Woodlands of the past

The excavation of wetland woods at Zwolle-Stadshagen (The Netherlands)

II. Development of the palaeo-landscape in its hydrological context

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Abstract

Micromorphology was used to reconstruct the palaeo-landscape in which a woodland had grown between about 150 BC and AD 600 in Zwolle-Stadshagen. The woodland developed in a depression between ridges of Weichselian aeolian coversands of the Twente Formation. Some time before 1500 BC a well-drained podzol had developed in the coversand depression. Micromorphological research showed that a rising groundwater level drowned the podzol. On top of the podzol organic material from a low herbaceous vegetation with a low quantity of trees, possibly a kind of moorland, accumulated in which sand was continuously blown-in from local coversand ridges. For more than 1500 years the ridges had to be cleared of vegetation by human, probably agricultural, activities. Peat growth on which a woodland was present started between AD 6-102 and was attributed to the general evolution of the mean sea level in the Holocene. The lower part of the peat was moderately acid and partly decomposed. The upper part was less acid and increasingly decomposed due to bioturbation by terrestrial worms, indicating drier conditions. At the same thin layers of almost pure clay (< 2 µm) were deposited. During this period a new active fresh watercourse, periodically either flooding or

draining the peat, must have been present. This might be a watercourse of the river Vecht preceding the course of the recent Zwarte Water. No traces of human activities nor animal foraging were found in the woodland peat. Peat growth and the existence of the wetland wood ended between AD 474 and 538. The peat became covered by a thick layer of pure clay (< 2 µm) representing a lacustrine deposit, indicative of the presence of an inland freshwater lake during a prolonged period.
This is the second article in a set of five on the integrated reconstruction of this woodland of the past.

Keywords:
Palaeo-landscape, micromorphology, C^{14} dates, wetland wood, hydrology.

Introduction

Nowadays more detailed information on former landscapes and vegetation structures as well as on the underlying determining factors is requested. Former landscapes and vegetation structures are being used as references for planning activities in the rural environment and can be used to analyse changes due to external site conditions, for example hydrological changes that may be triggered by large-scale variations in climate conditions. The discussion on past landscapes and vegetation was initiated by Vera (1997) who, on the basis of mostly palynological data, comes to the conclusion that the vegetation on the Northwest European continent during the Atlanticum was that of an open park-like landscape and not that of extensive closed forests. Several biologists, palynologists, botanists and archaeozoologists have opposed this view (e.g. Bremt *et al*. 1998, Zeiler & Kooistra, L.I. 1998), but arguments for and against were inconclusive due to lack of proof and the absence of adequate studies. A short time later, during a field survey of a site planned for a new urban extension near

Zwolle, many large pieces of subfossil wood were found in the subsoil in a peat layer, preserved below a thick clay deposit. The size of the area was such that a buried woodland could be expected. A group of specialists from different disciplines combined to excavate this buried woodland in an integrated way by using geological, micromorphological, ecological and dendrochronological data sets in order to refine, complement and strengthen each other's results, so as to arrive at a more complete reconstruction of the palaeo-landscape and -vegetation. Use was made of the experience gained by Kooistra M.J. & Kooistra, L.I. (2003), to analyse the strength's of micromorphology and palynology and the added value that can be obtained by a proper use of both disciplines in the reconstruction of former landscapes and vegetation structures. The research objectives, developed concept and the excavation are discussed in Kooistra L.I. *et al.* I, 2003. This article is the second of five, all published in this issue, and deals with the reconstruction of the palaeo-landscape and its hydrological context in the time frame in which the woodland developed. The results of the vegetation reconstruction and structure are discussed in Kooistra L.I. *et al.* III, 2003; the dendrochronological results in Sass-Klaassen & Hanraets, IV, 2003 and the synthesis in Kooistra M.J. *et al.*, V, 2003.

Geological and geomorphological setting based on literature

The excavated woodland is situated in Stadshagen, an area on the northwest side of the town Zwolle in the Mastenbroek Polder in the northwest of the Province of Overijssel (Fig. 1). The woodland remains occur in peaty Holocene deposits present between 0.4 – 1.2 m below surface level on top of Pleistocene sands, about 600 – 800 m west of the river Zwarte Water. The Pleistocene sands are Weichselian aeolian coversands of the Twente Formation. The Pleistocene surface had a considerable relief and consisted locally of elongated ridges, possibly river dunes, alternating with depressions on top of a system of braided river beds, with a slight west-facing slope (Kuijer & Rosing, 1994; Wolfert, 2001).

With the start of the warmer Holocene climate, about 10,000 years ago, the vegetation returned, the drifting sands became stabilized and soils started to develop. The mild climate resulted in a rise in sea-level and the coastline gradually moved inland. The sea-level rise caused an increase in the groundwater levels inland. When the groundwater level reached the surface, peat started to develop. In this Basal Peat wetland woods often developed. Depending on the relief of the Pleistocene soil surface and the position and impact of the inland rivers, peat growth started at a later date, reaching the lower parts of the study area from the northwest in the Late Subboreal around 1250 BC and continuing through the Roman Period. At the start of the early Middle Ages, around AD 500, the peat expansion stopped (Zagwijn, 1991). In the study area the peat became covered by a clay deposit which may be either fluviatile or marine. Two rivers were important in this area, the IJssel and the Vecht. The IJssel, discharging water from the Rhine, started to flow around the beginning of our era. During the period of extensive peat growth sedimentation was very limited, but from the early Middle Ages onwards, river-sediments from the IJssel began to accumulate (Lanting & Mook, 1977; Van de Meene, 1979; Willems, 1981; Zagwijn, 1991). After the start of reclamation activities along the IJssel around AD 1100, its meander belt was formed (Kuijer & Rosing, 1994). The influence of the Vecht on the contrary diminished during the Holocene and several abandoned river beds can be found east and southeast of Zwolle (Kuijer & Rosing, 1994; Wolfert, 2001). From the 14th century onwards the influence of the sea on the IJsselmeer area increased, as the connection with the North Sea widened. Around AD 1600 seawater reached the area northwest of Zwolle and marine clays were laid down along the Zwarte Water (Wiggers, 1955; Ente 1971). The sea was cut off by the construction of an enclosure dam in 1932 and no sedimentation from the sea has taken place in this area since (Eilander & Heijink, 1990; Kuijer & Rosing, 1994).

In Figure 1 two maps are given, elucidating the local situation. Figure 1A is a section of a geological map of the Netherlands showing the general distribution of the Pleistocene and Holocene deposits at or near the surface (Zagwijn, 1991). Figure 1B shows the geomorphological setting of the study area in more detail (Wolfert, 2001, based on Ente *et al.,* 1965). In both maps the location of the excavated wetland wood is given. From figure 1A it can be observed that the excavated wetland wood occurred in Holocene deposits near the boundary with Pleistocene deposits. Figure 1B shows the local situation in more detail. Based on this figure the wetland wood is present in peat below marine deposits. Kuijer & Rosing (1994), however, place the boundary of marine and fluvial deposits just north of the excavated wetland wood, so that the excavated site is covered with fluvial deposits.

The soils present in the study area are described as fluvial floodplain soils with a clay layer on top. Between 40 - 80 cm depth a peaty layer about 15 – 50 cm thick can be observed on top of Pleistocene sands in which a podzol has developed. These soils have AC profiles, with a weakly developed A1 horizon and a relatively high watertable (Kuijer & Rosing, 1994). They are classified according to the Dutch soil classification (Ten Cate *et al*., 1995) as *poldervaaggronden* (Rn47*wp*); the Soil Taxonomy, second edition (Soil Survey Staff, 1999), as Thapto-Histic Fluvaquents and after the World Reference Base for Soil Resources (FAO-UNESCO, 1997) as Thaptohistic Fluvisols. For centuries these soils were used as permanent pastures.

Materials and methods

Site conditions and sampling

In a preliminary survey a terrain of 3 ha was examined where the clay layer on top of the peat was removed and two trenches of 15 x 80 m were studied in detail. Based on the information obtained and the quality of the woody remains, four new trenches with artificially reduced groundwater levels were excavated starting from the surface down to the base of the buried woodland with a total area of ca. 1270 m^2. In the trenches the remains of the stumps and trunks of the former trees were present in their original positions. The base and top of the peat as well as all recognizable wood remains were levelled relative to Dutch O.D. and their position determined three-dimensionally in a local grid. The field techniques and sampling strategies used are described in Kooistra, L.I., *et al*. I, 2003.

The profile walls of the trenches were studied and their development and stratigraphy determined. The profile development and sequence in the four studied trenches was uniform, only the thickness of the peat layer and its base level showed slight variation, generally a few centimetres, with a maximum of 30 centimetres. As all profile walls were representative of themselves, one location for detailed sampling was selected (trench 5, Westprofile, see fig. 1 In: Kooistra, L.I., *et al*. I, 2003). The selected soil profile was studied in detail and samples for micromorphological and palynological research were collected at the same time next to each other to enable optimal integration of the results.

Methods and analyses

The selected soil profile was described after the Soil Taxonomy (Soil Survey Staff, 1999) and the colours refer to the moist conditions according to the Munsell Soil Color Charts (1954). Grain-size analyses were performed by laser diffraction with a Coulter LS230 apparatus (Buurman et al., 2001).

Bulk samples for C^{14} dates were collected from the pollen monolith tins. The Groningen calibration programme (version Cal25) was used for the calibration (Van der Plicht, 1993). The degree of smoothing of the calibration curve was based on Törnqvist & Bierkens (1994). The micromorphological samples cover a depth of 70 cm, from 57 – 126 cm – Dutch O.D. The samples were collected continuously in tins of 15 x 5 x 2.5 cm. The undisturbed micromorphological samples were freeze-dried, impregnated with a colourless unsaturated polyester resin and hardened by gamma radiation. The thin sections of 8 x 15 cm with a thickness of 25 μm were made from the undisturbed core of the hardened blocks (Jongerius and Heintzberger, 1975; Bisdom and Schoonderbeek, 1983). The thin sections were analysed with a polarization research microscope with magnifications up to x200. Overviews of procedures followed for the reconstruction of processes and the genesis of the landscape, the soils and human impact are given in Kooistra (1990, 1991).

Results

Profile description, grain-size analyses and C^{14} dates

The profile description of the location where the samples for micromorphological and palynological research were taken is presented below. In Figure 2 an overview is given of the profile information with sampling locations.

Profile description
Coordinates: x=200.256; y= 506.212; Rn47C*wp*; Trench no. 5, West profile.
Surface level 16 cm – Dutch O.D., Depths given in cm – Dutch O.D. Land use: meadow, grassland

16- 60 cm ACg Grey (10 6/1), with yellowish brown (10 5/6) mottles, clay (> 45 % < 2 μm); strongly developed, slightly rounded, large prisms (Ø ca. 20 cm), subdivided into weakly developed sharp angular blocky peds (Ø ca. 5 cm); Most grass roots between planes large prisms. Sharp smooth, boundary.

60- 68 cm 2AC Very dark greyish brown (10 3/2) clay-containing decomposed peat; clay content decreases with depth. Clear smooth boundary.

68- 79 cm 3AC Very dark grey (10 3/1) peat, largely decomposed, some small recognizable twigs and stems, common tree roots. Sharp slightly irregular boundary.

79- 81 cm 4AC Very dark grey (10 3/1) sandy humous layer, partly decomposed, with increasing depth sand content decreases strongly. Upward the humus accumulation becomes more peat-like. Sharp slightly irregular boundary.

81- 83 cm 4C Light grey (10 7/2) aeolian sand layer. Sharp slightly irregular boundary.

83- 92 cm 5AC Dark yellowish brown (10 3/4), sandy humous material. Clear smooth boundary.

92- 99 cm 6A Dark brown (10 4/3) coversand. Clear slightly wavy boundary.

99-103 cm 6E Greyish brown (10 5/2) coversand. Clear slightly wavy boundary.

103-110 cm 6B1 Dark yellowish brown (10 3/4) coversand, with some organic matter and a few larger vertical roots. Compact layer. Faint slightly wavy boundary.

110-124 cm 6B2 Dark yellowish brown (10 4/4) coversand with thin dark brown (7.5 3/2) organic layers. Faint slightly wavy boundary.

> 124 cm 6BC Brownish yellow (10 6/6) coversand.

Three grain-size analyses were performed by laser diffraction. They are from the following layers: I. AC, base of the clay layer, 55 cm – O.D.; II. 5AC, sandy humose material, 90 cm – O.D. and III. 6E, coversand, 101 cm – O.D. (Fig. 3). The composition of the coversand and the sand in the sandy peaty layer 5AC is almost identical, indicating that the sand present in the sandy peat is blown-in coversand. The clay layer on top of the peat is a very heavy clay, with hardly any fine silt, no coarse silt and no sand fraction. As the laser- diffraction method compared to the pipette-method underestimates the clay fraction < 2 μm (Buurman *et al.* 1997; Konert & Vandenberghe, 1997) probably almost the whole sample will be < 4 μm (pers. comm. Buurman).

Three bulk samples for C^{14} dates were collected from the pollen monolith tins of the following layers: 1. 2AC, top of the peat; 2. 3AC, the base of the peat and 3. 5AC, from the base of the sandy humous layer. The depths and results are given in table 1.

From the data presented the following sequence of events can be detected:
In a coversand depression a podzol developed. The groundwater level started to rise and a sandy organically rich layer accumulated at the surface. Based on the dating of the alkaline residue, the formation of this layer was well underway between 1630-1510 BC (1σ cal. age). In this parent material soil formation resulting in an accumulation of humous acid had taken place. The humous acid present in this sediment was dated between 1442-1370 BC (1σ cal. age).
The formation of the peat on top of this sandy humous material started when the groundwater level reached the surface and ended when the peat became covered with a clay deposit. Peat growth started between 6-102 AD (1σ cal. age) and ended between 474-538 AD (1σ cal. age). During this period the wetland wood existed.

To estimate whether the rise in groundwater level was due to a rise in regional or local water levels the C^{14} date of the base of the peat was plotted in the mean sea level-curve of Van de Plassche (1982). The result is presented in Figure 4. A detailed explanation of the background and layout of this figure can be found in Makaske et al., 2003. The date fitted well when the curve was extended to around the beginning of our era. As the samples could be precisely collected from 1. an excavated profile wall that was accurately levelled and 2. were also collected from a wetland wood growing at surface level the potential error sources in the C^{14}

dates would be low. Consequently the peat growth at Zwolle-Stadshagen could be attributed to a regional rise in groundwater level and is a consequence of the general evolution of mean sea level in the Holocene.

Micromorphology

Twelve layers and their transitions could be distinguished in the thin sections of the studied profile. They were described successively starting with the deepest layer. In this way the genesis and possible human influences could be studied chronologically from old to young. The data recording consisted of two parts: 1. analyses of the parent material and relevant features and 2. interpretation of these data giving insight in the processes that occurred, their sequence and interactions. The results of the first part are given as annex/box I. In figure 5 a selection of microphotographs of key features for the reconstruction of the landscape history is given.

Interpretation of the micromorphological analyses

Twelve layers could be distinguished in the studied depth of 70 cm of which the following interpretation could be made.

- Layer 1 (124-126 cm – O.D.) is a BC horizon of a truncated podzol, developed in aeolian coversand.
- Layer 2 (112-124 cm – O.D.), in the field resembling a Bh horizon of a podzol with thin bands of organic matter accumulation in the subsoil, is a sedimentary layer of coversand redeposited by wind and water and includes thin layers of organic debris deposited by water (see Fig. 5b).
- Layer 3, 4, 5 (96-112 cm – O.D.) form one aeolian coversand deposit.
- In layers 2, 3, 4, 5 (96-124 cm – O.D.) a podzol had developed with a humous mineral topsoil (Ah, layer 5: 96-103 cm – O.D.), a bleached, eluvial

layer (E, layer 4: 103-107 cm – O.D.) and accumulation layers of organic matter in combination with iron and aluminum forming amorphous coatings around sand grains (B1hs, layer 3: 107-112 cm – O.D., Fig. 5a; B2hs, layer 2: 112-124 cm – O.D.). This type of coating is formed in well-drained podzols developed on poor parent materials. If the bands of organic matter in layer 2 had been composed of illuviated organic matter, the podzol would have been a hydromorphic podzol.

In this well-drained podzol the groundwater level started to rise. Under fluctuating but steadily rising groundwater levels pyrite was formed in and near organic materials present in the podzol and the organic debris in layer 2. In the podzol Ah horizon, besides moder humus (largely consisting of excrements of mesofauna) also mor humus occurred as result of poorer (wetter) conditions for decomposition. The few moss-like tissues and sklerotia may indicate a change to a wet heather-like vegetation.

- Layers 6, 7, 8 (82-96 cm – O.D.) sandy, humous layers are the result of increasingly wet conditions, resulting in the accumulation of more or less decomposed organic matter. The presence of a few gypsum rosettes in layer 6 indicates local mesotrophic, non acidic conditions. This is supported by the presence of moder humus characteristic of a slightly acid pH. Towards the top (layer 8) the organic material becomes more peaty. Remarkable is the continuous input of blown-in coversand sand (Fig. 5c) from nearby sources in layers 6 and 8 and a pure sand layer about 2 cm thick blown in in one go (layer 7). The organic material is horizontally compressed by the weight of more superficial layers.
- Layer 9 (71-82 cm – O.D.) is a partly decomposed peat layer, with remnants of ferns of the Dryopteris type (fig. 5d) formed after the groundwater level reached the surface. Trees grew on the peat, as tree roots are common. The pH became more acidic as mesofauna was limited and bacterial decomposition common. Here too, organic material is horizontally compressed by the weight of superficial layers.
- Layer 10 (66-71 cm – O.D.) is also a woodland peat, but one that is periodically flooded whereby increasingly fine clay (< 2 μm) was deposited. In between, drier conditions prevailed, as many traces of terrestrial worms and mesofauna, especially enchytraids (Fig.

5e) were found. For their presence the pH had to increase to slightly acidic or neutral. Some wormcasts were present in the top of the lower peat layer, indicative of fluctuating groundwater levels also in this zone. The peaty material was compressed.

- Layer 11 (61-66 cm – O.D.) is a partly bioturbated humous clay of the same type as in layer 10 on which trees have grown. Prolonged periods with pure clay deposition from flooding alternated with longer drier periods in which organic matter accumulated and worms mixed clay and organic matter by ingestion (Fig. 5f). As the parent material contained less organic matter, mesofauna re-ingested about half of the recognizable organic matter in worm excreta. Some, most probably, local organic material is deposited at the base together with the clay.
- Layer 12 (57-61 cm – O.D.), composed of nearly 100 % pure clay, is a horizontally laminated water deposit (Fig. 5 g/h). As synsedimentary deposited organic matter is almost absent after a few centimetres and faunal influence stopped completely, the woodland present on the peat must have been inundated for prolonged periods.

Annex/Box 1. Micromorphological analyses of the sampled profile

Layer 1. 124 – 126 cm – O.D.

Parent material: Open packed coversand

Features: - Common loosely infilled fossil root channels, locally containing partly decomposed root remains. Infilling with parent material; decomposition organic remains mainly chemical/bacteriological.

- Common small accumulations of black framboïdal pyrite in and near decomposed root remains.
- Thin continuous humus-iron coatings up to 5 μm around coversand grains.

Layer 2. 112 – 124 cm – O.D.

Parent material: Laminated, weakly sorted, by water and wind redeposited coversand, with thin organic layers, 2 – 3 mm thick, composed of horizontally oriented non-woody, organic debris (Fig. 5b).

Features:
- Common loosely infilled fossil root channels, locally with partly decomposed root remains. Infilling with parent material; decomposition organic remains mainly by consumption by soil fauna.
- Common accumulations of black framboïdal pyrite mainly in and near the decomposed root remains
- Continuous humus-iron coatings up to 30 µm around coversand grains.
- Coversand in the infill of fossil root channels regularly devoid of coatings.

Layer 3. 107 – 112 cm – O.D.

Parent material: Open packed coversand

Features:
- Common loosely infilled fossil root channels, regularly containing partly decomposed root remains. Infilling with parent material; decomposition organic remains mainly by soil fauna. Root remains include tree roots.
- Common accumulations of black framboïdal pyrite in and near the decomposed root remains
- Continuous humus-iron coatings up to 40 µm around coversand grains (Fig. 5a), locally filling the packing voids between the mineral grains.

Layer 4. 103 – 107 cm – O.D.

Parent material: Open packed coversand

Features: Same as layer 3, except for the humus-iron coatings, which occur only locally as very thin, discontinuous coatings.

Layer 5. 96 – 103 cm – O.D.

Parent material: Open packed coversand

Features: - Common loosely infilled fossil root channels, regularly containing partly decomposed root remains. Infilling with parent material; decomposition organic remains mainly by soil fauna. They include tree roots. A few more or less intact organic remains of moss-like tissues and sklerotia. Local accumulations of more or less shapeless, black amorphous organic material. Organic material ca. 30 vol. %.

- Common accumulations of black framboïdal pyrite in and near the decomposed root remains and amorphous organic matter.

Layer 6. 87 – 96 cm – O.D.

Parent material: Accumulating humous soil material with aeolian coversand blown in at random (Fig. 5c). Ratio humous material, blown-in sand ca. 50 : 50 % v/v.

Features: - The peaty soil material is strongly decomposed by soil (meso)fauna and chemical/bacterial processes. Common root channels, regularly containing partly decomposed root remains. They include some, less decomposed, tree roots. A few more or less intact organic remains of moss-like tissues, buds and sklerotia.

- Common accumulations of black framboïdal pyrite in and near the peaty soil material.
- Locally a few gypsum rosettes in and near the peaty soil material. Ø rosettes around 190 µm.

Layer 7. 85 – 87 cm – O.D.

Parent material: Pure blown-in aeolian coversand.

Features: - A few loosely infilled fossil root channels, regularly containing partly decomposed root remains. Infilling with parent material; decomposition few organic remains mainly by soil (meso)fauna.

- A few accumulations of black framboïdal pyrite in and near the the organic remains.

Layer 8. 82 – 85 cm – O.D.

Parent material: Peaty soil material with aeolian coversand blown in at random. The peaty material increases upward from 40 to 70 % v/v and shows a horizontal lamination.

Features: - The peaty soil material largely consists of amorphous organic matter and recognizable epidermal tissues of roots and stems. The interior tissues are often missing and the complete epidermal tissues flattened and horizontally oriented by pressure exerted by the upper layers, accentuating a horizontal lamination. Also layers with mossy material. Common communition of mesofauna. Few fungal hyphen and fungal blackening of organic material.

- A few large remains of tree roots, one of oak.
- Common at random sklerotia.
- A few small accumulations of black framboïdal pyrite in and near organic material.

Layer 9. 71 – 82 cm – O.D.

Parent material: 100 % dark brown organic material, peat (Fig. 5d).

Features: - The peat is composed of ca. 60 % unrecognizable organic matter in which horizontal layers with epidermis tissues of ferns of the Dryopteris type occur (det. by D. van Smeerdijk and P. Cleveringa) and mossy material. Most unrecognizable organic matter became amorphous by chemical/bacterial processes.

- Common large remains of tree roots, most in the middle zone between 74

– 79 cm – O.D., Ø up to 1,5 cm.

- Common small irregular faunal voids due to communition in the peat and root remains. Locally small accumulations of organic faecal pellets, including those of Enchytraeïdae.
- In the top a few worm channels infilled with shapeless organo-mineral material composed of organic matter (> 50 % v/v) and clay (< 2 μm), Ø ca. 4 mm.

Layer 10. 66 – 71 cm – O.D.

Parent material: Dark brown organic material, peat, with about 20 % non-calcareous pure clay, < 2 μm, with a very few silt particles up to 4 μm.

Features: - Same composition peat as in layer 9.
- Few remains of tree roots.
- Common worm channels infilled with shapeless organo-mineral material composed of organic matter (> 50 %) and pure clay (< 2 μm), Ø ca. 4 mm (Fig. 5f). About 50 % of the layer bioturbated.
- Common small irregular faunal voids due to communition in the peat and root remains. Locally small accumulations of organic faecal pellets, including those of Enchytraeïdae and perhaps some mites (Fig. 5e). Peat area affected: about 20 %.

Layer 11. 61 – 66 cm – O.D.

Parent material: Humous pure non-calcareous clay, < 2 μm, very few silt particles up to 4 μm. Weak horizontal lamination due to differences in humus content. Clay content between 75 – 90 % v/v. Few elongated organic tissues horizontally oriented and embedded in clay laminae.

Features: - Common worm channels infilled with shapeless organo-mineral material composed of organic matter (> 50 %) and clay (< 2 μm), Ø ca. 4 mm. About 40 % of the layer bioturbated.

- Common small irregular faunal voids due to communition in the organic matter in the worm channels. Locally small accumulations of faecal pellets, including those of Enchytraeidae and perhaps some mites. Worm area affected: about 40 %.

Layer 12. 57 – 61 cm – O.D.

Parent material: 100% pure non-calcareous clay, < 2 μm, with a very few silt particles up to 4 μm, with a horizontal lamination. A very few small elongated organic tissues horizontally oriented and embedded in clay laminae (Fig. 5g/h).

Features: - At the base a very few worm channels infilled with shapeless organo-mineral material composed of organic matter and clay (< 2 μm), Ø ca. 4 mm. Organic material in excreta affected by communition of mesofauna.

Discussion

Concerning the results of the literature and micromorphological research the following subjects need to be highlighted. They are presented chronologically.

1. Firstly, the micromorphological analysis of the thin organic layers in the podzol present in the coversand between ca. 110 – 124 cm – O.D. showed that they consisted of redeposited organic debris and were part of the geogenesis of the parent material. They were not the result of illuviation which would have been the case if the podzol had developed under hydromorphic conditions. As a result the podzol present in the coversand developed under well-drained conditons.

2. Thereafter the local conditions changed considerably from well-drained to groundwater levels near the surface. Organic material accumulated at the surface and its decomposition changed from one under more mesotrophic conditions to more acidic ones. C^{14} dates of samples collected in the lower part of this layer showed that these conditions started before 1630-1510 BC (1σ cal. age). This soil material still has vertical drainage of water between 1442-1370 BC (1σ cal. age) as dated from the accumulated humous acids.
3. In the accumulating organic material on top of the podzol a continuous input of sand by wind occurred. The randomly blown-in sand could generally only be the result of sand catching in a low more or less closed, herbaceous vegetation, with a low quantity on trees. Trees catch more sand in the prevailing wind direction, resulting in an uneven distribution of sand in the same layer. Based on the detected remains of organic matter, a kind of moorland is possible.
4. The blown-in sand had the same grain-size distribution as the surrounding coversand ridges. The continuous input of blown-in sand indicated that the vegetation on the surrounding coversand ridges was not continuous for prolonged periods in which the depression became increasingly wet. As wetter conditions do not generally lead to an extended absence of vegetation, human activities on the surrounding coversand ridges would appear to be the most plausible explanation. Arable land use is the most probable kind of activity as here the land is kept cleared of vegetation.
5. Sand incorporation started well before 1630-1510 BC (1σ cal. age) and continued till the start of the actual peat growth, which occurred between 6-102 AD (1σ cal. age). The human agricultural activities could therefore have taken place for at least 1500 and probably for about 2000 year.
6. The lower half of the peat layer is a typical lowland peat formed after the groundwater level reached the surface. Trees grew on the peat as tree roots are common. Some roots were of oak, as the samples were taken next to an oak stump. The presence of remnants of ferns of the Dryopteris type generally coincide with the occurrence of Alnus trees in these

kinds of deposits as they are rather resistant to decomposition in that environment (pers. comm. P. Cleveringa).

7. In the upper half of the peat layer the hydrological conditions change. Thin layers of pure clay are deposited, indicating periods of flooding. The clay is composed of almost 100 % non-calcareous clay, < 2 µm, with very few silt particles up to 4 µm ø. This result is in accordance with Buurman's expectation that due to the method used this clay will probably be almost completely composed of mineral material < 4 µm ø. This clay cannot be marine as marine clays are deposited in mud flakes containing a substantial silt fraction with a rather constant ratio < 2 µm/ < 16 µm (Zuur, 1954; Wiggers, 1955). Consequently the clay deposit has to be a freshwater deposit. This is in accordance with the findings of Kuijer & Rosing (1994), who place the boundary of marine and fluvial deposits just north of the excavated woodland. The boundary between the marine and fluvial deposits as given in figure 2a, therefore, is not correct. Moreover the deposition of marine sediments took place from the 14th century onwards and this clay sedimentation started much earlier, about half way during the peat growth between 200 – 400 AD.
8. In the same period as that in which the flooding occurred during which clay was deposited, distinctly drier periods with increased drainage of the water were also present in which terrestrial worms were active in the topsoil and also entered the top of the underlying peat layer, showing that in this layer too, temporarily drier conditions prevailed. In the top of the upper half of the peat layer the quantity of clay increases, as does bioturbation by worms. The coarser organic matter present in the faecal material of worms is increasingly communated by Enchytraeidae. This coincidence of periods of flooding and drier periods points to a new active fresh watercourse periodically inundating and draining the woodland peat. Towards the top the inundations occurred more often.
9. Peat growth ended between AD 474 and 538 (1σ cal. age), when the peat was covered by clay. Micromorphological analysis showed that in this clay-cover no synsedimentary

deposited organic matter occurred after a few centimetres above the base and that faunal influence is absent. This deposit is composed for nearly 100% of pure undisturbed thinly laminated clay, < 2 μm. The woodland must have been inundated for prolonged periods, and as the input of organic material from e.g. leaves stopped, the woodland would have drowned.

At the same time peat growth stopped in a wider area. Ente (1986) documented that about 12 km NW of Zwolle-Stadshagen peat growth stopped at AD 520 ± 50 year (GrN 7492) and the peat became covered by a clay deposit.

10. As the clay did not contain fine and coarse silt, nor a sand fraction, it could not be a common flood plain deposit. In floodplain deposits generally a low percentage of sand grains occur. The floodplain deposits of the river IJssel about 15 km upstream of the same soil type (Rn47C) were composed of clay contents up to 50 %, fine silt fractions (2 – 16 μm) varied between 20 – 30 % and the coarse silt fraction (16 – 50 μm) between 15 – 25 % (Stiboka, 1966; Fig. 6). Moreover the meander belt along the IJssel was formed after the start of reclamation activities around AD 1100 (Kuijer & Rosing, 1994). A floodplain deposit of the river IJssel is therefore unlikely.
11. Kuijer & Rosing (1994) mapped present and former river courses of the Vecht. In Fig. 7 their figure extended slightly to the west is given. Based on this figure a change from a former watercourse of the Vecht to one that became the recent Zwarte Water seems possible.
12. The composition of the clay, almost only < 2 μm ø, may the result of a filtering of sediment by a closed herbaceous vegetation. During the temporary inundations when peat growth continued this could have been the case. To preserve such a low vegetation for prolonged periods when inundated during the sedimentation of a clay deposit of about 40-60 cm, without synsedimentary deposited organic material in a drowned woodland is not a real option. As the composition of the clay resembled a lacustrine deposit, most

probably a lateral slope (Reineck & Singh, 1974), the most logical option would appear to be a temporary lake drowning the woodland.

Conclusions

1. Micromorphological research enabled more precise and new information on the geogenesis, soil formation, the waterlevel movements and water quality, the decomposition of organic matter and the human impact to be obtained.
2. The locations of C^{14} samples of the peat were very precisely selected from the pollen monolith tins, using also the results of the microscopic analyses of the micromorphological study for a proper distinction of the dark coloured layers. As the levels and coordinates were accurately determined, the resulting radiocarbon dates will have a high reliability.
3. Based on the more precise and new information five phases can be distinguished in the development of the palaeo-landscape:
    a. The development of a well-drained podzol in aeolian coversand present in a geographical depression between two coversand ridges of the Twente Formation.
    b. An intermediate phase with a rising groundwater table reaching the surface in a more or less closed herbaceous vegetation, with a low quantity of trees. In this period there was a continuous input of blown-in sand derived from neighbouring coversand ridges, which can be attributed to a continuous use of arable land on these ridges for at least 1500 year.
    c. Lowland peat formed after the groundwater reached the surface, covered with trees including oak and alder, with ferns of Dryopteris spec. in the undergrowth. The start of the peat growth was attributed to the general evolution of the mean sea level in the Holocene.

    d. A wooded peatland within reach of a fresh watercourse, probably a new Vecht course, periodically inundating the peat and depositing fine pure clay alternated with drier periods in which the peat became partially drained and subsequently bioturbated by terrestrial worms.
    e. Formation of a fresh water lake in the first part of the sixth century AD drowning the woodland in which, through time, a clay deposit about 40 cm thick of pure fine clay < 2 µm, was laid down.
4. The five phases in the development of the palaeo-landscape were all characterized by a different hydrological regime and related water quality.
5. Besides the human presence on the coversand ridges before the peat started to grow, no other features related to human activities or presence of cattle or wild animals in the studied area were traced, viz. charred wood, burned vegetation remains, bone fragments, traces of pressure exerted on soil material by men or animals.

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Captions Figures

Figure 1. Maps of (A) the geological distribution of Pleistocene and Holocene deposits in the centre of the Netherlands after Zagwijn (1991) and (B) the geomorphological setting of the northwestern part of the Province of Overijssel after Wolfert (2001).

Figure 2. Profile of sampled excavation trench with location of the micromorphological sampled zone, pollen monoliths and field description, all ca. 50 cm from each other. In the micromorphologically sampled zone the microscopically distinguished layers are given and the locations of the microphotographs of figure 5. In the pollen monolith tins the locations of the C^{14} and grain size analysis samples are given.

Figure 3. Grain size analyses of the clay on top of the peat (ACg), the sandy humous layer (5AC) and the E horizon of the coversand podzol (6E).

Table 1. Radiocarbon dates from the studied section.

Figure 4. C^{14} dating basal peat wetland wood Zwolle plotted in the mean sea-level curve after Van de Plassche, 1982.

Figure 5. Microphotographs of key features for the reconstruction of the landscape history. The location of these features is given in figure 2, first column. Magnifications all x 25.

a. B1hs, amorphous coatings around coversand grains
b. geogenetic organic debris in B2hs
c. sandy humous layer with compressed epidermal tissues
d. peat with remnants of Dryopteris ferns.
e. decomposition peat by enchytraeids
f. decomposition peat by worms
g. base pure clay deposit with some synsedimentary deposited organic material, plain light

h. base pure clay deposit with some synsedimentary deposited organic material, crossed polarizers

Fig. 6. Grain size analyses reference profiles of the same soil unit in the same area from the soil map of the Netherlands 1:50.000. a. 14 km south of the excavation in the IJssel meander belt; b. 2 km northeast of the excavation near the Zwarte Water.

Fig. 7. Former and present river courses in the inland Vecht Delta (extended after Kuyer & Rosing, 1994).

Table 1.

Table 1. Radiocarbon dates from the studied section.

Sample name	Laboratory no.	Depth (cm below Dutch O.D.)	Material	^{C14}-age (BP)	Median cal. age[1] (BC/AD)	1σ cal. age range[1] (BC/AD)	2σ cal. age range[1] (BC/AD)
Zwolle I	GrN-27024	60.5-62.5	peat (bulk)	1540 ± 30	503 AD	474-538 AD	442-566 AD
Zwolle II	GrN-27025	76.5-79.0	peat (bulk)	1950 ± 40	51 AD	6-102 AD	42 BC-146 AD
Zwolle III	KIA-19154	89.5-91.5	soil (alkali residue)	3280 ± 45	1571 BC	1630-1510 BC	1670-1450 BC
Zwolle III	KIA-19154	89.5-91.5	soil (humous acid)	3145 ± 30	1406 BC	1442-1370 BC	1478-1334 BC

[1] The Groningen calibration program (version CAL25) was used (Van der Plicht, 1993). The degree of smoothing of the calibration curve was based on Törnqvist & Bierkens (1994): σ_s = 200 was applied.

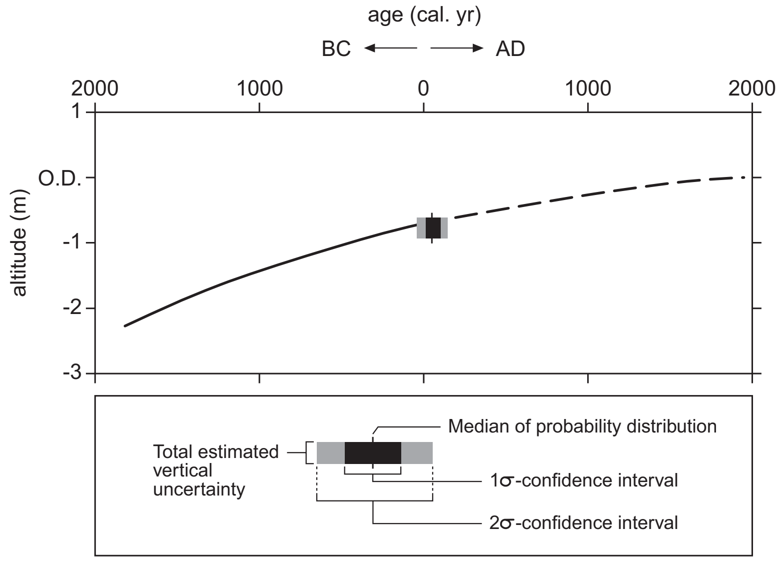
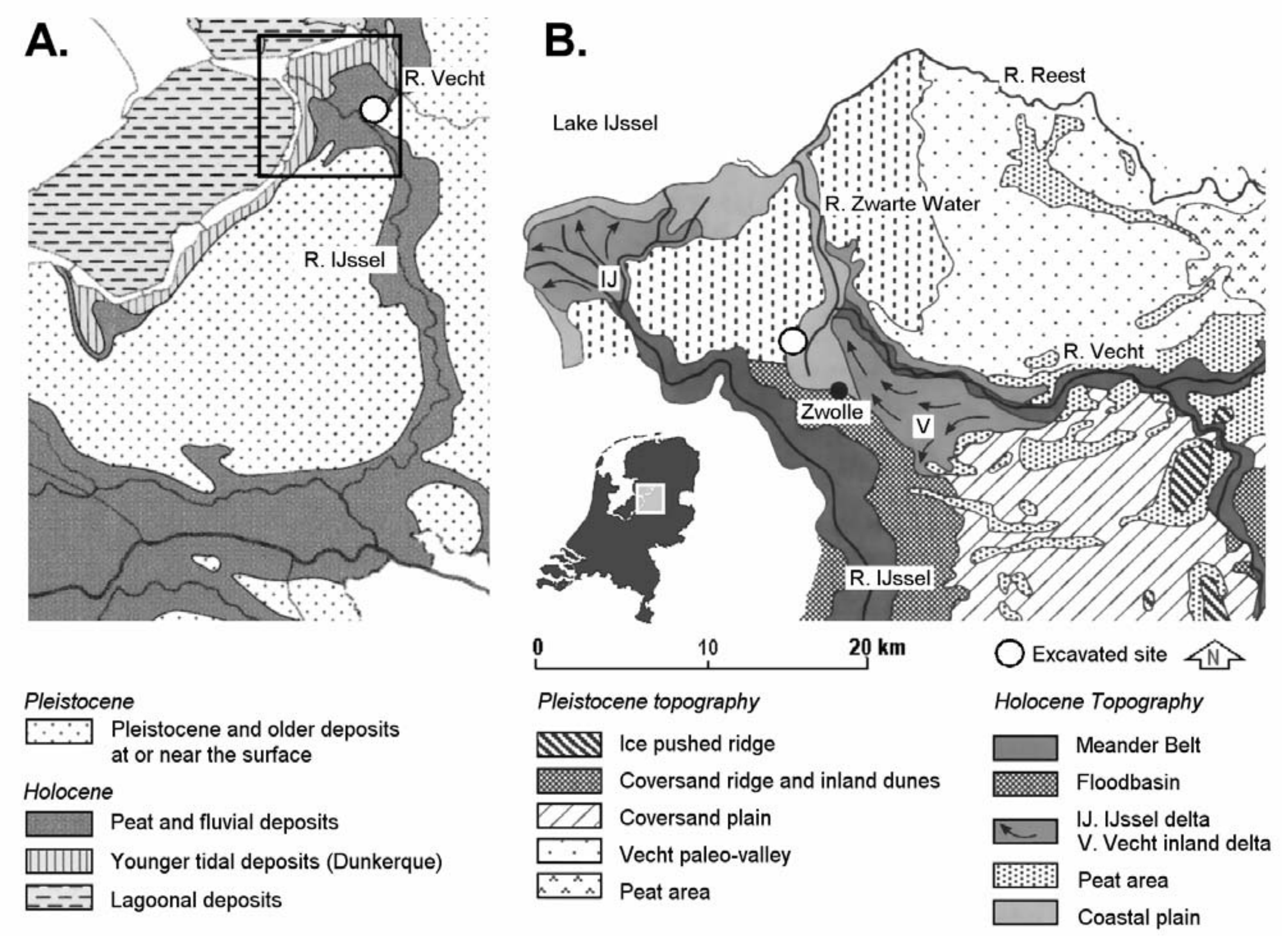
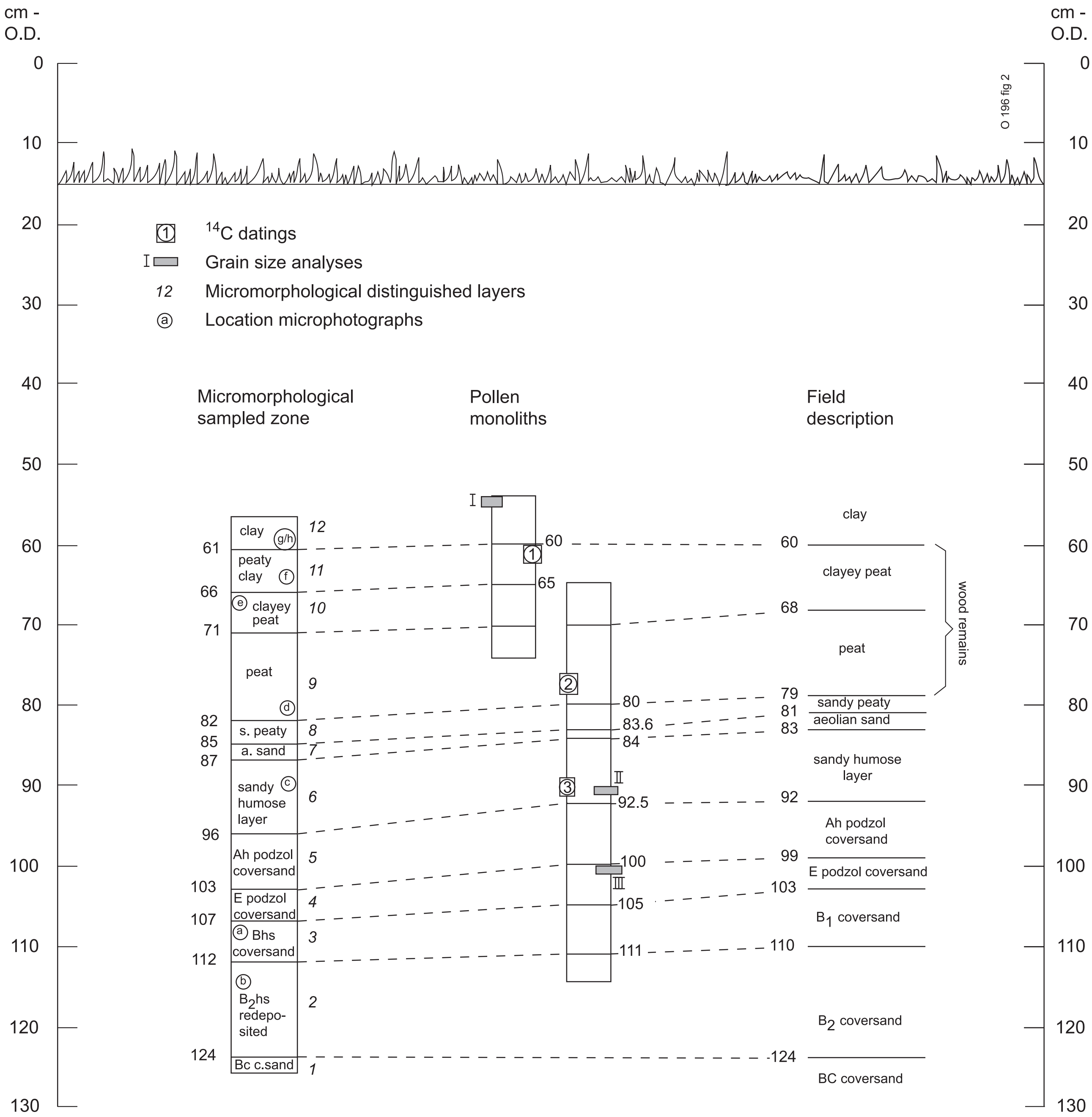

age (cal. yr)
BC
AD
2000
1000
0
1000
2000
1
O.D.
-1
-2
-3
altitude (m)
Median of probability distribution
Total estimated vertical uncertainty
1σ-confidence interval
2σ-confidence interval

Figure 4.

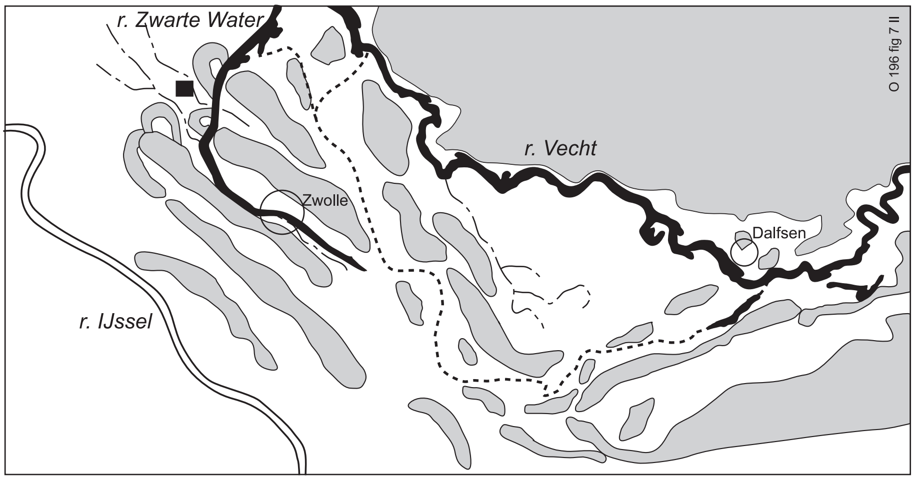


Figuur 1, Woodlands of the past II.

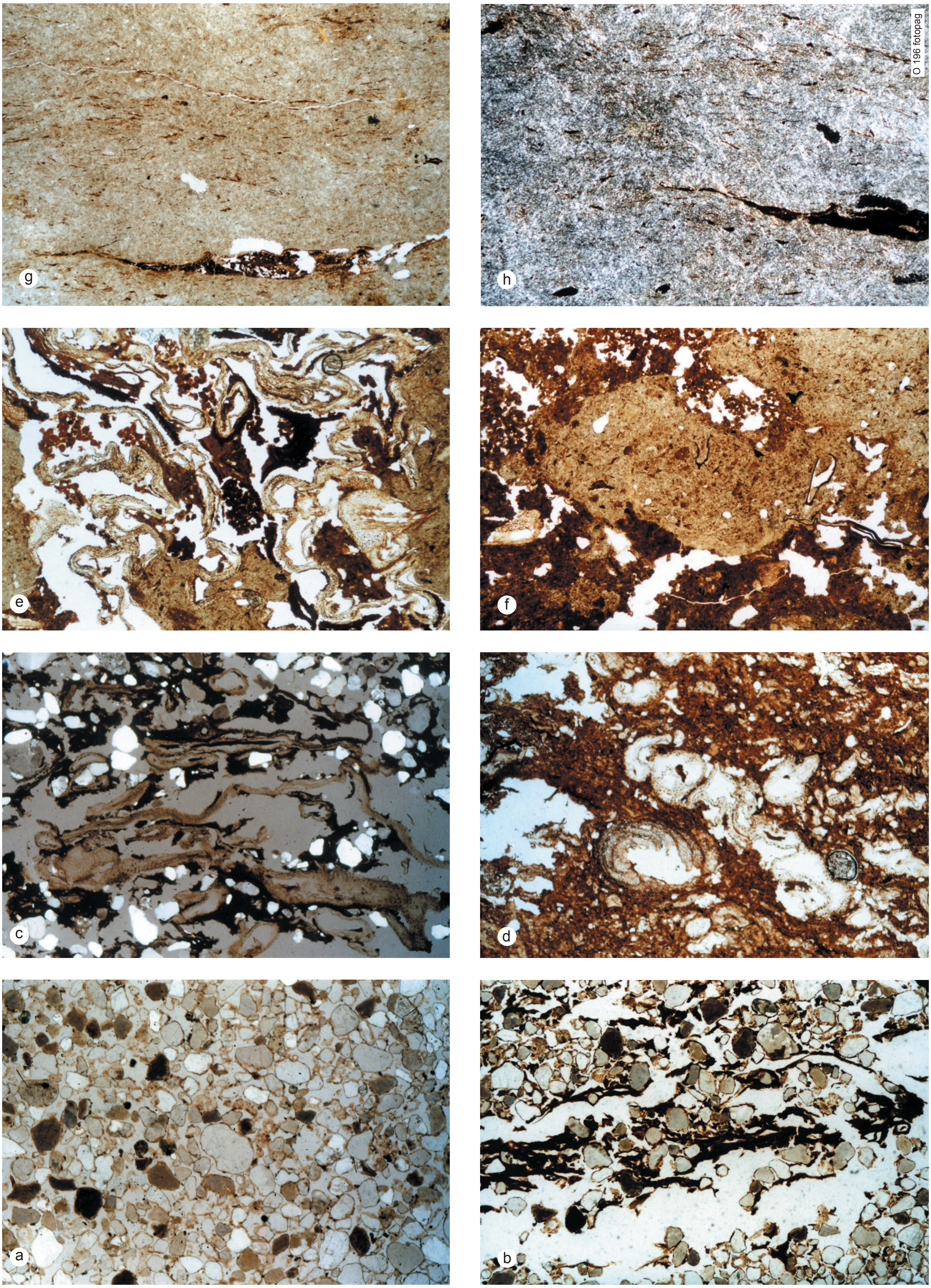
figuur is nu 17 cm groot



cm - O.D.
O 196 fig 2
14C datings
Grain size analyses
12 Micromorphological distinguished layers
a Location microphotographs
Micromorphological sampled zone
Pollen monoliths
Field description
clay
peaty clay
clayey peat
peat
s. peaty
a. sand
sandy humose layer
Ah podzol coversand
E podzol coversand
Bhs coversand
B2hs redeposited
Bc c.sand
clayey peat
sandy peaty
aeolian sand
sandy humose layer
E podzol coversand
B1 coversand
B2 coversand
BC coversand
wood remains



Riverdunes and coversand dunes and ridges
Actual course river Vecht and Zwarte Water
Possible course river Vecht before 200 y BC
Not defined former courses
Excavated area


g
h
O 196 fotopag
e
f
c
d
a
b

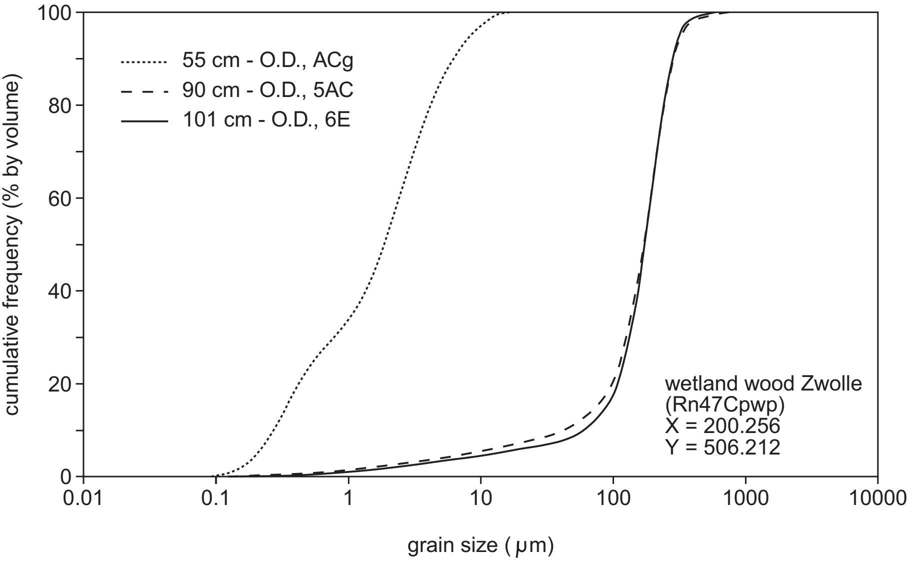
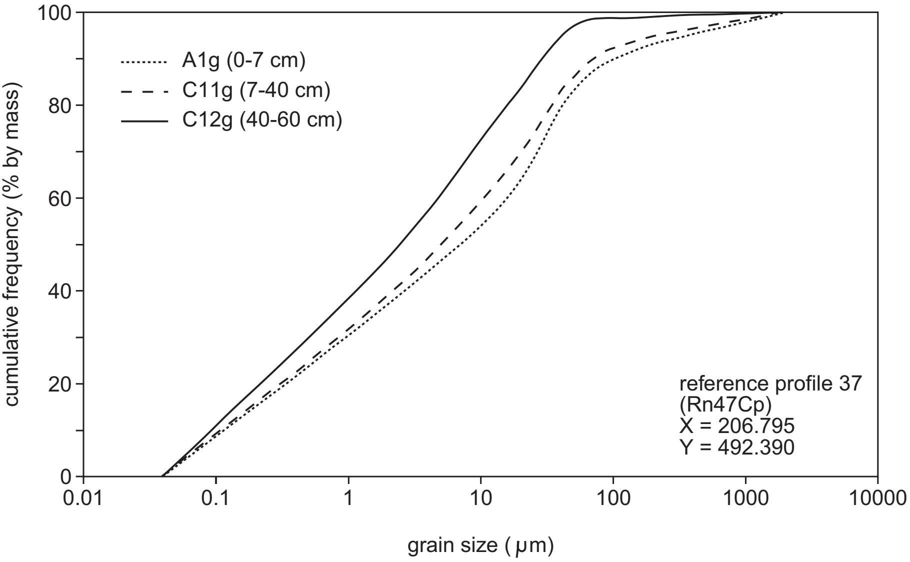

100
80
60
40
20
0
cumulative frequency (% by volume)
55 cm - O.D., ACg
90 cm - O.D., 5AC
101 cm - O.D., 6E
wetland wood Zwolle
(Rn47Cpwp)
X = 200.256
Y = 506.212
0.01
0.1
1
10
100
1000
10000
grain size (μm)

Figure 3



A1g (0-7 cm)
C11g (7-40 cm)
C12g (40-60 cm)
reference profile 37
(Rn47Cp)
X = 206.795
Y = 492.390
cumulative frequency (% by mass)
grain size (μm)
0
20
40
60
80
100
0.01
0.1
1
10
100
1000
10000

Figure 6a

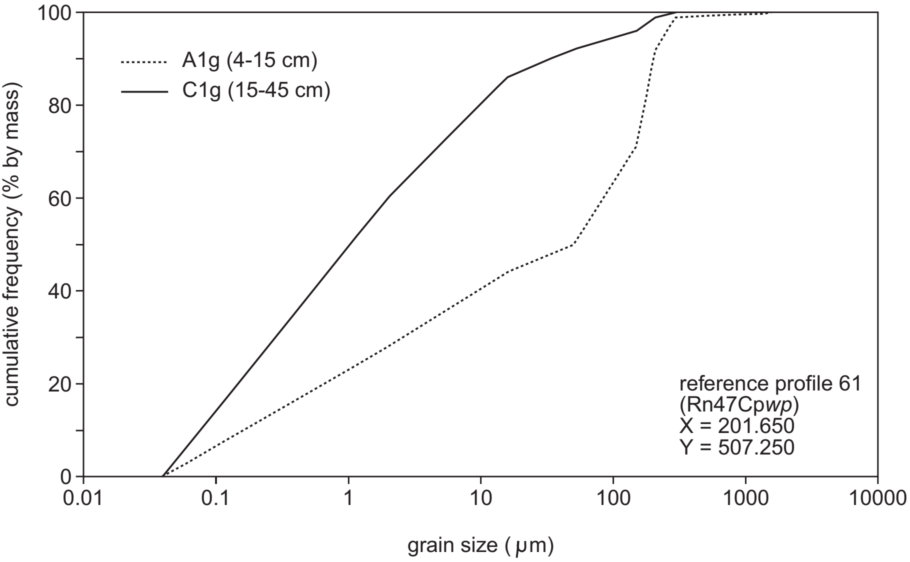
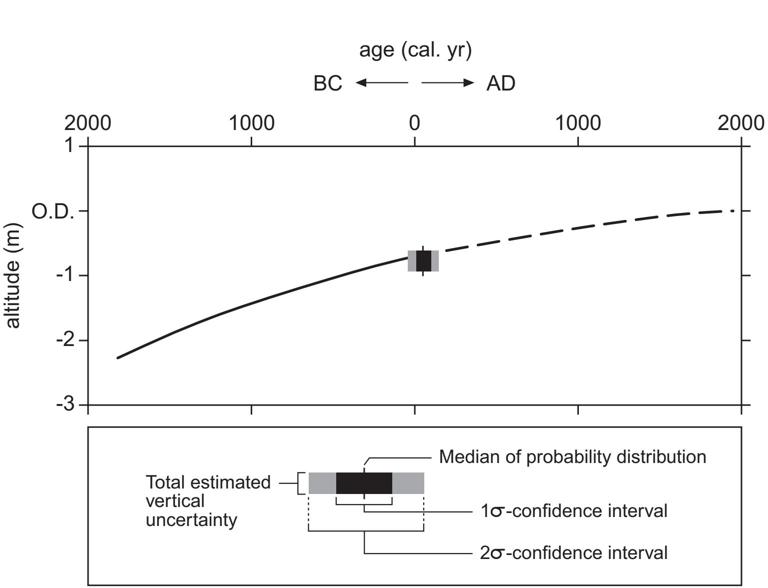

100
80
60
40
20
0
cumulative frequency (% by mass)
A1g (4-15 cm)
C1g (15-45 cm)
reference profile 61
(Rn47Cp*wp*)
X = 201.650
Y = 507.250
0.01
0.1
1
10
100
1000
10000
grain size (μm)

Figure 6b



age (cal. yr)
BC
AD
2000
1000
0
1000
2000
1
O.D.
-1
-2
-3
altitude (m)
Median of probability distribution
Total estimated vertical uncertainty
1σ-confidence interval
2σ-confidence interval