Woodlands of the past: results of the excavation of Zwolle-Stadshagen (The Netherlands) II, Development of the paleo-landscape in its hydrological context

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Abstract

Micromorphology was used to reconstruct the paleo-landscape in which a woodland had grown between about 200 BC and 600 AD 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 been 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 on trees, possibly a kind of moorland, accumulated in which continuously sand was blown-in from local coversand ridges. The ridges had to be cleared of vegetation for more than 1500 yr by human, probably acricultural, activities. Peat growth on which a woodland was present started between 6-102 yr AD and could be attributed to the general evolution of 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 more decomposed by bioturbation of terrestrial worms, indicating drier conditions. At the same time inundations occurred whereby thin layers of almost pure clay (< 2 μm) were deposited. During this period a new active fresh water course periodically inundating and draining parts of the peat had to be present. This might be a water course of the Vecht preceding the course of the recent Zwarte Water. No traces of human activities nor animal foraging were found in the woodland peat. Peatgrowth and the growth of the wetland wood ended between 474 and 538 yr AD. The peat became covered by a thick layer of pure clay (< 2 μm) representing a lacustrine deposit, indicative for the presence of an inland freshwater lake for a prolonged period. This is the second article of a set of five on the integrated reconstruction of this woodland of the past.

Keywords:
Paleo-landscape, micromorphology, ^{14}C dates, subfossil woodland, hydrology.

Introduction

Nowadays more detailed information on former landscapes and vegetation structures as well as on the underlying causes is requested. Former landscapes and vegetation structures are being used as references for planning activities in the rural environment and can be used to analyze changes due to external site conditions, for example hydrological changes and their triggers in larger scale variations in climate conditions. The discussion started bij 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 researchers reacted against this view (a.o. Bremt *et al*. 1998, Zeiler & Kooistra, L.I. 1998), but arguments for and against did not go anywhere by lack of proof and the absence of adequate studies. Shortly thereafter during a field survey of a terrain 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 extent of the area was such that a buried woodland could be expected. A group of specialists of different disciplines got together to discuss the options for an integrated approach by using geological, micromorphological, ecological and dendrochronological data sets in order to redefine the possibilities of reconstructing paleo landscapes and -vegetation. The experience gained by Kooistra M.J. & Kooistra, L.I. (accepted), 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 was used. 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 paleo-landscape and its hydrological context in the time frame the woodland has grown. 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 Polder Mastenbroek in the northwest of the Province of Overijssel (see figure 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 sealevel rise and the coastline gradually moved landinward. The sealevel rise caused increased grondwater levels inland. When the groundwater level reached the surface, peat started to develop. In this Basal Peat often wetland woods developed. Depending on the relief of the Pleistocene land surface and the position and impact of the inland rivers peat growth started at a later date. Peat growth reached the lower parts of the study area in the Late Subboreal around 1250 BC from the northwest and the expansion continued through the Roman Period. At the start of the early Middle Ages, around 500 y AD, peat expansion stopped (Zagwijn, 1991). In the study area the peat became covered by a clay deposit. This clay deposit can be fluviatile or marine. Two rivers were important in this area, the IJssel and the Vecht. The IJssel, discharging the water of the Rhine started again to flow around the start of our era. During the period of extensive peat growth sedimentation was very limited. From the early Middle Ages onwards, river-sediments from the IJssel started to accumulate (Lanting & Mook, 1977; Van de Meene, 1979; Willems, 1981; Zagwijn, 1991). After the start of reclamation activities along the IJssel around 1100 AC 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 Northsea widened. Around 1600 AD 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 of by the construction of an enclosure dam in 1932. Thereafter no sedimentation has taken place from the sea in this area (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 buried wetland wood is given. From figure 1A can be detected 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, whereby 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 starts of about 15 – 50 cm thickness on top of Pleistocene sands in which a podzol is 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. These soils were used as permanent pastures.

Materials and methods

Site conditions and sampling

In a preliminary survey a terrain of 3 ha where the clay layer on top of the peat was removed was examined and two trenches of 15 x 80 m were studied in detail. Based on the obtained information and quality of the woody remains four new trenches, with artificially reduced groundwater levels, starting from the surface with a total area of ca. 1270 m^2, were excavated till the base of the buried woodland. In the trenches the remains of the stumps and trunks of the former trees were present in their original position. 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 used field techniques and sampling strategies 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 hectares was uniform, only the thickness of the peat layer and its base level showed slight variation, generally a few centimeters, with a maximum of 30 centimeters. As all profile walls were representative on themselves one location for detailed sampling was selected next to a well preserved stump of an oak tree (trench 5, Westprofile. Tree number 1, see fig .. Kooistra, L.I., *et al*. I, 2003). In this way the tree roots present in the profile wall could be correlated with the adjoining tree stump and the growth of the tree related to the development of the soil profile and the peat. 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 ^{14}C 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 gammaradiation. 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 en Heintzberger, 1975; Bisdom en Schoonderbeek, 1983). The thin sections were analysed with a polarisation research microscope with magnifications up to 200 x. Overviews of used procedures 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 ^{14}C 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	AC	Gray (10 YR 6/1), with yellowish brown (10 YR 5/6) mottles, clay (> 45 % < 2 μm); strong developed, slightly rounded, large prisms (Ø ca. 20 cm), subdivided into weak 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 grayish brown (10 YR 3/2) clay-containing decomposed peat; clay content decreases with depth. Clear smooth boundary.
68- 79 cm	3AC	Very dark gray (10 YR 3/1) peat, largely decomposed, some small recognizable twigs and stems, common tree roots. Sharp slightly irregular boundary.
79- 81 cm	4AC	Very dark gray (10 YR 3/1) sandy humose 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 gray (10 YR 7/2) aeolian sand layer. Sharp slightly irregular boundary.
83- 92 cm	5AC	Dark yellowish brown (10 YR 3/4), sandy humose material. Clear smooth boundary.
92- 99 cm	6A	Dark brown (10 YR 4/3) coversand. Clear slightly wavy boundary.
99-103 cm	6E	Grayish brown (10 YR 5/2) coversand. Clear slightly wavy boundary.
103-110 cm	6B1	Dark yellowish brown (10 YR 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 YR 4/4) coversand with thin dark brown (7.5 YR 3/2) organic layers. Faint slightly wavy boundary.
> 124 cm	6BC	Brownish yellow (10 YR 6/6) coversand.

Three grain-size analyses were performed by laser diffraction. They are from the following layers: I. 1AC, base of the clay layer, 55 cm – O.D.; II. 5AC, sandy peat, 91 cm – O.D. and III. 6B1, coversand, 101 cm – O.D. (see Fig. 3). The compositions of the coversand and the sand in the sandy peaty layer 5AC are 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 a nearly negligible low percentage of 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 ^{14}C 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 middle zone of the sandy humose layer. The depths and results are given in table 1.

From the above presented data the following sequence of events can be detected:
In a coversand depression a podzol was developed. The groundwater level started to rise and at the surface a sandy organic rich layer started to accumulate. The formation of this parent material was, based on the dating of the alkali residue, well started between 1630-1510 yr BC (1σ cal. age). In this parent material soil formation resulting in an accumulation of humic acid has taken place. The humic acid present in this sediment is dated between 1442-1370 yr BC (1σ cal. age).
The formation of the peat on top of this sandy humose 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 yr AD (1σ cal. age) and ended between 474-538 AD (1σ cal. age). During this period the wetland wood existed.

To estimate whether the groundwater level rise was due to a rise in regional or local water levels the ^{14}C date of the base of the peat was plotted in the mean sea level-curve of Van de Plassche (1982) (Fig. 4). The date fitted well, when the curve was extended to around the beginning of our era. As the samples could be precisely collected from a well excavated profile wall that was accurately levelled and also was collected from a wetland wood growing at surface level the potential error sources 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 are described successively starting with the deepest layer. In this way the genesis and possible human influences can be studied chronologically from old to young. The data recording consists 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 by wind and water redeposited coversand and includes thin layers of by water deposited organic debris (see Fig. 5b).
- Layer 3, 4, 5 (96-112 cm – O.D.) form one aeolian coversand deposit.
- In layer 2, 3, 4, 5 (96-124 cm – O.D.) a podzol had been developed with a humose 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 aluminium forming amorphous coatings around sand grains (B1hs, layer 3: 107-112 cm – O.D., see Fig. 5a; B2hs, layer 2: 112-124

cm – O.D.). This type of coatings is formed in well-drained podzols developed on poor parent materials. When the bands of organic matter in layer 2 would have 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.

- Layer 6, 7, 8 (82-96 cm – O.D.) sandy, humose layers, are the result of increasing poorer conditions for decomposition of organic matter, due to increased wetness. Presence of a few gypsum rosettes in layer 6 indicates local mesothrophic, non acid, conditions. This is supported by the presence of moder humus characteristic for 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 layer 6 and 8 and a pure, in one time blown in, sand layer of about 2 cm thickness (layer 7). The organic material is horizontally compressed by the load 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 were growing on the peat as tree roots are common. The pH became more acid as mesofauna was limited and bacterial decomposition common. Also here organic material is horizontally compressed by the load of superficial layers.
- Layer 10 (66-71 cm – O.D.) is also a woodland peat, but one that is periodically flooded whereby increasingly more fine clay (< 2 μm) was deposited. In between drier conditions prevailed as many traces of worms and mesofauna, especially enchytraids (Fig. 5e) were found. For their presence the pH had to increase to slightly acid or neutral. Some wormcasts were present in the top of the lower peat layer, indicative for fluctuating groundwater levels also in that zone. The peaty material is still compressed.
- Layer 11 (61-66 cm – O.D.) is a partly bioturbated humose 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 wormexcreta. At the base together with the clay some, most probably, local organic material is deposited.
- Layer 12 (57-61 cm – O.D.) composed of nearly 100 % pure clay is a horizontally laminated water deposit (Fig. 5 g/h). As syn-sedimentary deposited organic matter after a few centimeters is almost absent and faunal influence stops completely, the woodland had to be 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 rootchannels, locally containing partly decomposed root remains. Infilling with parent material; decomposition organic remains mainly chemically/bacteriological.
- Common small accumulations of black framboïdal pyrites 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 rootchannels, locally with partly decomposed root remains. Infilling with parent material; decomposition organic remains mainly by consumption of soil fauna.
- Common accumulations of black framboïdal pyrites mainly in and near the decomposed root remains
- Continuous humus-iron coatings up to 30 µm around coversand grains.
- Coversand in the infilling of fossil rootchannels regularly devoid of coatings.

Layer 3. 107 – 112 cm – O.D.
Parent material: Open packed coversand
Features: - Common loosely infilled fossil rootchannels, 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 pyrites 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 pyrites in and near the decomposed root remains and amorphous organic matter.

Layer 6. 87 – 96 cm – O.D.
Parent material: Accumulating humose soil material with at random blown in aeolian coversand (Fig. 5c). Ratio humose material, blown-in sand ca. 50 : 50 vol. %.
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 pyrites in and near the peaty soil material.
- Locally a few gypsum rosettes in and near the peaty soil material. Ø 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 pyrites in and near the the organic remains.

Layer 8. 82 – 85 cm – O.D.

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

Features: - The peaty soil material largely consists of amorphous organic matter and recognizable epidermis tissues of roots and stems. The interior tissues are often missing and the complete epidermis 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 pyrites 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 feacal pellets, including those of enchytraeïdae.
- In the top a few worm channels infilled with shapeless organo-mineral material composed of organic matter (> 50 %) 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 feacal 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: Humic pure non calcareous clay, < 2 μm, with a 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 feacal 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. Organic material in excreta affected by communition of mesofauna.

Discussion

Concerning the results of the literature and micromorphological research the following subjects needs 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 that would have been the case when the podzol was developed under hydromorphic contitions. As a result the podzol present in the coversand was 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 mesothrophic conditions to more acid ones. ^{14}C dates of samples collected in the lower part of the more mesothrophic decomposition showed that these conditions started well before 1630-1510 yr BC (1σ cal. age). This soil material still has a vertical drainage of water between 1442-1370 yr BC (1σ cal. age) as dated from the accumulated humic acids.
3. In the accumulating organic material on top of the podzol a continuous input of sand by wind occurred. The incorporated blown-in sand was at randomly incorporated which generally only can be the result of the catching of sand 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 uneven distributions of sand in the same layer. Based on the detected remains of organic matter, a kind of moorland, is possible.
4. The incorporated sand had the same grain size distribution as the surrounding coversand ridges. The continuous input of blown-in sand indicates that the surrounding coversand ridges largely had to be cleared of vegetation for prolonged periods in which the depression became increasingly more wet. As wetter conditions generally do not lead to an extended absence of vegetation, human activities on the surrounding coversand ridges seem the most plausible explanation. Arable land use is the most probably kind of activity as here the land is kept cleared of vegetation.
5. Sand incorporation started well before 1630-1510 yr BC (1σ cal. age) and continued till the start of the proper peat growth, which occurred between 6-102 yr AD (1σ cal. age). The human, agricultural, activities therefore could have taken place for at least 1500 yr and probably for about 2000 yr.
6. The lower half of the peat layer is a typical lowland peat formed after the groundwater level reached the surface. Trees were growing on the peat as tree roots are common. Part

of the roots were of oak, as the samples are 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 in that environment rather resistant to decomposition (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 from nearby water courses. The clay is composed of almost 100 % non calcareous clay, < 2 µm, with a very few silt particles up to 4 µm ø. This result is in accordance with the expectation of Buurman that due to the used method this clay probably almost completely will be composed of mineral material < 4 µm ø. This clay can not 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 fresh water 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 14^{th} century onwards and this clay sedimentation started much earlier, about half way during the peat growth between 200 – 400 yr AD.
8. In the same time frame when the floodings occurred during which clay was deposited, also distinctly drier periods with increased drainage of the water were present in which terrestrial worms were active in the topsoil. They also entered the top of the preceeding peat layer without clay deposition, showing that also in this layer temporary drier conditions prevailed. In the top of the upper half of the peat layer the quantity on clay increases, as well as the bioturbation by worms. The coarser organic matter present in the feacal material of worms is increasingly communated by enchytraeidae. This coincidence of floodings and drier periods directs to a new active fresh water course periodically inundating the woodland peat and in between draining the peat. Towards the top the inundations occurred more often.
9. Peat growth ended between 474-538 AD (1σ cal. age), when the peat got covered with a clay deposit. Micromorphological research showed that in this clay cover after a few centimeters no syn-sedimentary deposited organic matter occurs and that faunal influence is absent. This deposit is composed for nearly 100% of pure undisturbed thinly laminated clay, < 2 µm. The woodland had to be inundated for prolonged periods, and as input of organic material from e.g. leaves stops, the woodland will have been drowned.
10. As the clay deposit does not contain fine and coarse silt, as well as 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 stream upward of the same soil type (Rn47C) are composed of clay contents up to 50 %, the fine silt fraction (2 – 16 µm) varies 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 1100 AC (Kuijer & Rosing, 1994). A floodplain deposit of the river IJssel is therefore not likely the case.
11. Kuijer & Rosing (1994) mapped present and former river courses of the Vecht. In Fig. 7 their slightly extended figure is given. Based on this figure a change from the former watercourse of the Vecht around 200 yr BC to the one that became the recent Zwarte Water seems possible.
12. The composition of the clay, almost only < 2 µm ø, can be 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 woodland that is drowned is not a real option. As the composition of the clay resembles a lacustrine deposit, most probably a lateral slope (Reineck & Singh, 1974), the most logical option seems a temporary lake drowning the woodland.

Conclusions

1. Micromorphological research enabled to obtain more precise or new information on the geogenesis, soil formation, the waterlevel movements and water quality, the decomposition of organic matter and the human impact.
2. The locations of ^{14}C 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 obtained five phases can be distinguished in the development of the paleo-landscape in the studied period:
   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 in between phase with rising groundwater tables reaching the surface when a low more or less closed herbaceous vegetation, with a low quantity on trees occurred. In this period a continuous input of blown-in sand derived from neighbouring coversand ridges took place, that can be attributed to a continuous arable land use for at least 1500 yr on these ridges.
   c. A typical lowland peat formed after the groundwater reached the surface, covered with trees including oak and alder, with in the undergrowth ferns of Dryopteris spec. The start of the peat growth could be attributed to the general evolution of the mean sea level in the Holocene.
   d. A wooded peatland within reach of a fresh water course, probably a new Vecht water course, periodically inundating the peat and depositing fine pure clay alternated with drier periods in which the peat became partially drained and bioturbated by terrestrial worms.
   e. Formation of a temporary lake in the first part of the sixth century AD drowning the woodland in which during time a clay deposit of about 40 cm thickness of pure fine clay < 2 µm, was laid down.
4. The five phases in the development of the paleo-landscape were all characterised by a different hydrological regime and related water quality (see also point 3).
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 was 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 Art. II

Figure 1. Maps of (A) the geological distribution of Pleistocene and Holocene deposits in the middle 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 + lagen + bemonsterde locaties + ^{14}C locaties + microfoto locaties
Figure 3. Grain size analysis
Table 1. ^{14}C dating
Figure 4. ^{14}C 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

a. B1hs, amorphous coatings around coversand grains
b. geogenetic organic debris in B2hs
c. sandy peat with compressed epidermis tissues
d. peat with remnants of Dryopteris ferns.
e. decomposition peat by enchytraeids
f. decomposition peat by worms
g. pure clay deposit, plain light
h. pure clay deposit, crossed polarizers

Fig. 6. Grain size analyses reference profiles IJssel meander belt
Fig. 7. Position recent Vecht water courses and its probable preceding ones (extended after Kuyer & Rosing, 1994).

Table 1.

Table 1. Radiocarbon dates from the studied section.

Sample name	Laboratory nr.	Depth (cm below Dutch O.D.)	Material	^{14}C-age (yr BP)	Median cal. age[1] (yr BC/AD)	1σ cal. age range[1] (yr BC/AD)	2σ cal. age range[1] (yr 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 (humic 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.

Figure 4.