Hornsea
Offshore Wind Farm Project One

REPORT

Hornsea Project One Offshore Wind Farm

Stage 3 Intertidal Geoarchaeological Assessment

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1. Introduction

Maritime Archaeology Ltd. has been commissioned by DONG Energy Wind Power A/S to provide a Stage 3 assessment of sub-samples recovered from geotechnical boreholes in the intertidal zone relating to the Hornsea Offshore Wind Farm Project One (the Project) (see Figure 1).

The Stage 3 geoarchaeological assessment correlates to the third element in the archaeological assessment of geotechnical data as defined in:

- *Offshore Geotechnical Investigations and Historic Environment Analysis: Guidance for the Renewable Energy Sector* (COWRIE, 2011).

This Stage 3 geoarchaeological report refines the results gained from micro and macro assessments undertaken on soils and deposits recovered from intertidal cores collected at Hornsea Project One Offshore Wind Farm. The samples assessed were submitted following the recommendations made in the Stage 1 and Stage 2 geoarchaeological assessments (Maritime Archaeology, 2017a; Maritime Archaeology, 2017b).

2. Scheme background

DONG Energy (DE) took over full ownership of Hornsea Offshore Wind Farm Project One (Hornsea Project One) on 4 February 2015 following years of development alongside SMartWind. Hornsea Project One was one of the three projects for which DONG Energy was awarded Final Investment Decision Enabling contracts (Contract for Difference (CfD)) by the UK Government in April 2014. Under this CfD the business will receive a fixed price per MWh of electricity produced by the wind farm for the first 15 years of operation following which DONG Energy will receive the market price.

Hornsea Project One has received final investment decision (February 2016) and DONG Energy will develop the project through into construction and operation.

Hornsea Project One will consist of 174 wind turbines each 7MW and will be located 120 km off the Yorkshire coast, covering approximately 407 square kilometres. Onshore construction of the project started in Q1 2016 with onshore landfall works scheduled to commence in April 2017. The offshore export cable installation works have commenced from September 2017. All other offshore works including foundation installation and inter-array cable installation (with the exception of scour protection) is currently scheduled to commence in Q1 2018. Scour protection works for the wind farm are planned to start in Q4 2017. Horizontal Directional Drill (HDD) landfall construction is planned for early 2017.

In September 2015, Allied Exploration and Geotechnics Ltd were contracted by the Project to perform ground investigation at Horseshoe Point comprising trial pits and six cable percussion boreholes (Figure 2). The boreholes demonstrated the presence of beach deposits overlying alluvium, in places recorded with organic inclusions including plant fragments. Testing of the cores for landfall design purposes is complete and the cores acquired from the cable percussion boreholes are no longer available. Bagged samples, however, were retained which assisted with the identification of sub-surface deposits and their archaeological potential.

In February 2017, a Stage 1 desk-based review of core logs was undertaken by Maritime Archaeology. The review concluded that it could be possible to recover material that may contain preserved macro and micro fauna of archaeological interest from the retained samples. Therefore, Stage 2 recording

and sampling was recommended on the retained samples outlined in the Stage 1 report (Maritime Archaeology, 2017a). The Stage 2 review concluded that was potential in the sediments to contain preserved macro and micro fauna of archaeological interest from the collected sub-samples leading to recommendations for Stage 3 assessment (Maritime Archaeology, 2017b).

Further Stage 3 assessment of this material is supported by the recommendations contained in the *Intertidal Written Scheme of Investigation (WSI) for Archaeology* (DONG Energy, 2016c), which has been submitted to the MMO along with its advisors at Historic England (HE).

The MMO confirmed on 13th December 2016 that they were content with the Hornsea Project One Intertidal WSI for Archaeology strategy and that the condition could be discharged in respect of the HDD phase of works as set out below.

DML 4, Pre-construction plans and documentation 13 (2)(g):

> *A written scheme of archaeological investigation in relation to Wind Farm Area 1 in accordance with industry good practice to include—*
> *(i) details of responsibilities of the licence-holder, archaeological consultant and contractor;*
> *(ii) a methodology for any further site investigation including any specifications for geophysical, geotechnical and diver or remotely operated vehicle investigations;*
> *(iii) analysis and reporting of survey data to be submitted to the MMO within four months of survey completion;*
> *(iv) delivery of any mitigation including, where necessary, archaeological exclusion zones;*
> *(v) monitoring during and post construction, including a conservation programme for finds;*
> *(vi) archiving of archaeological material; and*
> *(vii) a reporting and recording protocol, including reporting of any wreck or wreck material during construction, operation and decommissioning of the authorised scheme.*

2.1 Previous Geoarchaeological Work

The previous assessment of offshore geotechnical and geophysical survey data collected in the Project One area revealed the presence of Pleistocene fluvial and estuarine sediments with the potential to contain hominid remains beneath the Devensian glacial till (generally at depths of 15 m or more below the seafloor). Closer to the seabed surface this work identified that Early Holocene 'Upper Botney Cut' channels, generally up to 15 m deep and 80 m wide, are cut into larger late Glacial channels of considerably greater size containing reworked glacial till (Wessex Archaeology 2013:16).

The cable corridor crosses some Late Pleistocene and Early Holocene channels on its way to shore lying at variable depth below the surface. The most significant feature to the west of Inner Silver Pit is a large palaeochannel that extends 4 km from landfall and appears to be a segment of the palaeo-Humber (SMart Wind, 2013).

The likelihood of survival of the remains of Mesolithic activity and settlement in and particularly on the side of these later channels is high (Coles, 1998; Flemming 2004 and Boomer *et al.*, 2007), although there are no known prehistoric terrestrial sites within the Project area. Sampling undertaken during the Humber Regional Environmental Characterisation (REC) study (Tappin *et al.* 2011) has shown that these deposits generally lie close to the surface of the seabed. It is therefore likely that the general area contains important prehistoric archaeological sites and finds and palaeo-environmental evidence.

The Stage 1 review stated that the sequence in the cores showed a relatively homogenous stratigraphy with a base of till, a very stiff brown gravelly clay with inclusions of chalk laid down after the last glacial maximum with minimal geoarchaeological potential. The till is overlaid in some cores

by Holocene alluvium representing a short period of stability where grasses and plants had time to grow before the area was inundated by the sea. This deposit has the highest potential to yield material of geoarchaeological importance. The Holocene alluvium is overlain by a sandy seabed/intertidal sediment, probably marine or fluvial, which is not of geoarchaeological significance, however larger fossils commonly found in the submerged context might be present following reworking within the sandy context (Maritime Archaeology, 2017a).

Table 1 summarises the geoarchaeological campaigns undertaken to date.

Year	Samples acquired	Archaeological report	Report summary
2011	• 28 Near shore zone vibrocores • Offshore bagged samples	Palaeoenvironmental assessment of near shore and offshore cores from the Hornsea Zone (Krawiec et al. 2011).	28 VC logs examined, 6 cores assessed together with bagged samples from the offshore zone. The samples yielded mixed results, the pollen concentrations were extremely low in some of the samples and assessment counts were not always possible. The accuracy of the radiocarbon dates were questioned and further work was recommended.
2012	• 12 boreholes • 129 vibrocores	Round 3 Hornsea Offshore Wind Farm Subzone 1 and export cable route Stage 1 and 2 Geoarchaeological Assessment, (Wessex Archaeology, 2013).	12 borehole locations and 27 vibrocore samples from the export cable route were assessed. Glacial, fluvial, estuarine and coastal sediments relating to former potentially inhabited landscapes were identified Stage 3 samples were recommended to further understand the sequence.
2014-2015 ‘	• 3BHs • 5 Wireline Push Samples • Downhole push CPT’s (drilled)	Hornsea Project One Offshore Wind Farm Stage 1-2 Updated Geoarchaeological Assessment Report. (Maritime Archaeology, 2016)	Three boreholes and five Wireline Push Samples collected in 2014-2015 were assessed in terms of their archaeological and palaeoenvironmental potential. The small amount of samples recovered could not enhance the initial interpretation of the project area. It was recommended that further Stage 3 assessment should be undertaken with samples from all previous geoarchaeological campaigns.
2017	• 6 intertidal boreholes • 7 intertidal trial pits	Hornsea Project One Offshore Wind Farm Stage 1 Intertidal Geoarchaeological Assessment (Maritime Archaeology, 2017a)	Logs and photographs were reviewed to establish the potential for further geoarchaeological recording, assessment and analysis. The Stage 1 review showed that it was potentially possible to recover material containing preserved macro and micro fauna of archaeological interest from the retained samples and therefore a Stage 2 recording and sampling programme was recommended.
2017	• 6 intertidal boreholes • 7 intertidal trial pits	Hornsea Project One Offshore Wind Farm Stage 2 Intertidal Geoarchaeological Assessment (Maritime Archaeology, 2017b)	Further assessment of the material concluded that there was some potential in the sediments to contain preserved macro and micro fauna of archaeological interest resulting in Stage 3 recommendations being made.

Table 1 Previously undertaken geoarchaeological campaigns.

3. Project aims and objectives

The aim of this study is to inform the Project and provide continuity of geoarchaeological assessment regarding the archaeological potential of the intertidal development area. This has been achieved by sub-sampling and assessing the deposit collected at the intertidal zone at Hornsea Project One for environmental indicators.

The objectives of the archaeological Stage 3 recording and sub-sampling of the recommended deposits are to:

- Undertake an assessment of the deposits for environmental receptors;
- Highlight the geoarchaeological potential of certain types of sub-surface geological deposits containing environmental receptors;
- Clarify the potential for impacts to sub-surface geoarchaeological deposits and buried archaeology from activities at the landfall; and
- Identify requirement for further Stage 4 analysis based on the micro- and macro fossils present in the cores.

4. Methodology

The assessment of potential archaeological deposits follows the staged approach described in *Model Clauses for Archaeological Written Schemes of Investigation: Offshore Renewables Projects* (The Crown Estate, 2010), COWRIE's *Offshore Geotechnical Investigations and Historic Environment Analysis: Guidance for the Renewable Energy Sector* (COWRIE, 2011), and *Environmental Archaeology: a guide to the theory and practice of methods, from sampling to post excavation* (English Heritage, 2011). This comprises the following elements:

- Stage 1 – Desk-based Assessment: archaeological review of geotechnical logs (Maritime Archaeology Ltd., 2017a);
- Stage 2 – Splitting, recording geotechnical cores and sub-sampling (Maritime Archaeology Ltd., 2017b);
- Stage 3 – Assessment (This report); and
- Stage 4 – Analysis and dating.

The staged approach is designed to flow sequentially with each stage leading to the subsequent stage of work, or representing the end of the assessment if the findings of any stage show that no further work is beneficial.

4.1 Stage 3 Assessment

The geoarchaeological assessment was undertaken by utilising the geoarchaeological sub-samples collected during the Stage 2 process where material of archaeological interest was identified within the core samples during core logging and recording. Sub-samples between 1-250g were collected from the units of interest for archaeological laboratory assessment and analysis.

Sub-samples from cores BH-14, BH-15, BH-16 and BH-18 were assessed to ensure that all three units identified in the initial assessment were sub-sampled (Maritime Archaeology, 2017b). The sub-samples were thereafter sent for further assessment by the environmental specialists.

The results from the Stage 3 assessment have been compared with the earlier studies to clarify and strengthen our understanding of the sediments present and the nature of the pre-historic environment.

4.1.1 Pollen

Pollen is a valuable tool for reconstructing past environments. It can aid us in understanding the environmental landscape, economy and prehistoric human culture (English Heritage, 2011). Pollen are produced by higher plants (Vascular plants) and can, with the help of wind and/or water, travel relatively far. Pollen should therefore ideally be analysed with other environmental proxy evidence in order to gain a comprehensive understanding of the deposits (English Heritage, 2011).

A palynological investigation was undertaken on samples from cores BH-14, BH-15, BH-16 and BH-18. The study was undertaken to determine presence or absence of sub-fossil pollen and spores and, if present, to provide a preliminary picture of the palaeo-vegetation and environment of the site and local environs during the timespan represented by the sediments.

Standard techniques for pollen concentration of the sub-fossil pollen and spores were used on sub-samples of 1.5 ml. volume (Moore and Webb 1978; Moore et al. 1992), with the addition of micromesh sieving to aid removal of silica (clay/fine silt). Pollen counts of between c. 50 and 100 grains per level were made depending on the absolute numbers of pollen present. However, only minimal numbers (<10) were obtained from the lower levels of BH-16.

These procedures were carried out by Visiting Professor of Paleoecology, Dr Rob Scaife, in the Paleoecology Laboratory of the Department of Geography, University of Southampton. The results from the pollen assessment are presented in Section 5 and Appendix I.

4.1.2 Diatoms

Diatoms are freshwater and marine algae and, as the species are habitat-specific, they can be used to indicate water quality, temperature and salinity, nutrient and mineral levels, acidity and degree of oxygenation. Diatoms are most useful in when investigating coastal and estuarine sites, providing data on marine influence and phases of sea-level change (Historic England, 2011).

The diatom analysis forms part of a wider palaeoenvironmental investigation at the site. The purpose of carrying out a diatom assessment is to test for the presence or absence of diatoms and the potential of the sediments for further diatom analysis. The diatom assessment of each sample takes into account the numbers of diatoms, the state of preservation of the diatom assemblages, species diversity and their environmental preferences. Of particular interest here are the salinity conditions represented by diatom assemblages.

The diatom preparation followed standard techniques (Battarbee *et al*. 2001). Two coverslips were made from each sample and fixed in Naphrax for diatom microscopy. A large area of the coverslips on each slide was scanned for diatoms at magnifications of x400 and x1000 under phase contrast illumination.

Diatom floras and taxonomic publications were consulted to assist with diatom identification. These include Hendey (1964), Werff & Huls (1957-1974), Hartley et al. (1996), Krammer & Lange-Bertalot (1986-1991), Camburn & Charles (2000) and Witkowski et al. (2000). Diatom species' salinity preferences are indicated using the halobian groups of Hustedt (1953, 1957: 199). These salinity groups are summarised as follows:

1. Polyhalobian: >30 g l-1;
2. Mesohalobian: 0.2-30 g l-1;
3. Oligohalobian - Halophilous: optimum in slightly brackish water;
4. Oligohalobian - Indifferent: optimum in freshwater but tolerant of slightly brackish water;

5. Halophobous: exclusively freshwater, and;
6. Unknown: taxa of unknown salinity preference.

The Diatom assessment was carried out by Dr Nigel Cameron of the Environmental Change Research Centre Department of Geography University College London. The results from the assessment are presented in Section 5 and Appendix II.

4.1.3 Foraminifera and Ostracods

Foraminifera are a group of marine shell-bearing protozoans and their position in the sediment can be used for palaeoenvironmental study. Planktonic foraminifera live in marine waters of normal salinity and are very rare in brackish waters. These benthonic forms live at or near the sediment-water interface and occur in brackish to normal marine habitats, and at all depths. They are ideal for palaeoenvironmental analysis as many species have narrowly defined niches (Murray, 1991).

Ostracods are small bivalve crustaceans with calcareous shells that grow by shedding their old shell and secreting a new one. Ostracods inhabit nearly all types of aquatic environment from freshwater to marine, making them good indicators of changes in environment (Historic England, 2011).
Thirteen sediment samples from four boreholes (BH-14, BH-15, BH-16 and BH-18), were weighed and then broken into small pieces by hand, placed in ceramic bowls and dried in an oven. Boiling-hot water was then poured over them, with a little sodium carbonate added to help disaggregate the clay fraction, and then left to soak overnight. Washing was undertaken with hand-hot water through a 75 micron sieve, the remaining residue being returned to the ceramic bowl for final drying in the oven. The organic rich silts were, if required, processed twice and then the residues were stored in labelled plastic bags.

For examination, each sample was placed in a nest of sieves (>50, >250, >150 microns, and base pan) and thoroughly shaken. Each grade was then sprinkled onto a picking tray, a little at a time, and viewed under a binocular microscope. Organic remains were logged on a presence(x)/absence basis. The abundance of each species of foraminifera and ostracod was estimated semi-quantitatively (one specimen, several specimens, common and abundant/superabundant) by experience and by eye. For archive purposes, a representative fauna of foraminifera and ostracods was also placed in 3x1” faunal slides.

The foraminifera and ostracods were assessed and analysed by Dr John E. Whittaker, Honorary Associate (Micropalaeontology), Department of Earth Sciences, The Natural History Museum, London. The results from the assessment are presented in Section 5 and Appendix III.

4.1.4 Radiocarbon Dating

Organic sub-samples collected during sub-sampling that had the potential to yield reliable dates were analysed by the Scottish Universities Environmental Research Centre (SUERC) C14 laboratory in Glasgow.

Two samples were sent for dating, both of the samples contained enough material for Accelerator Mass Spectrometry (AMS) measurements, however one of the samples proved to be from the nuclear era (post 1950 AD).

The C14 age is quoted in conventional years BP (before 1950 AD). The error, which is expressed at the one sigma level of confidence, includes components from the counting statistics on the sample,

modern reference standard and blank and the random machine error. The carbon isotope ratios have been measured against Vienna Pee Dee Belemnite (VPDB).

The calibrated age ranges are determined from the University of Oxford Radiocarbon Accelerator Unit calibration program (OxCal v4). The marine calibration curve is based on Reimer *et al*. (2013).

The full specialist report from the C14 dating is presented in Appendix IV.

4.2 Interpretation of the results

The results from the sub-samples were assessed and then reviewed against the current understanding of the Holocene sediments within the development area to improve understanding of the deposits represented.

5. Results

The detailed results from the micro and macrofossil are presented below in Table 2 and discussed in context in Section 6. The reports carried out by the external experts, as outlined in Section 4, are included in appendices I to IV.

Core (Depth BGL)	***Date***	***Diatom***	***Ostracod***	***Pollen***	***Foraminifera***
BH-14 (8.90)		*Very low numbers and very poor preservation. Polyhalobous (Paralia sulcata) Mesohalobous (Campylodiscus echeneis, Nitzschia granulata, Nitzschia navicularis). Unknown Salinity Group (Synedra sp.)*	*Brackish (Cyprideis torosa (xx) Leptocythere lacertosa (o)*	*Trees & Shrubs Betula(1) Pinus (17) Ulmus (2), Quercus (36) Fagus (1) Tilia (1) Alnus (7) Corylus avellana type (10) Salix (1) Hedera helix (2) Lonicera (1) Herbs: Poaceae (12) Cyperaceae (3) Typha/Sparganium (1) Chenopodiaceae (3) Potentilla type (1) Plantago indet. (1) Plantago lanceolate Succisa (1) Unidentified/degraded (1) Ferns cf Lycopodium (1) Pteridium (1) Dryopteris type (9) Polypodium (1) Miscellaneous Pediastrum (2) Pre-Quaternary (61) Hystrichospheres (4)*	*Brackish (Trochammina inflata (xxx) Jadammina macrescens (x) Arenoparrella mexicana (x) Haynesina germanica (x) Outer (Ammonia batavus (x))*
BH-14 (9.50)		*Low numbers and very poor preservation. Polyhalobous (Cymatosira belgica, Paralia sulcata, Rhaphoneis amphiceros) Mesohalobous (Diploneis didyma, Nitzschia granulata, Nitzschia navicularіz)Unknown Salinity Group (Amphora sp., Diploneis sp.)*		*Trees & Shrubs; Betula (1) Pinus (22) Ulmus(2)Quercus (27)Tilia (2 (*))Alnus (6) Corylus avellana type (11) Erica (1) Herbs Poaceae (22) Cyperaceae (2)Typha/Sparganium (1) Chenopodiaceae (6) Dryopteris type (7) Ferns Sphagnum (2) Miscellaneous Pre-Quaternary (130) Hystrichospheres (3)*	*Brackish (Trochammina inflata (xx) Jadammina macrescens (x)*

Core (Depth BGL)	Date	Diatom	Ostracod	Pollen	Foraminifera
BH-15 (7.50)		*Low numbers and very poor preservation. Polyhalobous (Paralia sulcata, Rhaphoneis surirella) Polyhalobous to mesohalobous (Actinoptychus undulatus)*	*Brackish (Leptocythere psammophila (x) Cyprideis torosa (o) Outer (Pontocythere elongata, Hemicythere villosa, Paradoxostoma/Sclerochilusspp, Leptocythere pellucida (x),Palmoconcha guttata, Semicytheruraspp (0)*		*Brackish (Haynesina germanica (X) Ammoniasp, Elphidium williamsoni (o) Outer (Ammonia batavus (xx), Cibicides lobatulus, miliolids (x)*
BH-15 (8.50)			*Brackish (Leptocythere psammophila (xx) Cyprideis torosa (o) Leptocythere lacertosa (x) Outer (Pontocythere elongata, Hemicythere villosa (x) Semicytheruraspp (0) Palmoconcha laevata (o)*	*Trees & Shrubs Betula (6) Pinus (4) Ulmus (1) Quercus (2) Alnus (3) Corylus avellana type (3) Herbs Poaceae (large) (1) Brassicaceae (1) Chenopodiaceae (2) Rumex (2) Apiaceae (1) Scabiosa (1) Lactucoideae (5) Unidentified/degraded (6) Ferns Dryopteris type (1) Polypodium (5) Miscellaneous Sphagnum (1) Pediastrum (3) Pre-Quaternary (89) Hystrichospheres (20)*	*Brackish (Haynesina germanica (o) Ammoniasp, Elphidium williamsoni (o) Outer (Ammonia batavus (x), Cibicides lobatulus (x)*
BH-15 (9.30)		*Low numbers and poor preservation. Polyhalobous (Cymatosira belgica, Paralia sulcata, Rhaphoneis amphiceros, Rhaphoneis surirella) Polyhalobous to Mesohalobous (Caloneis westii, Cyclotella striata, Nitzschia punctata, Nitzschia granulata, Nitzschia navicularis) Unknown Salinity Group (Navicula sp.)*	*Outer (Pontocythere elongata (o), Hemicythere villosa (x)*	*Trees & Shrubs Betula (1) Pinus (18) Ulmus (2) Quercus (16) Alnus (5) Corylus avellana type (10) Erica (2) Herbs Poaceae (11) Poaceae (large) (3) Chenopodiaceae (7) Rumex (1) Plantago lanceolate (1) Rubiaceae (1) Anthemis type (1) Artemisia (1) Unidentified/degraded (2) Ferns Pteridium (1) Dryopteris type (13) Polypodium (1) Miscellaneous Sphagnum (3) Pediastrum (1) Pre-Quaternary (145) Hystrichospheres (5)*	*Brackish (Haynesina germanica (x) Outer (Ammonia batavus (xx) miliolids (x)*

Core (Depth BGL)	Date	Diatom	Ostracod	Pollen	Foraminifera
BH-15 (10.50)	5205 cal BC	Low numbers and poor preservation. Polyhalobous (Grammatophora sp., Paralia sulcata, Rhaphoneis amphiceros, Rhaphoneis minutissima, Rhaphoneis surirell) Polyhalobous to Mesohalobous (Actinoptychus undulatus, Diploneis smithii, Synedra gaillonii)Mesohalobous (Bacillaria paradoxa, Diploneis didyma, Nitzschia bilobata, Nitzschia punctata, Nitzschia granulata, Nitzschia naviculari) Unknown Salinity Group (Diploneis sp., Navicula sp., Synedra sp., Thalassiosira sp.)		Trees & Shrubs Betula (3) Pinus (17) Ulmus (1) Quercus (35) Tilia (2) Alnus (6) Corylus avellana type (17) Salix (1) Erica (1) Herbs Poaceae (11) Cyperaceae (4) Ranunculus type (1) Ferns Dryopteris type (3) Miscellaneous Sphagnum (3) Pre-Quaternary (33) Hystrichospheres (2)	Brackish (Trochammina inflata (xxx) Jadammina macrescens (xx)
BH-16 (5.50)		Extremely low numbers and poor preservation (Scoliopleura tumida)	Brackish (Leptocythere psammophila, Leptocythere lacertosa (o)) , Outer eustarine (Hemicythere villosa (x), Pontocythere elongata(0)		Brackish (Elphidium williamsoni, Haynesina germanica (x) outer eustraine/marine (Ammonia batavus, miliolids, Cibicides lobatulus (x)
BH-16 (11.50)		Very low numbers and very poor preservation polyhalobous (Paralia sulcata, Rhaphoneis amphiceros), polyhalobous to mesohalobous (Actinoptychus undulatus, Ardissonia crystallina) and benthic mesohalobous (Campylodiscus echeneis, Diploneis didyma, Nitzschia punctata, Nitzschia granulata and Nitzschia navicularis) Halophilous to oligohalobous indifferent diatom is present (Epithemia sp.)		Trees & Shrubs Betula (7) Pinus (13) Quercus (1) Alnus (5) Corylus avellana type (13) Calluna (1) Herbs Poaceae (8) Poaceae (large) (1) Cyperaceae (1) Typha/Sparganium (1) Lactucoideae (1) Ferns Dryopteris type (37) Pre-Quaternary (815) Hystrichospheres (1)	Brackish (Elphidium williamsoni (x) Trochammina inflata (0))
BH-16 (13.50)					Brackish (Elphidium williamsoni (x) Outer eustarine/marine (Cibicides lobatulus (0))

Core (Depth BGL)	Date	Diatom	Ostracod	Pollen	Foraminifera
BH-16 (14.50)				*Trees & Shrubs Pinus (3) Herbs Poaceae (3) Pre-Quaternary (416) Hystrichospheres (3)*	*Brackish (Elphidium williamsoni, (x) Haynesina germanica (0)*
BH-16 (17.50)			*Brackish (Leptocythere psammophila (o)*	*Trees & Shrubs Pinus (5) Miscellaneous Pediastrum (1) Pre-Quaternary (506) Hystrichospheres (3)*	*Brackish (Elphidium williamsoni, (x) Ammoniasp (0)*
BH-18 (11.00)		*Very low numbers and extremely low preservation of Mesohalobous (Cyclotella striata) Unknown Salinity Group (Inderminate centric sp.)*	*Outer (Pontocythere elongata (o) Hemicythere villosa (o)*		*Brackish (Haynesina germanica (x), Ammoniasp (x) Elphidium williamsoni (o)*
BH-18 (14.00)	*post 1950 AD*	*Very low numbers and very poor preseravation of Polyhalobous (Cymatosira belgica, Grammatophora sp., Paralia sulcata) Mesohalobous (Nitzschia punctata, Nitzschia granulata, Nitzschia navicularis) Unknown Salinity Group (Synedra sp.)*	*Brackish (Cyprideis torosa (o) Leptocythere lacertosa (o)*	*Trees & Shrubs Betula (1) Pinus (18) Quercus (1) Alnus (3) Corylus avellana type (11) Herbs Poaceae (9) Chenopodiaceae (14) Plantago maritima (1) Ferns Dryopteris type (3) Miscellaneous Sphagnum (1) Pediastrum (3) Pre-Quaternary (1236) Hystrichospheres (5)*	*Brackish (Haynesina germanica (x), Ammoniasp (o) Elphidium williamsoni (o), Trochammina inflata (o) Outer (Ammonia batavus (x), miliolid (x) Cibicides lobatulus (x)*

Table 2 Results from the Stage 3 assessment

6. Discussion

The assessment of the microfauna in BH-14 (8.90 and 9.50 BGL) shows that the area has been a brackish high to medium tidal salt marsh with limited marine input since marine transgression inundated the adjacent shoreline. Grasses, sedges and fern suggest that fern herb has grown in the vicinity. Traces from woodland vegetation derive from temperate broadleaf and mixed forests.

The sediments in BH-15 have proven to derive from a marine or brackish mid to high saltmarsh around 5205 Cal BC, developing into a brackish tidal flat with marine and estuarine influences. Grasses, sedges and fern suggest that fern herb grew in the vicinity. Again, traces from woodland vegetation derive from temperate broadleaf and mixed forests.

The results indicate that the area location where BH-14 and BH-15 were collected has not been completely inundated by the sea for several thousand years and probably not after the sea levels settled around 7000- 6000 BP.

BH-16 contains micro fauna from a poorly developed tidal flat, possibly estuarine, with a shallow water mud-surface. The vegetation is dominated by grasses with some indications of pine and oak. The influx of estuarine and marine species points towards a generally stable environment.

BH-18 supports the understanding of the area as a tidal mudflat and saltmarsh with an outer estuarine or marine component. Goosefoot, orache and samphire are present with sea plantain, grasses and sedges were also available with a temperate broadleaf and mixed forest within the pollen deposition

area. One C14 date from 14m BGL was dated to post 1950, demonstrating that the nature of the coring area is dominated by reoccurring episodes of sediment re-working. Furthermore it should be noted that the core sampling and storage methodology implies that, when collected, some contamination between sample depths may have occurred.

Results from a previous geoarchaeological assessment focusing on dating and pollen undertaken in the nearshore zone yielded mixed results (Krawiec *et.al.*, 2011). The 2011 report does not contain the exact positions of the cores samples but states that they were collected in the mouth of the Humber River, probably within 2 km of the cores presented in this report. The results from the 2011 report, while recognising the potential for the material to contain pollen for environmental reconstruction, also found that the samples produced an extremely low pollen concentration and that some reworking had occurred as pre-Quaternary spores were present in some of the samples.

The C14 dates gained from the report as presented in Table 3 show that the sediments, although taxonomically fairly similar, derive from older deposits than the ones sampled for the 2017 study. Krawiec does question the accuracy of the radio carbon dates but does agree that core sequences represent deposits from channel systems which began forming during the Late-glacial and early Holocene. The three cores assessed suggest deposition within a mid to low energy fluvial system. This in turn can explain a degree of reworking of the palynomorphs and possibly the material submitted for radiocarbon dating (Krawiec *et.al.*, 2011).

Core ID	Sub-sample depth	Radiocarbon date
CR1A 8	5.2	7360+40BP
CR1 2	3.87	14700+60BP
CR1A 2	5.03	11030+50BP

Table 3 Summary of carbon dates from Krawiec et.al, 2011

7. Recommendations

As the sub-samples were collected from disturbed material, the Stage 2 sub-sampling focused on deposits where micro- and macrofossils are more likely to survive i.e. fine grained material such as silt and clay. However, the results from the Stage 3 assessment of the material for environmental indicators has shown that very few species have survived and that those that have are poorly preserved. Further, the results from the dating sequence indicate that significant re-working has taken place in the intertidal area.

These factors, in combination with the overall condition of the disturbed samples, indicate that no further benefit is expected to be realised from continued analysis of the samples collected from the intertidal area at Hornsea Offshore Wind Farm. Nevertheless, the results presented in this report should be incorporated within the forthcoming Stage 3 assessment of offshore cores from the wind farm development. This is to contribute and support the dating and understanding of Holocene deposits in the area as limited material has been located from this epoch from offshore contexts.

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9. Figures

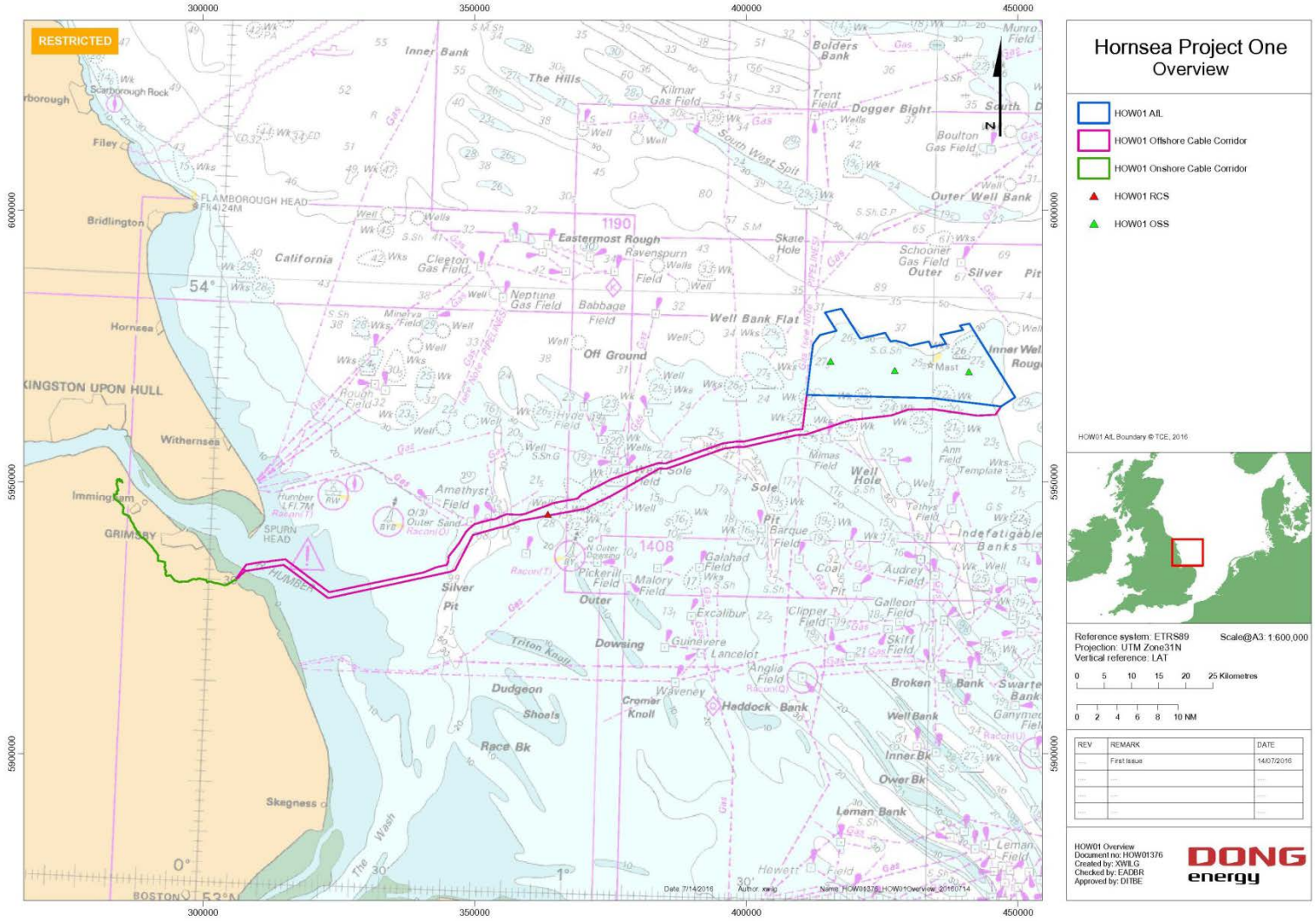

Figure 1 Hornsea One Offshore Wind Farm

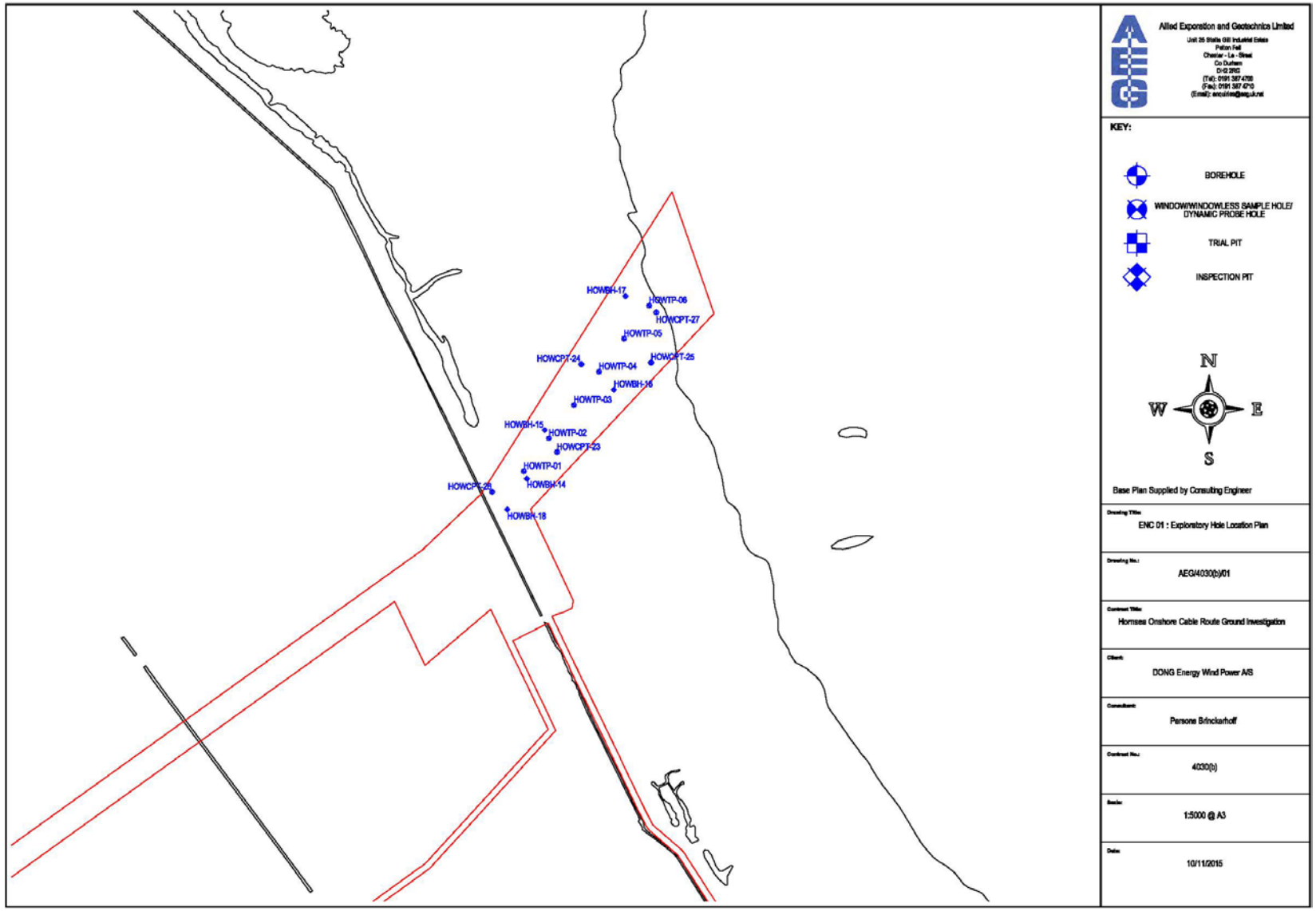

Figure 2 Borehole and trial pit locations (Allied Exploration and Geotechnics Ltd., 2015

10. Appendix I Pollen Assessment

Hornsea (HW01): Pollen analysis of the intertidal alluvium

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Introduction

Samples taken from the four core profiles of the alluvial sediment have been examined to determine if sub-fossil pollen and spores are present and, if so, to provide some preliminary information on the character of vegetation growing at the time of alluviation and possible age. Overall, the preservation was poor and numbers of Holocene pollen were small. However, some useful data have been obtained which are described in this report. All of the profiles produced pollen which is *tentatively* suggested as being of early Holocene Pre-Boreal (Flandrian chronozone 1 b-c) age and, possibly some very early middle Holocene (Atlantic period). That is, prior to marine incursion.

Pollen method

A total of 8 samples taken from boreholes 14, 15, 16 and 18 were examined for their sub-fossil pollen, spore and other microfossil content. Standard techniques for pollen concentration of the sub-fossil pollen and spores were used on these sub-samples of 1.5 ml. volume (Moore and Webb 1978; Moore *et al*. 1992) with the addition of micromesh sieving to aid removal of silica (clay/fine silt). Pollen counts of between c. 50 and 100 grains per level were made depending on the absolute numbers of pollen present. However, only minimal numbers (<10) were obtained from the lower levels of borehole 16. Pollen count data obtained are given in tables 1 and 2.

Taxonomy, in general, follows that of Moore and Webb (1978) modified according to Bennett *et al.* (1994) for pollen types and Stace (1991) for plant descriptions. These procedures were carried out in the Palaeoecology Laboratory of the School of Geography and Environment, University of Southampton. An extensive pollen reference collection was available for critical identifications.

3. The pollen data

Pollen preservation was found to be extremely variable but generally very poor throughout with low absolute pollen numbers. Pollen was absent in on sample at 13.50m in borehole 16. Pollen preservation and numbers overall are better in boreholes 14 and 15.

Overall, trees and shrubs are most important with herbs largely coming from the on-site wetland (autochthonous component).

Borehole	***BH14***	***BH14***	BH15	***BH15***	***BH15***
Depth (metres)	***8.90***	***9.50***	***8.50***	***9.30***	***10.50***

Borehole	***BH14***	***BH14***	BH15	***BH15***	***BH15***
Trees & Shrubs					
Betula	1	1	6	1	3
Pinus	17	22	4	18	17
Ulmus	2	2	1	2	1
Quercus	36	27	2	16	35
Fagus	1				
Tilia	1	2 (*)			2
Alnus	7	6	3	5	6
Corylus avellana type	10	11	3	10	17
Salix	1		‘		1
Erica		1		2	1
Hedera helix	2				
Lonicera	1				
Herbs					
Poaceae	12	22		11	11
Poaceae (large)			1	3	
Cyperaceae	3	2			4
Typha/Sparganium	1	1			
Ranunculus type					1
Brassicaceae			1		
Chenopodiaceae	3	6	2	7	
Potentilla type	1				
Rumex			2	1	
Apiaceae			1		
Plantago indet.	1		1		
Plantago lanceolata				1	
Plantago maritima					
Rubiaceae				1	
Succisa	1				
Scabiosa			1		
Anthemis type				1	
Artemisia				1	
Lactucoideae			5		
Unidentified/degraded	1		6	2	
Ferns					
cf *Lycopodium*	1				
Pteridium	1			1	
Dryopteris type	9	7	1	13	3
Polypodium	1		5	1	
Miscellaneous					

Borehole	***BH14***	***BH14***	BH15	***BH15***	***BH15***
Sphagnum		2	1	3	3
Pediastrum	2		3	1	
Pre-Quaternary	61	130	89	145	33
Hystrichospheres	4	3	20	5	2

Table 1: Pollen data from Boreholes BH14 and BH15.
(***** Suspected pre-Quaternary pollen form)

Borehole	***BH16***	***BH16***	***BH16***	***BH18***
Depth (metres)	***11.50***	***14.50***	***17.50***	***14.00***
Trees & Shrubs				
Betula	7			1
Pinus	13	3	5	18
Quercus	1			1
Alnus	5			3
Corylus avellana type	13			11
Calluna	1			
Herbs				
Poaceae	8	3		9
Poaceae (large)	1			
Cyperaceae	1			
Typha/Sparganium	1			
Chenopodiaceae				14
Plantago maritima				1
Lactucoideae	1			
Ferns				
Dryopteris type	37			3
Miscellaneous				
Sphagnum				1
Pediastrum			1	3
Pre-Quaternary	815	416	506	1236
Hystrichospheres	1	3	3	5

Table 2: Pollen data from Boreholes BH16 and BH18.
(Pollen was absent at 13.50m in BH16).

3.i.) Borehole 14: Two samples at 8.50m and 9.50m with moderate preservation. *Pinus* (pine), *Quercus* (oak) and *Corylus avellana* type (hazel) are the dominant taxa. There are small numbers and sporadic occurrences of *Ulmus* (elm), *Fagus* (beech), *Tilia* (lime/linden) and *Alnus* (Alder) and *Salix* (willow). Herbs comprise largely Poaceae (grasses). Wetland taxa include Cyperaceae (sedges), *Typha angustifolia*/*Sparganium* type (bur reed and reed mace) and *Succisa pratensis* (meadow scabious). Chenopodiaceae (goosefoot and orache) is probably from halophytic communities. There are substantial numbers of reworked/derived pre-Quaternary palynomorphs.

3.ii.) Borehole 15: Three samples from 8.50m to 10.50m. Moderate preservation. *Pinus*, *Quercus* and *Corylus avellana* type are the dominant taxa. *Betula* (birch), *Ulmus* and *Alnus* with sporadic occurrences of *Tilia*. There is a relatively diverse assemblage of herb taxa in these samples but with small absolute numbers. Poaceae is most important with some Chenopodiaceae. There are small numbers of algal Pediastrum and substantial numbers of pre-Quaternary palynomorphs including reworked Hystrichospheres.

3.iii.) Borehole 16: Three samples from 11.50m to 17.50m. Pollen preservation was found to be extremely poor and with very small numbers of pollen and absence in one sample at **metres and minimal numbers at 14.50m and 17.50m. Thus, pollen count totals are small. A sample at 11.50m proved most useful with higher numbers of preserved pollen albeit still poor. Here, *Pinus* and *Corylus avellana* type are most important with some *Betula*, and *Alnus* and single occurrence of *Quercus*. In this sample, Poaceae (grasses) are most important. There are very substantial numbers of pre-Quaternary palynomorphs.

3.iv.) Borehole 18: Two samples. As with BH16, pollen numbers and preservation are poor. The sample at 14.0m proves most useful although absolute numbers were still marginal to obtain a pollen count. *Pinus* and *Corylus avellana* type are most important with occasional *Quercus*, *Alnus* and sporadic *Betula*. Herbs comprise Poaceae and Chenopodiaceae. Small numbers of algal *Pediastrum* cysts were recorded. There are again, very substantial numbers of pre-Quaternary palynomorphs including Hystrichospheres.

4.) Discussion

In boreholes 16 only the sample at 11.50m in BH16 (table) has provided data; although this is less than satisfactory with only a total of 52 pollen grains identified. Samples from boreholes 14, 15 (table 1) and a single sample from BH18 (table 2) provide the best information.

4.i. The woodland vegetation: The pollen data from all of the profiles show the importance of pine (*Pinus*) and oak (Quercus) with hazel (*Corylus avellana*). Elm (*Ulmus*) and alder (*Alnus*) are present with sporadic occurrences of birch (*Betula*), beech (*Fagus*) and lime (*Tilia*). The former produces copious quantities of pollen and is anemophilous such that numbers recorded here are not regarded as of any significance. This contrasts with beech and lime/linden which are both poorly represented in pollen assemblages relative to the other taxa noted.

4.ii.) Dating: These assemblages, overall, are typical of those of early Holocene, Boreal (Flandrian chronozone 1b-c) age. That is, showing the period of re-establishment of woodland after the close of the Devensian cold stage at *c.* 10,000BP. Archaeologically, this equates to the early Mesolithic. The presence of lime and alder in the upper levels of BH15 might suggest the latter part of this period (Fl.Ic) and possibly early middle Holocene (Atlantic; Fl.II). The pollen record for beech (*Fagus*) is early and unusual.
Radiocarbon dating is required as pollen analysis is no longer regarded as dating technique and only suggestion as to age can be made based on comparison with regional data.

Thus, it has been suggested, based on the character of the woodland, that on the basis of the pollen assemblages, the sediment is of early Holocene age. It is, however, possible that the sediment is of much more recent age

4.ii.) Marine influence: As might be expected from these late-Boreal sediment profiles, there are traces of halophytes. These comprise predominately Chenopodiaceae (goosefoot, orache and samphire). These occur in boreholes 14, 15 and especially in 18. n the latter there is also sea plantain (*Plantago maritima*). These taxa imply that there was salt marsh within the catchment although fluvial as well as airborne transport of the pollen may have occurred. It is, probable that these halophytes were a precursor to the greater importance of salt marsh halophytic brackish and marine prior to complete marine transgression. This is in accord with Eisma *et al.* (1981) suggesting that the majority of the North Sea Basin was submerged in the early Holocene between *ca.* 10,000 and 7,000 BP and that there was an extension of tidal mudflats between 9,000 and 8000 BP (Cameron *et al.* 1987). The presence of freshwater algal *Pediastrum* suggests that the habitat was also probably brackish with freshwater input from rivers.

4.iii.) The on-site habitat: As noted, there appears to have been some marine water influences with evidence of halophytes. However, there is also a freshwater element present as might be expected in a floodplain

alluvial environment. Grasses (Poaceae), sedges (Cyperaceae) and occasional burr reed and/or reed mace (*Typha*/*Sparganium*) suggest that there was a fen herb community growing on and near the borehole sites. The small numbers of alder (*Alnus*) may be from occasional, localised growth along the fringes of the wetland (floodplain) although this taxon is usually very over represented in pollen assemblages and numbers of pollen here are relatively insignificant. Willow (*Salix*) is present in boreholes 14 and 15 and, as a low pollen producer may have been present in similar fringing habitats. In both cases, however, fluvial transport of their pollen from further afield may have occurred.

The very substantial numbers of pre-Quaternary palynomorphs come from reworked alluvial sediment or from bedrock in this region of strong coastal erosion. They are, however, typical of such alluvial sediment.

5.) Summary and conclusions
The following principal points have been made in this evaluation study.

- Pollen was found to be sparse and generally poorly preserved in all of the samples examined. However, some useful data have been obtained even though pollen count numbers were less than satisfactory.

- The main pollen components are from trees and shrubs. Pine, oak, alder and hazel are the most important tax with occasional beech and lime also present. The latter may have been fluvially transported from some distance.

- These assemblages have been tentatively suggested as being of early Holocene age. That is, probably Boreal Flandrian chronozones Ib and Ic. The arboreal vegetation is typical of the early Holocene, with the seral expansion and colonisation of trees and shrubs from their refuge during the Devensian cold stage. Borehole 14 has occasional lime and beech, and an early middle Holocene Atlantic age is indicated.

- Archaeologically, the pollen data and inferred vegetation provide information on the environment of the early Mesolithic.

- There are indications of salt marsh, possibly as prelude to marine transgression.

- The on-site habitat in the region of the boreholes was a grass-sedge herb fen probably growing on an alluvial floodplain.

- *Additional work:* Because of the poor pollen preservation, if additional analysis is required, as needed for publication, it is suggested that only one borehole sequence should be further examined. Either borehole 14 or borehole 15 would suffice. Sampling at 10cm intervals would provide adequate stratigraphically resolution. It may not be possible to obtain standard pollen count numbers due to the small APF values. It would, however, hopefully be possible to produce a pollen diagram showing in more detail character of the environment and changes through time.

Radiocarbon dating is required since, although an early Holocene age has been suggested, there is just a possibility that a very late Holocene age may apply. That is, if sedimentation was very rapid. Whilst suggestions can be mad, pollen analysis is not a technique for dating.

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11. Appendix II Diatom Assessment

Diatom assessment of samples from
Hornsea Offshore Windfarm
(Inshore area at Horseshoe Point, Lincolnshire)

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Introduction

Fourteen sediment sub-samples, taken from four borehole sequences at the Hornsea Offshore Windfarm site inshore area at Horseshoe Point, Lincolnshire have been prepared and assessed for diatoms.

Diatom analysis forms part of a wider paleoenvironmental investigation at the site. The purpose of carrying out the diatom assessment is to test for the presence or absence of diatoms and the potential of the sediments for further diatom analysis. The diatom assessment of each sample takes into account the numbers of diatoms, the state of preservation of the diatom assemblages, species diversity and diatom species environmental preferences. Of particular interest here are the salinity conditions represented by diatom assemblages.

Methods

Diatom preparation followed standard techniques (Battarbee et al. 2001). Two coverslips were made from each sample and fixed in Naphrax for diatom microscopy. A large area of the coverslips on each slide was scanned for diatoms at magnifications of x400 and x1000 under phase contrast illumination.

Diatom floras and taxonomic publications were consulted to assist with diatom identification; these include Hendey (1964), Werff & Huls (1957-1974), Hartley et al. (1996), Krammer & Lange-Bertalot (1986-1991), Camburn & Charles (2000) and Witkowski et al. (2000). Diatom species' salinity preferences are indicated using the halobian groups of Hustedt (1953, 1957: 199), these salinity groups are summarised as follows:

1. Polyhalobian: >30 g l-1

2. Mesohalobian: 0.2-30 g l-1

3. Oligohalobian - Halophilous: optimum in slightly brackish water

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

5. Halophobous: exclusively freshwater

6. Unknown: taxa of unknown salinity preference.

Results & Discussion

The diatom sample identification numbers, borehole numbers and sample depths are shown in Table 1 (Excel file attached). The results of the diatom evaluation are summarised in Table 2 below, and diatom species data are presented in Table 3 (Excel file attached) where the diatom taxa are grouped by salinity preferences.

Table 2. Summary of diatom evaluation results for Hornsea Offshore Windfarm (Horseshoe Point) borehole sequences (+ present; - absent; mod moderate; ex extremely; mar-bk marine-brackish; mar marine).

Diatom Sample No./BH	Diatoms	Diatom Numbers	Quality of Preservation	Diversity	Assemblage type	Potential for % count
BH14						
D1	+	v low	v poor	v low	bk-mar mar	v low
D2	+	low	v poor	low	bk-mar mar	low
BH18						
D3	+	ex low	ex poor	ex low	bk-mar	none
D4	+	v low	v poor	v low	bk-mar mar	none
BH16						
D5	-	ex low	poor	ex low	bk-mar	none
D6	-	-	-	-	-	none
D7	-	-	-	-	-	none
D8	-	-	-	-	-	none
D9	-	-	-	-	-	none
D10	+	v low	very poor	low	bk-mar	none
BH15						
D11	+	low	v poor	v low	mar mar-bk	low
D12	-	-	-	-	-	none
D13	+	low	poor	mod	mar mar-bk	some
D14	+	low	poor	mod	mar mar-bk	some

BH14 (samples D1-D2)

Diatoms are present in both samples assessed from BH14. The numbers of diatoms are low or very low and the quality of diatom preservation is very poor, with low or very low diatom species diversity. In both samples D1 and D2 (MA001 and MA002) the diatom assemblages are composed of brackish-marine and marine diatom taxa. These diatoms include the brackish-marine benthic diatom taxa Nitzschia granulata, Diploneis didyma and Campylodiscus echeneis. The most common benthic mesohalobous diatom is Nitzschia navicularis. These diatoms represent shallow water tidal, mud-surface habitats. In addition coastal marine diatoms are present, Paralia sulcata is present in both samples D1 and D2; Cymatosira belgica and Rhaphoneis amphiceros are present in sample D2. Freshwater diatoms are absent from these diatom assemblages. The poor quality of diatom preservation means that there is very low or no further potential for diatom analysis of the samples from BH14.

BH18 (samples D3-D4)

Diatoms are present in both samples assessed from BH18. The numbers of diatoms are very low or extremely low, with very poor quality of diatom preservation and very low diatom species diversity. However, in both samples D3 and D4 (MA004 and MA005) the diatom assemblages are comprised of brackish-marine and

marine diatom taxa. In sample D3 the diatoms identified are a very poorly-preserved fragment probably derived from the marine planktonic diatom Actinoptychus undulatus, and the planktonic mesohalobous diatom Cyclotella striata that is associated with estuaries.

In sample D4 the benthic mesohalobous diatom taxa Nitzschia navicularis Nitzschia granulata and Nitzschia punctata are common or present respectively. These diatoms represent shallow-water tidal, mud-surface habitats. In addition the coastal marine diatoms Paralia sulcata and Cymatosira belgica are present in D4, with girdle bands from Grammatophora sp. also present. Freshwater diatoms are absent from both diatom assemblages assessed from BH18. The poor quality of diatom preservation means that there is no further potential for diatom analysis of these samples.

BH16 (samples D5-D10)

Six samples from BH16 were assessed for diatoms. Diatoms are absent from four samples (D6 to D9). Diatoms are present in very low numbers and are very poorly preserved in samples D5 and D10, with low or extremely low species diversity.

In sample D5 the only diatom identified to the species level is the benthic mesohalobous species Scoliopleura tumida. A range of polyhalobous (Paralia sulcata, Rhaphoneis amphiceros), polyhalobous to mesohalobous (Actinoptychus undulatus, Ardissonia crystallina) and benthic mesohalobous (Campylodiscus echeneis, Diploneis didyma, Nitzschia punctata, Nitzschia granulata and Nitzschia navicularis) diatoms are present in sample D10. One halophilous to oligohalobous indifferent diatom is present (Epithemia sp.) in D10, but there are no oligohalobous indifferent, freshwater diatoms present. Again the taxa in both diatomaceous samples represent tidal, coastal or estuarine habitats, with shallow-water mud-surface diatoms present in both samples.

Neither of the samples from BH16 has further potential for diatom analysis.

The absence of diatom remains in four samples from BH16 and the generally poor preservation of other samples from the Hornsea Offshore Windfarm boreholes can be attributed to taphonomic processes (Flower 1993, Ryves et al. 2001). This loss of diatoms may be the result of diatom silica dissolution and breakage caused by factors such as extremes of sediment alkalinity or acidity, the under-saturation of sediment pore water with dissolved silica, cycles of prolonged drying and rehydration, movement of water, or physical damage to diatom valves from abrasion or wave action.

BH15 (samples D11-D14)

Four samples were assessed from BH15, diatoms are present in three of these samples, but are absent from sample D12. In the diatomaceous samples (D11, D13, D14) the numbers of diatoms are relatively low and the quality of diatom preservation is poor or very poor. In samples D13 and D14 diatom species diversity is moderately high, but in D11 diatom diversity is very low. There is low potential for percentage diatom counting of sample D11 and only some potential for further analysis of D13 and D14. The assemblages of all three diatomaceous samples from BH15 are comprised of polyhalobous, polyhalobous to mesohalobous and mesohalobous diatoms that represent marine or brackish-marine conditions.

Most common in all three samples is the coastal, marine planktonic diatom Paralia sulcata. Other polyhalobous taxa include Rhaphoneis surirella, Rhaphoneis amphiceros, Rhaphoneis minutissima, Podosira stelligera and Cymatosira belgica. The polyhalobous to mesohalobous, planktonic diatom Actinoptychus undulatus is present in all three samples. In samples D13 and D14 a range of benthic mesohalobous diatoms are common, these include Nitzschia navicularis, Nitzschia granulata, Nitzschia punctata, Diploneis didyma,

Nitzschia bilobata, Caloneis westii and Bacillaria paradoxa. The brackish water planktonic species Cyclotella striata is also present in sample D13. Freshwater diatoms are absent from the samples assessed from BH15

Conclusions

Diatoms were assessed from fourteen samples taken from four boreholes at the Hornsea Offshore Windfarm site inshore area, Horseshoe Point, Lincs.

Poorly-preserved diatom assemblages are present in both samples assessed from BH14. The diatom assemblages are composed of benthic, brackish-marine diatoms with some coastal marine diatom taxa. The diatom flora is consistent with predominantly shallow water tidal, mud-surface habitats. Freshwater diatoms are absent from the assemblages. There is no further potential for diatom analysis of the samples from BH14.

Poorly-preserved brackish-marine and marine diatoms are present in both samples assessed from BH18. In sample D3 a poorly-preserved fragment probably derived from a marine-brackish planktonic diatom is present along with and a planktonic mesohalobous diatom that is associated with estuaries. In sample D4 benthic mesohalobous diatom taxa are present; these diatoms represent shallow-water, tidal, mud-surface habitats.

In addition coastal marine, planktonic diatoms are present in D4. Freshwater diatoms are absent from both diatom assemblages assessed from BH18. There is no further potential for diatom analysis of these samples. Diatoms are absent from four (D6 to D9) of the six samples assessed from BH16. Diatoms are poorly preserved in samples D5 and D10. In sample D5 the only diatom identified to the species level is a benthic mesohalobous species. A range of polyhalobous, polyhalobous to mesohalobous and benthic mesohalobous diatoms are present in sample D10. One halophilous to oligohalobous indifferent diatom is present in sample D10 but there are no freshwater diatoms present in D5 or D10. Again, the diatoms in both samples from BH16 represent tidal, coastal or estuarine habitats, with shallow-water mud-surface diatoms present in both samples. Neither of the samples from BH16 has further potential for diatom analysis.

The absence of diatoms in four samples from BH16 and the generally poor preservation of assemblage in other samples from the Hornsea Offshore Windfarm boreholes can be attributed to taphonomic processes. Diatoms are present in three of the four samples assessed from BH15 but are absent from sample D12. In the diatomaceous samples (D11, D13, D14) the quality of diatom preservation is relatively poor. There is low potential for diatom analysis of sample D11 and only some potential for further analysis of D13 and D14. The assemblages of all three diatomaceous samples from BH15 are comprised of polyhalobous, polyhalobous to mesohalobous and mesohalobous diatoms that represent marine or brackish-marine conditions. Freshwater diatoms are absent from the samples assessed from BH15.

Acknowledgements

Thanks to Christin Heamagi of The Maritime Archaeology Trust, Department of Oceanography, University of Southampton for providing the samples for diatom assessment and for information about the Hornsea Offshore Windfarm site.

Table 1

UCL diatom sample	Borehole ID	Depth	MA ID
D1	BH14	8.90	MA001
D2	BH14	9.50	MA002
D3	BH18	11.00	MA004
D4	BH18	14.00	MA005

UCL diatom sample	Borehole ID	Depth	MA ID
D5	BH16	5.50	MA007
D6	BH16	11.50	MA008
D7	BH16	13.50	MA010
D8	BH16	14.50	MA011
D9	BH16	17.50	MA013
D10	BH16	11.50	MA015
D11	BH15	7.50	MA017
D12	BH15	8.50	MA018
D13	BH15	10.50	MA019
D14	BH15	9.30	MA022

Table 2

Diatom Taxon/Laboratory Sample Number	D1	D2	D3	D4	D5	D10	D11	D13	D14
Polyhalobous									
Cymatosira belgica		1		1					1
Grammatophora sp.				1				1	
Paralia sulcata	1	1		1		2	3	3	3
Podosira stelligera									1
Rhaphoneis amphiceros		1				1		1	1
Rhaphoneis minutissima								1	
Rhaphoneis surirella							1	1	1
Polyhalobous to Mesohalobous									
Actinoptychus undulatus			cf			1	1	1	1
Ardissonia crystallina						1			
Diploneis smithii								1	
Synedra gaillonii								1	
Mesohalobous									
Bacillaria paradoxa								1	
Caloneis westii									1
Campylodiscus echeneis	1					1			
Cyclotella striata			1						1
Diploneis didyma		1				1		2	
Nitzschia bilobata								1	
Nitzschia punctata				1		1		1	1
Nitzschia granulata	1	1		1		1		2	1
Nitzschia navicularis	3	3		2		1		2	2
Scoliopleura tumida					2				
Oligohalobous Halophilous to Indifferent									
Epithemia spp.						1			
Unknown Salinity Group									
Amphora sp.		1			1	1			
Diploneis sp.		1				1		1	
Inderminate centric sp.			1						
Navicula sp.								1	1
Synedra sp.	1			1				1	
Thalassiosira sp.								1	

Diatom Taxon/Laboratory Sample Number	D1	D2	D3	D4	D5	D10	D11	D13	D14
Unknown diatom fragment			1		1				1
Unknown naviculaceae					1	1			

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12. Appendix III Microfaunal assessment

HORNSEA PROJECT ONE WINDFARM, ONSHORE CABLE ROUTE: MICROFAUNAL ENVIRONMENTAL ASSESSMENT OF FOUR BOREHOLES

by John E. Whittaker

INTRODUCTION

The Hornsea Project One Offshore Windfarm, some 120-160km due east of Hornsea, on the Yorkshire coast, has one the largest, if not *the* largest, North Sea windfarm array. Its electricity cable route reaches landfall at Horseshoe Point, Lincolnshire, after which, onshore, it turns northwards roughly parallel to the shore. It is the landfall site at Horseshoe Point, where a number of boreholes and trial pits have been made, which is the subject of the microfaunal palaeoenvironmental assessment presented here. Thirteen sediment samples from four boreholes (14, 15, 16 and 18), situated in a SE-NW trending strip across the present-day intertidal area, were chosen by Christin Heamagi (Maritime Archaeology, Southampton) and these were received on June 21st 2017. Borehole 18 (with two samples) is the most landward, BH 16 (five samples) the most seaward and in them sedimentary sequences from intervals between 11.00 and 14.00m and between 5.50m and 17.50m, respectively, are analysed here. Boreholes 14 and 15 lie a little NE of BH18, opposite each other on either side of the strip; two and four samples in intervals between 8.90 and 9.50m and 7.50m and 10.50m, respectively, also form the subject of the present microfaunal palaeoenvironmental assessment. The borehole list, sample depths (in core), their Maritime Archaeology ID's and weights processed is given below under

Materials & Methods. According to Christin Heamagi (pers. comm.) the succession is likely to be Holocene alluvium on Till, under a cover of modern sandy seabed and beach material.

MATERIALS & METHODS

Borehole	Depth in core	MA ID	Weight processed
BH14	8.90m	MA001	20g
BH14	9.50m	MA002	20g
BH15	7.50m	MA017	30g
BH15	8.50m	MA018	25g
BH15	9.30m	MA022	25g
BH15	10.50m	MA019	35g
BH16	5.50m	MA007	25g
BH16	11.50m	MA008	25g
BH16	13.50m	MA010	15g
BH16	14.50m	MA011	15g
BH16	17.50m	MA013	25g
BH18	11.00m	MA004	25g
BH18	14.00m	MA005	35g

The samples were processed in the usual way. First, they were dried and then soaked in hot water with a little sodium carbonate added to remove any clay fraction. Washing was with hand-hot water through a 75 micron sieve. After final drying the residues were stored in plastic bags for subsequent examination. Then each sample was put through a nest of sieves (500, 250, and 150 microns) and a little of each fraction at a time was sprinkled onto a picking tray and a representative microfauna was placed in a 3”x1” faunal slide for archive

purposes. The species, on identification, were estimated semi-quantitively and shown on Figures 1-4, which accompanies this report. Other contained material of potential environmental importance were also noted, this time on a presence/absence basis only and included on the same figures.

RESULTS

The results of the microfaunal palaeoenvironmental assessment are shown in Figures 1-4 which accompanies this report. Figure 1 refers to BH14, Figure 2 to BH15, Figure 3 to BH16 and finally, Figure 4 to BH18. The uppermost table in each figure lists contained material of potential use in this and future assessments. The lower tables list the identified foraminifera and ostracods. They are suitably colour-coded to as to be able to see, at a glance, the environmental components. This data is taken from Murray (2006) for the foraminifera and Athersuch, Horne & Whittaker (1989) for the ostracods, and from personal experience.

The results are listed geographically - that is to say, the innermost borehole (BH18; Figure 4) on the present-day intertidal area of the north Lincolnshire coast, being taken first. The microfauna of the lower of the two samples (at 14.0m in the core) indicates brackish tidal flats and saltmarsh, but the microfossils are always low in number (just ones and twos). The upper sample (at 11.00m), however, contains a limited outer estuarine/marine component, in addition.

The results of BH14 and 15 are described next and are shown in Figures 1 and 2, respectively. BH14 contains three species of agglutinating foraminifera (colour-coded light green) all of which are herbivores and detritivores living in the vegetated part of mid-high saltmarsh; the other brackish components would be found in the associated muddy creeks of the marsh complex. In BH15 (Figure 2) this is similarly developed, but here the outer estuarine/marine component is much better developed in the upper part of the sequence, perhaps washed in by high tides (and/or through sea-level rise).

Borehole 16, which is the most seaward in present-day terms has rather sparse microfaunas (often single specimens or at most a few), although there is indication of (variously) brackish intertidal, saltmarsh and latterly, some outer estuarine components. The sediments here, in particular are quite stony and this may indicate a substrate of Till or reworked Till.

To summarise, the locality presents quite deep sedimentary sequences (14.00m in BH18 and 17.50m in BH 16) which may indicate a Holocene channel with both brackish and latterly outer estuarine/marine influences possibly if they were accompanied by sea-level rise. Boreholes 14 and 15 are shallower (down to only 9.50 and 10.60m, respectively) and in both of these, on the edges of this channel, there was quite well developed saltmarsh. The sequences presented here are not calibrated to O.D. (they are listed as depth in core in each case). Moreover, there is a great need of some dating control, if a better understanding of the history of the overall site is to be achieved.

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24th July 2017

HORNSEA PROJECT ONE WINDFARM (ONSHORE)

BOREHOLE 14 FIGURE 1

CONTAINED MATERIAL

MA ID	001	002
Depth in core	8.90m	9.50m
plant debris + seeds	x	x
brackish foraminifera	x	x
brackish ostracods	x	
outer estuarine/marine foraminifera	x	

Ecology	*Mid-high saltmarsh, latterly with limited washed-in marine input*

BRACKISH FORAMINIFERA

Trochammina inflata	xxx	xx
Jadammina macrescens	x	x
Arenoparrella mexicana	x	
Haynesina germanica	x	

BRACKISH OSTRACODS

Cyprideis torosa	xx	
Leptocythere lacertosa	o	

OUTER ESTUARINE/MARINE FORAMINIFERA

Ammonia batavus	x	

Contained material is recorded on a presence (x)/absence basis only

Foraminifera & ostracods are recorded: o – one specimen; x – several; xx – common; xxx – abundan

HORNSEA PROJECT ONE WINDFARM (ONSHORE)

BOREHOLE 15 FIGURE 2

CONTAINED MATERIAL

MA ID	017	018	022	019
Depth in core	**7.50m**	**8.50m**	**9.30m**	**10.50m**
plant debris	x		x	
molluscs	x	x	x	
?coal	x	x	x	
brackish formainifera	x	x	x	x
brackish ostracods	x	x		
outer estuarine/marine foraminifera	x	x	x	
outer estuarine/marine ostracods	x	x	x	
Ecology	*Brackish tidal flats with outer estuarine/marine influences*		*Mid-high saltmarsh, latterly with onset of marine influence*	
BRACKISH FORAMINIFERA				
Haynesina germanica	x	o	x	
Ammoniasp	o	o		
Elphidium williamsoni	o	o		
Trochammina inflata			xx	xxx
Jadammina macrescens			x	xx
BRACKISH OSTRACODS				
Leptocythere psammophila	x	xx		
Cyprideis torosa	o	o		
Leptocythere lacertosa		x		
OUTER ESTUARINE/MARINE FORAMINIFERA				
Ammonia batavus	xx	x	xx	
Cibicides lobatulus	x	x		
miliolids	x		x	
OUTER ESTUARINE/MARINE OSTRACODS				
Pontocythere elongata	x	x	o	
Hemicythere villosa	x	x	x	
Paradoxostoma/Sclerochilusspp.	x			
Leptocythere pellucida	x			
Palmoconcha guttata	o			
Semicytheruraspp.	o	o		
Palmoconcha laevata		o		

Contained material is recorded on a presence (x)/absence basis only

Foraminifera & ostracods are recorded: o – one specimen; x – several; xx – common; xxx – abundan

BOREHOLE 16 — FIGURE 3

CONTAINED MATERIAL

MA ID	007	008	010	011	013
Depth in core	5.50m	11.50m	13.50m	14.50m	17.50m
plant debris/peat fragments	x	x			
molluscs	x				
brackish foraminifera	x	x	x	x	x
brackish ostracods	x				x
outer estuarine/marine foraminifer	x		x		
outer estuarine/marine ostracods	x				

Ecology	*Poorly developed tidal flat and outer estuarine communities on a stony substrate (?Till)*

BRACKISH FORAMINIFERA

Elphidium williamsoni	x	x	x	x	x
Haynesina germanica	x			o	
Ammoniasp.					o
Trochammina inflata		o			

BRACKISH OSTRACODS

Leptocythere psammophila	o				o
Leptocythere lacertosa	o				

OUTER ESTUARINE/MARINE FORAM INIFERA

Ammonia batavus	x				
miliolids	x				
Cibicides lobatulus	x		o		

OUTER ESTUARINE/MARINE OSTRACODS

Hemicythere villosa	x				
Pontocythere elongata	o				

Contained material is recorded on a presence (x)/absence basis only

Foraminifera & ostracods are recorded: o – one specimen; x – several specimens

BOREHOLE 18

FIGURE 4

CONTAINED MATERIAL

MA ID	004	005
Depth in core	11.00m	14.00m
plant debris + seeds/peat fragments	x	x
molluscs	x	
brackish foraminifera	x	x
outer estuarine/marine foraminifera	x	
outer estuarine/marine ostracods	x	
brackish ostracods		x
Ecology	*Tidal mudflats and saltmarsh, latterly with an outer estuarine/marine component*	

BRACKISH FORAMINIFERA

Haynesina germanica	x	x
Ammoniasp.	x	o
Elphidium williamsoni	o	o
Trochammina inflata		o

OUTER ESTUARINE/MARINE FORAMINIFERA

Ammonia batavus	x	
miliolids	x	
Cibicides lobatulus	x	

OUTER ESTUARINE/MARINE OSTRACODS

Pontocythere elongata	x	
Hemicythere villosa	o	

BRACKISH OSTRACODS

Cyprideis torosa		o
Leptocythere lacertosa		o

Contained material is recorded on a presence (x)/absence basis only

Foraminifera & ostracods are recorded: o – one specimen; x - several specimens

13. Appendix IV Radiocarbon dating certificate

RADIOCARBON DATING CERTIFICATE
16 August 2017

Laboratory Code	SUERC-74448 (GU44626)
Submitter	Christin Heamagi Maritime Archaeology Ltd. Room 014/11 National Oceanography Centre Empress Dock Southampton SO14 3ZH
Site Reference	Hornsea Intertidal
Context Reference	BH18 -14.0
Sample Reference	MA006
Material	Wood
$\delta^{13}C$ relative to VPDB	-29.7 ‰
Fraction Modern F	1.0193 ± 0.0034

N.B. A fraction modern value above 1 indicates this sample was formed in the nuclear era (post 1950 AD).

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Conventional age calcu E. Dunbar

Scottish Universities Environmental Research Centre
Rankine Avenue, Scottish Enterprise Technology Park, East Kilbride, Glasgow G75 0QF, Scotland, UK
Director: Professor F M Stuart Tel: +44 (0)1355 223332 Fax: +44 (0)1355 229898 www.glasgow.ac.uk/suerc

RADIOCARBON DATING CERTIFICATE
16 August 2017

Laboratory Code	SUERC-74449 (GU44627)
Submitter	Christin Heamagi Maritime Archaeology Ltd. Room 014/11 National Oceanography Centre Empress Dock Southampton SO14 3ZH
Site Reference	Hornsea Intertidal
Context Reference	BH15 -10.5
Sample Reference	MA020
Material	Wood
$\delta^{13}C$ relative to VPDB	-24.1 ‰
Radiocarbon Age BP	6252 ± 28

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD) and requires calibration to the calendar timescale. The error, expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standard and blank and the random machine error.

Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. The laboratory GU coding should also be given in parentheses after the SUERC code.

Detailed descriptions of the methods employed by the SUERC Radiocarbon Laboratory can be found in Dunbar et al. (2016) *Radiocarbon 58(1) pp.9-23.*

For any queries relating to this certificate, the laboratory can be contacted at suerc-c14lab@glasgow.ac.uk.

Conventional age and calibration age ranges calculated by: E. Dunbar

Checked and signed off P. Nayont

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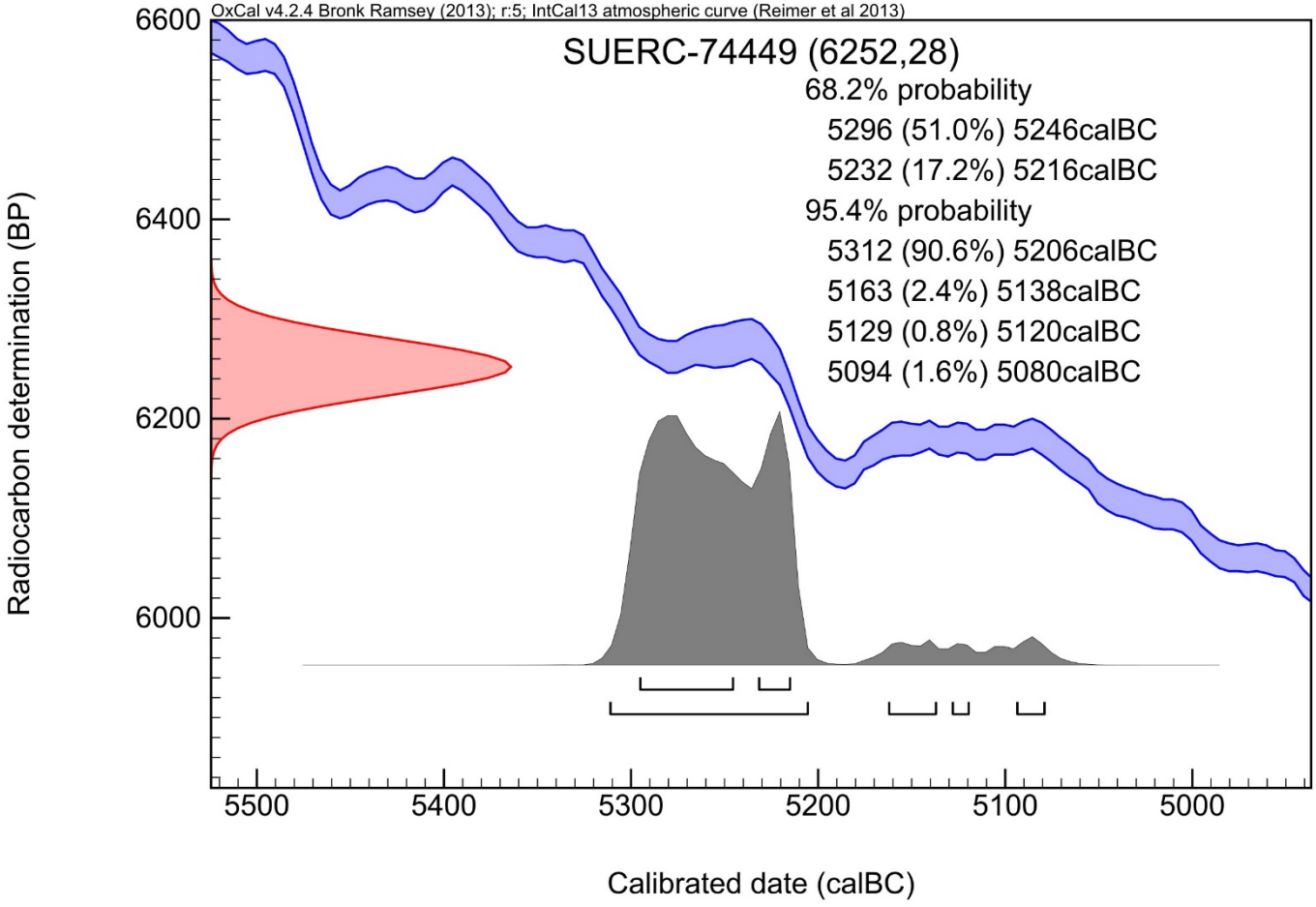

The radiocarbon age given overleaf is calibrated to the calendar timescale using the Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.*

The above date ranges have been calibrated using the IntCal13 atmospheric calibration curve.† Please contact the laboratory if you wish to discuss this further.

Checked and signed off P. Nayont