

OBSERVATIONS ON HUMAN ACTIVITY AND PALAEOLOGY OF RECENT EXPOSURES OF THE MID-HOLOCENE SUBMERGED PEATS AND ASSOCIATED SEDIMENTS AT BORTH, CEREDIGION

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Abstract

Since 2010 winter storms have resulted in significant coastal erosion around the British coastline. This paper reports on a series of new findings from the peats and submerged forest at Borth in Ceredigion, West Wales. In this paper we attempt to integrate this new information with previously unpublished data from the region. Following inundation by marine waters of the Dyfi at the end of the last cold stage the microfossil and pollen data recovered from a series of boreholes and sections documents shifts from saltmarsh to tidal flat/marine influenced environments and then a return to saltmarsh environments prior to formation of the main peatlands associated with the submerged forest. A major tidal channel has been identified

cutting through these peatlands. A date from a set of red deer antlers found in this channel suggests tidal conditions persisted into the Bronze Age in this location. Human activity in the peatland is unequivocally attested to through the presence of burnt stone in the upper parts of the main peat from the Early to Late Neolithic period, whilst further evidence for human presence exists in the form of isolated human footprints in the organic silts preserved above the main peat during the Early Bronze Age. For the first time it can be seen that the peats do not form a continuous presence from north to south along the coast, but are interrupted by at least one major drainage channel. The presence of woodland in the peat is also noted to vary depending upon location in the wetland.

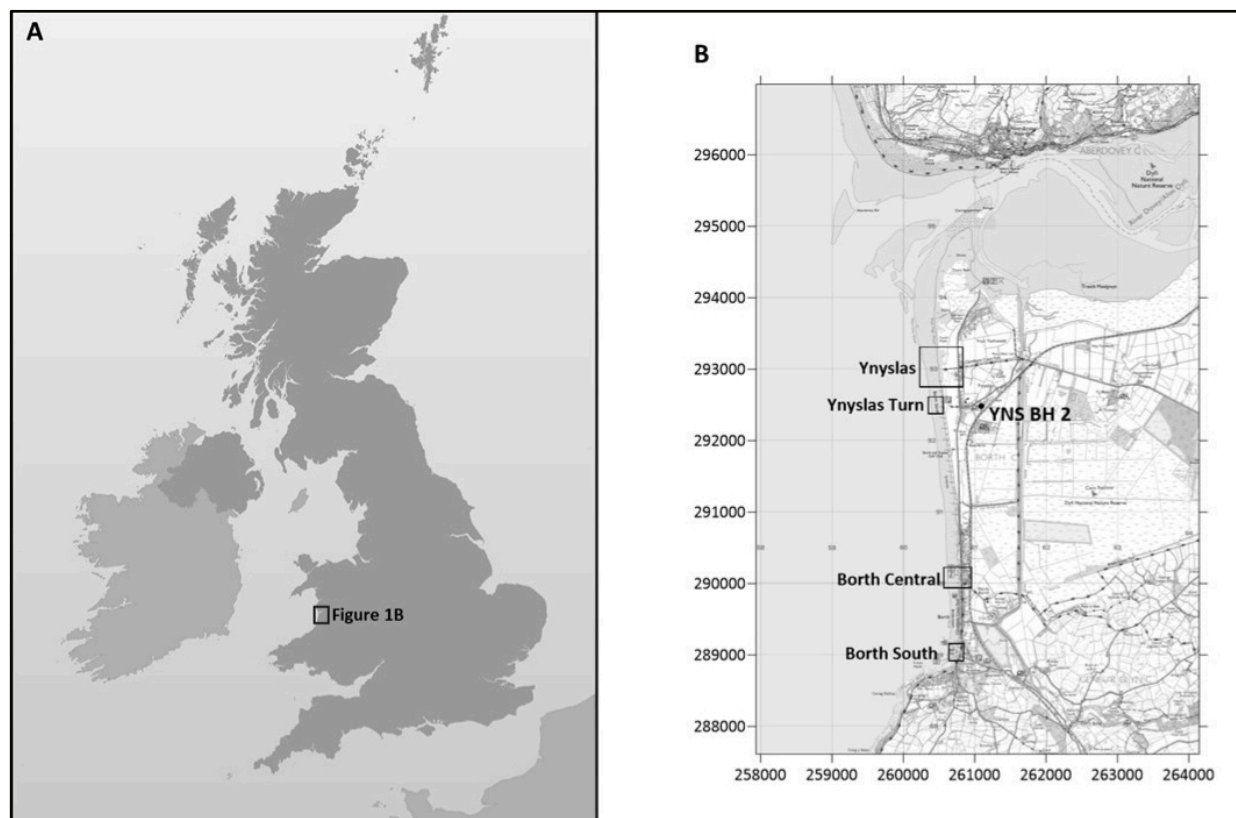


Figure 1: A - Site location plan for Borth; B - Borth to Ynyslas and the Dyfi Estuary showing areas of investigation

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Introduction

Between 2010 and the present winter storms have resulted in significant coastal erosion around the British coastline. This has resulted in loss of properties to the sea, infrastructure damage and flooding. However, the

consequence of these impacts has been to reveal hitherto unknown geological and archaeological records such as the early Middle Pleistocene hominid footprints at Happisburgh in Norfolk (Ashton *et al* 2014). Elsewhere, for example along the western seaboard of Wales (from Pembrokeshire in the south to Anglesey in the north) these events have resulted

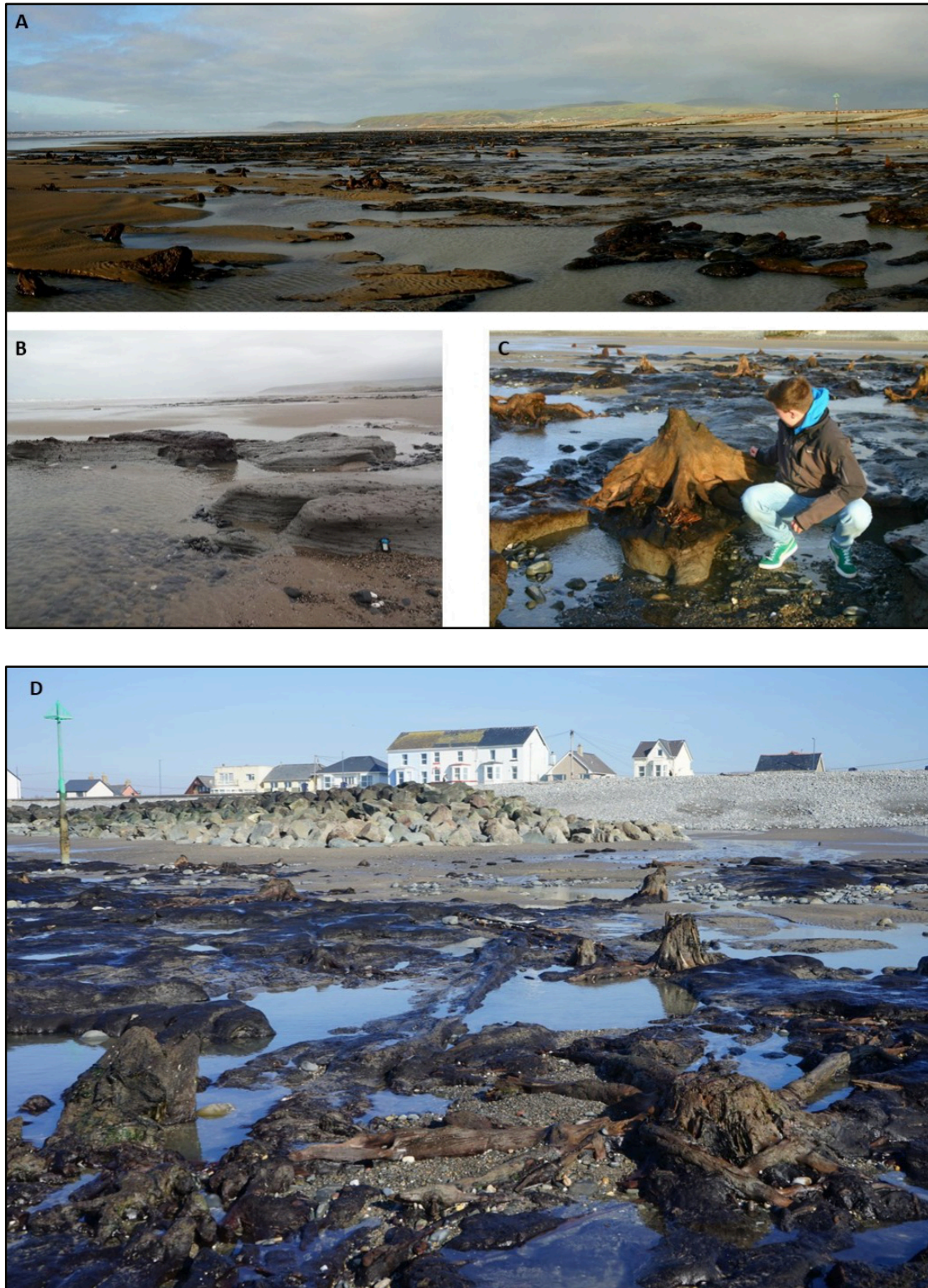


Figure 2: A - General view of submerged forest looking north towards Ynyslas and the Dyfi estuary; B - Laminated clay silts (Scrobicularia Clays); C - Pine tree stump and associated peat; D - fossil tree stumps rooted into peat overlain by peat containing fallen tree trunks

in the re-exposure of many middle Holocene sequences normally found buried beneath our beaches, and thus allowed new discoveries to be made and old finds to be fully contextualised.

Here we report on a series of new findings from the submerged forest and associated sequences at Borth in Ceredigion (Figure 1), a place often associated with the tale of Cantre'r Gwaelod (Kavanagh and Bates 2019). This stripping of the beach sand during storms has enabled the recording and sampling of the buried sedimentary sequences to be undertaken from late winter into the early summer in most years since 2012. The work has revealed a range of new geomorphological contexts within what had hitherto been perceived to be a relatively uniform forest sequence (Heyworth 1985). These observations have also revealed a human presence in parts of the sequence whilst new faunal remains have been recovered that shed light on the changing environments before, during and after forest growth.

Background to this research

Peat and associated trees have been known to be present beneath the beach in the area between Borth and Ynyslas (Figure 1B) (SN 60669 88909 to 60319 92799) as well as inland beneath Borth Bog (Cors Fochno) for at least 300 years. The earliest detailed records from the area were provided by the Reverend J Yates (1833) who described the submerged forest and drew attention to the observations of Mr Aikins (1797), the first geologist to observe the trees at Borth in 1792. This observation is however predated by that of Edward Lhuyd who, according to Morgan (1869), described trees on the foreshore at Borth in his travels through Wales in the late 17th/early 18th century. Lhuyd wrote in 1695 “As for roots or stumps, I have often observ'd them myself at a low ebb, in the Sands betwixt *Borth* and *Aber Divy* in Cardiganshire; but remember nothing of any impression of the Axe on them; but on the contrary, that many of them, if not all, were very smooth; and that they appear'd, as to substance, more like the cole-black Peat or Fuel-turf, than Timber.”

This early reporting was followed by the work of Keeping (1878) and Ashton (1920). Godwin and Newton (1938) published the work of the little-known Mrs Campbell James and provided the first pollen record for the area. This work was refined by Godwin (1943, 1956) while Godwin and Wills (1961) published the first radiocarbon dates from the bog. Additional palynological work was undertaken by Moore (1966, 1968) and the study of the foraminifera from the clays beneath the peat was made by Adams (1963), Adams and Haynes (1965) and Haynes and Dobson (1969).

Following this early palaeoenvironmental work Steers (1969) and Taylor (1973) summarised and contextualised the sequences at Borth. This work, along with the drilling by the University of Wales Aberystwyth of two deep boreholes at Ynyslas stimulated a series of PhD projects on aspects of the sequences (Wilks 1978, 1979; Heyworth 1985; Prince 1988 and Shi, 1992). These investigations focused on the chronology of the forest (Heyworth and Kidson 1982; Heyworth 1985) and the sedimentology of the sequences (Shi and Lamb 1991). More recently work on the bog has been conducted by Hughes and Schultz (2001) and Orme *et al* (2015) and the sequences at Borth have been placed in a national context by Strafford (2013).

These works established that two basic sequences exist within the area. Between Borth and Ynyslas the ‘classic’ submerged forest is present (Figure 2A) consisting of peats overlying a deep series of clays (the Scrobicularia Clays, Figure 2B). These Holocene sediments (actually a range of grain sizes from clays to sands) rest on bedrock or late Pleistocene gravels and in places may exceed thicknesses of 25m. The peats of the submerged forest present on the foreshore are typically less than 1m thick and contain common pine tree stumps (Figure 2C) and fallen trunks/branches as well as rarer oak remains. Along the foreshore organic silts and minerogenic sediments are occasionally seen above the main body of peats. Inland the forest peat is overlain by sphagnum/calluna peats (Godwin and Newton 1938; Godwin 1943; Hughes and Schultz 2001).

Dating of the sediments has previously been achieved through ¹⁴C. Early Holocene dates have been obtained from one of two deep boreholes drilled in the Ynyslas area at points below 25m AOD. Mid Holocene dates have been obtained from birch remains at Ynyslas, such as from *in situ* birch wood sampled at the base of the peat (6556-7250 cal BP; Godwin and Wills 1961) and from brushwood in the basal peat just above the underlying silts (6339-7155 cal BP; Godwin and Wills 1961). At Borth the earliest peat deposit has been dated to 5731-5985 cal BP (Bell 2007). Cessation of forest growth occurred by 5400 BP in the north, at Ynyslas, and 3900 BP in the south according to Campbell and Baxter (1979), whilst Campbell and Bowen (1989) suggest that much of the forest growth had already ceased by 4700 BP with the growth of the sphagnum bog beginning around 4500 BP. More recent work by the Dyfed Archaeological Trust (2012) suggests that oak trees were growing until 3100 BP at the southern end of the forest.

Archaeological remains are relatively rare within the sediments associated with the forest but a Mesolithic composite tool made of antler and two flints (dated by association with the peat to c4000 BP) was reported by the Dyfed Archaeological Trust (2012; Poucher 2009). Heyworth (1985) also described a burnt mound resting on peat close to the Ynyslas Turn. Faunal remains are rare but often appear after storms and are devoid of context. Taylor (1973, 1984) reported on the discovery in the late 1960s of “most of the post-cranial skeleton of the male bovid, *Bos primigenius*, on Borth beach” (Taylor 1973, 286), a find which has subsequently been lost.

Sedimentary sequences

Recent observations on the sediments associated with both the submerged forest peats and the underlying minerogenic sediments (Scrobicularia Clays) have been made through:

1. Direct observations made during periods of sand removal following winter storms,
2. Hand augering at key points along the beach,
3. Geophysical survey and
4. Conclusions drawn from geotechnical data gathered as part of recent sea defence construction works.

Considerable effort has been made since 2012 to observe, record and sample exposures along the coast. At times during winter/spring this has necessitated visits to the beach three or four times each week during tidal windows. It should be noted here that unlike other sites, at Borth extreme spring tides are not needed to reveal the sediment sequences. With the exception of all but the smallest neap

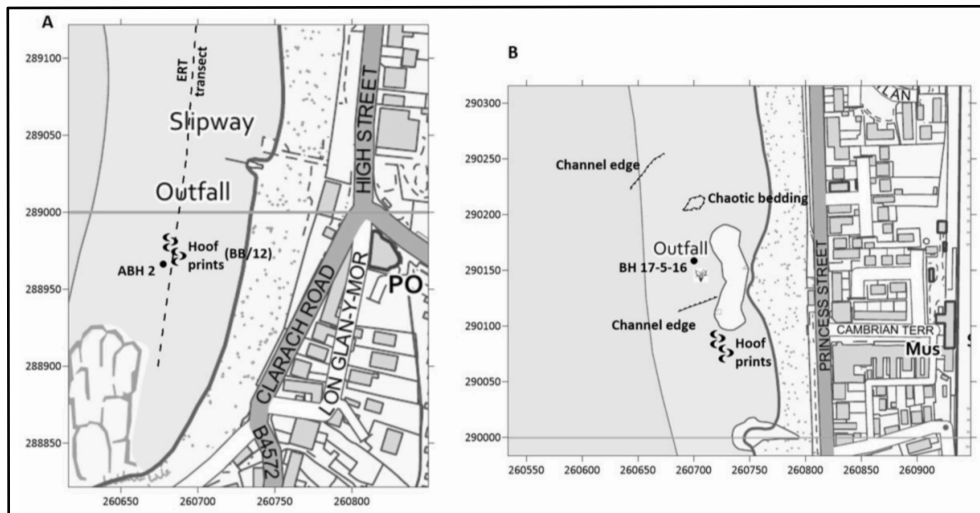


Figure 3: A - Borth South study area; B - Borth Central study area

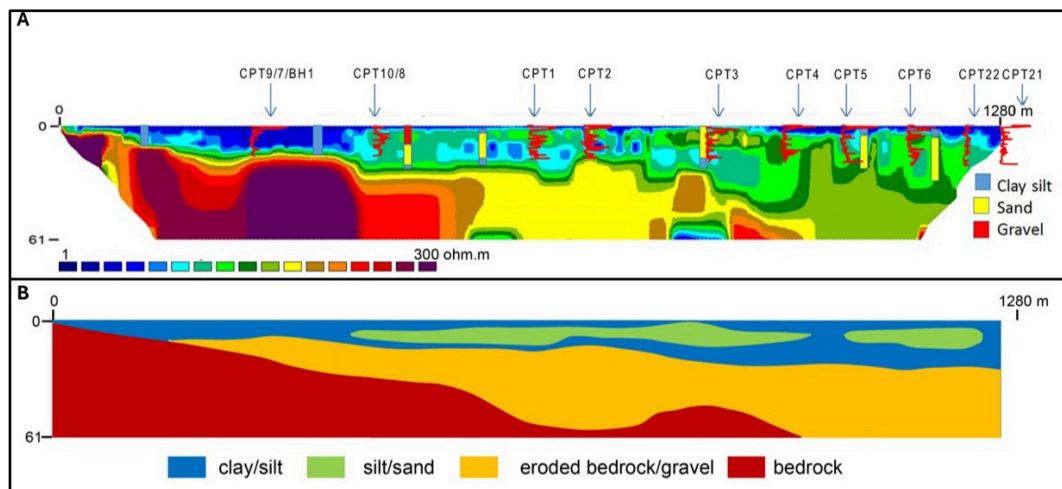


Figure 4: A - Inverted electrical resistivity section with superimposed CPT locations and results from transect along beach at Borth; B - simplified geological interpretation of geophysical section

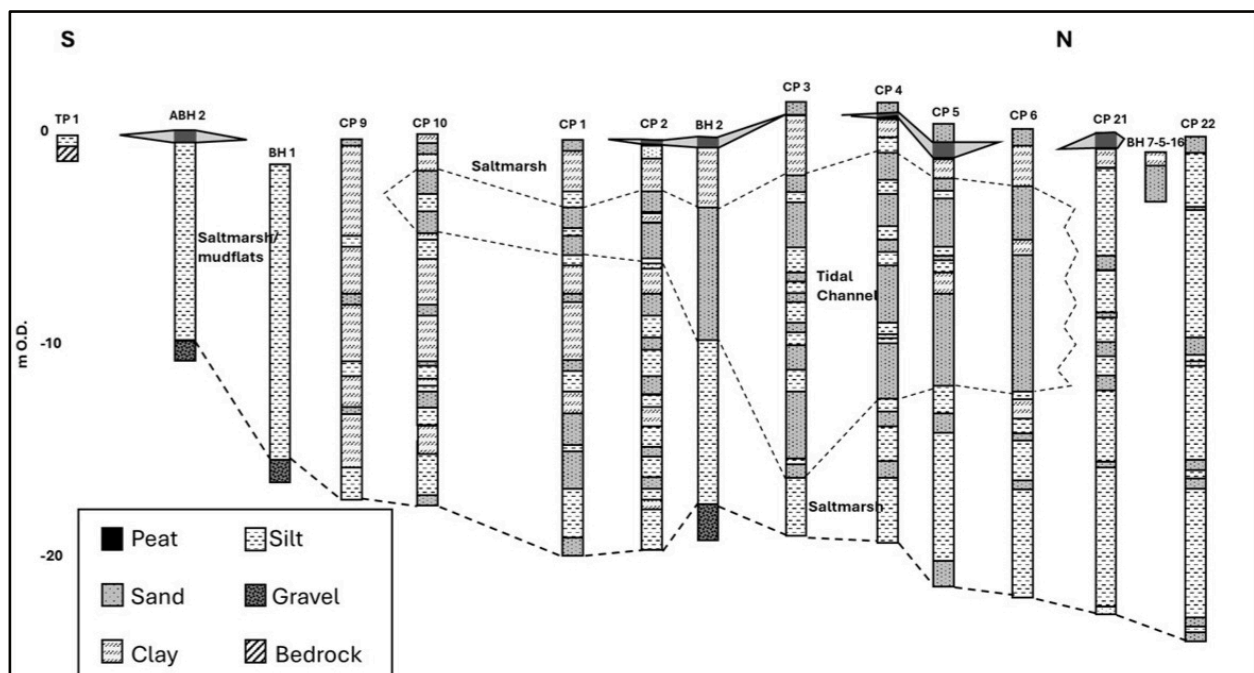


Figure 5: Borehole and interpreted CPT data from ground investigation along line of ERT profile

Id	Easting	Northing
CPT1	260725	289513
CPT2	260722	289574
CPT3	260761	289748
CPT4	260738	289862
CPT5	260734	289924
CPT6	260751	290000
CPT9	260701	289144
CPT10	260712	289304
CPT21	260731	290106
CPT22	260720	290195
BH 17-5-16	260746	290049
BH1	260781	289138
BH2	260764	289322
ABH 2	260674	288964
TP 1	260672	288909

Table 1: Borehole locations for Figure 5

tides the tidal fall at Borth usually allows access to the peats for three or more hours during each tidal cycle.

Geophysical survey and geotechnical data (Figures 3-5 (RB))

In order to understand the topography of the pre-inundation landscape of the Dyfi an Electrical Resistivity Tomography (ERT) survey was conducted northward from Upper Borth for approximately 1.2km (Figure 3A). Prior to survey a forward-modelling of the foreshore was conducted (Bates and Bates 2016). This modelling indicated that it should be possible to map the contrast between bedrock and the overlying salt-saturated sand, any channel sequences and possibly also the thin peat layers (depending on electrode intervals). In the field ERT data was acquired along a continuous profile from south to north along the foreshore. The survey was conducted using an ABEM Terrameter SAS4000 with 5m electrode spacings. A modified Wenner-Schlumberger gradient array was used for data acquisition in order to gain increased resolution in the near surface while improving data cover for the largest depths of investigation. The measured apparent resistivity data were converted to pseudo-section images (electrical resistivity tomograms) of modelled resistivity using finite-difference forward modelling with the RES2DINV software (Geotomo software, Malaysia) following the method of Loke and Barker (1995). The results are presented in Figure 4A. Ground truth methods included boreholes and Cone Penetration Tests (Bates and Stafford 2013; Bates and Bates 2016) derived from geotechnical ground investigations in advance of the replacement of the Borth sea defences.

The inversion results of the ERT field transect is shown together with CPT and boreholes results in Figure 4A and the overall interpretation in Figure 4B. The underlying bedrock, with resistivity greater than 80 ohm.m, was clearly mapped in the ERT and its upper surface showed a strong northerly dip with an associated increase in thickness of the Holocene sediments (10-30 ohm.m) and beach material (<15 ohm.m). There is a reasonable correlation with the CPT data for the site down to the depth of maximum CPT penetration (*ie* cone refusal on an impenetrable material) and also good correlation in the near surface with test pits. Variation in the near surface resistivity values also indicates

complexity within the Holocene sediment stack (particularly towards the northern end of the transect).

Borehole and converted CPT data are shown in Figure 5 (see Table 1, for locations) along the same line as the ERT profile. These data show a complex of different sedimentary units overlying gravel or impenetrable material (probably gravel or bedrock). Discernible patterns in sediment distribution are hard to determine, although it is clear that fine grained sedimentary units dominate towards the south while coarser grained facies (sands) become more common northwards. These data have been interpreted to show a complex sequence of fine-grained saltmarsh to the south, tidal mudflats and sandy tidal channels to the north lying between the underlying late Pleistocene fluvial gravels and the peat associated with the forest.

Sequences at Borth South (BB/12) (NGR SN 60644 88974) (Figures 6-8)

Peats were exposed in the winter/spring of 2012 at the south end of the beach (Figure 3A, around BB/12) as a result of storm stripping of the sand coupled with altered current patterns associated with the temporary creation of a haul road for the construction of the off-shore reef (part of a programme of sea defence works).

Hand augering through the peat and into the underlying sediments was undertaken at the location of Borehole ABH 2 (Figure 3A/6). Here the sediments consisted of a thick sequence of clay silts lying upon a hard, impenetrable gravel or bedrock (Figure 6). This sequence was overlain by approximately 0.5m of peat capped by a thin clay-silt and upper organic sediment.

The exposures also allowed a test pit to be dug into the sediments associated with the upper parts of the peat (Figure 7A) adjacent to ABH 2. Here, as in ABH 2 (see above), a thin sequence of minerogenic sediments overlain by organic silts was present above the main peat bed (Figure 7A/B) consisting of a dark brown to black humified peat (Figure 7B) in which there was a dense scattering of fragmented beach pebbles (Figure 8). The main scatter of rocks covered an area of about 3m by 5m and was restricted to the upper 5cm of the black, humified peat (Figure 7B). The rock fragments themselves appear to have been burnt beach pebbles. Burning is inferred by the bleaching of the outer cortex of the pebbles relative to the inner, unmodified pebble, in which the deep grey colour mirrors that of the bedrock in outcrop around Borth. These fragments of local rocks show they were once rounded pebbles, which were subsequently shattered (by firing and probably also by submergence in water); the broken edges of these showing no sign of post-depositional movement. No concentrations of charcoal or other structural remains were present; thus the stones just appeared to be a scatter of deliberately burnt material. Such practices are common in the later prehistoric archaeological record where their use for boiling water, either for cooking or as a heat source in a sweat lodge have been argued for (English Heritage 2011).

The uppermost organic sediments contain extensive evidence for animal hoof prints and human footprints (Figure 7C and 7D). Although no discernible tracks could be identified a range of print types are present including varying-sized cloven hooves as well as small human prints (Figure 7D). Surprisingly none of these prints appear in the underlying peats that are rich in burnt stone fragments. Consequently we can be certain that at least two phases of human activity are documented within the organic

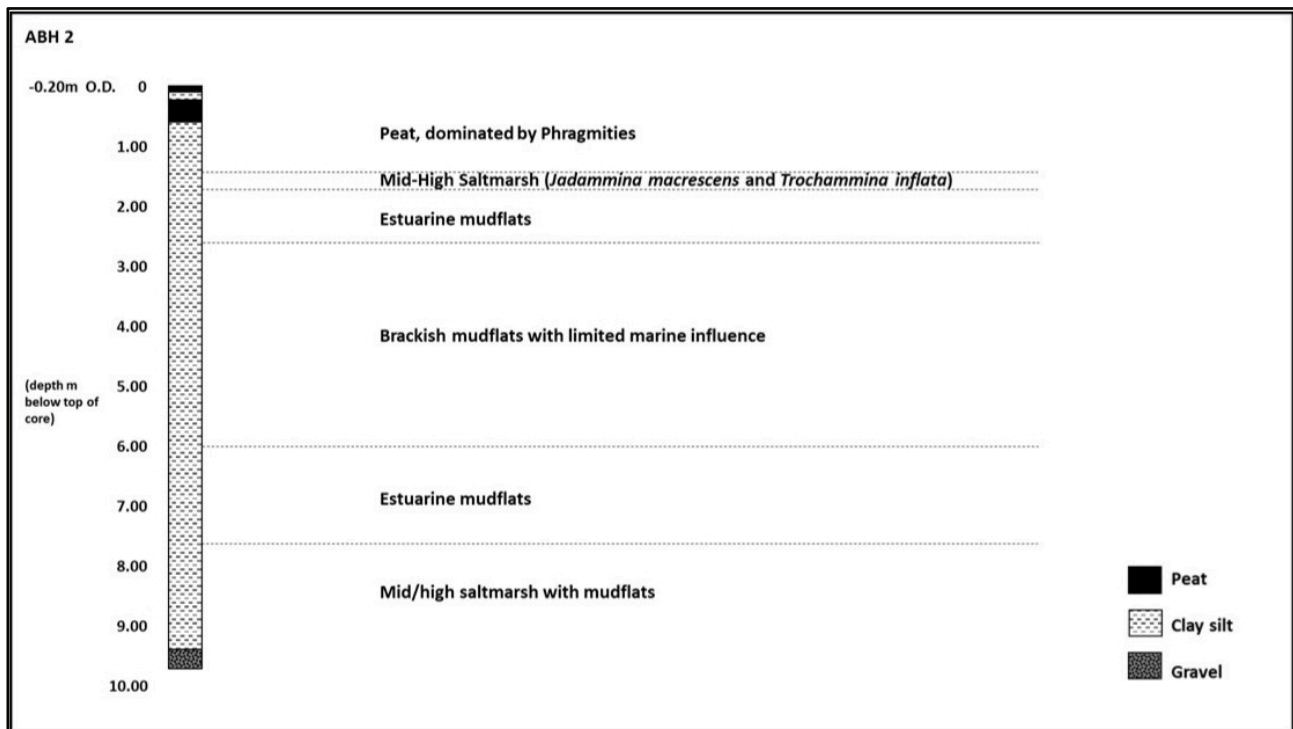


Figure 6: Lithology and ecological zones based on microfossil data from ABH 2

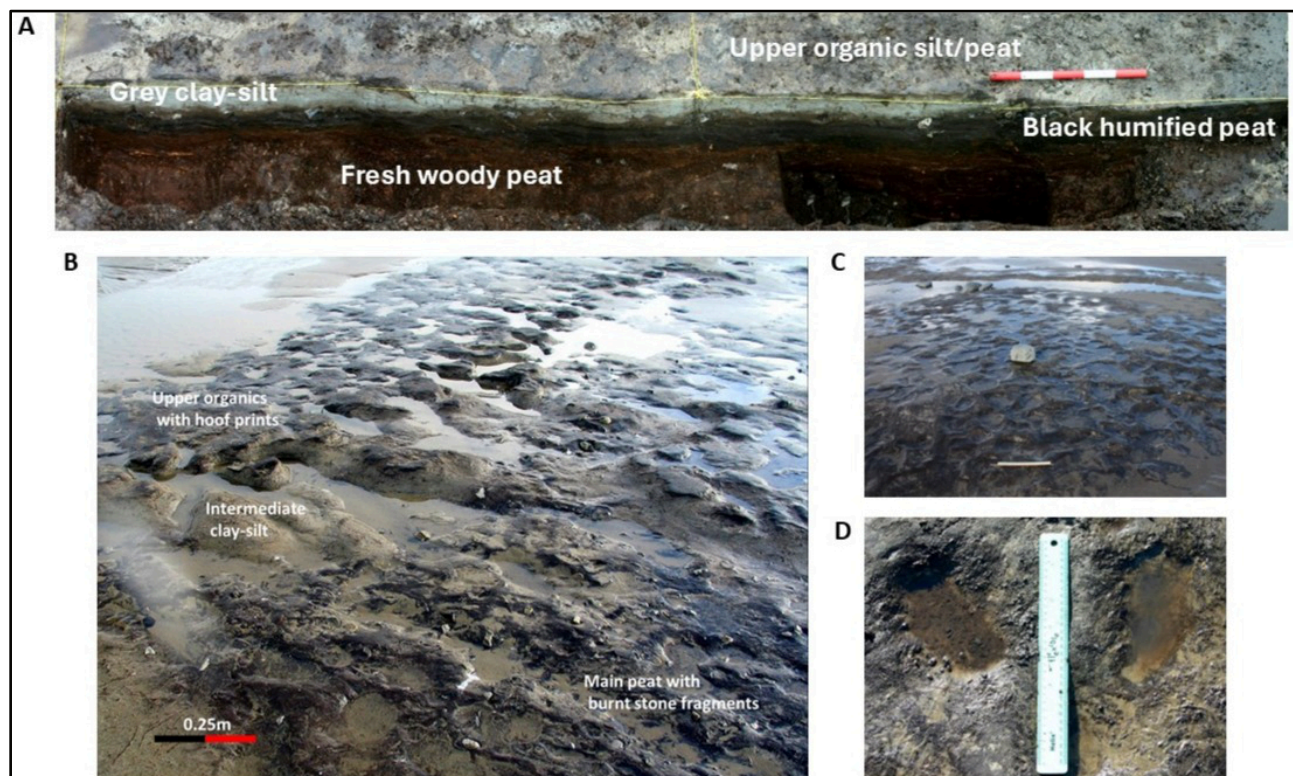


Figure 7: A - Test pit through sediments at BB/12; B - Main peat horizon with burnt stone fragments overlain by clay silts and upper organic silt with hoof prints; C - Upper organic silts with extensive hoofprints; D - juvenile footprints

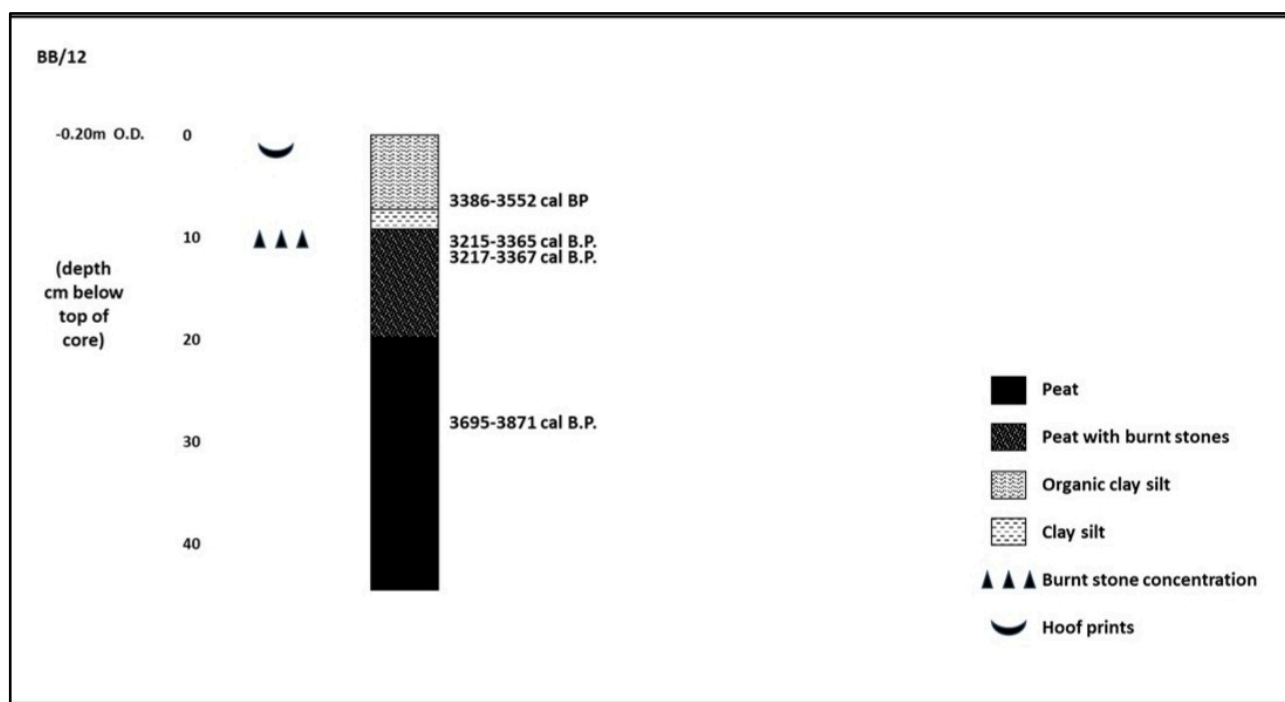


Figure 8: Schematic section through peats and organic silts at BB/12

sequences overlying the main forest horizon at the southern end of the beach.

The date of the peats in this trench are shown in Figure 8 where stratigraphic conformity and increased age are noted in the basal three 14C determinations. However, the uppermost date from the upper organic silts with the hoof prints in it appears to be reversed. This might be a function of disturbance of the uppermost organic sediments by bioturbation. In this case the top of the main peat with the associated burnt stone scatters in it dates to between 3215 and 3365 cal BP, or the end of the Early Bronze Age (Table 2, BOR, BB/12 dates).

Sediments preserved in the vicinity of Cambrian Terrace (Figure 3B) exhibit significantly different characteristics to those to the south of this and those further north. Storm damage and erosion experienced during the winters since 2013 have revealed that rather than a well-developed woody peat overlying the Scrobicularia Clays (as seen in Borth South) the peats here are thin or even absent. Instead, very well laminated silty sands are present overlain by thin peats (Figure 9A). However, this area, dominated by well laminated silts and sands, is bounded to the north by the reappearance of well-preserved wood with extensive tree remains (Figure 9B), the latter trending from south-west to north-east across the beach (Figure 3B). Immediately to the south of this isolated blocks of sediment survive (Figure 9C) that exhibit cross bedded structures in which particulate peat forms the sediment matrix. These features appear to be large bar forms in a tidal channel and are unlike any others recorded elsewhere on the beach. This appears to indicate the presence of a channel-like feature here, which cuts through, or is contemporary with the main peat forest at this point in the sequence, but with a sharp erosional edge

to the north. Some reworking of the older peat into this system appears to have taken place (Figure 9C).

This channel-like feature produced a significant find in Spring 2016 when a set of red deer antlers (Figure 10A-C) were found lying within the laminated clays described above. These were found adjacent to BH 7-5-16 (Figure 11) and were lying upside down in the clays (Figure 10A/B (see below)).

A second borehole, BH 7-5-16 (Figure 11), was drilled within the channel area adjacent to the location at which the red deer antlers were recovered. The sediments here consisted of a sequence of laminated sands and silts lying beneath 0.3m of reed peat. Bedrock or gravel was not attained in this borehole. Although no dates are available on the sediments themselves, the antlers have been dated by 14C dating to 2940 ± 30 BP (2968-3206 cal BP) dating this to the beginning of the Late Bronze Age (Table 2, Borth red deer antler).

North of Cambrian Terrace (Figure 2A) the complex nature of the peat formation can be seen. Here many of the trees are rooted into peat and, when preserved, the fallen trunks are also buried by peat without trees. This uppermost peat was almost certainly forming under conditions quite different to that of the forest peat, and a more open scrub grassland with isolated trees appears likely.

Sequences at Ynyslas Turn (SN 60434 92544 - 60556 93357) (Figure 12)

The northernmost extensive exposures of peat seen in recent times have come from close to the Ynyslas road turn (Figure 1B/12). Particularly noticeable in this area are the sinuous peat-filled forms that are clearly seen from the air (Figures 12A/B). These are typically 2-3m wide and exhibit a gentle

depression in the middle of the peat. The features are clearly channels associated with the underlying clay-silts into which the peat has subsequently subsided. Interestingly these features are often associated with extensive sets of animal hoof prints (Figure 12C/D), and this contrasts with an absence of prints in the adjacent areas of peat which are devoid of any channel-like features. The orientation of the hoof prints is also informative; the majority of these prints are orientated perpendicular to the axis of the channel, or else facing towards the centre of the channel and concentrated along either edge. This may imply that these features retained water in them during the lifespan of the forest and that they represent places at which the animals came to drink.

Further to the north (Figure 1B/3B/13) recent fieldwork has demonstrated the existence of a complex sequence of deposits unlike those present to south. The peat can be traced northwards from the area around Ynyslas Turn as far as the bedrock high at the northern end of the golf course (SN 60646 29973) (Figure 13) where the peat thins and is cut by a major channel complex.

Immediately to the south of this channel complex erosion has created a gully through the peat (Figure 14A) within which the peat is exposed and an extensive scatter of burnt beach pebbles composed of local rock was noted (YNS, Site 1) (Figure 14B/C; Figure 15). This is possibly the same scatter of burnt material noted by Heyworth in 1985. This scatter of burnt material lies some 30cm beneath the top of the peat shelf in this part of the beach, while here scatters of burnt beach pebbles are present throughout the top 30cm of peat in the area around the gully. Radiocarbon dating of the burnt wood indicates that this horizon dates to 5321-

5571 cal BP (Table 2, Figure 15), or the Early Neolithic. However, the top of the peat, which is still associated with scatters of burnt stone, has provided a date here of 3781-4058 cal BP *ie* the Early Bronze Age.

Moving north from YNS, Site 1 the peat thins and becomes organic silt until it is cut by a major channel cutting across the beach (Figure 13, Main Channel). On the south side of this channel hoofprints are common (Figure 16A/B). The channel here is filled with bedded silts with occasional shell beds. The northern margin of this channel (Figure 16C) clearly cuts the older silt deposits. This can be traced northwards where there appear to be at least two or more generations of similar channels (Figure 13). Faunal material (of cattle, sheep, dog) is present in these channels (SF 1-5, and 11). Two of the faunal remains have been dated (SF 2 and 4) to 2070-2312 cal BP *ie* the Iron Age (Table 2).

Further north it becomes more difficult to map individual channels and the sediments take on the appearance of well bedded sub-horizontal sediments interbedded with extensive shell beds (Figure 17A and B). Within these sequences, many of which are quite extensively gullied by erosion, faunal remains are once again present, although here the fauna is dominated by red deer. Dates from the shell beds fall within the range of 4416-5325 cal BP and 3865-4800 cal BP (YNS SB 1 and 2) *ie* Middle to Late Neolithic, whilst the date on the red deer antler SF 103 is 5053-5443 (Early Neolithic).

Thus at least two of the channelling events appear to be present in this area with deposition taking place during the Early to Middle Neolithic and then again in the Iron Age.

Finally, a new, deep borehole was drilled inland of the dune complex at YNS BH 2 (Figure 1B). This sequence of



Figure 9: A - well laminated clay silts in tidal channel at Borth Central; B - northern edge of tidal channel at Borth Central; C - block of chaotic sediments in tidal channel

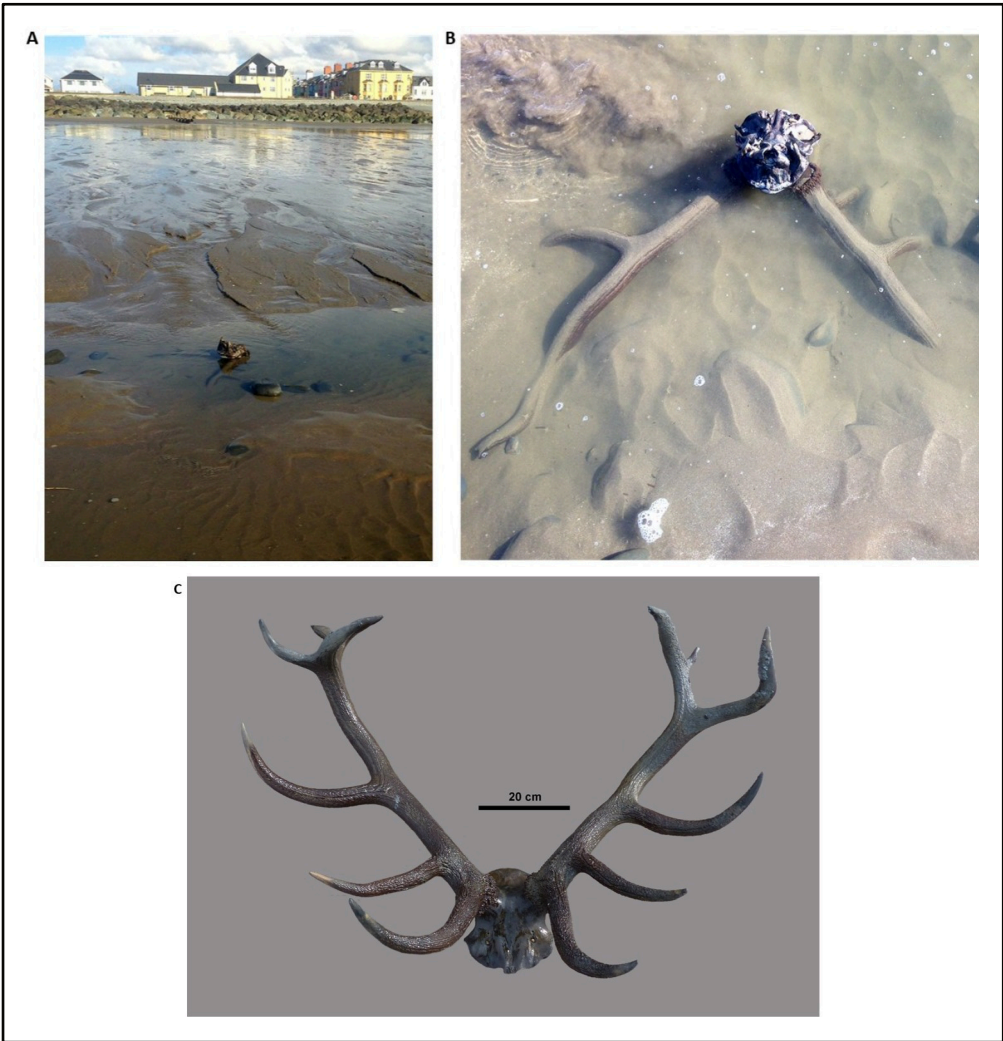


Figure 10: A - Red deer antlers in tidal channel at Borth Central; B - Close up of red deer antlers; C - Cleaned red deer antlers (photographs A and B by Julien Culham)

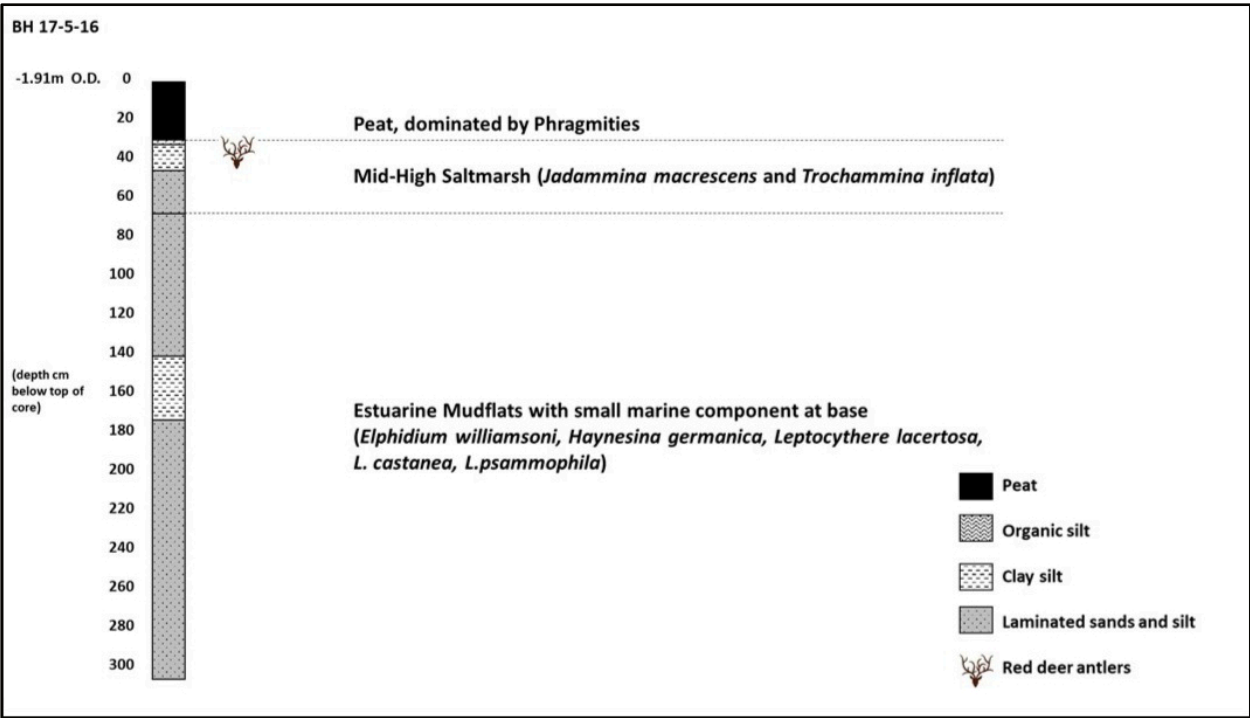


Figure 11: Lithology and ecological zones based on microfossil data from BH 17-5-16

24.2m depth recovered a sequence of sands resting on peat at a depth of 3m below ground surface. These sands are likely to be the equivalent of the dune sands seen around the Ynyslas area. Dating the top of the peat here to between 925 and 1050 cal BP would suggest that sand deposition post-dates the later Early Medieval period. The onset of sedimentation in the Dyfi appears to have taken place during the Late Pleistocene on the basis of the dates obtained from the bases of the borehole here.

Palaeontology

Micropalaeontology (AD/JW)

A total of 62 samples were examined from three boreholes (ABH 2, BH 7-5-16 and YNS BH2). Each sample was oven dried and following drying combined with a teaspoon of sodium carbonate and mixed to a slurry with hot water. Samples were then left to soak overnight. Samples were then washed with hot water through a 75-micron sieve and the residue dried. For most samples the residues from the >500 μ , >250 μ and >150 μ fractions were picked. Recording of the foraminiferal and ostracod species was semi-quantitative for boreholes ABH 2 and BH 7-5-16 (Figures 19 and 20) but quantitative data is also present for borehole YNS BH 2 (Table 3). The ecological preferences of the

microfaunas are based on the work of Murray (2006) for the foraminifera, and Athersuch *et al* (1989) and Meisch (2000) for the brackish/marine and freshwater ostracods, respectively.

Ecological reconstruction from borehole ABH 2 (Figure 19) spans the full depth of sediments sampled to rockhead (Figure 6). The microfossils clearly document a basal sequence characterised by brackish mudflats and salt marsh with large numbers of the agglutinating saltmarsh foraminifera *Trochammina inflata* and *Jadammina macrescens*. This gives way upwards to estuarine mudflat conditions in which *T. inflata* and *J. macrescens* disappear to be replaced by the calcareous foraminifera *Haynesina germanica*, *Elphidium williamsoni*, *Quinqueloculina sp.* (small), the ostracods *Leptocythere lacertosa* and *Leptocythere castanea* as well as a small number of outer estuarine foraminifera and ostracods. Above 6.1m upper salt marsh forms return while brackish and marine forms continue to be present until 2.7m when outer estuarine forms disappear. Finally brackish types begin declining in numbers leaving only high saltmarsh forms by 1.6m. This pattern clearly indicates a cyclical sequence initially becoming increasingly influenced by marine conditions and subsequently marine conditions, finally waning towards the top of the sequence.

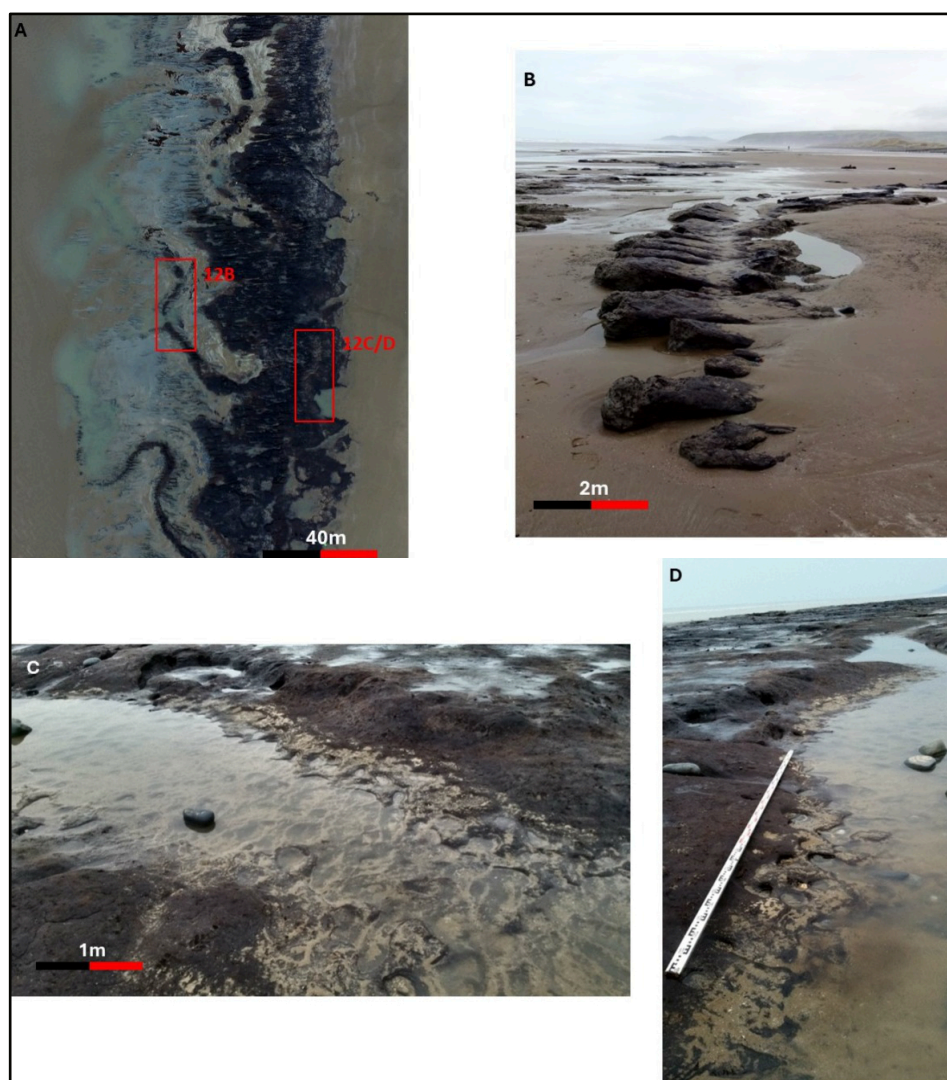


Figure 12: A - Peat filled channel morphology near to Ynyslas Turn; B - close up of peat filled channel in underlying *Scrobicularia* Clays; C - Hoofprints in channels; D - Close up of hoofprints along channel margin

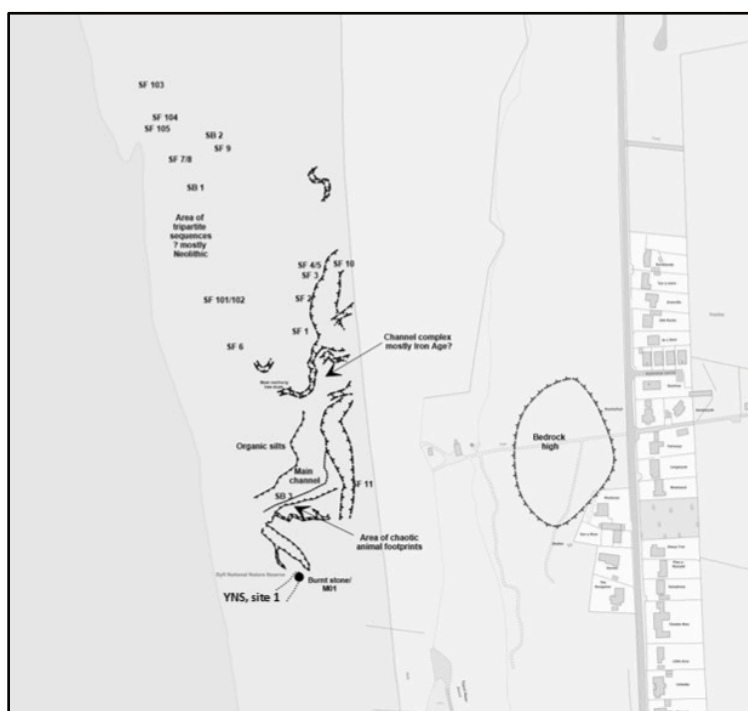


Figure 13: Location plan for Ynyslas site area observations



Figure 14: A - Eroded gully into peat (YNS, site 1) near northern margin of peat; B - Burnt stones in peat at YNS, Site 1; C - excavated burnt stone scatter

A shallow sequence of sediments was sampled in BH 7-5-16 (Figures 11 and 20), adjacent to the site of the red deer antlers, where a considerable depth of sediment remained unsampled to bedrock (Figure 5). In this borehole the basal samples contained saltmarsh, brackish and marine forms but with marine forms disappearing about 1.90m leaving only salt marsh and mudflat faunas. All brackish mudflat forms disappeared above 1.25m leaving only the upper saltmarsh forms *T. inflata* and *J. macrescens* at the top of the sequence. This pattern clearly documents regressive trends in which upper saltmarsh environments are dominant by the time the red deer antlers were incorporated into the sequence.

In contrast a longer sequence of sediments was sampled in borehole YNS BH 2 where the ostracod and foraminifera assemblages from 24.2-23.2m below ground level were characteristic of a relatively sheltered middle to outer estuarine locality. The abundance of brackish foraminifera was constant, suggesting a relatively stable environment was present during this time, shortly after the initial transgression of the Dyfi. The frequency of the Miliolidae family attested to a littoral environment situated fairly close to the estuary mouth and point to turbid conditions and weed growth. Dominant littoral ostracod species included *Hirschmannia viridis*, *Hemicythere villosa* and *Semicytherura nigrescens*, which also suggest that the sample site was situated fairly close to the estuary mouth. There was also a persistent presence of *Leptocythere castanea*, including juveniles and this species is exclusively found in brackish water in estuaries and is usually found on mud and algae. This signifies that the locality was likely to have been brackish in nature and situated perhaps closer to the middle reaches of the estuary. Taxa such as *Callistocythere littoralis*, *Palmoconcha laevata* and *Ammonia batavus* derive from littoral and sublittoral marine environments and were therefore likely swept into the sample site via tidal action. Samples from 17.52 to 12.5m contained less well-preserved ostracod assemblages and therefore provide less reliable data. However, the study results reflect a similar environment to the samples from 24.2-23.2m below ground level and therefore indicate continuity in the environments of deposition.

Samples from 10.6 to 9.38m below ground level preserved the highest abundances of brackish foraminifera

and ostracods from BH2. The species *Leptocythere lacertosa* and *Leptocythere castanea* characterise the presence of brackish tidal mudflats with algae. Meanwhile the presence of *Leptocythere porcellanea* points to the sample site being located within a sheltered creek system. The combined evidence of the brackish water species coupled with the frequency of outer estuarine/ marine taxa, suggests that these samples characterise mudflats situated within the outer limits of a sheltered creek system.

Samples 6.5-6.52 and 7.5-7.52 exhibited poor preservation of ostracods, however the foraminifera were suggestive of a continued sheltered brackish water environment. The brackish taxa *Ammonia beccarii*, *Haynesina germanica* and *Elphidium williamsoni* were abundant. *Trochammina inflata*, *Miliammina fusca* and *Jadammina macrescens* were commonly found from 3.86-5.62m below ground level, they are able to withstand extreme environmental variability and characterise a high salt marsh habitat. This suggests that a shift in environmental conditions occurred and that the location became exposed above mean high water.

Vertebrates (RC)

Faunal remains from the beach at Ynyslas consists of two groups. The first is of contextualised vertebrate remains recovered under controlled excavation (Table 4) and the second of decontextualised bones recovered as surface finds. Typically, the latter consist of isolated bones heavily stained but not necessarily of great antiquity. For example, isolated cattle limb bones with clear evidence of modern butchery are known from the surface collections that made by members of the public from the beach where the find context is vague. The animal bones in both groups consist of common species, mostly of red deer, but also domestic species, such as, cattle, dog and horse. Occasionally finds also include marine remains such as seal and fish. Also to note are the remains of an aurochs which was recovered and described historically (Taylor 1973, 1984). This discovery, from the foreshore near Cambrian Terrace, has unfortunately been lost since the mid 1970s. It is the excavated bones and those identified to a species that are considered in more detail here (Table 4).

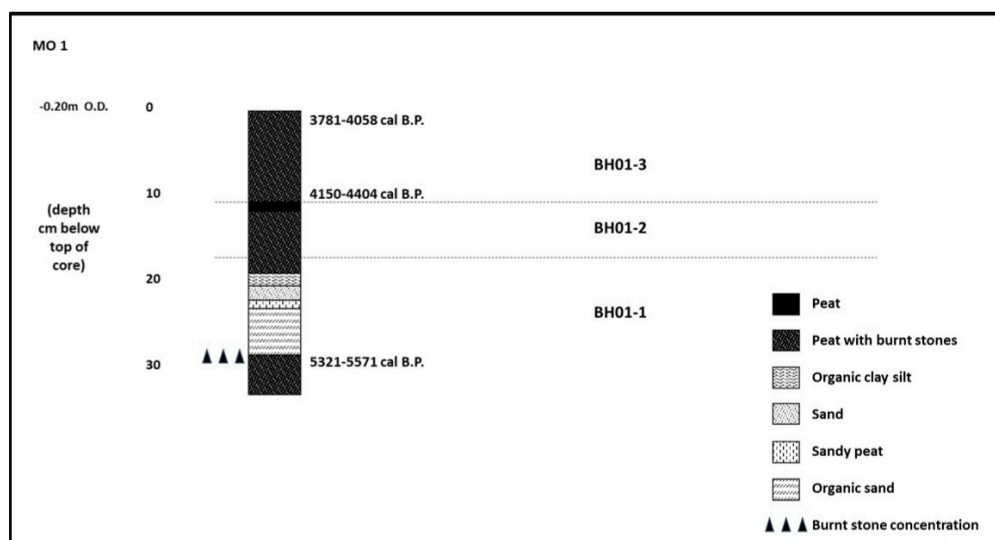


Figure 15: Schematic section through peats and organic sands at YNS, Site 1

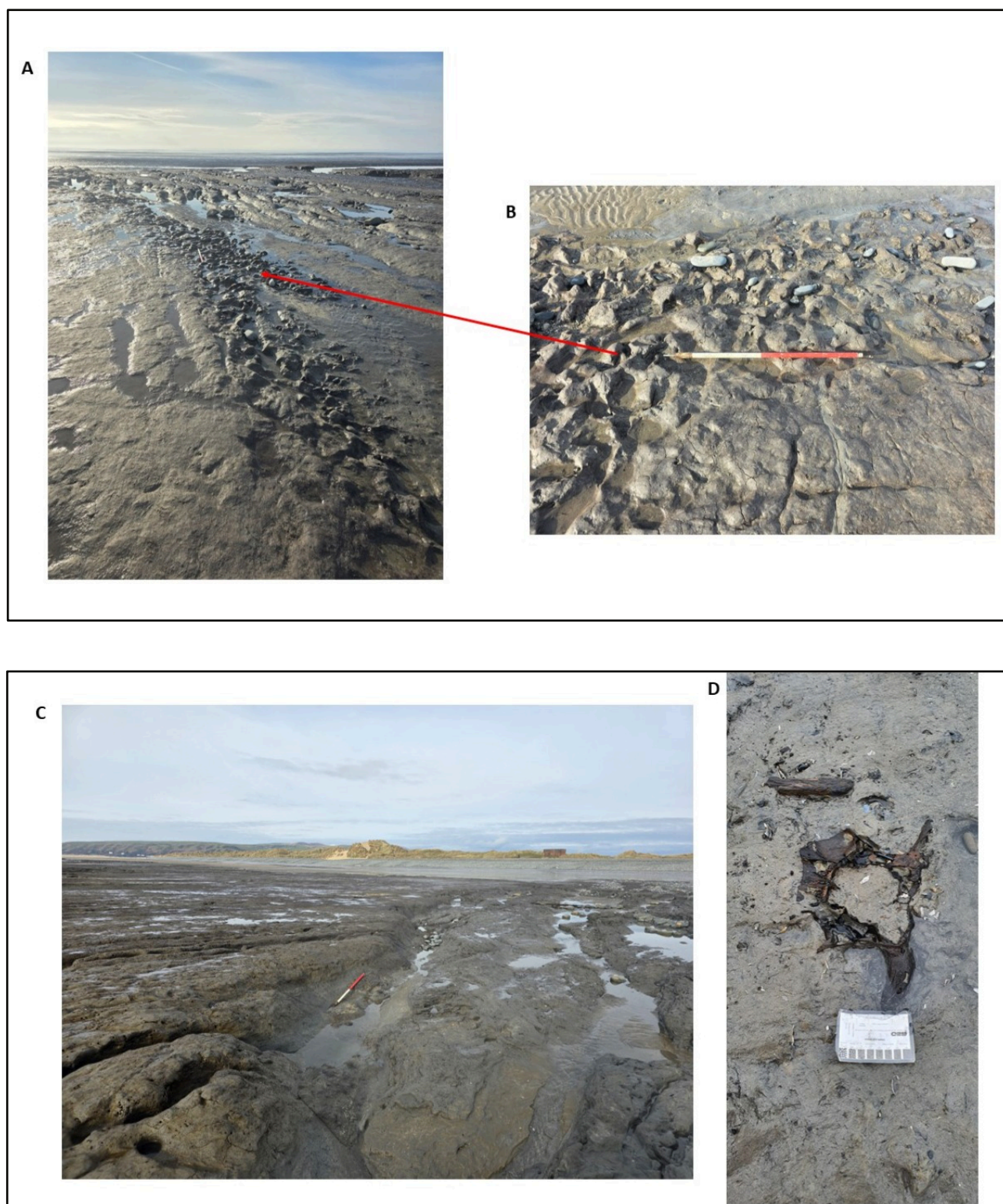


Figure 16: A - Southern boundary of Channel Complex showing hoofprints on channel edge; B - Close up of heavily trampled area on edge of channel; C - Northern edge of Channel Complex; D - Bos sp. skull in tidal Channel Complex



Figure 17: A - Bedded clays and sands with shell beds north of Channel Complex; B - Laminated silts and clays north of Channel Complex; C - Red deer antler fragments eroding out of laminated silts and clays north of Channel Complex; D - close up of red deer antler fragments (SF 7); E - Red deer prints in muddy organic sediment

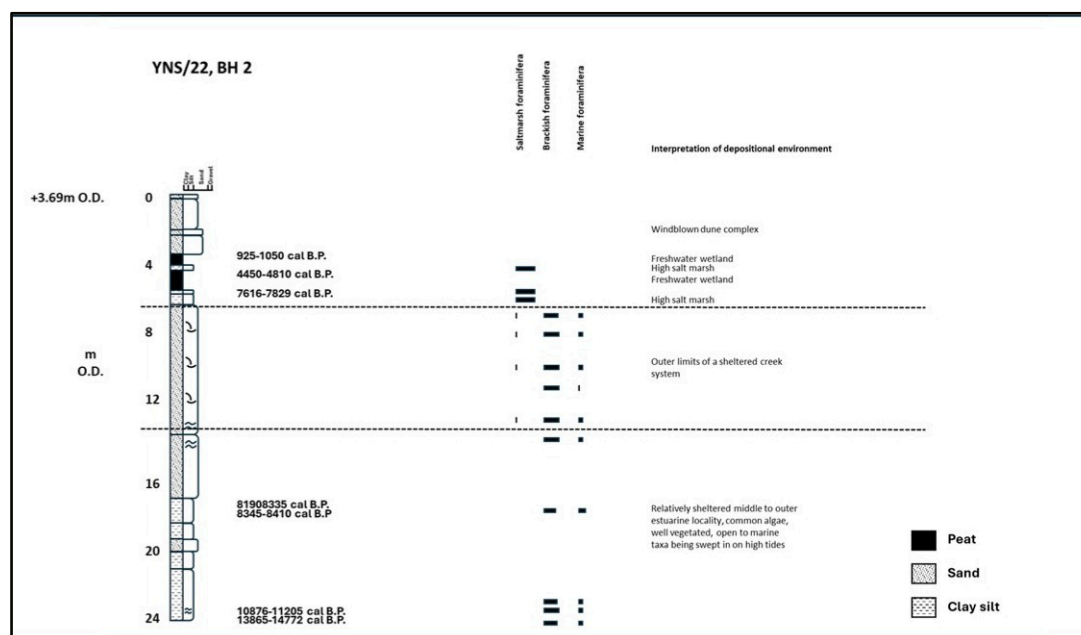


Figure 18: Lithology and ecological zones for borehole YNS/22, BH 2

The bone surface texture of all the excavated bone is good, and all of this derives from the Ynyslas area (Figure 13). The dominant species is red deer, comprising 57% of the assemblage ($N=8$), whilst cattle and dog are represented by 2 individuals (14% of the assemblage each), with horse and fish consisting just of a single individuals. Although we are not dealing with large numbers here, the dominance of red deer and specifically antler is note-worthy. Also worthy of note is the modification (evidence of cuts) to some of the red deer bone and antler

The first securely contextualised vertebrate material to be examined was a pair of red deer antlers discovered in April 2016 within the laminated sands and silts of a large tidal channel (Figures 9 and 10) opposite Cambrian Terrace (Figure 3B). The antlers were upside down with the top of the antlers facing seawards (Figures 10 A and B). The antlers are from a mature adult male with seven tines (an 'Imperial Stag') (Figure 10C). The animal died during a late summer/winter season as the antlers are already full grown and unshed. The antlers themselves are complete and remarkably well preserved. They remain largely unscathed by erosion, although some evidence of surface pitting, caused most probably by pebbles and stones hitting them, is evident. The remarkable levels of preservation, good surface detail and lack of deterioration suggest a relatively short period of re-exposure, this being true for all of the excavated material. In terms of other taphonomic signatures there is no evidence here of cut marks or other human modification to the antler tines. The dimensions of the Borth antler set are presented in Table 5. They are the largest within this collection and larger than those dredged up from the seabed in a fishing net north of Aberdyfi (Borth 92:241H, National Museum Cardiff). The measurements confirm the impression that this animal was an impressive individual. Radiocarbon dating of the Borth antler has produced a single age estimate of 2940 ± 30 BP (2968-3206 cal BP, the Late Bronze Age (Table 2)). All the other antlers found are

single, shed and fragmented to varying degrees. The shed antler YNS/23-SF103 produced a date of 4570 ± 30 BP (3317-3494 cal BC /5267-5444 cal BP) *ie* towards the end of Early Neolithic, indicating much earlier periods of use and exploitation, and a possible permanence of the red deer habitation within this area. Other anecdotal stories regarding deer remains from here include a pair of antlers held at the Primary School in Borth, their current whereabouts unknown.

The collection of shed antlers is of interest. All derive from the laminated sands and silts, which lie to the north of the peat deposits, within active tidal channels that often contain shelly lag gravels (Figure 17A-C). These indicate a population of male deer once their antlers are shed, at any time between late winter and early spring. Of interest is the fact that out of the six shed antlers that can be attributed to a specific side, four are from the right. The other two cannot be determined with confidence at this stage. Antler YNS/23-SF103 (Figure 21A/B) shows some modification in the form of a clear and clean transverse cut to the antler, but also the presence of several longitudinal, parallel striations. Although these latter taphonomic features may be suggestive of cutmarks, other causes are plausible. The clean transverse cut through the antler (Figure 21B) can only be a human modification and under a low-powered microscope the sawing action is visible. Modification to antler YNS-24/SF8 is less certain. Highly visible striations are evident on one side of the tine, consisting of broad, multi-directional grooves of varying length. Some striations do run parallel and form semi-consistent patterns of movement. A series of smaller clustered unidirectional striations, also running parallel, are evident on the converse side.

The other notable cut marked bone, YNS-23/SF102, is a juvenile pelvic bone most likely of red deer (Figure 21C/D). This fragment of ilium has two clearly marked parallel striations that are unidirectional and a third striation also running parallel which is much shorter. These clustered striations are suggestive of disarticulating and butchery. One striation shows a parallel groove within the cut mark, suggestive of stone tool use.

The dog crania are remarkably similar in both looks and size and could easily be from a similar breed. Although the measurements do not distinguish one being larger than the other (Table 6), one difference is that the sagittal crest on YNS/25-SF11 is slightly more marked running the full length of the neurocranium. In YNS/20-SF2 the sagittal crest reverts to being more of a ridge in the mid-cranium. This difference is most likely related to masticatory function and bite force, rather than to breed. Only three teeth remain in YNS/20-SF2 of which the cusps show some rounding, suggesting that it was not the youngest dog at the time of death. With a cephalic index of 56.7 this would make the dog mesocephalic. With the similarity of the neurocranial

measurements the same could be inferred for the YNS/25-SF11 dog.

Trace fossils in the form of footprints are also present from several animals, mostly cattle, red deer and very rarely aurochs, which are all readily identifiable (Figure 7C). Footprints of humans, certainly of child size, are also preserved. Figure 7D shows the left and right imprint of a single individual, in close association with animal prints. It suggests an individual in a standing pose. The animal footprints are generally isolated, meaning they do not easily relate to each other as in a fossilised footprint trail. The pattern is one of intermingling, of animals milling around (Figure 7C,) possibly grazing or drinking at freshwater channels (Figure 16A/B).

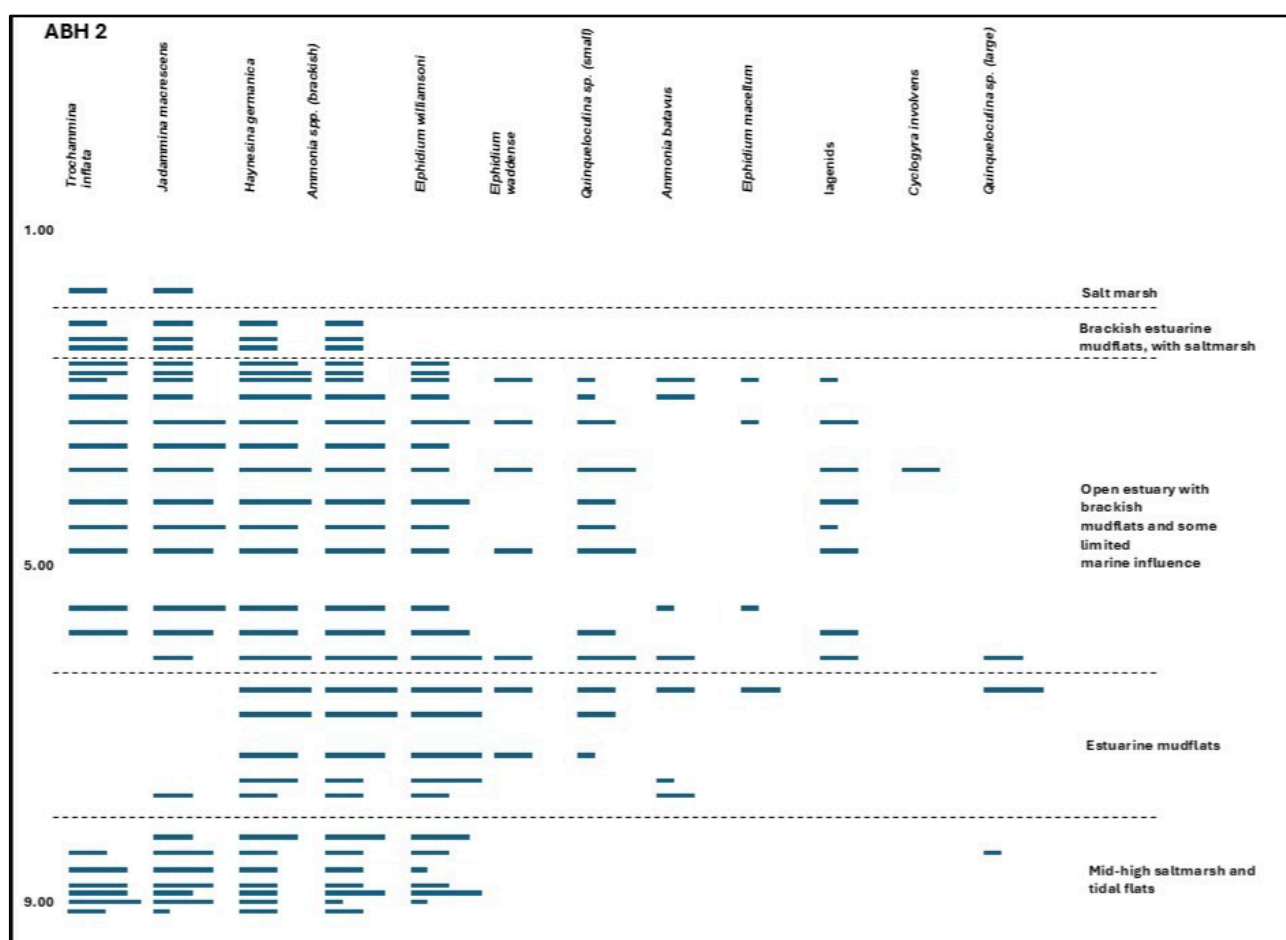


Figure 19: Chart for microfossils from borehole ABH 2

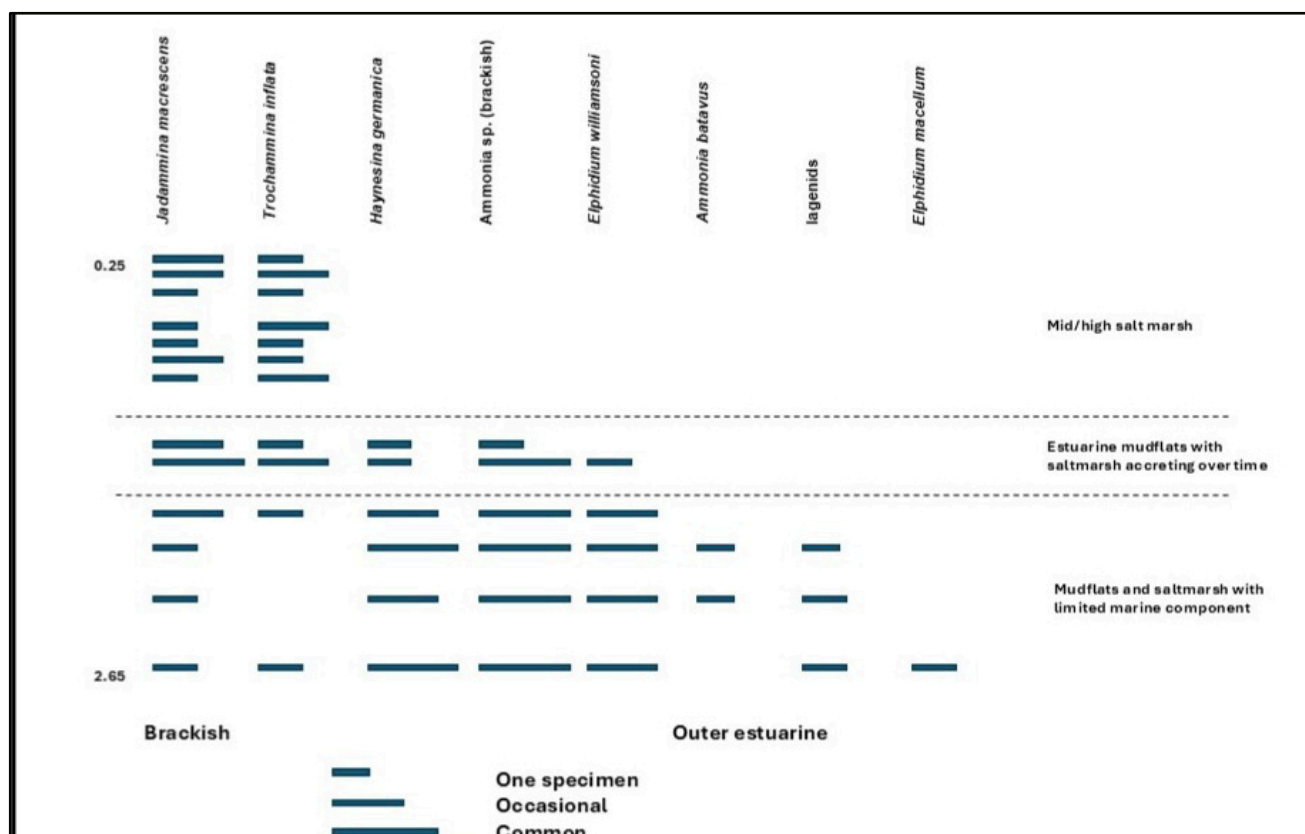


Figure 20: Chart for microfossils from borehole BH 17-5-16

Animal footprints identifiable as cattle fall in the range of 9-10.5cm in both width and length. One imprint is indicative of aurochs, and is preserved as a plaster cast. The footprint is virtually identical to that of the smaller cattle except for its size. Here the width is 14.5cm and the length 15.5cm making them half as big again as the cattle. The distinctive cloven imprints of red deer (Figure 17E) are also identifiable by their size (c6.0-7.5cm). The cleaves are not always sharply defined but are more rounded at the back of the cleave and symmetrically curved towards the tip. With these dimensions the red deer footprints fall into the size of some modern populations (Hows *et al* 2016), yet are shorter in length than the largest red deer recorded at the Mesolithic site of Goldcliff East (Scales 2006). Plaster casts of a small number of these prints have been taken as a more permanent record. The footprints are preserved to varying degrees, depending mostly on how long they have been re-exposed, as these erode very quickly.

Pollen

Pollen from the base of monolith M01 (Table 7, Figure 22) from YNS, Site 1 (Figures 13 and 15), was taken from the sediments resting immediately above the excavated area of burnt stone. These exhibit equal proportions of Arboreal Pollen (AP) to Non-Arboreal Pollen (NAP), with high levels of *Alnus glutinosa* (alder) and *Poaceae* (grasses). *Ulmus* (elm) and *Quercus* (oak) pollen are high at the base of BM01, with similarly high levels of microcharcoal and total pollen concentrations. Within pollen zone BM01-1 there is evidence of a possible elm decline at c26.75cm depth. The stratigraphy of the core changes from peat to sandy sediments within this zone, and this may influence the

pollen deposition mechanisms, with the sandy sediments more likely to include the secondary deposition of pollen grains.

Pollen zone BM01-2 sees a significant increase in woodland percentages. It is possible that both stratigraphic changes and pollen deposition mechanisms might account for this increase. However, the change to peat sediments coinciding with the start of this zone indicates that pollen deposition is less likely to be as strongly influenced by alluvial mechanisms. *Alnus* (alder) pollen is so high in this zone that it is likely that local conditions resemble alder carr woodland. This apparent increase in woodland cover may by itself account for the decreased values in anthropogenic indicators in this zone, this either causing a filtration effect to block other taxa reaching the site, or alternatively the exceedingly high pollen productivity (*cf* Broström *et al* 2008) is swamping the pollen record with alder pollen to the extent that other taxa hardly register within the total pollen count. Given that there seems to be a reduction in anthropogenic indicators (*eg* Cereal-type, *Plantago lanceolata*, *Rumex acetosa* and microcharcoal concentrations) the development of alder carr woodland might in itself be indicative of localised changes in drainage or climate change impacting the intensity of human activities in the surrounding area. This would seem to be supported by the stabilisation of peat accumulation in the core. Exceptionally high woodland percentages are likewise recorded by Mighall *et al* (2017) at Borth Bog during this same period, but that woodland was more mixed and deciduous in nature, containing more *Corylus* and *Quercus* pollen in comparison to *Alnus*.

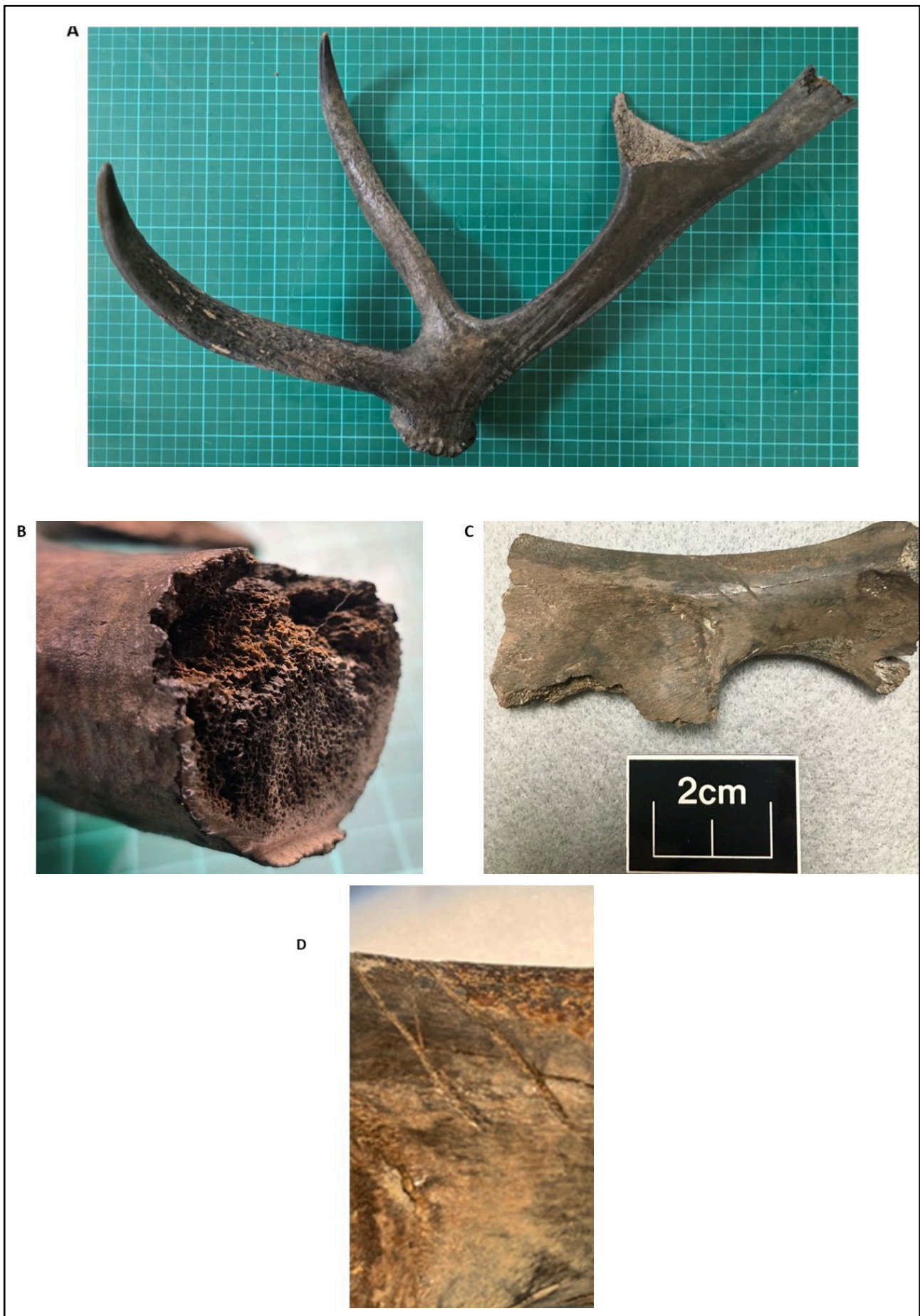


Figure 21: A - SF 103 Red deer antlers; B - Sawn end of tine SF 103; C - Red deer pelvis with cut marks; D - closeup of cut marks on red deer pelvis

From 10.5m the chronological framework and palaeoenvironmental record of the core is supported by radiocarbon dating, and this has been dated to the Late Neolithic or start of the Bronze Age. The pollen evidence shows woodland decline changing to increasingly open conditions, therefore declining *Pinus* (pine) pollen percentages and a similar gradual increase in Poaceae and Cyperaceae pollen. A slight increase in the *Corylus avellana*-type pollen, Ericaceae and other herbs are also seen, including Cereal-type, Chenopodiaceae, *Plantago lanceolata* and *Rumex acetosa*. A spike in *Plantago maritima* is also observed alongside a spike in Polypodium, increased Sphagnum spores and microcharcoal. It is difficult to determine whether the increase in disturbance indicators such as Cereal-type, *Plantago lanceolata*, *Rumex acetosa* pollen and microcharcoal concentrations are the cause of the increased open conditions, or whether there is a higher influx of these taxa as a result of anthropogenic influence. Both arable and pastoral indicators appear to recover to levels observed in the lowest part of the core, possibly indicating that localised activities by humans are occurring at similar intensities. The increase in wetland indicators such as Cyperaceae and Sphagnum occur in combination with elevated percentages of taxa associated with coastal wetlands (eg Chenopodiaceae, *Plantago maritima*), which may suggest that the increase in open conditions might relate to coastal inundation which occurred towards the end of the Early Bronze Age.

Discussion

Combining the disparate sets of data currently available enables us to clarify the environmental history of the Borth to Ynyslas sector of the Dyfi estuary with a degree of precision previously lacking. Furthermore, for the first time we can document with certainty a human presence in the area from at least the Early Neolithic through to the Iron Age. Our new data allows us to make the following observations (Figure 24):

- The onset of brackish/marine sedimentation in the Dyfi appears to have happened before the start of the Holocene, within the Late-glacial Interstadial (Table 2, Figure 24), as indicated by dates from the basal part of YNS BH 2 (Figure 18). However, there is nothing in the microfossil evidence from the base of the borehole (Table 3) to show that conditions were colder than at present during this event, so it remains to be determined exactly when this flooding took place. Certainly marine waters were present in the Dyfi at the start of the Holocene when Mesolithic people are likely to have been present in the area.
- The geophysical data (Figure 4) combined with the borehole and CPT evidence (Figure 5) clearly documents the northward dipping buried late Pleistocene surface upon which the Holocene sedimentation subsequently took place. This would suggest that dryland contexts, possibly utilised by Late Palaeolithic or Early Mesolithic peoples, would have existed in the base of the valley adjacent to the areas initially flooded by marine waters.
- The sedimentary data from the boreholes and the CPT data which document shifting environments between tidal mudflats and sand dominated channels finds some support in the microfossil data, although precise correlation between microfossil evidence and lithology is hampered by the poor sampling resolution of the sequences. Microfossil data from ABH 2 (Figure 19) documents a shift from saltmarsh to tidal flat/marine influenced environments followed by a return to saltmarsh environments prior to c6000 years ago during the Mesolithic period (Figure 24). Similar patterns were also observed in YNS BH 2 (Figure 18, Table 3). The evidence from ABH 2 suggests that saltmarshes fringed the estuary in Borth South, whilst more active estuarine conditions are documented by the microfossil evidence recovered from boreholes to the north (including historical ones: see Adams 1963; Adams & Haynes 1965; Hayes & Dobson 1969).
- The onset of peat formation across much of the study area appears to have commenced around 6000 years ago (Table 2, Figure 24), but the cessation of peat formation varies across space. Understanding the cessation of peat formation in the context of the modern foreshore sequences is problematic as we cannot be sure exactly how much erosion of the upper parts of the peat formation may have taken place. In borehole YNS BH 2 the top of the peat has been dated to the end of the Early Medieval period and consequently we must assume that the upper parts of the peat formation are missing from the intertidal zone today.
- The peat is not continuous from north to south and fossilized trees are only present in certain places in the intertidal zone. For example trees are scarce at the southern end of the beach (Borth South), and are absent in Borth Central, where a major channel feature adjacent to Cambrian Terrace exists. However, trees are common from the northern edge of this channel northwards to the car park at Ynyslas Turn, beyond which trees are rare. At Ynyslas to the north the peat disappears altogether and a series of tidal channels replace it (Figures 13,22 and 24).
- The presence of the channel in Borth Central, in which the red deer antlers were dated to between 2968 and 3206 cal BP is important. The latter find suggests the presence of a long-standing tidal channel within the peat landscape at this point (as evidenced also from the microfossils). Meanwhile the identification of a channel adjacent to Cambrian Terrace is significant because it might help contextualise previously discovered faunal remains from this area, such as the aurochs discovered in the 1960s (Taylor 1973, 1984). Taylor writing in 1973 suggests: "The discovery in the late autumn of 1968 of most of the post-cranial skeleton of the male bovid, *Bos primigenius*, on Borth beach near point B on Figure 1 (was) in the top of the *Scrobicularia* Clay and just below the eroded peaty surface layer." (Taylor 1973, 286)
- Unfortunately the position of point B referred to on the 1973 map is now difficult to ascertain due its scale, and as a consequence it is impossible to determine precisely where this find was made. In his later account of the find Taylor (1984) suggests that the find was made on the shore opposite the Grand Hotel (also known as Pantyfedwyn Hotel). It seems therefore likely that the find was made in approximately the same position as that of the red deer antlers ie within the channel itself. Thus Taylor's assertion that the find is approximately 6000 years old (being derived from the *Scrobicularia* Clays) is probably erroneous, as we now believe that the upper parts of this channel post-date much of the forest peat, therefore the aurochs are likely to be closer to 3000 rather than 6000 years in age.
- Activity in the peat wetlands is documented by the discovery of burnt stones in the peat at Borth South as

well as by human footprints associated with animal hoofprints at this same location. This has been dated to the end of the Early Bronze Age and might indicate the husbandry of animals in the wetland for grazing, accompanied by juveniles. In the north at Ynyslas the evidence for human activity likewise consists of burnt stone which has been dated to the Early Neolithic, with a persistence of burnt stone in the peat until the Late Neolithic or Early Bronze Age (Figures 23 and 24). We now know that this location in the landscape was close to the edge of the active peatlands, with tidal channels lying to the north of this (Figures 23 and 24). Pollen from the Ynyslas site indicates a possible human impact on the vegetation from at least in the Early Neolithic.

- Tidal channels of Neolithic date are now known to exist towards the north end of the Ynyslas site, with dates on both red deer antlers and shell beds confirming this (Figures 23 and 24). Human modification to the red deer remains is evidenced by the cut marks present on a red deer pelvis and the cutting of one set of antlers. Therefore human activity associated with the burning of stones appears to have taken place on the edge of an active estuary and this persisted for some time into the Early Bronze Age.
- A later sequence of tidal channels which are Iron Age in date, in which domestic animals were also present is evidenced by a series of radiocarbon dates obtained from the channel complex.

Conclusions

Previous investigations at Borth, Ynyslas and Cors Fochno have all focused on the vegetation history of the bog and the records of climate change. Little work has been undertaken to understand the palaeotopography of the area and in particular the nature of spatial change within the forest, the wetland peats and the underlying Scrobicularia Clays. The

storms of 2012 onwards have allowed the balance between the study of the peat and landscape reconstruction to be revised to take account of the changing nature of the sequences. Thus, for the first time it can be shown that the peats of the forest do not form a continuous presence from north to south along the coast but instead are interrupted by at least one major tidal channel. Furthermore, the simple equation of peat deposits with a submerged forest dating to 4000 - 6000 years old has been shown to be erroneous. Peat formation started with a reed swamp, developing into grassland which continued after the forest decline had begun. In addition the new evidence presented here indicates that the initial marine incursion into the Dyfi valley at around -20.5m AOD occurred towards the end of the Pleistocene. This confirms the notion that at the start of the Holocene the now submerged coastal lowlands of Cardigan Bay were most likely broken up into a series of parcels of low-lying land divided by narrow valleys into which long, sinuous estuaries penetrated many kilometres inland (Bates *et al* in press).

For the first time we are now able to demonstrate human activity within the peat wetland. Although a number of finds are previously recorded in the Dyfed HER, including a Mesolithic composite tool (PRN 30894) and numerous flints (PRN 30907), none of these are adequately published or provenanced, and so they remain an unknown quantity. Here we document and illustrate a number of other new and relevant finds. Whilst the nature of the human activity in Neolithic and Bronze Ages is difficult to ascertain it is clear that there is a persistent presence of humans in the area of the Dyfi estuary edge at Ynyslas for a considerable period, as well as in the south closer to the cliffs during the Bronze Age. This evidence might imply seasonal exploitation of the wetland margin and the use of fire for any associated activities. The recovery of red deer antlers with evidence of human modification might suggest that specialised processing activities were the focus of human activity in this

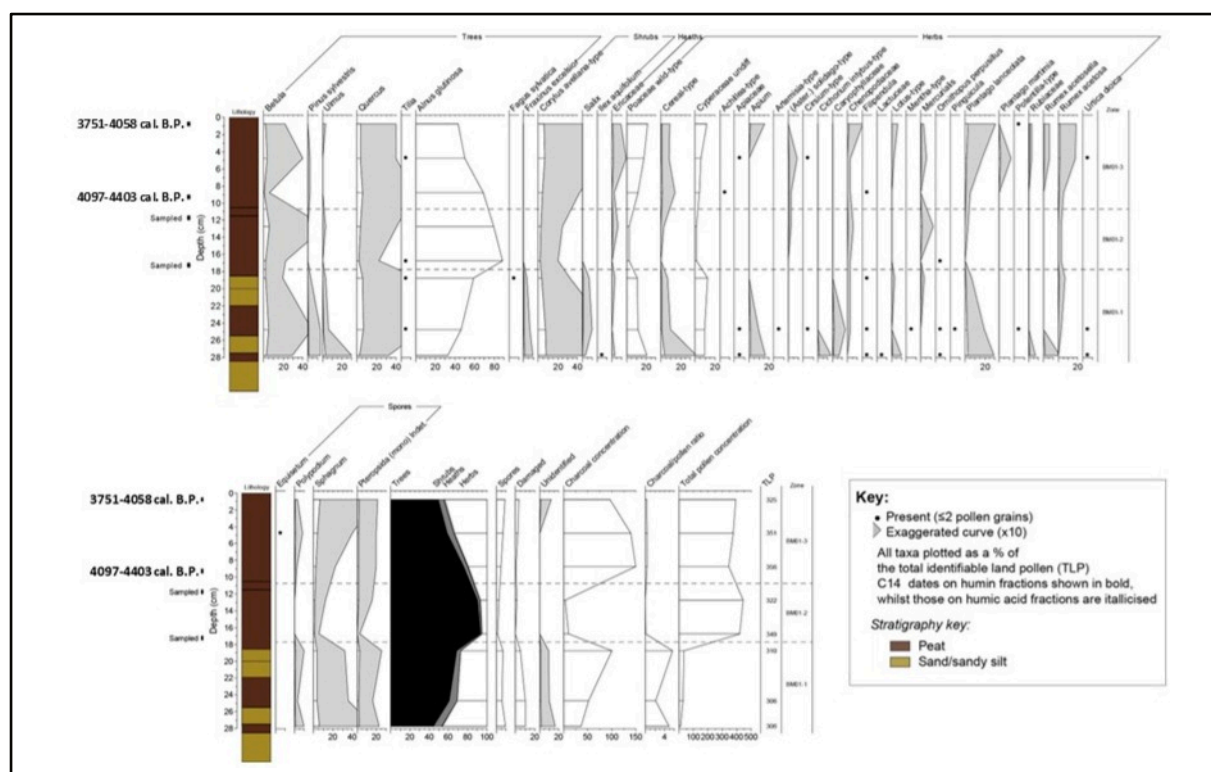


Figure 22: Pollen diagram for M01, YNS, Site 1

area. At the southern end of the peatland area animal husbandry might have been practiced during the Early Bronze Age. However, the evidence for human activity in these wetlands is low. Despite the large areas of fossil forest open for investigation, and the not inconsiderable time spent combing the exposures, evidence for human activity seems quite limited during the Neolithic and Bronze Age, whilst any direct evidence for Iron Age activity is missing altogether (although the presence of domesticated animal remains in the channel complex at Ynyslas is testament to this activity in the Dyfi at this time). This is surprising when comparisons are made to other areas of wetland around the UK where substantial evidence for human activity exists in similar wetland contexts (eg the Severn wetlands (Bell 2007) or the Thames marshes upstream of Dartford (Stafford *et al* 2012; Stasney *et al* 2021)). Perhaps this is a simple function of the availability of exposures for study, alternatively it might reflect real patterns of use in which particular parts of our wetlands are favoured while other parts are shunned. In this context the wetland sequences between Borth and Ynyslas may have seen only minimal use due to factors that are presently opaque to us as researchers.

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References

Adams, TD, 1963, *Holocene foraminifera from the Dovey (Dyfi) estuary and Cardigan Bay* unpublished PhD thesis, University of Wales Aberystwyth.

Adams, TD & Haynes, J, 1965, Foraminifera in Holocene marsh cycles at Borth, Cardiganshire (Wales), *Palaeontology* 8, 27 – 38.

Aikins, A, 1797, *Journal of a tour through North Wales and part of Shropshire with observations in mineralogy and other branches of Natural History*, London.

Ashton, W, 1920, *The evolution of a coast-line. Barrow to Aberystwyth and the Isle of Man. With notes on lost towns, submarine discoveries, &c*, Edward Stanford, London.

Ashton, N, Lewis, SG, De Groote, I de, Duffy, S, Bates, M, Bates, R, Hoare, P, Lewis, M, Parfitt, SA, Peglar, S, Williams, C & Stringer, C, 2014, Hominin footprints from Early Pleistocene deposits at Happisburgh, UK, *PLoS ONE* 9(2): e88329. Doi:10.1371/journal.pone.0088329

Athersuch, J, Horne, DJ & Whittaker, JE 1989, Marine and brackish water ostracods, In DM Kermack & RSK Barnes (eds), *Synopsis of the British Fauna (New Series)* 43, EJ Brill, Leiden (for the Linnean Society of London and The Estuarine and Brackish-water Sciences Association).

Bates, CR & Bates, MR 2016, Palaeogeographic Reconstruction in the Transition Zone: The Role of Geophysical Forward Modelling in Ground Investigation Surveys, *Archaeological Prospection* 23, 311-323.

Bates, MR & Stafford, E, 2013, *Thames Holocene: A geoarchaeological approach to the investigation of the river floodplain for High Speed 1, 1994-2004*, Wessex Archaeology, Salisbury.

Bell, M, 2007, The Mesolithic and Neolithic in the coastal zone of western Britain, In M Bell (ed) *Prehistoric Coastal Communities: The Mesolithic in Western Britain*, CBA Research Report 149, 1-18, York, Council for British Archaeology.

Broström, A, Nielsen, AB, Gaillard, MJ, Hjelle, K, Mazier, F, Binney, H, Bunting, J, Fyfe, R, Meltsov, V, Poska, A & Räsänen, S, 2008, Pollen productivity estimates of key European plant taxa for quantitative reconstruction of past vegetation: a review, *Vegetation history and Archaeobotany* 17(5), 461-478.

Campbell, JA & Baxter, MS, 1979, Radiocarbon measurements on submerged forest floating chronologies, *Nature* 278, 409 – 413.

Campbell, S & Bowen, DQ, 1989, *Quaternary of Wales*, Geological Conservation Review Series, 2, Nature Conservancy Council.

Clark, JGD, 1971, *Excavations at Star Carr: An early Mesolithic site at Seamer near Scarborough, Yorkshire*, Cambridge University Press, Cambridge.

Dyfed Archaeological Trust, 2012, *Dyfed Archaeological Trust Historic Environment Record Information*, Prepared by M Page, Dyfed Archaeological Trust, Produced for Laura Strafford, Search criteria: Details of prehistoric submerged forest/peat deposits recorded in the Dyfed HER, [Compiled 10th August 2012].

EMODnet Bathymetry Consortium, 2016, *EMODnet Digital Bathymetry (DTM)* <http://doi.org/10.12770/c7b53704-999d-4721-b1a3-04ec60c87238>

English Heritage, 2011, *Introduction to Heritage Assets. Burnt Mounds*, English Heritage, London.

Godwin, H, 1943, Coastal peat beds of the British Isles and the North Sea, *Journal of Ecology* 31, 199 – 247.

Godwin, H, 1956, *History of the British Flora*, Cambridge University Press, Cambridge.

Godwin, H & Newton, L, 1938, The submerged forest at Borth and Ynyslas, Cardiganshire, *New Phytologist* 37, 333 – 344.

Godwin, H & Willis, EH, 1961, Cambridge University natural radiocarbon measurements III, *Radiocarbon* 3, 60 – 76.

Haynes, JR & Dobson, MR, 1969, Physiography, foraminifera and sedimentation in the Dovey Estuary (Wales), *Geological Journal* 6, 217-256.

Heyworth, A, 1985, *Submerged forests: a dendrochronological and palynological investigation* unpublished PhD, University of Wales Aberystwyth.

Heyworth, A & Kidson, C, 1982, Sea level changes in southwest England and Wales, *Proceedings of the Geologists Association* 93, 91 – 111.

Hows M, Pilbeam, P, Conlan, H & Featherstone, R, 2016, *Cambridgeshire Mammal Atlas*, Cambridgeshire Mammal Group, Cambridge.

Hughes, PDM & Schultz, J, 2001, The development of the Borth Bog (Cors Focno) mire system and the submerged forest beds at Ynyslas, 104-112, In MJC Walker & D.

- McCarroll (eds), *The Quaternary of West Wales Field Guide*, Quaternary Research Association, London.
- Hughes, TM, 1913, On the occurrence of a portion of the skull and antlers of red deer of exceptionally large size in the estuary of the Gilpin, *Transactions of Cumberland and Westmorland Antiquarian and Archaeological Society* 2, 59-61.
- Kavanagh, KE & Bates, MR, 2019, Semantics of the Sea – Stories and Science along the Celtic Seaboard, *Internet Archaeology* 53, <https://doi.org/10.11141/ia.53.8>
- Keeping, W, 1878, Geology of Aberystwyth, *Geological Magazine* 5, 532 – 547.
- LLwyd, E, 1695, *Britannia*, Column 636, under 'Additions to Pembrokeshire'.
- Loke, MH & Barker, RD, 1995, Least-squares deconvolution of apparent resistivity pseudosections, *Geophysics* 60, 1682-1690.
- Meisch, C, 2000, Freshwater Ostracoda of Western and Central Europe, In J Schwoerbel & P. Zwick (eds), *Süßwasserfauna von Mitteleuropa* 8/3, Spektrum Akademischer Verlag, Heidelberg and Berlin.
- Mighall, TM, Timberlake, S, Martinez-Cortizas, A, Silva-Sanchez, N & Foster, IDL, 2017, Did prehistoric and Roman mining and metallurgy have a significant impact on vegetation? *Journal of Archaeological Science: Reports* 11, 612-625.
- Morgan, TO, 1869, *New guide to Aberystwyth and its environs; comprising notices, historical and descriptive, of the principal objects of interest in the town and neighbourhood with a view and map*, Whittaker and Co., London.
- Moore, PD, 1966, *Investigation of peats in central Wales* unpublished PhD thesis, University of Wales.
- Moore, PD, 1968, Human influence upon vegetational history in north Cardiganshire, *Nature* 217, 1006 – 1009.
- Murray, JW, 2006, *Ecology and Applications of Benthic Foraminifera*, Cambridge University Press, Cambridge.
- Orme, LC, Davies, SJ, Duller, GAT, 2015, Reconstructed centennial variability of Late Holocene storminess from Cors Fochno, Wales, UK, *Journal of Quaternary Science* 30, 478-488.
- Poucher, P, 2009, Wetland Margins Survey: Cors Fochno, Dyfed Archaeological Trust report no: 2008/114, Llandeilo: DAT. Available online at: www.cambria.org.uk/projects/corsfochnoreport.pdf [Accessed 27th September 2012].
- Prince, HE, 1988, *Late Glacial and post-glacial sea level movements in North Wales* unpublished PhD Thesis, The University College of Wales, Aberystwyth.
- Scales, R, 2006, *Prehistoric coastal wetland exploitation: The evidence of footprint-tracks and animal bones, with reference to the Severn Estuary* unpublished PhD Thesis, University of Reading.
- Shi, Z, 1992, *Late Quaternary stratigraphy and recent sedimentation in the Dyfi estuary, Wales* unpublished PhD Thesis, University of Wales Aberystwyth.
- Shi, Z & Lamb, HF, 1991, Post-glacial Sedimentary Evolution of a Micro-tidal Estuary, Dyfi Estuary, West Wales, UK, *Sedimentary Geology* 73, 227-246.
- Stafford, E, Goodburn, D & Bates, M, 2012, *Landscape and prehistory of the East London wetlands. Investigations along the A13 DBFO Road scheme. Tower Hamlets, Newham and Barking and Dagenham, 2000-2003*, Oxford Archaeology Monograph 17, Oxford.
- Stasney, P, Scaife, R, Gonzalez Carretero, L, Whittaker, JE, Cameron, N & Allison, E, 2021, Modelling Prehistoric Topography and Vegetation in the Lower Thames Valley, UK: Palaeoenvironmental Context for Wetland Archaeology and Evidence for Neolithic Landnám from North Woolwich, *Environmental Archaeology* : DOI: <https://doi.org/10.1080/14614103.2021.1880683>
- Steers, J A, 1969, *The Coastline of England and Wales*, Cambridge, Cambridge University Press.
- Strafford, L, 2013, *A study of the submerged forests and intertidal peats of Wales* unpublished MA Thesis, University of Wales Trinity Saint David, Lampeter.
- Taylor, J, 1973, Chronometers and Chronicles: a study of palaeoenvironments in west central Wales, *Progress in Geography* 5, 247 – 334.
- Taylor, JA, 1984, A Pictorial Reconstruction of the Lower Dyfi Estuary in 6,700 BP, *Nature in Wales* 3, 107-108.
- Wilks, PJ, 1978, *Flandrian sea level change in the Cardigan Bay area* unpublished PhD Thesis, University of Wales Aberystwyth.
- Wilks, PJ, 1979, Mid-Holocene Sea-Level and Sedimentation Interactions in the Dovey Estuary Area, Wales, *Palaeogeography, Palaeoclimatology, Palaeoecology* 26, 17-36.
- Yates, J, 1833, Notice of a submarine forest in Cardigan Bay, *The London and Edinburgh Philosophical Magazine and Journal of Science* Third Series, Volume 2 (No. 10), 241-243.

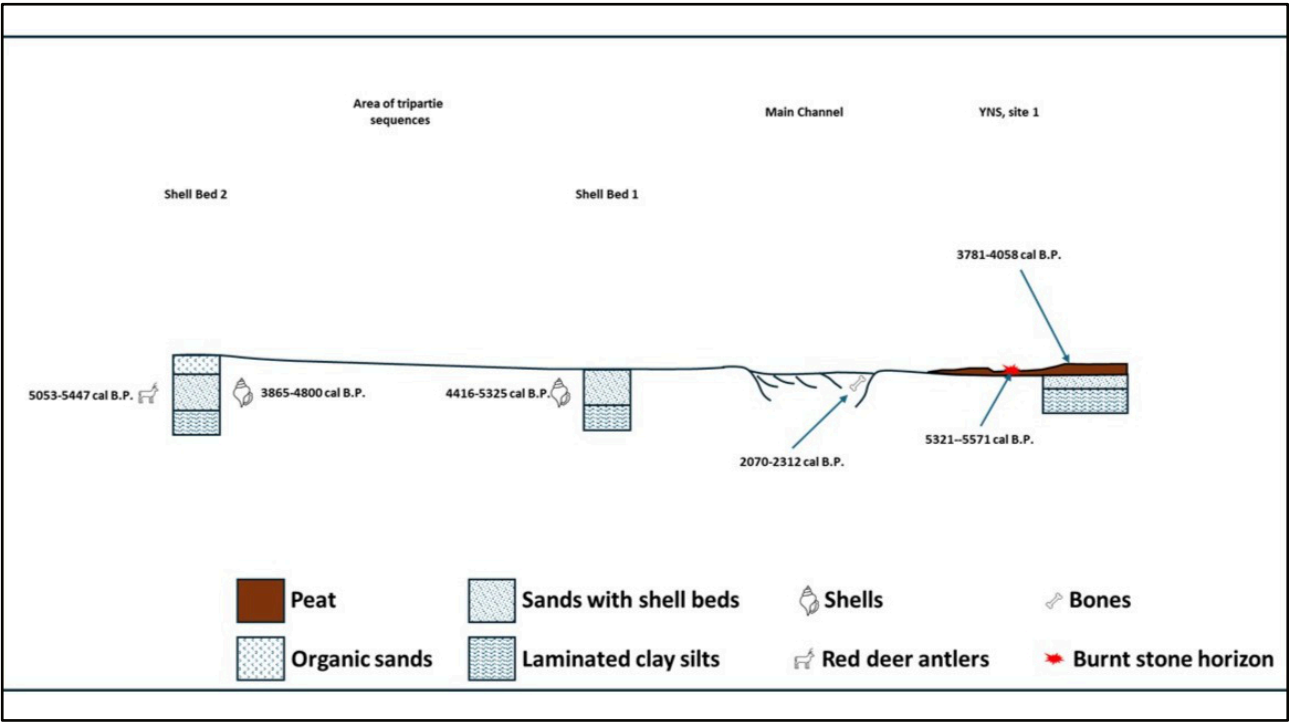


Figure 23: Schematic sketch profile for sequences at Ynyslas

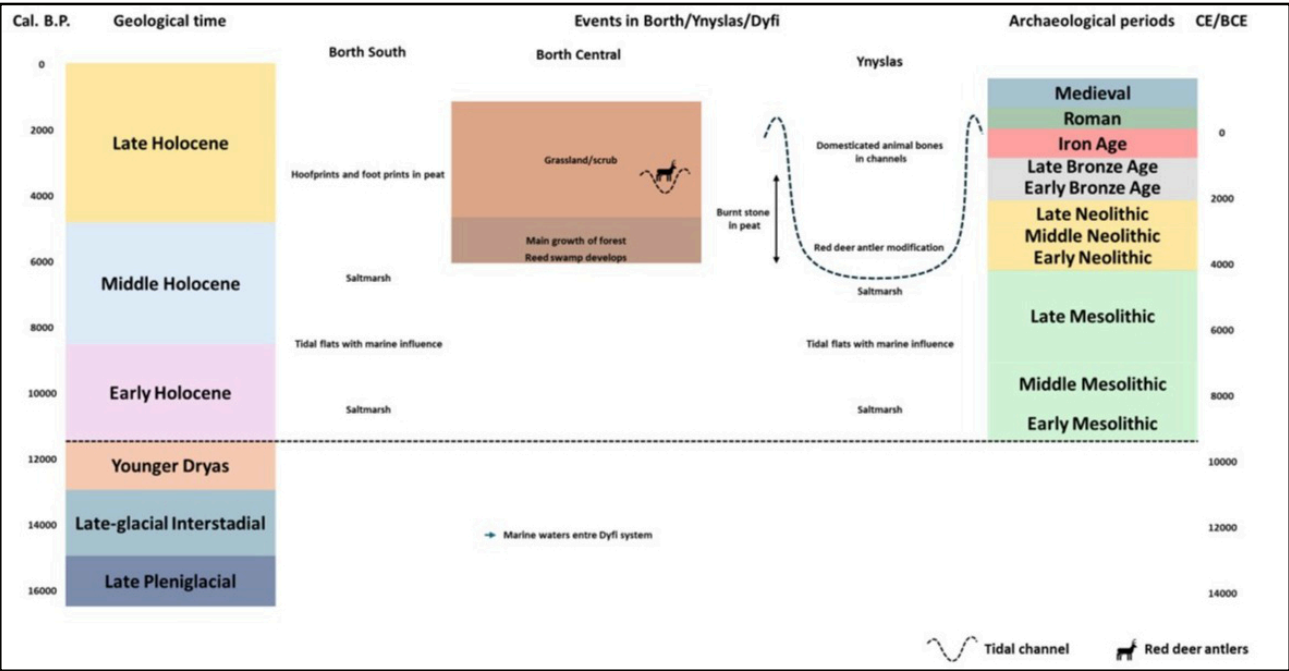


Figure 24: Summary of events in the Dyfi between Borth and Ynyslas

Site	Sample depths	Laboratory Number	Elevation m (O.D.)	Material	Measured 14C age	Calibrated age (B.P.)	Context/stratigraphic information	Source
Ynyslas		Q-380	?	Birchwood	6026±135	6556-7250 (LM)	Base of main peat	Godwin and Willis, 1961
Ynyslas		Q-382	?	Brushwood	5898±135	6399-7155 (LM)	Base of main peat	Godwin and Willis, 1961
Ynyslas BH 1		?	1.15	Organic material	3740±70	3891-4382 (LN)	Top of main peat	Wilks, 1977
Ynyslas BH 1		?	0.25	Organic material	4700±70	5313-5582 (EN)	Middle of main peat	Wilks, 1977
Ynyslas BH 1		HAR-1020	-0.25	Organic material	5150±90	5719-6175 (LM)	Base of main peat	Wilks, 1977
Ynyslas, BH 4		?	1.87	Organic material	1510±70	1300-1528 (EMd)	Organic silts above main peat	Wilks, 1977
Ynyslas, BH 4		?	0.99	Organic material	3050±70	3006-3442 (LBA)	Top of main peat	Wilks, 1977
Ynyslas, BH D		SRR-2503	-24.40 to -23.98	Organic material	9710±50	10808-11234 (EM)	Organic material in clay	Prince, 1988
Ynyslas, BH D		SRR-2504	-28.62 to -28.01	Organic material	9870±100	11098-11742 (EM)	Peat and clay mixed with gravel	Prince, 1988
Borth, Bw2, S1 ¹		B-432360	-1.66	Peat	5570±30	6298-6401 (LM)	Base of main peat	This study
Borth, Bw2, S2 ²		B-432362	-1.33	Peat	5460±30	6200-6304 (LM)	Base of main peat	This study
Borth, Red deer antler		B-436857	-2.30m	Antler	2940±30	2968-3206 (LBA)	Laminated silts and sands	This study
YNS, site 1	M01-1, 02-04-21, 0.5-1cm	B-648060	-0.215	Peat (humin)	3600±30	3781-4058 (LN/EBA)	Top of exposed peat	This study
YNS, site 1	M01-1, 02-04-21, 0.5-1cm	B-648059	-0.215	Peat (humic)	3450±30	3592-3830 (EBA)	Top of exposed peat	This study
YNS, site 1	M01-1, 02-04-21, 9-9.5cm	B-648062	-0.3	Peat (humic)	3830±30	4097-4403 (LN)	Middle of exposed peat	This study
YNS, site 1	M01-1, 02-04-21, 9-9.5cm	B-648061	-0.3	Peat (humin)	3840±30	4150-4404 (LN)	Middle of exposed peat	This study
YNS, site 1	2-4-21, burnt wood	B-639336	-0.53	Wood	4700±30	5321-5571 (EN)	Wood associated with burnt stones	This study
YNS, site 1	Bulk sample (humin)	B-674987	-0.53	Charred material	4700±30	5321-5571 (EN)	Charred material with burnt stones	This study
YNS, site 1	Bulk sample (humic)	B-674986	-0.53	Charred material	4350±30	4828-5026 (MN)	Charred material with burnt stones	This study
YNS, channel complex	SF 2	B-639334	0.1	Bone (Bos sp.)	2180±30	2070-2312 (IA)	Fauna in tidal channel	This study
YNS, channel complex	SF 4	B-639335	0.05	Bone (Canis sp.)	2180±30	2070-2312 (IA)	Fauna in tidal channel	This study
YNS, Shell Bed 1	SB 1	B-674988	-0.4	Shell (Cardium sp.)	4870±30	4416-5325 (MN/LN)	Shell beds in tidal channel	This study
YNS, Shell Bed 2	SB 2	B-674989	-0.45	Shell (Cardium sp.)	4430±30	3865-4800 (LN)	Shell beds in tidal channel	This study
YNS, channel complex	SF 103	B-670053	-0.5	Antler	4570±30	5053-5447 (EN/MN)	Fauna in tidal channel	This study
YNS, BH 2	3.02—3.03	UBA-50068	+0.67 to 0.68	Peat (humin)	1059±19	925-1050 (EMd)	Top of main peat	This study
YNS, BH 2	3.90-3.91	UBA-50062	-0.20 to -0.21	Peat (humic)	3984±33	4300-4528 (LN)	Middle of main peat	This study
YNS, BH 2	3.90-3.91	UBA-50063	-0.20 to -0.21	Peat (humin)	4099±27	4450-4810 (LN)	Middle of main peat	This study
YNS, BH 2	5.09-5.11	UBA-50064	-1.39 to -1.41	Peat (humic)	5318±35	5995-6263 (LM)	Base of main peat	This study
YNS, BH 2	5.09-5.11	UBA-50065	-1.39 to -1.41	Peat (humin)	6880±44	7616-7829 (LM)	Base of main peat	This study
YNS, BH 2	17.46-17.47m	B-648065	-13.76 to -13.77	Marine shell	7440±30	8190-8335 (LM)	Shell bed within tidal channel	This study
YNS, BH 2	17.8-17.9m	B-648066	-14.10 to -14.20	Marine shell	7570±30	8345-8410 (LM)	Shell bed within tidal channel	This study
YNS, BH 2	23.56-23.57m	B-648064	-19.86 to -19.87	Peat (humin)	9690±30	10876-11205 (EM)	Organic horizon within alluvium	This study
YNS, BH 2	23.56-23.57m	B-648063	-19.86 to -19.87	Peat (humic)	8500±30	9473-9538 (MM)	Organic horizon within alluvium	This study
YNS, BH 2	24.2	UBA-50066	-20.5	Peat (humic)	9983±55	11254-11705 (EM)	Organic horizon at base of alluvium	This study
YNS, BH 2	24.2	UBA-50067	-20.5	Peat (humin)	12197±62	13865-14777 (UP)	Organic horizon at base of alluvium	This study
BOR, BB/12	M03, 7.5-8cm	UBA-50426	-0.275 to -0.28	Peat (humic)	2962±39	2969-3318(E/LBA)	Organic silt with hoof prints	This study
BOR, BB/12	M03, 7.5-8cm	UBA-50427	-0.275 to -0.28	Peat (humin)	3244±28	3386-3557 (EBA)	Organic silt with hoof prints	This study
BOR, BB/12	M03, 10.5-11cm	UBA-50428	-0.305 to -0.30	Peat (humic)	2948±33	2970-3211(LBA)	Peat with burnt stones	This study
BOR, BB/12	M03, 10.5-11cm	UBA-50429	-0.305 to -0.30	Peat (humin)	3077±27	3215-3365 (EBA)	Peat with burnt stones	This study
BOR, BB/12	M03, 12-12.5cm	UBA-50430	-0.32 to -0.325	Peat (humic)	3025±31	3080-3344 E/LBA)	Peat with burnt stones	This study
BOR, BB/12	M03, 12-12.5cm	UBA-50431	-0.32 to -0.325	Peat (humin)	3083±28	3217-3367 (EBA)	Peat with burnt stones	This study

Table 2: List of radiocarbon dates from the Borth/Ynyslas area

Depth (m bgl)	2.00-2.02	2.98-3.00	3.86-3.88	5.20-5.22	5.60-5.62	6.50-6.52*	7.50-7.52*	9.38-9.40*	10.58-10.60*	12.50-12.52*	13.5-13.52*	17.50-17.52	23.20-23.22*	23.40-23.42*	23.60-23.62*	23.80-23.82*	24.00-24.02*	24.2*
Salt marsh foraminifera																		
Trochammina inflata			14	8	10	15											3	7
Jadammina macrescens			13		21	13	4	2		2								
Millammina fusca			34		1													
Brackish foraminifera																		
Ammonia beccarii						66	36	147	219	126	190	32	210	223	223	262	205	179
Haynesina germanica						180	114	112	54	84	70	15	45	54	39	21	64	110
Elphidium williamsoni						15	20	23	21	26	23	2	5	9	6	4	2	8
Outer estuarine/ marine foraminifera																		
Miliolinella subrotunda							3		1	7	12	16	23	12	13	33	17	18
Quinqueloculina sp.								7	10	18	4	5	8	7	14	8	20	12
Elphidium macellum								6					1	2	4		2	11
Nodosariidae						1	4	3	6	3		3	2	1			1	1
Elphidium earlandi						13	7	6	6	4	4	1	3		3	3	6	
Haynesina depressula										6	6	1					1	
Ammonia batavus						5	2				2	2	30	5	11	7		
Pateoris hauerioides															2			
Cibicides lobatulus							1						1					
Elphidium incertum									4									
Discorbidae							1	1										
Trifarina angulosa						1												
Total foraminifera	0	0	61	8	32	309	192	307	321	276	311	77	328	313	315	338	321	346

Table 3: Microfossils from borehole YNS/22, BH 2

Site code	Identification	Comments	Age estimate
YNS-23/SF101	Three fragments of bone. Weights 1.90 g, 3.24 g and 8.88 g.		
YNS-23/SF102	Fragment of pelvis, juvenile probably red deer, shaft of ilium, left side. The surviving fragment length 62 mm. Smallest breadth (SB) of the ilium is 18 mm and smallest circumference (SC) 4.9 mm. Weight 9.8 g.	Two clearly marked striations, running parallel around a portion of the ilium shaft. They are about 1.8 cm (18.8 mm), and 2.0 cm (220.9 mm) long, and 0.3 cm (3.0 mm) mm apart. Cutmarks.	
YNS-23/SF103	Shed single antler from <i>Cervus elaphus</i> , (Red deer) consisting of a beam and two surviving tines, the brow and bay tines, right side. Surviving fragment of beam is broken before the crown formation. The tray tine is also broken close to the beam.	Shows modification. Upper beam has a transverse saw mark. The cut is, in part, smooth, flat and clean. Multiple parallel striations, unidirectional running longitudinal to the beam. Max length of striation = 13.2 mm.	4570±30 B.P. (3317-3494 cal B.C/ 5267-5444 cal B.P.) End of Early Neolithic
YNS-23/SF104	Long bone fragment Weight 26 g.	(Distal femur?)	
YNS-23/SF 105	Shed single antler from <i>Cervus elaphus</i> , (Red deer) consisting of the lower beam and a broken brow tine, the coronet/burr is incomplete. Right side.	Three fragments of bone, including one long bone fragment	
YNS-20/SF1	Pelvis fragment, horse (<i>Equus</i>) left side of the pelvis, has a partially surviving acetabulum, a badly eroded partial ischium and ilium, the pubis area is also missing. All areas of the bone show erosion and past multiple breakages. Weight 177.6 g.		
YNS-20/SF2	<i>Canis familiaris</i> (domestic dog) a virtually complete cranium, with minimal damage to tympanic bullae areas, three teeth remaining in the maxillae. The dog is fully adult with evidence of all upper dentition being present at one time.	Three teeth remain as maxillary dentition, two M ² and one upper right carnassial. Rounded cusps. Cephalic index of 56.7 suggests a mesocephalic or medium skulled dog.	2180±30 B.P. (121-361 cal B.C/ 2071-2311 cal B.P.) Mid to Late Iron Age
YNS-20/SF3	Fish vertebra not currently identified to species. Centrum intact but all processes are broken. Weight 1.7 g.		
YNS-20/SF4	<i>Bos taurus</i> (cattle) mandible, near complete and from the right side of the animal. The symphyseal area, just after the mental foramen is missing making measurements limited but the height of the ascending ramus is 17.7 cm. The three molars (M ₁ , M ₂ , and M ₃), are present but all other teeth are missing. Molar row is 8.3 cm. and, as such, the measurements suggest this is not a large specimen of cattle. Weight 352.6 g.	The molars are all heavily worn, including the third cusp of the M ₃ , indicating an older adult.	
YNS-20/SF5	<i>Bos taurus</i> (cattle) frontal with two surviving horncores, right horncore damaged at the tip. The caudal side of the left horncore is eroded but otherwise complete. The distance between the horncore bases is 12.2 cm, the diameter of the horncore base 112 and 116 mm. The narrowest part of the frontal, just anterior to the horncores is 142 mm. These measurements suggest not large individual. Weight 367.3 g.	Also, in SF5 is a fragment of the cattle skull consisting of the upper region of the orbit or eye area from the right side of the animal. This conjoins with the cattle frontal, but the fracture is historical, and the join imperfect.	

Table 4: Summary of faunal remains from Ynyslas

	YNS/23-SF103	YNS/23-SF105	YNS/24-SF 6	YNS/24-SF 7	YNS/24-SF 8	YNS/24-SF 9	BOR-16 Right antler	BOR-16 Left antler
Length of beam	346mm	316mm	054mm	506mm	254mm	394mm	740mm	804mm
Length of brow tine	276mm	-	-	241mm	-	-	337mm	286mm
Length of bay tine	223mm	-	-	192mm	-	-	257mm	254mm
Length of tray tine	-	-	-	-	-	-	343mm	332mm
Circumference of coronet	188mm	-	214mm	224mm	-	-	285mm	281mm
Circumference of lower beam	123mm	161mm	-	138mm	-	-	165mm	165mm
Circumference of upper beam	-	-	-	108mm	164mm	134mm	140mm	147mm
Dry Weight	717.7g	476.8g	162.7g	1048.3g	335.3g	379.5g	NA	NA

Table 5: Measurements red deer antlers

	YNS/20-SF2	YNS/25-SF11
Total length	184.71mm	na
Greatest neurocranium breadth	59.74mm	59.2 mm
Least neurocranium breadth	37.48mm	37.2mm
Zygomatic breadth	99.29mm	102.1mm
Greatest mastoid breadth	62.17mm	69.07mm
Greatest diameter of the auditory bulla	17.21mm	18.27mm
Height of the occipital triangle	41.77mm	41.46mm
Dry weight	84.6g	151.2g

Table 6: Measurements of dog skulls

Site	Core pollen phase	Core depths (cm)	Approximate date ¹	Description
Borth M01	BM01-1	27.75-17.75	c.5,150-4,675 BP (c.3,200-2,725 BC)	Initial conditions indicate an almost equal proportion of Arboreal Pollen (AP) to Non Arboreal Pollen (NAP), with high levels of <i>Alnus glutinosa</i> (alder) and Poaceae (grasses), with slightly lower levels of <i>Betula</i> (birch), <i>Quercus</i> (oak), <i>Corylus avellana</i> -type (hazel-type) and Cyperaceae (sedges). Comparably high levels of <i>Ulmus</i> (Elm), <i>Fraxinus</i> (Ash), Cereal-type, <i>Apium</i> (Marshwort), Caryophyllaceae (Pink family) and <i>Plantago lanceolata</i> (ribwort plantain) are also observed. Woodland percentages increase through the zone with diminishing levels of Poaceae, Cereal-type and <i>Plantago lanceolata</i> . <i>Ulmus</i> and <i>Pinus sylvestris</i> (Scots pine) levels also fall.
	BM01-2	17.75-10.75	c.4,675-4,315 BP (c.2,725-2,365 BC)	Increased AP percentages from a substantial rise in <i>Alnus glutinosa</i> and decreased Poaceae and Cyperaceae pollen. Reduced percentages of <i>Quercus</i> and <i>Corylus avellana</i> are observed among woodland taxa and <i>Pinus</i> , <i>Ulmus</i> and <i>Fraxinus</i> disappear almost completely. Percentages of Cereal-type, <i>Plantago lanceolata</i> and <i>Rumex acetosa</i> pollen, <i>Polypodium</i> , <i>Sphagnum</i> and Pteropsida spores and microcharcoal concentrations fall. Total pollen concentrations rise substantially.
	BM01-3	10.75-0.75	c.4315-3740 BP (2,365-1,790 BC)	Decreasing AP percentages as <i>Alnus glutinosa</i> declines and Poaceae and Cyperaceae increase. Slight decline also observed for <i>Quercus</i> and small increase for several NAP taxa, including Ericaceae, cereal-type, Chenopodiaceae, <i>Plantago lanceolata</i> , <i>Rumex acetosella</i> and <i>Rumex acetosa</i> . Increased <i>Sphagnum</i> and <i>Polypodium</i> spores as well as microcharcoal concentrations are also observed.

Table 7: Pollen data from MO1, YNS, Site 1