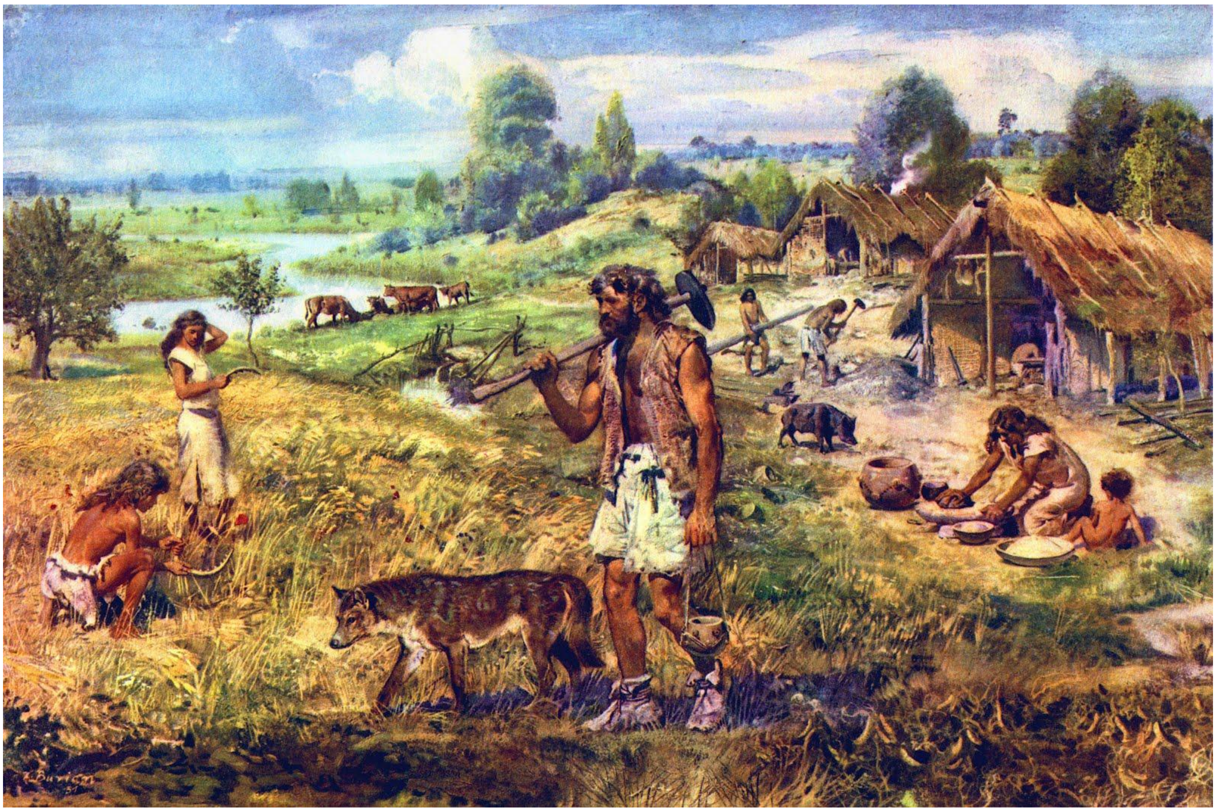
The impact of early farming on vegetation and driftsand patterns in Drenthe, NL and South Jutland, DK



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July 2016

Abstract

This study is focused on the first appearance of farming practicing in North-Western Europe. Hitherto it has been generally accepted that the Neolithic agricultural revolution started around 6ka BP. Reports of the development of heathland two millennia earlier however, give us reason to believe agriculture was present long before 6ka BP (Doorenbosch, 2013; Trondman *et al.,* 2015; Sevink *et al.,* 2013). To find out whether this is true, 33 possible pingos were drilled throughout Drenthe and Friesland, in the area surrounding the Aekingerzand. Of these 29 were found to be too sandy to drill through. Of the remaining 4 only 2 were acceptable, the Groote Veen and the Blauwe Gat, a partially excavated peat bog and an excavated lake respectively. Furthermore a sediment sample from the Aekingerzand was taken, containing a peat bog covered by driftsand. Two sites in South Jutland, Denmark were also drilled. A partially excavated lake near Rødding and an untouched peat bog near Padborg.

The resulting records were then taken to the lab and analyzed for their lithology, pollen composition and LOI (Loss On Ignition) curve. It was found that the Groote Veen record was disturbed and that the Mikkelborg site (near Rødding) did not contain any interesting signs of driftsand activity. The relevant cores taken from the Blauwe Gat were found to be slightly younger than the core taken at the Padborg site from their pollen assemblage.

The pollen assemblage for the Padborg site showed a decrease in arboreal pollen together with a rise in upland herbs and no significant increase in heathland for about 5ka BP. As this coincided with decreases in the LOI it was concluded that farmers of the Funnel Beaker culture might have had an establishment near the site back then, but only for a short period of time. The pollen diagram does show a fine example of ecosystem succession after disturbance. The Blauwe Gat showed a decrease in arboreal pollen as well, starting from about 9ka BP. This decrease however did coincide with a big increase in heathland vegetation, although the LOI did not decrease by a large amount. Therefore it was concluded that early farming must have taken place from 9-7ka BP, with small fields for agriculture, resulting in minimal driftsand activity and heathland formation, and a large amount of heathland maintained by livestock grazing.

The findings of the Blauwe Gat record are not corroborated by archeological evidence, as the consensus is that the LBK (Linear Band Keramik) culture was the earliest agricultural active culture in the Netherlands, introducing agriculture and animal husbandry in Limburg at about 7ka BP. The earliest signs of agriculture in Drenthe stem from the TRB (Trechterbeker) culture at about 5.8ka BP. This leaves a gap of about 3000 years of unexplained farming activity in Drenthe, inferred from the vegetation patterns, which requires follow-up research.

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Chapter 1: Introduction

The transition from the Mesolithic to the Neolithic is a chief chapter in the History of mankind. During the Mesolithic most tribes living throughout Europe and Western Asia were Hunter-Gatherers and still very much reliant on the forest for food production. Some 13ka BP this changed when tribes in what is now Western Asia, started practicing agriculture to have some control over the amount of food production (Pinhasi *et al*., 2005; Renfrew, 2006; see Figure 1). By about 9.2ka BP, agriculture was introduced in Europe via Greece (Renfrew, 2006). The further expansion throughout Europe, however, took about a thousand years to take off. By 8 ka BP the rest of Europe was cultivated in a giant agricultural wave, that was probably initiated by a sea level rise and consequent migration of the tribes practicing agriculture in Greece (Ammerman *et al*., 2006; Turney & Brown, 2007). At 5.5ka BP the Neolithic agricultural revolution was also well established on the British Isles (Forenbaher and Miracle, 2005; Pinhasi *et al*., 2005).

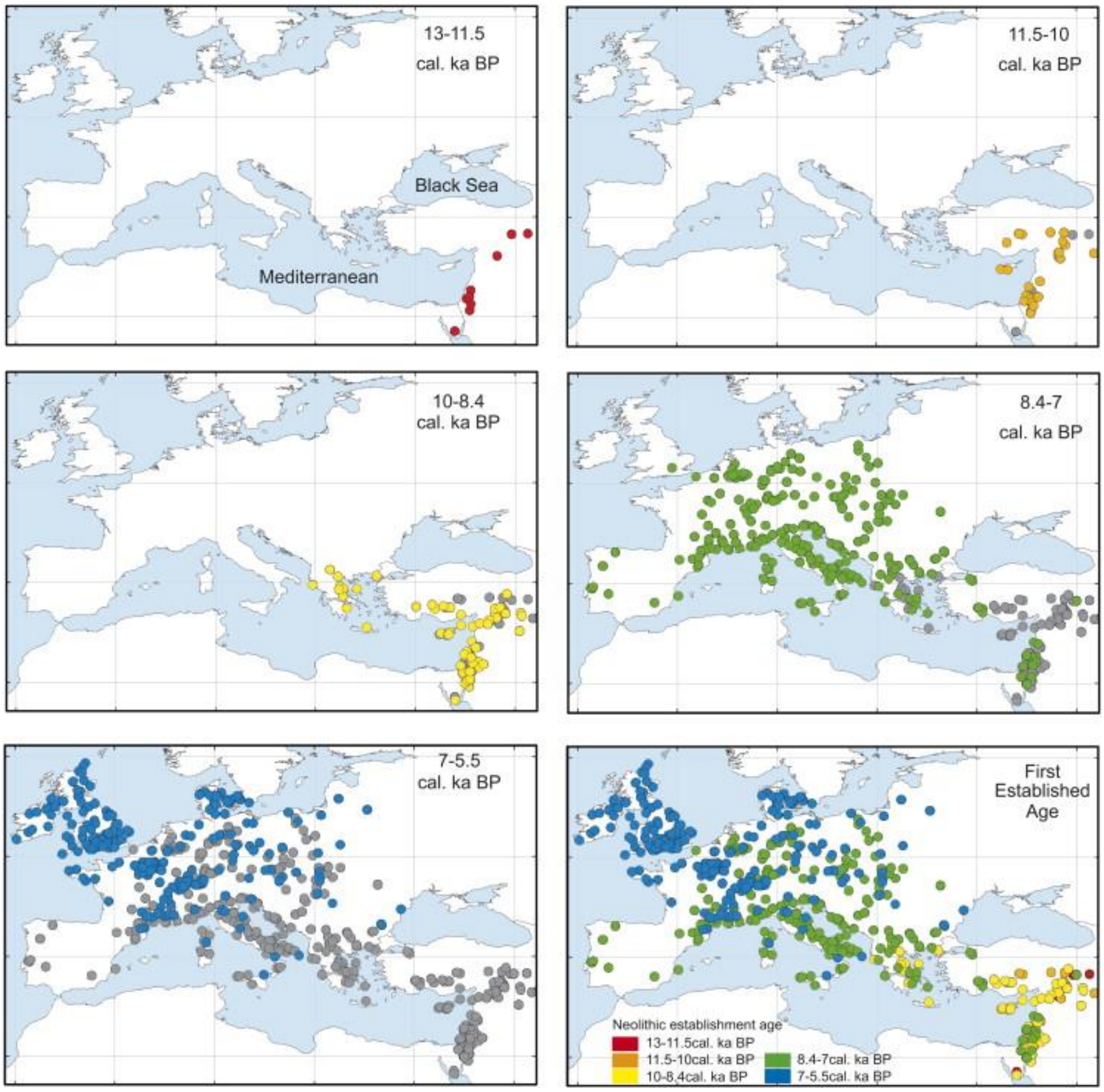

Figure 1 Map of Europe and Western Asia indicating the sites at which the first evidence for Neolithic farming was found based on median probability calibrated radiocarbon ages. Gray dots represent the location of the earliest Neolithic sites from the previous period. From Turney & Brown, 2007.

With the development of agriculture another major anthropogenic environmental component came into play: deforestation. For crops need light and space while the European continent was covered by the massive forests which covered the European continent again after the Ice Ages. In a way human forest management already took place long before agriculture was invented, as mankind was of considerable influence on the presence and distribution of large herbivores and thus played a significant part in the vegetation patterns during the early Holocene (Innes & Blackford, 2003). Mankind may have also directly influenced the forest openness by clearing and maintaining open spaces for hunting purposes (Simmons, 2003). Still the European forests reached a maximum tree cover around 7ka BP, during the expansion of agriculture across Europe (Kirby & Watkins, 2015). This maximum contained many larger and smaller open places which were not only the result of human activity, but indeed various other disturbances such as forest fires, diseases and major storms played a role in this as well (Bradshaw & Hannon, 1992; Angelstam, 1998; Grove and Rackham, 2001; Parker *et al.,* 2002; Gardiner *et al*., 2010).

With the arrival of agriculture from 8ka BP onwards, the decline of European forests began. Initially the farming activities were mainly focused in South-Eastern Europe, as agricultural practices had not yet spread to Northern Europe. This explains why the openness of German and Danish forests is estimated to have been only around 10-30% from 8ka BP to 4ka BP (Nielsen *et al*., 2012), as agricultural activity was still either very limited or non-existent in Denmark and Germany during this period. While forests were used for foraging and feeding of what little livestock was kept during the Neolithic, trees were felled mainly to supply wood for primitive forms of building which had started to develop (Kreuz, 1992; Rackham, 2003). After the concept of farming was properly introduced however, this changed within a few millennia. At the start of the Bronze Age settlements in North-Western Europe were few and far between, much like Islands in a sea of forest (Groenewoudt *et al*., 2007). During the Bronze Age however, the further development of woodcraft quickly increased the demand for wood significantly, along with the increased burning of wood to keep permanent farm housing warm (Kirby & Watkins, 2015). The possession of livestock also took off, which in turn required pastures. Therefore parts of the forest were cut down to allow the herbs and grasses preferred by the livestock to thrive in enclosed pastures (Kirby & Watkins, 2015). Also the introduction of the plough at around 4ka-4.5ka BP caused the demand for agricultural lands to increase greatly (Isager & Skydsgaard, 2013). So by the end of the Bronze Age the landscape and vegetation of Europe had changed significantly, with forests now starting to fail in favor of clearings, heathland and farmland.

At the start of the Iron Age and more or less the Roman Empire, forest management and deforestation had increased to the point where open landscapes with pastures and fields were the dominant landscape in Europe. Forests were still present but instead of encircling the patches of farmland and settlements, the farmlands and settlements now encircled patches of forest (Groenewoudt *et al*., 2007). The relatively stable living conditions that the might of the Romans provided, allowed mankind's numbers to explode throughout most of Southern Europe. Where previously, during the Bronze age, forest was mainly cut down to provide space for livestock and agriculture, now the focus shifted towards forest being cut down mainly for its wood content (Kirby & Watkins, 2015). The demand for wood to fulfill the increasing need for fuel and building materials, rose ever higher, significantly increasing the felling of trees. Consequently during the later stages of the history of the Roman Empire, erosion started to be a real problem (Hughes & Thirgood, 1982). This process was accelerated by the intensifying of agriculture, which exhausted fertile farmlands even faster. Especially around the Mediterranean Sea the farmlands started to give way to a far more barren landscape, due to a lack of permanent vegetation keeping the fertile soil from being washed away (Hughes & Thirgood, 1982). Only inaccessible areas retained their forest vegetation, such as mountainous areas.

In the Netherlands, deforestation quickly increased as well. Most of the forests on the Veluwe and much of Drenthe, were cut down during the Bronze Age (Doorenbosch, 2013). These were replaced by fields, heathlands and shrubs. Especially heathland became a dominant vegetation type throughout the course of the Bronze Age, which was maintained by the flocks of domestic sheep that foraged on the heather and thus kept succession at bay (Fokkens, 2005; Wijngaarden-Bakker & Brinkkemper, 2005). Burning was also a common practice to manage the heathland/forest balance (Schaminée *et al*., 1996). At the same time the forest demise, which had set in during the Mesolithic, continued. So by the start of the Iron Age, the landscape in The Netherlands was very much open. This effect was obviously enhanced when the Roman border was repositioned from the South, as the arrival of the Romans intensified the pressure on Dutch forests even more.

The heathland-pinewood dynamic in the coversand landscape of The Netherlands mentioned above deserves more attention. While some of the pinewood got replaced by natural mixed oak forest, large parts also got replaced by heathland as early as 8.5ka BP (Sevink *et al*., 2013). This is interesting as any transition from forest to heathland does not happen quickly. Heather is a pioneer vegetation which can grow in very sandy, slightly acidic soils that are very poor in nutrient content (Riksen, 2006; Hjelle *et al.,* 2010). When forest is cut down, the nutritious humus layer does not disappear with it. Therefore tree seedlings would easily be able to strike root and initiate a new forest vegetation. If however the nutrients were extracted after cutting down the trees, there would be no fertile soil for the new tree seedlings to grow on. This is where heather can obtain dominance. Nutrient extraction can happen in a variety of ways through (non-human induced) environmental changes. Blanket peat bogs are a fine example, with their potential to harbor wet heathland. Wet heathland needs a cold, wet climate however, to limit evapotranspiration and maximize nutrient leaching (Gimingham, 1992; Bunting, 1996). It is generally agreed upon that the Holocene has been a relatively stable epoch, without any major climatic variation. Therefore it is reasonable to assume that any prolonged forest to heathland conversions are instigated by human activities such as agriculture, which extracts nutrients from the forest soil, and animal husbandry, which prohibits succession by grazing and thus removing stored nutrients and tree seedlings (Webb, 1998). This land use would be accompanied by rises in driftsand activity, as exhausted farm lands usually lack any vegetation which enables aeolian activity to occur. The early presence of heathland at 8.5ka BP would thus suggest that farming activity was present at the time. However it is generally accepted that the Neolithic farming revolution started in North-Western Europe some 6ka BP, leaving us with a gap of 2.5ka of unexplained signs of agricultural activity (Doorenbosch, 2013).

The archives best suited for trying to certify these vegetation patterns, are probably found in Drenthe. For Drenthe was thinly inhabited for the last two thousand years which limited disturbance and relatively densely inhabited during the Neolithic Era and Bronze Age (Harsema, 1987; Vervloet, 1988). It also features loads of pingo remnants in the form of small circular lakes and peat bogs (which would have been lakes previously). Most of the sediment archives found in these span the time between today and the last ice age. Additionally in North-West Drenthe lies a driftsand plain, the Aekingerzand, which has been supplying all of the surrounding pingo remnants with sand during the Holocene. So any increase or decrease in drift sand activity during the last 10ka will have been recorded in those lakes and peatbogs. Inland drift sand activity during the late Holocene is mainly caused by human impact. Therefore any changes in vegetation patterns can be correlated to human interference through the amount of drift sand. It thus becomes possible to separate agriculturally induced vegetation pattern changes from other factors that change the vegetation composition. The Aekingerzand contains peatbogs as well, currently hidden under a few feet of sand. The study of late Holocene peat profiles is hampered by their current rare occurrence due to poor preservation, active excavation and drainage. At the Aekingerzand however peatbogs developed in the lower parts of the plain. The dynamic nature of the drift sand plain then caused these to be covered up with drift sand. Such drift sand hillocks are called fortresses.

A research area with a comparable setting and cultural history is Southern Denmark. Therefore it would be ideal to see whether any decrease in pinewood coincides with an increase in heathland there as well. It also has a similar geology, with loads of sand, gravel and clay deposits that were the result of the Weichselian ice age. It is unclear whether there are actual pingo remnants in Southern Denmark, but there are enough small lakes or peatbogs to be found.

This study focuses on the following research questions:

- Is there a relation between vegetation patterns and driftsand activity?
- Is the decrease in pinewoods related to the increase in heathland cover?
- Is there a difference in this relation between different sites and times?
- If so, is the pinewood decrease which set in during the Mesolithic indeed attributable to farming activity?
- How does archaeological evidence fit into the presumed early farming activity?

To answer these questions we have drilled several presumed pingo remnants around the Aekingerzand and we will sample the peat of the wall profile of a fortress at the Aekingerzand itself. We have also studied selected peatbogs in Southern Denmark. The sedimentological and palynological characteristics of the cores will be analyzed to acquire a general sense of drift sand activity, the age of the record and the vegetation distribution during the time of sedimentation.

Chapter 2: Site Review

§2.1 Study Area

§2.1.1 Drenthe

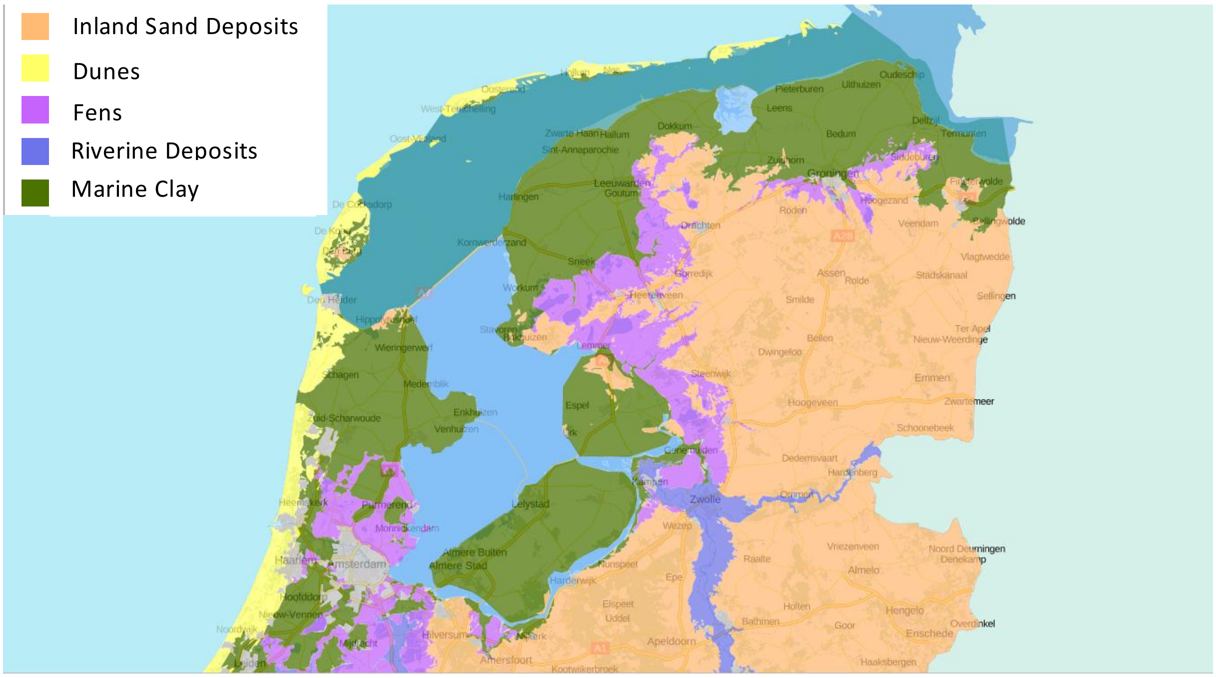

Figure 2 Overview of the northern part of The Netherlands, showing the major surface deposits. Map courtesy of the PDOK archives

Our study area in Drenthe lies in one of the three larger sand areas in The Netherlands: The Northern Sand area (see Figure 2). This sand area spans the entirety of Drenthe and parts of the provinces of Overijssel, Groningen and Friesland. It can be divided in three smaller regions: the Hunze Valley, Eastern Groningen and the Drents Plateau (Figure 3. Berendsen, 2005). The investigated pingo remnants from Denthe all lie on the Drents plateau which is a boulder clay plateau that is bounded on both the Eastern and Southern side by a series of push moraines. The glacial till, at several dozens of meters depth, consists of white sands which were transported by the Eridanos riversystem from the Baltic Sea and Northern Germany during the Miocene, Pliocene and Pleistocene (Appelscha formation). During the Cromerian era of the Pleistocene, the discharge from the Eridanos stopped in The Netherlands. From then on Drenthe in large part came under influence of the Rhine-Meuse delta, which deposited the Urk formation, a coarse grained deposition with a high gravel content (Berendsen, 2005).

Embedded in the Urk formation lies a meltwater deposit consisting of fine sand, which stems from the Elterian glaciation that cut large grooves in the formations lying underneath. In the valleys that were left after the Elterian glaciation a dark colored glaciolacustrine clay called 'Potklei' was deposited (Berendsen, 2005).

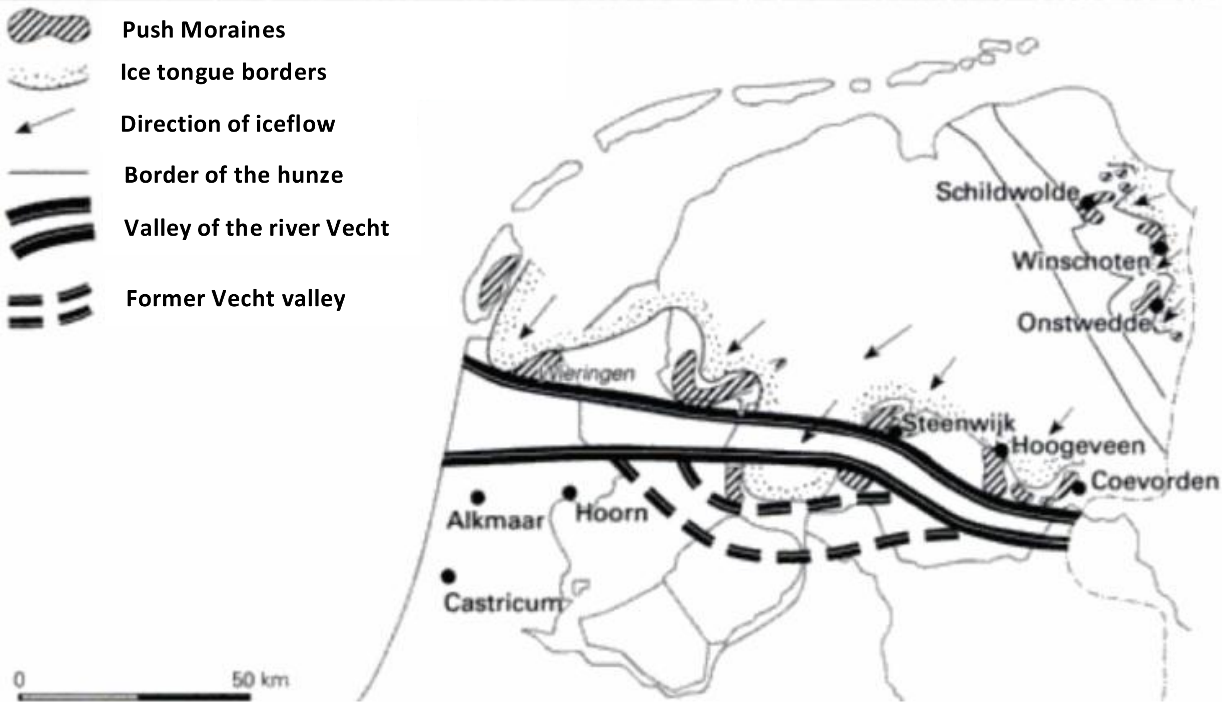

Figure 3 Overview of the impact and size of the Saalian ice advance in the Netherlands (Berendsen, 2005).

After the Elsterian glaciation, the Saalien ice advance moved down to The Netherlands (see Figure 3). It was during this glaciation that the Drents plateau was formed between what once were the push moraines of Schildwolde-Winschoten-Onstwedde to the North-East of the Drents plateau and the push moraines of Steenwijk-Het Gaasterland-Wieringen to the South (Figure 3. Berendsen, 2005). The plateau slopes downward towards the North-West, while to the South-West and East lie the ridges that are left of the push moraines that were over-ridden. These ridges have a ZW-NO and a ZZO-NNW direction respectively (Figure 3) . It is therefore thought that ice tongues initially moved to the South-West. At a later stage however, the push moraines which had formed around the original ice tongues were over-ridden. This can be explained by a large ice tongue moving in a South to South-Eastern direction across the East of Drenthe, through a corridor walled by blocks of calving ice. The glaciers left a boulder clay layer of 1-3 m in thickness, known as the Drenthe formation on top of the Urk formation (Berendsen, 2005. Figure 4). This boulder clay layer can however reach thicknesses of as much as 15 m in those parts of the landscape where the push moraines stood (Berendsen, 2005).

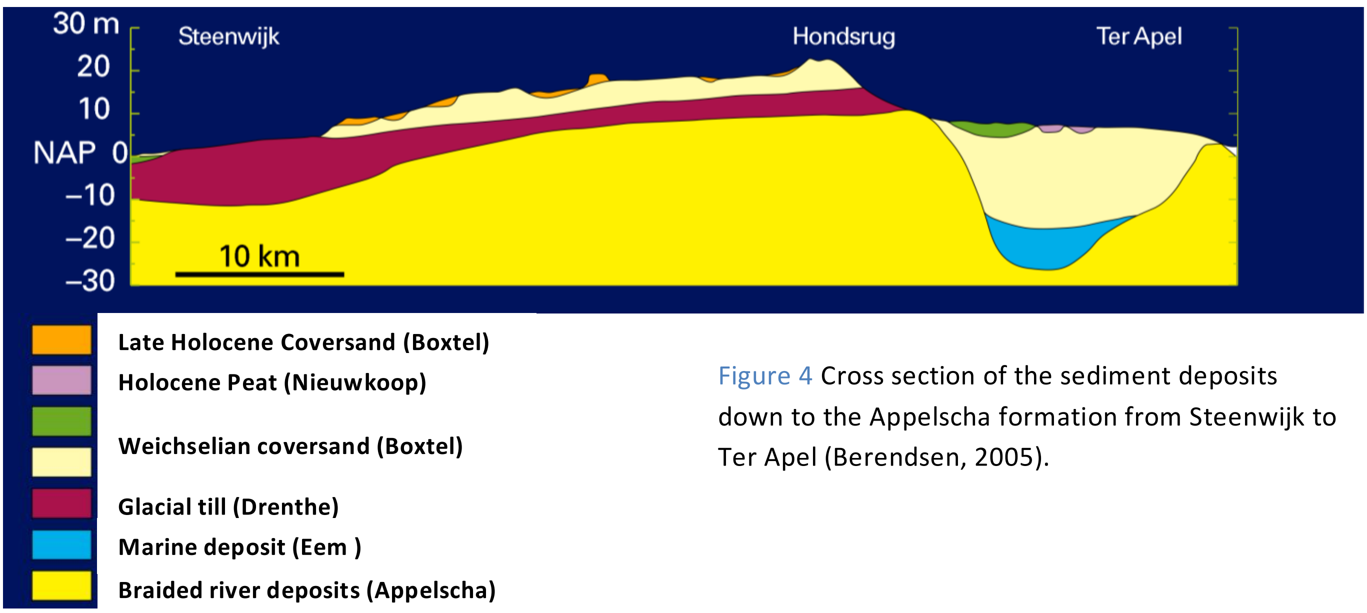

Figure 4 Cross section of the sediment deposits down to the Appelscha formation from Steenwijk to Ter Apel (Berendsen, 2005).

After the Saalien glaciation the boulder clay lay at the surface for an extended period of time. This caused the clay to erode and set the stage for soil formation to occur (Berendsen, 2005). At the same time a marine deposit was formed just beyond the North-Eastern edge of the Drents plateau, called the Eem formation (Berendsen, 2005. Figure 4).

During the Weichselian glaciation a 0,5-2,0 m thick pack of coversand, called the Boxtel formation (see Figure 4), was deposited over the boulder clay, which probably originated from a local erosion being the result of a disappearing vegetation due to climate change. This coversand consists of an older layer featuring alternating fine sand and clayey layers which was deposited during the Pleniglacial and a younger layer which was deposited during the Late-glacial. In the younger deposit the clayey layers are mostly absent and thus almost the entire pack consists of fine sand. There is however a peat layer to be found in the Late-glacial layer, which originates from the Allerød interstadial and is called the Usselo layer.

One of the most prominent features of the Northern Sand Area and the Drents Plateau in particular, are the pingo remnants that lie scattered across the landscape. Pingo remnants are the filled in lakes and peat bogs that formed after a pingo collapses. Pingos are hills with a core of ice that were formed in The Netherlands and especially Drenthe during the Weichselian glaciation (Berendsen 2005). They form in places where groundwater pressure is high, which causes the groundwater to break through weak places in the permafrost (Flemal, 1976). In this way an underground icelens forms, which is able to grow because of the supply of pressurized ground water that keeps seeping through the permafrost. If the icelens at some point grows too large, the sediment layers on top will start tearing and eventually will collapse. This initiates the melting of the icelens, as it is now under direct influence of the sun's rays. In the end we are left with a circular lake with a diameter of 30-600 m and a maximum depth of about 10 m (Flemal, 1976). Pingo remnants also feature an encircling rampart, which is the remainder of the collapsed crust that once encapsulated the ice lens. The infill of these lakes often dates back to the Weichselian (which is why it is thought that these lakes formed from Weichselian pingos in the first place) and can span the entire Holocene.

The presence of impermeable boulderclay in the subsurface of Drenthe led to large scale peat formation in Drenthe. Holocene human agricultural activity and deforestation caused drift sand activity and thus sand plain formation. Peat bogs got covered by the drift sand and retained it because of their wet nature and thus presence of vegetation. Therefore peat can be found inside sand dunes at the Aekingerzand. Drift sand activity was highest during the Middle Ages, when agriculture was intense and vegetation very scarce in Drenthe.

§2.1.2 South Jutland

The big difference between Drenthe and South Jutland (see Figure 5) is that Drenthe has only been reached by two major ice advances, while South Jutland has been overridden by all but two during the Weichselian glacial (see Figure 6). Therefore the prominent kind of sediment to be found in the underground layers of Jutland is till. The Elsterian general caused two sheets of ice from the Baltic Sea and Norway to grow to South Jutland. The Baltic ice advance would later also reach The Netherlands and Drenthe. This ice advance left the first till layer in the Quaternary on Jutland. After this the Holsteinian interglacial left a layer of glacial outwash, until the Saalien glacial started (Houmark-Nielsen, 1987).

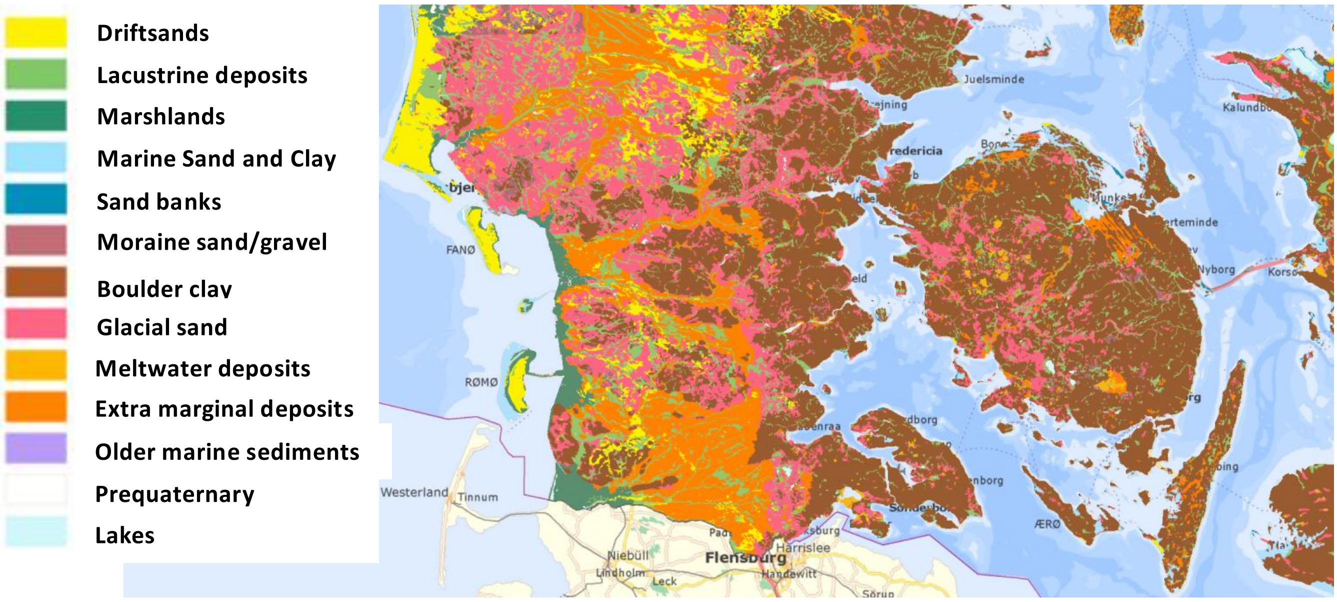

Figure 5 Overview of South Jutland, showing the major top deposits. Map courtesy of the GEUS institution.

The Saalien glacial consisted of three stadials, during all of which ice advances grew across South Jutland. First an ice advance originating from Norway rode over Jutland, after which, during the following interstadial, a layer of glacial outwash material was formed. During the following stadial, the main Saalien ice advance came in from the North-East and again covered South Jutland with an ice sheet. The following interstadial left not only outwash material, but also a soil, the Oksbøl layer. The third ice advance came from the Baltic sea again, leaving the third Saalien till layer. With its retreat the Saalien glacial ended and the Eemian interglacial started (Houmark-Nielsen, 1987).

During the early Eemian another layer of glacial outwash formed, after which interglacial limnic deposits suggest the forming of lakes and bogs (the Brørup bogs) in the area. Following the Eemian the Weichselian glacial started, although no ice advances are recorded in the sediment during the early Weichselian (Houmark-Nielsen, 1987). During the middle Weichselian however, glacial outwash returned, suggesting another ice advance. This came from the Baltic sea and was relatively shortlived, leaving a relatively thin till layer. An even shorter interstadial leaving glacial outwash followed, before another advance came shortly after from Norway. This advance however didn't make it to South Jutland and therefore the glacial outwash layer reaches all the way from the aforementioned first Baltic advance to the Main Weichselian advance, which only just made it to South Jutland, leaving a very thin till layer (Houmark-Nielsen, 1987). Another big layer of glacial outwash material is recorded overlaying this and then the younger and final Baltic ice advance developed, which stopped right at the edge of South-East Jutland (Houmark-Nielsen, 1987). The periglacial conditions probably resulted in the formation of several pingo's as the conditions would have been very similar to those needed for pingo formation in Drenthe during the Main Weichselian ice advance. One of these supposed Danish pingos was chosen as our research site.

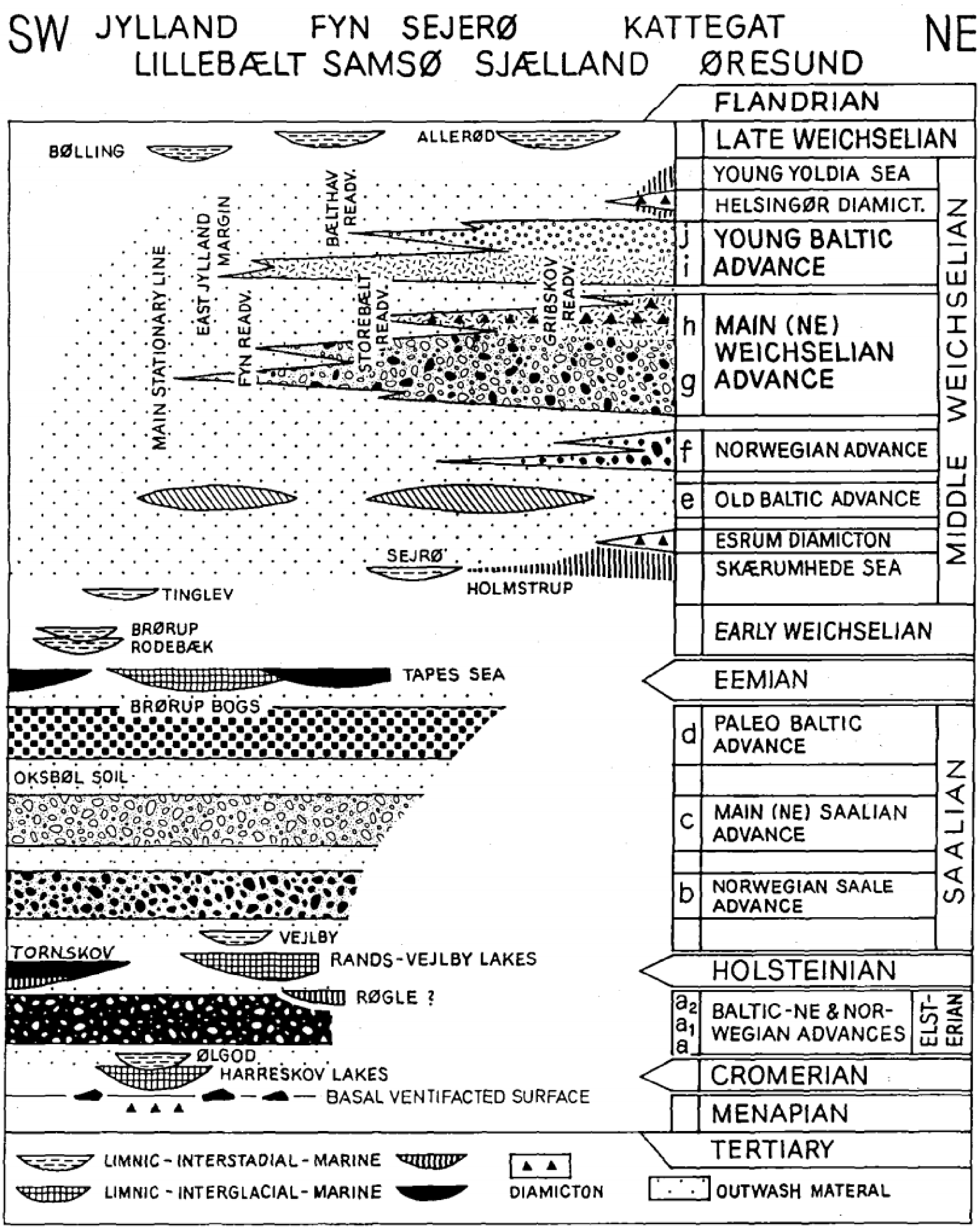

Figure 6 Cross section showing the lithology of Jutland from the south-west to the north-east, with the chronology on the right (Houmark-Nielsen, 1987).

During the late Weichselian no more major ice advances took place in Denmark. The stadial-interstadial dynamic was still present, resulting in the subsequent Oldest Dryas (stadial), Bølling (interstadial), Older Dryas (stadial), Allerød (interstadial) and Younger Dryas (stadial) (Houmark-Nielsen, 1987; Hoek, 1997). Of these the Younger Dryas lasted the longest, which resulted in a reduction of vegetation due to cooling. This greatly increased driftsand activity, resulting in a generally sandy sediment layer marking the Younger Dryas. The end of the Younger Dryas also marked the end of the Weichselian glacial period and the Pleistocene as a whole (Houmark-Nielsen, 1987; Hoek, 1997).

During the Holocene human disturbance started to become an increasingly large factor, just like in Drenthe. Deforestation took place and the fertile soil was turned into farmland throughout Denmark (Bogucki, 1988). This resulted in driftsand complexes like Stensbaek and Frøslev.

§2.2 Vegetation Patterns Review

During the last cold phase of the Weichselian Glacial period, the Younger Dryas, the forests and soils that had developed during the Allerød in North-Western Europe were once again deminished by the return of permafrost conditions. They gave way to open herbacious plant communities, akin to the tundra vegetations that can be found above the Taiga belt today. Indeed the period´s name is derived from the alpine-tundra flower *Dryas octopetala*. The tree species that had made up the dense forests of the Allerød, *Pinus*, *Betula* and *Quercus*, deminished in Northern-Europe (Finsinger *et al*. 2011). At 11.8 ka BP, mean summer temperatures went up by about 5 °C within a timespan of about 50 years (Hoek, 1997). With this the days of the Weichselian glacial were numbered and thus the transition between the Pleistocene and the Holocene was marked.

At the start of the Holocene, during the Preboreal, dense forests comprised of mainly *Betula* and later on *Pinus* formed (see Table 1). This composition changed little for the next 2000 years, followed by the Boreal climatic zone. Although the Boreal is treated as one zone by Blytt-Sernander, two different pollen zones within the Boreal are recognized by both Firbas (1949) and Jessen & Iversen (1935-1941). For during Firbas' Va or Jessen/Iversen's V the Mesolithic birch and pine decline set in, while *Quercus*, *Ulmus* and *Corylus* were able to expand their habitat. This trend continued into the second boreal pollen zone (Vb for Firbas and VI for Jessen/Iversen), but now *Pinus* and *Betula* had declined to the point where *Quercus, Ulmus* and *Corylus* became the dominant genera in the forests of North-Western Europe.

After the Boreal the slightly warmer and wetter Atlantic period began. During the early Atlantic (Firbas' VI) the mixed oak forest established itself in North-Western Europe, although the most important indicator would be the crossover between *Pinus* and *Alnus* (Figure 7/8). This was comprised of *Quercus*, *Tilia* and *Ulmus*. *Corylus* was still very much present, but not as dominantly as it used to. It would also not be uncommon to have local stands of *Pinus* and *Betula* at poorer soils. Spikes of *Betula* would also occur after forest clearings, if these clearings were left to recover. This mechanism in succession can be seen today as well, as even managed heathlands and bogs often contain a lone Birch tree (or are encircled by Birches). There were also already small populations of *Carpinus*, *Fagus* and *Abies* to be found, but these were often sparse and thus do not show up in pollen counts.

The late Atlantic (Firbas' VII) also featured a mixed oak forest with *Quercus* still being dominant. *Tilia* and *Ulmus* however subdued a little and they were replaced by *Fraxinus*. At the end of the late atlantic *Corylus* started to expand again. Also *Alnus* was dominant, but being a genus that likes wet soils this probably means that, like *Betula*, it is somewhat overrepresented in the records found in peatbogs next to the fact that its pollen production is on the high end. Therefore it is likely that *Alnus* was certainly very present, but probably not as dominant as most pollen counts it appears in. Meanwhile during this period *Fagus* and *Abies* still occur sporadically, but they quickly increased in number further South. The Subboreal is mainly characterized by the sharp decline in *Ulmus* during this period. Although *Ulmus* was already declining slightly during the late Atlantic, it now completely drops off and never really recovers. In Denmark this *Ulmus* decline coincides with a sharp *Hedera* decrease which is believed to have been caused by deterioration of the post-glacial optimum that comprises the Boreal and Atlantic (Wright, 1976). While it was previously thought that it was the detoriorating climate that caused the disappearance of *Ulmus*, nowadays the cause is sought in a sudden outbreak of Dutch Elm Disease (Wright, 1976).

years (cal BC)	Archaeological period	Blytt Sernander	Firbas (1949)	Jessen/ Iversen (1935-1941)	RGD	Vegetation development according to general pollen diagrams
	Modern History		X		Vb2	Anthropogenic indicators increase
AD 1500	Medieval Period				Vb1	*Fagus* >5% *Carpinus* >1%
AD 500	Roman Period	Subatlantic	IX	IX		
12	Late Iron Age					
250	Middle Iron Age				Va	*Fagus* >5% *Carpinus* <1%
500	Early Iron Age					
800	Late Bronze Age					
1100	Middle BA B					*Fagus* >1%) *Tilia* decreases
1500	Middle BA A				IVb	
1800	Early Bronze Age					
2000	Late Neolithic B					
2500	Late Neolithic A	Subboreal	VIII	VIII		
2900	Middle Neolithic				IVa	*Ulmus* decreases (<5%) *Fagus* increases Increase anthropogenic indicators
3750						
4200	Early Neolithic		VII			
4900		Atlantic	VI	VII	III	*Querus*, *Ulmus*, *Tilia* and *Alnus* dominant *Pinus* decreases
7000	Mesolithic	Boreal	Vb	VI	II	*Corylus*, *Quercus* and *Ulmus* dominant, *Alnus* and *Tilia* increase, *Pinus* decreases
			Va	V		*Pinus* dominant, but decreasing *Quercus*, *Ulmus*, *Corylus* increase
8000		Preboreal	IV	IV	I	*Pinus* and *Betula* dominant
10000						

Table 1 Major vegetation changes per Archaeological period and Blyth-sernander sequence, based on standardized pollen diagrams by Firbas, Jessen/Iversen and the RGD (the Dutch geological service). (Doorenbosch, 2013).

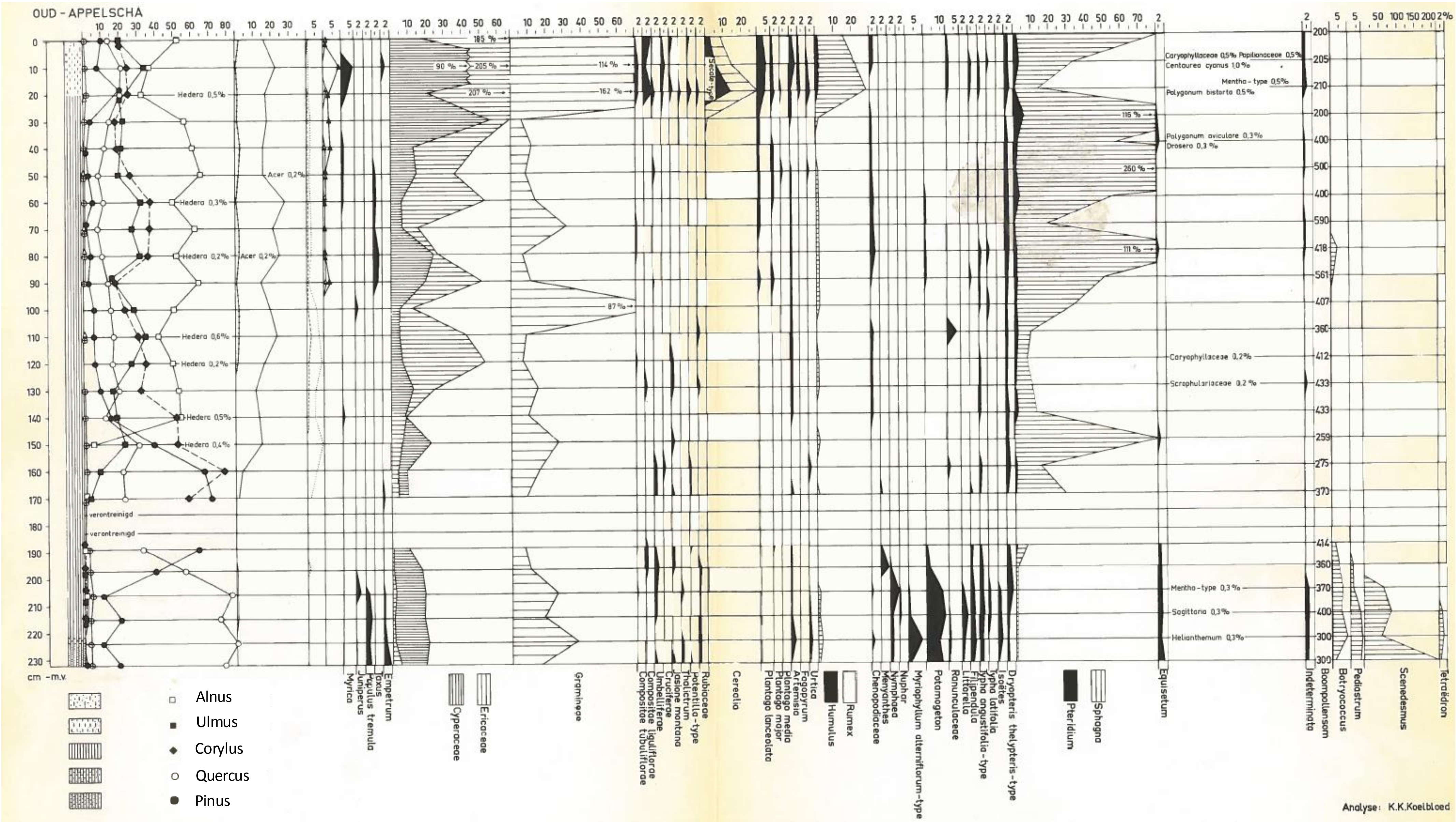

Figure 7 Pollen diagram showing the pollen distribution for the Oud -Appelscha pingo in Drenthe. From the STIBOKA archives

This coincided with the increased human forest management activity after the agricultural wave that swept over Europe (Wright, 1976). Therefore the *Ulmus* populations (and the individual trees themselves) were already damaged when the disease struck. This caused most of the *Ulmus* population to be wiped out within 10 years. Meanwhile the mixed Oak forest was declining, while *Fagus* and *Abies* established themselves firmly and were still expanding in North-Western Europe. The occurrence of Cereals also became increasingly common towards the end of the Subboreal, indicating that agricultural activity was really increasing in intensity at the time.

The Subatlantic is the climatic period we live in today. During this time *Fagus* continued its expansion and *Carpinus* became more numerous. It is also the period during which human activity was the most extreme. The forests that remained from the Bronze Age were further thinned until large parts of both The Netherlands and Denmark were cleared of trees. Only after the fall of the Roman Empire did the forest have a real chance at recovery, as the unrest caused by different peoples moving into new lands made life difficult for permanent settlements. This recovery was short-lived however, as by 900 AD mankind redoubled its agricultural efforts (Kirby & Watkins, 2015).

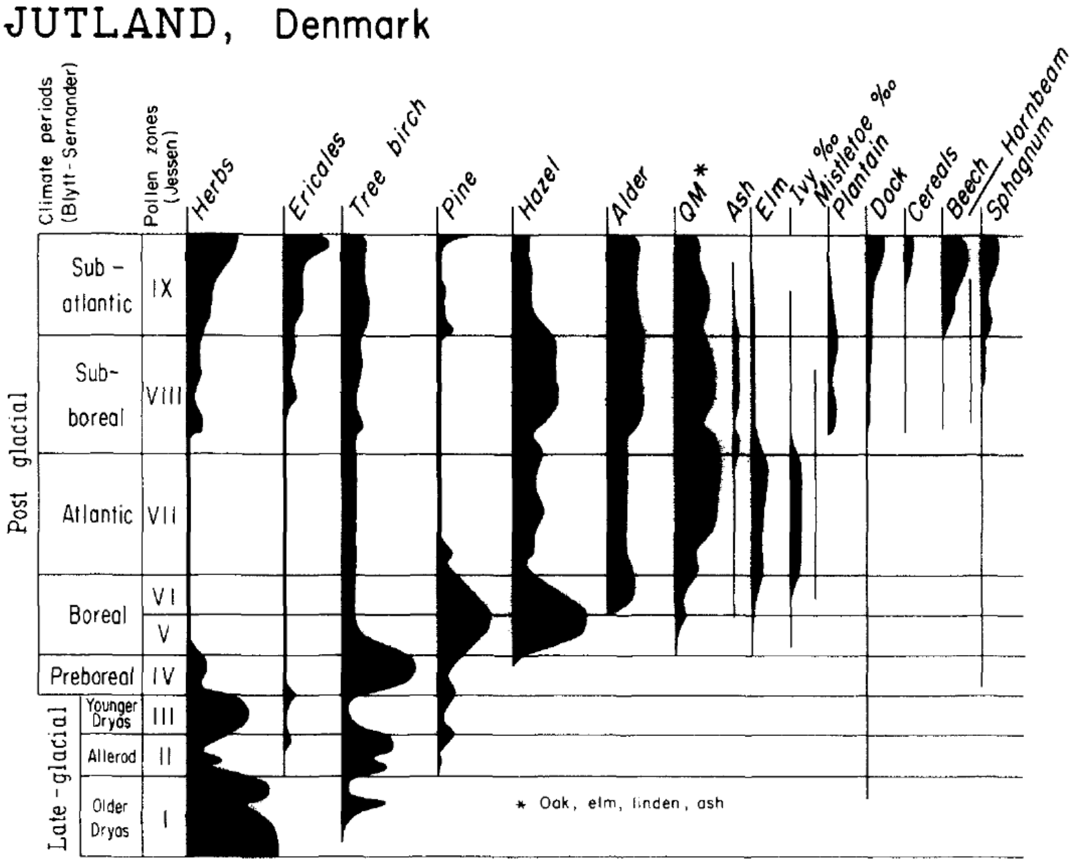

Figure 8 Standardized pollen diagram showing the pollen distribution for the entirety of Jutland with corresponding Blytt-sernander sequences (Iversen, 1941).

§2.3 Material & Methods

§2.3.1 Site selection

Drilling sites in Drenthe were selected based on the AHN (Dutch Lidar elevation map) viewer. Loads of circular depressions – possible pingo remnant candidates - can be found throughout Drenthe on this map. The depressions closest to the Aekingerzand were selected for drilling, as the assumption was that these depressions would have caught the drift sand that had been blown from the Aekingerzand (see Figure 9/10). We also selected a fortress for sampling, in which the peat was nicely preserved beneath the overlaying layer of sand.

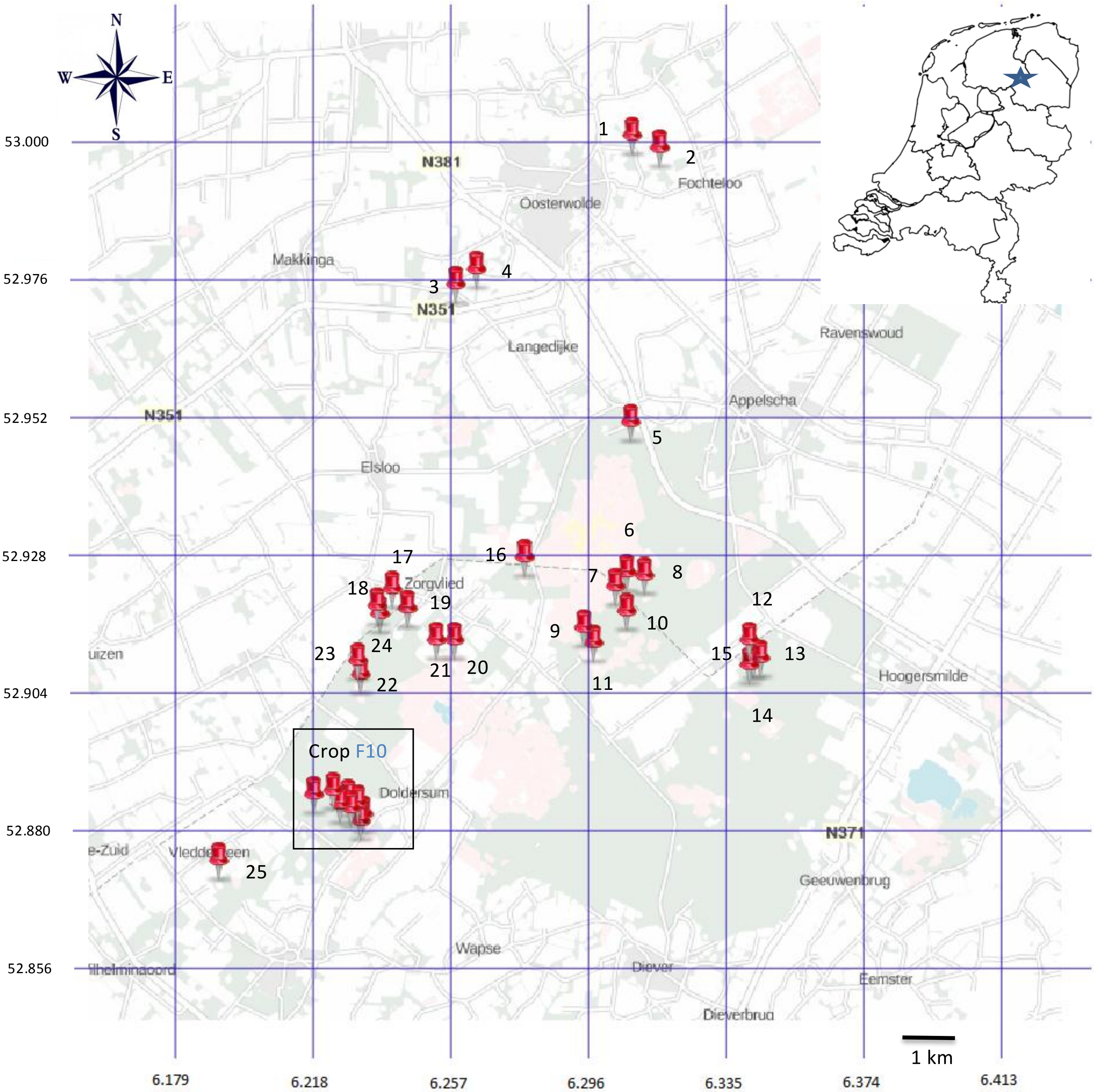

Figure 9 Map of the area around Zorgvlied, showing the various location that were drilled during the fieldwork with coordinates in DD. Coordinates for the various sites can be found in Table 2. Map courtesy of the online Arcgis archives.

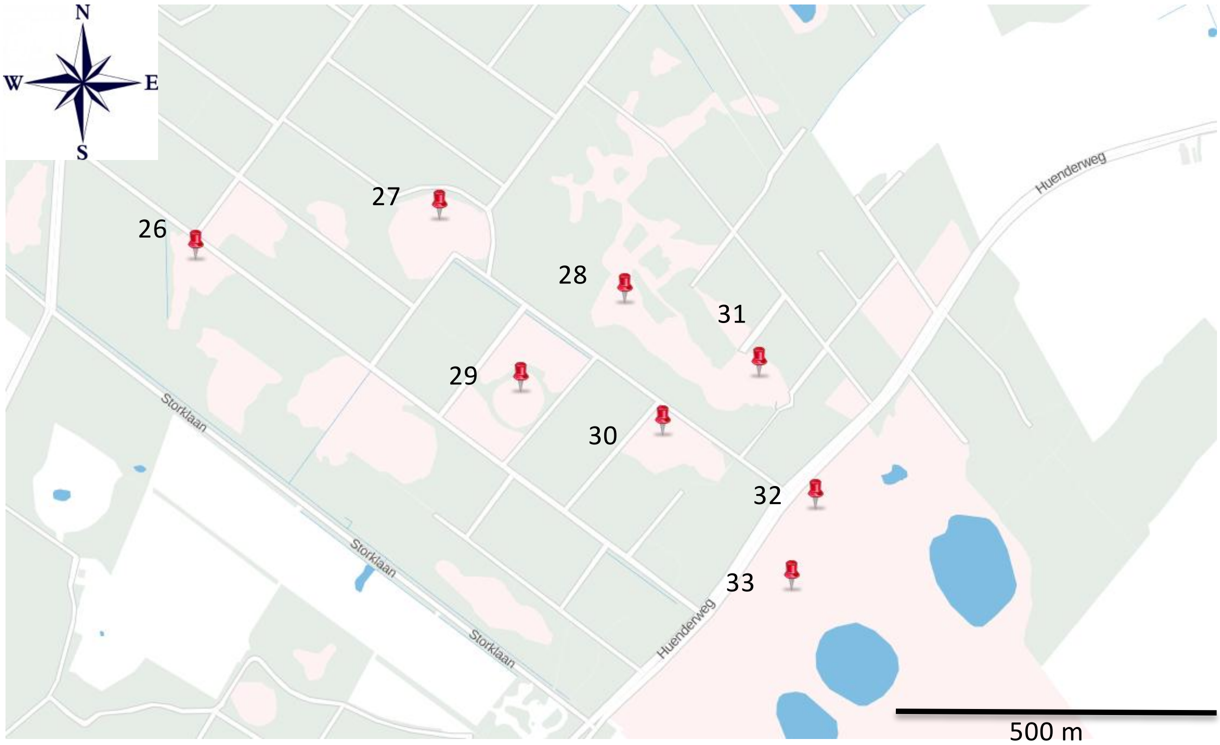

Figure 10 Crop detailing sites that lie close together in Figure 9. Map courtesy of the online Arcgis archives.

Unfortunately peat bogs in The Netherlands were often excavated for the harvesting of the peat for use as fuel. The bogs found around the Aekingerzand were no exception. Both our main sites, the Groote Veen and the Blauwe Gat, were to some extent excavated. Therefore we decided to drill the most elevated parts, assuming these were the most intact. Ironically the sites we found that were seemingly untouched, proved to to big a challenge to drill through, as a thick layer of sand was present in these, which our drills were not able to penetrate. This sand layer explains why the peat was untouched, as sandy peat leaves lots of ash when burned. In Denmark sites were chosen based on a more limited heightmap of the South-Jutland, together with satellite images provided by Google Maps. In the end the Mikkelborg and Padborg sites were chosen because of their pingo remnant like appearance, their accessibility and the presence of sand plains nearby (see Figure 19).

§2.3.2 Drilling methods

Edelman auger and gouge

The various supposed pingo remnants we pinpointed around the Aekingerzand, were drilled with an Edelman handauger and gouge (Figure 11). For most sites this equipment was found to be insufficient however, as a layer of coversand was present in almost all of the sites we tried to drill through. At the Aekingerzand a rectangular metal box was kicked into the side of an excavated raised peat bog. The Edelman gouge was used in Denmark as well, this time not just to analyze the sediment layers, but to actually take cores as well. This was done by relocating the contents of the gauge after drilling, into a pvc-line. For both the Mikkelborg and Padborg site this method was used.

Figure 11 Picture of a drilling set similar to the one used for our fieldwork. The gouges featured here have a diameter of 20, 30 and 60 mm and a length of 50 cm and 100 cm. We utilized the 30 and 60 mm version of the 100 cm gouge. Image courtesy of Eijkelkamp.com

Piston cores and coring platform

For the Blauwe Gat a UWITEC coring platform was used in combination with a Niederreiter piston corer (Figure 12). First the deepest point of the lake was determined using a Vexilar hand sonar after which the shallowest point was determined. Both these points were then drilled by hammering the piston core into the sediment, until it would go no deeper. The resultant cores, captured in pvc tubes, were then cut into segments of one meter in length for easier transport and analysis.
At the Groote Veen another, smaller, piston corer was used with a width of 60 mm. This was custom made and works in much the same way as the Niederreiter piston corer, except without of a core catcher.

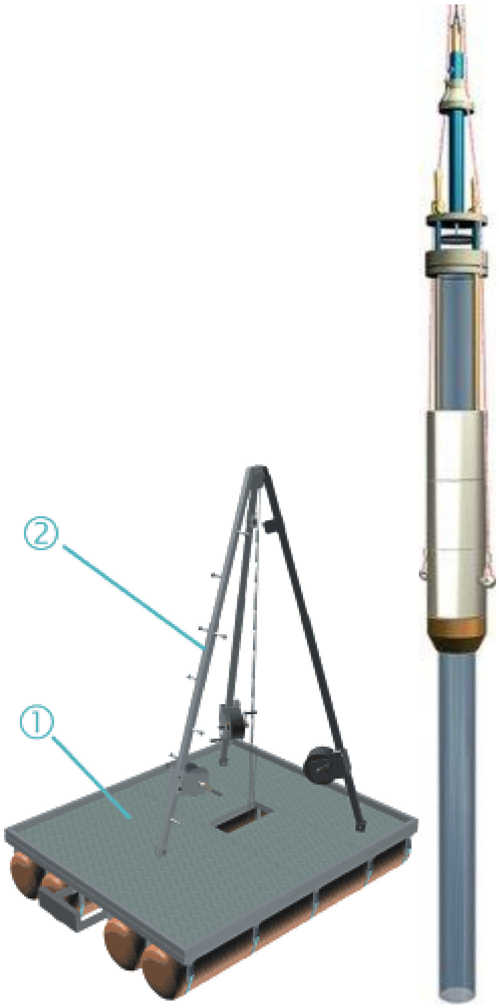

Figure 12 Schematic display of the UWITEC coring platform (1) with its detachable tripod (2) from which the Niederreiter piston corer can be suspended. During the practice of coring the piston inside the sampling tube is held in position, which allows the sediment to go up the sampling tube, thus creating an air tight seal preventing the core from falling out when winched back out of the sediment. A core catcher at the bottom ensures that every last bit of core stays in place. Images courtesy of UWITEC.com

§2.3.3 Sampling methods

LOI

The LOI was determined by sampling roughly 1 cm^3 of material out of every cm in length through the entire core. This was done by cutting grooves, one cm apart, towards the top of the core on both sides of the section we wanted to sample, after which small blocks of 1 cm were cut out between the grooves. This was also done from the bottom to the top of the core. These samples were then put in earthenware trays, after which they were weighed and put in a stove at 105 °C overnight to get rid of the water contained in the samples. The next day they were weighed again to measure their dry weight, after which they were put in an oven at 550 °C for 5 hours. The samples were weighed again after this to acquire the total loss of organic material which ignited in the oven (Heiri *et al*., 2001). The LOI was then calculated using the following formula:

$$LOI = (Wg-Wh)/(Wg-Wb)*100\%$$

Wb = weight of earthenware tray
Wg = dryweight of sample + tray
Wh = weight of sample after ignition + tray

Pollen sampling

Pollen sampling was done by subsampling in the actual core. This was done at a regular interval of 5 cm throughout the cores, apart from sections of the core which seemed especially interesting because of their lithology or depth. In such cases an irregular pattern of first 2 and then 3 cm length between samplings was used. Some sections of the cores also required us to sample right next to the point we actually wanted to sample, because of pieces of wood or other disturbances getting in our way.

The following pollen preparation method was derived from Faegri & Iversen (1989). The 0.3 cm^3 of sample which was put into 15 ml testtubes. These were then supplemented with distilled water, after which a Lycopodium suspension was added with a concentration of 1068 *lycopodia* pollen per millilitre. This was done to be able to get some measure of the actual concentrations of the counted pollen as they were in the core. To achieve this the *Lycopodia* spores in the finished slides were counted alongside the pollen originating from the core. As the amount of counted *Lycopodium* rises for a slide, the concentration of the original pollen decreases. Five ml of 5% KOH solution was then added to break the humus bonds in the mixture. To accelerate this process the samples were then placed in a 70°C oven for sixty minutes. After this the samples were sieved through a 200 µM sieve to get rid of any macrofossils. They were then washed out to remove the leftover KOH.

Acetolysis was performed to break down any remaining humic substances even further. This was done by first getting rid of the distilled water through washing the test tubes with acetic acid. Four ml of a nine part acetic anhydride/one part H_2SO_4 mixture was then added and subsequently the test tubes were put into a water bath of 100°C for 10 minutes. The acetolysis mixture was then washed out and replaced by distilled water again.

To further separate the humus debris from the pollen, four ml of sodium polytungstate was added to the tubes after decantation of the distilled water. The mixture was then centrifuged at 1700 rpm for 15 minutes to separate the pollen from heavier particles. The floating pollen were than decanted into another tube after which 10 ml of distilled water was added to the new tube and another 4 ml of sodium polytungstate was added to the original tube to make sure every last bit of pollen would end up in the new tube. The test tubes (both new and original) were then centrifuged again at 1700 rpm for 15 minutes and subsequently the sodium polytungstate/distilled water mixture in the new tubes was decanted. Then the leftover floating pollen in the second batch of sodium polytungstate in the original tubes were decanted into the new tubes again upon which the original tubes were thrown away.

The new tubes with the pollen content were then subjected to another 1700 rpm centrifuge round of 5 minutes after which the leftover sodium polytungstate was decanted again and the tubes were washed out. Ethanol was then added and the test tubes were vortexed to ensure an even mix of ethanol and centrifuge substrate. The contents of the test tubes were then decanted into Eppendorf cups and centrifuged at 1700 rpm for 2 minutes. The leftover ethanol was then decanted and an amount of glycerine, equal to the volume of the pollen substrate, was added. The Eppendorf cups were then placed into a 70°C oven for a night with the lids open to ensure that all the leftover water and/or ethanol would be evaporated. The glycerine/pollen substrate mixture was then properly mixed and put on slides to be viewed using a microscope. The slides with cover slips were sealed using heated candle wax.

§2.3.4 Pollen diagrams

Determination and structure

Pollen determination was done using ‘The Northwest European Pollen Flora’ (Punt *et al*., 2003) and ‘Pollen Anlysis’ (Moore & Webb, 1991). The resulting pollen counts were then stored in an Excel sheet, after which the pollen diagrams were made by importing the excel sheets into Tilia v. 2.0.41. The pollensum was chosen to only include pollen that are distributed on a regional scale. Therefore only wetland trees such as *Salix* and *Alnus* were left because of potential overrepresentation, while all the other, more dryland tree genera, were kept in. All aquatic vegetation was also taken out, as their pollen tend to not be spread further than the lake or pool they originate from and are thus overrepresented in the diagram as well. Finally fern and horsetail spores were kept out because of the dependence of the plants themselves on the plentiful availability of water, which thus also causes their spores to probably be overrepresented in lake sediments as they were probably standing very close to the lake (Lowe & Walker 2014). The size of the pollensum was chosen to be at least 150 if the amount of pollen in the sample was sufficient.

Age model

The pollen records were dated by comparing major vegetation transitions to those known from literature. For this purpose a study on the pollen record of the Oud-Appelscha pingo in Drenthe was utilized for the sites in the Netherlands (STIBOKA archives, see Figure 7). For dating the Padborg record in Denmark the standardized Jutland diagram by Iversen was used for lack of a better suited diagram from the area (Iversen 1941, see Figure 8).

Chapter 3: Lithological Results

§3.1 Netherlands

The sites we probed in The Netherlands for this study are listed in Table 2 and composed in the overview that Figure 9 and Figure 10 provide. From Table 2 it becomes clear that our equipment was indeed unfit for the overwhelming majority of the drilled sites, as 28 out of our 33 depressions were found to be covered by a recent sand influx. Therefore many sediment archives were simply not accessible to us. This left us with the sites 1, 9, 19, 22 and 25 as potential candidates for coring. However site 1 proved impossible to access because of a very thick reed vegetation standing on top of the depression. Site 19 was similar to site 1 in that reed occurred in this depression as well. All the peat found inside was found to be very young and disturbed. Also the piston corer failed to retain the sediment, which immediately slid out every time we tried to take a proper core. Site 22 seemed promising, but was too wet to get a cross-section or proper core from without a coring platform. Therefore the focus lies on 9 (Groote Veen) and 25 (Blauwe Gat).

#	N	E		#	N	E	
1	52.99705	6.31358	Sandy	18	52.91520	6.23787	Sandy
2	52.99478	6.32140	Sandy	19	52.91513	6.24665	Very young peat
3	52.97148	6.26170	Sandy	20	52.90904	6.26006	Sandy
4	52.97405	6.26794	Sandy	21	52.90906	6.25489	Sandy
5	52.94687	6.31229	Sandy	22	52.90321	6.23288	Potential, but too wet
6	52.92051	6.31049	Sandy	23	52.90564	6.23222	Sandy
7	52.91818	6.30712	Sandy	24	52.91396	6.23855	Sandy
8	52.92008	6.31559	Sandy	25	52.87093	6.19124	Blauwe Gat site
9	52.91095	6.29783	Groote Veen site	26	52.88244	6.21881	Sandy
10	52.91381	6.31006	Sandy	27	52.88295	6.22442	Sandy
11	52.90825	6.30042	Sandy	28	52.88176	6.22866	Sandy
12	52.90843	6.34574	Sandy	29	52.88054	6.22624	Sandy
13	52.90535	6.34887	Sandy	30	52.87991	6.22951	Sandy
14	52.90419	6.34544	Sandy	31	52.88071	6.23174	Sandy
15	52.90499	6.34678	Sandy	32	52.87887	6.23301	Sandy
16	52.92340	6.28088	Sandy	33	52.87774	6.23243	Sandy
17	52.91817	6.24247	Sandy				

Table 2 table detailing the coordinates of the various drilled sites featured in Figure 9/10. Sandy sites proved to be impossible to drill through with our equipment.

§3.1.1 Groote Veen

The Groote Veen (52.91095°N, 6.29783°E) is a peat bog located near the village of Zorgvlied in Drenthe (Figure 13). The central part of the depression is very clearly disturbed by human activity, as can be seen by the straight sides and the trench like lines that are lying in an orderly fashion. The overall contours however, seem to be more circular and therefore make it a pingo candidate. While navigating the Groote Veen to try and find suitable places to drill, the first impression of it being disturbed was further confirmed. Square pits in the peat, filled with water and *Sphagnum* moss, were scattered all over the site. There were however patches of seemingly undisturbed peat between the pits, so it was decided to drill those in as straight a line as possible. The depression measured about 125 m across.

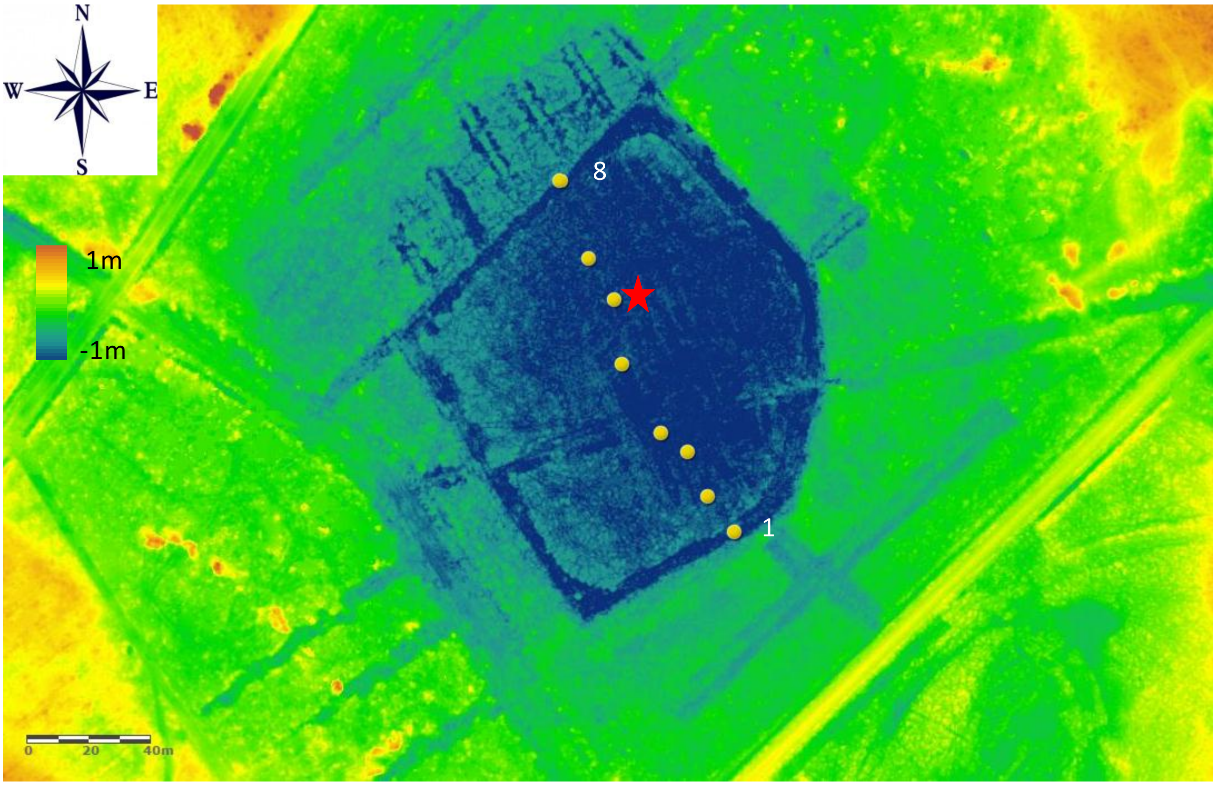

Figure 13 Heightmap showing the drilling (yellow dots) locations of the Groote Veen and the coring location (red star). Map courtesy of the online Arcgis archives.

Lithological description

The cross-section found in Figure 14 is based on 8 drillings with a gauge which were taken in a NNW direction (see Figure 13). From the cross-section it is clear that most of the infill consists of a mix of sand and organic material. The shape of the infill seems to be fairly symmetrical, although our most Northern drilling seems to have missed the margin of the depression by about 10 meters. The deepest point of the cross-section is defined by the deepest non fine sand layer found in our drillings. This was a small layer containing a mix of peat and fossil leaves which started at a depth of 267 cm and ended at 270 cm depth.

At the bottom of almost all drillings a layer of fine sand was found, which seems to mark the boundary of the infill. Superimposed lies a layer of gyttja, which at drilling 2 and 6 contained small patches of plant remains. It was also found to be somewhat sandy at drilling 4, which caused the border between the gyttja and fine sand to fade a little.
On top of the gyttja layer lies a sandy peat deposit. At some places, like drilling 5 and 7, this layer contained small bands of moss peat indicating that the Groote Veen has had similar vegetation populations to what it now has in the past.
Superimposed lies a layer of sand with a peaty appearance and texture. Herein also small stratified sand lenses can be found, indicating that most of the peaty sand layer stems from the Younger Dryas. At drilling 6 this layer reaches its maximum thickness of 110 cm and maximum depth of 230 cm. At the top lies a layer of sandy peat reaching a maximum depth and thickness of 160 cm at drilling 4. This peat layer probably spans the Holocene, judging from the very sandy infill laying beneath it.

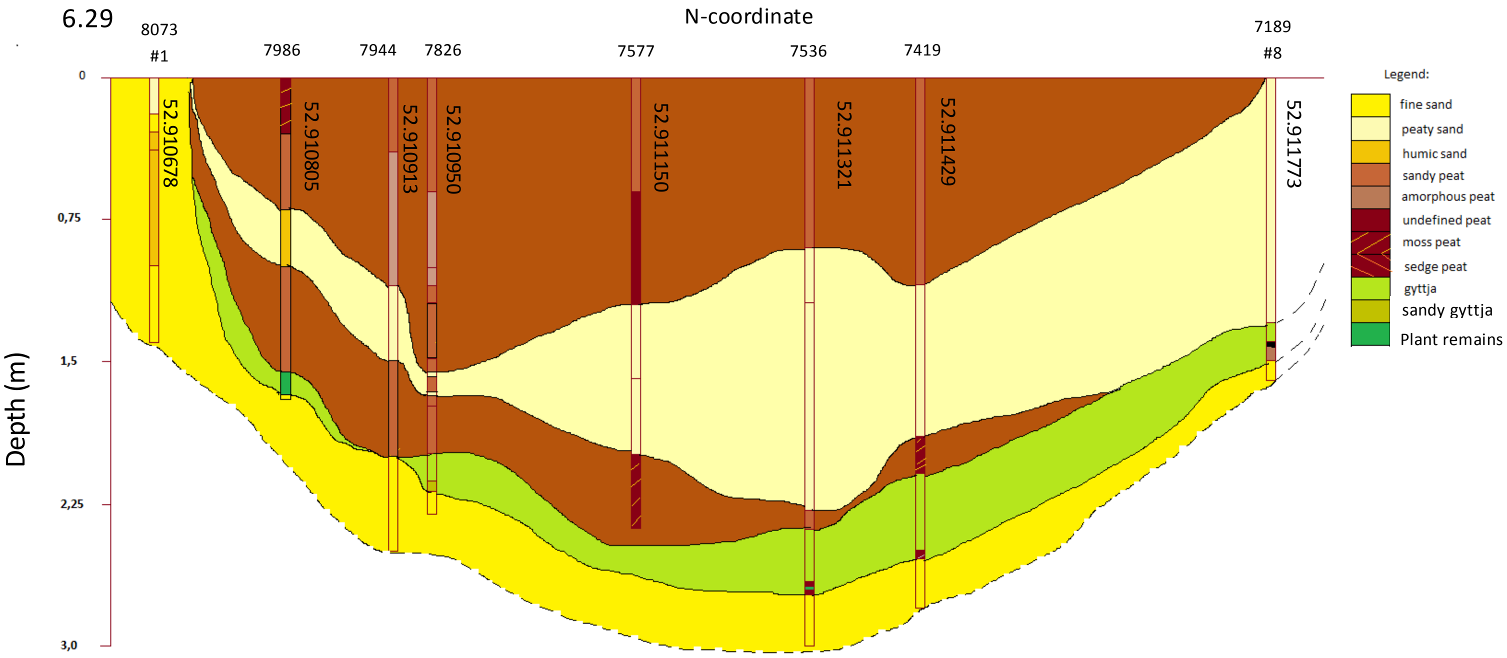

Figure 14 Cross section of the Groote Veen. Coordinates are in DD. Drillings are numbered 1 to 8 from left to right. E-coordinates are given vertically right of each drilling. The star shows the location the cores were taken from in the cross section.

At drilling 3 and 4 part of this layer was described as amorphous peat, lacking any form of stratification or other structure. Therefore it should be noted that at least part of this infill might still be disturbed, despite our efforts to drill around the excavated parts.

LOI

Several cores were taken using the custom made portable piston corer next to drilling 6 (52.911399E, 6.297446N). The LOI curve taken from these cores can be seen in Figure 15. It corroborates the cross-section of the Groote Veen, as it starts with low LOI values for the sandy bottom of the infill. After this the LOI rises, which is again in agreement with the lithology, as this shows peat and gyttja for the depths covered by the high LOI plateau. This relatively high LOI is followed up by an LOI drop which is corroborated by the large, very sandy, deposit that can be seen in the middle of the cross-section in the lithology. Above this section (at 100 cm) the LOI goes up again, which again can be seen in the

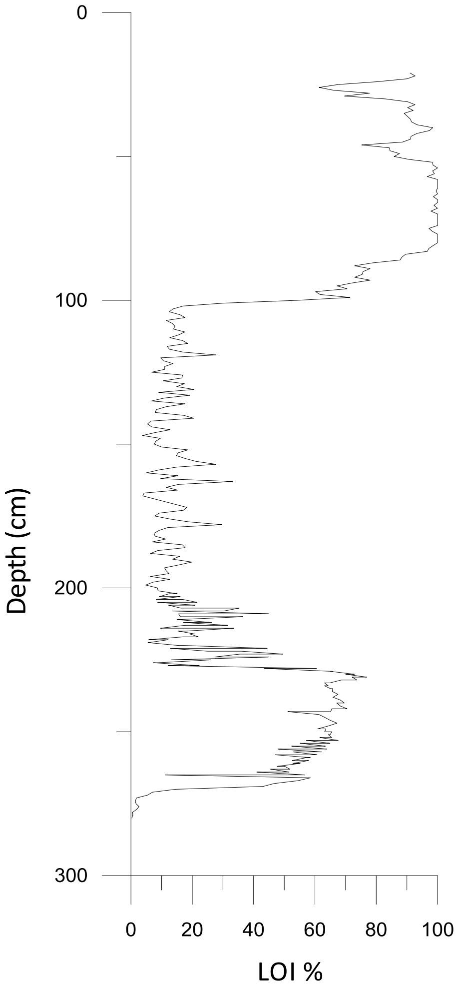

Figure 15 LOI curve for the Groote Veen core.

lithology as well, for upwards from 100 cm peat was again found in the core. Between 80 cm and 50 cm depth the LOI sits very stably near 100%. After this the stability is gone with two marked drops at 50 cm and 25 cm depth

Interpretation

If we assume that indeed the Groote Veen is a pingo remnant, it would make sense to place the bottom of the infill at the end of the Saalien. This fits nicely, for the high LOI at the bottom of Figure 15 and the gyttja/sandy peat deposits of Figure 14 may then be correlated to the Eemian interglacial. This means that the thick sandy deposit with the low LOI overlaying this section probably stems from the entire Weichselian glaciation, where vegetation would have been relatively scarce and thus drift sand activity ample. With the rising LOI and the comeback of sandy peat directly following the Weichselian section, the Holocene started, yielding a highly stable LOI for the next 30 to 40 cm. The LOI then becomes less stable, probably due to human activity.

§3.1.2 Blauwe Gat

The Blauwe Gat is a lake located near Vledder in Drenthe (Figure 16). During the first part of the 20th century it must have bared a lot of resemblance to the Groote Veen, as it was a partly excavated peat bog featuring standing water here and there. During the 60´s however, the water level was raised by about a meter and became the small lake it is today. The deepest part of the lake turned out to be 2,2 meters. During the bathymetry mapping we discovered a thin patch of the lake floor that lay very shallow, at about 0.6 meters depth, which was seemingly untouched by the peat excavation. At the Blauwe gat a piston corer and a small gravity corer were used in combination with a coring platform. The deepest and most shallow points described above were drilled. With a diameter of 190 m this was the largest depression we analysed.

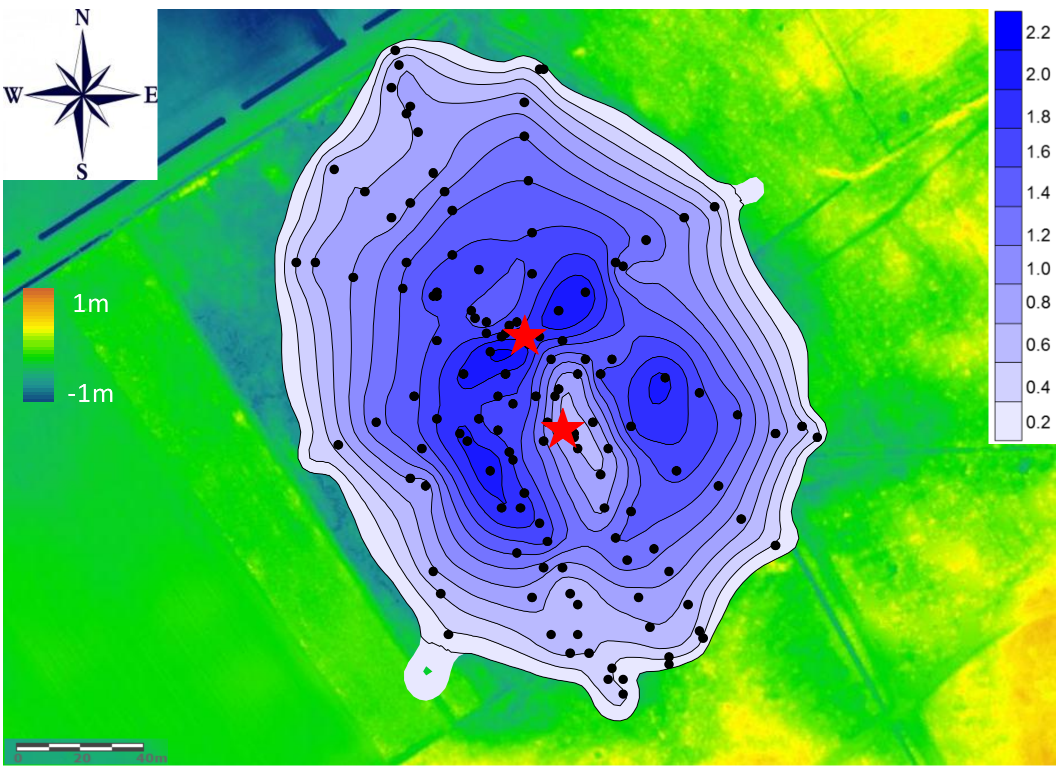

Figure 16 Heightmap and bathymetry showing the coring locations of the Blauwe Gat. Bathymetry legend is in meters. Map courtesy of the online Arcgis archives.

Lithological description

No cross-section was made as there were too little drilling points to be able to properly correlate the stratigraphy. The descriptions and positions of the taken cores can be seen in Figure 17 however. The cores were taken in two pairs of drillings, in which the paired drilling holes were very close to each other. As far as it is possible to say anything about the shape of the infill with only three cores reaching the bottom, it seems to be fairly symmetrical. The deepest part of all the taken cores was reached at the bottom of core B-2, which could not be hammered deeper than 450 cm from waterlevel. The deepest part of the infill found in our cores, which was identified as sandy gyttja, stopped at 419 cm depth at core B-2.

As with the Groote Veen, all three drillings that went through the entire infill landed in a layer of fine sand. Below the sand at B-2 at a depth of 248 cm, a layer of gravel was encountered, which ended up getting our piston core stuck. Overlaying the sandy layer a sandy gyttja layer was identified in A-2, B-2 and C-II2 at 395, 419 and 385 cm depth respectively. This sandy gyttja then turns into a normal gyttja in both core A-2 and B-2 at 387 and 413 cm depth, while in C-II2 it remains sandy. The gyttja in core B-2 was found to be fairly mossy. This gyttja layer turns into a slightly more sandy gyttja again in A-2 at 359 cm depth, while in B-2 this sandiness is absent. Overlaying the gyttja lies a thick deposit of peat in all three cores. In C-II2 (from 362 cm depth) this peat is sandy for the first 40 cm, after which it turns to sedge peat which was found in A-2 and B-2 as well (from 349 and 382 cm depth respectively). The entirety of core C-I2 (290-190 cm depth) is made up of sedge peat as well, just like all but the topmost 3 cm of core C-II1 (286-221 cm depth). This 3 cm consisted of amorphous peat, just like the entirety of both the C-I1 (190-160 cm depth) and Grav core (107-90 cm depth).

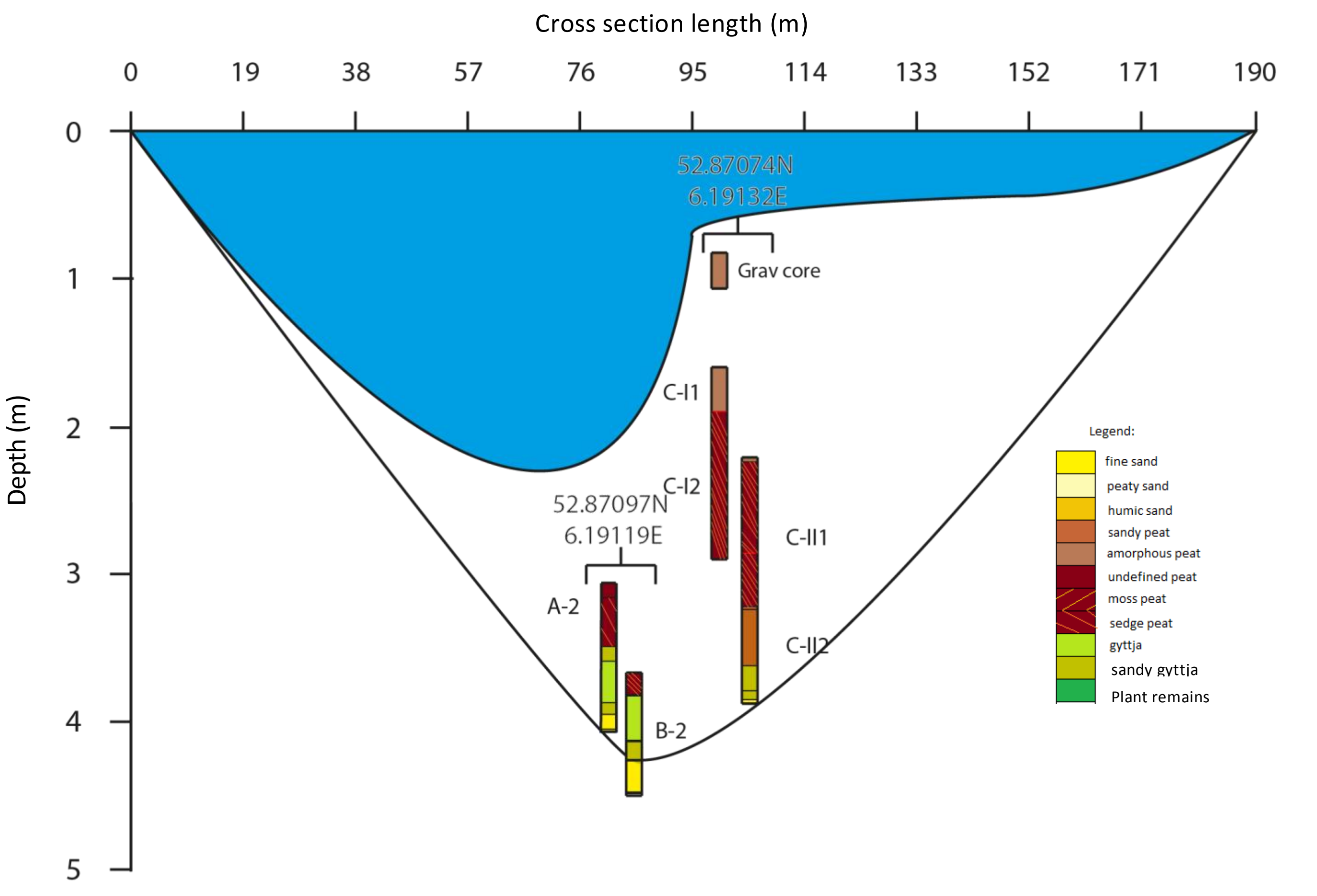

Figure 17 Positions of the cores taken at the Blauwe Gat. Coordinates are in DD.

LOI

In the LOI curves for A-2 and B-2 (Figure 18) the same basic trend can be seen as at the Groote Veen. Although there is a slight offset between the two curves, they both show a sudden peak in LOI right above the sandy bottom layer. After this first peak, a drop follows. Then both curves show a maximum, which could be the Allerød interstadial during which organic production would have increased again. Both curves then finally drop again because of the supposed Younger Dryas, at which point the curve for B-2 stops. The curve for A-2 starts going up again after the Younger Dryas drop, into the Holocene during which the LOI is near 100%.
The accumulated LOI curve for the C-cores shows this same basic story (Figure 18). The deepest drop is not as pronounced as in both core A and B, probably caused by the lack of a real peak at about 355 cm depth. The Younger Dryas drop, coming right after, is however clearly there and for these cores the Holocene LOI stays at a very stable near 100% as well. Only at the Grav core the LOI starts dropping off a little, which can probably be related to a great increase in human agricultural activity.

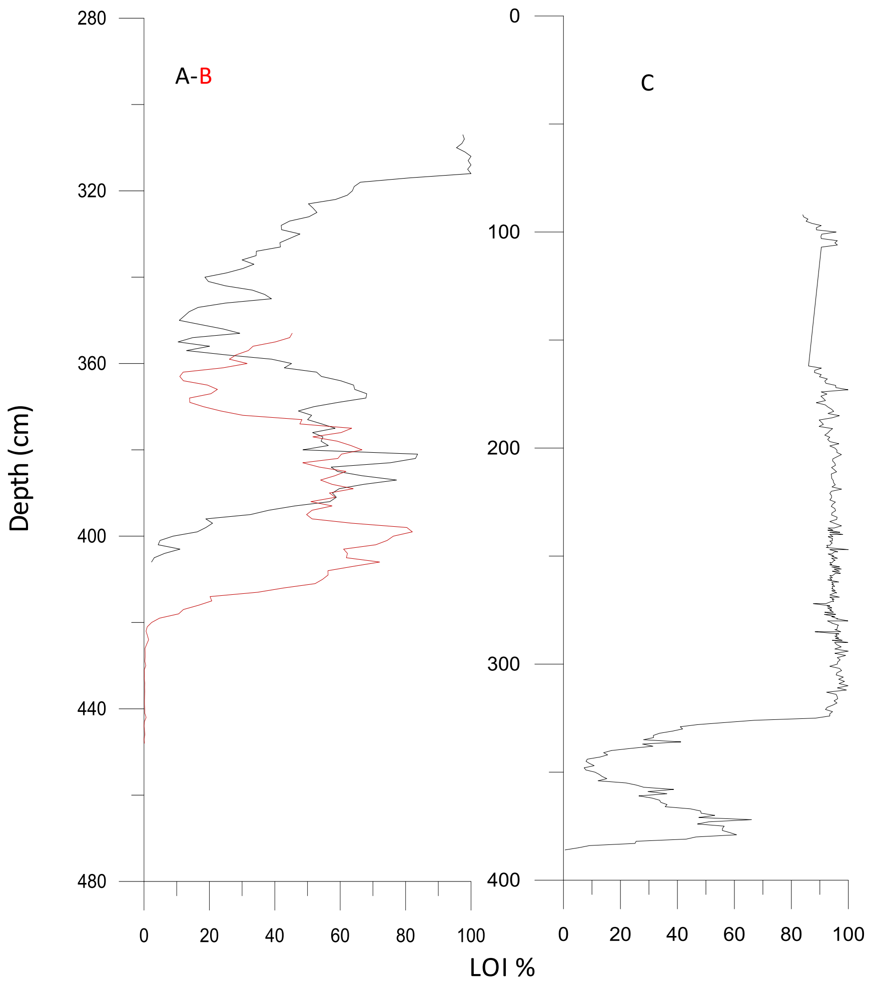

Figure 18 LOI curves for the Blauwe Gat cores, with core A and B (with B being the red curve) on the left and C on the right.

§3.2 Denmark

In Denmark we selected two depressions in South-Jutland, both with drift sand complexes nearby. This selection came down to a depression near Mikkelborg, in the middle of South-Jutland, and a depression near Padborg, some 10 km North of the border with Germany (see Figure 19).

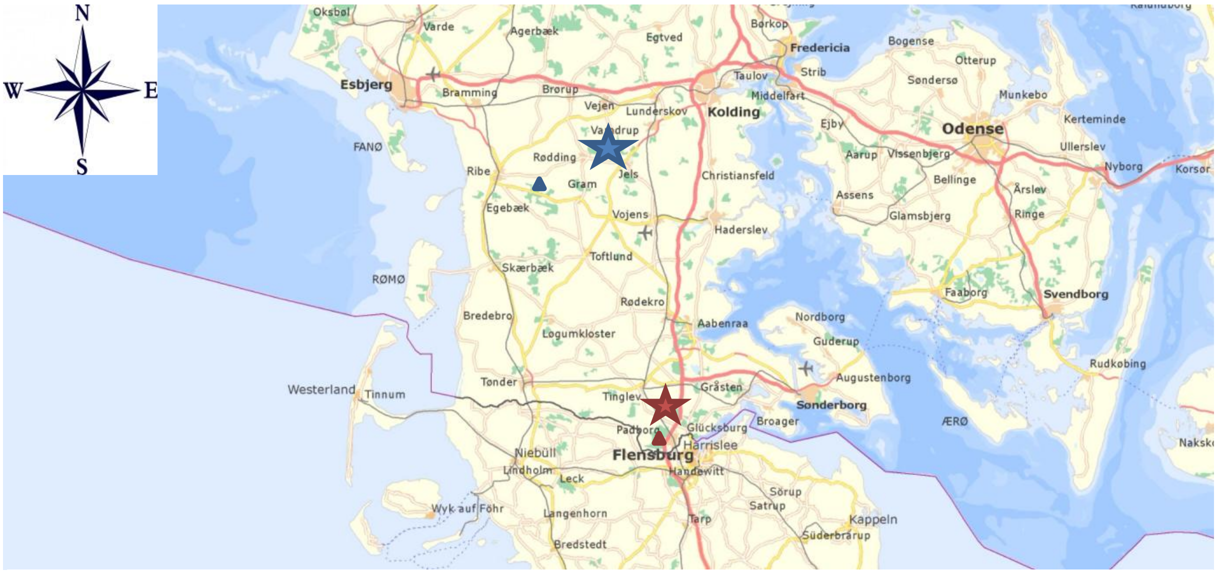

Figure 19 Map of South-Jutland showing the location of the Mikkelborg (blue star) and Padborg (red star) sites and the Stensbaek (blue triangle) and Frøslev (red triangle) sandplains. Courtesy of the GEUS institution.

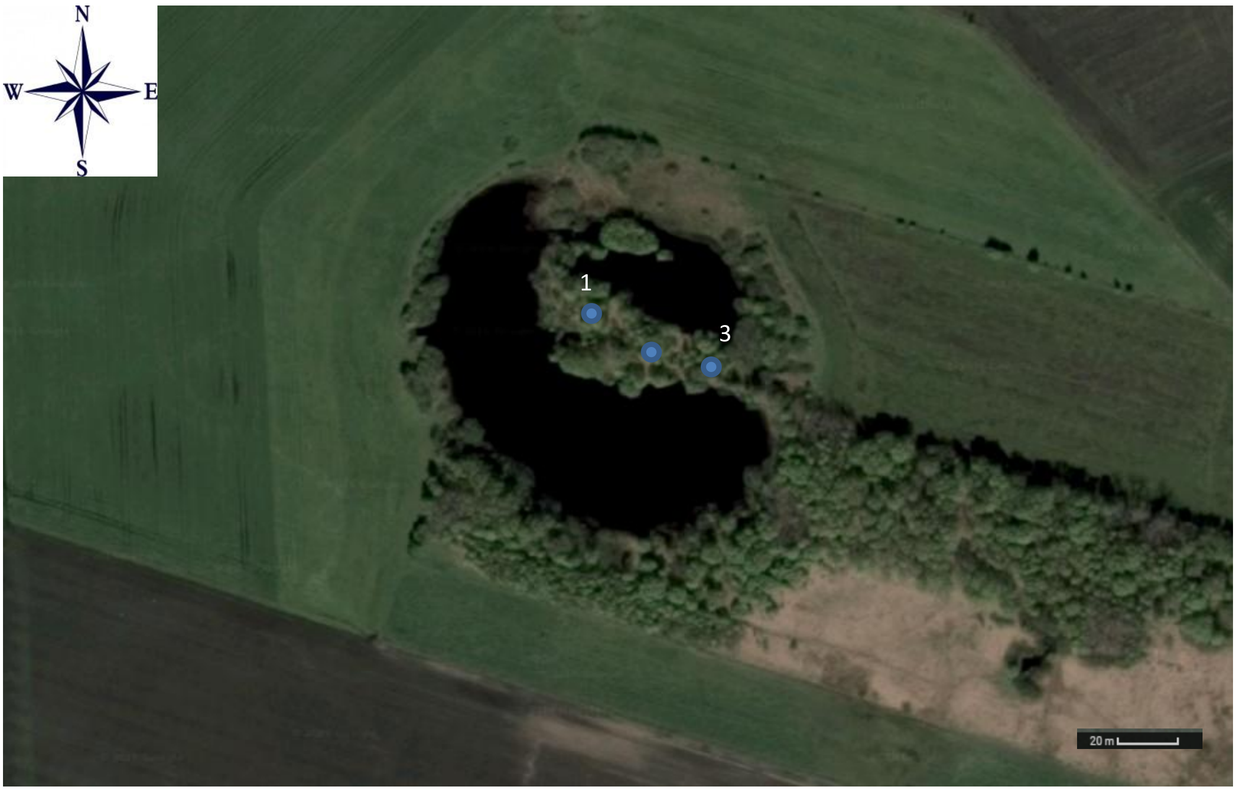

Figure 20 Satellite image showing the Mikkelborg site with the blue dots indicating drillings 1-3. Image courtesy of Google maps.

§3.2.1 Mikkelborg

The first depression we drilled in South-Jutland was located just North-East of Rødding, near the very small town of Mikkelborg (Figure 20). West of it lies the Stensbaek sandplain, from which driftsand was blown towards the Mikkelborg site where it was captured. The depression is similar to the Blauwe Gat in that it is a small circular excavated lake, with the subtle but important difference that the water level was not artificially raised at the Mikkelborg depression. Hence an elevated overgrown walking path, presumably used by peat cutters to transport the peat, was still usable to get to the middle of the depression without needing a coring platform. The depression measures about 170 m across.

Lithological description

Three drillings were done at the Mikkelborg depression, in a straight line along the walking path (see Figure 21). As the drilling line only stretched halfway across the depression, the actual shape of the infill remains unclear. The deepest point was reached in drilling 3, which stopped at 390 cm as the humic sand became too sandy. The deepest point of the actual infill must have been deeper therefore, as the humic sand layer was not the deepest layer we encountered in drilling 1 and 2 (see Figure 21). The contents of drilling 2 were used to produce a core.

At the bottom of drilling 1 we were able to drill through the sand layer which stopped at 170 cm depth, that usually marks the end of the infill. Below this we found a layer of glacial till, suggesting the depression was formed right after the last Weichselian ice advance in Denmark. In drilling two the aforementioned sand layer is present as well from 314 cm depth, although we were not able to drill through it. Overlaying the sand layer lies a deposit of humic sand in all drillings, with this layer starting at 140 cm depth in drilling 1, 314 cm at drilling 2 and at least 390 cm at drilling 3. In drilling 2 this humic sand layer ends up in a deposit containing fossil leaves at 210 cm depth. After the humic sand/fossil leaf layer a transition to a thick moss peat deposit is present in drilling 2 at 200 cm depth and 3 at 260 cm depth, which then transitions to a sedge peat layer (at 75 cm depth) and back to a moss peat layer (at 65 cm depth) for drilling 2. Drilling 1 cuts straight to the sedge peat layer at 90 cm depth after the humic sand and then also transitions to a moss peat deposit at 80 cm depth. The sedge peat layer is absent in drilling 3, which from 180 cm depth contains only undefined peat up until the top. Topping off both drilling 1 and 2 lies a layer of amorphous peat from 60 and 50 cm depth respectively.

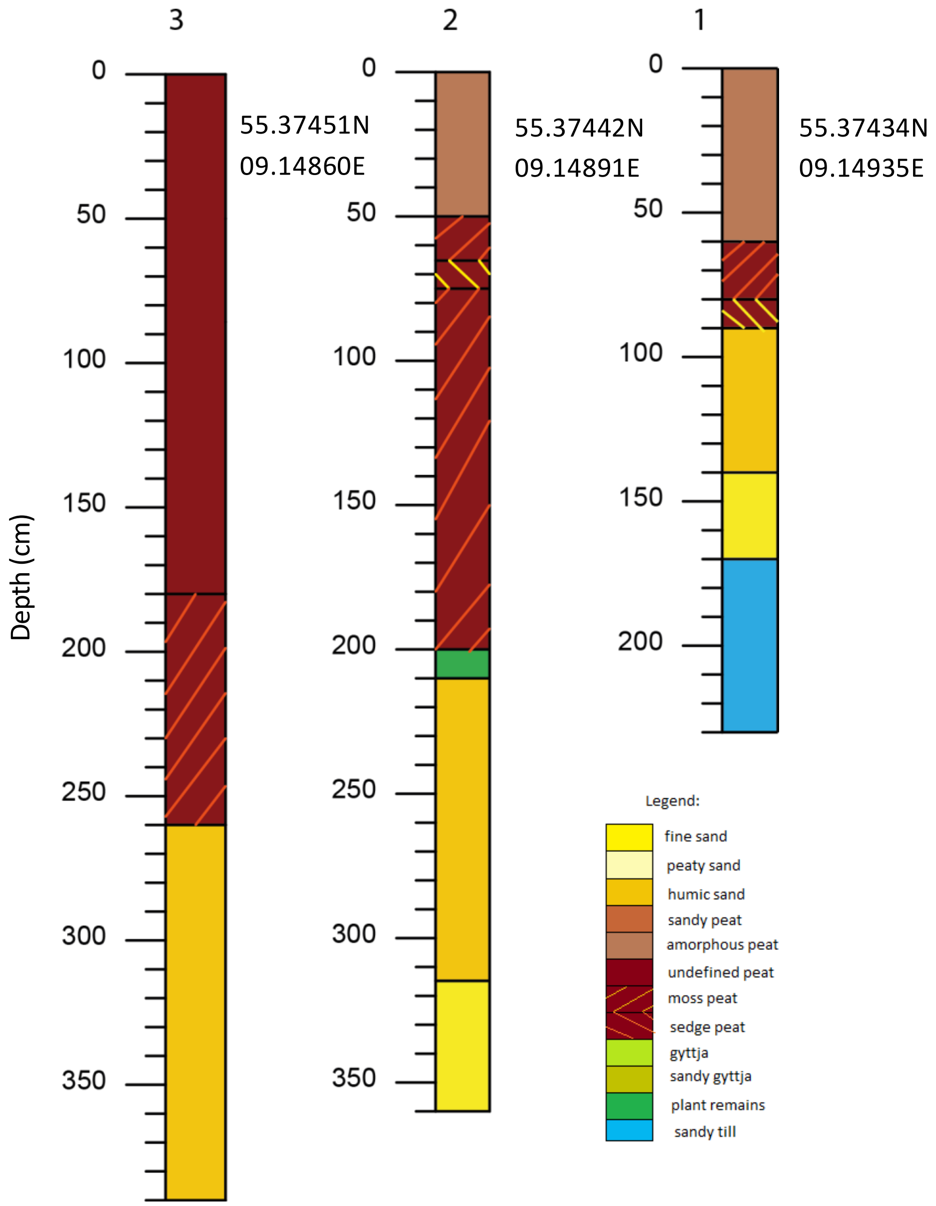

Figure 21 Lithological descriptions showing the contents of the drillings done at the Mikkelborg site. Coordinates in DD.

§3.2.2 Padborg

The second depression we drilled in South-Jutland was located North-West of the village of Padborg, near the Padborg airport (Figure 22). To the south of it lies the Frøslev sandplain, from which driftsand blew towards the Padborg site. With a diameter of about 115 m, it is the smallest depression we analysed. As it lies in the middle of a patch of farmland, the pingo rim it featured was very clearly visible. It was also probably the least disturbed of all the depressions we analysed as it was overgrown with trees and bushes and didn't show signs of any excavations (apart from some caterpillar tracks probably stemming from the last tree cutting).

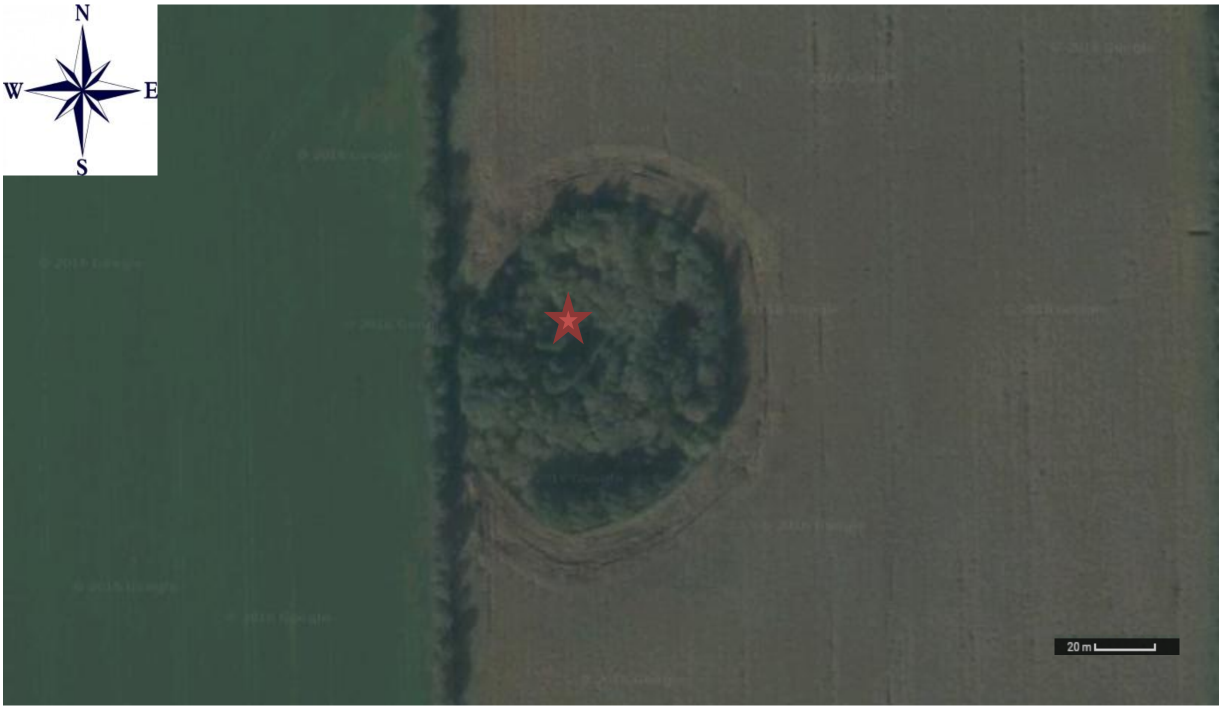

Figure 22 Satellite image showing the Padborg site with the red star indicating the location of the coring. Image courtesy of Google maps.

Lithological description

At the Padborg site only one core was taken and analysed (Figure 23). At this site the depression was 320 cm deep. At the bottom of the drilling a deposit of sand was found, again marking the end of the infill. A layer of sandy gyttja was found overlaying the sand layer at 306 cm depth. This transitions into a thick deposit of sedge peat at 280 cm depth, which is followed up by a layer of more sandy peat at 175 cm depth. This sandy peat then transitions back into undefined peat at 150 cm depth, after which the top layer contains (perhaps disturbed) amorphous peat showing very little stratification from 120 cm depth.

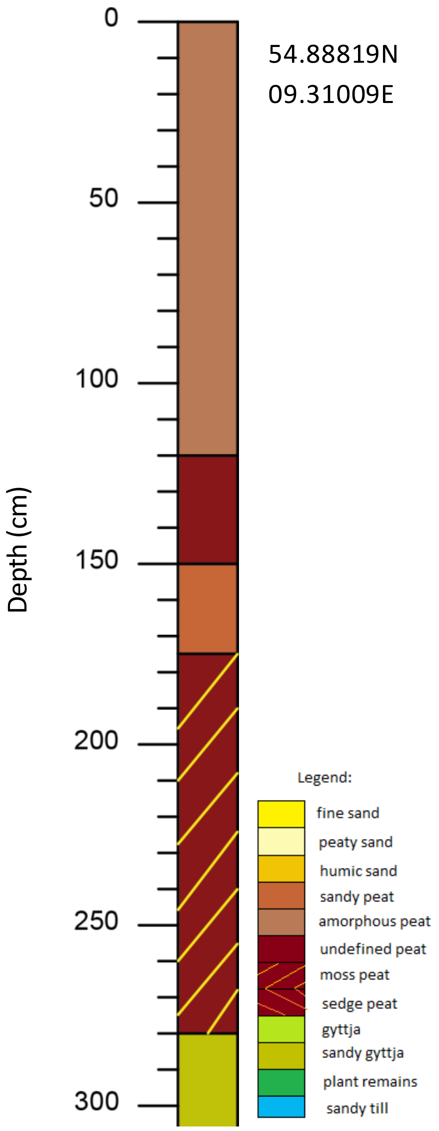

Figure 23 Image showing the contents of the coring done at the Padborg site. Coordinates in DD.

LOI

The LOI curve for the Padborg record shows somewhat of a strange picture (Figure 24). The bottom section clearly shows a driftsand influx, which abruptly transitions into a very high organic percentage at 230 cm depth. The curve then proceeds to slowly venture into the lower percentages again, indicating some sort of aeolian influx, whether it be anthropologically induced or caused by a climate change. The record then shows a slight offset for the next core section (the red curve) which promptly shows a major decrease in drift sand influx.

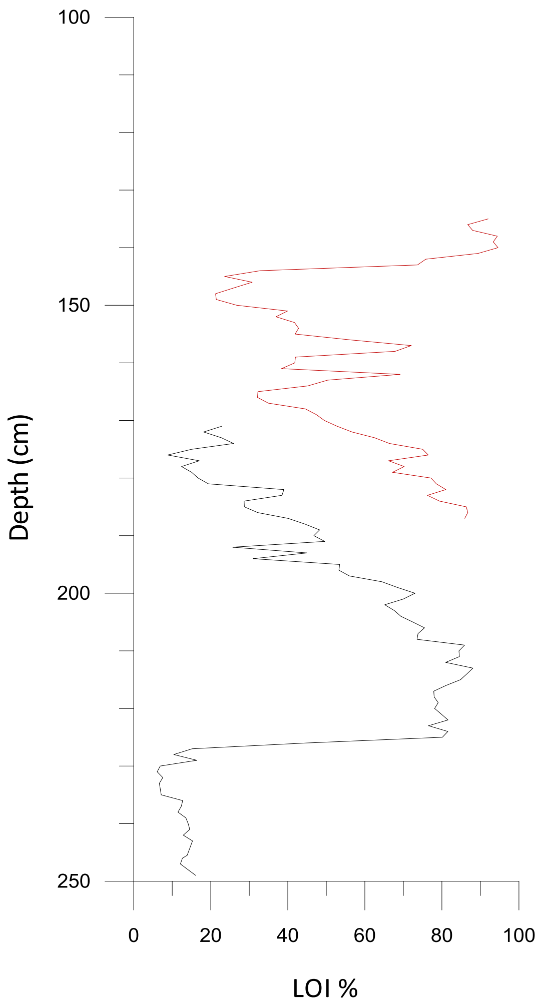

Figure 24 LOI curve for the Padborg core. The core was divided in two sections, which are shown here as the red and the black line.

Chapter 4: Pollen Results

Three sites were selected for pollen analysis; the two suitable Drenthe sites, Groote Veen and Blauwe Gat, and the Padborg site in Denmark. In Denmark the Padborg site was selected because the sediment infill showed a sandy influx. Only the top cores were analyzed, because we tried to find pollen records capturing the holocene. Different cores were matched on absolute depth.

§4.1 Blauwe Gat

Zone BG1 at the Blauwe Gat (Figure 25) shows a very dominant *Pinus* assemblage (71-80%) while *Corylus* shows a steady, but low percentage of 10-15%. The *Betula* count shows a fairly unstable assemblage with a maximum of about 15%. The arboreal assemblage is completed by *Juniperus* (1-2%), *Quercus* (<5%) and *Ulmus* (1-2%). Poaceae (<5%) and herb pollen were barely found, as the only consistently present family besides Poaceae was found to be Cyperaceae (1-2%).The heather percentage is at less than 1 percent. The Blauwe Gat itself seems to have been a small open lake at this point with a relatively high percentage (5-7%) of the vascular water plant *Potamogeton* and a lot of *Sphagnum* pollen (10%-25%). The dense arboreal vegetation found in the pollen archive is reflected by the LOI record, as it shows a very stable 100% throughout BG1, which indicates a very high organic production coupled with very low driftsand influx. Overall BG1 shows a Boreal pollen assemblage.

In BG2 the first signs of pine decline start showing. Although the *Pinus* pollen record is a little spiky throughout BG2, the general trend is a declining one (75%-50%). During BG2 *Corylus* starts to rise to its maximum (11-28%), while both *Quercus* and *Ulmus* stay relatively constant at percentages below 5. The upland herbs group also starts to increase a little relative to the arboreal pollen. Especially *Plantago* and *Rumex* show a little more of a constant presence (<5%). The heather group, in the form of *Calluna*, starts rising a little towards the end of the zone (0%-4%). So overall the regional pollen still indicate a *Pinus*/*Corylus* dominated dense forest, but in places it starts opening up a little, allowing more herbs to flourish. Since especially *Rumex* and *Plantago* are indicators for human activity, the vegetation changes may be related to human activity. The presence of *Sphagnum* which set in at BG1 continues throughout BG2 (15%), indicating the lake was slowly closing up. The LOI still shows a very constant 100% throughout the zone, thus corroborating the picture of a dense high forest cover painted above.

At the start of BG3 *Alnus* makes its introduction as a dominant genus (4%-22%). *Pinus* shows a last maximum before starting its significant demise midway through the zone (73%-18%). *Corylus* has a minimum in BG3 (40%-10%), which is probably caused by the relative maximum *Pinus* shows. So the *Corylus* pollen can be assumed to have been quite constant over BG3. Meanwhile both *Quercus* and *Ulmus* decrease a little at the start of the zone (again related to the *Pinus* increase), but start increasing towards the end of the zone to about 5%. The amount of herbpollen relative to the arboreal pollen stays about the same, but *Calluna* starts a strong increase towards the end of BG3 (0%-10%). This seeming increase might not be accurately represented however, as there is a lack of samples from a depth of 208 cm to 189 cm (the top end of core C-I2 proved impossible to sample due to extremely sedgy, fibrous peat). The increase is still quite rapid however, allowing the assumption that a higher resolution diagram of this part would show a similar pattern. Overall the regional pollen assemblage leaves the impression of an Atlantic vegetation distribution with the decreasing *Pinus* and increasing *Corylus*, *Tilia*, *Quercus, Ulmus* and *Alnus*. The increasingly stabe presence of local spore genera *Dryopteris* (2%) and *Equisetum* (4%), along with a massive *Sphagnum* peak (130%), indicate the further overgrowing of the lake at the end of BG3. *Potamogeton* (10%-4%) also decreases towards the end of the zone, further corroborating this notion. The LOI still sits at a stable 100% for the entire zone however, suggesting that an expected increase in driftsand influx did not occur simultaneously with the *Calluna* increase.

In zone BG4 *Pinus* has declined to a fairly stable 15%. At the same time *Corylus* has increased to about 35%, yet this peak is not as high as one might expect since *Corylus* is the dominant genus after *Pinus* and *Alnus* in BG3. The *Lycopodium* count also strongly increases at the start of BG4, signifying that the overall pollen concentration went down. Therefore it is likely that the actual *Corylus* population decreased going into BG4. In fact all of the arboreal genera decrease really fast considering the *Pinus* decline, as *Betula*, *Tilia*, *Quercus* and *Ulmus* all end up at a percentage of 0% after a fairly stable presence of 2-5%. Most of the herbs, especially *Rumex* (<1%-10%), increase at the BG3/BG4 transition, giving the impression of the vegetation becoming increasingly more open. This notion is supported by the strong increase in *Calluna* during BG4 (10%-35%). So indeed heathlands became commonplace going into the Subboreal. The increased presence of *Rumex* suggests an increase in primitive agricultural activity. This is somewhat reflected in the LOI curve as well, although the effect is very minimal with extremely small drops caused perhaps by small peaks in drift sand activity. The huge peak of *Sphagnum* at the end of BG3 is followed by a huge drop in BG4 (130%-20%), which stays at a low level after. The amount of *Potamogeton* is also decreasing throughout BG4 (8%-2%), supporting the idea that the lake had closed up at this point. Perhaps this closed lake may have supported a sizeable heathland vegetation, explaining the large amount of *Calluna* pollen. It is however hard to imagine that this *Calluna* vegetation stood and grew for nigh on 3ka on the closing lake.

Zone BG 5 shows large amounts of *Pinus* again (60%-80%). *Corylus* (15%-20%) and *Alnus* (5%-15%) are still dominant after *Pinus*, while *betula* (5%), *Quercus* (5%) and *Ulmus* (3%) are at fairly stable low concentrations. Meanwhile all the herbs are basically at the same level they were in BG4, except for *Rumex*, which went down somewhat (3%). *Calluna* also doesn't have as much of a presence as it did during BG4. The *Pinus* comeback can be explained by a very modern setting, as a lot of pine forest was planted in the Netherlands during the second half of the 20th century. Heather not being represented as well as in BG4 is interesting as the heathland cover in Drenthe has been high in the 20th century.

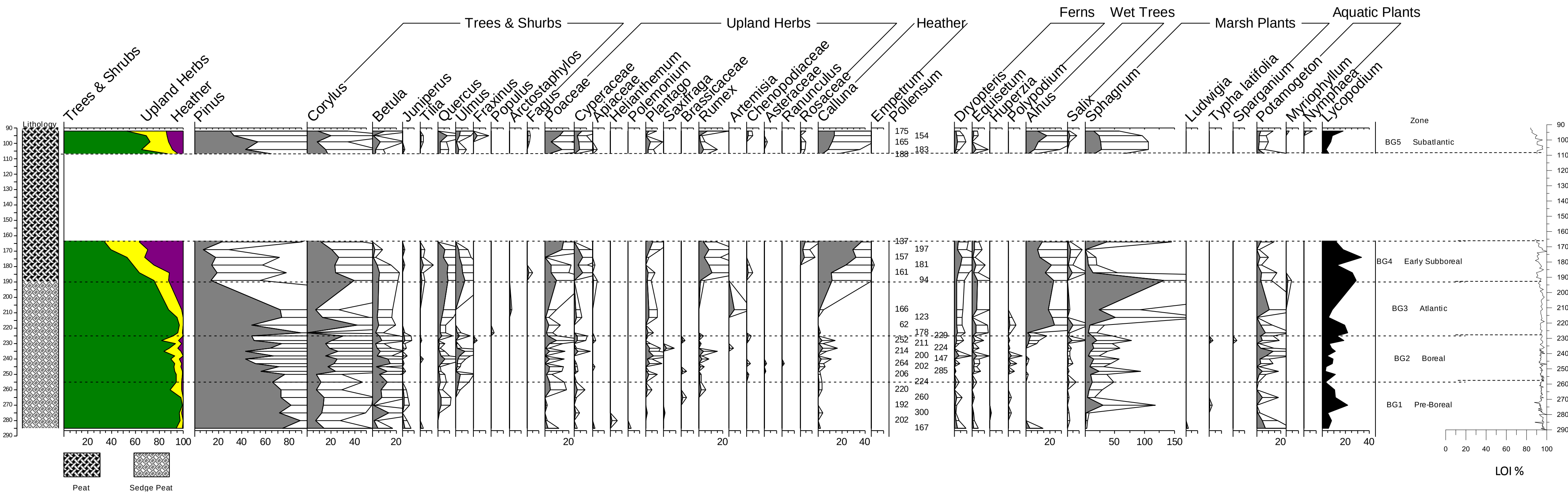

Figure 25 Pollen diagram of the counted samples taken from the Blauwe Gat record. The pollensum consists of the Trees & Shrubs, Upland Herbs and Heather groups to get rid of local signals. For the nameless zone there were no samples, as there was no piece of core found in our coring device for this depth.

§4.2 Groote Veen

Before going into the details of every separate pollen zone, it should be stated that the pollen diagram of the Groote Veen (Figure 26) shows a weird vegetation pattern. It was impossible to get an accurate impression of the ages of the different zones, as the sequence of the various switches of dominance does not make sense in the light of classical accepted pollen assemblages such as those of Jessen/Iversen and Firbas. Therefore it seems that the core the pollen samples were taken from, was at least to some degree disturbed, resulting in a fairly useless diagram.

Zone GV1 shows a very irregular *Pinus* curve, with it having two small peaks. *Corylus* is dominant throughout the zone, while *Betula* is rising from a very low starting point of 2%. Both *Quercus* and *Juniperus* show a stable but very low pollen percentage. The herbs group shows a stable 5% for Poaceae, which Cyperaceae also starts from. Cyperaceae then proceeds to have a dip towards the end of GV1 at 117 cm depth. *Plantago* is present on a very low percentage, just like *Artemisia* and *Rumex* towards the end of the zone. Meanwhile *Calluna* is at a stable 10%, except for a small dip in the middle of the zone. So we end up with a picture that shows a pretty open landscape with a few indicators of human activity. Meanwhile the LOI is very low at about 10%, indicating the influx of loads of driftsand, even though the pollen counts don't reflect this. The Groote Veen itself was closing up during this stage with *Sphagnum* showing a big peak at 122 cm depth.

In zone GV2 the *Pinus* percentage is still fairly low hovering at about 30%. *Corylus* however drops off quickly to completely disappear towards the end of the zone. The dominance it showed in GV1 is taken over by *Betula*, which becomes dominant in GV2. *Quercus* and *Juniperus* still show the low percentage stable presence they showed in GV1, apart from *Juniperus* increasing very rapidly at the very end of GV2. *Ulmus* has a stable but barely noticeable pollenpresence throughout GV2 as well. For the herbs Poaceae and Cyperaceae continue their stable presence from GV1, but now Cyperaceae peaks near the end of the zone instead of dropping like in GV1. *Plantago* shares this peak at 95 cm depth. Also *Rumex*, *Artemisia* and Chenopodiaceae are present throughout the zone, indicating some human activity. *Calluna* decreases to zero during GV2. So at the start of the zone the vegetation is somewhat open and it keeps opening up more until the end of the zone, where the arboreal pollen suddenly make a comeback with a massive influx of *Juniperus*. This is somewhat supported by the LOI curve, which sits firmly at about 10% for all but the last part of zone GV2. *Sphagnum* decreases throughout the zone to zero. There are also some water plants to be found with *Myriophyllum* and *Nymphaea* having a relatively large presence in GV2. *Equisetum* is also increasing towards the end of GV2. This suggests the lake was closing during this stage, with the waterplants growing in the small pools still available, while *Sphagnum* further clogged up the remaining smaller pools and *Equisetum* stood at the banks of the bog.

GV3 features the lowest *Pinus* stand of the whole record at about 10%. *Corylus* basically nonexistent, while *Betula* is has a fairly stable presence of about 25% throughout the zone (it does feature a dip, but this can be explained by considering the huge *Juniperus* spike at the same depth). *Juniperus* follows through on its rapid increase from the end of GV2 and produces a big peak. Meanwhile *Quercus* is still at a low, but stable percentage. The herbs are dropping a little overall during this stage, with both Cyperaceae and Poaceae showing a drop in their otherwise fairly stable pollen presence during GV3. *Plantago* and *Rumex* are both at low percentages throughout the zone, with *Plantago* increasing somewhat towards the end. *Calluna* is basically nonexistent during GV3, apart from the start of the zone. So after opening up a little in GV2, the vegetation now closes again with a big amount of *Juniperus* indicating a very dry sandy soil. This is supported by the LOI as it sits at about 100% for the entire zone, indicating that *Juniperus* did well in keeping the dry sandy soil from drifting. On the local scale *Myriopyllum* and *Nymphaea* pollen have disappeared while *Potamogeton* is still present to some extent. Therefore most of the pools in the peat bog seem to have closed at this point. *Equisetum* shows a huge peak, which supports this notion as the area featuring wet sandy soil suitable for *Equisetum* would grow with the further closing of the lake.

In GV4 *Pinus* becomes dominant and *Corylus* makes a small comeback as well. *Betula* decreases towards the end of the zone, while *Juniperus* almost disappears and presumably got taken over by *Pinus*. *Quercus* is still stably present at a low percentage. Fagus also shows a very small spike of pollenpresence. Poaceae shows the same stable presence as *Quercus*, while Cyperaceae and *Plantago* peak simultaneously before both dropping off entirely. Chenopodiaceae and *Artemisia* both have a very small presence during GV4. *Calluna* is nonexistent except for the last part of GV4, where it suddenly picks up. So basically during GV4 the closed, *Juniperus* featuring forest of GV3 transitions into a closed *Pinus* forest over the course of GV4. This is reflected by the LOI still sitting at 100%, except for the end of the zone where it drops slightly. The *Equisetum* that stood in the Groote Veen in GV3 slowly disappears during GV4, probably because of a transition to a less sandy soil.

Overall it can thus be concluded that the pollen GV1-GV4 all originate from at least the late Subboreal, although an exact dating is impossible because of the disturbance. The total lack of *Alnus* is a problematic however and undermines the validity of the notion that the record might be of Subboreal origin. This goes for the massive *Pinus* peak in GV4 as well, as one would not expect this much pine forest in the subboreal.

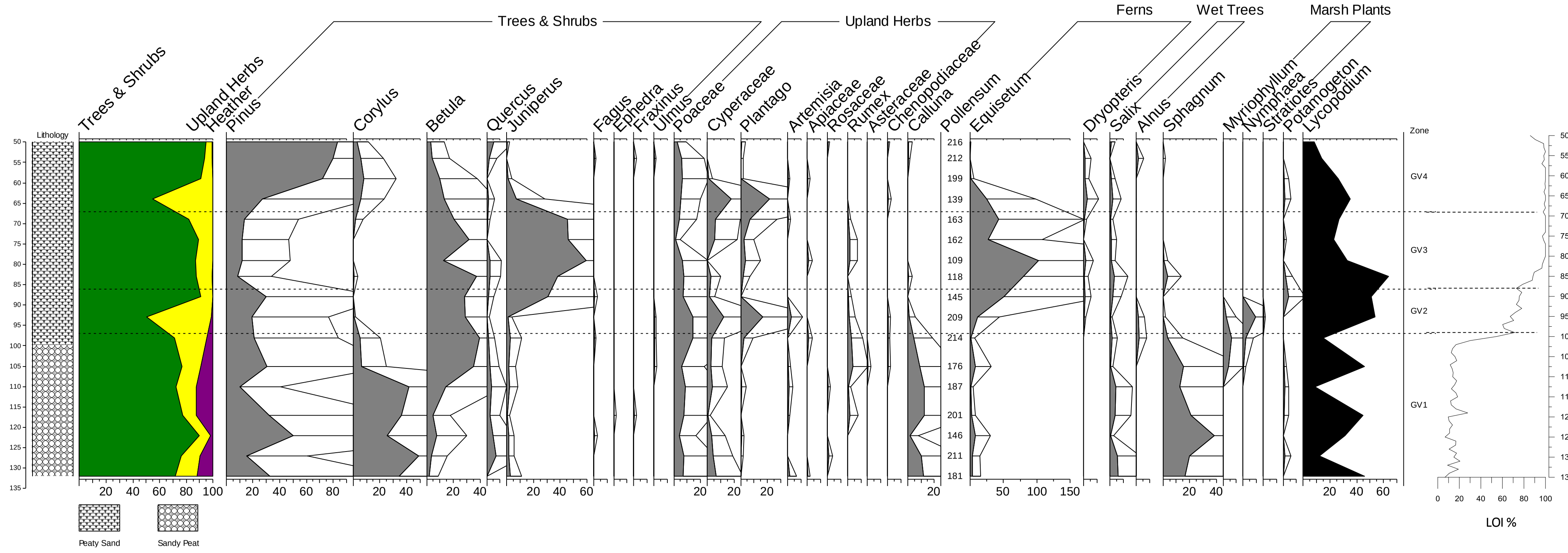

Figure 2 6 Pollen diagram of the counted samples taken from the Groote Veen recordThe pollensum consists of the Trees & Shrubs, Upland Herbs and Heather groups to get rid of any local signal.

§4.3 Aekingerzand

The Aekingerzand pollen record was found to be disappointing. Only two of the 6 samples taken contained any visible or recognizable pollen assemblages. Therefore no real pollen diagram could be constructed. Instead in Figure 27 the presence of genera are shown for the two samples that did contain pollen. Although no proportions can be seen in the diagram, it is clear that *Calluna* is present in both samples, together with human activity markers such as *Plantago* and Chenopodiaceae. It is also clear from the stacked diagram that heathland was the dominating form of vegetation during this part of the formation of the peat bog. It should be taken into consideration however that the pollensum for the upper sample is much lower making both samples somewhat difficult to compare. The deepest sample also contained *Fagus*, which suggests that we are dealing with a late Subboreal setting a least. It is interesting to note as well that *Dryopteris* and *Equisetum* seem to interchange their presence. With *Equisetum* doing well in sandy soil, this makes little sense as the LOI goes up in percentage during this exchange. It is therefore likely that the cause for this can be found in the smaller pollensum for the upper sample.

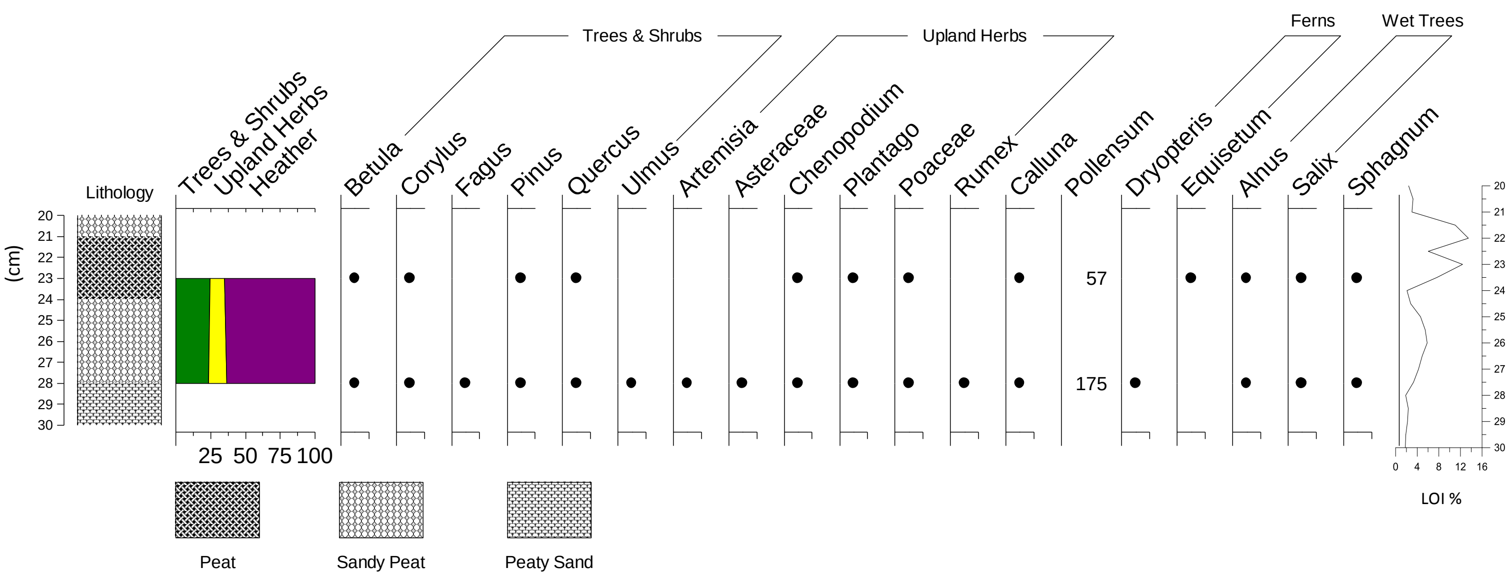

Figure 27 Pollen presence diagram of the two counted samples taken from the Aekingerzand record. The pollensum consists of the Trees & Shrubs, Upland Herbs and Heather groups to get rid of any local signal.

§4.4 Padborg

Zone DK1 (Figure 28) shows a fairly large percentage of herbs in comparison to both the Groote Veen and Blauwe Gat pollen, although there is a peak in arboreal pollen which can largely be attributed to a *Pinus* peak at a depth of 164 cm. *Pinus* is also dominant throughout this section (60%-80%). *Corylus* pollen are abundant as well, albeit showing somewhat of a decrease during the *Pinus* peak (20%-10%), which thus means its distribution was fairly stable through DK1. *Quercus*, *Betula*, *Juniperus* and *Ulmus* are all really stable throughout the zone. Poaceae in the herbs group is the second most dominant genus together with *Corylus*. It shows a decrease before rising to 20% at the end of the zone. *Plantago* (10%-2%) shows this same dip as well, while Cyperaceae and *Rumex* do not. Chenopodiaceae is present throughout the zone, but at a very low percentage. *Calluna* is basically absent in DK1, which is interesting with the suggested openness. So the pollen diagram suggests a *Pinus* dominated patchy forest landscape, with lots of fields in between. This is corroborated by the LOI curve, which shows fairly low percentages for DK1, suggesting the influx of some driftsand. There is however one LOI peak near the end of DK1, which almost coincides with the *Pinus* peak. It could be that the fairly low resolution of the diagram shows a gradual pine decline that should be more rapid, thus allowing the *Pinus* peak to fall together with the LOI peak and explaining why there was left driftsand during that time. While the *Pinus* curve suggests a Preboreal setting with its increasing dominance, the presence of mixed oak forest from the start of the zone contradicts this. Therefore Preboreal setting seems unlikely. Overall it seems that DK1 was formed during the early Subboreal. The *Pinus* dominance might be explained as being a local signal, stemming from nearby sand plains which went through succession with *Calluna* pioneering and then *Pinus* taking over.

DK2 shows a further expansion of Poaceae (10%-30%) and *Plantago* (0%-10%). Interesting to note is that *Pinus* decreases during DK2 without another arboreal genus taking its place (60%-25%). *Corylus* goes up somewhat during the *Pinus* drop, but this is to be expected if *Corylus* is presumed to remain constant (9%-28%). *Quercus* and *Betula* dip into very low percentages during DK2 (<5%), while both *Juniperus* and *Ulmus* retain their steady but very low percentages (2%-3%). Cyperaceae again stays constant (10%). *Rumex* seems stable but at a lower percentage than in DK1 throughout DK2 (5%-2%). At the end of the zone, however, it disappears. Chenopodiaceae is also present for some time, but disappears halfway through (1%). Meanwhile *Calluna* makes its introduction, but stays fairly low (1%-3%). So the vegetation opens up further during this time, with loads of herb fields and a little heathland between the patches of mixed pine forest. The LOI corroborates this with percentages hovering around 40%, except for one peak, which seem to coincide with the *Corylus* peak at the middle of DK2, suggesting a similar link to driftsand as with the *Pinus* peak in DK1. The LOI peak is also reflected in the local lake vegetation with the sandy soil loving *Equisetum* showing a drop during the LOI peak. Towards the end of the zone *Potamogeton* increases a little, suggesting the first signs of the lake starting to overgrow. At the same time *Dryopteris* has stable very low percentages throughout DK2.

DK3 mainly shows a quick *Pinus* recovery, leading to the arboreal pollen becoming more dominant again (50%-75%). *Corylus* is very stable throughout the zone, which means that it probably increases in number alongside *Pinus* (10%-15%). *Betula* drops off entirely towards the end of the zone. This while *Quercus* (3%-13%) and *Ulmus* (0%-3%) start to pick up at the end of the zone and *Pinus* decreases a little (75%-55%). Finally *Alnus* also starts increasing at the end of the zone (2%-24%). *Juniperus* stays at a stable low percentage again throughout the zone (3%). Poaceae (15%-4%) starts at a fairly high percentage at the start of the zone, but drops off and almost disappears towards the end, probably being replaced by *Pinus*. *Plantago* (6%) and *Cyperaceae* (3%) both maintain a steady low percentage throughout the zone, while *Rumex* has disappeared entirely. At the same time *Calluna* is present, but only just (<1%). So DK3 suggests that the forest and especially *Pinus* takes over again. While there probably still were herb overgrown open places, they would have been small and sparse compared to DK2. The LOI curve supports this with organic content percentages nearing 100% towards the end of DK3. With no major shifts in vegetation occurring, it seems that the whole record fits in a Subboreal setting. At the local level the lake is still slowly closing with an increased *Potamogeton* presence (apart from a small dip). *Typha latifolia* appears towards the end of the zone as well. After its peaks in DK2 *Equisteum* decreases to a steady low percentage in DK3, presumably for lack of a sandy soil because of the decreased driftsand activity. Its place is taken over briefly by *Dryopteris* before it disappears again as well.

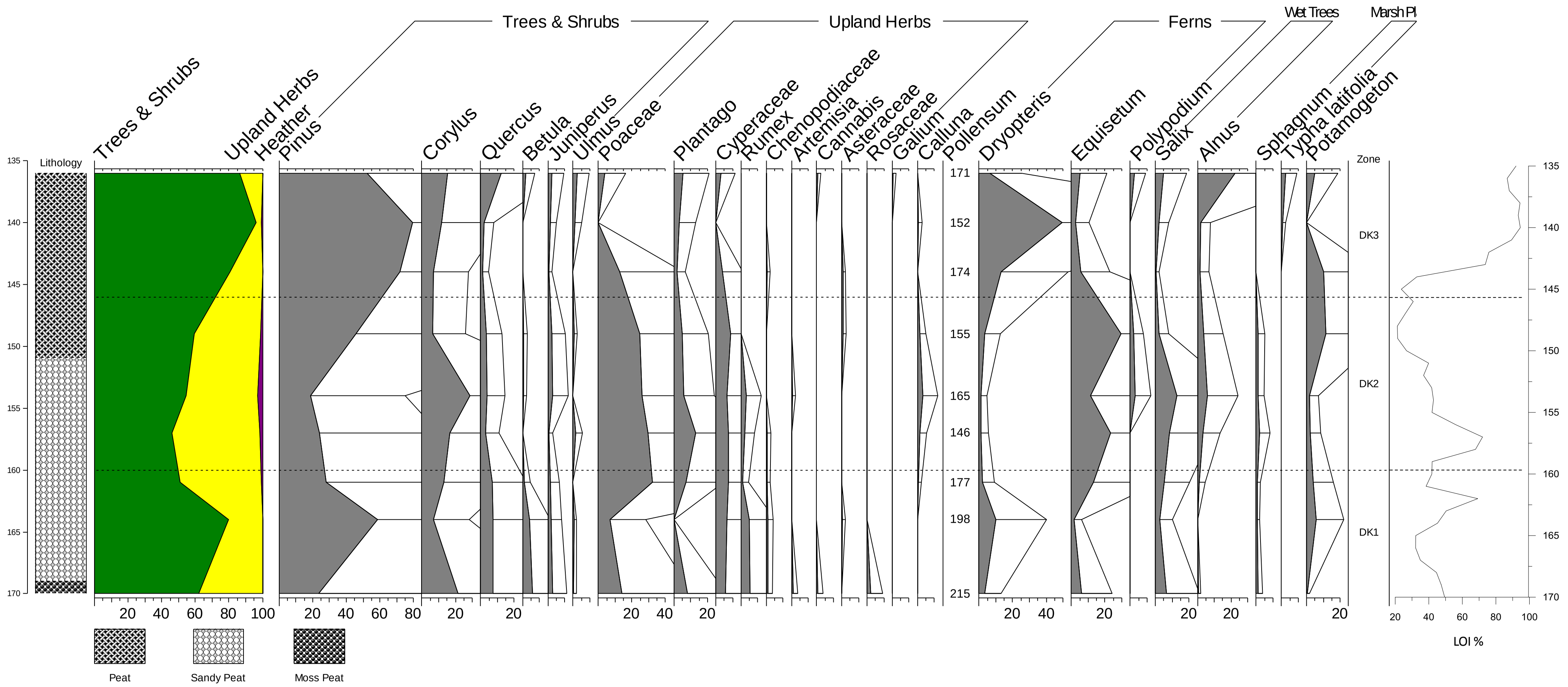

Figure 2 8 Pollen diagram of the counted s amples taken from the Padborg record. The pollensum consists of the Trees & Shrubs, Upland Herbs and Heather groups to get rid of any local signal.

Chapter 5: Discussion

The vegetation patterns for both the Blauwe Gat and Padborg are somewhat different for the time period they share. While the Blauwe Gat presents a very open landscape during the Subboreal, Padborg shows only a short total dominance herbs and grasses, before and after which *Pinus* is the dominant genus. It should be noted however that *Pinus* produces the most and most resilient pollen out of all genera shown in the diagrams here (Macdonald *et al*., 1998). Therefore *Pinus* pollen are overrepresented in most pollen records. This is especially true when the source of the pollen is close to the lake/bog the records are taken from (Macdonald *et al*., 1998). Therefore the strange Padborg records seems to be heavily biased by local pine pollen, as normally no large scale *Pinus* increases are to be found in the Subboreal. Indeed many sand plains lie near the Padborg site, so perhaps one of these harbored a pine forest. This pine forest was then probably partially cut down, after which some agriculture was practiced as the LOI goes down with the *Pinus* pollen percentage. Thus the pine forest is temporarily replaced by grassland and herbs. Interesting to note is that the heath vegetation barely reacts to what is causing *Poaceae* to flourish. The general retreat of the pine forests, and thus the increase in the openness of the landscape, should also have promoted the growth of heathland. To a very small extent it did, but if the soil was exhausted one would expect more heath to grow. This might thus be explained by the idea that the soil wasn't exhausted before the pine forest was allowed to recover. It seems that the agricultural activity that took place, only lasted for a short period of time, wherefore the availability of nutrients wasn't entirely cut short. The short increased presence of the human habitation marker *Plantago* supports this (Lappalainen, 1965). This presence was probably there in the form of the Funnelbeaker culture, which inhabited most of Jutland during the Subboreal (Gron & Rowley-Conwy, 2016). It thus seems that Padborg, after a short period of Funnelbeaker habitation, was abandoned, allowing *Pinus* to quickly take over the empty space left by the agricultural/foraging grounds of the Funnelbeaker people and their livestock (Gron & Rowley-Conwy, 2016). This is supported by the LOI curve, as during DK2 and thus the open vegetation period, the LOI drops and stays low, until *Pinus* becomes dominant again. The upper part of the pollen record thus shows a nice example of succession, with *Calluna*, *Corylus* and Poaceae first appearing during the human disturbance. With *Calluna* also being a genus that's also often overrepresented in the pollen record however, it seems that the *Calluna* population must have been very small (Pennington, 1984) Then *Pinus* takes over because of succession over *Calluna* and herbs/grasses. At the end of the record however, a drop in *Pinus* is already present, occurring simultaneously with the increase of deciduous trees such as *Quercus*, *Alnus* and *Salix*. This exemplifies the succession further and thus cements the idea that *Calluna* can not be the dominating genus for long without any form of disturbance or nutrient leaching.

For the Blauwe Gat pollendiagram can be concluded that the pine forest dominated until about 7ka BP. From there the pine forest suddenly declines and gets largely replaced by *Corylus* and *Calluna*. Indeed over the next 3ka *Calluna* becomes dominant in the pollen record. One might therefore be inclined to conclude that indeed *Calluna* was the dominant genus in Drenthe at about 4ka BP. This is however not necessarily the case. For heather pollen do not only offer a regional signal, but a local signal as well. This local signal can be formed when the right acidic, iron deprived peat forms in an overgrowing lake. *Calluna* will then be able to colonize the peat soil and thus precipitate its pollen straight into the peat or leftover pools. It however seems unlikely that this local *Calluna* dominance would last several thousands of years, without succession kicking in. Blanket peat bogs are known for being able to achieve this by continuous iron leaching (Gimingham, 1992; Bunting, 1996). This process needs a very rainy cold climate to persist however (see Chapter 1), wherefore wet heathland in warmer areas requires disturbance to keep pinetrees and birches from outcompeting the heath shrubs (Gimingham, 1992). and therefore it is not unreasonable to say that the *Calluna* rise at the Blauwe Gat is in fact a regional signal (Bunting, 1996). Also one would expect a lot of *Sphagnum* in a blanket peat bog (Clymo & Reddaway, 1974). Such a big *Sphagnum* peak does exist at about 190 cm in BG4, however the *Sphagnum* spores curve soon after goes back to normal values. This while *Calluna* keeps on increasing. One could argue that this is because the lake is closing, exemplified by the decreasing *Sphagnum*. Such a development would however also mean that at the fringes of the former lake, succession would be well underway to replace *Calluna* with more competitive genera such as *Pinus* and *Betula* (Mitchell *et al*., 1997).

The *Pinus* decline could be explained by natural succession of the ecosystem, because of the arrival of *Quercus*, *Tilia* and *Ulmus* (mixed oak forest). These genera show lower migratory speeds, which caused them to lag behind the likes of *Betula*, *Corylus* and *Pinus*. When they did arrive however, *Pinus* and *Betula* were outcompeted. This is partly what we see in the pollen diagram as well, with the members of the mixed oak forest all showing a marginal increase during the initial pine decline. They are then however quickly diminished by a quickly rising *Calluna*, indicating that some kind of forest clearing must have happened. This is consistent with Figure 1 from the introduction, which states that agriculture was practiced in the Netherlands from about 8ka BP onwards. The boundary of the big *Calluna* rise lies well within this range. Therefore it is reasonable to assume that the heathlands formed on bare exhausted farmlands. Whether or not the mixed oak vegetation had taken over before the forest was presumably cut down to accommodate farmlands, remains unclear from this record. For the unfortunate sample gap at the end of zone BG3 could have contained a steep but short mixed oak forest increase. Regardless it is reasonable to assume the forest (whatever it consisted of at the time) was cut down through human activity in its quest for new farming grounds over the course of the late Atlantic and early Subboreal. As *Rumex* together with *Plantago* increases along with *Calluna*, the idea that the sudden heathland/pine forest shift came about through a major increase in agricultural practices becomes very appealing (Lappalainen, 1965). This notion does however contain one major caveat. With the coming of large parts of exhausted farmlands one expects to find largescale driftsand activity as well (Riksen, 2006). No evidence indicating such an increased activity was however found in the LOI curve. Also agriculture alone does not keep heathlands from developing into forest, as heath takes on the role of colonizer in the succession of a sandy soil (Hjelle *et al.* 2010). It is therefore likely that animal husbandry was practiced in Drenthe from the middle stages of the Atlantic. Some form of agriculture must have been present, for otherwise the sandy, exhausted and slightly acid soils in which heath can outcompete forest development would not exist in the first place (Riksen, 2006; Hjelle *et al.,* 2010). Therefore it seems likely that agricultural fields were small and that new fields containing fertile soil were created through the cutting down of equally small patches of forest (whether it may have been mixed oak forest or pine forest) (Bakker, 1989). In this way driftsand activity would have been kept to a minimum because of the small size of the fields laying waste. In time heath would establish itself on these bare patches of land, after which sheep and cattle would be able to feed of it, thus keeping succession at bay. This in turn lead to a steady growth rate for heathland at about the same pace the forest was cut down, thus explaining the seeming inverse relation between arboreal vegetation cover and heath cover.

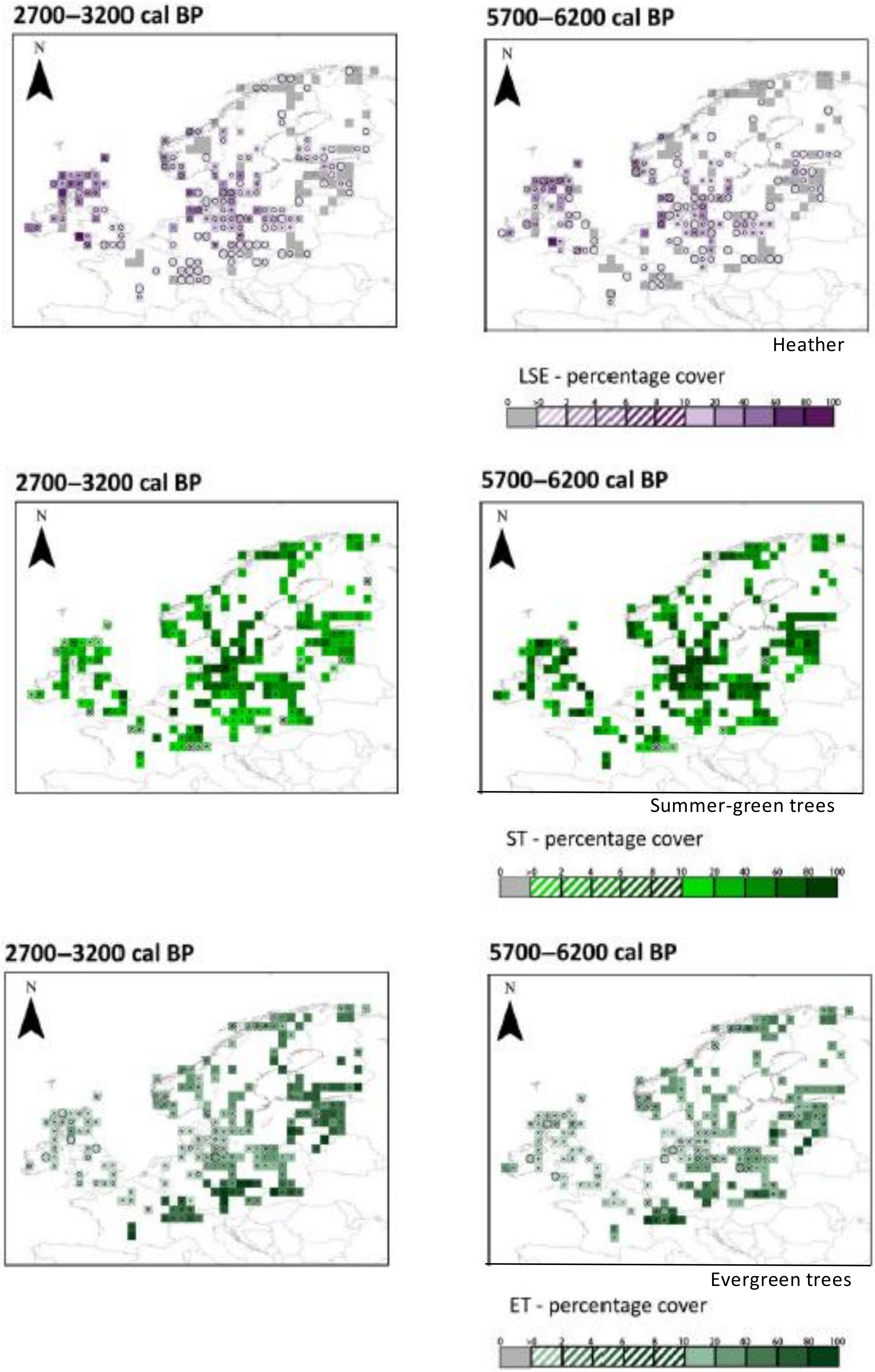

Figure 29 Maps of Europe showing the vegetation distribution throughout Northern to Central Europe for Calluna, Summer-green trees and Evergreen trees. Modified after Trondman *et al.,* 2015.

At the end of zone BG4 the LOI curve drops sharply, suggesting a sudden influx of driftsand from this point. A continuation of the record thus might have revealed a further dropping LOI, which would indicate intensification of agriculture as farming technology and efficiency improved over the course of the late Neolithic and early Bronze Age.

As such it is also a great pity that the Groote Veen record turned out to be impossible to place in any historical context, because of its disturbed nature. For, if undisturbed, it may have contained a section covering the large missing part in the Blauwe Gat record, presenting more information about the era immediately following the initial sharp *Calluna* incline/*Pinus* decline.

In other parts of Europe with a coversand topsoil, the prevailing trend of emerging *Calluna* at about 6-7ka BP is also present (see Figure 29, Trondman *et al*., 2015). It is unclear if those heathlands, unlike the Blauwe Gat, actually are accompanied by a significant driftsand influx, as there are no accompanying LOI records. It is however interesting to note that any grasslands or fields are scarce throughout the earliest time period, which indicates that no large scale agriculture was performed during the early Neolithic. This paired with a decrease of both the evergreen and summer trees makes for a similar picture to the one shown by the Blauwe Gat pollen record. This consistency in development of the vegetation across similar geographic regions in Europe, suggests a similar Neolithic farming development. The Denmark record ties into this nicely, as it shows that emerging *Calluna* certainly is not the standard mode of ecosystem recovery after deforestation. It therefore further cements the idea that a common anthropological development is responsible for the late Atlantic vegetation patterns seen throughout North-Western Europe.

Ascribing a defined culture to the time period captured by the pollen records is not an easy task. Most of the Meso- and Neolithic migration patterns are based on remains, such as fragments of pottery, skeletons and structures, of settlements found in the sediment. As such discoveries concerning the peoples of the Meso- and Neolithic are mostly governed by chance. Nevertheless the first *Calluna* rise seen in BG3 coincides with the presence of the the Linear Band Keramik (LBK) culture in the Netherlands. The LBK is thought to have originated from Hungary some 7.5ka BP, before moving west out of Central Europe and establishing itself in North-Western Europe over the course of mere centuries (Oelze *et al.,* 2011). With the coming of the LBK the Neolithic era finally expanded to North-Western Europe, as both the practice of crop cultivation and animal husbandry was common place among members of the LBK (Bannfy, 2004; Oelze *et al.,* 2011). No specific archaeological evidence for LBK inhabitation in Drenthe has been found as of yet however and it is generally agreed upon that the LBK did not move northward of the Rhine delta (Keeley, 1992).

The reason they refrained from expanding further northward, is thought to have been due to habitat restrictions of the crops they cultivated. These originated from South-Eastern Europe and would not have been suitable for the North-West European climate without some human induced changes to the fenotype (Bickle & Whittle, 2013). The earliest known agricultural activity in Drenthe is attributed to the Trechterbeker culture, which arrived at about 5.8ka BP (Bottema *et al.,* 2005). There is a discrepancy here however, since the earliest observable increase in *Calluna* lies about 20 cm below the start of the Neolithic era (which is defined by the arrival of the TRB culture) and other studies show the early *Calluna* increase as well (Sevink *et al.,* 2013). The lack of samples for those 20 cm may show a skewed image of the actual *Calluna* distribution trend, but the fact that at 5.8ka BP a very sizeable amount of *Calluna* is already present indicates that indeed some agricultural activity must have been going on before this moment. One might be inclined to suggest that the LBK culture, or some remnant of it, moved northward after crops would have become better suited for the climate with the application of primitive gene manipulation, such as cross-pollination. In doing so however, an age gap of about 1000 years would need to be crossed which makes it difficult to imagine that no remains of it have been found to this day. There is still the possibility that such remains are in fact present, but have yet to be discovered. Also it should be noted that a sharply defined Mesolithic-Neolithic boundary may not be possible, as there is evidence of Mesolithic Hunter-gatherers in the Drenthe area practicing very primitive forms of agriculture, which nonetheless still resulted in deforestation (Vigne, 2011). It also lays bare the problem with anthropological prehistory, for before the introduction of the written word, the only way to transmit any form of knowledge was through personal contact. This results in a very mosaic like distribution of different peoples adhering to different ideas within the same time span, thus creating difficulty in trying to identify one tribe as being responsible for vegetation patterns such as those discussed in this study. Be that as it may, it is strongly suggested that according to our data some type of agricultural activity must have been happening before the Mesolithic-Neolithic boundary as it is known in literature for the Netherlands.

Age model

A large part of this study is supported by the validity of the datings applied by comparison to other dated pollen records. Large well-known shifts in vegetation regimes are often easily recognizable and therefore supply us with ample age information. The resolution of such shifts however is rather low, leaving us with little information about the ages of pollen samples between the datable sections. As such any detailed analysis on the start of the Holocene heathland formation in North-Western Europe is hard to execute. Follow up studies with ample time available are therefore well advised to resort to more accurate dating methods, such as radiocarbon dating. This not only to acquire a workable high resolution dated record, but also to ensure smaller anomalies caused by disturbances in the record get noticed. The Groote Veen clearly offered a disturbed record, but smaller disturbances are less easily noticed. Especially if the disturbance consists of peat in a core section which already contained peat infill. Such disturbances can be easily identified by applying the right form of radio isotope dating.

Chapter 6: Conclusion

- Is there a relation between vegetation patterns and driftsand activity?

Yes, although not as straight forward as presented in the introduction. From our records it is clear that heathland growth does not necessarily mean a great influx of driftsand. At the Blauwe Gat the drift sand activity doesn't correlate very strongly to the openness of the vegetation. Granted it also doesn't show no driftsand activity. It is difficult to ascertain whether any agricultural activity lies at the root of driftsand activity and heathland formation. This being said however, it seems very likely that this link does exist.

- Is there a difference in this relation between different sites and times?

Yes. The Padborg core shows a substantial decrease in *Pinus*, just like the Blauwe Gat site, but instead of heath formation we see a rise in upland herbs and human activity indicators paired with a drop in the LOI curve. It is interesting to see that the ecosystem recovers very quickly after the human activity is gone, through *Pinus* growth and subsequent deciduous succession. It thus shows that the presence of farming significantly alters the way in which the ecosystem recovers from a tree die-off, which further cements the idea that heathland formation is an indicator for agricultural activity in combination with livestock grazing.

- Is the decrease in pinewoods related to the increase in heathland cover?

Not necessarily. In literature it is told that mixed oak forest first took over from the pine trees, before human activity truly started to develop and show its marks on the vegetation. This is however not what our Blauwe Gat record shows, which might be caused by the 19 cm gap in pollen samples. It might well be that mixed oak forest peaked during this time, wherefore no great peaks in *Tilia*, *Quercus* and *Ulmus* are shown in the diagram. It is however interesting to note that the amount of *Calluna* pollen found at the end of the gap is already very substantial, indicating that any mixed oak forest peak would have been very short-lived when extrapolating the after-gap growth trend for *Calluna* for the gap. Although the *Calluna* peak may be in part a local signal, the overall accelerating growth suggests that the peak can not be a local one only.

- If so, is the pinewood decrease which set in during the Mesolithic attributable to farming activity?

Probably not, as the pine decrease was largely governed by competition with the mixed oak forest. It all depends on whether the heathland development coincided with the pine decline. But since our records are inconclusive on this because of the sample gap, this study does not contribute much to answering this question. The Appelscha record does show an Ericaceae increase during the pine decline however, suggesting that farming activity might have at least accelerated the pine decline.

- How does archaeological evidence fit into the presumed early farming activity?

It simply does not. Most of the archaeological evidence suggests that farming in North-Western Europe started about 6ka BP. This and other studies however suggest that farming related changes in vegetation patterns and driftsand activity are found much earlier in the sediment record. Further research with better age calibration should be done to confirm this however. Maybe this could be done in conjunction with renewed efforts to find archaeological evidence for early farming activity as well.

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