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Later prehistoric vegetation dynamics and Bronze Age agriculture at Hobbister, Orkney, Scotland

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Abstract

The Bronze Age in Britain was a time of major social and cultural changes, reflected in the division of the landscape into field systems and the establishment of new belief systems and ritual practices. Several hypotheses have been advanced to explain these changes, and assessment of many of them is dependent on the availability of detailed palaeoenvironmental data from the sites concerned. This paper explores the development of a later prehistoric landscape in Orkney, where a Bronze Age field system and an apparently ritually-deposited late Bronze Age axehead are located in an area of deep blanket peat from which high-resolution palaeoenvironmental sequences have been recovered. There is no indication that the field system was constructed to facilitate agricultural intensification, and it more likely reflects a cultural response to social fragmentation associated with a more dispersed settlement pattern. There is evidence for wetter conditions during the later Bronze Age, and the apparent votive deposit may reflect the efforts of the local population to maintain community integrity during a time of perceptible environmental change leading to loss of farmland. The study emphasises the advantages of close integration of palaeoenvironmental and archaeological data for interpretation of prehistoric human activity. The palaeoenvironmental data also provide further evidence for the complexity of prehistoric woodland communities in Orkney, hinting at greater diversity than is often assumed. Additionally, differing dates for woodland decline in the two sequences highlight the dangers of over-extrapolation from trends observed in a single pollen profile, even at a very local scale.

Keywords: Agriculture · Bronze Age · Field systems · Orkney · Pollen analysis · Votive deposition

1. Introduction

In Britain the transition to the later Bronze Age marks a time of major landscape reorganisation, with the appearance of substantial evidence for division and exploitation of land. Extensive field systems were established in both lowland and upland regions (Bradley 1978; Barber and Brown 1984; Evans 1990; Carter 1993; Pryor 1996, 2001; Smith 1996; Yates 1999, 2007; Brück 2000; Fleming 2008), representing a significant change in the nature and organisation of the agricultural landscape. Recent archaeological literature interprets these field systems as either evidence for the development of a hierarchical society that required production of an agricultural surplus and therefore new ways of controlling and managing farming (Yates 1999; Fleming 2008), or as the formalisation of pre-existing territorial boundaries reflecting an increasing concern with structuring time and space in response to social fragmentation (Brück 2000; Johnston 2005). More traditional interpretations of land division in upland regions of Britain have focused on the perceived marginality of these areas, suggesting that their exploitation was a consequence of an increase in population which, coupled with a deteriorating climate, increased pressure on resources and led to a greater requirement for management and control of agricultural land (e.g. Bradley 1980; Burgess 1984; Cowie and Shepherd 2003). Recent palaeoenvironmental research advocates a more cautious approach to this environmentally deterministic view, recognising that a range of socio-economic, cultural and environmental factors are likely to have played a role in prehistoric attitudes to organisation of land-use (e.g. Gearey et al. 2000; Davies 2007; Amesbury et al. 2008; Fyfe et al. 2008).

Bronze Age field systems often form part of complex settlements which may be associated with contemporaneous cemeteries and ritual deposits, often of precious metalwork, in waterholes, field-boundary ditches and natural watercourses (Yates 1999, 2007; Pryor 2001, 2005; Bradley and Fraser 2010). Whilst deposits of metalwork made on dry land are usually interpreted as valuables that were either lost or hidden with the intention that they would be retrieved at a future date, metal objects deposited in wetland contexts from which it would have been difficult to retrieve them tend to be interpreted as votive offerings (Bradley 1998). They may represent a ritual deposition of valuable goods displaying the wealth and power of the depositing community, a form of conspicuous consumption (e.g. Champion 1999; Yates 2007), perhaps lending support to the idea that the development of field systems reflects the establishment of a hierarchical society (Yates 1999; Fleming 2008). Others suggest that deposition in wetland environments may have been a response to environmental change (Pryor 2001; Van de Noort 2001; Evans 2002; Brown 2003; Halkon and Innes 2005; Van de Noort and O'Sullivan 2006), and that votive deposition of precious artefacts along with construction of trackways across wetlands may be viewed as attempts to domesticate and control the changing landscapes during periods of increased wetness (Van de Noort and O'Sullivan 2006; Van de Noort 2013). Wetlands are frequently thought of as wilderness and may have been seen in the past as resistant to domestication, perhaps associated with supernatural powers that needed to be acknowledged and maybe even appeased in times of perceptible environmental change (Van de Noort 2001; Brown 2003; Van de Noort and O'Sullivan 2006). Some authors have attempted to distinguish between deposits made in different types of wetland (e.g. Van de Noort 2001; Fontijn 2002; Mullin 2012), but further investigation of all these hypotheses has to date been hampered by a high proportion of poorly provenanced finds and a lack of palaeoenvironmental information relating to the findspots (Van de Noort and O'Sullivan 2006; Yates and Bradley 2010).

Bronze Age palaeoenvironmental data in Orkney, northern Scotland (Fig. 1) is particularly sparse, as is settlement evidence for the period. Although the islands are arguably one of the best preserved and most intensively studied archaeological landscapes in the world, much of the attention has focused on the highly visible Neolithic and Iron Age structures, with the result that the Bronze Age has, until recently, been largely neglected. The gap in settlement evidence for this period is beginning to be addressed, with a wide range of Bronze Age settlement types now recognised (Downes 2005). Massive linear earthworks known as 'treb dykes' which run for long distances across the Orcadian landscape may be the remains of a Bronze Age land-allotment system (Lamb 1983). To date fewer than twenty finds of Bronze Age metalwork are known from Orkney, some of which have been recovered from bogs (e.g. Cursiter 1887, 1908; O'Connor and Cowie 1995), although the provenance of these objects is not well recorded and it is not possible to determine whether they were casual losses or intentional deposits.

In terms of palaeoenvironmental records, the period is covered by just three securely radiocarbon dated sequences and several fragmentary records. Palynological data from Glims Moss in west Mainland (Keatinge and Dickson 1979) and Loch of Knitchen on Rousay (Bunting 1996) provide evidence for environmental conditions from the Neolithic through to the Iron Age. A sequence from Mill Bay on Stronsay begins at ca. 2100 cal BC (Tisdall et al. 2013), around the time of the Neolithic-Bronze Age transition, and thus provides little prior context for the environmental changes that took place during the Bronze Age. Three short profiles date the onset of blanket peat formation in the west Mainland hills to the Bronze Age (Keatinge and Dickson 1979), but as a consequence of their marginal location they provide little evidence for human activity and land-use. Other pollen records from Mainland (Davidson et al. 1976; de la Vega-Leinert et al. 2007) are thought to include the Bronze Age, but only the earlier parts of the profiles are radiocarbon dated so there is no firm evidence to confirm this interpretation. The period may also be covered by a short profile recovered from a Bronze Age archaeological site on South Ronaldsay (Bartlett 1983), but the sequence is dated only by biostratigraphy, which has been shown to be inconsistent in Orkney (Farrell et al. 2014). Other putatively Bronze Age records are either poorly dated (e.g. Moar 1969; Keatinge and Dickson 1979; Bunting 1994) or are single context samples from archaeological sites (e.g. Jones 1975, 1977; Bunting et al. 2001) which provide a very localised and time-specific picture of environmental conditions.

Following the discovery of a late Bronze Age socketed axehead during peat cutting at Hobbister in Orphir, Mainland (Cowie and O'Connor 2006; see Fig. 1 for location), an archaeological survey identified several further sites (Sharman and Hollinrake 2007). Four sections of stone-lined dyke approximately 1.5 m in width were located and interpreted as the remains of a prehistoric field system, tentatively assigned a Bronze Age date on the basis of their position on the land surface beneath the peat (Sharman and Hollinrake 2007). A possible sub-circular stone structure ca. 8 m in diameter was also noted, although due to the effects of peat cutting it is unclear whether this feature is archaeological. Four low, sub-circular mounds ranging in diameter from 7 to 9 m were recorded and interpreted as probable Bronze Age burial mounds (Sharman and Hollinrake 2007). The discovery of a potential Bronze Age landscape buried by peat presented a unique opportunity to investigate Bronze Age land-use and environmental conditions using palaeoenvironmental techniques. This paper aims to establish the environmental context of the archaeological remains at Hobbister and evaluate the range of causal arguments for construction of field systems and votive deposition of precious metalwork in wetlands as they relate to this site.

2. Materials and methods

2.1 Field methods

Fieldwork focused on the area closest to where the axehead was discovered, based on the assumption that the peat in this area was likely to contain a Bronze Age palaeoenvironmental record. Stratigraphy was recorded according to Troels-Smith (1955) at multiple points using a gouge auger and by logging sections along an exposed peat cutting. The position of each sequence was recorded using a handheld GPS, and their relative surface heights measured using a dumpy level. Depths were measured from the present-day ground surface.

Two locations were sampled for laboratory analysis (Fig. 1; Fig. 2). Sequence A was recovered from the deepest area of peat (58° 56’ 33.74”N, 3° 3’ 3.93”W) with a 5 cm diameter Russian sampler and sequence B was taken from the exposed peat bank (58° 56’ 31.23”N, 3° 3’ 2.29”W) using 50×10×10 cm monolith tins. Cores and monolith tins were wrapped in clingfilm and aluminium foil in the field and on return to the laboratory were stored in the dark at 5 °C.

2.2 Laboratory methods

Organic content of the sediments was measured using loss-on-ignition (Bengtsson and Enell 1986). One cm^3 subsamples were prepared for pollen analysis following standard procedures (Moore et al. 1991), including treatment with hot 40% hydrofluoric acid, 5% sodium pyrophosphate and fine sieving as appropriate to remove mineral components. Pollen concentrations were established by adding a known concentration of *Lycopodium clavatum* spores to the samples before treatment (Stockmarr 1971). Residues were stained using aqueous safranin and mounted on microscope slides in silicone oil, then counted along evenly spaced traverses at a magnification of ×400, with ×1000 magnification and oil immersion used for critical identifications. A minimum of 300 terrestrial pollen grains and spores were counted per sample, and once this sum was reached counting continued until the end of the traverse, resulting in actual count sizes ranging from 300 to 400. Counts of this size are generally deemed sufficient to characterise the major components of most pollen assemblages (Maher 1972; Birks and Birks 1980; Moore et al. 1991), particularly those of low richness and high evenness (Keen et al. 2014). Pollen and spores were identified using the keys of Moore et al. (1991) and Beug (2004) and the reference collections of the Department of Geography, University of Hull. Cereal-type pollen was separated from that of wild grasses on the basis of grain size and annulus diameter (Andersen 1979). Pollen taxonomy follows Bennett (1995-2007a). Pollen percentage diagrams were plotted using Tilia and TiliaGraph (Grimm 1991). Numerical zonation of the diagrams based on optimal splitting by sum-of-squares (Birks and Gordon 1985; Bennett et al. 1992) was undertaken using psimpoll (Bennett 1995-2007b) on a subset of the pollen data containing all main sum taxa that constituted 2% or more of at least one sample.

Non-pollen palynomorphs (NPPs) that may have some value as grazing indicators were identified with reference to van Geel (1978, 2001) and van Geel et al. (1981, 1983, 1989, 2003), recorded during pollen counting and plotted as percentages of the sum of total land pollen and spores plus NPPs (Mighall et al. 2006). NPP nomenclature follows the protocol developed in the series of papers summarised by Haas (2010) and described in detail in Miola (2012). The microscopic charcoal content of samples was estimated using the point count method (Clark 1982). The concentration of microscopic charcoal ($cm^2\ cm^{-3}$) and the ratio of this to pollen concentration (Bennett et al. 1990) are plotted on the percentage pollen diagrams.

Material retained after sieving through a 100 µm mesh during pollen preparation was examined and the abundance of various elements of the sediment structure was recorded on a modified DAFOR scale (Kent 2012) as follows: dominant = 5, abundant = 4, frequent = 3, occasional = 2 and rare = 1. The ‘+’ symbol was used to record very rare occurrences of certain components, for example seeds or wood fragments. Seeds and fruits were identified with reference to Cappers et al. (2006).

Samples of 1 cm thickness from key points in the pollen stratigraphy were submitted to SUERC laboratories, East Kilbride, where AMS radiocarbon measurements were performed on humic acid extracted from the samples. Age models were constructed using CLAM 2.2 (Blaauw 2010), which also performs calibration of the ^{14}C dates using the IntCal13 calibration curve (Reimer et al. 2013). Various age models (Bennett 1994; Blaauw 2010) were tested for both sequences, but in the absence of a large number of age estimates none was found to give any significant improvement in fit over linear interpolation. The interpolations rely on the four AMS ^{14}C dates available for each profile, and AD 2007 which was assigned to the top of each profile.

A continuous surface showing the topography of the pre-peat landscape at Hobbister was generated by interpolating between measured peat depths using the inverse distance weighting function in ESRI ArcMap 9.2.

3. Results

3.1 Site stratigraphy

Peat depths for the area surveyed are illustrated in Fig. 2. Sequence A was recovered from a small (ca. 30 m radius) sub-peat depression in the northern part of the site, which contains peat up to 3.8 m thick and is surrounded by shallower peat. Another small sub-peat depression, from which sequence B was recovered, occurs at the western edge of the active peat face, and peat becomes shallower upslope to the east. Shallow freshwater sediments were recorded at the base of some boreholes (Fig. 2), indicating that the pre-peat landscape contained several small pools.

3.2 Age estimates

Calibrated age estimates for both sequences are given in Table 1 and age-depth models are presented in Fig. 3. The base of sequence A has an approximate age of 5270 cal BC, and the base of sequence B dates to ca. 2630 cal BC. The tops of both profiles are assumed to be modern, since there were no visible signs of cutting or disturbance of the peat surface. Ages for events referred to in the following discussion are derived from the age-depth models (Fig. 3). Where age ranges are cited, these bracket prolonged events such as woodland decline.

3.3 Core stratigraphy

The major lithostratigraphic units in both sequences are presented in Table 2. The sediments comprise of mainly peats with varying degrees of humification and amounts of plant macrofossils. A unit of fine organic lake mud is recorded in sequence A between 312 and 340 cm, and a similar unit with a higher silt content occurs between 197 and 202 cm in sequence B. The basal unit of sequence B consists of greyish-brown sand. This sand was also encountered at the location of sequence A during the initial survey of the site, but here it was too compact to be recovered by the Russian sampler. Unfortunately the exact location of the Bronze Age axehead within the stratigraphic sequence is unknown since it was discovered while turning previously cut peats (Cowie and O'Connor 2006). However sequence B was recovered from close to the findspot and, according to the peat cutters, the axe came from the lowest peat unit which is easily distinguished on the basis of colour and degree of humification (Table 2).

3.4 Reconstruction of Holocene environments at Hobbister

Pollen percentage diagrams are presented in Fig. 4 and Fig. 5. Pollen accumulation rates generally follow the trends seen in the percentage data (Farrell 2009), so pollen accumulation rate diagrams are not reproduced here. The results of loss-on-ignition and analysis of sieve residues retained during processing of pollen samples (referred to henceforth as 'macro-remains') are shown in Fig. 6 and Fig. 7. Local pollen assemblage zones are summarised in Tables 3 and 4, along with macro-remains and loss-on-ignition data.

The results of the stratigraphic survey (Fig. 2) suggest that before peat began to accumulate at site A at ca. 5270 cal BC the local landscape contained several small pools, and the sub-peat topography indicates that peat depths decrease upslope. It would appear that paludification took place from relatively small pre-existing wetland centres such as the landscape depressions described in section 3.1.

Within the basal samples of sequence A (HBA-1a, ca. 5230-4830 cal BC), non-arboreal pollen (NAP) is low (ca. 20%, Fig. 4) and the herbaceous component is dominated by *Filipendula*, Poaceae and Cyperaceae, suggesting that the site itself supported fen vegetation. This is supported by relatively abundant graminoid and moss fragments in the macro-remains (Fig. 6). Arboreal pollen (AP) percentages of around 50% suggest that some woodland was present in the wider landscape, with canopy-forming species including *Corylus*, *Betula*, *Salix* and *Alnus* and an understorey rich in ferns. This is in accordance with the composition of prehistoric woodland inferred from other Orcadian pollen records (e.g. Moar 1969; Keatinge and Dickson 1979; Bunting 1994, 1996; Blackford et al. 1996; de la Vega-Leinert et al. 2000, 2007).

The presence of *Pinus* and *Quercus* pollen in the record from Hobbister is more difficult to interpret. Several older studies concluded that pollen of these taxa in Orcadian sequences originates via long-distance transport from the Scottish mainland (Moar 1969; Davidson et al. 1976; Keatinge and Dickson 1979), whereas more recently others have suggested that they grew locally (Bartlett 1983; Bunting 1994; de la Vega-Leinert et al. 2007). Charcoal from both *Pinus sylvestris* and *Quercus* has been recovered from excavations at Skara Brae (Dickson 2000) and Barnhouse (Cartwright 2005), both in west Mainland, and has been interpreted as reflecting local growth of these taxa. However charcoal of non-native taxa such as *Larix* and *Picea* clearly must have arrived in Orkney as driftwood (Dickson 1992), and it is possible that *Pinus* and *Quercus* were also transported as driftwood. Pollen percentages of 20-30% are usually taken to indicate that pine grew locally (e.g. Bennett 1984; Gear and Huntley 1991; Charman 1994), although Lageard et al. (1999) demonstrate that percentages as low as 3-9% can reflect local presence of this species. It is therefore possible on the basis of pollen percentages of just over 20% at the base of sequence A (Fig. 4; HBA-1a) that pine was a component of the woodland around Hobbister at ca. 5230 cal BC, at about the same time that pine forest was at its maximum extent across northern Scotland (Bennett 1984), with evidence for local presence from as far north as Sutherland between ca. 5650 and ca. 4450 cal BC (Tipping et al. 2008). Unfortunately no pine stomata, which would provide unequivocal evidence for local presence (Parshall 1999; Sweeney 2004; Froyd 2005), were recorded at Hobbister. Low percentages (ca. 1%) of *Quercus* pollen may support the suggestion that oak grew at Scapa Bay, around 5 km to the east, from ca. 5850 cal BC (de la Vega-Leinert et al. 2007) and in west Mainland from ca. 5450 cal BC (Bunting 1994), but oak was probably not locally present at Hobbister.

In HBA-1b, AP begins to decline steadily at ca. 4730 cal BC, and by ca. 4200 cal BC falls to around 20%. These values persist until ca. 3250 cal BC, when AP declines further to just 10% (Fig. 4; HBA-2). There are very few indicators of human activity in the palaeoecological record at this time. Ascospores of *Sordaria*-type (HdV-55A) are recorded at low percentage values (Fig. 4) and may indicate the presence of large herbivore dung, possibly from domesticated grazers. Most Sordariales species are coprophilous, though some occur on rotting wood or other plant material (Lundqvist 1972; van Geel 1976; van Geel et al. 2003). In the absence of any other clear grazing indicators, it is perhaps most likely that these ascospores indicate the presence of dead wood, which would presumably have been plentiful at a time of woodland decline. The macroscopic charcoal (>100 µm; see Fig. 6) record suggests local burning of vegetation, probably due to natural fires. The lithostratigraphy indicates a slight increase in surface wetness at around the same time as the woodland decline, with a change from peat to organic lake mud and the occasional presence of Characeae oospores (Fig. 6) suggesting shallow open water (Haas 1994). Increased percentages of *Sphagnum* spores and Cyperaceae pollen (Fig. 4) support the inference of increased wetness, and increased amounts of identifiable organic matter in the sediment imply better preservation under wetter conditions (Fig. 6).

In the basal pollen assemblages from sequence B, dated to ca. 2570-2460 cal BC, AP is around 50% (Fig. 5; HBB-1a), the dominant taxa being *Betula* and *Corlyus*. This suggests that woodland was present near site B, although it is not recorded by the sequence from site A. This probably reflects differences in spatial sensitivity of the two sequences and will be considered further in the discussion. An alternative explanation for the discrepancy in AP values is that there is some uncertainty regarding the date of the base of sequence B, and it is possible that the basal sediments are actually older. However this implies a very slow accumulation rate for these sediments and is therefore considered unlikely. In HBB-1b AP declines sharply to around 20% at ca. 2430 cal BC, suggesting that this woodland fragment was largely removed. Following woodland loss at site B, Poaceae pollen percentages increase and several indicators of human activity are recorded (HBB-1b), including pollen of taxa that are often associated with pasture and grazing activity (Behre 1981) such as *Plantago lanceolata*, *Ranunculus acris*-type, *Rumex*, *Potentilla*-type, Asteroideae and Lactuceae. Similar suites of pollen taxa have been found to be indicative of local grazing pressure in surface sample studies in a range of habitats similar to those hypothesised to have been present in prehistoric Orkney (e.g. Gaillard et al. 1992, 1994; Hjelle 1998, 1999; Schofield 2007), and these taxa are often interpreted as pastoral indicators in the North Atlantic islands (e.g. Keatinge and Dickson 1979; Edwards and Whittington 1998; Vickers et al., 2005; de la Vega-Leinert et al. 2007, 2012; Lawson et al. 2008). *Sordaria*-type ascospores may indicate the local presence of herbivores or rotting wood. Low values for *Hordeum*-type pollen occur in both sequences just after the woodland decline recorded by sequence B (Fig. 4; HBA-2 and Fig. 5; HBB-1b). Whilst the annular diameter of *Hordeum* pollen falls into the same size class as that of some species of wild wetland grasses such as *Glyceria fluitans* (Andersen 1979), these grasses grow in or adjacent to still or slow-flowing freshwater. There are no indications from the data that this type of habitat was present locally at the time these grains are recorded, so they are assumed to be cereal grains. It seems likely that the cause of woodland decline at site B was at least partly anthropogenic.

Following the final woodland decline, AP generally remains between 10 and 20% for the remainder of both sequences. The exception to this occurs in HBB-1b (Fig. 5) between ca. 2270 and 1770 cal BC, where AP increases to ca. 30% due to an increase in *Alnus* values, indicating that a stand of alder carr woodland became established. This is not represented in the pollen assemblages from sequence A, suggesting the alder carr grew near to site B, perhaps along a stream bank or as a mire-edge community.

Peat is assumed to have spread across the wider landscape from small depressions such as the basin at site A. Peat began to accumulate at ca. 2460 cal BC at site B, about 80 m south and ca. 120 cm higher than site A. Prior to peat formation site B appears to have been a small pool, and the surrounding mire surface supported fen vegetation comprising taxa such as Poaceae, Cyperaceae, *Filipendula* and *R. acris*-type (Fig. 5; HBB-1a). Pollen percentages of heath taxa begin to gradually increase in both sequences in the early-mid Bronze Age, and in HBB-2a there is a large expansion in *Calluna* pollen between ca. 1530 cal BC and ca. 1160 cal BC. There is some evidence for local growth of *Calluna* at site B in the form of stem fragments (Fig. 7), and this may partially account for this short period of high *Calluna* pollen percentages.

The surrounding landscape appears to have been dominated by pastoral vegetation during the Bronze Age, and there are several indications of grazing activity including increased pollen percentages of *R. acris*-type, *Rumex*, *Potentilla*-type, and *P. lanceolata* (Fig. 4; HBA-3a/3b and Fig. 5; HBB-1b/2a/2b). Other grazing indicators such as Lactuceae occur as rare types (HBA-3a/3b). Percentages of *Sordaria*-type ascospores increase, and ascospores of *Podospora*-type (HdV-368), another coprophilous taxon (van Geel et al. 2003), are present in one sample from sequence A (Fig. 4; 219 cm). Given the pollen-based evidence for grazing activity, these ascospores probably reflect the presence of large herbivores. Surface sample studies show that coprophilous fungal spores provide a very localised record of grazing activity (Blackford and Innes 2006; Graf and Chmura 2006), suggesting that grazing may have taken place on the surface of the bog itself. *Hordeum*-type pollen suggests cereal cultivation close to the sampling site (Fig. 4; HBA-3a/3b and Fig. 5; HBB-1b/2a/2b), since cereal pollen is produced in small quantities and is not well-dispersed (Edwards and McIntosh 1988). Occasional occurrences of Caryophyllaceae and Chenopodiaceae pollen may represent an arable weed flora (Behre 1981), providing further evidence for cultivation. Although not common arable weeds today species belonging to these families, including *Chenopodium album*, *Cerastium* spp. and *Stellaria media* are often found as arable weeds in Orkney, both in archaeological contexts and in modern crop fields (Shirreff 1814; Lockton 2002; Hinton 2005; Bond 2007a, 2007b). However these families also contain several coastal, wetland and grassland species, so interpretation of their presence at Hobbister is not straightforward.

Macroscopic charcoal (>100 µm) is almost continuously present in both sequences from the start of the Bronze Age onwards (Fig. 6; Fig. 7) and presumably reflects burning of the local vegetation (Patterson et al. 1987; Whitlock and Larsen 2001; Froyd 2006). Management of heathland by burning can improve the quality of grazing by encouraging dense growth of new shoots of *Calluna*, which contain more nutrients than old-growth heather (Gimingham 1972), and by allowing Poaceae to grow in the gaps created by fire. Heathlands are also subject to natural fires (e.g. Radley 1965; Tipping 1996), but at Hobbister the surrounding landscape was clearly being exploited for agriculture, and the charcoal may therefore result from deliberate burning in an attempt to improve grazing on the site itself.

There is some evidence for a slight increase in surface wetness in zones HBA-3b and HBB-2b (late Bronze Age to early Iron Age), with more identifiable organic material in both sequences interpreted as better preservation under wetter conditions. The abundance of mosses in the macro-remains also increases in both sequences, and seeds/fruits of wetland taxa such as *Juncus*, *Carex* and *Scirpus* are present (Fig. 6; Fig. 7). Increased wetness is supported by a peak in *Filipendula* pollen and the presence of *Drosera* and *Menyanthes* in HBA-3b, and rare occurrences of *Potamogeton* in both HBA-3b (Fig. 4) and HBB-2b (Fig. 5). An increase in Cyperaceae pollen in HBB-2b and declines in *Calluna* in both sequences also suggest wetter conditions.

Major expansions in heath pollen percentages, mainly *Calluna*, occur in both sequences during the early Iron Age at ca. 600-400 cal BC (Fig. 4; HBA-4a and Fig. 5; HBB-3), probably reflecting the ongoing spread of peat and heathland into drier parts of the landscape. There is some evidence for farming, with pollen of pastoral indicators such as *R. acris*-type, *Rumex*, *Potentilla*-type and *P. lanceolata* represented throughout the Iron Age, though percentages are lower than previously. Other grazing indicators such as Asteroideae and Lactuceae are present as rare types. *Sordaria*-type ascospores are still present, and *Podospora*-type occurs at a single level in sequence A (Fig. 4; 83 cm). *Hordeum*-type pollen occurs sporadically, along with pollen of the potential arable weeds Caryophyllaceae and Chenopodiaceae. The almost continuous presence of macroscopic charcoal (>100 µm) in both sequences (Fig. 6; Fig. 7) implies that burning of local vegetation continued, and an increase in microscopic charcoal (Fig. 4; Fig. 5) may indicate that burning also occurred in the wider landscape. This might reflect greater efforts to improve grazing quality in response to the increasing proportion of heathland around the site.

After the Iron Age, it appears that the vegetation at Hobbister changed little. Heathland continued to expand. A lack of microscopic charcoal in the post-Iron Age record along with a decline in percentages of Poaceae pollen at ca. cal AD 670-790 (Fig. 4; HBA-4c; Fig. 5; HBB-4) implies that pasture in the vicinity was reduced and heathland management no longer occurred. Evidence that low intensity grazing continued is provided by low values for *P. lanceolata* pollen and *Sordaria*-type ascospores in both sequences. It appears that no arable farming took place near the site after the end of the Iron Age, though lack of evidence is perhaps due to larger sampling intervals in the later parts of the sequences. Human activity in the vicinity of the site seems to have been limited to low intensity stock grazing.

4. Discussion

4.1 Heathland formation

At Hobbister, peat began to accumulate from ca. 5270 cal BC, and paludification occurred from within multiple, relatively small basin centres. Peat had spread upslope to the location of sequence B by ca. 2460 cal BC, and *Calluna* heathland formed an important component of the landscape by the mid Bronze Age (ca. 1400 cal BC). An increase in surface wetness occurred in the later Bronze Age (ca. 1200-800 cal BC), and it is possible that this is linked to widespread climatic deterioration across north-west Europe at ca. 850 cal BC (see section 4.3). The shift to wetter conditions at Hobbister did not immediately result in widespread heath formation, which occurred in the early Iron Age (ca. 600-400 cal BC) when there is clear evidence for relatively intensive human activity around the site. It seems likely that the cause of heathland expansion was a combination of wetter conditions leading to soil deterioration via leaching and podsolisation (Gimingham 1972), and human pressure on the environment. Similar reasons were invoked by de la Vega-Leinert et al. (2007) for heathland development at the nearby site of Scapa Bay from ca. 650 cal BC. As with woodland decline (Farrell et al. 2014), the timing of heath formation in Orkney is asynchronous across the archipelago and the causes of both events are equally complex, involving a range of climatic, pedological and anthropogenic factors acting in combination and varying between sites (Jones 1979; Keatinge and Dickson 1979; Bunting 1996; de la Vega Leinert et al. 2007; Tisdall et al. 2013).

4.2 Woodland history

The woodland that was initially present at Hobbister was dominated by birch and hazel, and similar prehistoric woodland has been inferred from other Orcadian pollen records (e.g. Moar 1969; Keatinge and Dickson 1979; Bunting 1994, 1996; Blackford et al. 1996; de la Vega-Leinert et al. 2000, 2007). More recent palaeoecological studies on Orkney suggest that pine and oak were locally present on Mainland (Bunting 1994; de la Vega Leinert 2007; Farrell et al. 2014), as do archaeological finds of charcoal from both taxa (Dickson 2000; Cartwright 2005), and the palynological sequences from Hobbister support these interpretations. Birch woodland was a prized resource in the North Atlantic region during the Norse and medieval periods (e.g. Simpson et al. 2003; Church et al. 2007; Schofield and Edwards 2011), and presumably was similarly valued in Orkney. Greater woodland diversity in some areas would have increased the range of possible uses and value of the resource to the islanders (Farrell et al. 2014).

There is a long-held assumption that Orkney's woodland was almost entirely cleared to provide land for agriculture within a few hundred years of the onset of the Neolithic (Davidson and Jones 1985; Tipping 1994; Dickson 2000), but it is clear that woodland decline did not occur synchronously across the islands, and variations in timing of this event suggest that it resulted from complex interactions between local climatic conditions and pedological and anthropogenic factors that varied between sites (Farrell et al. 2014). The cause of the first woodland decline at Hobbister at ca. 4730 cal BC is unclear. Mesolithic human disturbance has been invoked as the cause of temporary woodland declines on Hoy

(Blackford et al. 1996) and in west Mainland (Bunting 1994), but there are few signs of anthropogenic activity in the palaeoecological record from Hobbister. There is evidence for an increase in surface wetness at the time of woodland decline, and in view of the early date of this event and the lack of any clear evidence for human activity, the main cause is likely to have been the change in local hydrological conditions and encroachment of peat across the wider landscape.

This woodland loss may have been quite local, as woodland was still present close to site B at ca. 2570 cal BC. Woodland decline in sequence B takes place at ca. 2430 cal BC in the later Neolithic, at a time when there is evidence for local grazing activity and cereal cultivation. Human activity has been invoked as the cause of woodland decline at several Orcadian sites, including Quoyloo Meadow (Bunting 1994), Scapa Bay (de la Vega-Leinert et al. 2007) and Blows Moss (Farrell et al. 2014), and is likely to have been at least partly responsible for the second episode of woodland loss at Hobbister.

Pollen taphonomy is complex, and pollen sequences from different sedimentary basins show distinct differences due to variations in spatial sensitivity. The relevant source area of pollen (RSAP), defined as the area beyond which the relationship between pollen loading and vegetation abundance does not improve (Sugita 1994), is mainly a function of basin size and of the spatial distribution and size of different vegetation patches within the landscape (Sugita 1994; Bunting et al. 2004; Broström et al. 2005; Nielsen and Sugita 2005; Hellman et al. 2009). It is assumed that the distribution of pollen remaining airborne with increasing distance from the source follows a declining trend with an initial rapid rate of decrease which then slows to form a long 'tail' where low amounts of pollen remain airborne over long distances (Prentice 1985). An example of such a curve is shown in Fig. 8. The 'tail' represents the contribution of the pollen source to the background or long-distance component of the pollen signal coming from beyond the RSAP. Sites A and B are located far enough apart that a substantial patch of woodland close to site B would only contribute 'background' pollen to the assemblage at site A. Studies of modern pollen-vegetation relationships demonstrate this rapid decline in arboreal pollen percentages within 100 m of the edge of substantial stands of woodland (Tinsley and Smith 1974; Gearey and Gilbertson 1997; Bunting 2002). The pollen profiles from Hobbister serve to further demonstrate the problems of detecting woodland remnants in a predominantly open landscape, and highlight the additional information that can be obtained by having more than one pollen profile.

4.3 The Bronze Age landscape at Hobbister

At the start of the Bronze Age (ca. 2000 BC) the landscape at Hobbister was largely open, with grassland being the predominant vegetation type. The landscape was utilised for pastoral agriculture, with several grazing indicators represented in the pollen record. The fungal spore evidence suggests that grazing took place locally, perhaps on the peatland surface itself, and there is evidence for grazing activity on wetlands elsewhere in Orkney at this time (Farrell 2009). There is also palynological evidence for low intensity cereal cultivation at Hobbister during the Bronze Age. The palaeoenvironmental evidence for agriculture seems to support the tentative interpretation of the sub-peat dykes as the remains of a Bronze Age field system (Sharman and Hollinrake 2007).

By ca. 1400 cal BC, in the mid Bronze Age, heathland was an important component of the landscape at Hobbister and there is evidence that grazing continued locally. The almost continuous presence of macroscopic charcoal (>100 µm) in both sequences from the early Bronze Age onwards is likely to reflect deliberate burning of the local vegetation in an effort to improve grazing quality both on the site itself and in the surrounding landscape. Evidence for management of heathland by burning in the Bronze Age occurs in environmental records from Denmark (Odgaard 1992; Karg 2008) and Norway (Prøsch-Danielsen and Simonsen 2000), and Bunting (1996) suggests that heathland on Rousay may have been managed in this way during the Iron Age. The exploitation of heathland as a grazing resource also took place on Stronsay throughout the Bronze Age (Tisdall et al. 2013).

In Orkney the Bronze Age settlement evidence and barrow cemeteries indicate a scattered settlement pattern and more land, including areas such as heathland that may previously have been perceived as too marginal for agriculture, would have been required to support this more dispersed population. Land management that included ‘infield-outfield’ may have been employed. In this system, fields nearest to a settlement (‘infields’) would have been cultivated more or less continuously through the addition of fertiliser in the form of dung, turf and seaweed, while those beyond (‘outfields’) would have been cultivated on a partial and temporary basis and manured only through the folding of livestock in the summer prior to cultivation (Dodgshon 1973; Whittington 1973). This form of land management was practised throughout Scotland during the historic period (Dodgshon 1973, 1980; Whittington 1973; Whyte 1979) and in west Mainland, Orkney from the late Norse period (ca. AD 1100-1230) until the late nineteenth or early twentieth centuries (Simpson 1993, 1997). Evidence from Tofts Ness on Sanday indicates that the development of intensive infield land management strategies at this site occurred as early as the Bronze Age, allowing continued cultivation in an increasingly marginal environment (Dockrill et al. 2007), and Jones and Richards (2005) suggest that at Barnhouse in west Mainland, cereals may have been grown within an infield system during the later Neolithic. In Denmark, Odgaard and Rasmussen (2000) demonstrate that the pattern of land-use present in the early nineteenth century has been in existence since the late Bronze Age, and it is distinctly possible that Orcadian land management practices have a similarly long history. On the basis of the palaeoecological evidence it seems likely that the field system at Hobbister, located ca. 250 m from the sampling sites (Fig. 1), represents part of an infield-outfield area where relatively intensive mixed agriculture based on cereal cultivation and livestock rearing took place. Given the small scale of the field system, and the necessity of protecting crops from freely roaming livestock, it seems most likely that the dykes represent part of the infield.

In southern Britain, various hypotheses regarding the social transformations that led to the development of field systems have been put forward, ranging from the emergence of an elite class requiring support from an agricultural surplus which would in turn have required new farming methods to facilitate intensification (Yates 1999; Fleming 2008), to the formalisation of territorial boundaries in response to social fragmentation (Brück 2000; Johnston 2005). Since the economy at Hobbister was predominantly pastoral, it might be expected that the effects of intensification would be most obvious in the outfield where livestock were concentrated. It seems likely that the pollen sequences were extracted from the outfield area, given their distance from the hypothesised infield system (ca. 250 m; Fig. 1) and the palaeoenvironmental data recovered from them indicate that levels of activity during the Bronze Age remained similar to those in the Neolithic. There is therefore little evidence to support the hypothesis that the Hobbister field system was constructed to facilitate agricultural intensification, and it is more likely that the stone dykes reflect a reorganisation of the agricultural landscape caused by social and cultural changes connected with a more dispersed settlement pattern.

At Hobbister, the suitability of land for cultivation would have been dependent on local hydrological conditions and increased wetness would have rendered the soil unable to support cereal crops, particularly in lower-lying areas. There is some evidence that the surface of the bog at Hobbister became slightly wetter during the later Bronze Age (ca. 1200-800 cal BC). This roughly coincides with a widespread shift to wetter conditions recorded at ca. 850 cal BC in several peat-derived climate records from north-west Europe (e.g. Charman 1995; van Geel et al. 1996; Chambers et al. 1997; Barber et al. 2004; Mauquoy et al. 2004; Blundell and Barber 2005; Swindles et al. 2007). Phases of increased storminess recorded between ca. 850 and 310 cal BC in the sequence from Mill Bay on Stronsay have been linked to this climatic deterioration (Tisdall et al. 2013). At that site, palaeoecological evidence indicates a reduction in grazing pressure following this event, perhaps due to increased accumulation of wind-blown sand, which would have reduced grazing quality. Despite this, the heathland at Mill Bay continued to be grazed throughout the Bronze Age (Tisdall et al. 2013). At Hobbister there is no indication of a decline in grazing intensity following the shift to wetter conditions, and there is evidence that cereal cultivation continued at least until the late Iron Age. However, local people would have been well aware of the gradual encroachment of peat onto formerly more productive land, and one response to this change may have been the votive deposition of a valuable bronze axehead in the postulated outfield at Hobbister.

Fontijn (2002) suggests that wetlands may have represented social boundaries in the past, and that rivers, having opposing banks, may have been seen as boundaries dividing different social groups, whereas bogs may have been viewed differently. Mullin (2012) argues that while the deposition of metalwork in rivers may have been a demonstration of power and prestige to other social groups, bogs may have been foci for acts of votive deposition aimed at reinforcing social cohesion within communities. There are few streams and no major river systems in Orkney, and it may be that the coastline with its numerous bays and inlets played a similar role in dividing communities here. If a revised form of Mullin’s (2012) hypothesis is accepted, then the deposition of the Hobbister axe may be viewed as an attempt by the people using the nearby field system to maintain community integrity during a time of perceptible environmental change resulting in the gradual loss of agricultural land. Votive deposition of precious metalwork has been interpreted as a response to the encroachment of peat over farmland elsewhere in Britain during the Bronze Age (Van de Noort 2001). Further distinctions regarding votive wetland deposits could be made, on the basis, for example, of types of artefacts or whether they were intact or broken when deposited (Yates and Bradley 2010). A more detailed study of existing Orcadian Bronze Age artefacts is clearly needed before drawing any firm conclusions, but this study demonstrates the potential value of detailed palaeoenvironmental reconstruction in the interpretation of votive deposits.

5. Conclusions

The peat sequences recovered from Hobbister are a valuable addition to current understanding of later prehistoric vegetation dynamics and environmental change in Orkney. The data have greatly improved our knowledge of Bronze Age environments in the islands, previously known from only three securely dated sequences. In spite of the relatively large volume of palaeoecological work that has been undertaken in Orkney, it is clear that there is still more to learn and that new palaeoenvironmental records have the potential to significantly enhance our understanding. The Hobbister sequences emphasise the site-specific nature and complexity of causal patterns with regard to woodland decline and the formation and expansion of heathland.

The data from Hobbister also highlight the limitations of palynological studies based on a single sequence, and demonstrate the need to interpret pollen data spatially. It is recognised that taking multiple cores from a site is not always feasible, but the danger of over-extrapolation from trends observed in a single pollen sequence is clear.

Whilst the palaeoenvironmental data from Hobbister do not categorically rule out, nor fully support, any of the arguments proposed by archaeologists for the construction of field systems and votive deposition of precious metalwork in wetlands during the British Bronze Age, this study has demonstrated the potential that detailed palaeoenvironmental data have for testing archaeological hypotheses and informing interpretation. There is a clear need for landscape-scale, multi-site studies incorporating archaeological, palaeoenvironmental and geoarchaeological data to enhance understanding of the Bronze Age in Orkney and more widely.

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Fig. 1 Location maps showing (A) the position of Orkney in Scotland; (B) location of Hobbister and other palaeoecological sites mentioned in the text (BM = Blows Moss; GM = Glims Moss; Ho = Hobbister; LK = Loch of Knitchen; MB = Mill Bay; QM = Quoyloo Meadow; SB = Scapa Bay); (C) detailed map showing contour lines (m), extent of the palaeoenvironmental survey at Hobbister, locations of peat sequences investigated, findspot of the Bronze Age axehead, and location of other archaeological sites recorded by Sharman and Hollinrake (2007)

Fig. 2 Sub-peat topography at Hobbister as revealed by the borehole survey. Lighter shading indicates areas of lower ground, as measured below an arbitrary field datum. Peat thickness at each borehole location is labelled in metres

Fig. 3 Age-depth models for sequences A and B based on linear interpolation and extrapolation using CLAM 2.2 (Blaauw 2010). For each calibrated date, 1σ and 2σ ranges are indicated. Shading at either side of the age-depth curve indicates 95% confidence limits

Fig. 4 Percentage pollen diagram, Sequence A. Shaded curves indicate x10 exaggeration (selected taxa only)

Fig. 5 Percentage pollen diagram, Sequence B. Shaded curves indicate x10 exaggeration (selected taxa only)

Fig. 6 Macro-remains and loss-on-ignition data for sequence A. Abundances as follows: 5 = dominant, 4 = abundant, 3 = frequent, 2 = occasional, 1 = rare, '+' = very rare/present. Abbreviations for macro-remains: a, achene; fr, fruit; lf, leaf; n, nutlet; s, seed; UOM, unidentifiable organic matter

Fig. 7 Macro-remains and loss-on-ignition data for sequence B. Conventions as in Fig. 6

Fig. 8 Conceptual model illustrating the mechanism by which it is possible for a substantial patch of woodland located close to site B to be unrecorded in the pollen sequence from site A. The distribution of pollen remaining airborne with increasing distance from the source is assumed to show an initial rapid rate of decrease which then slows to form a long 'tail' where low amounts of pollen remain airborne over long distances. Sites A and B are located far enough apart that a substantial patch of woodland near to site B would only contribute 'background' pollen to the assemblage at site A. If sequence A were studied in isolation, the low AP at ca. 2570-2460 cal BC might be interpreted as reflecting a complete lack of woodland in the surrounding landscape.

Table 1 Radiocarbon age estimates from the two Hobbister sequences. Calibrated ages are rounded to the nearest 10 years

Table 2 Lithostratigraphic units in the two Hobbister sequences

Table 3 Sequence A: local pollen assemblage zone characteristics, main macro-remains and loss-on-ignition data

Table 4 Sequence B: local pollen assemblage zone characteristics, main macro-remains and loss-on-ignition data

Fig. 1 Location maps showing (A) the position of Orkney in Scotland; (B) location of Hobbister and other palaeoecological sites mentioned in the text (BM = Blows Moss; GM = Glims Moss; Ho = Hobbister; LK = Loch of Knitchen; MB = Mill Bay; QM = Quoyloo Meadow; SB = Scapa Bay); (C) detailed map showing contour lines (m), extent of the palaeoenvironmental survey at Hobbister, locations of peat sequences investigated, findspot of the Bronze Age axehead, and location of other archaeological sites recorded by Sharman and Hollinrake (2007)

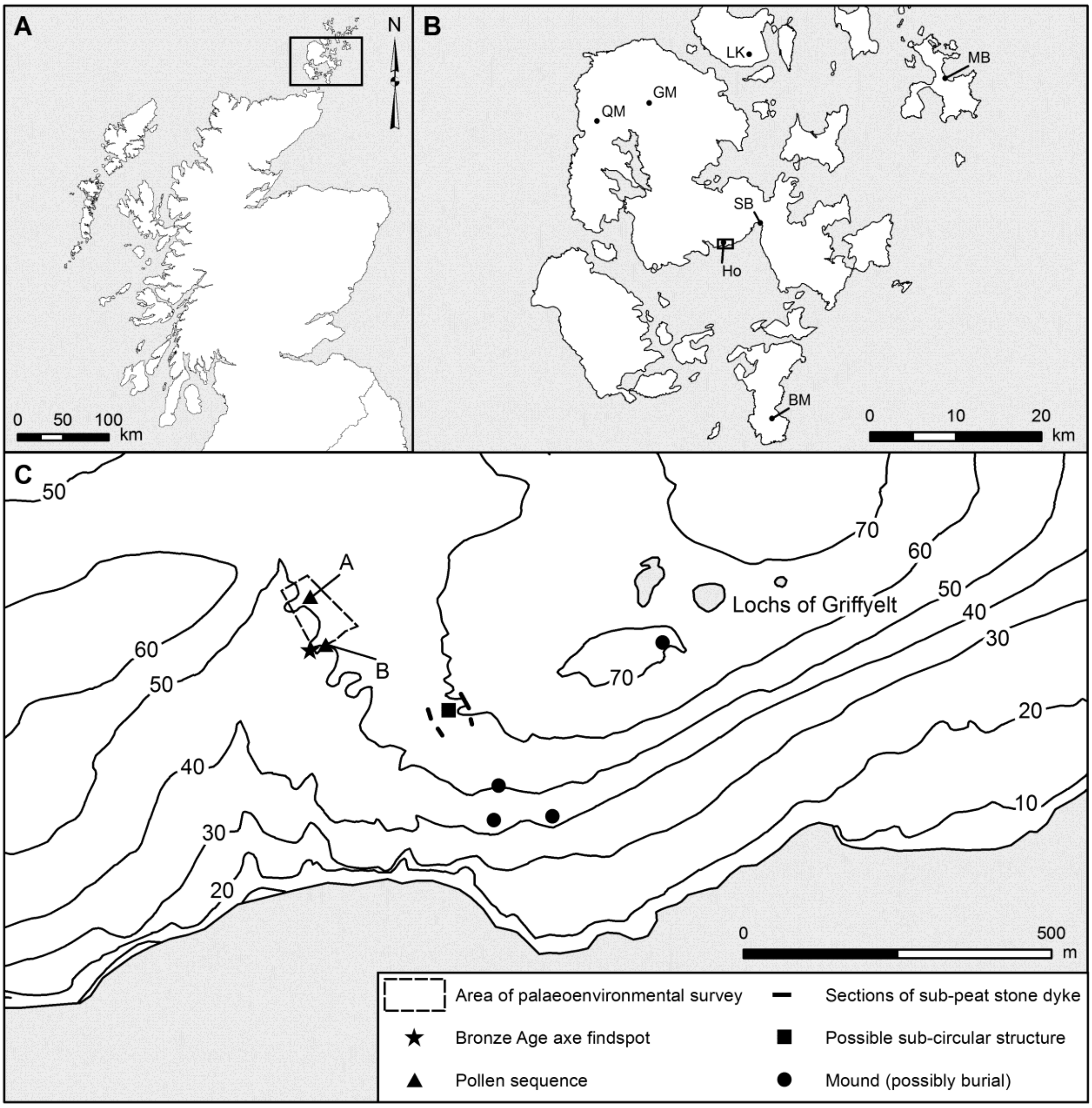


Fig. 2 Sub-peat topography at Hobbister as revealed by the borehole survey. Lighter shading indicates areas of lower ground, as measured below an arbitrary field datum. Peat thickness at each borehole location is labelled in metres

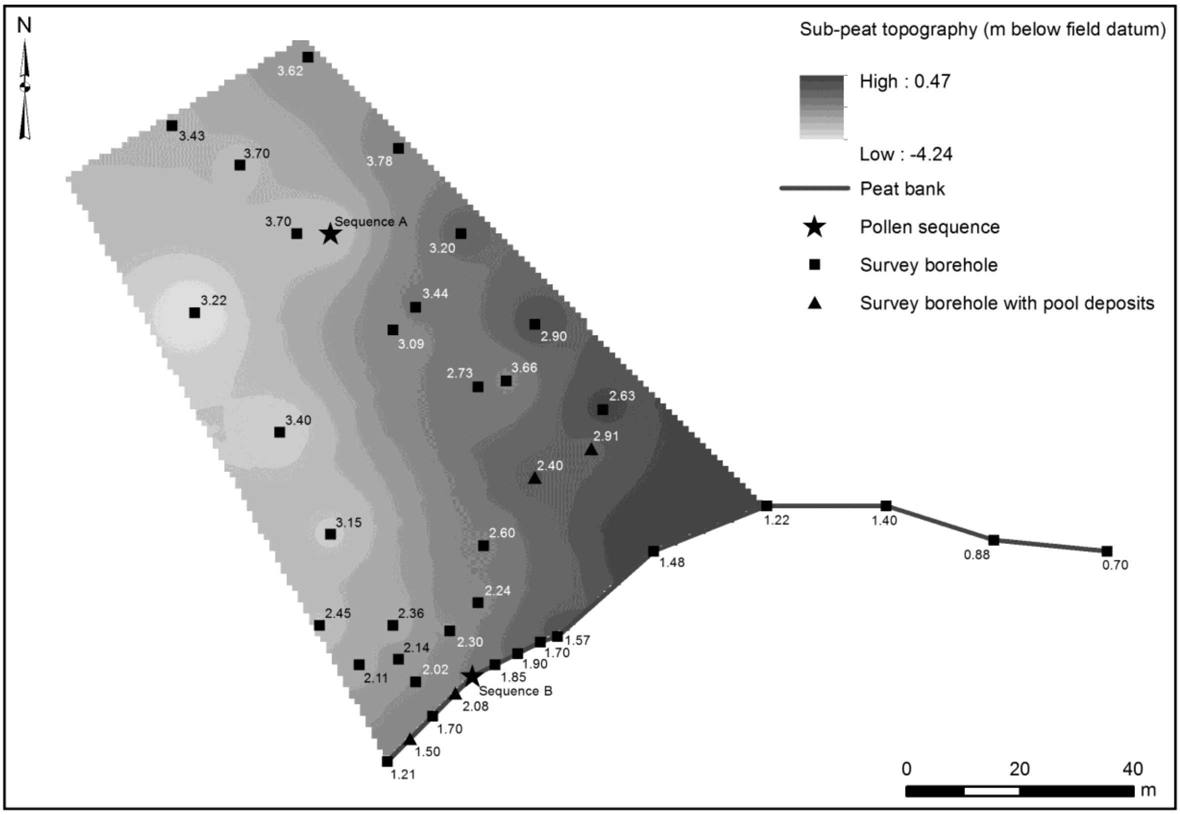


Fig. 3 Age-depth models for sequences A and B based on linear interpolation and extrapolation using CLAM 2.2 (Blaauw 2010). For each calibrated date, 1σ and 2σ ranges are indicated. Shading at either side of the age-depth curve indicates 95% confidence limits

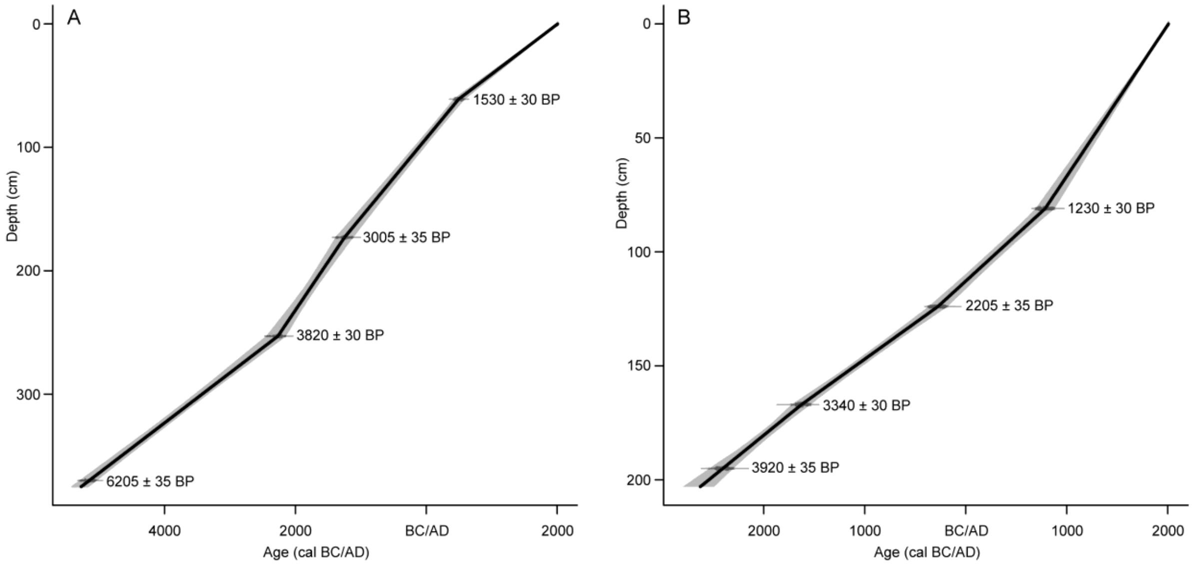


Fig. 4 Percentage pollen diagram, Sequence A. Shaded curves indicate x10 exaggeration (selected taxa only)

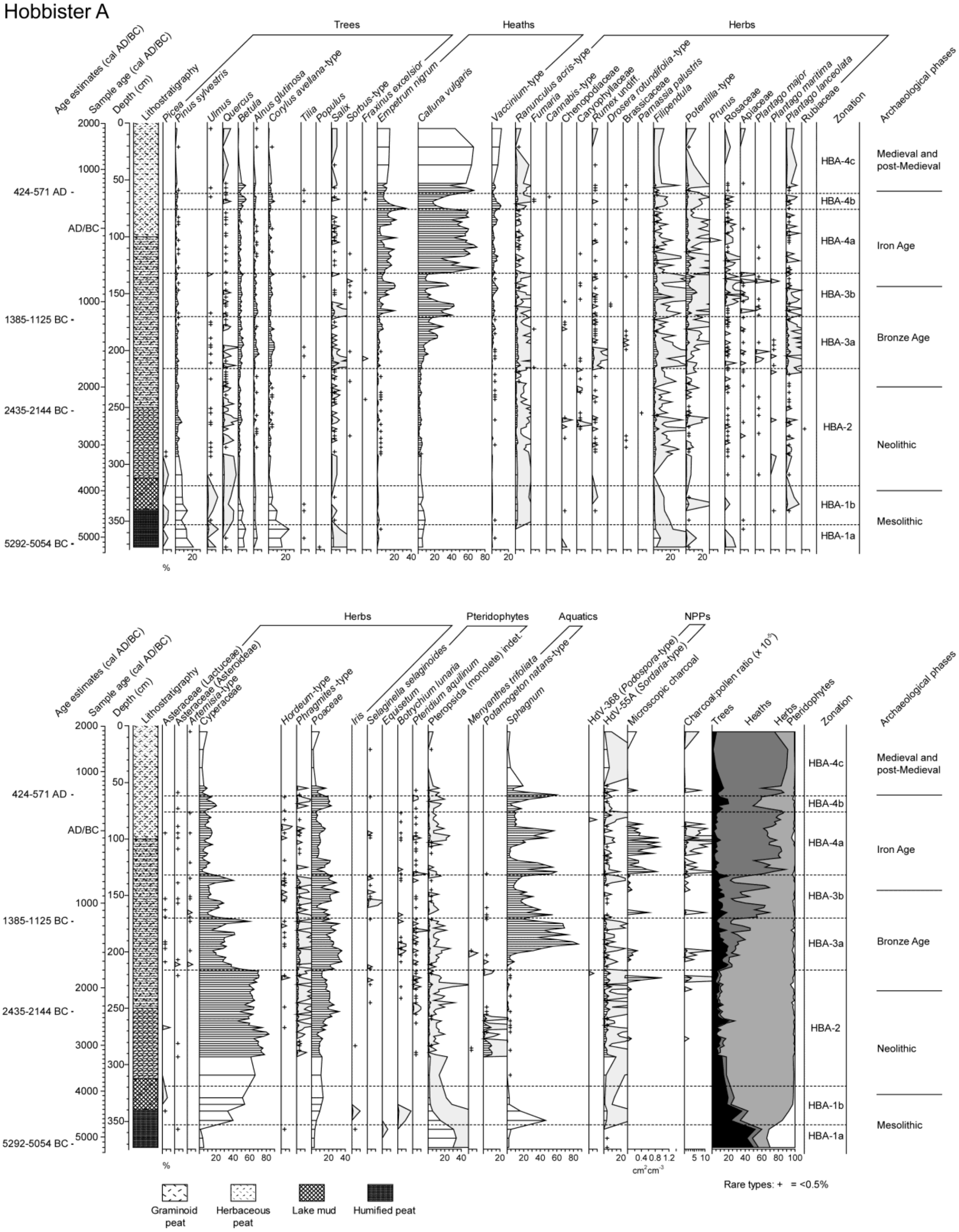


Fig. 5 Percentage pollen diagram, Sequence B. Shaded curves indicate x10 exaggeration (selected taxa only)

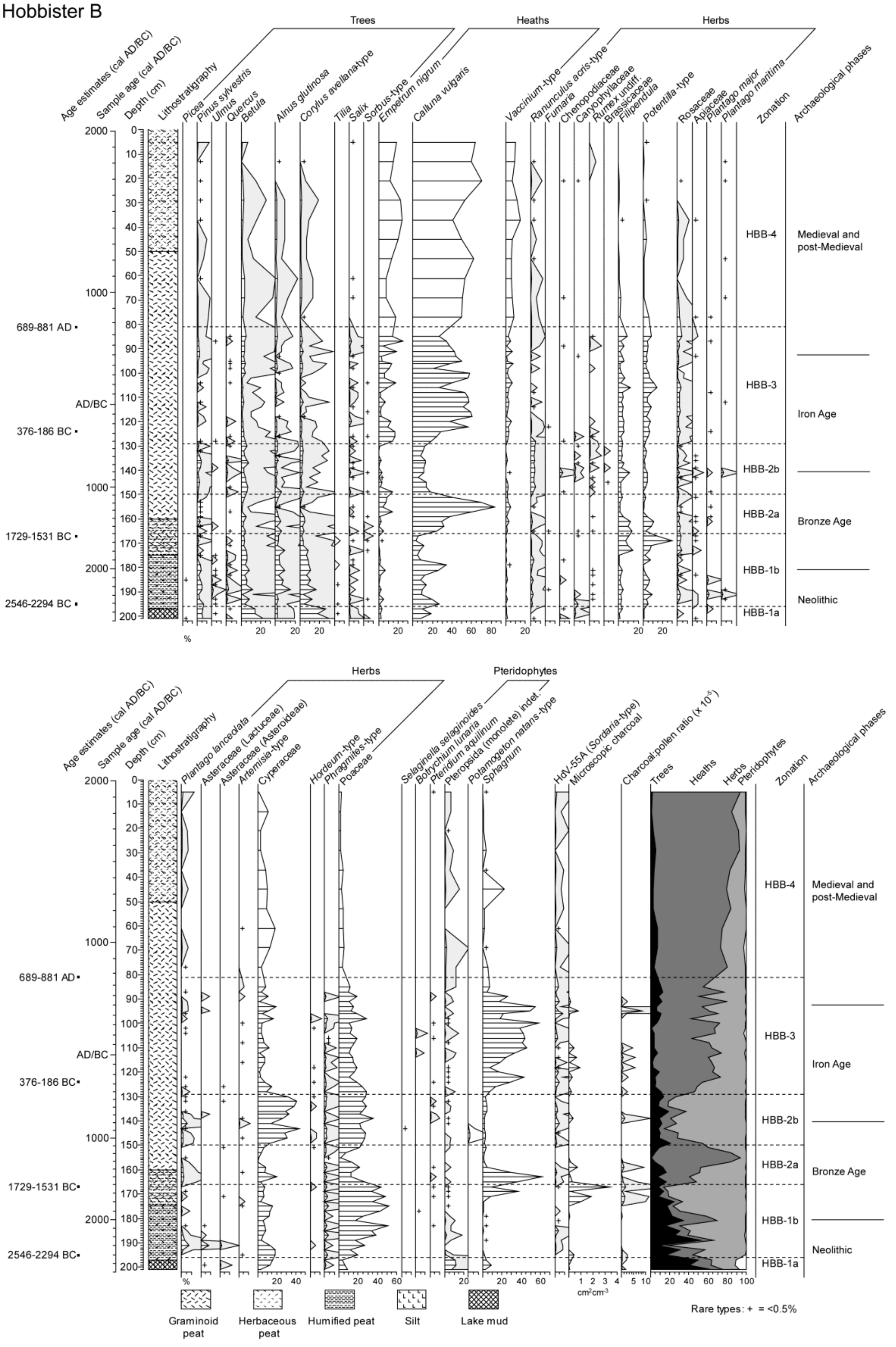


Fig. 6 Macro-remains and loss-on-ignition data for sequence A. Abundances as follows: 5 = dominant, 4 = abundant, 3 = frequent, 2 = occasional, 1 = rare, '+' = very rare/present. Abbreviations for macro-remains: a, achene; fr, fruit; lf, leaf; n, nutlet; s, seed; UOM, unidentifiable organic matter

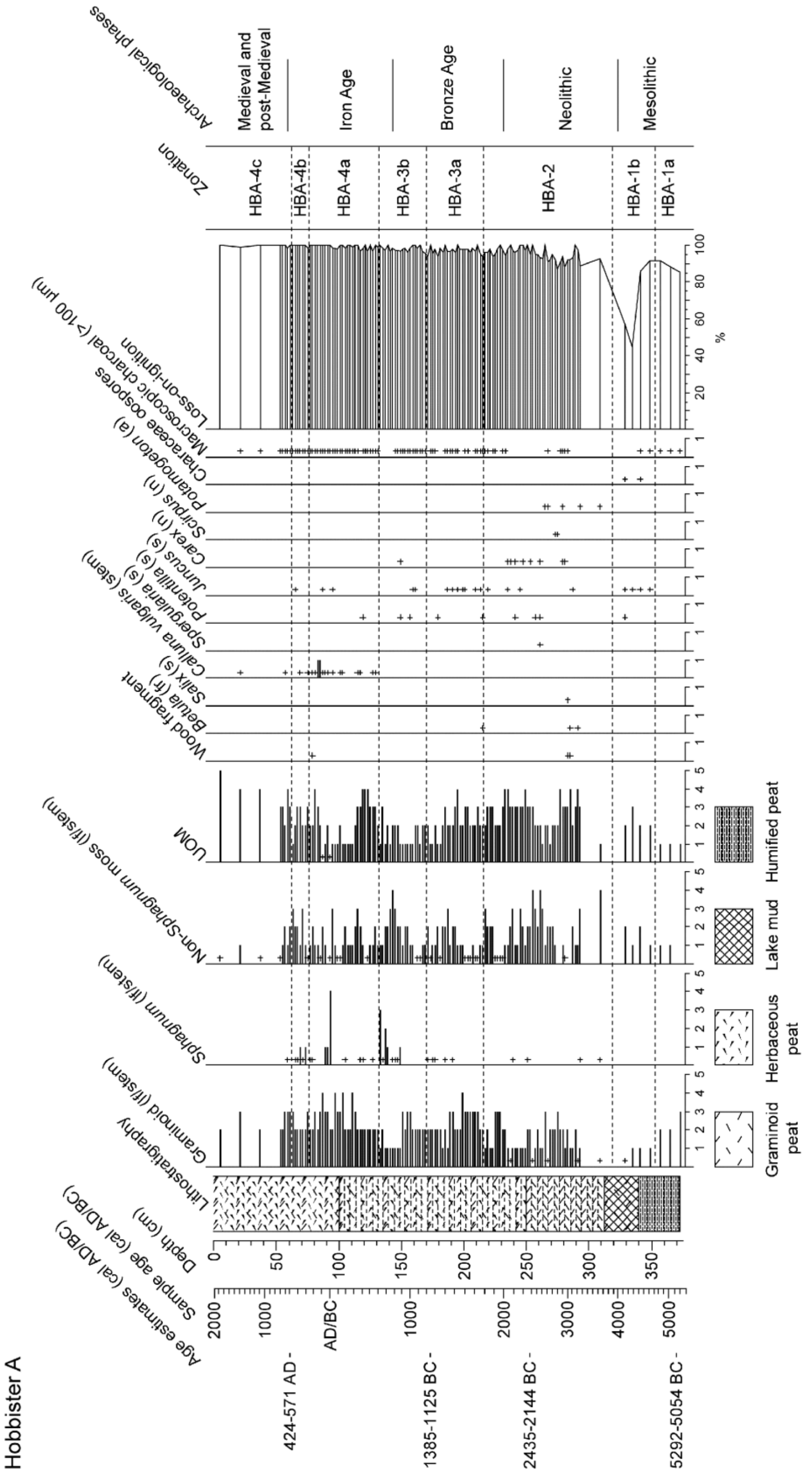
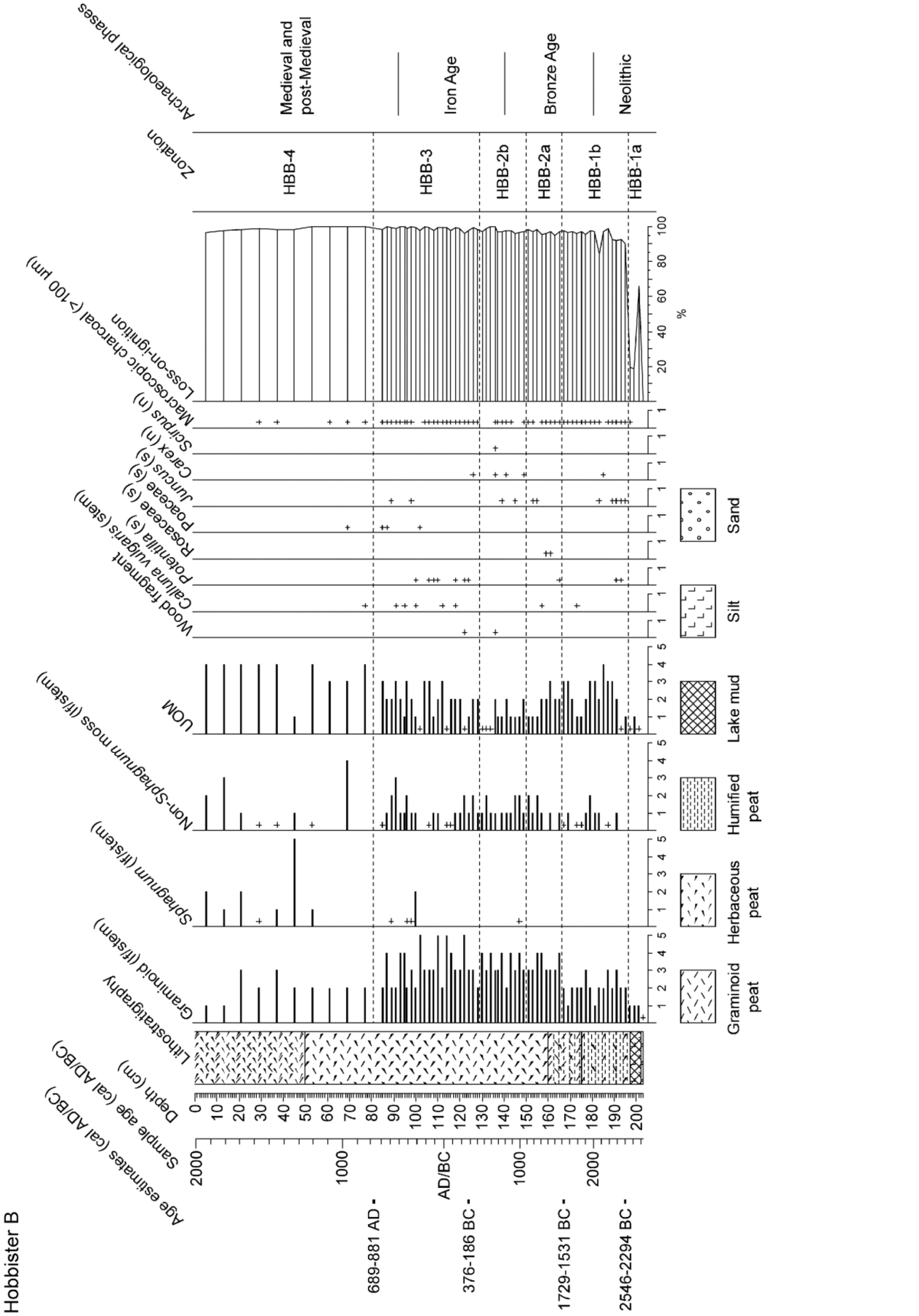


Fig. 7 Macro-remains and loss-on-ignition data for sequence B. Conventions as in Fig. 6



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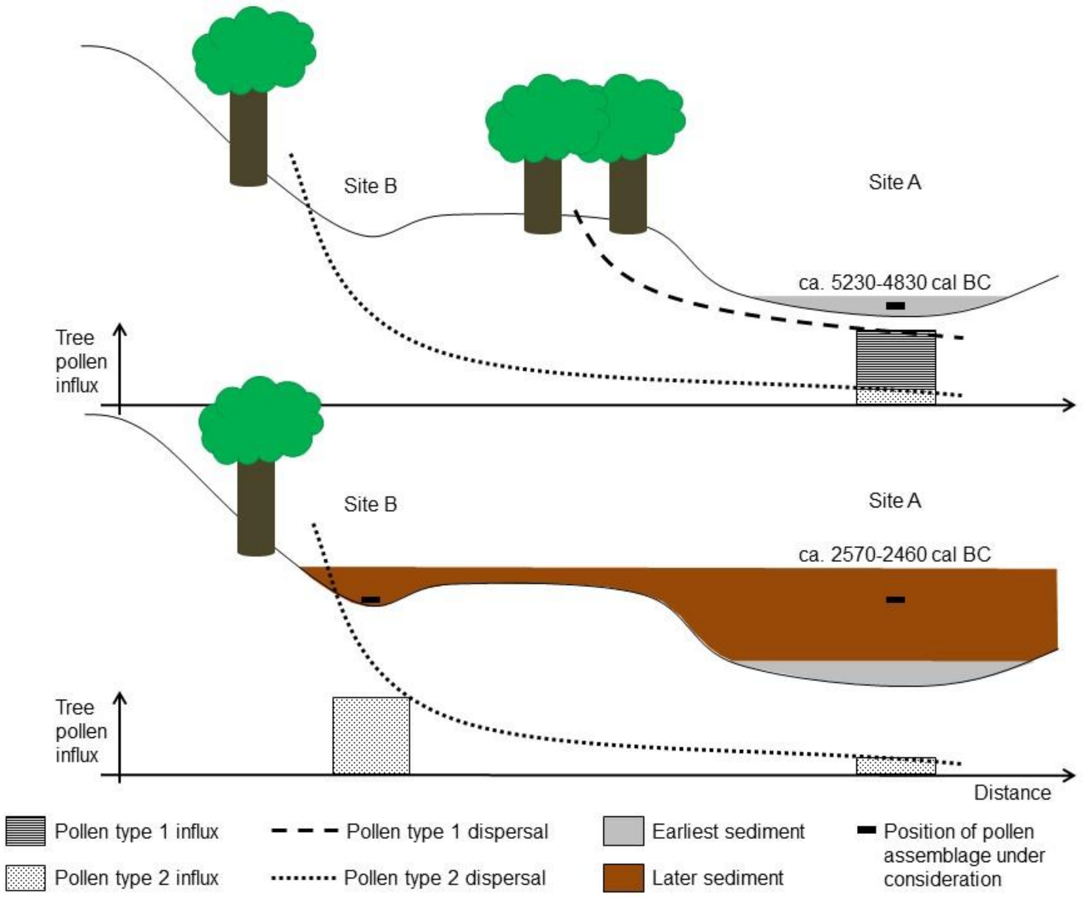

Table 1 Radiocarbon age estimates from the two Hobbister sequences. Calibrated ages are rounded to the nearest 10 years

Laboratory code	Depth (cm)	^{14}C age BP (1σ)	AMS $\delta^{13}C$	Calibrated age range BP (2σ)	Calibrated calendar age range (2σ)
Sequence A					
SUERC-19832	370	6205 ± 35	-27.1	7240-7000	5290-5050 BC
SUERC-22859	253	3820 ± 30	-28.2	4390-4090	2440-2140 BC
SUERC-19831	173	3005 ± 35	-29.7	3340-3080	1390-1130 BC
SUERC-22858	61	1550 ± 30	-26.8	1530-1380	AD 420-570
Sequence B					
SUERC-19837	195	3920 ± 35	-27.7	4500-4240	2550-2290 BC
SUERC-22864	167	3340 ± 30	-28.0	3680-3480	1730-1530 BC
SUERC-19833	124	2205 ± 35	-27.2	2330-2140	380-190 BC
SUERC-22860	81	1230 ± 30	-27.7	1260-1070	AD 690-880

Table 2 Lithostratigraphic units in the two Hobbister sequences

Depth (cm)	Troels-Smith (1955) classification	Munsell colour	Description
Sequence A			
0-100	Dh3, Dg1, Sh+	7.5YR 2.5/1 Black	Peat with identifiable fragments of herbaceous plants, mainly >2 mm
100-250	Dh2, Dg1, Sh1	10YR 2/2 Very dark brown	Peat with lower proportion of identifiable herbaceous plant fragments (mainly >2 mm); some humified organics beyond identification
250-312	Dg3, Sh1, Dh+	2.5YR 2.1/1 Black	Peat with identifiable herbaceous plant fragments <2 mm; some humified organics beyond identification
312-340	Ld3, Dg1, Ag+	10YR 4/3 Brown	Fine organic lake mud with some identifiable plant fragments <2 mm in size
340-375	Sh4, Dg+	10YR 2/1 Black	Well humified peat
Sequence B			
0-50	Dh3, Dg1, Sh+	7.5YR 3/4 Dark brown	Peat with identifiable fragments of herbaceous plants, mainly >2 mm
50-160	Dh2, Dg2	10YR 2/2 Very dark brown	Peat with identifiable fragments of herbaceous plants ranging from 0.1-2 mm
160-175	Dg2, Dh1, Sh1	7.5YR 2.5/1 Black	Peat with lower proportion of identifiable herbaceous plant fragments (mainly <2 mm); some humified organics beyond identification
175-197	Sh2, Dg1, Dh1	7.5YR 2.5/1 Black	Well humified peat with some identifiable herbaceous plant fragments 0.1-2 mm in size
197-202	Ld3, Ag1	10YR 4/2 Dark greyish brown	Fine organic lake mud with some silt content
202-203	Gmin4	2.5Y 4/2 Dark greyish brown	Fine greyish-brown sand

Table 3 Sequence A: local pollen assemblage zone characteristics, main macro-remains and loss-on-ignition data

Zone / Subzone*	**Description**
HBA-4 / HBA-4c 0-62 cal AD 480-1950	AP 5-10%; heath taxa increase to ca. 70%; herbaceous pollen ca. 10%; low values for AIs; *Sordaria*-type ca. 5%; small peaks of microscopic charcoal at base and top of subzone *Calluna* stem fragments occur sporadically; macroscopic charcoal in most samples; LOI almost 100%
HBA-4 / HBA-4b 62-76 cal AD 270-480	AP ca. 15%; heath taxa ca. 45%; herbaceous taxa ca. 35% (mostly Cyperaceae and Poaceae); low values for AIs; *Hordeum*-type pollen at base and top of subzone; low *Sordaria*-type Occasional *Calluna* stem fragments; macroscopic charcoal consistently present; LOI almost 100%
HBA-4 / HBA-4a 76-132 cal AD 270 – 610 cal BC	AP <10%; heath taxa dominant (ca. 70%); herbaceous taxa ca. 25% (mainly Cyperaceae and Poaceae); AIs less frequent than previously; *Hordeum*-type present sporadically; *Sordaria*-type ca. 1%; *Podospora*-type present; microscopic charcoal consistently present Wood fragments at 79 cm; *Calluna* stem fragments in several samples; occasional *Potentilla* and *Juncus* seeds; macroscopic charcoal consistently present; LOI 95-100%
HBA-3 / HBA-3b 132-170 610-1210 cal BC	AP ca. 10%; heath taxa (*Calluna* and *Empetrum*) and herbaceous taxa (Cyperaceae, Poaceae *Filipendula* and *Potentilla*-type) alternately dominant; low AI percentages; *Hordeum*-type present sporadically; *Sordaria*-type 1-2%; peak in microscopic charcoal near base of subzone Occasional remains of *Potentilla*, *Juncus* and *Carex*; macroscopic charcoal consistently present in lower part of subzone; LOI 95-100%
HBA-3 / HBA-3a 170-216 1210-1820 cal BC	AP ca. 15%; heath taxa increase to ca. 15%; herbaceous taxa ca. 70%; *P. lanceolata* 2-5%; other AIs present at low percentage values; *Hordeum*-type sporadic throughout upper half of subzone; *Sordaria*-type 1-2%; low peaks of microscopic charcoal in lower half of subzone *Betula*, *Potentilla* and *Juncus* remains; macroscopic charcoal in most samples; LOI 95-100%
HBA-2 216-319 1920-3920 cal BC	AP declines further to ca. 10%; herbaceous pollen ca. 90%; low AI percentages; occasional *Hordeum*-type in upper half of subzone; *Potamogeton* pollen ca. 10% from 291-263 cm; *Sordaria*-type consistently present (ca. 5-15%); *Podospora*-type at top of zone; very low, isolated peaks of microscopic charcoal Occasional wood fragments; *Betula*, *Salix*, *Spergularia*, *Potentilla*, *Juncus*, *Carex*, *Scirpus* and *Potamogeton* remains; macroscopic charcoal in middle and upper parts of zone; LOI 90-100%, increasing towards top of zone
HBA-1 / HBA-1b 319-353 3920-4760 cal BC	AP declines to ca. 20%; herbaceous taxa increase to ca. 70%; low AI percentages; pteridophyte spores decline to ca. 5%; *Sordaria*-type present Several *Juncus* seeds; occasional Characeae oospores; macroscopic charcoal in basal samples; LOI ca. 90% at base of subzone, declining to ca. 45% at 335 cm, increasing again to ca. 75% at top
HBA1 / HBA-1a 353-373 4760-5250 cal BC	AP ca. 50% (mainly *P. sylvestris*, *Betula* and *Corylus*-type); heath taxa ca. 5%; herbaceous taxa ca. 15% (*Filipendula*, *Potentilla*-type, Rosaceae and Poaceae); pteridophyte spores ca. 30% Macroscopic charcoal consistently present; LOI 85-90%

*Depth (cm) and age (based on age-depth curve) are also given

AP, arboreal pollen; AI, anthropogenic indicators; LOI, loss-on-ignition

Table 4 Sequence B: local pollen assemblage zone characteristics, main macro-remains and loss-on-ignition data

Zone / Subzone	**Description**
HBB-4 0-81 cal AD 770-1950	AP ca. 5%; heath taxa dominant (ca. 80%); herbaceous taxa ca. 15%; Poaceae percentages decline at start of zone; low percentages of AIs; *Sordaria*-type decreases to 1-2% *Calluna* stem fragments only at base of zone; ca. 30 Poaceae seeds at 69 cm; macroscopic charcoal presence sporadic; LOI almost 100%
HBB-3 81-129 cal AD 770 – 440 cal BC	AP 5-10%; heath taxa fluctuate between 30 and 65%; herbaceous taxa also fluctuate (20-60%); dominant herbaceous taxon is Poaceae, with Cyperaceae percentages much lower than previously; low AI values occur sporadically; *Hordeum*-type occasionally present but not above 98 cm; *Sordaria*-type increases slightly (3-8%); low peaks of microscopic charcoal throughout *Calluna* stem fragments in several samples; *Potentilla*, *Juncus*, and *Carex* remains present, along with ca. 100 Poaceae seeds at 102 cm; macroscopic charcoal in most samples; LOI 95-100%
HBB-2 / HBB-2b 129-150 440-1100 cal BC	AP ca. 10%; heath taxa ca. 15%; herbaceous taxa ca. 70% (mainly Cyperaceae and Poaceae, but also *R. acris*-type, *Filipendula* and *Potentilla*-type); low AI percentages; *Hordeum*-type occasionally present; *Sordaria*-type increases slightly (2-5%); small, isolated peak of microscopic charcoal at 139 cm Wood fragments at 136 cm; *Juncus*, *Carex* and *Scirpus* remains; macroscopic charcoal in several samples; LOI 95-100%
HBB-2 / HBB-2a 150-166 1100-1600 cal BC	AP ca. 10%; heath taxa 50-90%; herbaceous taxa 10-50%; low AI percentages; *Hordeum*-type at top of subzone; *Sordaria*-type 1-2%; low peaks of microscopic charcoal *Calluna* stem fragments at 157 cm; remains of *Juncus*, *Potentilla* and an unidentified Rosaceae; macroscopic charcoal throughout; LOI ca. 95%
HBB-1 / HBB-1b 166-196 1600-2450 cal BC	AP declines to ca. 10% by end of subzone; *Alnus glutinosa* increases to 5-10%; heath taxa average ca. 15% although percentages fluctuate; herbaceous taxa increase to ca. 60% (mainly Poaceae); AIs present throughout; occasional grains of *Hordeum*-type; pteridophyte spore percentages decline to <1%; *Sordaria*-type 1-3%; large peak of microscopic charcoal (2-3.5 $cm^2 cm^{-3}$) at top of subzone *Calluna* stem fragment at 173 cm; ca. 100 *Juncus* seeds at 195 cm; *Potentilla* and *Carex* remains; macroscopic charcoal in most samples; LOI 90-100%
HBB-1 / HBB-1a 196-201 2450-2590 cal BC	AP ca. 50% (mainly *P. sylvestris*, *Betula* and *Corylus*-type); heath taxa ca. 20%; herbaceous taxa ca. 20%; pteridophyte spores ca. 10%; small amounts of microscopic charcoal Organic fragments mainly graminoid; macroscopic charcoal at top of subzone; LOI low (ca. 20-60%)

*Depth (cm) and age (based on age-depth curve) are also given

AP, arboreal pollen; AI, anthropogenic indicators; LOI, loss-on-ignition