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LIFE BELOW THE WAVES: PALAEOLANDSCAPES PRESERVED WITHIN THE SUB-TIDAL BRISTOL CHANNEL

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Geophysical and geotechnical surveys offshore of Hinkley Point have revealed an extensive, yet fragmentary, Early Holocene submerged palaeolandscape. Radiocarbon dating indicates peat formation beginning c 7500 Cal BC, with brackish and marine inundation taking place c 7000 Cal BC. The comprehensive dating strategy has also demonstrated the difficulties of obtaining robust chronologies from peat deposits within the sub-tidal zone. Results from a suite of palaeoenvironmental techniques provide detailed insights into an Early Mesolithic landscape. Of particular note was the frequent presence of charred remains of reeds, sedges and grasses in the sub-tidal basal freshwater peats which might implicate deliberate Early Mesolithic human activity. Significantly, the record revealed by the work here complements, and extends, that recorded previously from shallower intertidal and inland sites. This helps to extend our knowledge of the less accessible, but equally important, now submerged terrestrial landscapes of the Bristol Channel and Severn Estuary region.

INTRODUCTION

The Severn Estuary and Bristol Channel have long been noted for their significant archaeological record and potential for future discoveries. This awareness has been driven by the impressive material recorded to date (Bell 2007; Webster (ed.) 2007, 273; Bell and Warren 2013, 39) and the well-preserved palaeoenvironmental signature locked in the fine-grained and organic sediments of the Somerset, Avon and Gwent Levels (Hosfield *et al* 2007a, 40). However, while there has been considerable research carried out within terrestrial and intertidal contexts, remarkably little archaeological work has been executed below the mean low water mark (MLWM; Webster 2007, 273). During the Late Pleistocene and Early Holocene, when sea levels were considerably lower, much of the current sub-tidal area would have been a terrestrial and riverine landscape also highly suitable for human activities. Evidence pertaining to this hidden palaeolandscape may be found in terrestrial peat deposits from the base of the Bristol Channel (Brown 1977) and radiocarbon dated peats at the base of deep palaeovalley sequences on the Bristol Channel margins (eg Kidson and Heyworth 1973; Godwin and Willis 1964, 123-125). Extending our knowledge beyond the intertidal zone is therefore of key importance for understanding the Late Palaeolithic and Mesolithic palaeogeography of the region (Hosfield *et al* 2007b).

The recently proposed development of a new nuclear power station at Hinkley Point, Somerset, has provided a rare opportunity to begin to rectify this, through acquisition and analysis of multiple new offshore datasets. This paper presents the results of work carried out for an area of *c* 90 km^2 which included the immediate offshore zones of Hinkley Point, Bridgwater Bay, Culver Sands and the lower reaches of the River Parrett (Figure 1).

BACKGROUND AND OBJECTIVES

The data presented here was acquired as part of the environmental impact assessment carried out ahead of the proposed construction of a temporary jetty, as part of the wider development at Hinkley Point. As such, the majority of material discussed relates to areas below the current MHWM. However, in order to properly contextualise this record, a broader account of activity and environmental change across the region was required. This is especially important given the significant changes in land/sea boundaries that have occurred in the study area over glacial and inter-glacial periods, with the entire submerged section of the study area having been a terrestrial

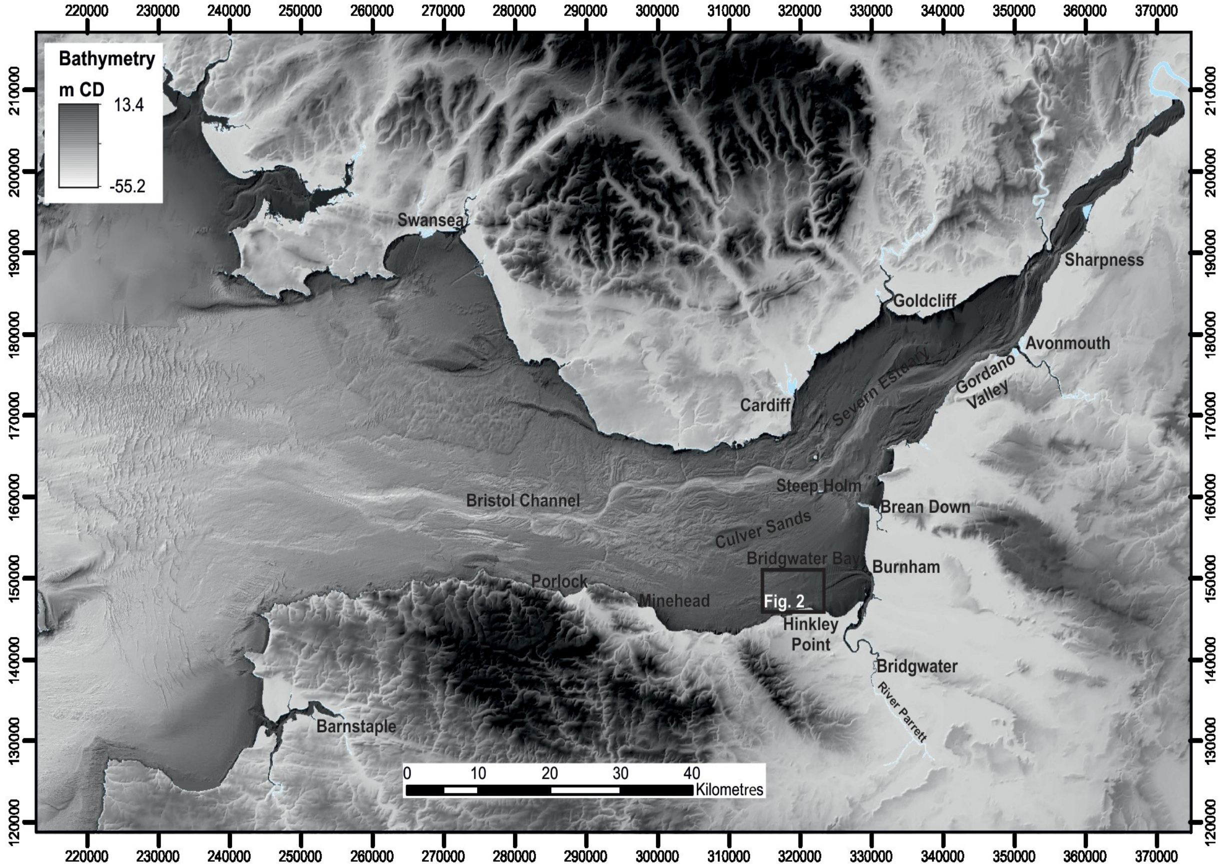


Figure 1: The regional scale UKHO derived bathymetry (bin size 20x30 m) of the Bristol Channel and Severn Estuary integrated with the OS Panorama topographic data (50x50 m bin size). Topography reproduced with the permission of Ordnance Survey on behalf of Her Majesty's Stationery Office. © Crown Copyright (2011). Bathymetry British Crown and SeaZone Solutions Limited. All rights reserved. Product Licence 032007.016.

landscape during the Late Pleistocene and Early Holocene (Bell 2007; Dix *et al* submitted; Sturt *et al* submitted).

Geological Context

Hinkley Point lies on the north Somerset coast, on the western edge of Bridgwater Bay, within the Inner Bristol Channel. During the Early Cretaceous deformation an east-west trending syncline was formed within which the current Bristol Channel basin resides. Large parts of the Bristol Channel are severely depleted in unconsolidated sediment, leaving the underlying bedrock exposed on the seafloor across large areas (Long *et al* 2002).

In the immediate vicinity of Hinkley Point, the exposed and partially buried bedrock is composed of a sequence of limestones, shales and mudstones; the Lower Jurassic Blue Lias Formation. At Hinkley Point, tidal action has eroded the softer mudstone to leave wide rock platforms of the more competent limestone bands extending out from the cliff lines up to 500 m offshore. An outlier of this erosion platform is also visible offshore at Stolford, separated from Hinkley Point by the incision of a now buried lowstand river channel.

The Quaternary geology of the Bridgwater Bay area has been dominated by cyclical changes in sea level, through a combination of eustatic and isostatic processes. During the lowstand phases, fluvial incision and associated floodplain accumulation were the dominant sedimentological processes, whilst during the transgressions deposition and erosion were controlled by rising base levels, leading first to estuarine and then full marine environments. Although these processes have been operating throughout the Quaternary, the remnant sedimentary record is dominated by sequences formed since the Last Glacial Maximum (LGM; *c* 26.5-19 ka BP). Since the LGM lowstand, the Bristol Channel has experienced a high rate of sea level rise through the Early Holocene, followed by a period of deceleration during the mid-Holocene, and then a relatively steady increase in sea level right up to the present (Haslett *et al* 1998; Allen 1991; Edwards 2006; Shennan *et al* 2012).

During the deglaciation of the LGM ice sheet, and subsequent Holocene climatic amelioration, the area has experienced both inundation and exposure due to the complex interplay of rising sea levels, highly differential sedimentation patterns, and changes in available accommodation space. This complex sequence of environmental change has left a record of intercalated muds, sands and peats that describe the growth (and subsequent decay) of a major estuary in the region that extended to at least 25 km inland.

The Holocene sedimentary sequence of the Severn Estuary and Bristol Channel has for a long time been recognised as exhibiting a broad tripartite lithostratigraphic division (Sollas 1883), most prominently defined in the Gwent Levels as the Wentlooge Formation (Allen and Rae 1987). Although the Wentlooge Formation is widely used to assign sequences to broad chronological periods and stratigraphy types, it is recognised that there is significant geographical variation in the nature of the intertidal and terrestrial Holocene deposits and therefore this is not universally applicable. For the Bridgwater Bay area Allen (2001, 23-4) states that the sequence 'differs from that in the Gwent Levels (where there are more and longer-lasting peats) possibly because in Somerset peat-formation was suppressed in favour of mineral sedimentation, perhaps due to high compaction rates favoured by the deep rockhead present beneath much of the area'. As a consequence it is unwise to attempt to directly correlate the Bridgwater Bay deposits with the Wentlooge Formation (and subsequent post-Roman foreshore formations; Allen and Rae 1987), particularly as the terrestrial sequences found throughout the Bridgwater Bay hinterland demonstrate highly spatially heterogeneous sedimentary variations (Mullin *et al* 2009).

Along the margins of Bridgwater Bay, numerous intercalated peats are exposed in the intertidal zone, including those dated at Brean Down (Bell 1990), Burnham-on-Sea (Druce 1998) and Stolford (Heyworth and Kidson 1982; Kidson and Heyworth 1976; Heyworth 1985; Hillam *et al* 1990), all attributed to the Late Mesolithic/Early Neolithic. Although many of these foreshore peats are subject to active erosion, some are thought to be contiguous with the intertidal and sub-tidal zones of the Bridgwater Bay area. Submerged forests and intercalated peats are also found further west along the Somerset coast within embayments at Minehead (Jones *et al* 2005) and Porlock (Jennings *et al* 1998; Godwin-Austen 1866), with the latter also containing some earlier, deeper, peat deposits. Small quantities of worked flint have been recovered from the foreshore around Stolford, Porlock and Minehead Bay (Mullin *et al* 2009; Canti *et al* 1995) implying human activity in the present intertidal zone, which is further enhanced by the suggestion of possible deliberate burning of reed swamps (Jones *et al* 2005) similar to that postulated in the Severn Estuary (Brown 2005; Timpany 2005; Bell 2007).

Pleistocene and Holocene Regional Land and Seascape Development

In order to provide a comprehensive account of the changing nature of human activity in the study area, as well as teasing out the story of the changing land- and seascapes, a wide range of data needed to be collected and analysed. Marine geophysics datasets included single and multi-beam bathymetry, boomer data and side-scan sonar supplied by EMU, CEFAS, SeaZone and Frugo, LiDAR from CEFAS and Channel Coastal Observatory, and topographic and cartographic data from Ordnance Survey – full details are given in Dix *et al* (submitted). The compilation of all these data sets ensured a seamless onshore-offshore landscape level analysis to be undertaken, permitting the subsequent borehole investigations to be placed within a firm palaeogeographic and geomorphic framework.

Figure 1 shows the bathymetric relief of the Bristol Channel and Severn Estuary. A channel can be clearly picked out running west from Sharpness. In the Severn Estuary region the channel has an open meandering form, varying in width from 300-600 m, with maximum depth ranging from -5 m OD (metres Ordnance Datum, Newlyn) at Sharpness to -25 m OD at Avonmouth. As the channel passes the Isles of Flat Holm and Steep Holm it broadens to a width of *c* 1-2 km, incised to a depth of 20 m (with thalwegs reaching -32 to -42 m OD). The channel itself has steep sides and narrow beaches running parallel to it. Eventually, the main palaeochannel becomes lost under the thickening sequence of sands and gravels in the Outer Bristol Channel. However, work by Fitch and Gaffney (2011) continues to identify the channel's course via seismic data.

In the Inner Bristol Channel, to the north of the main palaeochannel, there are at least seven meandering, dendritic, tributary channels which intersect the main channel at almost 90°. However, on the southern margin the bathymetry reveals a distinctly different story, with few channels identifiable in the irregular topography of the eroded Lower Lias bedrock. This bedrock platform exists between -24 and -18 m OD and covers an area of over 185 km^2. The Culver Sands have formed over part of this platform, in the wake of the Isle of Steep Holm. The accumulation of sands and silts continues to increase shoreward, with a reduction in grain size as the current shoreline is approached. These finer grain deposits form what is now the Bridgwater Bay mud patch; a thin deposit of intercalated sands and muds thought to have formed below the limits of wave influence (Mantz and Wakeling 1983; Long *et al* 2002).

The observed submerged channel systems are difficult to date precisely without site-specific investigation (beyond the remit of the proposed development). However, broadly they can be seen to have developed during glacial low-stand situations, before being inundated by rising sea-levels. As such, these submerged channels can be interpreted as part of the Late Pleistocene and Early Holocene hydrological system.

Analysis of the sub-bottom boomer data gathered by EMU Ltd revealed the presence of an extensive shallow gas blanket (representing small percentages of methane bubbles within pore waters of the near surface sediments) for the first three kilometres offshore from Hinkley Point (Figure 2A). This resulted in very limited penetration of the sub-surface for the near shore region, forcing a greater reliance on collected cores (see below) for our understanding of this area. Beyond the gas blanket the seismic data established the presence of a low relief bedrock platform at an altitude of -14 to -18 m OD, deepening slightly offshore in a NNW direction (visible in Figure 2A). The contour of the bedrock surface indicates minor east-west oriented palaeochannels, with widths of less than 250 m and depths of less than 1.5 m, incised into the Lower Lias bedrock.

Geotechnical Analysis and Deposit Modelling

A total of 23 boreholes and 62 vibrocores were recovered from the study area by Fugro Alluvial Offshore Limited (FAOL) during late 2009 and early 2010 (Figure 2A). To ensure consistency between datasets, the elevation for each borehole was derived from the swath bathymetry survey (EMU Ltd: 2009 survey; Figure 2B). This was due to several inconsistencies identified between the recorded core altitudes and the existent comparable bathymetric data sets, including that obtained in 2009 (provided by CEFAS). All elevations were converted from Chart Datum (CD) to m OD via a 5.9 m static shift (Simmons 2009; Larcombe and Fernand 2009).

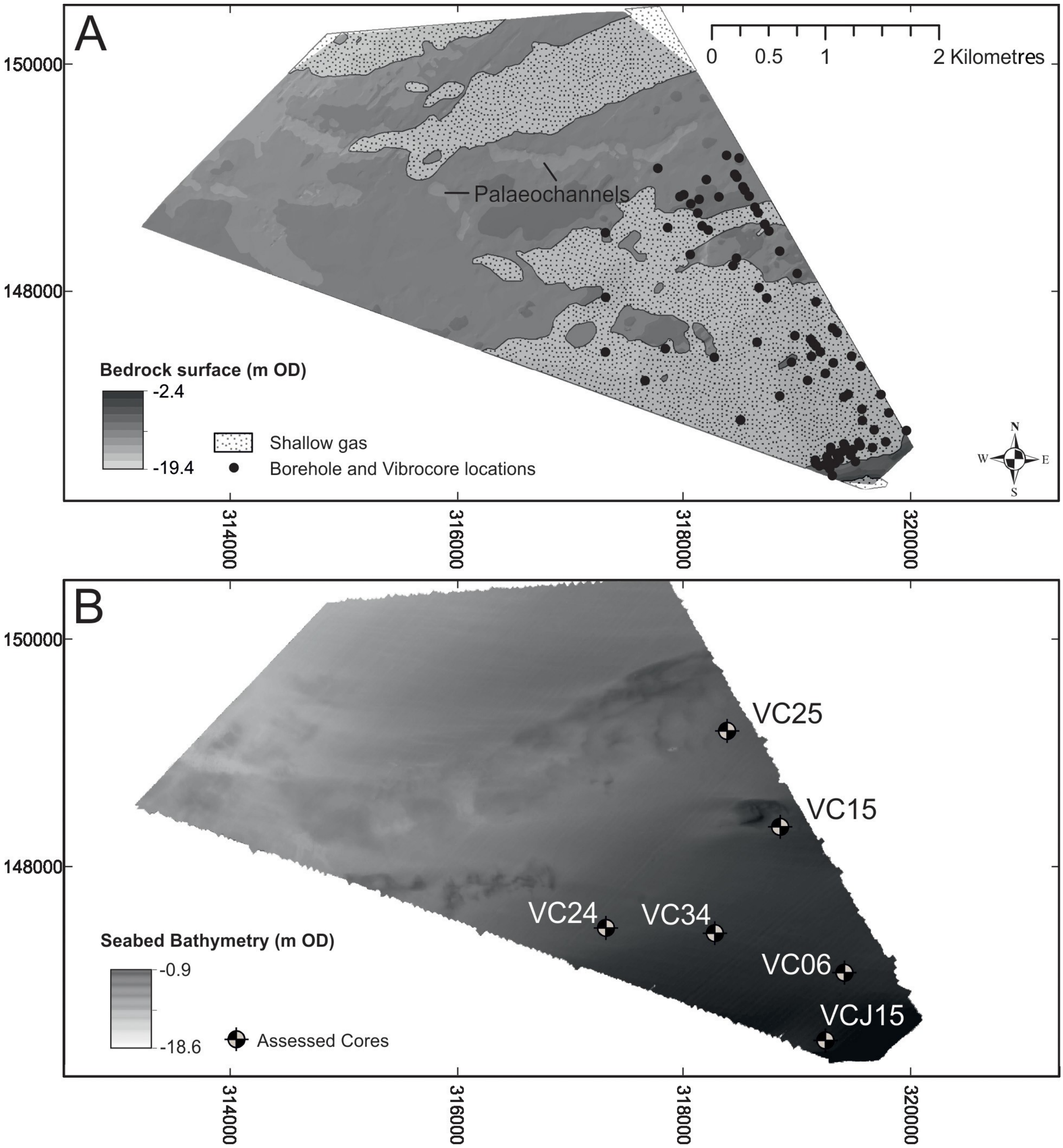


Figure 2: Study area showing A) Lower Lias Bedrock topography, palaeochannel incisions and distribution of all boreholes assessed; and B) Distribution of boreholes selected in this study plotted over seabed bathymetry.

The sequence revealed from the core analysis was broadly consistent across the study area, with a total of nine key units recognized (Table 1 and Figure 3). The large number of cores taken, and their broad spatial coverage, allowed for a three-dimensional deposit model to be created within Rockworks 15. Notably this allowed interpolation of trends within the area containing the gas blanket, where sub-bottom profiling had limited success. In forty-one instances, a thin compacted peat (unit 6) was found towards the base of the sequence over a terrestrial land surface (units 7 and 8) prior to marine inundation (unit 5). Four cores also revealed multiple organic intercalated deposits (units 2 and 4) within the sediment profile. The presence of this basal peat in many of the boreholes implied that an extensive, albeit fragmentary, peat horizon exists across an area of *c* 2.65 km^2 within the study area, attitudinally found generally between -12.25 to -14 m OD.

A sub-sample of six cores were selected to provide broad regional coverage moving from nearshore to offshore, whilst also allowing for targeting of key peat/silt sequences for detailed analysis (Figure 2B). Analysis was focused upon the lower stratigraphic units in order to understand the timing and nature of the transition from freshwater to marine conditions within Bridgwater Bay. Low sediment δ^{13}C values and C/N ratios in the unit 7 deposits, beneath the peat (unit 6), indicated deposition within a terrestrial environment associated with a strong freshwater influence (see Sturt *et al* submitted for details).

Unit	Description
1	Upper silts, sands and gravels
2	Upper Peat and organic rich silts
3	Marine Silts II
4	Thin intercalated peats and silts
5	Marine Silts I
6	Lower peat
7	Lower silts and clay
8	Lower Gravel
9	Lower Lias Bedrock

Table 1: The stratigraphic sequence offshore of Hinkley Point (see Figure 3 for details).

The lower peat (unit 6) was clearly identified in VC06, VC15, VC24, VC25 and VC34, while in VCJ15 a basal organic rich silt was recorded. Unit 6 varies in altitude from -12.58 m OD (VC06) to -13.74 m OD (VC15), while the organic rich silt in VCJ15 was found at -11.24 m OD. All organic deposits were heavily compacted with thicknesses between 6 and 9 cm. Within VC06, the unit 6 peat appeared to have an intact regressive contact grading into the overlying unit 5 estuarine and marine silts. Sediment δ^{13}C and C/N ratios (see Sturt *et al* submitted) confirmed a progressive change between these two units implying an unbroken sedimentary transition from freshwater towards marine conditions. All other unit 5-6 contacts were found to contain erosive contacts indicated by abrupt stratigraphic boundaries and sharp changes in isotope geochemistry.

To identify the palaeoenvironment and chronology associated with each borehole selected for analysis, a combination of pollen, mollusc, plant macrofossil, foraminifera, diatoms and radiocarbon dating investigations were undertaken across these six cores.

METHODOLOGIES

A total of 26 AMS radiocarbon dates were obtained (Table 2). Material from organic rich facies was sampled at 1 cm resolution to obtain, wherever possible, identifiable short-lived terrestrial plant macrofossils suitable for dating (following Bayliss *et al* 2008, xi). If sufficient suitable plant material was not forthcoming, a 1cm slice of bulk amorphous peat / organic silt was sampled which, during the later stage of the project, enabled duplicate carbon (acid insoluble/ alkali soluble (humic acid) and alkali/acid insoluble (humin)) fraction measurements to be made. Dates are calibrated against the IntCal13 Northern Hemisphere radiocarbon curve (Reimer *et al* 2013) using OxCal 4.2 (Bronk Ramsey 1995; 2001) and quoted as calibrated years BC using the maximum intercept method (Bayliss *et al* 2008). Date ranges are quoted using the 2σ calibrated range with end points rounded outwards to 10 years (Mook 1986). Duplicate dates, from the same horizon, have been subject to a T-test to identify whether they are statistically comparable (Ward and Wilson 1978). Where dates are statistically consistent a weighted mean date (using the R_Combine function in OxCal) has been used to date the organic horizon (stated in Table 2). A full discussion of the radiocarbon dating is given in Griffiths *et al* (submitted).

Pollen preparation followed standard methods (Moore *et al* 1991). The pollen sum ranged between 100 and 800 grains per level depending upon the state of preservation and absolute pollen frequency. Percentage calculations are given as percentage of the pollen sum (total dry-land pollen; TDLP) with the percentages for autochthonous taxa given as % TDLP + group. Nomenclature follows Moore and Webb (1978), modified according to Bennett *et al* (1994). Results are presented using TILIA 1.7.16 (Grimm 2011) with local pollen assemblage zones (LPAZ) defined using CONISS (Grimm 1987).

For foraminifera, *c* 10 cm^3 sediment samples were washed through a 500 µm mesh sieve and collected on a 63 µm mesh sieve. This residue was split into eight aliquots using a wet-splitter

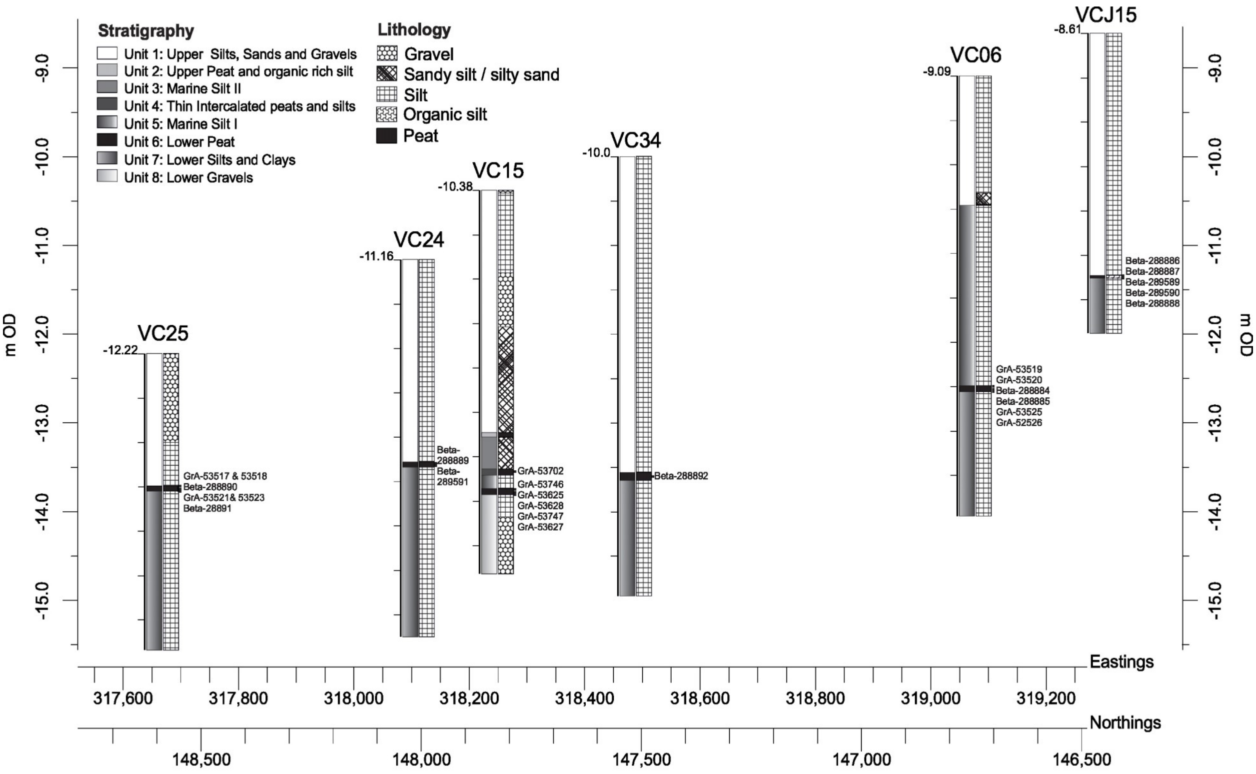


Figure 3 Borehole lithology and stratigraphy offshore at Hinkley Point (see Figure 2 for locations).

and complete aliquots counted wet under a binocular microscope. Where no foraminifera were encountered in the first aliquot the sample was recorded as barren. In samples where the foraminifera abundance was low the targeted minimum of 100 specimens was not reached. Low abundance samples (typically monospecific) are typical of high marsh environments toward the upper limit of marine influence. Nomenclature follows Murray (1971; 2000), Haynes (1973) and Horton and Edwards (2006).

Diatom preparation, counting and analysis followed standard techniques (Battarbee *et al* 2001). Diatom floras and taxonomic publications were consulted to assist with diatom identification; these include Hendey (1964), Werff and Huls (1957-1974), Hartley *et al* (1996), Krammer and Lange-Bertalot (1986-1991) and Witkowski *et al* (2000).

To retrieve plant macrofossils and molluscs for identification, samples of 1-3 cm vertical thickness (up to 160 ml) were disaggregated in warm water and washed through 250 and 500 µm sieves, resulting in small fragmented assemblages within each residue. Plant nomenclature follows Stace (2010) with molluscs following that given in the World Register of Marine Species (http://www.marinespecies.org).

RESULTS

Results of each borehole investigation are discussed sequentially from that furthest offshore, VC25, to that closest to the shoreline, VCJ15. Figure 3 provides a cross-section of the analysed cores.

Core VC25

The sequence consists of blue-grey silt (unit 7) beneath a thin compacted peat (unit 6), -13.77 to -13.71 m OD, which in turn is overlain by coarse silt and sandy/silty gravels (unit 1). Beneath the peat an organic rich silt was present, -13.84 to -13.77 m OD, which yielded a pollen assemblage, LPAZ VC25-1 (-13.82 to -13.76 m OD), dominated by *Pinus* (pine; 40%) and *Corylus avellana*-type (hazel; 46%) (Figure 4). *Ulmus* (elm; 5%), *Quercus* (oak; 2-3%) and Poaceae (grasses; up to 17%) are present, with *Dryopteris*-type (ferns; up to 28%), *Polypodium vulgare* (polypody; 22%) and pre-Quaternary palynomorphs (up to 23%) present in higher amounts, the latter implying the incorporation of reworked clastic material into the deposit.

Core	Depth (m OD)	Material	Laboratory Code	Radiocarbon Age (BP)	δ^{13}C (‰)	Calibrated Date Range (Cal BC; 2σ)
VC06	-12.58 to -12.59	Humin carbon fraction	GrA-53519	8040±45	-28.89	7080-6820
VC06	-12.58 to -12.59	Humic carbon fraction	GrA-53520	7905±40	-28.02	7030-6640
VC06	-12.58	Indet. wood fragment	Beta-288884	8140±50	-26.8	7320-7040
VC06	-12.60	Indet. plant macrofossil	Beta-288885	7980±40	-28.1	7060-6690
VC06	-12.64 to -12.65	Humin carbon fraction	GrA-53525	8110±45	-28.51	7190-7040
VC06	-12.64 to -12.65	Humic carbon fraction	GrA-53526	8605±40	-28.0	7680-7570
VC15	-13.56 to -13.58	Waterlogged Poaceae stem/ root	GrA-53702	3505±175	-25.5	2340-1430
VC15	-13.74 to -13.75	Humic carbon fraction	GrA-53746	8150±45	-27.78	7320-7050
VC15	-13.74 to -13.75	Humin carbon fraction	GrA-53625	7980±40	-28.29	7060-6690
VC15	-13.76 to -13.78	*Populus* spp.: 4 charred buds and 3 charred bark fragments	GrA-53628	8115±45	-29.97	7190-7040
VC15	-13.80 to -13.81	Humic carbon fraction	GrA-53747	8395±45	-27.39	7560-7340
VC15	-13.80 to -13.81	Humin carbon fraction	GrA-53627	8525±50	-27.61	7600-7510
GrA-53747 and GrA-53627 (T'=3.7; T'5%=3.8; ν=1) Weighted mean: 8454±34 BP						*7580-7480*
VC24	13.46	Indet. plant macrofossil	Beta-288889	7900±50	-26.3	7040-6630
VC24	13.46	Indet. organic sediment	Beta-289591	8130±40	-27.5	7290-7040
VC25	-13.73 to -13.74	Humic carbon fraction	GrA-53517	7940±40	-28.63	7050-6650
VC25	-13.73 to -13.74	Humin carbon fraction	GrA-53518	8025±40	-29.18	7070-6810
VC25	-13.73	*Phragmites* leaves	Beta-288890	7900±40	-27.6	7030-6640
GrA-53517, GrA-53518 and Beta-288890 (T'=5.1; T'5%=6.0; ν=2) Weighted mean: 7956±24 BP						*7040-6690*
VC25	-13.75 to -13.76	Humic carbon fraction	GrA-53521	8065±40	-27.81	7130-6840
VC25	-13.75 to -13.76	Humin carbon fraction	GrA-53523	7940±40	-26.99	7050-6650
VC25	-13.75	*Phragmites* leaves	Beta-288891	7920±40	-26.6	7040-6640
GrA-53523 and Beta-288891 (T'=0.1; T'5%=3.8; ν=1) Weighted Mean: 7930±29 BP						*7040-6680*
VC34	-13.62	*Phragmites* leaves	Beta-288892	7950±40	-27.9	7050-6680
VCJ15	-11.28	Indet. wood fragment	Beta-288886	7820±40	-27.9	6750-6590
VCJ15	-11.32	Indet. organic sediment	Beta-288887	8540±50	-27.2	7610-7520
VCJ15	-11.32	Indet. plant macrofossil	Beta-289589	8220±40	-27.6	7360-7070
VCJ15	-11.34	Indet. organic sediment	Beta-289590	8340±40	-27.0	7520-7310
VCJ15	-11.34	Indet. wood fragment	Beta-288888	7760±50	-31.0	6690-6470

Table 2: Radiocarbon dates from Hinkley Point

Charred Poaceae stem fragments were observed within this deposit.

The peat, at -13.75 m OD, was dated using *Phragmites australis* (common reed) leaves, and humic and humin carbon fractions. The leaves (Beta-288891) and humin carbon fraction (GrA-53523) were statistically comparable, yielding a weighted mean date 7040-6680 Cal BC, whereas the humic fraction (GrA-53521) yielded a statistically older date. Towards the top of the peat, at -13.73 m OD, these three fractions were again dated and were all found to be statistically comparable, yielding a weighted mean date of 7040-6690 Cal BC (Beta-288890, GrA-53517 and GrA-53518).

The pollen assemblage from the peat deposit, LPAZ VC25-2 (-13.76 to -13.70 m OD), shows a notable change in the pollen flora with

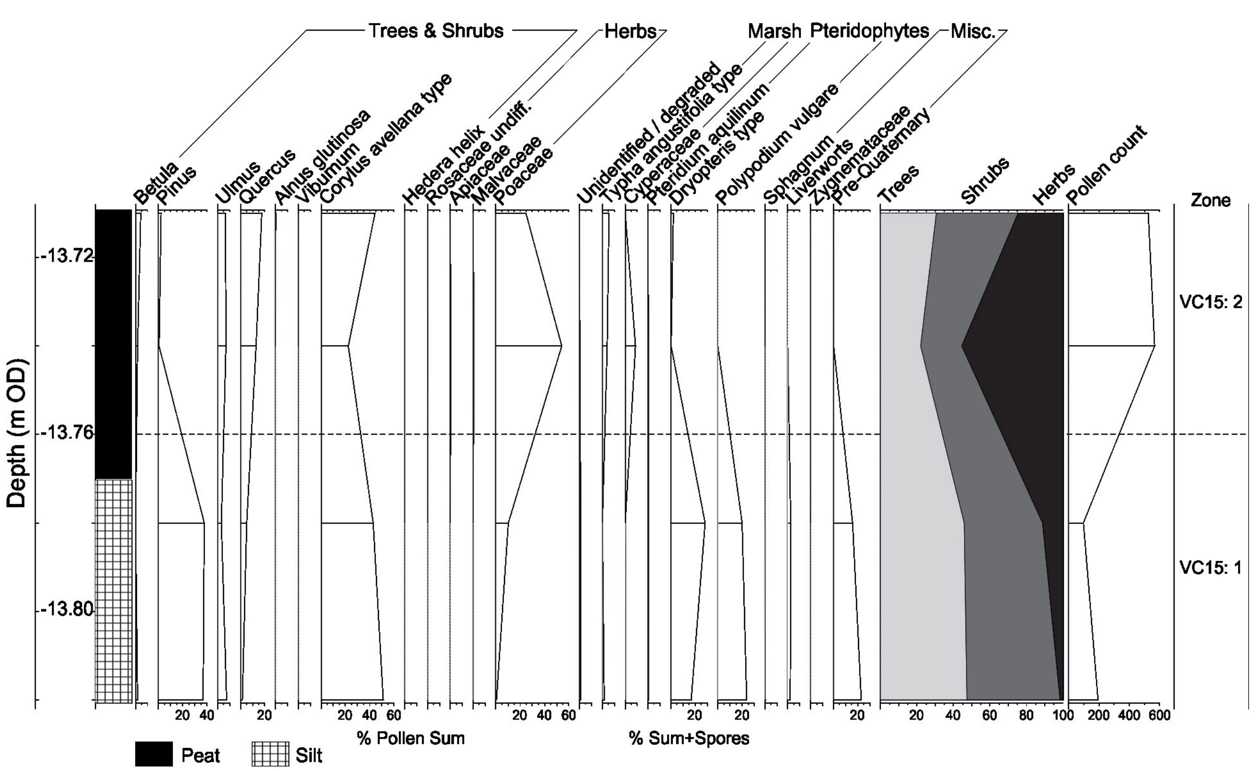


Figure 4: Pollen percentage diagram from VC25.

increases in *Quercus* (up to 20%), *Ulmus* (8%), *Corylus avellana*-type (35%) and Poaceae (up to 58%), while *Pinus*, spores and pre-Quaternary palynomorphs now only represent a minor constituent of the pollen assemblage. Increases in Cyperaceae (sedges; 8%) and *Typha angustifolia*-type (lesser bulrush; up to 7%) attest to local marsh / fen conditions. *Phragmites australis* stem and culm nodes, and root fragments, were present throughout the peat along with marsh fen taxa including *Lycopus europaeus* (gypsywort) and *Ranunculus* subg *Batrachium* (crowfoot), although this subgenus includes species with both fresh and brackish water preferences. Similarly, *Chenopodium rubrum / glaucum* (goosefoot) can tolerate both fresh and brackish ground conditions. There are also charred seeds of *Cladium mariscus* (great fen-sedge) and *Sparganium erectum* (branched bur-reed), along with charred Poaceae stems. No palaeoenvironmental investigations on the overlying silt deposits (unit 1) were undertaken in this core.

Core VC24

The sequence consisted of a basal silt (unit 7) overlain by a thin peat (unit 6), -13.50 to -13.44 m OD, and subsequently overlain by further silt deposits (unit 1). A pollen sample from the top of the basal silt, designated LPAZ VC24-1 (-13.48 to -13.46 m OD), contains an assemblage dominated by *Pinus* (40 %), *Corylus avellana*-type (24 %) and Poaceae (17 %), along with *Ulmus* (4 %) and *Quercus* (13 %), indicating the local vegetation prior to peat formation. The onset of peat formation contains a sharp change in the pollen assemblage (LPAZ VC24-2, -13.46 to -13.38 m OD). *Corylus avellana*-type (up to 50%) and Poaceae (up to 47%) dominate the assemblage alongside *Ulmus* (up to 9%) and *Quercus* (up to 20%). The presence of *Potamogeton*-type (pondweed), *Typha latifolia*-type (bulrush) and *T. angustifolia*-type indicate local freshwater habitats, an interpretation supported by the presence of seeds of *Lycopus europaeus*, *Mentha* (mint), *Ranunculus lingua* (greater spearwort), *R. sceleratus* (celery-leaved buttercup) and *R.* subg *Batrachium*. Between -13.50 to -13.48 m OD remains of *Phragmites australis* stem / root fragments, some of which were charred, and charred Cyperaceae stems and nutlets, were present. This assemblage indicates that the peat accumulated within predominantly freshwater grass-sedge-reedswamp communities.

Two radiocarbon dates were obtained from -13.46 m OD and yielded statistically inconsistent dates. Similar to those from VCJ15 (see below), dates were obtained from sub-optimal material with the date from the bulk sediment (Beta-289591) yielding an older date than that derived from plant macrofossil material (Beta-288889), dated 7040-6630 Cal BC.

A partial, poorly preserved, but moderately diverse diatom assemblage (Figure 5) at the very top of the peat (unit 6), at -13.44 m OD, is dominated by mesohalobous attached and benthic species, such as *Achnanthes brevipes, Diploneis didyma* and *Nitzschia navicularis,* along with some polyhalobous diatoms such as *Paralia sulcata*. At the same level, a foraminifera assemblage contains agglutinated taxa (eg *Jadammina macrescens*) commonly associated with high intertidal settings and is dominated by calcareous taxa (*Ammonia* sp and *Haynesina germanica*) typical of brackish estuarine settings.

Similar diatom and foraminifera assemblages are found in the overlying silt (unit 1). Diatoms are dominated by mesohalobous (58%) and polyhalobous (32%) diatoms (Figure 5). In particular the attached mesohalobous species *Achnanthes brevipes*, commonly growing as an epiphyte in brackish-marine environments, is dominant (42%) with the polyhalobous planktonic diatom *Paralia sulcata* (26%). Overlying samples, at -13.32 and -13.12 m OD, show a shift towards marine domination. Here polyhalobous taxa comprise 71-77% of the total diatoms whilst the mesohalobous component is reduced to less than 11%. The most common polyhalobous diatom is *Paralia sulcata* which reaches a maximum of 44%, along with *Cymatosira belgica, Rhaphoneis* spp and *Actinoptychus undulatus*. The shift from an epiphyte and benthic mesohalobous dominated diatom assemblage to a planktonic polyhalobous dominated diatom assemblage suggests that there was increasing salinity and deeper water at the site of deposition. Similarly, the foraminifera contain an increase in taxa commonly associated with shelf settings (eg *Brizalina* sp) suggesting more open/higher energy conditions.

The pollen assemblage associated with the upper silts, LPAZ VC24-3 (-13.38 to -13.24 m OD), shows an expansion of halophytes, notably

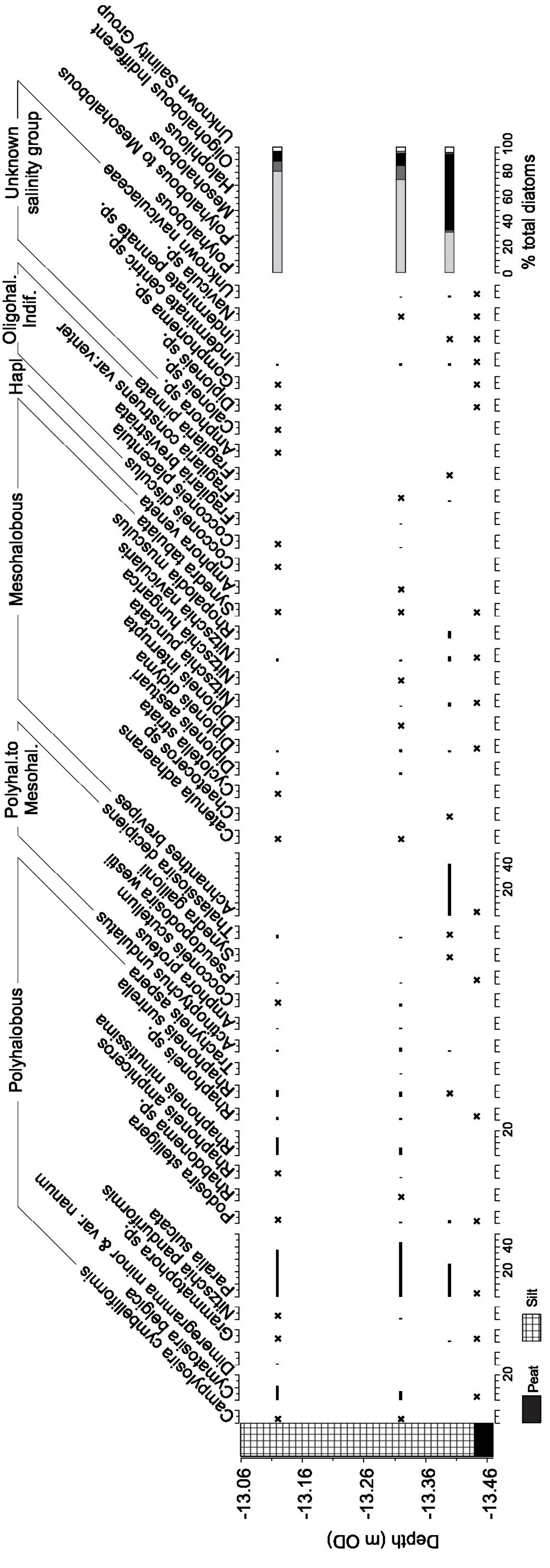


Figure 5: Diatom percentage diagram from VC24. The sample at -13.44 m OD failed to yield sufficient diatoms to calculate percentage abundance; presence / absence is only provided for this sample.

Chenopodiaceae (up to 6%) and occasional *Plantago maritima* (sea plantain), supporting the interpretation derived from the diatoms and foraminifera. *Quercus* (15%), *Corylus avellana*-type (50%) and Poaceae (20%) remain the dominant pollen taxa. Pre-Quaternary palynomorphs increase towards the top of the zone (up to 24%) indicating an increased deposition of reworked clastic material associated with changing sediment loads.

Core VC15

The sequence comprises a basal gravel (unit 8) overlain by a silt (unit 7) and basal peat (unit 6). This, in turn, is overlain by a series of marine silts (units 5 and 3) and intercalated peats (units 4 and 2) and subsequent upper sands, gravels and silts (unit 1).

The pollen assemblage in LPAZ VC15-1 (-13.88 to -13.77 m OD) is dominated by *Corylus avellana*-type (up to 69%), indicating it was the most important constituent of woodland growing on, or adjacent to, the site at the time of sediment accretion, along with *Pinus* (33%). Also present were *Ulmus* (2%) and *Quercus* (generally low but with a single peak of 20%), along with a low amount of Poaceae (up to 5%), Cyperaceae (14%) and occasional *Typha angustifolia*-type. High amounts of *Dryopteris*-type (56%) and *Polypodium vulgare* (24%) indicate a high abundance of ferns, while the high numbers of *Pediastrum* algal cysts (33%) imply a freshwater environment, such as a slow flowing river channel, though the constant presence of pre-Quaternary palynomorphs (16%) implies the incorporation of some reworked sediment sources. Duplicate measurements (GrA-53627 and GrA-53747) on humin and humic carbon fractions from the base of the peat, at -13.80 m OD, are statistically consistent, providing a weighted mean for deposition of 7580-7480 Cal BC. At -13.76 m OD charred buds and bark of *Populus* sp (poplar) yielded a date of 7190–7040 Cal BC (GrA-53628).

LPAZ VC15-2 (-13.77 to -13.70 m OD) shows a reduction in *Corylus avellana*-type (58%), coupled with decreases in *Pinus* (from 46%), *Dryopteris*-type, *Pediastrum* and pre-Quaternary palynomorphs, and an increase in *Quercus* (11%) and *Ulmus* (2%). Marginal aquatic plants increase, including Cyperaceae (10%) and occurrences of *Typha latifolia*-type, *T. angustifolia*-type and *Menyanthes trifoliata* (bogbean). At the top of the peat, at -13.74 m OD, duplicate measurements (GrA-53625 and GrA-53746) on humin and humic carbon fractions again produced statistically different results, with the latter yielding an earlier age range and the former producing a date of 7060–6690 Cal BC.

In LPAZ VC15-3 (-13.70 to -13.58 m OD) there is a substantial change in the pollen assemblage, coinciding with a change from peat to overlying silts (unit 5), with a further reduction in *Corylus avellana*-type (7%) and *Pinus* (22%) but a persistent presence of *Quercus* (10%) and *Ulmus* (7%). Poaceae (16%) increases, as does the presence of halophytes; notably Chenopodiaceae (30%) with occurrences of *Spergularia* (spurrey) and *Plantago maritima.* At -13.60 m OD the benthic marine-brackish diatoms *Diploneis interrupta* and *Nitzschia navicularis* are present. This implies the onset of marine conditions, most probably saltmarsh vegetation, given the overlying presence of incipient peat layers and its geographical position closer to the shoreline than most of the other boreholes. Throughout the peat, monocotyledon stem and root fragments were noted, including some *Phragmites australis* culm bases and root fragments. A radiocarbon date from the overlying intercalated peat, (unit 4), at -13.56 m OD, yielded an aberrant radiocarbon date of 2340-1430 Cal BC (GrA-53702) derived from Poaceae stem / root. Given the possibility that this material is root derived, the young radiocarbon age may be related to intrusive younger root material and should be treated with caution.

Pollen was absent in the overlying intercalated peat (unit 4) and silty sand sediments (unit 3). However, pollen was preserved in a thin intercalated peat (unit 2) occurring between -13.03 and -13.14 m OD (LPAZ VC15-4). The pollen assemblage differs from the preceding pollen zones in having fewer Chenopodiaceae than zone LPAZ VC15-3 or *Pinus* found in LPAZ VC15-1 to 3. Poaceae dominated the assemblage, with tree taxa indicated by *Corylus avellana*-type (30%), *Quercus* (15%) and *Ulmus* (4%). At -13.10 to -13.14 m OD seeds of freshwater marsh / fen taxa were present, including *Lycopus europaeus*, *Mentha*, *Carex* sp (sedges) and *Ranunculus* cf *lingua*, along with occasional charred Poaceae and Cyperaceae stem fragments. Also present was the salt-water tolerant aquatic *Ruppia* (tasselweed) and brackish indicators including *Suaeda maritima* (annual sea-blite) and *Chenopodium rubrum / glaucum*.

Diatoms from the top of the peat and overlying sandy silts (unit 1), between -13.06 to -12.56 m OD, produced an assemblage dominated by open water polyhalobous taxa (80–93%). The main polyhalobous taxa are the marine planktonic diatom *Paralia sulcata* (50%) and *Cymatosira belgica* (up to 30%). Other common marine taxa are *Rhaphoneis* spp, including *Rhaphoneis minutissima* and *Rhaphoneis surirella*, and *Dimeregramma minor*. The marine brackish species *Actinoptychus undulatus* comprises about 5% of the assemblage at -13.06 m OD. The relatively small components of benthic mesohalobous (constant presence of *Cyclotella striata*), halophilous and oligohalobous indifferent taxa, suggests a sedimentary environment in relatively deep tidal water.

Core VC34

Core VC34 consists of a basal dark brownish grey silt overlain by a thin compacted peat (unit 6), -13.65 to -13.56 m OD, in turn overlain by brown / grey silts (unit 1), in places containing lamination. The peat contains a pollen assemblage, LPAZ VC34-1 (-13.65 to -13.58 m OD), dominated by *Corylus avellana*-type (up to 50%) and Poaceae (up to 62%), with *Ulmus* (5%), *Quercus* (21%) and *Typha angustifolia*-type present throughout. Chenopodiaceae (2-3%) increased slightly towards the top of the peat. Seeds present included *Mentha*, *Lycopus europaeus*, *Ranunculus sceleratus* and *R.* subg *Batrachium*, along with Poaceae and Cyperaceae stem fragments, some of which were charred, and frequent small indeterminate wood charcoal. A single radiocarbon date from the centre of the peat, at -13.62 m OD, on *Phragmites australis* leaves, yielded a date of 7050-6680 Cal BC (Beta-288892). A scarce presence of calcareous foraminifera (*Ammonia* spp) was detected within the peat and is likely to reflect inwash or disturbance of the peat as these foraminifera would usually be dissolved in acidic, organic sediments.

Foraminifera immediately overlying the transgressive peat-silt contact, at -13.56 to -13.54 m OD, was dominated by *Haynesina germanica, Elphidium williamsoni* and *Ammonia* spp which are characteristic of brackish low intertidal to subtidal environments. At the same depths, a diatoms assemblage was present containing relatively high percentages of oligohalobous indifferent (49-53%) and halophilous (30-38%) diatoms. There are relatively small components of allochthonous marine (6-11%) and mesohalobous (12-18%) diatoms. These freshwater and halophilous assemblages are dominated by *Fragilaria* taxa, such as *Fragilaria pinnata, Fragilaria construens* var *venter, Fragilaria brevistriata* and *Fragilaria construens* var *subsalina*, which have wide salinity tolerance (although their salinity optima for growth may be in fresh or only slightly brackish water). These opportunist diatom taxa are able to colonise unstable environments and to withstand periods of higher salinity, which are suggested by the smaller polyhalobous and mesohalobous components of the diatom assemblages. The diatom assemblages from the top of the peat (-13.56 m OD) indicated that initially there was a small input of salt water, perhaps through flooding, though by the sample overlying this (-13.54 m OD) there had been a shift to a fully tidal environment.

The pollen assemblage at this level, LPAZ VC34-2 (-13.58 to -13.28 m OD), shows a clear increase in halophytes upwards, with Chenopodiaceae and *Plantago maritima* indicating increasing ingress of brackish or marine water conditions. Typically, the change in sediment regime also caused changes with the pollen taphonomy with increases in pre-Quaternary palynomorphs and dinoflagellates indicating the incorporation of reworked clastic sediments. Diatoms from within the overlying silt and sand tidal couplet deposit, at -13.50 m OD, show a change to an assemblage dominated by polyhalobous (49%) and mesohalobous (25%) taxa. Oligohalobous indifferent and halophilous group totals decline to 11% and 3% respectively. The main oligohalobous indifferent taxa are again diatoms with broad salinity tolerance, such as *Fragilaria pinnata* and *Fragilaria construens* var *venter*. The polyhalobous group is composed of diatoms such as *Paralia sulcata* (32%), *Cymatosira belgica* (7%) and *Rhaphoneis* spp. The mesohalobous group is comprised of non-planktonic taxa such as the brackish marine epiphyte *Achnanthes brevipes* (10%) and benthic taxa such as *Navicula digitoradiata, Nitzschia punctata, Nitzschia navicularis* and the attached species *Rhopalodia musculus*.

Foraminifera from overlying tidal rhythmite deposits (unit 1), at -13.44 m OD, show a mixed assemblage with contributions from taxa associated with saltmarsh / intertidal settings (eg *Jadammina macrescens and Trochammina inflata*), but also taxa associated with outer estuary and shelf environments. This may indicate that these deposits were accumulating sub -tidally, but adjacent to an area where more extensive intertidal environments were accumulating. The resulting deposit is therefore a mixture of allochthonous and autochthonous material incorporating intertidal, shallow sub-tidal and open estuarine / shelf material.

Core VC06

Basal sediments below -12.65 m OD (unit 7) were found to only contain an impoverished plant macrofossil assemblage of *Carex* sp seed fragments, although some small (< 0.5 mm) wood charcoal fragments were found. Within the basal peat (unit 6), LPAZ VC06-1 (-12.65 to -12.60 m OD), the pollen assemblage is dominated by *Pinus* (42%) and *Corylus avellana*-type (35-40%), with some *Quercus* and *Ulmus* (Figure 6). Radiocarbon dating at -12.64 m OD, on humic and humic acid measurements, produced statistically different results, with the humic acid fraction (GrA-53526) earlier than the humin fraction (GrA-53525), the latter yielding a date of 7190-7040 Cal BC.

The peat also contained quantities of pre-Quaternary palynomorphs suggesting that fluvial conditions pertained along with some sediment reworking and / or bedrock erosion. Small numbers of Chenopodiaceae (5%) indicate that this may have been subjected to brackish water ingress or situated close to a salt marsh containing a typical halophyte assemblage. Plant macrofossils from the peat were sparse but included Poaceae indeterminate stem fragments and seeds of Chenopodiaceae, *Carex* sp, *Mentha* and *Lycopus europaeus*, indicative of damp wetland vegetation, along with occasional small wood charcoal fragments.

The transition in the pollen assemblage to LPAZ VC06-2 (-12.60 to -10.53 m OD) is associated with a significant change from peat to silts (unit 5). The *Pinus – Corylus* dominance found in LPAZ VC06-1 is now replaced, in VC06 -2, by *Quercus* (up to 38%) and *Corylus avellana*-type (up to 44%). The pollen assemblage also shows a significant increase in halophytes, including Chenopodiaceae (up to 17%) and a presence of *Plantago maritima* (along with less diagnostic taxa including *Spergularia, Plantago coronopus* type (buck's-horn plantain) and *Aster*-type (daisies)), indicating stronger brackish or marine conditions. There is also a sharp expansion of pre-Quaternary

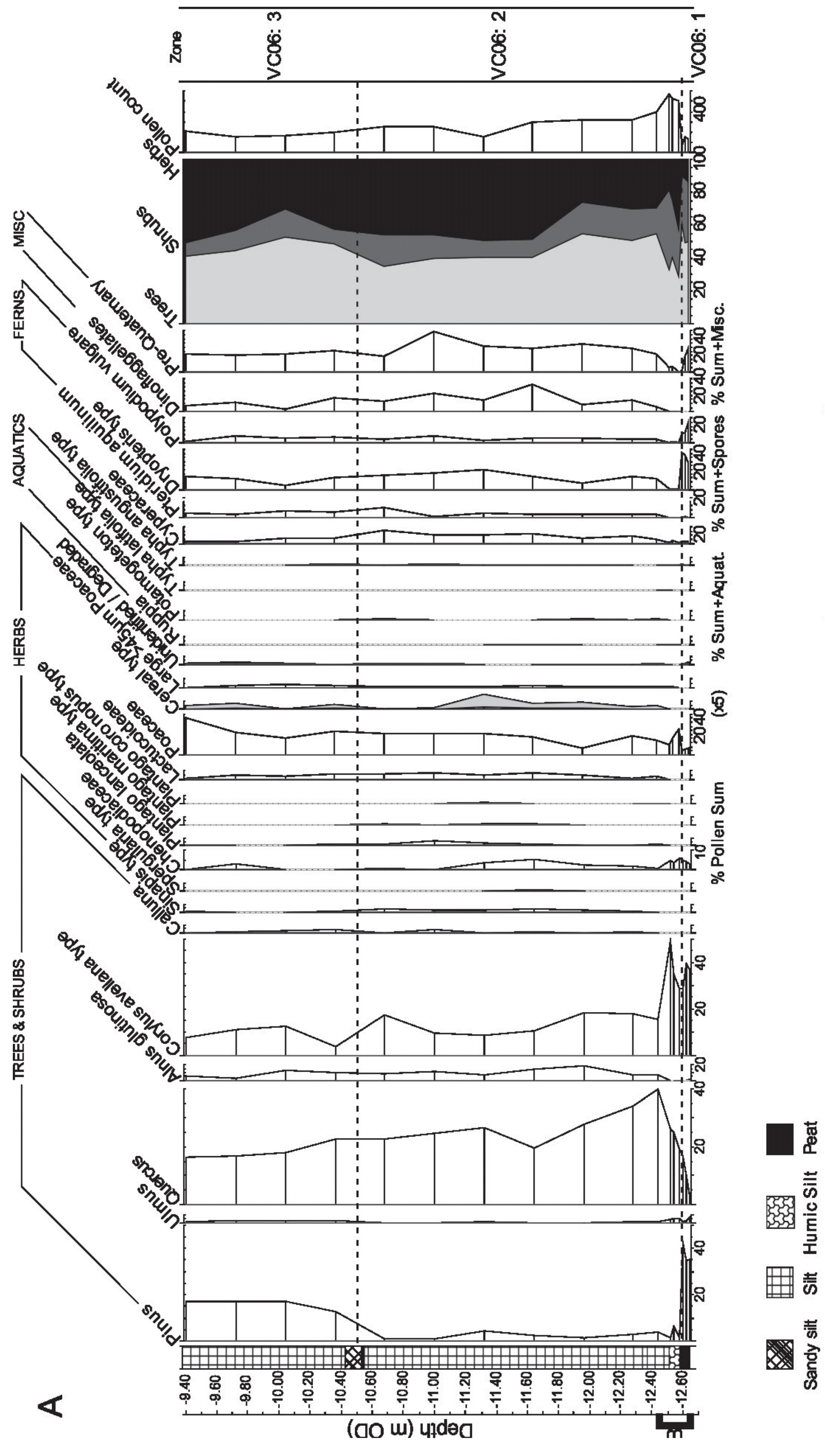
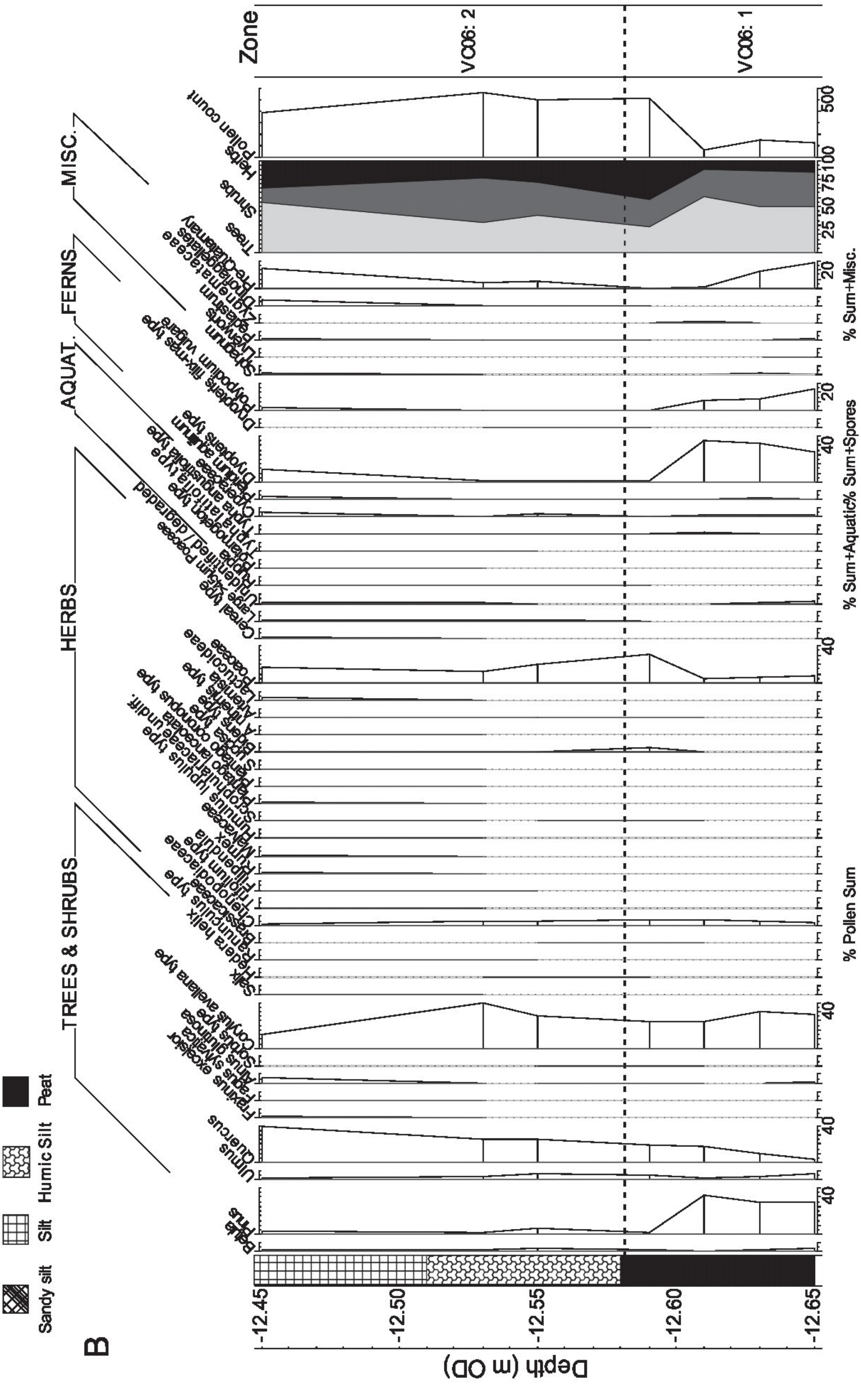


Figure 6: VC06 Pollen Diagram: A) Summary diagram of the full pollen sequence; B) [see page 55] Full pollen assemblage associated with the basal peat in Local Pollen Assemblage Zones VC06-1 and the base of VC06-2.



palynomorphs, as well as dinoflagellates, indicating the inclusion of reworked sediment and / or increased marine conditions. The appearance of cereal-type pollen and other anthropogenic indicators (eg *Plantago lanceolata*;

ribwort plantain) may indicate that these sediments are late prehistoric and indicative of human activity. However, it has demonstrated that some of these pollen types

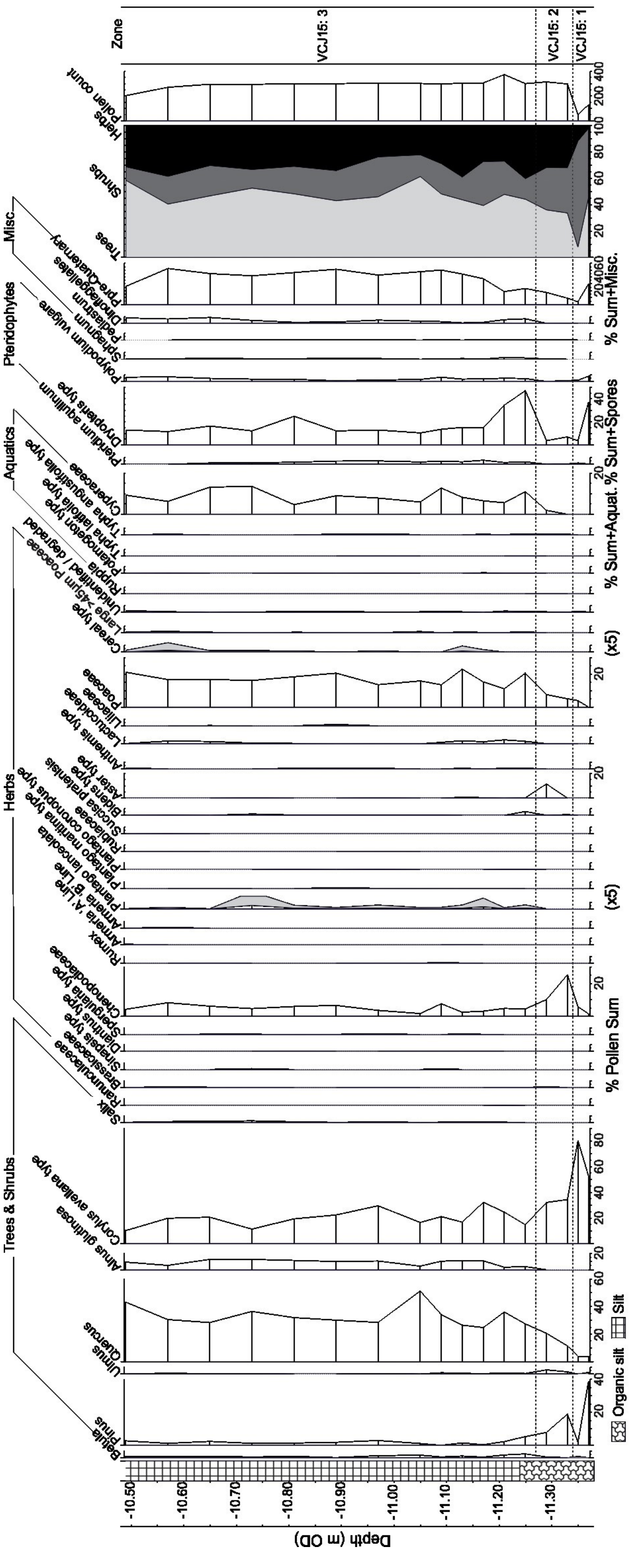


Figure 7: Foraminifera assemblage from VC06.

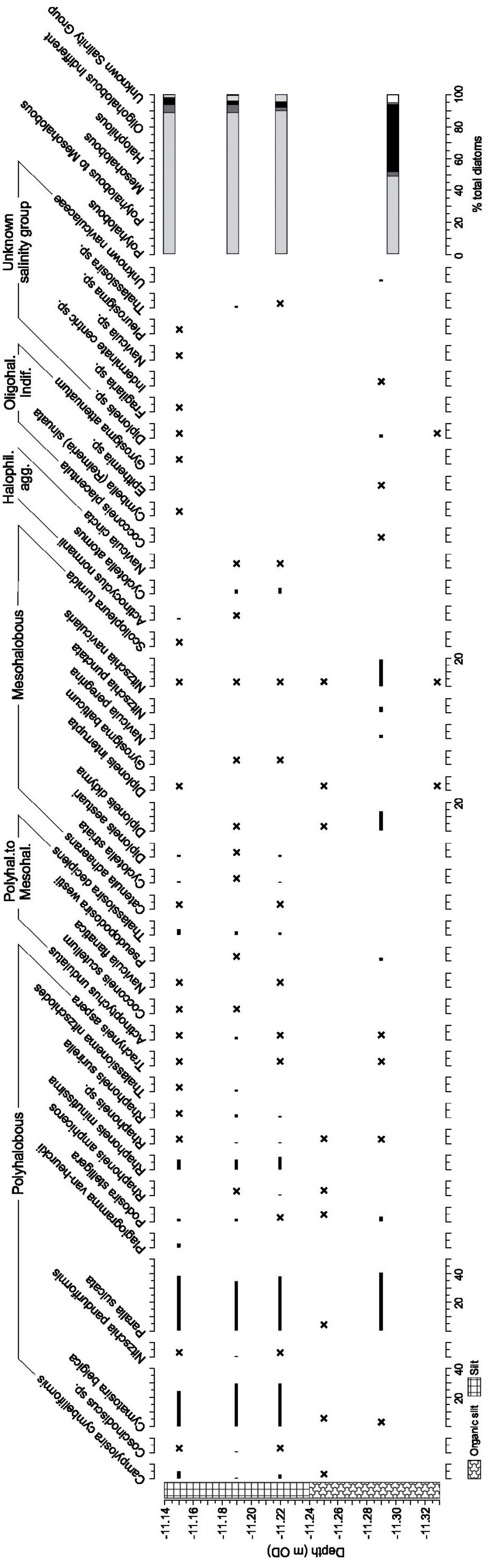


Figure 8: Pollen percentage diagram from VCJ15.

may, when in an estuarine setting, have originated from native wetland communities, notably wild grasses such as *Glyceria* (sweet-grass), *Elytrigia* (couch) or *Spartina* (cord-grass) spp (Waller and Grant 2012), with Allen and Dark (2008), based upon studies in the Gwent Levels, urging caution in the interpretation of the presence of cereal-type pollen at prehistoric sites in the coastal zone.

The top of the peat (unit 6), between -12.61 to -12.59 m OD, contained a low abundance, low diversity, foraminifera assemblage (Figure 7) characterised by the agglutinated taxa *Jadammina macrescens* and *Haplophragmoides* spp, indicative of a saltmarsh environment accumulating toward the upper limit of marine influence. Overlying this, above -12.57 m OD, the characteristic high marsh taxa are replaced by a more diverse assemblage of calcareous foraminifera, along with low numbers of the agglutinated species *Miliammina fusca*, collaborating trends seen in the pollen data. These species are typical of a brackish environment (probably sub-tidal) although the presence of some more fully marine species (eg *Ammonia batavus*) suggests proximity to more open marine conditions.

The onset of marine conditions is further supported by the superabundance of shells of *Macoma balthica* along with abundant *Nucula nucleus*, between -12.51 to -12.44 m OD, implying their presence in lower / middle intertidal zone areas inhabiting fine sediments such as sand, mud and muddy sand. A low diversity diatom assemblage, between -11.65 to -9.41 m OD, was found to contain diagnostic taxa associated with marine and brackish water conditions. The former includes a marine diatom assemblage with planktonic polyhalobous taxa including *Paralia sulcata* and *Podosira stelligera.* Other taxa were open water species, including *Paralia sulcata*, the attached marine-brackish species *Cocconeis scutellum* and very occasional benthic mesohalobous diatoms such as *Diploneis didyma* and *Nitzschia navicularis*.

Attempts to date the start of this transition towards marine conditions were based upon two horizons at the top of the peat. At -12.60 m OD, an unidentified plant macrofossil was dated to 7060-6690 Cal BC (Beta-288885). From the top of the peat, at -12.58 m OD, all three radiocarbon dates are statistically inconsistent. The result on the unidentified wood fragment (Beta-288884), dated 7320-7040 Cal BC, is potentially too old due to an inbuilt old-wood offset (Bowman 1990) and predates the underlying radiocarbon dates (GrA-53525 and Beta-288885). In this case the humic acid fraction is younger than the humin fraction (the only example of this difference from all six pairs of sediment fractions analysed). Based upon the results in the rest of the cores, the humin date (GrA-53519) is tentatively accepted as the most reliable for the date of the upper peat

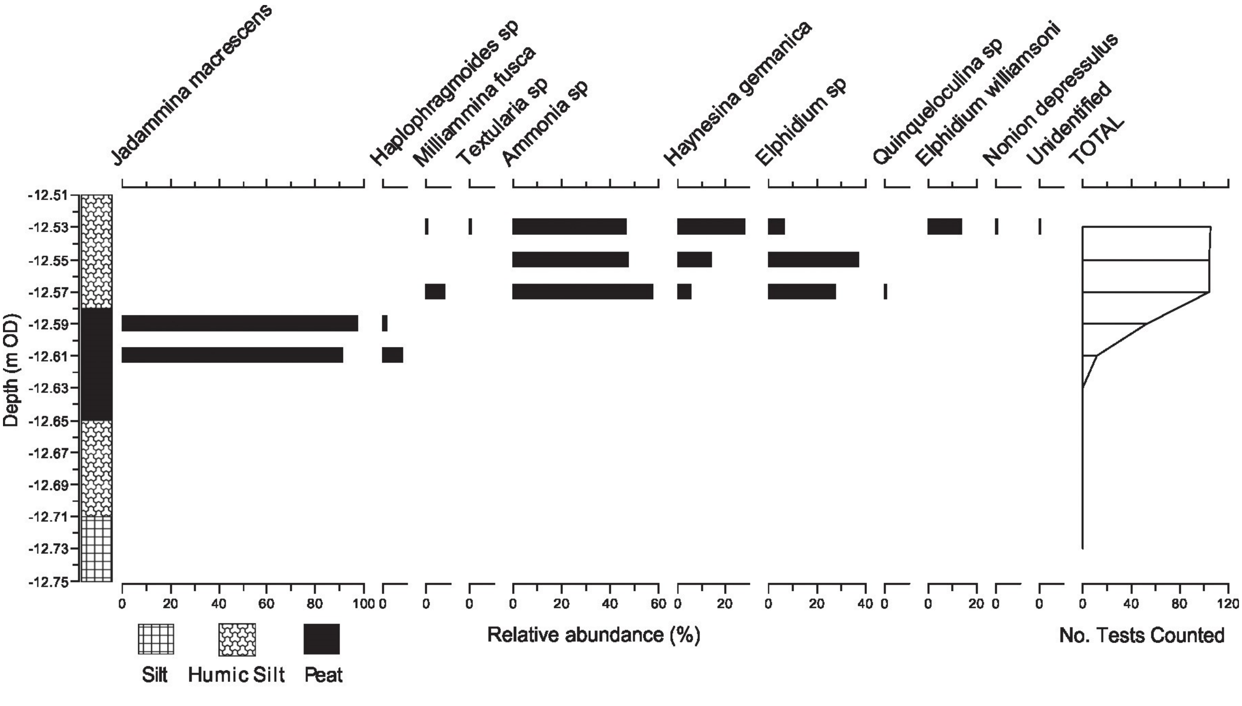


Figure 9: Diatom percentage diagram from VCJ15. Samples at -11.25 and -11.33 m OD failed to yield sufficient diatoms to calculate percentage abundance; presence/absence is only provided for these samples.

contact, at 7080-6820 Cal BC, supported by its close agreement with the immediately underlying radiocarbon date (Beta-288885).

Although changes in the pollen assemblage, between LPAZ VC06-1 / 2, appeared abrupt, the similar transition recorded in the foraminifera, coupled with the sediment isotope analysis (Sturt *et al* submitted), across the upper peat – silt boundary, implies that an intact transgressive contact is present (see Waller *et al* 2006) with the upper peat capable of providing a meaningful date for the onset of brackish conditions at this locality during the Early Holocene. However, autocompaction of the peat (Allen 1999) means that the sampling resolution used for the pollen analysis (2 cm) may have been insufficient to have revealed any gradual pollen transition that may be present across the transgressive contact.

Above unit 5 there is thin sandy peat (unit 4), at -10.54 m OD, probably indicative of a stabilisation horizon and representing a stasis point in the record, with a subsequent change to silt with banded fine sand (unit 1). The pollen record contains a notable increase in *Pinus* (20%) in LPAZ VC06-3 (-10.53 to -9.44 m OD). *Pinus* generally disappears from southern England after its Early Holocene dominance (Bennett 1984; Groves *et al* 2012), so the observed increase is attributed to the introduction of *Pinus* into ornamental gardens and coniferous plantations during the past *c* 300 years. Increases in *Pinus* pollen are often found within the upper levels of salt-marsh profiles (Long *et al* 1999), as well as recent sediments in the North Sea (Zagwijn and Veenstra 1966).

Core VCJ15

This sequence consisted of a basal compacted silt (unit 7) overlain by an organic silt (unit 6; -11.38 to -11.24 m OD) and subsequent silts and sandy silts (unit 1). Five radiocarbon dates were obtained from the organic silt, though all paired dates, albeit on sub-optimal material, were statistically inconsistent. Paired dates from -11.32 and -11.34 m OD both yielded older age estimates from the bulk sediment (Beta-288887 and Beta-28959) than the associated plant macrofossils (Beta-28958 and Beta-288888), though failed to yield dates in a coherent stratigraphical order. As a consequence, the dating of VCJ15 should be treated with caution, though the range of the dates obtained are broadly comparable to the dated organic deposits in the other cores analysed.

LPAZ VCJ15-1 (-11.37 to -11.34 m OD; Figure 8) contains high amounts of *Corylus avellana*-type (up to 80%) and *Pinus* (up to 39%). Subsequently, in LPAZ VCJ15-2 (-11.34 to -11.21 m OD), *Pinus* (5-10%) and *C. avellana*-type (20-40%) are present in lower amounts, with *Quercus* (up to 40%) and *Ulmus* more prevalent. An increase in Chenopodiaceae, *Aster*-type and Poaceae (up to 10%), along with the presence of *Ruppia* cf *maritima*, probably indicate the development of salt marsh communities. This is supported by the presence of remains of *Phragmites australis* root and stem fragments and seeds of *Atriplex* (oraches) and *Aster tripolium* (sea aster) within the organic silt, along with several charcoal fragments. A poorly-preserved diatom assemblage from this unit, (Figure 9), at -11.33 m OD, contained benthic, brackish- marine taxa (*Nitzschia navicularis* and *Diploneis interrupta*). Overlying this, at -11.29 m OD, the assemblage is dominated by a mixture of polyhalobous (48%) and mesohalobous (41%) diatoms. The polyhalobous diatom component is dominated by the planktonic species *Paralia sulcata* (41%), whilst the mesohalobous diatoms are dominated by benthic taxa such as *Diploneis didyma, Navicula peregrina, Nitzschia punctata* and *Nitzschia navicularis*.

The transition to the overlying silt deposits (unit 1), at -11.24 m OD, is accompanied by a notable change in the pollen and diatom floras. LPAZ VCJ15-3 (-11.24 to -10.46 m OD) is dominated by *Quercus* (up to 50%), *Corylus avellana*-type (20-30%), Poaceae (up to 22%) and Cyperaceae (up to 18%), with Chenopodiaceae (10%) and pre-Quaternary palynomorphs abundant throughout. The presence of *Plantago lanceolata* (2-3%) and cereal-type pollen may indicate anthropogenic activity, though again such an interpretation should be treated cautiously. In addition to Chenopodiaceae, other halophytes present included *Plantago maritima, Spergularia* and *Armeria/Limonium* (thrift/sea lavender). The increase in pre-Quaternary palynomorphs and dinoflaggellates throughout the zone probably represents the establishment of mud flats after final marine transgression. Diatoms, between -11.22 to -11.15 m OD, show an increase in polyhalobous diatoms (85-87%) whilst the individual components of marine-brackish, mesohalobous and halophilous species is small (maximum of 6%); and oligohalobous indifferent diatoms are almost absent (Figure 9). *Paralia sulcata* (35-39%) remains the dominant polyhalobous species, along with *Cymatosira belgica* (25-30%) and *Rhaphoneis minutissima* (7-9%). These samples indicate a transition from a shallower water environment associated with the underlying organic rich silt (unit 4/6) into a fully tidal open water environment dominated by marine plankton in the overlying silts (unit 1).

INTERPRETATION AND DISCUSSION

The multiple cores investigated in this study show a general pattern of consistency in both the nature of the record contained and its timing. Overlying the Lower Lias bedrock (unit 9) impersistent gravel (unit 8) and/or freshwater silts (unit 7) were present. The silts were generally devoid of palaeoenvironmental material but occasional organic silt horizons provided opportunities to investigate these deposits. In one example (core VC15) the organic silt clearly predated peat initiation, though it is likely, given the pollen and plant macrofossil content, that these deposits are broadly chronologically comparable (as indicated by the dating strategy) and simply reflect local variations in underlying topography and local hydrological controls. Pollen derived from this deposit, and some of the lower peat deposits, contained a flora dominated by *Pinus*, *Corylus,* fern spores and pre-Quaternary palynomorphs (LPAZ VC6-1; VC24-1; VC25-1, VC15-1 and VCJ15-1). Although these deposits contain an element of reworked clastic sediments, which may have led to an over-abundance of certain pollen types through differential preservation, they confirm a typical Early Holocene vegetation composition in the local area.

Elevation of basal water levels led to the initiation of organic sediments, including peats, across the study area from *c* 7500 Cal BC onwards. This change in ecology would have been driven directly by sea-level rise, forcing groundwater levels upwards. Pollen analysis indicates a shift from a *Pinus – Corylus* dominated assemblage to one where *Corylus, Quercus* and *Ulmus* become increasingly important. This pattern is consistent with the regional contemporary changes in woodland composition (eg Birks 1989; Hosfield *et al* 2007a). LPAZ VCJ15-2 and VC15-2 demonstrate this transitional phase. The stage by which *Pinus* has declined fully and *Ulmus*, *Quercus* and *Corylus* have become the dominant woodland taxa alone is shown in LPAZs VC6-2, VC24-2, VC25-2 and VC34-1. Although dominant in the pollen assemblage, there was no direct evidence of these trees in the plant macrofossil record that was obtained, with the only tree being identified through macrofossil remains being that of *Populus* sp in VC15. Trees, such as *Quercus*, are known to be tolerant of some freshwater marsh conditions and are likely to have been present in the wetland, along with the adjacent dryland. Such patterns are seen elsewhere along the coastline within the submerged forests (eg Timpany 2005; Heyworth 1985). The plant macrofossil remains do, however, confirm the local presence of a freshwater marsh/fen environment, associated with both the organic silts and peats, with a range of species including reeds, sedges and grasses. Most notably, in every core investigated was the presence of charred remains of grasses/sedges, along with some evidence of the burning of reeds. The dating of one episode of burning is directly confirmed in VC15 where charred *Populus* sp buds and bark provided a radiocarbon date of 7190-7040 Cal BC (GrA-53628).

The extensive presence of burnt plant material within the organic deposits does strongly allude to human activity within the current sub-tidal zone during the Mesolithic, *c* 7000 Cal BC. Evidence of Late Mesolithic burning along the margins of the Bristol Channel and Severn Estuary is well established (eg Brown 2005; Timpany 2005; Jones *et al* 2005; Bell *et al* 2002; Bell 2007). Within these deposits charred plant remains demonstrate the burning of herbaceous plants which has been suggested as a clear sign of the deliberate burning of reed-swamp by humans. Such burning may have been utilised to remove the build-up of litter and encourage edible plants and tender new growth that may have enticed game to specific locations on the floodplain, as well as maintaining route ways through the wider landscape, as witnessed at important Mesolithic sites such as Star Carr (Mellars and Dark 1998), Thatcham (Barnett 2009) and Three Ways Wharf (Grant *et al* 2014a). If these burning events are related to deliberate human activity then it supports the view that Mesolithic people expanded natural openings, including those at the edge of water, by manipulating them through fire. However the possibility that these fires are the result of natural factors and ecological processes cannot be ruled out (eg Brown 1997; Moore 2000; Tipping 1996), with several recent studies suggesting that episodes of fire activity were relatively common in the Early Holocene and were consistent with climate changes (eg Power *et al* 2008; Marlon *et al* 2013; Grant *et al* 2014b). Whether the burning is natural or anthropogenic in origin, the evidence collected offshore at Hinkley Point clearly demonstrates that the Early Holocene wetland vegetation in this area did burn and notably it predates evidence for burning found in other Mesolithic intertidal peat deposits within the wider area by at least 1500 years. This indicates that some form of burning was taking place in the current offshore area long before that found at sites such as Goldcliff (Bell *et al* 2002;

Timpany 2005) and may indicate, if originating from humans, activity across wetland areas that was progressively driven inland as sea levels rose and freshwater environments laterally migrated inland as a result of estuary expansion. The occurrence of charred plant remains across the study area clearly enhances the archaeological potential of the sub-tidal zone for Early Mesolithic archaeology.

The large number of radiocarbon dates obtained from this study provides an opportunity to assess the robustness of results obtained from submerged peats in the sub-tidal zone (see Griffiths *et al* submitted for a full discussion). The statistical inconsistency between duplicate humin and humic acid measurements demonstrated, in several cases, that humic acid fractions produced the older dates. Similar age discrepancies have been observed in other studies from wetland environments (eg Shore *et al* 1995; Blaauw *et al* 2004). *Phragmites australis* leaves, which are fragile and unlikely to survive significant translocation (Törnqvist *et al* 1992), have provided dates that are statistically consistent with the humin carbon fractions, supporting the conclusion that these may provide reliable *in situ* age estimates for peat formation. Humic acids are insoluable in water under acidic conditions, but are soluble at higher pH values, making them mobile in neutral/alkaline conditions. This means they may leach downwards (or translocate upwards) in percolating ground waters (see Nilsson *et al* 2001; Turetsky *et al* 2004). The nature of the increasingly brackish environment, which might include complex, carbon-cycling effects, in combination with fluctuating water tables and ground water, could be the cause of the old humic acid effect, perhaps specific to saline environments and/or exacerbated by low energy submerged conditions (Avrahamov *et al* 2013). In contrast the humin fraction is water insoluble at all pH states and may be taken as being more representative of a true sediment age. However, discrepancies in ages can still occur as both fractions originate from decomposition of plant material, which may include intrusive younger root material (Brock *et al* 2011) or older in-washed/reworked carbon (eg Waller *et al* 2006), the latter possibly indicated by the presence of large numbers of reworked pre-Quaternary palynomorphs in some sedimentary units.

In cores VCJ15 and VC24 dates were obtained from bulk sediments, as opposed to extracted carbon fractions, and were found to be consistently older than plant material dated from the same horizon. In this instance, however, the sources of carbon dated within these bulk samples is very uncertain and should be treated very cautiously as such material (compared to carbon fraction dating) provide a less reliable approach to dating sediment formation. Problems of dating floodplain sediments, often in the absence of suitable *in situ* plant macrofossil remains, is well understood (eg Howard *et al* 2009; Bayliss *et al* 2008; Stevens *et al* 2012, 345-49) and the need for careful selection of material used in radiocarbon dating is most pertinent in these situations. Most important is that decisions are based upon an understanding of the sample taphonomy and origin, the site context and geomorphology, and the reason for undertaking the dating in the first place.

The end of peat formation is best recorded in core VC06, where there appears to be an intact peat-silt contact, demonstrating the local onset of brackish water conditions and end of peat formation, at 7080–6820 Cal BC (GrA-53519), and subsequent full marine conditions. All proxies investigated show good agreement in the nature of the transition from freshwater to salt water conditions across all cores investigated, though in some this transition is likely to be fragmentary due to erosion of the upper peat (Waller *et al* 2006). However, the presence of intercalated organic deposits in some cores, notably VC15 and VC06, demonstrate that this was not in a single smooth transition but instead identify brief periods where sediment supply into the wetland outstripped sea-level rise and saltmarsh could establish over mudflats. This resulted in a localised progradation of the coast, prior to marine inundation once again. Seen together, the above evidence illustrates the complexity of the story of inundation and coastal change in this region.

Being able to add this extra level of detail to our knowledge of Early Holocene landscapes is important in its own right. However, the work above gains additional significance by extending our knowledge of known sequences into new areas; through offering a tightly dated sequence from the offshore zone. It is now clearly apparent that, at least in fragmentary form, processes well documented within the fine grained and archaeologically rich intertidal deposits found along the edge of the Bristol Channel and Severn Estuary have the potential to be followed into the sub-tidal zone. Not only can these deposits be laterally traced but they may offer the opportunity to extend our current knowledge of Mesolithic wetland activities, with evidence for burning predating those previously recorded within the intertidal deposits by at least 1500 years (eg at Goldcliff in the Gwent Levels; Bell *et al*, 2000).

CONCLUSIONS

The data gathered as a part of this project has allowed for detailed characterisation of the changing palaeogeography of the region, and given insights into the developing nature of the local seascape, particularly as this was an area of the Bristol Channel that was previously poorly understood (Allen 2001). The documentation of a fragmentary, yet potentially extensive Early Holocene wetland landscape, offshore of Hinkley Point, is significant for several reasons. It offers a contrasting record of change to that reported in contemporary deposits such as those found with the Gordano Valley (Hill *et al* 2007) and the Porlock embayment (Jennings *et al* 1998). At Hinkley Point a shallowly shelving, yet open, coastline is present, in direct contrast to the more sheltered situations described at either of these other two locations. In addition, analysis of material from a series of vibrocores has helped extend knowledge well into the present sub-tidal zone.

While there is no direct material evidence for Mesolithic activity in the study area, the consistency of charred plant remains within each core sampled, along with evidence for it within the wider landscape (Bell 2007; Canti *et al* 1995), strongly implies a human presence in the current sub-tidal zone. As such, the ability to better characterise the nature of the space that existed, and the rate at which it changed, enhances appreciation of the context within which Mesolithic activity was occurring. As Bell and Warren (2013), and Sturt and Van de Noort (2013) argue, this is a key step towards developing improved accounts of land and seascape use in prehistory. It is through building up knowledge of regional sequences that archaeologists and earth scientists can move away from overly generalised accounts of the impact of large scale processes, such as sea-level and climate change, on past populations.

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