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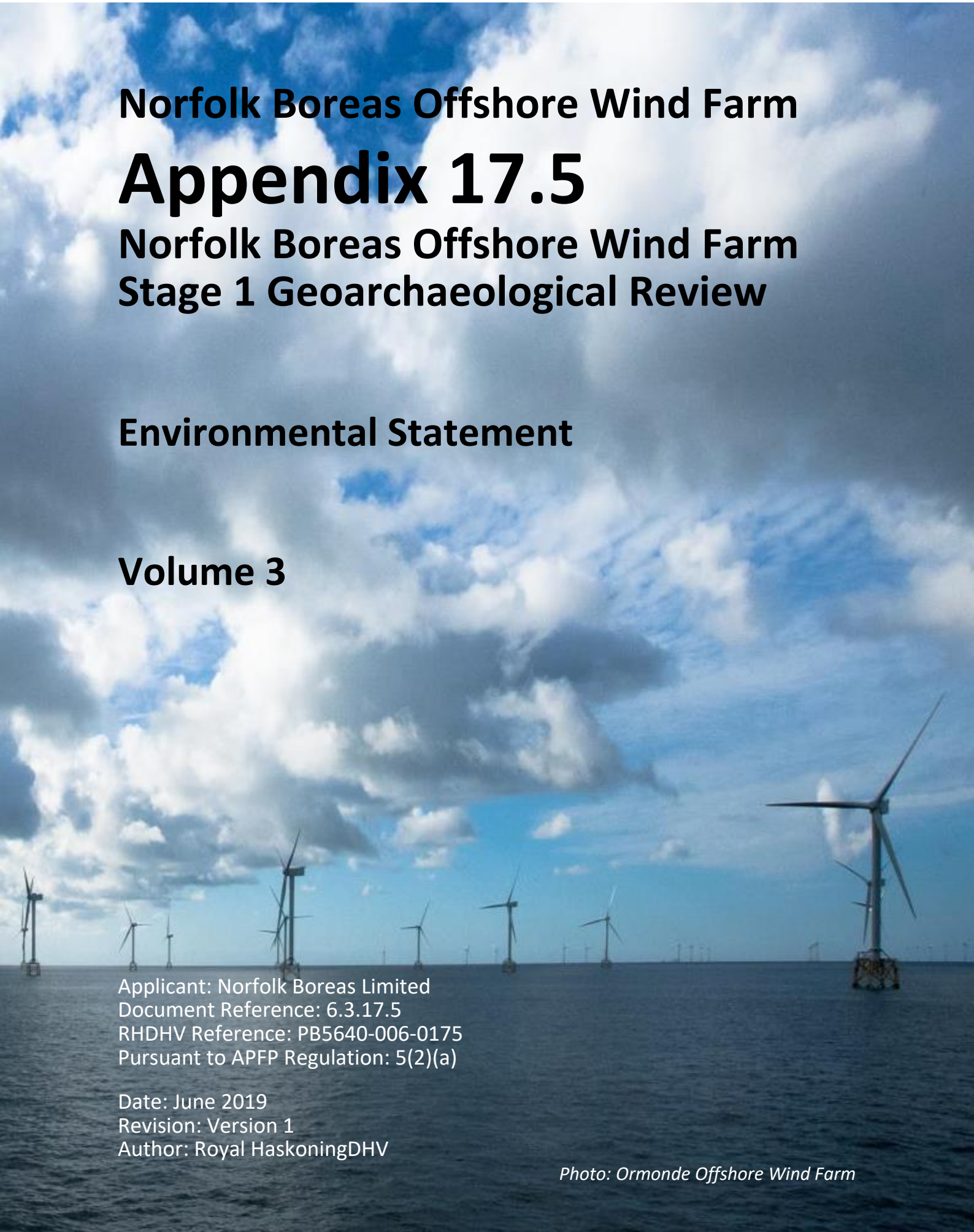
Norfolk Boreas Offshore Wind Farm

Appendix 17.5

Norfolk Boreas Offshore Wind Farm Stage 1 Geoarchaeological Review

Environmental Statement

Volume 3



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Norfolk Boreas Offshore Wind Farm

Stage 1 Geoarchaeological Review

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Norfolk Boreas Offshore Wind Farm

Stage 1 Geoarchaeological Review

Contents

List of Figures

List of Tables

Norfolk Boreas Offshore Wind Farm

Stage 1 Geoarchaeological Review

Summary

Wessex Archaeology was commissioned by Royal HaskoningDHV to undertake a Stage 1 review of 61 vibrocore logs from 50 locations across the Norfolk Boreas Offshore Wind Farm, hereby referred to as the Norfolk Boreas site. Vibrocores were assigned a high, medium and low priority status based on the perceived geoarchaeological potential of the sediments recorded in the geotechnical vibrocore logs.

The vibrocores contain a consistent sequence of Pleistocene clays/sandy clays locally overlain by early Holocene peat and sealed by marine shelly sands. The Pleistocene deposits were recorded in 25 vibrocores, with peat recorded in three vibrocores (**VC028, VC032** and **VC039**). Marine shelly sands were recorded in 55 of the 61 vibrocores and were the only sediment recorded in just over half (31) of all the vibrocores.

Five vibrocores were assigned a high priority status, containing peat (**VC028, VC032** and **VC039**) and substantial depths of probable Brown Bank Formation (**VC016** and **VC047**) of high geoarchaeological potential. Sediments of the Brown Bank Formation relate to the palaeogeographic development of the southern North Sea during Marine Isotope Stage (MIS) 3/2, which is poorly understood but a key period for *Homo neanderthalensis* and modern humans in NW Europe. The high priority vibrocores are recommended for further Stage 2 geoarchaeological recording and sampling.

Eight vibrocores (**VC003, VC005, VC005a, VC010, VC013a, VC024, VC029** and **VC033**) were assigned a medium priority status and were monitored at Fugro House (Wallingford) during geotechnical logging and sampling. No deposits of geoarchaeological interest were noted and no further geoarchaeological work is recommended on these vibrocores.

The remaining 48 vibrocores were assigned a low priority status; 31 vibrocores recorded only modern seabed sediment with remainder containing relatively shallow depths of Pleistocene clay/sandy clay.

Norfolk Boreas Offshore Wind Farm

Stage 1 Geoarchaeological Review

Acknowledgements

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Boreas Offshore Wind Farm

Stage 1 Geoarchaeological Review

1 INTRODUCTION

1.1 Project background

1.1.1 Wessex Archaeology (WA) have been commissioned by Royal HaskoningDHV to undertake a geoarchaeological review of geotechnical logs in support of the proposed Norfolk Boreas Offshore Wind Farm, herby referred to as the Norfolk Boreas site (**Figure 1**).

1.1.2 The Norfolk Boreas site is located approximately 72 km (39 nautical miles) north-east 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 during the last one million years (Bicket and Tizzard, 2015). The region preserves Pleistocene and Holocene landforms and sediments formed during periods when sea level was lower than present day, when this part of the southern North Sea basin was a landscape suitable for human occupation.

1.1.3 This report summarises the results of the review of 61 vibrocore logs from 50 locations across the Norfolk Boreas site. At the time of completion of this report, the vibrocores have been assigned high, medium and low priority status based on their perceived geoarchaeological potential. Monitoring of geotechnical logging and sampling of medium priority vibrocores has been completed and high priority cores delivered to Wessex Archaeology for Stage 2 geoarchaeological recording.

1.2 Scope of report

1.2.1 To help frame geoarchaeological investigations of this nature, Wessex Archaeology 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.

Stage	Method	Description
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 GEOLOGY AND GEOARCHAEOLOGICAL BACKGROUND

2.1.1 The Norfolk Boreas site is located in an area dominated by Pleistocene and Holocene sediments (Cameron et al. 1992), comprising clays, silts, sands and gravels with occasional organic-rich deposits (peats), sealed 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 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, cold peri-glacial conditions and the close proximity of ice sheets 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 include the Brown Bank Formation, tentatively dated to the late Ipswichian interglacial to early Devensian glaciation (Limpenny et al. 2011).

2.1.5 The Brown Bank Formation includes deposits of silty sand and sandy silt in addition to deposits of sandy clay/clay, in places up to 20 m thick. The sandy clay/clay deposits are here termed the Upper Brown Bank Formation, to distinguish them from the underlying deposits of silty sand and sandy silt that characterise both the Lower Brown Bank and underlying Eem Formation (the latter also considered to date to the Ipswichian Interglacial (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 as 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 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).

3 AIMS AND OBJECTIVES

3.1.1 The principal aims of the Stage 1 geoarchaeological review are as follows:

- Review geotechnical logs to identify sediments of potential archaeological interest, assigning low, medium and high priority status;
- Monitor geotechnical logging and sampling of medium priority vibrocores;
- Make recommendations for further Stage 2 geoarchaeological recording.

4 METHOD

4.1 Review of preliminary vibrocore logs

4.1.1 Each of the 61 preliminary vibrocore logs were reviewed by a trained geoarchaeologist in order to determine their potential for further geoarchaeological works. Vibrocores were assigned either a high, medium or low priority status based on their perceived geoarchaeological significance itemised in **Appendix 1** and shown on **Figure 3**. Those

vibrocores identified as high priority were retained and sent to Wessex Archaeology for further Stage 2 geoarchaeological recording.

4.2 Monitoring of geotechnical logging and sampling

4.2.1 Vibrocores assigned a medium priority status were monitored by a geoarchaeologist during geotechnical logging and sampling at Fugro House, Wallingford (31st October – 1st November 2017). Geoarchaeological logging and sampling will take priority in the event medium priority cores contain deposits of high priority, ensuring adequate samples are retained for further geoarchaeological work.

4.3 Low priority vibrocores

4.3.1 Low priority vibrocores will be geotechnically logged without a geoarchaeologist present, but with advice given to geotechnical engineers on recognising and putting aside sediments of archaeological and geoarchaeological significance.

5 RESULTS

5.1 Introduction

5.1.1 The results of the Stage 1 review involved an examination of 61 individual vibrocore logs, with the aim of identifying sediments of potential geoarchaeological interests, with recommendations made for further geoarchaeological work. The logs are itemised in **Appendix 1** (vibrocore locations shown on **Figure 1**), accompanied by a brief preliminary interpretation of the deposits.

5.1.2 Monitoring of geotechnical logging and sampling of medium priority vibrocores (**VC003, VC005, VC005a, VC010, VC013a, VC024, VC029** and **VC033**) took place at Fugro House, Wallingford from the 31st October to 1st November 2017. No deposits of geoarchaeological significance were noted during the course of monitoring.

5.2 Pleistocene sediments

5.2.1 Very dark grey to very dark greyish brown compact clay and fine to medium silty and sandy clay were recorded in 25 vibrocores (**Appendix 1**). In several cases the deposits are thinly laminated and include traces of organic matter and shells. The sediments are comparable to deposits widely recorded from the surrounding area and classified as Brown Bank Formation, dating broadly to the late Ipswichian and Devensian (Bicket and Tizzard 2015; Tizzard et al 2015).

5.2.2 Variable thicknesses of clay/sandy clay have been recovered in vibrocores depending on the thickness of overlying sediment and depth of vibrocore penetration, varying between 0.3 m (**VC013**) and 5.2 m (**VC016**). As the clay/sandy clay deposits were present in 28 of the 61 vibrocore logs, vibrocores that recovered the greatest thickness of these deposits (**VC016** and **VC047**), or those overlain by peat deposits (**VC032** and **VC039**), were assigned a high priority status. Vibrocores with an intermediate depth of clay/sandy clay (between 2.4–3.2 m) were assigned a medium priority status (**VC003, VC005, VC005a, VC010, VC013a, VC024, VC029** and **VC033)** and monitored during geotechnical logging and sampling (**see section 5.5**).

5.2.3 The remaining 13 vibrocores contained ≤ 2 m of Pleistocene clay/sandy clay and will be geotechnically logged and sampled without a geoarchaeologist present.

5.3 Early Holocene sediments

5.3.1 Three vibrocores (**VC028**, **VC032** and **VC039**) contained deposits of peat of likely early Holocene date, resting on Pleistocene sandy clays and sealed by marine sediment. Geotechnical logs suggest the peat is at least 0.32 m thick in **VC028**, approximately 0.6 m thick in **VC032** and perhaps 0.1 m thick in **VC039**. All three vibrocores were assigned a high priority status owing to the geoarchaeological significance of the peat.

5.4 Recent seabed sediments

5.4.1 Marine sediments were recorded in 55 of the 61 vibrocore logs (**Appendix 1**), typically comprising unconsolidated fine to medium shelly sands of olive-brown, greenish-grey, dark greenish-grey, dark greyish brown and dark grey to black hue.

5.4.2 The marine shelly sand was the only deposit recorded in 31 of the 61 vibrocore logs, but was recorded sealing peat in three vibrocores (**VC028**, **VC032** and **VC039**) and Pleistocene clay/sandy clay (Brown Bank Formation) in a further 22 vibrocores (**Appendix 1**). Seabed sediments were absent in five vibrocores (**VC007**, **VC007a**, **VC027**, **VC30a** and **VC036**) where underlying Pleistocene sediments appear to be exposed at seabed.

6 DISCUSSION

6.1.1 61 vibrocore logs were reviewed with high, medium and low geoarchaeological priority status assigned based on the perceived geoarchaeological significance of the sediments (**Figure 3; Appendix 1**).

6.1.2 The vibrocores collectively comprise a sequence of Pleistocene clays/sandy clays, in places overlain by peat most probably of early Holocene date, and sealed by more recent marine shelly sands. The Pleistocene clays/sandy clays were recorded in 25 vibrocores, with peat recorded in three vibrocores (**VC028**, **VC032** and **VC039**). Marine shelly sands were recorded in 55 of the 61 vibrocores and were the only sediment recorded in just over half (31) of all the vibrocores.

6.1.3 Five vibrocores (**VC016, VC028, VC032, VC039** and **VC047**) were assigned a high priority status and have been retained for further geoarchaeological works (**Figure 3**).

6.1.4 Vibrocores **VC028**, **VC032** and **VC039** were assigned a high priority status based on the presence of semi-terrestrial peat deposits of high geoarchaeological significance (**Figure 3**), likely to date to the early Holocene prior to the inundation of the southern North Sea basin. The peat deposits have the highest potential for preserving material for radiocarbon dating, along with a range of palaeoenvironment remains (e.g. pollen, plant macrofossils) suitable for reconstructing past landscape and environmental change and investigating the evidence for human activity (e.g. evidence for burning or manipulation of vegetation).

6.1.5 Vibrocores **VC016** and **VC047** were assigned high priority status based on the greatest recorded depths amongst the vibrocores of Pleistocene clay/sandy clay, considered to represent the Brown Bank Formation. Since Pleistocene clay/sandy clays were present in 25 vibrocores, only a small selection of those vibrocores with the greatest depth of this deposit were assigned a high priority status.

6.1.6 The Brown Bank Formation is interpreted as a shallow lagoon environment, but it remains unclear whether it formed over a short period early in the Devensian, or over an extended time during the early to late Devensian. Internal features (laminations, patches of organic material and shelly inclusions) suggest a complex depositional history, whilst the lagoon

shores and areas of raised ground could have provided suitable locations for human occupation and activity.

6.1.7 Eight vibrocores contained an intermediate depth of clay/sandy clay, and were assigned a medium priority status (**Appendix 9.1; VC003, VC005, VC005a, VC010, VC013a, VC024, VC029** and **VC033).** No deposits of geoarchaeological significance were noted during monitoring of geotechnical sampling and logging**.**

6.1.8 Forty-nine vibrocores were assigned a low geoarchaeological significance (**Appendix 9.1**) and will be geotechnically logged and sampled without a geoarchaeologist present.

7 RECOMMENDATIONS

7.1.1 Further stage 2 geoarchaeological recording is recommended on the five vibrocores (**VC016, VC028, VC032, VC039** and **VC047**) assigned a high priority status (**Figure 3**), with the aim of describing and interpreting the deposits and making suitable recommendations for Stage 3 palaeoenvironmental assessment.

7.1.2 No deposits of geoarchaeological significance were noted during the monitoring of geotechnical logging and sampling of medium priority vibrocores (**VC003, VC005, VC005a, VC010, VC013a, VC024, VC029** and **VC033**). No further work is recommended on these vibrocores.

7.1.3 Should any deposits of geoarchaeological significance be encountered during geotechnical logging and sampling of low priority vibrocores, sufficient samples should be made available to Wessex Archaeology for geoarchaeological logging and recording, with suitable recommendations made where appropriate for Stage 3 palaeoenvironmental assessment.

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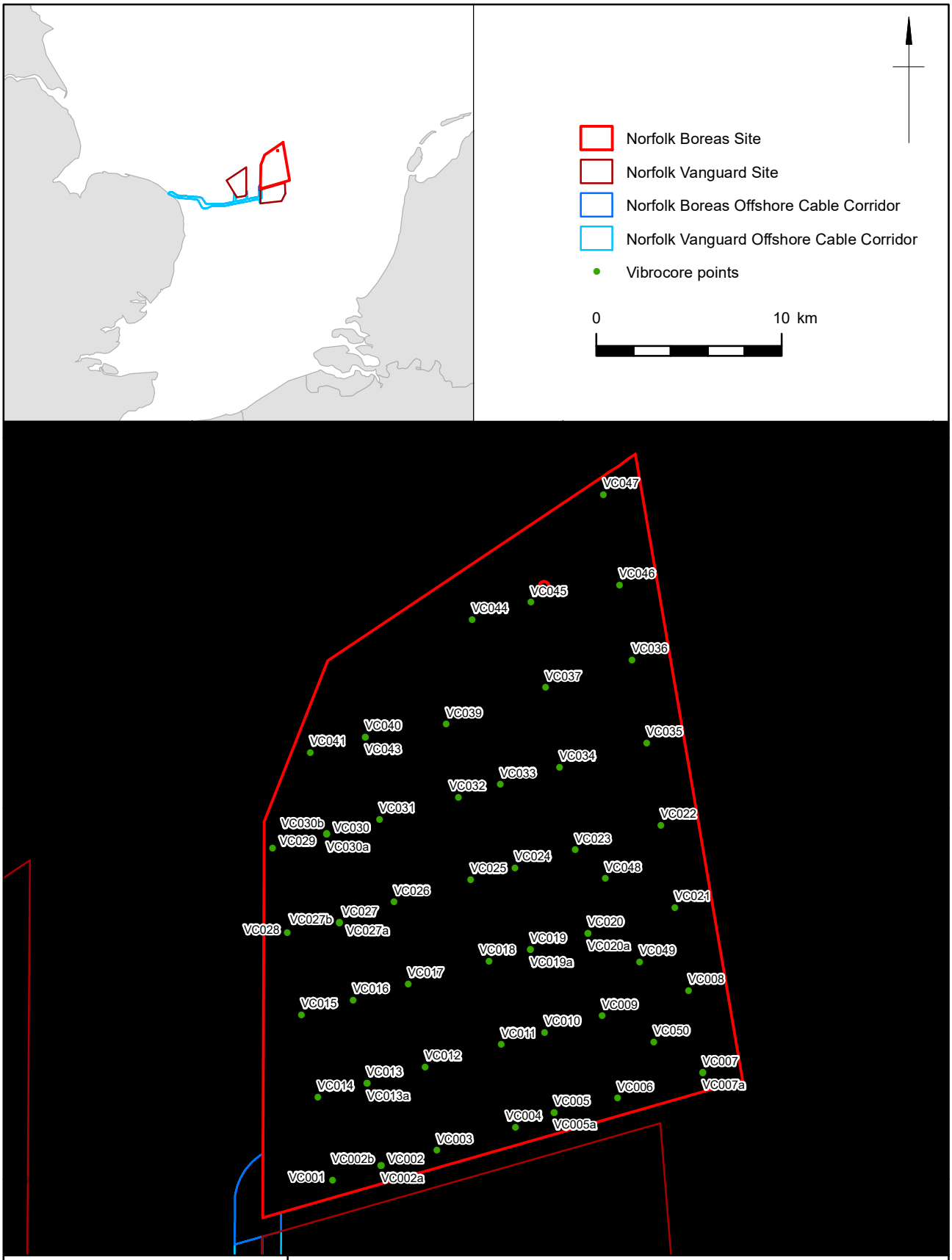
APPENDIX I

Norfolk Boreas vibrocores, priority status and preliminary interpretation

Vibrocore	Priority	Depth of recovery (m)	Preliminary Interpretation
VC001	Low	6	Marine sand
VC002	Low	1.7	Marine sand (0.8m) overlying Pleistocene deposits (0.9m)
VC002a	Low	1.9	Marine sand (0.8m) overlying Pleistocene deposits (1.1m)
VC002b	Low	1.9	Marine sand (0.8m) overlying Pleistocene deposits (1.1m)
VC003	Medium	5.1	Marine sand (2.7) overlying Pleistocene deposits (2.4)
VC004	Low	4.8	Marine sand
VC005	Medium	2.9	Marine sand (0.5m) overlying Pleistocene deposits (2.4m)
VC005a	Medium	3.1	Marine sand (0.5m) overlying Pleistocene deposits (2.6m)
VC006	Low	5.5	Marine sand
VC007	Low	1.9	Pleistocene deposits
VC007a	Low	1.5	Pleistocene deposits
VC008	Low	5.9	Marine sand (5m) overlying Pleistocene deposits (0.9m)
VC009	Low	4.4	Marine sand
VC010	Medium	3.9	Marine sand (1m) overlying Pleistocene deposits (2.9m)
VC011	Low	5.8	Marine sand
VC012	Low	4.4	Marine sand
VC013	Low	1.1	Marine sand (0.8m) overlying Pleistocene deposits (0.3m)
VC013a	Medium	4	Marine sand (0.8m) overlying Pleistocene deposits(3.2m)
VC014	Low	2.8	Marine sand
VC015	Low	4.8	Marine sand
VC016	High	5.9	Marine sand (0.6m) overlying Pleistocene deposits (5.2m)
VC017	Low	6.2	Marine sand
VC018	Low	5.8	Marine sand

VC019	Low	1.4	Marine sand (0.5) overlying Pleistocene deposits (0.9m)
VC019a	Low	2.7	Marine sand (0.5) overlying Pleistocene deposits (2.2m)
VC020	Low	1.3	Marine sand
VC020a	Low	1.9	Marine sand
VC021	Low	4.6	Marine sand
VC022	Low	4.2	Marine sand
VC023	Low	6	Marine sand
VC024	Medium	5	Marine sand (1.9m) overlying Pleistocene deposits (3.1m)
VC025	Low	5.8	Marine sand
VC026	Low	3.7	Marine sand
VC027	Low	0.9	Pleistocene deposits
VC027a	Low	1.9	Marine sand
VC027b	Low	2	Marine sand
VC028	High	3.1	Marine sand, with peat (2.31-.63)
VC029	Medium	5.8	Marine sand (3.0m) overlying Pleistocene deposits (2.8m)
VC030	Low	2.3	Marine sand (0.8m) overlying Pleistocene deposits (1.5m)
VC030a	Low	2.2	Pleistocene deposits
VC030b	Low	2.4	Marine sand (0.8m) overlying Pleistocene deposits (1.6m)
VC031	Low	5	Marine sand
VC032	High	4.7	Marine sand (4.7) with peat (~4-4.6)
VC033	Medium	5.3	Marine sand (2.8m) overlying Pleistocene deposits (2.4m)
VC034	Low	3.8	Marine sand
VC035	Low	5.8	Marine sands
VC036	Low	3.8	Pleistocene deposits
VC037	Low	6	Marine sand
VC038	Low	4.6	Marine san

VC039	High	3.7	Marine sand (3.0m) with peat (~0.1 or 0.7m?)
VC040	Low	5.1	Marine sand
VC041	Low	4.3	Marine sands (3.0m) overlying Pleistocene deposits(1.3m)
VC042	Low	5.8	Marine sand
VC043	Low	5.1	Marine sand
VC044	Low	4.8	Marine sand
VC045	Low	3.9	Marine sand
VC046	Low	4	Marine sand (2.8m) overlying Pleistocene deposits(1.2m)
VC047	High	5.4	Marine sand (2.0m) overlying Pleistocene deposits(3.4m)
VC048	Low	6	Marine sand
VC049	Low	4.4	Marine sand
VC050	Low	3.4	Marine sand (3.0m) overlying Pleistocene deposits(0.4m)



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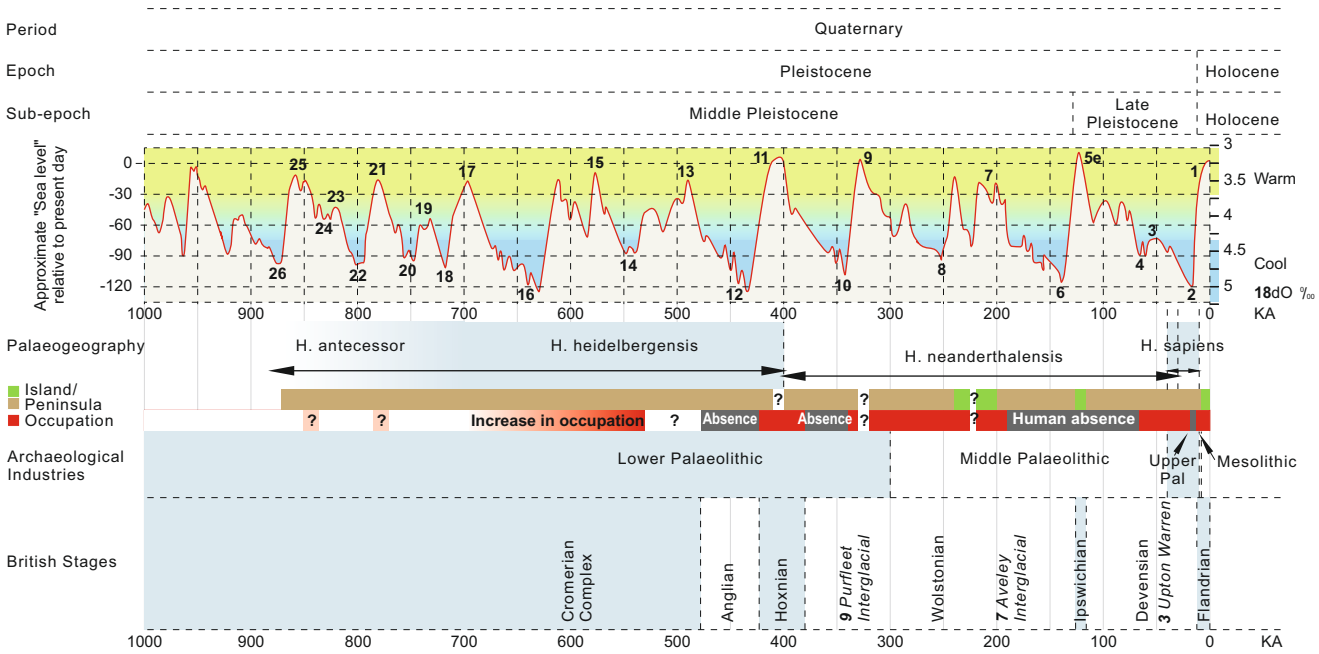
Site location

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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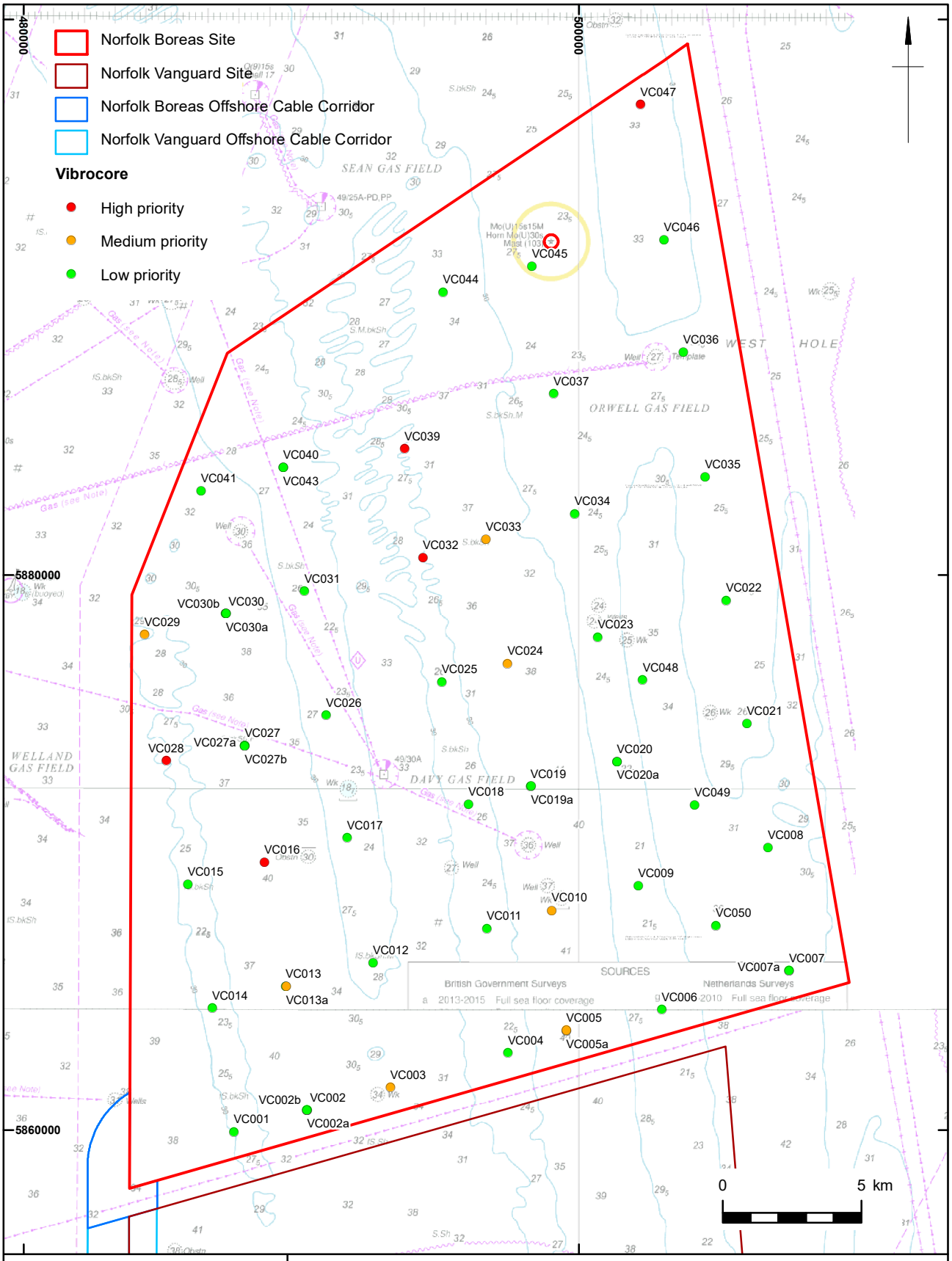
Chronostratigraphic timeline for the last one million years

Figure 2



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High, medium and low priority vibrocores

Figure 3

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