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Kasse, C.

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Excursion on 20th September 2011

Geological and landscape evolution of the Rhine-Meuse delta; natural processes and human activity

Kees Kasse

Introduction

The aim of this field trip is to demonstrate the geological evolution of the delta plain in the western and central Netherlands by means of a west to east transect (fig. 1). The trip will start in the west at the present-day coast and ends in the Pleistocene ice-pushed landscape in the east. On our way to the east the following items will be shown in the landscape and by hand corings: coastal barriers and dunes, water management and lake drainage at Cruquius, tidal and lagoonal deposits related to the Holocene transgression, peat formation due to Holocene sea-level rise, peat digging and polder formation, fluvial systems in the peat landscape, glacial basins and ice-pushed ridges.

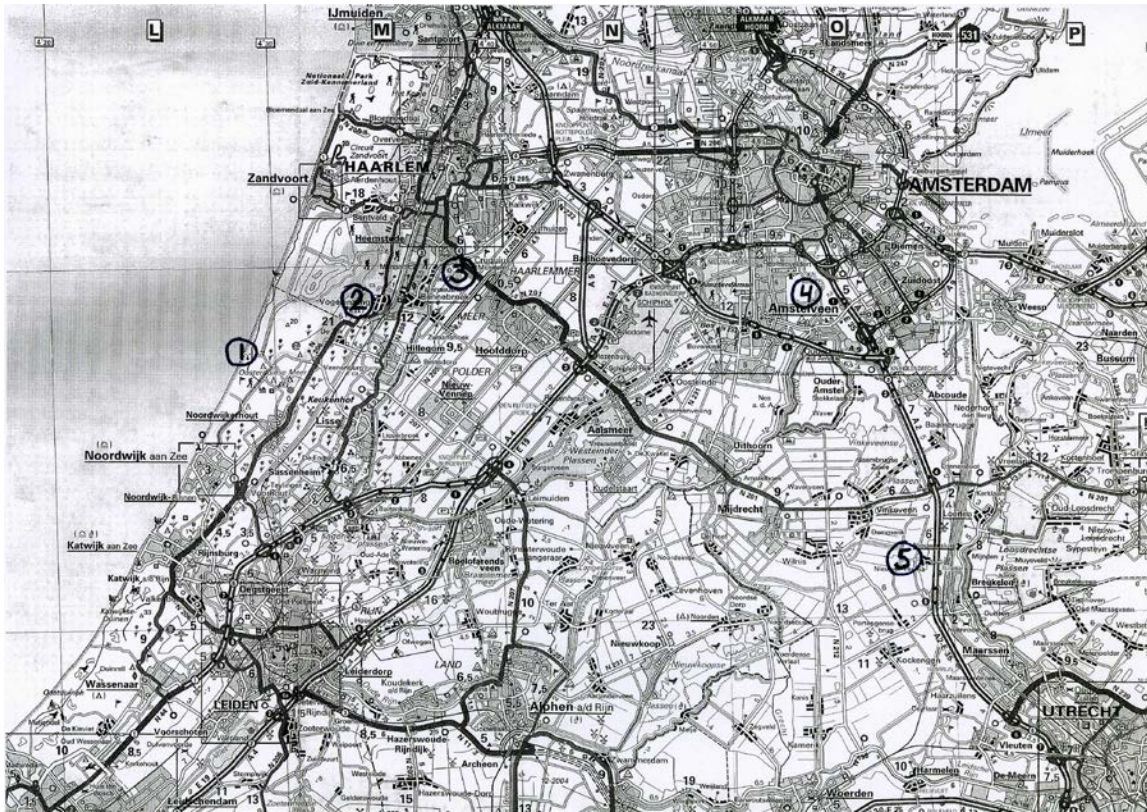


Fig. 1 Excursion route

Geological and paleogeographical development

The Netherlands are situated in a delta formed by the Rhine, Maas, Schelde and, before the Middle Pleistocene, by rivers from Germany and the Baltic region. The position of the rivers is the result of the interplay between tectonic processes, Scandinavian glaciation of the delta and climate change (De Gans, 2007). The major Quaternary subsidence areas are situated in the northwest of the Netherlands (Zagwijn & Doppert, 1978). Before the (second last) Saalian glaciation the flow direction of the Rhine/Maas was to the northwest. The Saalian glaciation totally changed the flat morphology of the delta (stop 6). The

Fennoscandian ice sheet reached the central part of the Netherlands from Amsterdam in the northwest to Nijmegen in the southeast. Up to 100 m high ice-pushed ridges were formed, that mainly consist of pre-glacial fluvial sands and gravels. Southwest of the ice-pushed ridges large outwash plains were formed by fluvial-glacial processes. The courses of the Rhine and Maas were diverted to the west, the dominant stream direction until the present day (Zagwijn, 1974).

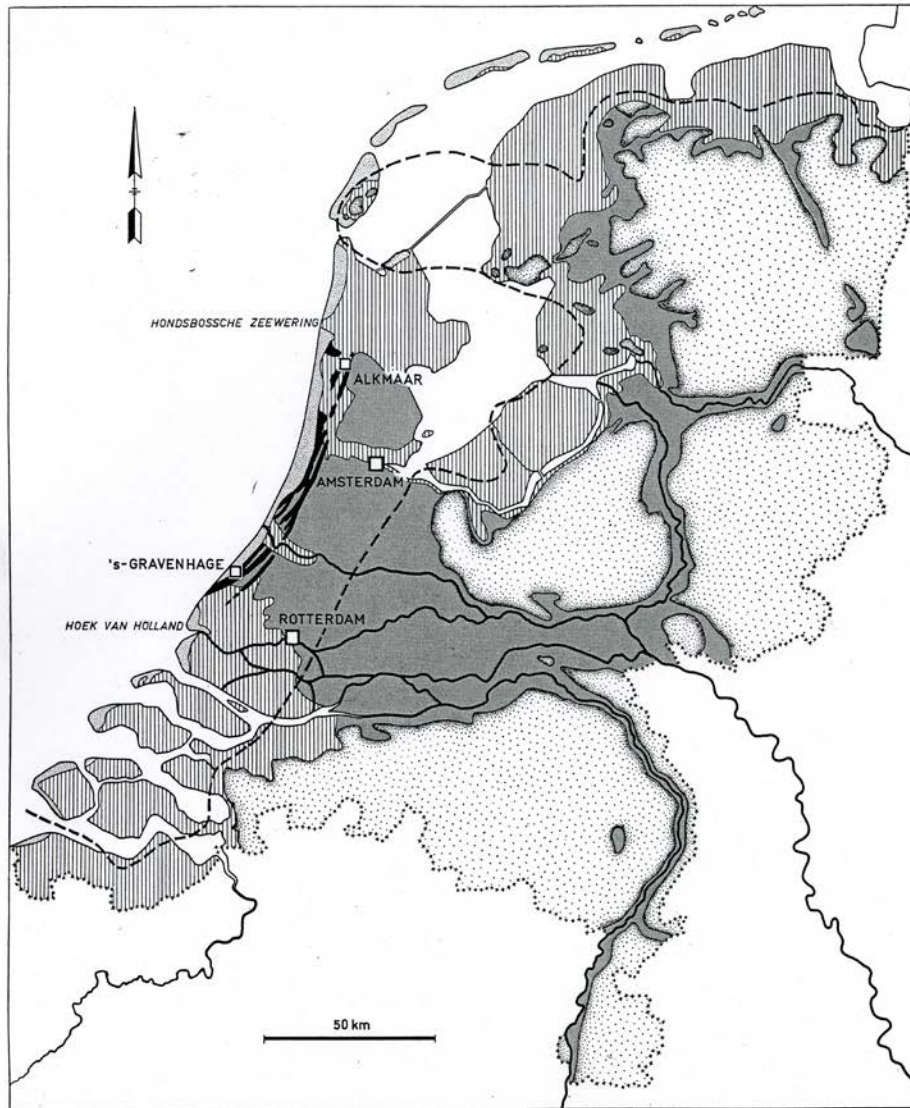


FIG. 2 — Generalized geological map of The Netherlands

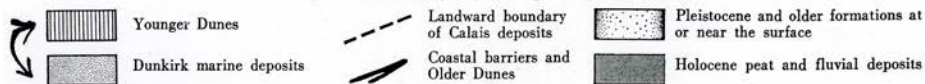
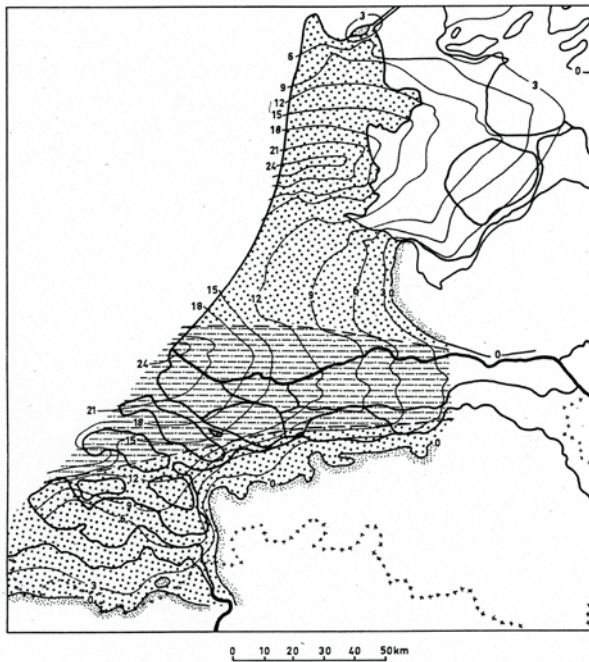


Fig. 2 Generalized geological map of the Netherlands (Jelgersma et al., 1970).

During the last Pleistocene ice age (Weichselian) the Scandinavian ice cap reached northern Germany. The Netherlands experienced very cold and dry climatic conditions and aeolian coversands were deposited on higher grounds. In the river valleys braided river deposits aggraded due to the high sediment supply (Kasse, 2002). Rhine and Maas flowed over the dry North Sea area to the southwest through the Dover Strait into the Atlantic Ocean. At the end of the Pleistocene period a fairly flat, generally westward dipping sand area existed in the western Netherlands (fig. 3).



- Contours of top the Pleistocene, in metres
- Pleistocene at or near the surface
- Fluvatile area with local riverdunes
- Coversand area

Fig. 3 Depth contours of the top of the Pleistocene deposits (Hageman, 1969).

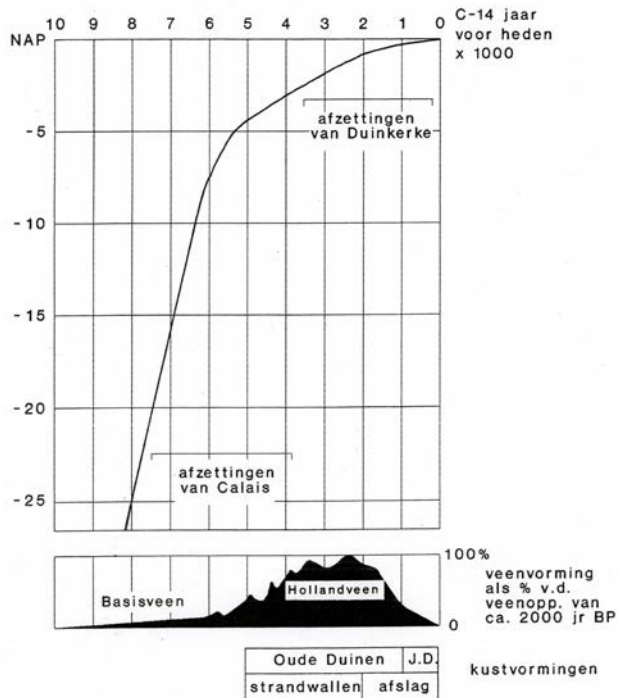


Fig. 4 Holocene sea-level rise for the Netherlands (Rappol & Soonius, 1994).

During the Weichselian Late Glacial and start of the Holocene period the climate became warmer and as a consequence the ice sheets melted, causing a rapid sea-level rise (Jelgersma, 1961) (fig. 4). By the sea-level rise the ground-water level in the sandy plain of the western Netherlands rose as well. As a consequence the area became marshy and peat began to develop (so-called Basisveen = Basal Peat, at the base of the Holocene succession) (fig. 5: stage I). Because of the sea-level rise this Basal Peat is time transgressive; being older in the west than in the east of the coastal plain.

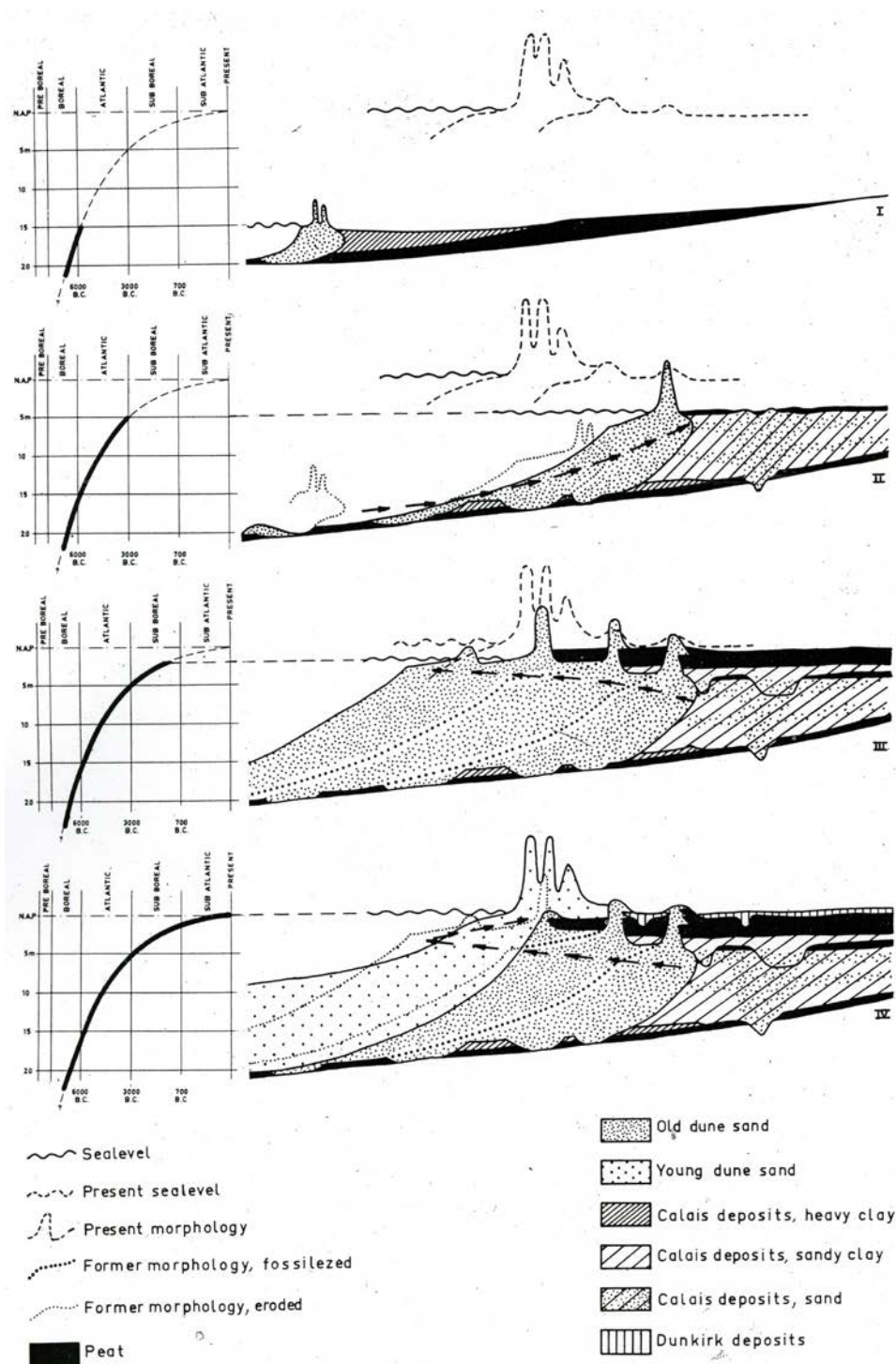


Fig. 5 Holocene sea-level rise and development of the coastal region (Hageman, 1969).

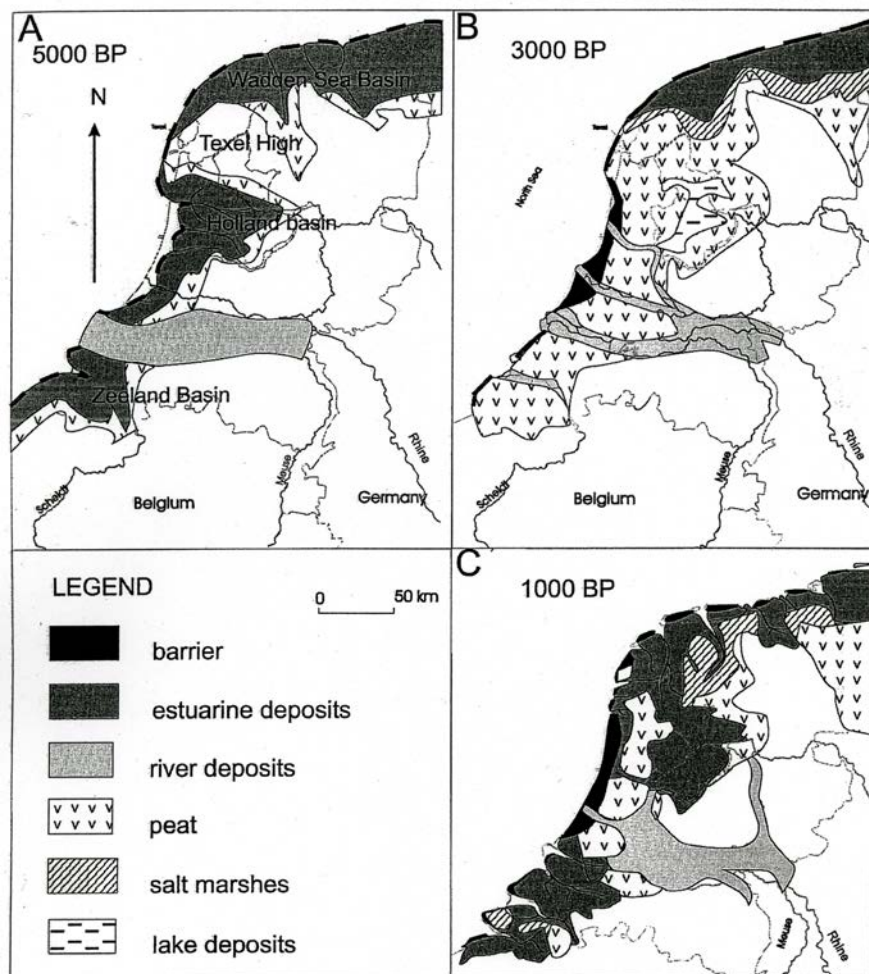


Fig. 6 Palaeogeographic maps of the Dutch coastal plain at 5000 BP (maximal transgression), 3000 BP (regression) and 1000 BP (transgression) (Beets & Van der Spek, 2000).

During the Early and Middle Holocene (until c. 5000 BP) sea-level rise was rapid. Therefore, first lagoonal, later followed by tidal environments expanded to the east, burying the Basal Peat (Hageman, 1969; De Jong, 1971). These tidal sediments are incorporated in the Wormer Member (formerly "Calais Deposits" (fig. 5: stage II) (excursion stop 4). The Calais Deposits are generally clayey in the eastern, distal part of the tidal environment where they grade laterally into clayey reed peats that formed in a lagoonal environment. In the western more proximal parts of the tidal environment, closer to the tidal inlets, the Calais Deposits are more sandy and exhibit a marine fauna with *Hydrobia* and *Cerastoderma*. The exact positions of the coast line and barriers are unknown during this transgressive phase, as the barriers were constantly eroded and shifted rapidly to the east (Beets et al., 1992). The barriers were probably situated in between the tidal inlets. The position of the tidal inlets could be reconstructed based on the associated sandy sediments.

About 5000 years ago sea-level rise strongly decreased (fig. 4). As a consequence the back-barrier area silted up, most of the tidal inlets were closed and a more or less continuous beach barrier came into existence (fig. 5: stage II; fig. 6A). From that moment onwards the sediment supply on the coast from previous ebb-tidal deltas and Pleistocene uplands exceeded the sediment demand of the slowly increasing accommodation space in the back barrier region (Beets & Van der Spek, 2000). This positive sediment balance resulted in coast line progradation and the formation of new beach barriers west of the existing ones (fig. 5: stage III) (Van der Valk, 1996). This regressive phase lasted approximately until the Roman period. These coast lines and barriers and low overlying dunes have been preserved in the coastal record as the so-called 'Older Dunes' (excursion stop 2).

The closure of the tidal inlets and the formation of a broad barrier belt after 5000 BP resulted in a decreased marine influence in the back barrier region. Clastic sedimentation stopped and in the wet back-barrier environment peat growth started (so-called Holland Peat), covering the marine Calais deposits (figs. 6B, 7) (Zagwijn, 1986). At first reed peats developed in brackish eutrophic conditions. Gradually the nutrient influx (from the subsoil and by rivers/sea) in the peat bog dropped and mesotrophic (sedge) and oligotrophic (spagnum) peats accumulated. In the central parts of the peat bogs peat growth occurred under oligotrophic rain-water depended conditions. Under such conditions convex-shaped, high-lying, peat domes developed which had a natural drainage towards the larger and smaller river courses. Only close to the rivers, flowing through the bog, eutrophic conditions prevailed and brook peats were formed dominated by Alder (excursion stop 5). The large thickness of the peat (more than 5 m) can be explained by the gradual sea level rise after 5000 BP creating accommodation space for peat formation.

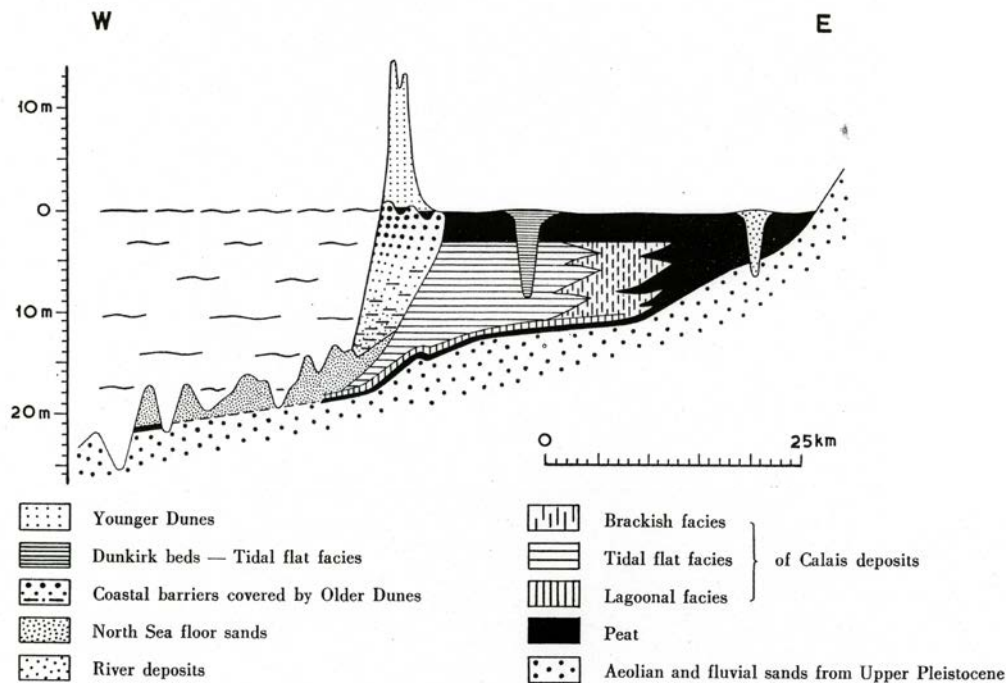


Fig. 7 Schematic cross section of the Holocene deposits in the western Netherlands (Jelgersma et al., 1970).

In the central part of the Netherlands peat growth continued till about 1100 AD. From that time on reclamation took place starting from the levees along the river courses (Lambert, 1971). These higher-lying somewhat better-drained levees were the access routes through the otherwise inaccessible peat bogs (excursion stops 4 and 5). Man reclaimed the dome-shaped peat bogs by natural draining through ditching. Reclamation occurred in a large-scale, well-organized manner resulting in a very regular structure of narrow (c. 110 m), but long (c. 1250 m) parcels perpendicular to the reclamation axis (levee) and extending into the former peat bogs (so-called 'Cope' reclamations) (excursion stop 5). Initially the drainage was so efficient that the drained peat bogs were used as arable land (rye, barley, flax, hemp). However, due to the drainage, compaction and oxidation of the peat the land surface dropped to sea level and arable land was replaced by meadows. The development of wind-driven water mills (first mentioned in 1404 AD) enabled to cope with gradual sea level rise and peat subsidence and the ground water level was lowered below sea level (KNAG, 1978). The peat that was dug out of the ditches originally sufficed the need for fuel. In the course of the 17th century population increased and the cities grew. Large areas were excavated (below the water table) for peat production ('turf') and as a consequence large lakes originated (Heslinga et al., 1985) (see fig. 12). Gradually the central part of the western Netherlands was transformed in a lake region (Dutch 'Plassen'). From the beginning of the seventeenth century onward (Dutch Golden Age) the lakes were drained by wind mills pumping the water out. The former lake bottom was transformed into good arable land on the marine Calais Deposits (Dutch 'droogmakerijen' = making dry) (excursion stops 3 and 4). These low-lying polders (4 to almost 7 m below sea level) were first drained by wind mills, later by steam engines and nowadays by diesel and electric pumps.

Excursion stops

Stop 1: Younger Dunes

Location: Langevelder Slag

Elevation: up to 25 m above sea level

Geomorphology: The Younger Dunes have at their eastern limit a steep frontal slope to the Older Dunes / beach barrier area. The Younger Dunes migrated over and buried the Older Dunes (fig. 8). The Younger Dunes are up to 5 km wide and in contrast to the Older Dunes have high relief. Parabolic dune forms indicate a dominant WSW-wind direction during their formation.

Geology: The Younger Dunes have been formed since the Middle Ages. Radiocarbon dates on buried tree trunks and archeological finds indicate the onset of Younger Dune formation around 1000 AD (fig. 9) (Jelgersma et al., 1970). The cause for this massive dune formation is not well known (Wiersma, 1991; Roep et al., 1991). The sand is calcareous and contains fresh shell fragments. Therefore, it is concluded that the sand was not derived by deflation from the underlying Older Dunes that are weathered by soil formation. The Younger Dune sand was derived from the beach and shore face zone. It has been argued that steepening of the shore face profile resulted in higher waves, higher and dryer beaches and beach berms, from which the sand was blown inland by the predominant westerly winds (Beets et al., 1984). The reason for shore face steepening may have been the continuing sea-level rise and negative sediment budget or a stronger wind and wave regime along the Dutch coast in the late Middle Ages. Based on the calculated volume of Younger Dune sand the position of the coast line preceding the Younger Dune phase has been reconstructed. Along the Holland coast the coast line was situated 1.5-2 km west of the present day coast line (Wiersma, 1991).

According to Zagwijn (1984) three stages can be distinguished in the formation of the Younger Dunes. The initial phase (1000-1180 AD) had the character of a sand sea with large transverse dunes and slipface lamination. During the second phase (c. 1180-1330 AD) deposition continued in a sand sheet with predominantly horizontal bedding. Finally (c. 1330-1600 AD) parabolic dunes were formed due to the gradual stabilization of the surface by vegetation.

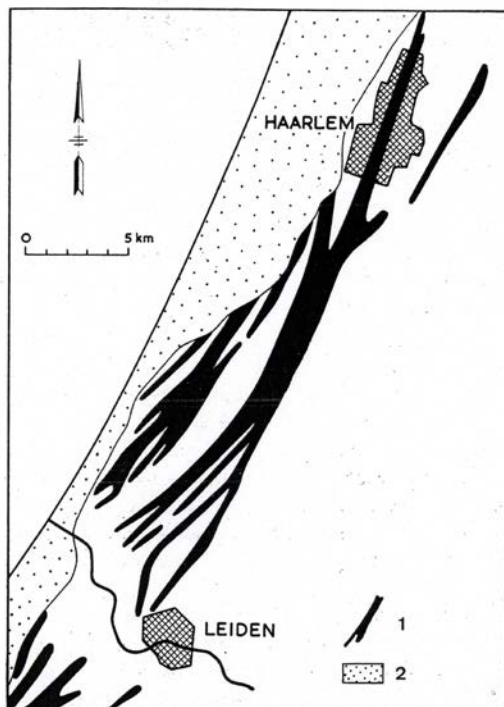


Fig. 8 Location of the beach barriers and Older Dunes (black) and overlying Younger Dunes (stippled) north of the 'Old Rhine' course near Leiden (Jelgersma & Van Regteren Altena, 1969).

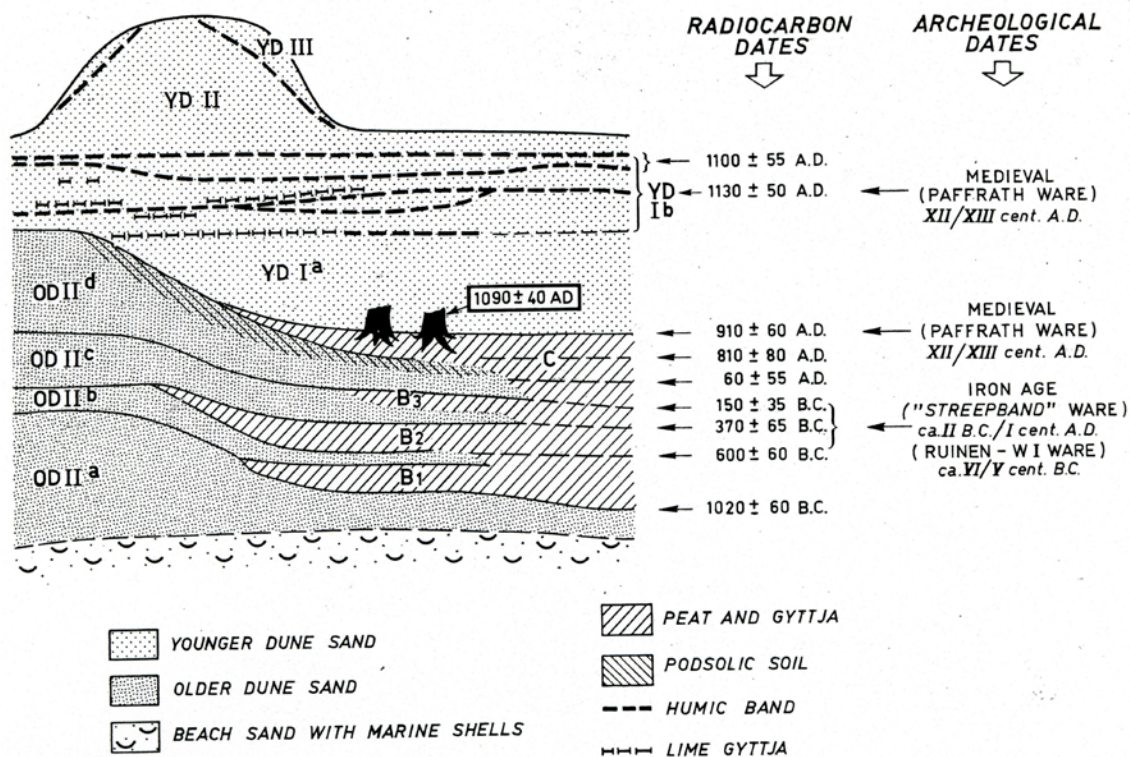


Fig. 9 Synthesized cross section and dates of the Younger Dunes (YD) and beach barriers/Older Dunes (OD) southwest of Haarlem (Jelgersma & Van Regteren Altena, 1969).

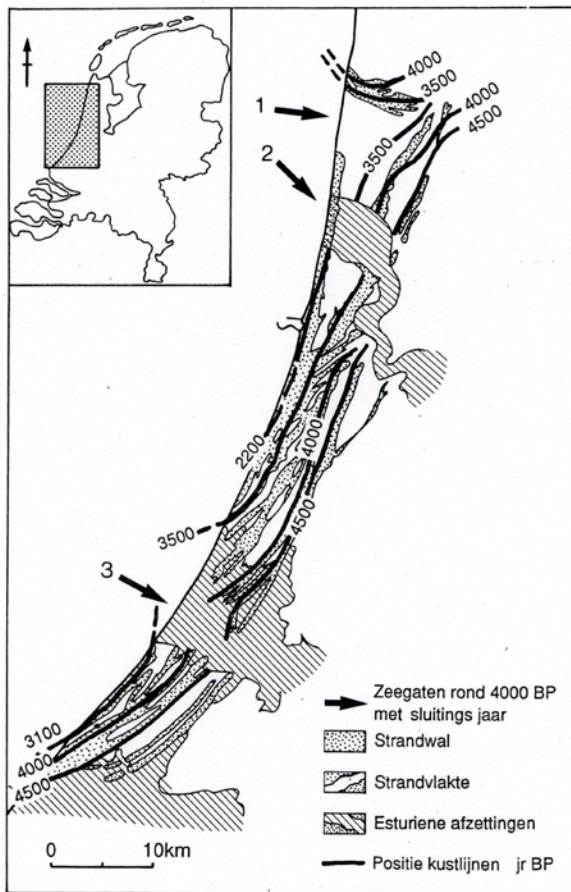
Stop 2: Beach barriers and Older Dunes

Location: Vogelenzang

Elevation: barriers at 2.9 m above sea level; interbarrier flats at 0.6 m above sea level

Geomorphology: Generally north-south trending barriers covered by low dunes and interbarrier flats covered by thin clay or peat beds. The direction of the old roads and the location of the villages were controlled by the north-south orientation of the higher-lying barriers. The original morphology has been strongly modified/destroyed by man. Sand excavation has been reported already in the late Middle Ages (1415 AD) (KNAG, 1978). Topographic names like 'Zandvaart' (sand canal) on 17th and 18th century maps testify sand transport and excavation. The sand was partly used to raise the wet peat soil in town enlargement projects. The excavated and leveled barriers appeared to be very suitable for bulb farming. The rapid increase of bulb farming (tulips etc.) after 1850 AD strengthened the excavation of the beach barriers. Most barriers have been excavated now and occur at sea level.

Geology: During the early and middle Holocene rapid sea-level rise barriers migrated rapidly to the east and were not preserved in the geological record. At c. 5000 BP sea-level rise diminished and the coast line stabilized at the easternmost barrier (fig. 10). From that time onwards sand supply surpassed sea-level rise and successive beach barriers were formed westward of older ones (Van der Valk, 1996). Progradation of the coast continued at least till the Roman Period (2000 BP) (fig. 11). Following that period coast line retreat became dominant again. The Roman fort Brittenburg at the mouth of the 'Old Rhine' near Leiden was destroyed by the sea. In general the present-day coast line is retreating and sand addition by man is undertaken regularly.



- 1 Alkmaar Bergen (3300 BP)
- 2 Oer ij (2000 BP)
- 3 Oude Rijn (1100 AD)

Fig. 10 Position and age of the prograding beach barriers (stippled) in the western Netherlands between 5000 and 2000 BP. Arrows 1, 2, 3 are tidal inlets with closure dates (Roep et al., 1991).

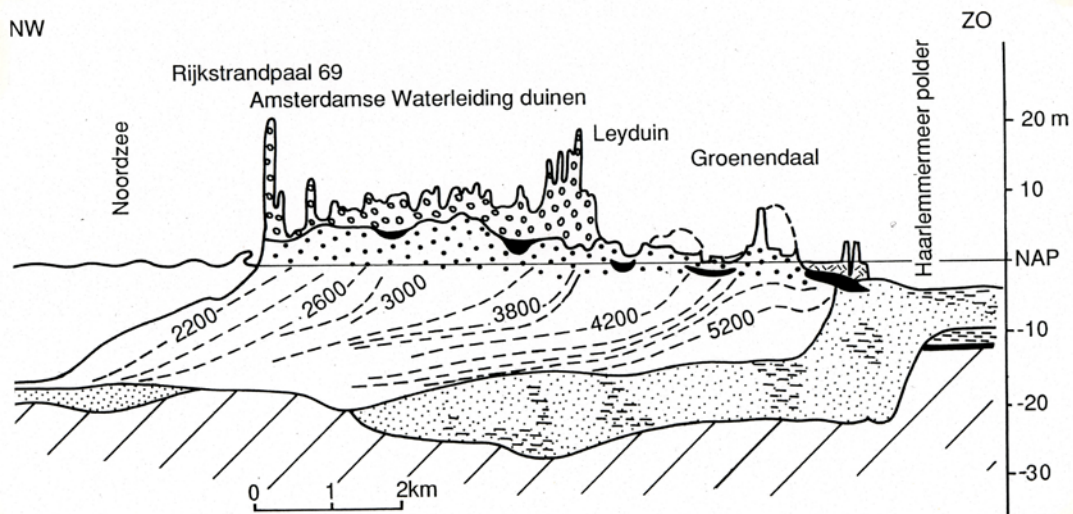


Fig. 11 Cross section over the prograding beach barriers south of Haarlem (Roep et al., 1991).

Stop 3: Cruquius Museum

Location: Cruquius, Haarlemmermeer Polder

Elevation: -4.5 m below sea level

Geomorphology: flat low-lying man-made polder (1848 AD). The original peat (Holland Peat) has been excavated or was abraded by wave action in the Haarlemmermeer (= Lake of Haarlem). The underlying marine Calais Deposits occur now at the surface. The former lake expanded from 7000 ha in 1250 AD to 13000 ha in 1550 AD and 18000 ha in 1848 AD and became a threat to the cities of Amsterdam and Leiden (Lampert, 1971). With the availability of steam power (Cruquius pumping engine) it was technically possible to drain the lake and to create one of the largest 'droogmakerijen' of the Netherlands. It's encircling dike and canal is 60 km long.

Stop 4a: Peat reclamation and excavation history

Location: Amstel and Amstelveen – Middelpolder

Elevation: -2.0 to -5.4 m below sea level

Geomorphology: Amstel river at 0 m N.A.P., peat landscape at -2.0 m ('bovenland') and low-lying, man-made polder at -5.4 m ('droogmakerij').

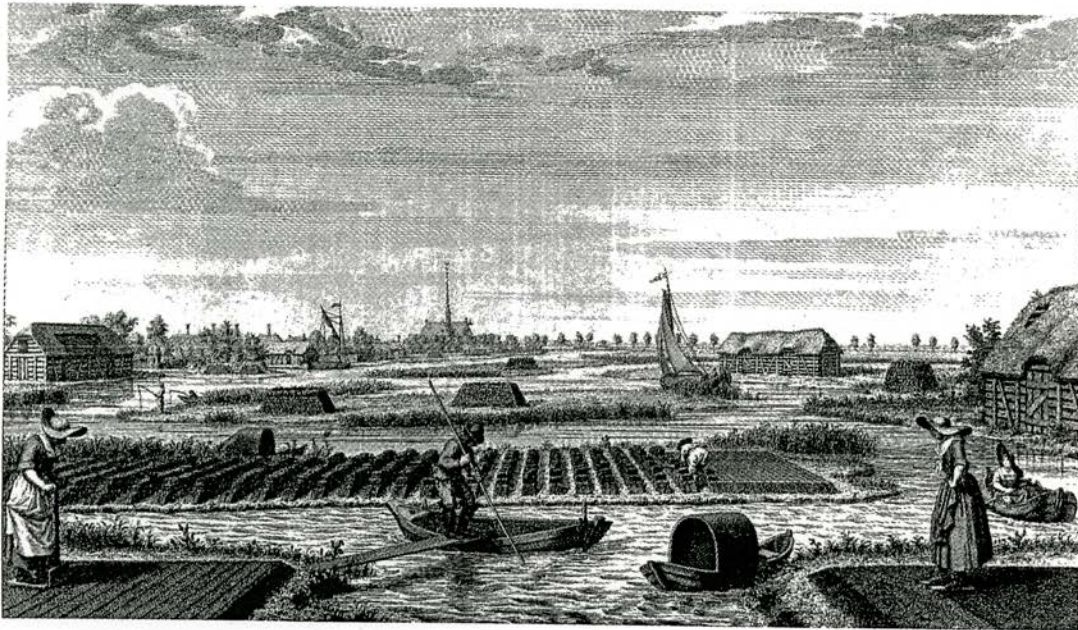
Geology: The peat is part of the Holland Peat that began to form after circa 5000 BP when the beach barriers in the west stabilized by a decrease in sea level rise (Van der Valk, 1996). Peat formation in a dome-shaped bog stopped in the late Middle Ages (circa 1100 AD) by peat reclamation and draining.

Human activity: The name Amstelveen means peat (veen) along the river Amstel. Reclamation of the wilderness (peat bog) occurred in a large-scale, well-organized manner. A very regular structure of narrow (c. 110 m), but long (c. 1250 m) parcels and ditches was developed perpendicular to the reclamation axis (levee of the river Amstel) and extending into the former peat bogs (so-called 'Cope' reclamations) (Lambert, 1971; KNAG, 1978).

Peat excavation for fuel already started in the 13th century (Poelman, 1966). In the 16th and 17th century peat digging for fuel, but also for brick factories and breweries, became very important due to the rapid expansion of the cities (Amsterdam, Leiden, Rotterdam, Delft etc) (Heslinga et al., 1985). Fig. 12 shows the different steps in the peat digging process: dredging of the peat, trampling, cutting in blocks, drying in piles and barns. The peat of the Middelpolder area was excavated in the 18th and 19th century and the area changed into a temporal lake. This lake was drained and the lake bottom that consists of marine Calais Deposits was transformed in arable land and meadows (fig. 13).

In general, especially the oligotrophic Sphagnum peats of the original peat bogs were excavated because of their high quality. The eutrophic and sometimes clayey peats along the rivers were not excavated because they yielded a higher ash content. In this way most of the originally high-lying oligotrophic peats in the centers of the peat domes were transformed into lakes (dutch 'plassen') and polders (dutch 'droogmakerijen'). The originally low-lying clayey peats along the rivers were not excavated and occur nowadays as relatively high-lying areas in the landscape (fig. 13).

At the excursion stop the difference in elevation between the non-excavated peat surface and the former lake bottom is circa 3 m. The two landscapes are separated by a low 'dike' to prevent the water from flowing into the deep polder. This small dike (Dutch 'kade') mostly consists of local peat material, which did its job over the last 150 years. However, the summer of 2003 was exceptionally dry and on 26th of August a similar low dike at Wilnis collapsed and the village of Wilnis was partly flooded. There were no casualties but the material loss was high. Geotechnical research has demonstrated that because of the long-lasting dry period the peat in the dike had been desiccated (Cleveringa & Weerts, 2003). Therefore, the dike lost its weight and could not withstand the pressure from the water in so-called ring canal. Circa 60 m of the dike were pushed into the low-lying polder and the water of the ring canal flowed into the village. This event increased the public awareness of the vulnerability of the Netherlands for future climate change, with more extreme weather conditions. On the one hand higher rain-fall events leading to higher river discharges and a need for higher river dikes. On the other hand longer lasting dry periods leading to increased peat drainage, oxidation and land subsidence and increased salinization of deep polders (like the Middelpolder) by seepage of brackish ground water.



Veen, of Turfboer.



*Het veen, gebaggert uit de slooten,
 Getreden en gesneën aan mooten,
 Op 't veld gedroogt en in de schuur,
 Geeft aanden haart een dienstig vuur*

*Deze gravure geeft een
 overzicht van de
 verschillende fases van
 het maken van turf
 (collectie HAGA)*

Fig. 12 Peat excavation near Amstelveen (1741 AD) showing the different steps of 'turf' making: dredging of the peat, trampling, cutting in blocks, drying in piles and barns (Dessens et al., 1996).

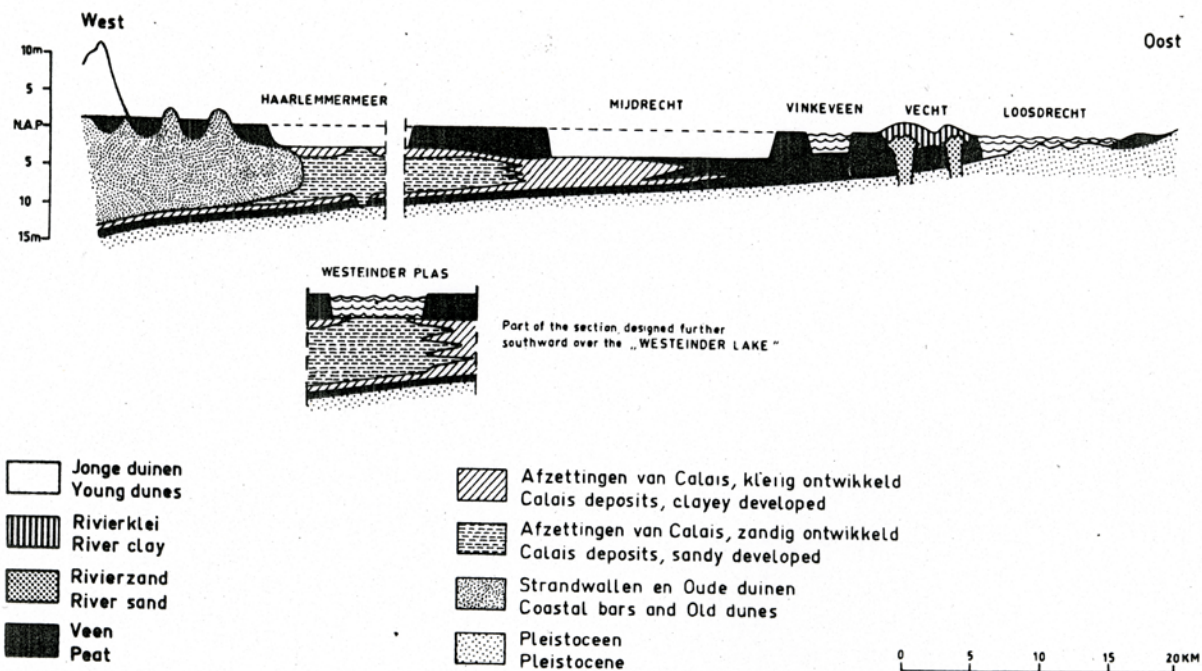


Fig. 13 Schematic geological cross section of the Holocene deposits in the western Netherlands and location of lakes and polders formed by peat excavation (Mijdrecht, Loosdrecht).

Stop 4b: Tidal and lagoonal Calais Deposits

Location: Amstelveen – Middelpolder

Elevation: -5.4 m below sea level

Geomorphology: fairly flat low-lying man-made polder (19th century). The original peat (Holland Peat) has been excavated and the underlying marine Calais Deposits occur at the surface. Locally, to the south, the tidal creek pattern of the Calais Deposits is visible at the surface due to drainage of the polders and differential compaction (fig. 14).

Geology: The marine Calais Deposits in this area are distal deposits of the Holocene transgression (maximum flooding surface of the Rhine delta). The sediments are c. 6 to 7 m thick and consist of fine sandy loams, except for the tidal creeks that consist of fine sand. They overlie the so-called Basal Peat because of the early and middle Holocene transgression (figs. 6A, 7). During this transgressive phase, until 5000 BP, the beach barriers shifted rapidly eastwards. The beach barriers were probably small and many tidal inlets existed. Amstelveen is situated 20 km east of the easternmost barriers. Therefore, the tidal channel and tidal flat sediments are silty and clayey. The presence of *Scrobicularia*, *Cerastoderma* and *Hydrobia* in the sediment indicates tidal flat conditions. More to the east the marine facies interfingers with peat deposits (figs. 13, 14) (Cleveringa & Weerts, 2003).

The Calais Deposits are the result of the rapid early and middle Holocene sea-level rise before 5000 BP (fig. 4). The dates in the cross section (fig. 15) of 5395 and 4805 BP on peat layers overlying the Calais Deposits also indicate that the marine transgression in this area stopped around 5000 BP by decreasing sea-level rise and closure of the barrier island coast.

The distal Calais sediments in the eastern part of the coastal plain often have a high sulphur content in the form of black iron sulphides (FeS) (Bennema, 1953). These sulphides have been formed syngenetically in the sediment by reduction of sulphate (SO_4^{2-} from sea water) and anaerobic oxidation of organic matter. After peat digging and reclamation the soils were drained and oxidation of the sulphidic components led to the formation of yellow jarosite ($\text{KFe}_3(\text{SO}_4)_2(\text{OH})_6$) and sulphuric acid (H_2SO_4). These acidified soils are known as Acid Sulphate Soils (dutch 'Katteklei') and have low agricultural potential (Polder Mijdrecht).

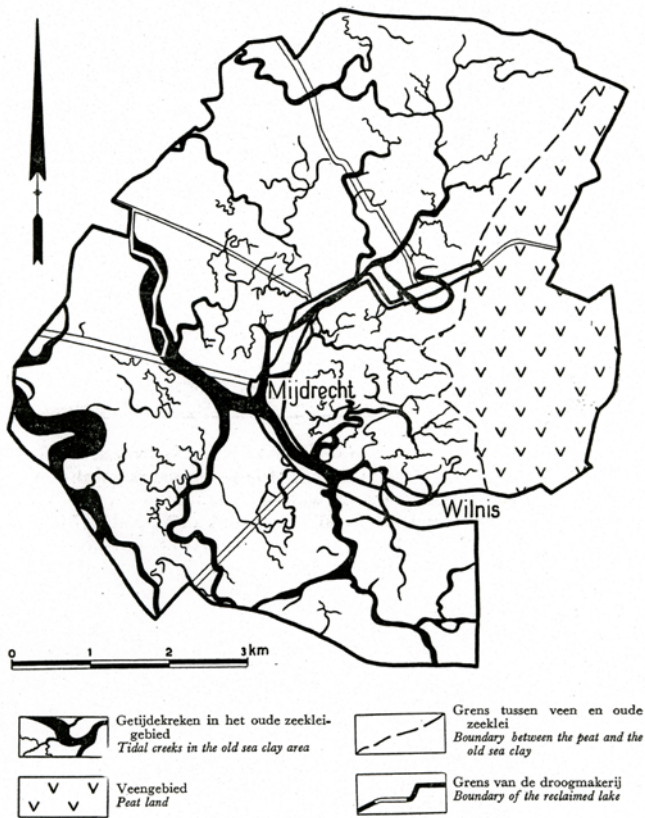


Fig. 14 Tidal creek pattern at the top of the Calais Deposits (c. 5-6 m below sea level) in Polder Groot Mijdrecht (Bennema, 1953).

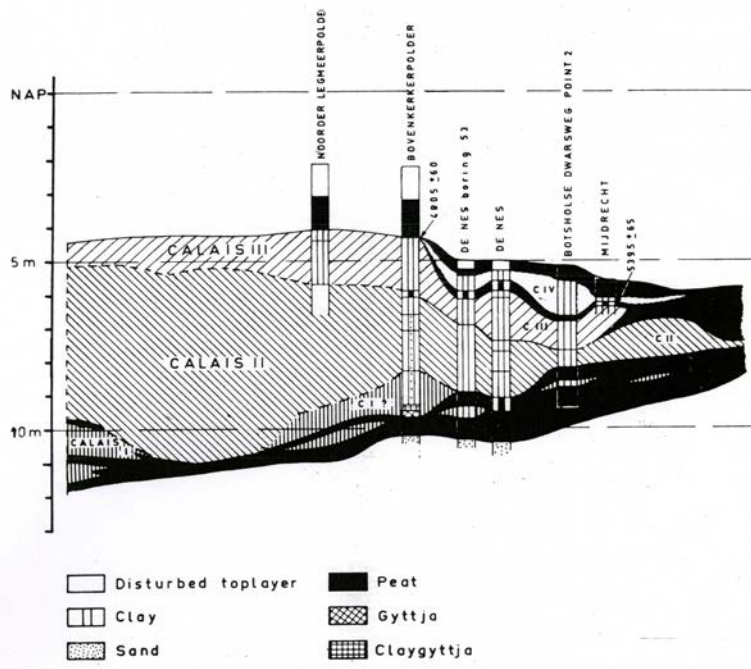


Fig. 15 Geological cross section showing the eastward thinning and fining of the Calais Deposits.

Stop 5: Vecht (Rhine) river course through a peat bog

Location: Nieuwer ter Aa

Elevation: -1.5 to 0 m below sea level

Geomorphology: low-lying peat landscape (-1.5 m) and higher-lying (0 m) former river course of the Vecht. Relief inversion has occurred by strong subsidence of the originally higher-lying peat bog and minor subsidence of the channel belt that is incised in the Pleistocene sandy subsoil.

Geology: The peat is part of the so-called Holland Peat that formed in the back-barrier area due to the Holocene sea level rise. Holocene marine deposits are not present here because this point is situated east of the maximum marine transgression. Peat formation started at circa 6000 BP. Peat composition is mesotrophic and eutrophic due to ground water seepage from the higher Pleistocene region in the east and by river water influx (fig. 16).

The higher lying former river course of the Vecht consists of clay and loam in the levees and sand in the center of the channel belt. This Vecht system was the northernmost tributary of the Rhine delta during the Holocene. It came into existence at circa 2600 BP due to an avulsion of the 'Old Rhine' course near Utrecht (Weerts et al., 2002). The abandonment of the active course is dated at c. 1700 BP. From that moment on the Vecht was a local river draining the peat bogs and ground water seepage from the east. Corings will be done to demonstrate the fluvial sediments in the peat landscape.

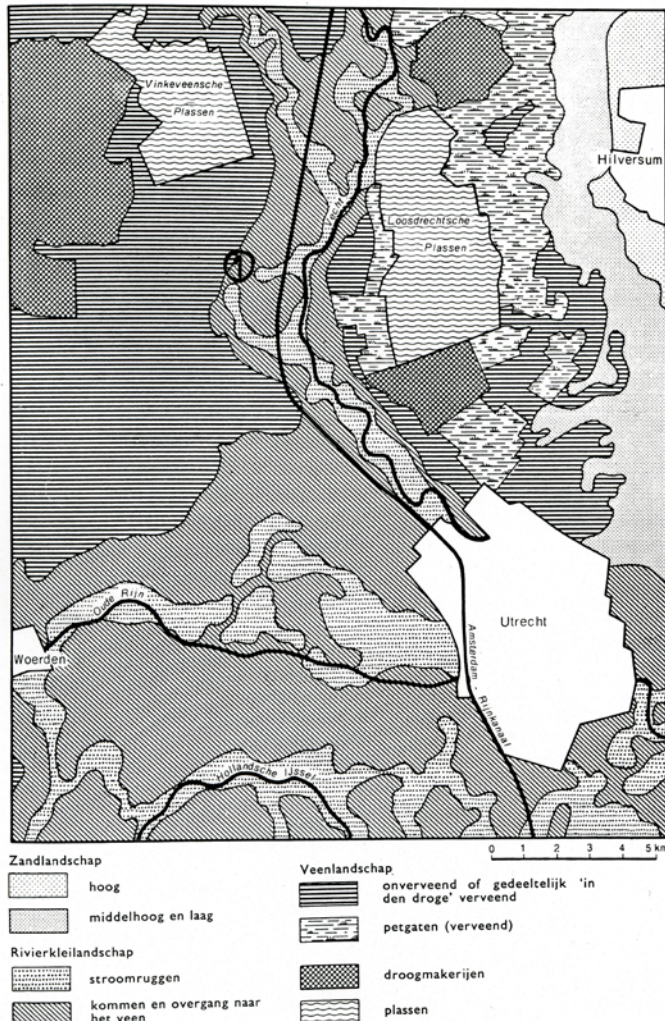


Fig. 16 Geology and geomorphology of the Vecht river region (zand=sand; rivierklei=river clay; veen=peat).

Stop 6: Glacial basin and ice-pushed ridges of Saalian age

Location: groeve Kwintelooijen, Gelderse Vallei

Elevation: 60 m + N.A.P.

Geomorphology: view point from ice-pushed ridges up to 60 m high over the glacial basin of the Gelderse Vallei at 10 m N.A.P.

Geology: Before the (second last) Saalian glaciation the flow direction of the Rhine/Maas was to the northwest. The Saalian glaciation totally changed the flat morphology of the delta. The Fennoscandian ice sheet reached the central part of the Netherlands from Amsterdam in the northwest to Nijmegen in the southeast. Up to 100 m high ice-pushed ridges were formed, that mainly consist of pre-glacial fluvial sands and gravels. The presence of loam layers in the delta sequence, that acted as shear planes during the glaciotectionic deformation, favored the formation of the ice-pushed ridges in the Central Netherlands. Human artifacts have been found in these pre-glacial fluvial sands, that therefore predate the Saalian glaciation (~150 ka), and belong to the oldest human remains in the Netherlands (~200 ka). Southwest of the ice-pushed ridges large outwash plains were formed by fluvial-glacial processes. The courses of the Rhine and Maas were diverted to the west, the dominant stream direction until the present day (Zagwijn, 1974). In between the ice-pushed ridges glacial basins developed up to 100 m deep (northern part Gelderse Vallei, IJssel Valley).

After the Saalian glaciation climate improved during the Eemian and the glacial basins were inundated by the sea and marine and coastal deposits were formed in the Gelderse Vallei, that to the north extends into the Eem Valley, the type locality of the Eemian.

Following the Eemian, during the Weichselian glacial, the Gelderse Vallei was filled with local sediments of fluvial (fine sand and gravel), lacustrine (loams and peat) and aeolian (fine sand) origin. The aeolian landforms in the Gelderse Vallei, dating from the final stage of the Weichselian, indicate a gradual shift from dominant northwesterly to southwesterly winds. The sediments in the Gelderse Vallei are mostly derived from the nearby ice-pushed ridges that were lowered by erosional processes like gelifluction, sheet flow and deflation.

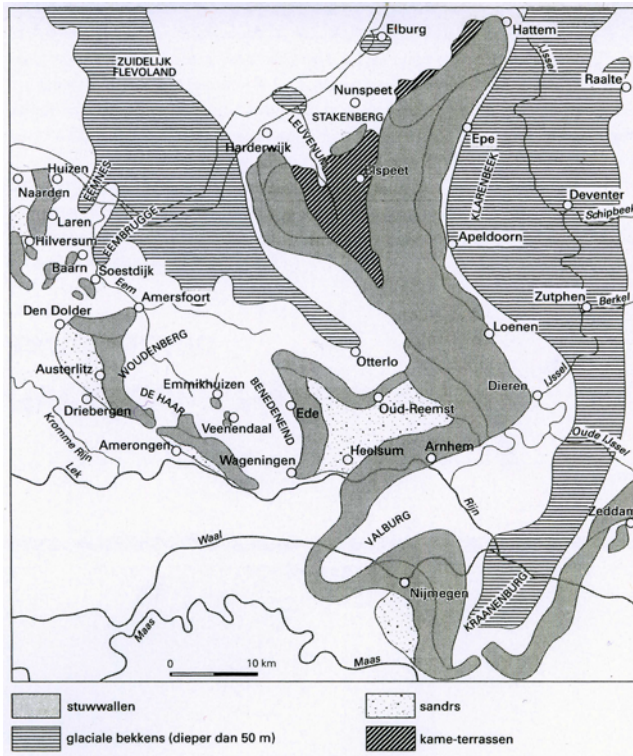


Fig. 17 Ice-pushed ridges (*stuwwallen*) and glacial basins (*glaciale bekken*) in the central Netherlands (Maarleveld, 1981)

In the Holocene soil formation occurred on the higher ice-pushed ridges (brown and podzolic soils) while peat formation occurred in the low-lying Gelderse Vallei. Thick peats beds, up to 6 m, formed that were excavated by man from the 15th century onwards. Along the southern margin of the ice-pushed ridges, between Rhenen and Wageningen, the Rhine has eroded the ridges completely and, if dikes were not present, the present-day Rhine would enter the Gelderse Vallei. Indeed, during dike breaches in 1651 and 1855 Rhine water flowed through the Gelderse Vallei in a northern direction.

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