The missing hominin –

A palynological investigation of the habitability of Beeston, England, during the Pleistocene

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Cover: picture of *Picea* pollen from
the pre-Anglian sediments near
Beeston (E. Egberts 2012).

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1. Introduction and research questions

Resent archaeological discoveries at the East Anglian coast of Britain are importantly attributing to the understanding of hominin dispersal into north-western Europe before 500,000 years ago. At the East Anglian coast one of the best studied Pleistocene stratigraphical sequences are exposed and exceptionally well preserved fossils and evidence of hominin presence are situated therein. This wealth of information, together with the high rate of erosion of the cliffs, strongly advocates for further intensive research of the pre-glacial deposits along the East Anglian coast.

The archaeological potential of other localities along the coast may be illustrated by the discoveries at the Happisburgh sites and near Pakefield. But the unstable nature of the cliffs makes excavating a life threatening job. Preliminary environmental investigations of exposed pre-glacial (overlain by Anglian glacial till) sediments should be conducted and can now be applied to predict the archaeological potential of the deposits based on our increased understanding of hominin ecological preference and tolerance. The particular depositional and environmental contexts present at the East Anglian coast provide good preservation until cliff collapse.

The environmental reconstruction of the pre-glacial deposits near Beeston, provide palaeoenvironmental information as such, informs on the archaeological potential of the site and in addition may offer a starting point for wider contextual research of hominin dispersal and presence adding off-site environmental information to the debate.

The organic rich pre-glacial sediments exposed near Beeston, Norfolk, UK, were sampled and investigated to answer the following research questions:

- What was the palaeoenvironment near Beeston in pre-glacial times?
- What vegetation prevailed at the sample location and in its vicinity?
- What environmental and climatic conditions can be inferred from the reconstructed vegetation?
- Based on the environmental reconstruction, could hominins have lived near the sample location?

The correlation of the Beeston samples to other sites can be inferred from its stratigraphical position offering an approximation of the age of the sediments.

- What is the bio- and lithostratigraphy of the sequence?
- What inferences can be made on its age?

To answer these research questions this thesis is divided in several relevant chapters. First the context of the research will be discussed. This includes the stratigraphical context, the palaeogeography of East Anglia and the current understanding of hominin presence in northwest Europe.

Because the basis for the palaeoenvironmental reconstruction of the pre-glacial sediments at Beeston is pollen, and taphonomic processes of pollen are complex, these will be addressed next.

Subsequently the site at Beeston is introduced with a short overview of the research history of the East Anglian coast and a description of the position of the sampled profile.

In the chapter on materials and methods is explained how the results are achieved and described. The results are discussed in the following chapter. Here not only the results of the pollen analysis for this thesis are presented, but additional information from small vertebrate remains and plant macro fossils are included. As data presentation is an important aspect of palynological research, this subject is also given attention in this chapter.

In the discussion chapter, the data are interpreted and combined with the results from the small vertebrate remains and plant macrofossils to come to an interpretation on the palaeoenvironment near Beeston in pre-glacial times and its stratigraphy and age. This leads to the final conclusions.

2. Context of the study

2.1. Stratigraphy of East Anglia

To study the history of the Earth, stratigraphic and dating techniques are used to put events in chronological order and enable correlation. The principles of stratigraphy provide a tool for establishing the chronology of depositions and fossils within them (Nichols 2009). The relation of stratigraphical sequences to others is often more problematic and apart from age-equivalent horizons (such as those defined using palaeomagnetism), stratigraphical sequences need to be related to other chronological frameworks. Methods of radiometric dating provide an age for sediments by measuring the radioactive decay and radiation (e.g. OSL – optically stimulated luminescence (Pawley *et al.* 2008; Walker 2005)). Relative dating techniques can be used to establish the relative chronology of various deposits (such as AAR – amino acid racemisation (Penkman *et al*. 2007, 2011; Walker 2005)). Sediments can also be characterised on the basis of specific fossil assemblages, their combined first and last appearances, and evolution, and form a biostratigraphy.

An important aspect of Quaternary stratigraphy and relative dating techniques is their relation to the marine oxygen isotope stages (MIS) (Jansen 1989). These isotope stages, recognised in deep-ocean cores, reflect ice sheet growth that is related to the major and some minor climatic changes the Earth underwent. These climatic changes have left important traces on the Earth’s surface as well, such as glacial deposits due to glacial expansions during the cold stages. Because the MISs appear to be orbitally tuned (Cronin 2010; Hays *et al.* 1976), a numerical date is obtained for the various Isotope Stages. When morphologic traces, lithostratigraphical units, biostratigraphical compositions and magnetostratigraphy can be linked to this time scale, a numeric date can be proposed for events, including for hominin presence.

The sedimentary sequence of the East Anglian coast forms an extensive record of the Pleistocene stratigraphy of Britain. Although complex and with large hiatuses, the sequence of the East Anglian coast provides well-preserved evidence of the lowland glaciations and pre-glacial periods and now also evidence of the currently known earliest occupation of northwest Europe (Parfitt *et al.* 2010).

The East Anglian coast is situated in the Crag basin, the south-western margin of the North Sea basin (fig 1). During the Pliocene and Early Pleistocene this Crag basin formed a marine embayment where shallow seas deposited shelly sands forming the Crags, overlying Cretaceous chalk deposits. These Crags, the Coralline-, Red-, Norwich- and Woxham Crag Formation, are overlain by a complex succession of marine, estuarine and freshwater sediments, which themselves are overlain by glacial till.

The pre-glacial sediments, sandwiched between the Crags and the glacial till of the North Sea Drift Formation and the Lowestoft Formation, are deposited during the long period of the Early and early Middle Pleistocene. These pre-glacial sediments are richly fossiliferous, drawing attention from geologist, fossil collectors and archaeologists for over two centuries. The remarkable presence of upright tree stumps invited Reid (1882 in Preece and Parfitt 2012) to name the deposits the Cromer Forest-bed series. Reid recognised that both periods of arctic and temperate climates prevailed during the deposition of the sediments. And he found evidence for freshwater rivers and estuaries concealed within them. He divided the pre-glacial deposits in the Weybourne Crag, overlain by the Cromer Forest-bed series. The Cromer Forest-bed series contained an upper- and lower freshwater-bed, sandwiching an estuarine forest-bed.

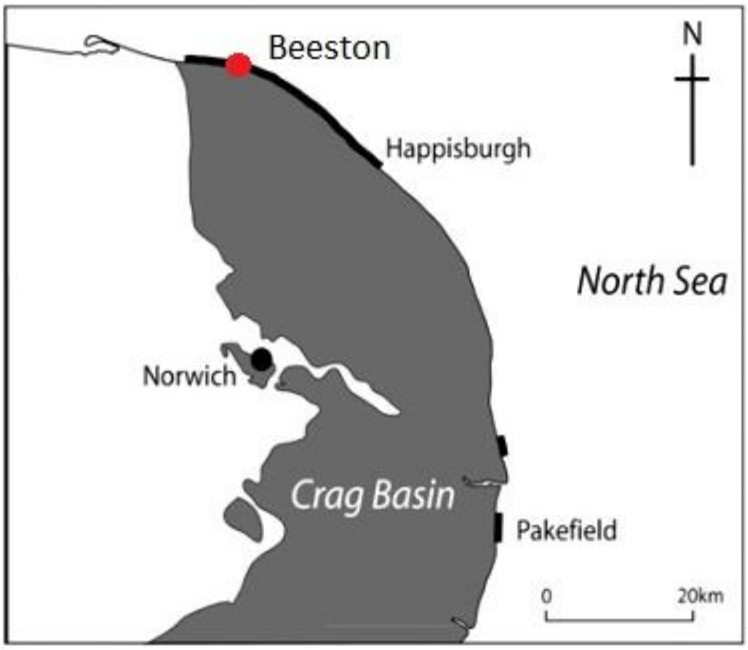


Figure 1. Map of East Anglia showing the Crag Basin and sites mentioned in the text (after Preece and Parfitt 2012, 8).

Additional research on the pre-glacial sediments, including the extensive palynological investigations by West (1980a, b), resulted in a different division of the sediment sequence. West (1980a) proposed two formations, the Norwich Crag Formation including the pre-Pastonian a substage, and the Cromer Forest-bed Formation, including Pre-Pastonian b, c, and d substages, the Pastonian, Beestonian and Cromerian Stages and the early Anglian substage. In this scheme a temperate Stage, the Pastonian, is followed by a cold Stage, the Beestonian, which is followed by the temperate Cromerian Stage. The early Anglian substage was the announcement for the following Anglian cold Stage, during which the concealing glacial till was deposited. These till deposits sealed off the for convenience often called ‘pre-glacial’ or ‘pre-Anglian’ sediments.

Rose *et al.* (2001) introduced the term the Wroxham Crag, which includes Reid’s Weybourne Crag and the overlying marine sediments from the Cromer Forest-bed Formation, together named Wroxham Formation.

The Anglian glaciation is related to the Elsterian glaciation on the mainland related to MIS 12 (the deposition of the Anglian till during MIS 12 has been challenged by e.g. Hamblin *et al.* 2005, Lee *et al.* 2004, 2006 but see below) (See figure 2). The relation of the Pastonian, Beestonian and Cromerian Stages to those recognised on the continent remains mainly problematic (Gibbard *et al.* 1991). The Cromerian as defined by West (1980a) is a single temperate stage in the early Middle Pleistocene with its stratotype at West Runton. In the Cromerian stratotype at West Runton West (1980a) recognised an entire interglacial cycle of vegetational change (towards a fully developed temperate forest and back to open vegetation in the cooling period) on the basis of pollen zones, coded CrI-IV. Thus this Cromerian comprises a single palaeoclimatic unit. The Cromerian Complex Stage in the Netherlands is climatically more complex, with four warm temperate and three cold substages (Gibbard *et al.* 1991). Now it is clear that the sediments attributed to the East Anglian Cromerian Stage, do not result from one and the same interglacial either. Especially on the basis of biostratigraphy various temperate stages could be recognised. An important temporal division of the Cromerian is based on the different occurrence of the water vole *Mimomys savini* and its descendant *Arvicola* (Von Koenigswald and Van Kolfschoten 1996 in Preece and Parfitt 2012), the first not occurring after MIS 15, when it seems to be succeeded by the latter. Additional biostatigraphical research on molluscs (Preece

2001), and mammals (Stuart and Lister 2001) from the Cromerian, resulted in the identification of five temperate episodes within the 'Cromerian Complex' in Britain (Preece 2001; Suart and Lister 2001). Following Preece and Parfitt (2012) this complex sequence of temperate and cold stages, previously assigned to the Cromerian, may be defined as everything between the Brunhes-Matuyama boundary and the Anglian glaciation. The Brunhes-Matuyama boundary is dated to 780 Ka (MIS 19), but the timing of the Anglian glaciation has been debated (Preece *et al.* 2009). The Anglian glacial tills consist of the lower North Sea Drift Formation and the overlying Lowestoft Formation. The former shows three diamictons, the Happisburgh, Walcott and Bacton Green/Runton tills. The question arose (Hamblin *et al.* 2005, Lee *et al*. 2004; 2006) whether these tills were the result of one glaciation or more. In a 'new glacial stratigraphy' Hamblin *et al.* (2005) and Lee *et al.* (2004, 2006) identified evidence for a pre-Anglian glaciation in the Happisburgh Formation (or the Happisburgh diamiction or first Cromer Till (Preece *et al.* 2009). In the 'new glacial stratigraphy' these sediments were related to MIS16 (Hamblin *et al.* 2005; Lee *et al.* 2004, 2006). This has an important bearing on the dating of the tills and therefore on the dating of the underlying Cromerian Complex and its included archaeology. Based on biostratigraphy and aminostratigraphy, Preece *et al.* (2009) could constrain the age of the Anglian tills to that of one glaciation, during MIS12. The Anglian till therefore provides the minimum age of the Cromerian Complex of ~478 Ka. In addition, the till has been dated by OSL dating, of which the results led to the same conclusion (Pawley *et al.* 2008).

Now flint artefacts are also found in underlying Early Pleistocene sediments with reversed palaeomagnetic polarity at Happisburgh site 3 (Parfitt *et al.* 2010). The Early Pleistocene age of these sediments is also indicated by the presence of exotic plant species such as *Tsuga* and *Ostrya*-type. *Tsuga* is unknown in Europe after the Early Pleistocene (Magri *et al.* 2010; LePage 2003). *Ostrya*-type includes species native to southern Europe but that are absent from the British Isles today (Parfitt *et al.* 2010 supplementary information). The artefacts were interstratified in sediments that could be related to their equivalents in a borehole from 1966 (Preece and Parfitt 2012), in which the sediments were attributed to the Pastonian Stage (West 1980a).

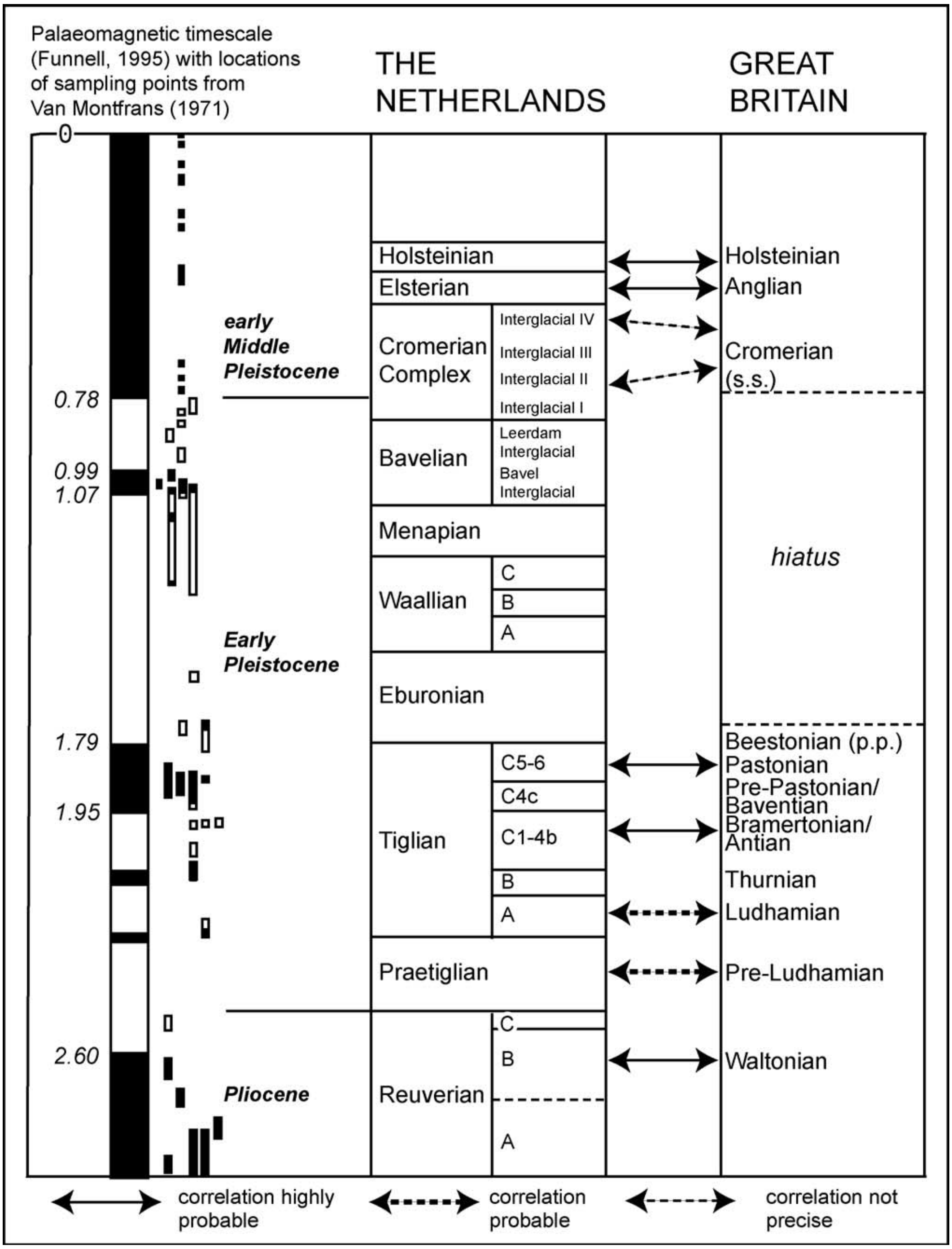


Figure 2. The British and Dutch Early and Middle Pleistocene stratigraphy and possible correlations, in relation to the palaeomagnetic time scale (Rose 2009, 5).

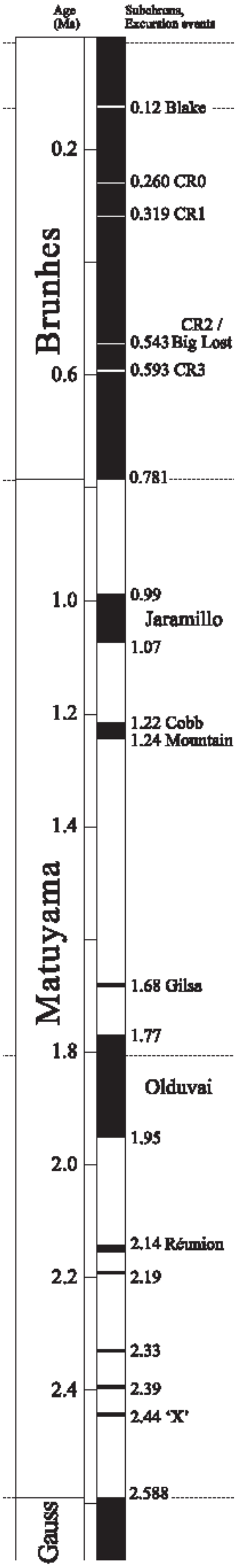


Figure 3. Quaternary magnetostratigraphy with normal (black) and reversed (white) magnetic polarity (after International Commission on Stratigraphy website 2012).

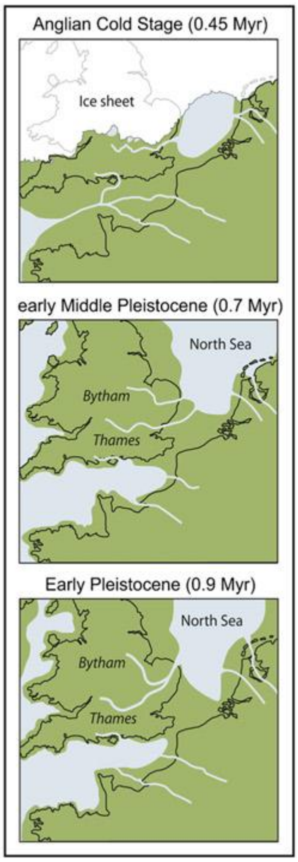
The Pastonian Stage is linked to the Early Pleistocene, to be correlated with the Late Tiglian (TC5-6) of the Dutch succession (Gibbard *et al.* 1991) (fig 2).

However, sediments attributed to the Pastonian Stage on the basis of palynology, and those from Happisburgh site 3 contain different faunal assemblages. The animal assemblages of Pastonian sediments appear to be composite (Lister 1998), indicating that also the Pastonian Stage, by West (1980a) suggested to present a complete vegetational succession of a single temperate stage, comprises more than one temperate stage.

Preece and Parfitt (2012) suggest, on the basis of comparison of vole assemblages from Pastonian sediments and Happisburgh 3, that these ‘Pastonian’ sites may be separated by a large interval of time. Another indication for a more complex nature of the Pastonian Stage and its representation in the East Anglian stratigraphy is found in the absence of the vole *Allophaiomys* from the East Anglian sediments. This vole is present in the records of Europe from immediately before the Olduvai until the Jaramillo Subchron palaeomagnetic events (See figure 3 for magnetostratigraphy). Its absence from the East Anglian sediments may point to a large hiatus (Gibbard *et al.* 1991). Thus, the Pastonian Stage does not only comprise more than a single temperate stage, a large time interval of the Pastonian may be unrepresented in the East Anglian stratigraphy. Happisburgh site 3 is related to MIS 25-23 (Parfitt *et al.* 2010; Preece and Parfitt 2012), hence placed in the late Early Pleistocene on one end of the hiatus, many other Pastonian sediments may be situated about 1 Ma years earlier in the chronological sequence (Preece and Parfitt 2012).

2.2. Palaeogeography of East Anglia

During the Pliocene and Early Pleistocene boundary, around 2.6 Ma, high global sea-levels caused the area of East Anglia to be the bottom of the North Sea. The North Sea was then to the southwest connected to the Atlantic Ocean and therefore forming the British Isles. In this environment, the Coralline and Red Crag were deposited. Relatively short thereafter, around 2.5 Ma, sea-levels dropped as a result of global climatic changes. Together with a progressive progradation, due to increased bedload transport in the rivers from the continent flowing into the North Sea basin, the falling sea-levels allowed Britain to be connected to the European mainland (fig 4). The land bridge between Britain and the continent obstructed the North Sea from the Atlantic Ocean. Instead, the North Sea formed a large delta that from 1.7 Ma onwards prograded further north. In this Ur-Frisia Delta, large rivers from the continent as well as from the peninsula Britain drained in the North Sea embayment. Fluctuations in sea-levels alternately created estuary and off-shore environments and fluvial plains during periods of lower sea-levels. This dynamic environment is the origin of the wide variety of marine, estuarine and fluviatile deposits attributed to the 'Cromerian Complex' (Funnell 1996).



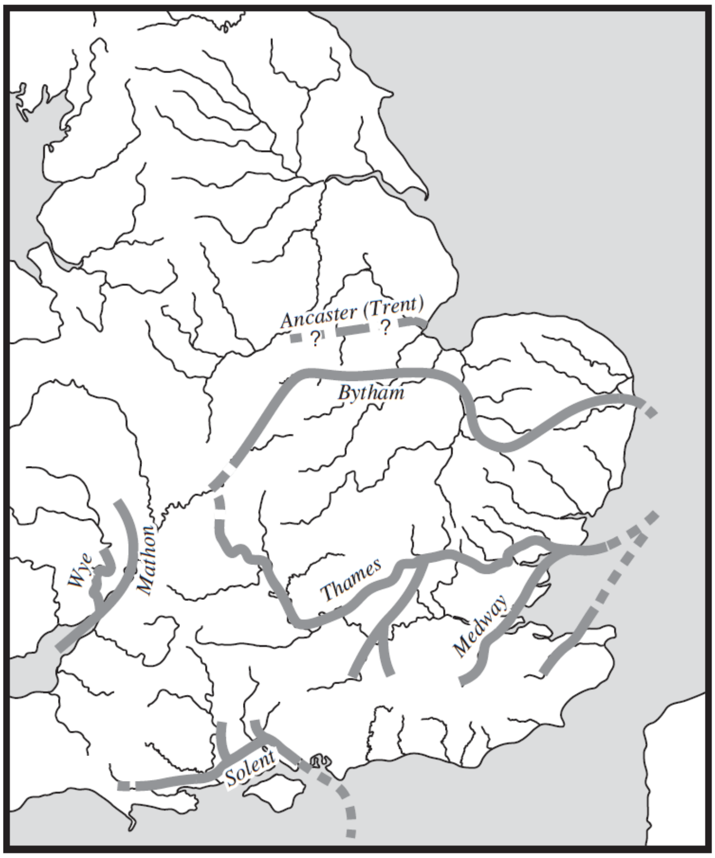


Figure 4. Map of southern England showing its palaeogeography during the Early and early Middle Pleistocene and the extend of the Anglian glaciation around 0.45 Ma (after Preece and Parfitt 2012, 9).
Figure 5. Map of East Anglia illustrating the pre-Anglian river courses (after Bridgland 2010, 438).

Rivers that flowed into this coastal plain include the Rhine and Meuse from the continent, and the Bytham, Thames, Solent and Ancaster-Trent draining the British peninsula (Bridgland 2010). Together with the main rivers (fig 5) smaller rivers and streams flowing into the North Sea basin are indicated by the presence of infilled river channels, cut-off river arms, and pools in the Cromerian deposits (as indicated by the environmental reconstructions in various works i.e. Field 2012; Field and Peglar 2010; Parfitt *et al.* 2005, 2010; West 1980a). In this context, enabled by the land bridge, plants, animals and hominins could disperse into Britain.

2.3. Hominin dispersal into East Anglia

2.3.1. Considerations on human evolution

During the past 6 million years the Earth and its inhabitants have undergone major changes. Climatic oscillations caused the world's surface to change radically. New conditions evoked organisms to adapt to the new environments, giving rise to evolutionary processes finally resulting in many of the species we know today. This includes our own species, *Homo sapiens*.

Our ancestors emerged in tropical climates, but expanded their range during the course of evolution. Modern humans are now dispersed over the entire Earth, occupying nearly every ecological niche and habitat. The evolutionary steps that finally enabled modern *Homo* to take in a global geographic range may be retraced in the fossil and artefact records of its ancestors. Evolutionary change is the result of genetic processes against an environmental background. Therefore, in the search of explaining evolutionary change, apart from genetic studies, the environmental context is gaining interest.

Especially the European record provides an informative study area where the dispersal of *Homo* based on the now available record can be retraced and its changing environment can be reconstructed enabling inferences to be made on physical, behavioural, social and technological adaptations. What changes in physiology and anatomy, tolerance and adaptive versatility took place in the evolution of *Homo*?

Physiological and anatomical adaptations forming during the course of evolution may be abstracted from fossil evidence. Although, this is a relatively sparse source, important insights related to for example locomotion, brain size and diet are obtained from skeletons and teeth (e.g. Green and Alemseged 2012).

When reconstructing the environmental context of the dispersed hominins, the expansion of their geographic range and ecological tolerance can be studied. Apart from physiological and anatomical adaptations deduced from fossil evidence hominins may have been adapting to their environment through technological, behavioural and social adaptations as well. These kind of adaptations do not leave tangible proof, or proof is obscured by effects of taphonomy and recovery. However, from environmental data it may be inferred that some social, behavioural and technological prerequisites must logically have pertained in sake of surviving (Roebroeks 2006).

To understand the processes, fossil-, artefactual,- and environmental data should be related in time and space. This requires a time frame in which the evidence on hominin evolution, dispersal and its environmental context can be situated in. In this regard, an important problem remains the matching of climate oscillations and the resulting environmental changes to evolutionary processes and the patterns of hominin dispersal. Additionally, it proved to be difficult to disentangle hominin habitat preference from biases in habitat preservation (Cohen *et al.* 2012).

2.3.2. Human evolution and climate

Thoughts about hominin evolution evolved over time. The first considerations on human evolution were especially focused on intrinsic explanations for the development of our species. When the evolution of adaptations is considered an intrinsic phenomenon, it is thought that one adaptation sets the stage for a new adaptation. With bipedal locomotion the hands came free to use and make tools, and with tools our ancestors became able to add meat to their diet. In this scenario, only once the environment is involved in our evolution. The environment triggered the first adaptation, bipedal locomotion, during the initial divergence of forest-dwelling apes and proto-humans. It was then that drought caused savannas to develop in which proto-humans had to survive, aided by the ability of bipedal locomotion and tool making. Tools enabled them to expand their diet (i.e. meat), and broad about other technological advances (fire and hunting), resulting in complex sociality and language (Potts 2012).

After the 1970s the environmental background of early human evolution gained attention and led to extrinsic explanations of human evolution. E.S. Vrba developed the Turnover-pulse hypothesis (TPH) which suggests that periods of drought caused origination and distinction of lineages (Potts 2012).

An alternative extrinsic explanation of (human) evolution is the Variability Selection Hypothesis (VSH) (Potts 1998). This hypothesis suggests that especially varying habitats result in new adaptations. During periods when habitats are more variable 'heritable traits that enhance plasticity (adaptive versatility) are favoured' (Potts 2012). Therefore adaptive versatility is improved and organisms become more competent in adjusting to environmental change and new habitats and/in new geographic locales. A more variable climate would therefore enhance speciation and stimulate adaptability to a greater variety of habitats and geographic locales (Potts 2012).

Human evolution and its environmental background as it is understood today is discussed in the following paragraph. See figure 6 for an illustration of the phylogeny of primates.

The divergence of Anthropoidea (as included in the Haplorhini suborder) from the other primates (Strepsirrhini suborder) possibly took place around ~77 Ma. About ~31 Ma Hominoidea diverged from the other Anthropoidea (Steiper and Young 2006) when tropical and subtropical forests extended into Europe (Andrews 2007). Within this forested environments apes, Hominoidea, had diversified and spread over the world, further evolving into a multitude of species. During the Miocene a climate cooling caused the forests to decline. The inhabiting ape species began to dwindle until at the end of the Miocene only a small group survived, geographically restricted to a small part of Africa. From this group the ancestors of the hominins, diverged from the other apes between 8.8-6.6 Ma. It was probably a subsequent cooling and drying phase that caused the development of more extensive grasslands (Toth and Schick 2009) which possibly set the scenery for the bipedal locomotion of *Australopithecus*. Although climbing probably remained an important aspect of the locomotor repetoire of *Australopithecus* as well (Green and Alemseged 2012) and on the other hand shows its ancestor, *Ardipithecus*, already some specialisations for walking upright (Potts 2012).

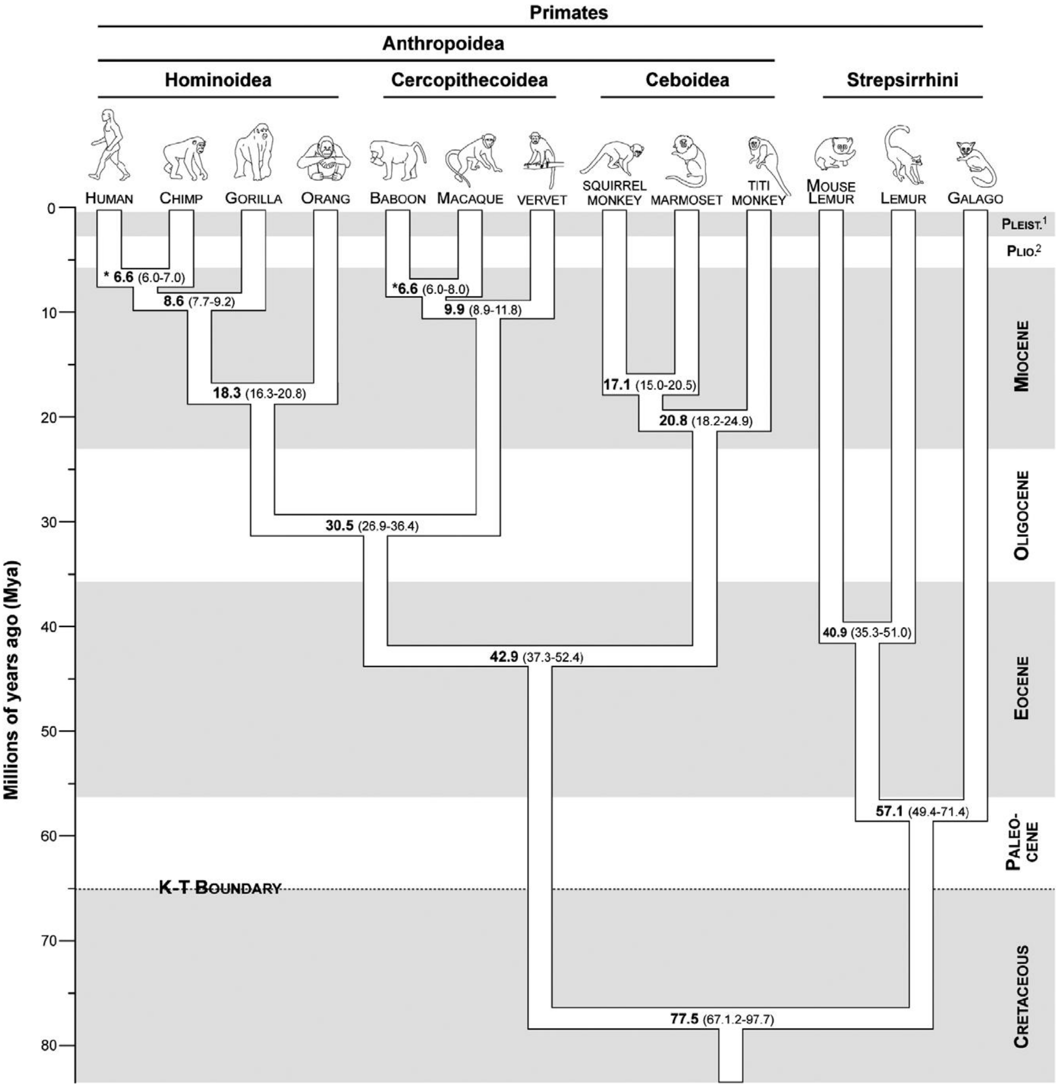


Figure 6. Phylogeny of primates with molecular divergence dates based on genomic data (Steiper and Young 2006, 389).

A subsequent period of cooling and drying around 2.8 Ma may have given rise to the diversification of Australopithecines. The development of the first recognisable stone tools of the Oldowan industry (Mode 1) may be attributed to this period. Around 2 Ma the genus *Homo* emerged from the diversified Australopithecines, about the period to which the earliest finds of the Acheulean industry (Mode 2) stone tools are dated. From then on *Homo* seems to disperse out of Africa into the world. The currently known geographical expansions of *Homo* by that time include the dispersal into southern Africa and Asia (Carrión *et al.* 2011; Toth and Schick 2009). The dispersal of *Homo* may have been facilitated by the presence of familiar open grassland landscapes from North Africa to the

Levantine corridor and Central Asia, which had developed as a result of climatic changes. It is possible that in Southwest Asia this first dispersed *Homo* evolved into *Homo erectus,* developing the adaptations needed for further dispersal into Eurasia. Southwest Asia may have formed the 'central area of dispersals of Eurasia' (Dennell *et al.* 2010).

2.3.3. Hominin dispersal into Europe

From here focus will be on the dispersal of *Homo* into Europe. The first spread into Europe probably coincided with an opening of the forests that until then characterised the Early Pleistocene vegetation. The fragmented and open landscape offered a diversity of habitats presenting hominins a wide resource base. Moving west into Southern Europe where mild climates with low seasonality and environmental fluctuations prevailed, hominins reached Iberia around 1.4-1.2 Ma (as indicated by sites such as Pirro-Nord, Italy, ~1.6-1.3 Ma, (Arzarello and Peretto 2010), Sima del Elefante, Spain, ~1.2 Ma and Gran Dolina TD-6, Spain, 960-780 Ka (Carbonell *et al.* 1995, 2008)).

The archaeological sites discovered in southern Europe, and the absence of convincing archaeological sites in northern Europe dated to before 500-600 Ka, led to the conclusion that hominins did not pass the Alps and Pyrenees before that date (Roebroeks and Van Kolfschoten 1994 in Roebroeks 2001), suggesting a "short chronology" of hominin dispersal into Europe. Geographical reasons as well as climatic (more northern latitudes) and the lacking ability of early hominins to colonise these regions have been put forward to explain this pattern. But the possible influence of the glaciations, obscuring archaeology in the more northern regions, was already appreciated by Wymer (1999).

With the discovery of flint artefacts at Pakefield, Suffolk, England, in sediments dated to ~700ka (Parfitt *et al.* 2005), this proposed pattern of dispersal could no longer hold stand. Environmental data from the same sediments suggested warmer temperatures at the site during occupation, than known in England today. This may be indicated by the presence of fossil evidence of thermophilous plant genera such as Water chestnut *Trapa natans*, Floating fern *Salvinia natans* and Portuguese Crowberry *Corema album* and the occurrence of Hippo *Hippopotamus* (Parfitt *et al*. 2005).

The presence of hominins in higher latitudes was explained by what may be called a 'Mediterranean' perspective. The dispersal of hominins was regarded as an 'ebb and flow' movement, with hominins only expanding from southern refugia into Northern latitudes when similar conditions as in the Mediterranean region prevailed, during a fully temperate climate (Roebroeks 2006).

The discovery of Happisburgh site 3 (HSB3), dated by biostratigraphy and palaeomagnetism to ~0.99-0.78 Ma, changed this perspective entirely. Environmental data from HSB3 includes Pine *Pinus* and Spruce *Picea* which presence, together with the recovered beetle assemblage, suggest a habitat similar to the southern edge of the boreal zone, indicating cooler conditions than known in England today (Parfitt *et al.* 2010).

To fit in the new evidence from HSB3 and Pakefield an 'Atlantic' explanation of hominin dispersal is proposed by Cohen *et al.* (2012). The authors suggest that the early hominin dispersal may have been facilitated by the milder temperate Atlantic climate existing in the coastal regions. In this proposal the coastal zone includes 'fresh water ecotones of the inland coastal plains, the lower reaches of river valleys that feed these plains and the hill slopes bounding the coastal plains and lower valleys' (Cohen *et al*. 2012, 71). Apart from mild climatic conditions, the coast would have offered the necessary additional aquatic food resources more constantly available than terrestrial sources in increased seasonality. In this way the coastal and riverine areas would have offered a wider resource base (Cohen *et al*. 2012; Parfitt *et al.* 2010), especially important during winters when vegetal resources diminished. However often overlooked, will tubers and roots still be available during winter. This plant food resource can still be exploited even when the plants are in winter dormancy and may have added to the diet of hominins (M. Field pers. comm. 2012). The ecotonal situation of the river plain or estuary would have offered a variety of plants and thus a variety of tubers and roots.

Furthermore, the coast may have formed a corridor for dispersal through which hominins reached Britain from the south. Figure 6 provides a map of the proposed dispersal and sites with archaeological potential regarding this geographic range model.

According to this dispersal pattern, it is only after 500 Ka that inland sites are occupied, then also during really cooler conditions like at sites as Schöningen and Bilzingleben. These groups of hominins would have originated in the coastal regions. With the occupation of the cold interior of the continent, controlled use of fire and hunting developed (Cohen *et al.* 2012). However, the cold winters in Britain during the occupation of various early sites (Happisburgh site 3, site 1, High Lodge, Boxgrove, but also the winters at Pakefield) may already have necessitated some technological adaptations like shelter, rudimentary clothing and fire (Pettitt and White 2012).

The research of Ashton and Lewis (2012) focuses on the habitats of Early and Middle Pleistocene sites in Britain, concluding that hominins were 'able to survive in a range of climatic and vegetational zones from the earliest occupation in the Early and the early Middle Pleistocene.' (Ashton and Lewis 2012, 50). Table 1 summarises the assumed temperatures and the local and regional environments of nine selected British sites.

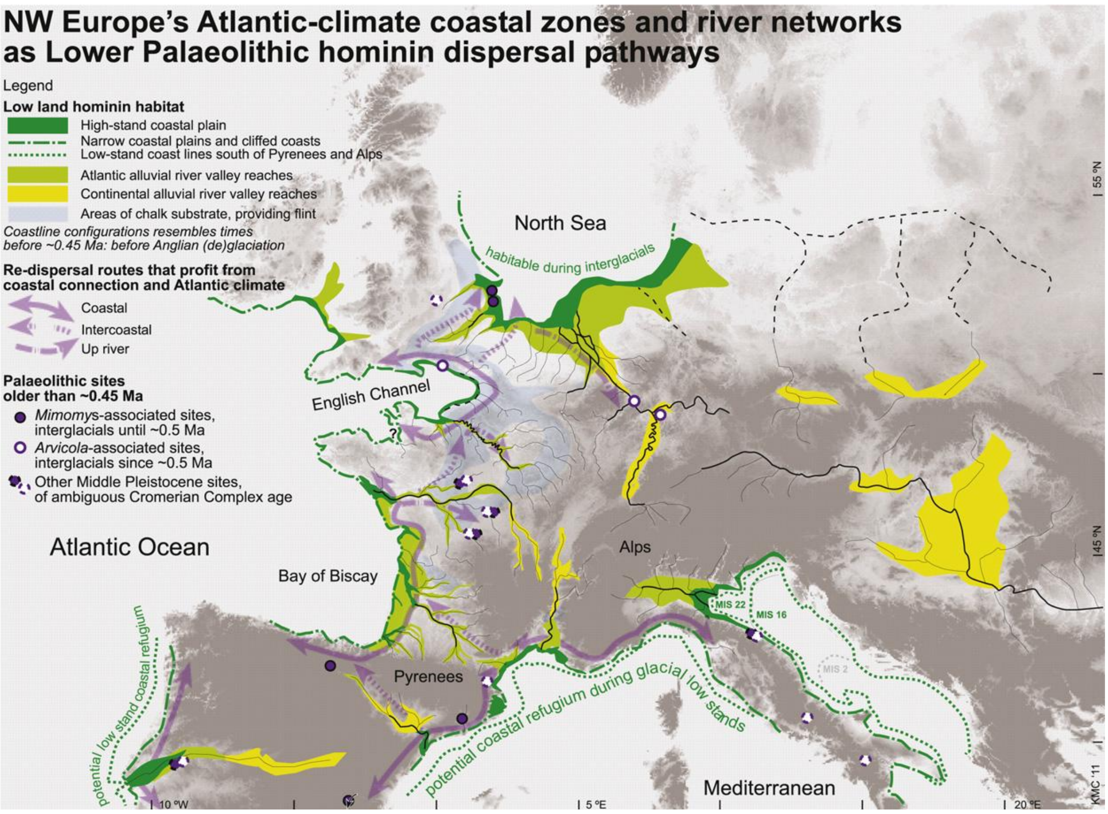


Figure 7. Early and Middle Pleistocene hominin dispersal pathways along rivers and coastal zones as proposed in the 'Atlantic perspective' by Cohen *et al.* 2012 (p.79).

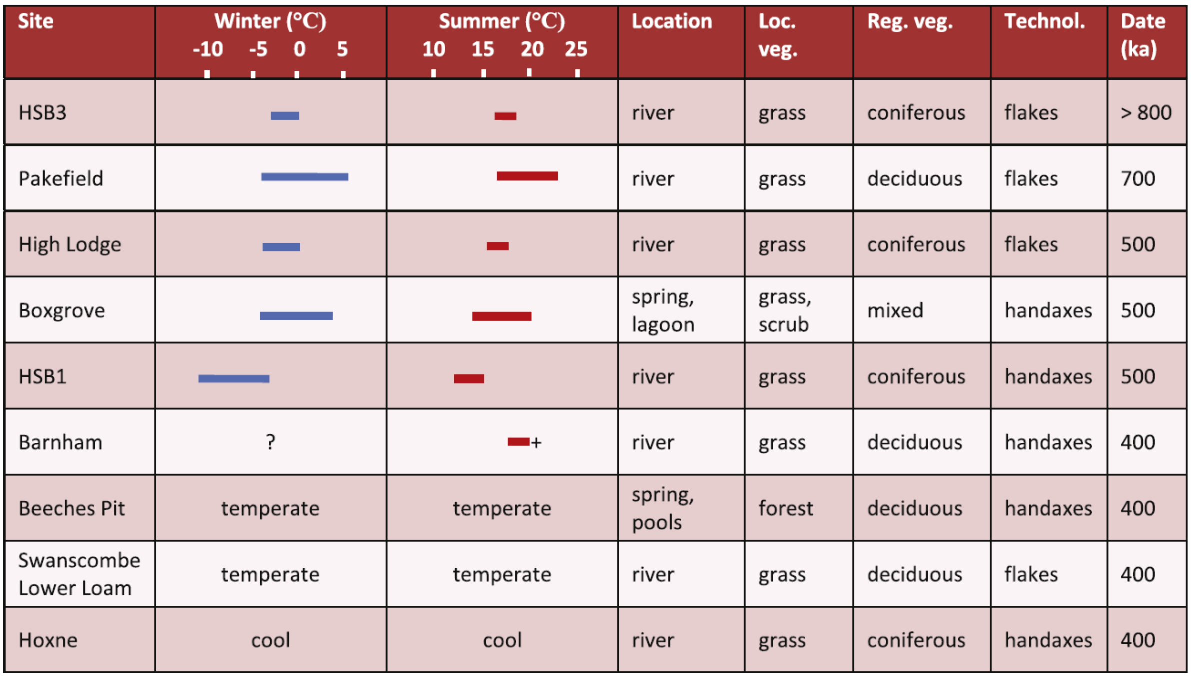
As different environments, from warm Pakefield to temperate boreal HSB3, are reconstructed the habitat preferences of hominins appears more diverse than ever. One pattern that might prevail is the occupation of open river valleys or fresh water springs and pools. Although this pattern may be attributed rather to processes of preservation than habitat preference, it may be logically induced that access to fresh water was of vital importance as it is for many organisms.

Moreover, the river valley (or spring or pool) provides an ecotone from where various habitats could be exploited, including aquatic food resources, access to lithic raw material, the attraction of other animals to the water and the open landscape next to the water-body where grazing animals roamed (and were killed providing carrion and possibilities for scavenging). Additionally, the nearby coast provided marine resources (Ashton and Lewis 2012; Cohen *et al.* 2012; Parfitt *et al.* 2010).

In colder areas, plant food resources critically diminish during the winter. To survive, hominins would have been more dependent on less seasonal resources such as meat and marine food. These food resources may have been available in the riparian and coastal ecotones. Not only were these resources a good substitute for the diminished plant foods, keeping warm in the cold is energy-costly. Animal fats and proteins provide effective energy sources (Pettitt and White 2012).

The high dependence on these types of food resources necessitates efficient scavenging of meat from other carnivores. This requires cooperation especially when aggressive confrontational scavenging was applied. Therefore increased social behaviour may be expected (Pettitt and White 2012).

The occupation of the more northern regions of Europe still seems to have been sparse prior to 500 Ka. After that it may have been the advanced *Homo heidelbergensis* (over *Homo antecessor*) with new technologies and a larger brain that was able to settle more permanently (Ashton and Lewis 2012).



Site	Winter (°C) -10 -5 0 5	Summer (°C) 10 15 20 25	Location	Loc. veg.	Reg. veg.	Technol.	Date (ka)
HSB3	▬	▬	river	grass	coniferous	flakes	> 800
Pakefield	▬	▬	river	grass	deciduous	flakes	700
High Lodge	▬	▬	river	grass	coniferous	flakes	500
Boxgrove	▬	▬	spring, lagoon	grass, scrub	mixed	handaxes	500
HSB1	▬	▬	river	grass	coniferous	handaxes	500
Barnham	?	▬+	river	grass	deciduous	handaxes	400
Beeches Pit	temperate	temperate	spring, pools	forest	deciduous	handaxes	400
Swanscombe Lower Loam	temperate	temperate	river	grass	deciduous	flakes	400
Hoxne	cool	cool	river	grass	coniferous	handaxes	400

Table 1. British sites and their reconstructed environments, summer and winter temperatures, lithic technology and age (Ashton and Lewis 2012, 59).

3. Taphonomic considerations in palynology

3.1. Pollen production

An important part of the biological evidence of Quaternary environments consists of pollen and spores. For convenience, in the following text the term pollen is used to include spores. Fægri and Iversen (1989) and Moore *et al.* (1991) provide textbooks on pollen analysis and are here, among others, used in the discussion on pollen taphonomy.

Pollen are produced by the anthers of seed-producing plants. Pollen grains contain the male-gametes of the plant which aim to reach the female gamete, the ovule, for fertilisation. This process is in essence a process of transport.

In the reproduction process of some plants this route of transport is short, for example in obligate autogamous plants where self-fertilisation takes place within a flower. To secure the fertilisation some flowers, of cleistogamous plants, do not open at all (Fægri and Iversen 1989). These plants will be underrepresented in a pollen assemblage, if presented at all.

In case of allogamous plants, pollen grains must travel farther distances to reach the stigma of another flower on the same or on another plant so that cross-fertilisation can take place. Plants developed various means to overcome the distance between the male-gametes and the female-gametes. Some aquatic plants (e.g. *Ceratophyllum*), disperse pollen grains in the water for sexual reproduction, termed hydrophily (Philbrick and Les 1996). Pollen of this type are often less persistent and will be underrepresented in fossil pollen assemblages (Fægri and Iversen 1989). Other plants attract animals with nectar or the pollen itself (then a high surplus of pollen is produced) and pollen grains stick unto the visiting animal. The animals will stop over other flowers and in that way be the medium of transport. Pollination by animals is called zoophily. Is the pollinator specifically an insect the pollination is denoted as entomophily (Fægri and Iversen 1989). Because the transport is often very effective, zoophilous plants are less well represented than wind-pollinated plants.

The most important means of transport for palynology is wind-pollination, termed anemophilous pollination. Plants that fertilise by wind, produce great quantities of pollen, specialised for being airborne (e.g. by air sacs) (Culley *et al.* 2002; Friedman and Barrett 2009). Only a fraction of these pollen will reach the stigma. All other pollen grains will be dispersed in the air and at a certain point settle down as the ‘pollen rain’ (Fægri and Iversen 1989).

The pollen rain of airborne pollen, together with a smaller amount of the other pollen types, accumulate on the ground, in water-bodies, bogs, and ocean floors and get incorporated in the sediment. If non-oxidising conditions are present the pollen grains fossilise and are preserved in the sediments (Birks and Birks 1980; Moore *et al.* 1991) and can be recovered for analysis. As already mentioned above will the different modes of pollination will influence the representation of the parent plants in the recovered pollen assemblage. Hence, there is an important difference between the representation of plants in a pollen assemblage and it’s presence in the source vegetation and no one to one relationship exists. Airborne pollen are often over represented, and the other types underrepresented if present at all.

There are, however, additional aspects that influence the representation of the plant assemblage. For example pollen production varies from species to species, per year, per season, during the day, individually, and in relation to ecological parameters and climatic changes (Birks and Birks 1980; Fægri and Iversen 1989 and references therein). When a pollen sequence is studied that is assumed to have been formed over a longer period of time, the annual and smaller variations may be neglected (Fægri and Iversen 1989).

But pollen productivity also varies with the position of the parent plant in the landscape and related to other plants. A tree in an open field produces more pollen than one in a forest. Generally, a forest is still a high pollen producer. But an open area may well be represented in a pollen assemblage as well, comparable to that of a forest (per unit area). The comparable production of these vegetation units makes that the forest density can be reconstructed from the representation of arboreal pollen (from trees) and non-arboreal pollen (from herbaceous plants) (Fægri and Iversen 1989).

Because the different pollen productivity of plants is depending on many aspects, correction for this varying productivity and representation in the sediments is difficult (Birks and Birks 1980). It can just be stressed that these variations should be kept in mind. Moreover, is the differential dispersal and deposition an important factor of influence on the representation of the parent plants in the pollen assemblage.

3.2. Pollen dispersal and deposition

The dispersal and deposition of pollen varies with the size, shape and weight of the different pollen-types. These factors influence the suspension of the grains both in air as well as in water (Fægri and Iversen 1989; Hopkins 1950).

In medium winds (5-10 m/sec.), most pollen grains will get airborne. As soon as pollen are suspended, they can be considered as part of the air and their dispersal can be approached trough studies of air movement (Fægri and Iversen 1989). Before pollen reach the turbulent air, however, they have to exceed the more quit air mass near the vegetation surface. The turbulence free layer of air is laminar and may vary in thickness with wind velocity and roughness of the vegetation surface. By shaking branches or anthers, local turbulence may cause the needed air movement to get pollen in suspended in the true turbulent air mass. Suspended pollen can travel local distances and exceed the regional area. Reconstructing the dispersal pathways as shortly lined out above, increases the understanding of what plants of the past vegetation are how represented in the pollen assemblage.

Therefore, the pollen rain may be divided into three different components that add to the pollen assemblage. These components have undergone a different dispersal and will reflect a different part of the plant assemblage under reconstruction. These three different components of the pollen rain are proposed by Fægri and Iversen (1989) denoted the gravity component, the local component and the regional component. The division of the pollen rain in various components was first proposed by Tauber (1965). Fægri and Iversen (1989) appreciate Tauber’s differentiation of the otherwise ostensible vertically falling pollen rain but propose somewhat differently defined components, discussed here.

The gravity component (corresponding to Tauber’s ‘trunk space’ component) consists of those pollen that fall straight to the ground. In this group horizontal transport of the pollen grains is minimal. In a forest, for example, the horizontal air movement is limited by undergrowth that in the same time scavenges pollen from the air. The pollen grains that straight fall down, or settle on the leafs and get washed down by the rain are included in the gravity component. Other attributors are grains that failed to separate into single grains, or that were still attached to the anther, flower or leaf when the latter got incorporated in the sediments (Fægri and Iversen 1989).When clods of pollen grains are found in a pollen sample they are part of the gravity component and the parent plants can be considered as locally present.

The local component of the pollen rain underwent some influence of turbulence and wind. This component is diffused as a cloud of which the centreline remains more or less parallel to the ground. In the course of horizontal transport the pollen grains are scavenged by the ground cover. Ground cover means the top surface of the vegetation under consideration, whether this is the top of the canopy or plants directly on the ground. Vertical transport of the local component is minimal and pollen grains do not enter the permanent turbulent air strata (Fægri and Iversen 1989). The gravity and local component can be considered as autochtonous pollen.

The regional component of the pollen rain contains the pollen that get airborne and transported over further distances. These grains are caught by air mass movements such as thermal collumns which transport pollen into higher air masses (Fægri and Iversen 1989). Pollen in these air masses can be transported far away from the parent vegetation and deposit in a different environment as the allochthonous component.

But as part of the air mass, thermal columns will indeed rise, but cooled air will fall. Thermals usually commence during day time, and will collapse when the air cools down in the evening and night or above a cool water surface. Therefore, the major portion of pollen grains brought into the air during day-time settles down during night. This would mean that most pollen only stay airborne for maximum a day. The maximum transport distance corresponding to that would be between 50 and 100 km. But many occasions are known of further distances covered by airborne pollen (Fægri and Iversen 1989). These long distances may be covered by pollen that are brought into the permanent turbulent air strata, beyond the influence of weather but this is a rather small portion of the suspended pollen. In lower air masses precipitation can ‘rain-out’ the pollen content from the air (Fægri and Iversen 1989).

But whereas the pollen dispersal mainly follows the course of the air masses, during deposition an important difference between the air and its content occurs. When the air is meeting an object or surface, it is rather unaffected by this, except for changing its course. The pollen, however, may stick onto the surface or object that is met and be scavenged from the air. The efficiency of the scavenging, or filtering, is both determined by the morphology of the surface as by its physical characteristics (Fægri and Iversen 1989). Pollen may be most efficiently deposited on rough and wet surfaces. Therefore water-bodies are efficient scavengers. In addition the body of water is usually colder than the surrounding ground, causing downdrafts above the water. Wind directly reaches the water surface depositing the suspended pollen.

A difference between pollen deposition on soils or peat bog and on a water surface is that in the latter scenario the final deposition of the grain may be importantly delayed. Because fluvial, lacustrine, marine, estuarine, oceanic and palustrine deposits form an important source of fossil pollen the transport of pollen by water and the influence of the environment of deposition on the pollen assemblage will be discussed here.

Pollen grains may float on the water surface (Hopkins 1950) and stay suspended in the water-body. The deposition of pollen grains in a water-body may depend on the size, shape and weight of the pollen grain. In a larger water-body with some current this may result in the differential deposition of certain pollen types (because of differing sinking velocities) throughout the water-body.

Moreover, the size of the water-body influence what part of the vegetation is deposited in the water-body. Pollen from sediments of a small pond will mainly represent the local vegetation, whereas a large lake records the regional environment (Jacobson and Bradshaw 1981).

In suspension the pollen are easily transported. Before final deposition the pollen may be transported over great distances by rivers, water streams and surface run-off, and are subject to internal resedimentation in the water-body (Bonny 1978; Davis 1968; Fægri and Iversen 1989). Understanding the sedimentation history of the sampled sequence, aids the interpretation of the recovered pollen assemblage. When the environment of deposition is understood inferences can be made on the catchment area represented in the pollen assemblage (West 1980a).

Not only the dispersal and deposition of pollen by air, but also by water are greatly influencing what plants from the past vegetation are represented by the pollen in an assemblage. The mechanisms of dispersal in water and air are closely related to the shape, size and weight of the pollen grains. These characteristics are often the result of adaptations to the mode of pollination.

3.3. Pollen redeposition

After dispersal, transport and deposition on the soil or in a water-body pollen may be redeposited by bioturbation, water movements and sediment erosion. Recognising redeposited pollen aids the evaluation of the integrity of the recovered assemblage.

The recognition of redeposited pollen is not always straightforward. Three commonly known indications can be put forward. On the basis of corrosion it may be suggested that pollen were transported over a long distance. Another indication might be the presence of pollen that seem to have originated from a different environment than reflected by the other pollen grains. Both methods are not very objective and in the latter case, when no modern counterpart of the reconstructed habitat is known, pollen may invalidly be registered as reworked (Birks and Birks 1980; Fægri and Iversen 1989). A third indication for redeposition is given by high proportions of old pollen. Old pollen or ‘fossil’ pollen are pollen deposited in geologic eras preceding the period under study. For example the inclusion of Jurassic pollen in Pleistocene samples emanated from the erosion of old polleniferous deposits (Birks and Birks 1980). When high numbers of ‘fossil’ pollen are present in the sample, processes of sediment erosion may have attributed to the pollen content in the sampled sediments. With sediment erosion surface run-off may also include extra contemporary pollen washed from the sediment surface.

Processes of redeposition may affect the appearance of the pollen grains. Characteristic deterioration can sometimes be related to specific transport and deposition that add to the understanding of the genesis of the pollen assemblage.

3.4. Pollen preservation

Differential preservation of individual pollen grains, between pollen types or within various sediments impact the pollen assemblage. Cushing (1967) describes different types of deterioration: 1) *corroded* grains are grains of which the exines (see 5.4. Pollen morphology and identification) are distinctly etched or pitted. When the exine is structurally rearranged, such as structural details that are fused the pollen are 2) *degraded*. Wrinkled, folded and collapsed pollen grains are classed as 3) *crumpled*. Pollen grains often show at least some folding or wrinkling and the real crumpled grains are defined as folded, wrinkled and collapsed in several planes of the grain. The crumpled grains can be divided in a class of grains crumpled with thinned exines and 4) *crumpled with normal exines*. This division, however, is quite subjective. Grains with ruptured exines can be classified as 5) *broken*. By observing the proportion of each preservation class in a sample, the state of preservation of the pollen assemblage can be described and even inferences can be made on the environment of deposition (Cushing 1967).

Pollen grains may be determinable, including known (as a formally named taxon) and unknown pollen. Indeterminable pollen are those heavily deteriorated or those obscured by other particles in the sample (Cushing 1967).

3.5. Influence of taphonomic processes on pollen assemblages

In pollen analysis a reconstruction of the past vegetation is based on the pollen grains this vegetation dispersed. A great variety of factors intervene between the plant assemblage, the life assemblage, and the pollen assemblage, the dead assemblage (the concepts of life and dead assemblages is taken from Birks and Birks 1980). In the life assemblage the pollen production and dispersal mechanisms vary from plant to plant, causing (in most cases) over representation of wind-pollinated species. Further transport of pollen by air masses may bring certain pollen far away from the parent assemblage. These pollen are considered as allochtonous material as soon as they deposit in a different environment. The locally present vegetation produces the autochtonous pollen material as long as these pollen are not in turn dispersed over far distances.

Both the autochtonous and allochthonous pollen material form the dead assemblage when they are deposited and incorporated in the sediment. Before this final deposition however, pollen may undergo further transportation by water, bioturbation and redeposition. Here selective transportation, bioturbation and redeposition may further cause a disturbance of the representation of the original life assemblage of plants. Heavy grains have a high sinking velocity and may quickly be deposited. Grains that have good floatability can more easily reach other depositional environments. Finally, processes of fossilisation may cause differential preservation and therefore alter the representation of the life assemblage.

This complexity can only be emphasised and no correction will be sufficient to overcome the difference between the original life assemblage and the recovered dead assemblage. In reconstructing the life assemblage based on the dead assemblage, the complex genesis of the latter must be considered.

Taking into account the above mentioned processes, an environmental reconstruction of the pre-glacial sediments at Beeston, England, was conducted.

4. The pre-glacial sediments at Beeston, Norfolk, UK

4.1. Research history of the East Anglian coast

Beeston is located on the East Anglian coast of England between Sheringham and West Runton (fig 8). Along the coast sediments are overlain by the glacial till attributed to the Anglian glaciation. These sediments underlying the glacial till will be referred to as pre-glacial sediments. This stretch of coast has been subject to research for over two centuries. Here, because of cliff erosion, pre-glacial deposits are exposed at different localities, unveiling the complex stratigraphical succession of the region. This stratigraphical succession is of relevance for understanding the lowland glacial, the geographical and environmental history of East Anglia as well as providing an important relative dating tool for the now known earliest hominin presence in England, and the dispersal of hominins into the north-western corners of the Pleistocene world (Parfitt *et al.* 2005, 2010; Preece and Parfitt 2012).

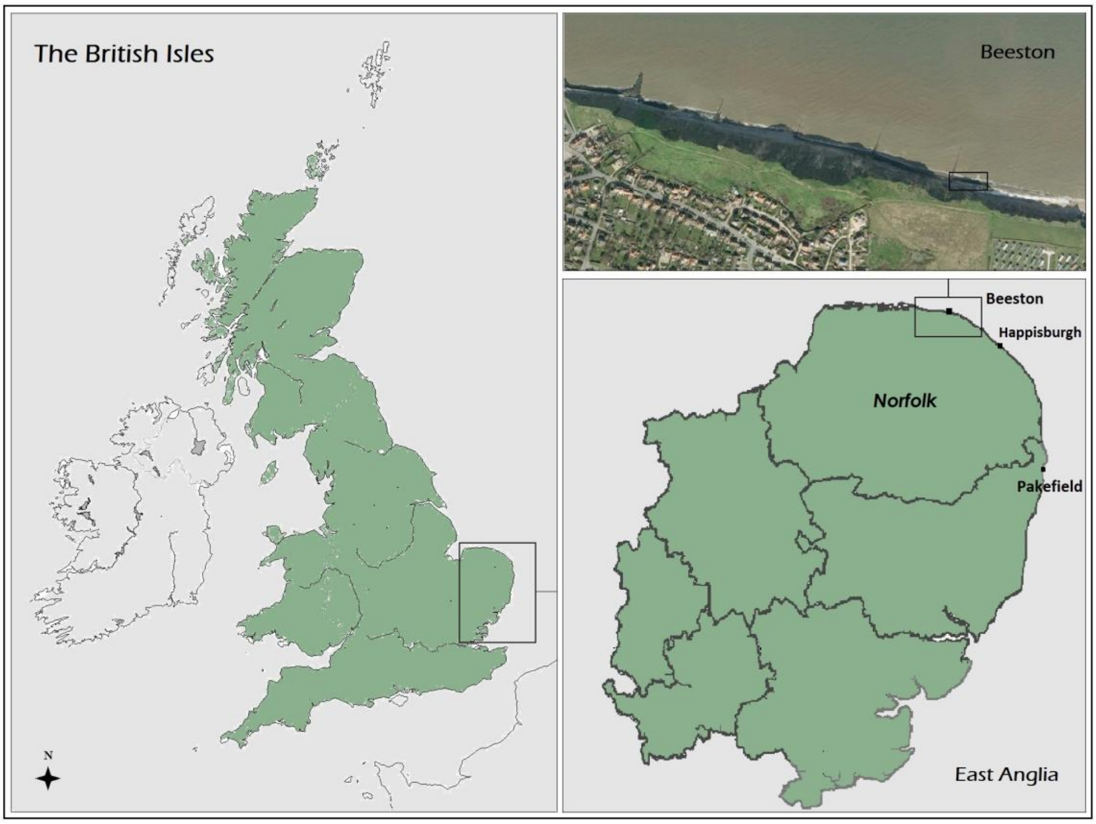


Figure 8. Map of the British Isles indicating the region of East Anglia. Detail of East Anglia showing the sites mentioned in the text and the sample location near Beeston (Composed by the author after Craig Asquith website 2012, Google Maps 2012).

Already for two centuries the stratigraphical sequence of East Anglia, especially the fossiliferous pre-glacial deposits has been a focus of research (Lyell 1863; Reid 1890). The pre-glacial sediments containing a wide variety of floral and faunal fossils, including entire trees stumps and elephant bones (Reid 1890), have been registered along the coast from Southwold in Suffolk to Sheringham in Norfolk (Reid 1913). That humans could have been present in these ancient coastal forests was already suggested by Lyell in 1863. It took, however, over two centuries to find the proof.

The apparent lack of archaeology dated to the pre-glacial period in this region, but the (doubtful) beach finds of cut bone and flints led, in the 1990s, to the reinvestigation of these finds of bones from the Cromerian complex (Parfitt 2005 in Preece and Parfitt 2012). The result was the discovery of cut marks on a *Bison* bone once collected from the beach near Happisburgh by A.C. Savin more than a century ago. In 2000, renewed investigations of the Cromer forest-bed Formation near Happisburgh led to the discovery of more cut-marked bones, flint artefacts and a hand-axe. A team of Leiden University continued the excavations at this site (Happisburgh site 1), unearthing refitting flints and plant macrofossils for environmental research.

The Ancient Human Occupation of Britain project, started in 2001 intensive (re)investigations on the archaeological record of Britain. The main goal of the project was investigating the occupation of Britain, from the earliest time, its archaeology and its relation to the European mainland and the environmental aspects of this early occupations (AHOB website, 2012).

Apart from the discoveries at Happisburgh site 1, were flint artefacts found at Pakefield, Suffolk. Based on the biostratigraphical context of the finds the archaeology of Pakefield is dated to early in the ‘Cromerian complex’, probably around 700ka (Parfitt *et al.* 2005).

In the vicinity of Happisburgh site 1, four other sites of various age, are recovered. Especially of significance is site 3, were flint artefacts are recovered from magnetically reversed sediments providing, along with biological data, an age determination between 980ka and 780ka (Parfitt *et al.* 2010).

Beeston is located about 20km northwest of Happisburgh. Here the most north-western extension of the Cromerian deposits are preserved (West 1980a).

The East Anglian coast is importantly attributing to our understanding of the British stratigraphy, providing exceptionally well preserved environmental data from the Pleistocene and now of early hominin presence. Together with the high rate of erosion of the cliffs and, therefore, loss of data and information, further intensive research of the pre-glacial deposits along the East Anglian coast is strongly advocated.

The archaeological potential of other localities along the coast may be illustrated by the discoveries of the Happisburgh sites and Pakefield. The unstable nature of the cliffs makes excavating a life threatening job. Preliminary environmental investigations of exposed pre-glacial sediments should be conducted and can now be applied to predict the archaeological potential of the deposits based on our increased understanding of hominin ecological preference and tolerance. Apart from the preference and tolerance of hominins, do particular depositional and environmental contexts provide good chances for preservation.

The environmental reconstruction of the pre-glacial deposits near Beeston, provide environmental information as such, informs on the archaeological potential of the site and, in addition, may offer a starting point from which the apparent absence of archaeology may be explained from an ecological point of view.

4.2. Position and stratigraphy of the profile studied

With the intensive research on the East Anglian coast conducted by the Ancient Human Occupation of Britain (AHOB) project exposure of pre-glacial organic rich sediments are closely monitored. When, in the summer of 2011, organic rich layers became exposed near Beeston, Norfolk (52° 56′ 7″ N, 1° 13′ 35″ E) (fig 9) the layers were sampled by M. Field and S. Parfitt for plant macro- and micro fossils and small vertebrate remains (M. Field pers. comm. 2012).

The exposed sediments were located about approximately 50 metres East of the concrete sea wall (Figure 10 provides an indication of the sample location, with reference to the concrete sea wall) and situated at the base of the cliff. The cliff consists of several metres of glacial till, deposited during the Anglian Stage (MIS 12, see 2.1. Stratigraphy of East Anglia) (Fig 8). Two different layers of organic mud were exposed, separated by a layer of sands. The lower organic mud was sampled for the here presented research (Fig 10).

Figure 9. The lower organic mud at the base of the cliff near Beeston (photo S. Parfitt 2011).
Figure 10.Photograph illustrating the distance to the concrete sea defence (photo S. Parfitt 2011).

5. Materials and methods

5.1. Sampling the sediments

The organic mud collected for this research was found near Beeston, East Anglia (UK) situated between gravels and sands (figure 10, discussed in more detail in 6.1. Lithostratigraphy of the pre-glacial sediments at Beeston). After removing the loose underlying and overlying sediment layers the organic mud could be sampled *en bloc* and transported to Leiden to be subsampled under laboratory conditions for plant macro- and micro fossil analyses.

Subsamples of 1 cm^3 were taken from the sediment sequence with intervals of 10 cm in the upper and lower part of the sequence, and with a 5 cm interval between 20 cm and 25 cm deep. To measure the exact volume of the subsamples a measuring cylinder (Moore *et al.* 1991) was used.

5.2. Sample preparation

To remove the minerogenic and organic matrix from the pollen samples a number of chemical and physical methods were applied. Standard chemical procedures were followed (Fægri and Iversen 1989). To execute the chemical and physical methods, the samples were stored in tubes.

First, the subsamples were deflocculated by boiling the material in 10% Potassium hydroxide (KOH). Subsequently 10% Hydrochloric acid (HCl) was added to the boiling KOH to dissolve any chalk present in the sample. In all the samples only a minor reaction with the HCl was recorded, indicating chalk poor sediments. At this stage a *Lycopodium* tablet was added to each sample.

After sieving the samples through a 180 μm mesh size strainer, the samples were washed with water to remove the KOH and HCl. The washing procedure consists of several steps, executed every time the samples were washed, but for convenience not repeated hereafter. After adding water the samples were centrifuged for two minutes at 4800 rounds per minute (rpm). By this procedure the pollen grains and other material were concentrated at the bottom of the tubes. All fluid was tapped off with the pollen grains remaining at the bottom of the tubes. To wash the material again, for another time water was added to the concentration of pollen. By using a whirl the pollen grains were suspended in the water again. This suspension was centrifuged and again a concentration of the pollen grains and the remainder material was obtained at the bottom and the water could be tapped off again. This process was repeated until the tapped off water was colourless.

After washing the material with water, the same washing procedure (as described above) was conducted with 96% acetic acid (CH_3CO_2H).

To remove organic material from the samples the material was submitted to acetolysis. For this nine parts acetic anhydride ($(CH_3CO)_2O$) and one part sulphuric acid (H_2SO_4) were mixed and added to the pollen samples. The samples were boiled in a dry bath for ca. 10 minutes. During this process the fluid changes colour and the pollen grains are coloured.

After 10 minutes of boiling the samples were washed (as described above) two times with acetic acid, four times with water and three times with 96% ethanol (C_2H_6O). Only minerogenic material is left in the concentrations after this procedure. To remove that fraction a specific gravity division was executed by adding a bromoform/ethanol mixture with a specific gravity of 2.0. The samples with the bromoform ($CHBr_3$) were centrifuged for 10 minutes at 1500 rpm. In the liquid the pollen and other organic matter is separated from the minerogenic material. The minerogenic material is transported to the bottom. Matter of lower specific gravity will stay in suspension in the collar of the centrifuge tube. The collar was poured in a tube filled with 96% ethanol, mixed and centrifuged at 4500 rpm. Because of the addition of the ethanol the specific gravity of the bromoform declines and pollen will settle at the bottom of the tube again. After centrifuging the fluid was tapped off and the pollen was washed one more time with ethanol. The remaining pollen residues of all the samples were stored in residue tubes with a few drops of glycerol. By heating the residues for one night at ca. 40-50 degrees the last remaining ethanol and/or water was vaporised.

From the five samples a tiny drop of subsample was taken and mounted on a microscope slide and covered with a cover slip. With nail polish the cover slip was secured to the microscope slide and the mounted residue sealed off from air. The microscope slides were labelled and ready for analysing.

5.3. Analysis

5.3.1. Counting procedures

After the preparation of the samples the isolated pollen, spores, and non-pollen palynomorphs were studied under a Leica light microscope using 100-400 times magnification. The microscope slides were examined in a systematic way in rows from the far left of the slide to the far right, and from top to bottom. Thus in closely spaced transverse sections. In this way the entire microscope slides were examined and the non-randomness of the pollen distribution over the microscope slide was overcome (Brookes and Thomas 1967 in Fægri and Iversen 1989; Peck 1974).

All slides were examined in a similar manner until a sufficient number of pollen was counted. A sufficient number of pollen grains is such an number that a random count of the pollen types present in a sample can be reproduced with the same counts as result. Because pollen counts will never be exactly reproducible, counts should be reproducible within 0.95 confidence limits (Maher 1972a). It is often excepted that a count of 300-500 pollen grains per sample is statistically representative (Birks and Birks 1980). This will give a statistical base for percentage calculations of the pollen assemblage.

Because the percentage calculations are based on the pollen sum, which is often different from the total number of pollen grains counted (see below), it is necessary to know beforehand what pollen types are included in the pollen sum to reach the minimal pollen count with that pollen. In this research the basic pollen sum is that of pollen from tree, shrub, and herb taxa (Woodland and open, disturbed and bare ground). Of each sample the pollen grains were counted until at least 500 pollen grains from these groups were counted. In case this count was not reached in the analysis of one microscope slide, an additional slide was prepared and counted in the same way as described above. The assemblages recovered are presented in diagrams 1, 2, 3 and 4 and further discussed below.

5.3.2. Taxonomy

A pre-existing modern taxonomy is used for the classification of the fossils studied here. In this extrinsic taxonomic classification individual fossils are reconstructed and identified on the basis of reference to modern counterparts (Birks and Birks 1980).

The pollen grains were identified with the aid of the identification key in Fægri and Iversen (1989) and in addition Beug (2004), Moore *et al.* (1991) and (Punt *et al.* 1976-1995) were used for comparison and identification. Subsequently, the fossil pollen grains were compared to the modern pollen reference collection of the palaeoecology department of Leiden university. The taxonomy and nomenclature follows Van der Meijden (2005).

When the identification of a pollen grain was certain, the pollen was counted as such. Unknown pollen (Cushing 1967) were given a code (e.g. B4.1A) and counted, and the coordinates of proto-types were noted for further study and discussion. Pollen that were indeterminable because of their position or physical state were counted and included in the diagram as an indication of the preservation of the fossil material (Cushing 1967).

Non-pollen palynomorphs were identified following Van Hoeve and Hendrikse (eds) (1998). Only those present in significant numbers and of ecological and environmental significance or related to a particular taxon (as described by Van Hoeve and Hendrikse (eds), 1998), were included in the diagram.

5.3.3. Nomenclature

Pollen identification is based on morphologic features. In case the morphology is typical for a family, genus, or species the pollen are classified as such. However, often a few plant genera or species produce similar pollen grains. When two species, e.g. *Plantago major* and *Plantago media*, produce indistinguishable pollen grains these grains are classified under both names as follows: *Plantago major* / *Plantago media*. As soon as more than three taxa can be subsumed under one pollen taxon, these grains will be classified as –type, with the most common genus or species giving its name to the type. For example, *Ranunculus acris*-type is a pollen grain that can have been produced by several species of the genus *Ranunculus*. When a family or genus is determined and some morphological types have been distinguished within that family or genus, after the name of highest taxonomic rank undifferentiated (undiff.) is added. The abbreviation cf. (Latin: *confer*, compare) is added in the case a pollen grain could not be identified with confidence to a certain taxon because of state of preservation, an insufficient reference collection, and other sources for uncertainty (Birks and Birks 1980; Beug 2004; Fægri and Iversen 1989).

5.4. Pollen morphology and identification

Pollen grains are identified through analysing the morphological features of the grain. An extensive terminology exists for describing pollen grains and various terms are in use for the same morphological characteristics (compare Beug 2004; Moore *et al.* 1991; Fægri and Iversen 1989). The explanation of terms can be found in Punt *et al.* (2007).

In fossil pollen grains often only the exine of the original pollen persists. The exine is the outer wall of the originally three layered pollen grain. This layer consists of sporopollenin, a very resistant material (Birks and Birks 1980). It is on and in the exine that the morphological characteristics of a pollen grain manifests. Therefore, a short account on the exine will be provided here.

The exine itself consists of four layers. The inner layer of the exine is called the endexine (a homogeneous membrane). This endexine is assumed to be fairly similar in gymnosperm and angiosperm pollen grains. This is not the case for the outermost set of strata in the exine, the ektexine (Fægri and Iversen 1989; Moore *et al.* 1991). The following description of the ektexine will be based on that of angiosperms. The outermost layer is the tectum, which is connected to the footlayer by a stratum of collumellae. These collumellae are formed by granules in the ektexine. On and in this set of layers sculptures (external features) and structures (texture built up in the ektexine) are formed (Moore *et al.* 1991). Structure and sculpturing are important determining characteristics and an extensive terminology is available for describing the different features (Punt *et al.* 2007). Many variations in morphologic features find their origin in the tectum, collumellae, and footlayer (Fægri and Iversen 1989). A thorough understanding of the structure of these layers is essential for interpreting what is seen under the microscope, to name the observations, be able to use identification keys and to come to an identification of the pollen grains.

Before dealing with the sculpturing and structure of pollen grains, first other distinctive characteristics can be used. First of all the pollen grain itself is described on the basis of its form. For example air-sacs (vesiculate grains e.g. *Pinus*) or grains composed of several grains (composite grains e.g. *Typha* spp.) are distinctive characteristics. The most common grain shape, however, is the rotational ellipsoidic grain, including ovate, prolate, and oblate variations. This group is further broken down first on the basis of their apertures, then the structure and sculpturing and finally their size.

The apertures of pollen grains are openings in the ektexine and endexine. Usually they appear in two forms, pores and furrows. Pores (pori) are those apertures with both diameters of equal size. Furrows (colpi) are apertures with one diameter exceeding the other (Birks and Birks 1980). Various numbers and combinations of pores and furrows exist and provide a good guidance for identifying pollen grains. Different keys may use different terminology (variations can be found in the identification keys of Beug 2004; Fægri and Iversen 1989; Moore *et al*. 1991).

The number, shape, distribution etc. are not always easy to detect and might vary within a pollen type (Beug 2004, provides percentages on the appearance of different numbers of apertures observed within a pollen type). The apertures may be accompanied by other determining morphologic features aiding the identification of pollen grains, such as vestibula, annuli, margi, costae (equatorialis). Furthermore, can the size of the polar area be of diagnostic value. The polar area is that part of the pollen grain which is situated higher than all apertures, annuli or margins.

After considering all these diagnostic factors, size can be a final important distinctive character between similar looking grains. Size, however, is a variable characteristic even within the same pollen type.

Variation in size of pollen grains can depend on many different factors so this characteristic must be used with caution. The life history of the grain, chemical treatment, mounting medium and geographical origin may influence the size (Fægri and Iversen 1989). The size of pollen grains from a certain type can have been more variable in earlier geologic times (F. Bunnik and T. Donders pers. comm. 2012). This is of importance when studying old pollen material and using modern reference collections.

Pollen grains may show great variations in all kinds of morphological features due to for example deterioration, the medium pollen are mounted in, natural variation, depositional history. The spectrum of variation within a single pollen type will be better recognised with increased experience.

6. Results

6.1. Lithostratigraphy of the pre-glacial sediments at Beeston

The organic mud, sampled from the cliff section near Beeston, is situated at the base of the cliff. The cliff exists of several metres of glacial till, deposited during the Anglian Stage (MIS 12, 2.1. Stratigraphy of East Anglia) (fig 9).

Two different layers of organic rich sediments were shown, separated by layers of sand of various thickness (fig 11). The lower organic mud was sampled for the here presented research. This organic rich layer was underlain by gravels of rounded clasts in a matrix of light grey sands with some iron staining, visible for about 40cm from the base of the organic layer to the level of the modern beach. The organic sediments themselves formed a 26cm thick layer, overlain by oxidised and grey sands with silt lenses visible for about 23cm. Above that the profile was obscured by instable till material (fig 11 and 12).

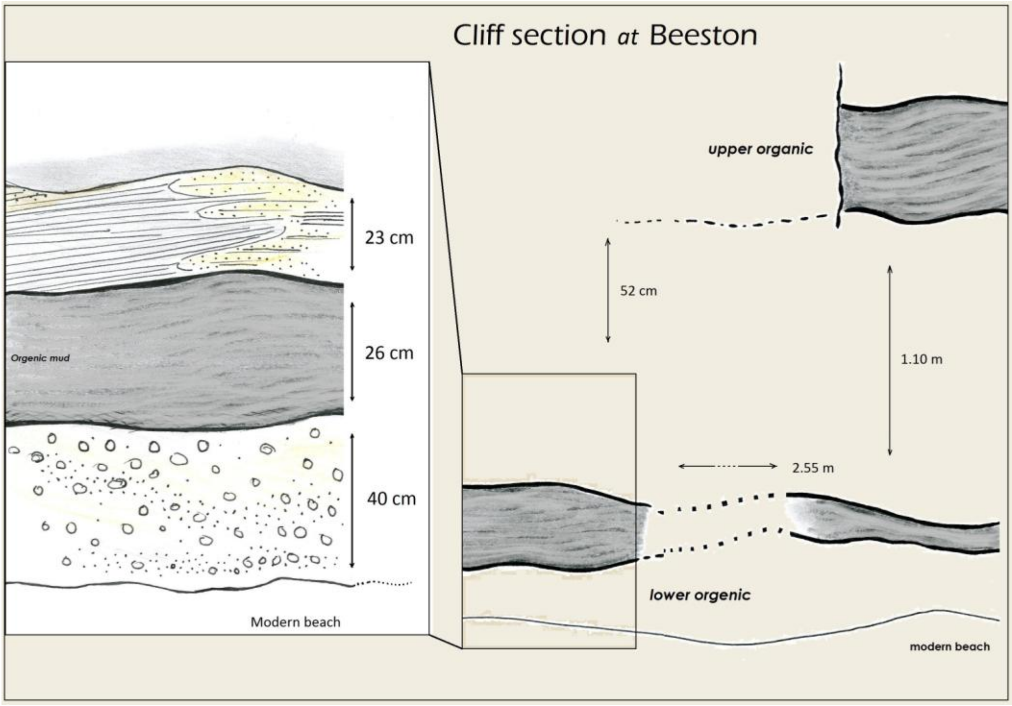
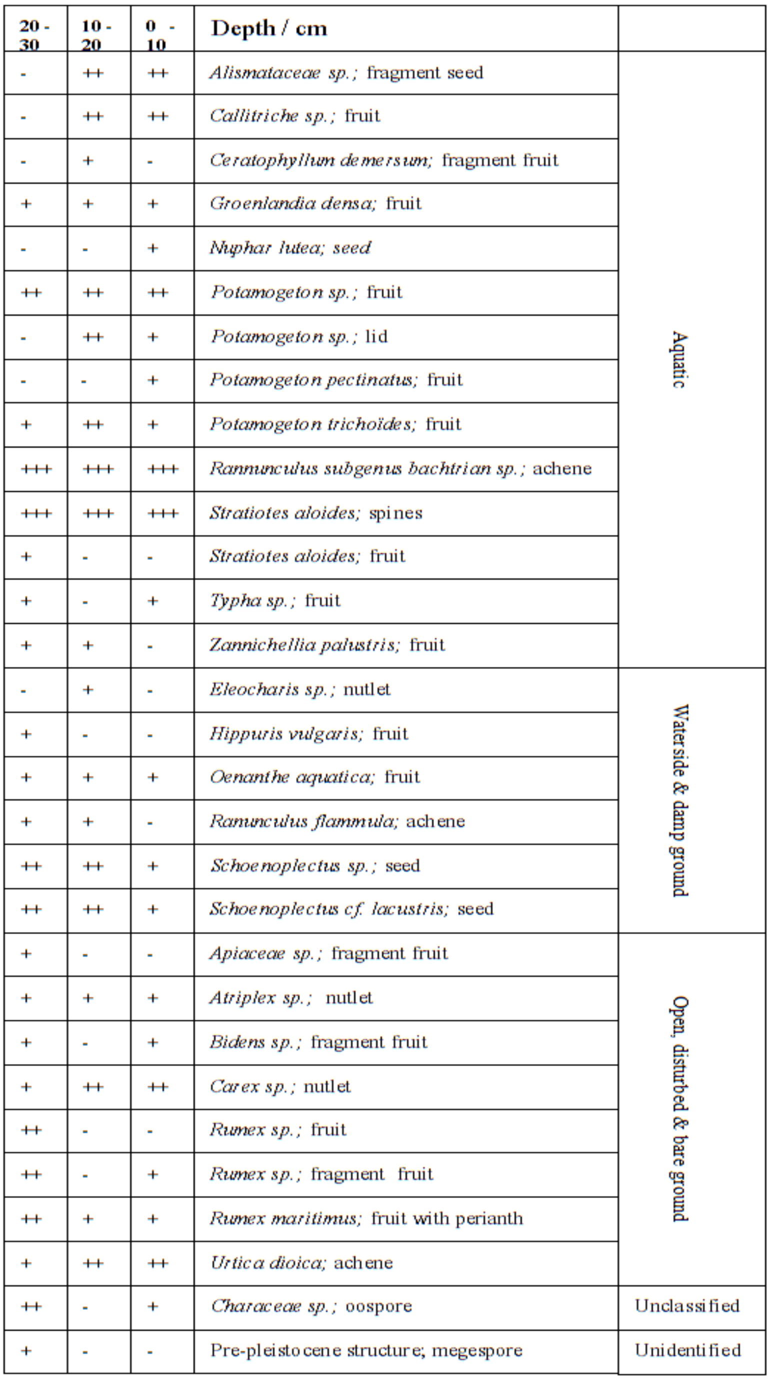


Figure 11. Cliff section at Beeston. The position of the upper and lower organic mud and a detail of the lower organic mud (drawing E. Egberts).

Figure 12. Picture of the lower organic mud and its stratigraphic position, underlain by gravels of rounded clasts in a matrix of light grey sands with some iron staining and overlain by oxidised and grey sands with silt lenses (photo S. Parfitt 2011).

6.2. Plant macrofossils from the pre-glacial sediments at Beeston

Plant macrofossil analysis were carried out by third year bachelor students of the botany specialisation course. Their results are presented in table 2.



20 - 30	10 - 20	0 - 10	Depth / cm	
-	++	++	*Alismataceae sp.*; fragment seed	Aquatic
-	++	++	*Callitriche sp.*; fruit	
-	+	-	*Ceratophyllum demersum*; fragment fruit	
+	+	+	*Groenlandia densa*; fruit	
-	-	+	*Nuphar lutea; seed*	
++	++	++	*Potamogeton sp.*; fruit	
-	++	+	*Potamogeton sp.*; lid	
-	-	+	*Potamogeton pectinatus*; fruit	
+	++	+	*Potamogeton trichoïdes*; fruit	
+++	+++	+++	*Rannunculus subgenus bachtrian sp.*; achene	
+++	+++	+++	*Stratiotes aloides*; spines	
+	-	-	*Stratiotes aloides*; fruit	
+	-	+	*Typha sp.*; fruit	
+	+	-	*Zannichellia palustris*; fruit	
-	+	-	*Eleocharis sp.*; nutlet	Waterside & damp ground
+	-	-	*Hippuris vulgaris*; fruit	
+	+	+	*Oenanthe aquatica*; fruit	
+	+	-	*Ranunculus flammula*; achene	
++	++	+	*Schoenoplectus sp.*; seed	
++	++	+	*Schoenoplectus cf. lacustris*; seed	
+	-	-	*Apiaceae sp.*; fragment fruit	Open, disturbed & bare ground
+	+	+	*Atriplex sp.*; nutlet	
+	-	+	*Bidens sp.*; fragment fruit	
+	++	++	*Carex sp.*; nutlet	
++	-	-	*Rumex sp.*; fruit	
++	-	+	*Rumex sp.*; fragment fruit	
++	+	+	*Rumex maritimus*; fruit with perianth	
+	++	++	*Urtica dioica*; achene	
++	-	+	*Characeae sp.*; oospore	Unclassified
+	-	-	Pre-pleistocene structure; megespore	Unidentified

Table 2. Plant macro fossils results from the pre-glacial lower organic mud near Beeston. '-' not present, '+' is 1 to 5 fossils, '++' is 5 to 100 fossils and '+++' is 100+ fossils (3rd BA botany specialisation course 2011).

6.3. Small vertebrate remains from the pre-glacial sediments at Beeston

Preliminary research on the small vertebrate remains from both the lower and upper organic muds (bed i and bed k respectively) is conducted by Simon Parfitt and presented in table 3.

Small vertebrate remains		bed i	bed k
Insectivores	*Sorex* cf. *minutus*		+
	Sorex (*Drepanosirex*) *savini*		+
	Talpa cf. *europea*	+	
	Desmana sp.	+	+
Rodents	*Mimomys savini*		+
	Microtus (*'Terricola'*) sp.		+
	Microtus sp.	+	+

Table 3. Small vertebrate remains from the upper (bed k) and lower (bed i) organic muds from Beeston + is present (unpublished data, S. Parfitt 2012).

6.4. Palynological investigation

The here presented pollen diagrams are the result of the pollen analysis performed for this thesis. In palynological investigations data presentation takes in an important place and will therefore be shortly discussed before presenting the diagrams.

6.4.1. Data presentation

6.4.1.1 Groups

After identifying all pollen and spores, the pollen types were grouped in meaningful clusters to present the data in a structured way and aid the interpretation. The groups in which pollen may be presented vary with different research questions but should always pursue clarity.

Here pollen and spores are grouped according to the assumed habitat to which their parent plants were related. Because pollen are often only classified to family or genus level, and habitat preferences may well vary within families or genera, not all pollen could be grouped in a habitat class and were grouped as unclassified. The groups that are presented describe generalised habitats to limit chances of wrong classification and emphasise for the various environmental conditions in which the included plants may occur. More specific ecological and environmental conditions will be reconstructed in the Discussion chapter.

The groups presented here are a classification based on modern observations on the habitat preferences of the plants involved. However, the ecological tolerances and preferences of these plants may have changed and these plants may have lived in a past habitat with no modern counterpart.

The habitat groups presented here are *woodland*, including all pollen from tree taxa, *open, disturbed and bare ground,* which group comprises pollen of light demanding plants, including most herbaceous plants. The disturbed component is made up of plants growing in disturbed and walked on (by animals) and bare grounds. Plants grouped as *waterside and damp ground* occupy the waterside and damp ground but are not obligate aquatic. Pollen types of obligate aquatic plants are classified under *aquatic*. The category unclassified groups all pollen which were either identified to too high a taxonomic level to be habitat specific or of which the parent plants occupy various habitats.

The local vegetation may be represented by pollen from aquatic, waterside and damp ground and open, disturbed and bare ground plants. The pollination of most of these plants is zoophilous, resulting in a more local distribution of the pollen grains. The opposite is the case with the woodland pollen, of which most are dispersed by wind (but e.g. *Salix* is insect-pollinated), spreading regionally (Fægri and Eversen 1989). When available, the pollen assemblages may be compared to the plant macrofossil assemblages. Macrofossils often underwent only limited transportation away from the plants they originated from and therefore are assumed to reflect the local vegetation (Lowe and Walker 1997). When a sample contains a clod of pollen from one type, this also indicates the local presence of the parent plant of that pollen.

Because pollen are often recovered from aquatic sedimentary environments, aquatic and marshy, waterside plants can be considered as reflecting the local vegetation. Especially when this is in accordance with the macrofossils. The definition of aquatic and waterside plants on the basis of pollen alone, is sometimes problematic. For example when dealing with marshy grounds where the grass family Poaceae pollen may reflect the presence of Common reed *Phragmites* instead of open and dry grounds to which it is often attributed (Moore *et al.* 1991).

The distinction between local and regional vegetation is based on the broader vegetation picture derived from the data (Fægri and Eversen 1989). As it seems that locally a more open, waterside is present bordered by a regionally extended woodland, the open, disturbed and bare ground, waterside and damp ground and aquatic groups represent the local vegetation and the woodland is considered the regional vegetation.

6.4.1.2. Calculating percentage and absolute diagrams

When pollen data are recovered from a stratigraphical sequence, it is most clearly presented in a pollen diagram. Pollen diagrams presented here are calculated and drawn using TILIA and TGView version 1.7.16 (E.C. Grimm 1991-2011).

In a pollen diagram the pollen content of one horizon (pollen assemblage) is plotted on the y-axis against its depth in the stratigraphical sequence or against time. On the x-axis the number of pollen grains per pollen type (or group of pollen types) are depicted.

In a pollen diagram changes in the pollen assemblages from various depths can clearly be illustrated and the changes in vegetation during the time of deposition of the sediment sequence can be reconstructed (Fægri and Iversen 1989; Lowe and Walker 1997).

The pollen counts can be presented in percentages and concentrations per horizon, in which different aspects of the pollen data may be highlighted.

In a percentage diagram, a pollen sum is chosen to which the amounts of all pollen can be expressed. Often the pollen sum is different from the total pollen counted. What pollen are included in the pollen sum depends on the focus of the research. In many diagrams pollen of aquatic and waterside plants are excluded from the pollen sum. This group is representing the very local vegetation, reflecting the site of deposition rather than the vegetation bordering the water-body. Moreover, may this group be highly over represented, suppressing the percentage values of other pollen types and obscuring possible variations in the presence of these pollen.

Because the abundance of a pollen type is presented as a percentage of the pollen sum, the percentages of the pollen are interdependent. The increase in number of one pollen type, results in the suppression of the percentages of all other pollen types. This may not necessarily reflect the ecological factors. The interdependence in percentage calculations is the most important drawback of percentage diagrams. Moreover, a sufficient number of pollen should be included in the pollen sum to make percentage calculations statistically relevant (Birks and Birks 1980; Lowe and Walker 1997).

The pollen sum (PΣ) represents 100%, in relation to which the proportions of the different pollen types included in the sum, can be expressed. A common pollen sum consists of all pollen from tree-, arboreal pollen AP, and from herb taxa, non-arboreal pollen NAP. This pollen sum is referred to as AP-NAP pollen sum (Fægri and Iversen 1989).

The percentages of taxa not included in the pollen sum (e.g. aquatics) are calculated as percentages of the pollen sum plus the sum of the group the taxon is part of. In this manner the percentages will not exceed 100% (Birks and Birks 1980).

Percentages calculations of pollen taxa inside the pollen sum:

$$\text{Percentage of taxonX} = \frac{\text{Number of pollen of taxonX}}{\text{Pollen sum}} \times 100$$

For example:

$$\text{Percentage of } \textit{Pinus} = \frac{245\ \textit{Pinus}}{631\ (\Sigma\text{AP+NAP})} \times 100 = 38{,}8\ \%$$

Percentages of pollen outside the pollen sum:

$$\text{Percentage of taxonY} = \frac{\text{Number of pollen of taxonY}}{\text{Pollen sum + pollen sum of group}} \times 100$$

For example:

$$\text{Percentage of } \textit{Nuphar} = \frac{2\ \textit{Nuphar}}{631(\Sigma\text{AP+NAP}) + 29\ (\Sigma\text{ of aquatic group})} \times 100 = 0{,}3\%$$

The percentage diagram is presented in diagram 1.

Absolute-, influx or concentration diagrams are developed as a response to the interdependence of percentage diagrams, in which the ‘absolute’ numbers of pollen are presented instead of percentages (Davis 1963 in Colinvaux 1978). The term ‘absolute’ however, is only rarely really applicable, thus terms as concentration and influx diagram are better suited (Colinvaux 1978).

In concentration and influx diagrams the number of pollen are expressed per unit volume. Then, when the accumulation rate of the sediment is known the pollen influx per unit time can be calculated. This would result in ‘absolute’ data. However, the sediment accumulation rate is only rarely precisely known and the variable time can not be included in the calculations. Still can the number of pollen be expressed per unit volume or mass of sediment. When the sediment can be considered as accumulated in a constant rate, fluctuations in pollen concentrations in the unit volume or mass can be informative. This kind of a diagram is a concentration diagram (Colinvaux 1978; Moore *et al*. 1991). With different sedimentary environments and different sedimentation rates, variations in pollen concentrations may be expected.

To establish the pollen concentration in a sampled sediment, a fixed unit of sediment must be analysed to which the pollen concentration can be related. This can be done by volumetric (Davis 1966) and weighing (Jørgensen 1967) methods. In volumetric and weighing methods, all pollen grains in the final subsamples (not the entire volume but the aliquots taken from that volume or a portion of the weighed volume), must be counted. From the total pollen counted, the pollen concentration in the initially weighed or measured volume can be calculated. This requires elaborate calculations, with increasing margin of errors. A reasonable number of pollen must be counted to make any calculations and assumptions statistically valuable. Therefore, when taking the subsample, assumptions must be made on the expected density of the pollen in order to count enough pollen (Peck 1974).

Another method for calculating pollen concentrations in a sample is the addition of a marker grain (Matthews 1969). When a known number of marker grains is added to the sample of fixed volume, prior to further laboratory procedures, the counted number of fossil pollen can be expressed against the counted number of marker grains. Thus also the concentration of pollen per unit volume can be calculated.

Extracting precise volumes of sediment a measuring cylinder was used. *Lycopodium* was added as a marker grain (Moore *et al.* 1991). Because the *Lycopodium* grains are added to the sample prior to all laboratory procedures, they are subject to the same processes as the fossil pollen and mistakes in laboratory procedures can be retraced.

Pollen concentrations are calculated as follows (Birks and Birks 1980):

Concentration of fossil pollen of taxon P in sample =

$$\frac{\text{[(no. of marker grains added / no. of marker grains counted) x no. pollen of taxonP counted]}}{\text{volume of subsample}}$$

For example:
Number of *Lycopodium* grains added (per tablet) = 12077
Lycopodium spores counted = 90
Pinus counted in sample = 245
Volume of subsample = $1cm^3$

=[(12077/90)*245]/1 = 32876,28

Calculating the total fossil pollen present in a unit volume of sediment:

$$\text{Total fossil pollen} = \frac{\text{Total fossil pollen counted x total number of marker grains}}{\text{Marker grains counted}}$$

Concentration diagrams are presented in diagrams 2, 3 and 4.

However, because pollen concentration diagrams depend on the sedimentation rate, these diagrams are more difficult to compare when sites with different depositional contexts are to be related. Percentage diagrams then offer a better base for comparison. Concentration diagrams offer a possibility to overcome the influence of interdependence in the percentage diagram and both methods should be used complementary.

6.4.1.3 Types of diagrams

After calculating the percentages or concentrations of the pollen, the results can be depicted in various types of diagrams.

The *cumulative diagram* is used for percentage data only. The data of the included pollen taxa or groups of taxa cumulate up to 100% and thus the cumulative diagram depicts the composition of the pollen sum. The percentages are cumulatively added and the width of the area of one group of pollen corresponds to its percentage within the pollen sum. This type of diagram is used at the start of a percentage diagram to summarise the percentages of the taxa or groups of taxa included in the pollen sum and show their variations in a glance (diagram 1).

In the *composite diagram* the percentages or concentrations of pollen per taxa or group of taxa are set out from the same base line and thus overlap. This may aid the comparison of the variations of different taxa. Especially in a concentration diagram in which ‘absolute’ numbers of pollen from different taxa are presented, the problem of interdependence is overcome and alternating curves of two taxa can be assigned to true alternations in the number of pollen instead of suppression as might be seen in a percentage diagram. This is applied to the tree taxa (diagram 4) because the succession and alternation of some trees may be characteristic for the forest succession during interglacials or near the timberline (Hick 2001; Maher 1972b). The vegetation succession after glaciations can show quite particular patterns in the succession and alternation (Hicks 2001). To clearly see these patterns it is useful to use concentration diagram instead of a percentage diagram because of the effect of interdependence.

The symbols used in the diagrams presented here mostly follow conventional symbols, first introduced by Von Post in 1916 (Fægri and Iversen 1989). In some instances other symbols were used to obtain more clarity.

The composite diagram is used on the tree taxa because the trees apparently show some vegetation succession pattern (see discussion below). To be able to exclude the interdependence as cause of this apparent pattern, concentrations were calculated for each taxa and set out from the same base line to aid comparison of the values. The same is, experimentally, done for the habitat groups and the ‘local groups’ alone, to trace possible changes in the representation of the habitat groups.

The resolved diagram displays all pollen types as separate curves, set out from individual base-lines. In this type of diagram no crowding occurs but more space is needed. In very large diagrams the interrelationships are more difficult to overview. The resolved diagram is the most classic way of presenting the results of stratigraphical pollen analysis (Fægri and Iversen 1989).

The combination of a composite diagram at the start of each diagram followed by a resolved diagram is informative. The composite diagram provides the summary of the diagram and shows the relative importance of the habitat groups included in the pollen sum. The resolved diagram shows what taxa were included in the individual habitat groups, how these separate taxa were present in the sample and how these taxa attributed to the habitat group.

The combination of the various calculation techniques and presentation techniques elucidate how these techniques influence the appearance of the data in diagrams and complementary use results in a more complete base to start interpreting the data.

Diagram 1. Percentage diagram of pollen, spores and non-pollen palynomorphs collected from pre-glacial sediments at Beeston. Percentages are based on the sum of woodland and open, disturbed and bare ground (AP-NAP pollen sum) pollen taxa. Percentages of pollen, spores and non-pollen palynomorphs outside the pollen sum are based on the pollen sum plus the sum of the group considered. Percentages are expressed against depth / cm (E. Egberts 2012).

6.4.2. Pollen diagrams of the pre-glacial sediments at Beeston

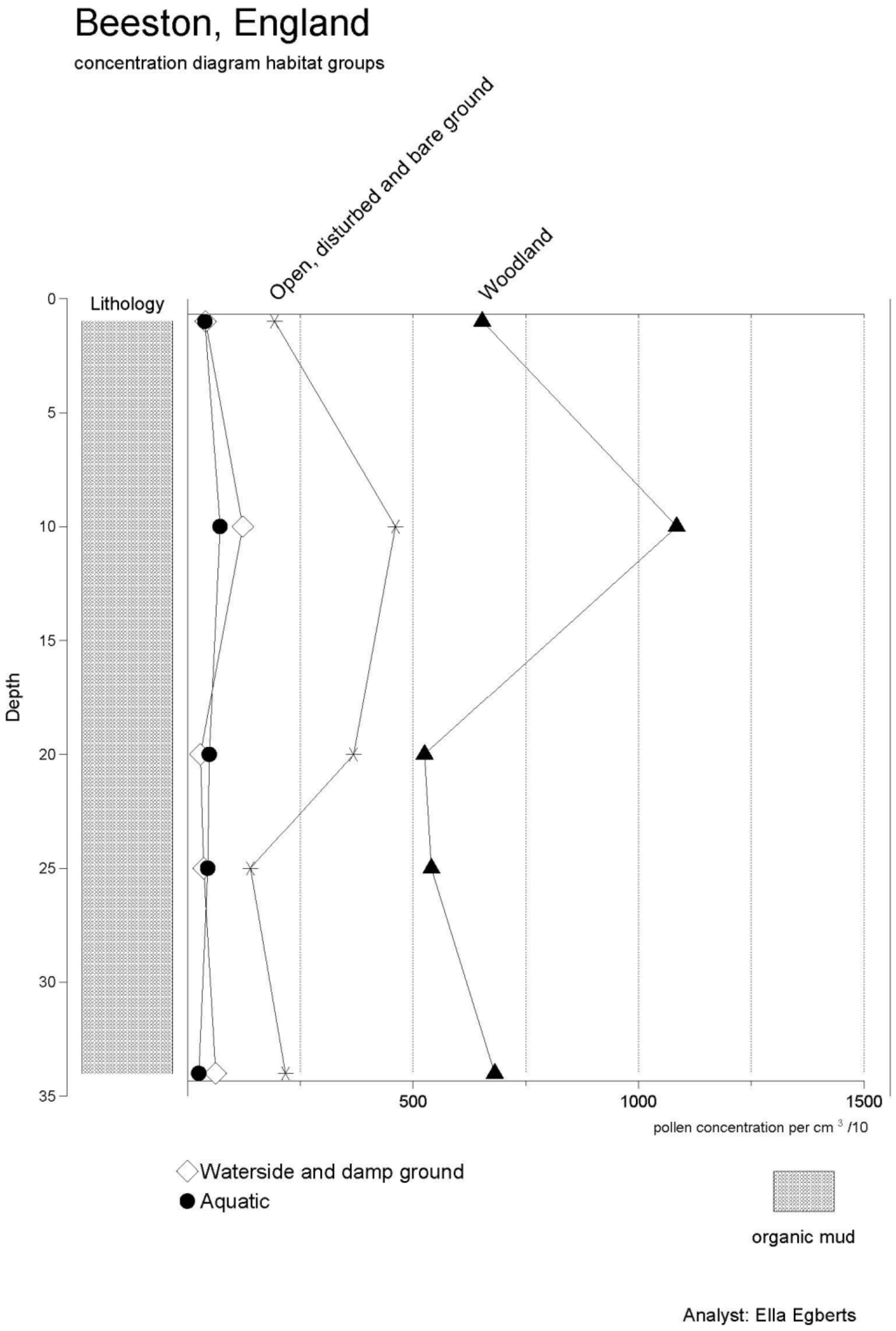


Diagram 2. Concentration diagram of the habitat groups as reconstructed from the pollen assemblages collected from pre-glacial sediments at Beeston. Pollen concentrations are expressed as concentration per cubic centimeter. The pollen concentrations are divided by 10 to improve the clarity of the diagram. Expressed against depth / cm (E. Egberts 2012).

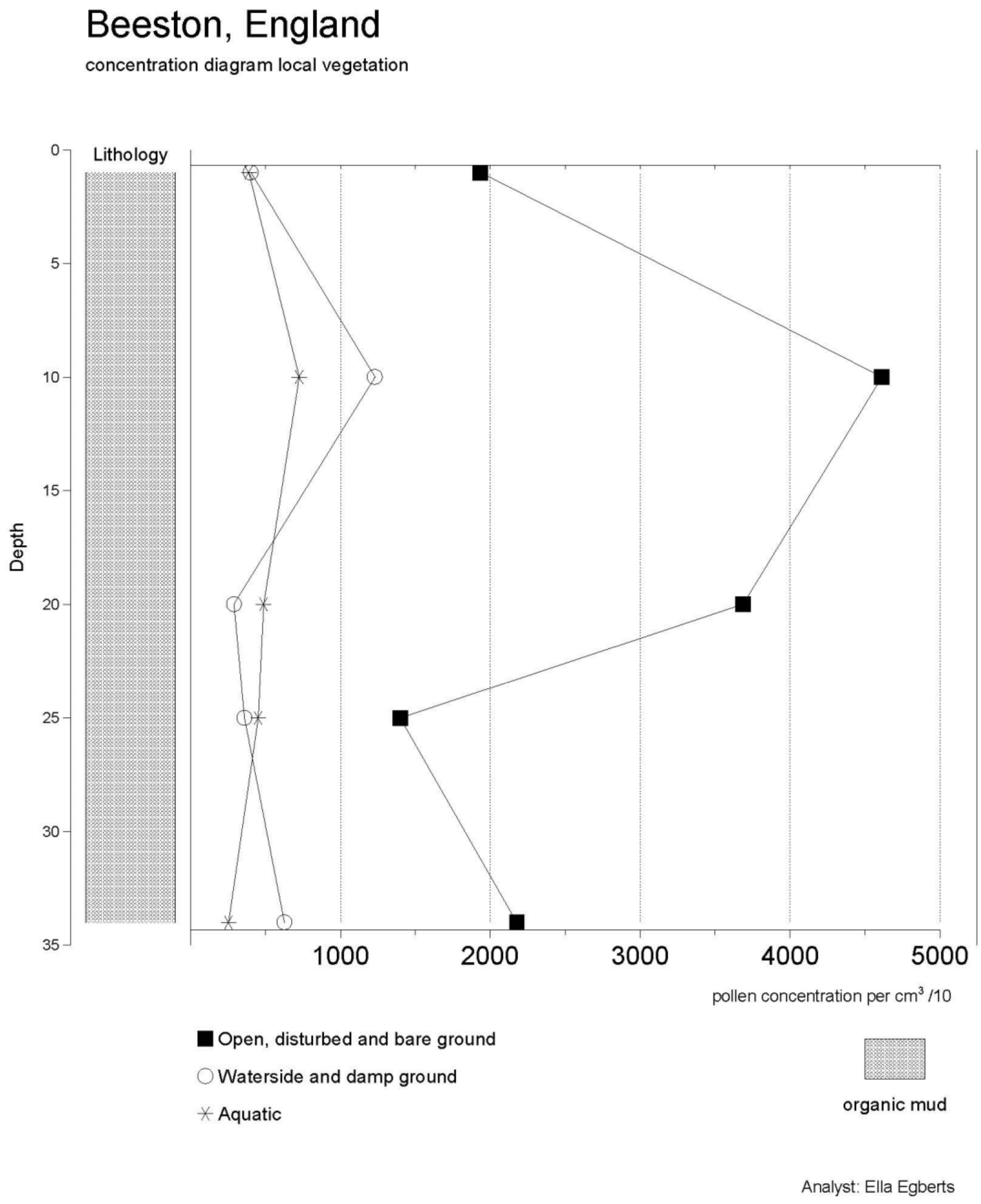


Diagram 3. Concentration diagram of the local vegetation as reconstructed from the pollen assemblages collected from pre-glacial sediments at Beeston. Pollen concentrations are expressed as concentration per cubic centimeter. The pollen concentrations are divided by 10 to improve the clarity of the diagram. Expressed against depth / cm (E. Egberts 2012).

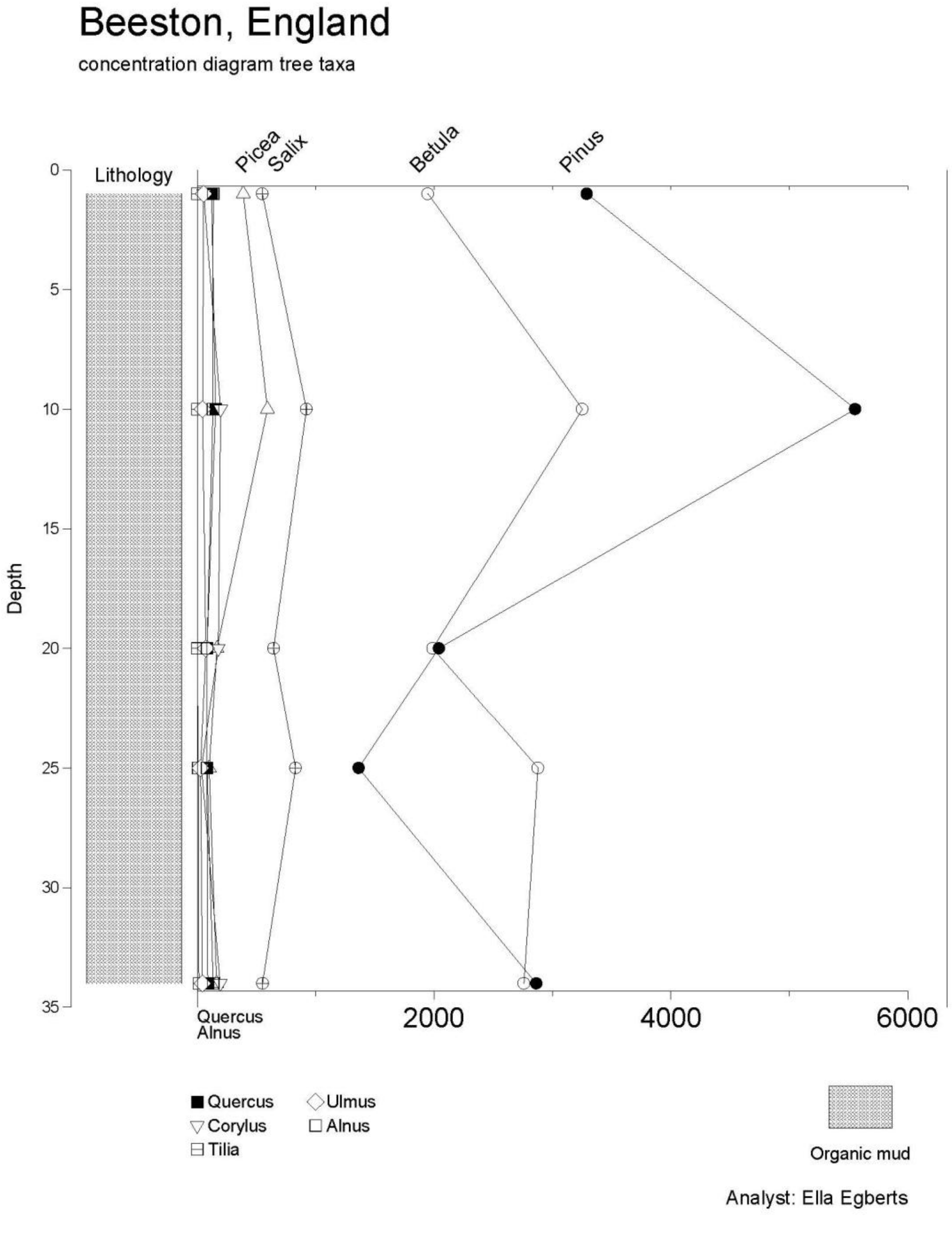


Diagram 4. . Concentration diagram of tree taxa collected from pre-glacial sediments at Beeston. Pollen concentrations are expressed as concentration per cubic centimeter. The pollen concentrations are divided by 10 to improve the clarity of the diagram. Expressed against depth / cm (E. Egberts 2012).

6.4.2.1 General description of the pollen assemblage

A total number of 58 pollen and spores types were identified from the Beeston sediments. Eight pollen types could be identified to family level, including the Asteraceae family which is divided into Tubuliflorae and Liguliflorae types (Fægri and Iversen 1964). 22 pollen types could be identified to genus level, eight to species level. Three pollen types were identified only as comparable to a known pollen type (cf.). Six pollen types are classified as – type (see 5.3.3. Nomenclature).

Apart from pollen and spores seven non-pollen palynomorphs are registered in the diagrams. Only the non-pollen palynomorphs considered as informative on environmental conditions were counted. For example *Azolla filiculoides* is represented by glochidia. The terminal septations of glochidia are species specific enabling the identification (Field 1999; West 1953).

Three unknown pollen types were coded and included in the diagram as B4.1.A, B4.1.B and B5.1.A (fig 12, 13 and 14). These three unknown pollen grains will be discussed further below.

Three types of pre-Pleistocene pollen grains were found in the samples. The “fingerprint fossil” and “trilete fossil” (fig 15 and 16), could not be further identified but are commonly found and probably emanate from Tertiary and Cretaceous sediments (Frans Bunnik pers. comm. 2012). The third pre-Pleistocene pollen grain could be identified as *Callialasporites turbatus* (fig 17) and is of Jurassic age (S. Kerstholt-Boegehold pers. comm. 2012).

Figure 13. Three photographs of the unknown pollen grain B4.1.A, focusing on the sculpture and structure of the exine (photo E.Egberts 2012).

Figure 14. Three photographs of the unknown pollen grain B4.1.B, focusing on the sculpture and structure of the exine (photo E.Egberts 2012).

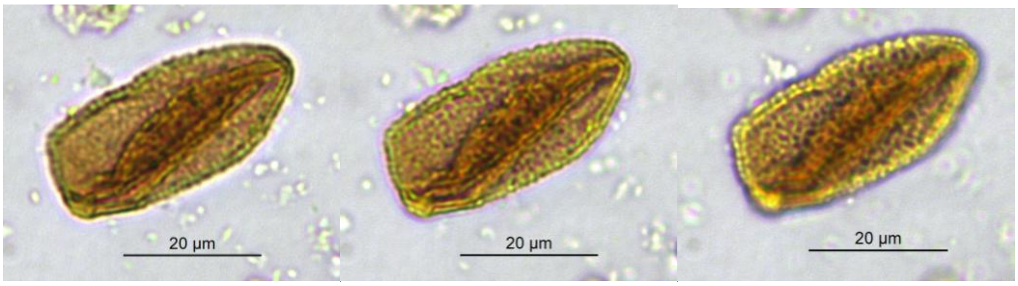


Figure 15. Three photographs of the unknown pollen grain B5.1.A, focusing on the sculpture and structure of the exine (photo E.Egberts 2012).

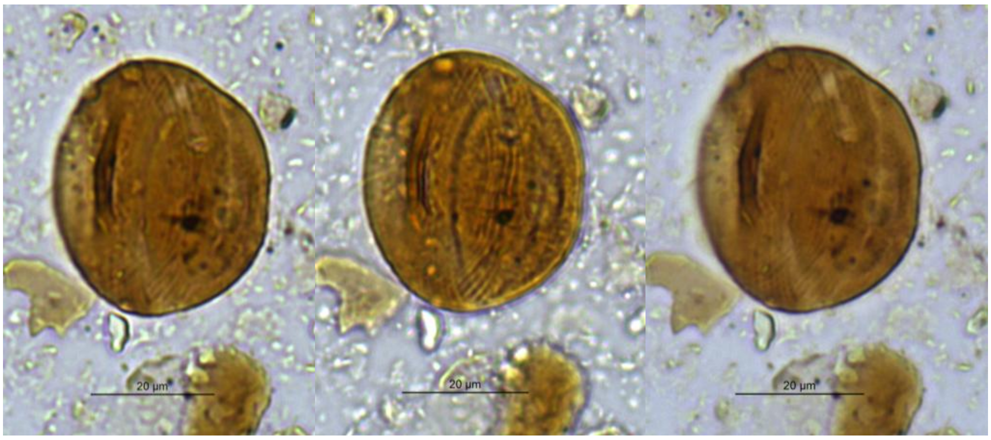


Figure 16. Three photographs of the fingerprint fossil pollen, focusing on the sculpture and structure of the exine (photo E. Egberts 2012).

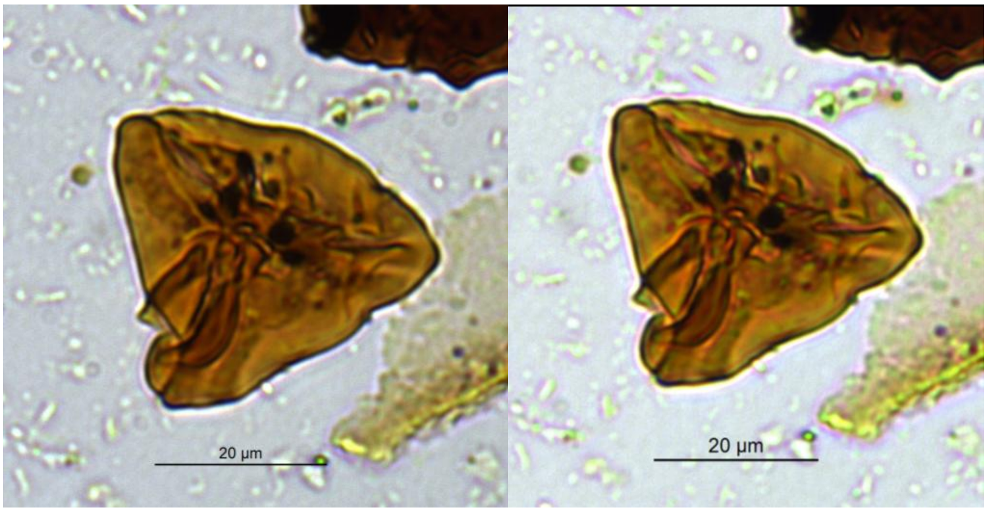


Figure 17. Two photographs of the trilete fossil pollen, focusing on the sculpture and structure of the exine (photo E.Egberts 2012).

Figure 18. *Callialasporites turbatus* fossil pollen (photo E. Egberts 2012).

6.4.2.2. Description of unknown pollen grains

The unknown pollen grain B4.1.A is 20 μm long and 10 μm wide. The monocolpate pollen has one long, meridional furrow, restricted to the distal side of the grain. The ends of the furrow are more open, in the middle part the aperture is quite narrow. The tectum is imperforate and psilate (under 400x magnification). No columellae can be distinguished. The endexine and tectum are of similar thickness of about 1 μm (fig 12).

Another unknown pollen grain is coded B4.1.B. The more or less ellipsoidic and between 18-20 μm. No clear apertures can be distinguished. The tectum is scabrate to rugulate (fig 13).

The third unknown pollen grain is 37 μm long and about 18 μm wide, and is elongated and folded. One long meridional furrow extends from pole to pole but is restricted to the distal side of the grain. The grain is reticulate with brochi larger than 1 μm. The columellae are clearly visible. The pollen grain resembles the description of an unknown pollen grain by West (1980a, 112), called monocolpate X. It is not certain if the same pollen type is described here and by West (1980a), therefore the pollen grain is termed differently: B5.1.A (fig 14).

6.4.2.3. Taphonomy

For taphonomic processes on pollen grains are complex, these are discussed in more detail in chapter 3 (Considerations on taphonomy in palynology). Here the knowledge on these processes is applied to the samples studied when relevant.

In all samples pollen preservation (Cushing 1967) was good, as indicated by the small numbers of unidentifiable grains. The deteriorated pollen were mostly crumpled and/or broken. These types of deterioration are most common and not specific to any type of sediment (Cushing 1967). Especially Pine *Pinus* and Spruce *Picea* pollen were broken, in which case often air sacks were ripped lose or missing. Air sacs may be more susceptible to breakage on the edge of attachment to the grain. Another explanation might be that especially saccate grains are easily transported by wind and water, and therefore subject to more mechanical stress. Only some pollen were corroded. Overall the pollen are exceptionally well preserved (see for cover). Moreover, *Salix* is considered as a pollen type susceptible to oxidation. The good preservation and representation in all samples is indicating good oxygen low preservation conditions (Low and

Walker 1997). Pollen of water-pollinated plants can be considered as underrepresented (Fægri and Iversen 1989). This is clearly illustrated by the absence of *Ceratophyllum* pollen grains, which presence in the vegetation is shown by its leaf-spines in the samples.

The mode of dispersal, size, shape, weight and taphonomic factors influence the rendering of pollen in the sediments (Fægri and Iversen 1989). Moreover, is the sedimentary environment of influence on the proportional representation of the pollen types, and from what area the pollen originated (West 1980a). Therefore, changes in the pollen assemblage may be the result of changes in the taphonomy and lateral changes of sedimentary environments rather than climatic fluctuations. A change in sedimentation may be indicated by the changes in pollen concentrations throughout the sequence. This is illustrated in diagram 2.

Redeposition of the pollen grains during the time of sedimentation and later during fossilisation seems to have been quite insignificant because the pollen assemblage and the lithology seem coherent and only a few pre-Pleistocene pollen were present in the sample. Influx of fossil pollen is indicating erosion of pre-Pleistocene sediments including the ‘fossil’ pollen. A small portion of these pollen is common in all samples.

7. Discussion

For the reconstruction of the vegetation, use was made of the works of Ellenberg (1979), Schaminée *et al.* (2010), Tamis *et al.* (2004), and Weeda *et al*. (2005). Environmental information derived from the non-pollen palynomorphs is based on Van Hoeve and Hendrikse (eds) (1998).

The pollen assemblage reflects a local environment consisting of a mosaic of habitats with fresh-water slow-flowing streams, pools, drier bare and disturbed grounds and waterside habitats of damp ground adjoining the water. The regional vegetation consisted of coniferous **woodland** with Pine *Pinus* and Birch *Betula* as the most important components on the well-drained, nutrient poor grounds, possibly accompanied by Spruce *Picea*. However, small percentages of *Picea* are recorded (1-4% with AP-NAP). So its presence is debatable because only when values reach over 4% the presence of *Picea* is probable (Hicks 2001).

The composition of this forest resembles the coniferous forests found in the region of Fennoscandia today (Godwin 1975). Together with elements of thermophilous deciduous forest including Oak *Quercus*, Hazel *Corylus*, Elm *Ulmus*, and Lime *Tilia* that could be found probably on the more basic grounds, forming the southern edge of the boreal coniferous forest. The Common polypody *Polypodium vulgare* was possibly present in shady places within the deciduous forest.

Closer to the site of deposition, the wetter and more mineral- and nutrient-rich grounds were occupied by Alder *Alnus* and Willow *Salix*. These tree taxa grow in more open and light places some distance away from the denser stands of deciduous forest. *Salix* and *Alnus* can stand flooding and can grow on wet grounds. Comfrey *Symphytum* and Broadleaf plantain *Plantago major* may have grown in a similar habitat type. But *Plantago major* is also occurring in light and open areas with compacted, disturbed, and bare ground. Together with the pollen grains of Goosefoot family *Amaranthaceae* (formerly *Chenopodiaceae* (Van der Meijden 2005)) Mugwort *Artemisia*, *Echium*, Broadleaf plantain/Hoary plantain *Plantago major*/*media*, and Common Knotgrass *Polygonum aviculare* the presence of this habitat-type may be illustrated. This habitat-type is often subject to mechanical stress, like trampling or sediment deposition and characterised as **open, disturbed, and bare ground**.

The combination of *Filipendula* together with Marsh Euphorbia *Euphorbia palustris* may point to a reed swamp developing on wet, nitrogen-rich, now and then flooded grounds.

A wet, nitrogen-poorer, slightly acidic to neutral substrate occurring adjacent to various types of water-bodies, including lakes, rivers, and cut-off river channels may be the habitat of Yellow loosestrife *Lysimachia vulgaris* together with Bog Myrtle *Myrica gale*, growing on half open places. *Sphagnum* moss is often found in association with *Myrica gale* and the Fern *Osmunda* may be an resident of this environment as well, or appear in woodlands, growing on peaty soils.

Another **waterside and damp ground** habitat, but of more nutrient-, carbonate-, phosphate-rich, and fresh to slightly brackish water, may be indicated by pollen grains of Bur-reed *Sparganium erectum*, Bulrush *Typha latifolia*, and Marsh Euphorbia *Euphorbia palustris*. *Sparganium erectum* grows in more open riparian habitats not to much dominated by other vegetation. These plants together may develop to an infilling vegetation adjacent to brooks, small lakes and channels, in floodplains and cut-off river channels. It is a pioneering community in stagnant or slow flowing, clear waters that can cope with fluctuating water levels which occasionally cause soils to fall dry. Common Mare's tail *Hippuris vulgaris*, Spikerush *Eleocharis*, Fine-leafed water dropwort *Oenanthe aquatica* (all three only represented in the plant macrofossils) and Yellow water-lily *Nuphar* may be indicators of this nutrient-rich habitat as well.

Often found in association with the previously mentioned taxa, but **obligate aquatic** plants, are the European bur-reed *Sparganium emersum* and Arrowhead *Sagittaria*. These plants may reside in water of some decimetres deep (up to 80cm) that is periodically flowing.

Also an obligate aquatic plant represented in the samples is the Water soldier *Stratiotes aloides*. This plant is also found in the transition between the water-body and the riparian grounds and plays an important role in the vegetation development to infilling water-bodies. When *Stratiotes aloides* is dominant in the vegetation water depth may lay between half a metre and two metres. *Stratiotes aloides* often occurs together with Hornwort *Ceratophyllum demersum*, in infilling cut-off river channels. *Ceratophyllum* is represented by leaf-spines in the palynological samples and is identified to species level by the presence of fruit fragments. This is a submerged plant residing in shadowy conditions. These shadowy conditions may be caused by layers of floating plants like Yellow water-lily *Nuphar* or the Water fern *Azolla filiculoides*. The latter is represented in the sample by glochidia. The presence of *Nuphar* is indicated by pollen, trichosclereids and a seed. *Azolla filiculoides* likes nutrient-rich, basic, fresh to brackish, stagnant waters. This habitat is also home of Eurasian watermilfoil *Myriophyllum spicatum*, *Stratiotes*, *Nuphar*, and Pondweed *Potamogeton*. *Potamogeton* pollen are present in the sample, species identification was only possible from the plant macrofossils, including *P. pectinatus* and *P. trichoïdes*. The genus *Potamogeton* includes many species with different habitat preferences but are all aquatic. Whorled watermilfoil *Myriophyllum verticillatum* also occurs in still or slow flowing fresh waters, but may survive on soils that occasionally fall dry.

The presence of a substantial number of pollen originally dispersed by obligate aquatic plants indicate a year round wet environment. All plants represented by the fossil pollen grains can endure brackish conditions, but none of the plants is halophyte. Only one possible signal of more saline conditions may be the pollen grain of Sea plantain *Plantago maritima*. Note that this pollen grain is a ‘type’ and is including different species (*P. maritima*, *P. alpina*, *P. maritima* subsp. *serpentina* (Beug 2004)). When macro fossils are included in the considerations Saltbush *Atriplex* and Club-rush *Schoenoplectus* may be indicative for the proximity of a more saline environment, under influence of the sea. *Filipendula* is often salt evading as is Horned pondweed *Zannichellia palustris*, the latter only represented in the macro fossils. The non-pollen palynomorphs *Pediastrum* and *Mougeotia* are two genera of algae inhabiting fresh water environments. So is *Spirogyra*, also an Algae, indicating fresh, stagnant, shallow water. Therefore, the environment of deposition was one of slow-flowing fresh-water, situated in the upper part of an estuary. Open grasslands were bordering a slow-flowing river with a dynamic course through the river-plain finding new pathways to the sea causing old river-channels to be cut off and occasional flooding creating pools and damp grounds. This open habitat was accompanied by some trees or shrubs that could stand this wet and dynamic landscape, like *Salix* and *Alnus*. Farther away from the site but still in the vicinity established a coniferous forest.

7.1. Considering environmental and climatic change

7.1.1. Changes in the local vegetation

All samples show quite similar pollen assemblages. When focussing on the cumulative diagram, summarising the percentages of the habitat-groups included in the pollen sum (diagram 1), an increase in the proportion of open, disturbed, and bare ground (herbaceous) pollen is noticed between 25 and 20 cm deep, reaching 40% at 20cm deep. From 20cm up to the upper part of the diagram the proportion of woodland pollen regains about its previous value of 75-80%.

The increasing numbers of herbaceous pollen grains could indicate an opening of the landscape. To exclude the influence of interdependence in a cumulative diagram, a concentration diagram was drawn (diagram 2) where the absolute abundance of a pollen grain or group of pollen grains in the sample is provided. In the concentration diagram of the habitat groups the coinciding increase in herbaceous pollen and minor decrease in woodland pollen can be noticed between 25 and 20cm depth, thus the bias caused by the interdependence of the percentage diagram is ruled out. An increase in herbaceous plants is often interpreted as indicating drier-, colder conditions, or forest clearance.

In this concentration diagram (diagram 2) it can be noticed that the concentration of pollen in the sediment is lower between 25 and 20 cm. But an isolated increase, the other habitat-types remain low in numbers of pollen grains or even further diminish (woodland), is seen in the number of herbaceous pollen grains at a depth of 20cm. The decrease in pollen concentration in the sediment at this depth may support the suggestion that circumstances were drier during the time of deposition of these sediments.

When climatic wetness increases, or the vegetation cover decreases, the sedimentation rate in a water-body can increase because of increased surface runoff. With high water velocities coarser sediments may be attributed to the sedimentation. Increased water supply in low-energy environments (in low relief) transports only the fine sediments, like clay, silt and pollen. The fine sediments in throughout the sequence, indicate low water velocity, flow volume and turbulence (Taylor 2008). Increased wetness may cause more pollen to be washed down into the site of deposition and processes of erosion may cause pollen-rich sediments to accumulate in the water-body including fossil pollen. The damage to the pollen grains in such depositions can be characterised as crumbled and folded (Moore *et* *al.* 1991). This may be the case around 10cm deep, where a clear increase in the pollen concentration of all the habitat-types can be seen, as well as an increase in fossil pollen. The input of pollen from the floodplain vegetation may become more accrete, as indicated in the concentration diagram of the local vegetation (diagram 3) showing that waterside and damp ground pollen numbers are exceeding the number of aquatic pollen grains. Aquatic pollen grains are present in more constant numbers what may be explained by the fact that the sediments accumulated in a water-body. Variations within the aquatic plants will therefore be more informative on the conditions in the water as presented in diagram 1.

Potamogeton, *Azolla filiculoides*, *Myriophyllum spicatum* and *M. verticillatum* are more abundant in lower samples and all except *M. verticillatum* disappear totally from the diagram in the upper sediments. These plants prefer nutrient-rich, basic water and can endure (except *Azolla filiculoides*) some currents and waves in open water-bodies. *Azolla filiculoides* is only present in samples from 20 and 25cm deep. In shallow, nutrient-rich water with a muddy substrate *Myriophyllum spicatum* is soon overruled by *Ceratophyllum*. The number of *Ceratophyllum* leaf-spines increase towards the upper layers of the sediment. *Ceratophyllum* is a companion of *Stratiotes*, which two increase coincidently. The growing presence of *Nuphar* may cause the shadowy conditions, preferred by *Ceratophyllum*, possibly repulsing *Myriophyllum spicatum*. Contrary to *Myriophyllum spicatum* does *M. verticillatum* not entirely disappear from the diagram and remains also present in the upper samples. *M. verticillatum*, *Ceratophyllum*, *Nuphar*, *Stratiotes aloides*, *Sparganium emersum* and *Sagittaria* prefer stagnant to slow flowing or periodically running, not to deep water. Coinciding with the increase in this group of aquatic plants is the increase in the pollen of the waterside and damp ground plant *Sparganium erectum* and a constant presence of *Typha latifolia*.

Other waterside and damp ground plants, including *Filipendula*, *Lysimachia vulgaris*, *Myrica gale*, *Spagnum* diminish towards the upper sediments. As do *Thalictrum*, *Epilobium* and *Valeriana*. This vegetation was maybe becoming less important. An increase in sedimentation together with an accretion in waterside and damp ground plants may indicate a growing importance of this habitat type or the infilling of the water-body. The accumulated deposition of fine sediments can point to wetter conditions in a low relief environment. The vegetation development in the water-body grew possibly under influence of eutrophic conditions (caused by enhanced nutrient supply from sediments and water, and maybe by a slightly warming climate).

On the basis of what is discussed above, it may be suggested that a period of drier conditions (20cm deep) was followed by a period of increased surface runoff causing a growing washload including pollen grains. Other evidence pointing to wetter conditions may be found in the increase in *Nuphar*, *Stratiotes*, and *Sparganium erectum*. And in addition a greater number of fossil pollen.

However, it should be noticed that the remarkable increase in herbaceous pollen is specially caused by an increase in Poaceae and Cyperaceae. These pollen are almost always included in the herbaceous plant-group. However, they may be part of a waterside and damp ground vegetation as well. For example Common reed *Phragmites,* is in the Poaceae family. The same may count for Cyperaceae, including various types of Rush like Spike rush *Eleocharis*. *Phragmites* and *Eleocharis* are only examples of Cyperaceae and Poaceae genera inhabiting watersides and wet grounds illustrating that the increase in herbaceous plants not necessarily means drier conditions. Together with *Filipendula*, *Thalictrum*, *Euphorbia palustris*, *Valeriana*, *Lysimachia vulgaris*, *Epilobium*, *Galium* and in the plant macro fossils *Urtica dioica* and *Eleocharis* sp. Poaceae and Cyperaceae may also have formed part of a reed swamp. The presence of *Eleocharis* in the plant macro fossil assemblage coincides with the spike of Cyperaceae in the pollen diagram.

Higher in the diagram 1 *Sparganium erectum*, *Stratiotes*, *Sagittaria*, (*Sparganium emersum*), and *Nuphar* become more important in the samples indicating a reorganisation of the local vegetation on the waterside and damp grounds and in the water-body.

7.1.2. Changes in the regional vegetation

When considering the regional vegetation, variations in the composition of the forest are regarded. Regional variations in the vegetation are considered to reflect climatic variations rather than edaphic or small environmental variations as discussed above.

For closely investigating alternations in forest composition pollen concentration diagrams are again useful to rule out interdependence of the observed variations. Simultaneously, this diagram offers an insight the proportional representation of pollen in the percentage diagrams. For example, when pollen accumulation rates are low, the long-distance transport component such as tree pollen may become over represented in the percentage diagrams (Huntley 1996).

A remarkable pattern is the alternation of *Betula* and *Pinus*, especially clear in the pollen concentration diagram of the tree taxa (diagram 4). In the sample from 25cm deep *Betula* is the most important tree taxon, outran by *Pinus* from 20cm depth onwards. Also *Picea* is slowly increasing towards the top of the diagram.

This pattern resembles quite well the typical forest development pattern after an ice age or near the timberline (Hicks 2001). This would suggest that the sediments deposited during the beginning of an Interglacial or interstadial. Yet another transition is then expected to show in the diagram. Namely, the transition of plants adapted to minerogenic conditions (an example may be the Common sea-buckthorn *Hippophae rhamnoides*, pioneering on minerogenic grounds attributing to the development of soils) to plants growing on more organic substrates (M. Field pers. comm. 2012). Which does not appear. Moreover, variations due to taphonomic processes (i.e. increased *Pinus* and *Picea* influx by surface runoff because of high floatability), natural variations in pollen production or changes in edaphic conditions are difficult to disentangle from possible climatic variations. In addition, when a shorter period of time is recorded in the sediments, the taphonomic factors may be of more prominent influence than will be the case when the sediments are deposited during thousands of years. The depositional environment of the pollen sequence discussed here rather suggests a relative short period of sedimentation with high biological productivity due to nutrient-rich waters and soils and sediment deposition by processes of flooding of the fluvial plain and inwash of sediments from the catchment area. Therefore, no climate variations can be pointed out nor can a suggestion be made on the position of the sequence in a glacial-interglacial cycle or interstadial.

However, based on the vegetation it can be concluded that the sediments were deposited during temperate climatic conditions. Boreal conditions are suggested by the presence of the *Pinus* and *Betula* (and *Picea*), comparable to the temperate boreal forest of Fennoscandia today. Winters would have been moderately cold, as suggested by the presence of *Azolla filiculoides*. Since the sexual structures of *A.* f*iliculoides*, the sporophytes, do not survive prolonged exposure to temperatures below -4°C (Janes 1998a, b). The occurrence of *A. filiculoides* in Britain today is restricted to the southern regions (West 1953). Together with other temperate climate indicators such as *Tilia*, it is probable that the site was situated near the southern limit of the boreal zone.

The occurrence of *Ostrya*-type pollen in the samples can neither be proved nor with certainty be rejected (S. Parfitt pers. comm. 2012) (Fig 18). Recognising the *Ostrya*-type pollen can be of biostratigraphic importance since it seems to occur only in the Early but not during the Middle Pleistocene (S. Parfitt pers. comm. 2012). The recognition of this pollen-type is not straight forward however, and must be considered with care.

The *Ostrya*-type pollen subsumes the Hop-hornbeam *Ostrya*, Oriental hornbeam *Carpinus orientalis* and European hornbeam *Ostrya carpinifolia*. The latter two are native in southern Europe, and absent from the British flora today. Nevertheless, more northern species from North America may be included in this type as well (Parfitt *et al.* 2010, supplementary information). The identification as well as the climatic significance of the *Ostrya*-type is uncertain and therefore dismissed from the climatic inferences made here. For the same reasons it is dismissed from the considerations on the stratigraphic position of the pollen sequence.

Figure 19. Three photographs of a possible *Ostrya*-type pollen from pre-Anglian sediments at Beeston. Focus on the vestibulum, exine and sculpture (photo E. Egberts 2012).

7.2. Stratigraphic considerations

Because most probably only a small time period is represented by the pollen sequence discussed here, correlation with other pollen sequences is difficult. Therefore considerations on the stratigraphic position of the sequence is limited.

The only pollen grains of biostratigraphic significance are *Azolla filiculoides* and *Picea*. *Azolla filiculoides* provides a minimum age of the sequence, as *A. filiculoides* became extinct during the late Middle Pleistocene (Godwin 1975). *A. filiculoides* did not occur in Britain from the Ipswichian (the Last Interglacial MIS5) Stage onwards until it was reintroduced in 1880 (West 1953). It probably extinguished in the Wolstonian cold Stage preceding the Ipswichian (Godwin 1975). Note that only two glochidia were found, which presence may be explained by processes of secondary deposition.

Also the presence of *Picea* pollen provide a minimum age as it was probably the severest phase of the Weichselian (the last glacial, MIS2) that exiled *Picea* from the British Isles, being non-native ever since. Especially during the Middle Pleistocene *Picea* becomes well represented (Godwin 1975).

The extensive palynological research undertaken by West (1980a, b), resulted in a subdivision of the entire Pleistocene as it was known until then, into 8 temperate stages with forest. The pre-Anglian Pleistocene was considered to show a threefold climate change, including the Pastonian and Cromerian as temperate stages and the intervening Beestonian as a cold stage. The Pastonian was related to the Early Pleistocene, the Cromerian to the early Middle Pleistocene. According to West (1980a, b) did the temperate stages existed of 4 sub-stages, each characterised by its own pollen assemblage or sequence resulting in pollen assemblage biozones. Now, it is suggested that even the Cromerian (complex) alone already comprise five discrete temperate episodes (Preece 2001; Preece and Parfitt 2012; Stuart and Lister 2001). It is unlikely that these temperate episodes can be related to the major climate cycles in the isotope record, more likely they represent smaller climate oscillations.

Because the pollen sequence presented here may represent only a snapshot of the vegetation history of the British Pleistocene, no certain correlation with the pollen assemblage biozones of West (1980a, b) is possible. The resemblance of this pollen sequence from Beeston to the pollen assemblage biozone Pa Ia and b, is carefully suggested. The absence of some important tree taxa like *Carpinus*, may be explained by the short period of deposition at the beginning of the development of the forest. This not necessarily relates to climatic changes, but can also be explained by the colonisation of the river plain by trees (e.g. Rose 2009). As the Pastonian is related to the Early Pleistocene one might expect Tertiary plant taxa in the pollen assemblage. However, these taxa are rather scarce, especially in a cold environment as presented in the Beeston pollen assemblages (S. Parfitt pers. comm. 2012).

The completeness of the pollen sequences and the derived vegetation history of the Pleistocene by West (1980a, b) may be doubted as more and more temperate and cold stages and interstadials and the complexity of the pre-glacial stratigraphy are recognised (Preece and Parfitt 2012). This increases the number of temperate stages to which the pollen sequence from Beeston presented here, possibly can be related to. This only augments the uncertainty of correlations.

On the pollen sequence alone, no conclusions can be made on the age of the sediments except a minimum age older than the Wolstonian based on the presence of *Azolla filiculoides* and a minimum age older than the Weichselian based on the presence of *Picea*.

The lithostratigraphy, however, provides an important age constraint. As the sampled sediments are overlain by glacial till attributed to result from the land ice advance during the Anglian cold Stage, this cold Stage provides a minimum age of ~478 Ka (the base of MIS12) (Lisiecki and Rymo 2005 in Preece and Parfitt 2012). Although the dating of this glaciation and its deposits has been subject to debate (see 2.1.Stratigraphy of East Anglia) its dating to MIS 12 is adopted here. This only provides a minimum age, and theoretically the maximum age of the sediments can only be restricted by the underlying Crag basins (see 2.1. Stratigraphy of East Anglia).

Fortunately, the fauna assemblage allows further inferences on the age of the sediments. The presence of a *Microtus* molar (S. Parfitt pers. comm. 2012) indicates for a minimum age of ~1 Ma (Maul *et al.* 2007), since this vole is unknown prior to this date in Europe. From the overlying upper organic mud *Mimomys savini* is recovered (S. Parfitt pers. comm. 2012). The transition from *M. savini* to *Arvicola* is well studied and related to MIS 15. Transitional populations from Mauer have been dated to ~600 Ka (Wagner *et al.* 2010), providing a minimum age for the overlying organic mud. The age of the Beeston sediments studied in this thesis may therefore be constrained to between ~0.6 and ~1 Ma.

Furthermore, Comparison to West's (1980a) description of the sediment sequence, suggests that the lower organic and upper organic discussed here, can be related to his bed i and k respectively (S. Parfitt pers. comm. 2012). West (1980a) proposed a threefold division of the sediments of which the middle member consists of marine transgression sediments, laminated silts and clay (bed k) and fresh water sediments (bed i). Between the latter two thin pebble gravel was registered (bed j). Bed i might correspond to the lower organic mud, sampled for the here presented research. Bed i, as described by West (1980a, 35) is '60cm of dark gray, freshwater, silty mud with occasional stones [that] occurs above the grey sand with silt laminae of [bed] g. This horizon is very extensive in the Beeston sections. It is the peaty loam of the Beeston cliffs described by Reid (1882[a], p. 26). It was correlated by Reid with the Cromerian West Runton Freshwater Bed, though it in fact belongs to a temperate stage older than the Cromerian, as will be shown later.' West (1980a) indicated bed i as containing pollen assemblage biozones Pastonian Ia and Ib. Interestingly, the pollen assemblage recovered for this thesis best resembles that of West's Pastonian Ia and Ib. This would place the Beeston sediments right within the 'Pastonian problem' (Preece and Parfitt 2012). The Beeston sediments are dated to between ~0.6-1 Ma, but might be related to West's 'Pastonian' sediments, which are Early Pleistocene (Preece and Parfitt 2012).

A similar situation occurred at Happisburgh site 3, where sediments were related to the Pastonian Stage (Parfitt *et al.* 2010 supplementary information; Preece and Parfitt 2012; West 1980). But the age of Happisburgh 3 is constrained to between ~0.99-0.78 Ma (Parfitt *et al.* 2010), differing in age from other 'Pastonian' for about 1 Ma (see 2.1. Stratigraphy of East Anglia). Thus it seems that the 'Pastonian' spans more than one temperate stage (Preece and Parfitt 2012), and a large interval of time. But if the Beeston sediments can indeed be related to West's Pastonian sediments, the dating of Beeston on the basis of small vertebrates does not fit and a similar discrepancy as at HSB3 may be revealed.

In Beeston the presence of *Microtus* places the sediments in the later part of the extended 'Pastonian', post dating ~1 Ma. So the sediments can not be related to the much older dated 'Pastonian' sediments (~2.0 Ma Preece and Parfitt 2012).

The absence of Tertiary plant taxa also advocates for a younger age early in the Middle Pleistocene, as does the small vertebrate assemblage that appears to resemble that of West Runton (S. Parfitt pers. comm. 2012).

Despite these considerations the possible age range for the Beeston sediments remains 400,000 years, between ~0.6 and ~1 Ma.

7.3. Relevance of the palaeoenvironment at Beeston to hominin dispersal, biogeography and understanding their ecological tolerances

The reconstructed environment of Beeston can be characterised as a river plain with pools, backwaters, infilling cut-off river arms, and slow running water at the very upper part of an estuary. Bordering the river plain a coniferous forest extended over a larger area, alternated with small stands of deciduous trees.

The local environment near the site of deposition was rich in aquatic and waterside plants. In the river plain, drier patches of ground where colonised by herbaceous plants possibly attracting grazing animals. The climatic conditions that prevailed during the time of deposition of the sediments are not totally without ambiguity. Since the coniferous forest may indicate boreal conditions, but the presence of frost sensitive aquatic plants such as *Azolla filiculoides* point to more moderate conditions (see above).

Whether this was a climate and environment hominins could have lived, can be approached through the comparison of the palaeoenvironment of Beeston to known hominin sites. Especially the overview of Ashton and Lewis (2012) offers a useful tool for reviewing the climatic tolerance and maybe the environmental preference of hominins (see table 1).

As pointed out by Ashton and Lewis (2012) does evidence for hominin presence occur in various environmental and climatic conditions. The possibly cold winters of Beeston may resemble the cold winters of Happisburgh 3 and 1. Solely based on these conditions, hominin presence at Beeston can not be precluded.

A different pattern that occurs in the overview of Ashton and Lewis (2012) is the occupation of fluvial sites or in the vicinity of another running water resource. Whether this is a pattern of preservation rather than preference remains questionable. Anyhow, apparently riparian areas offer good chances for archaeology and advocate for a close monitoring of the pre-glacial sediments at Beeston.

The present understanding suggests that the East Anglian coast formed the edge of hominin dispersal during the Pleistocene, this area is of interest for studying possible patterns of hominin dispersal that may inform us on their adaptations and behaviour. But for identifying spatio-temporal patterns, recognising both hominin presence as well as absence is of value (Roebroeks 2006). Off-site environmental data may importantly attribute to getting the spatio-temporal pattern and explaining it. The apparent absence of archaeology at Beeston can be put to use in inferences on the presence of hominins at other localities along the East Anglian coast. As the environmental context of Beeston resembles that of known hominin sites, may there be other explanations for the apparent absence of hominins?

8. Conclusions

Based on the pollen analysis carried out on the organic rich pre-glacial sediments obtained from the cliff section near Beeston on the East Anglian coast, a reconstruction of the past vegetation and environment could be made.

The samples were taken from an infilling fresh water river channel in a river plain as could be concluded from the sediment and vegetation reconstruction. The aquatic plants that are present, suggest a permanent wet locality. An increase in waterside and damp ground plants towards the upper part of the sampled sequence together with an increase in sedimentation indicate the infilling of the channel. In the river plain both back waters, pools and slow-flowing streams were probably present. The water was bordered by waterside and damp ground vegetation. Openings in the waterside vegetation may have let animals (and hominins) access the water. The river plain formed an open area where various animals may have roamed. In the vicinity the river plain was bordered by a coniferous forest with some deciduous elements. The sampled locality was located in the upper, fresh water part, of an estuary, as salt tolerant plants are only represented in small numbers in the micro- and macro fossils.

The coniferous forest points to cooler conditions at the site than known in Britain today. The composition of the forest may have been comparable to that seen in modern south Scandinavia, forming the southern edge of the boreal forest. The local vegetation, especially the aquatic plants, indicate moderate cold winters. The combination of the coniferous forest and local vegetation indicate both cold and temperate conditions.

In this type of climate particularly the winters will have been scarce of food resources. This scarcity of food could have prevented hominins to disperse into these regions. However, the locality near the water (and estuary), at an ecotone, in an open patch of land, where resources from various habitats could be exploited, may have provided the additional food supply necessary for hominins to survive the winter.

As this climate and ecological niche is reconstructed for various archaeological sites, on the basis of the environmental reconstruction of Beeston the site formed a potential locality for hominins to settle.

Up to today no indications for hominin presence are found near Beeston. On the basis of the environmental reconstruction, it can be stated that it was not the ecological niche or climate that can explain the apparent absence of hominins. Unfortunately, the position of the sediments at the base of the high cliff has hampered excavations and could explain the lack of archaeological finds near Beeston. Nonetheless, can the environmental data from the pre-glacial sediments at Beeston provide the wider environmental context of hominin presence in the region. Moreover, may the information from Beeston and the apparent absence of archaeology offer a starting point for recognising spatio-temporal patterns. To use the information from Beeston in a wider context, the chronological relation of the Beeston sediments to other sites must be understood.

The age constraints of the pre-glacial sediments at Beeston are established from lithostratigraphical and biostratigraphical research. The overlying glacial till, deposited during the Anglian Stage, provides the minimum age of the Beeston samples as ~478 Ka. The presence of *Mimomys savini* in the small vertebrate assemblage of the overlying upper organic layer further restrict the minimum age to ~600 Ka (MIS 15). A maximum age of the sampled sediments is inferred from the presence of a *Microtus* molar. *Microtus* is not known in Europe from before ~1 Ma.

The pre-glacial sediments at Beeston may be situated in the early part of the ‘Cromerian Complex’. The possible age range of the Beeston samples covers the period to which the now known earliest hominin occupation and subsequent hominin presence in Britain is dated. If the Beeston samples can more precisely be situated in time, it is a site of great value for reconstructing the wider context of this early occupation, with a good possibility of finding archaeology at the site.

Abstract

Pollen from pre-Anglian sediments at Beeston, Norflok, UK, were investigated to reconstruct the palaeoenvironment and climate at the locality during the time of deposition. The results of the environmental reconstruction are integrated in the debate on hominin presence in northwest Europe during the Pleistocene, their dispersal, biogeography, and the understanding of their ecological tolerances.

Based on the pollen assemblages identified from the sediment sequence the presence of an infilling fresh water river channel in a river plain could be reconstructed. The presence of aquatic plants suggest a permanent wet locality. An increase in waterside and damp ground plants towards the upper part of the sampled sequence together with an increase in sedimentation indicate the infilling of the channel. In the river plain both back waters, pools and slow-flowing streams were probably present. The water was bordered by waterside and damp ground vegetation. The river plain formed an open area where various animals may have roamed. In the vicinity the river plain was bordered by a coniferous forest with some deciduous elements.

The climate and ecological habitat reconstructed from the pre-glacial sediments at Beeston, resemble that of known archaeological sites in the region. The age of the sediments, based on lithostratigraphy and biostratigraphy, could be constrained to between ~0.6 and ~1 Ma. This possible age range covers the period to which the now known earliest hominin occupation and subsequent hominin presence in Britain is dated.

Based on this environmental reconstruction the locality of Beeston would have formed a habitable niche for hominins during the time of deposition.

Up to today no indications of hominin presence are found near Beeston. Although excavations of the pre-glacial sediments at Beeston is today impossible, the environmental reconstruction and the apparent absence of archaeology from Beeston can be used for reconstructing the wider context of hominins in northwest Europe and form a basis for further inferences on hominin dispersal, biogeography and ecological tolerances.

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Appendix 1. Pollen counts

	Depth/cm	1	10	20	25	34
Pinus		245	253	196	148	192
Picea		29	27	16	11	11
Betula		145	148	191	312	185
Quercus		9	7	8	9	6
Corylus		4	9	17	4	13
Tilia		0	0	0	1	1
Ulmus		4	2	7	3	3
Alnus		10	6	8	9	9
Salix		41	42	62	90	37
Amaranthaceae - Chenopodiaceae		6	7	9	12	7
Artemisia		4	1	5	10	4
cf. *Echium*		0	0	0	0	1
Plantago major/ P media		2	2	5	11	7
Plantago maritima-type		0	0	0	1	0
cf. *Polycnemum*		0	0	0	0	2
Caryophyllaceae		5	1	1	1	2
Polygonum aviculare-type		0	0	0	0	1
Poaceae		66	80	128	43	55
Cyperaceae		58	119	203	70	63
Polypodium vulgare		3	0	0	0	0
Rumex acetosa-type		0	0	3	3	3
Ericaceae		0	0	0	1	1
Myrica gale		0	0	0	0	3
Sphagnum		2	3	7	7	0
Lysimachia vulgaris		1	1	0	0	2
Osmunda		0	0	3	0	0
Filipendula		10	9	6	17	15
Symphytum		2	2	1	8	1
Typha latifolia-type		5	3	2	3	3
Euphorbia palustris		0	0	0	1	0
Sparganium erectum		10	38	9	3	18
Sparganium emersum-type		19	15	29	22	4
Sagittaria		7	4	8	0	0
Myriophyllum verticillatum		0	1	0	4	4
Myriophyllum spicatum		0	0	0	5	1
Azolla filiculoides		0	0	1	1	0
Stratiotes		1	6	3	1	0
Potamogeton		0	0	6	16	8
Nuphar		2	7	0	0	0
Brassicaceae		1	5	3	6	0
Apiaceae		25	31	51	100	33
Ranunculaceae		52	45	36	47	32
Ranunculus acris-type		0	0	1	11	1
Asteraceae tub.		15	17	19	39	33
Asteraceae lig.		1	2	11	5	2
Galium		2	5	11	9	6
Thalictrum		1	4	12	13	6
cf. *Solanum*		0	0	2	0	0
Monocolpate X		0	0	0	1	1

Valeriana	0	0	0	1	0
Rumex aquaticus-type	0	0	0	1	0
Polygonum persicaria-type	0	0	0	0	1
Epilobium	0	0	0	0	1
trilete psilate	3	4	4	1	3
monolete psilate	9	3	23	19	22
Mougeotia	2	1	5	3	2
Spirogyra	8	17	22	13	17
Pediastrum	1	3	2	1	0
ascospore	7	9	18	23	19
Ceratopyllum leaf-spines	8	7	2	2	6
Scalariform perforation plate	0	2	1	1	2
Trichosclereids of Nyphaceae	4	5	1	0	0
B41A	0	0	0	9	3
B41B	0	0	0	2	1
Fossil pollen type 1	1	3	5	2	2
Fossil pollen type 2	2	6	3	2	0
Lycopodium	90	55	116	131	81
Undetermined	18	12	10	15	14

Appendix 2. Percentages pollen AP-NAP

	depth	1	10	20	25	34
Pinus		38,8	35,9	22,8	20,0	31,8
Picea		4,6	3,8	1,9	1,5	1,8
Betula		23,0	21,0	22,2	42,2	30,7
Quercus		1,4	1,0	0,9	1,2	1,0
Corylus		0,6	1,3	2,0	0,5	2,2
Tilia		0,0	0,0	0,0	0,1	0,2
Ulmus		0,6	0,3	0,8	0,4	0,5
Alnus		1,6	0,9	0,9	1,2	1,5
Salix		6,5	6,0	7,2	12,2	6,1
Amaranthaceae -		1,0	1,0	1,0	1,6	1,2
Artemisia		0,6	0,1	0,6	1,4	0,7
cf. Echium		0,0	0,0	0,0	0,0	0,2
Plantago major/ P media		0,3	0,3	0,6	1,5	1,2
Plantago maritima-type		0,0	0,0	0,0	0,1	0,0
cf. *Polycnemum*		0,0	0,0	0,0	0,0	0,3
Caryophyllaceae		0,8	0,1	0,1	0,1	0,3
Polygonum aviculare-type		0,0	0,0	0,0	0,0	0,2
Poaceae		10,5	11,4	14,9	5,8	9,1
Cyperaceae		9,2	16,9	23,6	9,5	10,4
Polypodium vulgare		0,5	0,0	0,0	0,0	0,0
Rumex acetosa-type		0,0	0,0	0,3	0,4	0,5
Ericaceae		0,0	0,0	0,0	0,1	0,2
	pollen sum	631	704	859	739	603