locations

Brown Bank Formation extents

Geotechnical sample locations

GEMS 2010

Fugro 2017

Features of archaeological potential

Holocene (Pre-Transgression), Channel

Devensian, Acoustic Blanking

Ipswichian or Devensian, Infilled Depression

Pre-Anglian, High Amplitude Reflector

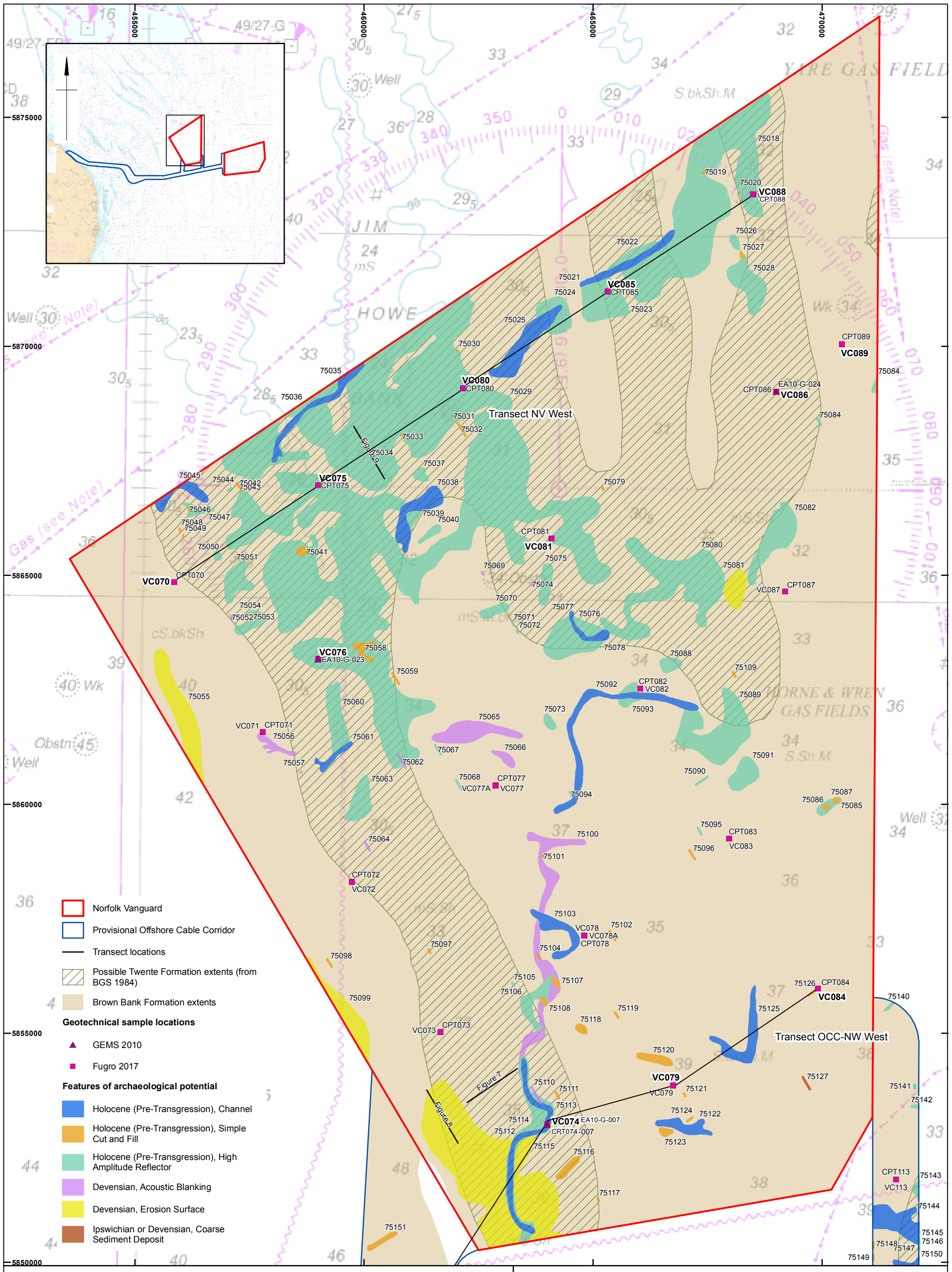
0 2.5 km

Coordinate system:
ETRS1989 UTM Z31N

Date:	09/10/2017
Revision Number:	0
Scale:	1:80,000 at A3
Illustrator:	KJF/ND
Path:	W:\Projects\112380\GIS\
	FigsMXD\Geoarch Stage 2\2017_10_09

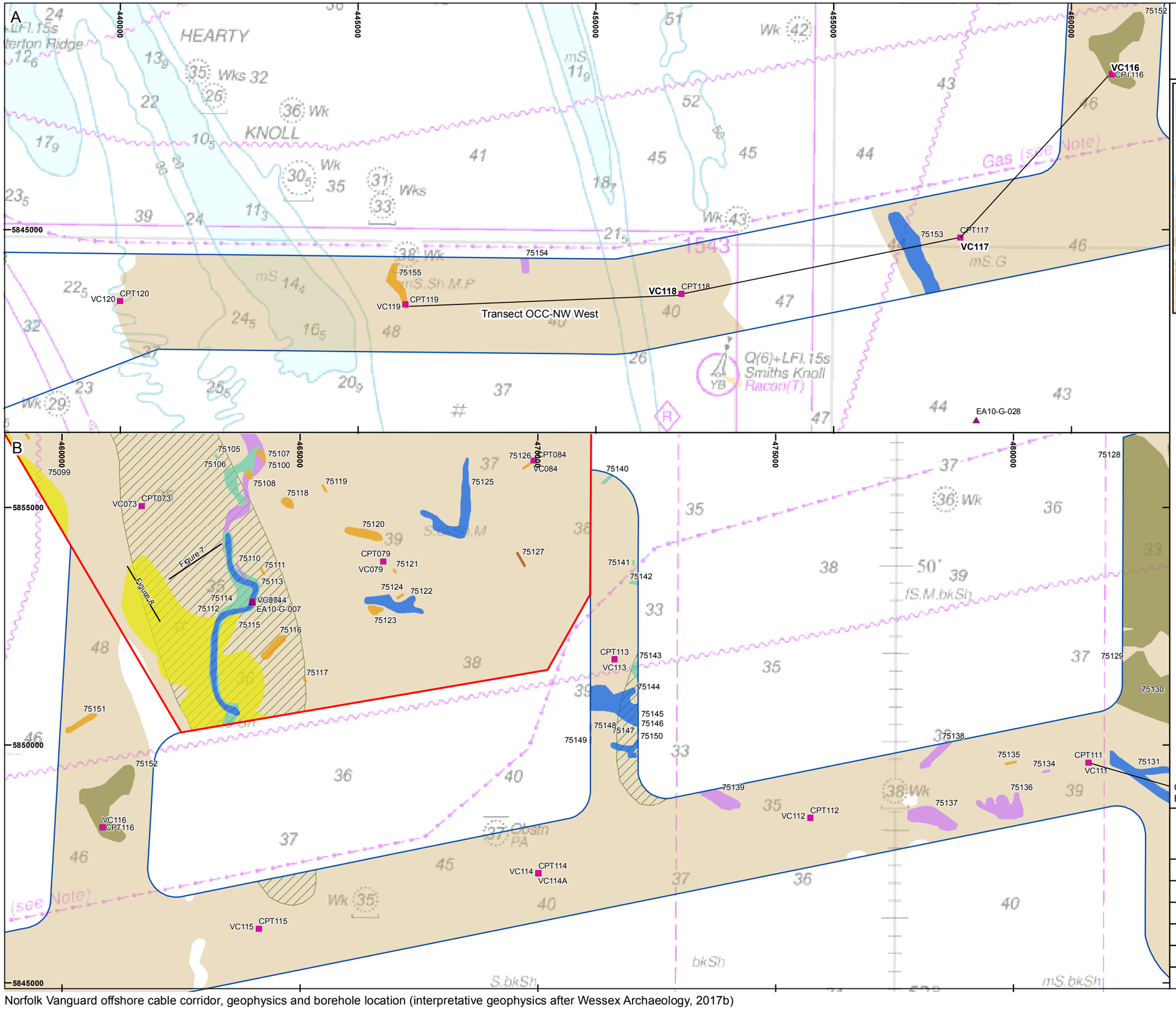
Norfolk Vanguard East, geophysics and borehole location (interpretative geophysics after Wessex Archaeology, 2017b)

Figure 2



Date:	09/10/2017	Revision Number:	0
Scale:	1:80,000 at A3	Illustrator:	KJF/ND
Path:	W:\Projects\112380\GIS\FigsMXD\Geoarch Stage 2\2017_10_09		

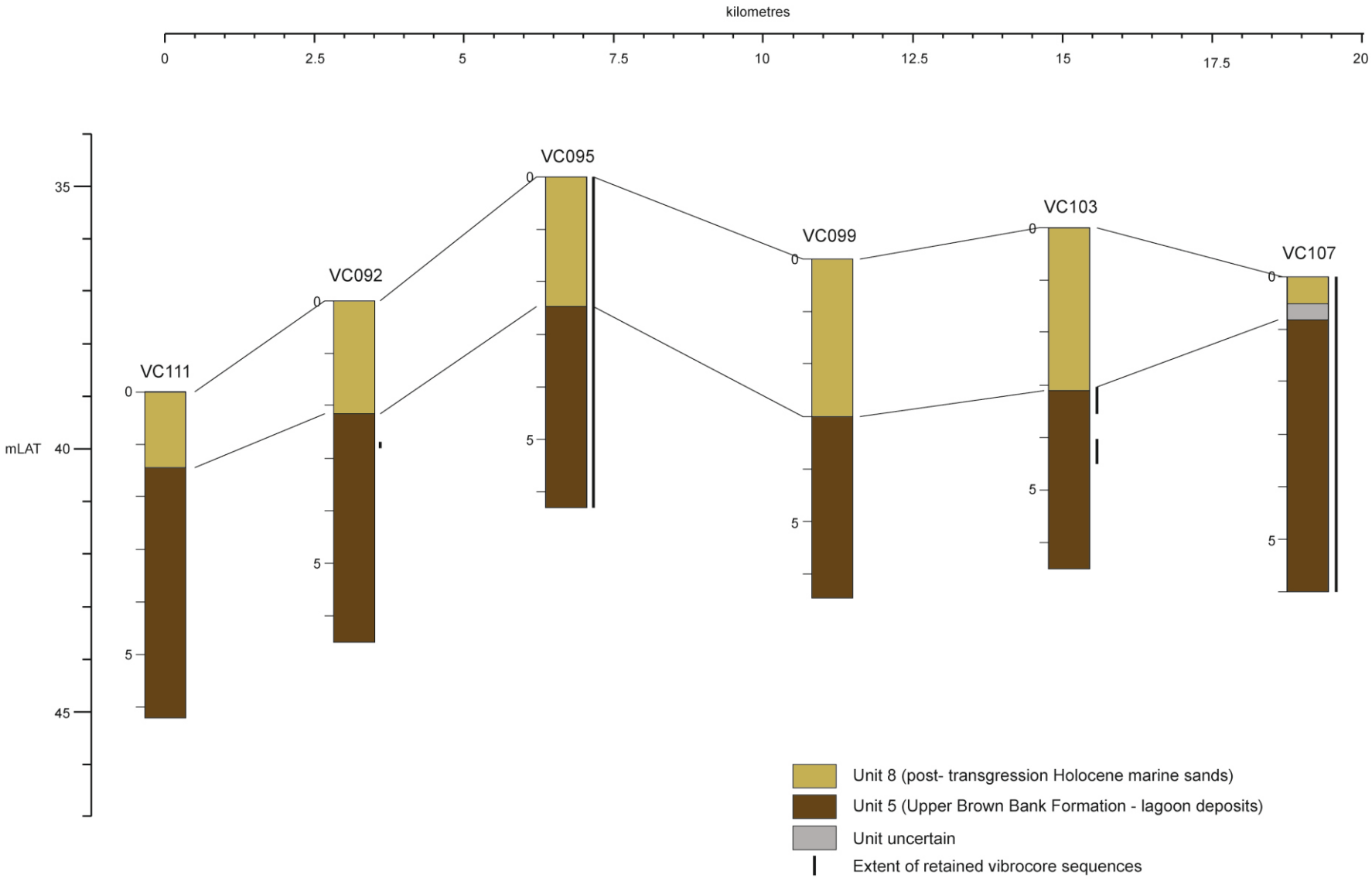
Norfolk Vanguard West, geophysics and borehole location (interpretative geophysics after Wessex Archaeology, 2017b) Figure 3



Date:	09/10/2017
Revision Number:	0
Scale:	1:80,000 at A3
Illustrator:	KJF/ND
Path:	W:\Projects\112380\GIS\
FigsMXD\Geoarch Stage 2\2017_10_09	

Norfolk Vanguard offshore cable corridor, geophysics and borehole location (interpretative geophysics after Wessex Archaeology, 2017b)

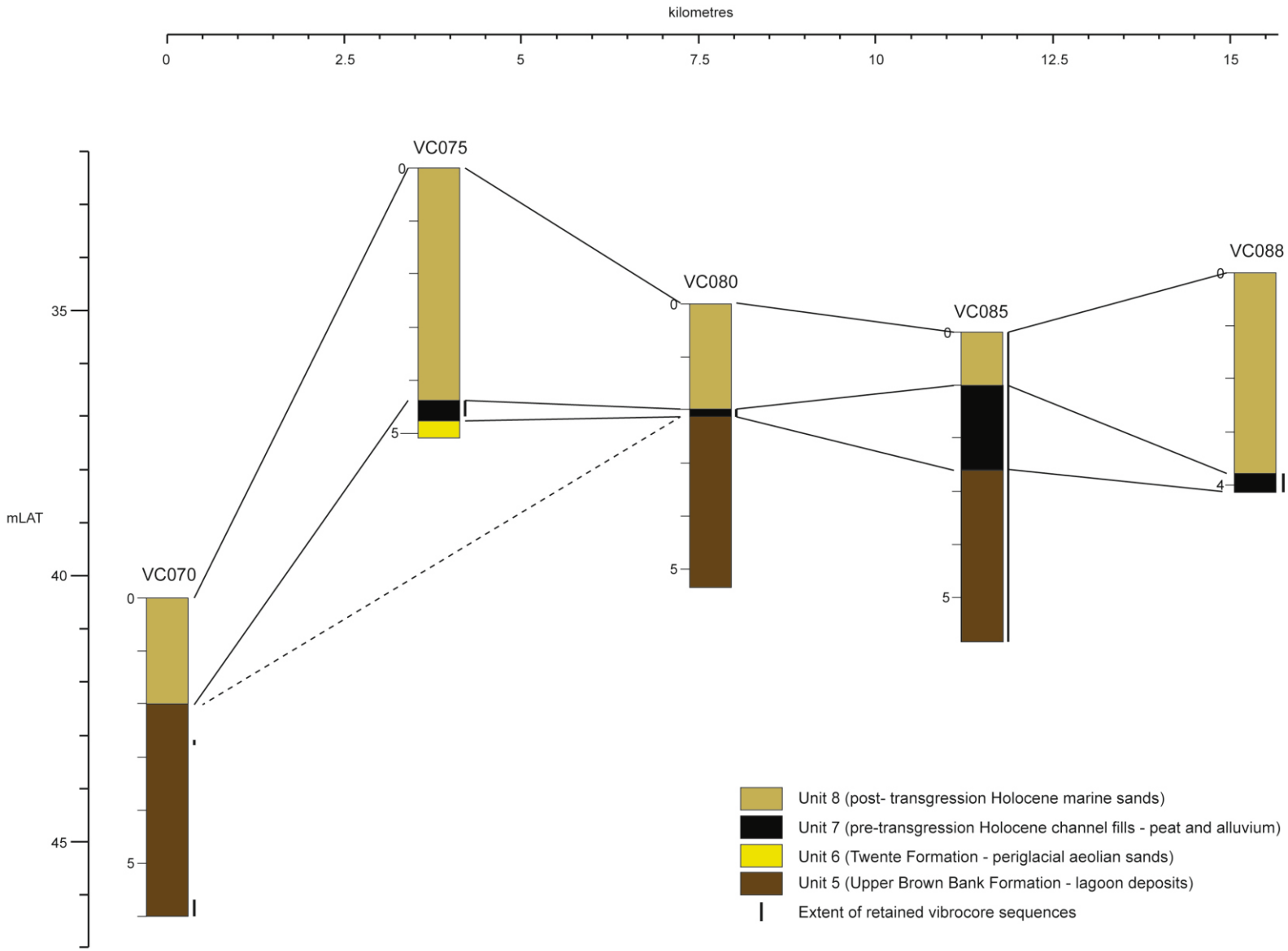
Figure 4



Date:	09/10/2017	Revision Number:	0
Scale:	see bar scale	Illustrator:	ND
Path:	W:\Projects\112380\Graphics_Office\Rep figs\Geoarch Stage 2\2017_10_09		

Transect NV East

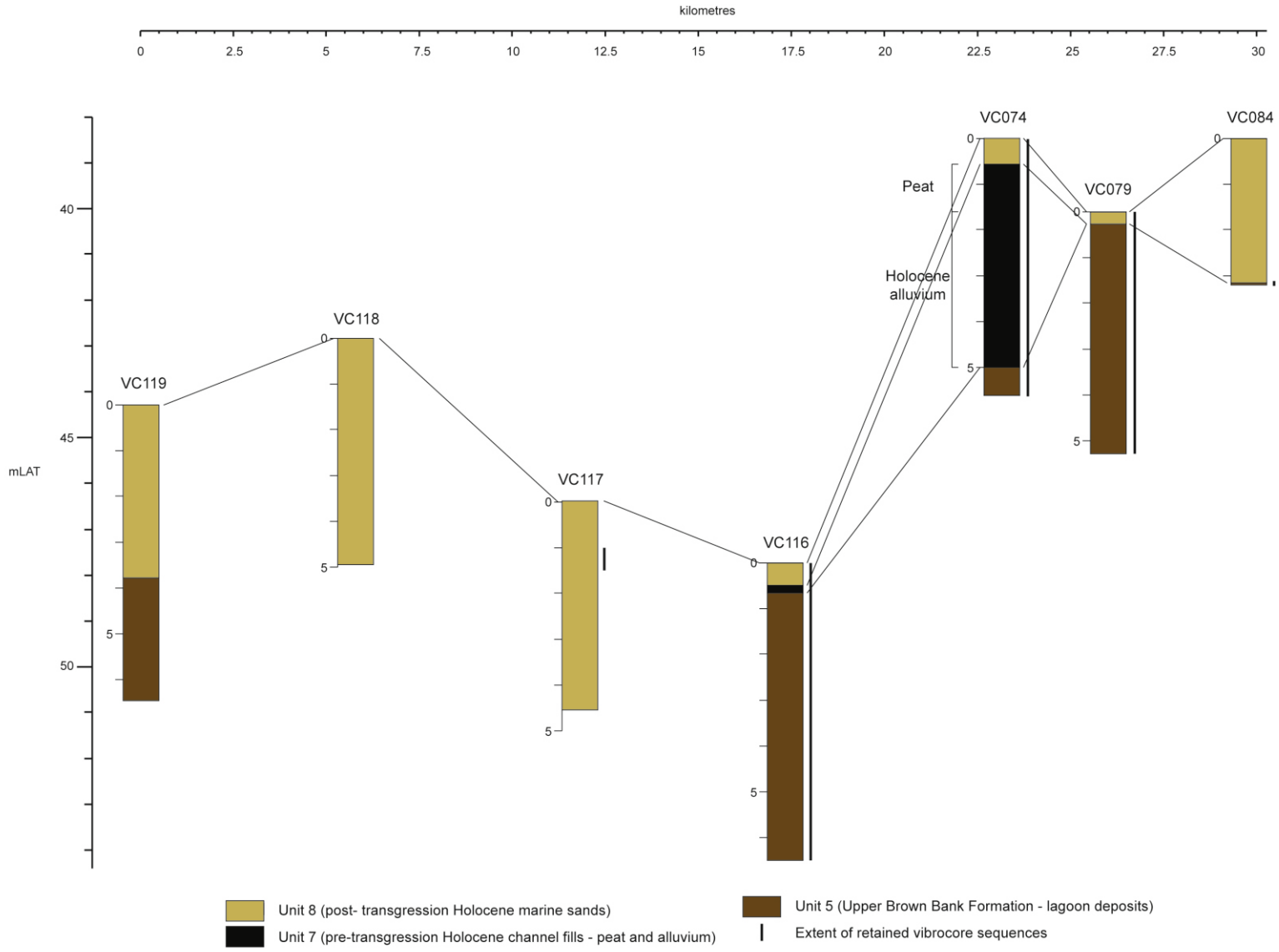
Figure 5



Date:	09/10/2017	Revision Number:	0
Scale:	see bar scale	Illustrator:	ND
Path:	W:\Projects\112380\Graphics_Office\Rep figs\Geoarch Stage 2\2017_10_09		

Transect NV West

Figure 6



Date:	09/10/2017	Revision Number:	0
Scale:	see bar scale	Illustrator:	ND
Path:	W:\Projects\112380\Graphics_Office\Rep figs\Geoarch Stage 2\2017_10_09		

Transect OCC-NV West

Figure 7

Wessex Archaeology Ltd registered office Portway House, Old Sarum Park, Salisbury, Wiltshire SP4 6EB
Tel: 01722 326867 Fax: 01722 337562 info@wessexarch.co.uk www.wessexarch.co.uk

FS 606559