Late Weichselian permafrost distribution and degradation

A pingo based reconstruction for the Netherlands

H.A.G.Wooldering (3379817)
Supervisor: dr. W.Z.Hoek
Co-supervisor: dr. C.Kasse

Utrecht University
Faculty of Geosciences
Department of Physical Geography

10-july-2014

Universiteit Utrecht

Abstract

Permafrost was present throughout the Netherlands during the Late Pleniglacial. Evidence of this permafrost consists of several periglacial features of which pingo remnants are the most prominent. Permafrost distribution, minimum depth and characteristics of decay of permafrost throughout the Netherlands during the Weichselian Late Pleniglacial and the following Weichselian Late-glacial was reconstructed by information derived from pingo remnants. Relict pingos provide not only an indication of the (minimal) depth of former permafrost, but might also contain a unique lithological and botanical record of environmental change since the last deglaciation. While relict pingos are abundant in the northern Netherlands, few have been recognized in the southern part of the Netherlands. Based on Lidar indicated circular depressions, together with fieldwork in the area of Heeze-Leende, the presence of relict pingos in this region has been investigated. From a previously investigated relict pingo, Klein Hassels Ven, a new core was obtained in order to reconstruct regional environmental changes in the area since the Last Glacial Maximum. It is concluded that permafrost occurred throughout the northern, central and southern Netherlands during the Late Pleniglacial. Minimum depth of permafrost varied between 5m and 16 meters in the northern and middle Netherlands while permafrost depth was shallower in the southern part of the Netherlands, with a minimum depth of 2m to 5 meters. Southern Netherlands pingo remnants contain a comparable Late-glacial vegetation development as indicated by pingo remnants in the northern Netherlands. Based on the presumable hydraulic origin of the pingos throughout the Netherlands, permafrost is concluded to be discontinuous during pingo formation. Decay of permafrost in the Netherlands occurred simultaneously throughout the Netherlands due to climatic warming at the onset of GI-1e (correlating to Bølling), as indicated by the basal infill of the investigated pingo remnants.

Preface and acknowledgements

This master thesis is conducted within the track Integrated Stratigraphy and Sedimentary Systems of the MSc Earth, Life and Climate at the faculty of Earth Sciences, Utrecht University. Many are to thank for their contribution to this thesis but I would especially like to thank dr. Wim Hoek for all the support during the field and lab-work, and for the time and effort spent on being the main supervisor. Furthermore I would like to thank dr. Kees Kasse for acting as the second supervisor for this thesis. Additionally special thanks to Marjolein Gouw-Bouman for her valuable contribution in the palynology involved in this study. Furthermore I would like to thank Staatsbosbeheer for approving the fieldwork at Klein Hassels Ven, with special thanks to Jap Smits for valuable information concerning Klein Hassels Ven en for approving and help conducting the fieldwork at this site. Finally, I would like to thank Brabant water for approving the fieldwork in their domain, with special thanks to Mark Bartels for providing the information needed to work in this area.

Table of content

List of Figures

List of Tables

List of Appendices

Chapter 1. Introduction

Reconstruction of former permafrost environments is based on detection, recognition and evaluation of permafrost indicators such as ice-wedge casts, sand-wedge casts, remnants of pingos and palsas, traces of segregation ice, absence of speleothems in caves and cryoturbations. Permafrost is defined as ground in which the temperature remains below 0°C over at least two consecutive years (Brown & Kupsch, 1974; Harris et al. 1988). Permafrost occurred throughout the Netherlands during the Weichselian Late Pleniglacial, providing the conditions needed for pingo formation. Pingos are defined as perennial frost mounds consisting of a core of massive ice, produced primarily by injection or segregation of water, which are covered with soil and vegetation (Harris et al. 1988). Pingos develop within the permafrost, below the active layer and are relatively stable features as they are an integral part of the permafrost (Gurney, 1998). Furthermore, pingos may have a diameter up to 600 meters, a height up to 50 meters (Ballantyne and Harris, 1994) and are generally circular to oval shaped. Progressive melting of the pingo ice core eventually leads to an inverted relief of the original pingo during degradation, leading to so-called pingo remnants. These relict features, representing what was once an active pingo, have been described from numerous localities and environments in both modern and past permafrost regions (Flemal, 1976). Pingo remnants might act as a site of secondary deposition, resulting in accumulation of organic debris, wind-blown debris, washed-in debris from adjacent sites or debris welled up by rising groundwater (Flemal, 1976). Therefore, pingo remnant infills in the Netherlands form a unique record of environmental change since the last deglaciation containing for instance pollen, aeolian sand, chironomids, and tephra (Hoek et al. 2012). The number of pingo remnants found in the northern Netherlands is large (Hammen, 1951; Ter Wee, 1966; Cleveringa et al. 1977; Paris et al., 1979; De Gans & Shol, 1981; De Gans, 1982; Kluiving et al. 2010), although pingo remnants are scarce in the southern Netherlands (Van Leeuwaarden & Janssen 1987; Kasse and Bohncke, 1992; Hoek, 1997; van Asch et al, 2013).

This study aims to reconstruct former permafrost distribution, minimum depth and characteristics of decay of permafrost, based on pingo remnants throughout the Netherlands during the Weichselian Late Pleniglacial and the following Weichselian Late-glacial. Special attention is given to the differences in permafrost depth between northern and southern Netherlands and a possible time delay regarding the moment of permafrost degradation. The main research question therefore is:

What were the distribution, minimum permafrost depth and characteristics of decay of permafrost throughout the Netherlands during the Late-glacial Maximum and the following Weichselian Late-glacial?

To obtain an answer to this main research question the following sub questions were posed:

- ***Are pingo remnants present in the southern Netherlands?***
  A case study with accompanying fieldwork after 5 Lidar indicated circular depressions in the area of Heeze-Leende has been undertaken, together with a literature study after known pingo remnants in the southern Netherlands.
- ***Do the southern Netherlands pingo remnants provide a climatic record?***
  Palynological analysis has been performed in order to reconstruct vegetation development and derive age estimations for the depressions introduced in this study. Literature study provided further information on known pingo remnants in the southern Netherlands.
- ***How do pingo remnants throughout the Netherlands compare to each other?***
  Differences and conformities concerning depth, diameter and infill of pingo remnants throughout the Netherlands are discussed.
- ***Is there a spatial relationship between pingo remnants and brook valleys and what are the implications for pingo origin?***
  A GIS analysis provided more knowledge on the relationship between brook valleys and pingo remnants. Furthermore, the implications of these results are discussed concerning pingo origin.

This thesis comprises six chapters. After this introduction, a literature review is given in chapter 2. This literature review focuses on permafrost, pingos and related ground-ice phenomena, past periglacial environments of north-west Europe and pollen analysis, Late-glacial vegetation development, regional geology, and finally known pingo remnants throughout the Netherlands. Chapter 3 describes the methods used for the field and laboratory work after which chapter 4 contains the results of the fieldwork and laboratory analysis. Chapter 5 provides a discussion on the results derived in this study compared to known literature, based on the sub research questions mentioned above. Finally, in chapter 6 an overview is presented on the conclusions derived from this study.

Chapter 2. Literature review of former periglacial Netherlands

2.1 Permafrost, related phenomena and environments

2.1.1 Permafrost

Periglacial climates are determined predominantly by latitude, altitude and continentality (Ballantyne and Harris, 1994). Based on these factors, different periglacial climates can be classified in a number of groups, such as "polar desert" and "continental" climates. More detailed information on classification in these climatic groups can be found in Ballantyne and Harris (1994). Permafrost is defined as ground in which the temperature remains below 0°C over at least two consecutive years (Brown & Kupsch, 1974; Harris et al. 1988). This definition does not state that permafrost should be accompanied by ice, so Ballantyne and Harris (1994) indicate that permafrost is by definition cryotic (temperature less than 0°C) ground that may or may not contain ice. Development of permafrost occurs when mean annual ground temperatures fall below 0°C, the top layer (active layer) thaws annually however, in response to summer warming. Three main sorts of permafrost can be distinguished, continuous permafrost, discontinuous permafrost and sporadic permafrost. Areas of continuous permafrost are completely embraced by permafrost, except beneath large bodies of water (Ballantyne and Harris, 1994). Areas of discontinuous permafrost are characterized by breaks in the continuity of the underlying permafrost (Figure 1). These breaks are mostly caused by the insulation provided by vegetation, rivers, small ponds and deep snow cover (Ballantyne and Harris, 1994). Finally, sporadic permafrost predominantly consists of unfrozen ground with local areas of permafrost.

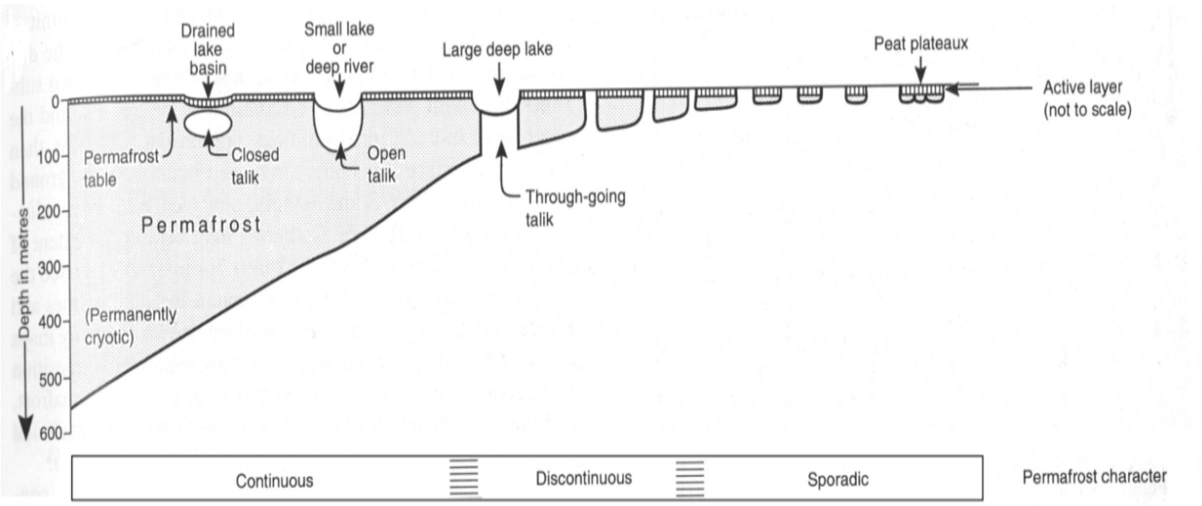


Figure 1: Permafrost characteristics in a north-south transect (Ballantyne and Harris, 1994)

If water is present in the subsurface, permafrost is often ice-rich. The water will result in the formation of ground ice, of which four major types are classified; pore ice, segregation ice, vein or wedge ice, and intrusive or injection ice (Mackay, 1972). Pore ice will result in “ice cemented” frozen sediments, which can overall be considered impermeable (Ballantyne and Harris, 1994). Development of segregation ice is a result of soil water migration towards an advancing freezing front, behind which the water freezes (Ballantyne and Harris, 1994). Percolating water or snow accumulating into thermal contraction cracks will form vein or wedge ice. At last, injection ice is formed by the accumulation and subsequent freezing of pressurized water.

Although geomorphological processes within permafrost may result in a number of phenomena such as ice-wedge cast, polygons and cryoturbations (Ballantyne and Harris, 1994) the focus of this study lies on (relict) pingos. Pingos are chosen for this study as they do not only indicate permafrost conditions but may, after decay of the ice-lense, also contain a record of environmental changes since the decay of the pingo. A short review concerning the development of pingos and related ground ice phenomena can be found in 2.1.2.

2.1.2 Pingos and related ground-ice phenomena

Pingos represent a family of features whose members have differing geneses and morphologies (Pissart, 1988), but are most commonly defined as a perennial frost mound consisting of a core of massive ice, produced primarily by injection of water, which is covered with soil and vegetation (Harris et al. 1988). According to Ballantyne and Harris (1994) pingos can develop in a variety of unconsolidated sediments such as till, slope deposits and alluvial silts, sands and gravels. Although there are different genetic types of pingos, a common requirement for pingo formation is a pressure gradient which acts to provide a supply of water to form the ice core of the pingo (Gurney, 1998).

2.1.2.1 Hydrostatic pingos

Hydrostatic (or closed-system) pingos develop due to water expulsion during permafrost aggradation (Ballantyne and Harris, 1994). Porsild (1938; 55) indicated that closed system pingos are formed by; ‘local upheaval due to the expansion following the progressive downward freezing on all sides of a body or lense of a semi-fluid mud or silt enclosed between bedrock and the frozen surface soil’. In order to provide a lense of semi-fluid sediments, the formation of hydrostatic pingos is linked to a place of unfrozen sediments within the continuous permafrost, so-called “talik”. Taliks often underlay thaw lakes (water-filled depression created by naturally induced thawing), and the drainage or infilling of these thaw lakes results in refreezing of the talik just beneath the floor of the thaw lake. This results in the surrounding of the talik by permafrost, which in turn causes the contained water from the saturated talik sediments to expel ahead of the freezing front, resulting in the formation of a solid ice core underneath the thaw lake floor (Gurney, 1998). Figure 2 indicates the formation of these types of hydrostatic pingos.

As not all pingos form in situations where the sub-lake talik formed a pingo ice core, there may also be situations (i.e. areas with a dense concentration of lakes) in which multiple taliks are joined at depth (in principal resulting in an open system pingo), the term hydrostatic pingo was induced by Mackay (1979). Although hydrostatic pingos are primarily associated with continuous permafrost this does not have to be the case. An impermeable layer (i.e. clay) beneath a talik may also provide the conditions needed for hydrostatic pingo formation.

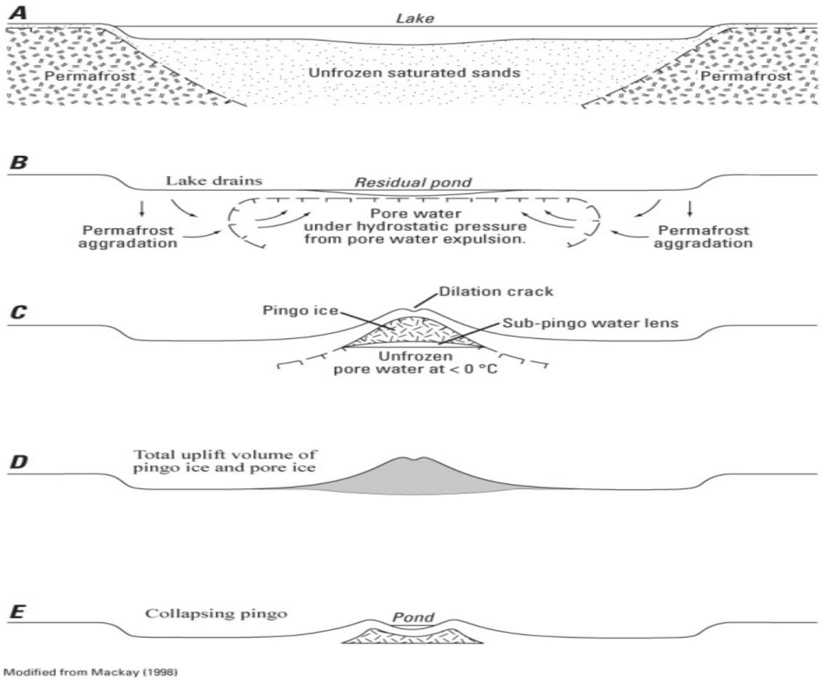


Figure 2: Formation of hydrostatic pingo (Mackay, 1998)

2.1.2.2 Hydraulic pingos

Open system pingos (Müller, 1959) or hydraulic pingos (Mackay, 1979), result from groundwater movement beneath shallow discontinuous permafrost (Ballantyne and Harris, 1994). Water that infiltrates on hillsides or higher elevated areas moves downward through permeable sediments or fractured bedrock, resulting in artesian groundwater pressure under permafrost at the foot of the slope or on the valley floor (Ballantyne and Harris, 1994). At the point of least resistance, most often the point with the thinnest permafrost, the freezing of the groundwater will lead to the formation of a pingo ice core (Figure 3). Hydraulic pingos appear to group in small numbers, in contrast to more solitary appearance of the hydrostatic type pingos, which appears to be due to the varying location of the upwelling pingo groundwater that forms the hydraulic pingos (Gurney, 1998). Furthermore, hydraulic pingos often occur at or near the transition between slope sediments and valley fill deposits (Ballantyne and Harris, 1994). Although hydraulic pingos are broadly recognized and the general concept of their formation is understood, debate remains concerning local differences in groundwater injection (Gurney, 1998). More detailed information concerning the formation of hydraulic pingos can be found in Ballantyne and Harris (1994), Gurney, (1998) and Mackay (1998).

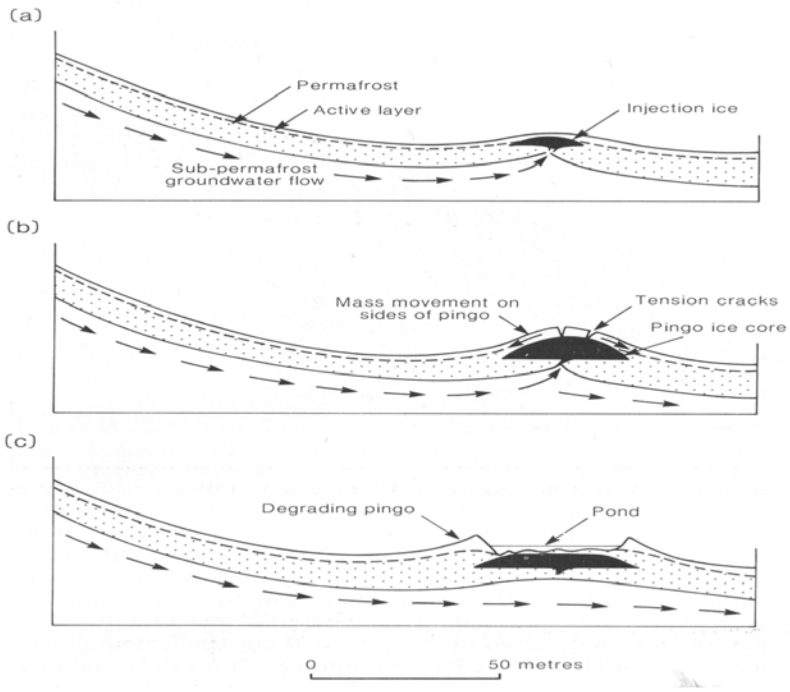


Figure 3: Formation of hydraulic pingo (Ballantyne and Harris, 1994)

2.1.2.3 Pingo collapse and remnants

With the growth of a pingo the mineral and organic overburden must either stretch in response to the increase in surface area of fail in tension (Mackay, 1998). It must be noted that for this theory the diameter of a pingo is thought to be established early on in the growth cycle and the majority of the subsequent growth is in the height of the pingo (Mackay 1998). Mackay (1998) furthermore indicates that in addition to the mechanically induced failure of the overburden, the pingo ice itself is also deformed by several causes (see Mackay, 1998). Pingos that are more than several meters in height are often crossed by a dilation crack (summit crack), and continuing growth of the pingo results in further widening and deepening of the dilation cracks, often into the ice core. The widening of the dilation cracks may result in the formation of a so-called pingo crater, exposing the pingo ice beneath the overburden, see figure 4. Besides summit failure, circumferential failure (leading to radial cracks), hydrofractures and peripheral failure will eventually occur at most pingos. More information concerning these forms of pingo failure can be found in Mackay (1998). Eventually the pingo ice core will be exposed, inducing thermal degradation of the pingo. The time that is needed for the collapse of pingos is uncertain and even partial collapsed pingos might persist for a long period under permafrost conditions (Mackay, 1988).

Besides the mechanical failure of pingos, which can occur in stable permafrost conditions, degradation of permafrost due to a warming climate will also cause collapse of pingos as pingos are intra permafrost phenomena. Mackay (1988) also indicates that for the growth of pingos a Mean Annual Ground Temperature (MAGT) of 0°C to -2°C is needed. If this temperature is exceeded by a long term warming trend, the occurrence of pingos will diminish. The exact process of pingo degradation by climate warming is, however, not fully understood as up to now no complete study has been or could have been performed.

Pingo scars, or pingo remnants are the relict features of what was once an active pingo. Pingo scars have been described from numerous localities and environments in both modern and past permafrost regions (Flemal, 1976). The stages of decay of pingos and the development of pingo remnants are schematically indicated in figure 4. Progressive melting of the ice core eventually leads to an inverted relief of the original pingo, forming a depression and defining a pingo remnant (Flemal, 1976). Pingo remnants at this stage might begin to act as a site of secondary deposition resulting in accumulation of organic debris, wind-blown debris, washed-in debris from adjacent sites or debris welled up by rising groundwater (Flemal, 1976). Additionally a rampart may be formed by eroded material of the original slopes of the pingo, or material which originates from the original up-thrusting of the dome (Flemal, 1976). It is described by Flemal (1976) that such ramparts may be destroyed by slumping into the depression or as the result of erosion. Discussion remains concerning the preservation of pingo remnants in former permafrost regions as Flemal (1976) describes that an overprint of thermokarsts might be imposed on all pingo scars, diminishing the relief of these features.

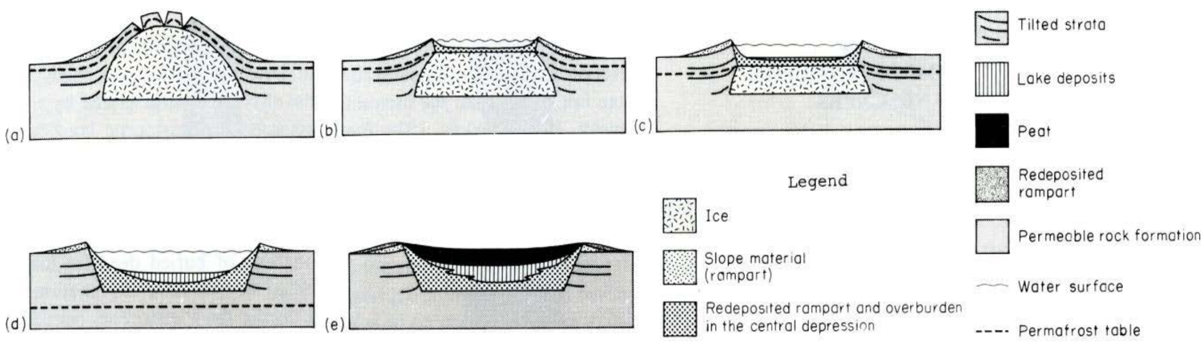


Figure 4: Degradation of pingo and formation of pingo remnant (de Gans, 1988)

Although there seems to be a large variation in form, size and depth of pingo remnants (see Flemal, 1976) presence of a pingo remnant in the field can be indicated by the following criteria;

- Minimal diameter of the pingo remnant is 25 meters with a minimum depth of 1.5 meters (De Gans, 1982, 1988).
- Bottom of central depression lies below surrounding topography and is floored by material sufficiently permeable to allow migration of groundwater (De Gans, 1982, 1988).
- Pingo remnants are more or less circular in outline, or have a fairly uniform diameter (Mackay, 1998).
- A rampart or at least part of a rampart surrounds the pingo remnant (De Gans, 1982, 1988; Mackay, 1998). Although (parts of) the rampart might be eroded or leveled.
- Pingo remnants occur on flat ground or on slopes with a gradient up to 5° (De Gans, 1982, 1988).

- Pingo remnants are accompanied by other permafrost phenomena (De Gans, 1982, 1988).
- Sides of the erosional form represent steep slopes (Mackay, 1998).
- Depressions are filled with peat or other organic material (Mackay, 1998).
- Pingo remnants are of Weichselian age (De Gans, 1982, 1988).

As it has not been possible up to now to investigate the degradation of pingos caused by degradation of the permafrost itself, it is hard to indicate if pingo remnants resulting of such degradation measure up to all of the above criteria.

For this study a pingo remnant is therefore defined as a circular to oval depression with a minimum depth of 1.5 meters, a diameter of 25 meters or greater, which has a (partial) organic infill and is of Weichselian age.

With a partial organic infill of a pingo remnant as criterium, it is often possible to retrieve age estimation by means of palynological analysis. Such palynological analysis might indicate regional environmental changes since the decay of the pingo. As pingo remnants often contain a peat or gyttja fill, a summary of pollen accumulation in a peat and lake environment is given below. Pingo remnants also indicate former permafrost conditions. As discussed above pingos are intra-permafrost features which can only exist in perennially frozen ground. It is therefore assumed that pingo remnants indicate not only the former presence of permafrost but also have a direct relation with the minimum depth of the permafrost.

Pingo remnants occur in a variety of sediment types and are often located on valley floors, plains, and lower valley sides, with the ability for groundwater seepage to take place (Flemal, 1976; de Gans, 1988). It is indicated by De Gans (1988) that pingo depressions in the Netherlands range from 2 to 17 meter in depth with an average depth of 4-5 meters. A great number of pingo remnants in the Netherlands occur in groups, which suggest several "generations" of pingos developed at the same locality, which in turn is a characteristic form of open-system pingo development and thus discontinuous permafrost conditions (Müller, 1959). However, debate remains if closed system pingos might also have developed in the Netherlands (see De Gans, 1982). The start of pingo formation is difficult to reconstruct, and it can only be concluded that the pingo has formed somewhere in between the deposition of the substrate they are formed in, and the age of the basal infill of the (partially) decayed pingo.

2.1.2.4 Related ground-ice phenomena

Not all ground-ice depressions necessarily represent sites of former pingos. Cryogenic mounds, any mound-shaped landform produced by ground freezing combined with groundwater movement or the migration of soil (Harris et al. 1988), are common within the discontinuous permafrost zone and may also occur in areas of sporadic permafrost (Ballantyne and Harris, 1994). An example of such a cryogenic mound is a mineral palsa. Mineral palsas are mounds formed in mineral soils and reflect the growth of segregation ice, as opposed to pingos which are most often formed by injection ice (Ballantyne and Harris, 1994). It must however be noted that many pingos also contain significant amounts of segregation ice (Mackay, 1979a) which makes distinction between the two even more difficult. Mineral palsas may grow up to 40 meters in diameter and 6 meters in height and leave and circular ridge surrounding a thermokarst pond when degraded (Pissart & Gangloff, 1984). Figure 5 indicates the suggested growth and decay of a pingo-like ground ice mound. In addition to cryogenic mounds, thermokarst depressions may occur in permafrost regions. Changes in ground surface conditions or climatic changes may induce disturbance of the thermal equilibrium of permafrost (Ballantyne and Harris, 1994). If ground surface temperatures increase as a consequence of such a disturbance, permafrost degradation will occur. With the degradation of ice-rich permafrost, subsidence of the land might occur leading to the formation of thermokarst depressions. More detailed information concerning the formation of thermokarst depressions can be found in Harry and French (1983); Ballantyne and Harris (1994).

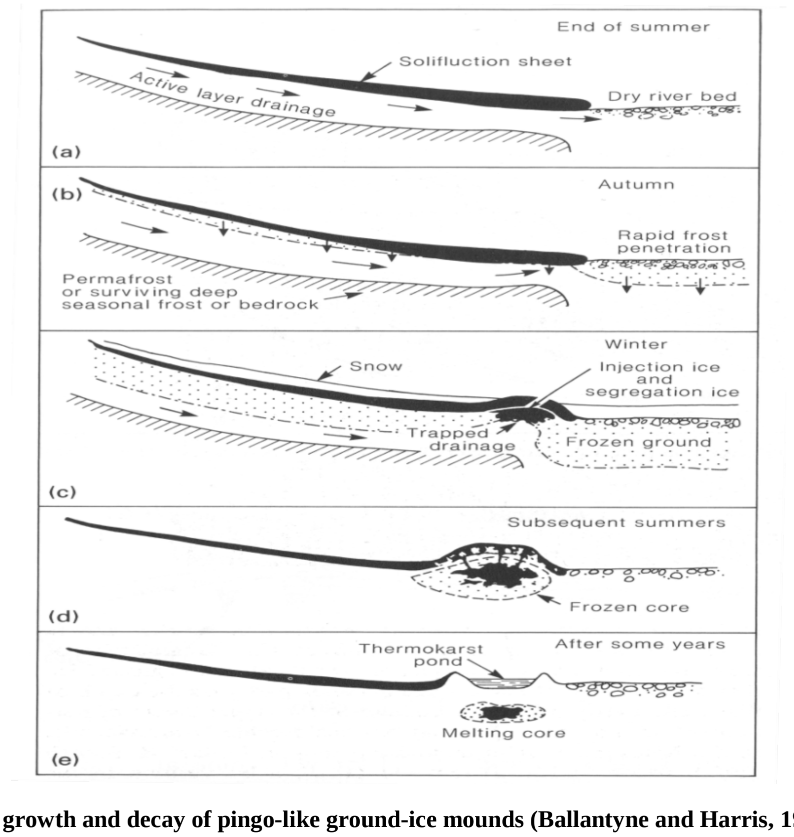


Figure 5: Suggested growth and decay of pingo-like ground-ice mounds (Ballantyne and Harris, 1994)

2.1.3 Past Periglacial environment of north-west Europe

Frost-thaw action provides many diagnostic geomorphological forms and sedimentary structures which, if preserved, permit reconstruction of periglacial conditions (Vandeberghe and Pissart, 1993). Former periglacial conditions and permafrost are therefore well documented in the geological evolution of Europe (Vandeberghe and Pissart, 1993). Reconstruction of former permafrost environments is based on detection, recognition and evaluation of permafrost indicators such as ice-wedge casts, sand-wedge casts, remnants of pingos and palsas, traces of segregation ice, absence of speleothems in caves and cryoturbations. It is outside the scope of this study to consider all of these permafrost indicators individually, and more information about these permafrost phenomena can be found in Washburn (1980) and Vandenberghe and Pissart (1993). As the study of permafrost distribution and extent throughout north-west Europe since the Last Glacial is a subject on its own, with extensive literature concerning this subject, only a general summary is given in this study. Furthermore, the focus is on the Weichselian Middle Pleniglacial (61-27 ka), Weichselian Late Pleniglacial (~27-13 ka) and Weichselian Late-glacial (~13-10.9 ka) (figure 6) as traces from this period are widespread, generally well preserved (Vandeberghe and Pissart, 1993) and fall within the scope of this study.

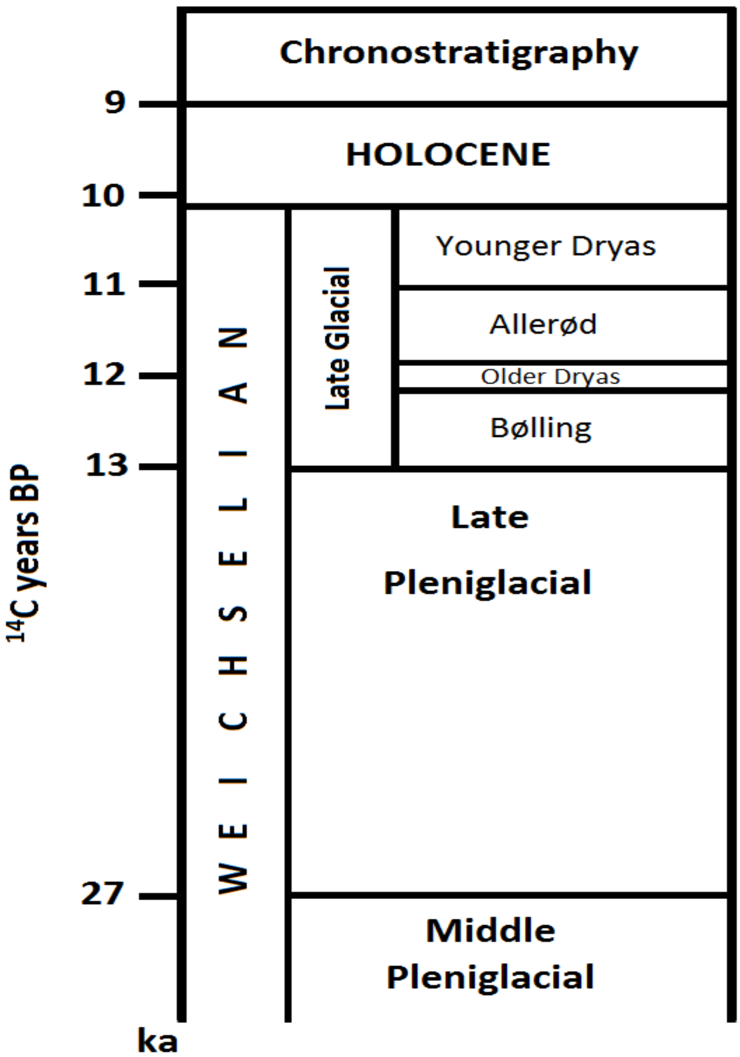


Figure 6: Chronostratigraphy for the period Pleniglacial to Holocene (modified after Kasse, 1999)

2.1.3.1 Weichselian Middle Pleniglacial.

The Weichselian Middle Pleniglacial (oxygen isotope stage 3) has been recognized as a milder period in between the preceding and next cold stage (Vandeberghe and Pissart, 1993). Occurrence of ice-wedge cast and large cryoturbations suggest that probably only discontinuous permafrost was present during this time interval and that mean annual temperatures were about -5°C (Vandeberghe and Pissart, 1993).

2.1.3.2 Weichselian Late Pleniglacial

The Weichselian Late Pleniglacial (~27-13 ka) is a period in which the last major ice advance took place (Van der Hammen, 1957) and permafrost aggraded into previously deposited tills (Vandenberghe and Pissart, 1993). Ice-wedge casts and cryoturbations have been described by numerous authors (see Vandenberghe and Pissart, 1993) throughout Europe during this period. Furthermore, numerous pingo remnants are reported in the northern Netherlands and some circular mound have been interpreted as pingo remnants in the southern Netherlands, although these mounds might also reflect the previous existence of ground ice lenses (Kasse and Bohncke, 1992). With the occurrence of the permafrost features mentioned above, and the absence of speleothems in Belgium, the presence of former continuous permafrost could be reconstructed for the Weichselian Late Pleniglacial (Vandeberghe and Pissart, 1993). Figure 7 indicates the mean winter, annual and summer temperature as well as former periglacial indicators for the Weichselian Late Pleniglacial.

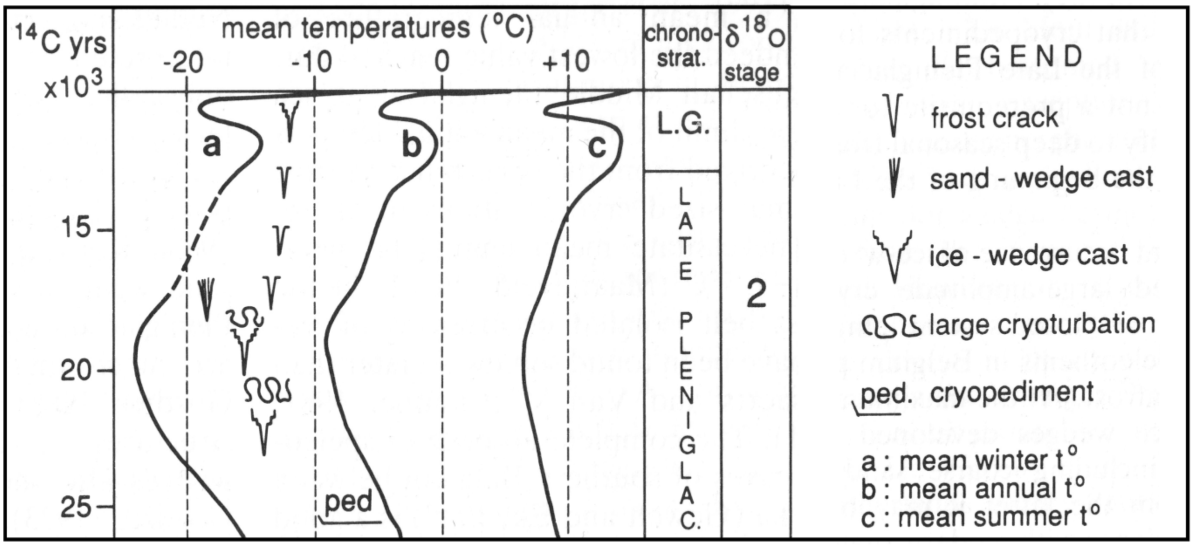


Figure 7: Mean annual, summer and winter temperatures during the Weichselian Late Pleniglacial in the Netherlands and Belgium (Vandeberghe and Pissart, 1993)

During the final (dry) phase of the Late Pleniglacial (ca 17-13ka), aeolian activity resulted in the formation of large deflation areas and large quantities of loess or cover sand (Vandeberghe and Pissart, 1993). Additionally, fluvial activity was reduced and periglacial structures in the northwest European lowland were limited to small frost fissures at this time. Figure 8 shows a map of western and central Europe, indicating the southern permafrost limits as proposed by several authors. More detailed information concerning Late Pleniglacial permafrost extent can be found in a.o. Poser (1948), Kaiser (1960) Maarleveld (1976) Velichko (1982) and Vandeberghe and Pissart, (1993).

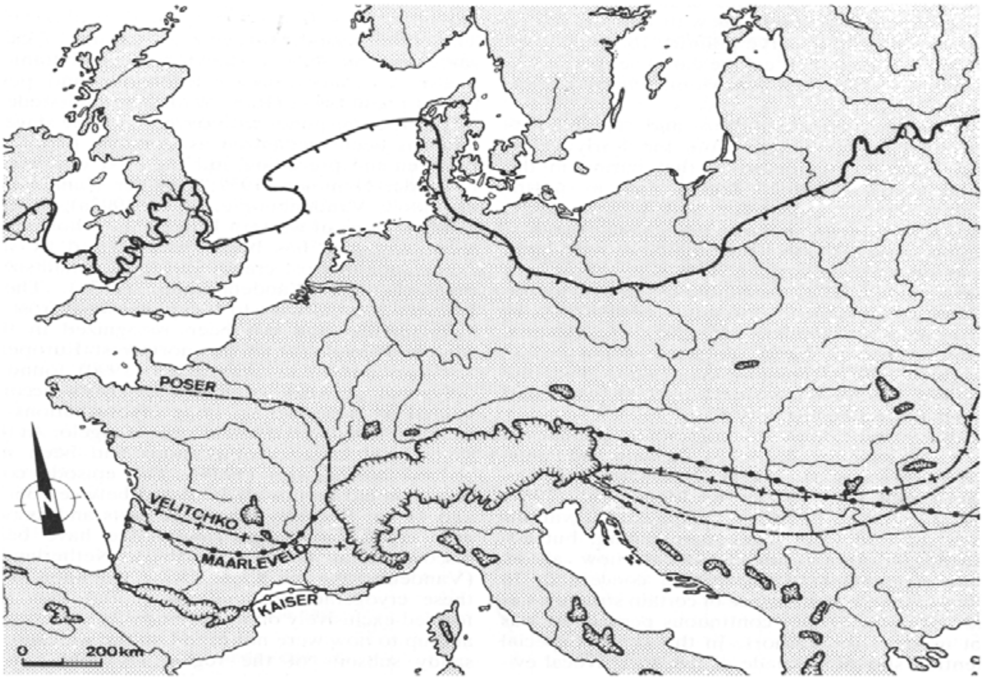


Figure 8: Map of western and central Europe showing the southern permafrost limits as proposed by Poser (1948), Kaiser (1960), Maarleveld (1976) and Velichko (1982) according to the distribution of periglacial phenomena dated from the last cold maximum (Vandeberghe and Pissart, 1993)

2.1.3.3 Weichselian Late-glacial

The Weichselian Late-glacial (~13-10.9 ka) is characterized as a period of climatic improvement with warmer summers and interstadial conditions (GI-1). However, winters remained cold (Bohncke et al., 1987) which enabled the development of seasonal frost cracks (Maarleveld, 1976). Within the Late-glacial a period of severe cooling persisted, GS-1 sensu Rasmussen et al. (2006) (correlating to Younger Dryas). This cooling was characterized by re-advance of alpine glaciers and ice caps, cryoturbations, ground-ice depressions (de Groot et al. 1987), frost mounds (Pissart, 1956), and many landforms of periglacial conditions such as gelifluction and slope deposits (Karte, 1988). Vandeberghe and Pissart (1993) indicate that these well documented and dated phenomena are characteristic of the first part of GS-1 (ending at 10,550 BP) and that these features allow reliable climatic reconstruction of this episode of cooling (Vandenberghe et al. 1991). Additionally Vandeberghe and Pissart, (1993) indicate that underdevelopment and sparse occurrence of ice-wedges during this period point to a sporadic to discontinuous permafrost in the northwest European lowlands during GS-1.

The last part of GS-1 is characterized by the disappearance of local permafrost in the lowlands of northwest Europe. It is furthermore characterized by slightly increased temperatures and a decrease in precipitation and river activity, while dune formation was significant (Vandeberghe and Pissart, 1993). The extension of permafrost during GS-1 is shown in Figure 9, which also contains an overview of northwest European permafrost distribution throughout the entire Weichselian as described by van Vliet-Lanoë (1989). However, the proposed extension of continuous permafrost by van Vliet-Lanoë (1989) during (at least) stage 2 is thought to be too severe, as continuous permafrost for the Netherlands during this period is under debate within this study.

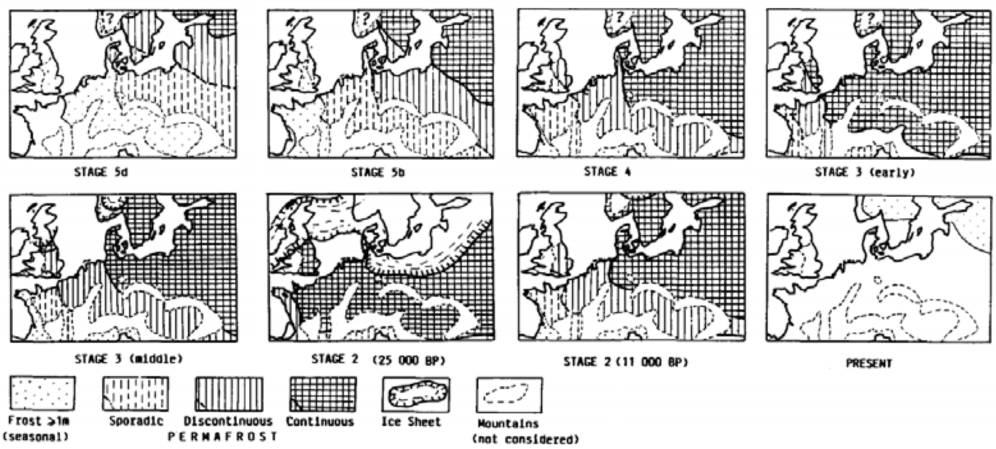


Figure 9: Extent of Weichselian permafrost based on permafrost indicators (Van Vliet-Lanoë, 1989)

2.2 Pollen Analysis

Pollen analysis is one of the most widely adopted and versatile techniques used in the reconstruction of Quaternary environments (Lowe and Walker, 1997). The method has served as a means of correlating Quaternary stratigraphic units and reconstructing vegetational history (Huntley & Birks, 1983; Delcourt & Delcourt, 1991). Pollen grains are formed in the anthers of the seed-producing plants, and contain the male gamete which aims to reach the stigma of the female part of the flower in order for fertilization to take place (Lowe and Walker, 1997). Additionally spores are often included in palynological analysis, as they represent the sporophyte stage of plants such as ferns and mosses. In order to maximize pollination or gametophyte growth, pollen grains and spores are frequently dispersed in large quantities (Lowe and Walker, 1997). This often leads to incorporation of pollen grains (especially wind-pollinated plants) and spores in the geological record. The outer layer (or exine) of pollen consist out of sporopollenin, a highly resistant substance, which promotes conservation. Nevertheless preservation of pollen membranes varies with the nature of the deposits in which they are found. Deposits such as waterlogged, anaerobic layers of peat form the ideal environment for pollen conservation.

Distribution of pollen and spores includes a variety of means. Although spores are usually dispersed by wind, pollen grains are distributed also by water, insects and animals (including humans) (Lowe and Walker, 1997). The plants which produce wind dispersed pollen (anemophilous) generally produce a greater quantity of pollen than the plant taxa that rely on faunal distribution of pollen (entomophilous). This leads to fact that some plant taxa may be under-represented in the geological record whilst others are over-represented. Below a short summary of pollen dispersal factors is given as an overview on the factors that should be kept in mind for each individual site from which pollen are extracted from the sedimentological record. Furthermore, an overview of pollen incorporation in peat and lake deposits is given, as these two environments are the most prominent catchments of pollen in this study. Besides peat and lake deposits, pollen can be found in a great number of other environments but is out of scope of this study to cover all these.

2.2.1 Pollen dispersal models

Although the full extent of pollen dispersal cannot be described in the context of this study, it is important to briefly consider the sources of the pollen in the sediment, and the means by which it arrived at the site of preservation. It is only in this way that one can interpret the pollen assemblage in terms of past vegetation (Moore et al, 1991). There are five main components in the dispersal of pollen as indicated by the adapted model of (Tauber, 1965) in Moore et al. (1991);

- Trunk space component (Ct) i.e. pollen that falls from the tree canopy or is produced by shrubs and herbs beneath the canopy and in carried by sub canopy air movements.
- Canopy component (Cc) i.e. pollen produced within the canopy, or escaping from below, which are carried along by air currents above the canopy itself.
- Rain component (Cr) i.e. pollen grains which act as nuclei around which water droplets form which leads to fallout of pollen from the atmosphere into the basin
- Local or gravity component (CI) i.e. pollen from aquatic plants growing in a lake, or from wetland species growing on the surface of a mire.
- Secondary or washed-in component (Cw) i.e. washed-in fossil or younger pollen by means of (ground) water.

It should be noted that this is a general model (figure 10) which is based on a forested environment and that there may be need to adapt the model for any particular site location. Furthermore, when dealing with a successional sequence adaption of the model for different stage in site development may be needed (Moore et al, 1991).

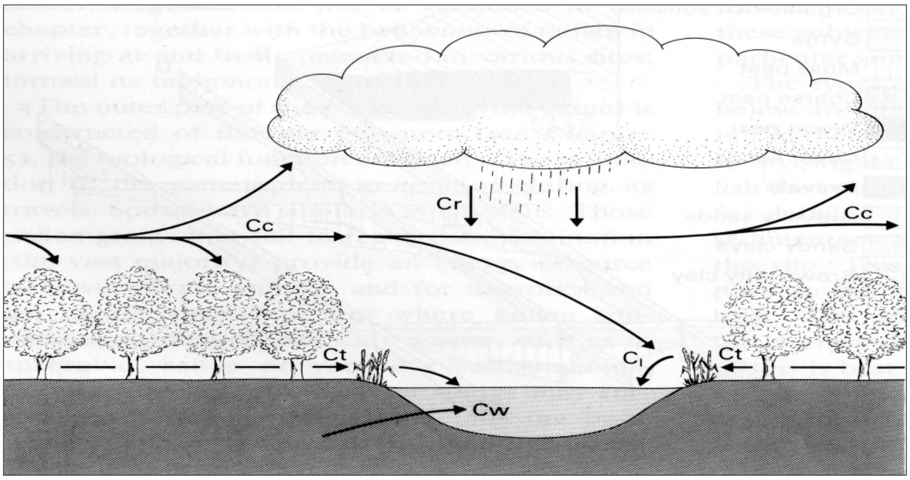


Figure 10: Various sources of pollen in a small lake or mire within a wooded landscape (Moore et al, 1991)

2.2.2 Peat deposits

Peat deposits form when the rate of organic material formation exceeds the rate of organic material decomposition. This leads to accumulation of organic detritus, out of which peat consist. An overview of different sorts of peat formation can be found in o.a. Moore et al. (1991) and Moore and Bellamy (1974). Figure 11(a/b) provides a basic model of pollen arrival at mire sites (peat forming ecosystems) as described by Moore et al. (1991). In this figure a distinction is made between mires fed by groundwater (rheotrophic) and those fed by only rainwater (ombrotrophic). Hydrological differences between these two types are also represented in the supply of extra local pollen. The geographical location of the mires may also be of influence for the pollen assemblage which is eventually represented in the sediment. More information about the influence of the location of mires on behave of pollen input in the geological record can be found in Moore et al. (1991).

The most important feature of peat deposits is the development of a stratified and often waterlogged sequence. This facilitates favourable conditions for the preservation of pollen and results in a sequence of palynological changes over time. It should however be noted that not all pollen which arrives at the surface of the mire is eventually incorporated into the record. As peat develops several factors may promote the decay of organic material, including pollen. Figure 11c indicates a scheme in which the behavior of pollen within a developing peat profile is illustrated. The bulk of the material accreting in peat environments is autochthonous (Moore et al. 1991).

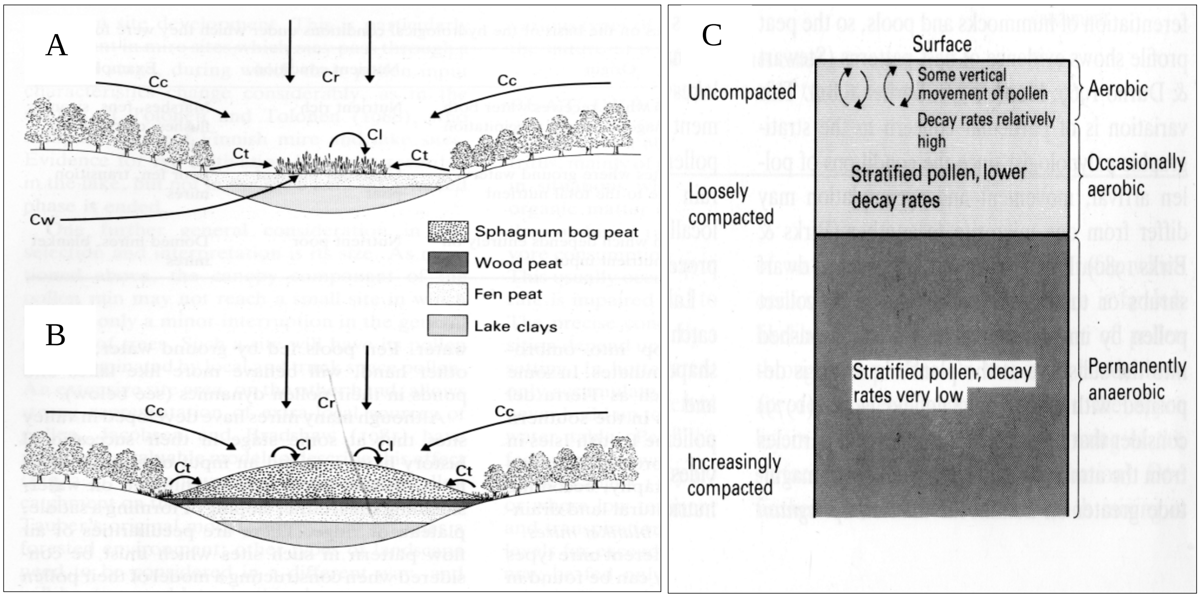


Figure 11: a) Input of pollen to a rheotrophic mire b) input of pollen to an ombrotrophic mire c) behavior of pollen within a developing peat profile (Moore et al., 1991)

2.2.3 Lakes

In contrast to peat deposits, much of the material sedimented within lakes is allochthonous (from outside the confines of the lake itself) to which autochthonous matter derived from plants and animal living within the lake is added (Moore et al. 1991). As lake sediments contain inorganic and organic allochthonous sediments together with local organic material, pollen assemblages in lake sediments may not only consist of in situ pollen but may also contain reworked pollen from nearby eroding peat formations or soils. Figure 12 provides a schematic overview of the sources and transport processes of pollen to a lake site.

In contrast to peat deposits, lake sediments do not experience the same downward movement of water through the sediment profile, providing less likelihood of downward movement op pollen through the profile (Moore et al. 1991), although bioturbation (mixing of sediment by animals within the surface layers of sediments) may cause disturbance of stratigraphy of pollen. Furthermore, lateral and vertical mixing of the water column in the lake may result in loss of resolution in the pollen archive. As the erosion of the surface sediments tends to be greatest in shallow water near the lake margin (Moore et al. 1991), coring of lake sediments can best be executed near the deepest part of the lake, although every site should be examined by a transect of corings over the lake for the best suitable point at that site.

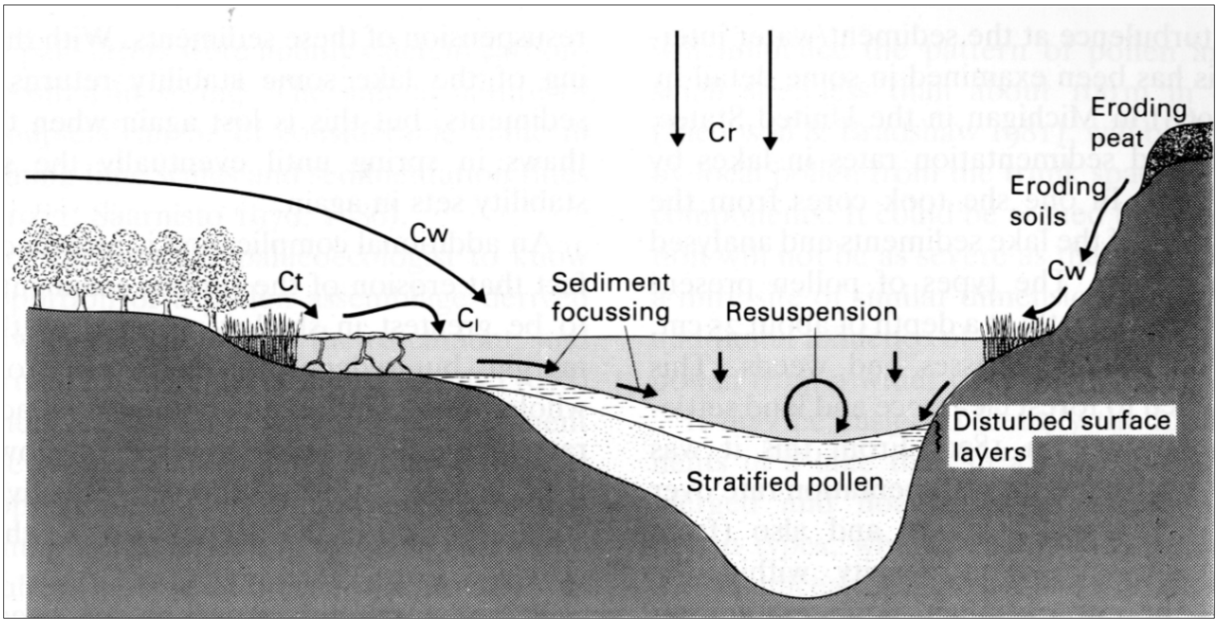


Figure 12: Sources of pollen at a lake site and its subsequent behavior (Moore et al., 1991)

2.3 Late-glacial vegetation development in the Netherlands

In order to compare palynological data from different sites in the Netherlands a reference is needed. Although the incorporation of pollen into the geological record depends on local conditions, it is most often possible to retrieve a regional signal from the records. Alternations and common trends in the regional pollen signal, which are here assumed to represent regional vegetational changes, can be compared to a reference diagram with well dated regional pollen zones. Inter-comparison between sites and the reference diagram may in this way lead to an age estimation of the organic infill from which the pollen was retrieved. The possibility of local disturbance of the pollen assemblage should however be kept in mind when comparing diagrams. Bohncke (1993) provided selected Late-glacial pollen diagrams for the Netherlands which can act as a reference of Late-glacial vegetational development in the Netherlands. However for this study the radiocarbon chronology of vegetation development in the Netherlands on the basis of a large data set from the Netherlands and neighboring countries (Hoek, 1997) was used. Although biostratigraphy and chronostratigraphy should be separated at all times, the original terminology for biostratigraphical zones (Bølling, Allerød) has often been used in a chronostratigraphic sense (Walker, 1995; Hoek, 1997). In order to avoid confusion, the review of Late-glacial vegetation development in the Netherlands is considered in a chronological context.

2.3.1 General vegetation development

Taxa that determine the vegetation aspect and may reflect regional trends were used for biostratigraphical zonation of Hoek (1997). Zonation is predominantly based on fluctuations in *Betula, Pinus* and *Salix*, while shifts in the percentages of arboreal pollen (AP), non-arboreal pollen (NAP), *Juniperus, Populus, Artemisia* and *Empetrum* have also been used for the zonation (Hoek, 1997). The zonation of Hoek (1997) was attached to an uncalibrated radiocarbon timescale in order to establish a regional chronological framework. More detailed information concerning the radiocarbon timescale used can be found in Hoek (1997). The regional zonation is briefly described below. Table 1 shows the regional pollen zonation scheme for the Late-glacial and Early Holocene as published by Hoek (1997), while figure 13 shows a generalized Late-glacial and Early Holocene pollen diagram for the Netherlands sensu Hoek (1997).

Table 1: Regional pollen zonation scheme for the Late-glacial and Early Holocene in the Netherlands (Hoek, 1997)

age BP	zone level1	sub-level2	sub-level3	pollen percentage characteristics
	5	5	5	
9,500				*Pinus* ↑↑
	4	4c	4c	
9,750				*Betula* ↑, *Populus* ↑
	4	4b	4b	
9,950				*Betula* ↓, Gramineae ↑, AP ↓
	4	4a	4a	
10,150				*Betula* ↑↑, *Juniperus* ↑, NAP ↓
	3	3b	3b	
10,550				*Empetrum* ↑
	3	3a	3a	
10,950				*Pinus* ↓, *Betula* ↓, AP ↓, NAP ↑
	2	2b	2b	
11,250				*Pinus* ↑↑
	2	2a	2a2	
11,500				*Betula* ↓, *Pinus* ↑, *Juniperus* ↓
	2	2a	2a1	
11,900				*Betula* ↑↑, *Salix* ↓, AP ↑↑, NAP ↓↓
	1	1c	1c	
12,100				*Betula* ↓, *Salix* ↑, *Juniperus* ↑, NAP ↑
		1b	1b	
12,450				*Betula* ↑, AP ↑
	1	1a	1a	
12,900				*Artemisia* ↑
	Late Pleniglacial (LP)			

(↑=increase, ↑↑=strong increase, ↓=decrease, ↓↓=strong decrease)

2.3.1.1 Late Pleniglacial (LP)

The Weichselian Late Pleniglacial was characterized by a sparse vegetation cover consisting predominantly out of Gramineae, Cyperaceae, Saxifragaceae, *Artemisia*, Chenopodiaceae, *Salix* and *Betula nana* shrubs (Hoek, 1997). Furthermore, low pollen production or high sediment accumulations rates characterize the Late Pleniglacial and high percentages of *Pinus* and thermophilous trees may occur due to reworking of older sediments (Hoek, 1997).

2.3.1.2 Zone 1 (12,900-11,900 BP)

Zone 1 (*Betula-Salix* PaZ) is characterized by an increase of *Artemisia* and AP percentages rising towards 50%. Furthermore, herbaceous plant communities and dwarf scrubs developed as a result of temperature rise (Hoek, 1997). Zone 1 can be subdivided into three subzones. Subzone 1a (12,900-12,450 BP) is characterized by a rise in the *Artemisia* curve along with AP percentages still below 20%. These low arboreal pollen percentages indicate an open landscape and reflect a transition from tundra towards shrub-tundra environment. The start of subzone 1b (12,450-12,100 BP) is indicated by an increase in *Betula* pollen (Hoek, 1997). Percentages of arboreal pollen types rise to values around 50%, and the landscape is predominantly open with small birch copses. Subzone 1b can be considered equivalent to the Bølling sensu van Geel et al (1989). The start of subzone 1c (12,100-11,900 BP) is characterized by a decrease in *Betula* percentages while NAP values rise (Hoek, 1997). Additionally *Salix* percentages rise and *Juniperus* reaches a maximum at the end of this subzone. A relative open landscape with sparse vegetation is suggested for this subzone and the relative importance of *Salix* may indicate wetter conditions towards the end of this period (Hoek, 1997). Subzone 1c can be considered equivalent to the Earlier Dryas sensu van Geel et al. (1989).

2.3.1.3 Zone 2 (11,900-10,950 BP)

Zone 2 (*Betula-Pinus* PaZ) is characterized by a strong rise in AP (up to 80%) while heliophilous herbs became less important (Hoek, 1997). While the whole of zone 2 can be considered as equivalent to the Allerød (sensu van Geel et al., 1989), it is subdivided into two subzones. Subzone 2a (11,900-11,250 BP) is characterized as the *Betula* phase with percentages rising to over 60% and a relative importance of *Juniperus* pollen at the beginning of this subzone (Hoek, 1997). Subzone 2a is divided into 2a1 and 2a2 based on two minor temporary decreases in *Betula* percentage. The start of sub-zone 2a2 (11,500 BP) is indicated by a decrease in *Betula* percentages (Figure 13) while *Pinus* percentages rise to 15%. The decreases in *Betula* tree pollen in favour of NAP implies that birch forest opened, enabling long distance transport of *Pinus* pollen (Hoek, 1997). Sub-zone 2b (11,250-10,950 BP) is indicated as the *Pinus* phase of the Allerød, which is characterized with *Pinus* percentages constantly higher than 20%, indicating that pine was growing locally (Hoek, 1997).

2.3.1.4 Zone 3 (10,950-10,150 BP)

Zone 3 (NAP-*Empetrum* PAZ) is characterized by a drop in AP percentages while low percentages of thermophilous tree pollen may be present due to reworking of older deposits (Hoek, 1997). Zone 3 as a whole can be considered equivalent to the Late Dryas zone sensu van Geel et al. (1989). Additionally zone 3 can be subdivided into two zones. Zone 3a (10,950-10,550) is characterized by a strong decrease in *Pinus* percentages, or in cases were *Pinus* does not decrease, by a decrease in *Betula* (Hoek, 1997). Subzone 3b (10,550-10,150 BP) is characterized by a rise in *Empetrum*, while AP percentages fluctuate at low level (Hoek, 1997). The expansion of *Empetrum* coincides with an influx of aeolian sandy material in many pollen diagrams, indicating more open vegetation during the Younger Dryas (Late Dryas).

2.3.1.5 Zone 4 (10,150-9500)

Zone 4 (*Betula* PaZ) is characterized by an increase in AP percentage to high values and at which birch forest became more dense with the start of the Holocene (Hoek, 1997). This expansion of birch forest is expressed by high percentages (~80%) of *Betula,* and the zone can be considered equivalent to the Preboreal zone sensu Behre (1966). Zone 4 can be subdivided into 3 subzones. Sub-zone 4a (10,950-9,950 BP), equivalent of Friesland oscillation sensu van Geel et al. (1981), is characterized by a rise in *Betula* percentages to around 80% while *Juniperus* percentages are also relatively high. Sub-zone 4b (9950-9750 BP), equivalent to Rammelbeek phase sensu van Geel et al. (1981), starts with a decrease in AP in favour of Gramineae and the birch forest opened for a short period during this phase (Hoek, 1997). Sub-zone 4c (9750-9500 BP) starts with a rise in *Betula* percentages towards values of 80% (Hoek, 1997).

2.3.1.6 Zone 5 (9500-9150 BP)

Zone 5 (*Pinus* PaZ) is characterized by a rise in *Pinus* to values exceeding 80%. Furthermore the appearance of *Corylus* (+- 9150 BP) indicates the start of the Holocene with the development of deciduous forest (Hoek, 1997). Zone 5 can be considered equivalent to the first part of the Boreal zone sensu Behre (1966). Other thermophilous trees such as *Quercus, Tilia, Ulmus* and *Alnus* are supposed to be absent during the Late-glacial and Preboreal in the Netherlands and appeared later on in the Holocene (Hoek, 1997).

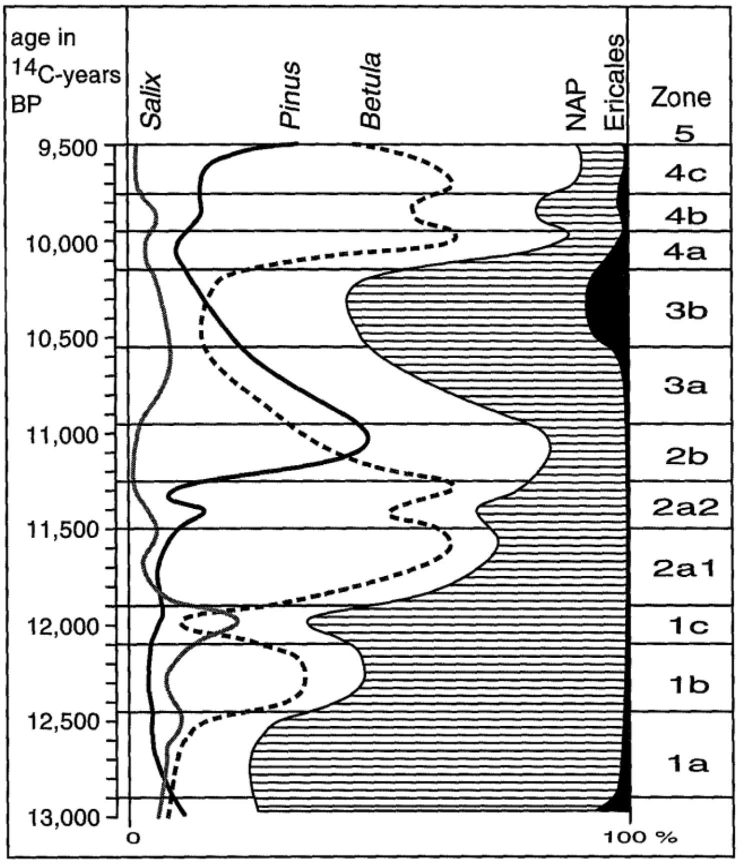


Figure 13: Generalized Late-glacial and Early Holocene pollen diagram for the Netherlands (Hoek, 1997)

2.3.2 Late-glacial climatological, vegetational and geomorphological events

Changes in climate during the Weichselian Late-glacial did not only influence vegetation cover but the whole landscape due to changes in hydrology, erosion, sedimentation and soil development (Hoek and Bohncke, 2002). As changes in the abiotic landscape are influenced by vegetation development and vice versa (Hoek, 2000), it is necessary to compare different environmental phenomena. Figure 14 gives a schematic overview of Late-glacial climatological, vegetational and geomorphological events plotted against a calibrated C^{14} time-scale as given by (Hoek and Bohncke, 2002). It should, however, be noted that not the changes in climate directly, but the associated developing vegetation cover formed one of the major causes for the changes in geomorphological processes during the Late-glacial (Hoek and Bohncke, 2002).

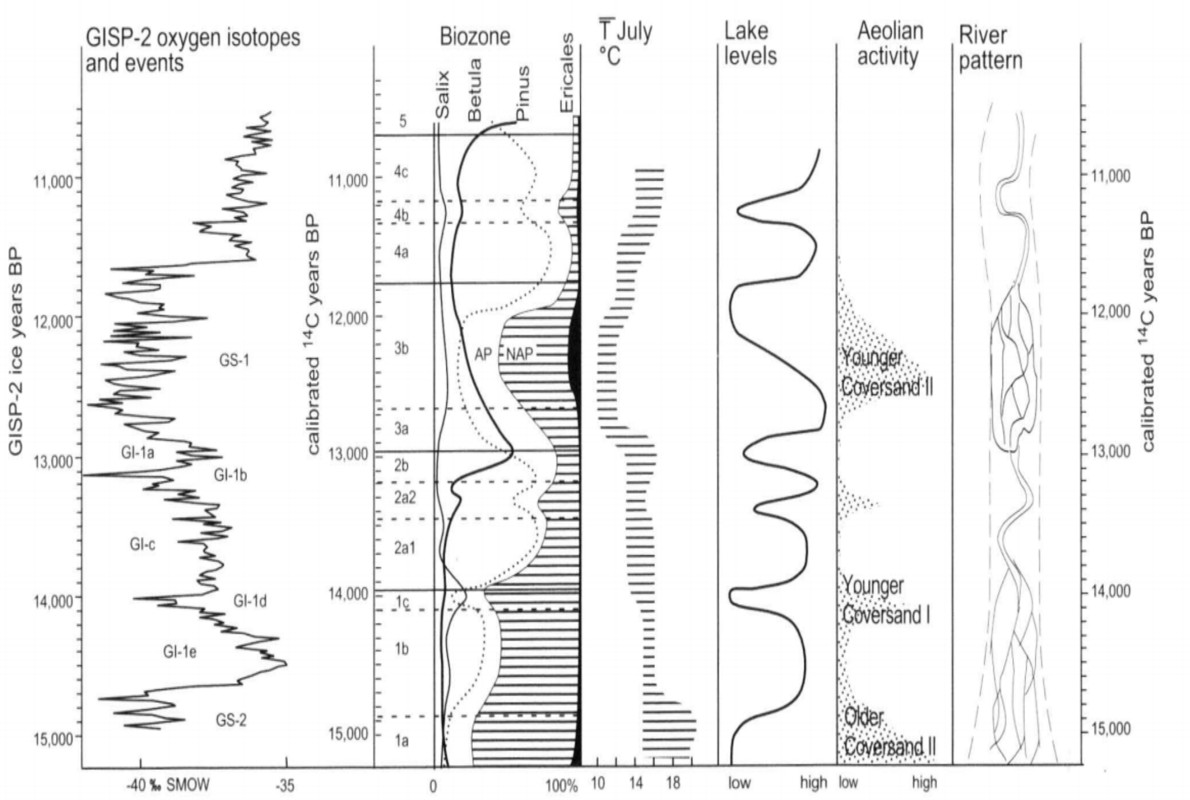


Figure 14: schematic overview of Late-glacial climatological, vegetational and geomorphological events plotted against a calibrated 14C time-scale (Hoek and Bohncke, 2002)

The main conclusion that can be derived from figure 14 is that phases of aeolian activity coincide with a more open vegetation cover and relative dry conditions. The presence and disappearance of permafrost during the Late-glacial seemed to have played a large role in the environmental changes during the Late-glacial. The climatic warming that started at 14.7 ka cal. BP had an important role in the melting of the permafrost, as when relic permafrost disappeared completely around 14.0 ka cal. BP vegetation and rivers reacted almost simultaneously (Hoek and Bohncke, 2002). The study by Hoek and Bohncke (2002) describes that the Weichselian Late-glacial, a period of rapid change, is accompanied by a complex interrelationship between climate and landscape.

2.4 Regional geology

The regional geology for the northern, central and southern Netherlands is described separately below. Although the geology and geomorphology is diverse within the regions, the aim in this study is to provide a broad indication of the geology as it is beyond the scope of this research to provide detailed geological information for all regions. The focus for this study is on (Middle and Late) Weichselian deposits as pingo remnants are mainly found in these deposits and older geological deposits are, therefore, not discussed. An overview of the geological Formations throughout the Netherlands during the Weichselian can be found in figure 15. A more detailed overview of the geology and geomorphology of the Netherlands can be found in (Berendsen, 2008).

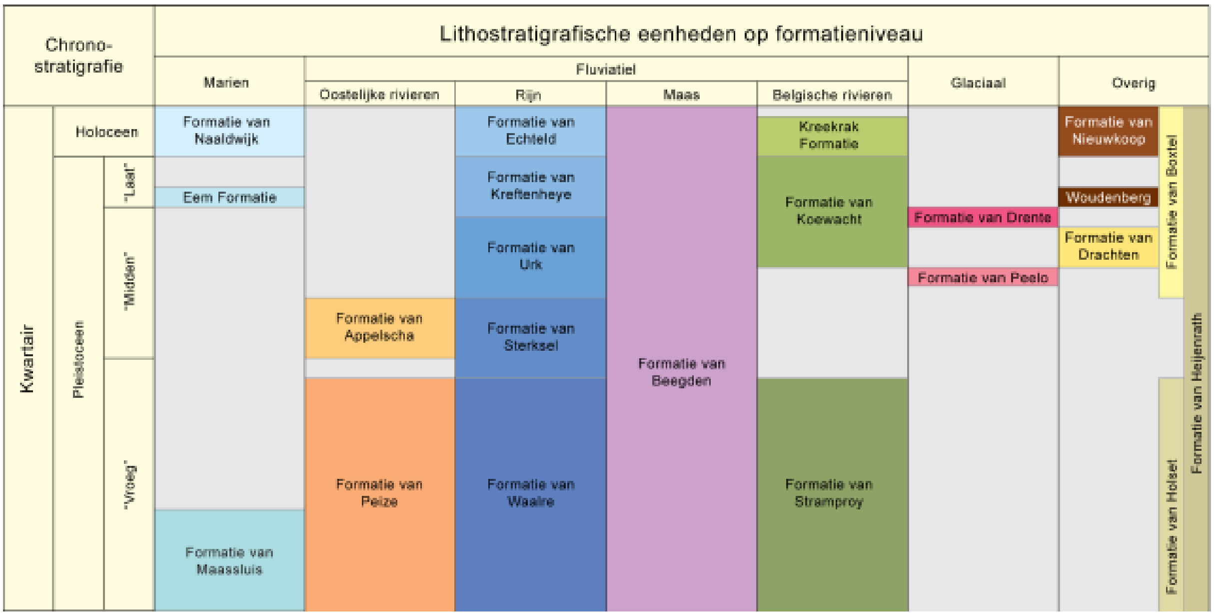


Figure 15: Late Pleistocene lithostratigraphic units of the Netherlands. Based on TNO, 2014

2.4.1 Northern Netherlands

Most of the pingo remnants in the northern Netherlands are located in the so-called Drents plateau. The subsurface of this region (Figure 16A) is diverse but consists in general of the following units. At the base, very coarse quartz sands were deposit by the Eridanos river system during the Middle Pleistocene (Appelscha formation) (Berendsen, 2008). During the Elsterian glaciation deep sub-glacial valley systems developed, which were filled with glaciofluvial and glaciolacustrine deposits (mostly fine sands and clays) after retreat of the continental ice sheet (Peelo formation and Nieuwolda member) (TNO, 2014).

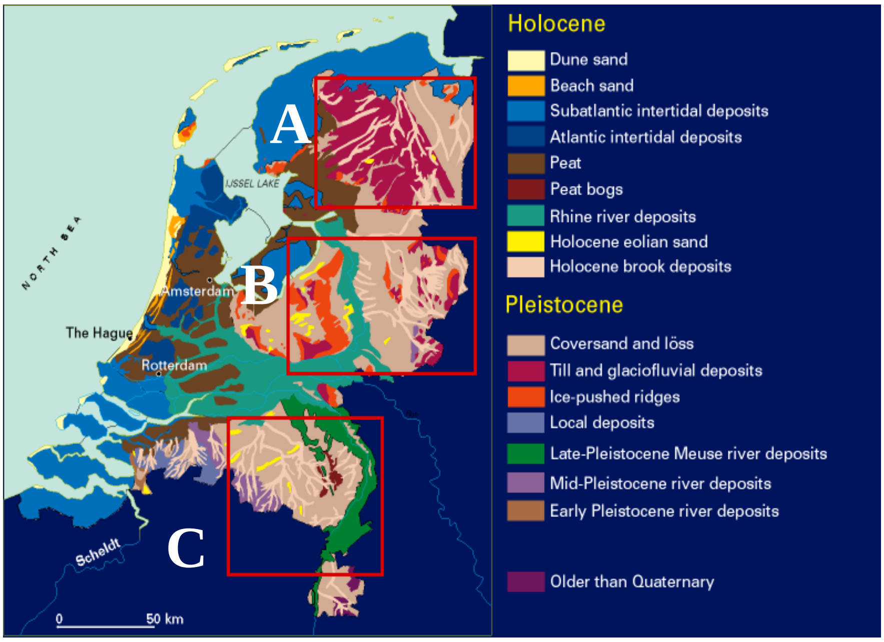
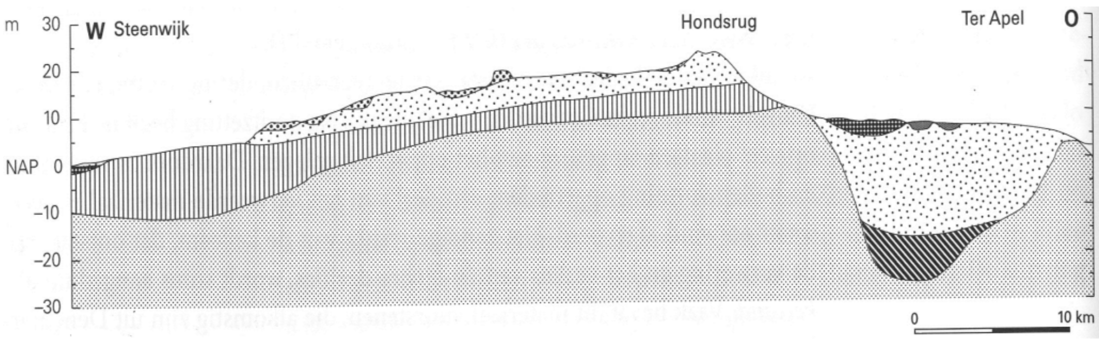


Figure 16: Geological map of the Netherlands with A) northern Netherlands (2.4.1) B) central Netherlands (2.4.2) and C) southern Netherlands (2.4.3) (Faculty of geosciences Utrecht University, 2014)

Following the Elsterian, the Saalian glaciation resulted in the dispersion of the Drenthe Formation. The Drenthe Formation has a variable lithological composition but can overall be interpreted as a glacial till consisting of sandy loams, clay, and unsorted gravelly sand with weak to high gravel content (TNO, 2014). Higher up in the sequence the Drenthe Formation may be covered by deposits of the Boxtel Formation. The Boxtel Formation in the region is mostly represented by the Wierden member. The Wierden member consists of fine to medium coarse windblown sands, the so-called coversands (TNO, 2014). A general lithological cross-section through the northern Netherlands study area is given in figure 17.



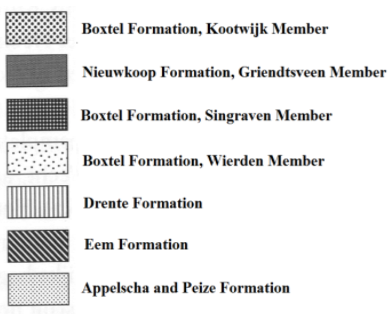


Figure 17: Geology of the northern till region (Berendsen, 2008)

2.4.2. Central Netherlands

The central Netherlands are characterized by landforms resulting from the coverage of the area by the continental ice sheet during the Saalian glaciation. The most prominent features are the ice-pushed ridges, which can reach up to ~100 meters +NAP. These ridges mainly consist of pre-Saalian river deposits from the river Rhine and Meuse (Berendsen, 2008). Furthermore, deep glacial basins are present in the central Netherlands, which are filled with Saalian glaciolacustrine deposits. Glaciofluvial deposits are found alongside the ice-pushed ridges, resulting from the outwash of melt-water from the continental ice sheet. The deposits in the central Netherlands (figure 16B) which are related to the presence of the continental ice sheet belong to the Drenthe Formation (Berendsen, 2008). Besides depositions related to continental ice sheet, the central Netherlands are characterized by coversands. These coversands belong to the Boxtel Formation (Berendsen, 2008) which was mainly deposited during the Pleniglacial and following Late-glacial. Figure 18a gives a general geological cross-section through the central Netherlands.

East of the river IJssel the central Netherlands are characterized by a somewhat different geology and geomorphology (Figure 18b). The coverage of the area by the continental ice sheet during the Saalian glaciation was of importance for the geomorphology of the area. The ice-pushed ridges in the region consist of marine clay deposits from the Eocene, Oligocene and Miocene but also contain sandy deposits of the Eridanos river system (Appelscha and Peize Formation) (Berendsen, 2008). Furthermore the region provides glacial till deposits and is for the main part covered by coversands and fluvioperiglacial deposits (Boxtel Formation). On a smaller scale local river deposits and peat can also be found.

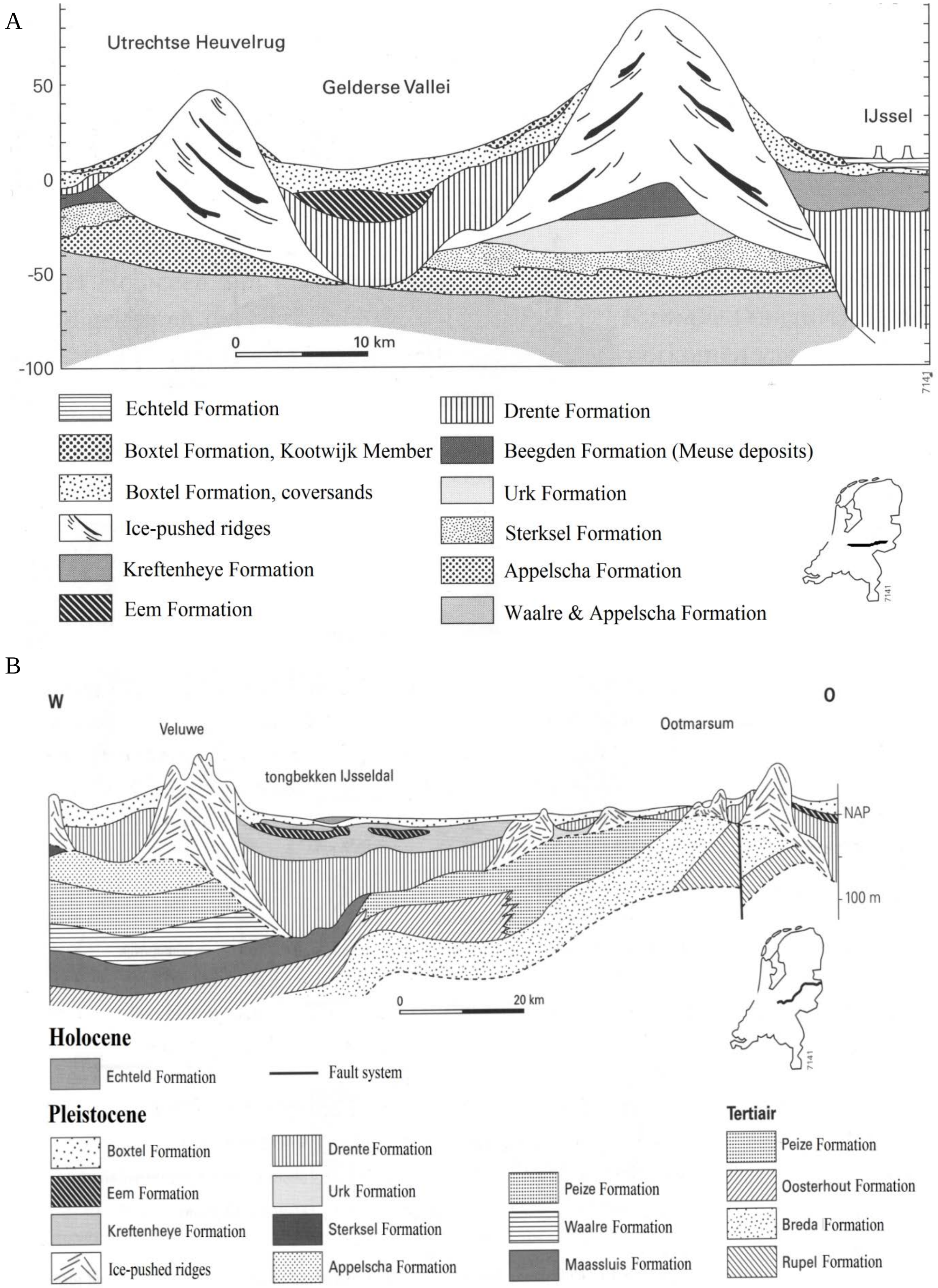


Figure 18: a) Geology of the central Netherlands from Zeist to Deventer b) Geology of the central Netherlands from the Veluwe to Ootmarsum (Berendsen, 2008)

2.4.3 Southern Netherlands

The southern Netherlands (figure 16c) are characterized by coversands of the Boxtel Formation. These coversands consist mainly out of fine to medium coarse wind-blown sands, with low gravel content. The sands originate from both the Saalian and Weichselian glaciations but are hard to distinguish in the field and, therefore, both belong to the Boxtel Formation (Berendsen, 2008). Below the coversands the geology is dominated by river deposits from the river Rhine and Meuse. The presence of a thick loam layer in parts of the region is characteristic. More detailed information on the regional geology can be found in Schokker (2003). Within the coversands in the region several brook valleys occur. A schematic cross-section through such a brook valley is given in figure 19. These valleys are in general broad and shallow, indicating the fact that the shape of the valleys originates from periglacial processes in this region during the Weichselian (Berendsen, 2008). The development of coversand ridges during the Weichselian prevented discharge of local streams which caused stagnation of water and in turn caused gyttja deposits in shallow depressions during the Younger Dryas, and the development of peat bogs during the Holocene (Berendsen, 2008).

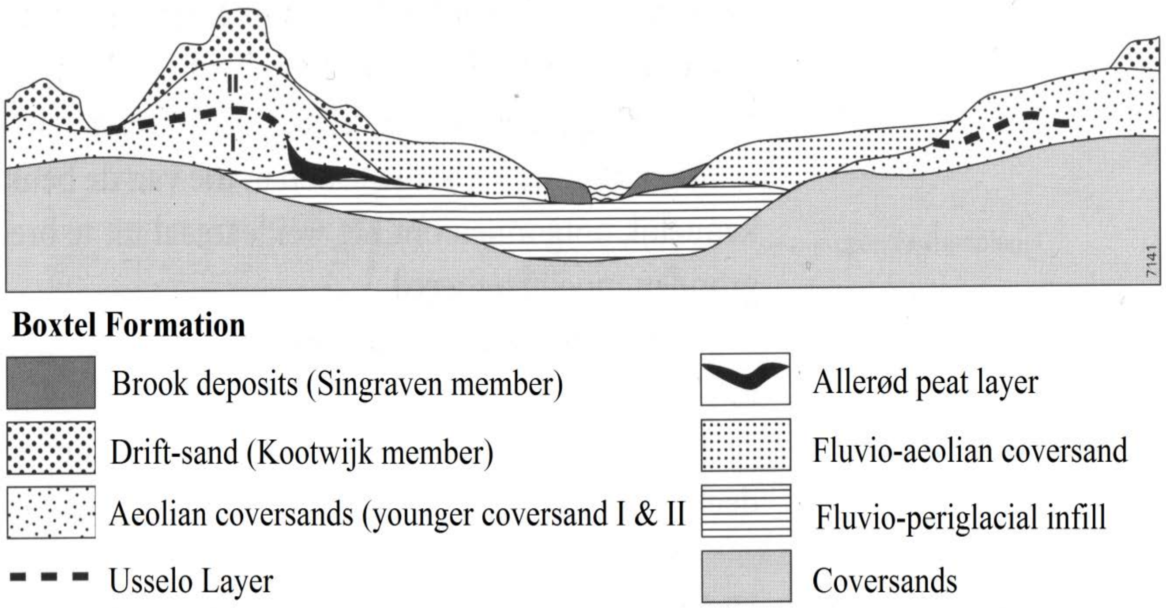


Figure 19: Geology of a typical southern Netherlands brook valley system (Berendsen, 2008)

2.5 Pingo remnants throughout the Netherlands

Many of the known pingo remnants contain an organic infill and, therefore, pollen analysis is often performed in order to reconstruct vegetation and indicate the age of the basal infill. As this study tries to reconstruct permafrost depth/distribution since the Weichselian Late Pleniglacial, and the characteristics of decay of the permafrost, age control on the pingo remnant fills is of importance. In order for pingo remnants to develop a record of environmental changes, sediment accumulation is needed. As discussed the most pronounced sediment accumulation starts to occur after (at least) partial decay of the pingo. The age of the basal infill is therefore an indication for the minimal age of the decay of the pingo, which in turn indicates the minimum age of decay of permafrost. As a time delay might occur concerning permafrost degradation in the northern and southern Netherlands due to spatial differences, a distinction between pingo remnants in the northern, central and southern Netherlands was made. As much information concerning age, lithology and palynology was collected for each pingo remnant. As the start of infill is of most importance for this study, only the Late-glacial part of the infill is taken into account.

The number of pingo remnants in the northern Netherlands is numerous and it is, therefore, that only a selection of the pingo remnants in this region is used in this overview. Although less numerous than in the northern Netherlands, pingo remnants in the central Netherlands are well known, which resulted again in a selection of the pingo remnants used for this study. Finally, the number of known pingo remnants in the southern Netherlands is relatively low compared to the northern and central Netherlands which resulted in the fact that most known pingo remnants in this region are listed in this study. Figure 20, together with table 2, shows an overview of the pingo remnants used in this study while also considering the most important characteristics of these pingo remnants.

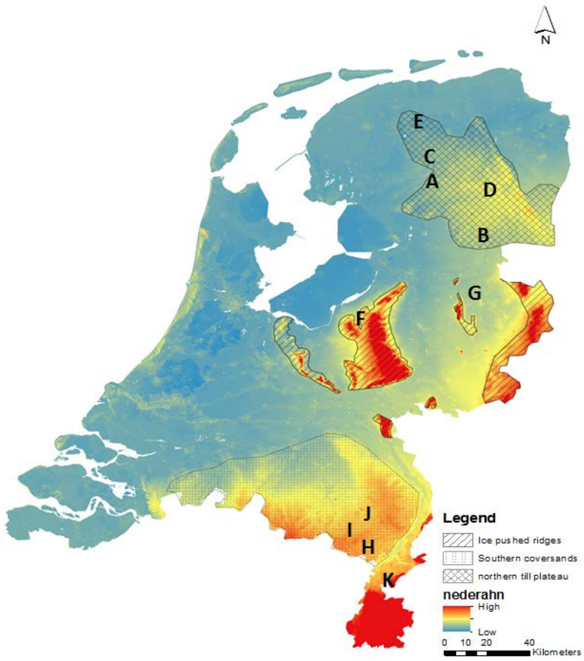


Figure 20: Overview pingo remnants used for this study.

Table 2: Overview considering the most important characteristics of the pingos and basal infill used for this study. Letters in front of pingo remnant name indicate locations given in figure 20.

Name pingo remnant	X	Y	Top (m+/- NAP)	Bottom (m +/- NAP)	Diameter (m)	Depth (m)
(A) Groote Veen	173875	367675	+8.5	+5.5	200	3
(B) Mekelermeer	238000	532000	+15.9	+3.9	200	12
(C) Stokersdobbe I	207850	565695	+2.5	-5.5	100	8
(D) Uteringsveen II	241000	548000	+16.0	+12.0	150	4
(E) Veenklooster	202861	587124	-0.5	-5.5	170	5
(F) Bleekemeer	165232	377030	+25.0	+17.0	200	8
(F) Uddelermeer	180450	473200	+25.9	+9.9	300	16
(G) Daarle	232325	492700	+7.6	+2.6	200	5
(H) Vliegersgat	175925	369225	+26.9	+21.9	80	5
(H) Berkenven	174100	367925	+27.9	+24.9	80	3
(H) Klein Ven	173775	367725	+28.5	+26.0	70	2.5
(H) Groot Ven	173875	367675	+28.5	+26.5	70	2
(I) Mierlo Ven Hoenderboom	172520	377860	+24.0	+20.5	50	3.5
(J) Maartensdobbe	184075	372710	+28.2	+25.2	100	3
(K) Gulickshof	190729	341214	+30.2	+27.2	200	3

2.5.1 Northern Netherlands

Pingo remnants are numerous in the northern Netherlands. Most pingo remnants occur in the glacial till plateau. The pingo remnants in the northern Netherlands are of varying depth (Kluiving et al., 2010). Chemical precipitation is found in many of the pingo remnants in the northern Netherlands (de Bruijn, 2012), indicating groundwater seepage. Descriptions of some key pingo remnants in the northern Netherlands are given below.

2.5.1.1 Groote Veen (De Jong, 1959)

Groote Veen pingo remnant is located in the northern Netherlands till region, in the valley of the Vledder A (figure 20/24). The depression has a diameter of ~200 meters and measures 3 meters in depth (de Jong, 1959). The basal infill of Groote Veen is dated to 1b based on correlation with the regional vegetation development for the Netherlands (Hoek, 1997). Furthermore, the pollen diagram of Groote Veen (figure 25) indicates a Late-glacial vegetational development with the presence of pollen zones 1b to 4c sensu (Hoek, 1997).

2.5.1.2 Mekelermeer (Bohncke et al., 1988)

The Mekelermeer is located in the northern Netherlands till plateau and in the surrounding of the lake a large number of pingo remnants are present. Figure 20/24 shows the location of the Mekelermeer which has a diameter of 200 meters and a depth of 12 meters. A lithological cross-section and further information concerning the local geology is given by de Gans and Sohl (1981), figure 21. The Mekelermeer depression is filled with gyttja and blown-in sand since the beginning of the Late-glacial (Hoek, 1997). The pollen diagram of Mekelermeer is given in figure 25. The start of the infill is considered to be at subzone 1a sensu Hoek (1997). This start of infill during the Late-glacial is supported by a radiocarbon date of 12.380 ^{14}C yr. BP taken near the bottom part of the depression. (Bohncke et al., 1988).

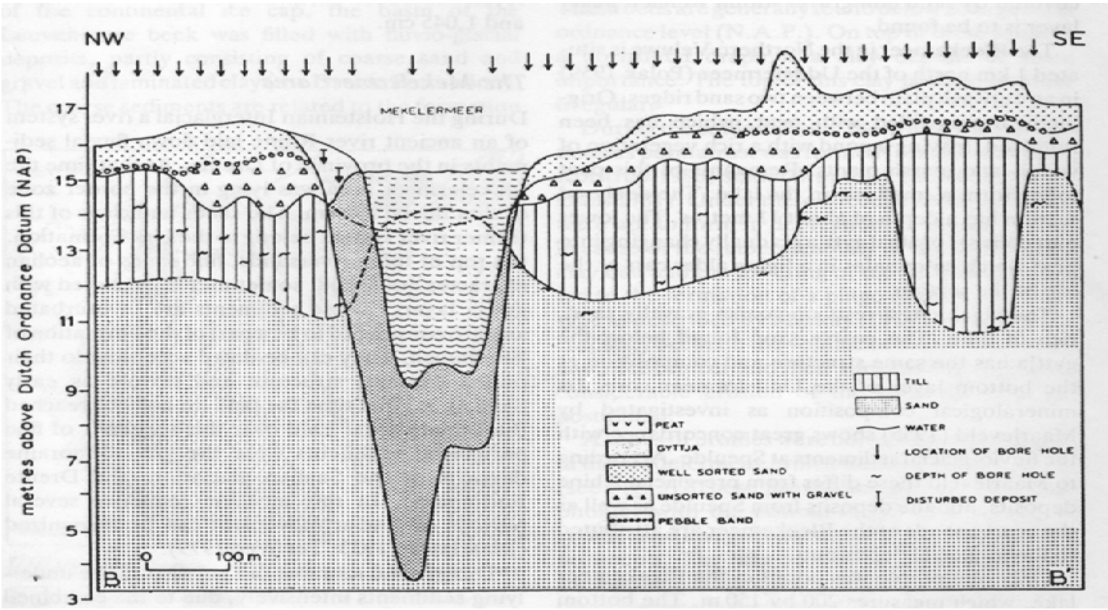


Figure 21: Lithological cross-section of the Mekelermeer (de Gans and Sohl, 1981)

2.5.1.3 Stokersdobbe I (Paris et al., 1979)

Stokersdobbe I is located in the till region in the northern Netherlands (Figure 20/24). The pingo was formed in a small Pleniglacial river valley, has a diameter of 100 meters and a depth of 8 meters (Paris et al. 1979). The pingo remnant is filled with gyttja and the pollen diagram derived from the depression is shown in figure 25. The pollen diagram indicates a Late-glacial vegetation development with a basal infill of the depression starting at pollen-zone 1b (Bølling) up to and including zone 4 (sensu Hoek, 1997).

2.5.1.4 Uteringsveen II (Cleveringa et al., 1977)

Uteringsveen II is also located in the till region in the northern Netherlands Figure 20/24. The pingo remnant has a diameter ~150 meters, a depth of 4 meters and was formed in a valley during the Pleniglacial. The depression is filled with gyttja, peat and windblown sand to varying extent (Cleveringa et al., 1977) (figure 22). The pollen diagram of Uteringsveen II is shown in figure 25. It can be derived from the pollen diagram that the basal infill started at pollen subzone 1b (equivalent of Bølling) and continues up to at least pollen subzone 4c (Hoek, 1997).

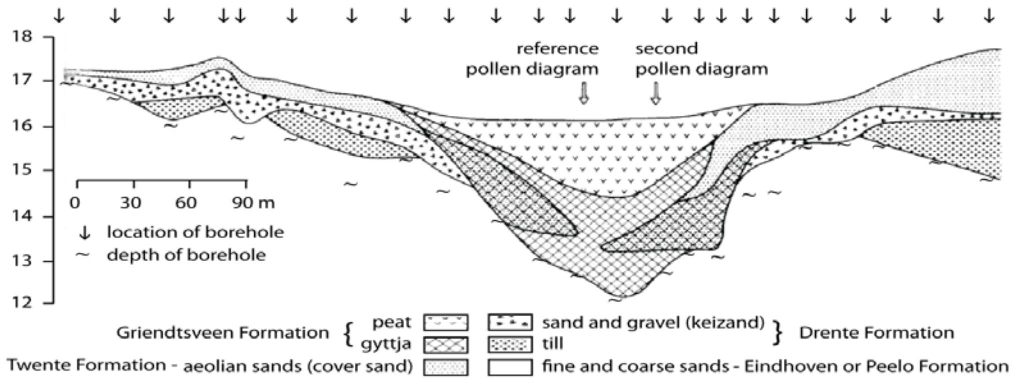


Figure 22: Lithological cross-section of the Uteringsveen pingo remnant (Cleveringa et al., 1977)

2.5.1.5 Veenklooster (Kluiving et al., 2010)

Veenklooster is located in the northern Netherlands (Figure 20/24). The substrate in which the veenklooster depression is found consists mainly of deposits originating from the Elsterian, Saalian and Weichselian glaciations. A detailed cross-section of Veenklooster pingo remnant as published by Kluiving et al. (2010) is given in figure 23. The basal infill of Veenklooster pingo remnant is dated to 12,450 +/- 95 ^{14}C (a BP) (Kluiving et al. 2010) which coincide with the dated age of the onset of the Bølling. Unfortunately, any further palynological study of the Veenklooster infill is lacking in this study.

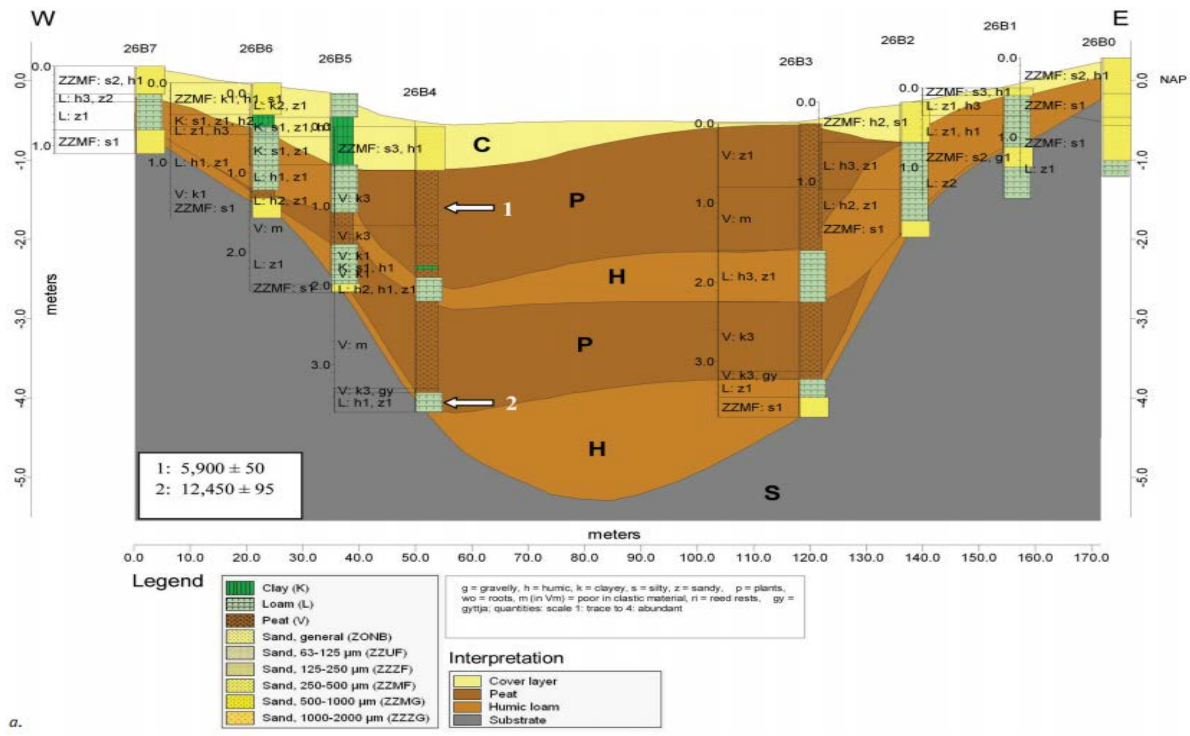


Figure 23: Lithological cross-section of Veenklooster (Kluiving et al. 2010)

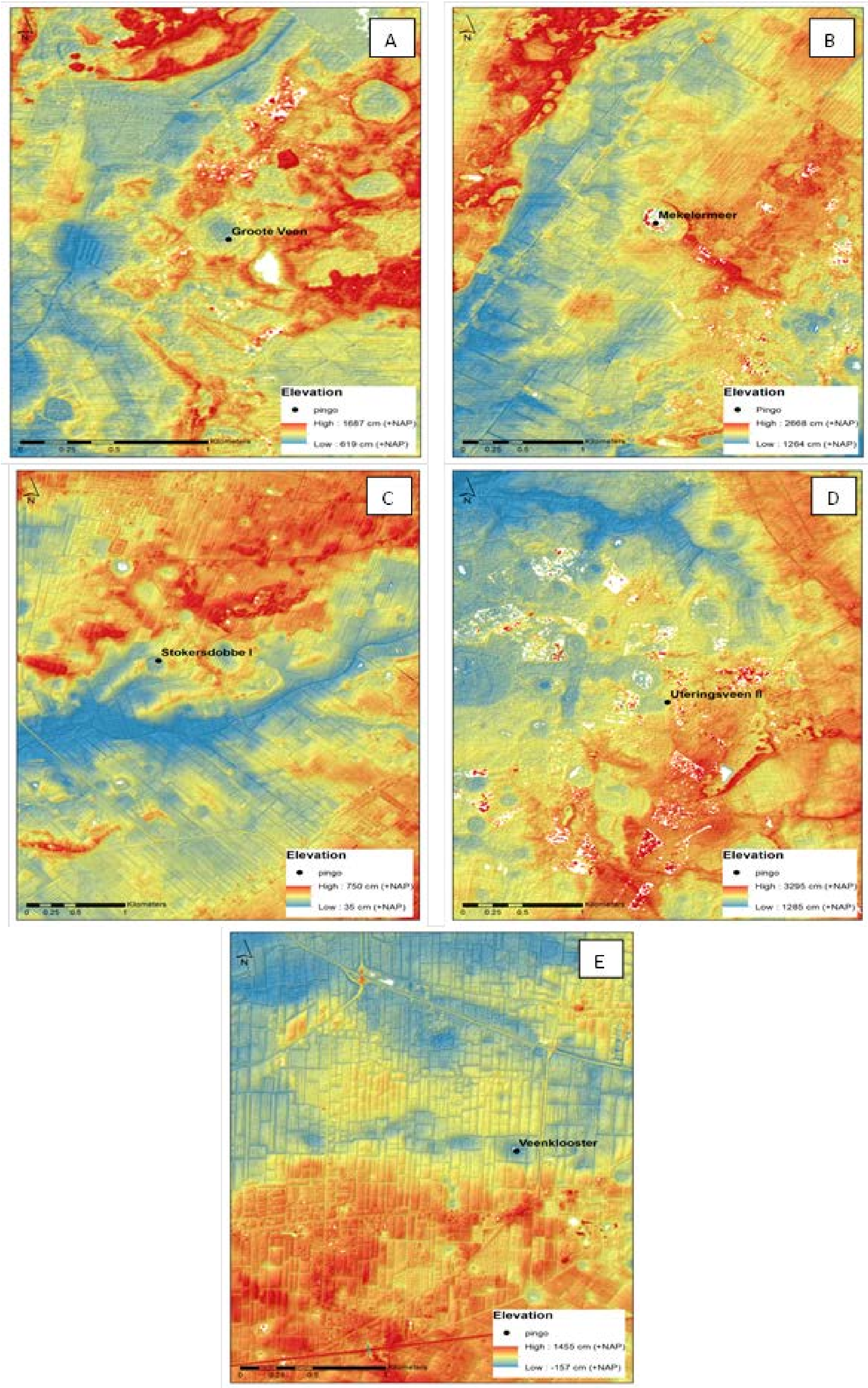


Figure 24: Locations of pingo remnants in the northern Netherlands; (a) Groote Veen (b) Mekelermeer (c) Stokersdobbe I (d) Uteringsveen II (e) Veenklooster. Some pingo remnants show a clear indication of a rampart while others seem to lack in such a rampart (Lidar image modified from AHN).

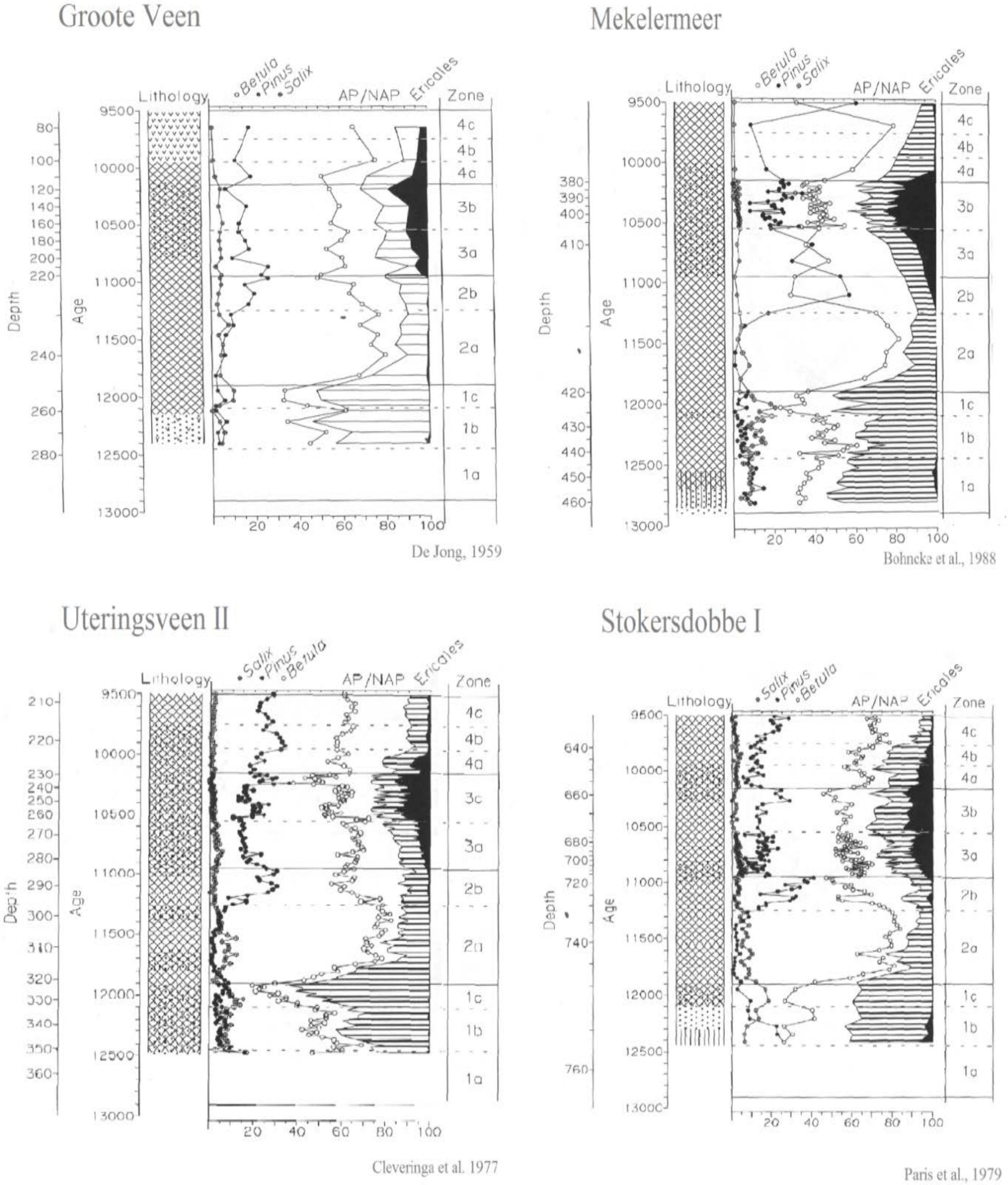


Figure 25: Pollen diagram for Groote Veen, Mekelermeer, Uteringsveen II and Stokersdobbe I (modified after Hoek, 1997

2.5.2 Central Netherlands

2.5.2.1 Uddelermeer and Bleekemeer (Bohncke et al., 1988)

The Uddelermeer (~300 by 200 meters) and Bleekemeer (~200 by 150 meters) are 2 pingo remnants which are only ~400 meters apart and are located in the basin of the Leuvenumse beek (Bohncke et al. 1988) (Figure 20/28). The area is characterized by deposits from the penultimate glaciation. Melting of the continental ice sheet at the end of the Saalian resulted in the deposition of fluvio-glacial deposits in the Leuvenumse beek. During the Weichselian melt-water deposits and coversand deposits filled the basin, while during the Holocene the stream area of the Leuvensumse beek was filled with clay, sand and organic sediments (Bohncke et al. 1988). Figure 26 shows a geological cross-section through the Bleekemeer and Uddelermeer area. The impermeability of the underlying clay bed and the lowering of permafrost resulted in the formation of pingos in depressions in the clay layer during the coldest part of the Weichselian (Bohncke et al. 1988). The basal part of the pollen diagrams for Uddelermeer is shown in figure 29. The Uddelermeer diagram shows a start of the infill during the Bølling (pollen zone 1b). The basal part of the infill furthermore shows a Late-glacial pollen profile including pollen zones 1b to 4a (Hoek, 1997). The Bleekemeer pollen diagram (Appendix E) as published by (Bohncke et al. 1988) indicates a start of the infill before the Bølling zone. This however, in this study is thought not to be the start of the infill but rather indicates reworked pollen entrapped in the sandy sediments at the base of the depression. The start of infill is placed at 1,077cm at the Bleekemeer. The pollen diagram shows an increase in *Betula* accompanied with a rise of arboreal pollen up to ~60%. This places the start of the infill in pollen zone 1b sensu Hoek (1997) and therefore can be correlated to the Bølling biostratigraphic unit.

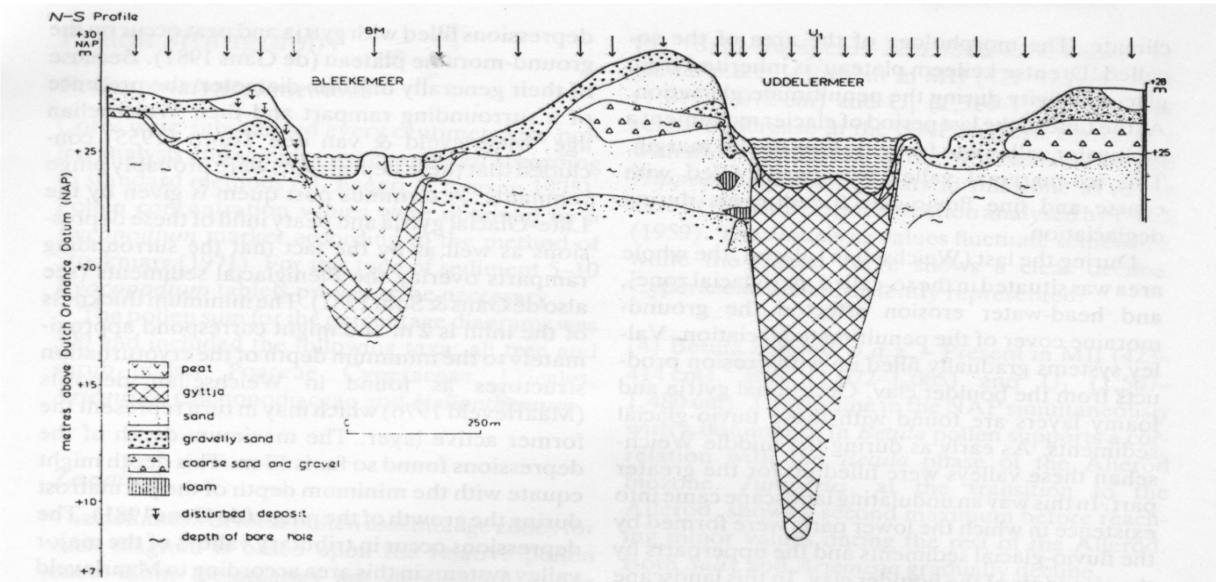


Figure 26: Lithological cross-sections of Bleekemeer and Uddelermeer (Bohncke et al. 1988)

2.5.2.2 Daarle (Bijlsma and de Lange, 1983)

The Daarle pingo remnant is situated in the eastern Netherlands (figure 20) in a relatively low-lying gently undulating plain which in turn is situated between ice-pushed ridges (figure 28). Figure 27 shows a cross-section through the Daarle pingo remnant as published by Bijlsma & de Lange (1983). The pingo remnant has a diameter of ~200 meters and a depth of ~5 meters, although the upper 150cm was disturbed by peat excavations. The pollen diagram of Daarle is given in figure 29. The base of infill is placed in pollen zone 1b (sensu Hoek, 1997), and continues until at least the Younger Dryas (zone 3b) (Hoek, 1997).

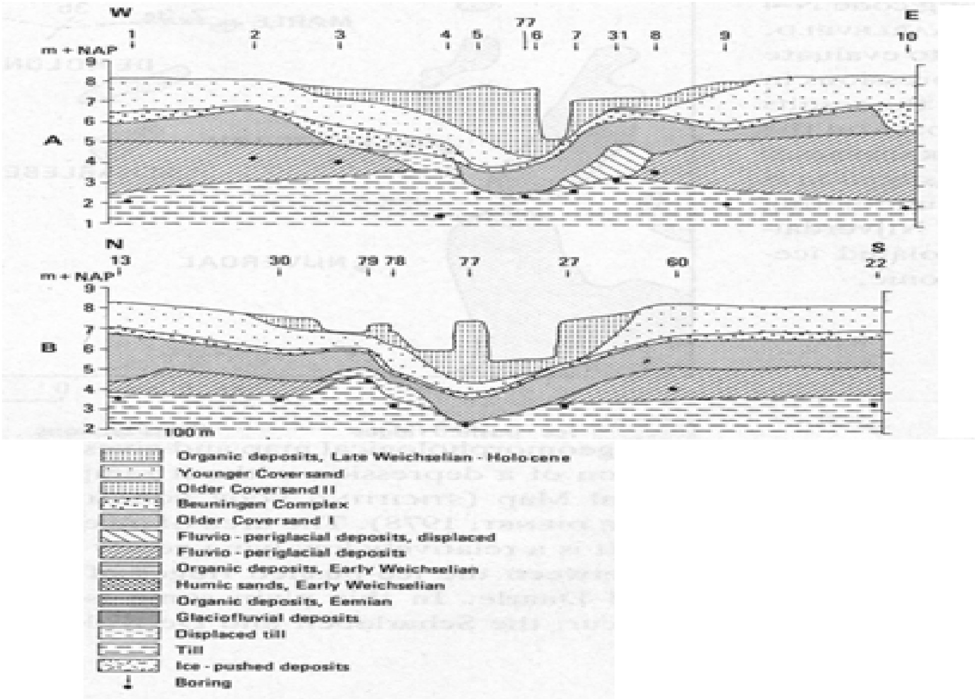


Figure 27: Lithological cross-section of the Daarle pingo remnant (Bijlsma & de Lange, 1983)

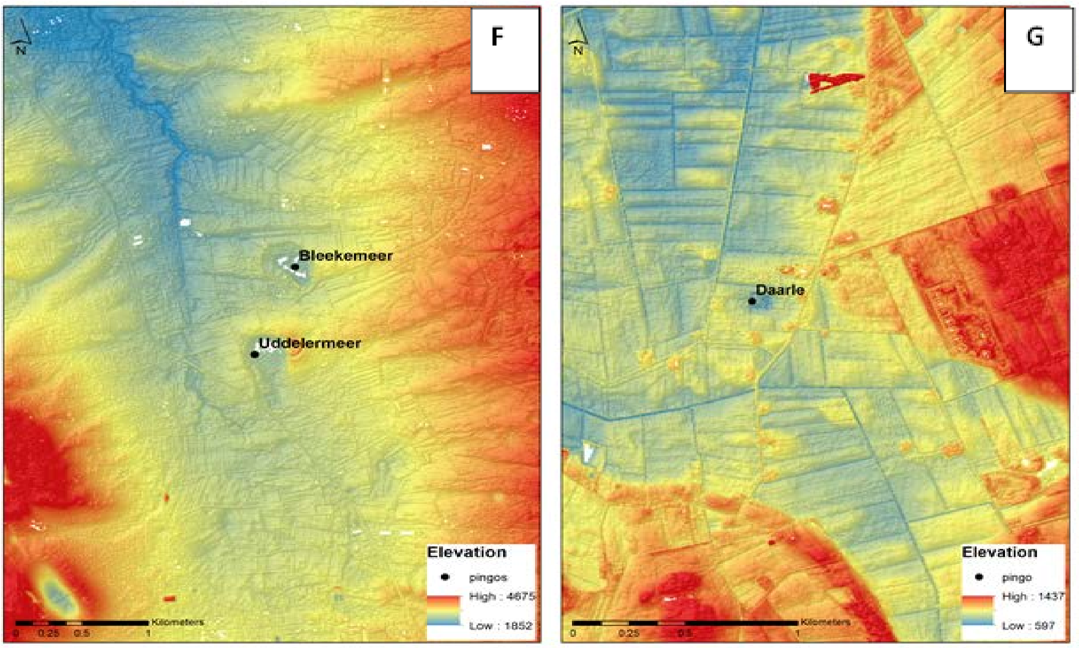


Figure 28: Locations of pingo remnants in the central Netherlands; (F) Bleekemeer & Uddelermeer (G) Daarle. A clear rampart is visible at the Uddelermeer and Daarle pingo remnant (Lidar image modified from AHN).

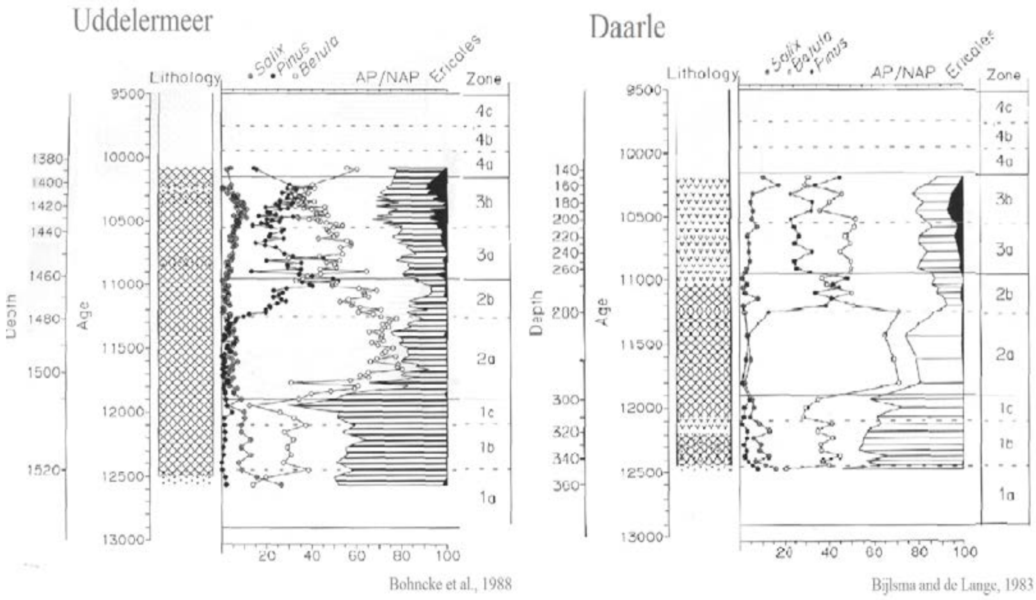


Figure 29: Pollen diagram for Uddelermeer and Daarle (modified after Hoek, 1997)

2.5.3 Southern Netherlands

2.5.3.1 Weerterbos (van Asch et al., 2013)

Reconstruction of permafrost depth and the time of permafrost decay in the southern Netherlands are a.o. based on pingo remnants in the Weerterbos region. The Weerterbos study site is located in the southern Netherlands (figure 20/30). Several circular depressions could be recognized in the coversand ridge in the Weerterbos study area. The depressions are located nearby an extensive loam area (figure 30).

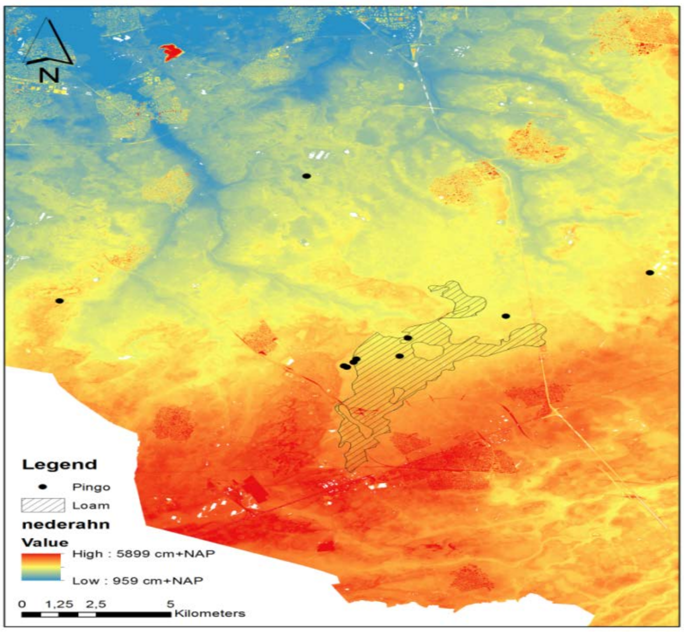


Figure 30: Overview of Weerterbos pingo remnants (Lidar image modified after AHN)

Lithological cross-sections of the Weerterbos depressions (figure 31) were published by Hoek & Joosten (1995). The depressions, Klein Ven (KV), Groot Ven (GV), Berkenven (BV) and Vliegersgat (VG) range in diameter from ~70 to 80 meters. The maximum thickness of infill ranges from 2 to 5 meters (van Asch et al. 2013). The infill of the depressions consist of calcareous gyttja deposits of Late-glacial age, which presumably formed as a result of seepage of carbonate rich groundwater after melting of the ground-ice lenses (Hoek and Bohncke, 2001; van Asch et al., 2013). Figure 31 indicates that lithology for all depressions consist of a basal infill of silty sand /sandy silt covered by lake marl, gyttja and peat. The chronostratigraphy of the pollen records of the Weerterbos pingo remnants has been established by van Asch et al (2013) based on correlation of the pollen records with the biostratigraphical framework of Hoek (1997a).

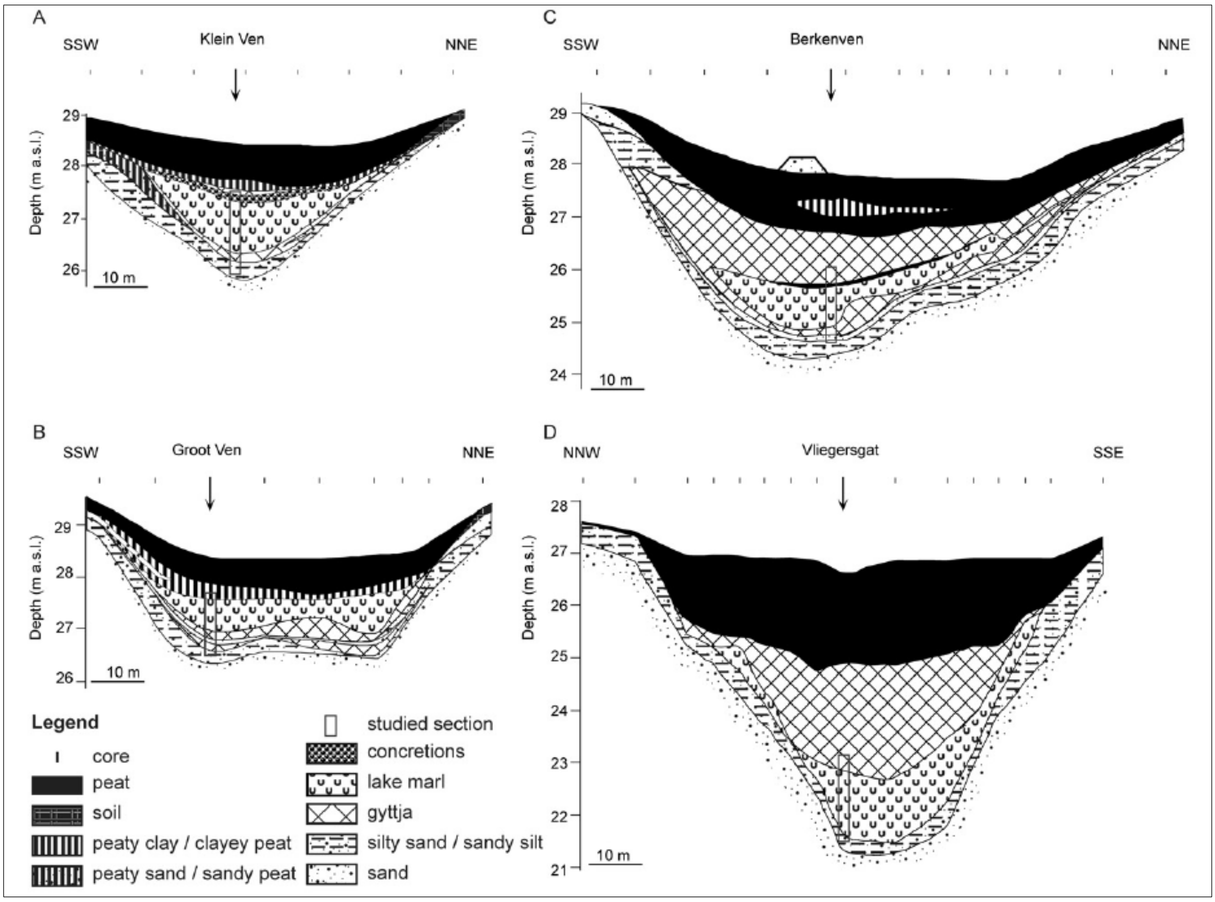


Figure 31: Lithological cross-section through the Weerterbos pingo remnants (van Asch et al., 2013)

Table 3 shows changes in main pollen taxa in the Klein Ven record compared with the regional pollen assemblage zones of Hoek (1997a) as described by van Asch et al. (2013). This data indicates that the basal infill of the Klein Ven pingo remnant started in pollen assemblage zone (PAZ) 1b as described by Hoek (1997a). The start of the infill, therefore, started between 12.450 and 12.100 ^{14}C (a BP), during the Bølling biostratigraphical unit. AMS radiocarbon dated plant macrofossils of the Klein Ven support the pollen data with an age of 12,670 +/- 290 ^{14}C (a BP). Figure 32 shows the pollen diagram of the Klein Ven record.

Table 3: Changes in the main pollen taxa in the KV record compared with the regional pollen assemblage zones of Hoek (1997a) (van Asch et al. 2013)

Local PAZ	Depth (m)	Main pollen taxa	Regional PAZ Hoek (1997a)
KV-p4	0.94–0.97	*Pinus*, *Corylus*, *Betula* *Pinus* ↑, *Betula* ↓, *Corylus* ↑	B
KV-p3	0.97–1.07	*Betula*, *Pinus* *Pinus* ↑, (*Empetrum* ↑, *Corylus* ↑)	*NA*
KV-p2B	1.07–1.25	*Betula* *Betula* ↑, *Juniperus* ↓, *Salix* ↓, NAP ↓	2a
KV-p2A	1.25–1.48	*Betula*, *Salix*, *Juniperus* *Betula* ↑, Poaceae ↓, *Juniperus* ↑, Cyperaceae ↓	2a
KV-p1B	1.48–1.55	Poaceae, *Salix*, *Betula*, Cyperaceae *Salix* ↑, *Betula* ↓, Cyperaceae ↑	1c
KV-p1A	1.55–1.96	Poaceae, *Betula*, *Salix*	1b

The pollen diagram of Groot Ven (GV) (Figure 32) indicates a start of the infill at PAZ 1b as described by Hoek (1997a) as well. AMS radiocarbon dating however shows some difficulties at Groot Ven (see van Asch et al., 2013), as one date is considered too old while another is considered too young. A radiocarbon date of 12,040 +/- 90 ^{14}C (a BP) at ~1.05 cm depth of the Groot Ven core however supports the idea that the start of infill of Groot Ven started at PAZ 1b.

Pollen diagrams of Berkenven and Vliegersgat (Figure 32) show that the start of infill of the depressions took place around the Bølling. As the onset of the Bølling is dated at 12,450 ^{14}C (a BP) (Hoek, 1997a) for the Netherlands it can therefore be correlated to stage GI-1e (Hoek and Bohncke, 2001).

Van Asch et al. (2013) conclude that the Klein Ven basin formed during the Bølling, when landscapes were still relatively open and for which chironomid-inferred mean July temperatures of ~16.0-16.5°C were reconstructed. Furthermore the Older Dryas was recognized in the pollen diagram of the Klein Ven depressions as a peak in Cyperaceae pollen. The Older Dryas is considered to be a drier period (van Geel & Kolstrup, 1978; Bohncke, 1993). Additionally van Asch et al. (2013) conclude that this phase of regressive vegetation coincides with a temporary decrease in chironomid-inferred temperatures (to ~14.5-15.0°C) in the Klein Ven record.

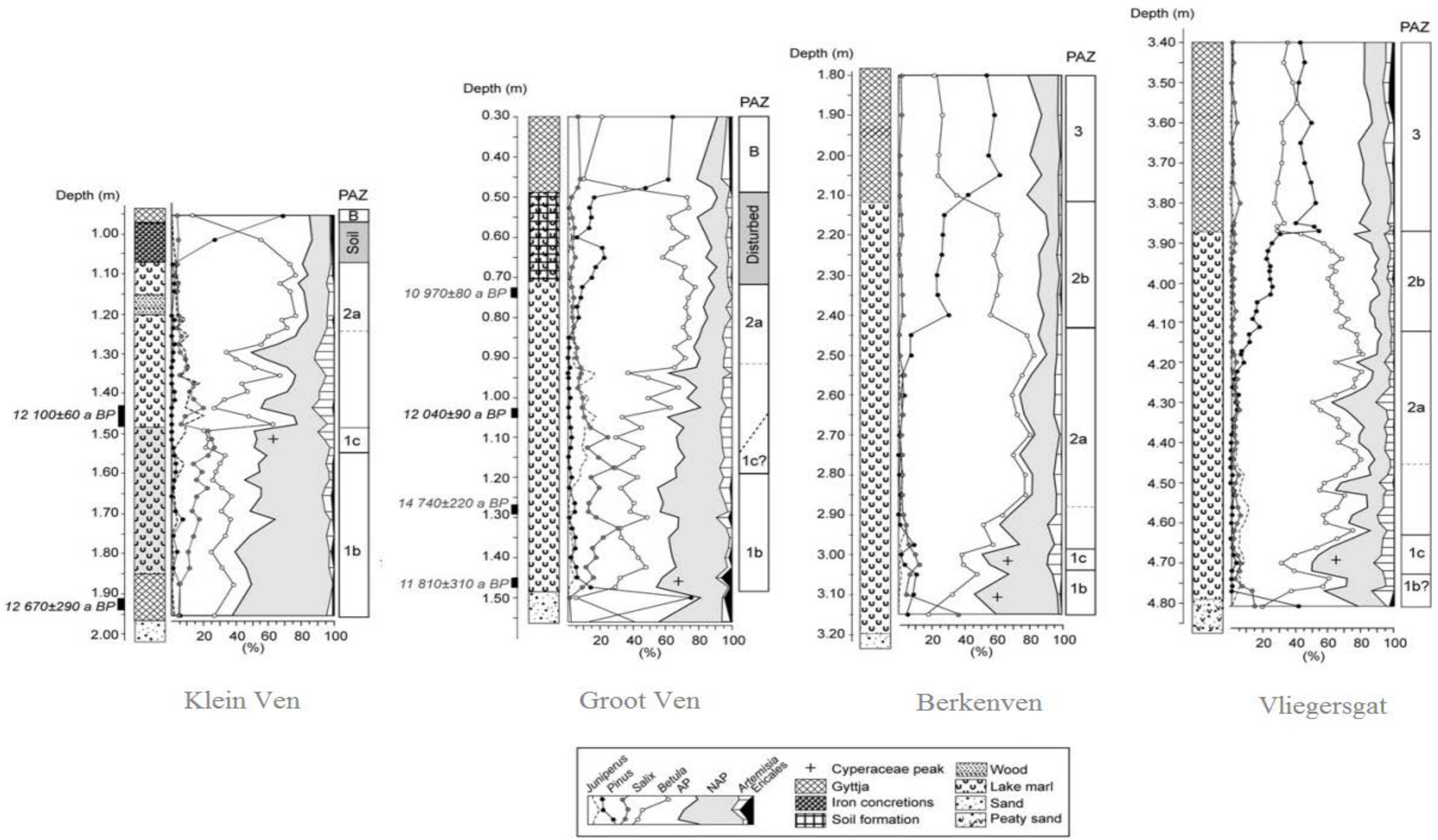


Figure 32: Pollen diagrams of the Weerterbos pingo remnants (modified after van Asch et al. 2013)

2.5.3.2 Mierlo Ven Hoenderboom (Zagwijn, 1971)

Mierlo Ven Hoenderboom is located in the eastern part of the southern coversand region (Figure 20/35). The pollen diagram of Mierlo Ven Hoenderboom (figure 36) was obtained from a small pingo remnant with a depth of ~3.5 meters and a diameter of 50 meters. The infill of the depression predominantly consists out of peat and gyttja. The start of infill is set to the Bølling (zone 1b sensu Hoek, 1997) based on the increase in *Betula* tree pollen, together with the rise in arboreal pollen types to values around ~50%.

2.5.3.3 Maartensdobbe (Kasse and Bohncke, 1992)

Late Pleniglacial land surface in the Groote Peel (southern Netherlands) is characterized by numerous circular to oval depressions, which are up to 90 meters wide; 3 meters deep and sometimes are surrounded by low ridges (Kasse and Bohncke, 1992). The Groote Peel nature reserve is situated west of the Peel Horst in the Central Graben (Figure 30/35). The lithostratigraphy of the Maartensdobbe depression (Kasse and Bohncke, 1992) is shown is Figure 33. The base of the depression cuts through a paleosol (unit 2) of Eemian age (Kasse and Bohncke, 1992).

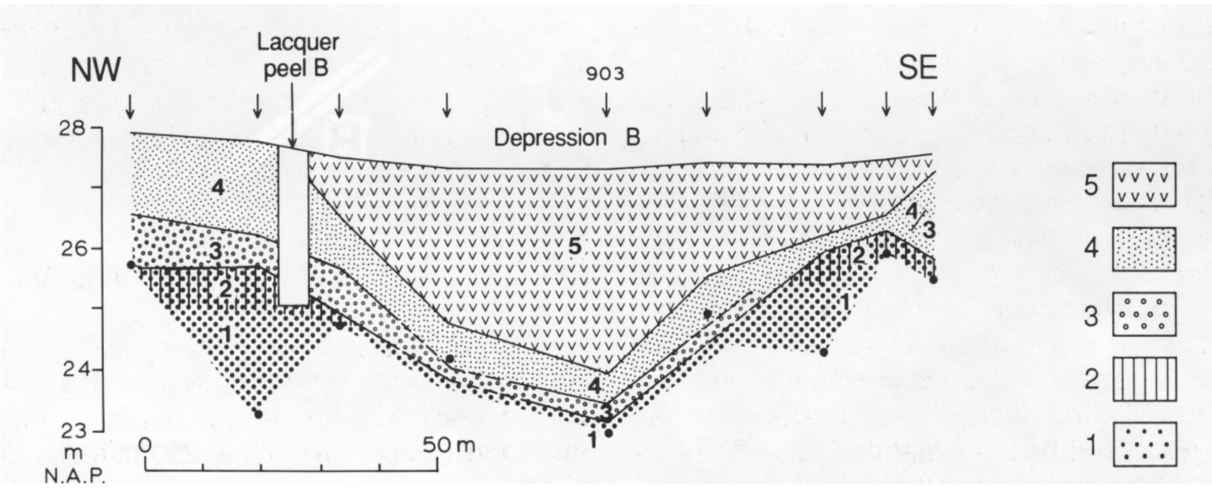


Figure 33: Lithological cross-section of Maartensdobbe depression. 1= fine to medium sand, 2=Eemian palaeosol, 3=fine sand with Beuningen gravel bed at the top, 4= fine sand, 5= peat and gyttja (Kasse and Bohncke, 1992)

The basal infill of the depression could not be correlated to known biostratigraphical zones with any accuracy, but due to high *Helianthemum* percentages combined with a first rise in *Artemisia* it might indicate the Oldest Dryas sensu van der Hammen (1951) (Kasse and Bohncke, 1992). Local zone MDB-2 (Kasse and Bohncke, 1992) was correlated to the Older Dryas (zone 1c sensu Hoek, 1997a) (figure 34) by the authors based on the relative increase and subsequent fluctuation of *Betula,* rise in *Artemisia* and start of the spread of *Salix* and *Juniperus*. Zone MDB-3, according to Kasse and Bohncke (1992), indicates the *Betula* and *Pinus* phase of the Allerød (pollen zones 2a and 2b respectively according to the pollen zonation of Hoek (1997a)). Furthermore the development of more open herbaceous vegetation during zone MDB-4 indicates the presence of the Younger Dryas period (zone 3 sensu Hoek, 1997a) in the record (Kasse and Bohncke, 1992). Finally zone MDB-5 represents the last part of the Preboreal (zone 5 sensu Hoek, 1997a), with a gradual rise of *Pinus* and a diminishing *Betula*. Additionally the gradual increase of *Corylus* in the top part of the section preludes the Boreal (Kasse and Bohncke, 1992). Overall it can be concluded that the Maartensdobbe depression was formed before 12.100 ^{14}C (a BP), as this marks the onset of the Older Dryas according to Hoek (1997a). Additionally a hydraulic origin of the pingo remnant is favored over a hydrostatic origin as the depression is situated on the flank of a shallow Weichselian valley, whereas no lacustrine or substantial fluvial sediments of Weichselian age have been found around the depression to indicate the presence of a talik.

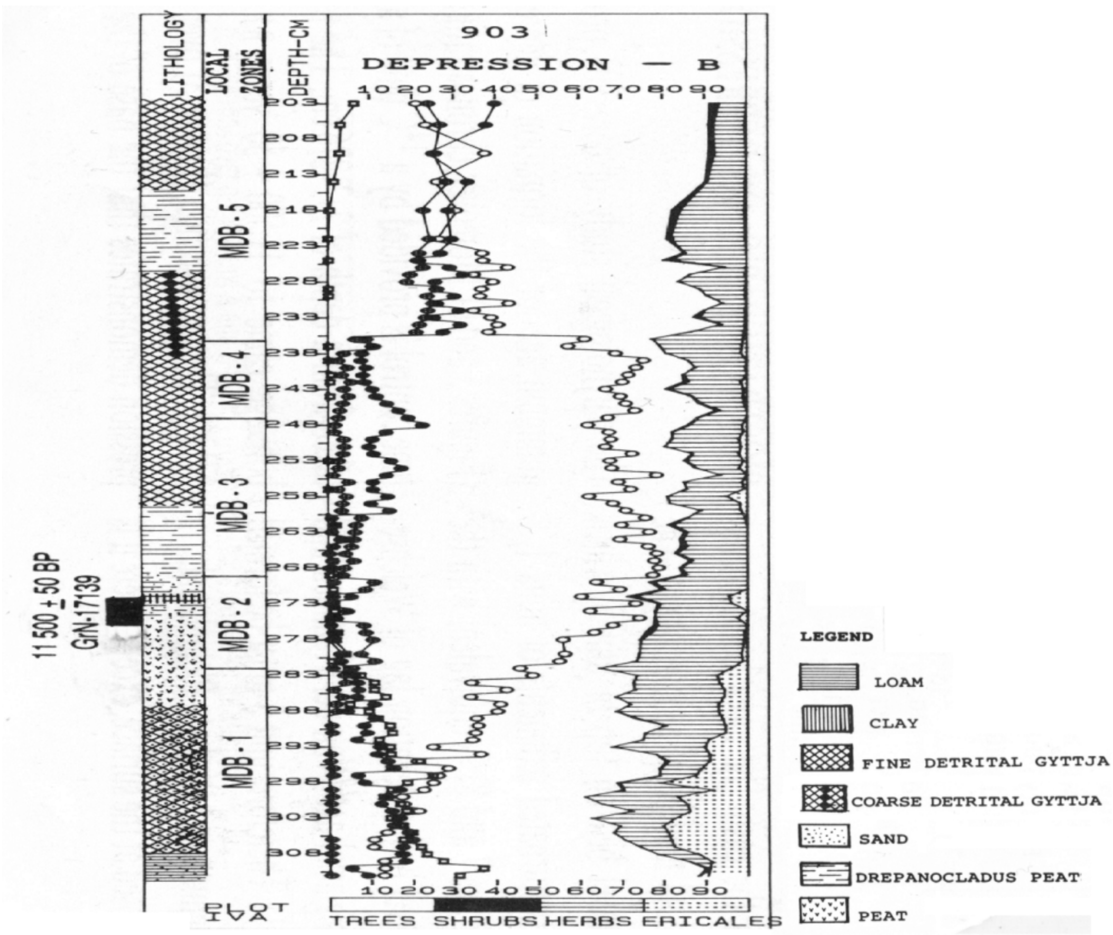


Figure 34: Pollen diagram of Maartensdobbe (Kasse and Bohncke, 1992)

2.5.3.4 Gulickshof I (Hoek et al. 1999)

Gulickshof I is located in the Maas Valley north of the Loess region in the southern Netherlands (figure 20/35). The depression has a diameter of 200 meters, a depth of 3 meters and the fill consist out of calcareous gyttja. The depression is presumably of ground-ice origin and lies within a larger basin (~1km^2) (Hoek, 1997a). The pollen diagram of Gulickshof I (figure 36) indicates a start of the infill during the Bølling (zone 1b sensu Hoek, 1997). Furthermore the pollen diagram shows a Late-glacial profile with the presence of subzones 1b to 3b, spanning the time interval ~12,450 to ~10,550 ^{14}C (a BP).

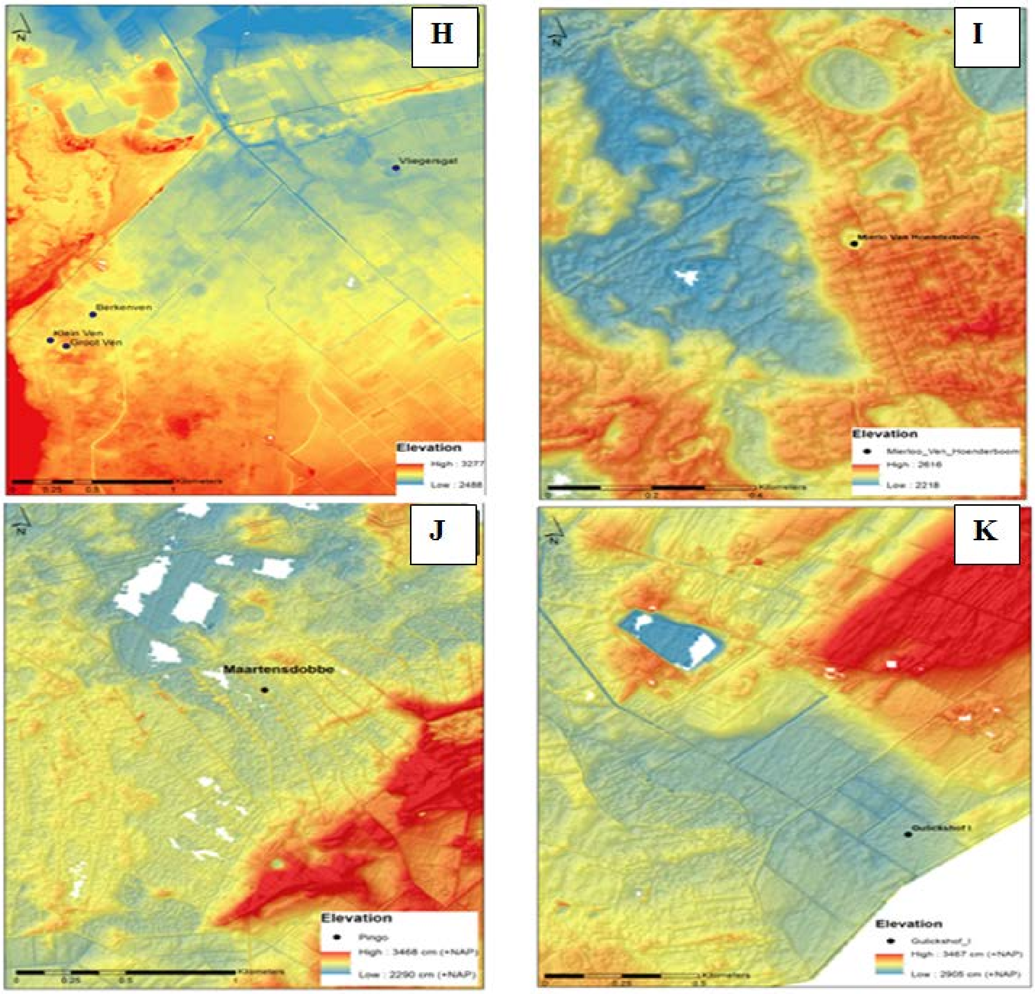


Figure 35: Locations of pingo remnants in the southern Netherlands; (H) Weerterbos pingo remnants, (I) Mierlo Ven Hoenderboom, (J) Maartensdobbe, (K) Gulickshof I. (Lidar image modified from AHN)

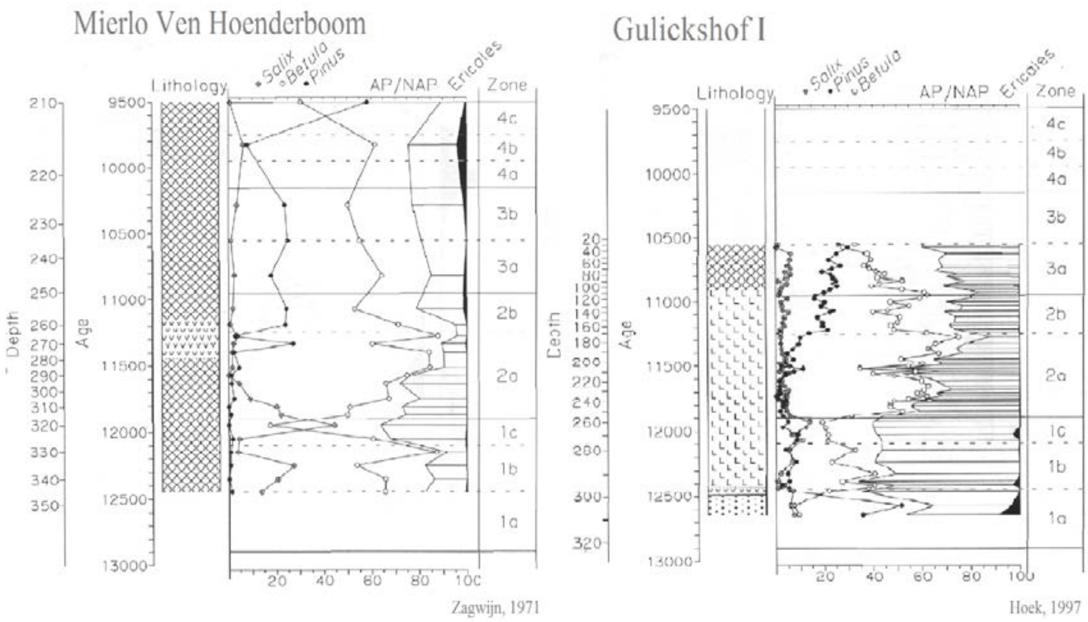


Figure 36: Pollen diagram of Mierlo Ven Hoenderboom and Gulickshof I (Hoek, 1997)

Chapter 3. Methods

3.1 Sampling

3.1.1 Coring

After identification of depressions in the Dutch Lidar data (AHN), which could indicate pingo remnants, a field study after these depressions was carried out. A transect of boreholes over the depressions was performed in order to indicate the lithology of the depressions. Coring of these transects was performed using an Edelman hand auger for the clastic materials in combination with a gouge (25 mm) for peat. Furthermore a Van der Staay corer was used to obtain clastic sediments which were below groundwater. A lithological description of the material was made in the field in order to draw cross sections of the depressions. Additionally the presence of $CaCO_3$ was tested with a 10% HCL solution in the field. The cores were predominantly described on lithology and color, although special features were also indicated in the lithological descriptions. The cores from the Kempen and depression 4 were lithological described in the field in order to provide the most detailed description, as they were directly subsampled in the field.

3.1.2 Field sampling pollen

The quality of pollen analysis depends amongst others on the amount of disturbance of the stratified sequences during the sampling process. For the coring of the sequences which were later used for pollen analysis in this study, three types of corers were used; a 20 mm gouge, a Van der Staay-corer and a Livingstone piston sampler. The gouge was used for the smaller, shallower depressions. The Van der Staay corer is usually exclusively used for coring sandy sediments beneath the groundwater level, but in case of depression 4 contained a perfect compact (sandy) peat sequence which was retrieved and sampled from the corer at ~1 cm resolution. The longer core from Klein Hassels Ven was retrieved from the depression using the Bohncke modified Livingstone corer. To indicate the location at which the most complete sequence for pollen analysis (and LOI) could be retrieved, and to obtain a better insight in the morphology of the depression, two transects of corings were first taken with a 20 mm gouge. As the surface layer of the peat deposit in Klein Hassels Ven was very loosely compacted, and thus easily deformed by the coring process, the uppermost 1.40 meters were not sampled.

3.1.3 Livingstone piston sampler

As described a modified version of the Livingstone piston sampler with a diameter of 6 cm was used to obtain a sediment core from the Klein Hassels Ven depression whilst inflicting the least amount of disturbance on the sediment as possible. The operation principal of a piston corer is that a hollow tube is driven vertically down into the sediment, but at the same time the piston is withdrawn up the tube creating the negative pressure which prevents compression and distortion of the sediment column.

A schematic drawing of the Bohncke-modified Livingstone piston sampler (de Bruijn, 2012) can be found in Appendix I. Although the modified Livingstone piston sampler is used to reduce disturbance of the sediment, there comes a point at which the tube is fully filled or sediment may be blocked at which further insertion into the sediment may result in the compression of sediment beneath. It is therefore important to retrieve the sampler and extrude the core at such a point to prevent distortion.

3.2 Laboratory methods

3.2.1 Sub-sampling

After field sampling, the cores were sub-sampled in the laboratory. The sub-samples were taken from the center part of the cores to minimize contamination by the coring process. The samples were extracted in the fall (October) when atmospheric pollen is at a minimum, and appropriate laboratory measures were taken in order to prevent contamination of the samples. For the bottom 70 cm of Klein Hassels Ven core sub samples for pollen analysis were taken every 2 cm to provide a high resolution diagram of the basal infill. Further upward the resolution was decreased to 5 cm subsampling. The core of depression 4 was sub-sampled at 2 cm resolution for pollen analysis while the Kempen core was sampled at a 5 cm resolution. Sub-sampling for Loss On Ignition was performed on a 1 to 2 cm interval, depending on the core.

3.2.2 Loss On Ignition

Loss on ignition (LOI) is a common method for estimating the organic and carbonate content of sediments (Dean, 1974; Bengtsson & Enell, 1986; Heiri et al., 2001). This estimation is provided using the linear relations between LOI values and organic and inorganic content (Santisteban et al., 2004). LOI of organic matter at 500-500°C results in oxidation into carbon dioxide and ash. In a first step samples were obtained from the sediment cores collected for this study. LOI of the sediment cores was performed on a 1 cm resolution, with a volume of ~1 cm^3 for each sample. The samples were then dried at 105^0C for a period of 12-24 hours, removing all moisture from the samples. With the moisture removed from the samples, the samples were weighted ($DW_{105°C}$). After the drying period the samples were placed in a muffle furnace and heated for a period of 4 hours at 550°C. After combustion of organic material was completed the samples were then again weighted ($DW_{550°C}$), providing values for the determination of the weight percent organic matter content in the samples. With the data obtained performing the above methods, the LOI can then be calculated with the formula in given below, where LOI_{550} represents LOI at 550 °C (as a percentage), DW_{105} represents the dry weight of the sample before combustion and DW_{550} the dry weight of the sample after heating to 550 °C (both in g) (Heiri et al., 2001).

$$LOI_{550}(\%) = \frac{DW_{105} - DW_{550}}{DW_{105}} * 100$$

3.2.3 Pollen preparation

Laboratory proceedings for pollen analysis consist mainly out of removal of the non-pollen matrix in the sediment. The laboratory protocols are based upon the small size of pollen grains and spores, coupled with their resistance to many corrosive chemicals (Moore et al., 1991). Figure 37 shows the laboratory protocol used for obtaining pollen from the sub-samples and preparation of the samples for microscope analysis.

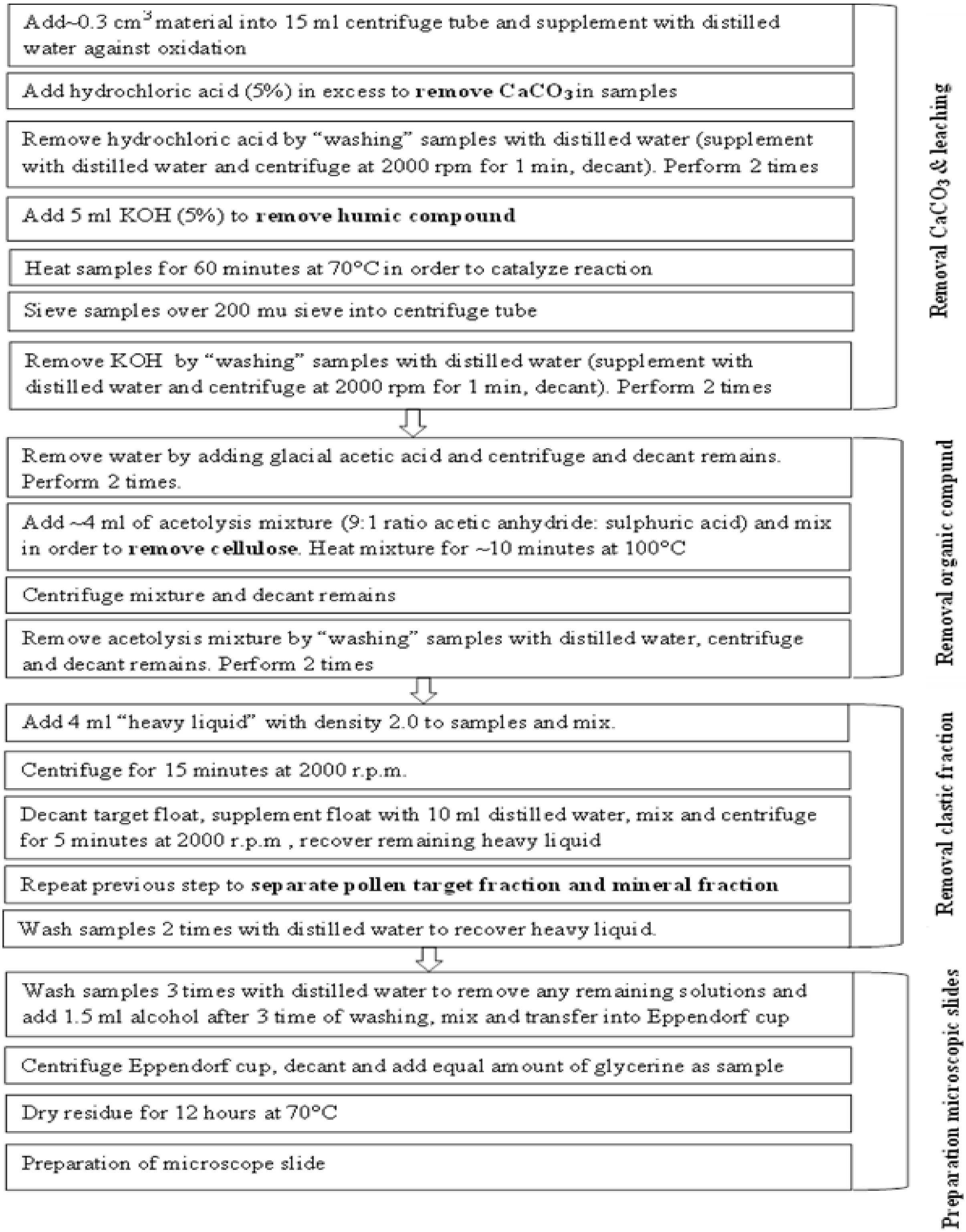


Figure 37: Pollen preparation scheme

3.2.4 Pollen analysis

The microscope analysis of the pollen (i.e. counting of different taxa) results in the pollen spectrum of each specific sample (or depth). Analysis of a series of spectra may show alternations in pollen assemblage which may be interpreted as temporal changes in vegetation cover in the area adjacent to the site (Lowe and Walker, 1997). Results of the microscope analysis for this study are presented as relative pollen diagrams. The number of pollen grains identified at each sample varies with the amount of pollen present in a sample. The aim was to obtain at least a number of 100 pollen per sample, although this goal was not always achieved. Relative pollen diagrams were produced for all cores investigated. For these diagrams a pollen sum of all terrestrial pollen was used to express each pollen and spore type as a percentage of this pollen sum. All aquatic taxa were excluded from the pollen sum as they are produced locally. Furthermore spores were also excluded from the pollen sum as they are formed in a different way and have a different function as pollen grains (Lowe and Walker, 1997). A problem concerning the relative pollen diagrams is that the curves for individual taxa are interdependent, i.e. an influx of taxa A will automatically lead to a suppression of the percentages of taxa B (Lowe and Walker, 1997). In order to achieve a better understanding of the data in the pollen diagrams, the diagrams were subdivided into pollen zones (pollen stratigraphic units) as described for the Late-glacial in the Netherlands by Hoek (1997). This classification of intervals within the pollen diagrams to well dated pollen zones, enabled a local vegetation reconstruction over time. More information concerning the interpretation of pollen diagrams can be found in Lowe and Walker (1997) and Moore et al. (1991).

3.2.5 GIS analysis

In order to obtain a better insight in the spatial distribution of pingo remnants related to brook valleys a GIS analysis was performed. Figure 38 indicates a flow diagram of the steps involved in executing the analysis. The initial inputs were derived from the geomorphological map of the Netherlands (Alterra, 2008) and a pingo database for the Netherlands (Ruiter, 2012). Although there are multiple functions for calculating distances between point features and polygon features in GIS, Esri's ArcGIS "Near" function was used in this study. The Near analysis determines the distance from each feature in the input features (pingo remnants) to the nearest feature in the near features (brook valleys). More detailed information concerning the calculation of distance by proximity tools can be found on the resources webpage of ArcGIS.

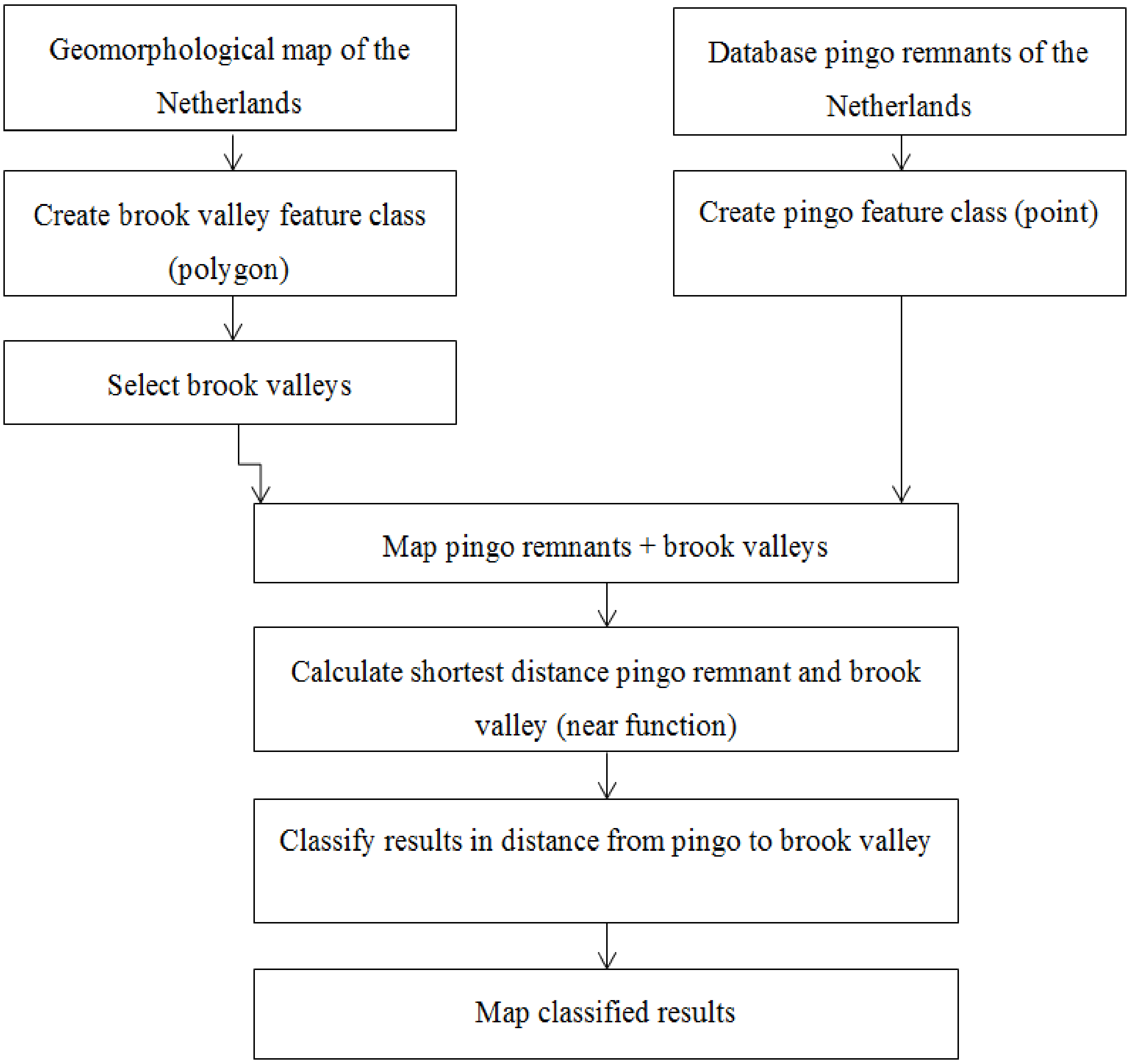


Figure 38: Flow chart GIS analysis

Chapter 4. Field and analysis results

4.1 Investigated depressions

In the following section the results of the field study will be discussed. Five depressions were investigated in the field (Figure 39), of which three contained sufficient organic material in order to preform loss on ignition and pollen analysis. The depressions will be discussed individually by location, lithology, organic matter content and palynology if applicable. The location of the depressions is given in the national coordinate system Rijksdriehoekstelsel (RD). After the description of the results an interpretation concerning the genesis of the depression will be given (i.e. pingo remnant or non-pingo remnant). Depression 1 and 2 were discarded for further analysis, as prospection cores revealed that these depressions were not suitable for this study

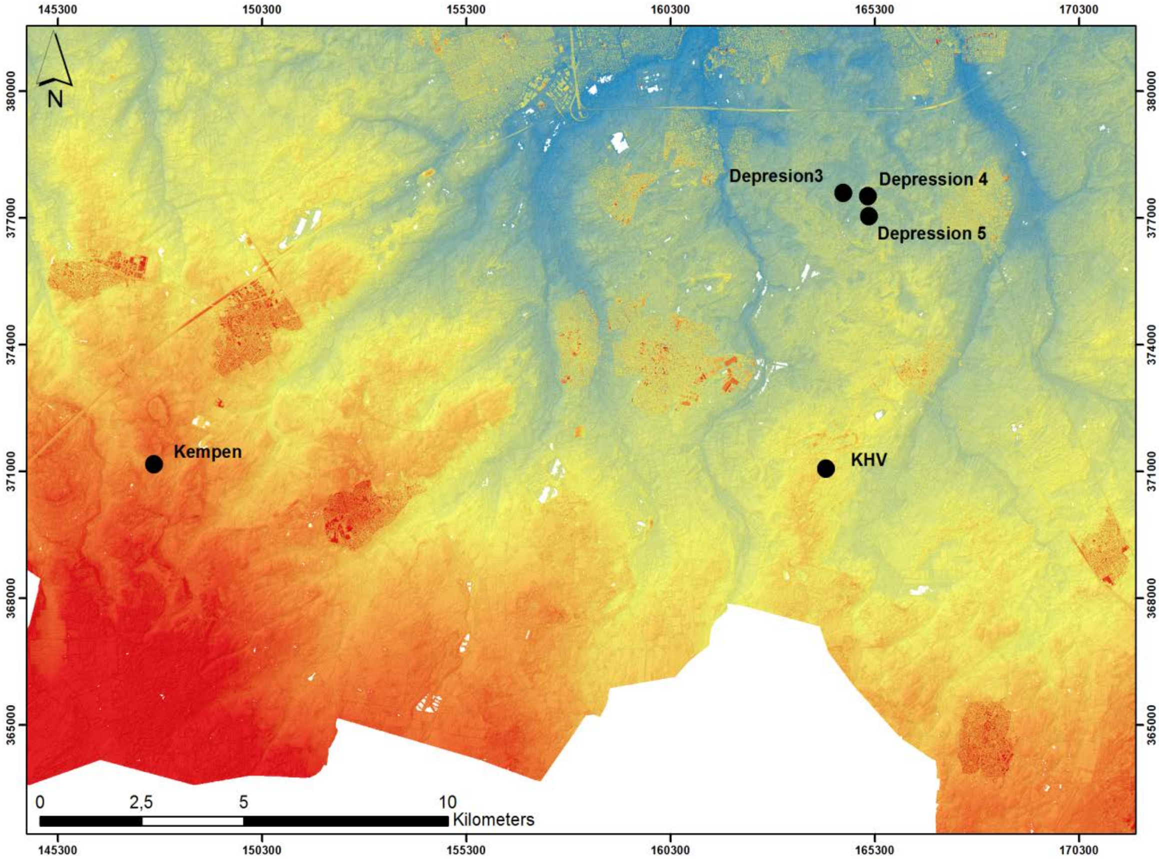


Figure 39: Circular depressions investigated in the southern Netherlands (Lidar image modified after AHN)

4.2 Depression 3

Depression 3 (164.602/377.565) is located in the southern Netherlands coversand region (figure 16), approximately 3 kilometers west of Heeze (province of Noord-Brabant) nearby the Huisvenseweg (300 meters north). The region is characterized by the presence of coversands, interrupted by brook valleys. Numerous round to oval shaped depressions are present in the area. Figure 40 shows an aerial photograph of the depression, alongside a laser altimetry based digital elevation model (DEM). The depression has a diameter of ~150 meters and a height difference of ~1 to 1.5 meters between the center of the depression and the surrounding higher elevated sediments.

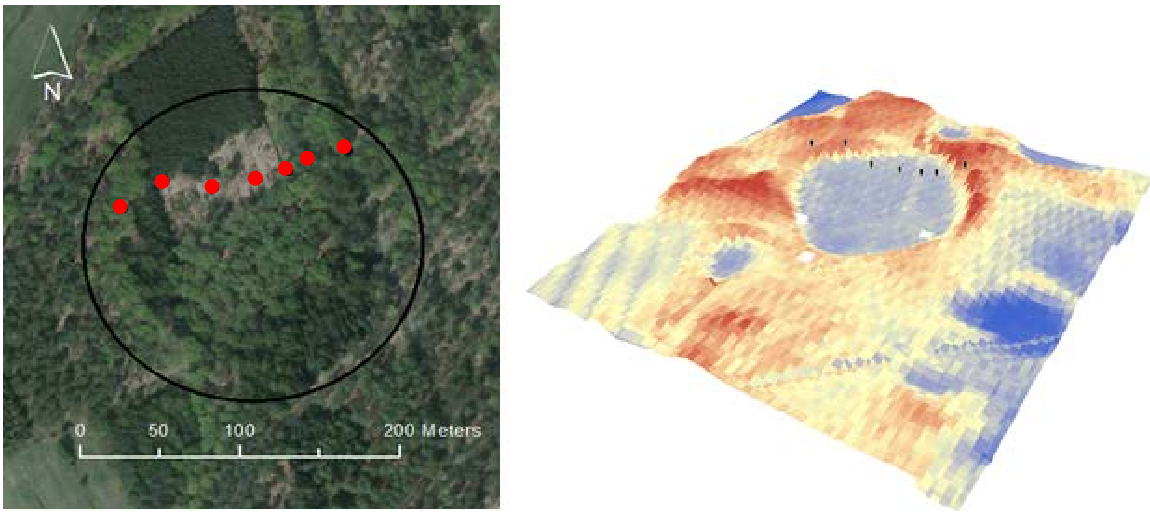


Figure 40: Aerial photograph and digital elevation model of depression 3. A clear rampart is visible in the Digital Elevation Model.

4.2.1 Lithology

In order to gain a better insight in the lithology of the depression, a transect of corings was made over the depression. The corings were described using the protocol given in the methods. Lithological core descriptions can be found in Appendix A. Based on the core descriptions a lithological cross-section was generated (figure 41). The cross section indicates an overall sandy depression of fine (150-210 µm) to medium coarse (210-300 µm) sands. The top of the depression is covered by a sandy and humic soil. Two intervals of loamy sands were indicated in the cross section, one at the western part of the depression (coring 3A7 and 3A6) at a height of ~20.5 meters +NAP and another in the middle of the depression (core 3A1, 3A3 and 3A5) at ~20 meters +NAP. Additionally, two distinct humic sandy layers were found within the depression. Although there were some humic layers (~2cm) present in the corings, these were not considered sufficient for LOI and pollen analysis. It must be indicated that the dotted lines in the cross section represent uncertain boundaries of the layers.

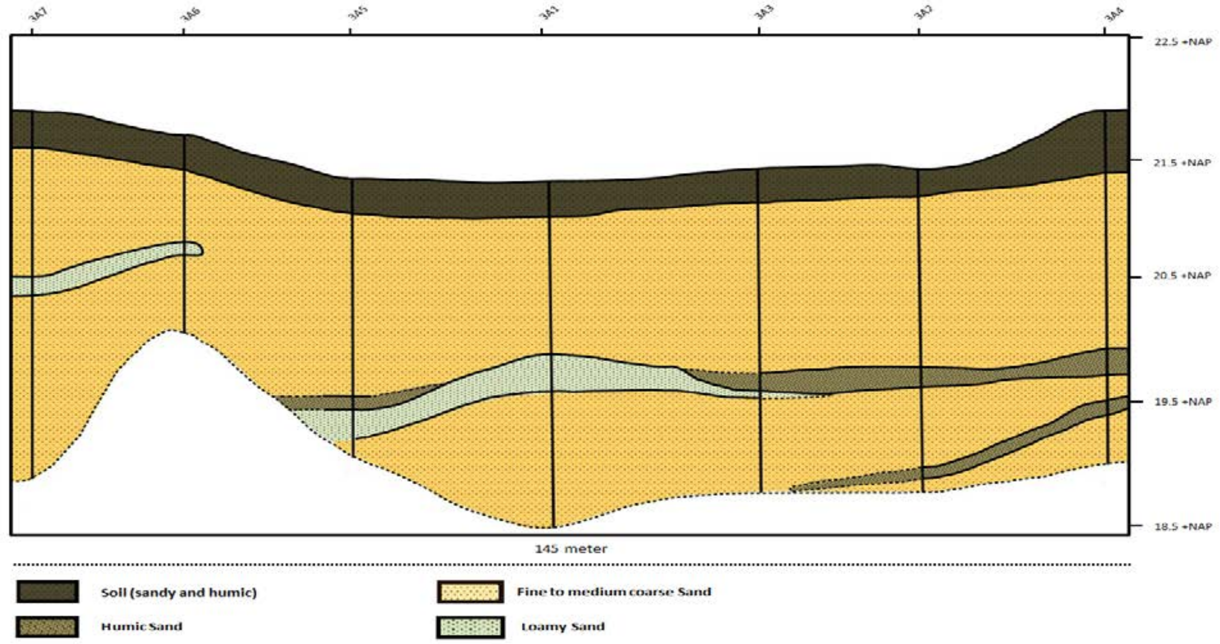


Figure 41: Lithological cross-section of depression 3

4.2.2 Genesis and age

Depression 3 was selected as a possible pingo remnant based on the indications for pingo remnants that it has a more or less circular outline with a fairly uniform diameter greater than 25 meters. Although these factors may indicate a pingo remnant, depression 3 lacks an organic infill. It was therefore impossible to give an age estimation based on palynology and it could not be concluded that the depression is of Weichselian age. Based on this information the depression does not meet the definition of an pingo remnant as discussed in this study, i.e. *a circular to oval depression with a minimum depth of 1.5 meters, a diameter of 25 meters or greater, which has a (partial) organic infill and is of Weichselian age* and therefore is not considered to be a pingo remnant. Although it is concluded that the depression is not a pingo remnant, the genesis of the depression by a form of ground-ice is not discarded. The depression may indicate a cryogenic mound, thermokarst depression or mineral palsa as discussed in the literature review. For this conclusion however more detailed research after this individual depression is needed.

4.3 Depression 4

Depression 4 (165.224/377.117) is located in the southern Netherlands coversand region (figure 16) around 2.5 kilometers west of Heeze (province of Noord-Brabant) and 500 meters south-east of depression 3, which is south of the huisvenseweg. Figure 42 indicates an aerial photograph of the depression, alongside a laser altimetry based digital elevation model (DEM). The depression has a diameter of ~140 meters and a height difference of ~1 meter between the center of the depression and the surrounding higher elevated sediments. A transect was cored over this depression (figure 42) in order to produce a lithological cross section.

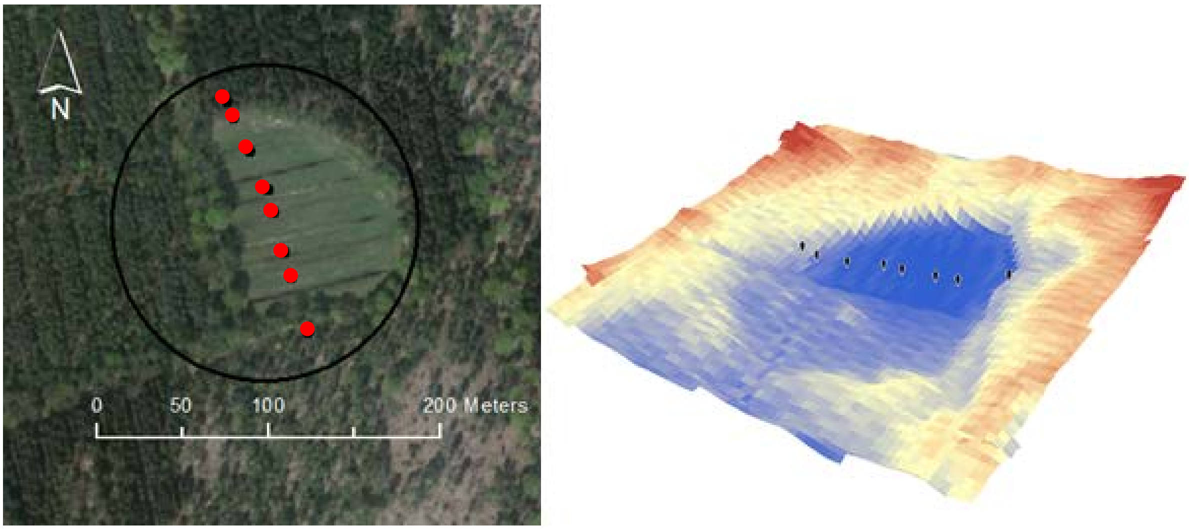


Figure 42: Aerial photograph and digital elevation model of depression 4

4.3.1 Lithology

The corings were described using the protocol given in the methods. Lithological core descriptions can be found in Appendix A. Based on the core descriptions a lithological cross-section was generated (figure 43). The depression is covered by a sandy, humic soil. The depression contains a distinct loamy sand layer throughout the overall fine to medium coarse sand filled depression. Outside the depression a distinct stiff, homogenic, greenish grey sandy loam layer is found. This loam layer is interpreted as the Liempde Member of the Boxtel formation (Schokker, 2007). Within core 4A8 (figure 43) gravel is found above this loam layer (at ~100 cm beneath the surface). A comparable band of gravel is also found in core 4A7, 4A6 and 4A3, although lower beneath the surface of the depression. Core 4A6 and 4A3 indicated a slightly humic sandy layer near the deepest part of the corings. At 250 cm beneath the surface a 30 cm peat layer was found in core 4A7. The top of this peat layer corresponds to a humic sand layer in the adjacent core 4A6 although no peat was found in this core. A core from the geological survey has been described close to the depression and the lithological description of that core (Appendix G) indicated a peat deposit of 60 cm at a depth of 16.5 meters +NAP.

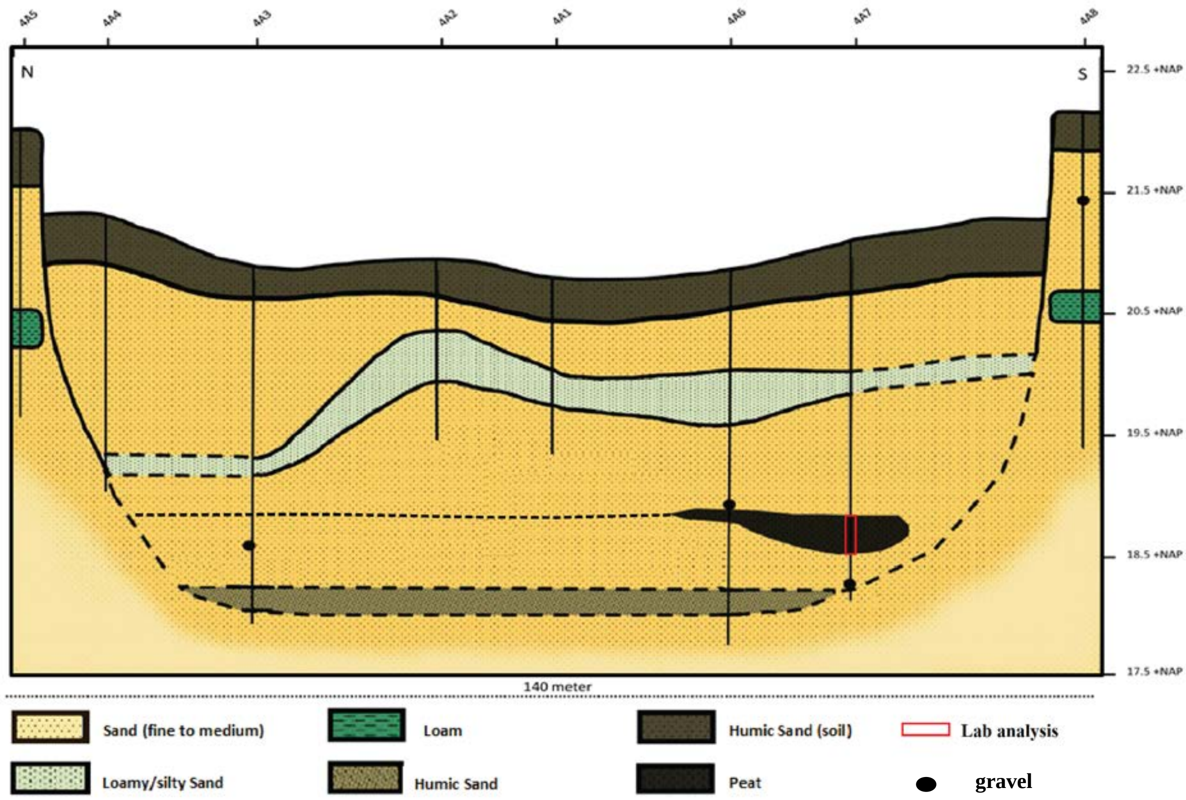


Figure 43: Lithological cross-section of depression 4

4.3.2 Loss On Ignition

Loss On Ignition (LOI) was performed on the peat layer retrieved from core 4A7. The results of the LOI are shown in figure 44. It can be derived from the figure that the top and bottom of the peat layer are in contact with sandy deposits as LOI values at the top and base are low at ~10%. The peat layer itself has a LOI percentage of ~30% to 35%, although some variance is represented within the peat layer.

4.3.3 Palynology

The peat layer found within core 4A7 in depression 4 was analyzed for pollen. The results of this analysis are given by figure 44. Figure 44 only describes the most indicative taxa in order to give a good overview of the palynology. The complete pollen diagram of depression 4 can be found in Appendix F. What can be derived from figure 44 is that the *Betula* curve shows values of around 25% to 30% for almost the entire peat layer with an exception of *Betula* rising up to ~55% at a depth of 274 cm. The *Pinus* curve varies in the interval 278cm to 265 cm between 10% and 30% after which the presence of *Pinus* increases from 265cm upward with values around 30% or higher. *Salix* is continuous low with a small increase at 265 and 262 cm until it reaches a percentage of 10% at 254cm. Furthermore *Alnus* is present at low percentages from 265cm upward. Some *Corylus* pollen was found in the samples at 270cm and 258cm, although these occurred in relative low percentages. The upland herbs in the diagram are dominated by Ranunculaceae and Gramineae although *Artemisia* is also present in lower percentages. The diagram shows a high importance of Cyperaceae with percentages ranging from 15% up to 50%.

Pollendiagram 4A7

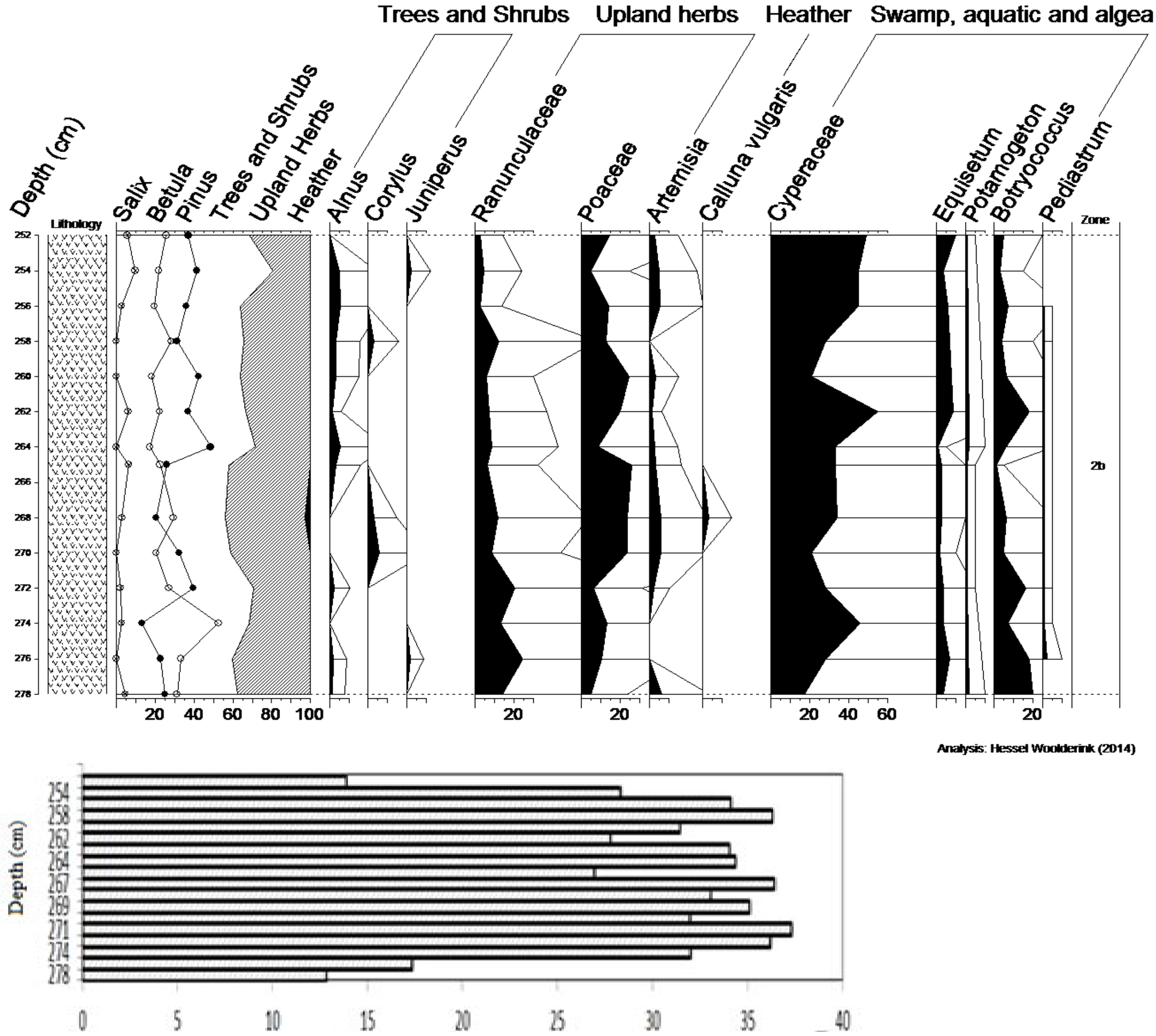


Figure 44: pollen diagram depression 4 together with the measured LOI values for core 4a7.

4.3.4 Genesis and age

Based on the information given by the pollen diagram of depression 4, the chronostratigraphy of depression 4 has been obtained by biostratigraphical correlation to the regional vegetation development of for the Netherlands (Hoek, 2007). Based on the relative high percentage of *Pinus* (~30%), relative low percentages of *Betula* (~20%) together with the presence of *Artemisia*, the local pollen diagram might be correlated to subzone 2b sensu Hoek (1997). The present *Alnus* and *Corylus* in the core are thought to be of allochthonous origin because of their low percentages and the lack of other thermophilous trees in the samples. Additionally the LOI percentages indicate ~40% organic matter content, which is often seen in Allerød peat within pingo remnants (see de Bruijn, 2012). The relative high percentages of local taxa such as Cyperaceae support the lithological data, indicating a relative small and local peat deposit within the depression.

The gravel present in some of the cores is thought to be a representative of the Beuningen gravel bed, an erosion surface overlain by a deflation lag (van Huissteden et al., 2001), which formed during the coldest and driest phase of the Pleniglacial (Berendsen, 2008). Combining the interpretation of the palynological results of the peat deposits (Allerød biostratigraphical unit (11,900-10,950 ^{14}C years BP)) with the presence of a Beuningen gravel bed like facies (mid Pleniglacial), it is concluded that the depression was formed at least before the Weichselian Late -glacial. The presence of *Alnus* and *Corylus* might be explained as washed in material from the peat layer found at greater depth in a core of the Geological Survey (TNO). Additional research is however needed to investigate the presence of the deeper peat layer within the depression. A more detailed pollen diagram may give a better indication of the site within the biostratigraphy for the Netherlands, as the peat may be older/younger than claimed here. Within this perspective it is recommended to investigate the age of the peat by means of radiocarbon dating. Based on the information provided above, the depression does not meet the definition of a pingo remnant as discussed in this study, and is therefore not considered to be a pingo remnant. For this reason the genesis of the depression remains unknown although the presence of a subsurface ice lense is thought to have played a role in the formation of the depression, based on the presumable age and geomorphology of the depression.

4.4 Depression 5

Depression 5 (164.234/377.125) is located in the southern Netherlands coversand region (figure 16), around 2.5 kilometers west of Heeze (province of Noord-Brabant) and ~ 250 meters south of depression 4. Figure 45 indicates an aerial photograph of the depression, alongside a laser altimetry based digital elevation model (DEM). The depression has a diameter of ~160 meters and a height difference of ~1.5 meter between the center of the depression and the surrounding higher elevated sediments. A transect was cored over this depression (figure 45) in order to produce a lithological cross section.

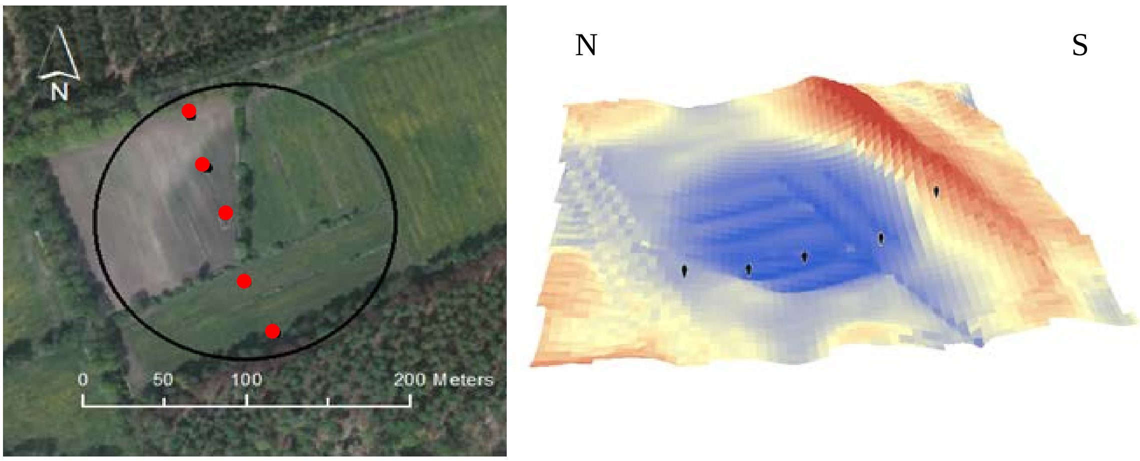


Figure 45: Aerial photograph and digital elevation model of depression 5

4.4.1 Lithology

Lithological core descriptions of depression 4 can be found in Appendix A. Based on the core descriptions a lithological cross-section was generated (figure 46). The depression is covered by a humic sandy soil. Beneath the soil a layer of fine to medium coarse, homogenic sand was found. Underlying the sand, sandy clay with plant remains was located in cores 5A1, 5A2 and 5A4. The two cores (5A3/5A5) outside the depression on the higher elevated locations indicated a loamy/silty sand layer at equivalent heights. Core 5A3 shows sandy clay at the bottom of the core which contained carbonate after testing with HCl. At the base of the cores within the depression itself humic sand was found. This layer consisted predominantly of fine to medium coarse sands but was significantly coarser and less well sorted than the overlying sands. Although core 5A3 and 5A5 did not reach the equivalent depth of the humic sands at the bottom of the cores within the depression, the humic sand is thought to continue laterally. This hypothesis is supported by a core taken by the Geological Survey, which is located within a couple of meters of core 5A5. This core indicates a sandy peat layer of almost 3 meters at 18.79m-15.89m +NAP (Appendix G). This peat/humic layer is thought to be the equivalent of the peat layer, described by the geological survey core nearby depression 4, which described a peat layer of ~0.6 meters at 16.5 meters +NAP.

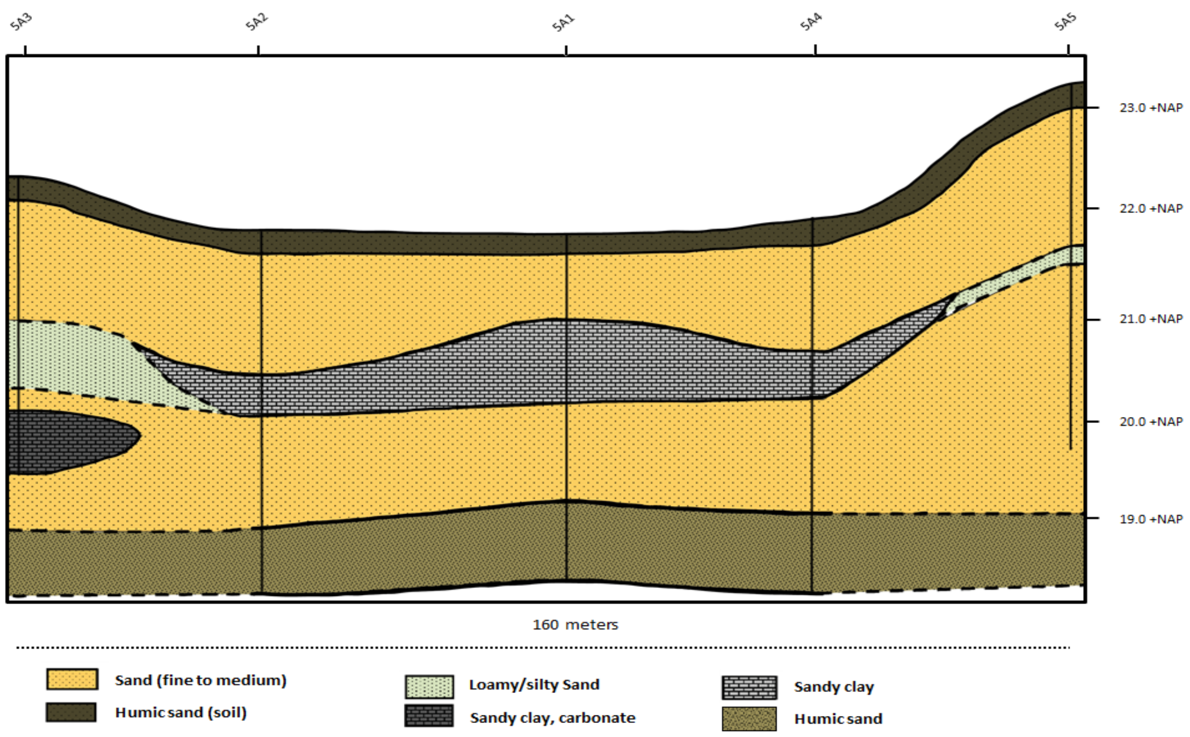


Figure 46: Lithological cross-section of depression 5

4.4.2 Genesis and age

Depression 5 was selected as a possible pingo remnant based on the indications for pingo remnants that it has a more or less circular outline with a fairly uniform diameter greater than 25 meters. Although organic material was found within the depression, no peat or gyttja was found. It was therefore decided to leave out pollen analysis as time limitations during this study prevented the analysis of all organics found within the depressions. As a consequence no palynological age estimation could be given for this depression. It is therefore concluded that depression 5 lacks evidence to appoint it as a pingo remnant. Although it is concluded that the depression is not a pingo remnant, the genesis of the depression by a form of ground-ice is not discarded. However, more extensive study after for instance the sedimentary structures within the depression is needed to verify this hypothesis and discard genesis by for instance wind deflation.

4.5 De Kempen

The Kempen depression (147.677/371.163) is located in the southern Netherlands coversand region (figure 16), around 4 kilometers southwest of Eersel (province of Noord-Brabant) along the Postelseweg. Figure 47 shows an aerial photograph of the depression, alongside a laser altimetry based digital elevation model (DEM). The depression has a diameter of ~50 meters and a height difference of ~1.5meter between the center of the depression and the surrounding higher elevated sediments. A transect was cored over this depression (figure 47) in order to produce a lithological cross section.

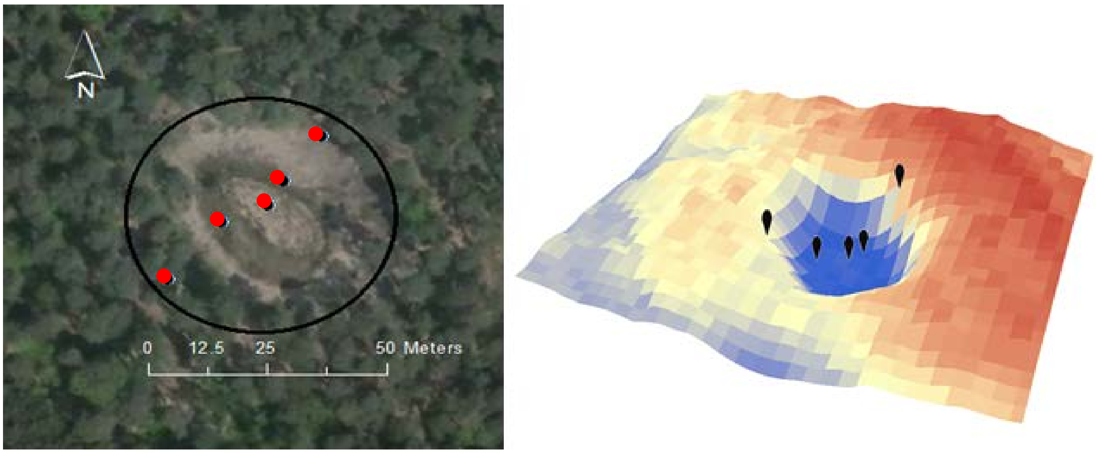


Figure 47: Aerial photograph and digital elevation model of de Kempen depression

4.5.1 Lithology

The corings were described using the protocol given in the methods. Lithological core descriptions can be found in Appendix A. Based on the core descriptions a lithological cross-section was generated (figure 48). The depression is situated in a sandy environment with fine to coarse sands. The top ~20 cm of the sand surrounding the depressions consist of a soil. The depression is filled with an alternation of sandy peat, humic sands and gyttja, covered by vegetation. A lithological core description for lab analysis can be found in table 4.

Table 4: Lithological description Kempen core

Interval (cm)	description
80-69	Fine sand
68-47	Sandy Peat
46-30	Gyttja

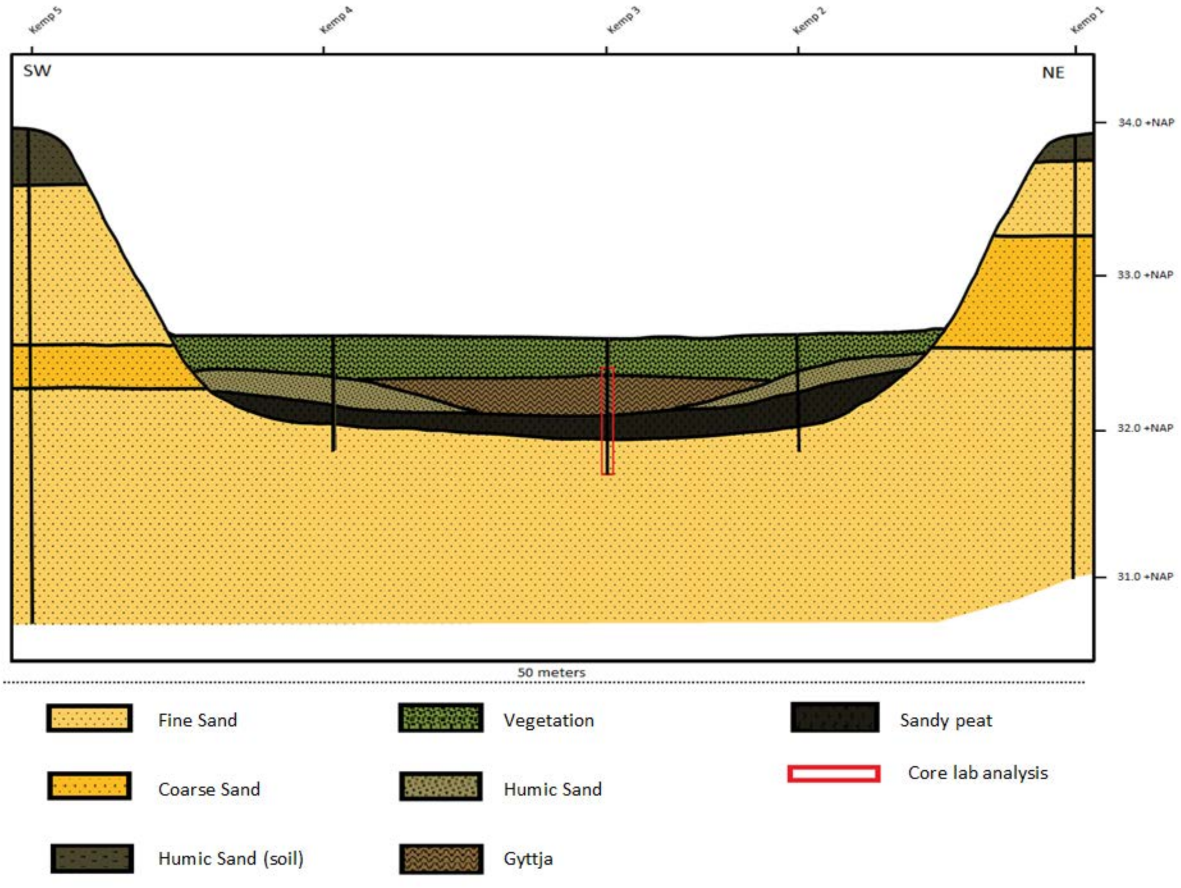


Figure 48: Lithological cross-section of de Kempen depression

4.5.2 Loss on ignition

Loss On Ignition (LOI) was performed on the peat layer retrieved from the Kempen core. The results of the LOI are indicated in figure 49. The LOI diagram shows relative low LOI values at the bottom of the core (80cm-70cm) caused by the high clastic fraction of the sediment in which the depression formed. After this the organic matter fraction increases to values of 40% within the interval 70cm-58cm. The top part of the core (starting at 58cm) show relative high organic matter percentages of ~70%. These high values at the beginning and end of the interval 58cm-28cm are interrupted by somewhat lower LOI values of 45%-50%.

4.5.3 Palynology

The core derived from de Kempen was analyzed for pollen. The results of this analysis are given by figure 49. Figure 49 only shows the most indicative taxa in order to give a good overview of the palynology. The complete pollen diagram of de Kempen can be found in Appendix F.

The pollen diagram has been subdivided into two local pollen zones. The first zone (Kemp-A) ranges from 80cm to 57cm, and the second zone (Kemp-B) from 57cm-45cm. Local zone Kemp-A is characterized by relative high percentages of *Betula* (~60%) and *Salix* (~20%) while *Pinus* is low (~5%). AP values are high around 75%-80% and *Juniperus* is present at low values while Gramineae vary between 10%-20%. Additionally *Equisetum* and *Botryococcus* vary between 10%-20% as well.

Local zone Kemp-B is characterized by relative high *Pinus* values (~35%-40%) while *Betula* and *Salix* values decrease. The presence of Heater increases during this zone till percentages up to 20%. Additionally, thermophilous taxa as *Corylus*, *Alnus* and *Quercus* are present in this zone. Table 5 shows remaining taxa found in the Kempen core during a so-called pollen quick-scan, in which a global overview of the taxa present in the core is given without counting the actual number of pollen present. Special attention is given to the occurrence of *Carpinus* at 40 cm, of which the first occurrence is placed during the Iron-age (1000 cal. years B.C.). After the indicated presence of *Carpinus* at 40 cm beneath the surface, additional samples at 55 cm and 60cm were investigated for the presence of *Carpinus* in order to invigorate the boundary between local zone Kemp-A and Kemp-B, indicated between 60-55 cm below surface based on the pollen diagram. The sample at 55 cm contained *Carpinus* while the sample at 60 cm did not. Additionally a strong increase in charcoal was noticed in the samples from 55 cm and upward compared to the bottom samples.

Table 5: Pollen quick scan de Kempen depression

Kempen (40 cm)	Kempen (35 cm)	Kempen (30 cm)
Carpinus	Quercus	Sphagnum
Alnus	Pinus	Pinus
Pinus +	Corylus	Dryopteris
Sphagnum ++	Calluna ++	Corylus
Betula	Alnus	Secale
Caluna	Sphagnum	Calluna
Dryopteris	Caryphyllaceae	Rumex acetosella
Tilia	Fagus	Alnus
Poaceae	Betula	Quercus
Fagus	Ulmus	Poaceae
Corylus	Polygonum aviculare	Tilia
Empetrum	Sporormiella	Empetrum
Quercus	Empetrum	Betula
Ulmus	Poaceae	Ulmus
Hedera	Picea	Pediastrum
Gelasinospora	Tilia	Salix
Plantago lanceolata	Rumex acetosella	Carpinus
Artemisia	Salix	Centaurea cyanus
Aster type	Succisa	Hedera
Picea	Pteridium	Plantage lanceolata
Salix	Carpinus	Asteraceae liguliflorеae
		Campanula

4.5.4 Chronology and vegetation development

Based on the pollen information described above the chronostratigraphy was established by correlation of the local pollen zones with the generalized Late-glacial and Early Holocene regional vegetation development for the Netherlands sensu Hoek (1997) and pollen zonation of the Holocene. Local pollen zone Kemp-A is correlated to regional pollen zone 2a sensu Hoek (1997) based on the presence of *Juniperus* at the beginning of the zone while *Betula* is the main tree-pollen component and AP values are high at ~80%. Furthermore, *Salix* values are relatively high and *Pinus* values low which excludes the second phase of the Allerød. Local pollen zone Kemp-B is correlated to the Subatlantic based on the occurrence of thermophilous taxa and especially the (incidental) presence of *Carpinus* alongside an increase in heathers which may indicate human impact on the vegetation. This chronology indicates a hiatus between 60cm and 55cm, between the Allerød and Subatlantic. It is thought that this hiatus is caused by excavation or burning of peat somewhere between the Allerød and early Subatlantic. This is based on the fact that the hiatus is not only visible in the pollen diagram but also in the LOI diagram and lithology. The hiatus is placed between a sandy peat (LOI values ~40%) and a much less sandy peat with LOI values ~75%. It is, therefore, thought that the peat within the depression has been excavated until the sandy peat which contained too much sand for proper combustion of the peat.

4.5.5 Genesis and age

De Kempen depression was selected as a possible pingo remnant based on the indications for pingo remnants that it has a more or less circular outline with a fairly uniform diameter greater than 25 meters. Furthermore, the bottom of the central depression lies below surrounding topography and the depression is floored by sand which is sufficiently permeable to allow migration of groundwater. The depression is filled with peat and although the present organic infill is less than 1.5 meters, the height difference between the base of the depression and the surrounding higher elevated sediments (~2.5 meters), suggests that the infill might well exceeded 1.5 meters. This supports the hypothesis that the depression has been excavated for its organic infill somewhere in the past. It can however not be concluded that the Kempen depression is a pingo remnant or not. Its relative small size and the start of infill of the depression during the early Allerød does not exclude the possibility of a pingo remnant nor does it provide enough evidence to sustain the hypothesis of a pingo remnant. The genesis of this depression therefore remains unknown, although the formation by some form of ground-ice is suggested in this study.

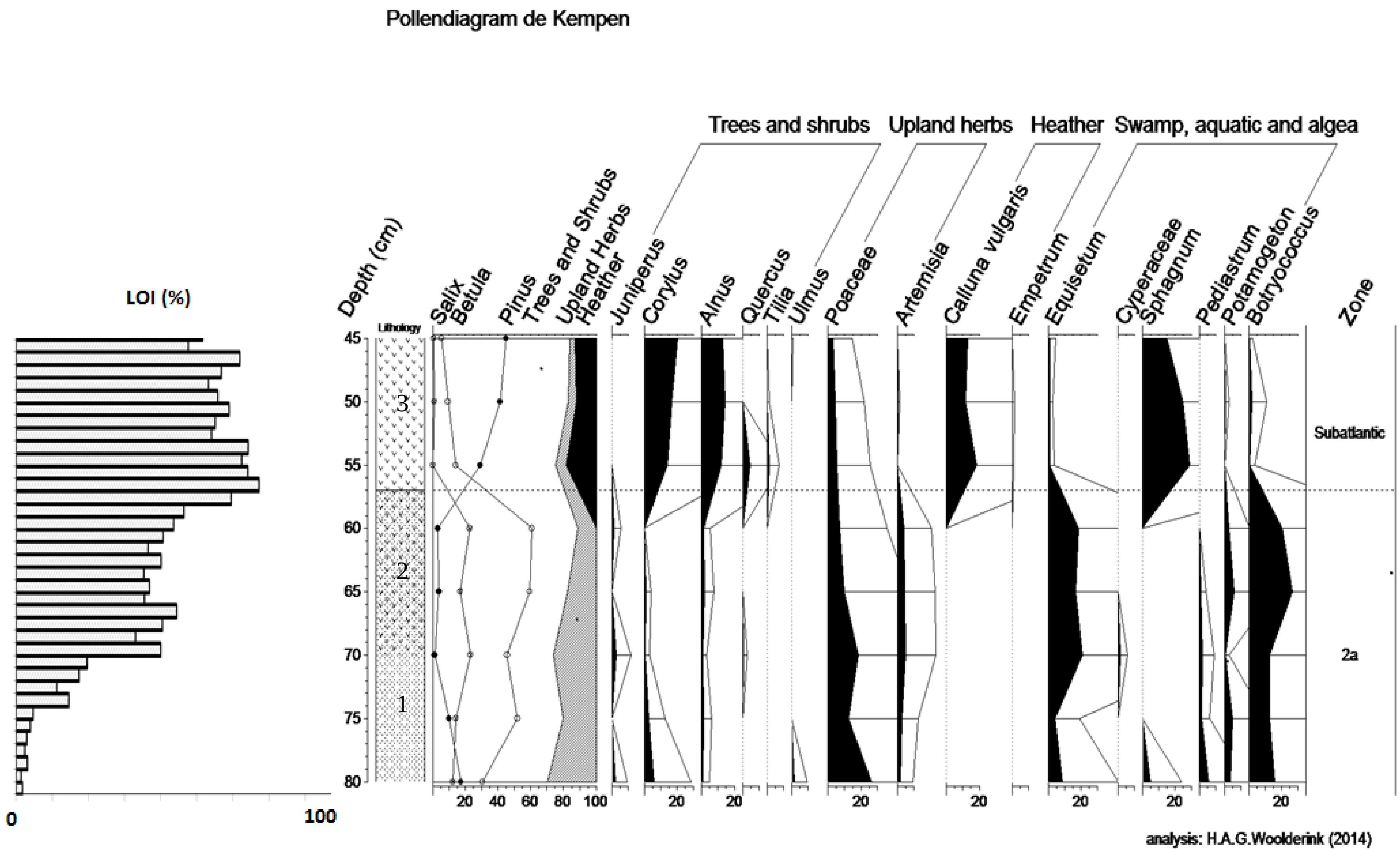


Figure 49: Pollen diagram of main taxa for de Kempen with LOI percentages 1= humic sand, 2= sandy peat, 3= gyttja

4.6 Klein Hassels Ven

The depression "Klein Hassels Ven" (164.130/371.120) is located in the southern Netherlands coversand region (figure 16), around 3 kilometers south-west of Leende (province of Noord-Brabant) in the so-called Leenderbos. Figure 50 indicates an aerial photograph of the depression, alongside a laser altimetry based digital elevation model (DEM). The depression has a diameter of ~140 meters and a height difference of ~1.0 meter between the center of the depression and the surrounding higher elevated sediments. Data from Klein Hassels Ven has previously been published in the study of van Leeuwarden and Janssen (1987). A transect was cored over this depression (figure 50) in order to produce a lithological cross section.

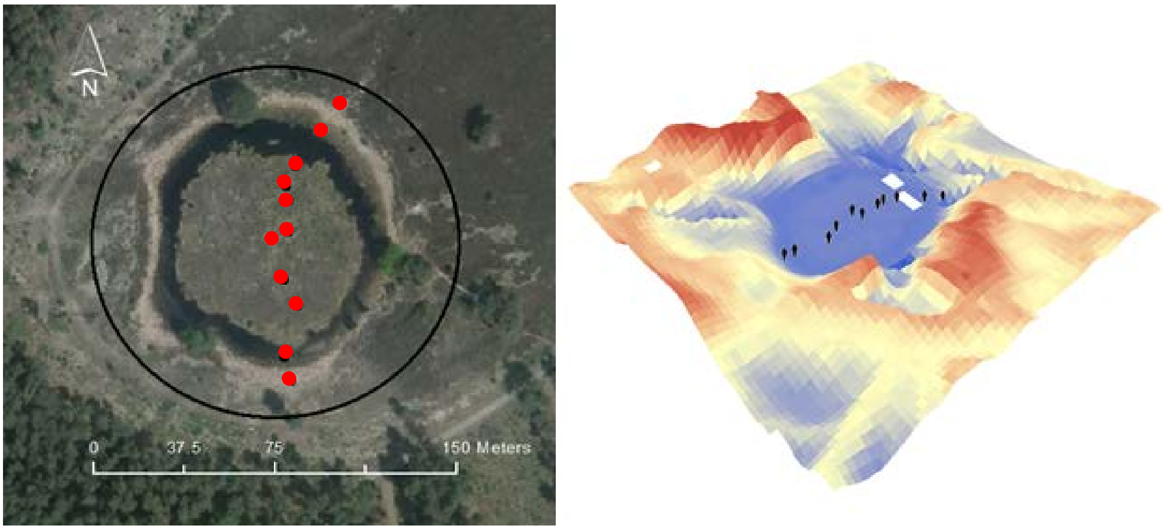


Figure 50: Aerial photograph and digital elevation model of Klein Hassels Ven

4.6.1 Lithology

The corings were described using the protocol indicated in the methods. Lithological core descriptions can be found in Appendix A. Based on the core descriptions a lithological cross-section was generated (figure 51). The cross-section shows that the upper part of Klein Hassels Ven consist of a floating fen, which has a variable thickness over the depression. Overall, the floating fen covers an organic infill of respectively peat, gyttja, peat. The northern side of the depression is characterized by a lense of fine, humic sand. A core (164.129/371.126) was taken from the site (figure 51) for more detailed lithological description. This detailed lithological description together with the core photographs can be found in Appendix C and D, respectively.

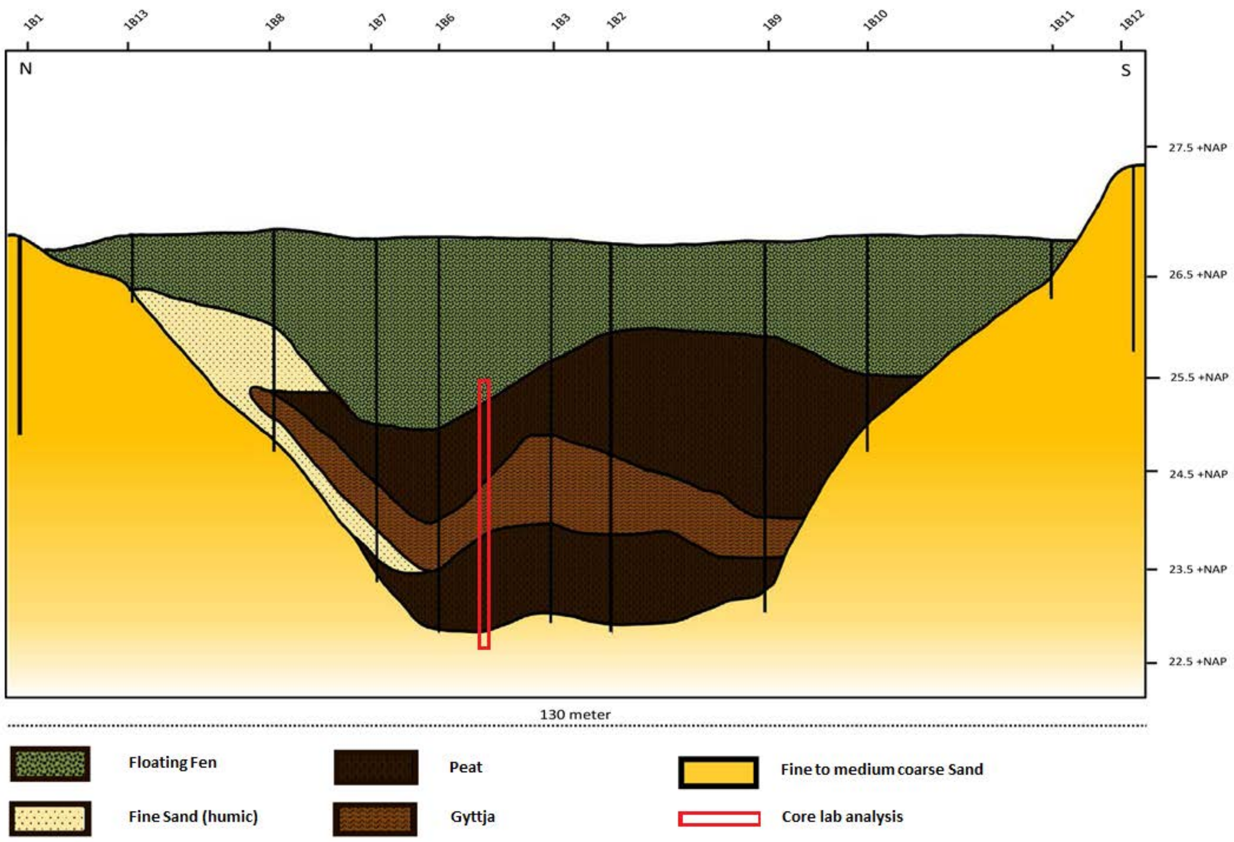


Figure 51: Lithological cross-section of Klein Hassels Ven

4.6.2 Loss On Ignition

Loss On Ignition (LOI) was performed on the peat layer retrieved from core Klein Hassels Ven. The results of the LOI are presented in figure 52. Overall the core from Klein Hassels Ven shows five different intervals in the LOI diagram. The first interval ranges from 390cm-382cm, where LOI values are low between 5%-10%. The second interval ranges from 382cm-350cm. During this interval LOI values rise to an average ~35%. During the second part of this interval a peak of LOI percentages of ~55% is indicated in the diagram, which precedes the sudden drop in LOI percentage into the third stage. The third interval (350cm-323 cm) starts with relative low LOI percentages of ~15%. After this LOI values increase up to an average of ~20%, before decreasing again to values ~10%, which marks the transition to the fourth interval. The fourth interval in the Klein Hassels Ven ranges from 323cm-285cm and is characterized by relative stable LOI values of ~15%. The fifth and final interval ranges from 285cm-170cm and is indicated by a fast rise in LOI values greater than 50%. The fifth interval is furthermore characterized by large fluctuations in LOI values but overall has percentages between 50%-100% LOI.

4.6.3 Palynology

The core derived from Klein Hassels Ven has been analyzed for pollen. The results of this analysis are given in figure 52. Figure 52 only shows the most indicative taxa in order to give a good overview of the palynology. The complete pollen diagram of Klein Hassels Ven, as well as the diagram presented by van Leeuwarden and Janssen (1987) can be found in Appendix F and J, respectively.

Local pollen zone KHV-A (390cm-380cm) is characterized by low *Pinus* values, with a relative high occurrence of *Salix* pollen (~10%) although *Betula* is the main tree taxa with values around 30%. Non-arboreal pollen (NAP) is high with percentages over 50%. Additionally, *Alnus* and *Ulmus* pollen are found in this interval, and *Juniperus* varies around values of 5%. *Artemisia* and Gramineae occur at relative high percentages while heliophile herbs are also well represented in the diagram. Special attention is given to the occurrence of *Onobrychis* and *Empetrum*. Furthermore Cyperaceae, *Potamogeton*, *Equisetum* and *Botryococcus* are present at relative high percentages.

Local pollen zone KHV- B (379cm-364cm) is dominated by *Betula* with values amongst 40% to 50%. *Salix* values are still relatively high at 10%-15% while *Pinus* values are negligible. AP values increase at the start of this interval to values up to 75%. *Juniperus* is of relative importance in this interval with a peak of 20% at the start of the interval (~377cm) after which values decrease to ~10%. Thermophilous taxa are negligible in this interval. Upland herbs are dominated by *Artemisia* and Gramineae with percentages ranging between 10% and 15%. *Galium* and Umbelliferae are present at low values and Caryophyllaceae reaches values up to 5%. *Potamogeton* decreases compared to the previous interval while *Equisetum* is still relative important with values reaching up to 20%. Additionally, *Botryococcus* shows high values ranging around 20%, *Pediastrum* reaches 10% values and *Nymphaea* increase in the latter part of the interval to values around 15%.

Local pollen zone KHV-C (363cm-355cm) is still dominated by *Betula* with values up to 80%. *Salix* values range between 10%-15% while *Pinus* shows a peak 20% at 360cm. During this interval *Juniperus* values decrease to ~5%. *Artemisia* and Gramineae levels are still at the same level as the previous interval although a distinct dip in *Artemisia* coincides with the peak in *Pinus* at 360cm. Heliophilous herbs like Caryophyllaceae and Umbelliferae are present at low values. *Potamogeton* and *Equisetum* decrease to values of ~5%. *Botryococcus* values lie around 15% while *Nymphaea* shows a peak of 25% at 356cm.

Local pollen zone KHV-D (354cm-350cm) shows a clear dip in *Betula* values while *Pinus* values reach a peak of 40% at the same time. *Salix* values diminish during this zone. *Artemisia* and Gramineae values are low during this interval while Umbelliferae and Caryophyllaceae remain present at low values. *Potamogeton* values are almost negligible and *Equisetum* remains low. *Botryococcus* remains at percentages around 10% while *Nymphaea* diminishes.

Local pollen zone KHV-E (349cm-326cm) is characterized by a sharp decrease in *Pinus* compared to the peak in zone D, after which values of *Pinus* increase and then stabilize at values ~20%. The same sharp decrease is also recognized in *Betula* which drops from values up to 80% to values around 60% and stabilizes around these values. AP values remain high at values around 75%. *Juniperus* values increase in this interval to ~3%. *Corylus* and *Alnus* pollen are also present at this interval in low values. *Artemisia* remains relatively low while Gramineae values rise to values of ~10%. Additionally the presence of heliophilous herbs increases and *Empetrum* appears as the first heather. *Equisetum* is still present at values around 5% while sphagnum values increase up to 5%. *Botryococcus* and *Nymphaea* are relatively low and also *Nuphar* occurs at low values. Special attention should be given to the occurrence of *Trapa* in this interval.

Local pollen zone KHV-F (325cm-285cm) shows a rise of *Pinus* from values 25% in the first half of the interval to values around 45% in the latter part. *Betula* values decrease at the same time from values of 60% to values around 45%. A small peak in *Salix* can be seen at the beginning of this zone. Additionally, heaters increase during this interval. *Juniperus* increases in value up to ~5% while some *Corylus* and *Alnus* pollen is present. *Artemisia* and Gramineae values are stable at ~5% and a great variety of herbs is present during this interval. The interval is furthermore characterized by the relative high occurrence of *Empetrum*, while other heathers like *Calluna vulgaris* are also present. *Potamogeton* values increase as well as *Nymphaea*.

Local pollen zone KHV-G (284cm-265cm) indicates a rise of *Pinus* values up to 60% while *Betula* values drop to values of 20%. A small peak in *Salix* can be seen at the beginning of this zone. *Corylus*, *Alnus* and *Quercus* start to increase respectively at the beginning of this zone as well as other thermophilous trees like *Tilia* and *Ulmus*. Furthermore *Artemisia*, Gramineae and other herbs decrease to low values or diminish. *Calluna vulgaris* remains present during this zone. *Potamogeton* and *Equisetum* values decrease while sphagnum values increase. Additionally *Nymphaea* and *Nuphar* values diminish as well.

4.6.4 Chronology and vegetation development

Based on the pollen information described above the chronostratigraphy was correlated to the generalized Late-glacial and Early Holocene regional vegetation development for the Netherlands sensu Hoek (1997). Table 6 indicates the correlation of the local pollen zones to the Pollen Assemblage Zones (PAZ) sensu Hoek (1997).

Table 6: Correlation of local pollen zones to PAZ sensu Hoek (1997)

Local PAZ	Depth (cm)	Main pollen taxa	Regional PAZ Hoek (1997a)
KHV-G	284-265	*Pinus, Corylus, Quercus* *Pinus*↑↑, *Corylus*↑, *Quercus*↑	5
KHV-F	325-285	*Empetrum* *Empetrum*↑	3b
KHV-E	349-326	*Betula, Empetrum* *Pinus*↓*Betula*↓, AP↓, NAP↑	3a
KHV-D	354-350	*Pinus, Betula* *Pinus*↑↑, *Betula*↓↓	2b
KHV-C	363-355	*Betula, Salix, Pinus* *Pinus*↑, *Salix*↓, *Juniperus*↓	2a2
KHV-B	379-364	*Betula, Salix, Juniperus* *Betula*↑↑, *Salix*↓, *Juniperus*↑,*AP*↑↑, *NAP*↓	2a1
KHV-A	390-380	*Salix*, *Betula*, *Juniperus*, *Artemisia*, Cyperaceae *Salix*↑, Cyperaceae ↑, NAP↑	1c

Local pollen zone A is correlated to PAZ 1c based on the high NAP values and the rise in *Salix* percentages towards values higher than those of *Betula* at the end of this zone (figure 52). This is emphasized by the occurrence of *Empetrum* and high *Juniperus* values. This subzone can be considered as the Earlier Dryas zone as defined by van Geel et al. (1989). Local pollen zone KHV-B is correlated to regional PAZ 2a1 sensu Hoek (1997). This correlation is based on the relative importance of *Juniperus* at the beginning of this zone although Betula is the main tree-pollen component. Local pollen zone KHV-C is correlated to regional PAZ 2a2 sensu Hoek (1997) based on a distinct increase of *Pinus* to 15% after which *Pinus* percentages again decrease to low values at the end of this zone. Furthermore, an increase in NAP can be recognized in this zone and *Juniperus* decreases to low values. Local pollen zone KHV-D is correlated to regional PAZ 2b sensu Hoek (1997) based on the relative importance of *Pinus* in favour of *Betula*. Local pollen zone KHV-E is correlated to regional PAZ 3a sensu Hoek (1997) based on a strong decrease in *Pinus* at the start of this subzone while *Betula* also indicates a decrease. Local pollen zone KHV-F is correlated to regional PAZ 3b sensu Hoek (1997) based on the characteristic occurrence of *Empetrum* in this subzone. Local pollen zone KHV-G is correlated to regional PAZ 5 sensu Hoek (1997) based on a characteristic rise in *Pinus* and the appearance of *Corylus* and other thermophilous trees such as *Quercus*.

From the pollen data can be concluded that infill of the depression started at the Earlier (Older) Dryas (12,100-11,900BP) which is characterized by an open vegetation cover. Wet conditions prevailed in the basins, based on the relative importance of *Salix* (Hoek, 1997). The occurrence of thermophilous trees is subscribed to reworking of older deposits. The presence of *Onobrychis* indicates a former carbonated substrate as this plant is most often present in bare, carbonated sediments (Weeda et al., 1987). This might indicate former occurrence of deep groundwater seepage. LOI values indicate low organic matter content during this interval (figure 52). Following the Older Dryas the Klein Hassels Ven infill shows changing vegetation during the Allerød, starting at 11,900 ^{14}C BP, into a rather open *Betula* forest during the first part of the Allerød and *Pinus* forest during the latter part. LOI values indicate an increase in organic matter content during this interval. After the Allerød the infill of the Klein Hassels Ven depression continued though it shows an interruption in the development to a more dense vegetation cover. This interruption relates to the start of the Younger Dryas (10,950 ^{14}C BP) during which the *Pinus* and *Betula* woods diminished in size, herbaceous plant communities developed and heliophilous herbs became relatively more frequent which resulted in an opening of the preceding boreal forest (Hoek, 1997). This decrease in vegetational cover is also represented in the LOI diagram for this depth interval. The peak of LOI values indicated in the first part of this interval is subscribed to partial reworking of older deposits. This hypothesis is supported by the pollen diagram that indicates *Trapa* pollen in this interval, which occurs only in warm to temperate environments and is most likely reworked from older deposits. Although the Younger Dryas is well represented in the pollen diagram of Klein Hassels Ven it seems that after this Younger Dryas period sedimentation within the depression ceased. The pollen diagram indicates a sharp transition from the Younger Dryas vegetation into a Late Preboreal vegetation with an increase in *Pinus* (dated to 9500 ^{14}C BP (Hoek, 1997)) and the appearance of *Corylus* around 9150 ^{14}C BP (Hoek, 1997). It is, therefore, concluded that a hiatus is present between the Younger Dryas and the latter development of closed deciduous forest during the Late Preboreal. The LOI diagram shows an increase in organic matter content during this interval but the presence of a hiatus could only be concluded from the pollen diagram.

4.6.5 Genesis and age

Klein Hassels Ven was selected as a possible pingo remnant based on the indications for pingo remnants that it has a more or less circular outline with a fairly uniform diameter greater than 25 meters. It, furthermore, has a depth greater than 1.5 meters and the bottom of the central depression lies below surrounding topography. The depression is floored by sand which is sufficiently permeable to allow migration of groundwater and the depression is filled with organic material. Palynological results indicate a start of the infill of the depression between 12,100-11,900 BP. This indicates that the depression was at least partially formed before this time. This hypothesis is supported by a radiocarbon date of 11,450 +- 90 ^{14}C BP at a depth of 340cm within the Klein Hassels Ven depression as published by van Leeuwaarden & Janssen (1987). Combining these results, Klein Hassels Ven fits the definition of a pingo remnant as set in this study namely; a circular to oval depression with a minimum depth of 1.5 meters, a diameter of 25 meters or greater, which has a (partial) organic infill and is of Weichselian age.

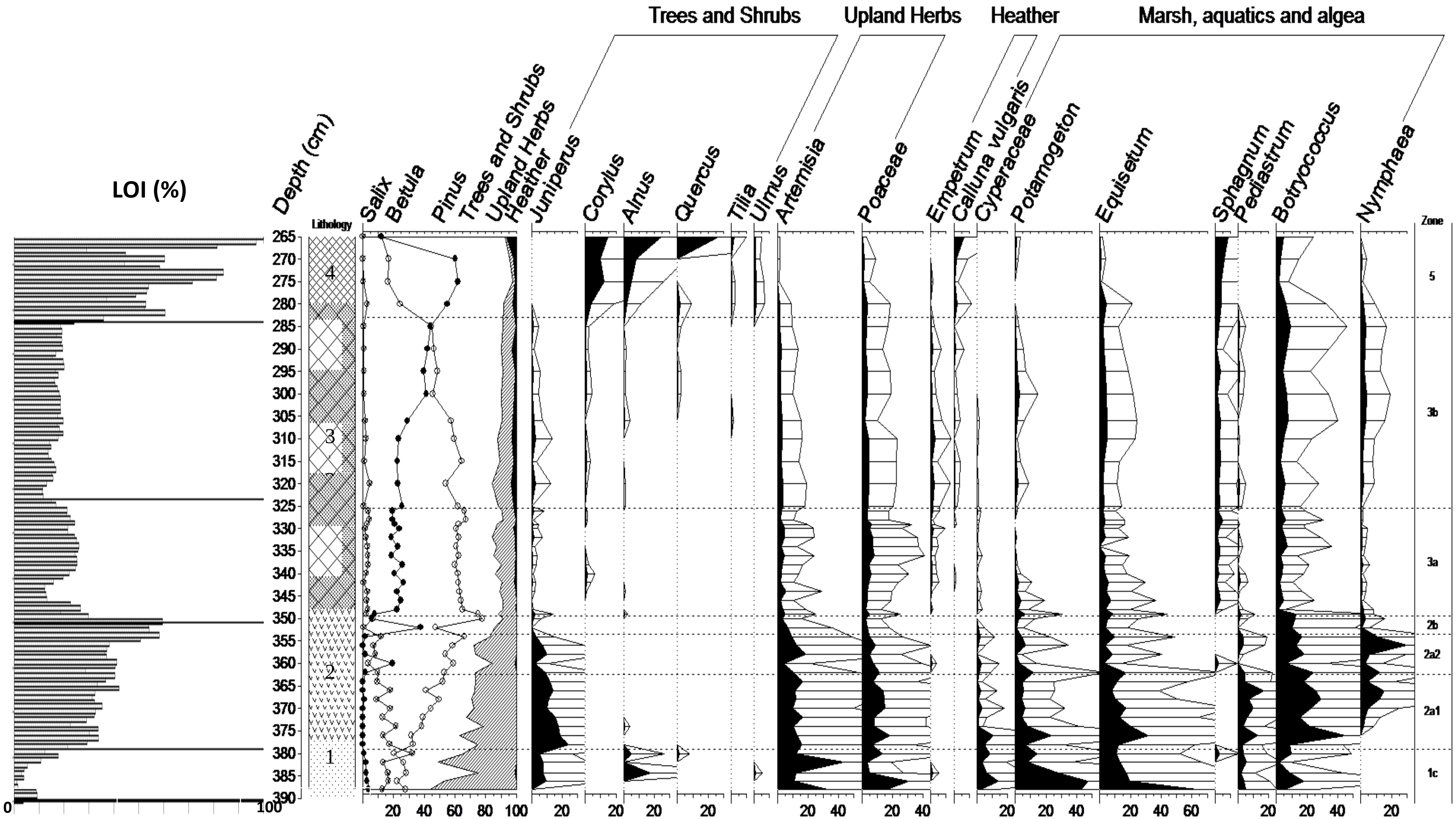


Figure 52: Pollendiagram of main taxa for Klein Hassels Ven with LOI percentages (1=sand, 2= sandy peat, 3=gyttja, 4=peat)

It remains however uncertain if the pingo was of hydraulic or hydrostatic origin and more detailed study should be performed on the internal lithological structures of the depression and the surrounding and underlying geology in order to gain a conclusion on this matter. The depression is however situated nearby a brook valley and no evidence of former talik was found during this study, which might hence towards a hydraulic system pingo origin.

4.6.6 Correlation Klein Hassels Ven cores

This section will show the correlation of the Klein Hassels Ven pollen record presented in this study and the record described in Van Leeuwarden and Janssen (1987). Van Leeuwarden and Janssen (1987) describe that the start of infill of Klein Hassels Ven is characterized by the *Betula* - NAP phase, or phase 3 (11,500-11,000), at depth interval ~340-315 cm. This zone is equivalent to zone KHV B-D. Van Leeuwarden and Janssen state that no material of the preceding phase 1 (prior to 12.000) was available for Klein Hassels Ven. This study describes, however, that the infill of Klein Hassels Ven started during regional PAZ 1c (12,100-11,900 BP) sensu Hoek (1997) at the depth interval 390-380 cm of the new core. This shows that the core taken by Van Leeuwarden and Janssen (1987) did not fully reach the bottom of the depression. Phase 4&5, at depth interval ~315-245 cm of the Van Leeuwarden and Janssen core, are characterized by *Betula* percentages of ~45% - 75% and *Pinus* pollen values of 15% - 45%. The decrease of *Artemisia* values and the relatively high percentage of Ericaceae during these phases indicate that the open *Betula-Juniperus* forest disappeared and was replaced by heather vegetation. These zones can be correlated to regional PAZ 3a sensu Hoek (1997) and local PAZ KHV-E (349-326 cm) in this study. Phase 6 sensu Van Leeuwarden and Janssen (1987) is considered equivalent to local PAZ KHV-F in this study, and regional PAZ 3b sensu Hoek (1997), based on the relative importance of *Pinus* and *Empetrum*. Finally, phase 7 sensu Van Leeuwarden and Janssen (1987) is correlated to local PAZ KHV-G, based on the *Pinus-Corylus* assemblage in this zone.

Overall the two diagrams show a similar vegetational development contained within the Klein Hassels Ven, which could be expected as the cores are taken from the same depression. However, the core retrieved for this study shows that the Older Dryas (zone 1c) is present in the Klein Hassels Ven depression, which was missing in the core from the study by Van Leeuwarden and Janssen (1987). Figure 53 shows a correlation of the pollen zones for the Klein Hassels Ven defined in this study, and those defined by Van Leeuwarden and Janssen (1987).

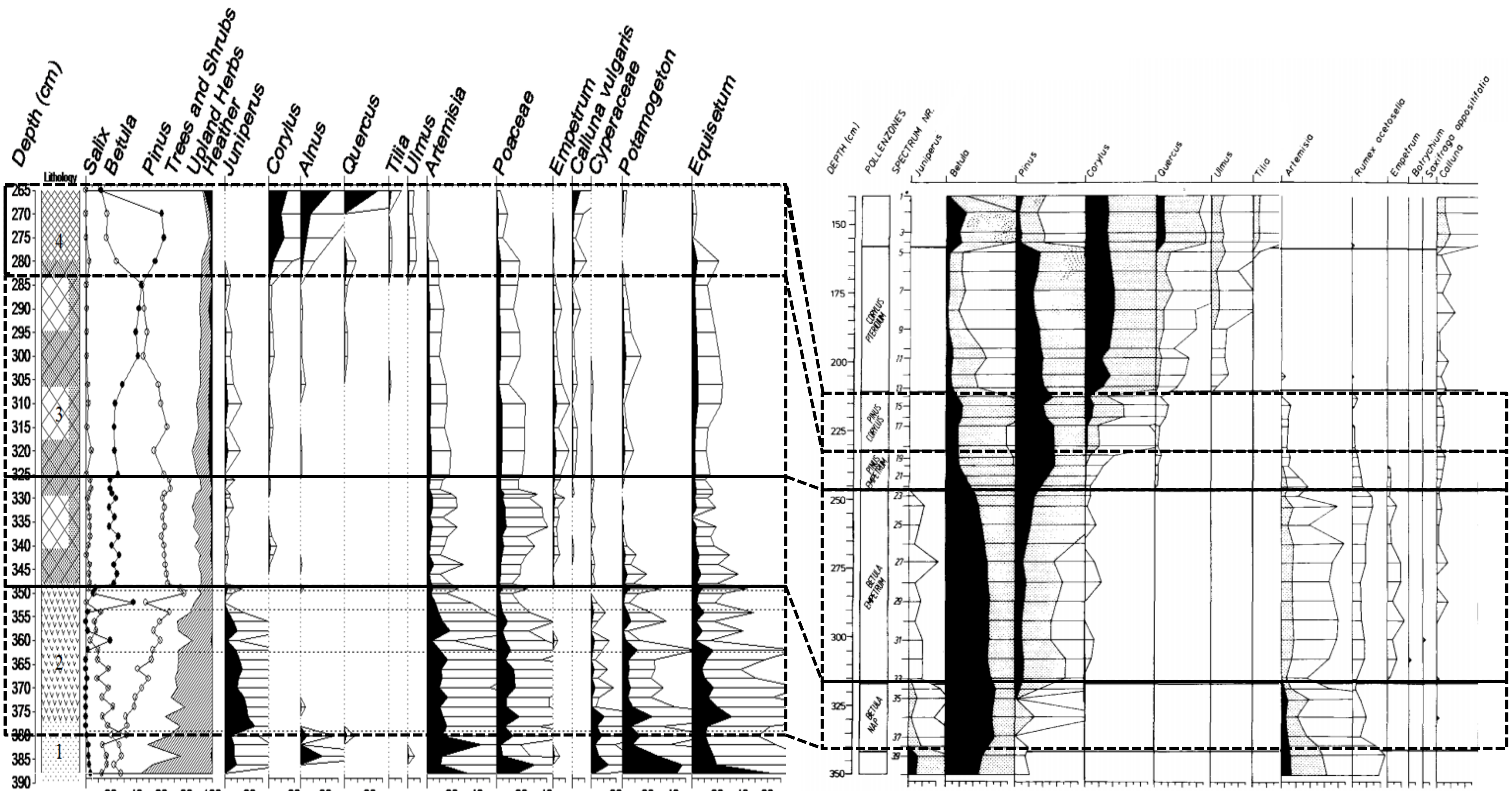


Figure 53: correlation of the pollen zones defined in this study for the Klein Hassels Ven, and those defined by Van Leeuwarden and Janssen (1987)

4.7 Pingos in the study area

Five depressions were investigated in the field (figure 39), of which three contained sufficient organic material in order to preform loss on ignition and pollen analysis. Table 7 indicates the location of the depression in the national coordinate system Rijksdriehoekstelsel (RD), the minimum age of the infill of the depression based on palynology (if applicable) and if the depressions represent a pingo remnant according to the requirements given in paragraph 2.1.2.3.

Table 7: Overview of characteristics of the investigated depressions

Depression	Location (X,Y)		Minimum age	Pingo remnant
3	164.602	377.565	n/a	no
4	165.224	377.117	Before Late-glacial	no
5	164.234	377.125	n/a	no
Kempen	147.677	371.163	Before 11,900 ^{14}C yr. BP.	uncertain
Klein Hassels Ven	164.130	371.120	Before 12,100 ^{14}C yr. BP.	yes

It can be concluded that pingo remnants are present in the southern Netherlands. However, not all depressions which can be recognized in the digital elevation model (AHN) represent such pingo remnants. It is therefore recommended that all depressions should be studied individually before a conclusion can be made concerning the question if the depression is a pingo remnant or not. This study should contain at least a lithological cross-section over the depressions and some form of age estimation based on for example palynology or radiocarbon dating. Although it has been concluded that depressions 3, 4 and 5 do not represent pingo remnants, the genesis of these depressions by some form of ground-ice is not excluded. Minimum ages were indicated for three out of the five depressions; however time of formation of the depressions could not be established from the study results.

4.8 Pingo remnants and brook valleys

In order to obtain a better insight in the spatial distribution of pingo remnants related to brook valleys a GIS analysis was performed. The initial inputs were derived from the geomorphological map of the Netherlands (Alterra, 2008) and a pingo database for the Netherlands (Ruiter, 2012). The distance between a known pingo remnant and the most nearby brook valley system was calculated during this analysis. The results of this analysis are presented in figure 56. The results are classified into several classes, pingo remnants that are within 1 kilometer of a brook valley are subdivided into classes of 100 meters (figure 54). Pingo remnants that have a distance of more than one kilometer from a brook valley are classified into the classes 1000m-1500m; 1500m-2000m; 2000m-2500m and a final class of >2500 meters. Appendix H shows a table with the precise distance between pingo remnants from the database to the Alterra brook valleys. It must be noted that this analysis was performed as a pilot study and much more detail and accuracy could be achieved with a more detailed study. Furthermore, the analysis focuses on brook valleys solely; large river valleys were not incorporated into this study which may provide alternative results. Based on the results indicated in figure 56, two histograms were created to indicate the distribution of pingo remnants related to brook valleys. Figure 54 shows the percentage of the total amount of pingo remnants in the database (87 pingo remnants) within the classes described above. It can be derived from the figure that ~ 15% of the pingo remnants are within 100 meters of a brook valley. Furthermore ~20% of the known remnants are situated within a distance of 1000-1500 meters from a brook valley while ~13% is situated in the class 1500-2000 meters and about the same percentage has a distance greater than 2500 meters to the nearest brook valley.

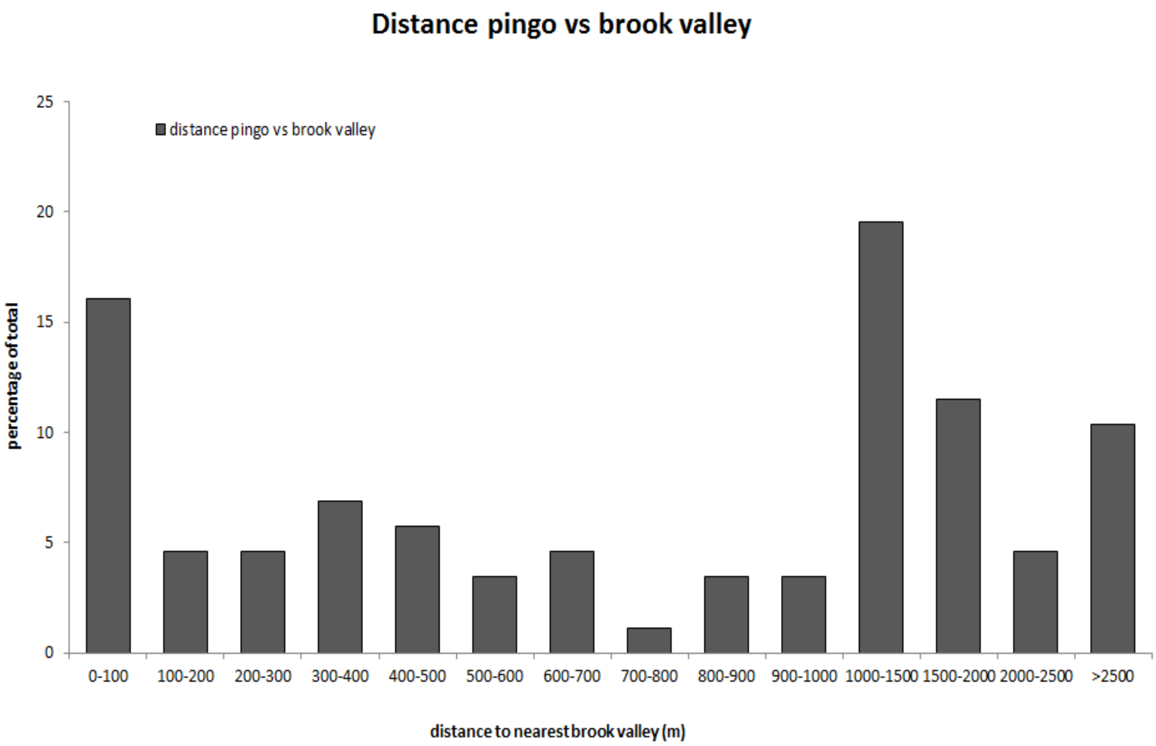


Figure 54: Distance pingo vs brook valley

In order to provide a more general overview of the distance of pingo remnants to brook valleys, a cumulative histogram was created (figure 55). This figure indicates the cumulative percentages of the classes used. It can be concluded that 50% of the know pingo remnants in the Netherlands are situated within 900 meters of a brook valley. The majority, ~73% is situated within a distance of 1500 meters to a brook valley, and 85% within a distance of 2000 meters.

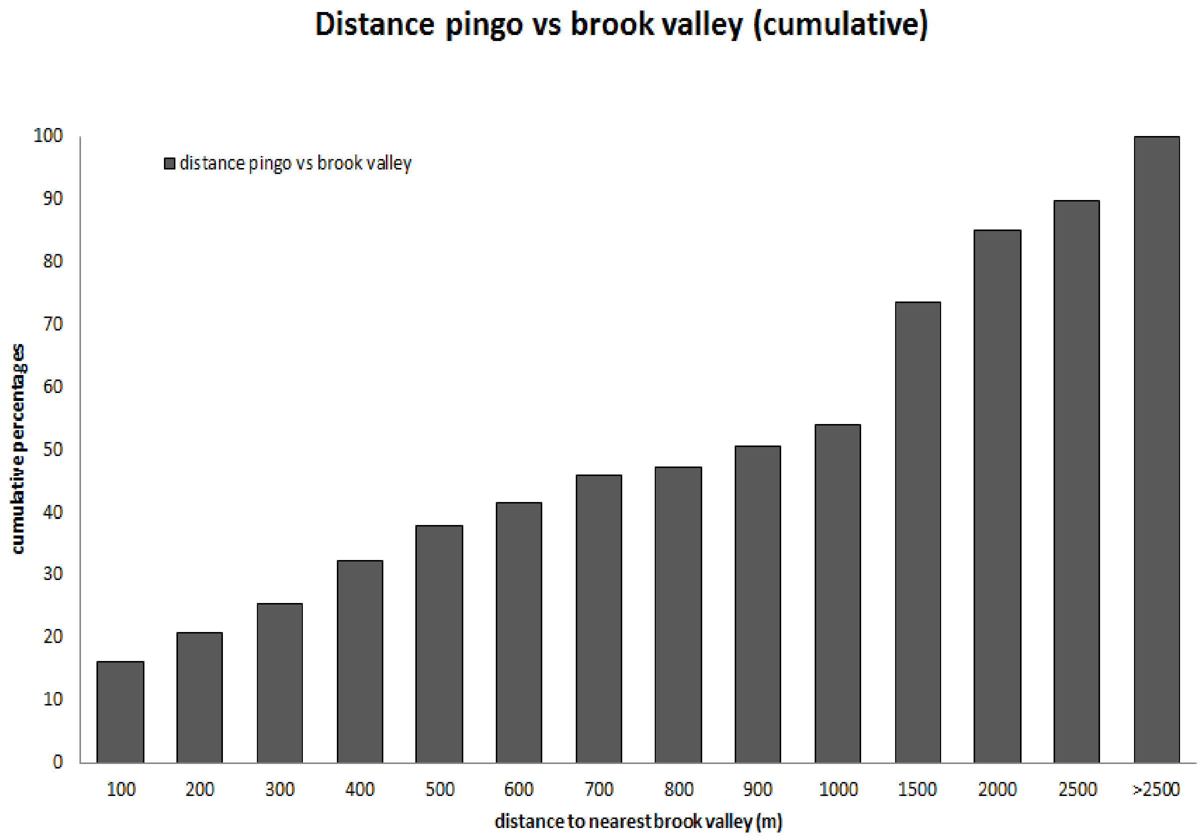


Figure 55: Distance pingo vs brook valley (cumulative)

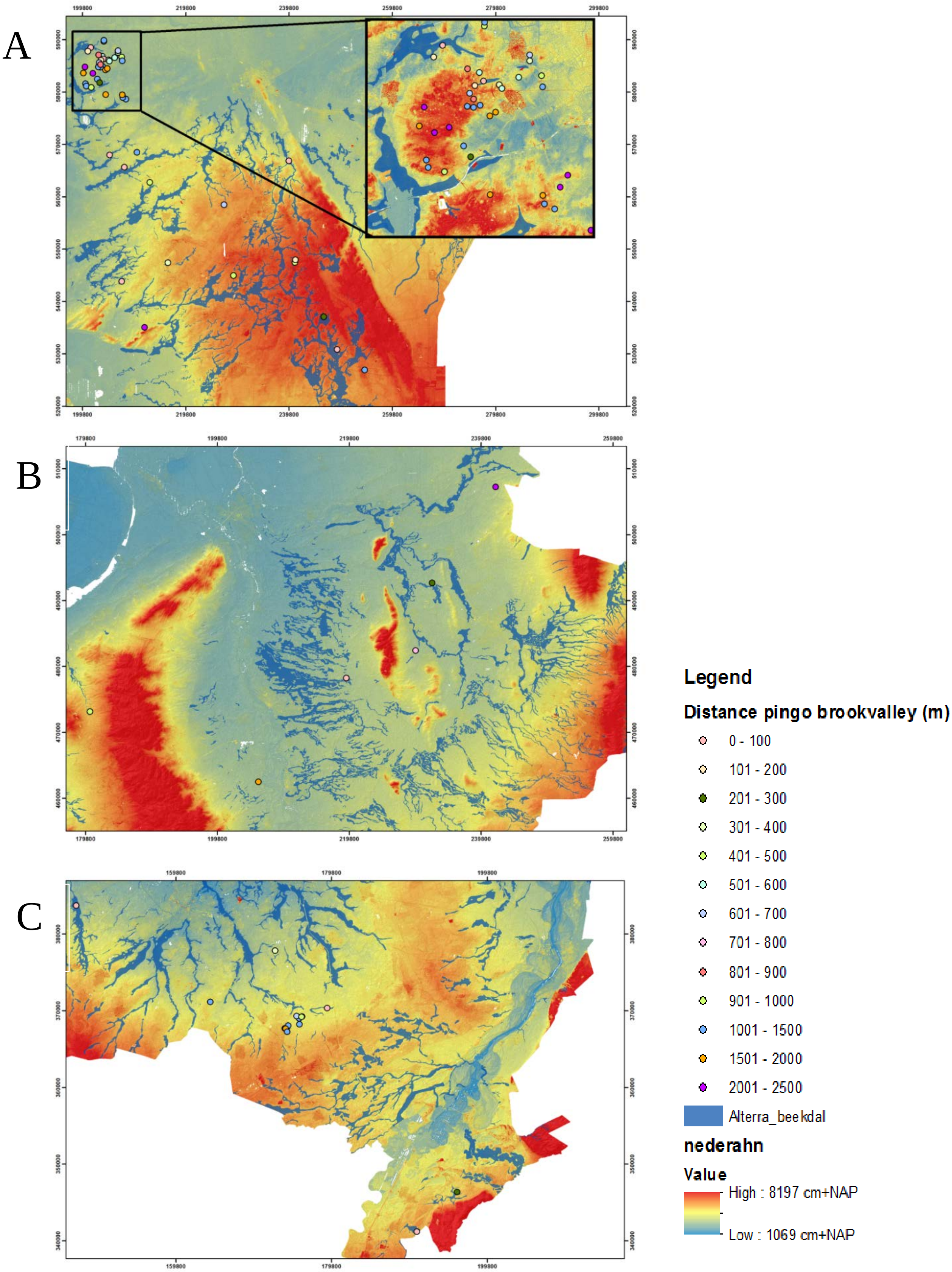


Figure 56: Overview distance of dutch pingo remnants to brook valleys for the selected study areas in the northern, central and southern Netherlands. For full image see appendix K

Chapter 5. Discussion

5.1 Pingo remnants in the southern Netherlands

Numerous pingo remnants are identified in the northern Netherlands, although few were recognized in the southern part of the Netherlands. However, circular shaped depressions can also be widely recognized in southern Netherlands, which might indicate the presence of pingo remnants. Five depressions were investigated in detail for this study in order to examine the possibility of a pingo remnant. It is concluded that depressions 3, 4 and 5 do not represent pingo remnants (table 7). However ice-cored terrain does not only include morphologically distinctive ice-cored features such as pingos (Kasse and Bohncke, 1992). Cryogenic mounds are common within the discontinuous permafrost zone (Ballantyne and Harris, 1994) as well as areas of flat or undulating terrain which are underlain by bodies of massive ice (Harry, 1988). It is, therefore, concluded that these depressions most probably indicate relicts of such massive ice bodies. It is however also possible that the depressions indicate mineral palsas as the investigated depressions resemble the remnants of mineral palsas in the Hautes Fagnes (Belgian Plateau) as described by Pissart (2003). The Kempen depression meets most of the criteria set in this study to label it as a pingo remnant. Although it seems that the organic infill of the depression might have been of sufficient depth before probable excavation, it does not presently meet the criteria set in this study. The genesis of the Kempen depression, therefore, remains unknown. Klein Hassels Ven is concluded to be a pingo remnant, based on its lithology and palynology of its organic infill. The start of the infill is placed between 12,100 and 11,900 ^{14}C BP (PAZ 1c sensu Hoek, 1997) based on palynological evidence. This age control is supported by a radiocarbon date of 11,450 +- 90 ^{14}C BP at a depth of 340cm within the Klein Hassels Ven depression as published by van Leeuwaarden & Janssen (1987). It must be noted that this date originates from a bulk ^{14}C dating and an AMS dating is therefore advised. The occurrence of pingo remnants in the southern Netherlands is also supported by other studies after other possible pingo remnants in the southern Netherlands. Van Asch et al (2013) described the presence of four pingo remnants in the Weerterbos region. Furthermore, Mierlo Ven Hoenderboom (Bisschops, 1973) and Maartensdobbe (Kasse and Bohncke, 1992) represent pingo remnants as well, although a massive ice body is suggested for the latter by the authors. Additionally, the Gulickshof more to the south is described by Hoek et al. (1999) as a possible pingo remnant. This study, therefore, shows that pingo remnants are present in the southern Netherlands, although, the number of pingo remnants in this region is smaller compared to the northern part of the Netherlands. The reason for this larger number of pingo remnants in the northern Netherlands is still under debate. Nonetheless, differences in regional geological and hydrological factors are thought to play an important role in this differentiation, as the northern part of the Netherlands is on a large scale underlain by glacial tills, which will act as an impermeable layer and increases groundwater pressure (Mackay,1983), while the southern Netherlands lacks such a broad-scaled impermeable layer near the surface. However, local loam layers occur in the geology of the southern Netherlands (Schokker, 2003), which may act in the same manner as the glacial tills, increasing groundwater pressure during permafrost conditions leading to favourable conditions for pingo formation. The occurrence of grouped pingo remnants in the Weerterbos which is located nearby an area of extensive loam occurrence supports this hypothesis, although this will most probably be not the only causes for the pingo remnants in the Weerterbos area. Further research after the conditional factors for pingo formation in the (southern) Netherlands is needed to come to a decisive conclusion.

5.2 Inter-comparison of pingos and their infill throughout the Netherlands

As this study shows that pingo remnants are indeed present in the southern Netherlands, the question remains whether these remnants are comparable to the pingo remnants present in the northern and central Netherlands. Table 8 shows the diameter, depth and presumable age of the pingo remnants in the northern, central and southern Netherlands. It can be derived from table 8 that the pingo remnants in the northern Netherlands have a greater diameter (~150-200 meters) compared to the pingo remnants in the southern Netherlands (~100 meters). Diameters of the described pingo remnants in the central part of the Netherlands roughly coincide with the diameters of pingo remnants in the northern Netherlands. Additionally, the pingo remnants in the northern and southern Netherlands vary in depth. The northern remnants have a depth varying between 3 and 12 meters. It must, however, be noted that a selection was made from known pingo remnants in the northern Netherlands and that more detailed study after all known pingo remnants in the northern Netherlands may yield more varying results concerning diameter and depth. In the central Netherlands a similar depth range of the pingo remnants has been recorded, although the depth of Uddelermeer reaches ~16 meters. Compared to the depth of the remnants in the central and northern Netherlands, the pingo remnants in the southern Netherlands are less deep varying between 2 and 5 meters in depth. Overall it is suggested here that pingo remnants in the southern Netherlands are smaller and shallower than those in the central and northern part of the Netherlands. Pingo remnants in the northern and central part of the Netherlands seem to roughly coincide concerning diameter and depth.

Table 8: Overview characteristics pingo remnants used in this study (p = date on pollen stratigraphy d = radiocarbon date)

Name pingo remnant	Diameter (m)	Depth	Age (^{14}C a BP)	PAZ (Hoek, 1997)
Veenklooster	170	5	12,450 +/- 95 (d)	n/a
Stokersdobbe I	100	8	12,450 - 12,100 (p)	1b
Groote Veen	200	3	12,400 (p)	1b
Uteringsveen II	150	4	12,100 – 11,900 (p)	1c
Mekelermeer	200	12	12,450 - 12,100 (p+d)	1b
Daarle	200	5	12,450 - 12,100 (p)	1b
Bleekemeer	200	8	12,450 - 12,100 (p)	1b
Uddelermeer	300	16	12,450 - 12,100 (p)	1b
Mierlo Ven Hoenderboom	50	3.5	12,450 - 12,100 (p)	1b
Maartensdobbe	100	3	12,450 – 11,900 (p)	1b-1c
Klein Hassels Ven	140	3.9	12,100 – 11,900 (p)	1c
Vliegersgat	80	5	12,450 – 11,900 (p+d)	1b-1c
Berkenven	80	3	12,450 - 12,100 (p)	1b
Klein Ven	70	2.5	12,450 - 12,100 (p+d)	1b
Groot Ven	70	2	12,450 - 12,100 (p)	1b
Gulickshof	200	3	12,450 - 12,100 (p)	1b

Although differences in diameter and depth of the remnants are indicated between the remnants in the central/northern part of the Netherlands and those in the southern part, the start of infill of the depressions seems to coincide throughout the Netherlands. Most pingo remnant basal infillings are correlated to PAZ 1b or 1c sensu Hoek (1997). While differences occur concerning to which part of the Bølling the start of the infill is correlated, the depressions overall started to record between 12,450 and 11,900 ^{14}C a BP. It must be noted that it is assumed in this study that the locations at which cores were taken from the pingo remnants are the most suitable locations within the lakes/peat bogs for this purpose. As discussed in the literature review the location within a peat bog or lake is of influence on the pollen assemblage on that location, which should be kept in mind when interpreting the diagram. Furthermore, it should be noted that a selection was made from the pingo remnants in the northern Netherlands and that other pingo remnants in this area might have a different age at which the infill of that depression started. It is however thought that the selection made in this study is an accurate representation of the pingo remnants found in the northern Netherlands.

5.3 Spatial distribution and genesis of pingos with respect to brook valleys

Hydraulic pingos result from groundwater movement beneath shallow discontinuous permafrost, which results in artesian groundwater pressure under permafrost at the foot of a slope or valley floor, causing growth of an ice-lense (Ballantyne and Harris, 1994). Additionally, hydraulic pingos appear to group in small numbers due to the varying location of the upwelling groundwater, and often occur at or near the transition between slope sediments and valley fill deposits (Gurney, 1998; Ballantyne and Harris, 1994). In the Netherlands the presence of pingo remnants seems to coincide with the occurrence of brook valleys (Ruiter, 2010). The presence of (former) brook valleys can be well recognized in laser altimetry images of the Netherlands (AHN). The (southern) brook valleys are often situated in broad and shallow valleys which originate from periglacial processes during the Weichselian (Berendsen, 2008). The performed GIS analysis in this study indicates that most pingo remnants in the Netherlands are indeed located considerably close to brook valleys. It is concluded that 50% of the studied pingo remnants in the Netherlands in located within 900 meters of a brook valley, and 73% is situated within a distance of 1500 meters. This results in the hypothesis that the most pingo remnants in the Netherlands were presumably of hydraulic origin. This hypothesis is supported by the Maartensdobbe pingo remnant, as (Kasse and Bohncke, 1992) indicate that this depression is situated on the flank of a shallow Weichselian valley, and that lacustrine or substantial fluvial sediments of Weichselian age have not been found around the depression which makes a hydrostatic pingo origin unlikely. Additionally Ruiter (2012) and de Bruijn (2012) indicate that most pingo remnants in the Netherlands and adjacent north Germany are of hydraulic origin based on the cone-shape of the depressions and observations of seepage and chemical precipitation within the depressions, which is also present in the Weerterbos pingo remnants. Although the general concept of hydraulic pingo formation is relatively well understood, debate remains concerning local differences in groundwater injection (Gurney, 1998). This debate is supported by this study as differences in regional geology and hydrology occur between the northern, central and southern Netherlands. As mentioned the correspondence between all investigated areas is that the pingo remnants most often occur near brook valleys. As discussed, pingo remnants within brook valley systems often occur at or near the transition between slope sediments and valley fill deposit, which is probably due the intersection of groundwater levels with the surface of the valley slope. This hypothesis might also explain the grouping of hydraulic pingo in small numbers (Gurney, 1998) as fluctuations in groundwater levels may introduce different upwelling locations. Overall it is concluded that most pingo remnants in the Netherlands are of hydraulic origin as they seem to appear near (brook) valleys (i.e. natural locations of (ground) water accumulation under a gradient), often indicate (former) seepage of groundwater and are not surrounded by relict indicators of taliks.

5.4 Distribution and decay of permafrost

Based on this study, a reconstruction of permafrost distribution, minimum permafrost depth and characteristics of decay of permafrost throughout the Netherlands during the Weichselian Late Pleniglacial and the following Weichselian Late-glacial has been made. Pingo remnants were chosen for this purpose as these features do not only indicate presence and minimum depth of the permafrost, as pingos are an integral part of the permafrost (Gurney, 1998), but also form a unique record of environmental changes since the last glaciation containing for instance pollen, aeolian sands, chironomids and tephra (Hoek et al., 2012). Results of this study show that pingo remnants can be recognized in the northern, central and southern part of the Netherlands. The minimum depth of permafrost in the northern Netherlands during the Weichselian Late Pleniglacial varied between 12 to 5 meters below the surface. Pingo remnants in the central Netherlands indicate a minimum permafrost depth varying between 5 to 16 meters. The southern Netherland minimum permafrost depth was between 2 and 5 meters below the surface. The pingo remnants in the Netherlands were presumably formed during the Pleniglacial. Although debate remains concerning the origin of pingos in the Netherlands (i.e. hydrostatic vs hydraulic) investigated pingo remnants in this study are thought to be of hydraulic origin. Due to this conclusion the permafrost is assumed to be discontinuous (Ballantyne and Harris, 1994) throughout the Netherlands during the formation of the pingos. Vandeberghe and Pissart (1993) however indicate that former continuous permafrost was present during the Weichselian Late Pleniglacial (~27-13 ka). This implies that pingos in the Netherlands already formed before the Weichselian Late Pleniglacial, as during the antecedent milder period between ca. 35-41 ka sporadic or discontinuous permafrost occurred according to Vandeberghe and Pissart (1993). This hypothesis is contradicted by the study from Bijlsma & de Lange (1983) and de Gans (1982) as they conclude that start of (in their consideration hydrostatic) pingo formation occurred during the Late Pleniglacial. The start of pingo formation, however, remains difficult to reconstruct, as it can only be concluded that the pingo formed somewhere in between the deposition of the substrate they are formed in, and the age of the basal infill of the (partially) decayed pingo.

It is, therefore, assumed in this study that pingo remnants were at least present during the Weichselian Late Pleniglacial although the actual start of formation of the pingos remains unknown. When reconstructing permafrost throughout the Netherlands in a North-South profile, permafrost within the river landscape in the middle Netherlands was left out of the profile as no evidence of pingo remnants was found up to now in this region.

This, however, does not indicate that permafrost was not present in this region. Figure 58 shows the minimum permafrost depth during the Last glacial Maximum within a North-South profile (figure 57) throughout the Netherlands, as resulting from this study.

Sediment accumulation starts to occur after (at least) partial decay of the pingo. The age of the basal infill is supposed to be an indication for the minimal age of the decay of the pingo, which in turn indicates the minimum age of decay of permafrost. Pingo remnants used within this study indicated a start of basal infill which could be correlated to the Bølling (ca. 12,450-11,900 ^{14}C a BP). However, differences occur between the distinct pingo remnants during which part of the Bølling infill started (table 8). This leads to a broad time range of up to some 500 ^{14}C years for the start of the infill of the pingo remnants. Despite this time range, it is concluded that all the pingos used for this study were (at least partially) decayed during the onset of the Bølling. This supports the hypothesis that pingo decay in the Netherlands was presumably caused by the warming climate during this period. The differences concerning basal infill of the remnants are thought to indicate local differences in vegetation development and accumulation within the depressions rather than a real time delay in the decay of permafrost between the northern and southern Netherlands. It is, therefore, concluded that decay of permafrost throughout the Netherlands occurred more or less simultaneously with the climatic warming at the onset of the Bølling.

Improvements in the time constraint during which pingos started to decay can be made by accurately dating the basal infill of all investigated remnants by means of AMS dating. Furthermore, more accurate minimum permafrost depths can be accomplished by increasing the amount of studied pingo remnants within the profile.

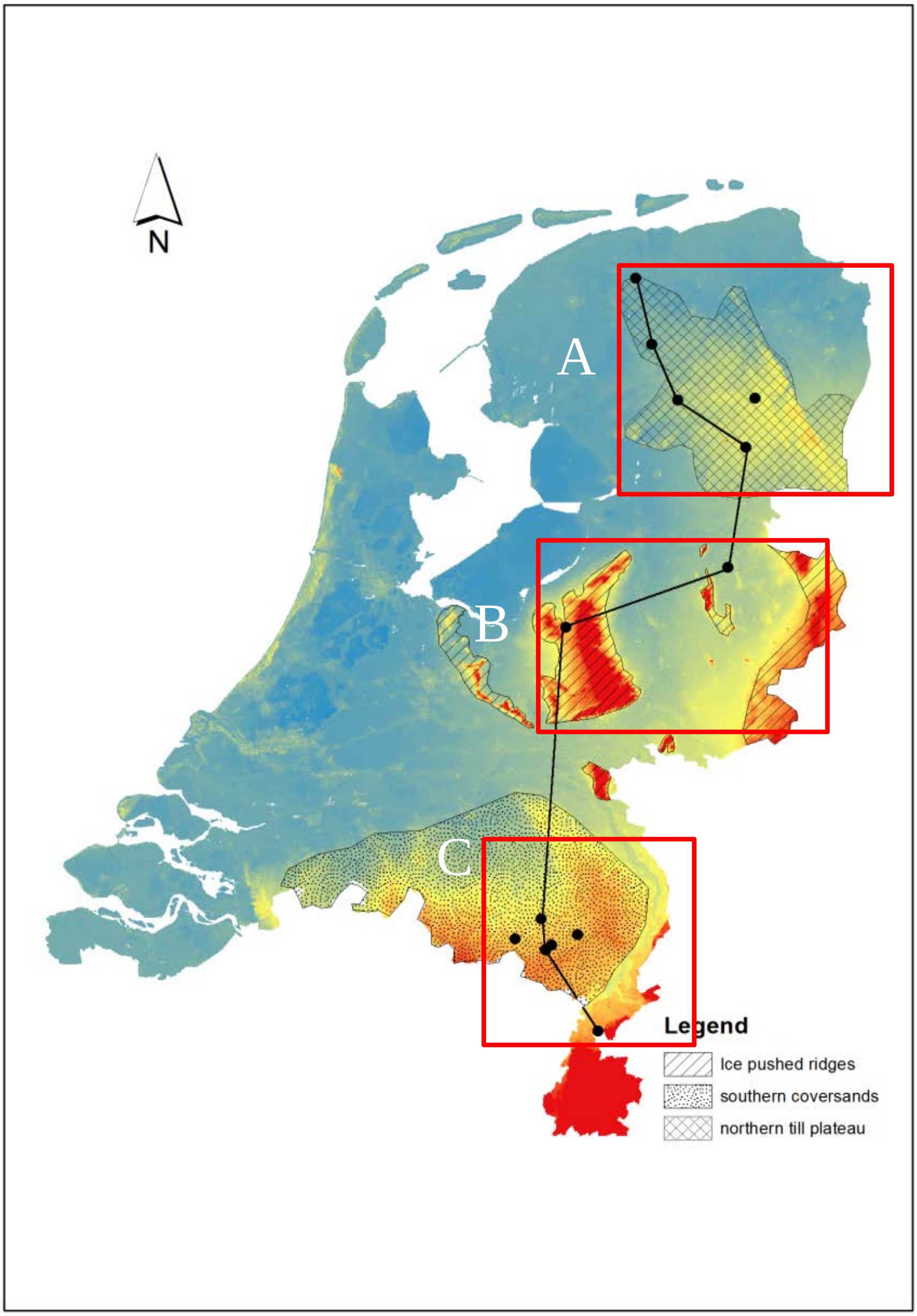


Figure 57: Geographical overview of north-south transect through selected pingo remnants in the Netherlands

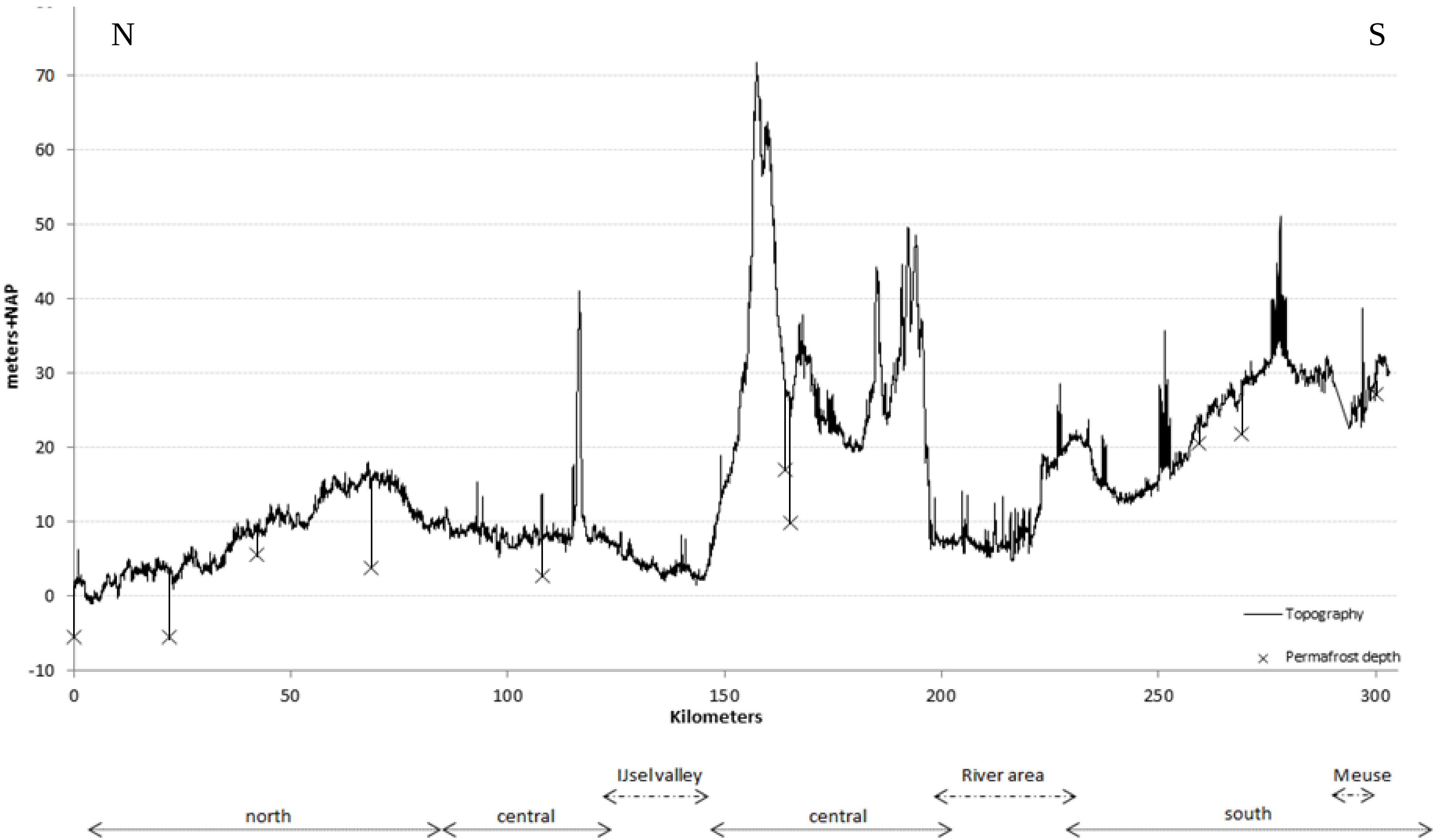


Figure 58: North-south transect through the Netherlands with proposed minimum permafrost depth under current topography during the Weichselian Late Pleniglacial as indicated by selected pingo remnants

Chapter 6. Conclusion

Based on the information derived from field results and literature review the following conclusion can be drawn. Detailed answers to the research questions below will provide the basis for an answer of the main research question;

What were the distribution, minimum permafrost depth and characteristics of decay of permafrost throughout the Netherlands during the Late-glacial Maximum and the following Weichselian Late-glacial?

- Based on this study it can be concluded that pingo remnants are present in the southern Netherlands. Out of the five investigated depressions at least one was concluded to be a pingo remnant. Furthermore, literature describes the presence of pingo remnants which were not investigated in the field in this study. However, not all circular depressions which might indicate pingo remnants in fact do so. Many depressions are concluded to be formed by some sort of cryogenic mound or ground-ice, although precise genesis could not be reconstructed.

- This study shows that the southern Netherlands pingo remnants provide a climatic record. It was defined that pingo remnants should contain an organic infill, and results from this study showed that all studied remnants contained a climatic record. This climatic record was analyzed based on palynology and results show an overall start of the infill of the pingo remnants during the Bølling (ca. 12,450-11,900 ^{14}C a BP). Subsequently, most remnants contained a vegetational record which could be correlated to the Late-glacial vegetation development for the Netherlands.

- Pingo remnants throughout the Netherlands differ from each other in various ways. The pingo remnants in the northern Netherlands have a larger diameter and depth than the remnants in the southern Netherlands. Pingo remnants in the northern and central part of the Netherlands have more or less similar diameters and depths. Northern, central and southern Netherlands pingo remnants are formed in different geological areas and subsequent substrates. Although pingo remnants vary in the start of their infill, this difference is likely to be caused by local factors rather than regional differences. It is concluded that pingos throughout the Netherlands were at least partly decayed during the onset of the Bølling (ca. 12,450-11,900 ^{14}C a BP). The pingo remnants are most likely of hydraulic origin, although debate remains about this hypothesis.

- A spatial relationship exists between pingo remnants and brook valleys. It is concluded that 50% of the studied pingo remnants in the Netherlands is located within 900 meters of a brook valley, and 73% is situated within a distance of 1500 meters. This conclusion provides additional evidence for the hypothesis that pingo remnants in the Netherlands are of hydraulic origin as the brook valley will most often provide the hydraulic gradient needed for hydraulic pingo formation.

Based on this study it is concluded that permafrost occurred throughout the northern, central and southern Netherlands during the Late Pleniglacial. Minimum depth of this permafrost varied between 5m and 16 meters in the northern and middle Netherlands while permafrost depth was shallower in the southern part of the Netherlands with a minimum of 2m to 5 meters. Based on the presumable hydraulic origin of the pingos throughout the Netherlands, the permafrost is, furthermore, concluded to be discontinuous during pingo formation. Decay of permafrost in the Netherlands is concluded to occur simultaneously throughout the Netherlands due to climatic warming at the onset of GI-1e (correlating to Bølling). Local to discontinuous permafrost prevailed during the GS-1 (correlating to Younger Dryas) which is not based on pingo occurrence but other periglacial features. However palynological data from studied pingo remnant infills also indicate evidence of this cold Younger Dryas period.

References

Alterra Wageningen (2008). *Geomorfologische kaart van Nederland schaal 1:50.000,* ALTERRA-research Institue for the Green World – centrum Landschap.

Ballantyne, C. & C. Harris (1994), *The Periglaciation of Great Britain*. Cambridge University Press.

Behre, 1966 K.E. (1966), *Untersuchungen zur spätglazialen und frühpostglazialen Vegetationsgeschichte Ostfrieslands*. Eiszeitalter Gegenwart, 17, pp. 69–84

Bengtsson, L. & M. Enell. (1986), *Chemical analysis*. Handbook of Holocene palaeoecology and palaeohydrology, pp.423-451.

Berendsen. H.J.A. (2008). *Landschappelijk Nederland: de fysisch-geografische regio's*. Uitgeverij Van Gorcum.

Berendsen. H.J.A. (2008). *Landschap in delen: overzicht van de geofactoren*. Uitgeverij Van Gorcum.

Berendsen. H.J.A. (2008). *De vorming van het land: Inleiding in de geologie en de geomorfologie*. Uitgeverij Van Gorcum.

Bijlsma, S. & G. Delange. (1983), *Geology, palynology and age of a pingo remnant near Daarle, province of Overijssel, The Netherlands*. Geologie en Mijnbouw 62(4), pp.563-568.

Bisschops, J. & Dienst, R. G. (1973), *Toelichtingen bij de Geologische kaart van Nederland 1: 50.000,*.blad Eindhoven Oost (51 O).

Bohncke, S. & L. Wijmstra. (1988), *Reconstruction of Late-Glacial lake-level fluctuations in The Netherlands based on palaeobotanical analyses, geochemical results and pollen-density data*. Boreas 17(3), pp.403-425.

Bohncke, S., L. Wijmstra., J. van der Woude., H. Sohl (1988), *The Late-Glacial infill of three lake succesions in the Netherlands: Regional vegetational history in relation to NW European vegetational developments.* Boreas 17, pp. 385-402.

Bohncke, S. (1993), *Late-glacial environmental changes in the Netherlands: Spatial and temporal patterns: A contribution to the 'North Atlantic Seaboard Srogramme'of IGCP-253,'Termination of the Pleistocene'*. Quaternary Science Reviews 12(8), pp.707-717.

Brown, R. J. E. & Kupsch, W. O. (1974), *Permafrost terminology*. National Research Council of Canada Associate Committee on Geotechnical Research. Ottawa.

Bruijn, R. de. (2012), *Pingo remnants in the northern Netherlands and north-western Germany*. MSc thesis in Igitur Archive, Utrecht.

Cleveringa, P., W. de Gans, E. Kolstrup et al. (1977), *Vegetational and climatic developments during the Late-glacial and the early Holocene and aeolian sedimentation as recorded in the Uteringsveen (Drente, the Netherlands).* Geologie en Mijnbouw 56(3), pp.234-242.

Dean, W.E., Jr . (1974), *Determination of carbonate and organic-matter in calcareous sediments and sedimentary-rocks by Loss On Ignition- comparison with other methods.* Journal of Sedimentary Petrology 44(1), pp.242-248.

Degroot, T., P. Cleveringa & B. Klijnstra. (1987), *Frost-mound scars and the evolution of a Late Dryas environment (northern Netherlands).* Geologie en Mijnbouw 66(3), pp.239-250.

Delcourt, H. R. & Delcourt, P. (1991), Quaternary ecology: a paleoecological perspective. Springer.

Erdtman, G. (1969), *Handbook of palynology: morphology, taxonomy, ecology. An Introduction to the Study of Pollen Grains and Spores.* Munksgaard, Copenhagen

Faculty of Geosciences Utrecht University. Geological map of the Netherlands. Available at: http://www.geo.uu.nl/fg/palaeogeography/rhine-meuse-delta. Accessed March 17, 2014.

Faegri, K. (1975), & J. Iversen (1975), *Textbook of pollen analysis*. Munksgaard, Copenhagen.

Flemal, R.C. (1976), *Pingos and pingo scars: Their characteristics, distribution, and utility in reconstructing former permafrost environments.* Quaternary Research 6(1), pp.37-53.

de Gans, W. (1982), *Location, age and origin of pingo remnants in the Drentsche Aa valley area (The Netherlands).* Geologie en Mijnbouw 61(2), pp.147-158.

de Gans, W. (1988), *Pingo scars and their identification.* Advances in periglacial geomorphology, pp.299-322.

Gurney, S. (1998), *Aspects of the genesis and geomorphology of pingos: perennial permafrost mounds.* Progress in Physical Geography 22(3), pp.307-324.

*Hammen, T.*van der. (1951), *Late-glacial flora and periglacial phenomena in the Netherlands. Leidse Geol. Meded., XVII (1951), pp. 71–183*

Harry, D. & H. French. (1983), *The orientation and evolution of thaw lakes, southwest banks island, canadian arctic.* Paper presented at the Fourth International Conference on Permafrost, pp.456-441.

Heiri, O., A.F. Lotter & G. Lemcke. (2001), *Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results.* Journal of Paleolimnology 25(1), pp.101-110.

Hoek, W.Z., N. van Asch & S. Bohncke. (2012), *Pingo remnants as recorders of Late Weichselian climate and environmental change.* Quaternary International-Journal of the InternUnion for Quaternary Research 279, pp.203.

Hoek, W. Z., Bohncke, S. J., Ganssen, G. M., & Meijer, T. (1999), *Late-glacial environmental changes recorded in calcareous gyttja deposits at Gulickshof, southern Netherlands.* Boreas, 28(3), 416-432.

Hoek, W.Z. & S. Bohncke. (2002), *Climatic and environmental events over the Last Termination, as recorded in The Netherlands.* Netherlands Journal of Geosciences 81(1), pp.123-138.

Hoek, W.Z. & J. Joosten. (1995), *Pingo-ruïnes en kalkgyttja in het Weerterbos.* Natuur Historisch Maandblad 84, pp.234-241.

Hoek, W.Z. (1997), *Atlas to palaeogeography of Late-glacial vegetations. Maps of Late-glacial and early Holocene landscape and vegetation in the Netherlands, with an extensive review of available palynological data.* Nederlandse Geografische Studies 231

Hoek, W.Z. (1997), *Late-glacial and early Holocene climatic events and chronology of vegetation development in the Netherlands.* Vegetation History and Archaeobotany 6(4), pp.197-213.

Hoek, W.Z. (1997), *Palaeogeography of Late-glacial vegetation: aspects of Late-glacial and early Holocene vegetation, abiotic landscape, and climate in The Netherlands.* Nederlandse Geografische Studies 230

Hoek, W.Z. (2000), *Abiotic landscape and vegetation patterns in the Netherlands during the Weichselian Late-glacial.* Geologie en Mijnbouw/Netherlands Journal of Geosciences 79(4), pp.497-509.

Huntley, B. & H.J.B. Birks. (1983), *atlas of past and present pollen maps for Europe, 0-13,000 years ago.* Cambridge University Press.

de Jong, J. (1959), *Palynologisch onderzoek van een opvulling van een zogenaamde pingo te Oostvierdeparten onder Vledder.* Rapport 204, Palaeobotanisch Laboratorium, Geologische Stichting, Haarlem.

de Jong, J. (1959), *Palynologisch onderzoek van een pingo-opvulling in de omgeving van het buurtschap Wateren.* Rapport 223, Palaeobotanisch Laboratorium, Geologische Stichting, Haarlem.

Kaiser, K. (1960), *Klimazeugen des periglazialen Dauerfrostbodens in Mittel-und Westeuropa: Ein Beitrag zur Rekonstruktion des Klimas der Glaziale des quartären Eiszeitalters.* Quaternary Science Journal Vol. 11 No 1, -

Karte, J. (1988), *Das Pleistozane Periglaziar im nordostlichen Rheinischen Schiefergebirge.* Berichte zur Deutschen Landeskunde 62(2), pp.371-384.

Kasse, K. & S. Bohncke. (1992), *Weichselian upper pleniglacial aeolian and ice-cored morphology in the southern Netherlands (Noord-Brabant, Groote Peel).* Permafrost and Periglacial Processes 3(4), pp.327-342.

Kasse, C. (1999). *Late Pleniglacial and Late-glacial aeolian phases in the Netherlands.* GeoArchaeoRhein, 3, 61-82.

Kluiving, S., A. Verbers & W. Thijs. (2010), *Lithological analysis of 45 presumed pingo remnants in the northern Netherlands (Friesland): substrate control and fill sequences.* Netherlands Journal of Geosciences-Geologie en Mijnbouw 89(1), pp.61-75.

Lowe, J. J. & Walker, M. J. (1997), *Reconstructing quaternary environments*. Longman Londen.

Maarleveld, G. (1976), *Periglacial phenomena and the mean annual temperature during the last glacial time in the Netherlands.* Biuletyn Peryglacjalny 26, pp.57-78.

Mackay, J.R. (1972), *The world of underground ice*. Annals of the Association of American Geographers 62(1), pp.1-22.

Mackay, J.R. (1979), *Pingos of the Tuktoyaktuk Peninsula area, Northwest Territories*. Géographie physique et Quaternaire 33(1), pp.3-61.

Mackay, J.R. (1998), *Pingo growth and collapse, Tuktoyaktuk Peninsula area, western arctic coast, Canada: A long-term field study*. Géographie physique et Quaternaire 52(3), pp.271-323.

Moore, P. D. & Bellamy, D. J. (1974). *Peatlands.* Elek Science London.

Moore, P. D., Webb, J. A. & Collison, M. E. (1991), *Pollen analysis*. Blackwell scientific publications.

Müller, F. B. (1959), *Beobachtungen über Pingos: Detailuntersuchungen in Ostgrönland und in der kanadischen Arktis*. CA Reitzel.

Paris, F., P. Cleveringa & W. de Gans. (1979), *The Stokersdobbe: geology and palynology of a deep pingo remnant in Friesland (The Netherlands).* Geologie en Mijnbouw 58(1), pp.33-38.

Pissart, A. (1988), *Pingos: an overview of the present state of knowledge*. Advances in periglacial geomorphology, pp.279-297.

Pissart, A. (2003), *The remnants of Younger Dryas lithalsas on the Hautes Fagnes Plateau in Belgium and elsewhere in the world*. Geomorphology 52(1), pp.5-38.

Pissart, A. & P. Gangloff. (1984), *Les palses minérales et organiques de la vallée de l'Aveneau, près de Kuujjuaq, Québec subarctique*. Géographie physique et Quaternaire 38(3), pp.217-228.

Pissart, A. & Goossens, R. (1956), *L'origine périglaciaire des viviers des Hautes Fagnes: Les niveaux d'aplanissement du Bassin de la Haute Amblève*. Wyckmans.

Porsild, A.E. (1938), *Earth mounds in unglaciated arctic northwestern America*. Geographical Review, pp.46-58.

Poser, H. (1948), *Äolische Ablagerungen und Klima des Spätglazials in Mittel-und Westeuropa.* Naturwissenschaften 35(9), pp.269-276.

Rasmussen, S.O., K.K. Andersen, A. Svensson et al. (2006), *A new Greenland ice core chronology for the last glacial termination.* Journal of Geophysical Research: Atmospheres (1984–2012) 111(D6)

Ruiter, A., W. Hoek & K. Cohen. (2012), *Relict pingos and permafrost A comparison between active landforms in the Canadian Arctic and relict permafrost features in the Netherlands and adjacent Germany.* MSc thesis in Igitur Archive, Utrecht.

Santisteban, J.I., R. Mediavilla, E. Lopez-Pamo et al. (2004), *Loss on ignition: a qualitative or quantitative method for organic matter and carbonate mineral content in sediments?* Journal of Paleolimnology 32(3), pp.287-299.

Schokker, J., H. Weerts, W. Westerhoff et al. (2007), *Introduction of the Boxtel Formation and implications for the Quaternary lithostratigraphy of the Netherlands*. Netherlands Journal of Geosciences 86(3), pp.197.

Schokker, J. (2003), *Patterns and processes in a Pleistocene fluvio-aeolian environment*. Nederlandse Geografische Studies.

S.A. Harris, H.M. French, J.A. Heginbottom, G.H. Johnston, B.Ladanyi, D.C. Sego, R.O. van Everdingen (1988), *Glossary of permafrost and related ground-ice terms. Associate Committee on Geotechnical Research,* National Research Council of Canada, Ottawa

Tauber, H. (1965), *Differential pollen dispersion and the interpretation of pollen diagrams, with a contribution to the interpretation of the elm fall.* C. A. Reitzel i komm, 69 p.

TNO. *Lithostratigrafische nomenclator van de ondiepe ondergrond*. Available at: http://www.dinoloket.nl/overzichtstabel. Accessed at March 15, 2014

Van Asch, N., O. Heiri, S.J. Bohncke et al. (2013), *Climatic and environmental changes during the Weichselian Late-glacial Interstadial in the Weerterbos region, the Netherlands.* Boreas 42(1), pp.123-139.

van der Hammen, T. (1957), *A new interpretation of the pleniglacial stratigraphical sequence in Middle and Western Europe.* Geologie Mijnbouw 19, pp.493-498.

van Geel, B., S. Bohncke & H. Dee. (1980), *A palaeoecological study of an upper Late-glacial and Holocene sequence from "De Borchert", The Netherlands.* Review of palaeobotany and palynology 31, pp.367-448.

van Geel, B. & E. Kolstrup. (1978), *Tentative Explanation of Late-glacial and Early Holocene Climatic Changes in North-western Europe.* Geol. Mijnb., 57 (1) (1978), pp. 87–89.

van Geel, B., G.R. Coope & T. Van Der Hammen. (1989), *Palaeoecology and stratigraphy of the Late-glacial type section at Usselo (the Netherlands).* Review of palaeobotany and palynology 60(1-2), pp.25-38.

van Huissteden, J.K., P.L. Gibbard & R. Briant. (2001), *Periglacial fluvial systems in northwest Europe during marine isotope stages 4 and 3.* Quaternary International 79(1), pp.75-88.

van Leeuwaarden, W. & C.R. Janssen. (1987), *Differences between valley and upland vegetation development in eastern Noord-Brabant, The Netherlands, during the Late-glacial and Early Holocene.* Review of Palaeobotany and Palynology 52(2), pp.179-204.

Vandenberghe, J., S. Bohncke & M. Verbruggen. (1991), I*nteractions between the Late-glacial fluvial and aeolian processes and environments in Dutch lowland basins.* Aardkundige Mededelingen 6, pp.195-201.

Vandenberghe, J. & A. Pissart. (1993), *Permafrost changes in Europe during the Last Glacial.* Permafrost and Periglacial Processes 4(2), pp.121-135.

Vandenberghe, J., S. Bohncke, W. Lammers et al. (1987), *Geomorphology and palaeoecology of the Mark valley (southern Netherlands): geomorphological valley development during the Weichselian and Holocene.* Boreas 16(1), pp.55-67.

Velichko, 1982 A.A. *Osnovnye osobennosti poslednego klimaticheskogo makrocikla i sovremennie sostoyanie prirodnoi sredy I.P. Gerasimov,* Paleogeografiya Eveopy za Poslednie 100 Tysyach Let, Nauka, Moscow (1982), pp. 131–143

Vliet-Lanoë, B.V. (1989), Dynamics and extent of the Weichselian permafrost in western Europe (substage 5e to stage 1). Quaternary International 3, pp.109-113.

Walker, M. (1995), *Climatic changes in Europe during the last glacial/interglacial transition.* Quaternary International 28, pp.63-76.

Washburn, A.L. (1980), *Geocryology: a survey of periglacial processes and environments*. Edward Arnold, London

Wee, M. ter. (1966), *Toelichtingen bij de geologische kaart van Nederland 1: 50.000*. Blad Steenwijk Oost (160)

Weeda, E., R. Westra, C. Westra et al. (1987), *Nederlandse Oecologische Flora*. Wilde planten en hun relaties 2, Haarlem

Zagwijn, W.H. (1971), *Pollenanalytisch onderzoek van drie laatglaciale secties uit het gebied Den Bosch-Helmond.* Rapport 607, Afdeling Palaeobotanie, Rijks Geologische Dienst, Haarlem.

Appendix A

Lithological core descriptions

core	1B1	**datum**		
x	**y**	**Z (m)**	**diepte**	
164152	371176			

Details	in low part after "rampart"
	gb =coarse fraction included
	ms = moderately sorted
	* = well sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	FZ			zwbr		150-210		1					roots
20	FZ			zwbr		150-210		1					roots
30	FZ			robr		150-210		1					gb
40	FZ			robr		150-210		1					ms
50	FZ			robr		150-210		1					ms
60	FZ			glgr		150-210		1					*
70	FZ			glgr		150-210		1					*
80	FZ			gr		150-210		1					loamy
90	FZ			gr		150-210		1					*
100	FZ			gr		150-210		1					*
110	FZ			orgl		150-210		1					*
120	FZ			orgl		150-210		1					*
130	FZ			orgl		150-210		1					*
140	FZ			gl		150-210		1					*
150	FZ			gl		150-210		1					*
160	FZ			gl		150-210		0					*
170	FZ			gl		150-210		0					*
180	FZ			gr		150-210		0					ms gb
190	FZ			gr		150-210		0					ms gb
200	FZ			gr		150-210		0					ms gb
210	FZ			gr		150-210		0					ms gb
220	FZ			gr		150-210		0					ms gb
230	FZ			gr		150-210		0					ms gb
240	FZ-MZ			brgr		150-300		0					ms/ pebbels
250	FZ-MZ			brgr		150-300		0	GW				ms/pebbels
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

Boorpunt nr	core	datum		23-9-2012
x	y	Z (m)	diepte	
164124	371117			

details	more sand from 360 upward
wood peaces	
! Transition at 310	
& coarse grained sand and meniantis	

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	floating fen												
20	floating fen												
30	floating fen												
40	floating fen												
50	floating fen												
60	floating fen												
70	floating fen												
80	floating fen												
90	floating fen												
100	peat	V3	Z	br									
110	peat	V3	Z	br									
120	peat	V3	Z	br									
130	peat	V3	Z	br									
140	peat	V3	Z	br									
150	peat	V3	Z	br									
160	peat	V3	Z	br									red wood part
170	peat	V3	Z	br									
180	peat	V3	Z	br									
190	peat	V3	Z	br									
200	peat	V3	Z	br									sandy
210	peat	V3	Z	dbr									sandy
220	peat	V3	Z	bdr									sand from 220
230	gyttja	V3	Z	bdr									sandt gyttja
240	gyttja	V3	Z	bdr									sandt gyttja
250	gyttja	V3	Z	bdr									sandt gyttja
260	gyttja	V3	z+m	bdr									sandt gyttja
270	gyttja	V3	z+m	bdr									sandt gyttja
280	gyttja	V3	z+m	bdr									sandt gyttja
290	gyttja	V3	z+m	bdr									sandt gyttja
300	gyttja	V3	z+m	bdr									sandt gyttja
310	gyttja	V3	z+m	bdr									sandt gyttja!
320	gyttja/peat	V2		br									somewhat sandy
330	gyttja/peat	V2		br									somewhat sandy
340	gyttja/peat	V2		br									somewhat sandy
350	gyttja/peat	V2		br									somewhat sandy
360	gyttja/peat	V2		br									somewhat sandy
370	gyttja/peat	V2		br									somewhat sandy
380	gyttja/peat	V2		br									somwhat sandy&
390	gyttja/peat	V2		br									somewhat sandy

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
400	gyttja/pe	V2		br									somewhat sandy
410	gyttja/pe	V2		br									somewhat sandy
420	FZ	plr		gngr		150-210							transition at 410
430	FZ	plr		gr		150-210							
440													
450													
460													
470													
480													
490													
500													
510													
520													
530													
540													
550													
560													
570													
580													
590													
600													
610													
620													
630													
640													
650													
660													
670													
680													
690													
700													
710													
720													
730													
740													
750													
760													
770													
780													
790													
800													
810													
820													
830													
840													
850													
860													
870													
880													

core	1B3	datum	23-9-2012
x	y	Z (m)	diepte
164131	371120		

details
! = 365 transition from sandy peat to organic part (less sandy down)
sand from ~395 cm
*potamogeton at 340cm

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	floating fen												
20	floating fen												
30	floating fen												
40	floating fen												
50	floating fen												
60	floating fen												
70	floating fen												
80	floating fen												
90	floating fen												
100	floating fen												
110	floating fen												
120	floating fen												
130	floating fen												
140	peat	V3		zw									
150	peat	V3		zw									
160	peat	V3		zw									
170	peat	V3		zw									
180	peat	V3		zw									
190	peat	V3		zw									
200	peat	V3		zw									
210	gyttja	V2		dbr									
220	gyttja	V2		dbr									
230	gyttja	V2		dbr									
240	gyttja	V2		dbr									
250	gyttja	V2		dbr									
260	gyttja	V2		dbr									
270	gyttja	V2		dbr									
280	gyttja	V2		dbr									
290	gyttja	V2		dbr									
300	gyttja	V2		dbr									
310	gyttja/peat	V2		br									transition at 305 sandy
320	gyttja/peat	V2		br									sandy
330	gyttja/peat	V2		br									zandig
340	gyttja/peat	V2	*	br									sandy sample nutt+pel
350	gyttja/peat	V2		br									sandy
360	gyttja/peat	V2		br									sandy
370	gyttja/peat	V2		br									sandy
380	gyttja/peat	V2		br									sandy
390	gyttja/peat	V2		br									sandy

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
400	gyttja/peat	V2		br									sandy
410	FZ			gr									
420	FZ			gr									
430													
440													
450													
460													
470													
480													
490													
500													
510													
520													
530													
540													
550													
560													
570													
580													
590													
600													
610													
620													
630													
640													
650													
660													
670													
680													
690													
700													
710													
720													
730													
740													
750													
760													
770													
780													
790													
800													
810													
820													
830													
840													
850													
860													
870													
880													

core	1B4	datum	23-9-2012
x	y	Z (m)	diepte
164139	371120		

details
east of 1B3

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	floating fen												
20	floating fen												
30	floating fen												
40	floating fen												
50	floating fen												
60	peaty	v3											
70	peaty	v3											
80	peaty	v3											
90	peaty	v3											
100	peaty	v3											
110	peaty	v3											
120	peaty	v3											
130	peaty	v3											
140	peaty	v3											
150	gyttja (l)	v3		dbr-zw									
160	gyttja (l)	v3		dbr-zw									
170	gyttja (l)	v3		dbr-zw									
180	gyttja (l)	v3		dbr-zw									
190	gyttja (l)	v3		dbr-zw									
200	gyttja (l)	v3		dbr-zw									
210	gyttja (l)	v3		dbr-zw									
220	gyttja	v2		dbr									sandy
230	gyttja	v2		dbr									sandy
240	gyttja	v2		dbr									sandy
250	gyttja	v2		dbr									sandy
260	gyttja	v2		dbr									sandy
270	gyttja	v2		dbr									sandy
280	gyttja	v2		dbr									sandy
290	gyttja	v2		dbr									sandy
300	gyttja	v2		dbr									sandy
310	peat	v2		br									sandy
320	peat	v2		br									sandy
330	peat	v2		br									sandy
340	FZ			gr									with organic layer
350													
360													
370													
380													
390													

core	1B5	datum		23-9-2012
x	y	Z (m)	diepte	
164116	371123	epe 3.7		

details % = messy layer to top of sandy gyttja
340 = transition to sandy gyttja light brown
410 transition to sand with organic layer
425 sharp transition to sand

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	drijftil												
20	drijftil												
30	drijftil												
40	drijftil												
50	drijftil												
60	drijftil												
70	drijftil												
80	drijftil												
90	drijftil												
100	drijftil												
110	gyttja	v3		zw									
120	gyttja	v3		zw									
130	gyttja	v3		zw									
140	gyttja	v3		zw									
150	gyttja	v3		zw									
160	gyttja	v3		zw									
170	gyttja	v3		zw									
180	gyttja	v3		zw									
190	gyttja	v3		zw									
200	gyttja	v3		zw									
210	gyttja	v2		dbr									somewhat sandy
220	gyttja	v2		dbr									somewhat sandy
230	gyttja	v2		dbr									somewhat sandy
240	gyttja	v2		dbr									somewhat sandy
250	gyttja	v2		dbr									somewhat sandy
260	gyttja	v2		dbr									somewhat sandy
270	gyttja	v2		dbr									somewhat sandy
280	gyttja	v2		dbr									somewhat sandy
290	gyttja	v2		dbr									somewhat sandy
300	gyttja	v2		dbr									somewhat sandy
310	gyttja/peat	V2		br									%
320	gyttja/peat	V2		br									
330	gyttja/peat	V2		br									
340	gyttja/peat	v2		br									sandy
350	gyttja/peat	v3		br									sandy
360	gyttja/peat	v4		br									sandy
370	gyttja/peat	v5		br									sandy
380	gyttja/peat	v6		br									sandy
390	gyttja/peat	v7		br									sandy

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
400	gyttja/peat			br									sandy
410	FZ			br		150-210							
420	FZ			br		150-210							
430	FZ			gr		150-210							
440	FZ			gr		150-210							
450													
460													
470													
480													
490													
500													
510													
520													
530													
540													
550													
560													
570													
580													
590													
600													
610													
620													
630													
640													
650													
660													
670													
680													
690													
700													
710													
720													
730													
740													
750													
760													
770													
780													
790													
800													
810													
820													
830													
840													
850													
860													
870													
880													

core	1B6	datum	23-9-2012
x	y	Z (m)	diepte
164131	371134		

details	
	395 transition from sandy peat layer to sand with organic layer (~20cm)
	402 = transition to sand
	365-370 = dark brown layer ^^

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	floating fen												
20	floating fen												
30	floating fen												
40	floating fen												
50	floating fen												
60	floating fen												
70	floating fen												
80	floating fen												
90	floating fen												
100	floating fen												
110	floating fen												
120	floating fen												
130	floating fen												
140	floating fen												
150	floating fen												
160	floating fen												
170	floating fen												
180	floating fen												
190	floating fen												
200	floating fen												
210	peat	v3		zw									
220	peat	v3		zw									
230	peat	v3		zw									
240	peat	v3		zw									
250	peat	v3		zw									
260	peat	v3		zw									
270	peat	v3		zw									
280	peat	v3		zw									
290	peat	v3		zw									
300	peat	v3		zw									
310	gyttja	v3		dbr									sandy
320	gyttja	v3		dbr									sandy
330	gyttja	v3		dbr									sandy
340	gyttja	v3		dbr									sandy
350	gyttja	v3		dbr									sandy
360	peat	v2		br									sandy ^^
370	peat	v2		br									sandy
380	peat	v2		br									sandy
390	peat	v2		br									sandy

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
400	FZ	h1		brgr									
410	FZ	h1		brgr									
420	FZ	h1		brgr									
430	FZ			gr									
440													
450													
460													
470													
480													
490													
500													
510													
520													
530													
540													
550													
560													
570													
580													
590													
600													
610													
620													
630													
640													
650													
660													
670													
680													
690													
700													
710													
720													
730													
740													
750													
760													
770													
780													
790													
800													
810													
820													
830													
840													
850													
860													
870													
880													

core	1B7	**datum**	23-9-2012
x	**y**	**Z (m)**	**diepte**
164130	371140	epe 4.8	

details

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	floating fen												
20	floating fen												
30	floating fen												
40	floating fen												
50	floating fen												
60	floating fen												
70	floating fen												
80	floating fen												
90	floating fen												
100	floating fen												
110	floating fen												
120	floating fen												
130	floating fen												
140	floating fen												
150	floating fen												
160	floating fen												
170	floating fen												
180	floating fen												
190	floating fen												
200	floating fen												
210		V3											
220		V3											
230		V3											
240		V3											
250	gyttja	v2		dbr									sandy
260	gyttja	v2		dbr									sandy
270	gyttja	v2		dbr									sandy
280	gyttja	v2		dbr									sandy
290	gyttja	v2		dbr									sandy
300	hs/peat	h2		br		150-210							
310	hs/peat	h2		br		150-210							
320	hs/peat	h2		br		150-210							
330	hs/peat	h2		br		150-210							
340	peat			br		150-210							sandy
350	FZ	h2		br		150-210							
360													
370													
380													
390													

core	1B8	**datum**		23-9-2012
x	**y**	**Z (m)**	**diepte**	
164134	371149			

details

Depth	**Texture**	**org**	**plr**	**color**	**or**	**M50**	**Ca**	**Fe**	**GW**	**M**	**lkl**	**Strat**	**details**
10	floating fen												
20	floating fen												
30	floating fen												
40	floating fen												
50	floating fen												
60	floating fen												
70	floating fen												
80	floating fen												
90	floating fen												
100	FZ	h1											
110	FZ	h1		br/zw									sandy
120	FZ	h1		br/zw									sandy
130	FZ	h1		br/zw									sandy
140	FZ	h1		br/zw									sandy
150	FZ	h1		br/zw									sandy
160	FZ	h1		br/zw									sandy
170	FZ	h1		br/zw									sandy
180	gyttja	V2		br									sandy
190	gyttja	V2		br									sandy
200	FZ	h2		br									
210	FZ	h2		br									
220	FZ	2h		brgr									
230	FZ			gr									transition 235
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	1B9	**datum**			23-9-2012
x	**y**	**Z (m)**	**diepte**		
164129	371099	epe 5.7			

details 375-385 sand with organic layers
385-400 grey sand

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	floating fen												
20	floating fen												
30	floating fen												
40	floating fen												
50	floating fen												
60	floating fen												
70	floating fen												
80	floating fen												
90	floating fen												
100	floating fen												
110		v3		zwbr									
120		v3		zwbr									
130		v3		zwbr									
140		v3		zwbr									
150		v3		zwbr									
160		v3		zwbr									
170		v3		zwbr									
180		v3		zwbr									
190		v3		zwbr									
200		v3		zwbr									
210		v3		zwbr									
220		v3		zwbr									
230		v3		zwbr									
240	peat	v2		zwbr									
250	peat	v2		zwbr									
260	peat	v2		zwbr									
270	peat	v2		zwbr									
280	peat	v2		zwbr									
290	peat	v2		zwbr									
300	gyttja	v2		br									
310	gyttja	v2		br									
320	gyttja	v2		br									
330	gyttja	v2		br									
340	gyttja	v2		br									
350	peat	v2		br									
360	peat	v2		br									
370	peat	v2		br									
380	FZ	H2		brgr		150-210							
390	FZ			gr		150-210							

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
400	FZ			gr		150-210							
410													
420													
430													
440													
450													
460													
470													
480													
490													
500													
510													
520													
530													
540													
550													
560													
570													
580													
590													
600													
610													
620													
630													
640													
650													
660													
670													
680													
690													
700													
710													
720													
730													
740													
750													
760													
770													
780													
790													
800													
810													
820													
830													
840													
850													
860													
870													
880													

core	1B10	datum	23-9-2012
x	y	Z (m)	diepte
164135	371088	epe 8.6	

details

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	floating fen												
20	floating fen												
30	floating fen												
40	floating fen												
50	floating fen												
60	floating fen												
70	floating fen												
80	floating fen												
90	floating fen												
100	floating fen												
110	floating fen												
120	floating fen												
130	floating fen												
140	floating fen												
150	floating fen												
160		v3		zw									
170		v3		zw									
180		v3		zw									
190		v3		zw									
200		v3		zw									
210	peat	v2		br									sandy
220	peat	v2		br									sandy
230	FZ	H2		gr		150-210							
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	1B11	datum	26-9-2013
x	y	Z (m)	diepte
164129	371065		

details	edge water/land

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	vegetation			br			0	0					
20	vegetation			br			0	0					
30	vegetation			br			0	0					
40	vegetation			br			0	0					
50	vegetation			br			0	0					
60	FZ			dbr		150-210	0	0					
70													
80													
90													
100													
110													
120													
130													
140													
150													
160													
170													
180													
190													
200													
210													
220													
230													
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	1B12	datum		26-9-2013
x	y	Z (m)	diepte	
164132	371055			

details	edge depression
	ms= moderately sorted
	gb=coarse fraction

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	Fz			zw		150-210	0	1					wrtls
20	Fz			zw		150-210	0	1					wrtls
30	Fz			br		150-210	0	1					ms
40	Fz			br		150-210	0	1					ms
50	Fz			brgr		150-210	0	0					ms
60	Fz			robr		150-210	0	1					ms
70	Fz			robr		150-210	0	1					ms + gb
80	Fz			robr		150-210	0	1					ms + gb
90	Fz			robr		150-210	0	1					ms + gb
100	Fz			robr		150-210	0	1					ms + gb
110	Fz			robr		150-210	0	1					ms + gb
120	Fz			robr		150-210	0	1					ms + gb
130	Fz			robr		150-210	0	1					ms + gb
140	Fz			robr		150-210	0	1					ms + gb
150	Fz			robr		150-210	0	1					ms + gb
160	Fz			robr		150-210	0	1					ms + gb
170	Fz			robr		150-210	0	1					ms + gb
180	Fz			robr		150-210	0	1					ms + gb
190	Fz			robr		150-210	0	1					ms + gb
200	Fz			robr		150-210	0	1					ms + gb
210													
220													
230													
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	1B13	datum	26-9-2013
x	y	Z (m)	diepte
164149	371165		

details	edge water-vegetati e

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	vegetation			br			0	0					
20	vegetation			br			0	0					
30	vegetation			br			0	0					
40	vegetation			br			0	0					
50	vegetation			br			0	0					
60	FZ			zwbr		150-210	0	0					ms
70													
80													
90													
100													
110													
120													
130													
140													
150													
160													
170													
180													
190													
200													
210													
220													
230													
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	3A1	datum		
x	y	Z (m)	diepte	
164601	377609	17.5	-7	EPE

details

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	VZ			br	O	150-210	0	1					roots
20	VZ			br	O	150-210	0	1					roots
30	FZ	H1	plr	glbr		150-210	0	1					
40	FZ	H1		glbr		105-150	0	1					
50	FZ			brgl		150-210	0	1					
60	FZ			brgl		150-210	0	1					less brown down
70	FZ			brgl		150-210	0	1					
80	FZ			brgl		150-210	0	1					from
90	FZ			brgl		150-210	0	1					
100	FZ			brgl		150-210	0	1					70 t0 120 cm
110	FZ			brgl		150-210	0	1					
120	FZ			brgl		150-210	0	1					
130	FZ			gl		150-210	0	0					
140	FZ			gl		150-210	0	0					
150	FZ			gr		150-210	0	0					
160	FZ			gr		150-210	0	0					
170	FZ			gr		150-210	0	0					
180	(L) LZ	H1		dgr		150-210	0	0	GW				top humic
190	(L) LZ	H1		dgr		150-210	0	0					
200	(L) LZ	H1		dgr		150-210	0	0					
210	FZ			gr		150-210	0	0					coarse sand fractio
220	FZ			gr		150-210	0	0					
230	FZ			gr		150-210	0	0					
240	FZ			gr		150-210	0	0					
250	FZ			gr		150-210	0	0					
260	FZ			gr		150-210	0	0					
270	FZ			gr		150-210	0	0					
280	FZ			gr		150-210	0	0					
290	FZ			gr		150-210	0	0					
300	FZ			gr		150-210	0	0					
310	FZ			brgr		150-210	0	0					
320	FZ			brgr		150-210	0	0					
330													
340													
350													
360													
370													
380													
390													

core	3A2		datum		
x	y		Z (m)	diepte	
164633	377622	EPE (9.2)	19		

details start of the depression

! = organic at 192 (inval of insitu?)laomy down to 197cm

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	VZ			zwbr	O		0	1					
20	VZ			br	O		0	1					
30	FZ	h1		br	O	150-210	0	1					*
40	FZ			glbr	O	150-210	0	1					*
50	FZ			brgl	O	150-210	0	1					*
60	FZ			brgl	O	150-210	0	1					brownish *
70	FZ			brgl	O	150-210	0	1					brownish *
80	FZ			brgl	O	150-210	0	1					brownish *
90	FZ			brgl	O	150-210	0	1					brownish *
100	FZ			gl	O	150-210	0	1					*
110	FZ			gl	OR	150-210	0	1					*
120	FZ			gl	OR	150-210	0	1					*
130	FZ			brgl	OR	150-210	0	1					*
140	FZ			brgl	OR	150-210	0	1					*
150	FZ			brgl	OR	150-210	0	1					*
160	FZ			brgl	OR	150-210	0	1					*
170	FZ			glgr	OR	150-210	0	0					*
180	FZ			glgr	OR	150-210	0	0					*
190	FZ			glgr	OR	150-210	0	0					*
200	FZ	H1		gr	R	150-210	0	0					! Sample *
210	FZ-MZ	H1		gr	R	150-300	0	0					sample; ms
220	MZ			gr	R	210-300	0	0					ms
230	MZ			gr	R	210-300	0	0					ms
240	MZ			gr	R	210-300	0	0					ms
250	MZ			gr	R	210-300	0	0					ms
260	FZ			gr	R	150-210	0	0					*
270	FZ			gr	R	150-210	0	0					*
280	FZ			gr	R	150-210	0	0					*
290	FZ	H1		brgr	R	150-210	0	0					sample (291) organic
300	FZ			brgr	R	150-210	0	0					*
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	3A3		datum	##	
x	y		Z (m)	diepte	
164621	377614	EPE 6.2			

Details Near gully

Organic band at 218cm small organic band at 216 cm

* = well sorted

ms = medorately sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	FZ	H2	wr	dbr	O	150-210	0	0					wrtls
20	FZ	H2	wr	rogl	O	150-210	0	0					wrtls
30	FZ	H1	wr	rogl	O	150-210	0	1					wrtls
40	FZ	H1	wr	rogl	O	150-210	0	1					wrtls
50	FZ			rogl	O	150-210	0	1					*
60	FZ			brgl	O	150-210	0	1					*
70	FZ			brgl	O	150-210	0	1					*
80	FZ			brgl	O	150-210	0	1					*
90	FZ			brgl	O	150-210	0	1					pebbels
100	FZ			gl	O	150-210	0	1					*
110	FZ			gl	O	150-210	0	1					*
120	FZ			gl	O	150-210	0	1					*
130	FZ			gl	OR	150-210	0	0					*
140	FZ			gl	OR	150-210	0	0					*
150	FZ			glgr	OR	150-210	0	0					*
160	FZ			glgr	OR	150-210	0	0					*
170	FZ-MZ			gr	R	150-300	0	0					ms
180	FZ-MZ			gr	R	150-300	0	0					ms
190	FZ-MZ			gr	R	150-300	0	0	GW				ms
200	MZ			gr	R	210-300	0	0					ms
210	FZ	H1		gr	R	150-210	0	0					! Samples
220	(L)LZ			dgr	R	150-210	0	0					ms
230	FZ-MZ			gr	R	150-300	0	0					ms
240	FZ-MZ			gr	R	150-300	0	0					ms
250	FZ-MZ			gr	R	150-300	0	0					ms
260	FZ-MZ			gr	R	150-300	0	0					ms
270	FZ-MZ			gr	R	150-300	0	0					ms
280	FZ-MZ			gr	R	150-300	0	0					ms
290	FZ-MZ			gr	R	150-300	0	0					ms
300	FZ-MZ			gr	R	150-300	0	0					ms
310													
320													
330													
340													
350													
360													
370													
380													
390													

Core 3A3		datum		16-9-2013
x	y	Z (m)	diepte	
164658	377629			

Details Close to road
230 cm 1 organic band/ 240 cm sharp transition to organic (sample = 230-250cm)
Organic band at 280-283 cm (=sample)
Organic at 287 cm * =well sorted/ ms = moderately sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	FZ	H1		grbr	O	150-210	0	0					wrtls disturbed
20	FZ	H1		grbr	O	150-210	0	0					wrtls disturbed
30	FZ	H1		grbr	O	150-210	0	1					wrtls disturbed
40	FZ	H1		grbr	O	150-210	0	1					wrtls
50	VZ	H2		zwbr	O	150-210	0	0					*
60	VZ	H2		zwbr	O	150-210	0	1					*
70	FZ			robr	O	150-210	0	1					*
80	FZ			robr	O	150-210	0	1					*
90	FZ			robr	O	150-210	0	1					*
100	FZ			robr	O	150-210	0	1					*
110	FZ			robr	O	150-210	0	1					*
120	FZ			robr	O	150-210	0	1					*
130	FZ			robr	O	150-210	0	1					*
140	FZ			rogr	O	150-210	0	1					* loamy
150	(l)LZ			gr	OR	150-210	0	0					*
160	FZ			brgr	OR	150-210	0	0					*
170	FZ			brgr	OR	150-210	0	0					*
180	FZ			brgr	OR	150-210	0	0					*
190	FZ-MZ			brgr	OR	150-300	0	0					ms
200	FZ-MZ			brgr	OR	150-300	0	0					ms
210	FZ			brgr	OR	150-210	0	0					*
220	FZ			brgr	OR	150-210	0	0	GW				*
230	FZ	H1		brgr	R	150-210	0	0					! Sample
240	FZ	H1		brgr	R	150-210	0	0					! sample
250	FZ	H1		brgr	R	150-210	0	0					! Sample
260	FZ			brgr	R	150-210	0	0					*
270	FZ			brgr	R	150-210	0	0					*
280	FZ	H1		brgr	R	150-210	0	0					sample
290	FZ			gr	R	150-210	0	0					*
300	FZ			gr	R	150-210	0	0					*
310	FZ			gr	R	150-210	0	0					*
320	FZ			gr	R	150-210	0	0					*
330	FZ			gr	R	150-210	0	0					*
340													
350													
360													
370													
380													
390													

core 3A5			datum	
x	y		Z (m)	diepte
164574	377603			

details	
near middle of depression	*=well sorted
193 cm organic =5mm (sample)beneath org glgr->gr	ms = moderately sorted
transiton 235 =& (207 cm =sandy loam =%)	

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	VZ			zwbr		150-210	0	0					wortels*
20	VZ			zwbr		150-210	0	0					wortels*
30	FZ			brgl		150-210	0	0					wortels*
40	FZ			brgr		150-210	0	0					*
50	FZ			brgr		150-210	0	0					*
60	FZ			brgr		150-210	0	0					*
70	FZ			brgr		150-210	0	0					*
80	FZ			brgr		150-210	0	0					*
90	FZ			brgr		150-210	0	0					*
100	FZ			brgr		150-210	0	0					*
110	FZ			glgr		150-210	0	0					*
120	FZ			glgr		150-210	0	0					*
130	FZ			glgr		150-210	0	0					*
140	FZ			glgr		150-210	0	0					*
150	FZ			glgr		150-210	0	0					*
160	FZ			glgr		150-210	0	0	GW				*
170	FZ			glgr		150-210	0	0					*
180	FZ			glgr		150-210	0	0					*
190	FZ			glgr		150-210	0	0					*
200	FZ	H2		gr		150-210	0	0					sample at 193 (h2)
210	FZ-MZ			gr		150-300	0	0					% ms
220	(l)LZ	h1?		dgr		150-210	0	0					sample
230	(l)LZ	h1?		dgr		150-210	0	0					& *
240	FZ			gr		150-210	0	0					*
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core 3A6		datum	
x	y	Z (m)	diepte
164543	377607 (epe=8.2)		

Details	*=well sorted
western edge depression	ms = moderately sorted
% = organic band at 185 cm	

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	VZ			zwbr		150-210	0	1					wrtls
20	VZ			zwbr		150-210	0	1					wrtls
30	FZ	H2		zwbr		150-210	0	1					wrtls
40	FZ	H2		zwbr		150-210	0	1					wrtls
50	FZ			drobr		150-210	0	1					*
60	FZ			drobr		150-210	0	1					*
70	FZ			Robr		150-210	0	1					*
80	FZ			Robr		150-210	0	1					*
90	FZ			Robr		150-210	0	1					*
100	FZ			glgr		150-210	0	0					*
110	(l)LZ			gr		150-210	0	0					* loamy
120	(l)LZ			gr		150-210	0	0					
130	FZ			grgl		150-210	0	0					*
140	FZ			grgl		150-210	0	0					*
150	FZ			grgl		150-210	0	0					*
160	FZ			grgl		150-210	0	0					*
170	FZ			grgl		150-210	0	0	GW				*
180	FZ			grgl		150-210	0	0					*
190													
200													
210													
220													
230													
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core 3A7			datum		
x	y		Z (m)	diepte	
164517	377588	(epe 4.6)			

Details	
Near road	
! = GZ addition	
& = ends in gr sand at ~208cm	

*=well sorted
ms = moderately sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	VZ			zwbr		150-210	0	1					wrtls
20	VZ			zwbr		150-210	0	1					wrtls
30	VZ			zwbr		150-210	0	1					wrtls
40	FZ	H2		zwbr		150-210	0	1					*
50	FZ			gl		150-210	0	1					*
60	FZ			gl		150-210	0	1					*
70	FZ			gl		150-210	0	1					*
80	FZ			gl		150-210	0	1					*
90	FZ			gl		150-210	0	1					*
100	FZ			gl		150-210	0	1					*
110	FZ			gl		150-210	0	1					*
120	FZ			glgr		150-210	0	1					*
130	FZ			glgr		150-210	0	1					*
140	FZ			glgr		150-210	0	1					*
150	FZ			glgr		150-210	0	1					*
160	(l) LZ			gr		150-210	0	2					sample
170	(l) LZ			gr		150-210	0	2					
180	LZ	h1	plr	gr		150-210	0	0					sandy
190	LZ	h1	plr	gr		150-210	0	0					sandy
200	LZ	h1	plr	gr		150-210	0	0					sandy
210	FZ-MZ			glgr		150-300	0	0					! *
220	FZ-MZ			glgr		150-300	0	0					! *
230	FZ			gr		150-210	0	0					! *
240	FZ			gr		150-210	0	0					! *
250	FZ			gr		150-210	0	0					ms/ laomy/silt
260	FZ			gr		150-210	0	0					*
270	FZ			gr		150-210	0	0					*
280	FZ			gr		150-210	0	0					*
290	FZ			gr		150-210	0	0					!
300	FZ			gr		150-210	0	0					*
310	FZ-MZ			gr		150-300	0	0					ms
320	FZ-MZ			gr		150-300	0	0					ms
330	FZ-MZ			gr		150-300	0	0					ms
340	FZ-MZ			gr		150-300	0	0					ms
350													
360													
370													
380													
390													

core 4A1			datum	
x	y		Z (m)	diepte
165183	377534	EPE 4.5	-17	

details

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	ZV	H2		zwbr				1					wrtls
20	ZV	H2		zwbr			0	1					wrtls
30	ZV	H2		zwbr			0	1					wrtls
40	ZFZ	H1		br		105-150	0	1					
50	ZFZ			br		105-150	0	1					
60	ZFZ			br		105-150	0	1					
70	ZFZ			br		105-150	0	1					
80	ZFZ			br		105-150	0	1					
90	ZFZ			br		105-150	0	1					
100	(l)LZ			gr		105-150	0	0					
110	(l)LZ			gr		105-150	0	0					
120	(l)LZ			gr		105-150	0	0					
130	zand			gr		105-150	0	0	GW				end
140													
150													
160													
170													
180													
190													
200													
210													
220													
230													
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core 4A2			datum		12-9-2013
x	y		Z (m)	diepte	
165180	377547	EPE 4.2	18.7		

Details	^=sample
	* = wel sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	FZ	H1		zw	O	150-200	0	1					soil *
20	FZ	H1		zw	O	150-200	0	1					soil *
30	FZ	H1		zw	O	150-200	0	1					soil *
40	FZ			zwbr	O	150-200	0	1					*
50	FZ			zwbr	O	150-200	0	1					*
60	FZ			br	O	150-200	0	1					*
70	FZ			br	O	150-200	0	1					*
80	FZ			grbr	O	150-200	0	1					loamy*
90	(l)LZ			gr	OR	105-150	0	1					
100	(l)LZ			gr	OR	105-150	0	0					
110	(l)LZ			gr	OR	105-150	0	0					
120	FZ			gr	R	150-210	0	0					^coarser than above
130	FZ			gr	R	150-210	0	0					
140	MZ			gr	R	210-300	0	0	GW				less well sorted
150	MZ			gr	R	210-300	0	0					less well sorted
160	MZ			gr	R	210-300	0	0					less well sorted
170													
180													
190													
200													
210													
220													
230													
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core 4A3		datum	12-9-2013
x	y	Z (m)	diepte
165169	377570	EPE 3.5	17.7

details: * well sorted
medium sorted = ms

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	FZ	H1		zw	O	150-210	0	1					soil*
20	FZ	H1		zw	O	150-210	0	1					soil*
30	FZ	H0		zwbr	O	150-210	0	1					soil*
40	FZ			robr	O	150-210	0	1					brownish*
50	FZ			robr	O	150-210	0	1					brownish*
60	FZ			robr	O	150-210	0	1					brownish*
70	FZ			robr	O	150-210	0	1					brownish*
80	FZ			brgl	O	150-210	0	1					*
90	FZ			brgl	O	150-210	0	1					*
100	FZ			brgl	OR	150-210	0	1					pebbels*
110	FZ			brgl	OR	150-210	0	1					*
120	FZ			gl	OR	150-210	0	1					*
130	FZ			gl	OR	150-210	0	0					*
140	FZ			gl	OR	150-210	0	0					*
150	FZ			gngl	OR	150-210	0	0					to MZ *
160	FZ			gngr	OR	150-210	0	0					to MZ *
170	FZ			gr	R	150-210	0	0					*
180	FZ			gr	R	150-210	0	0					*
190	FZ-MZ			dgr	R	150-210	0	0					ms/loamy?/ sample
200	FZ			gr	R	150-210	0	0	GW				end
210	FZ			gr	R	150-210	0	0					*
220	FZ			gr	R	150-210	0	0					*
230	FZ			gr	R	150-210	0	0					*
240	FZ			gr	R	150-210	0	0					*
250	FZ-MZ			gr	R	150-210	0	0					pebbels*
260	FZ			gr	R	150-210	0	0					*
270	FZ			gr	R	150-210	0	0					*
280	FZ			gr	R	150-210	0	0					*
290	FZ			gr	R	150-210	0	0					*
300	FZ	H2		brgr	R	150-210	0	0					sample*
310	FZ	H1		brgr	R	150-210	0	0					*
320	FZ			gr	R	150-210	0	0					*
330													
340													
350													
360													
370													
380													
390													

core	4A4	datum		12-9-2013
x	y	Z (m)	diepte	
165160	377589	EPE 6.8		

details

near forest
* well sorted
ms = medium sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	FZ	H1		zwbr	O	150-210	0	0					soil*
20	FZ	H1		zwbr	O	150-210	0	0					soil*
30	FZ	H1		robr	O	150-210	0	1					soil*
40	FZ	H1		grbr	O	150-210	0	1					soil*
50	FZ			robr	O	150-210	0	1					*
60	FZ			gl	O	150-210	0	1					*
70	FZ			gl	O	150-210	0	0					*
80	FZ			gl	O	150-210	0	0					*
90	FZ			gl	O	150-210	0	0					*
100	FZ			rogl	O	150-210	0	1					*
110	FZ			rogl	O	150-210	0	1					*
120	FZ			rogl	O	150-210	0	1					*
130	FZ			rogl	O	150-210	0	1					*
140	FZ			rogl	O	150-210	0	1					*
150	FZ			grgl	O	150-210	0	1					*
160	FZ			glgr	OR	150-210	0	0					*ms+coarse additio
170	FZ			glgr	OR	150-210	0	0					*ms+coarse additio
180	FZ			glgr	OR	150-210	0	0					*
190	FZ			gr	R	150-210	0	0					sample
200	MZ			gr	R	210-300	0	0					*ms+coarse additio
210	MZ			gr	R	210-300	0	0	GW				*ms+coarse additio
220													
230													
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	4A5	datum	12-9-2013
x	y	Z (m)	diepte
165156	377598	EPE=9.4	

details

in forest
* = well sorted
80 down is better sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	bosgr	H2		grzw	O		0						soil
20	bosgr	H2		grzw	O		0						soil
30	FZ	H2		zwbr	O	150-200	0	1					soil
40	FZ	H2		zwbr	O	150-200	0	1					soil
50	FZ			robr	O	150-200	0	1					soil
60	FZ			gl	O	150-200	0	1					*
70	FZ			gl	OR	150-200	0	0					*
80	ZFZ			gl	OR	105-150	0	0					ZFZ of FZ *
90	ZFZ			gl	OR	105-150	0	0					ZFZ of FZ *
100	ZFZ			gl	OR	105-150	0	0					ZFZ of FZ *
110	ZFZ			gl	OR	105-150	0	0					*
120	ZFZ			gl	OR	105-150	0	0					*
130	ZFZ			gl	OR	105-150	0	0					*
140	ZFZ			gl	OR	105-150	0	0					*
150	ZFZ			glgr	OR	105-150	0	0					*
160	ZL			gngr	R		0	0					loam
170	ZL			gngr	R		0	0					loam
180	(L)LZ			gngr	R	105-150	0	0					*
190	FZ			grgl	R	150-210	0	0					*
200	FZ			grgl	R	150-210	0	0					*
210	FZ			glgr	R	150-210	0	0					*
220	FZ			glgr	R	150-210	0	0					*
230	FZ			gr	R	150-210	0	0					*
240	FZ			gr	R	150-210	0	0					*
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	4A6	datum	12-9-2013
x	y	Z (m)	diepte
165189	377511	EPE = 6.9	

details	ms = moderate sorted
	* = well sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	VZ	H2	plr	zw	O		0						soil
20	VZ	H2	plr	zw	O		0						soil
30	VZ	H1		zwbr	O		0	1					
40	FZ	H0		br	O	150-210	0	1					10% MZ ms
50	FZ			br	O	150-210	0	1					10% MZ ms
60	FZ-MZ			br	OR	150-300	0	0					ms
70	FZ-MZ			br	OR	150-300	0	0					ms
80	FZ			brgr	OR	150-210	0	0					*
90	FZ			brgr	OR	150-210	0	0					*
100	FZ			brgr	OR	150-210	0	0					*
110	(l)LZ			gr	R	150-210	0	0					ms loamy*
120	(l)LZ			gr		150-210	0	0					*
130	(l)LZ			dgr		150-210	0	0					sample*
140	(l)LZ			dgr		150-210	0	0					*
150	(l)LZ			dgr		150-210	0	0					sample*
160	FZ			gr		150-210	0	0					*
170	FZ			gr		150-210	0	0					*
180	FZ			gr		150-210	0	0					*
190	FZ			gr		150-210	0	0					*
200	FZ			gr		150-210	0	0					*
210	MZ			gr		210-300	0	0					ms
220	MZ			gr		210-300	0	0					Beuningen? Ms grin
230	FZ	H2		dgr		150-210	0	0					sample/organic
240	MZ			gr		210-300	0	0					
250	MZ			gr		210-300	0	0					
260	MZ			gr		210-300	0	0					
270	MZ			gr		210-300	0	0					
280	MZ			gr		210-300	0	0					
290	MZ			gr		210-300	0	0					
300	FZ	H2		brgr		150-210	0	0					sample/organic*
310	FZ	H1		gr		150-210	0	0					*
320	FZ			gr		150-210	0	0					*
330	FZ			gr		150-210	0	0					*
340	FZ			gr		150-210	0	0					*
350													
360													
370													
380													
390													

core	4A8	datum	13-9-2013
x	y	Z (m)	diepte
165193	377496		

details ms = moderate sorted
* = well sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	VZ	H2		zw	O	150-210	O	0					soil
20	VZ	H2		zw	O	150-210	O	0					soil
30	VZ	H2		zwbr	O	150-210	O	1					*
40	FZ	H1		br	O	150-210	O	1					*
50	FZ			robr	O	150-210	O	1					*
60	FZ			robr	O	150-210	O	1					*
70	FZ			robr	O	150-210	O	1					
80	FZ			robr	O	150-210	O	1					*
90	FZ			robr	O	150-210	O	1					*
100	FZ			br	OR	150-210	O	1					*
110	FZ			br	OR	150-210	O	1					*
120	FZ			brgr	OR	150-210	O	1					*
130	(l)LZ			gngr	OR	150-210	O	1	GW				*
140	FZ			gr	R	150-210	O	0					*
150	FZ			gr	R	150-210	O	0					*
160	FZ			gr	R	150-210	O	0					*
170	FZ			gr	R	150-210	O	0					*
180	FZ			gr	R	150-210	O	0					*
190	FZ			gr	R	150-210	O	0					*
200	FZ			gr	R	150-210	O	0					*
210	FZ			gr	R	150-210	O	0					*
220	FZ			gr	R	150-210	O	0					*
230	FZ			gr	R	150-210	O	0					*
240	FZ			gr	R	150-210	O	0					*
250		V2		br	R		O	0					
260		V2		br	R		O	0					
270		V2		br	R		O	0					tm 276 V2 tm 278 V1
280	MZ			gr	R	210-300	O	0					ms *
290	MZ			gr	R	210-300	O	0					ms*
300	MZ			gr	R	210-300	O	0					pebbels
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	4A8	datum	13-9-2013
x	y	Z (m)	diepte
165203	377464		

details	
	ms = moderate sorted
	* = well sorted
	loam = silty on top, sandy at bottom

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	FZ	H2		zw	O	150-210	0	1					soil
20	FZ	H2		zw	O	150-210	0						*
30	FZ	H2		zwbr	O	150-210	0	1					*
40	FZ	H1		robr	O	150-210	0	1					*
50	FZ			robr	O	150-210	0	1					*
60	FZ			brgl	O	150-210	0	1					*
70	FZ			brgl	O	150-210	0	1					*
80	FZ			brgl	O	150-210	0	1					*
90	FZ			brgl	O	150-210	0	1					*
100	FZ			brgl	O	150-210	0	1					pebbels (line)
110	FZ			gl	O	150-210	0	1					*
120	FZ			gl	O	150-210	0	1					*
130	FZ			gl	O	150-210	0	1					*
140	FZ			gl	O	150-210	0	1					*
150	FZ			gl	O	150-210	0	1					*
160	LZ			gngr	R	150-210	0	0					*
170	LZ			gngr	R	150-210	0	0					*
180	L			gngr	R	150-210	0	0					*
190	L			gn	R	150-210	0	0					*
200	LZ			gr	R	150-210	0	0					*
210	FZ			gr	R	150-210	0	0					*
220	FZ			gr	R	150-210	0	0					*
230	FZ			gr	R	150-210	0	0					*
240	FZ			gr	R	150-210	0	0					*
250	FZ			gr	R	150-210	0	0					*
260	FZ			gr	R	150-210	0	0					*
270	FZ			gr	R	150-210	0	0					*
280	FZ			gr	R	150-210	0	0					*
290	FZ			gr	R	150-210	0	0					*
300	FZ			gr	R	150-210	0	0					*
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	5A1	datum		20-9-2013
x	y	Z (m)	diepte	
165191	377110 (epe 4.9)			

details		
	H1# =h1 at 257	
		~ light at top (FZ-MZ) humic down = sample
GS= no sample		op 328-330
		sample 228-300 / sample top 325

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	VZ			zw		150-210	0	0					wrtls
20	VZ			zw		150-210	0	0					wrtls
30	FZ			brgl		150-210	0	1					*
40	FZ			brgl		150-210	0	1					*
50	FZ			brgl		150-210	0	1					*
60	FZ			gr		150-210	0	0					loamy
70	FZ			gr		150-210	0	0					loamy/ sample
80	FZ-MZ			gr		150-300	0	0					
90	LK		plr	gr			0	0					
100	LK		plr	gr			0	0					
110	LK		plr	gr			0	0					
120	LK		plr	dgr			0	0					sample
130	LK		plr	dgr			0	0					
140	LK		plr	dgr			0	0					sample
150	LK		plr	dgr			0	0					
160	MZ		plr	gr			0	0					light band at 165
170	FZ			gr		150-210	0	0					ms
180	FZ			gr		150-210	0	0					ms
190	FZ			gr		150-210	0	0					ms
200	FZ			gr		150-210	0	0					ms
210	FZ			gr		150-210	0	0					ms
220	FZ			gr		150-210	0	0					ms
230	FZ			gr		150-210	0	0					ms
240	FZ			gr		150-210	0	0					ms
250	FZ-MZ	H1#		gr		150-300	0	0					ms
260	FZ-MZ	H1	plr	brgr		150-300	0	0					ms / sample
270	FZ-MZ	H1		grbr		150-300	0	0					ms
280	FZ-MZ	H1		grbr		150-300	0	0					ms / sample
290	FZ-MZ	H1		grbr		150-300	0	0					ms
300	FZ-MZ	H1		grbr		150-300	0	0					ms / sample
310	FZ-MZ	H1		grbr		150-300	0	0					ms
320	FZ-MZ	H2		grbr		150-300	0	0					sample ~
330	GS												
340	GS												
350	GS												
360													
370													
380													
390													

core	5A2	datum		20-9-2013
x	y	Z (m)	diepte	
165180	377143 (epe=5.1)			

details	near edge depression	*=well sorted
& = organic at 285 cm		ms
% = plr org band at 297		ms= moderately sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	VZ			zw		150-210	0	1					wrtls
20	VZ			zw		150-210	0	1					wrtls
30	FZ			br		150-210	0	1					*
40	FZ			glbr		150-210	0	1					*
50	FZ			glbr		150-210	0	1					*
60	FZ			glbr		150-210	0	1					*
70	FZ			brgr		150-210	0	1					* silty
80	FZ			brgr		150-210	0	1					*
90	FZ			brgr		150-210	0	1					*
100	FZ			brgr		150-210	0	1					*
110	FZ			brgr		150-210	0	1					*
120	FZ-MZ			gr		150-210	0	0					coarse addition
130	FZ-MZ			gr		150-210	0	0					coarse addition
140	LK			gr			0	0					
150	LK		plr	dgr			0	0					
160	LK		plr	dgr			0	0					
170	LK		plr	dgr			0	0					
180	FZ			gr		150-210	0	0	GW				
190	FZ-MZ			gr		150-300	0	0					coarse addition
200	FZ-MZ			gr		150-300	0	0					coarse addition
210	FZ			gr		150-210	0	0					ms
220	FZ			gr		150-210	0	0					ms
230	MZ			gr		150-300	0	0					ms
240	FZ			gr		150-210	0	0					ms
250	FZ-MZ			gr		150-300	0	0					ms
260	FZ-MZ			gr		150-300	0	0					ms
270	FZ-MZ			brgr		150-300	0	0					ms
280	FZ			brgr		150-300	0	0					ms / &
290	FZ	H1		brgr		150-210	0	0					* / %/ sample
300	FZ			grbr		150-210	0	0					*
310	FZ	H2		dbr		150-210	0	0					* transition at 315
320	FZ	H2		dbr		150-210	0	0					*
330	FZ	H2		dbr		150-210	0	0					*
340	FZ	H1		br		150-210	0	0					*
350													
360													
370													
380													
390													

core	5A3	datum		20-9-2013
x	y	Z (m)	diepte	
165170	377179 (EPE=4.1)			

details	at heigher elevation

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	FZ			dbr		150-210	0	0					wrtls
20	FZ			dbr		150-210	0	1					wrtls
30	FZ			dbr		150-210	0	1					*
40	FZ			glbr		150-210	0	1					*
50	FZ			brgl		150-210	0	1					*
60	FZ			brgl		150-210	0	1					*
70	FZ			glbr		150-210	0	1					*
80	FZ			glbr		150-210	0	0					*
90	FZ			glbr		150-210	0	0					*
100	FZ			glbr		150-210	0	0					*
110	FZ			glbr		150-210	0	0					*
120	FZ			glbr		150-210	0	0					*
130	FZ			glbr		150-210	0	0					*
140	(l)LZ			glgr		150-210	0	0					or silty
150	(l)LZ			gr		150-210	0	0					or silty
160	(l)LZ			gr		150-210	0	0					or silty
170	(l)LZ			gr		150-210	0	0					or silty
180	(l)LZ			gr		150-210	0	0					or silty
190	(l)LZ			gr		150-210	0	0					or silty
200	FZ			blgr		150-210	0	0					loamy
210	FZ			blgr		150-210	0	0	GW				loamy
220	LK	H2		dbr			1	0					
230	LK	H2		dbr			2	0					sample 238-240
240	LK	H1		dbr-brgr			2	0					bandjes org/ sample
250	LK	H1		brgr			2	0					
260	LK	H1		brgr			2	0					sandy interval 270
270	LK	H1		brgr			2	0					2 cm sample
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	5A4	datum	20-9-2013
x	y	Z (m)	diepte
165203	377063 (EPE=3.5)		

details

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	FZ			ZW		150-210	0	1					wrtls
20	FZ			ZW		150-210	0	1					wrtls
30	FZ			ZW		150-210	0	1					*
40	FZ			robr		150-210	0	1					*
50	FZ			robr		150-210	0	1					*
60	FZ			robr		150-210	0	1					*
70	FZ			grbr		150-210	0	1					*
80	FZ			brgr		150-210	0	1					*
90	FZ			brgr		150-210	0	1					*
100	FZ			brgr		150-210	0	1					*
110	FZ-MZ			gr		150-300	0	1					ms
120	FZ-MZ			gr		150-300	0	1					ms
130	FZ-MZ			gr		150-300	0	1					ms
140	LK	H2		dgr			0	0					ms
150	FZ-MZ	H1		dgr		150-300	0	0					ms
160	FZ-MZ	H1		dgr		150-300	0	0					ms
170	FZ-MZ	H1		dgr		150-300	0	0					*
180	FZ			gr		150-210	0	0					*
190	FZ		z	gr		150-210	0	0					*
200	FZ		z	gr		150-210	0	0					*
210	FZ		z	gr		150-210	0	0					*
220	FZ			gr		150-210	0	0					*
230	FZ			gr		150-210	0	0					*
240	FZ			gr		150-210	0	0					*
250	FZ-MZ			gr		150-300	0	0					pebbels
260	FZ-MZ			brgr		150-300	0	0					transition at 265
270	FZ-MZ			brgr		150-300	0	0					sample
280	FZ-MZ	H1		grbr		150-300	0	0					ms
290	FZ-MZ	H1		grbr		150-300	0	0					ms
300	FZ-MZ	H1		grbr		150-300	0	0					ms
310	FZ-MZ	H1		grbr		150-300	0	0					pebbels
320	FZ-MZ	H1		grbr		150-300	0	0					pebbels
330	FZ-MZ	H1		grbr		150-300	0	0					pebbels
340	FZ-MZ	H1		grbr		150-300	0	0					pebbels
350													
360													
370													
380													
390													

core	5A5	datum		20-9-2013
x	y	Z (m)	diepte	
165222	377027 (EPE=6.8)			

details
at higher southern part

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	FZ			ZW		150-210		1					wrtls
20	FZ			ZW		150-210		1					wrtls
30	FZ			brgl		150-210		1					*
40	FZ			brgl		150-210		1					*
50	FZ			brgl		150-210		1					*
60	FZ			glgr		150-210		1					*
70	FZ			glgr		150-210		1					*
80	FZ			glgr		150-210		1					*
90	FZ			glgr		150-210		1					*
100	FZ			glgr		150-210		1					*
110	FZ			orgr		150-210		1					*
120	FZ			orgr		150-210		1					*
130	FZ			orgr		150-210		1					*
140	FZ			orgr		150-210		1					*
150	FZ			orgr		150-210		1					*
160	FZ			orgr		150-210		1					laomy
170	FZ			orgr		150-210		1					loamy
180	FZ			orgr		150-210		1					*
190	FZ			orgr		150-210		1					*
200	FZ			gr		150-210		1					*
210	FZ			gr		150-210		1					*
220	FZ			gr		150-210		1					*
230	FZ			brgr		150-210		1					*
240	FZ			brgr		150-210		1					*
250	FZ			brgr		150-210		1					*
260	FZ			brgr		150-210		1					*
270	FZ			gr		150-210		1					*
280	FZ			gr		150-210		0					*
290	FZ			gr		150-210		0					*
300	FZ			gr		150-210		0					* silty or loamy
310	FZ			gr		150-210		0					* silty or loamy
320	FZ			gr		150-210		0					* silty or loamy
330	FZ			gr		150-210		0					*
340	FZ			gr		150-210		0					*
350													
360													
370													
380													
390													

core	kempen 1		datum		2-10-2013
x	y		Z (m)	diepte	
147691	371184	4.2			

details	ms is moderately sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	bosgrond			zw			0	0					soil
20	bosgrond			zw			0	0					soil
30	FZ			robr		150-210	0	1					ms
40	FZ			robr		150-210	0	1					ms
50	FZ			robr		150-210	0	1					ms
60	FZ			gl		150-210	0	1					coarse addition
70	FZ			gl		150-210	0	1					ms
80	FZ+MZ(20%)			gr		150-300	0	1					ms + coarse addition
90	FZ+MZ(20%)			brgr		150-300	0	1					ms + coarse addition
100	FZ+MZ(20%)			br		150-300	0	1					ms + coarse addition
110	FZ+GZ (20%)			gr		150-600	0	1					ms, silty
120	FZ+GZ (20%)			gr		150-600	0	1					ms, silty
130	FZ+GZ (20%)			gr		150-600	0	1					ms, silty
140	FZ+GZ (20%)			gr		150-600	0	1					ms, silty
150	FZ+GZ (20%)			gr		150-600	0	1					ms, silty
160	GZ			gr		420-600	0	1					grind + silty
170	GZ			gr		420-600	0	1					grind + silty
180	GZ			gr		420-600	0	1					grind + silty
190	GZ			glgr		420-850	0	1					ps
200	GZ			glgr		420-850	0	1					ps
210	GZ			glgr		420-850	0	1					ps
220	GZ			glgr		420-85	0	0					ps
230	GZ			glgr		420-850	0	0					ps
240	GZ			brgr		420-850	0	0					ps transition nr brgr op 245
250	GZ			brgr		420-850	0	0					ps
260	GZ			brgr		420-850	0	0					grover band 260-263
270	GZ			brgr		420-850	0	0					pebbels
280	GZ			brgr		420-850	0	0					pebbels
290	FZ-MZ	h2		dbrgr		150-300	0	0					ms wood at 290-295
300	GZ			dgr		420-600	0	0					ps
310	GZ			dgr		420-600	0	0					ps
320													
330													
340													
350													
360													
370													
380													
390													

core	kempen 2	datum		2-10-2013
x	y	Z (m)	diepte	
147683	371173	4		

details ms is moderately sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	gm												
20	gm												
30	FZ	h2		zw		150-210	0	0					roots
40	Zandig Veen	plr		dbr			0	0					roots, transition at 35cm
50	Zandig Veen	plr		dbr			0	0					roots
60	Zandig Veen	plr		dbr			0	0					roots
70	FZ	plr		br		150-210	0	0					transition at 65 cm
80													
90													
100													
110													
120													
130													
140													
150													
160													
170													
180													
190													
200													
210													
220													
230													
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	kempen 3	**datum**		2-10-2013
x	**y**	**Z (m)**	**diepte**	
147680	371167	4.4		

details	ms is moderately sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	gm												
20	gm												
30	gyttja		plr	zw			0	0					fluffie
40	gyttja		plr	zw			0	0					fluffie
50	gyttja		plr	zw			0	0					fluffie
60	zandig veen			dbr-zw			0	0					less sandy than 60-70
70	zandig veen			br		150-210	0	0					
80	FZ			br		150-210	0	0					
90													
100													
110													
120													
130													
140													
150													
160													
170													
180													
190													
200													
210													
220													
230													
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

core	kempen 4	datum	2-10-2013
x	y	Z (m)	diepte
147670	371163	6	

details ms is moderately sorted

Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	gm												
20	gm												
30	gm												
40	FZ	H2		zw		150-210	0	0					
50	FZ	H2		zw		150-210	0	0					
60	zandig Veen		plr	dbr			0	0					
70	FZ	h1		br		150-210	0	0					
80													
90													
100													
110													
120													
130													
140													
150													
160													
170													
180													
190													
200													
210													
220													
230													
240													
250													
260													
270													
280													
290													
300													
310													
320													
330													
340													
350													
360													
370													
380													
390													

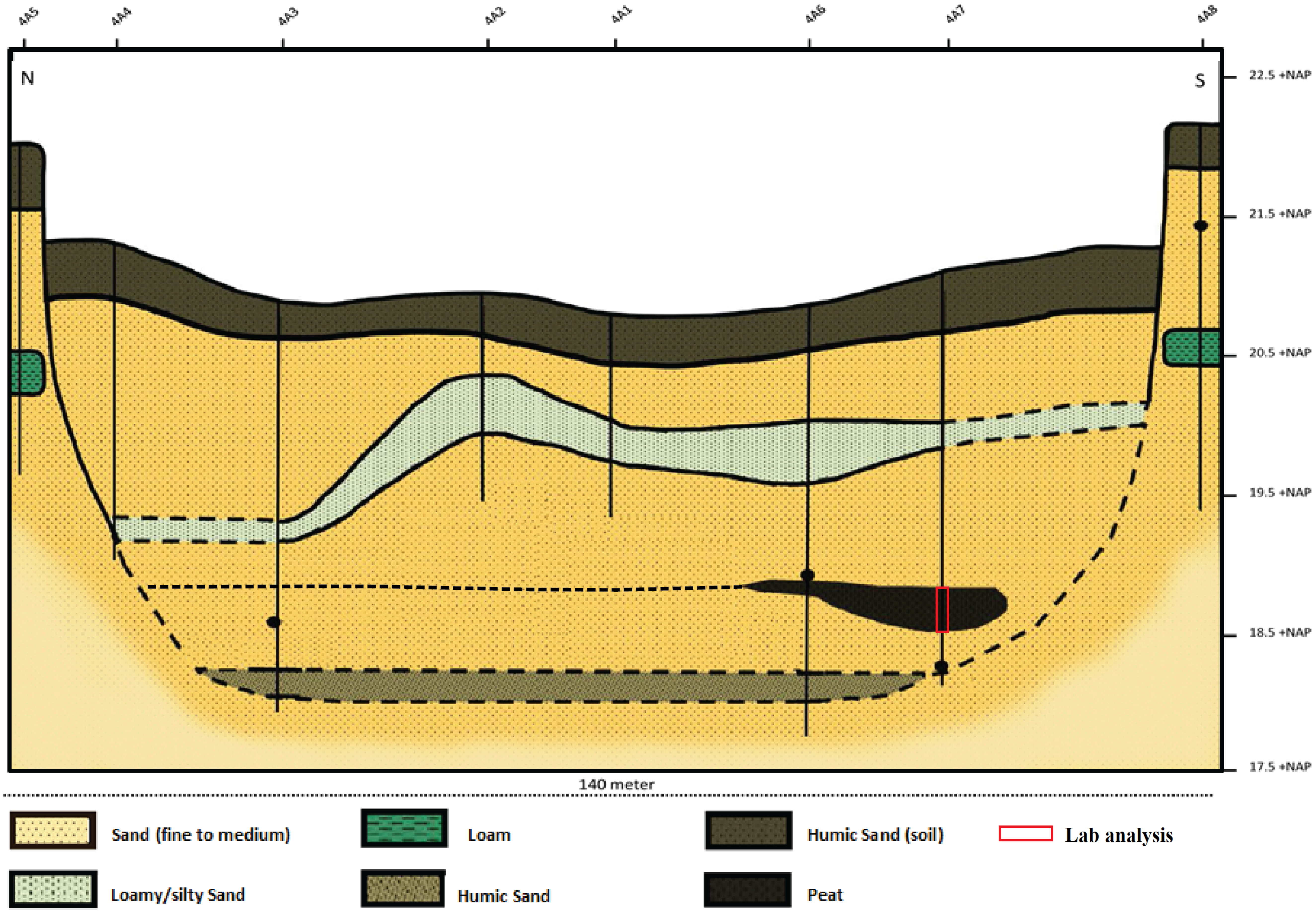
core	kempen 5	**datum**	2-10-2013
x	**y**	**Z (m)**	**diepte**
147659	371149	5	

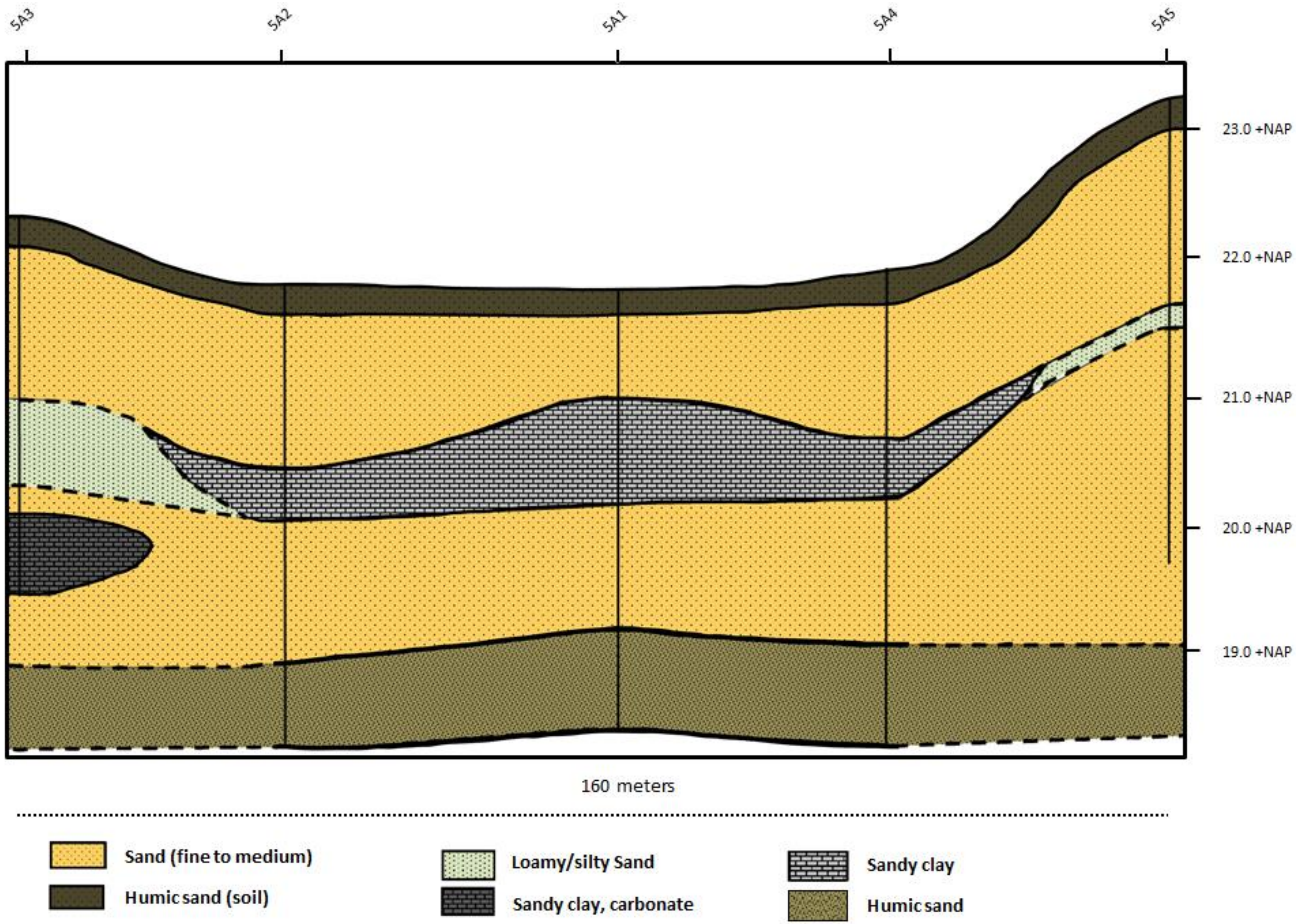
details	ms is moderately sorted

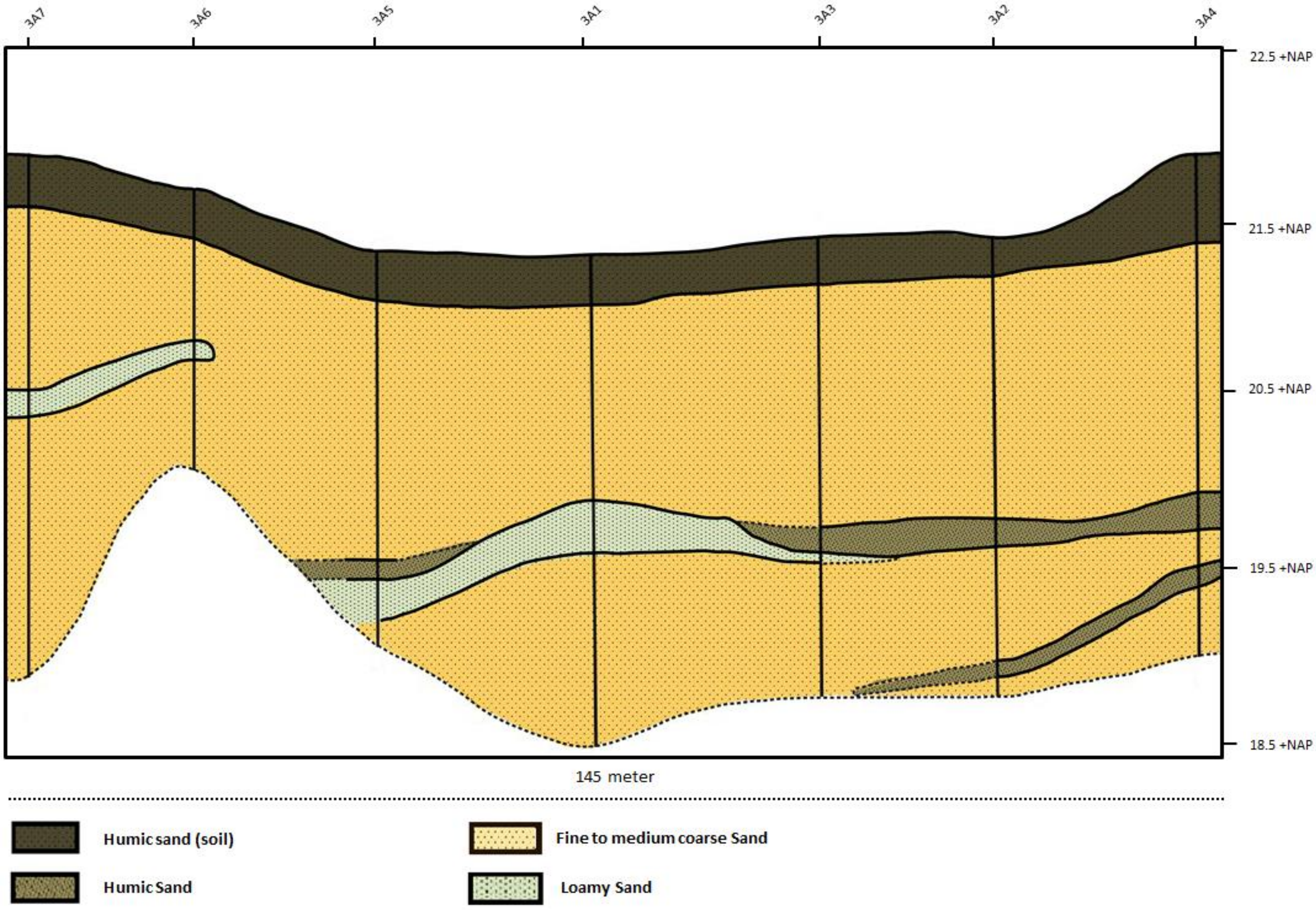
Depth	Texture	org	plr	color	or	M50	Ca	Fe	GW	M	lkl	Strat	details
10	bosgrond			zw									
20	bosgrond			zw									
30	bosgrond			zw									
40	bosgrond			zw									
50	FZ			robr		150-210	0	1					ms
60	FZ			robr		150-210	0	1					ms
70	FZ			robr		150-210	0	1					ms
80	FZ			robr		150-210	0	1					ms
90	FZ			robr		150-210	0	1					ms
100	FZ			glbr		150-210	0	1					ms +coarse addition
110	FZ			glbr		150-210	0	1					ms +coarse addition
120	FZ			gl		150-210	0	1					ms +coarse addition
130	FZ			gl		150-210	0	1					ms +coarse addition
140	FZ			gl		150-210	0	1					ms +coarse addition
150	FZ			gl		150-210	0	1					ms +coarse addition
160	FZ+GZ(20%)			gr		150-210	0	1					ms, silty
170	FZ+GZ(20%)			gr		150-210	0	1					ms, silty
180	FZ+GZ(20%)			gr		150-210	0	1					ms, silty
190	FZ			gr		150-210	0	0					silty?
200	FZ			gr		150-210	0	0					silty?
210	FZ			gr		150-210	0	0					ws
220	FZ			gr		150-210	0	0					ws
230	FZ			gr		150-210	0	0					ws
240	FZ			gr		150-210	0	0					ws
250	FZ			gr		150-210	0	0					ws
260	FZ			gr		150-210	0	0					ws
270	FZ			gr		150-210	0	0					ws
280	FZ			gr		150-210	0	0					ws
290	FZ			gr		150-210	0	0					ws
300	FZ			gr		150-210	0	0					ws
310	FZ			gr		150-210	0	0					ws
320	FZ			gr		150-210	0	0					ws
330	MZ			brgr		300-420	0	0					GZ additon + pebbels
340	MZ			brgr		300-420	0	0					GZ additon + pebbels
350													
360													
370													
380													
390													

Appendix B

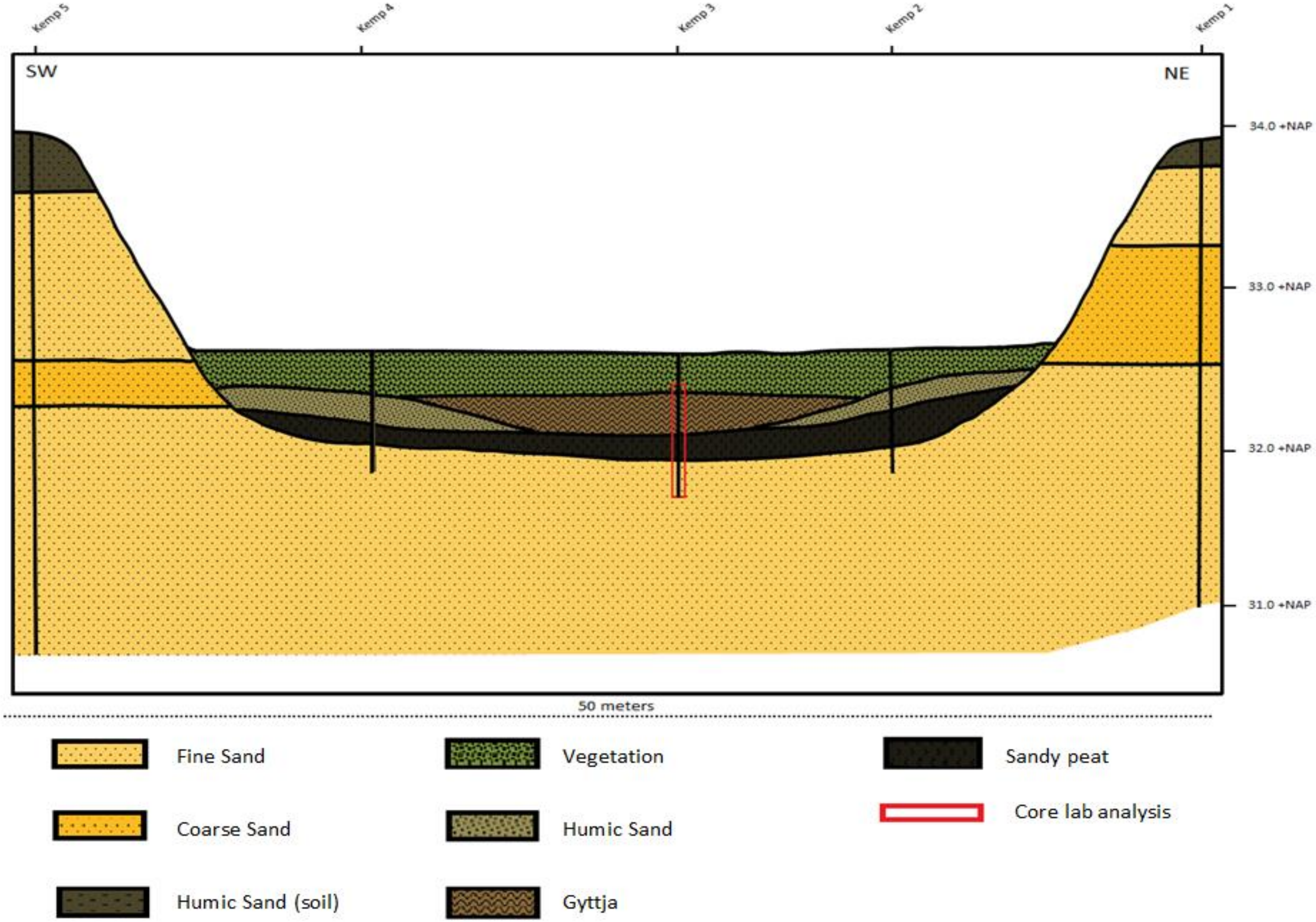
Cross-sections


4A5
4A4
4A3
4A2
4A1
4A6
4A7
4A8
N
S
22.5 +NAP
21.5 +NAP
20.5 +NAP
19.5 +NAP
18.5 +NAP
17.5 +NAP
140 meter
Sand (fine to medium)
Loam
Humic Sand (soil)
Lab analysis
Loamy/silty Sand
Humic Sand
Peat

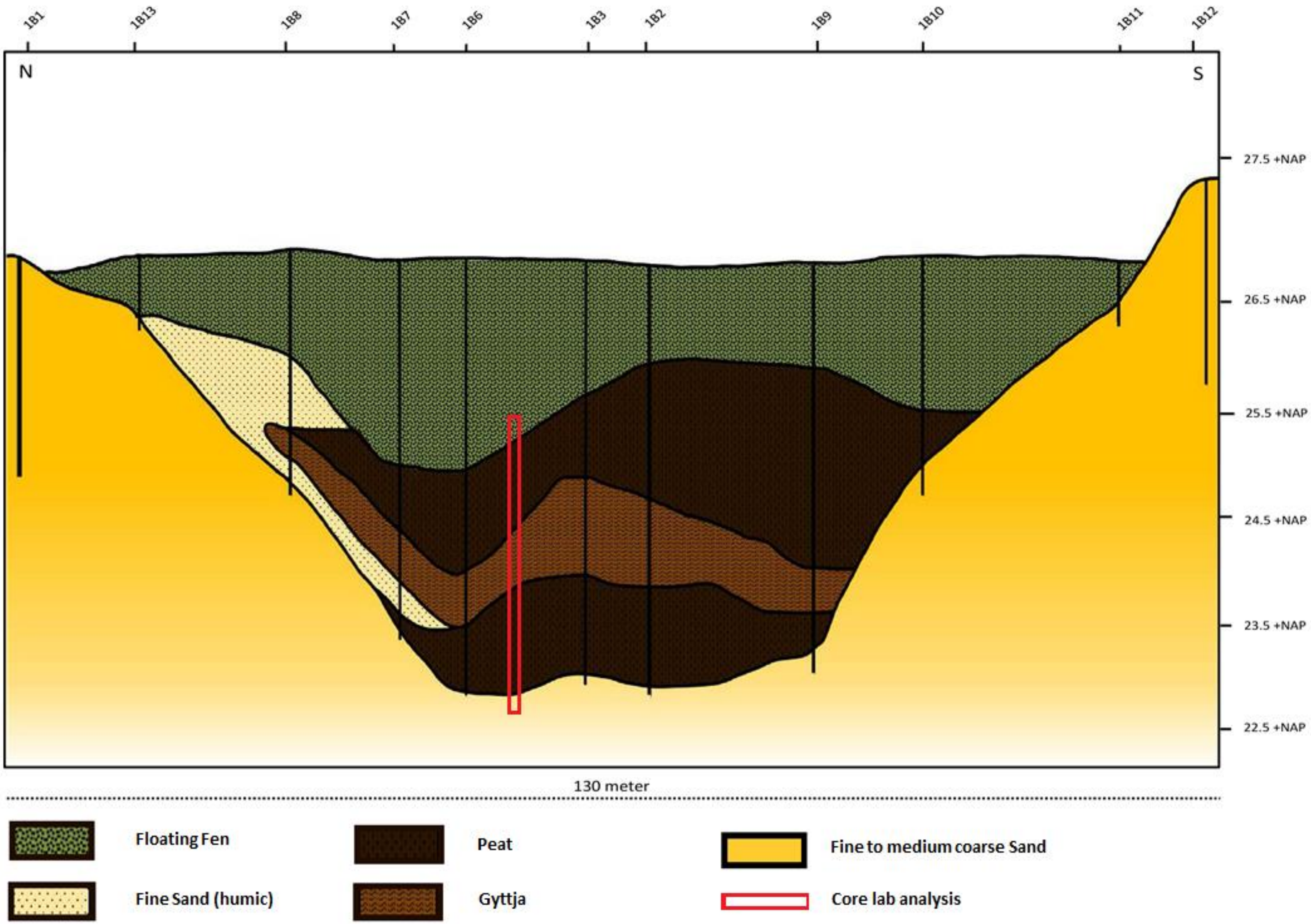

5A3
5A2
5A1
5A4
5A5
23.0 +NAP
22.0 +NAP
21.0 +NAP
20.0 +NAP
19.0 +NAP
160 meters
Sand (fine to medium)
Humic sand (soil)
Loamy/silty Sand
Sandy clay, carbonate
Sandy clay
Humic sand



3A7
3A6
3A5
3A1
3A3
3A2
3A4
22.5 +NAP
21.5 +NAP
20.5 +NAP
19.5 +NAP
18.5 +NAP
145 meter
Humic sand (soil)
Humic Sand
Fine to medium coarse Sand
Loamy Sand



Kemp 5
Kemp 4
Kemp 3
Kemp 2
Kemp 1
SW
NE
34.0 +NAP
33.0 +NAP
32.0 +NAP
31.0 +NAP
50 meters
Fine Sand
Vegetation
Sandy peat
Coarse Sand
Humic Sand
Core lab analysis
Humic Sand (soil)
Gyttja



1B1
1B13
1B8
1B7
1B6
1B3
1B2
1B9
1B10
1B11
1B12
N
S
27.5 +NAP
26.5 +NAP
25.5 +NAP
24.5 +NAP
23.5 +NAP
22.5 +NAP
130 meter
Floating Fen
Peat
Fine to medium coarse Sand
Fine Sand (humic)
Gyttja
Core lab analysis

Appendix C

Klein Hassels Ven core description

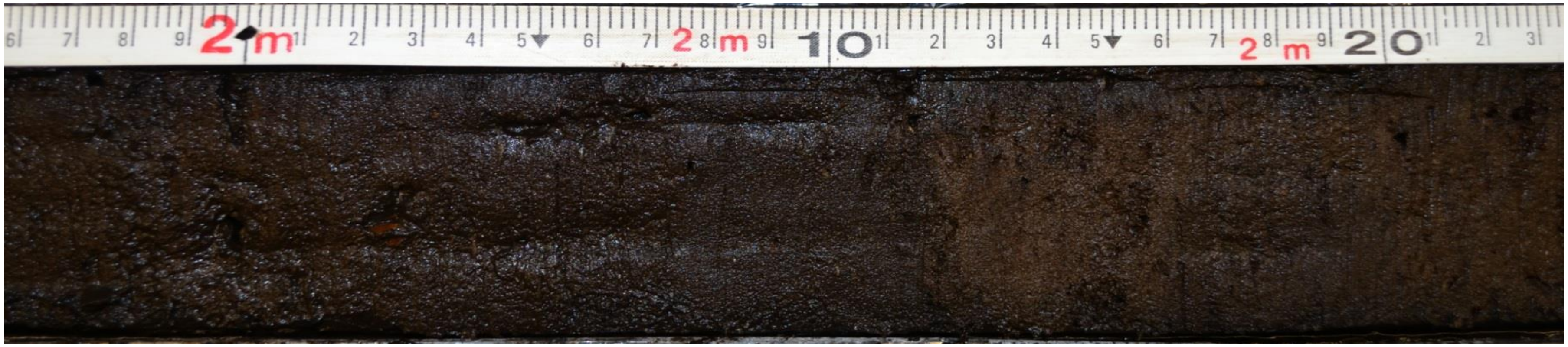
Interval (cm)	Description
390-383	>Sand /Yellow-grey/Organic layers at 386-389 and 384-385
383-376	>Interwoven sand-organics/Cryoturbation?/Start irregularity at 383 cm/Seed at 378 cm
376-372	>Peat/Dark-brown/Compact
372-364	>Peat/Brown/Compact
364-357	>Peat/Dark-brown/Compact/Sandy
357-348	>Peat/Compact/Some Seeds/sharp transition at 348 to somewhat lighter brown compact peat
348-346	>Somewhat lighter brown peat than above >Compact and more sand
346-344	>Sandy layer, brown-grey /Coarse sand grains visible
344-290	>Gyttja/Brown/Compact/Black charcoal spots
290-280	Transition brown gyttja to black-brown peat
280-265	>Peat/Black-brown/very loose
265-260	>Black intrusion
260-240	>Peat/Black/Very loose
240-210	>Peat/black-brownish/Very loose
210-170	>Peat/Black/Very loose

Appendix D

Klein Hassels Ven core photographs

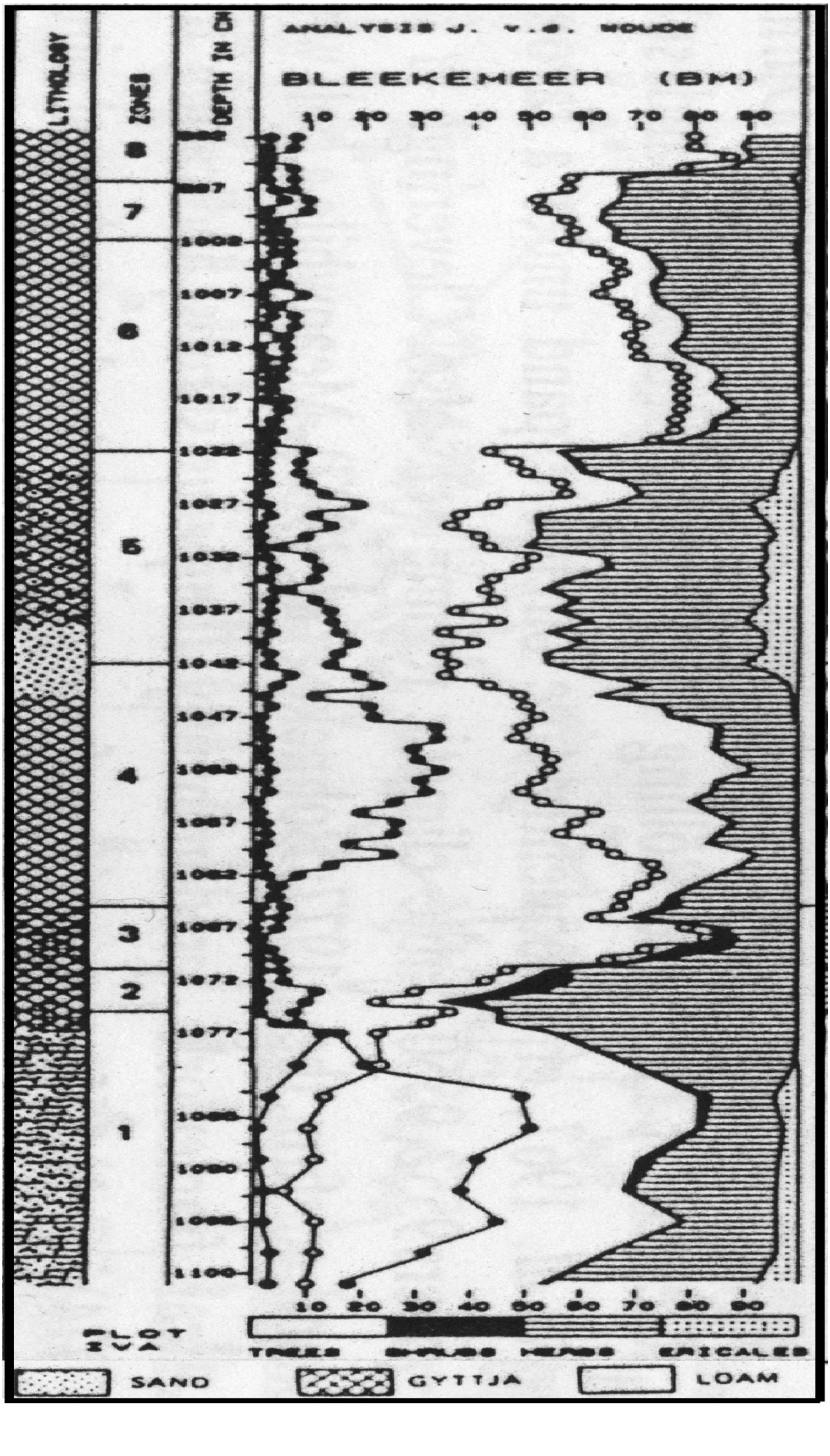

3 m 60 3 m 70 3 m 80 3 m 90


3 m 30 3 m 40 3 m 50 3 m 60



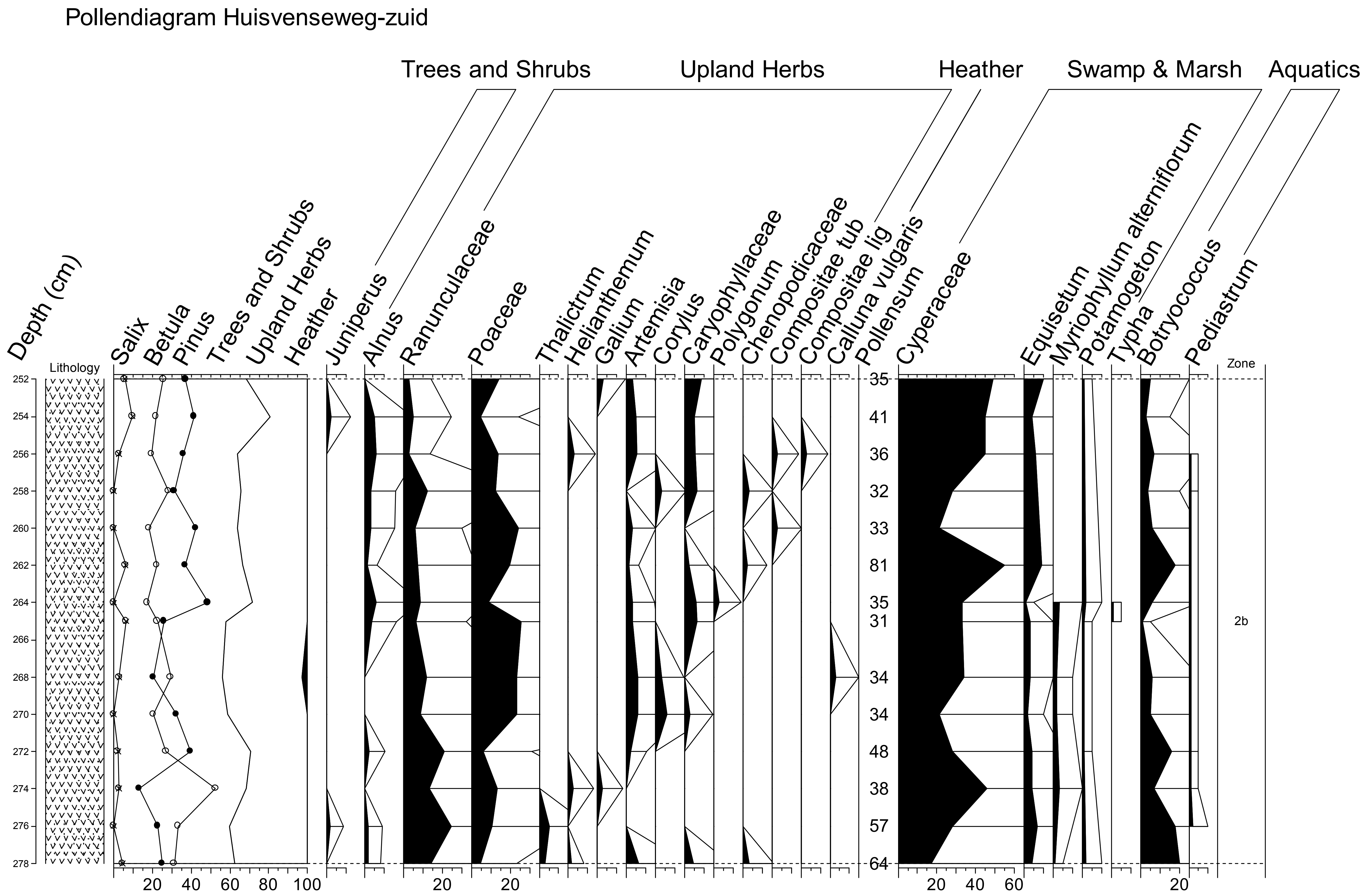
Appendix E

Bleekemeer pollen diagram

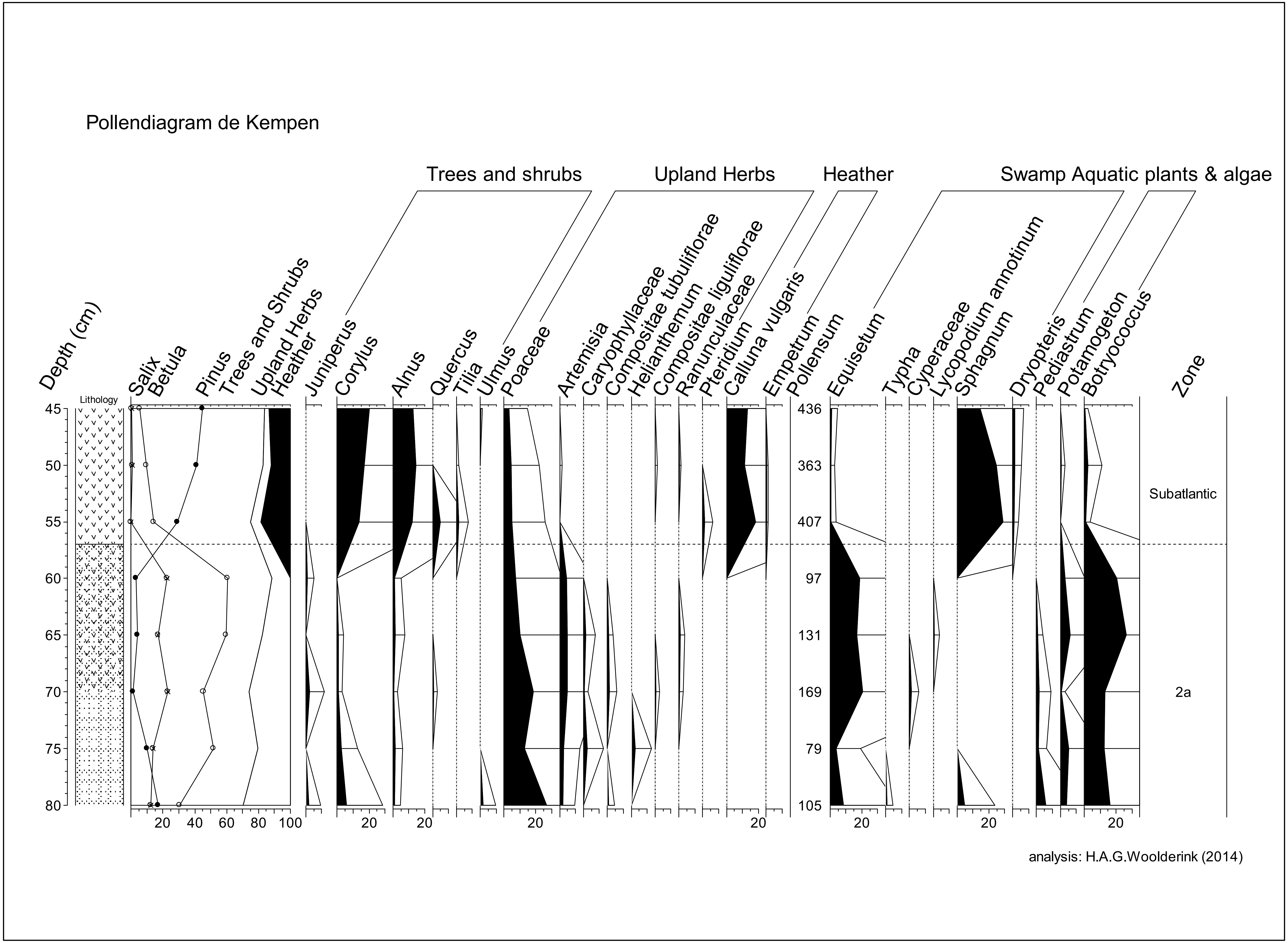

LITHOLOGY
ZONES
DEPTH IN CM
ANALYSIS J. v.d. WOUDE
BLEEKEMEER (BM)
10 20 30 40 50 60 70 80 90
PLOT IVA
TREES
SHRUBS
HERBS
ERICALES
SAND
GYTTJA
LOAM

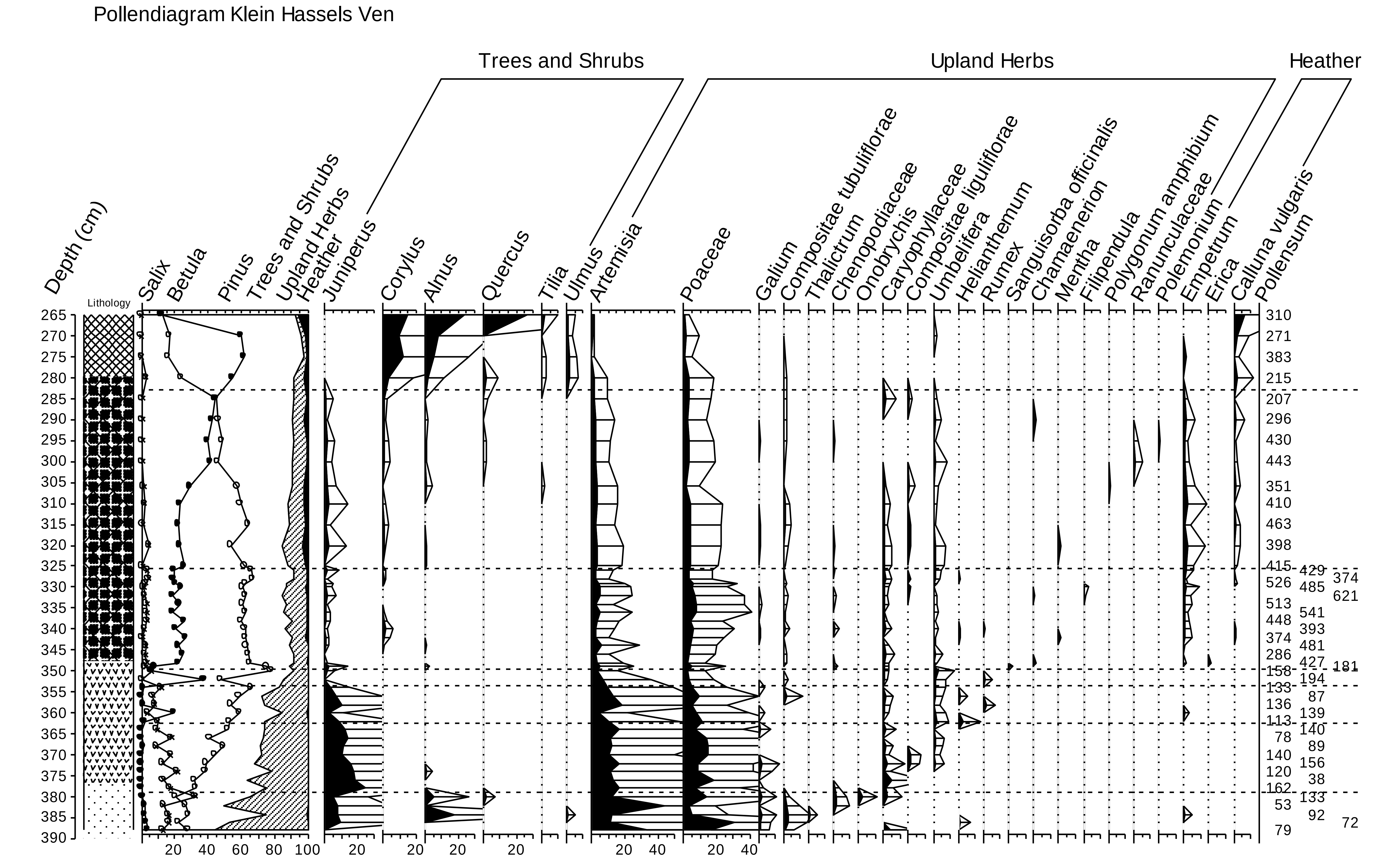
Appendix F

Complete pollen diagrams

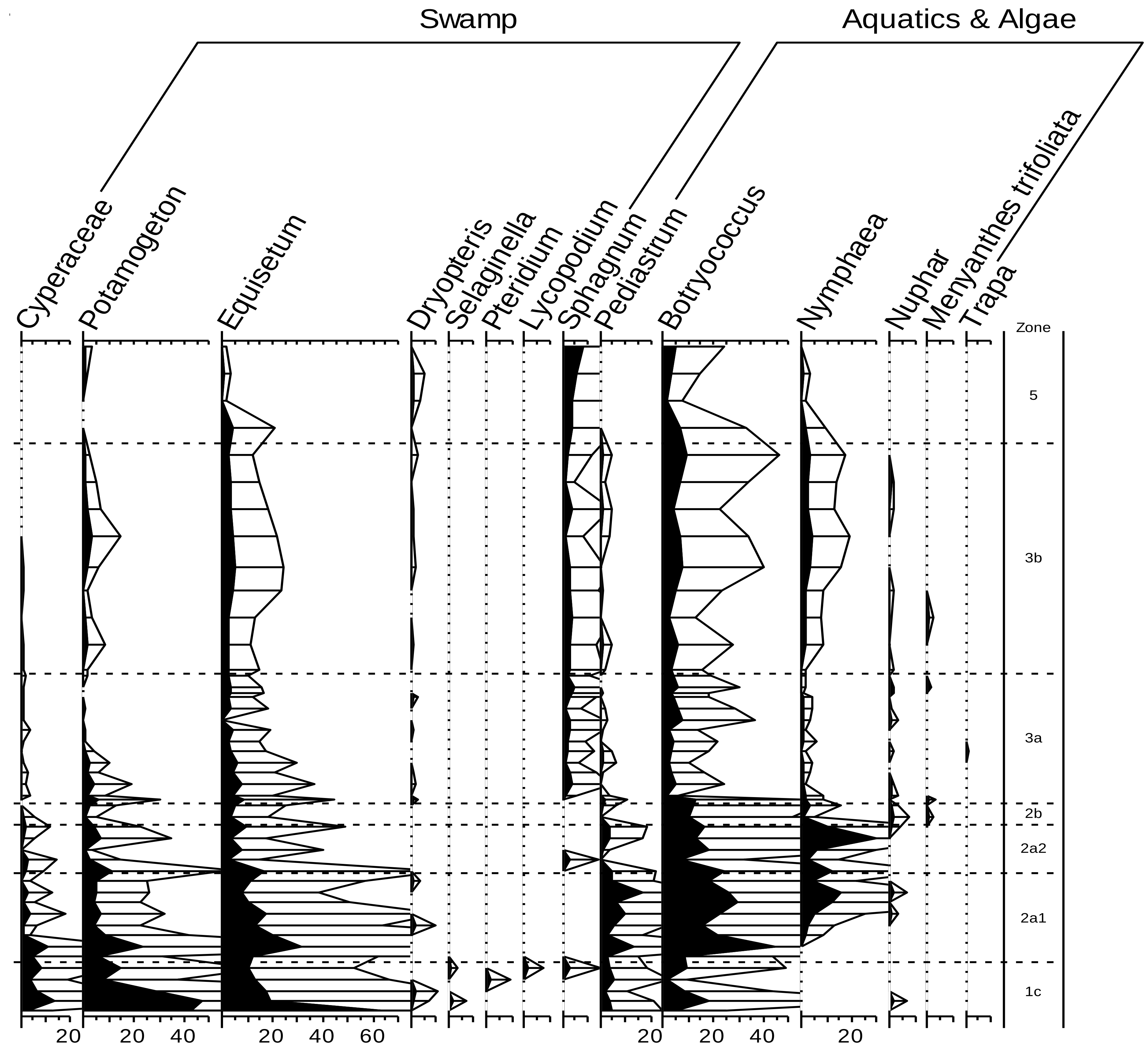


Analysis: Hessel Woolderink (2014)


Pollendiagram de Kempen
Trees and shrubs
Upland Herbs
Heather
Swamp Aquatic plants & algae
Depth (cm)
Lithology
Salix
Betula
Pinus
Trees and Shrubs
Upland Herbs
Heather
Juniperus
Corylus
Alnus
Quercus
Tilia
Ulmus
Poaceae
Artemisia
Caryophyllaceae
Compositae tubuliflorae
Helianthemum
Compositae liguliflorae
Ranunculaceae
Pteridium
Calluna vulgaris
Empetrum
Pollensum
Equisetum
Typha
Cyperaceae
Lycopodium annotinum
Sphagnum
Dryopteris
Pediastrum
Potamogeton
Botryococcus
Zone
45
50
55
60
65
70
75
80
436
363
407
97
131
169
79
105
Subatlantic
2a
20 40 60 80 100
20
analysis: H.A.G.Woolderink (2014)



Pollendiagram Klein Hassels Ven
Trees and Shrubs
Upland Herbs
Heather
Depth (cm)
Lithology
Salix
Betula
Pinus
Trees and Shrubs
Upland Herbs
Heather
Juniperus
Corylus
Alnus
Quercus
Tilia
Ulmus
Artemisia
Poaceae
Galium
Compositae tubuliflorae
Thalictrum
Chenopodiaceae
Onobrychis
Caryophyllaceae
Compositae liguliflorae
Umbelifera
Helianthemum
Rumex
Sanguisorba officinalis
Chamaenerion
Mentha
Filipendula
Polygonum amphibium
Ranunculaceae
Polemonium
Empetrum
Erica
Calluna vulgaris
Pollensum



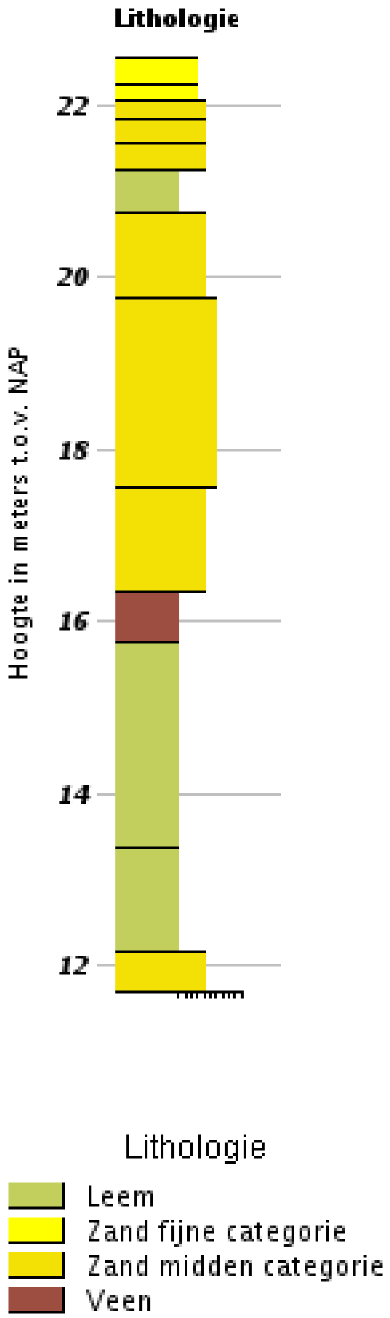
Analysis: Hessel Woolderink (2014)

Appendix G

TNO cores

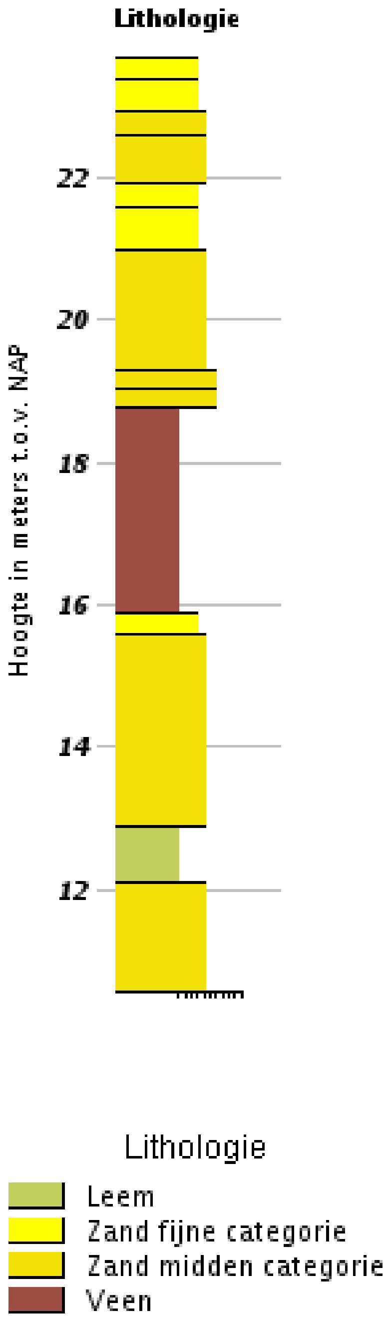
Boormonsterprofiel

Identificatie: B51G0355
Coördinaten: 165150, 377450
Maaiveld: 22,56 m t.o.v. NAP
Dieptetraject t.o.v. NAP: 11,69 m - 22,56 m



Boormonsterprofiel

Identificatie: B51G0356
Coördinaten: 165230, 377030
Maaiveld: 23,69 m t.o.v. NAP
Dieptetraject t.o.v. NAP: 10,57 m - 23,69 m



Appendix H

Distances brook valleys and pingos

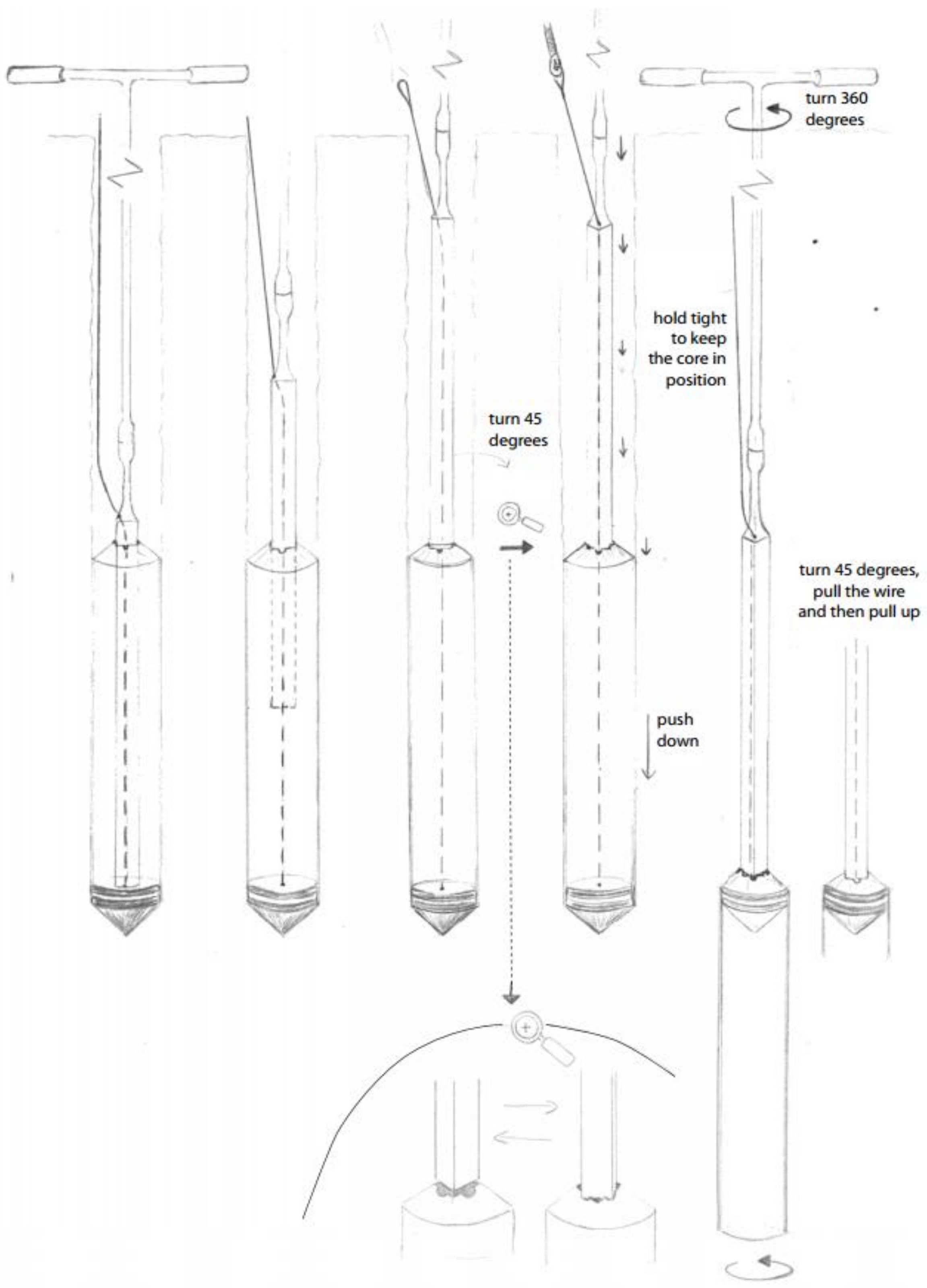
NAME	LITERATURE	X_RD	Y_RD	NEAR_DIST
Elper Noorderveld	Cleveringa & De Gans, 1978	239700	566900	0
Gulickshof I	Hoek, 1997	190729	341214	0
Gulickshof II	Hoek, 1997	190729	341214	0
Halder	Hoek, 1997	150075	406825	0
Middelbeers Meerven	DLO-Staring, unpubl	146945	383750	0
Sleenerstroom I	Ruiter en De Bruijn	249056	530848	0
Stokersdobbe I	Paris et al, 1979	207850	565695	0
Stokersdobbe III	Paris et al, 1979	207850	565695	0
Kievitsloop	Koelbloed, 1969	179225	370380	7
46	Kluiving, 2010	201348	588525	43
96	Kluiving, 2010	203845	586380	47
Oostvierdeparten	Hoek, 1997	207375	543900	64
Koordes	Paleobotanie 27H-2, 1964	219310	478260	66
Selmien-Ureterperverlaat	Cnossen, 1971	205000	568000	77
47	Kluiving, 2010	200800	587833	119
Uteringsveen I	Cleveringa et al, 1977	241000	548000	125
Uteringsveen II	Cleveringa et al, 1977	241000	548000	125
575	Kluiving, 2010	203311	586119	175
Vlierendijk	Ruiter en De Bruijn	246482	537116	201
Daarle	Bijlsma and de Lange, 1983	232325	492700	257
424	Kluiving, 2010	203059	581819	260
Putbroek	Janssen and Ijzermans-Lutgerhorst, 1973	195900	346400	262
360	Kluiving, 2010	204805	586156	303
100	Kluiving, 2010	206648	587601	340
Groote Veen	Ter Wee, 1966	216270	547450	349
Hoenderboomven	Bisschops, 1973	172520	377860	381
Mierlo Van Hoenderboom	Bisschops, 1973	172520	377860	381
Scheemda A	De Groot et al, 1987	172520	377860	381
Uddelermeer	Bohncke et al, 1988	180450	473200	413
418	Kluiving, 2010	201447	580934	464
Waskemeer	Casparie and van Zeist, 1960	212800	562800	464
Elper Noorderveld C	unpubl	240900	547500	473
Hijkermeer	Van der Hammen, 1949 AND De Gans & Sohl, 1981	229000	545000	493
5	Kluiving, 2010	205989	586616	545

NAME	LITERATURE	X_RD	Y_RD	NEAR_DIST
361	Kluiving, 2010	204956	585942	556
23	Kluiving, 2010	203578	586894	578
Molenmoer	Hoek en Joosten, 1995	175275	369325	653
Esmeer	Ruiter, unpublished	227150	558500	655
102	Kluiving, 2010	206658	587953	660
576	Kluiving, 2010	202992	585653	698
Lichtenbergerveld II	Paleobotanie 28C-5, 1981	229825	482465	775
26	Kluiving, 2010	202861	587124	868
Egypte	Ruiter en De Bruijn	203225	585303	872
Mallemoer	Hoek en Joosten, 1995	175975	369275	885
99	Kluiving, 2010	207375	586702	913
Vliegersgat	Hoek en Joosten, 1995	175925	369225	944
40	Kluiving, 2010	203878	589708	968
41	Kluiving, 2010	203906	589923	1006
Siegerwoudstermeer	Jäger, -	210300	568500	1006
181	Kluiving, 2010	200466	581181	1022
342	Kluiving, 2010	202629	582489	1054
In den Vloed	Hoek en Joosten, 1995	175600	369050	1072
Dobbe Bakker	Paleobotanie 17H-4, 1957	254435	526930	1119
373	Kluiving, 2010	203632	584938	1190
Het Peelke	Hoek en Joosten, 1995	175650	368250	1235
Klein Hasselsven	Van Leeuwarden & Janssen, 1987	164200	371200	1302
Zuidven	Hoek en Joosten, 1995	174075	367300	1324
180	Kluiving, 2010	200343	581636	1330
376	Kluiving, 2010	203230	584800	1356
409-e	Kluiving, 2010	207547	579000	1385
603	Kluiving, 2010	207435	586030	1420
Grashut	Hoek en Joosten, 1995	174200	368100	1428
379	Kluiving, 2010	202842	584860	1433
408	Kluiving, 2010	208178	578686	1482
Achterste Hout	Hoek en Joosten, 1995	174125	367800	1514
412-f	Kluiving, 2010	207452	579506	1582
Berkenven	Hoek en Joosten, 1995	174100	367925	1606
Empe	Hoek & van Asch, unpubl.	206000	462500	1612
439	Kluiving, 2010	204245	579553	1646
Groot Ven	Hoek en Joosten, 1995	173875	367675	1665
Weerterbos	Van Joolen, 1996	173875	367675	1665
Klein Ven	Hoek en Joosten, 1995	173775	367725	1777

NAME	LITERATURE	X_RD	Y_RD	NEAR_DIST
Laarzenpad	Ruiter en De Bruijn	204571	584515	1809
780	Kluiving, 2010	204216	584295	1924
400	Kluiving, 2010	199924	583682	1927
Doezen	Ruiter, unpublished	211748	535103	2176
Nieuwe Veen	Bijlsma, 1983	241984	507286	2410
68	Kluiving, 2010	200218	584827	2465
543	Kluiving, 2010	201740	583600	2476
486	Kluiving, 2010	200846	583282	2597
Mekelermeer	Hammen, 1951	238000	532000	2648
Mekelermeer MII	Bohncke et al, 1988	238000	532000	2648
403-d	Kluiving, 2010	208517	579995	2718
Maartensdobbe	Kasse & Boncke, 1992	184075	372710	2718
Opende	Ruiter en De Bruijn	210386	577409	3309
Wartena	Hoek, 1997	190000	573425	3469
401	Kluiving, 2010	208983	580723	3506

Appendix I

Bohncke boor



(de Bruijn, 2012)

Appendix J

Klein Hassels Ven (van Leeuwarden and Janssen)

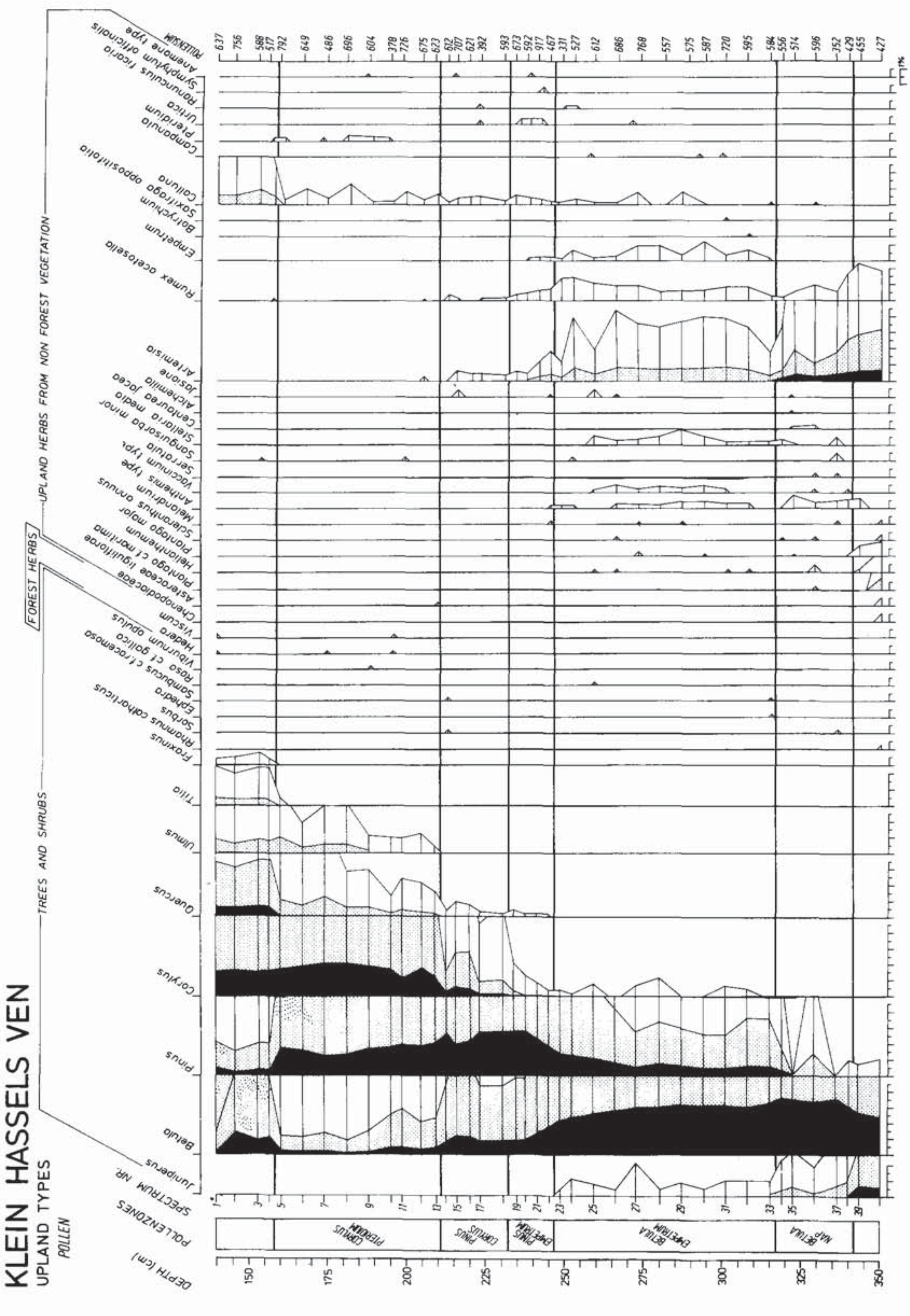
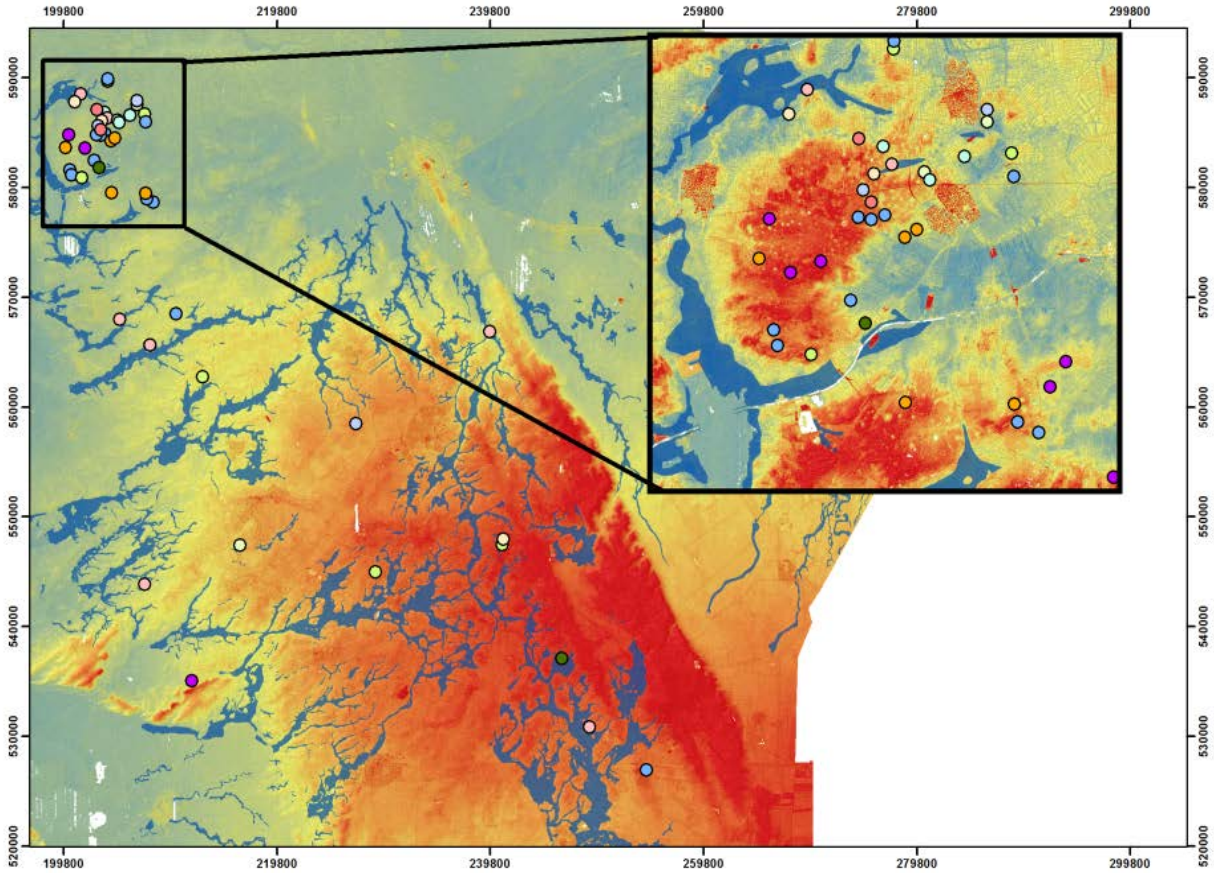


Fig.7. Pollen diagram of upland pollen types of Klein Hassels Ven.

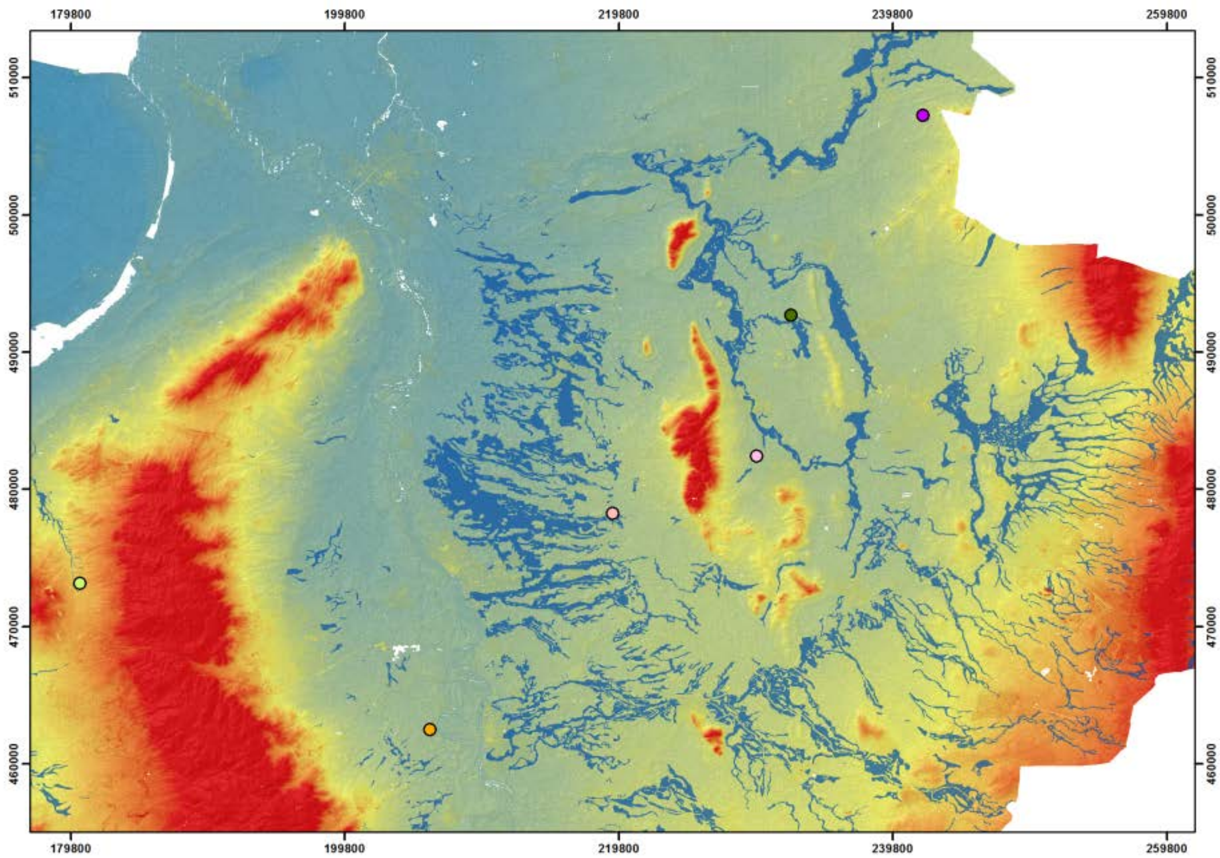
Appendix K

Overview distance pingo remnants and brook valleys

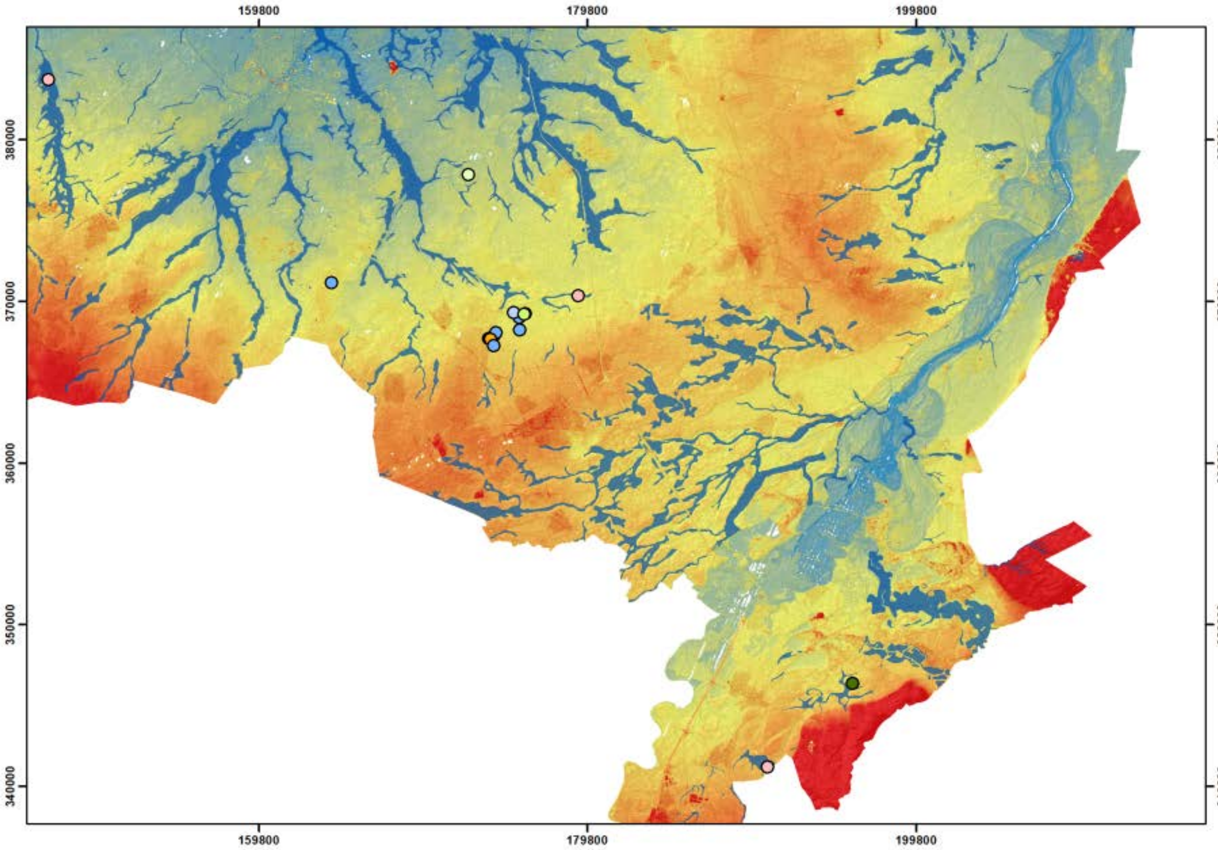
North



Central



South



Legend

Distance pingo brookvalley (m)

- 0 - 100
- 101 - 200
- 201 - 300
- 301 - 400
- 401 - 500
- 501 - 600
- 601 - 700
- 701 - 800
- 801 - 900
- 901 - 1000
- 1001 - 1500
- 1501 - 2000
- 2001 - 2500

Alterra_beekdal

nederahn

Value

High : 8197 cm+NAP

Low : 1069 cm+NAP