A palaeoenvironmental investigation of two prehistoric burnt mound sites in Northern Ireland

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ABSTRACT

This paper provides a summary of the palaeoenvironmental evidence from a spread of Late Mesolithic burnt material and two Late Neolithic to Early Bronze Age burnt mounds. The burnt mounds were up to 10 m diameter, had an amorphous shape and were consistently less than 0.8 m thick. Monoliths were collected from two sites, Ballygawley and Roughan, in Co. Tyrone, Northern Ireland. This provided an opportunity to use a detailed palaeoecological approach for the first time to investigate the use and function of burnt mounds. Pollen, non-pollen palynomorphs, micro- and macroscopic charcoal were used to place these features within their environmental context, and to establish if such an approach could provide further insights into their function. The palynological results shared similar characteristics: high microscopic charcoal values, repetitive fluctuations in tree and shrub taxa, increased *Sphagnum* and the presence of NPPs HdV-114 and HdV-146, all of which could be diagnostic indicators of burnt mound use in palynological records. While the data do not allow us to ascribe a specific function for the burnt mounds, their environmental setting is discussed. A 'seesaw' pattern of arboreal pollen, combined

with the macroscopic charcoal data, indicate possible species selection and management of local woodland for fuelwood.

Keywords: Mesolithic, Late Neolithic, Early Bronze Age, burnt mounds, pollen, non-pollen palynomorphs, charcoal, Northern Ireland.

INTRODUCTION

Anthropogenically-constructed mounds commonly appear in the archaeological record and have various ages, shapes and sizes, as well as different types of construction material, including earth, stone and remnants of burnt fuel. These include presumed burial mounds, dating back 6000 years in Louisiana (Keenan & Ellwood, 2014), earthen burial and platform mounds in southeast and southwest of North America (Lindauer & Blitz, 1997; Pluckhahn et al., 2015) , the Stege Mounds (middens) of California (Eerkens et al., 2014), monumental building of flat-topped mounds in central Georgia, USA, (Bigman & Lanzarone , 2014) and numerous Pre-Columbian earthworks to build dwellings in the Amazon (Lombardo & Prümers, 2010). Outside the Americas, mounds are also widely distributed including the Anatolian mounds in the Near East (Steadman, 2000), the monumental mound of Silsbury Hill and burial mounds in southern Britain (Bayliss et al., 2007; Semple, 1998), and burnt mounds across the British Isles (Buckley, 1990).

Burnt mounds or '*fulacht fiadh*' are a common feature in the Irish and British archaeological record (Brindley et al., 1989; Buckley, 1990; Feehan, 1991). They date from the Neolithic to the medieval period (Anthony et al, 2001; Ó Néill, 2009) and were widely used during the second millennium BC. They occur in various shapes and sizes. Crescent- or horseshoe- shaped burnt mounds are typical in Ireland but they can also be also circular, oval- and d-shaped. Their size ranges from over 1 metre in height and range over 30 metres in diameter (O'Sullivan and Downey, 2004) whereas in north Wales burnt mounds have more amorphous shapes and sizes ranging from 3 metres in diameter to spreading over 15 metres (Fairburn, pers comm.) Despite being ubiquitous, we know little about their function. The most favoured hypothesis is cooking (O'Kelly, 1954; Hawkes, 2013) but this theory continues to be contested. Other alternative uses include brewing (Quinn & Moore, 2007; Wilkins, 2011), butter-making (Sayce, 1945), bathing (O'Drisceòil, 1988), dying and textile processing (Jeffrey, 1991), butchery (Tourunen, 2008), leather working, saunas/sweat lodges and baths (Barfield and Hodder, 1987; O'Sullivan and Downey, 2004), the rendering of animal fats (Monk, 2007) and funerary and ritual practices (Bradley, 1978). However, cooking continues to be the most likely activity (Hawkes, 2013). There have been few attempts to progress these generalised interpretations. Whilst these functions are plausible, all are falsifiable and require convincing evidence. Consequently burnt mounds remain an archaeological enigma.

Few palaeoenvironmental studies have focussed specifically on understanding the function and wider environmental context of burnt mounds (e.g. Innes, 1998; Gonzalez et al., 2000). Palaeoenvironmental analyses can provide useful insights into the history and function of an archaeological site and provide an environmental setting for past activities (Dimbleby, 1985; Whittington and Edwards, 1994; Tipping *et al*, 2009). The combination of palynological and anthracological studies is now well established to provide complementary data sets to investigate changes in woodland composition (Gowen et al., 2005; Newman et al., 2007; Nelle et al., 2010) and management (Ludemann et al., 2004; Mighall *et al.*, 2010; Wheeler, 2011; Crew and Mighall, 2013). Such an approach is adopted in this study. The study aims to: (i) place these burnt mounds into their environmental context; (ii) reconstruct any vegetational changes associated with the use of the burnt mounds using pollen, NPPs, microscopic charcoal data and archaeo-anthracological data; and (iii) determine if the palaeoenvironmental record can provide insights into the function of burnt mounds.

ARCHAEOLOGY AND SITE DETAILS

This study centres around two Late Neolithic/Early Bronze Age burnt mounds from two sites, Ballygawley and Roughan. Palaeoenvironmental sampling was carried out as part of the archaeological evaluation and excavation strategy associated with the A4/5 road improvement scheme between Dungallen and Ballygawley, Co Tyrone, Northern Ireland, undertaken by Headland Archaeology Ltd. A total of 25 sites were evaluated, with 12 of these sites going on to excavation, between August 2006 and April 2007. Excavation across these sites revealed 29 burnt mounds and associated features (e.g. hearths and troughs), Bronze Age cremation burials and ring ditches, two Early Christian ringforts, and an Early Christian cemetery (Figure 1a, b).

Ballygawley

The Ballygawley site is located in low lying pasture approximately 5 km east of the Ballygawley Water, on the edge of the floodplain that lies at the foot of higher ground formed by drumlins (Figure 1b, c). Palaeochannels and alluvial islands, representing a system of lateral migration and anastomosing channels (Lewin et al., 2005), run across the site. These palaeochannels were infilled with intercalated deposits of peats and alluvial silts and clays (Figure 1c). Upon excavation 23 burnt mounds were discovered, including ten wooden and wicker-lined troughs (in eight different styles) dated from the Neolithic to the medieval period (e.g. Supplementary Figure 1a,b), some being *Sphagnum* lined and with associated pits and hearths (Bailey, 2010a; Bamforth et al., 2010). The analysis of planks and wattle sails, which were made of mainly hazel, used in the construction of troughs associated with the burnt mounds suggest that some form of woodland management was practiced, possibly coppicing or new growth cut within an interval of less than 10 years (Bamforth et al., 2010). One burnt mound deposit (9031) was sampled at this location, measuring 3.7 m x 3.2 m. The deposit was up to 0.14m thick (Bailey, 2010a).

A monolith was collected from the northern limit of excavation and truncated a single-phase section of burnt mound [context no 9031] (Figure 1c). Charcoal from the base of the feature was radiocarbon-dated to 3865 $\pm$ 35 (2465-2210 cal yr BC, 2σ; GU-17350). A section of the stratigraphy of the sediments is shown the figure 2a.

A radiocarbon chronology of these features indicates that activity took place at Ballygawley from c. 3350 cal yr BC to cal yr AD 1270 (Supplementary Figure 2); with six burnt mounds dated to the Late Neolithic to Early Bronze Age. The earliest radiocarbon date from a burnt mound is dated to 2830-2475 cal yr BC (2σ) and the youngest has been dated to cal yr AD 1040-1220 (2σ). A hiatus of activity of approximately 900 years occurred between the Late Iron Age and early medieval period at the site, yet the overall longevity of activity indicates Ballygawley was a place that people returned to in order to use hot stone technology. The construction of new burnt mounds followed the migration of the palaeochannels and their changing course to maintain access and proximity to a water supply (Figure 1c).

The finds assemblage recovered from Ballygawley is amongst the largest from any Irish burnt mound complex, with a considerable quantity of material coming from the palaeochannel deposits. The majority of finds were of prehistoric age including pottery fragments relating to five different vessels from the Late Neolithic/Early Bronze Age, together with 16 flint scrapers and two bone points indicative of butchery practices and hide preparation. Butchery is also indicated by the faunal bone assemblage, which consists of cattle, pig and sheep/goat, largely contains parts associated with slaughter (skull, mandible, lower leg bones) and primary butchery (upper leg bones) (Tourunen, 2009). However, the lack of blades recovered suggests meat preparation was not taking place (Lochrie, 2010a, 2010b, 2010c).

Roughan

Roughan is located on an area of low-lying pasture approximately 9 km to the south west of Ballygawley (Figure 1d), fringing an area of reclaimed peatland. The site lies within a small valley running from east to west with ground rising to the north and further low-lying land to the south. Excavations at Roughan revealed a group of six burnt mounds, which are amorphous in shape ranging from 1 m to 10 m diameter and less than 1 m thick (Figure 1e). Burnt mound (8413*)* measured 8.80 m by 4.90 m and up to 0.25 m thick. Associated features included troughs and pits. Troughs were found to be mainly unlined, although one trough did contain a layer of organic material which may have been the remains of a lining (Bailey, 2010b).

Observations made during the course of the excavation indicated that there had been two possible attempts to stabilize the surface of the peat around the burnt mounds during prehistory. The first used collected brushwood (no evidence of tool marks were found (Bamforth et al., 2010)) and the second utilized actual burnt mound material in a linear spread leading from one of the mounds (Bailey, 2010b). There was a dearth of finds at Roughan.

A monolith was taken through the base of one of the burnt mounds [context no 8413] (Figure 1e; Figure 2b, c). A radiocarbon date (3885$\pm$35; 2466-2208 cal yr BC; GU-15850) places this feature into the Bronze Age, and is comparable with a series of radiocarbon dates from other features which suggest that burnt mound use took place during the third millennium BC between c. 2900 to 2100 cal yr BC (Supplementary Figure 3). An earlier spread of burnt material was discovered at the base of the monolith, confirmed by radiocarbon dating to be of Late Mesolithic age c. 6400-5900 cal yr BC (Supplementary Figure 3).

METHODS AND MATERIALS

In order to obtain pollen sequences that could be linked directly to periods of burnt mound use, it was decided to take samples directly through the mounds. Monoliths were analysed which encompassed the burnt mound layers (charcoal and heat-fractured stone), together with intercalated peat and/or alluvial deposits. This allowed for the close-interval sampling for periods of activity immediately preceding, during and after burnt mound use.

Microfossils

Sub-samples from both monoliths were taken over selected intervals (112-66 cm at Ballygawley and from 58 to 18 cm at Roughan). Each 1cm^3 sub-sample was prepared for pollen and NPPs analyses following Barber (1976). The organic component of each sub-sample was separated from the mineral component using density flotation (Nakagawa et al., 1998). A sum of 500 total land pollen (TLP) was achieved for all sub-samples except for the burnt mound material at Ballygawley. Data are expressed as a percentage of the TLP, with spores and aquatic taxa excluded from the TLP sum. NPPs were also counted during routine pollen analysis (cf. van Geel et al. 1982/1983, 2003) and they are expressed as a percentage of TLP plus total NPPs. Rare types are indicated by a cross (+), where one cross is equal to one pollen grain or NPP. Pollen samples were spiked with *Lycopodium clavatum* tablets (Stockmarr, 1971) in order to calculate pollen concentrations using the method described by Benninghoff (1962). Identification, including cereal-type pollen, was aided by reference keys in Fægri et al. (1989), Moore et al. (1991), Beug (2004) and Reille (1999), and supported by a modern type-slide reference collection housed at the University of Aberdeen. As the separation of *Myrica gale* from *Corylus avellana*-type can be difficult these pollen grain types are classified as *Corylus avellana*-type (Edwards 1981). Plant nomenclature follows Stace (2001). Basic land use designations interpreted from the pollen records follow Brown et al.(2007). Microscopic charcoal was counted in three fractions (<21µm, 21-50µm, and >50µm). Loss on Ignition percentages (LOI) were also determined (Schulte and Hopkins, 1996).

Radiocarbon dating

Selected bulk sediment, humic acid fraction or charcoal samples were carefully extracted from the monoliths and submitted to the NERC Radiocarbon Laboratory and Poznań Radiocarbon Laboratory for AMS radiocarbon dating.

Macroscopic charcoal

A maximum of fifty charcoal fragments were selected from each sub-sample based on size to allow for positive species identification and also to maximise ring curvature data. The standardised quantitative sampling strategy (Asouti, 2001; Wheeler, 2007) was deemed appropriate to provide adequate material for inter-feature/inter-site assessments. Standard methods of identification followed Leney & Casteel (1975) with charcoal samples being fractured to reveal the three sectional surfaces (transverse section (TS), tangential longitudinal section (TLS), and radial longitudinal section (RLS) necessary for microscopic wood-type identification to genus. Charcoal fragments were securely positioned onto slides for examination under an incident light microscope at magnification 100x, 200x and 400x. Identifications were assisted by using wood keys by Schweingruber (1990) and a modern reference collection. Nomenclature follows Schweingruber (1990). Ring curvature was measured using the key in Marguerie and Hunot (2007): where weak curvature is thought to denote large-sized timbers; medium curvature, medium-sized timbers; and strong curvature representative of small-sized timbers or branchwood. When ring curvature could not be observed or genus not identified, an indeterminate result was recorded.

RESULTS

Stratigraphy

The monoliths were described using the Troels Smith (1955) classification and they are provided in Table SI1.

Radiocarbon Dating

All radiocarbon dates quoted in this paper are listed in Table 1 and Supplementary Figures 1 and 2. The radiocarbon dates are given to + 1 σ and calibrated ages to a two σ age range, using Calib 7.0 software (Reimer et al., 2009) in conjunction with Stuiver and Reimer (1993). An age-depth model for Roughan was constructed using CLAM (Blaauw, 2010) and shown in Figure 3. As clay dominated the stratigraphy at Ballygawley prevented reliable dates from being obtained on sediment above the burnt mound material. Only two radiocarbon dates were determined at the top and bottom of the burnt mound and this is considered an insufficient number to model.

There are some uncertainties with all radiocarbon dates and some of these might apply to this study. There has been some discussion over which fraction of the peat to date (Shore et al., 1995; Brock et al., 2011). Dating the humic acid fraction of a sample can be problematic as humic acids are mobile and generally yield dates which are younger than the humin fraction of the same sample (Shore et al., 1995; Brock et al., 2011). For example, Bartley and Chambers (1992) suggest that the humin fraction is preferable for dating purposes although Johnson et al. (1990) recommend using the humic acid fraction in certain contexts. AMS dates from bulk sediment can also be badly skewed by small amounts of intrusive material (e.g. Chapman and Gearey, 2013). There could be a significant old wood offset with radiocarbon dates obtained from charcoal and charcoal of different ages could have been included in the same deposit (Pilcher, 1991). Moreover, the differences in ages between GU-15850 and GU-15852 indicate a possible hiatus or very slow rates of accumulation. There is significant potential for disturbance to the on-site deposits given the evidence for repeated human activity.

While recognising the limitations described above, radiocarbon dates from the humic acid fraction and charcoal at Ballygawley (GU-15849 & GU-17350) do not have any great offset compared to one another, and dates from bulk sediment and the humic acid fraction at Roughan produce similar ages (GU-15852 & Poz-46459). Furthermore, the radiocarbon dates from Ballygawley and one from Roughan (GU-15850) fit the chronological framework provided by the radiocarbon dates from other archaeological structures at these sites (Figure SI2 & 3). Any age-offset is therefore not considered to adversely affect comparisons with the palaeoenvironmental records and the archaeological features.

When interpreting fossil peat archives, Telford *et al*. (2004) and Piotrowska et al. (2010/2011) consider that all radiocarbon dates and all age-depth models are uncertain. The limited number of radiocarbon dates (3 for Roughan and 2 for Ballgawley) associated with the monolith sequences compromise the robustness of the CLAM age-depth models (Figure 3). Therefore the models should be treated with caution. Unless stated otherwise all cited ages are derived as best estimates from the CLAM models.

Microfossils

The pollen and non-pollen palynomorphs (NPPs) diagrams for both monoliths were constructed using Tilia.graph (Grimm, 2004) and are presented in Figures 4, 5, 6 and 7. The diagrams have been divided into local pollen assemblage zones (LPAZs) using CONISS (Grimm 1987). Preservation is variable across all zones in both diagrams. Poor pollen preservation ranges between 20 and 40% across all damaged categories of indeterminate pollen; with the exception of two sequences of raised indeterminate peaks in Ballygawley LPAZ BG1.

INTERPRETATION

Ballygawley

BG1 (113-102 cm) (Figures 4 and 5)

A Late Neolithic date (c. 2470-2270 cal yr BC) was determined for the top of this zone. Tree and shrub percentages exceed 60% TLP and indicate local woodland. As Martin and Mehringer (1965) have shown, most pollen found in alluvial sediments is derived from a local source. Therefore, the high values of *Alnus*, *Salix* and possibly *Corylus avellana*-type are indicative of a local carr (Waller et al. 2005). Deciduous woodland, whilst local, was probably situated on higher ground, and is characterised by *Quercus*, *Corylus avellana*-type, *Betula* and *Ulmus* with *Polypodium* occupying shaded areas beneath the woodland canopy. Repetitive peaks and troughs create a 'see-saw' pattern in the pollen curves for *Corylus avellana*-type and also for *Quercus*, *Alnus* and Poaceae at the base of the burnt mound material (from 107 cm up core). Rough, wet pasture is inferred by the representation of *Plantago lanceolata*, Ranunculaceae, *Rumex acetosa*, *Aster*-type and Caryophyllaceae (Brown et al., 2007). Cyperaceae, *Pedicularis palustris*-type, *Peucedanum palustre*-type and *Filipendula* are all commonly found on fens. Indicators of disturbance include Chenopodiaceae and *Urtica*.

The pollen record in the basal zone, immediately before the deposition of the burnt mound deposits, is characterised by a number of noteworthy observations. As expected, microscopic charcoal counts, indicative of burning, increased from 105 cm with this rise sustained until 94 cm. Wood detritus can be inferred from the occurrence of scalariform perforation plates (SPPs) (HdV-114), which peaked at 106.5 cm, and grazing and/or the presence of decayed wood from *Sordaria*-type (HdV-55A). Small peaks in *Glomus* cf. *fasciculatum* chlamydospores (HdV-207) between 107 cm and 105 cm may also represent an inwash of debris as this particular NPP is considered to be a marker for erosion in fluvial/lacustrine contexts (van Geel et al., 1983, 2003) but not for peat (Kołaczek et al., 2013). HdV-184 is associated with the deposition of sandy clay (van Geel, 1983).

Relatively high amounts of indeterminate, degraded, folded/crumpled and corroded pollen grains occurred throughout the zone, which most likely represents inwash from the palaeochannels (Delcourt and Delcourt, 1980; Moore et al., 1991). Pollen corrosion and degradation can also be caused by chemical and biochemical oxidation, raised pH (Moore et al., 1991) and/or the result of increased eutrophication. Eutrophication is suggested by the presence of HdV-150 and HdV-167. *Gloeotrichia* (HdV-146), an aquatic pioneer, is indicative of nutrient poor conditions and has the ability to fix nitrogen (van Geel, 2005). Consistently higher numbers of *Sphagnum* spores and the occurrence of *Tilletia sphagni* (HdV-27) at 106 cm were recorded. These features all occurred from 107 cm depth, which is tentatively dated using a polynominal regression age-depth model (using Clam; Blaauw, 2010) to a best estimate of c. 2760 cal yr BC. The earliest burnt mound use (BM 9003, see Figure 1c) at the site is dated to 2833 to 2475 cal yr BC and therefore the changes described above could be associated with contemporary burnt mound use.

LPAZ BG2 (102-94.5cm)

The age-model model tentatively places this zone between c. 2470 and 2200 cal yr BC. At 103 cm the stratigraphy changed from clay to burnt mound material. The burnt mound material appears to have been deposited over a short period of time as indicated by the radiocarbon dates. High microscopic charcoal values characterise this zone, indicative of intense burning. This has adversely affected the preservation of pollen, probably as a result of exposure to high temperatures (Delcourt and Delcourt, 1980; Havinga, 1967). This possibly explains the loss of the repetitive fluctuations of tree taxa and the decline in total tree pollen percentages. Although the latter might also be the result of a loss of woodland cover as a result of sustained burnt mound use from c. 2800 cal yr BC to 1420 cal yr BC. *Sphagnum* (used as a lining in the burnt mound troughs) peaked but SPPs (HdV-114) and *Gloeotrichia* (HdV-146) were only recorded in trace amounts until 96 cm when both increased in percentage. HdV-184 was regularly recorded in trace amounts, being associated with the deposition of sandy clay.

The occasional trace of Poaceae >35μm may be representative of cereal-types and/or wild grasses (Dickson, 1988; Edwards and Borthwick, 2010), possibly in wet meadow/fen or within the floodplain system along with Cyperaceae and

Peucedanum palustre-type. The lack of cultural, herbaceous pollen taxa is probably the result of poor pollen preservation rather than a lack of human activity or grazing. *Cercophora*-type (HdV-112) and *Sordaria*-type (HdV-55A) were recorded at the end of the LPAZ suggesting low intensity grazing and/or the presence of decayed wood. Whereas the re-occurrence of *Glomus* cf. *fasciculatum* chlamydospores (HdV-207) can be associated with the inwash of eroded material.

LPAZ BG3 (94.5-75cm)

The age range of this zone is uncertain given the lack of radiocarbon dates for the top 90 cm. An immediate decline in microscopic charcoal in this zone suggests the use of the burnt mound [context no 9031; Figure 1c] subsided. The continual presence of microscopic charcoal implies less intense burning in the immediate vicinity (>50 µm fraction), and/or more distant burning, most probably within the wider burnt mound complex (<21 µm and 21-50 µm fractions). However, the radiocarbon chronology across the site suggests a pause in burnt mound use between c. 2100 and 1900 cal yr BC.

The pollen and NPP records replicate those observed in the end of LPAZ BG1. Relatively stable total arboreal pollen (AP) percentages, similar to those noted just before the deposition of the burnt mound material, were recorded. Repetitive changes in *Corylus avellana*-type and possibly *Quercus* continued until 89 cm but the pattern is less evident for *Alnus*, *Ulmus* and *Betula*. Wet pasture/marsh indicators were present including Poaceae >35 µm, *Rumex acetosa* and *Plantago lanceolata*, Cyperaceae, *Galium*-type and *Peucedanum palustre*-type, together with indicators of disturbed ground, such as Chenopodiaceae and Apiaceae (Brown et al., 2007).

Coprophilous fungi *Cercophora*-type (HdV-112) and *Sordaria*-type (HdV-55A) were also recorded suggesting that herbivores grazed nearby (Mighall et al., 2008).

Sphagnum, SPPs (HdV-114) and *Gloeotrichia* (HdV-146) all reappeared and may relate to continued burnt mound use, which could have continued for approximately another 100 years in proximity of the sampling site. These patterns continued until approximately 87 cm when the sampling resolution becomes coarser and/or activities on the site either changed or ceased.

Microscopic charcoal values increased slightly at 85 cm and may reflect a resumption of burnt mound use at the site (for e.g.) BM9011 at location 9009; Figure 4). This activity did not have a major impact on woodland cover. Total tree and shrub percentages did not diminish but show a pattern of occasional decline and recovery. Grazing indicators *Cercophora*-type (HdV-112) and *Sordaria*-type (HdV-55A) occurred in trace amounts. A suite of herbaceous taxa normally associated with pasture (Brown et al., 2007) were recorded in trace amounts, including Ranunculaceae, *Rumex acetosella*, *Plantago lanceolata*, *Plantago media/major* and Caryophyllaceae. *Urtica, Sphagnum*, SPPs (HdV-114) and *Gloeotrichia*-type (HdV-146) were also regularly recorded but at much lower values. *Tilletia sphagni* (HdV-27) occurred sporadically.

LPAZ BG4 (75-66cm)

Mixed carr and deciduous woodland, comprising *Alnus*, *Salix*, *Corylus avellana*-type, *Quercus* and *Ulmus*, were still present locally. *Corylus avellana*-type pollen values see-sawed again. Poaceae has an inverse pattern with *Corylus avellana*-type. The appearance of cereal-type pollen at 72cm and *Triticum*-type (wheat) pollen at 70 cm implies the onset of small-scale cereal cultivation. Their occurrence corresponds with a continual presence of *Plantago lanceolata* and *Plantago media/major*. *Aster*-type and other indicators of disturbed ground and pasture remained present from the preceding zone but only in trace amounts. Any grazing, as suggested by the presence of *Sordaria*-type (HdV-55A), appears to have been at a lower intensity at this time. LOI peaked at 72 cm suggesting that inwash from the palaeochannel has subsided. Microscopic charcoal values remained fairly stable and might be related to another phase of burnt mound activity. *Gloeotrichia*-type, SPPs (HdV-114) and *Sphagnum* were all recorded but sporadically and in low values. If changes in these taxa were related to burnt mound use, they were minor, despite the sampling site being within 100-150 metres.

Roughan

LPAZ Rou1 (Figures 6 & 7)

The radiocarbon date of 6385-6100 cal yr BC at 51-52 cm (Poz-46459) confirms a Late Mesolithic date for this LPAZ. *Corylus avellana*-type pollen was abundant, peaking at 51-50 cm, indicating a strong local presence of hazel and typical of early Holocene woodlands across the British Isles (Huntley, 1993). Its abundance might relate to quantitative over-representation (Binney et al., 2005). *Pinus*, *Betula*, *Quercus* and *Ulmus* formed mixed woodland with *Corylus*. Fluctuations in the pollen of *Corylus avellana*-type, and to a lesser extent, *Quercus*, *Ulmus*, *Alnus*, *Betula* and *Salix* created a 'see-saw' pattern in the total tree and shrub pollen sum leading up to the deposition of burnt material. The presence of *Viburnum* in association with *Prunus*-type (*P. avium* and *P. spinosa* were both present in the charcoal record) suggests open woodland, possibly comprising fringe vegetation with enough shade to support pteridophytes. Carr woodland, comprising *Alnus* and *Salix*, was also present. Rough wet grassland and/or damp woodland floor indicators were present, including Poaceae, Cyperaceae, *Aster*-type, *Narthecium ossifragum*, *Filipendula* and *Galium*-type. Disturbed ground taxa (e.g. *Urtica* and Apiaceae) also occurred (Brown et al., 2007). The presence of *Urtica* suggests that local soils had relatively high nutrient levels (Yeloff et al., 2007).

SPPs (HdV-114), indicative of woody debris, and *Glomus* cf. *fasciculatum* chlamydospores (HdV-207) appear to be associated with the inwash of eroded material. HdV-150 and 167 indicate shallow eutrophic water. In contrast, *Gloeotrichia*-type (HdV-146) indicates the presence of nitrogen poor conditions (van Geel, 2005). *Sphagnum* was also consistently recorded.

LPAZ Rou2

This LPAZ represents the burnt material. Two radiocarbon dates either side of this deposit confirm the burning took place during the Mesolithic (Table 1). There is a cross-fraction increase of microscopic charcoal across the LPAZ boundary and values remain much higher throughout the burnt material. It is not clear whether this represented a fire deliberately set by humans or a natural occurrence (cf. Chambers, 1993). An increase in the total amount of tree pollen was characterised by *Alnus* and *Quercus*, whereas *Corylus avellana*-type declined from 72% to 56% TLP, allowing for the greater representation of other trees and shrubs (Waller et al., 2005). This fluctuation could represent an actual change in woodland structure, or alternatively be a taphonomic variable. *Ilex* and *Prunus*-type suggest that woodland was open.

Higher percentages of Poaceae suggest that open areas existed within the woodland or at the woodland edge. Some taxa, considered to be disturbance indicators (e.g. Apiaceae and *Urtica*; Brown et al., 2007), recorded in the microfossil diagrams may reflect natural perturbations operating in a floodplain environment (e.g. Anderson et al., 2000). Herbivores may have grazed pasture and/or wet meadow close by as *Sordaria*-type (HdV-55A) also occurred. *Sordaria*-types HdV-55A/B are commonly recorded during Mesolithic disturbance phases suggesting the presence of dead wood and/or that animals were making use of openings in woodland (Mighall et al., 2008). Obligate coprophilous fungi, however, have not been recorded. The lack of these fungi supports the idea that these disturbances are natural as is it possible that the fungi occurred on dead wood. Woody debris is also indicated by the presence of SPPs (HdV-114) throughout the burnt material. *Glomus* cf. *fasciculatum* (HdV-207) and *Eurycerus cf. lamellatus* (HdV-72D) may also represent an inwash of debris (van Geel et al., 1982/83, 2003).

Wet meadow/fen vegetation is inferred locally by the presence of Poaceae (including those >35µm), Cyperaceae, *Filipendula* and *Peucedanum palustre*-type. Taxa often associated with pasture and disturbance were also recorded in trace amounts, including Apiaceae, Ranunculaceae, *Plantago lanceolata*, *Rumex acetosa*, *Aster*-type and Caryophyllaceae (Brown et al., 2007). Indicators of nutrient poor conditions included *Sphagnum* and *Gloeotrichia*-type (HdV-146).

LPAZ Rou3

The radiocarbon date of 6070-5910 cal yr BC (GU-15852) at 43-42 cm provides a Late Mesolithic date for the beginning of this LPAZ which culminates in the Late Neolithic, *c*. 2470-2415 cal yr BC. A phase of carr and mixed woodland expansion is suggested by the steady, gradual rise of total tree pollen. Immediately after the deposition of burnt material ends a see-saw pattern was observed in many of the tree and shrub taxa and Poaceae percentages. Percentages of *Salix* and, to a lesser extent, *Pinus*, *Betula*, *Quercus*, *Corylus avellana*-type and Cyperaceae have an inverse relationship to *Alnus* and Poaceae. A strong signal of *Salix* pollen suggests local on-site growth (Waller et al., 2005) which may have replaced *Corylus* on the floodplain as its percentages decrease from the start of the zone to 38 cm. A constant background signal for burning is inferred from the microscopic charcoal, which is dominated by the <21 μm fraction, until the upper part of the LPAZ. These patterns continued until approximately 38 cm (c. 5520 cal yr BC) when the sampling resolution becomes coarser.

There was a major increase in Poaceae and Cyperaceae values indicating an expansion of wet grassland/fen. Taxa often associated with pasture and disturbance were also recorded in trace amounts, and albeit more sporadically than compared to the previous zone. Such taxa include Apiaceae, Ranunculaceae, *Plantago lanceolata*, *Rumex acetosa*, *Aster*-type, *Artemisia*-type, Caryophyllaceae and *Urtica*. Isolated traces of *Sordaria*-type (HdV-55A) and *Cercophora*-type (HdV-112) indicate that grazing may have occurred locally. *Agropyron*-type (wheat-grass) is recorded as a rare-type mid-LPAZ; it is possible that it was used by humans as the leaves, tuber and seeds are edible, and the roots also produce a grey dye (Coon, 1978).

The total percentage of trees and shrubs peaked at 23 cm. The finer resolution of the pollen data reveals a see-saw pattern particularly for *Salix* and Poaceae. The major tree taxa also fluctuate: *Pinus*, *Quercus*, *Ulmus* and *Corylus* generally have an inverse relationship with *Alnus*. These changes may be a response to the decline of relatively high pollen producers such as *Alnus* and Poaceae. Once *Alnus* and Poaceae recover and started to produce large quantities of local pollen, the dispersal of pollen particularly from the trunk space and canopy signal from the trees on higher, drier ground became spatially restricted.

Grazing intensity appeared to increase from 22 cm as the amount of *Sordaria*-type (HdV-55A) rose. This observation is supported by the increased occurrence of pasture and disturbance indicators, including Poaceae and Chenopodiaceae from 24 cm to the top of the LPAZ. Microscopic charcoal values peaked at 22 cm and remained slightly higher, especially the <21 and 21-50 µm fractions. This suggests increased burning, and may represent a major phase of burnt mound use at the site. A burnt spread (context 8467) and mound (context 8422) have been radiocarbon dated to the Neolithic period c. 2850 cal yr BC (Supplementary Figure 3), which equates to 22 cm in the pollen diagram. This represents a new phase of activity at the site with activity lasting until c. 2040 cal yr BC. Local soils appear to become less eutrophic at this time as *Urtica* percentages fall in value throughout the LPAZ.

Sphagnum was recorded at consistently higher levels from 34 cm onwards, together with HdV-146 (*Gloeotrichia*-type). The occurrence of HdV-62, HdV-128 and HdV-143 on the upper LPAZ zone boundary indicates that the water was meso- to eutrophic (van Geel, 1978; van Geel et al., 2003). Woody debris and decomposed wood is indicated by HdV-114 and an isolated occurrence of *Kretzschmaria deusta* (HdV-44). This may indicate the presence of local trees as the ascospores are generally dispersed only several metres from their source (van Geel, 2005), but they may have travelled further within the palaeochannel network.

LPAZ Rou4

The radiocarbon date at 19-18 cm provides a Late Neolithic/Early Bronze Age date of 2466-2208 cal yr BC (GU-15850; Table 1) for the charcoal (considered part of the burnt mound material) at the top of the sequence. Repetitive fluctuations in *Corylus avellana*-type, *Alnus, Quercus*, *Pinus* and *Ulmus* were apparent in the arboreal and shrub pollen sums. The synchronicity between *Alnus* and Poaceae weakened. *Alnus* and *Quercus* had an inverse relationship with *Corylus avellana*-type. Fluctuations were also witnessed in the Poaceae and Cyperaceae pollen curves. Rises in micro-charcoal counts across all fractions also began at this point, being most evident in the lowermost sample of the burnt material.

Other changes observed in association with burnt material were also recorded. *Sphagnum* increased slightly, together with possible woody debris indicators *Sordaria*-type (HdV-55A) and SPPs (HdV-114); the latter being representative of *Betula*, *Alnus* or *Corylus* (van Geel, 1978; Hather, 2000). Increases in eutrophy are suggested by the presence of *Zygnemataceae* (HdV-62), *Diporotheca rhizophila* (HdV-143) and HdV-128 (van Geel et al., 1983; Kuhry, 1985).

Fen/wet meadow vegetation remained present, which may have been used for grazing animals due to the presence of possible disturbance indicators *Cicuta virosa*, *Plantago media/major* pollen and the reappearance of coprophilous fungal spores: *Sporormiella*-type (HdV- 113) and *Cercophora*-type (HdV-112) (van Geel et al., 2003). Their presence coincided with a large increase of microscopic charcoal at

18.5 cm and, assuming the monolith chronology is sufficiently robust, the probable resumption of burnt mound use across the site (Figures 5, 6).

Macroscopic charcoal

The charcoal results presented are collated from those burnt mounds and associated features (e.g. troughs and pits) that have been dated to the Late Neolithic to Early Bronze Age period are shown in Figures 8 and 9. Notwithstanding the limitations of the age-depth models, they are of broadly comparable age to the pollen sequences taken at Ballygawley through burnt mound [9031], and at Roughan through burnt mound [8413].

The charcoal condition varied from firm and well preserved to poor and friable. In some cases charcoal fragments were partially vitrified, caused by exposure to temperatures in excess of 800°C (Prior and Alvin, 1983). A fraction of the charcoal assemblage was in a poor condition due to orange mineral discolouration, a common feature associated with material from burnt mounds, as waterlogged conditions can result in the charcoal incorporating minerals such as calcium and iron, which hinders identification (Stuijts, 2007). The anthracological information gained from the charcoal analysis provides a complementary data set to the pollen analysis and reveals the presence of insect pollinated arboreal taxa such as Maloideae sp. fruitwoods and *Sorbus* sp. Trace amounts of *Prunus*-type are regularly recorded at both sites. However, these taxa are low pollen producers, with their pollen being difficult to detect, unless they grow close to the sampling site (Stuijts 2005).

Ballygawley

A total of 1109 charcoal fragments were analysed from six burnt mound groups of Late Neolithic to Early Bronze Age date (Figure 8). Eleven different taxa were identified as fuelwood from the burnt mound deposits. Individual mounds have fuelwood assemblages of between 1 and 10 taxa. However, a potential skewing of results is acknowledged as some burnt mound features have more samples analysed than others (e.g. burnt mound [9782] compared with burnt mound [9031]). The most dominant taxa within the assemblage are *Alnus glutinosa* and *Corylus avellana*, with *Alnus glutinosa* in particular being prominent in all six burnt mound deposits, and especially from burnt mounds 9782, 9034 and 9986. Other taxa present include *Salix* sp., *Quercus* sp., Maloideae sp. (a group including *Pyrus communis*, *Malus sylvestris* and *Crataegus* sp., which cannot be differentiated based on their anatomical composition), *Ulmus* sp. and *Prunus avium*, together with *Prunus spinosa*.

The growth ring curvature of the charcoal fragments indicates that all taxa were representative of small- to medium-sized wood, with strongly to moderately curved growth rings, suggesting the bulk of the fuel wood assemblage consisted of branch wood. Large-sized timbers, such as trunk wood indicated by weakly curved growth rings were also present in the assemblage, and were limited to three taxa: *Quercus* sp., *Corylus avellana* and *Alnus glutinosa*.

Roughan

A total of 601 charcoal fragments were analysed from five burnt mound (or spread) groups of Late Neolithic to Early Bronze Age date (Figure 9). Eight taxa were identified at Roughan. *Alnus glutinosa* is the dominant fuel wood but it is not most prevalent in all burnt mound fuel wood deposits. *Corylus avellana* and *Quercus* sp.

are the most abundant species within the assemblage. Other taxa identified include *Betula* sp., *Salix* sp., *Ulmus* sp., *Prunus avium* and *Prunus spinosa*.

The growth ring curvature of the charcoal fragments from Roughan is similar to that at Ballygawley with all taxa present being represented by strongly to moderately curved growth rings. This indicates the use of small- to medium-sized timbers suggestive of branch wood. However, there is more variety of taxa with weakly-curved growth rings suggesting the utilisation of large-sized timbers with six taxa represented: *Quercus* sp., *Corylus avellana*, *Betula* sp., *Alnus glutinosa*, *Salix* sp. and *Prunus avium*.

DISCUSSION

Mesolithic burning

The earliest evidence of burning has been dated to the Late Mesolithic period at Roughan. This episode of burning has been labelled a “burnt spread” as no related features or finds were discovered. Only a single fragment of *Corylus avellana* charcoal was found in the spread. The pollen data indicate that burning of *Corylus*-scrub woodland took place (Figure 6a). Burning appears to have been spatially constrained as other tree and shrub taxa do not appear to have been adversely affected except *Salix* which was possibly used for fuel but without charcoal data it is difficult to establish.

Simmons and Innes (1996) suggested that Mesolithic peoples deliberately burnt the ground layer of woodlands or exploited naturally created openings to encourage browsing of animals. In the absence of any archaeological evidence for Mesolithic activity in this study, it is not possible to firmly ascribe this burning episode to human activity. Tipping (2004) has suggested that the likelihood of natural fire was arguably much higher during the Early Holocene. However, the changes recorded in the Roughan pollen diagram (Figure 6a,b) do share similar characteristics with woodland openings attributed to Mesolithic activity. Support for disturbance to create areas of browse for wild animals is suggested by taxa often linked with disturbance (e.g. Innes & Blackford, 2003) from the pollen assemblage in the burnt material. Evidence for herbivore grazing from the NPP record was less forthcoming with only *Sordaria*-type (HdV-55A; Figure 7) present in trace amounts. In the absence of red deer and other major herbivores, it has been suggested that Mesolithic people in Ireland did not have a reason to maintain clearings (Woodman et al., 1997). The primary target for any hunters would be wild pig (Woodman et al., 1999): *Pteridium* is a favoured food of wild pigs (Grigson, 1982) and it features in the latter part of LPAZs Rou1 and Rou2 (Figure 6b). *Rumex* and *Pteridium* often occur naturally in woodlands and they would respond in increased numbers and wider dispersal if the woodland canopy was more open (Tipping, 2004). Alternatively the disturbance indicators simply could be responding to natural perturbations in and around the palaeochannel system.

Evidence for Mesolithic burning is rarely recorded in pollen studies from Northern Ireland, possibly because previous studies have not included microscopic charcoal analysis as part of their study (e.g. Pilcher, 1973; Pilcher and Smith, 1979; Smith and Goddard, 1991). Peaks in microscopic charcoal have been recorded at Ballynahatty, Co. Down, and they were interpreted as a possible domestic fire as there was no evidence for any detrimental impact on the woodland (Plunkett *et al.*, 2008). However, the presence of Late Mesolithic populations is well established from archaeological evidence (e.g. Bayliss and Woodman, 2009; Meiklejohn and Woodman, 2012), in particular along the Bann River Valley (e.g. Mitchell, 1955; Woodman, 1977, 1985; Spaulding et al., 1999), while finds of Mesolithic flints occur in Co. Tyrone (Ivens and Simpson, 1988). The phase of burning at Roughan adds to this body of evidence and it represents possibly the only Mesolithic archaeology discovered along the new road corridor.

Late Neolithic/Early Bronze Age

Environmental setting of the burnt mounds

Pollen evidence from the Late Neolithic/Early Bronze Age phase of burnt mound use (c. 2860 cal yr BC to 2140 cal yr BC) reveals that this activity took place in a landscape where mixed woodland and *Alnus* carr were both locally predominant (Figures 4 and 6). High pollen percentages of *Alnus* and *Corylus* derived from trees growing on both floodplains places the burnt mounds at a fen carr-edge, where the pollen source area could have been limited to anywhere between 50 and >100 m radius (Binney et al., 2005; Bunting et al., 2005).

A decline in total arboreal pollen percentages at Ballygawley coincided with the deposition of the burnt material. This possibly represents a short-lived phase of woodland clearance associated with the use of the burnt mound. However, this decrease might be artificial as the pollen content of the burnt material was extremely low. Therefore counts will not be an accurate reflection of the local vegetation. Moreover, arboreal pollen percentages recover to their original values when the deposition of the burnt material ends at 93 cm (Figure 4). The radiocarbon chronology is insufficient to firmly ascertain the impact of later burnt mound use in the local area. Assuming that that subsequent period of use is recorded in the peat above burnt mound deposit, and notwithstanding the coarser sampling resolution, the microfossil and microscopic charcoal records suggests that any impact was mute. Microscopic charcoal values remained low and there were no major perturbations in total arboreal pollen or for individual tree and shrub taxa. Non-arboreal pollen taxa and coprophilous fungi commonly associated with human activity and disturbance only occurred in trace amounts and sporadically. This suggests that the impact of other burnt mounds close to the sampling site was not detected due the pollen source area being spatially restricted (Figure 1b).

There was an apparent hiatus in the Roughan archaeological record between the Mesolithic and the latter half of the third millennium BC. The coarse resolution of the pollen diagram in LPAZ Rou3 hinders any attempt to identify any human impact (Figure 6a,b). Radiocarbon dates from a stone spread [8502], a burnt spread [8467] and a burnt mound [8422] (Supplementary Figure 3) provide the next definitive evidence for human activity at Roughan c. 2870 cal yr BC. Notwithstanding the crude chronology and slow sediment accumulation rate between 43 and 18 cm, this phase of activity tentatively correlates with around 21 cm in the pollen diagram. This is slightly later than the resumption of the see-saw pattern in the arboreal pollen and the increase and/or regular presence of pollen taxa and NPPS often associated with human activity (Figures 6a,b and 7). Microscopic charcoal values also increased during this time. Until the chronology is improved it is unclear as to whether this represents human presence before the burnt mounds were used. Notwithstanding this, the evidence for human activity is still relatively mute given the close proximity of the burnt mounds.

The data have also revealed a common set of features in the pollen and NPP records at both sites which appear to be associated with the burnt material. These trends are discussed further below.

i) Regular fluctuations in the pollen of the tree and shrub taxa

Regular fluctuations in the pollen values of tree and shrub taxa have been recorded prior to and following the burnt spread and mounds recorded in the two monoliths. The exact reason for what we describe as the 'see-saw' pattern is unknown. In particular these peaks and troughs are recorded in the pollen curves of *Quercus* and *Corylus avellana*-type at Ballygawley and *Pinus*, *Ulmus*, *Salix*, and to a lesser extent, *Alnus, Quercus* and *Corylus avellana*-type at Roughan (Figures 3 and 5). The high values of both *Alnus* and *Corylus avellana*-type pollen infer that these tree types were growing near to the burnt mound sites (Brown, 1999; Waller et al., 2005). The macroscopic charcoal records suggest that they were used for fuelwood (Figures 8 and 9).

In order to determine if the see-saw pattern was real rather than an artefact of expressing the pollen data as percentages, and to negate the effect of the abundance of one pollen type depressing the value of others (Simmons & Innes, 1988), concentrations were also calculated. Pollen concentrations for major taxa from Ballygawley and Roughan are shown in Supplementary Figures 4, 5a and b. With the exception of some minor differences, they show a consistent pattern which suggests that they have been influenced by changing sediment accumulation rates and possible variations in pollen productivity. When the pollen concentrations are normalised against the total pollen concentrations (excluding each taxon), the see-saw pattern is clearly seen (Supplementary Figure 4c-e). This suggests that the see-saw pattern observed reflects real changes in the vegetation. The normalised pollen concentrations patterns are in good agreement with the percentage data for each taxon. Such see-saw patterning in pollen diagrams is enigmatic. The patterns could be the result of several processes including woodland management, natural fluctuations or taphonomic processes. A discussion of each of these possibilities follows:

Human activity

The see-saw pattern seen in the pollen data infers that some form of management may have been practised to maintain local woodland availability. This might have been inadvertent assuming there were sufficient trees available to provide a continuous supply of wood fuel for the burnt mounds or through deliberate coppicing and/or pollarding. Rackham (2005) also observes that trees such as *Corylus avellana* are best coppiced on a short rotation cycle so that the wood can be easily worked. Thus, if the hot stone technology associated with the burnt mounds required a significant volume of wood fuel, the use of fairly intensive coppicing (4-7 years) may have been required in order to resource this activity without completely removing areas of woodland.

Attempts to recognise episodes of coppicing within pollen diagrams have met with limited success (e.g. Waller and Schofield, 2007). Waller et al. (2012) also found it difficult to identify cutting cycles and growth responses within pollen diagrams. Using a modelled scenario of coppice within *Alnus glutinosa* carr on a 20-year rotation, Waller et al. (2012) showed a shift in pollen productivity (declining *A.*

glutinosa and increasing *C. avellana)*. This scenario might explain the inverse relationship between these taxa in the pollen record at Roughan. Despite being dominant species in the charcoal record (Figure 8) *Alnus* does not demonstrate a see-saw pattern at Ballygawley. If this species was managed, any rotation or management markers could not be identified in the pollen record.

Corylus avellana-type is the second most and most abundant type of charcoal recovered from the burnt mounds (Figures 8 and 9). Its exploitation may explain the see-saw pattern in the pollen percentage and concentration data (Figures 4, 6, Supplementary Figures 4 and 5). However, the known rotation patterns described above (6-20 years) are probably much shorter than the see-saw pattern observed in the pollen records here. The pollen data are constrained by a limited chronology and the time span encapsulated in a 0.5 cm thick sample is unknown.

Quercus and *Betula* are also common in the Roughan macroscopic charcoal assemblages. At Llwyn Du, northwest Wales, a see-saw pattern for both taxa was reconstructed from fine resolution pollen data during iron production at a medieval bloomery. Crew and Mighall (2013) argued that the pattern was probably caused by woodland management of oak and birch. Wheeler (2007, 2011) also observed correlating see-saw patterns at Rievaulx and Bilsdale in North Yorkshire. Wickham et al*.* (2010) observed that short rotation coppicing (2-3 years) of willow can lead to a higher wood yield which may explain the see-saw pattern in the *Salix* pollen record at Roughan, although *Salix* wood was only recovered in small quantities (Figure 11).

Corylus, *Quercus* and *Alnus* charcoal is commonly recovered from burnt mounds (Stuijts, 2005; O'Donnell, 2007, 2009; Miller and Ramsey, 2009). The differences in the frequency of trees from site to site may also reflect changes in the composition of woodland (Ludemann et al., 2004; Ludemann, 2009) rather than preferential selection.

Growth ring curvature of the charcoal fragments indicates that the majority of the fuel wood was derived from small to medium-sized wood such as twigs, branch wood and possibly rods/stemwood. These sizes might indicate the deliberate collection through coppicing and/or pollarding (Boyd, 1988). Larger pieces of wood were also used, probably trunk wood, suggested by charcoal fragments displaying weakly curved growth rings (Marguerie and Hunot, 2007). At Ballygawley these larger timbers are restricted to *Corylus avellana*, *Alnus glutinosa* and *Quercus* sp., while at Roughan they include *Betula* sp., *Salix* sp. and *Prunus avium* suggesting some deliberate selection or simply a wider availability.

The worked wood analysis of planks and wattle sails used in the construction of troughs also suggest that some form of woodland management was practiced. Wattle sails were mainly constructed from long straight hazel stems that had similar ring counts (4-7 years) and diameter sizes (10-30 mm). This stemwood may have been from coppiced or new growth cut within an interval of less than 10 years (Bamforth et al., 2010).

Natural fluctuations and taphonomic processes

Other explanations may have also influenced the pattern of pollen percentages and concentrations. Fluctuations in arboreal pollen assemblages are to be expected within local *Alnus* carr-woodland, reflecting natural cycles of woodland in a floodplain environment (Waller, 1998; Waller et al., 2005). These *Alnus glutinosa*-dominated communities often exhibit small-scale heterogeneity due to the instability of the ground substrates and tree weight (Rodwell, 1991). Changes in the herbaceous pollen assemblage, mainly of Poaceae and Cyperaceae pollen, also may indicate some opening of the local carr and increased presence of fen-reedswamp.

ii) Increases across the cross-fraction micro-charcoal

There is a cross-fraction increase in microscopic charcoal values during burnt mound activity (Figures 5 and 6). These elevated charcoal levels are expected given the nature of the hot stone technology and large quantities of macroscopic charcoal present. This is particularly evident in the >50 µm size class, signifying the intensification of local on-site burning.

iii) Greater presence of wood detritus

An increase in probable dead wood indicators, SPPs (HdV-114) and *Sordaria*-type (HdV-55A) (van Geel et al., 1983, 2003) in levels associated with burnt mound deposits occurred at both sites. *K. deusta* (HdV-44) was also present at Roughan and HdV-72D also feeds off vegetation debris. It is likely that the SPPs represented a combination of decomposed *Corylus avellana*, *Alnus glutinosa* and *Betula* sp. remains (Schweingruber, 1990). Chopping and/or storing of wood fuel may have occurred near to the burnt mounds with fungi (e.g. *Sordaria* sp.) attacking stored wood (Feist et al., 1973). Fungal hyphae were observed within macroscopic charcoal fragments, which could also represent the use of deadwood for fuel (Marguerie and Hunot, 2007) or simply woody debris derived from the catchment. There is no evidence of working debris from the waterlogged wood recovered from Ballygawley. Wood may have been fashioned prior to being brought to site to line the troughs.

Alder bark can also be used to create a black dye (Stuijts, 2005), so an increase in SPPs indicative of detritus may be related to bark stripping. Stone scrapers were present within the finds assemblage (Lochrie, 2010b).

iv) Presence of herbivores and cereal cultivation

It appears that burnt mound activity is strongly associated with a pastoral economy. Coprophilous fungal spores occur in both assemblages suggests that animals were present locally. Cugny et al. (2010) consider *Cercophora*-type (HdV-112) to be a reliable dung indicator. Evidence for pasture is strong in the pollen records and the discovery of burnt bone has indicated that animal butchery was taking place at Ballygawley (Tourunen, 2009). Such activity has also been advocated for other burnt mound sites in Ireland (Tourunen, 2008).

Evidence for cereal cultivation is less forthcoming. Only one *Triticum*-type was recorded at Ballygawley and it is not associated with the burnt mound. Poaceae grains (>35 µm in diameter) were recorded at both sites. However, these could be wild grasses such as *Glyceria* and *Elytrigia* (Stace, 2001; Tweddle et al., 2005). Moreover, the poor dispersal ability of large grasses and cereal pollen, combined with relatively dense woodland, might have dampened any cultivation signal in the pollen record (Vuorela, 1973; Tweddle et al., 2005).

v) Increased levels of eutrophy and peaks in Sphagnum

Sphagnum peaks occur during the phase of burnt mound use and could be related to the use of bogmoss in the lining of troughs. Increased levels of meso- or eutrophy were also implied by *Diportheca rhizophila* (HdV-143), HdV-62, HdV-128 and possibly

HdV-55A at Roughan (Pals et al., 1980; van Geel et al., 1983). This could be the result of water either used in the troughs, pooling during periods of non-activity, or from stagnant water lying close by. In contrast, high amounts of *Gloeotrichia*-type (HdV-146) are indicative of nutrient poor conditions.

CONCLUSIONS

The results of this study suggest that burnt spread and mound activity can be characterised in the following way:

1. Activity appears to have had a small non-permanent impact on the local environment during the Mesolithic, Late Neolithic and Bronze Age. The spatial impact of such activity appears to have been restricted but needs to be constrained by multiple pollen profiles and more robust chronologies for the palaeoenvironmental deposits.

2. Activity took place at water side locations in small clearings with pasture close by, as suggested by the occurrence of herbs associated with pasture and the regular presence of coprophilous fungi. However, despite the wealth of local activity especially from the Late Neolithic onwards, the occurrence of non-arboreal pollen taxa associated with human activity is generally limited to trace amounts. This might be due to taphonomic effects including a limited pollen source area and/or pollen filtering by high arboreal pollen producers and relatively dense woodland. Natural perturbations in a floodplain environment could also account for some of the changes recorded.

3. Burnt mound use appears to be associated more with local pasture rather than cereal cultivation. Cereal-type pollen only occurred in trace amounts and then only

sporadically in the pollen records. Although not conclusive, evidence for animal butchery and pasture point towards cooking as the most likely activity.

4. Each burnt mound deposit/burnt spread was associated with specific changes in the pollen, NPPs and microscopic charcoal records, irrespective of the age of the burnt material. These included a repetitive see-saw pattern in the pollen percentages and concentrations of major trees, shrubs and herbs, high microscopic charcoal values, presence of coprophilous fungi, peaks in *Gloeotrichia*-type (HdV-146), SPPs (HdV-114) and peaks in *Sphagnum*. Whether these are indicative of burnt mound use is unclear but possible.

5. It is reasonable to suggest that: (a) charcoal is associated with fuelwood and repetitive exploitation of wood for fuel (e.g. deliberate cyclical coppicing) is known in prehistory (Rasmussen, 1990) which could be implied in the context of the burnt mounds at Ballygawley and Roughan; (b) increases in SPPs (HdV-114) and *Sordaria*-type (HdV-55A) may represent detritus from possible wood preparation (e.g. chopping/leaf stripping/bark removal etc.) which may have been taken from trees that were naturally present in the floodplain environment; (c) *Sphagnum* was used to line and seal the troughs; and (d), burnt mound activity changed water conditions leaving them eu- to mesotrophic. These markers may be diagnostic indictors of burnt mound use in the palaeoecological record but this hypothesis now requires further testing.

Although the results of this study provide little direct insight into the function of burnt mounds, they do provide us with a greater understanding of human-environmental interaction at these enigmatic sites. Further multi-proxy studies would provide useful information.

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REFERENCES

Anderson, E., Harrison, S., Passmore, D., & Mighall, T.M. (2000). Holocene alluvial fan development in the MacGillycuddy's Reeks, south-west Ireland. Bulletin of the Geological Society of America, 112, 1834-1849.

Anthony, I.M.C., Sanderson, D.C.W., Cook, G.T., Abernethy, D., & Housley, R.A. (2001). Dating a burnt mound from Kilmartin, Argyll, Scotland. Quaternary Science Reviews, 20, 921-925.

Asouti, E. (2001). Charcoal analysis from Çatalhöyük and Pinarbaşi, two Neolithic sites in the Konya Plain, south-central Anatolia, Turkey. Unpublished doctoral thesis, University College London.

Bailey, E. (2010a). Archaeological Excavations at Ballygawley, Co. Tyrone in advance of the A4/A5 Road Improvement Scheme. Unpublished Report. Edinburgh: Headland Archaeology Ltd.

Bailey, E. (2010b). Archaeological Excavations at Roughan, Co. Tyrone in advance of the A4/A5 Road Improvement Scheme. Unpublished Report. Edinburgh: Headland Archaeology Ltd.

Bamforth, M., Gray L., & Taylor, M. (2010). Waterlogged wood analysis report; A4/A5 corridor improvements (Dungannon-Ballygawley). Unpublished Client Report. Chester: L-P Archaeology.

Barber, K.E. (1976). History of vegetation. In S.B. Chapman (Ed.) Methods in plant ecology, (pp. 5-83). Oxford: Blackwell.

Barfield, L., & Hodder, M. (1987). Burnt mounds as saunas and the prehistory of bathing. Antiquity, 61, 370–379.

Bartley, D. D., & Chambers, C. (1992). A pollen diagram, radiocarbon ages and evidence of agriculture on Extwistle Moor, Lancashire. New Phytologist, 121, 311-320.

Bayliss, A., McAvoy, F., & Whittle, A. (2007). The world recreated: redating Silbury Hill in its monumental landscape. Antiquity, 81, 26-53.

Bayliss, A., & Woodman, P.C. (2009). A new Bayesian chronology for Mesolithic occupation at Mount Sandel, Northern Ireland. Proceedings of the Prehistoric Society, 75, 101-123.

Benninghoff, W.S. (1962). Calculation of pollen and spore density in sediments by addition of exotic pollen in known quantities. Pollen et Spores, 4, 332-333.

Beug, H-J. (2004). Leitfaden der pollenbestimmung für mitteleuropa und angrenzende gebiete. München: Verlag Dr. Friedrich Pfeil.

Bigman, D. P., & Lanzarone, P. M. (2014). Investigating Construction History, Labour Investment and Social Change at Ocmulgee National Monument's Mound A, Georgia, USA, Using Ground-penetrating Radar. Archaeological Prospection, 21, 213-224.

Binney, H. A., Waller, M. P., Bunting, M. J., & Armitage, R. A. (2005). The interpretation of fen carr pollen diagrams: the representation of the dry land vegetation. Review of Palaeobotany and Palynology, 134, 197-218.

Blaauw, M. (2010). Methods and code for ‘classical’ age-modelling of radiocarbon sequences. Quaternary Geochronology, 5, 512-518.

Bradley, R. (1978). The prehistoric settlement of the British Isles. London: Routledge & Kegan Paul.

Brindley, A. L., Lanting, J. N., & Mook, W. G. (1989). Radiocarbon dates from Irish fulachta fiadh and other burnt mounds. The Journal of Irish Archaeology, 5, 25-33.

Brock, F., Lee, S., Housley, R. A., & Ramsey, C. B. (2011). Variation in the radiocarbon age of different fractions of peat: a case study from Ahrenshöft, northern Germany. Quaternary Geochronology, 6, 550-555.

Bronk Ramsey, C. (2009a). OxCal 4.1. OxCal Project. Oxford: University of Oxford.

Bronk Ramsey, C. (2009b). Bayesian analysis of radiocarbon dates. Radiocarbon, 51, 337-360.

Brown, A.G. (1999). Biodiversity and pollen analysis: modern pollen studies and the recent history of a floodplain woodland in S.W. Ireland. Journal of Biogeography, 26, 19-32.

Brown A.G., Carpenter, R.G., & Walling, D.E. (2007). Monitoring fluvial pollen transport, its relationship to catchment vegetation and implications for palaeoenvironmental studies. Review of Palaeobotany and Palynology, 147, 60-76.

Boyd, W.E. (1988). Methodological problems in the analysis of fossil non-artifactual wood assemblages from archaeological sites. Journal Archaeological Science, 15, 603-619.

Buckley, V. (1990). Burnt offerings: International contributions to burnt mound archaeology. Dublin: Wordwell Ltd Academic Publications.

Bunting, M.J., Armitage, R., Binney, H.A., & Waller M. (2005). Estimates of 'relative pollen productivity' and 'relevant source area of pollen' for major tree taxa in two Norfolk (UK) woodlands. The Holocene, 15**,** 459-465.

Chambers, F. M. (1993). Climate change and human impact on the landscape: studies in palaeoecology and environmental archaeology. London: Chapman and Hall.

Chapman, H.P. and Gearey, B.R. (2013). Modelling Archaeology and Palaeoenvironments in Wetlands: The Hidden Landscape Archaeology of Hatfield and Thorne Moors. Oxford, Oxbow.

Coon, N. (1978). The dictionary of useful plants: The use, history, and folklore of more than 500 plant species. Market Harborough: Rodale Press.

Crew, P., & Mighall, T.M. (2013). The fuel supply and woodland management at a 14th century bloomery in Snowdonia, a multi-disciplinary approach. In J. Humphris, & T. Rehren (Eds.), The World of Iron (pp. 473-482). London: Archetype Publications.

Cugny, C., Mazier, F., & Galop, D. (2010). Modern and fossil non-pollen palynomorphs from the Basque mountains (western Pyrenees, France): the use of coprophilous fungi to reconstruct pastoral activity. Vegetation History and Archaeobotany, 19, 391-408.

Delcourt P.A.,& Delcourt H.R. (1980). Pollen preservation and environmental history in the south-eastern United States. Palynology, 4, 215-321.

Dickson, C. (1988). Distinguishing cereal from wild grass pollen: some limitations. Circaea, 5, 67-71.

Dimbleby, G.W. (1985). The Palynology of Archaeological Sites. London: Academic Press Inc.

Edwards, K.J. (1981). The separation of *Corylus* and *Myrica* pollen in modern and fossil samples. Pollen et Spores, 23, 205-218.

Edwards, K.J., & Borthwick, D.M. (2010). The pollen content of so-called "ancient" field systems in Suðuroy, Faroe Islands, and the question of cereal cultivation. In S.A. Bengtson (Eds.), Dorete – her book – being a tribute to Dorete Bloch and to Faroese nature (pp. 96-116). Torshavn: Faroe University Press.

Eerkens, J. W., DeGeorgey, A., Spero, H. J., & Descantes, C. (2014). Seasonality of Late Prehistoric Clamming on San Francisco Bay: Oxygen Isotope Analyses of

Macoma nasuta Shells from a Stege Mound, CA-CCO-297. California Archaeology, 6, 23-46.

Fægri K., Iversen J., Kaland P.E., & Krzywinski K. (1989). Textbook of Pollen Analysis. London: Blackwell.

Feehan, J. (1991). Fulachta fiadh in the South Midlands. Tipperary Historical Journal, 4, 202-207.

Feist, W.C., Springer, E.L., & Hajny, G.J. (1973). Spontaneous heating in piled wood chips - contribution of bacteria. Tappi, 56, 148-151.

Gonzalez, S., Innes, J.B., Huddart, D., Davey, P.J. & Plater, A.J. (2000). Holocene coastal change in the north of the Isle of Man: stratigraphy, palaeoenvironment and archaeological evidence. In K. Pye, & J. Allen (eds.) Coastal and Estuarine Environments: Sedimentology, Geomorphology and Geoarchaeology, (pp. 343-363) London: Geological Society Special Publication No. 175.

Gowen, M., Ó Néill, J., & Philips, M. (2005).The Lisheen Mine Archaeological Project 1996-8. Bray: Wordwell.

Grigson, C. (1982). Porridge and pannage: pig husbandry in Neolithic England. In: M. Bell & S. Limbrey (Eds.), Archaeological aspects of woodland ecology (pp 297-314). British Archaeological Report International Series 146. Oxford: Archaeopress.

Grimm, E.C. (1987). CONISS: A Fortran 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. Computers and Geosciences 13, 13-35.

Grimm, E.C. (2004). TGView 2.0.2. Illinois: Illinois State Museum.

Hather, J.G. (2000). The identification of the Northern European Woods: A guide for archaeologists and conservators. London: Archetype Publications.

Havinga, A.J. (1967). Palynology and pollen preservation. Review of Palaeobotany and Palynology, 2, 84-98.

Hawkes, A. (2013). The beginnings and evolution of the *fulucht fiadh* tradition in early prehistoric Ireland. Proceedings of the Royal Irish Academy, 114C, 1-51.

Huntley, B. (1993). Rapid early-Holocene migration and high abundance of hazel (*Corylus avellana* L.): alternative hypotheses (pp 205-215). In F.M. Chambers (ed.), Climate change and human impact on the landscape. London: Chapman and Hall.

Innes, J.B. (1998). The pollen analysis. In P. Topping, The excavation of burnt mounds at Titlington Mount, north Northumberland. Northern Archaeology, 15/16, 3-25.

Innes, J. B., & Blackford, J. J. (2003). The ecology of late Mesolithic woodland disturbances: model testing with fungal spore assemblage data. Journal of Archaeological Science, 30, 185-194.

Ivens, R.J., & Simpson, D.A. (1988). Excavations at Lislear, Baronscourt, Co. Tyrone, 1987. Ulster Journal of Archaeology, 51, 61-68.

Jeffrey, S. (1991). Burnt mounds fulling and early textiles? Burnt mounds and hot stone technology. Sandwell: Sandwell Metropolitan Borough Council.

Johnson, R. H., Tallis, J. H., & Wilson, P. (1990). The Seal Edge Coombes, North Derbyshire - a study of their erosional and depositional history. Journal of Quaternary Science, 5, 83-94.

Keenan, S. W., & Ellwood, B. B. (2014). Geophysical Evaluation of the Richland and Holloway Mounds, Southeastern Louisiana, USA. Geoarchaeology, 29, 312-325.

Kołaczek, P., Zubek, S., Błaszkowski, J., Mleczko, P., & Margielewski, W. (2013). Erosion or plant succession — How to interpret the presence of arbuscular mycorrhizal fungi (Glomeromycota) spores in pollen profiles collected from mires. Review of Palaeobotany and Palynology, 189, 29-37.

Kuhry, P. (1985). Transgression of a raised bog across a cover sand ridge originally covered with an oak-lime forest. Palaeoecological study of a Middle Holocene local vegetational succession in the Astven (northwest Germany). Review of Palaeobotany and Palynology, 44,303-353.

Leney, L. & Casteel, R.W. (1975). Simplified procedure for examining charcoal specimens for identification. Journal of Archaeological Science, 2, 153-159.

Lewin, J., Macklin, M.G., Johnstone, E. (2005). Interpreting alluvial archives: sedimentological factors in the British Holocene fluvial record. Quaternary Science Reviews, 24, 1873-1889.

Lindauer, O., & Blitz, J. H. (1997). Higher ground: The archaeology of North American platform mounds. Journal of Archaeological Research, 5, 169-207.

Lochrie, J. (2010a). Pottery (pp. 43-44). In: E. Bailey (Ed.), Archaeological Excavations at Ballygawley, Co. Tyrone in advance of the A4/A5 Road Improvement Scheme. Unpublished Report. Edinburgh: Headland Archaeology Ltd.

Lochrie, J. (2010b). Lithics (pp. 44-58). In E. Bailey (Ed.) Archaeological Excavations at Ballygawley, Co. Tyrone in advance of the A4/A5 Road Improvement Scheme. Unpublished Report. Edinburgh: Headland Archaeology Ltd.

Lochrie, J. (2010c). Worked Bone (pp. 58-60). In E. Bailey (Ed.), Archaeological Excavations at Ballygawley, Co. Tyrone in advance of the A4/A5 Road Improvement Scheme. Unpublished Report. Edinburgh: Headland Archaeology Ltd.

Lombardo, U., & Prümers, H. (2010). Pre-Columbian human occupation patterns in the eastern plains of the Llanos de Moxos, Bolivian Amazonia. Journal of Archaeological Science, 37, 1875-1885.

Ludemann, T. (2009). Past fuel wood exploitation and natural forest vegetation in the Black Forest, the Vosges and neighbouring regions in western Central Europe. Palaeogeography, Palaeoclimatology, Palaeoecology 291, 154-156.

Ludemann, T., Michiels, H-G., & Nöken, W. (2004). Spatial patterns of past wood exploitation, natural wood supply and growth conditions: indications of natural tree species distribution by anthracological studies of charcoal-burning remains. European Journal of Forest Research, 123, 283-292.

Marguerie D., & Hunot J.Y. (2007). Charcoal analysis and dendrochronology: data from archaeological sites in north-western France. Journal of Archaeological Science, 34, 1417-1433.

Martin, P. S., & Mehringer, P. J. (1965). Pleistocene pollen analysis and biogeography of the Southwest. na.

Meiklejohn C., & Woodman P.C. (2012). Radiocarbon dating of Mesolithic human remains in Ireland. Mesolithic Miscellany, 22, 22-41.

Mighall, T.M., Timberlake, S., & Crew, P. (2010). Vegetation changes in former mining and metalworking areas of Wales and Ireland during prehistoric and medieval times (pp. 19-26). In P. Belford, M. Palmer, M., & R. White (Eds), Footprints of Industry. British Archaeological Reports British Series 523. Oxford: Archaeopress.

Mighall, T.M., Timpany, S., Blackford, J.J, Innes, J.B., O'Brien, C., O'Brien, W.F., & Harrison, S. (2008). Vegetation changes during the Mesolithic and Neolithic in Co. Cork, SW Ireland. Vegetation History and Archaeobotany, 17, 617-628.

Miller, J., & Ramsay, S. (2009). Botanical Evidence (pp. 27-29). In I. Banks, P.R.J. Duffy, G. MacGregor (Eds), Archaeology of landscape change in south-west Scotland, 6000 BC –AD 1400: Excavations at William Grant and Sons Distillery, Girvan. Edinburgh: Society of Antiquaries of Scotland.

Mitchell, G.F. (1955). The Mesolithic Site at Toome Bay, Co. Londonderry. Studies in Irish Quaternary Deposits; No. 10. Ulster Journal of Archaeology, 18, 1-16.

Monk, M. (2007). A greasy subject. Archaeology Ireland, 21, 22-24.

Moore P.D., Webb J.A., & Collinson, M.E. (1991). Pollen Analysis. Oxford: Blackwell Science.

Morgan, R.A. (1983). Tree-ring studies in the Somerset Levels: the examination of modern hazel growth in Bradfield Woods, Suffolk, and its implications for the prehistoric data. Somerset Levels Papers, 9, 44-48.

Nakagawa, T., Brugiapaglia, E., Digerfelt, G., Reille, M., de Beaulieu, J-L.,& Yasuda, Y. (1998). Dense-media separation as a more efficient pollen extraction method for use with organic sediment/deposit samples: comparison with the conventional method. Boreas, 27, 15-24.

Nelle, O., Dreibrodt, S., & Dannath, Y. 2010. Combining pollen and charcoal: evaluating Holocene vegetational composition and dynamics. Journal of Archaeological Science, 37, 2126-2135.

Newman, C., O'Connell, M., Dillon, M., & Molloy, K. (2007). Interpretation of charcoal and pollen data relating to a late Iron Age ritual site in eastern Ireland: a holistic approach. Vegetation History and Archaeobotany, 16, 349-365.

O'Donnell, L. (2007). Environmental archaeology: Identifying patterns of exploitation in the Bronze Age, Charcoal and wood (pp. 27-65). In E. Grogan, L. O'Donnell, P. Johnston (Eds), The Bronze Age landscapes of the pipeline to the west. An integrated archaeological and environmental assessment. Bray: Wordwell Ltd.

O’Donnell, L. (2009). Charcoal analysis (pp. 113-124). In C. Baker (Ed.) The Archaeology of Killeen Castle, Co. Meath. Bray: Wordwell Ltd.

Ó Drisceóil, D. (1988). Burnt mounds: cooking or bathing? Antiquity, 62, 671-680.

O'Kelly, M.J. (1954). Excavations and experiments in ancient Irish cooking-places. Journal of the Antiquaries of Ireland, 84, 105–155.

Ó Néill, J. (2009). Burnt mounds in Northern and Western Europe: A study in prehistoric technology and society. Saarbrücken: VDM Verlag Dr. Müller.

O'Sullivan, M.,& Downey, L. (2004). Fulachta fiadh. Archaeology Ireland, 17, 35-37.

Pals, J.P., van Geel, B., & Delfos, A. (1980). Palaeoecological studies in the Klokkeweel bog near Hoogkarspel (Noord Holland). Review of Palaeobotany and Palynology, 30, 371-418.

Pilcher, J.R. (1973). Pollen analysis and radiocarbon dating of a peat on Slieve Gallion, Co. Tyrone, N. Ireland. New Phytologist, 72, 681-689.

Pilcher, J. R. (1991). Radiocarbon dating. Quaternary Dating Methods-A user's Guide. Quaternary Research Association Technical Guide, 4, 16-36.

Pilcher J.R., & Smith A.G. (1979). Palaeoecological investigations at Ballynagilly, a Neolithic and Bronze Age settlement in County Tyrone, Northern Ireland. Philosophical Transactions of the Royal Society, B, 286, 345-369.

Piotrowska, N., Blaauw, M., Mauquoy, D., & Chambers, F. M. (2011). Constructing deposition chronologies for peat deposits using radiocarbon dating. Mires and Peat, 7, 1-14.

Pluckhahn, T.J., Hodson, A.D., Rink, W.J., Thompson, V.D., Hendricks, R.R., Doran, G., Farr, G., Cherkinsky, A. & Norman, S.P. (2015). Radiocarbon and luminescence age determinations on mounds at Crystal River and Roberts Island, Florida, USA. Geoarchaeology, 30, 238-260.

Plunkett, G., Carroll, F., Hartwell, B., Whitehouse, N.J., & Reimer, P. (2008). Vegetation history at the multi-period prehistoric complex at Ballynahatty, Co. Down, Northern Ireland. Journal of Archaeological Science, 35, 181-190.

Prior, J. & Alvin, K.L. (1983). Structural changes on charring woods of *Dichrostachys* and *Salix* from southern Africa. IAWA Bulletin, 4, 197-206.

Quinn B., & Moore D. (2007). Ale, brewing and fulachta fiadh. Archaeology Ireland, 21, 8-11.

Rackham, O. (2006). Woodlands. London: Harper Collins.

Rasmussen, P. (1990). Pollarding of trees in the Neolithic: Often presumed – Difficult to prove (pp. 77-99). In D.E. Robinson (Ed.) Experimentation and reconstruction in environmental archaeology. Oxford: Oxbow.

Reille, M. (1999). Pollen et spores d'Europe et d'Afrique du nord. Marseille: Laboratoire de Botanique Historique et Palynologie.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C., Blackwell, P.G., Buck, C.E., Burr, G., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.L., Freidrich, M., Guilderson, T.P., Hughen, K.A., Kromer, B., McCormac, F.G., Manning, S., Bronk Ramsey, C., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J., & Weyhenmeyer, C.E. (2009). Quaternary Isotope Laboratory, Radiocarbon Calibration Program. Washington: University of Washington. **http://radiocarbon.pa.qub.ac.uk/calib/calib.html**

Rodwell, J.S. (1991). British Plant Communities Volume 1: Woods and scrub. Cambridge: Cambridge University Press.

Sayce, R. (1945). Canoes, coffins and cooking-troughs. Proceedings of the Society of Antiquaries of Scotland, 79, 106-111.

Schulte, E.E., & Hopkins, B.G. (1996). Estimation of organic matter by weight loss-on-ignition. In F.R. Magdoff (Ed.), Soil organic matter: Analysis and interpretation (pp.21-31). Madison, WI: SSSA Special Publication 46.

Schweingruber, F.H. (1990). Microscopic Wood Anatomy. Birmensdorf: Eidgen-ssische Forschungsanstalt WSL.

Semple, S. (1998). A fear of the past: The place of the prehistoric burial mound in the ideology of middle and later Anglo-Saxon England. World Archaeology, 30, 109-126.

Shore, J. S., Bartley, D. D., & Harkness, D. D. (1995). Problems encountered with the 14 C dating of peat. Quaternary Science Reviews, 14, 373-383.

Simmons, I.G., & Innes, J.B. (1988). Late Quaternary vegetational history of the North York Moors. IX. Numerical analysis and pollen concentration analysis of Flandrian II peat profiles from North Gill, Glaisdale Moor. Journal of Biogeography, 15, 273-297.

Simmons, I.G., & Innes J.B. (1996). Disturbance Phases in the Mid-Holocene Vegetation at North Gill, North York Moors: Form and Process. Journal of Archaeological Science, 23, 183-191.

Smith, A.G., & Goddard, I.C. (1991). A 12500 year record of vegetational history at Sluggan Bog, Co. Antrim, N. Ireland (incorporating a pollen zone scheme for the non-specialist). New Phytologist, 118, 167-187.

Spaulding, G.L., Moore, D.G, Barker, A., Bradle, M., Busby, A.B., Jones, K., Moseley, L., Patterson, P.E., Ravel, P., Scott, R., & Skinner A. (1999). Lithic Material from the River Bann at Molloy's Ford, Glentone TD., Co. Londonderry. Ulster Journal of Archaeology, 58, 143-147.

Stace, C. (2001). New flora of the British Isles. Cambridge: Cambridge University Press.

Steadman, S. R. (2000). Spatial patterning and social complexity on prehistoric Anatolian tell sites: Models for mounds. Journal of Anthropological Archaeology, 19, 164-199.

Stockmarr, J. (1971). Tablets with spores used in absolute pollen analysis. Pollen et Spores, 13, 615-621.

Stuijts, I. (2005). Wood and charcoal identification (pp. 137-186). In M. Gowen, J.O., Neill, M. Philips (Eds.), The Lisheen Mine Archaeological Project 1996-8. Bray: Wordwell.

Stuijts, I. (2007). Wood and charcoal research in Ireland (pp. 179-93). In E.M. Murphy & N.J. Whitehouse (Eds), Environmental Archaeology in Ireland. Oxford: Oxbow Books.

Stuiver M., Reimer .J (1993). Extended 14C database and revised CALIB radiocarbon calibration program. *Radiocarbon* 35: 215-230.

Telford, R. J., Heegaard, E., & Birks, H. J. B. (2004). All age–depth models are wrong: but how badly? Quaternary Science Reviews, 23, 1-5.

Tipping, R. (2004). Interpretative issues concerning the driving forces of vegetation change in the Early Holocene of the British Isles (pp. 73-82). In A. Saville (Ed.), Mesolithic Scotland and its neighbours. Edinburgh: Society of Antiquaries of Scotland.

Tipping, R., Bunting, M.J, Davies, A.L., Murray, H., Fraser, S., & McCulloch, R. (2009). Modelling land use around an early Neolithic timber 'hall' in north east Scotland from high spatial resolution pollen analyses. Journal of Archaeological Science, 36, 140-149.

Tourunen, A. (2008). Fauna and *Fulachta fiadh*: animal bones from burnt mounds on the N9/N10 Carlow Bypass (pp. 37-44). In J. O'Sullivan, & M. Stanley (Eds.), Roads, Rediscovery and Research Archaeology and the National Roads Authority Monograph Series No. 5. Dublin: National Roads Authority.

Tourunen, A. (2009). Final report on the faunal remains from Ballygawley (Site 1), Co. Tyrone. Unpublished Report. Edinburgh: Headland Archaeology Ltd.

Troels-Smith, J. (1955). Karakterisering af lose jordarter. Characterization of unconsolidated sediments. Geological Survey of Denmark IV. Series. Vol. 3 n. 10, pp 73.

Tweddle, J. C., Edwards, K.J., & Fieller, N.R.J. (2005). Multivariate statistical and other approaches for the separation of cereal from wild Poaceae pollen using a large Holocene dataset. Vegetation History and Archaeobotany, 14, 15-30.

van Geel, B. (1978). A palaeoecological study of Holocene peat bog sections in Germany and the Netherlands. Review of Palaeobotany and Palynology, 25, 1-120.

van Geel B. (2005). Non pollen palynomorphs. In J.P. Smol, H.J.B. Birks, W.M. Last (Eds), Tracking environmental change using lake sediments (pp.99-119). Kluwer Academic Publications, Dordrecht, pp.99-119.

Van Geel, B., Bos, J. M., & Pals, J. P. (1983). Archaeological and palaeoecological aspects of a medieval house terp in a reclaimed raised bog area in North Holland. *Ber. Rijksd. Oudheidk. Bodemonderz*, *33*, 419-444.

van Geel, B., Buurman, J., Brinkkemper, O., Schelvis, J., Aptroot, A., van Reenen, G., & Hakbijl T. (2003). Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi. Journal of Archaeological Science, 30, 873-883.

van Geel, B., Hallewas, D.P.,& Pals J.P. (1982/1983). A late Holocene deposit under the Westfriese Zeedijk near Enkhuizen (Prov. Of Noord-Holland, The Netherlands): palaeoecological and archaeological aspects. Review of Palaeobotany and Palynology, 38, 269-335.

Vuorela, I. (1973). Relative pollen rain around cultivated fields. Acta Botanica Fennica, 102, 1-27.

Waller, M.P. (1998). An investigation into the palynological properties of fen peat through multiple pollen profiles from south-eastern England. Journal of Archaeological Science, 25, 631-642.

Waller, M.P., & Schofield, J.E. (2007). Mid to Late Holocene vegetation and land use history in the Weald of south-eastern England: multiple pollen profiles from the Rye area. Vegetation History and Archaeobotany, 16, 367-384.

Waller, M.P., Grant, M.J., & Bunting, M.J. (2012). Modern pollen studies from coppiced woodlands and their implications for the detection of woodland management in Holocene pollen records. Review of Palaeobotany and Palynology, 187, 11-28.

Waller, M.P., Binney, H.A., Bunting, M.J., & Armitage, R.A. (2005). The interpretation of fen carr pollen diagrams: pollen-vegetation relationships within the fen carr. Review of Palaeobotany and Palynology, 133, 179-202.

Wheeler, J. (2007). The implications of iron-working on the woodlands of Rievaulx and Bilsdale, North Yorkshire, United Kingdom: Historical, Palaeoecological and Palaeoenvironmental Perspectives circa 1068-2000. Unpublished PhD thesis, University of Bradford, Bradford.

Wheeler, J. (2011). Charcoal analysis of industrial fuelwood from medieval and early modern iron-working sites in Bilsdale and Rievaulx, North Yorkshire, UK: evidence for species selection and woodland management. Environmental Archaeology, 16, 15-35.

Whittington, G., & Edwards, K.J. (1994). Palynology as a predictive tool in archaeology. Proceedings of the Society of Antiquities of Scotland, 124, 55-65.

Wickham, J., Rice, B., Finnan, J., & McConnon, R. (2010). A review of past and current research on short rotation coppice in Ireland and abroad. Unpublished manuscript. Prepared for COFORD and Sustainable Energy Authority of Ireland.

Wilkins, B. (2011). Past orders: the archaeology of beer. Current Archaeology, 256, 28-35.

Woodman, P.C. (1977). Recent excavations at Newferry, Co. Antrim. Proceedings of the Prehistoric Society, 43, 155-199.

Woodman, P.C. (1985). Excavations at Mount Sandel 1973-77. Northern Ireland Archaeological Monographs. Department for the Environment for Northern Ireland. Belfast: Her Majesty’s Stationery Office.

Woodman, P.C., Anderson, E., & Finlay, N. (1999). Excavations at Ferriter’s Cove 1983-1995: last foragers, first farmers in the Dingle Peninsula. Bray: Wordwell Ltd.

Woodman, P.C., McCarthy, M., Monaghan, N. (1997). The Irish Quaternary Fauna project. Quaternary Science Reviews, 16, 129-159.

Yeloff, D., Van Geel, B., Broekens, P., Bakker, J., & Mauquoy, D. (2007). Mid- to late-Holocene vegetation and land-use history in the Hadrian's Wall region of northern England: The record from Butterburn Flow. The Holocene, 17, 527-538.

Figure captions

Figure 1 Location of study sites (a) in Northern Ireland; (b) in Co Tyrone, Northern Ireland; (c) excavation site at Ballygawley showing the palaeochannels and burnt mounds (circles); (d) excavation site at Roughan showing Area C (e) the location of the monoliths and burnt mounds in Area C, Roughan.

Figure 2 Stratigraphic sections for (a) Ballgawley; (b) Roughan; (c) Burnt mount context 8413 and the position of the Roughan monolith taken in this study.

Figure 3 Age depth graph for Roughan (smooth spline model) using Clam (Blaauw, 2010).

Figure 4a Percentage pollen diagram of trees, shrubs, dwarf shrubs and microscopic charcoal from Ballygawley, Co. Tyrone. Rare types are indicated by a cross (+), where one cross is equal to one pollen grain or NPP.

Figure 4b Percentage pollen diagram of herbs from Ballygawley, Co. Tyrone. Rare types are indicated by a cross (+), where one cross is equal to one pollen grain or NPP.

Figure 5 Percentage NPP diagram from Ballygawley, Co. Tyrone. Rare types are indicated by a cross (+), where one cross is equal to one pollen grain or NPP.

Figure 6a Percentage pollen diagram of trees, shrubs, dwarf shrubs and microscopic charcoal from Roughan, Co. Tyrone. Rare types are indicated by a cross (+), where one cross is equal to one pollen grain or NPP.

Figure 6b Percentage pollen diagram of herbs from Roughan, Co. Tyrone. Rare types are indicated by a cross (+), where one cross is equal to one pollen grain or NPP.

Figure 7 Percentage NPP diagram from Roughan, Co. Tyrone. Rare types are indicated by a cross (+), where one cross is equal to one pollen grain or NPP.

Figure 8 Charcoal identifications from Late Neolithic and Early Bronze Age Features at Ballygawley, Co. Tyrone.

Figure 9 Charcoal identifications from Late Neolithic and Early Bronze Age Features at Roughan, Co. Tyrone.

Supplementary Figure 1a. An example of a trough of the late Neolithic/Bronze Age found during this study at Ballgawley.

Supplementary Figure 1b. An example of a trough of the late Neolithic/Bronze Age found during this study at Ballgawley.

Supplementary Figure 1c, d. Examples of the burnt mounds at Ballgawley.

Supplementary Figure 2. Chronology of the archaeological features radiocarbon dated from Ballygawley, Co. Tyrone. Radiocarbon dates have been calibrated using OxCal 4.1 (Bronk Ramsey, 2009a) to 93.4% probability using IntCal04 (Bronk Ramsey, 2009b). All calibrated dates are referred to in calibrated years AD/BC.

Supplementary Figure 3. Chronology of the archaeological features radiocarbon dated from Roughan, Co. Tyrone. Radiocarbon dates have been calibrated using OxCal 4.1 (Bronk Ramsey, 2009a) to 93.4% probability using IntCal04 (Bronk Ramsey, 2009b). All calibrated dates are referred to in calibrated years AD/BC.

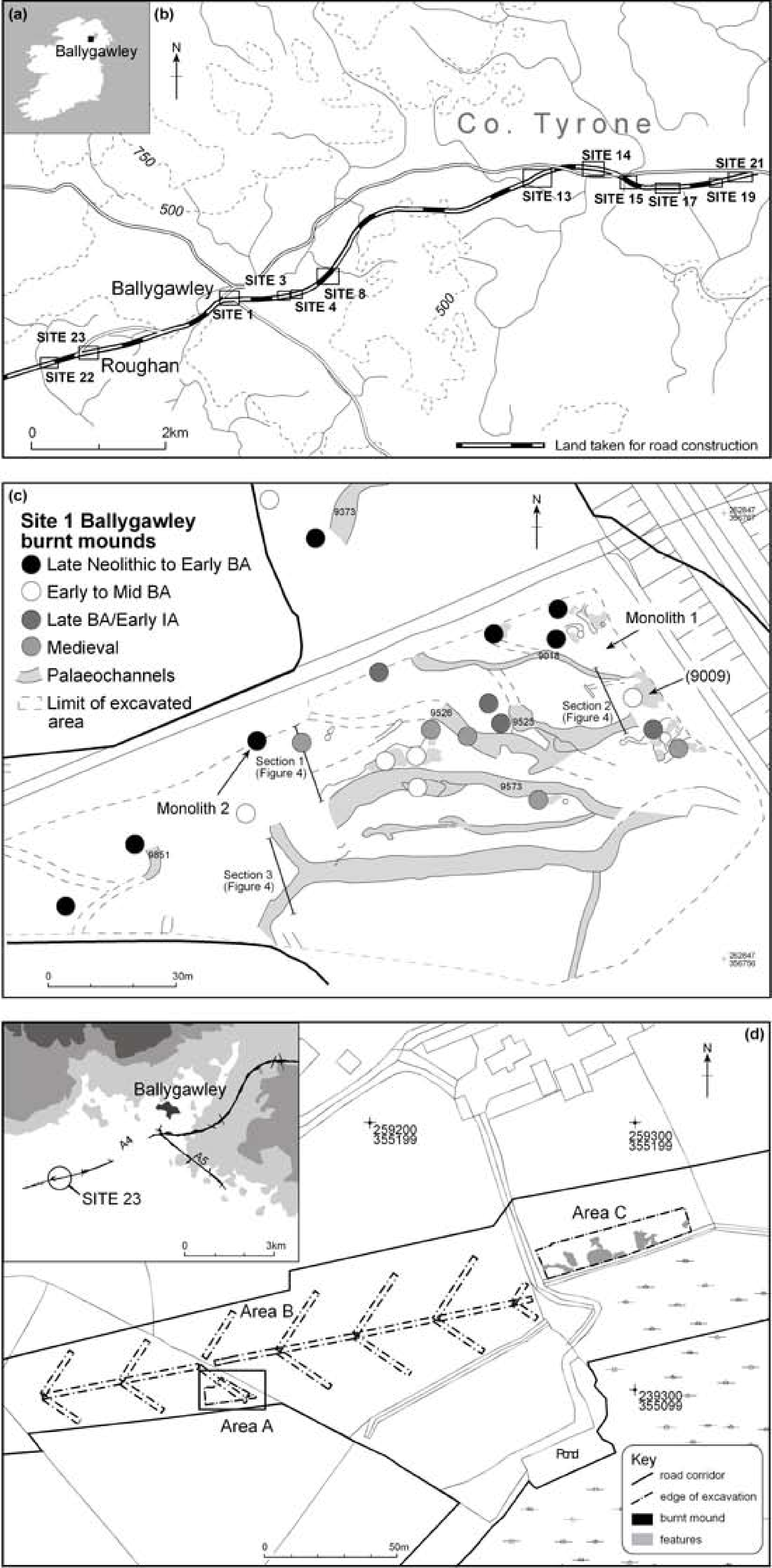
Supplementary Figure 4. Pollen concentrations for selected taxa from Ballygawley, Co. Tyrone. (a) total pollen concentrations; (b) Pollen concentrations for major taxa; (c) normalised pollen concentration ratio for *Corylus* and Cyperaceae; (d) normalised pollen concentration ratio for *Quercus* (Values between 94 and 102 cm were excluded as they were much higher than those data plotted in order to see the patterning either side of the burnt deposit. The pattern seen is not affected by their exclusion). Each taxon is expressed as ratio of individual taxon concentration divided by total pollen concentration minus the individual taxon (to avoid any effects derived from auto correlation); (e) Normalised Poaceae concentration ratio; (f) Normalised *Alnus* concentration ratio.

Supplementary Figure 5a Pollen concentrations for selected taxa from Roughan, Co. Tyrone. (a) total pollen concentrations (dashed line for all graphs) and *Corylus* pollen concentrations (solid line); (b) Cyperaceae (solid line); (c) *Alnus* (solid line); (d) *Quercus* (solid line); (e) *Salix* (solid line); (f) Poaceae (solid line).

Supplementary Figure 5b Normalised pollen concentrations for selected taxa from Roughan, Co. Tyrone. Each taxon is expressed as ratio of individual taxon concentration divided by total pollen concentration minus the individual taxon (to avoid any effects derived from auto correlation). (a) *Corylus*; (b) Cyperaceae; (c) *Alnus*; (d) *Quercus*; (e) *Salix*; (f) Poaceae.

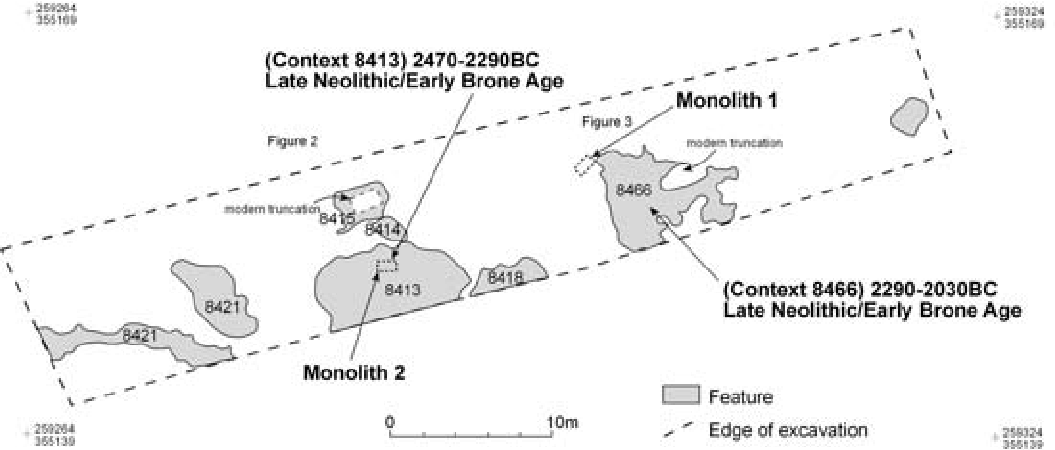
Table 1. Radiocarbon dates from the burnt mound monoliths (Ballygawley and Roughan).

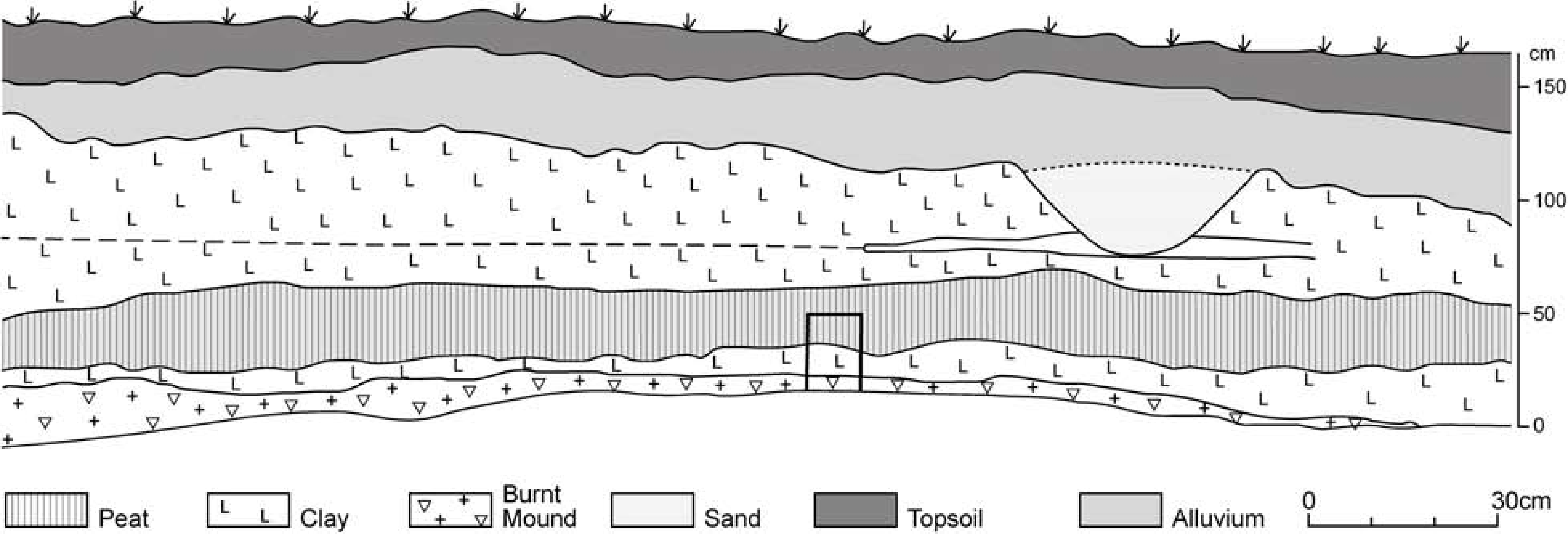
Supplementary Table 1. Stratigraphical description of the monoliths used in this study.

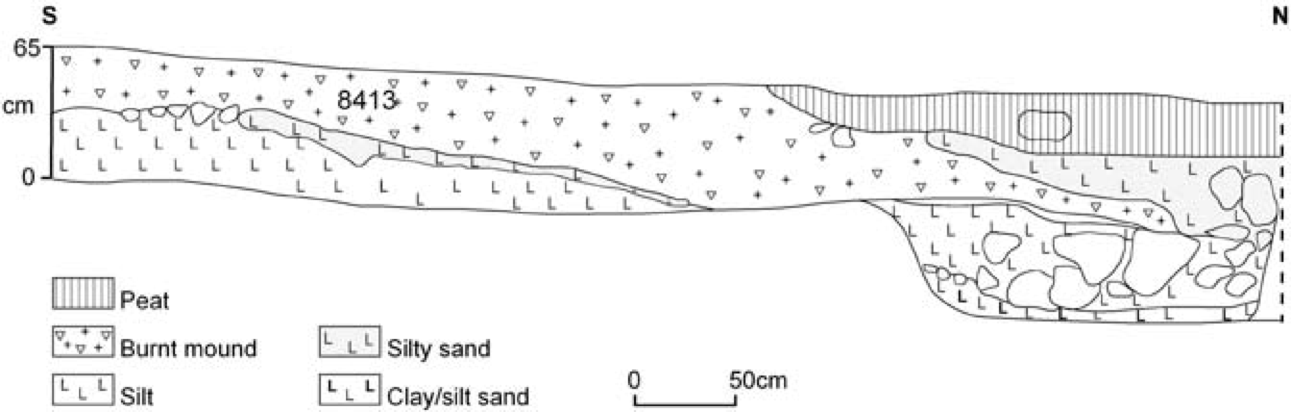


(a)
Ballygawley
(b)
N
Co. Tyrone
750
500
500
SITE 14
SITE 21
SITE 13
SITE 15
SITE 17
SITE 19
SITE 3
SITE 8
SITE 4
SITE 1
Ballygawley
SITE 23
SITE 22
Roughan
0
2km
Land taken for road construction
(c)
Site 1 Ballygawley burnt mounds
Late Neolithic to Early BA
Early to Mid BA
Late BA/Early IA
Medieval
Palaeochannels
Limit of excavated area
9373
N
Monolith 1
9018
(9009)
Section 2 (Figure 4)
9526
9525
Section 1 (Figure 4)
9573
Monolith 2
9851
Section 3 (Figure 4)
0
30m
(d)
Ballygawley
A4
A5
SITE 23
0
3km
N
259200
355199
259300
355199
Area C
Area B
Area A
239300
355099
Road
Key
road corridor
edge of excavation
burnt mound
features
0
50m

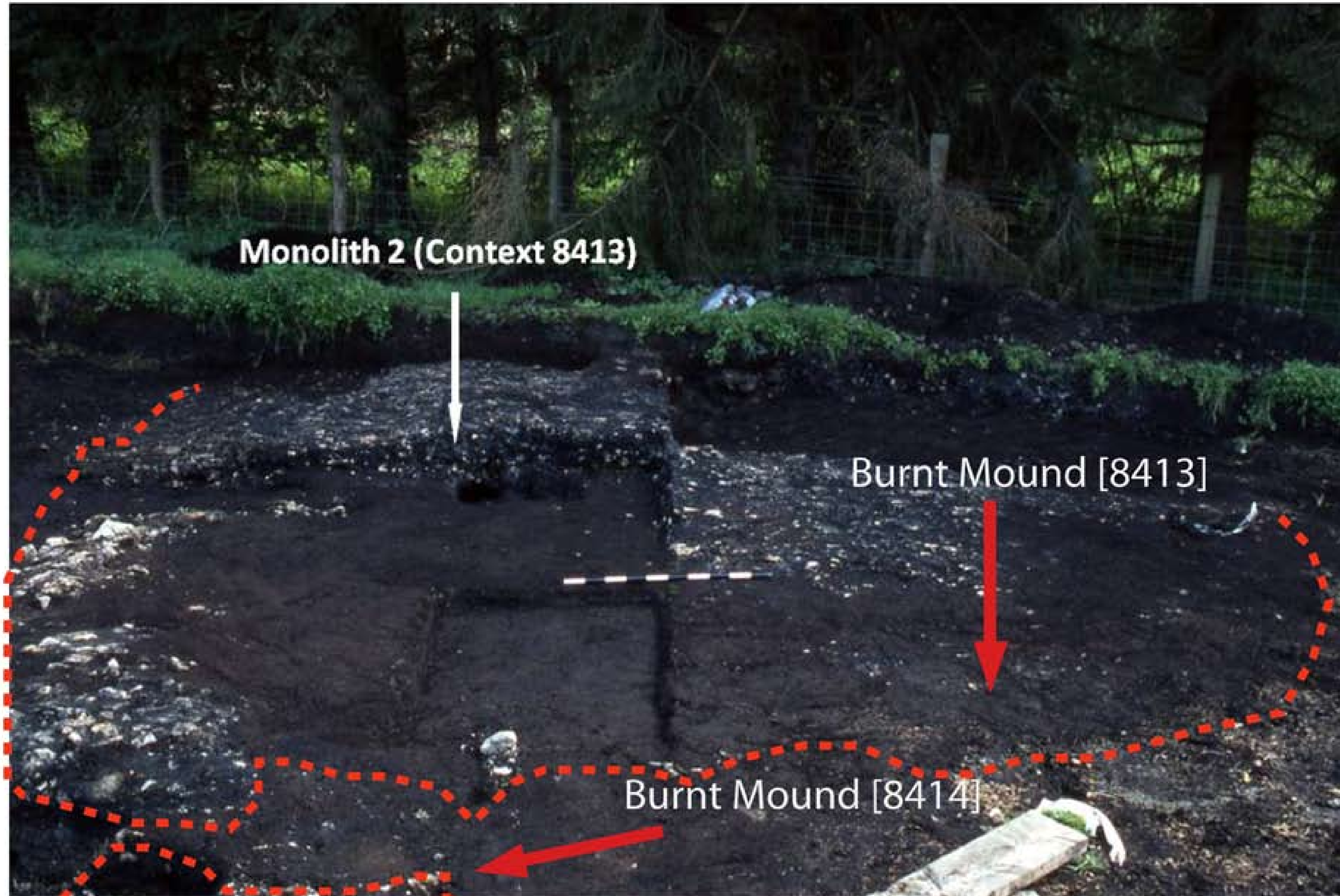
(e) **Roughan [Site 23]**

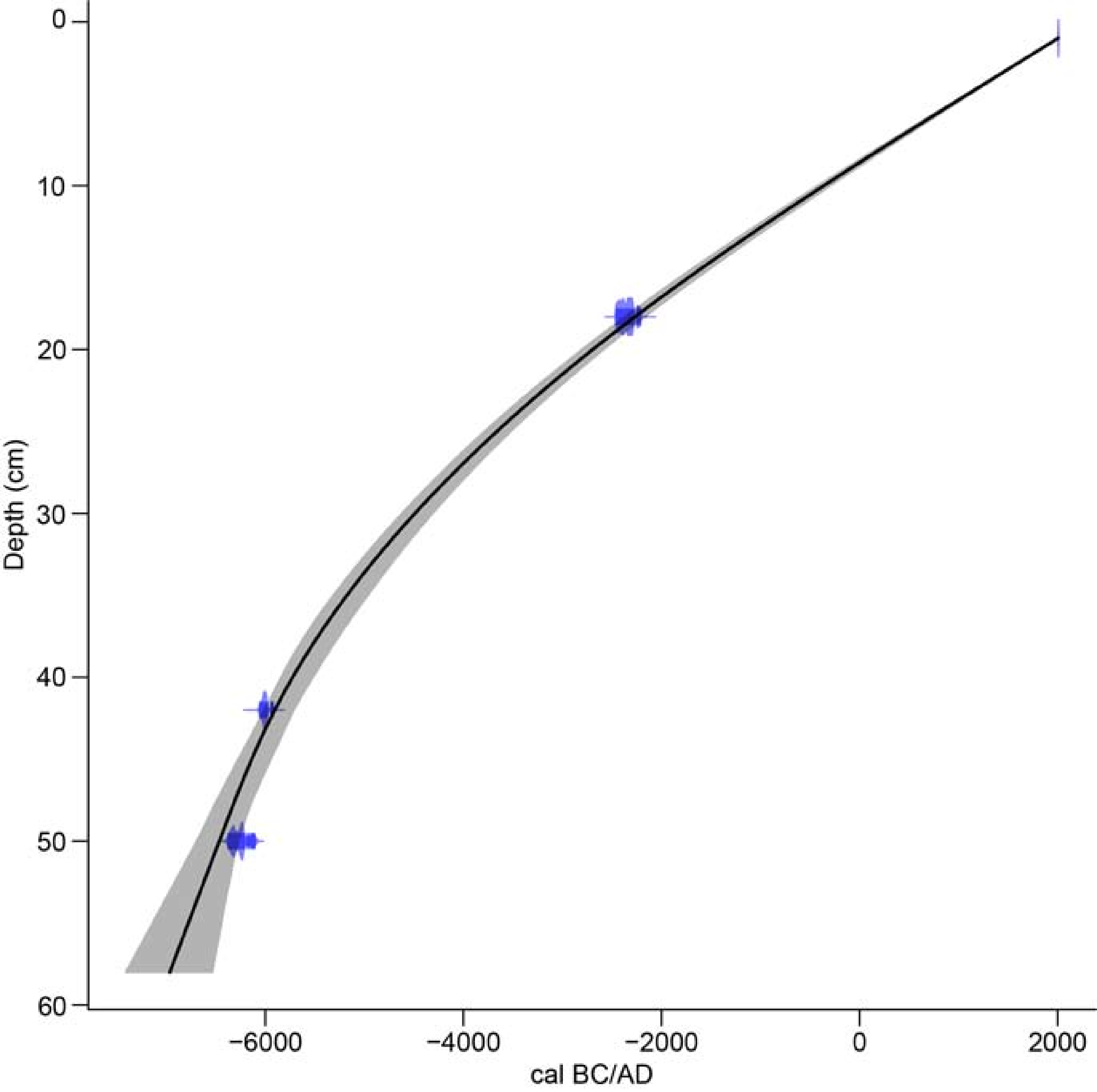



cm
150
100
50
0
Peat
Clay
Burnt Mound
Sand
Topsoil
Alluvium
0
30cm

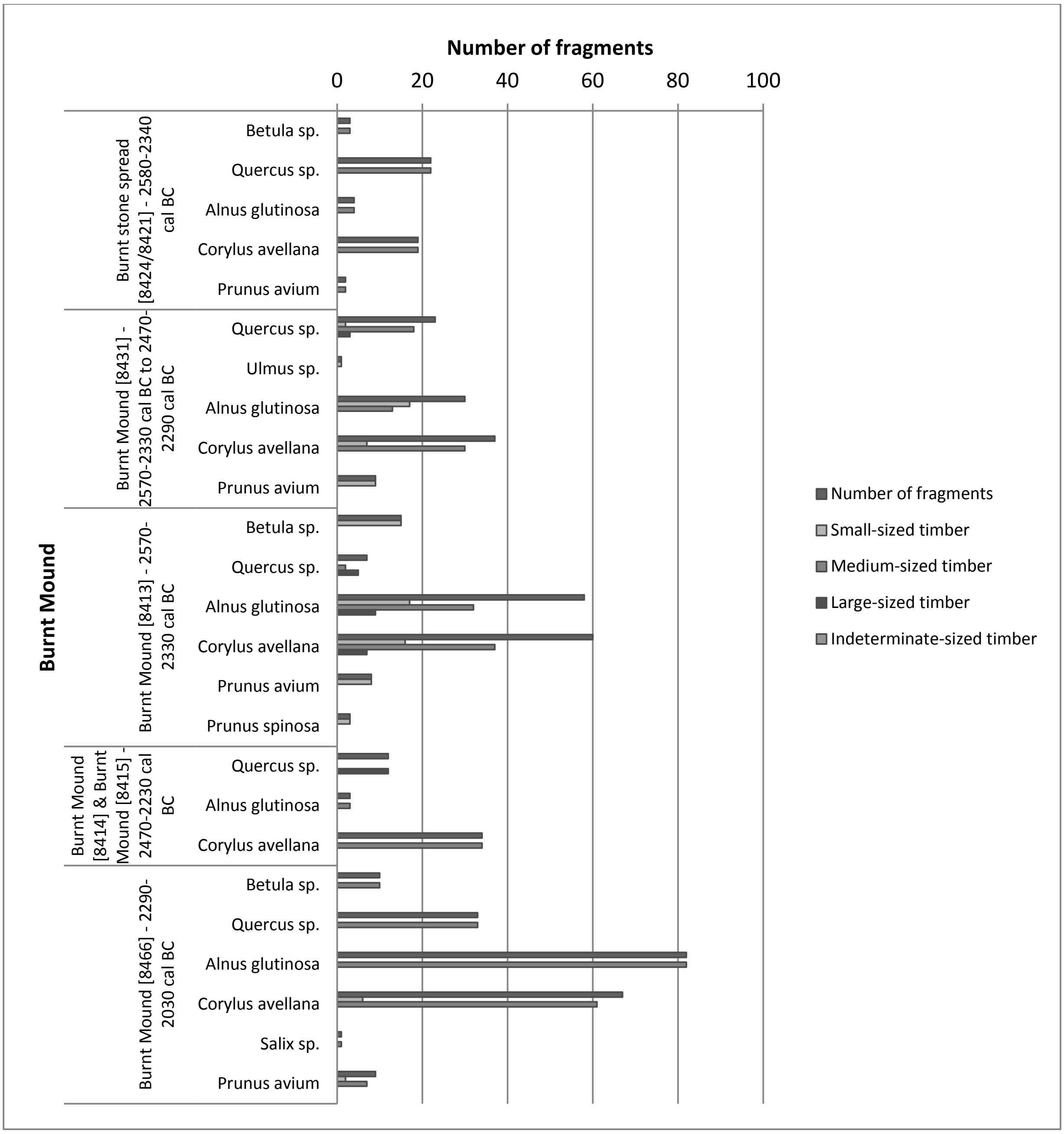


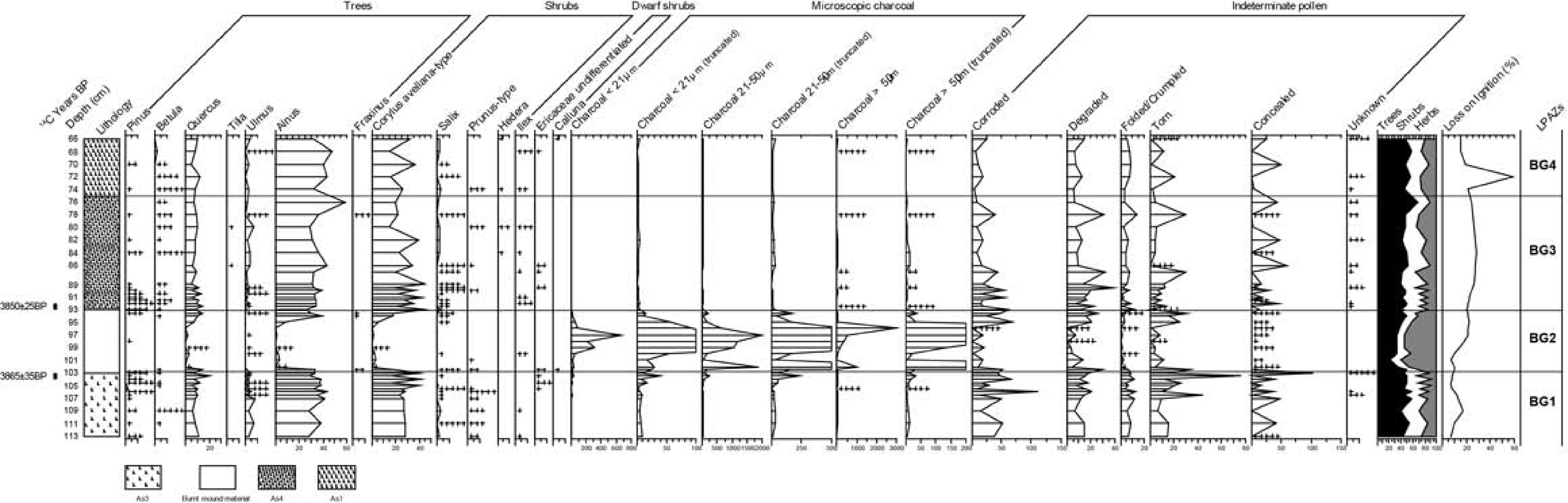
S
N
65
cm
0
8413
Peat
Burnt mound
Silt
Silty sand
Clay/silt sand
0
50cm


Monolith 2 (Context 8413)
Burnt Mound [8413]
Burnt Mound [8414]

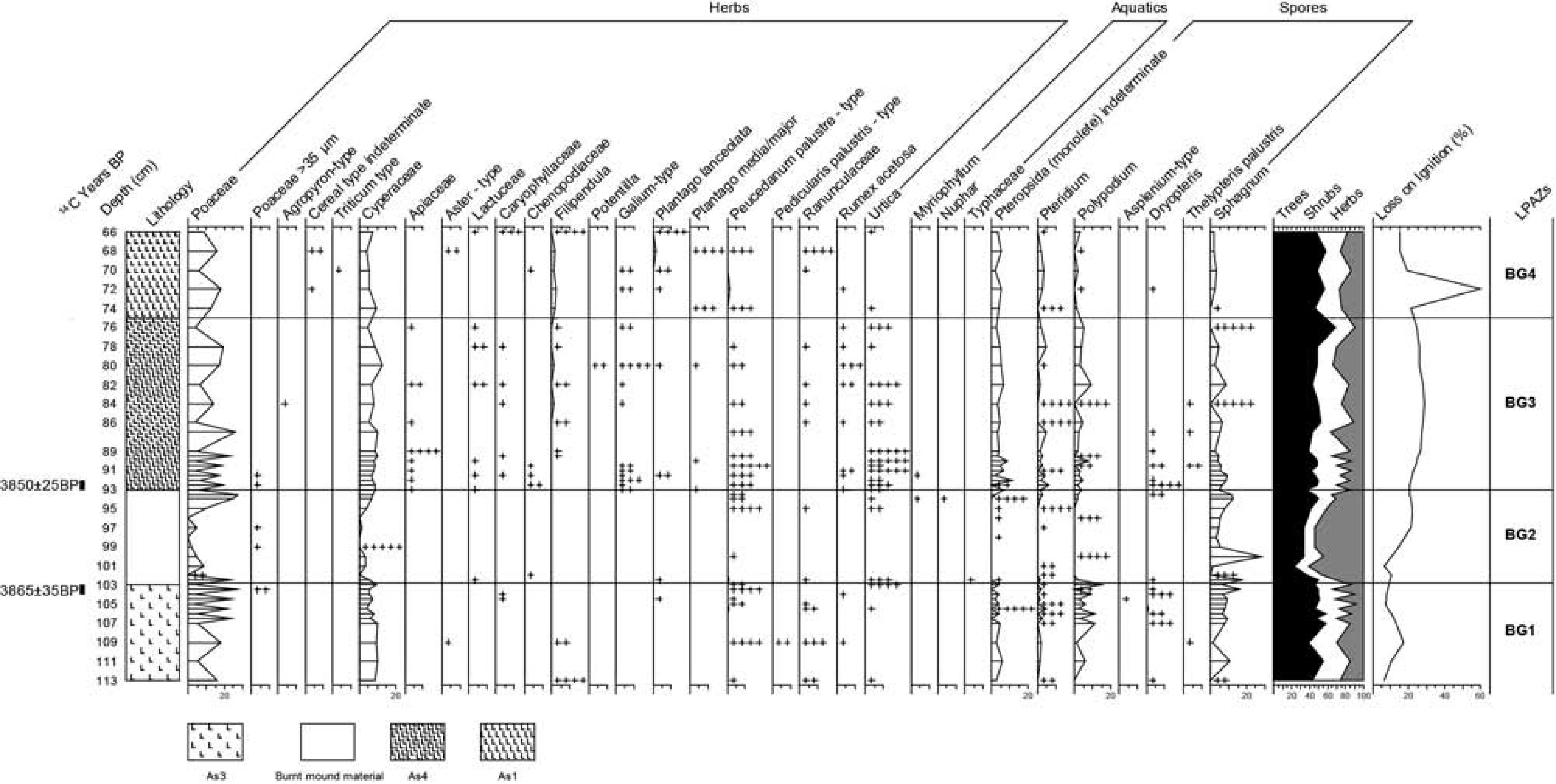


0
10
20
30
40
50
60
Depth (cm)
−6000
−4000
−2000
0
2000
cal BC/AD

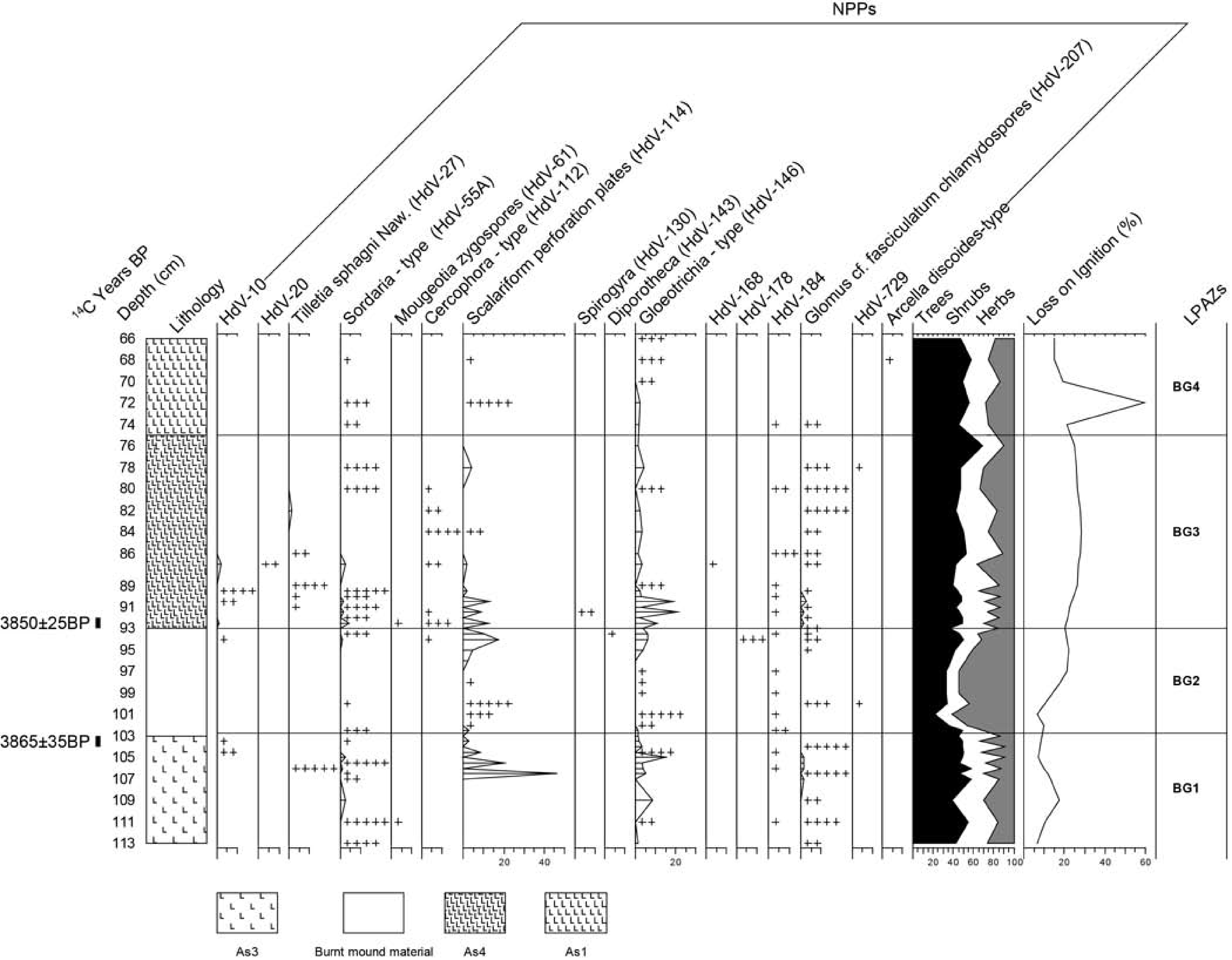

Number of fragments
0
20
40
60
80
100
Burnt Mound
Burnt stone spread [8424/8421] - 2580-2340 cal BC
Betula sp.
Quercus sp.
Alnus glutinosa
Corylus avellana
Prunus avium
Burnt Mound [8431] - 2570-2330 cal BC to 2470-2290 cal BC
Quercus sp.
Ulmus sp.
Alnus glutinosa
Corylus avellana
Prunus avium
Burnt Mound [8413] - 2570-2330 cal BC
Betula sp.
Quercus sp.
Alnus glutinosa
Corylus avellana
Prunus avium
Prunus spinosa
Burnt Mound [8414] & Burnt Mound [8415] - 2470-2230 cal BC
Quercus sp.
Alnus glutinosa
Corylus avellana
Burnt Mound [8466] - 2290-2030 cal BC
Betula sp.
Quercus sp.
Alnus glutinosa
Corylus avellana
Salix sp.
Prunus avium
Number of fragments
Small-sized timber
Medium-sized timber
Large-sized timber
Indeterminate-sized timber



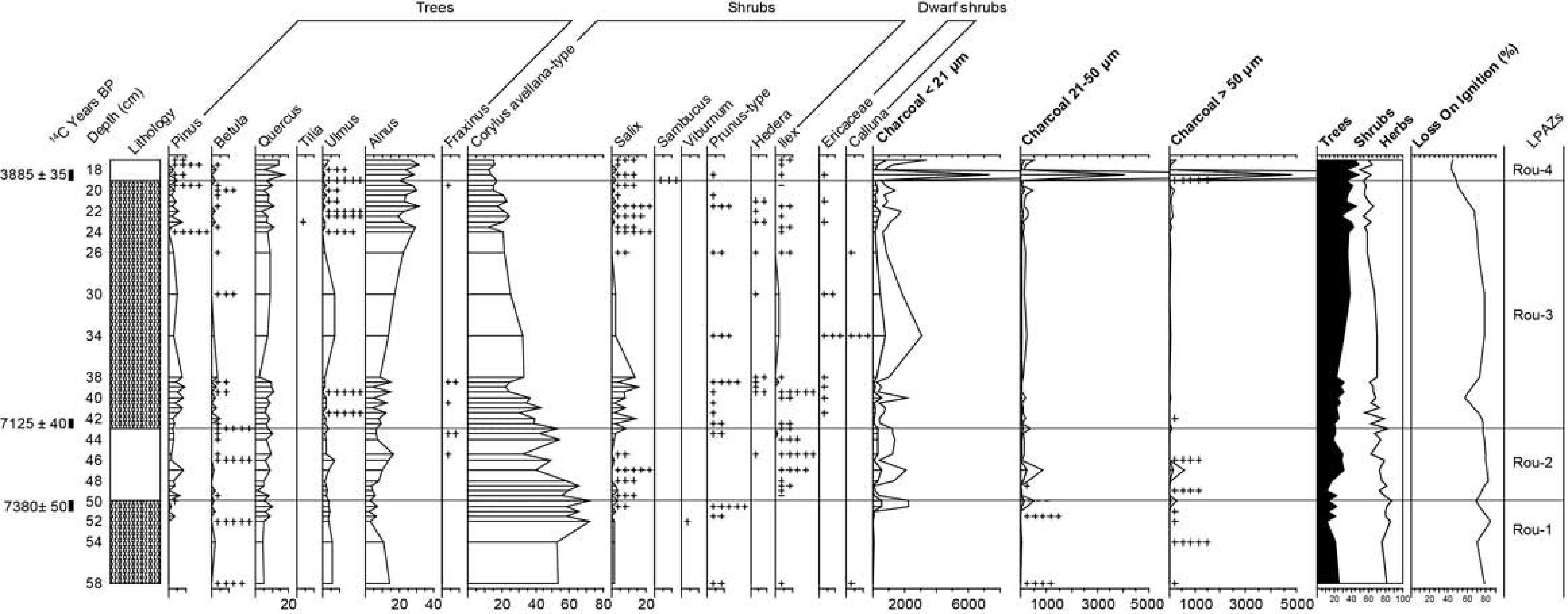
Trees
Shrubs
Dwarf shrubs
Microscopic charcoal
Indeterminate pollen
¹⁴C Years BP
Depth (cm)
Lithology
Pinus
Betula
Quercus
Tilia
Ulmus
Alnus
Fraxinus
Corylus avellana-type
Salix
Prunus-type
Hedera
Ilex
Ericaceae undifferentiated
Calluna
Charcoal < 21µm
Charcoal < 21µm (truncated)
Charcoal 21-50µm
Charcoal 21-50µm (truncated)
Charcoal > 50µm
Charcoal > 50µm (truncated)
Corroded
Degraded
Folded/Crumpled
Torn
Concealed
Unknown
Trees
Shrubs
Herbs
Loss on Ignition (%)
LPAZs
3850±25BP
3865±35BP
BG4
BG3
BG2
BG1
As3
Burnt mound material
As4
As1



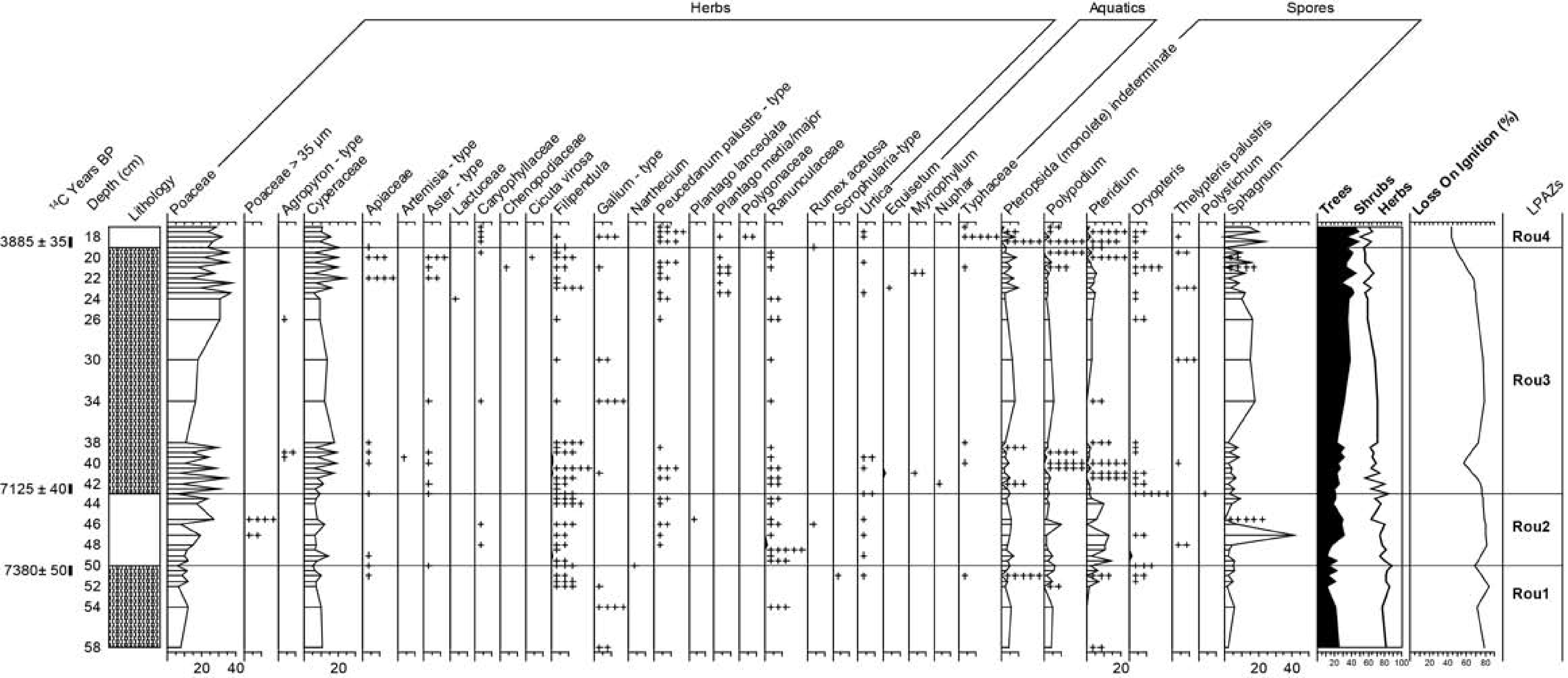
Herbs
Aquatics
Spores
¹⁴C Years BP
Depth (cm)
Lithology
Poaceae
Poaceae >35 µm
Agropyron-type
Cereal type indeterminate
Triticum type
Cyperaceae
Apiaceae
Aster - type
Lactuceae
Caryophyllaceae
Chenopodiaceae
Filipendula
Potentilla
Galium-type
Plantago lanceolata
Plantago media/major
Peucedanum palustre - type
Pedicularis palustris - type
Ranunculaceae
Rumex acetosa
Urtica
Myriophyllum
Nuphar
Typhaceae
Pteropsida (monolete) indeterminate
Pteridium
Polypodium
Asplenium-type
Dryopteris
Thelypteris palustris
Sphagnum
Trees
Shrubs
Herbs
Loss on Ignition (%)
LPAZs
BG4
BG3
BG2
BG1
3850±25BP
3865±35BP
As3
Burnt mound material
As4
As1



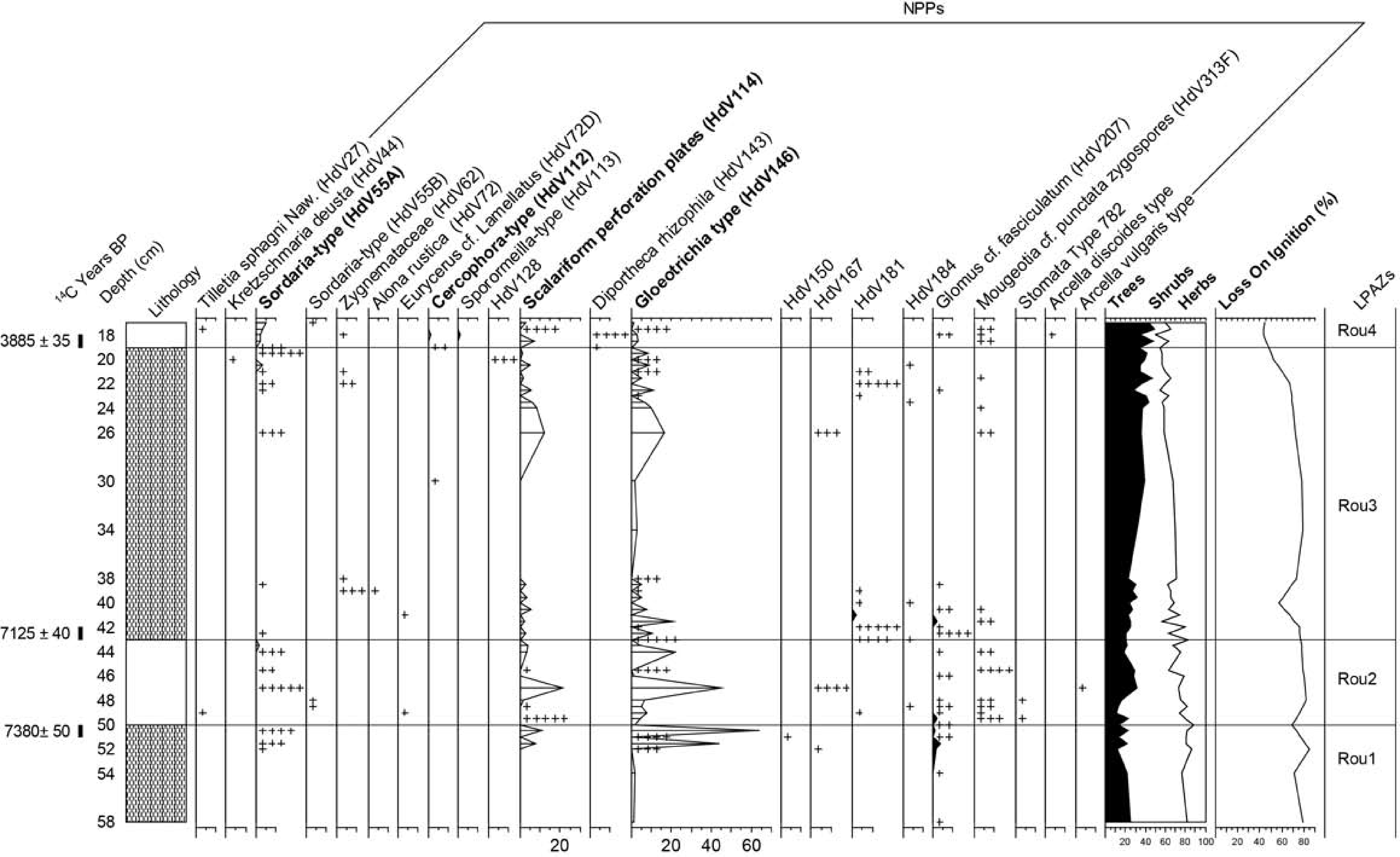
NPPs
14C Years BP
Depth (cm)
Lithology
HdV-10
HdV-20
Tilletia sphagni Naw. (HdV-27)
Sordaria - type (HdV-55A)
Mougeotia zygospores (HdV-61)
Cercophora - type (HdV-112)
Scalariform perforation plates (HdV-114)
Spirogyra (HdV-130)
Diporotheca (HdV-143)
Gloeotrichia - type (HdV-146)
HdV-168
HdV-178
HdV-184
Glomus cf. fasciculatum chlamydospores (HdV-207)
HdV-729
Arcella discoides-type
Trees
Shrubs
Herbs
Loss on Ignition (%)
LPAZs
3850±25BP
3865±35BP
BG4
BG3
BG2
BG1
As3
Burnt mound material
As4
As1



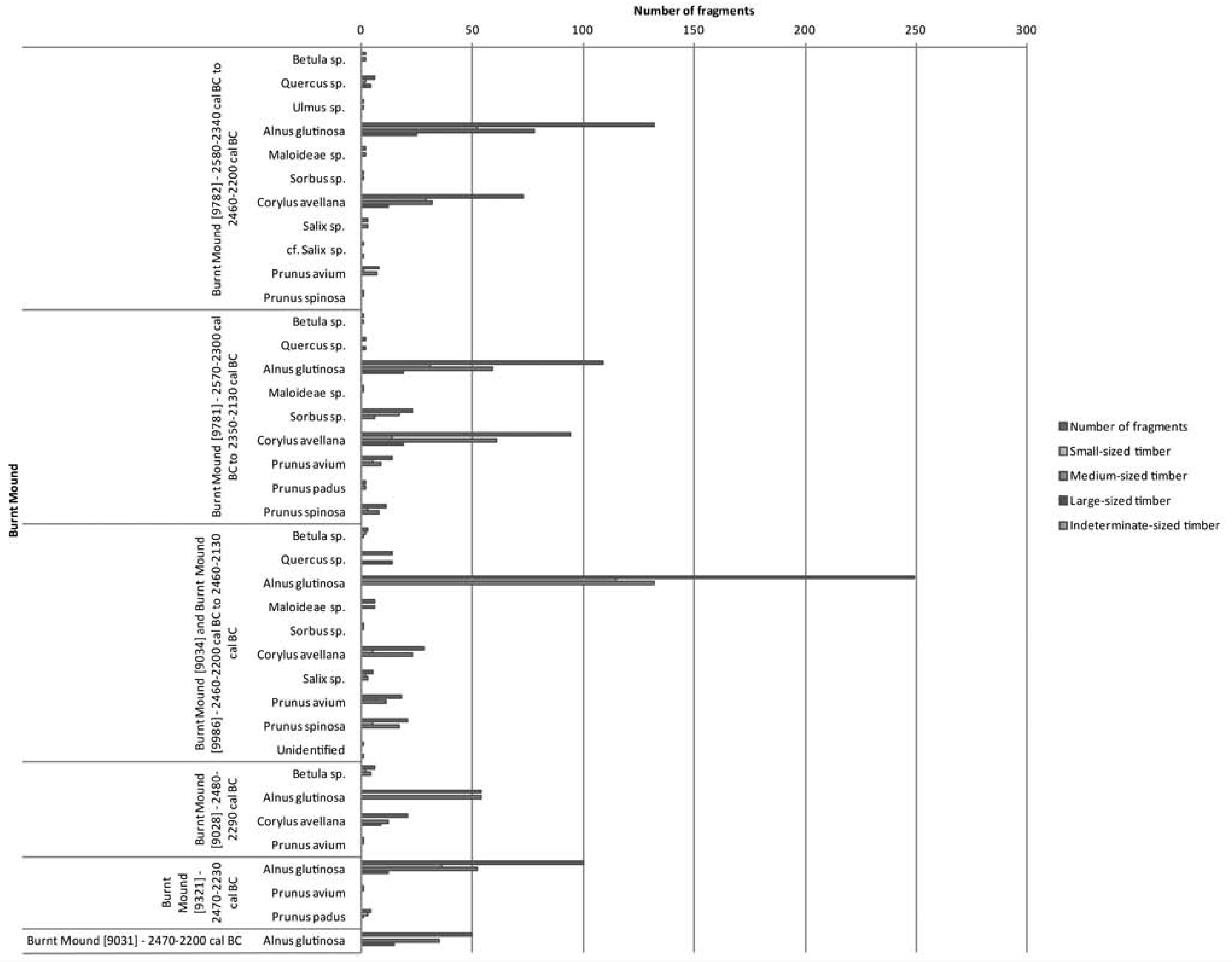
Trees
Shrubs
Dwarf shrubs
14C Years BP
Depth (cm)
Lithology
Pinus
Betula
Quercus
Tilia
Ulmus
Alnus
Fraxinus
Corylus avellana-type
Salix
Sambucus
Viburnum
Prunus-type
Hedera
Ilex
Ericaceae
Calluna
Charcoal < 21 µm
Charcoal 21-50 µm
Charcoal > 50 µm
Trees
Shrubs
Herbs
Loss On Ignition (%)
LPAZs
3885 ± 35
7125 ± 40
7380± 50
Rou-4
Rou-3
Rou-2
Rou-1



Herbs
Aquatics
Spores
14C Years BP
Depth (cm)
Lithology
Poaceae
Poaceae > 35 µm
Agropyron - type
Cyperaceae
Apiaceae
Artemisia - type
Aster - type
Lactuceae
Caryophyllaceae
Chenopodiaceae
Cicuta virosa
Filipendula
Galium - type
Narthecium
Peucedanum palustre - type
Plantago lanceolata
Plantago media/major
Polygonaceae
Ranunculaceae
Rumex acetosa
Scrophularia-type
Urtica
Equisetum
Myriophyllum
Nuphar
Typhaceae
Pteropsida (monolete) indeterminate
Polypodium
Pteridium
Dryopteris
Thelypteris palustris
Polystichum
Sphagnum
Trees
Shrubs
Herbs
Loss On Ignition (%)
LPAZs
3885 ± 35
7125 ± 40
7380± 50
Rou4
Rou3
Rou2
Rou1



NPPs
14C Years BP
Depth (cm)
Lithology
Tilletia sphagni Naw. (HdV27)
Kretzschmaria deusta (HdV44)
Sordaria-type (HdV55A)
Sordaria-type (HdV55B)
Zygnemataceae (HdV62)
Alona rustica (HdV72)
Eurycerus cf. Lamellatus (HdV72D)
Cercophora-type (HdV112)
Sporormeilla-type (HdV113)
HdV128
Scalariform perforation plates (HdV114)
Diportheca rhizophila (HdV143)
Gloeotrichia type (HdV146)
HdV150
HdV167
HdV181
HdV184
Glomus cf. fasciculatum (HdV207)
Mougeotia cf. punctata zygospores (HdV313F)
Stomata Type 782
Arcella discoides type
Arcella vulgaris type
Trees
Shrubs
Herbs
Loss On Ignition (%)
LPAZs
3885 ± 35
7125 ± 40
7380± 50
Rou4
Rou3
Rou2
Rou1



Number of fragments
0
50
100
150
200
250
300
Burnt Mound
Burnt Mound [9782] - 2580-2340 cal BC to 2460-2200 cal BC
Betula sp.
Quercus sp.
Ulmus sp.
Alnus glutinosa
Maloideae sp.
Sorbus sp.
Corylus avellana
Salix sp.
cf. Salix sp.
Prunus avium
Prunus spinosa
Burnt Mound [9781] - 2570-2300 cal BC to 2350-2130 cal BC
Betula sp.
Quercus sp.
Alnus glutinosa
Maloideae sp.
Sorbus sp.
Corylus avellana
Prunus avium
Prunus padus
Prunus spinosa
Burnt Mound [9034] and Burnt Mound [9986] - 2460-2200 cal BC to 2460-2130 cal BC
Betula sp.
Quercus sp.
Alnus glutinosa
Maloideae sp.
Sorbus sp.
Corylus avellana
Salix sp.
Prunus avium
Prunus spinosa
Unidentified
Burnt Mound [9028] - 2480-2290 cal BC
Betula sp.
Alnus glutinosa
Corylus avellana
Prunus avium
Burnt Mound [9321] - 2470-2230 cal BC
Alnus glutinosa
Prunus avium
Prunus padus
Burnt Mound [9031] - 2470-2200 cal BC
Alnus glutinosa
Number of fragments
Small-sized timber
Medium-sized timber
Large-sized timber
Indeterminate-sized timber

Roughan	**Depth (cm)**	**Material**	**Lab number**	**^{14}C age (BP)**	**Calibrated age range (95.4%)**
Monolith	18-19	*Corylus avellana* charcoal	GU-15850	3885 ± 35	2466-2208 BC
	42-43	Peat – humic acid	GU-15852	7125 ± 40	6068-5913 BC
	50-51	Bulk sediment	Poz-46459	7380 ± 50	6385-6100 BC
Ballgawley	**Depth (cm)**	**Material**	**Lab number**	**^{14}C age (BP)**	**Calibrated age range (95.4%)**
Monolith	91-92	Peat – humic acid	GU-15849	3850 ± 35	2460-2200
	103-104	*Corylus avellana* Charcoal	GU-17350	3865 ± 35	2465-2210