CASE STUDY 3N – SOUTHWESTERN NETHERLANDS

Case Study Area: Vergulde Hand West and Yangtze Harbor, Southwestern Netherlands

Main geomorphological types: Estuary, Tidal basin, Beaches, Dunes

Main coastal change processes: Natural erosion, Natural flooding, Breaching, Human induced

Primary Resources used: Archaeological/Palaeoenvironmental Data

Summary: In this case study, fieldwork results and analysis for two test sites, Vergulde Hand West and Yangtze Harbor are presented. Both areas are located in the Southwestern Netherlands. During the archaeological excavations in Vergulde Hand West geological research was carried out in order to reconstruct the palaeoenvironments of the periods during which man was present in the area. At Yangtze Harbor, the geogenetic approach (targeting the optimal locations for prehistoric settlements in the subsurface based on landscape reconstructions) to detect nowadays drowned archaeological sites in the transgressive palaeo-deltaic environment of the Holocene Rhine-Maas delta was applied.

Recommendations: The techniques used in this case study, could also be applied in other regions of interest. Especially the geogenetic approach, stepwise deployed, provided the insights needed to do targeted high-resolution research, at locations optimal for prehistoric habitation, and to select the best methods and techniques for mapping the palaeolandscape and proving human presence in it.

Coastal managers face an ongoing battle to moderate impacts from the sea in the face of a changing climate and pressures from human use of the coastal zone. The challenges that lie ahead are forecast to increase while resources are being forced to go further.

This case study report is part of the technical report on the Arch-Manche project, which quantifies the value of under-used coastal indicators that can be applied as tools to inform long term patterns of coastal change. In addition, it provides instruments to communicate past change effectively, model areas under threat and interpret progressive coastal trends.

This case study report introduces the study area and why it was chosen as part of the project, the results of the archaeological and palaeoenvironmental study are then presented.The analysis of these results and the potential for demonstrating the scale and rate of coastal change are then presented. For further details about the project methodology see Section 2.

3N.1 Introduction to the Netherlands Study Area

In this study, fieldwork results and analysis for two test sites, Vergulde Hand West and Yangtze Harbor (Figure 3N1), are presented. The fieldwork has been conducted in several campaigns, and by several institutions, including the Port of Rotterdam and BOOR.

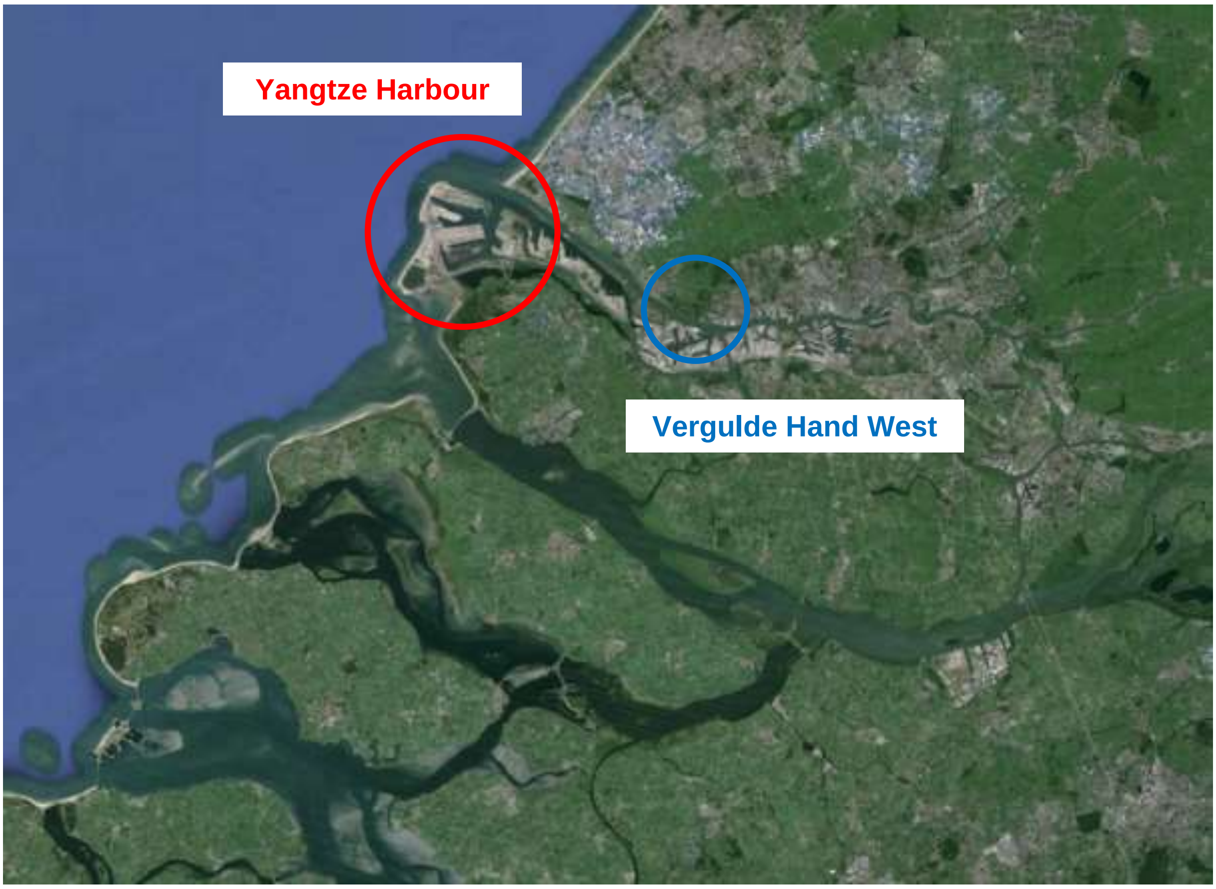


Figure 3N1: Rotterdam and surroundings with (rough) indication of the field study areas.

The first section of this study presents an overview of the paleogeographical and archeological evolutions in the Southwestern Netherlands, with a “zoom-in” on the Scheldt and Rijn-Meuse Delta´s. The report then goes on to describes the goals, methods and results of the fieldwork in the two test sites. After this, the results are analyzed, with a focus on paleolandscape reconstructions. Finally, the broader meaning of the two test cases is described.

3N.1.1 Geology and Geomorphology of the Southwestern Netherlands

During the first half of the Holocene the rise in sea level in particular was the driving force in the evolution of the coastal landscape. As a result of the rapid rise in sea level the major part of the southwestern Netherlands was drowned. About 5500 BC this area had been changed into an extended tidal landscape with tidal channels, mud flats, and salt marshes (Figure 3N3 and Figure 3N4, for the legend see Figure 3N2). The peat areas lay in the transition area between the tidal area and the higher Pleistocene sands in Brabant and Zeeuws-Vlaanderen and in the river delta of the Rhine and Meuse. Humans lived in this drowning coastal- and river landscape and occupied the higher dry-lying grounds such as the coastal barriers and the high river dunes (Pleistocene dunes) in the mouth of the Rhine-Meuse.

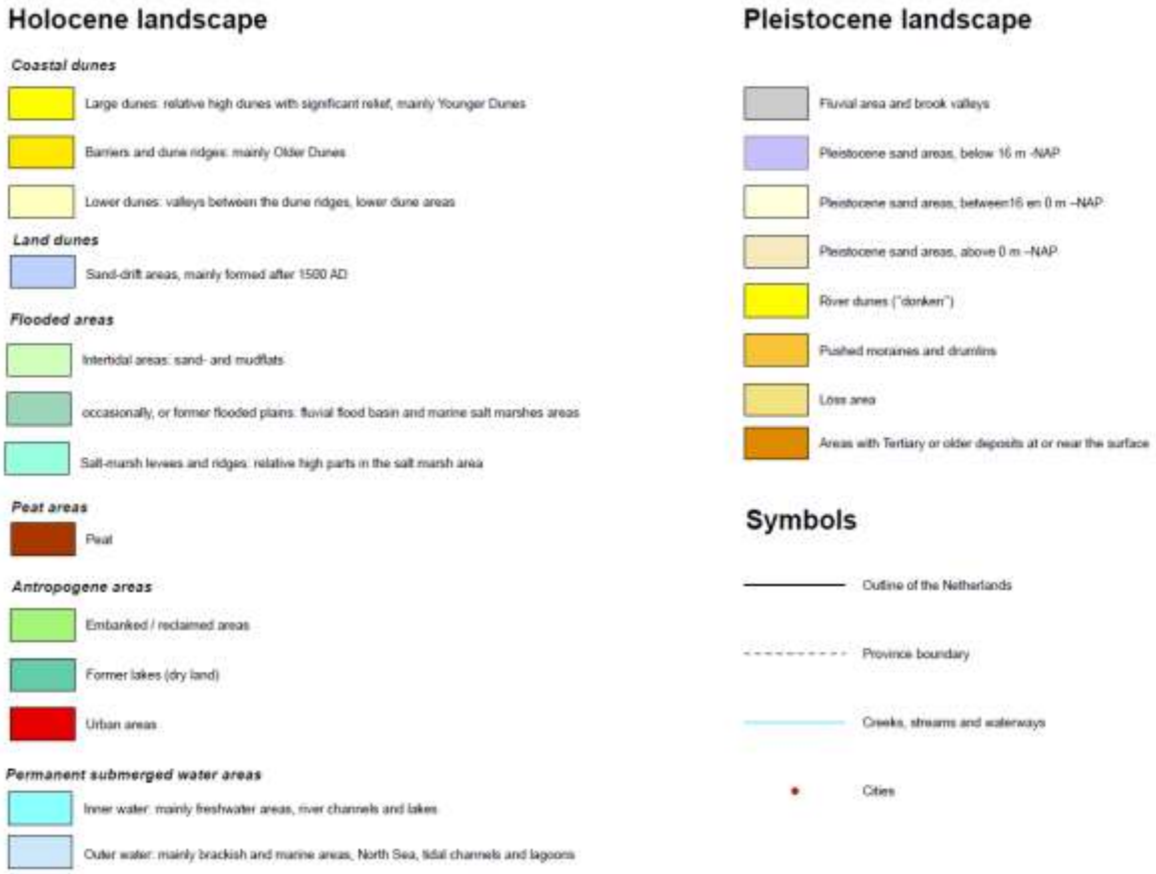


Figure 3N2: Legend for the palaeogeographical reconstructions.

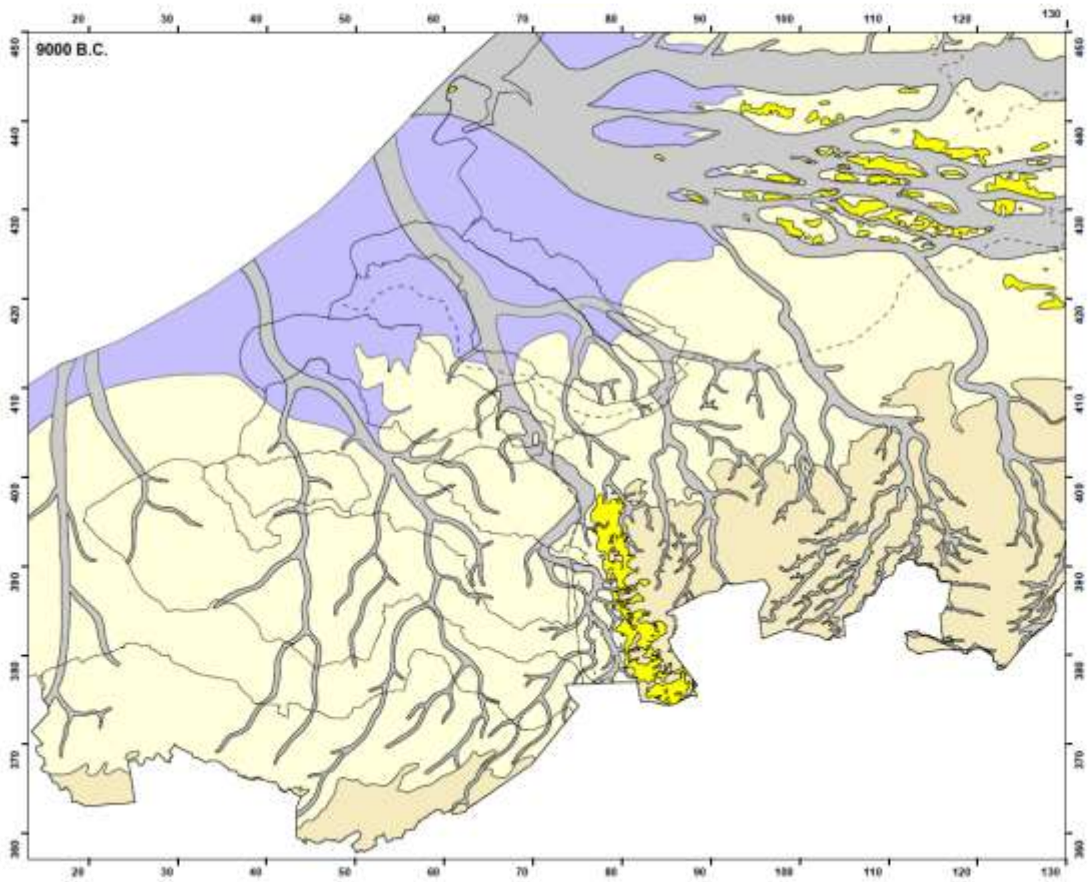


Figure 3N3: Palaeoegeographical reconstruction of the Southwestern Netherlands about 9000 BC.

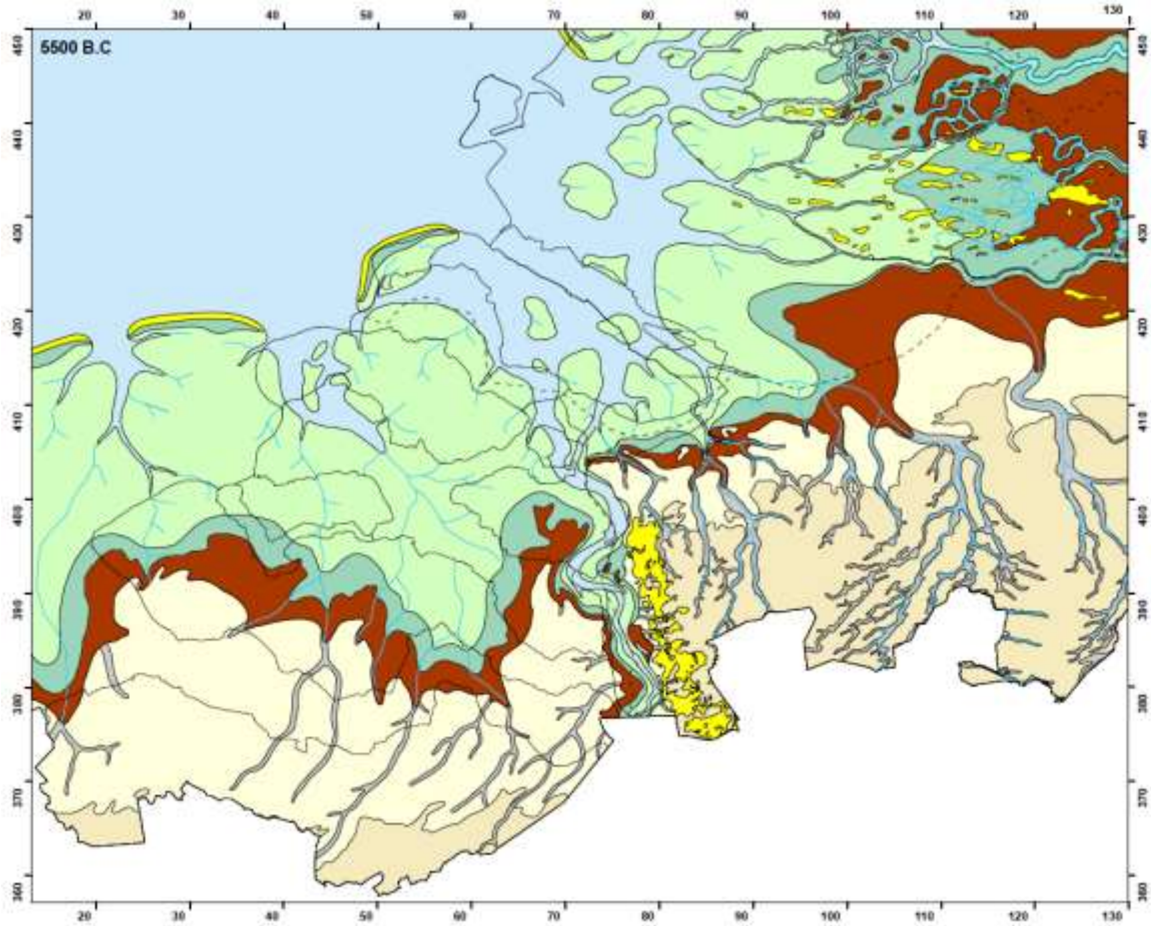


Figure 3N4: Palaeoegeographical reconstruction of the Southwestern Netherlands about 5500 BC.

From about 5000 BC onwards the rise in sea level slowed down and as a consequence sedimentation took over causing the coastal area to be raised. About 3850 BC this resulted in a strong silting-up of the tidal area enabling the intertidal-, supratidal- and peat areas to expand seaward (Figure 3N5) Man benefited from the silting up of the tidal areas by occupying -- besides the coastal barriers and the river dunes – the higher dry-lying parts of the mud flats (e.g. the Vlaardingen Culture). In the province of Zeeland, a few Neolithic sites on the top of the tidal deposits indicate human occupation in this period (Vos and van Heeringen 1997). The question of whether or not the tidal area was inhabited (permanently or seasonally) could not be answered on the basis of the loose finds. The fact that only a few Neolithic finds have been found until now might be explained by the relatively deep position of the tidal deposits (in general 1.5 m or more below surface level) and the relative minor building activity on land in this rural area.

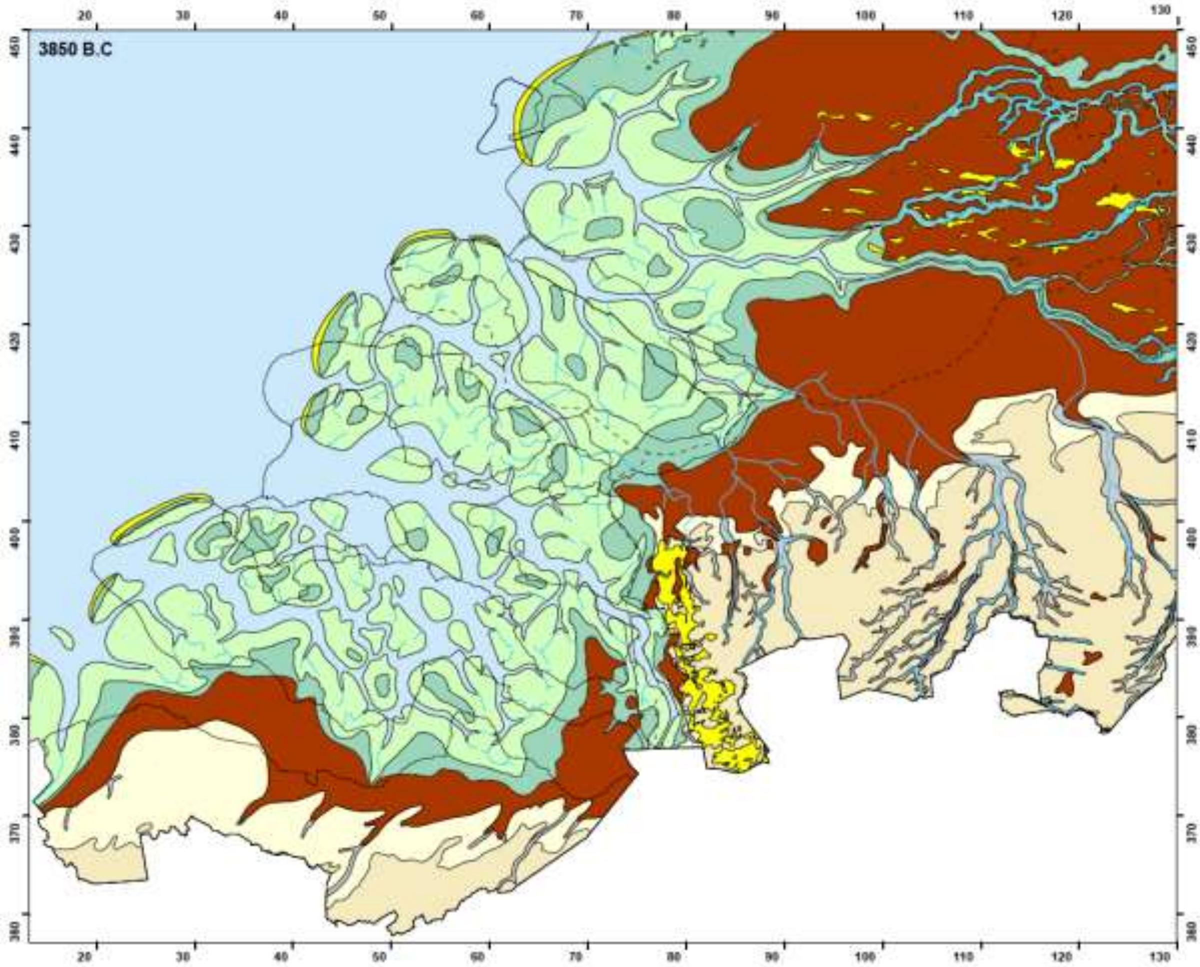


Figure 3N5: Palaeoegeographical reconstruction of the Southwestern Netherlands about 3850 BC.

Further sediment accretion led to considerable reductions in the tidal channels and the tidal outlets and extended coastal barriers and dunes were formed along the coastline. In the course of the next millennia these coastal barriers increasingly protected the tidal area in the hinterland from the sea. An almost closed coastline was formed with coastal barriers and dunes and a few outlets related to rivers such as the Rhine, Meuse and Scheldt (Figure 3N6). As a result the coastal area became isolated from the sea and the peat could expand. By about 2000 BC the higher mud flats became uninhabitable again due to poor drainage and peat growth (wetland). Still human occupation persevered, in particular on the tidal barriers and dunes, which were still dry, and the infilling river beds.

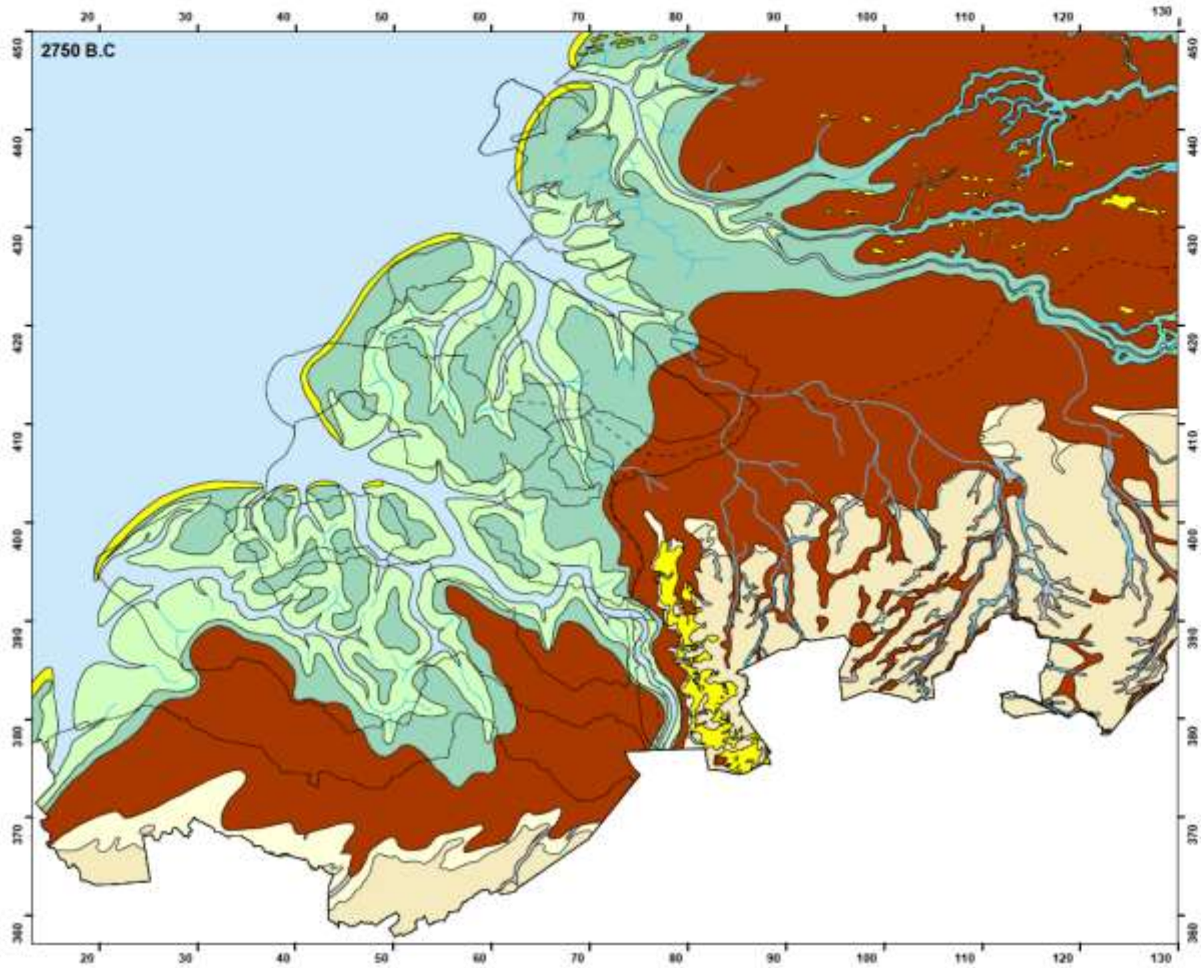


Figure 3N6: Palaeoegeographical reconstruction of the Southwestern Netherlands about 2750 BC.

The situation of an almost closed coastline with a couple of river outlets (Figure 3N7) remained until about 600 BC. Between 500 BC and the beginning of our era the coastal barriers and dunes off Zeeland slowly broke down and small inlets developed with “funnel-shaped” supratidal areas (Vos and van Heeringen, 1997) (Figure 3N8). This coastal erosion was due to a deficiency of sediment caused by changing tidal currents. The sea did not yet reach far inland because the peat in the hinterland had grown up to 1 m or more above the maximum storm surge level.

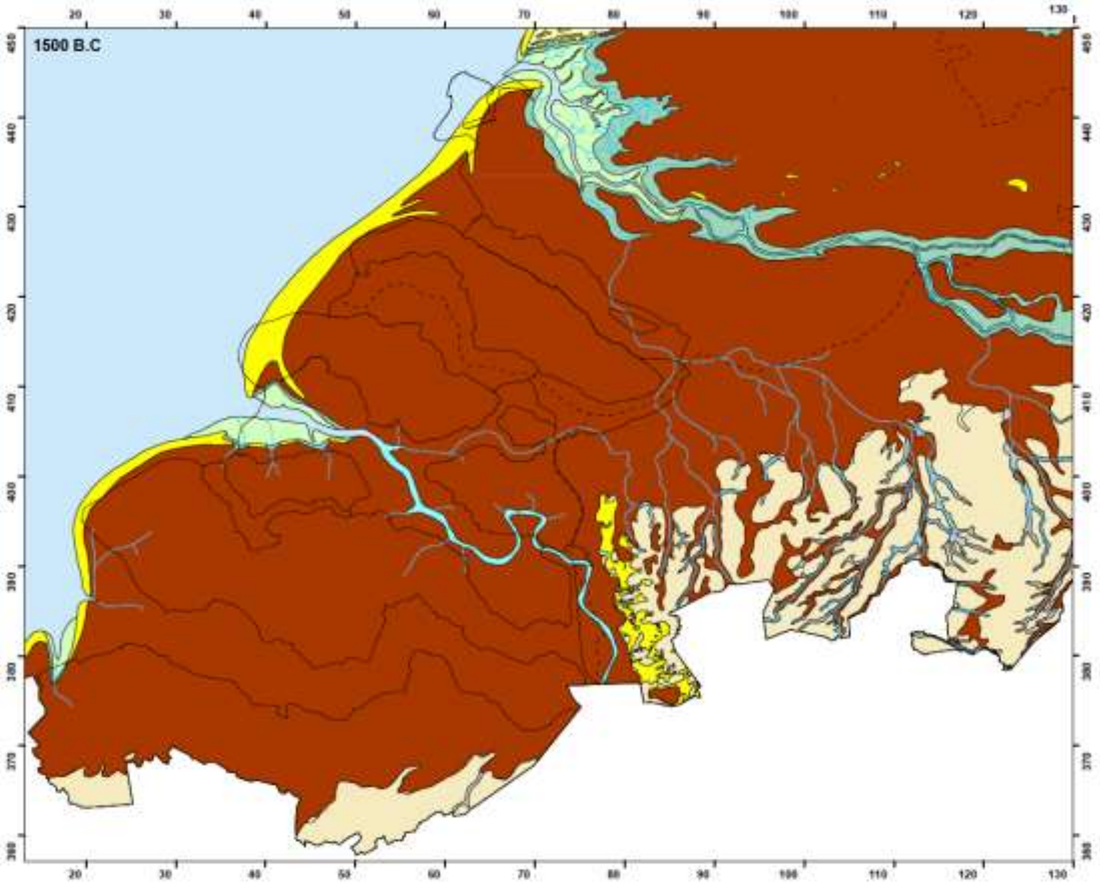


Figure 3N7: Palaeoegeographical reconstruction of the Southwestern Netherlands about 1500 BC.

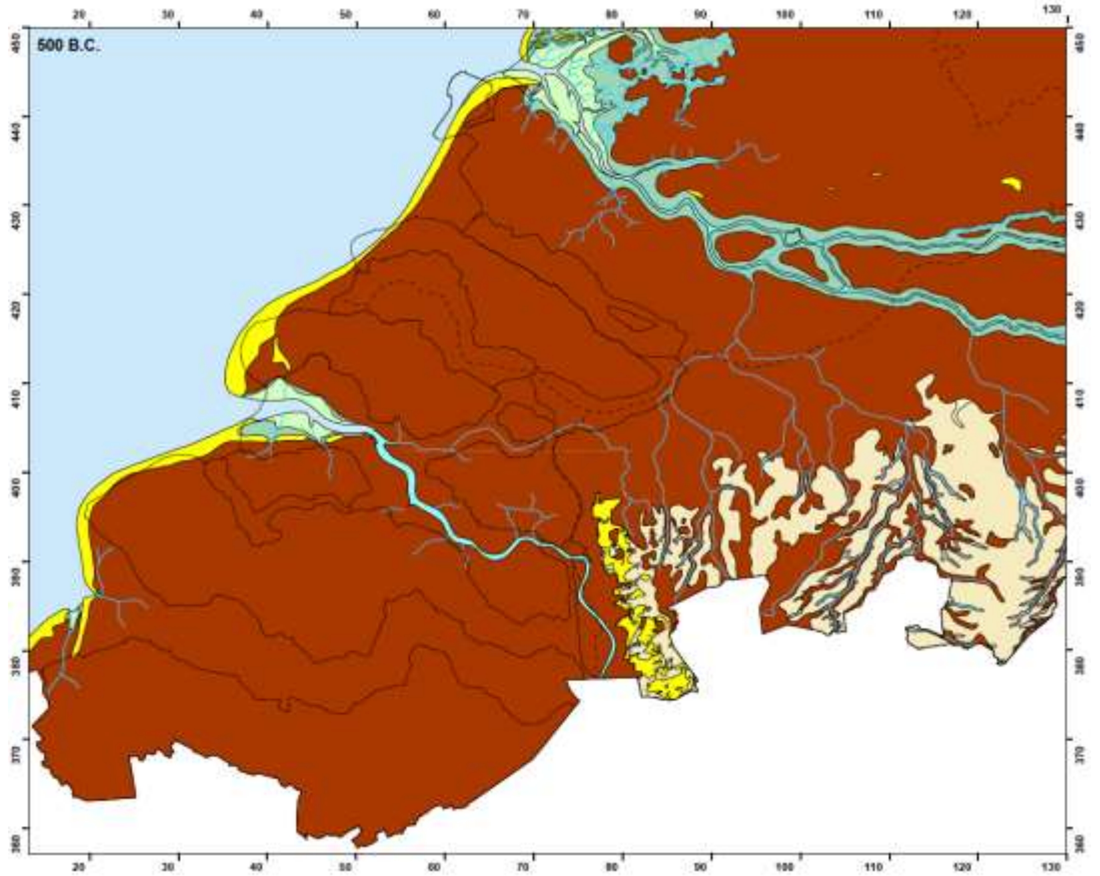


Figure 3N8: Palaeoegeographical reconstruction of the Southwestern Netherlands about 500 BC.

3N.1.2 Summary of the Archaeology and History of the Study Area

The Increasing role of humans on the landscape evolution

Humans took advantage of the new landscape in Zeeland. During the Iron Age, but in particular during Roman times the tidal channels that breached the coastal barriers were used to drain the high peat areas in the hinterland (Figure 3N9, Edelman (1958). Ditches and channels were connected to the tidal channels such that the higher elevated peat areas in the hinterland were drained and became habitable. The drained peat was also extracted at a large scale for industrial purposes (Van den Berg and W., 1986).

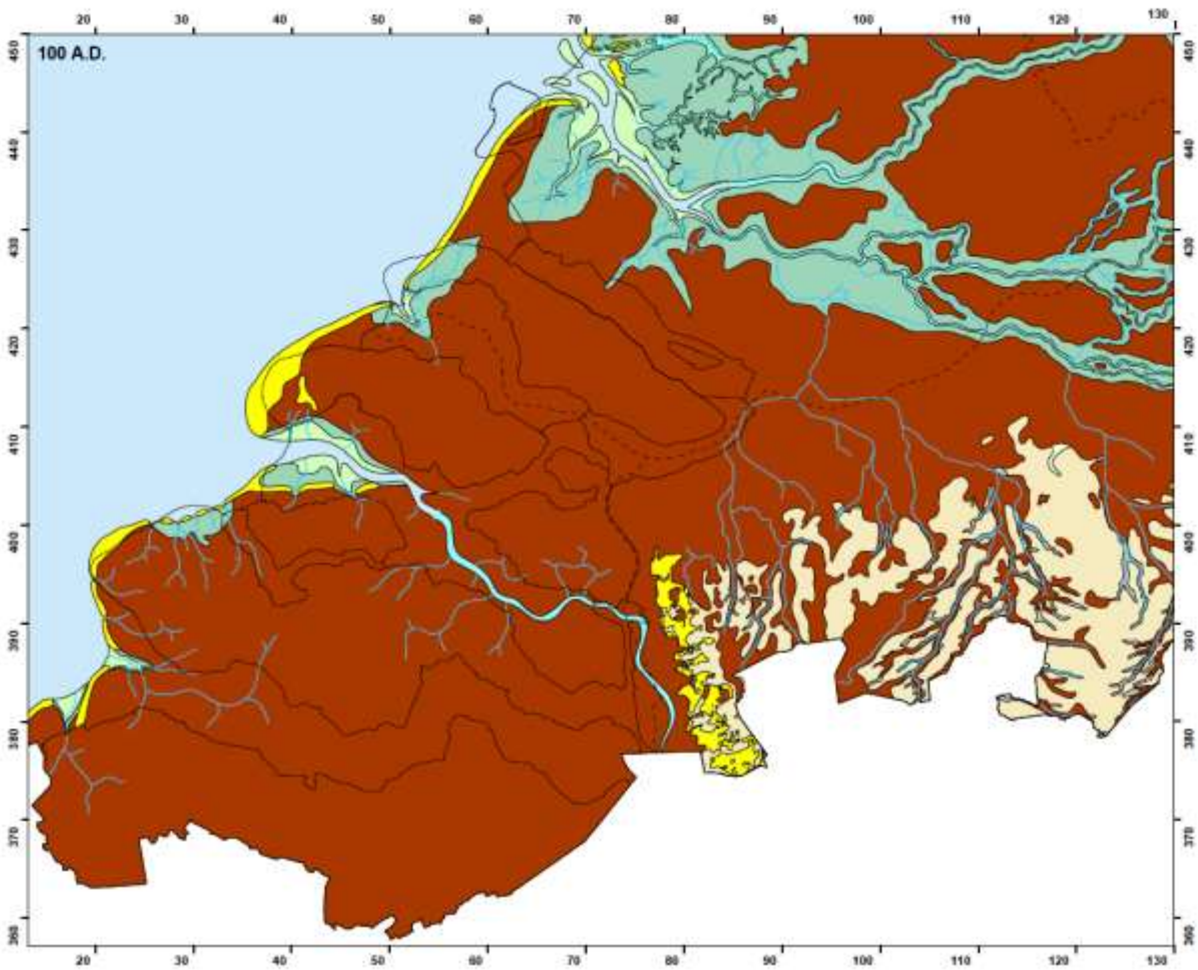


Figure 3N9: Palaeoegeographical reconstruction of the Southwestern Netherlands about 100 AD.

The consequences of these large-scale Roman peat extractions were disastrous. Because of lowering of the surface major parts of the peat areas were flooded and the tide storage area increased considerably. As a response the tidal channels increased strongly in size and also their erosive force, causing complete erosion of peat near the tidal outlets. This process of vanishing peat in its turn led to a further increase in the tidal storage capacity. About 270 AD a self-reinforcing process of peat erosion, lowering of the surface, increase in tidal storage capacity and expansion of tidal channels came into being causing the Roman peat excavation areas to be completely submerged by 350 AD such that habitation and peat excavation in those areas had become impossible. The process of drowning of peat areas continued there until about 800 AD when almost the whole of Zeeland was flooded (Figure 3N10; and the schematic profile reconstruction in Figure 3N11).

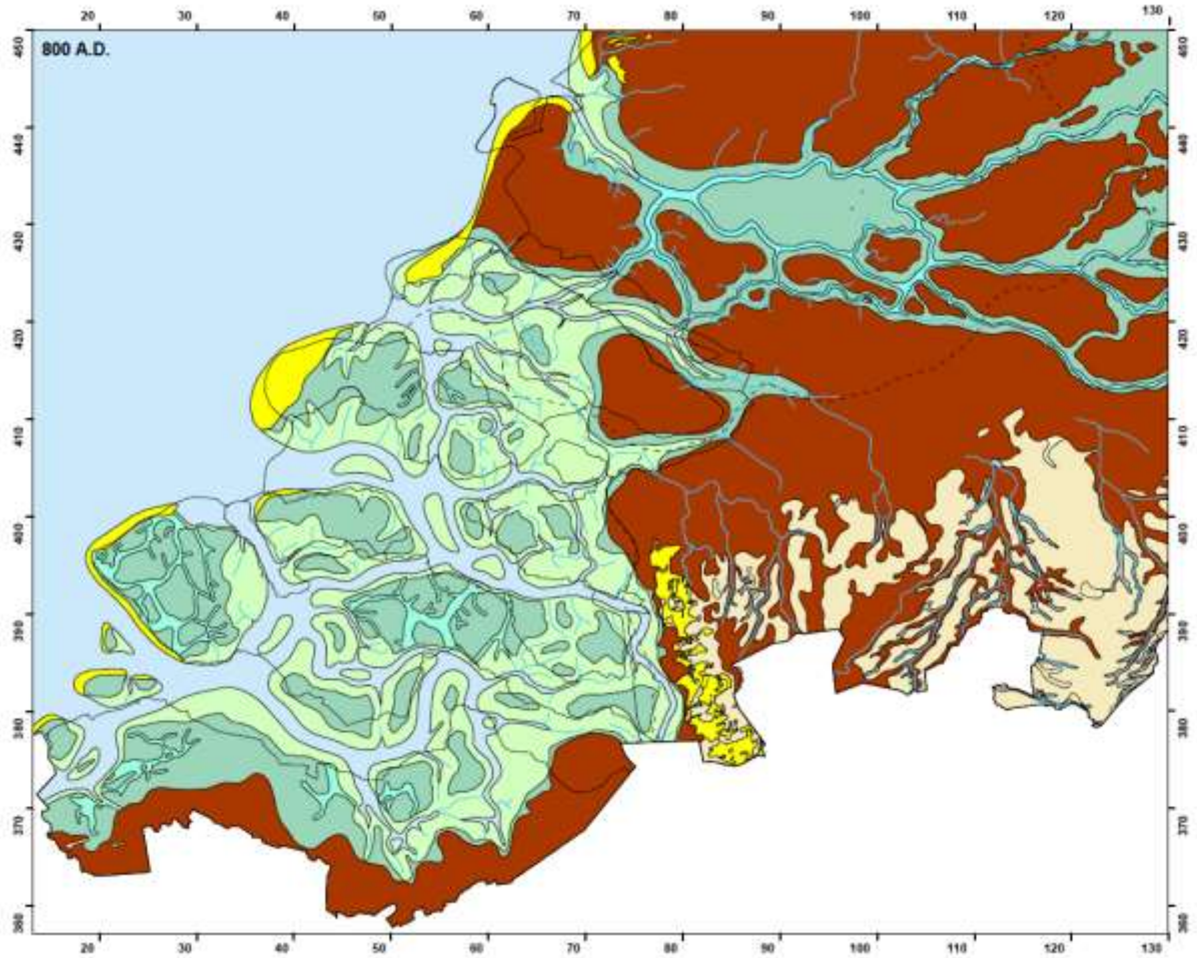


Figure 3N10: Palaeoegeographical reconstruction of the Southwestern Netherlands about 800 AD.

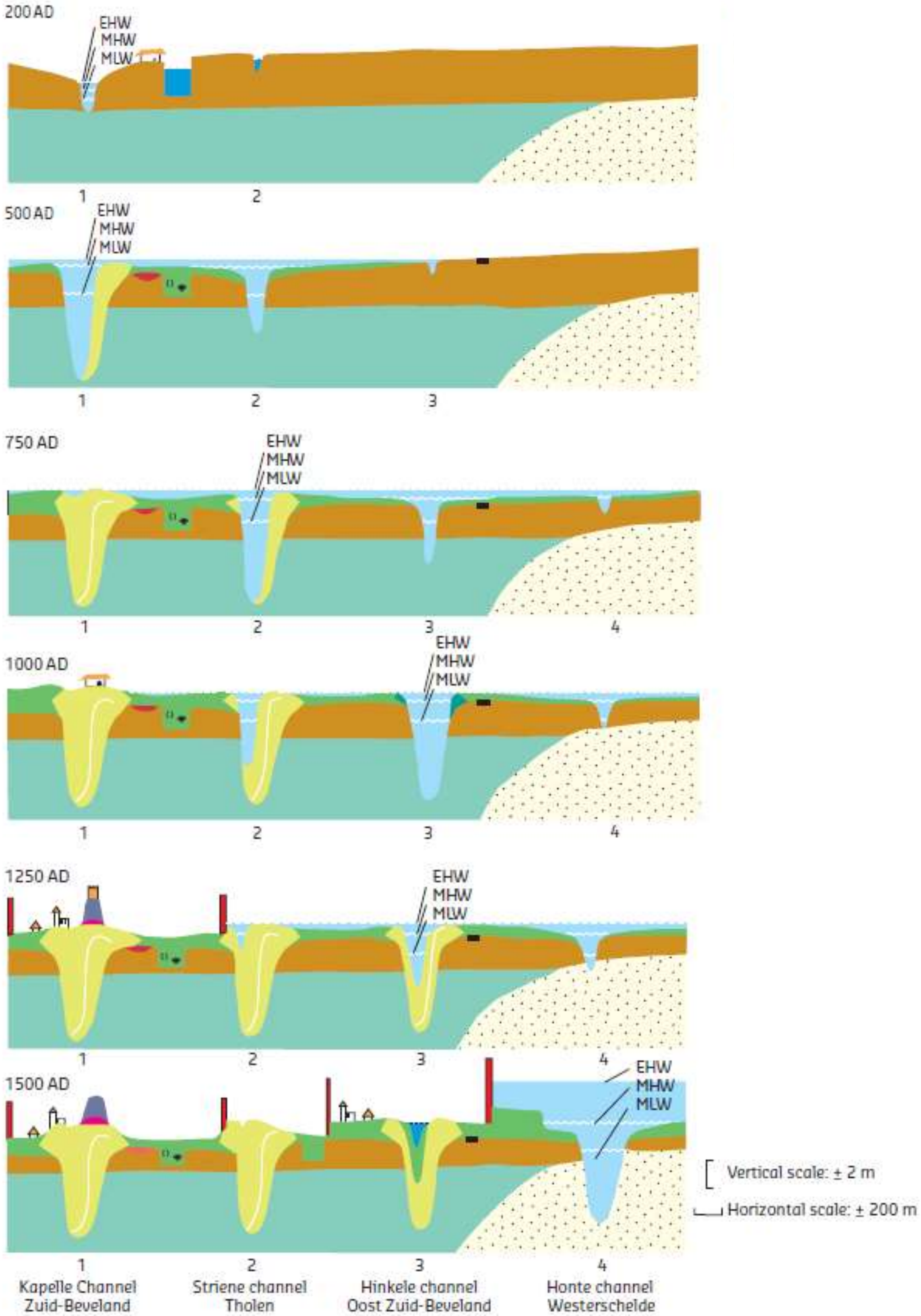


Figure 3N11: Schematic cross-section showing the development of four generations of channels, embankment, subsidence of the land surface and increase of the maximum tide levels in Zeeland.

Silting up and large-scale embankment of the landscape

After 800 AD a change occurred in the coastal evolution. Natural sedimentation (clay and sand) began to outweigh the process of lowering of the peat surface again. Consequently, the tidal area which had come into being between the third and eighth centuries AD started to gradually silt up again which led to the expansion of the salt marsh areas. As a consequence the mud flats which had risen by accretion were flooded less frequently. In the course of the tenth century parts of the newly formed salt marshes even fell dry permanently and *Flachsiedlungen* (non-raised dwellings) were built on the highly elevated mud flat deposits. Investigations of *mottes* (*châteaux à motte*) in Zeeland have revealed that during the 11th century the *Flachsiedlungen* – which are located below the dwelling mounds – were elevated by soil such that about 1 m high dwelling mounds were formed (Vos and van Heeringen, 1997). Also historical sources (Gottschalk, 1955-1958) indicate that in the coastal area of Belgium and Zeeuws Vlaanderen people lived on dwelling mounds (Locwirde, Commerswerve) during this period. During the 11th century the occupants were troubled more often by storm surges than during the 10th century (Dekker, 1971).

In the course of the 11th century humans locally began to dike in parts of the salt marshes in Zeeuws Vlaanderen. However, in the northerly located Zeeland area the systematic, large-scale impoldering of the major part of the salt marsh area took place during the 12th and 13th centuries (Figure 3N12, Dekker (1971). In addition to the favorable landscape situation (highly silted-up salt marsh areas) also social-economical factors were important to these large-scale diking-ins. The community was well organized owing to the rise of the churches and the region was prosperous due to the textile industry, in particular in Vlaanderen. The textile industry had a need for sheep wool which were kept on the salt marshes.

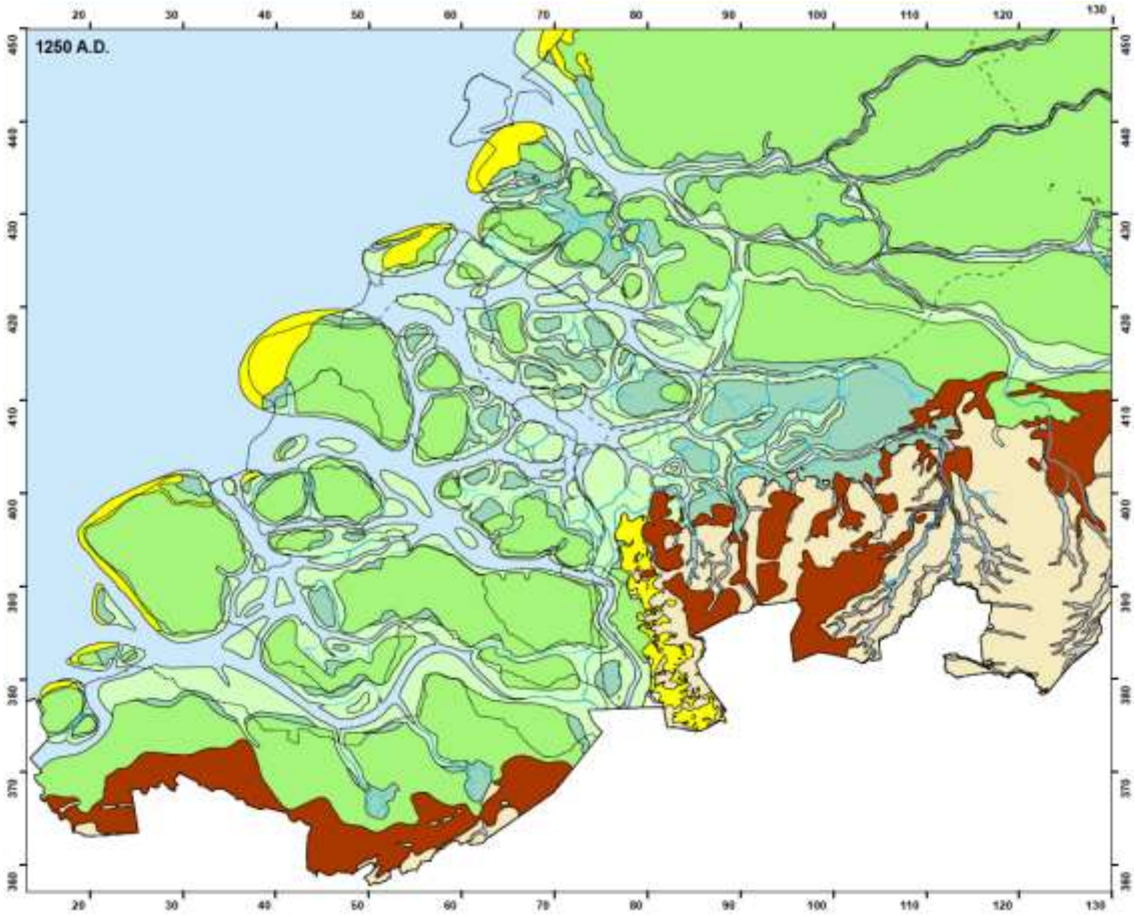


Figure 3N12: Palaeoegeographical reconstruction of the Southwestern Netherlands about 1250 AD.

The embankments had far-reaching consequences for the landscape and the tidal processes in the areas that were not diked-in. Because the major part of the salt-marsh area had been diked-in the seawater could not flow over these areas during storm surges. Since the water thus did not have an outlet anymore it was dammed up against the dikes, the result being that the storm surge level in the non diked-in tidal area was raised. The smaller the water storing capacity of the salt-marsh area, the higher the storm surge level and the higher the dikes had to be raised.

Flooding disasters

By building dikes in Zeeland humans created a landscape which was favorable for the occurrence of flooding disasters. Not only had the embankment of large parts of the salt-marsh areas caused the maximum storm surge levels to be raised considerably, but also the surface level of the diked-in polder areas was lowered due to human interference (a result of artificial drainage through sluice systems). The most significant lowering of the surface level occurred in those polders where the soil consisted mainly of peat (peat areas with a thin layer of clay). Also the excavations for the building of dikes and for salt production contributed to the artificial lowering of the surface. During the Late Medieval period large-scale salt extractions from peat drenched with seawater took place in the clay-on-peat areas (''*moernering''*). This technique of salt production, at which salt was extracted from peat by boiling, is called “selnering” (Figure 3N13).

Figure 3N13: Darinck delven or selnering (peat digging for salt extraction) in Zeeland around the 16/17th century. Pronk (1745, www.rijksmuseum.nl, 13/8/2014).

Thus humans created a large difference between the maximum storm-surge level in the open sea inlets and the surface level in the reclaimed polders (Figure 3N11). This difference in level could rise as much as several meters. When a dike breached (see dramatical depiction in Figure 3N14) this had catastrophic consequences: the seawater flowed violently into the lower lying polders. Since the inhabitants did not live on elevated dwelling mounds in the southwestern Netherlands this led to casualties and extensive damage.

Figure 3N14: Historic pictures of the catastrophic effect of a dike burst in 1651.

The flooding disasters which took place in the southwestern Netherlands have been brought into vision by means of a storm surge calendar (Figure 3N15) . This ''calendar'' distinguished between major disasters (inundation of large parts of the southwestern Netherlands) and minor ones (inundation of only one or a few polders) and also the military inundations are mentioned. The storm surge calendar shows that major disasters occurred in particular during the 14th to 17th centuries; afterwards they decreased in number. The high frequency of the occurrence of disasters during this period cannot be straightforwardly attributed to climate change; negligence of the dikes, insufficient coordination, incompetence, political circumstances, wars and economic crises all played important roles.

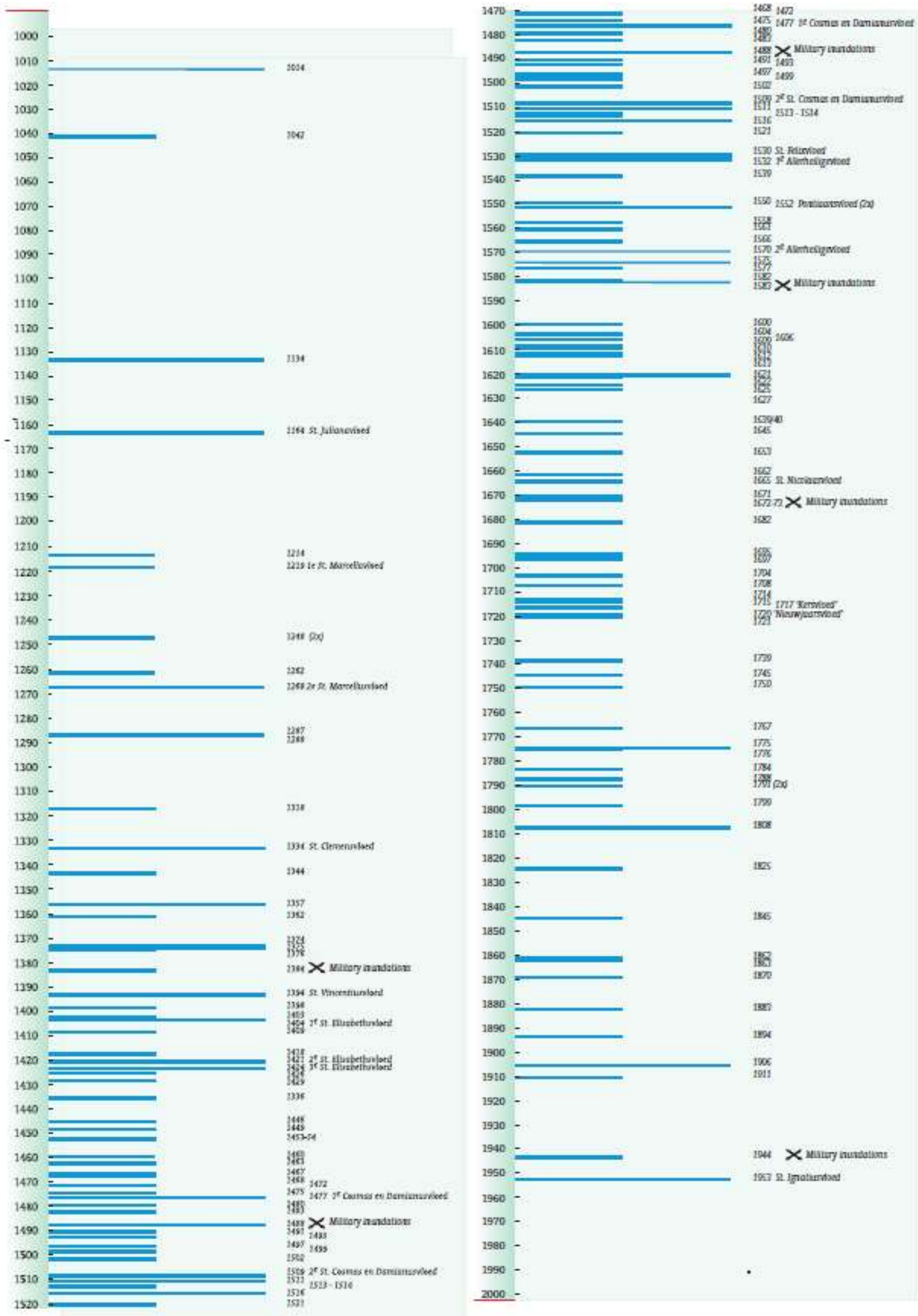


Figure 3N15: The storm surge calendar of the Southwestern Netherlands (made by F.D. Zeiler)

The floods have led to long-lasting and even permanent loss of land in certain parts of the southwestern Netherlands (compare Figure 3N12, Figure 3N16 and Figure 3N17). The area around the Braakman in the central part of Zeeuws Vlaanderen was inundated during the floodings of 1375/1376 and 1404 (St. Elisabeth Flood, see Gottschalk (1955-1958). It has taken 600 years for the area to be silted up sufficiently high such that it could be reclaimed completely. Areas which have been lost for a large part until present are the Verdronken Land van Zuid-Beveland and the Verdronken Land van Saeftinghe. The Verdronken Land van Zuid-Beveland was lost during the St. Felix Flood in 1530 (*St Felix quade saterdag*) and the storm surge of 1532 (Wilderom, 1964; Dekker, 1971; Leenders, 1986). As mentioned above, the loss of the Verdronken Land van Saeftinghe was due to military causes connected to the siege of Antwerp in 1585.

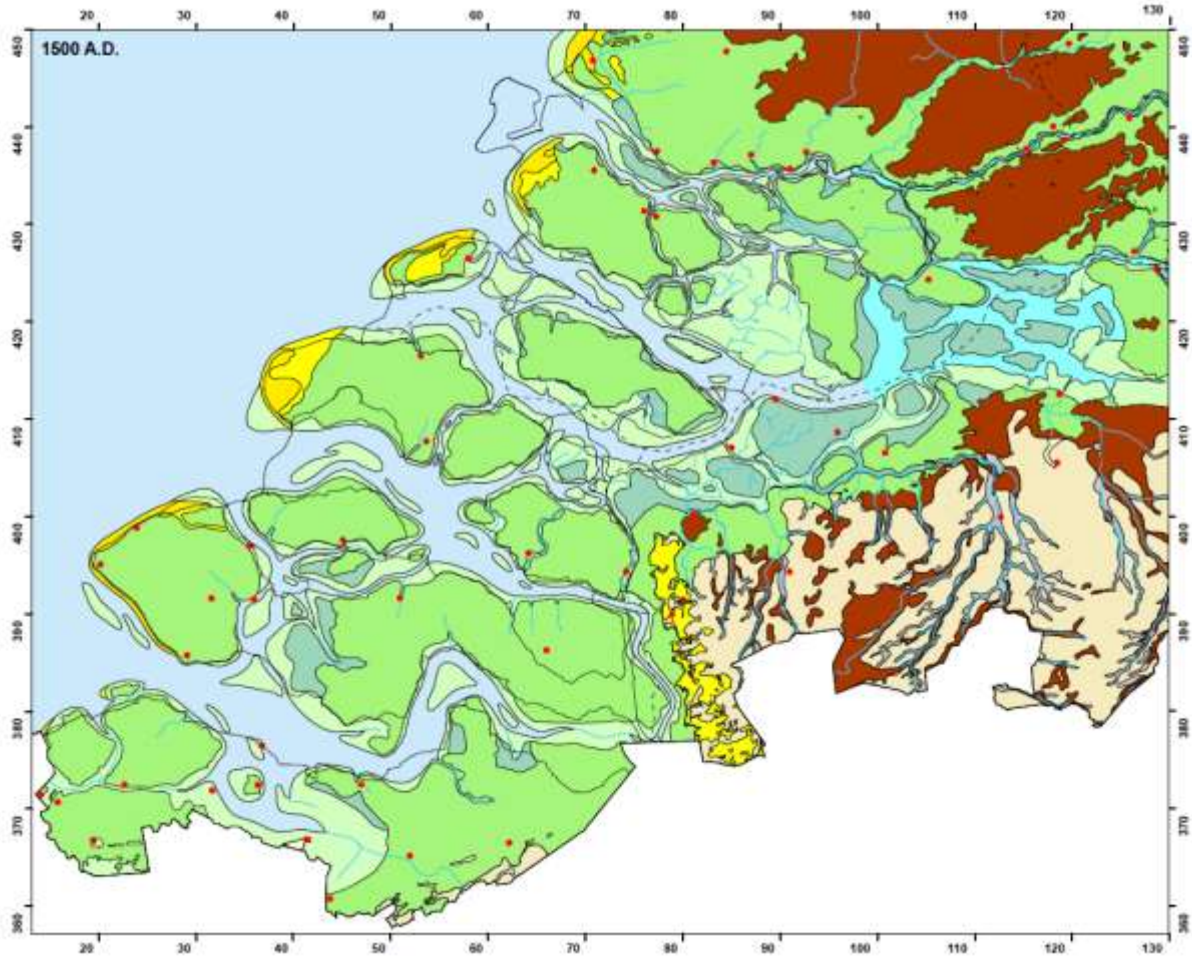


Figure 3N16: Palaeoegeographical reconstruction of the Southwestern Netherlands about 1500 AD.

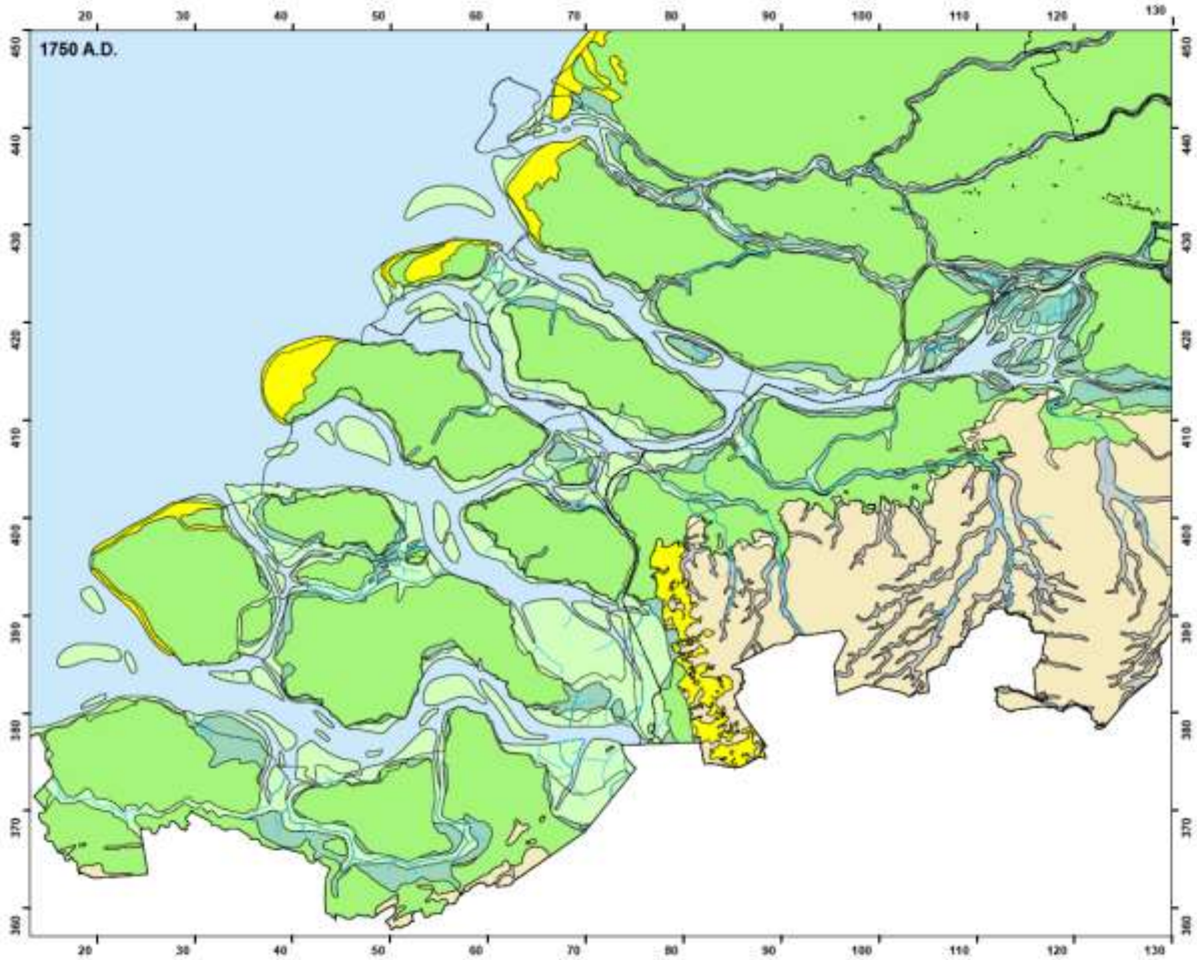


Figure 3N17: Palaeoegeographical reconstruction of the Southwestern Netherlands about 1750 AD.

The changing course of the river Scheldt

The course of river Scheldt and the mouth of the later Western Scheldt were separated at least until the Early Middle Ages, since north-west of the Verdronken Land van Saeftinge, a raised peat bog on top of the Pleistocene ridge was present. By then, the Eastern Scheldt formed the main outlet of the river. The connection between the Western Scheldt area and the river Scheldt east of Saeftinge, probably came into existence before 843 AD (Leenders, 1986). During the 10th century, the Honte was a relatively important sea branch because this connection was mentioned in historical sources as 'Mare' (Vlam, 1946; Gottschalk, 1971; Brand, 1983). The enlargement of the Honte was possibly the result of the floods of 1014, 1042 (Brand, 1983) and 1134 AD (Gottschalk, 1971; Brand, 1983). Notwithstanding the increase in size of the Honte connection, the Honte was not deep during the 13th century and could only be navigated during high water by shallow-drawing inland ships.

Around 1400, however, the Honte connection became increasingly important. The improved navigation conditions in the Honte were the result of inundations in the foreland of the Western Scheldt area (Denucé, 1933; Brand, 1983).

The storm surges of 1530 and 1532 had a decisive role for the final take-over by the Western Scheldt from the Eastern Scheldt as the main discharge of the river Scheldt (Brand, 1983). These inundations resulted in a shift of the watershed, which finally tipped the balance in favor of the Western Scheldt as the main outlet of the river Scheldt (Brand, 1983; Vlam, 1946).

Rijn-Maas Delta: The Striene connection

In the literature, a connection between the rivers Scheldt and Rijn-Maas is suggested already for the Roman Period (e.g. Hettema, 1951). The authors assumed - on the basis of a text by Julius Caesar - that the Roman Scheldt-Maas connection was the predecessor of the medieval Striene, a tidal channel which, during the 13th century, was silted up, blocked off and embanked (Wilderom, 1964). However this view is contested. The inferred Roman course of the Striene has always remained uncertain due to a lack of pedologic evidence (Kuipers, 1984; Steur and Ovaa, 1960). Also geological mapping in the 1990's has not been able to confirm the existence of a Roman Striene connection. Therefore, it is generally recognized now that the Striene was an Early Medieval connection between Scheldt and Maas. This connection came into existence after the Post-Roman inundation of the peat areas of Tholen, St. Philipsland and the area of the present-day Volkerak. Only southeast of Poortvliet (Tholen), the Striene tidal channel used the eastern part of the remnant channel of the Subboreal Scheldt meander.

Archaeology of the Rijn-Maas delta

Throughout the Holocene humans were present in the delta of the Rijn-Maas estuary. The drowning, and thus the appearance of the delta, began in this region in the Mesolithic around 7500–7000 BC at a depth of 22–20 m – NAP (Hijma et al., 2009; Hijma and Cohen, 2011; Cohen et al., 2012). At that time, especially the higher situated river dunes were inhabited.

When around 6500 BC the whole Maasvlakte area had come within the marine sphere of influence and the higher parts of the dune sites there disappeared completely by coastal erosion (Rieu et al., 2005), the occupation of higher lying dune locations shifted to the east. Mesolithic and Neolithic settlements on river dunes like those of Hardinxveld-Polderweg (ca. 5400 BC) and Molenaarsgraaf (Hazendonk, from about 4000 BC onwards) are examples of this. Also the wetlands were penetrated and encampments were built. The Mesolithic find location of Bergschenhoek around 4300 BC demonstrates these wetlands were used by humans (Louwe Kooijmans, 1985).

From the Neolithic (c. 5000 BC) onwards the area around the Verguide Hand West was part of the higher silted-up clay–peat area to the north of the main courses of the Rhine–Maas rivers (deposition of layer 6; Figure 3N23). The oldest known sites in the Maas estuary region belong to the river dune settlements such as the Piet Heinplaats in Vlaardingen and the one of Schipluiden-Noordhoorn (3900–3500 BC; De Ridder (2000)). In the subsequent period (ca. 2900–1800 BC) also the adjacent tidal levees that had been formed along the tidal creeks were taken in use. The remains of the younger settlements of the Vlaardingen culture are located in this landscape. The most famous settlements of this culture are those of the Vlaardingen Westwijk and Hekelingen in Spijkenisse (Louwe Kooijmans, 1985).

Archaeological remains from the Bronze Age area are scarce in the Maas estuary region. In the Early Iron Age the bogs along the Maas were first inhabited. Although the region was not inhabited densely in this period, settlements with houses have been found at slightly elevated peat bogs (''*peat cushions*'') in Rotterdam, Spijkenisse and Vlaardingen (Van Trierum, 1992; Wind, 1973).

In Roman times the Maasmond was part of the Roman Empire. At that time the Rijn–Maas channel was an important waterway. In the first century AD the region became intensively inhabited again. The peak of the occupation phase was in the second century AD.

During the 3rd century AD habitation decreased strongly and up to 1250 AD little is known about the nature and distribution of the settlements and their positions in the landscape. This is mainly due to a lack of well-preserved remains of settlements from this period. In particular, insufficient light has been shed on the Early Medieval traces of habitation, partly because the sites are oxidized (peat area) or eroded (marine area).

3N.2 Archaeological and Palaeoenvironmental Fieldwork Methods and Results

The fieldwork carried out at the site of Vergulde Hand West is presented first, followed by the work carried out at Yangtze Harbour.

3N.2.1 Vergulde Hand West

Fieldwork Aims

The site 'Vergulde Hand West' (VHW) is located at the west side of the municipality of Vlaardingen, immediately north of the Nieuwe Waterweg (Figure 3N18). In 2005, large-scale excavations of archaeological remains from the time periods between the Middle Bronze Age and the Middle Ages were carried out at this site. The archaeological remains which occurred at a depth of approximately 2 m below ground level were threatened by the construction of a new industrial estate. During the archaeological excavations geological research was carried out in order to be able to reconstruct the palaeoenvironments of the periods during which humans were present in the area. The geological and palaeoenvironmental research has been published in a report by Deltares (Vos and Eijskoot, 2009). This report formed the basis for the palaeolandscape synthesis in the final archaeological publication (Eijskoot et al., 2011). In this part of the study, the geological and palaeolandscape research of the VHW is summarized and the main conclusions regarding the regional landscape development are discussed. We will examine a number of special post-sedimentary layer deformations which occurred in the area of the site VHW.

Figure 3N18: Location of the study area of Vergulde Hand West (VHW) in the Vlaardingen Township (province of Zuid-Holland; The Netherlands).

Fieldwork Methodology

The area of the excavation of the 'Vergulde Hand West' (VHW) site in the summer of 2005 was about 500 m by 500 m (approximately 25 ha). The excavations were led by the Vlaardings Archeologisch Archaeological Office. During the excavations, the site was divided into four sectors, namely the sectors East, West, Middle and Canoe (Figure 3N18 and Figure 3N19). From an archaeological point of view, the sector East was relevant in particular for the Early and Middle Iron Ages and the preceding period. In the sector Middle especially the layers from the Bronze Age, Middle Iron Age and Late Iron Age were important. In the sector West interesting archaeological material was found mainly in the deposits from the Roman period and the Middle Ages. In the research of the landscape in the sector Canoe the main question was how the canoe had ended up in older peat layers. An impression of excavation and the main archaeological features found in 2005 on the VHW location are presented in Figure 3N20.

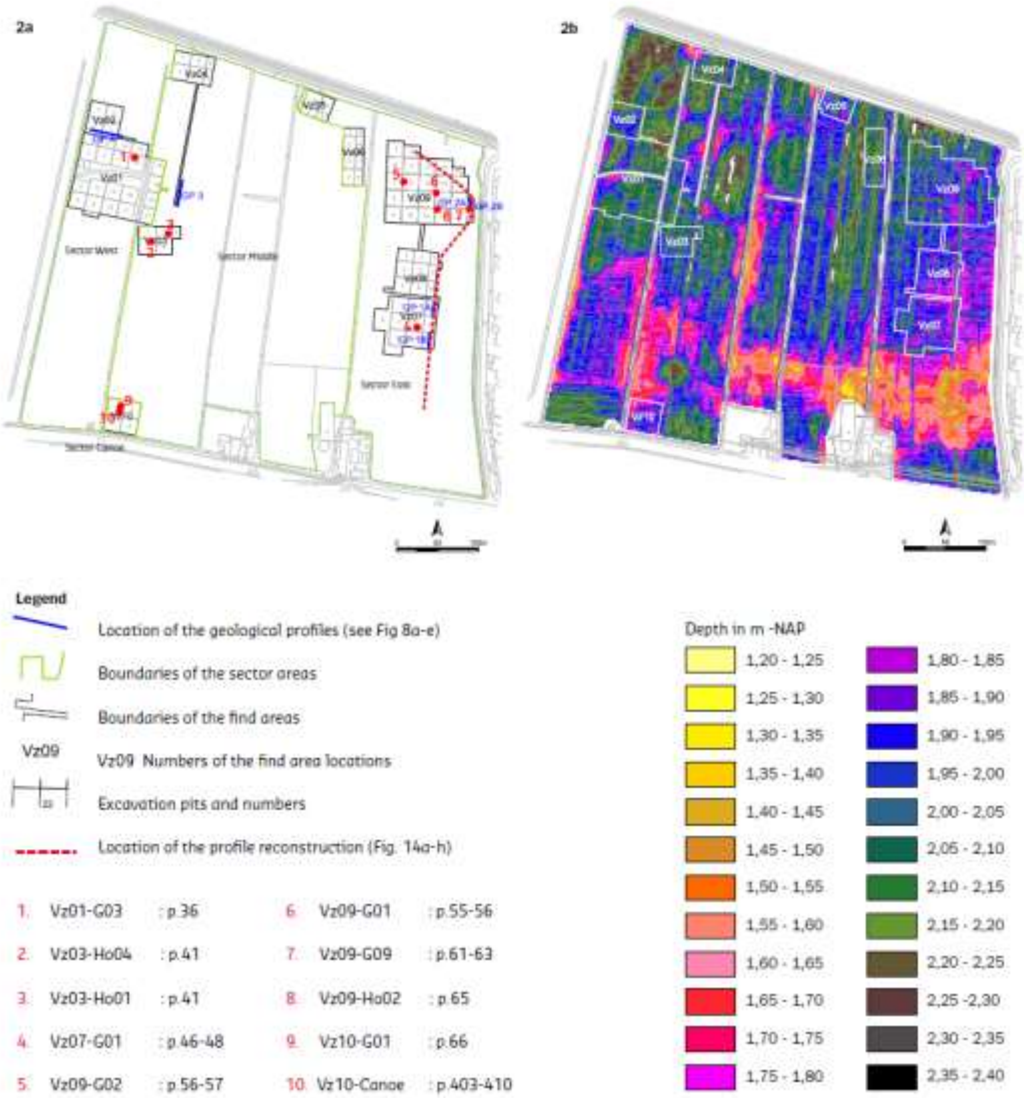


Figure 3N19: Map of the VHW study area with the location of the sectors West, Middle East and Canoe. Figure 3N19a. Topographical map with positions of the geological profiles (Figure 3N25) and main archaeological sites. Figure 3N19b. Lidar elevation map (AHN) of the VHW.

Figure 3N20: Impressions of the VHW excavation in 2005. Figure 3N20a. Excavation of find location area Vz09 in sector East (see also Fig. 2a); Figure 3N20b. Floor and house wall of branches from the Middle Iron Age (Vz09-G01; sector East); Figure 3N20c. Foundation posts of a granary from the Middle Iron Age in sector East (find location area Vz09 in sector East) Figure 3N20d. Foundation posts of a wooden structure dated around 992 AD (Vz02-Ho01 in sector West); the posts are struck in the preserved medieval peat layer (Hv-1, see Fig. 7); Figure 3N20e. Path of branches from the Middle / Late Iron Age (Vz09-P01; sector East); Figure 3N20f. Remains of wooden structure from the Middle Bronze Age at the base of the Spuipolder layer (Vz10-Ho01 in sector Canoe); Figure 3N20g. The 11 m long canoe made of oak (find location area Vz10, sector Canoe); Fig. 3h. Ditch from the 2nd century AD which was dig in the Binnenpolder layer of sector East (find location area Vz08, sector East).

The landscape history formed an important part of this archaeological study, because of its relevance to the understanding of the relationship between the development of this landscape and human activity in the area. Also the relationship with the surroundings, such as water connections, was part of this geogenetic and archaeo-landscape research. From the Neolithic onwards (period after 4000 BP) the area of the VHW was geographically part of the north side of the Rijn–Maas delta (Figure 3N4). During this period, the depositional environment of the VHW was above the palaeo-MHW level and the deposition of clay sedimentation and peat formation alternated. Landscape environments which occurred were brackish marsh deposits, freshwater tidal deposits, reed bogs, alnetum fens and oligotrophic peat bogs. The geological / palaeo-landscape research that was carried out had a strong chronological approach. For each of the sectors of the VHW a stratigraphic model of the layer units was composed (peat – clay) which have been formed from the Middle Bronze Age onwards (Figure 3N22, Figure 3N23 and Figure 3N24).

The lithological and archaeological layer units were dated by means of a large number of ^{14}C datings, more than 200 in total (Eijskoot et al., 2011). By using wiggle-match techniques and dendrochronological studies of oak and ash piles, datings of archaeological pole structures could be obtained with a 2-sigma reliability of less than 10 years (Eijskoot et al., 2011). Due to the high precision of the datings from amongst other Mid / Late Iron Age settlements also the drowning of these archaeological structures could be determined fairly accurately.

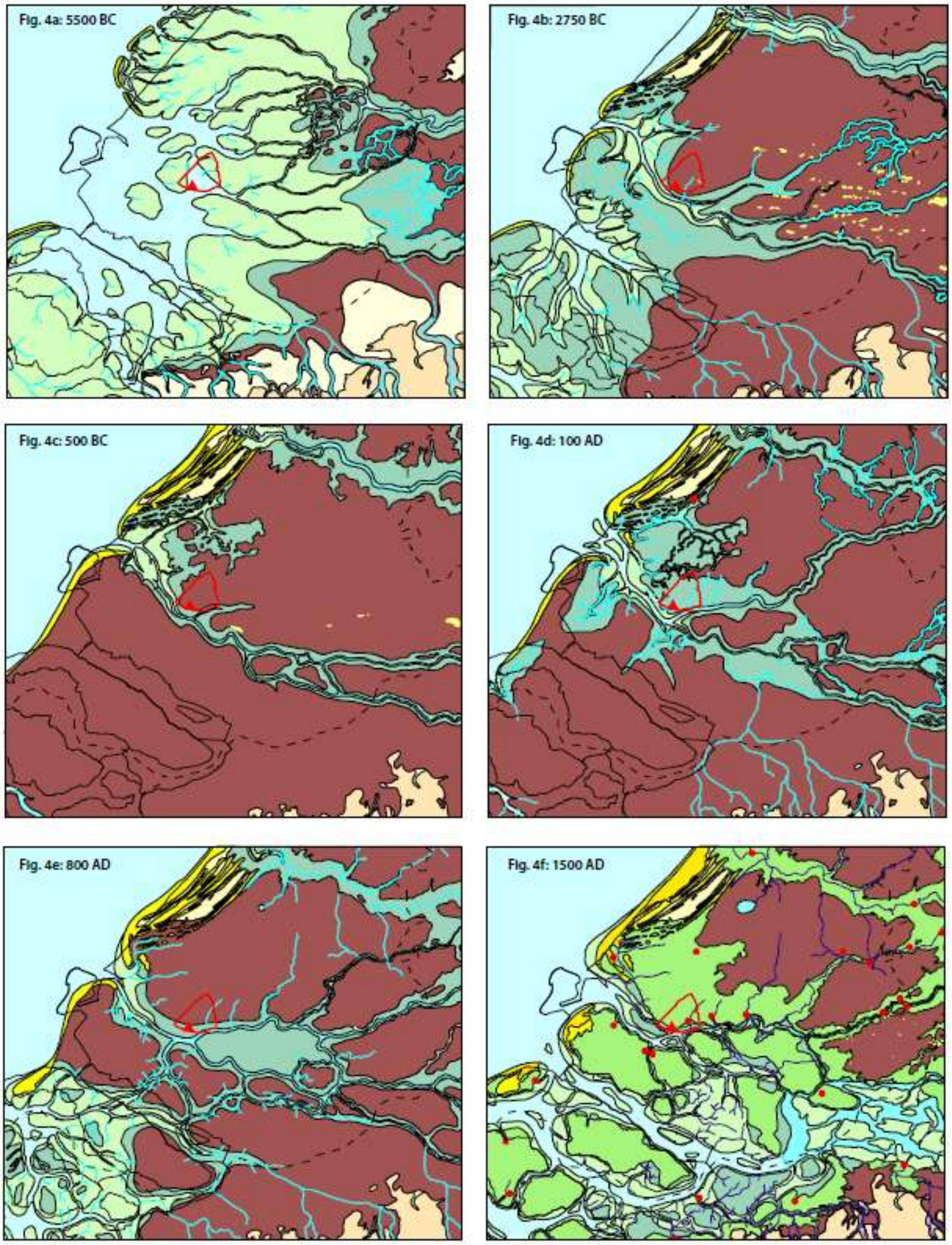


Figure 3N21: Regional landscape reconstruction of the Rijn-Maas delta during the Holocene: an excision from the palaeogeographical maps of the Netherlands for the Maasmond area, after Vos et al., 2011.

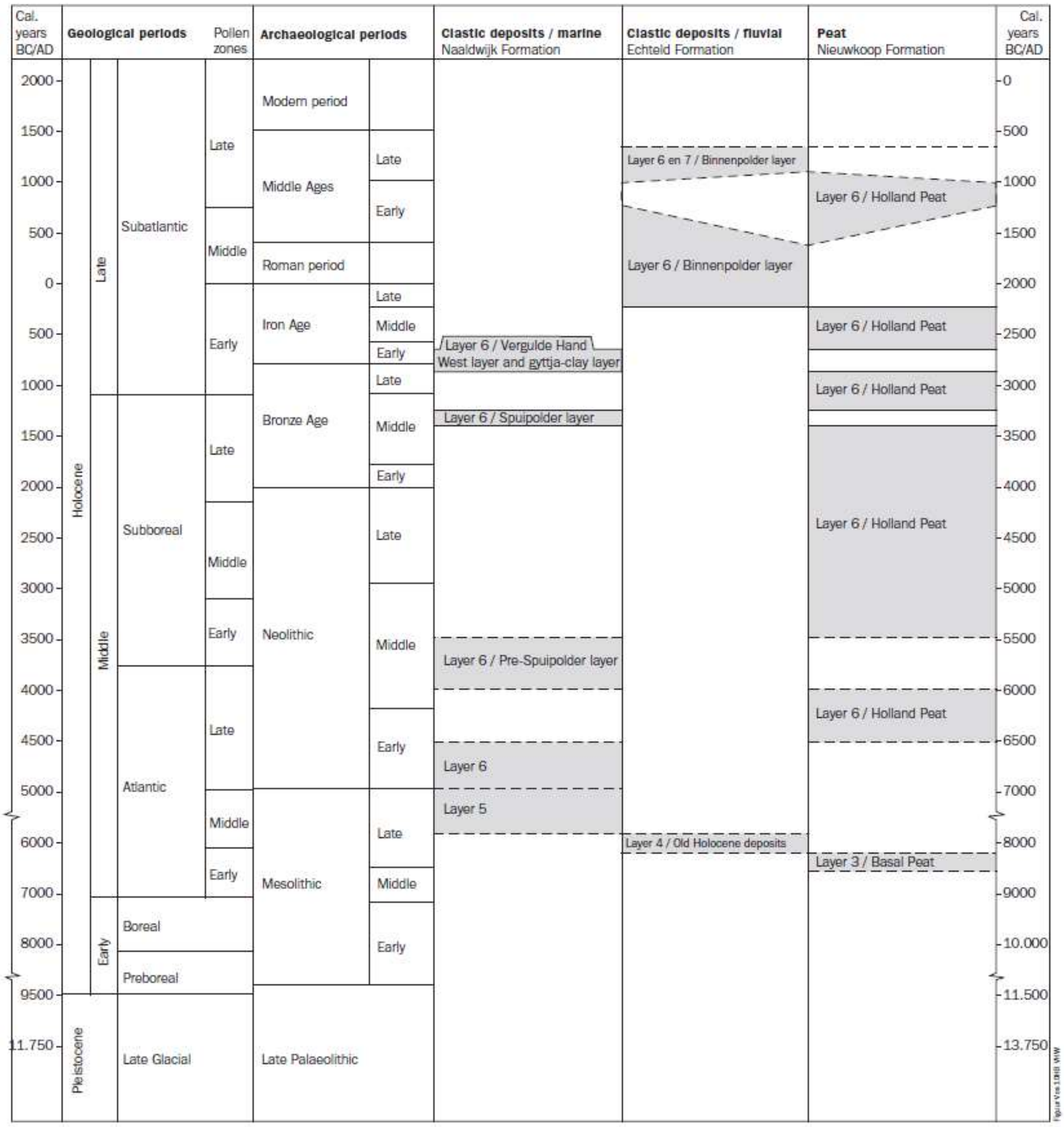


Figure 3N22: Geological and archaeological chronostratigraphical scheme of the Holocene with the regional lithostratigraphy in the area of the VHW (main layers 1 up to 7; see also Figure 3N23 and Figure 3N24).

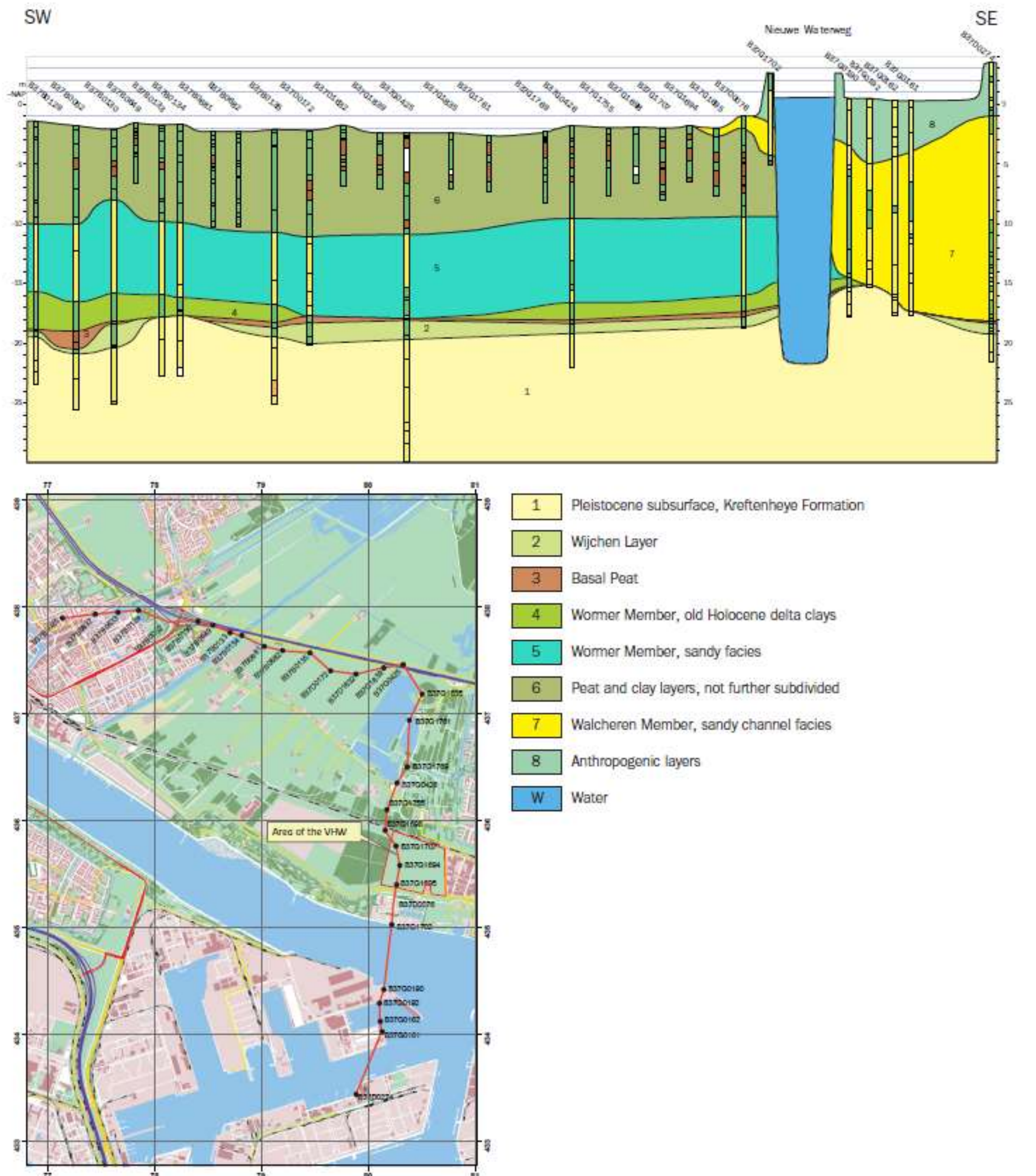


Figure 3N23: Location map and lithostratigraphic cross-section of the Holocene deposits of the VHW and surrounding area; for the chronostratigraphical classification of the layers, see Figure 3N22.

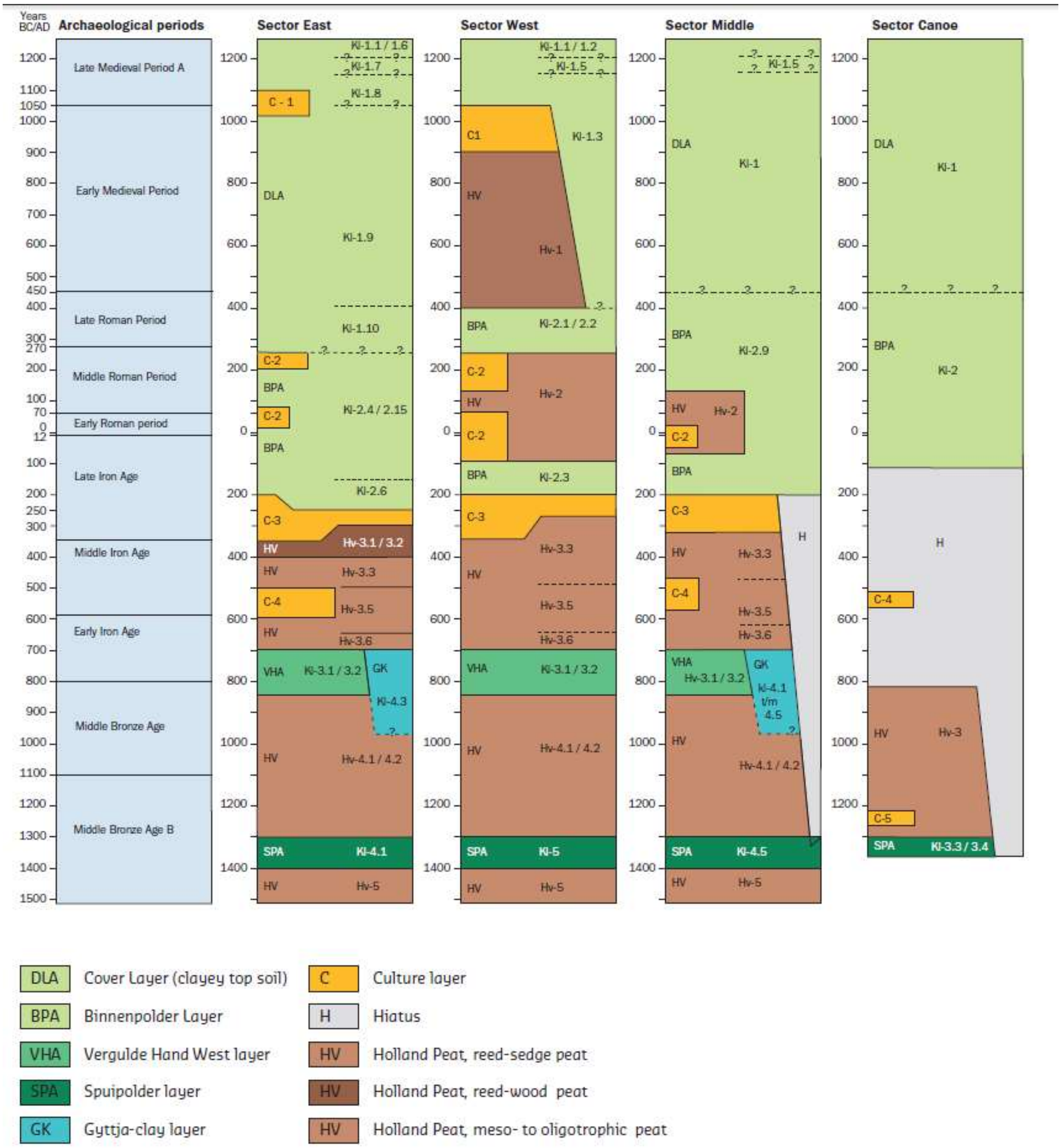


Figure 3N24: Stratigraphic scheme of the VHW location, in which the local lithological layers of the sectors East, West, Middle and Canoe are classified in time.

In order to be able to reconstruct the landscape evolution in detail for each sedimentation phase extensive multidisciplinary, palaeo-ecological research has been conducted on both the natural and the archaeological cultural layers. This research concerned pollen grains (pollen analysis), diatoms (silica algae), molluscs, botanical macro remains (larger plant litter; Vos and Eijskoot (2009)) and micromorphological research on sediment slices. In addition, from the archaeological cultural layers also mites, beetles and Chironomidae ("midges"), which provide information on the palaeoenvironment, were examined (Eijskoot et al., 2011).

The archaeological remains themselves also provide information about the palaeoenvironment. For instance, the presence of a Middle / Late Iron Age permanently inhabited settlement in a bog proves that this peat area was drained and the growth of peat had come to an end at that location. A constructed wood path of branches (Figure 3N20e) indicates that at the time when the path was used the peat was (periodically) swampy and difficult to access.

Holocene sequence or surroundings of the VHW
Holocene layer units which occur in the subsoil of the area around the Vergulde Hand West are shown in a geological overview profile of the site location and its immediate surroundings. From the profile (Figure 3N23)– based on 29 boreholes from the DINO database of Geological Survey of TNO Netherlands – it can be derived that the Pleistocene fluvial deposits, including the Layer of Wijchen, lie below a depth of approximately 18 m - NAP (layers 1 and 2). The Basal Peat and Early Holocene inundation clays lie at a depth of about 15–18 m - NAP (layers 3 and 4). These old Holocene deposits are covered with sandy, estuarine tidal deposits, which are counted among the Wormer Member (layer 5 in the overview profile). The top of the Wormer sands lies at a depth between 8 and 10 m - NAP. For the sediment facies of the older Holocene deposits in the area, see also the descriptions in the publication of the Blijdorp pit (Cohen and Hijma, 2008).

On top of the Wormer Member a sequence of clays and peat was formed (layer 6). These belong to the estuarine and fluvial delta deposits of the Rijn and Maas. In the profile of individual peat and clay, layers have not been stratigraphically subdivided any further because the sediment sequence at scale level of the profile is too complex. This is due among others to the presence of post-sedimentary deformations in the subsoil, such as the occurrence of *intrusion clays* (in Dutch: *oplichtingskleien* of *klapkleien*; in German *Klappkleis*; Behre (2005)) and local subsidence of clay soils in the peat by autocompaction

The Basal Peat in the surroundings area of the VHW has been dated to around 8500 cal. BP (Hijma et al., 2009); layer 3, at a depth of about 18 m - NAP). The basis of the clay–peat complex in the region has been dated between about 6500 and 7000 cal. BP (Hijma et al., 2009). Based on these datings the formation of the sandy tidal deposits (layer 5) has been placed in the Mid Atlantic (Figure 3N22). In the excavation pits of the VHW the peat–clay profile had been opened up to 1 to 2.5 m below ground level (approximately 2.5 to 4 m - NAP). The ages of the peat and clay layers exposed, have a time range that lies between the Mid Bronze Age and Late Middle Ages. At one particular location in sector East also deeper lying peat deposits from the Middle Neolithic have been sampled for age determination. This dated peat lay around 6 m - NAP and has been dated to about 5750 cal BP (GrA-34130 and GrA-33011, in Figure 3N25c).

Lithostratigraphy of the subsurface deposits of the VHW
The subsurface of the VHW *down* to a depth of 2.5 m – NAP, which had been exposed during the archaeological excavations, consisted of clay and peat layers. In the stratigraphic overview profile (Figure 3N23) all of these layers have been combined into a single layer, unit 6. Within the area of the VHW, these layers have been subdivided in further detail for the 4 sector areas (Figure 3N24 and 3NFigure 3N25). In the pictures of Figure 3N26 an impression is given of the litho-facies of the different stratigraphic layers.

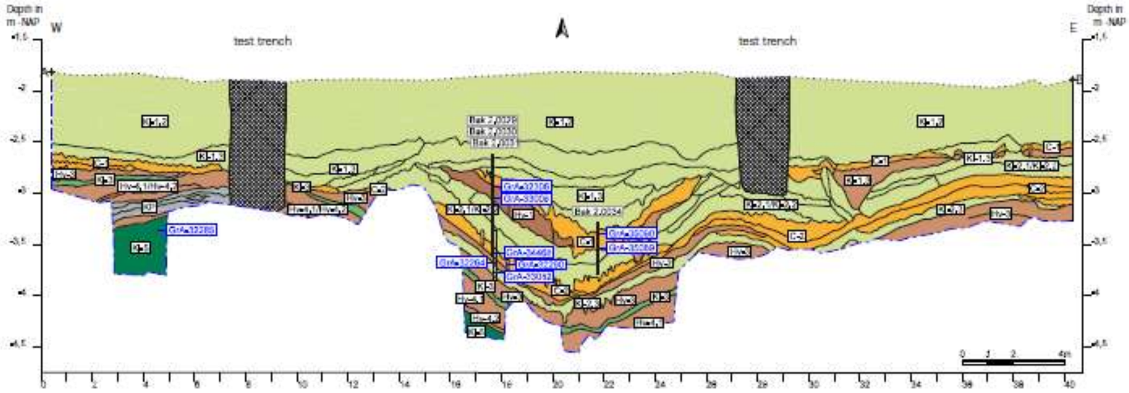


Fig. 8d. Geological profile 4

RD-/NAP coordinates (x-, y- and z-values)
A 80,223/435,756, -1,80
B 80,273/435,748, -1,90

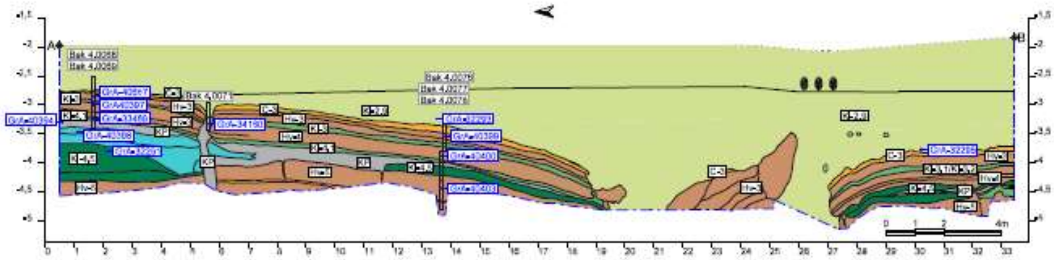


Fig. 8e. Geological profile 3

A 80.346/435.695, -2,00
B 80.340/435.663, -1,85

^{14}C-dates of profile 8d

Groningen-code	BP	2σ date-range
GrA-35090	1150 ± 40	778-978 AD
GrA-35089	1380 ± 40	592-764 AD
GrA-32306	1820 ± 35	88-318 AD
GrA-33008	1705 ± 25	258-402 AD
GrA-34488	1950 ± 60	90 BC - 217 AD
GrA-32284	2095 ± 35	199-40 BC
GrA-32290	2035 ± 35	161 BC - 62 AD
GrA-33082	2180 ± 35	370-121 BC
GrA-32285	3080 ± 35	1420-1267 BC

^{14}C-dates of profile 8e

Groningen-code	BP	2σ date-range
GrA-34180	2145 ± 35	354-54 BC
GrA-32295	2215 ± 35	379-201 BC
GrA-32293	2240 ± 35	390-203 BC
GrA-40687	2250 ± 50	398-201 BC
GrA-40399	2255 ± 25	391-208 BC
GrA-40394	2255 ± 30	392-207 BC
GrA-33488	2500 ± 40	794-418 BC
GrA-40397	2540 ± 30	800-545 BC
GrA-40398	2630 ± 30	829-792 BC
GrA-40400	2915 ± 25	1203-1020 BC
GrA-32291	3080 ± 35	1420-1267 BC
GrA-40403	3410 ± 30	1880-1628 BC

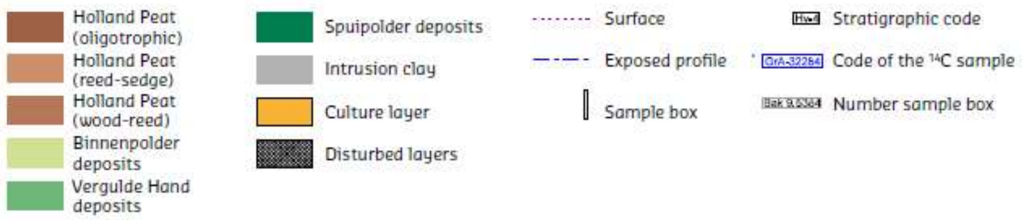


Figure 3N25: Lithostratigraphic cross-sections of the pit profiles of the sectors West, Middle and East. Figure 3N25a. Geological profile 1A in sector East; Figure 3N25b. Geological profile 2A and B in sector East; Figure 3N25c. Geological profile 1B in sector East; Figure 3N25d. Geological profile 4 in sector West; Figure 3N25e. Geological profile 3 in sector Middle. For the location of the profiles, see Figure 3N19; and explanation stratigraphic codes in the profiles, see Figure 3N24.

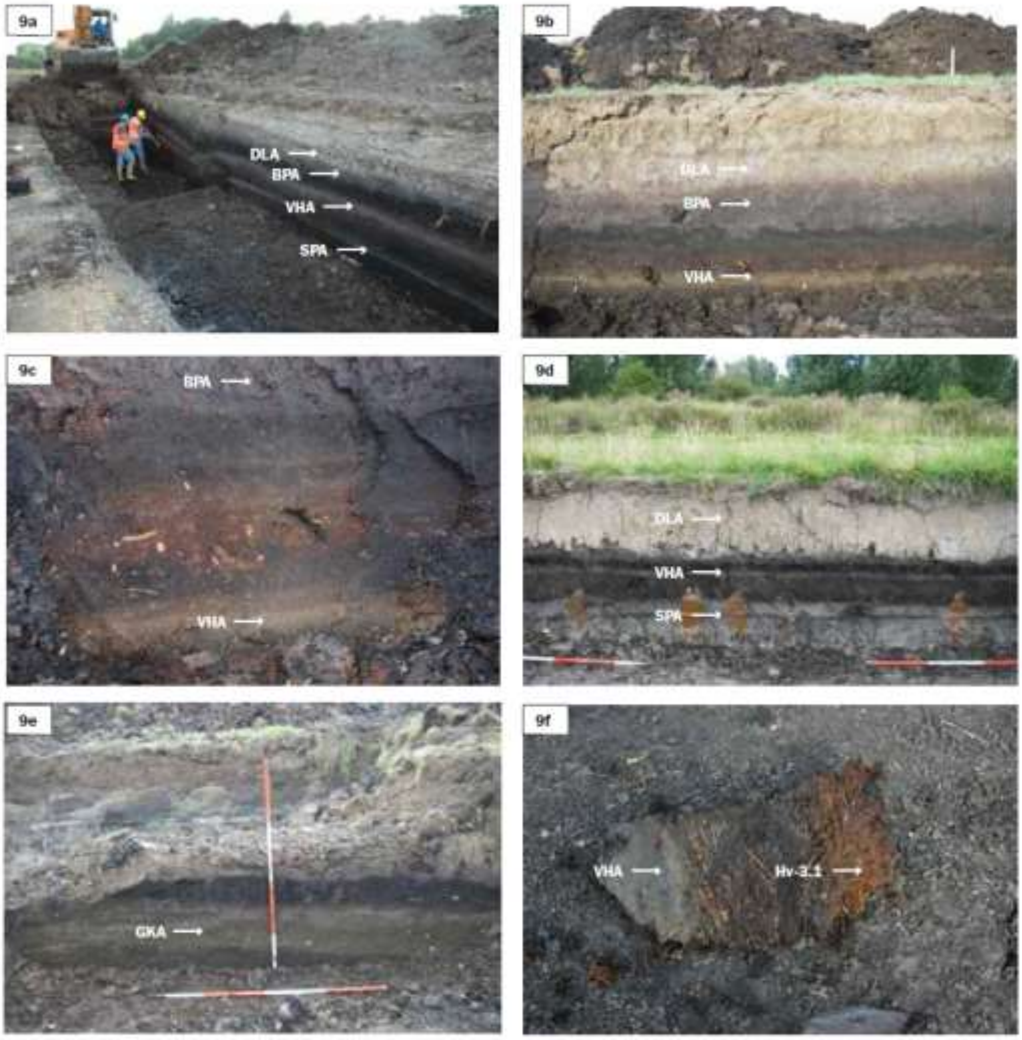


Figure 3N26: Pictures of the lithostratigraphical units exposed in the pit profiles of the VHW. See Figure 3N24 for the explanation of the stratigraphic codes of the sediment layers. Figure 3N26a. BPA, VHA and SPA layers embedded in peat, find location area Vz07 in sector East; Figure 3N26b. Peat layer (Hv-3) situated between the BPA and VHA layers, on top of the peat layer the Middle Iron Age soil disturbance is visible in the dark irregular layer (culture layer C3), find location area Vz07 in sector East; Figure 3N26c. Peat layer (Hv-3) situated between the BPA and VHA layers, in the peat layer - from the base to the top - the subunits Hv-3.6 (reed peat in a black matrix), Hv-3.5 (reed-sedge peat with alder wood), Hv-3.3 / C3 (dark brown mesotrophic peat, the top is disturbed by man) are exposed, find location area Vz08 in sector East; Figure 3N26d. BPA, VHA and SPA layers and intercalated peat layers (Hv-3 and 4), find location area Vz01 in sector West, in this sector the grey clay layer of the SPA unit relative thick. Figure 3N26e. Gyttja-clay deposits (GK) below the peat layer Hv-3, in find location area Vz06 in sector East. Figure 3N26f. Peat lump of the Hv-3 unit from a pit profile in find location area Vz09 in sector East, layers from left to right: VHA, HV-3.5/6 and Hv-3.3 (Sphagnum peat).

The estuarine deposits of the Rijn–Maas delta which were formed in a brackish to marine environment are counted among the Walcheren Member (part of the Formation of Naaldwijk). The fluvial delta deposits (river- and freshwater tidal deposits) are rated among the Formation of Echteld (Westerhof et al., 2003)). The distinction between the estuarine and fluvial deposits has been made on the basis of the presence of remains of trees in the river delta deposits. Here this concerns trunks, roots of wood and dispersed wood such as leaf matter (mainly 'alder swamp forest elements'). Another difference is that the fluvial delta deposits generally are richer in humus, and therefore more brownish in color. The estuarine clays consisted mainly of marsh deposits that were rooted by reed. All peat layers were counted among the Holland

Peat, which is part of the Formation of Nieuwkoop. Subsequently, at layer-level subunits were distinguished within these clastic and organic main units. These layers occur locally and for that reason have a stratigraphic significance only within the VHW site and immediate surroundings. The names of the clastic layer units (Binnenpolder-, Vergulde Hand-, Spuipolder deposits) have been derived from the topographical names from the surrounding area.

Within the investigated estuarine delta deposits of the VHW, two clastic layers have been distinguished:

1. Vergulde Hand deposits (VHA): Grey clays, usually strongly rooted by reed and slightly humic. The layer lies above the Spuipolder deposits and is separated from that layer by a layer of reed peat.
2. Spuipolder deposits (SPA): Grey clays similar to the Vergulde Hand deposits. These clays too are often rooted by reed.

The marine clastic layers under the Spuipolder layer (clay layer about 4 m below ground level) are called the pre-Spuipolder deposits. These deposits had been opened up only in sector East.

The fluvial clastic delta deposits consist of:
1. Gyttja-clay deposits (GK): Green-brown to grey-brown gyttja and strongly humic clays. These deposits contain much organic matter including detritus (fine and coarse), leaf litter and also wood. They are lake bottom sediments which occur only in sector Middle and the northwestern part of sector East.
2. Binnenpolder deposits (BPA): Grey to grey-brown clays, often humic to strongly humic, with wood and remains of roots of wood. Locally also reed fragments and roots of reed may occur in the clay. To the Binnenpolder deposits also belong the clays above the peat from the Mid- and the beginning of the Late Iron Age, which have been deposited in pools or depressions. Due to their very weight these clays have subsided into in the underlying peat layers (differential setting). Also the creek deposits, which were exposed in the profiles of the excavation pits of the sectors East, Middle and Canoe are counted among this layer unit.

The *intrusion clays (KP)* make a separate clastic layer unit because they have been deposited in cracks and fissures within the peat by buoyancy of the peat and therefore they are younger than the above- and underlying peat (Figure 3N27). The intrusion clays are associated with the first floods that marked the start of the deposition of the Binnenpolder layer. For that reason, the intrusion clays – in the peat – can observed as a part of the Binnenpolder layer.

Figure 3N27: Pictures of the intrusion clays in peat profiles of the VHW. Figure 3N27a. Horizontal view of a crack in the peat, filled in with intrusion clay, in find location area Vz07 in sector East. Figure 3N27b. Horizontal view of a crack in the peat filled in with intrusion clay, in find location area Vz07 in sector East. Figure 3N27c. xx; Vertical view of grey intrusion clays (Kp), through the HV-3, VHA and Hv-4 layers in find location area Vz07 in sector East. Figure 3N27d. Vertical view of grey intrusion clays (Kp), split up in several layers, through the HV-3, VHA and Hv-4 layers in find location area Vz07 in sector East (see also profile of Figure 3N25a). Figure 3N27e. Vertical view of grey intrusion clays (Kp), with the direct contact with the upper laying BPA layer, and breached out in the HV-3, VHA and Hv-4 layers, in find location area Vz04 in sector Middle (see also rofile of Fig 8a). Figure 3N27f. Peat blocks which are pushed against each other as a result of the floating of the peat in the period between 250 and 200 BC, in find location area Vz09 in sector East. Fig. 10f. Peat block which was drifted away during the floating of the peat between 250 and 200 BC and later filled in with intrusion clay (Kp) and Binnenpolder clay (BPA layer), in find location area Vz01 in sector West.

Also the *cover layer (DLA;* Figure 3N24*)* are a special unit because the characteristics of the unit are mainly determined by pedological processes and these processes alternate the oridional sediment structure. Therefore, the pedogenesis obscures the original geological features of the sediments in the cover layer. The DLA layer lies above the groundwater level and for that reason the clays have been oxidized and highly fragmented (crumbly because of many crimp- and swell cracks). Due to the oxidation the iron in the soil layer has a reddish brown color (rusty spots) and all (initially present) remains of plants have been decomposed. Originally peaty layers – and also the organic archaeological material – within the oxidation zone of the DLA layer have vanished completely. At the very most these organic levels in the covering layer are recognizable by the dark gray (humic) discoloration which resemble 'vegetation horizons'. Because of the differential subsidence and accretion of the layers, they are not lying on the same level everywhere. The relative high situated BPA and VHA layers may occur locally within the oxidation zone of the soil. In that case, these older clastic deposits cannot be distinguished - lithologically and stratigraphically - since the separating peat layer is missing. At those locations the older VHA clays are part of the DLA layer. Stratigraphically the DLA layer is counted as a part of the BPA layer because in terms of volume most of the sediment consists of fluvial / fresh water tidal deposits which belong to the Formation of Echteld.

In the stratigraphic table the clastic layers and intrusion layers are indicated by code Kl and Kp, respectively. In each sector, from top to bottom the layers have been assigned a serial number (Kl-1, 2 etc.) and each sublayer a second serial number. Thus, for example, a sublayer within the VHW layer in sector East, has been assigned a code Kl -3.2 (Figure 3N24). The various peat and cultural layers in the stratigraphic sequence are indicated by a code: Hv for peat layers and C for cultural layers. These layers too have been assigned serial numbers from top to bottom; for example, a peat layer in between the VHW and SPA layers in sector West has the code Hv -4.1 (Figure 3N24). It is emphasized that within the sectors the layer codes are not always synonymous. This is due to the fact that the assignments concerned a field coding where the peat layers were counted from top to bottom. In the sector Canoe, however, a peat layer was lacking. Therefore in this sector the numbering of the peat layer sequence differs from those in the sectors West, Middle and East, see Figure 3N24.

The peat in the subsoil of the VHW consisted generally of reed peat, reed peat with wood or brook peat consisting mainly of alder. Oligotrophic peat with a.o. heather twigs (*Ericaceae*) and peat moss (*Sphagnum*) has been found in sector East only (Hv 3.1 / 3.2).

In Figure 3N24 the lithostratigraphic layer units of the VHW have been placed in time on the basis of ^{14}C datings of the top and bottom of the peat layers and the archaeological datings of the cultural layers. The most important dates of the layers are shown in the pit profiles of the four sectors (see Figure 3N25; and references in Tables 3N1a–1d). The Pre-Spuipolder layer in sector East was formed about 3750 BC, the SPA layer between about 1400 and 1300 BC, the VHA layer between about 850 and 700 BC and the BPA was formed after about 225 BC. In the Roman Period and Early Middle Ages (400 – 1000 AD) peat formation occurred in the VHW area. Remnants of this peat have been preserved only in the sectors West and Middle because there parts of the peat are lying below the groundwater level. In the sectors East and Canoe the peat has vanished completely because there the peat had been raised to above the groundwater level and was therefore fully decomposed by oxidation. Remnants of this peat can only be recognized by the dark layer levels in the BPA layer.

Post-sedimentary layer deformations

During the geological investigation of the profile walls of the excavation pits in the four sectors it appeared that layers had been deformed after their deposition. Three post-sedimentary deformation processes can be distinguished:

- Formation or intrusion clays: fissuration in the peat because parts of the peat became buoyant / floating and therefore loose from the subsoil during periods of high water.

- Autocompaction: subsidence of peat layers in the subsurface as a result of (differential) gravitational forces of the covering clay layer.
- Peat oxidation, oxidation of the organic material of peaty deposits.

These three deformation processes changed the location and stratigraphic position of the layers, including the archaeological layers and features, in the shallow subsurface of the VHW. The causes of the deformation processes will be briefly discussed below.

Intrusion clays
In the natural depositional sequences, in general, younger sediments are found on top of the underlying older sediments. However, there are exceptions to this rule when the layers are displaced and turned around by large-scale tectonic movements. Also intrusion clays are an exception to the rule that younger deposits are found on top of older deposits because these clays are not formed on top but within a peat layer. An intrusion clay layer can be formed when a peat layer becomes submerged. Then the top of the peat layer can become buoyant and tear loose from the peat subsurface. The top of the peat can become buoyant when the gravity of the peat is lighter than the gravity overlying water. There are two reasons to explain why the top of the peat has a lower specific gravity than the flood water:

1. The flood water is salty and that is heavier than the fresh groundwater in the peat (Behre, 2005).
2. The top of the peat is drained and contains a lot of air which is encapsulated and does not escape immediately after flooding. The oxygen containing peat is similar to polystyrene (foam) which has big buoyancy.

At occasional high water levels that are higher than the surface of the peat, the relatively light top of the peat will not be submerged but become buoyant. Because of the upward force horizontal and vertical cracks are formed in the peat. Those parts of the peat that were torn loose will become buoyant peat islands at high tide. When the water levels are lowered the peat islands will subside and the peat will lie on the subsoil again. During the interim period between high and low tide intrusion clay was deposited under the peat island. When the flooding occurs frequently, the peat will go up and down and below the peat island a layer of intrusion clay of a few centimeters up to over a cm thick can be formed (Figure 3N27). The intrusion clay layers are characterized by sharp lower and upper limits and the lack of rooting. The clay is heavy and often layered on (flat) remnants of plants and on humus content. After the peat has lost its buoyancy and is no longer lifted up during floods, also the vertical peat cracks get filled with clay. This clay deposit is not layered.

In the area of VHW the intrusion clays in the peat were formed between 250 and 200 BC. Due to the archaeological finds that occurred in the top of the peat in sector East, the process of intrusion clay formation could be dated fairly accurately. On the basis of wiggle match datings it could be established that the latest farmhouse (Vz01 - G01) was occupied around 250 BC and must have been abandoned once and for all a decade later (Eijskoot et al., 2011).

It is very likely that man continued to live on the bog during the floating of the peat and the formation of the intrusion clay since a wood path of branches was built on top of a clay-filled fissure in the peat (Eijskoot et al., 2011). How long the occupation of the floating peat islands continued is unclear; it may have been a couple of years, but also a few decades. Because, due to the repeatedly going up and down, the peat continued to tear further, the living conditions became increasingly unfavorable. Also within the settlements and in the farm houses cracks filled with intrusion clay have been observed. An example is a settlement Vz03 - Ho04 which was pulled out of its joints by fissuring peat (Eijskoot et al., 2011).
Archaeological remains were deposited through the cracks and fissures in the intrusion layer under the peat surface. These remains concern settlement waste matter, a large amount of building wood and even a sheaf of flax, complete with seeds, capsules and stems. This sheaf

of flax indicates that in the period immediately before the cracking of the peat, arable farming was still practised in the area of the VHW. Another example of where cracks in the peat influenced the original deposition of archaeological remains is the location of the canoe. This canoe is found along a tidal creek in the peat marsh. By uplift and intrusion of the peat the canoe was carried from the creek side into the peat fissure (Eijskoot e.a., 2011; p. 403-410). For that reason the canoe, dated to the Early Iron Age, is younger than the below- and above-lying peat which was dated to the Bronze Age.

During the water-level changes the floating chunks of peat blocks went back and forth horizontally. In some places it has been observed that the peat chunks were pushed up against each other during high water periods (Figure 3N27) but also that they were dispersed and the resulting hole was filled with BPA clay (Figure 3N27). Around 200 BC the peat blocks lost their buoyancy permanently, probably because the oxygen content in the package had been reduced strongly.

In the situation of the VHW the greater specific gravity of the flood water will have played not more than a limited role in the buoyancy of the peat. The fact is, the intrusion clays and the overlying clays of the BPA layer were formed in a predominantly freshwater environment, causing the specific gravity of peat water to be close to that of the flood water. Probably humans played an important role in the aeration of the peat resulting from the drainage in the Middle / Late Iron Age. By digging trenches and connecting them to the natural drainage pattern on the south side of the VHW site, the peat area might have been drained. However, due to the strong compaction of the peat and later oxidation of parts of the peat, the expected shallow ditch-trench structures in the peat surface could not be demonstrated archaeologically. The fact that in the Iron Age farmhouses were built, indicates that during this occupation period the peat was drained and thus the peat soil must have contained oxygen at the time before the floods.

Autocompaction

After the peat surface had been flooded in the Late Iron Age and the BPA clay layer had been formed a different deformation process occurred: that of autocompaction (e.g. Long et al., 2006). When clay is deposited on a soft peat subsoil, the subsoil will subside as a result of the weights of the deposited clay and the overlying water column during the flooding. Most of the clay was deposited in the local depressions and along the edges of the natural creeks. Due to the low position more clay could be deposited in depressions and along the creeks as a result of which the subsidence due to the gravitational pressure there was enhanced (Figure 3N28a-d). Some depressions, particularly in sector East, were so deep that water remained in them. These ponds or small lakes still contained water at times when the higher lying surroundings fell dry. In one of these pools, a considerable amount of hand-made pottery was thrown in the 1st century AD (Van Heeringen, 2010). The process of autocompaction continued until the subsoil had settled sufficiently. The differential subsidence stopped therewith and in the next period the depression was filled up gradually.

Figure 3N28: Picture of differential subsidence of the BPA clay layer caused by autocompaction of the peat which was induced by gravitational forces during the clay deposition of the BPA layer. Figure 3N28a. Loading structure of the BPA clay. The Medieval peat (Hv-1), only found below the loading structure, is not affected by oxidation because the peat layer was come down below the groundwater level, in find location area Vz02 in sector West. Figure 3N28b. .Loading structure of the BPA clay on top of the Hv-3 peat layer. The BPA clays are the lateral deposits of a creek, in find location area Vz07 in sector East; Figure 3N28c. Loading structure of the BPA clay on top of the Hv-3 peat layer. The BPA cays are the lateral deposits of a creek, in find location area Vz09 in sector East. Figure 3N28d. Depression caused by loading of the BPA clay in the Hv-3 peat layer, in find location area Vz09 in sector East. Figure 3N28e. Subrecent loading of the BPA layer in the Hv-3 peat layer, after the removal of the central ground depot of the excavation in 2005, the maximum subsidence of the surface level was more than 1,5 m, in find location area Vz01 in sector West.

Peat oxidation

Peat decomposes or "oxidizes" when it is exposed to the air. This can also happen with peat layers in the soil which are lying above the local groundwater level are and where oxygen can penetrate through the cavities present in the soil. Thus, for a good preservation of peat (and other organic residues) a high water table is required. The rate of oxidation depends on the duration and the extent to which oxygen can penetrate into the soil. Due to anthropogenic draining, the oxidation of the peat surface already took place during the Middle and Late Iron Age, Early and Middle Roman period and in the Late Middle Ages. The oxidation (palaeo-soil formation) in the peat can be recognized by the dark brown to black colour, and the granular structure and amorphous characteristics of the peat. The remains of plants in the soil layers have been conserved less well.

Much more drastically than in prehistoric times was the oxidation that has taken place over the past few hundred years in the soil. Due to large-scale reclamations and lowering of the water levels in ditches and the associated lowering of groundwater levels the top of the peat surface – under the covering clay layer – has completely disappeared from the area of the VHW. In many places of the VHW the oxidation / reduction boundary in the soil has penetrated down to the level of the Iron Age. Relatively young peat layers – such as the Early Medieval peat layer – have been preserved only locally (Figure 3N28a), in those places where, due to differential subsidence, they have subsided to deeper levels in the soil. Also older peat layers (Iron Age) have vanished, if they were situated relatively high, and rose above the groundwater level. As a result, also many archaeological remains have decayed and / or passed down fragmentarily. The oxidation of the peat has – together with the subsidence of peat by drainage – led to a considerable drop in the level of the surface of the VHW area. Originally – before the medieval reclamations – the ground level lay more than 1m above NAP. In the time of the excavation campaign the surface of the area lay around 2 m - NAP. This means that the subsidence of the VHW site since the Middle Ages amounts to at least 3 m, and possibly 4 to 5 m.

3N.2.2 Yangtze Harbour

Fieldwork Aims

This part of the study presents the geogenetic approach to detect currently drowned archaeological sites in the transgressive palaeo-deltaic environment of the Holocene Rhine-Maas delta. A stepped and practical approach is advocated in which subsurface archeological predictions are based on geological mapping and palaeo-environmental reconstruction at the underwater location. The study area is located in the Maasvlakte harbour extension of the Port of Rotterdam, formerly a part of the North Sea. The dredging of a new harbour (Yangtzehaven) would disturb the subsurface to about -21 m below present mean sea level.

The stepped approach started with a desk study of existing data. During this phase, a first conceptual geological model was compiled, to indicate the depth of the geological layers which had the highest chance of finding late Palaeolithic / early Mesolithic artefacts. It defined the strategy of the investigations in the next phase, in which dredging was performed as part of the engineering work of the harbour, down to 17 m water depth. With the top layer of the younger sea sands removed, this improved the opportunities to survey the fluvial and deltaic layers of Mesolithic archaeological expectation exposed underwater.

A full-area site investigation was carried out using geophysics and corings. It allowed us to reconstruct the long-drowned former landscape, which included inland dune areas and local drainage systems that are regarded to have high archaeological potential as typical Mesolithic settling areas. Two such areas were selected for detailed investigation as part of the next phase. Again, but now at higher resolution, geophysics and corings were collected and palaeoenvironmental analysis performed, and the palaeolandscape model was detailed. Cores and large grab-samples from the selected inland dune area yielded the first in-situ evidence of early to middle Mesolithic occupation of this Early Holocene wetland region in the Netherlands and southern North Sea. Besides the roles in the prospection and sampling strategy leading to the discovery of the site - elaborated in the case study report - the palaeo-landscape context provided by the stepwise geogenetic approach is also of scientific value in the archaeological interpretation.

Methodology
The archaeological potential of the continental shelf has been recognized for a long time. Driven by large fluctuations in sea-level, palaeo-landscapes with prehistoric coastal archaeological sites are now submerged. Compared to land campaigns, underwater investigations are relatively challenging in terms of costs, failure risks and data uncertainties (Bailey, 2004). An underwater archaeological study will thus be carried out with substantially less sampling than an equivalent terrestrial study. Palaeogeographical reconstruction, i.e. the creation of ‘paleo-landscape models’ based on combined geological mapping, dating and palaeo-environmental research, is an essential method to determine areas with high archaeological potential, especially in tectonically subsiding areas that experienced sea level rise, such as the North Sea. Furthermore, the palaeo-landscape models are essential to place archaeological finds in their environmental context when discovered.

Site investigation with multiple techniques is key to the construction of palaeo-landscape models. Geophysical methods are commonly applied in offshore environments (e.g. Gaffney et al., 2007). Correlation of geophysical data with more rarely obtainable in-situ data such as corings, allows for the identification of relevant layers in the geophysical data. By constructing the palaeo-landscape models that combine Holocene sea-level rise data with palaeo-surface elevations and environmental conditions, the human settlement locations and trekking patterns can be understood (e.g.Dolukhanov et al., 2010; Veski et al., 2005). With such knowledge the archaeological potential of an area can be charted (archaeological prediction maps). Archaeological prospection and heritage management efforts can then be focused on the areas with the highest chance of finding archaeological objects; enabling systematic, efficient prospection of large areas and maximized recovery of archaeology.

This part of the study presents the outcomes of the design of an innovative, stepped method to predictive underwater mapping for the Yangtze harbour area (Port of Rotterdam). In describing not only the method but also the paleolandscape results, this case study report succeeds the earlier Vos et al. (2012) short publication. Understanding the geological sequence of the subsurface is the foundation of the approach. Importantly, the geogenetic approach addresses archaeological prospection at the level of these lithological units that together comprise the subsurface (Vos and Bazelmans, 2002). For each type of lithological layer that could be encountered, a palaeo-environmental assessment was made and the change in finding archaeology in these units elaborated.

To connect the Maasvlakte 2 new seaward harbour extension of the Port of Rotterdam (The Netherlands; Figure 3N29), to the existing Maasvlakte 1 area, the Yangtze harbour was extended and deepened. The Maasvlakte 1 area was built in the 1970s and early 1980ies. Maasvlakte 2 is the latest enlargement of the Port of Rotterdam, one of the largest and busiest harbours globally. The final cut-through occurred in 2012 (Figure 3N30).

Figure 3N29: Location of the Yangtze harbour within the Maasvlakte area (Port of Rotterdam, the Netherlands).

Figure 3N30: Aerial view of the Yangtze harbour aer the cut-through of ther hatbour between Maastvlakte 1 and 2 in 2013 (Foto's Port of Rotterdam).

Previous research in the Maasvlakte 1 area had shown that fluvial deposits of Pleistocene age in the area in places contained Stone Age archaeology. Palaeolithic and Mesolithic discoveries were found in dredged sand on the beach of the Maasvlakte 1 area in the 1970s and 1980s (Louwe Kooijmans, 1975; Louwe Kooijmans, 2005; Verhart, 1988; Verhart, 2005) The then dredged sands were mainly Late Pleistocene and Early Holocene fluvial deposits, originating from dredged harbours and offshore locations in the direct surrounding of the Maasvlakte and came from a depth of about 20 to 40 m –NAP (e.g. Hijma et al., 2012).

The area of investigation of the Yangtze harbour, the study area, is given in Figure 3N31 and Figure 3N32. As the geological framework in the approach, a lithological-geological layer model of the study area was constructed. Besides new collected data for this archaeological project, the layer model incorporated the site investigation and engineering data collected for the larger Maasvlakte 2 project, and archived data from earlier projects. The sedimentary environmental conditions represented by the various lithological units (lithofacies) were logged, mapped and described. Subsequently, an assessment was made of the time period in which each of the lithofacies was formed, based on regional insight in sea-level rise (e.g. Hijma & Cohen, 2010). With this information, a paleolandscape model was made, in which the archeologically most promising locations could be highlighted and next steps of surveying strategy could be determined.

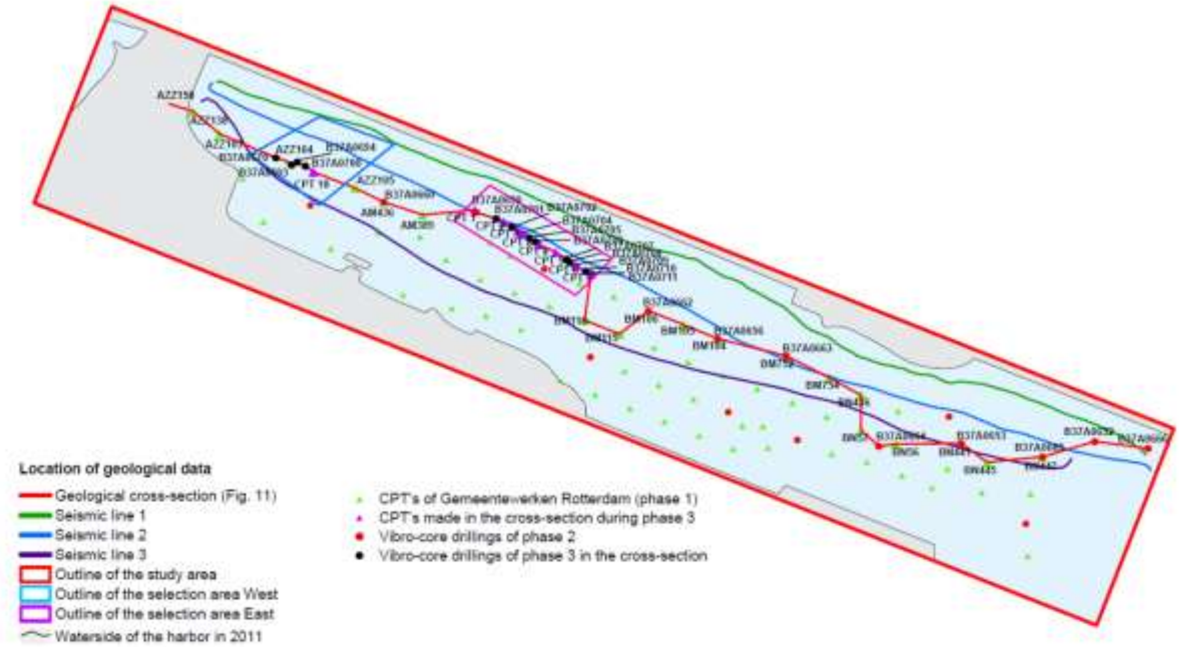


Figure 3N31: Location map of the Yangtze harbour study area.

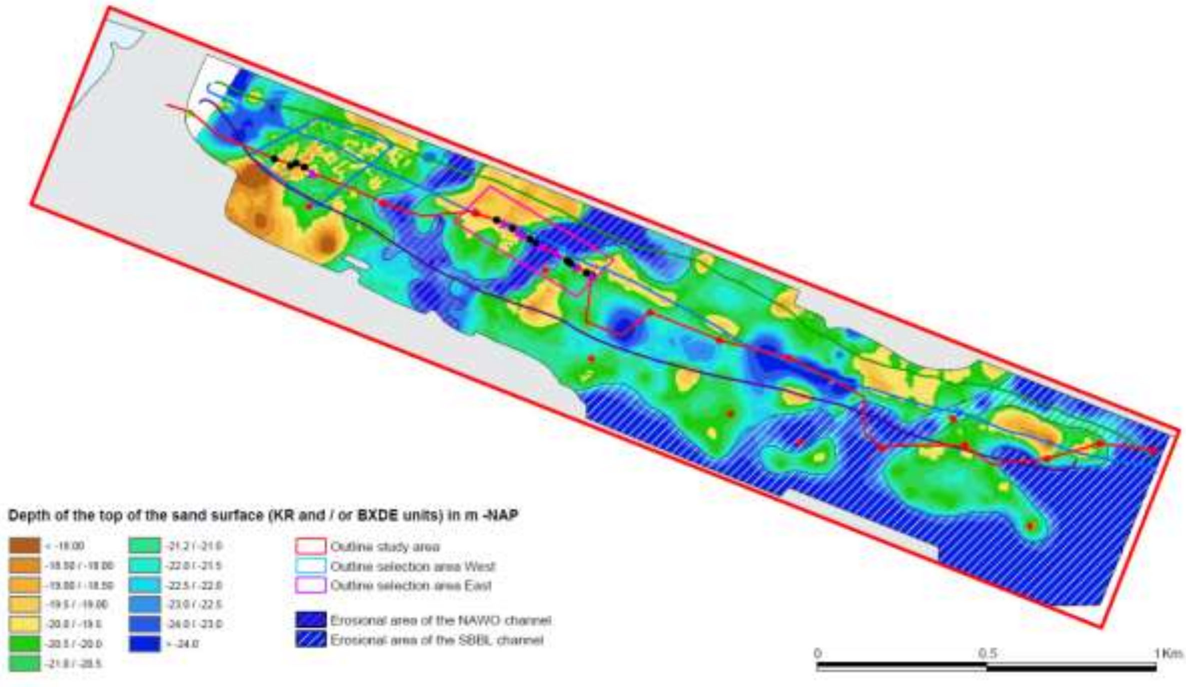


Figure 3N32 Map of the top of Late Pleistocene / early Holocene sand surface (top of the KR and BXDE units) of the Yangtze harbour study area.

For each lithological layer in the geological model, the archaeological expectation is evaluated and the likelihood of finding artefacts mentioned on the base on the palaeo-environmental conditions during and after the deposition of the sediment layer. The top of the Pleistocene substrate, from earlier studies was expected at about 20 to 22 m –NAP and to mark a buried valley floor of the end of the Last Glacial (Staalduinen, 1979), with inland aeolian dunes forming local highs (Hijma et al., 2009). These 'river dunes' are considered to be particularly promising as Mesolithic and Early Neolithic settling locations in past times of wetland environment (e.g. Louwe Kooijmans, 1980; Louwe Kooijmans, 1985; Louwe Kooijmans, 2005).

In the absence of direct dating, the age-model for the top of the fluvial sand included information on terrace stratigraphy (subtle elevation differences; lower is younger) and style of aeolian cover (sheet of coversand is older, isolated dunes is younger). Depth and thickness of floodplain overbank facies also gives age information. These sandy sediments are covered by deltaic peat and clay layers, from drowned Holocene landscapes. Their age-model includes information on post-glacial sea-level rise. These deposits are part of a transgressive sequence that culminated in the Rhine-Maas delta in the Middle and Late Holocene (landward shifting of the landscape zones depicted in Figure 3N33). This buried the valley landscape with the dunes that had persisted in the first millennia of the Holocene.

Over large areas of the harbour floor, an Early Holocene drowned landscape lies preserved from this time. At the time of the transition of the Boreal to the Atlantic (about 7000 BC) the study area still had fluvial landscape (conceptual model in Figure 3N34; analogue modern environment in Figure 3N35), with swampy floodbasins that received freshwater discharge from main channels of the Rhine and Maas river system (Hijma et al., 2009; Hijma & Cohen, 2011) and a river mouth to be found in further offshore areas downstream (Hijma et al., 2012; Sturt et al., 2013). In this landscape, local channel systems in the floodplain are assigned a higher likelihood to the presence of archaeology because it was assumed that humans would move through these waterways and would settle along the edges of these watercourses. Above this sequence, at a depth of about 17 m –NAP, former seafloor marine sands occur. Associated marine tidal channel structures have locally eroded the older sequence, and these zones were regarded of low stone-age archaeological priority.

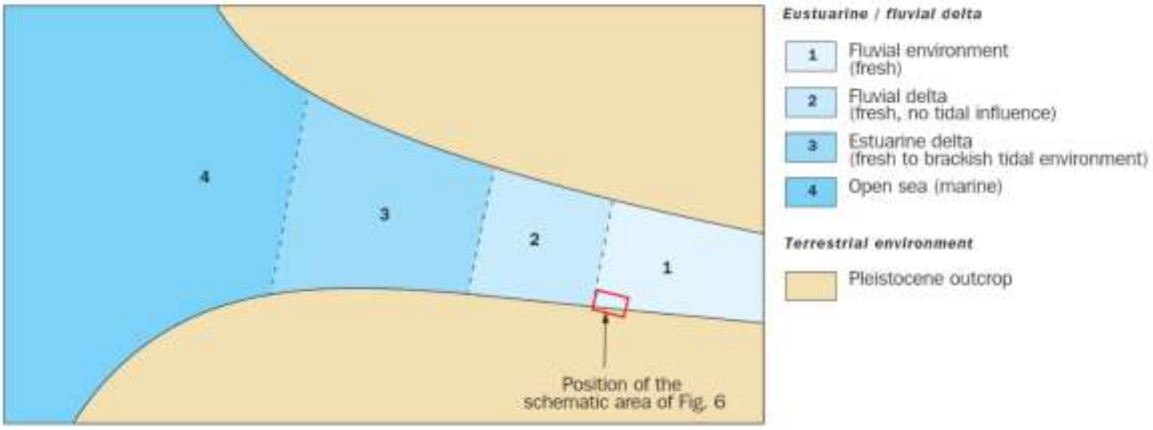


Figure 3N33: Schematic classification of the main landscape types within a funnel shaped river mouth. The position of the Yangtze harbour around 7000 BC in this schematic area is shown with a box (box in Figure 3N32).

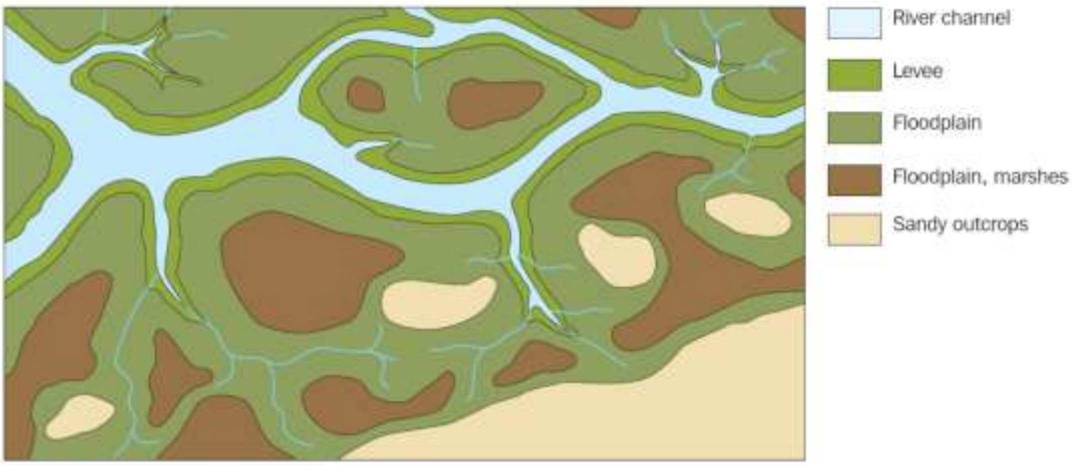


Figure 3N34: Schematic representation of the sedimentary environments in the Yangtze harbour area around 7000 BC.

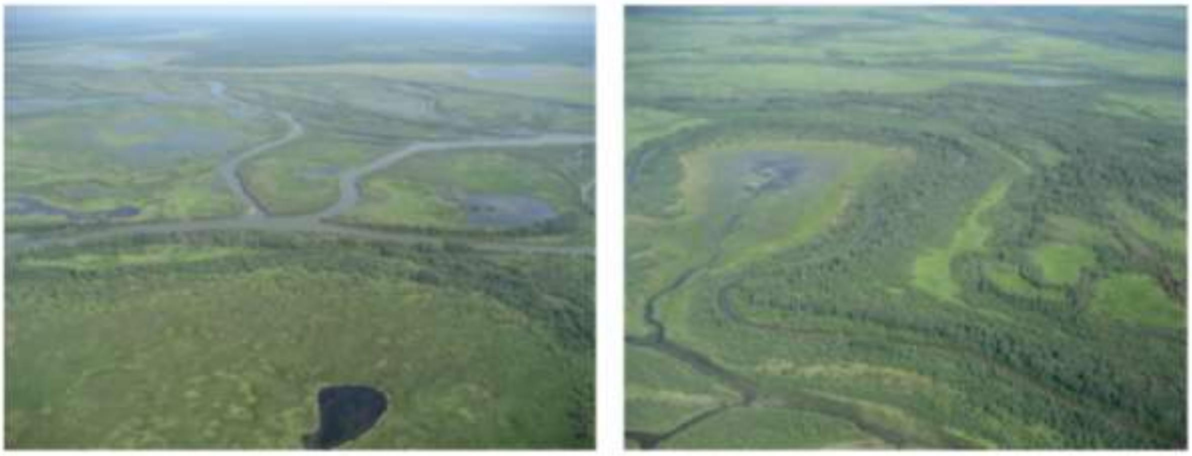


Figure 3N35: Contemporary airial view of the Cumberland Marshes in Canada, a representative picture of the landscape of the Yangtze harbour around 7000 BC.

The methodology used can be divided into four phases:

Phase 1: Desk study, intake and preparation existing geological data.
Antropogenic young overburden dredged away.
Survey design Phase 2
Phase 2: Implementation of the inventory field survey (survey and coring),
Reporting and analysis of the paleolandscape data
Decision on selection areas to densify the survey Phase 3
Phase 3: Detailed investigation in two selected areas (survey and coring),
Reporting and analysis of the paleolandscape data
Decision for archaeological excavation
Determining the locations for excavation
Phase 4: Execution of archaeological excavation (using a crane from a pontoon)
Completion of reporting paleolandscape results.
Integration of paleolandscape results with archeological results

Phase 1: Desktop study
The prospective investigation of the study area was a multi-phase research to trace the different depositional environments at a depth of 17 – 22 m –NAP and select the most promising archaeological locations for excavation (Vos et al., 2012; Figure 3N36):

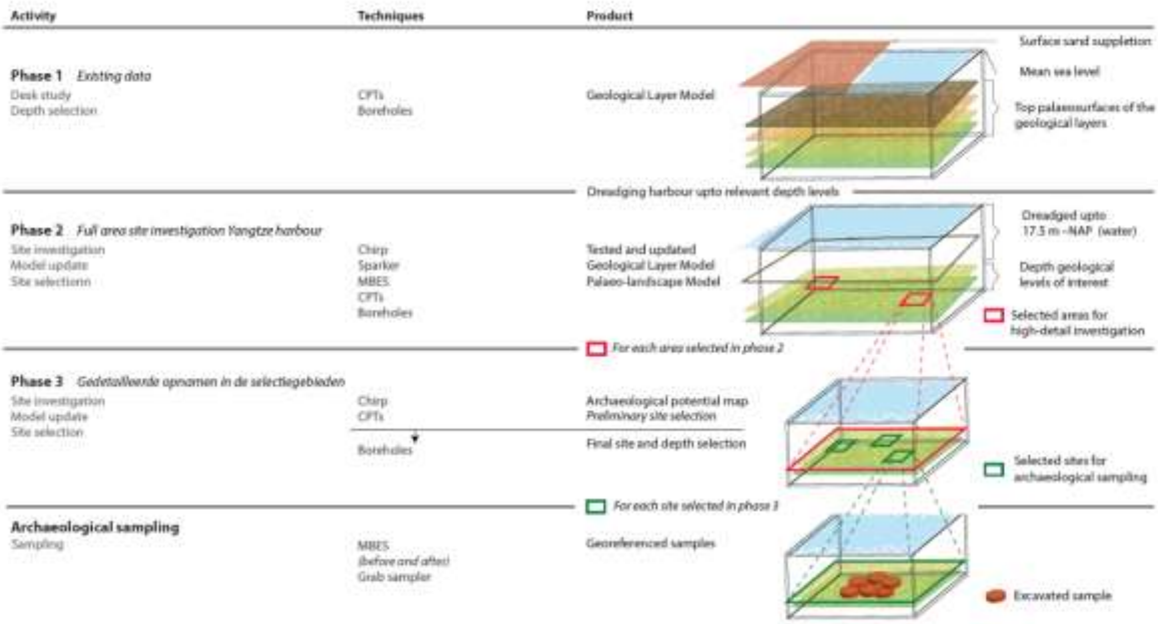


Figure 3N36: Geogenetic, stepped approach applied in the prospection study of the Yangtze harbour. For each phase, the activities carried out, the techniques used products delivered are mentioned.

In the first phase an estimate was made of the most likely depth of possible archaeological remains. Using existing data from CPTs and boreholes made for the construction of the harbour (by *Gemeentewerken Rotterdam*), a preliminary geological model of the study area was built. At this stage (2007), the surface area of the plan was still about 5 m +NAP. For the study area 133 CPTs were available (Figure 3N31 and Figure 3N32), of which eight were coupled to boreholes. Most of the CPTs penetrated down to the Pleistocene substrate, thus including the relevant layers. The cone resistance and friction parameters obtained with the CPTs were translated to lithological units (using correlation with boreholes) and subsequently grouped into a geological model. In the model, the palaeosurfaces of the top of the Pleistocene sand and the top of the deltaic deposits were interpolated between data points (using Kriging techniques) and manually adjusted for inconsistencies.

The surfaces in the palaeolandscape model of phase-1 represents the interfaces between different geological formations. As such, the model serves to draw the first hypotheses to localize the higher sand outcrops, the fluvio-deltaic environment and the complex or (Subatlantic) tidal channel incisions. This palaeo-landscape model was used to make the first rough estimate of the depth levels associated with the highest archaeological potential and to make a plan for the next step in the research, the fieldwork of the full site investigation of the study area.

Phase 2: In site investigations

Geophysical site investigation was carried out using an Edgetech X-Star Chirp Sub Bottom Profiler and a Geo-resources Sparker system. Position information was provided by a DGPS system. Both surveys were carried out at a speed of 2–3 knots. Shortly after the site investigation, a multibeam survey (MBES) was performed to accurately determine the bathymetry of the full Yangtze harbour. Seventeen boreholes were drilled from the seabed using a Vibrocore system, with a sampling core length of 5 m. As the Early Holocene clay deposits were very stiff, the core experienced high friction, yielding 2.2–4.5 m recovered sample length. From all the cores photographs were taken in the laboratory (Figure 3N37).

Figure 3N37: Image of the Yangtze harbour cores in sediment description laboratory of Deltares / TNO in Utrecht.

In the part of the harbour which had been dredged down to 17 m deep, three large west–east running lines of direction have been sailed (seismic lines 1 to 3, Figure 3N31 and Figure 3N32) which have been recorded using the above-mentioned seismic systems Chirp and Sparker. The records showed good results. The palaeosurfaces of the top of the Pleistocene fluvial sand (including the river dune sands) and the top of the organic and clayey delta deposits were clearly visible on the seismic reflection images. Also the tidal channel incisions were easy to recognize on these images and on the base of this the spatial distribution pattern of the palaeo-tidal channels could be reconstructed. In the western part of the study area a palaeo-dune topography was visible on the seismic profiles. These dunes had not been recognized as such in the CPT data used in phase 1. The reason was that the cones resistance was relatively low and variable. In phase 1 these sands were interpreted – wrongly - as a gully facies. Seventeen vibrocores were taken to yield high-quality information on the sedimentary characteristics of the lithological layers of interest between 17 and 22 m –NAP .

With the phase-2 results the geogenetic paleolandscape model was reiterated and improved. At this stage, three palaeosurfaces were modelled: the top of the sand surface (top of KR and BXDE unit), the top of the peat and clay layers (top of the combined unit of KRWY, NIBA, EC and NAWO) and the seafloor elevation in the harbour at the time of survey (spring 2011). The palaeosurface of the top of the sand surface of the study area was the main layer from the archaeological expectation point of view. This surface, generated from the 3D model, is depicted in Figure 3N32. In the western part of the study area a higher river dune area (elevation higher than 20 m –NAP; yellow-brownish colour) can be recognized and in the middle and south-eastern parts tidal channel incisions. The vibrocore data pointed out that the fill of the middle palaeochannel consisted of NAWO deposits and the south-eastern channel fills of SBBL deposits.

The sedimentary sequence of the harbour floor in 2011 is shown in a geological west–east cross-section. For the location of the used drilling- and probe data in the geological profile, see Figure 3N38. The top of the sand surface (KR and BXDE sand) ranges from circa 27.5 m –NAP within the eroded parts to 18.5 m –NAP at the highest parts of the river dune. The west–east channel incision in the middle part of the profile dates from the Atlantic (NAWO layer: green colour) and the channels in the eastern part from the Subatlantic (SBBL layer: yellow colour). The latter category is much sandier and has a larger grain size than the NAWO channel deposits which are laminated with fine sands and thin clay layers.

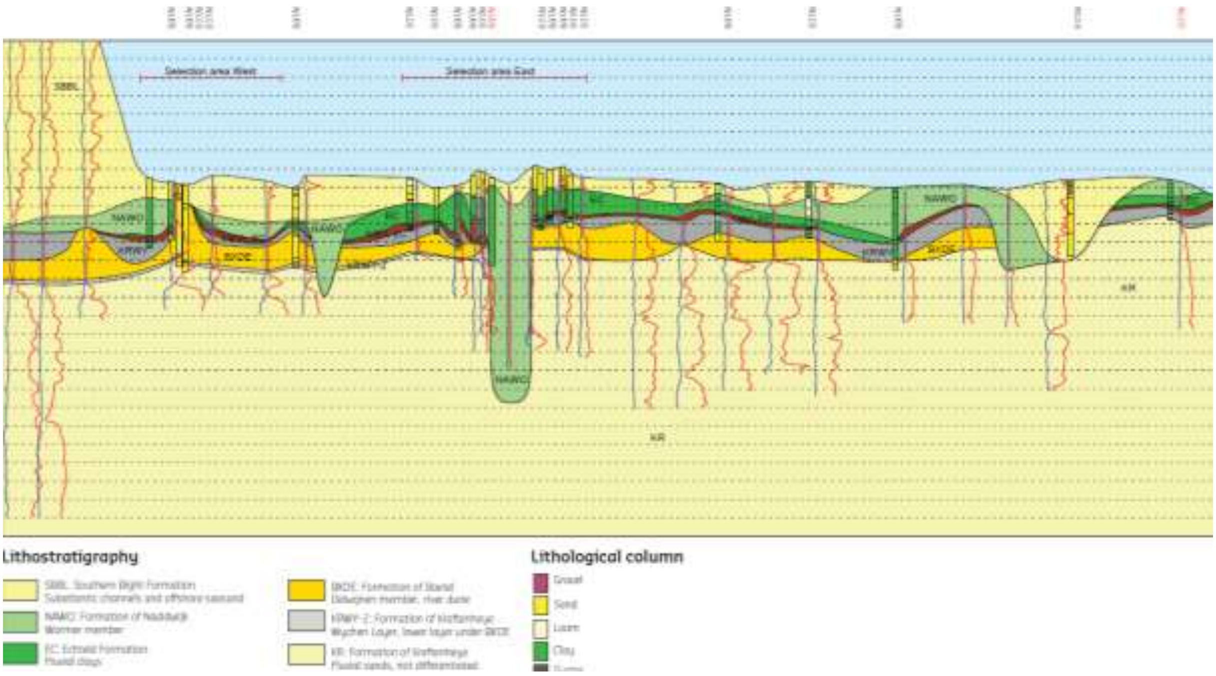
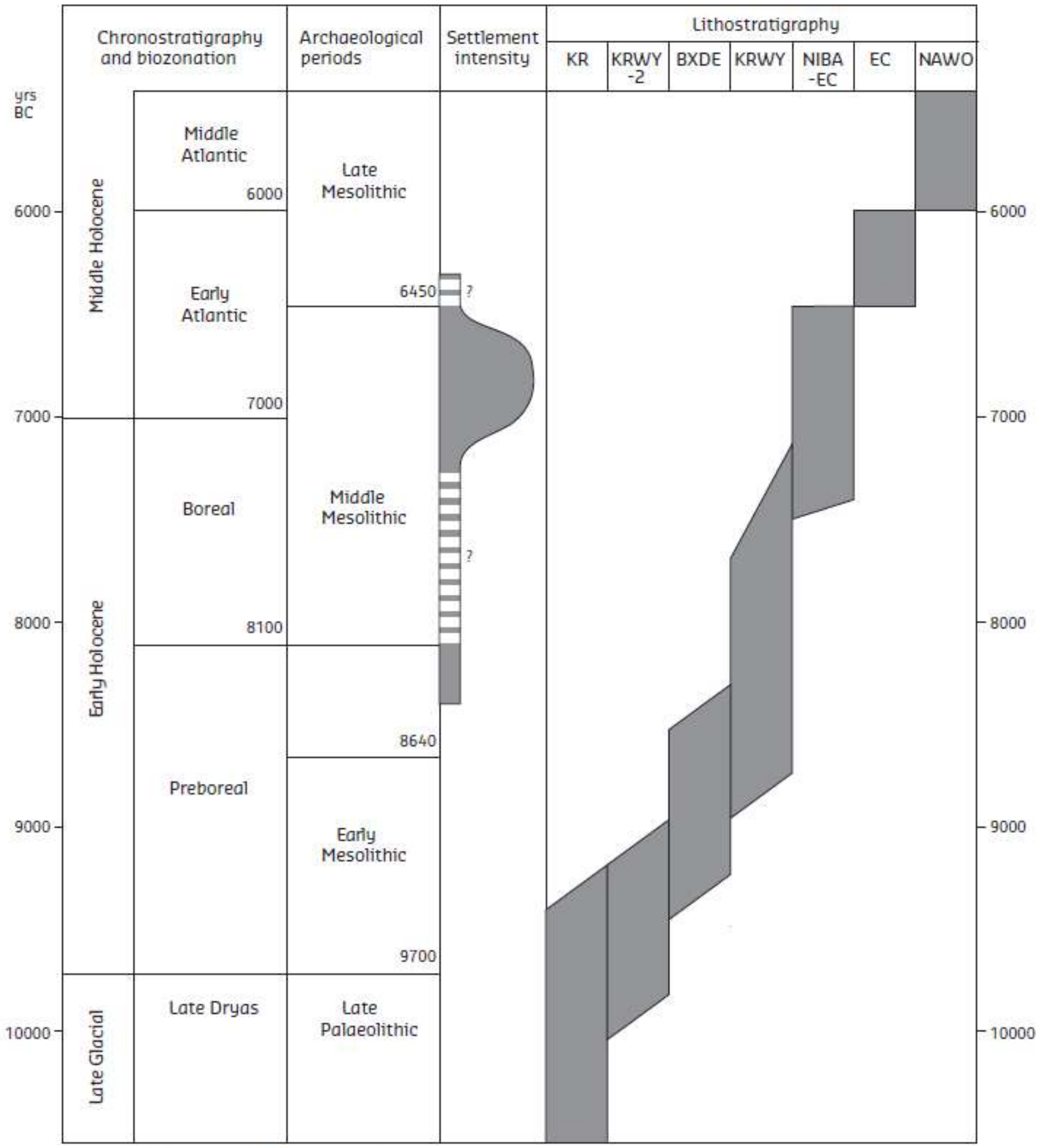


Figure 3N38: Geological west – east cross-section through the Late Pleistocene / early Holocene deposits of the study area. Location profile, see Figure 3N31 and3N Figure 3N32.

To obtain direct age-estimates for the lithostratigraphical units as encountered in the study area itself, a suite of radiocarbon (^{14}C) and optic stimulated luminescence (OSL) samples were obtained from the cores. Samples have also been taken from core material from the selection areas, collected during phase 3 (W and O sample codes). The ^{14}C-dating has been carried out by laboratories in Põznan (Poland; Poz nrs.) and Groningen (Netherlands; GrN nrs.) and are from organics in the KRWY, NIBA, and EC layers. The OSL dating has been carried out by the Netherlands Centre for Luminescence dating (NCL) in Delft (nowadays relocated to Wageningen), from river dune sands (BXDE).

By the end of Phase 2, a first batch of ^{14}C datings had returned from the lab, of use for planning Phase 3 and Phase 4 activities. In this case study report, we present the set in and age-attributions to the site lithological stratigraphy only in its final form (Figure 3N39).



KR: Fluvial sands of the Kreftenheye Formation
KRWY-2: Floodplain clayes of the lower Wijchen Layer
BXDE: Rivierdune sands of the Boxtel Formation
KRWY: Floodplain clayes of the (upper) Wijchen Layer
NIBA-EC: Basal peat, of the Nieuwkoop Formation, often clayey
EC: Deltaic deposits of the Echteld Formation
NAWO: Estuarine deltaic deposits of the Wormer Member

Figure 3N39: Stratigraphic table of the Early Holocene, with the time stratification of the lithological units of the study area.

Phase 3 and 4: High detail site investigation in selected areas

Selecting features for detailed archeological prospection

When the first Phase-2 radiocarbon dates had returned from the lab, and with the first cores scanned on palynological content and palaeo-environmental context, two selection areas (‘East’ and ‘West’; Figure 3N31 and Figure 3N32) were chosen to be subject of detailed geoarcheological research in Phase 3. The feature of most interest in Area East were the banks of a suspected palaeochannel, as Mesolithic humans might have settled here, using the channels for transport through backswamp area between the dry hinterland and the active river channel, in seasons most suitable for hunting and gathering in these respective environments. The feature of most interest in Area West was an inland dune complex. Inland dunes from areas further inland are known to be rich Mesolithic sites, and seem to have offered optimal places to settle because of the relative elevation of the dune above surrounding river plain wetlands.

Phase 3: High-resolution geophysics and dense coring

Areas East and West were subjected to further high-detail site investigation. At these locations high-detail geophysical surveys with a Chirp system were carried out and CPT measurements were made. The seismic lines in the selection areas were measured with an in-between distance of approximately 50 m, both in the longitudinal and the transverse direction (Figure 3N40 and Figure 3N41). Based on the initial results from this geophysical investigation supplementary borehole locations were chosen. Boreholes were again carried out with a Vibrocore system, yielding recovered samples of 2.3–5.0 m in length. For Area East this concerned 21 holes and for Area West 31 holes.

In Figure 3N42, the Chirp data set for Area East is shown together with the CPT and borehole data on the seismic line 38. This information forms the base of the geological profile of Figure 3N40. The incision of the channel structure is clearly visible.

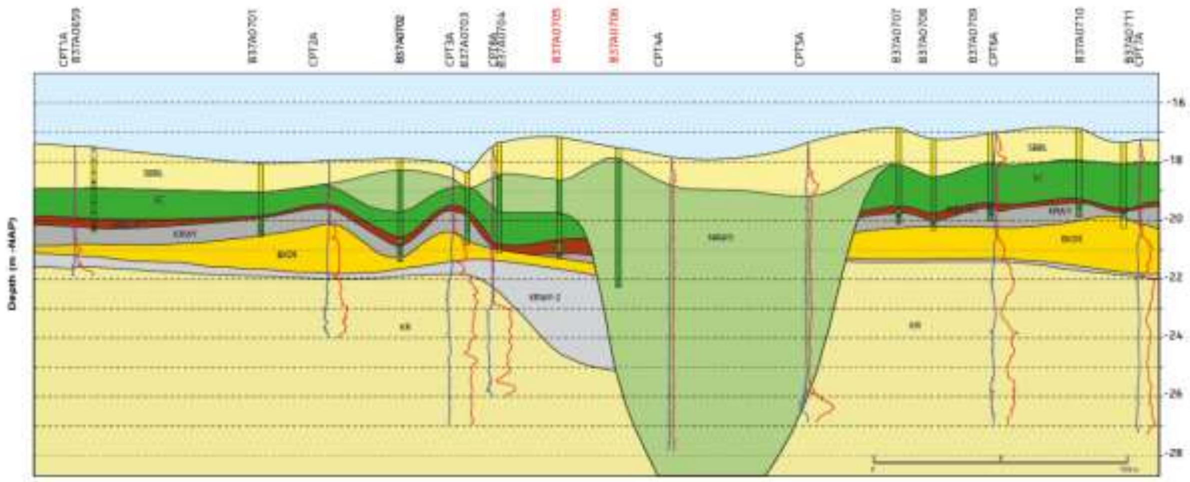


Figure 3N40: East-west cross-section of selection area East, geological interpretation based on the data presented in Figure 3N42. Legenda see Figure 3N38.

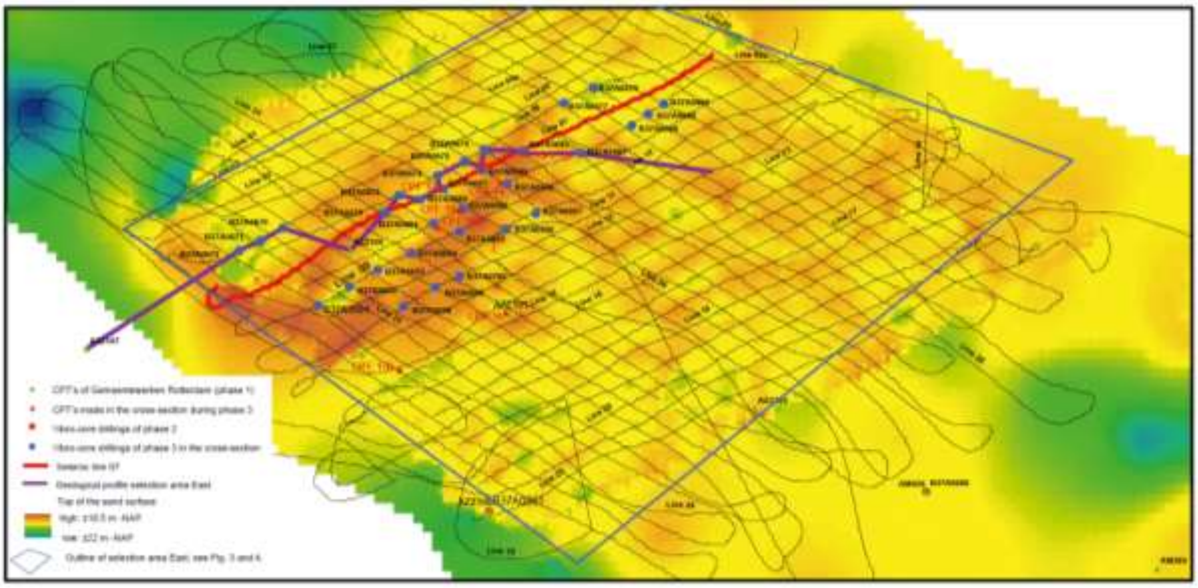


Figure 3N41: Map of the top sand surface of the Late Pleistocene / early Holocene deposits of selection area West (top of the KR and BXDE units) with the location of the boreholes and seismic lines.

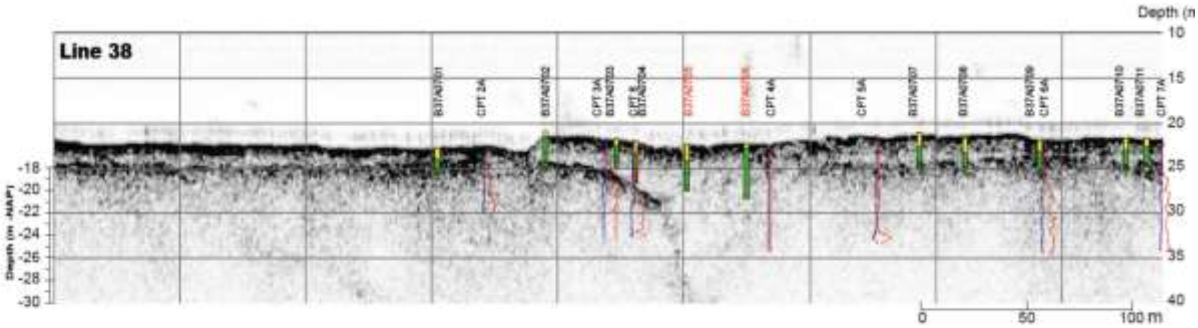


Figure 3N42: Results of the seismic survey of line 38 of selection area East, including CPT and bore hole data.

In Figure 3N43, Chirp data for Area West is shown together with the CPT and borehole data on the seismic line 07. The seismic reflections show a ‘’camel back’’ dune structure. The depression in between the two dune ridges (borehole B37A0680) is filled in with peat (NIBA) and clayey deposits (EC and NAWO). The geological sequence of the ‘’camel ridge’’ dune structure is depicted in Figure 3N44.

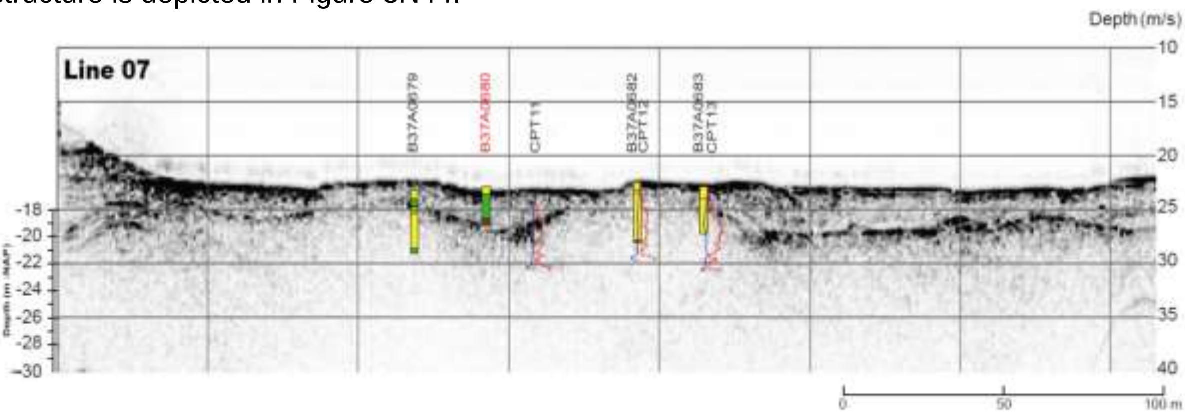


Figure 3N43: Results of the seismic survey of line 07 of selection area West, including CPT and bore hole data.

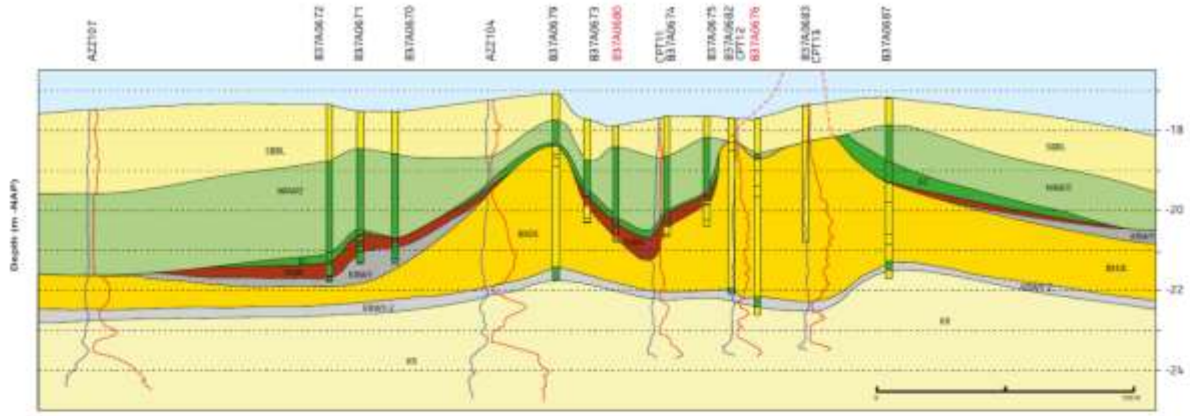


Figure 3N44: East-west cross-section of selection area West, geological interpretation based on the data presented in Figure 3N43. Legend, see Figure 3N38.

The sediments of 21 cores of Area East and 31 cores of Area West were examined on the presence of archaeological artifacts. A vibro-core with a core diameter of 10 cm was used for the archaeological sampling.. In Area West, 7 out of 31 cores contained archaeological evidence in the form of small flint artefacts and fine burned bone material in the top of the dune sands (Schiltmans, 2012). In cores B37A0673, B37A0675, B37A0676, B37A0696 and B37A0698 fine particles of burned bones and flint artefacts were found. On the base of these finds, it was decided that on these borehole locations the archaeological excavation with the crane should take place. In the cores of Area East no archaeological remains were found, no dig was executed.

Phase 4: Underwater archaeological dig using large grab samples
The archaeological underwater sampling was carried out with a pontoon crane (Figure 3N47a) at three find locations on the river dune of selection area West. Sample Pit 1 was dug out around the borehole locations of B37A0675 of B37A0676, Pit 2 around borehole B37A0673 and Pit 3 around borehole B37A0678. The third sampling Pit was carried out on the top of an eroded river dune, consisting of four separate parts of 2x3 m (Schiltmans, 2012).

Multibeam surveys were made of all three locations both before and after the excavation, allowing for accurate positioning of the acquired samples. Precise positioning is required to relate archaeological finds to the geological layer they come from. Knowing the position of in-situ finds in the local stratigraphy significantly increases the scientific value of the objects and enhances future investigation campaigns.

At the surface, on the pontoon, the samples were brought in a container. Each recovered sample was assessed by an archaeologist (Figure 3N47b). If a sample contained river dune sediments, it was preserved. For each sample, a small portion was taken for specialized research, while the bulk sediment was collected in big bags and subsequently sieved at a nearby site at the waterfront (Figure 3N47c). Sieving was carried out using high-capacity sieves with mesh widths of 10 mm and 2 mm. A total number of 46067 finds have been reported (Figure 3N47d), comprising mainly of charcoal, flint and fragments of animal bones. Both burnt and unburnt bone fragments have been found. The bones and sampled plant remains such as fruits and turnips gave a good impression of the food regime of the Mesolithic people who lived on the dune (Kubiak-Martens et al., 2013; Zeiler, 2012).

Additional sampling: Palaeo-environmental reconstruction
During phase 2, a total of 77 samples of the KRWY, NIBA-EC, EC and NAWO layers – derived from several borehole cores in the study area – were taken for pollen- and diatom research. The pollen and diatom slides were examined in a "scan research" and a global palaeo-

environmental interpretation of the investigated layers was accomplished. (Cremer and Bunnink, 2010). This preliminary interpretation was used for the palaeolandscape reconstruction of the archaeological expectation model of phase 3. In the last stage of the investigation, the final report, 41 pollen samples and 24 diatom samples were analysed (Cremer et al., 2013). Also, from eight new boreholes of the selection areas East and West (phase 3) 80 pollen and diatom samples were scanned on their palaeo-environmental significance. Twenty samples for each discipline were selected and analysed. A representative borehole in which the whole sequence or KRWY, NIBA-EC, EC and NAWO layers were investigated on pollen and diatoms, is B37A0705 from selection area East. The pollen and diatom diagrams are shown in Figure 3N45 and Figure 3N46.

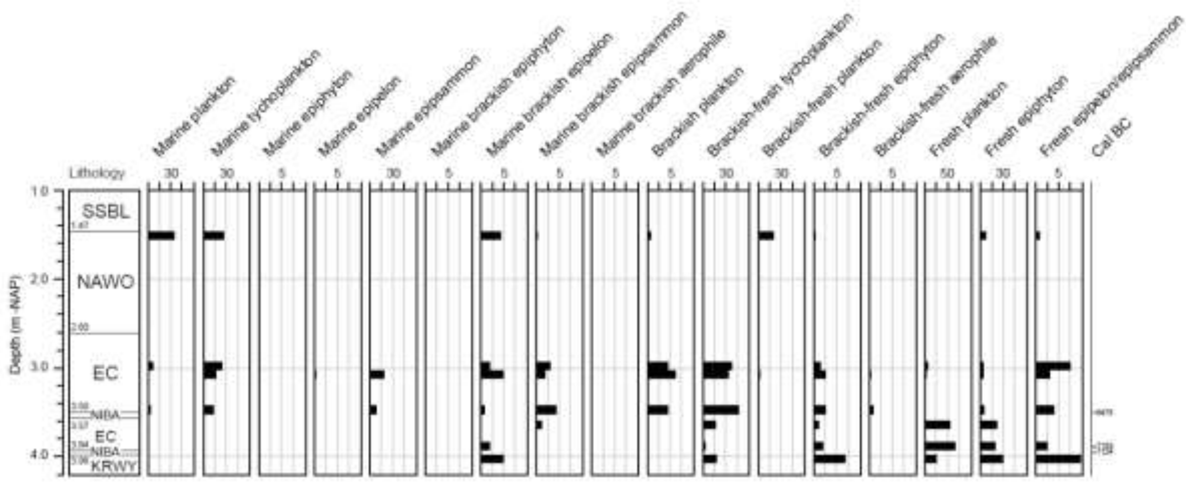


Figure 3N45: Diagram of percentages of the relative abundance of the ecological diatom assemblages (groups) analyzed in samples of dierent lithological units present in the cores of borehole B37A0705 (selection area East).

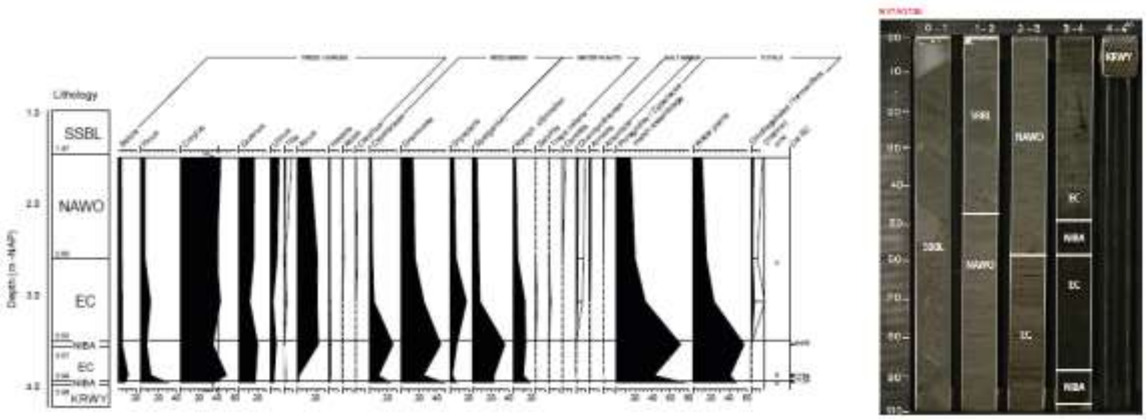


Figure 3N46: Diagram of the pollen assemblages analyzed in samples of different lithological units present in the cores of borehole B37A0705 (selection area East). Wedlands species are excluded from the pollen sum.

Figure 3N47: The underwater ''excavation'' recorded in pictures of the archaeological survey in 2012. Figure 3N47a: Computer controlled sampling with a crane; Figure 3N47b: Sampling en control of the digged up sediment; Figure 3N47c: Transport of the big bags samples to sieving location; Figure 3N47d: Sieving and archaeological selection of the sieved material.

The archaeological finds of the Yangtze harbour are the first in-situ scientific proof for Mesolithic hominin occupation in the lower part of Rijn-Maas delta sequence, west of the city of Rotterdam. In other parts of the country, mainly scattered remains of flint have been found; but the organic remains have been preserved as well as those found in the Yangtze harbour site. The preservation of these bones may have been favoured by the damp conditions at and around river dunes and the latter covered with sediment. The archaeological results will be published in 2014 in a special publication about the Yangtze harbour investigations.

3N.3 Analysis

3N.3.1 Vergulde Hand West: Landscape and occupation history

Due to the extensive geological, palaeoenvironmental and archaeological research the landscape and occupation history can be reconstructed in detail. The landscape history of the VHW has been visualized in a series of local palaeogeography maps (1600 BC – 1050 AD; Figure 3N48) and in a profile reconstruction (550 BC – 2000 AD; Figure 3N49). In Figure 3N50, a summary was made - in a schematic overview - of the observed activities by Man in the 4 sector areas of the VHW. This overview is based on all the archaeological finds and anthropogenic indications discovered in the samples of the studied proxies.

Figure 3N48: Landscape reconstruction of the VHW location (1600 BC – 1050 AD).

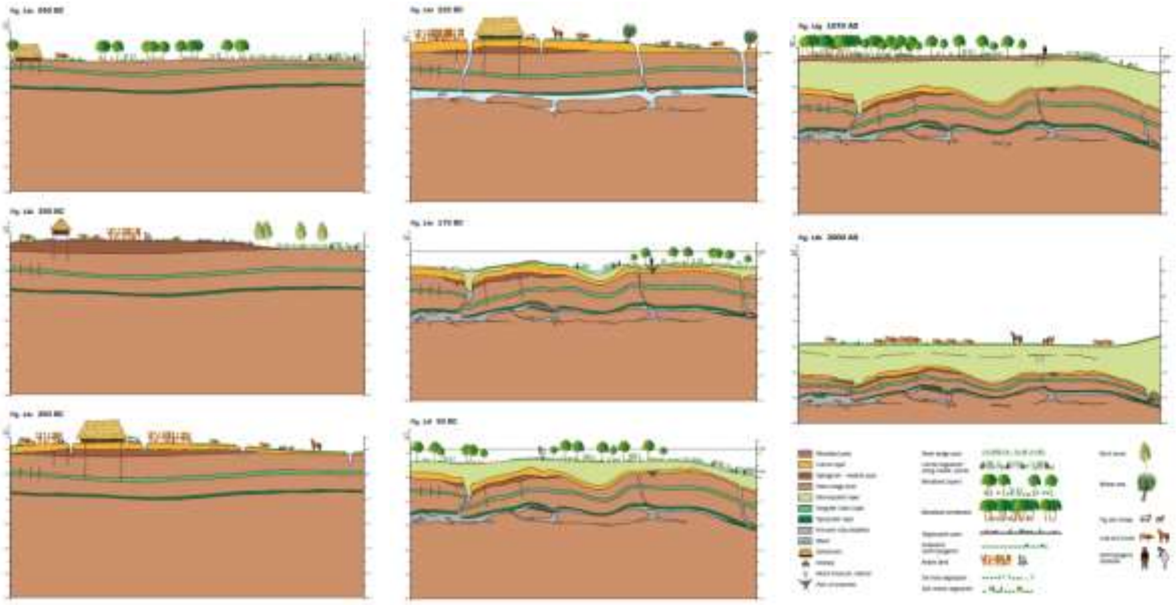


Figure 3N49: Profile reconstruction of the landscape in sector East between 550 BC –2000 AD. Location of the profile, see Figure 3N19.

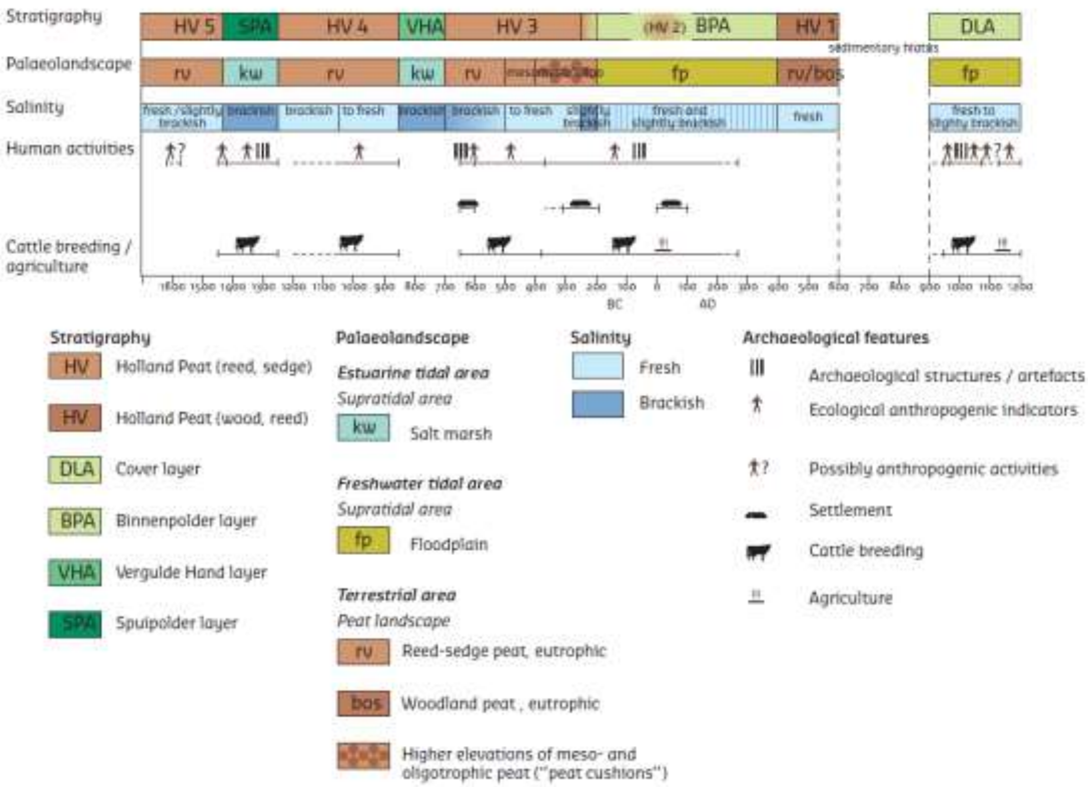


Figure 3N50: Summary of the archaeological indicators found in the peat and clay layers of the different sectors on the VHW location. See Figure 3N24, for the explanation of the stratigraphic codes.

The subsurface of the VHW - down to 5 m below the ground level - consists mainly of peat. In the peaty subsurface a number of clay layers have been formed. The deepest layer of clay which was exposed during the excavations, concerned the pre-Spuipolder layer in the sector East. This layer occurred at a depth of about 4.0–4.5 m below ground level (6.0–6.5 m - NAP) and was formed around 3650 BC. The environmental conditions in which this happened can be characterized as a brackish salt marsh environment in an estuary. The macro botanical remains from the clay layer do not rule out the possibility that people were present in the area at that time. Between about 3650 and 1400 BC predominantly reed peat grew in the area. This peat is eutrophic and in certain sections also clayey. This indicates that the peat was regularly flooded with nutrient-rich water. The peat was formed particularly in a fresh to slightly brackish water environment. The older peat (before around 1400 BC) has been insufficiently studied palaeoecologically for distinguishing specific phases or peat formation or for being able to pronounce on variations in salinity during the formation of the peat. During the last phase of the development of the peat, from about 1800 BC onwards, humans were present in the area and the vegetation was disturbed locally. Between about 1400 and 1300 BC the area was flooded repeatedly during high water. As a result, throughout the VHW a clay layer was deposited, the 'Spuipolder layer'. It is a salt-marsh clay, which was formed in a predominantly brackish water environment. Only in the sector Canoe there is palaeo-ecological evidence indicative of humans having been active in the area of the VHW.

Between about 1300 and 850 BC the area changed into a reed peat bog, rich in fern, in the supra- tidal zone of a freshwater tidal area which was occasionally flooded by the sea during periods of high water levels and storm surges. Furthermore, bank vegetation, grasslands, isolated bog-like vegetation and alnetum peat occurred. In the course of the development of the peat the marine influence increased. Humans were present in the area of the VHW at that time and has left his mark. Poles with cutting marks which have been pound in the sector Canoe are the strongest evidence of this, but also the palaeo-botanical and micromorphological data show anthropogenic effects on the landscape. This data indicate that human presence became more prominent in the Late Bronze Age. Between about 850 and 700 BC clay was deposited all over the area of the VHW. In the Middle part (sector Middle and the northwestern part of sector East), there was a shallow lake and along its edges marsh clay was deposited. This implies that at that time the area was frequently flooded by the sea during storm surges and was located in the sphere of influence of the estuary. These marsh clay deposits are rated among the 'Vergulde Hand depositions' and the sediments in the shallow lake are rated among the gyttja-clays. The granary (in Dutch: *'spieker'*) from around 650 BC. in the sector Canoe indicates human activities in the VHW during the deposition of the Vergulde Hand layer (Eijskoot et al., 2011). In the lake sediments rich in organic matter were formed, consisting of brown-gray clays and humic green-brown-gray gyttja's. Initially the depositional environment of the lake was still brackish, but at a later stage freshwater conditions were predominant in the shallow lake. The formation of these packages started in the Late Bronze Age. However, an accurate dating of gytjja from this early stage is not available and therefore the coming into existence of the lake cannot be determined with more precision.

Between about 700 and 500 BC another period of reed peat formation came. Around 700 BC (sectors West, Middle and East, layer Hv-3.6) there was still a limited amount of marine influence in the region (occasionally flooded during storm surges), but in the subsequent period the area became almost entirely fresh. Also the shallow lake turned to peat at that time. In the next phase (ca. 650 and 500 BC) alder trees grew locally in the peat (wood fragments in the reed peat) and there was no longer any marine influence (sectors West, Middle, East, layer Hv- 3.5). Locally, where the peat grew high, environmental conditions arose in the peat that were poorer in nutrition. In the phase during which the reed peat formation took place (750-500 BC) humans were present in the area. This is evident not only from the palaeo-ecological research, but also from the archaeological investigations. The archaeological traces include: a dugout wooden canoe of oak, a settlement and the remains of two off site buildings. Only in the settlement a macroscopically recognizable cultural layer formed during this phase. Between about 500 and 350 BC In the sector East the peat grew so high that it came to lie beyond the sphere of influence of the river and / or flooding by the sea. There mesotrophic (sector East, layer Hv-3.3) and oligotrophic peat (sector East, layers Hv-3.2 and Hv-3.1) developed. In the other parts of the VHW such peat development seems not to have come about. Here nutrient-rich environmental conditions were dominant. Throughout this phase, people were active in the area and between 400 and 350 BC the first buildings were erected in the sector East.

Between about 350 and 200 BC people lived and worked on the relatively high and dry lying peat. Remains of settlements from this period have been found in the sectors East, Middle and West. Field weeds, cultivated plants and a possible ploughshare, which were found in the cultural layer, indicate that agriculture was practised on the peat. In addition, livestock was bred. Cultural layers from this period have been found in the sectors East, Middle and West. In the areas which were inhabited, the peat must have been drained. At the residences and in the immediate vicinity of these locations the peat formation stopped. Due to tillage, treading and drainage a cultural layer came into existence there. In the vicinity of the dugout canoe the cultural layer of the Middle Iron Age was missing because the top layer of the peat (with the cultural layer) was gone by erosion from the adjacent creek.

Between about 250 and 200 BC periods of high water levels occurred repeatedly in the area of the VHW. The high water levels of predominantly fresh to slightly brackish water indicate periodically large river discharges at that time. Initially the top of the peat did not drown but became buoyant. The buoyant peat blocks (*"peat islands"*) tore loose from the underlying peat/clay subsoil and in these cracks and fissures clay was deposited, the intrusion clay. In the early stages these buoyant peat islands were still suitable for habitation. However, since due to repeatedly going up and down the peat tore more and more, the habitational conditions became less and less favourable. Also within the settlements and in the farmhouses cracks filled with intrusion clay have been observed. How long the occupation of the buoyant peat islands still continued is unclear; it may have been a couple of years but also 2 to 5 decades.

Around 200 BC the peat blocks lost their buoyancy. As a result the peat was flooded during high water periods and a clay layer was deposited on the peat (the so-called 'Binnenpolder deposits'). The flooding began along the edges of the creek in the southern and Middle parts of the VHW. After 200 BC the entire area was gradually flooded. The depositional environment of the clay was still predominantly fresh. Occasionally the area of the VHW could become brackish temporarily during major storms; the allochthonous coastal marine diatoms which occur in the clay are indicative of this. Over the whole year, the freshwater conditions dominated; the alders which could grow in the BLA layer show this. Archaeological traces show that in the beginning of the flood stage people were still bustling in the area. Also clay was trodden into the top of the peat on a large scale. However, the intensity of human presence decreased rapidly, and for the remainder of the flood stage in the 2nd century BC only micromorphological research still points to the possibility that people were active in the area.

The deposition of the clay layer on the relatively soft peat subsoil led to a process of autocompaction and differential subsidence. At those places where a strong subsidence occurred the organic archaeological remains have been preserved best because they are lying below the (current) groundwater level. Therefore, these residues have not
exposed to the air and the organic archaeological material has not decayed.

The freshwater tidal depositions of the Binnenpolder clay continued until about Birth of Christ. Archaeological traces show that in the 1st century BC man was active again in all of the area. A second phase of activities with archaeological remains would follow in the 1st century AD. During this phase there was a settlement in the sector West and in the sectors Middle and East off site activities took place which have left behind archaeological traces The third and final phase of activities with archaeological traces was in the 2nd and 3rd centuries AD. By then the sectors East and West had been parcelled with two large ditch systems. During these phases of activity in the VHW, largely the same vegetation types and environmental conditions occurred as those in the 2nd century BC. The area remained part of the supra- tidal zone of the freshwater area. Also, occasionally the area was flooded during which brackish water was brought in. Given the nature of the archaeological traces, in the Roman Ages, the frequency and intensity of floods decreased. The sedimentation of clay – during high water periods – in a tidal freshwater environment continued until approximately 400 AD. Possibly, also the creek in the centre and south of the VHW was still active. However, geological dating evidence for this is lacking. The increasing wet conditions seem to be unfavourable for the human presence in the area. After about 250 AD, no anthropogenic traces have been found which explicitly indicate human activity in the area of the VHW decreased.

Between 300 and 900 AD another period of peat formation occurred within the area of the VHW. However, a lot of the original peat has disappeared by oxidation. Only in sector West the peat has remained well preserved due to subsidence of the peat by autocompaction. By the lowering of the peat, the peat has become below the oxidation – reduction level in soil, so that it was not oxidized. The preserved peat mainly concerned a brook peat with much alder wood. This indicates that the peat was formed beyond the direct marine influence. Possibly, this peat bog was still visited by people during its formation; however, the indications thereof are not in the least univocal.

In the 10th century the brook peat was brought into cultivation and a cultural layer developed which was almost fully formed due to human influence. On the cultural layer remains of timber have been found dating around 991 AD. This cultural layer too, like layer Hv-1, has only been preserved in sector West. However, in sector East remains of buildings actually have been found. These have been dated around 1072 AD.

In the 12th century, the area of the VHW was diked-in and cultivated on a large scale. Due to the strong drainage, compaction and oxidation of the peat, the area subsided strongly in the following centuries and the ground level came to lie below sea level (deeper than 2 m - NAP). The peat – including the organic archaeological remains – which lay in the soil above oxidation level / groundwater level decayed between the 13th century and this day. Little is left of the post-Roman peat. Also the pre-Roman peat which locally lay relatively high (and above groundwater level) has disappeared completely. The old pre- and post-Roman peat has only preserved at those places where it lay below the oxidation / groundwater level.

In the cover layer (DLA) humus horizons occurred. Due to the lack of plant remains these layers could not be dated. The genesis of these humus layers in the DLA layer remains unclear. It cannot be ruled out that the remains belonged to former peat layers which fully decayed later on.

3N.3.2 Yangtze harbor

Groundwater and sea-level rise
The main driver for the accumulation of the Early Holocene deposits burying the valley floor and the inland dunes was the rise of the groundwater table, for which sea-level rise in areas downstream of the study area was the main driving factor. In the very beginning of the Holocene (ca. 9.500 BC) the mean sea-level had still been low, about 35 to 40 m in the southern North Sea (Kiden et al., 2002; Sturt et al., 2013). The area of the central part of the North Sea were still dry land and England was connected with the European continent at that time. As post-glacial eustatic sea-level rise proceeded, the southern North Sea drowned and the palaeo-coastline approached the present-day coastline (e.g. Beets and Van der Spek, 2000).

The results from Phase 2 (further confirmed and scrutinized using data from Phase 3) show the study area became part of the deltaic wetlands that are the landward boundary of base level rise at the river mouth from about 7500 BC onwards. At 20.8 m –NAP Basal Peat began accumulating ca. 7250 BC, at 19.0 m –NAP about 6650 BC. The contact of the Basal Peat with freshwater tidal muds (EC) dates to 6500 BC based on samples from the top of the Basal Peat. This environment persisted until ca. 6000 BC, after which the area was clearly subaqueous shallow marine. The time frame 7500 BC to 7000 BC appears to have seen steady, still relatively slow rise of the groundwater table, by 7250 BC positioned at a depth of 21.0 to

20.5 m – NAP. Thereafter the groundwater rise seems to have accelerated a little, due to continued sea-level rise and the coast line / river mouth approaching the study area as part of transgressive processes. Around 6500 BC, peats encroached the river dune flank to a height of approximately 18.75 m –NAP. In the period between 7250 and 6500 the rise of the groundwater table was about 30 cm / century (Figure 3N51). In the most distal groundwater-locked places, organic deposits accumulated, while in equally wet areas that received more fine sediments during floods, humic clays dominated. This explains why the Basal Peat stratigraphic level in the area (our NIBA-EC unit) is an intercalation of true peats (NIBA) and fluvial humic clays (EC). So, the sea-level rise stimulated (indirect) the accumulation of organic and clastic deposits between 7250 and 6500 BC in the study area. If areas closer to the main Rhine channel of the time to the North of the study area are also included (Hijma and Cohen, 2010; Hijma and Cohen, 2011), peat formation can be considered to have started 7500 BC.

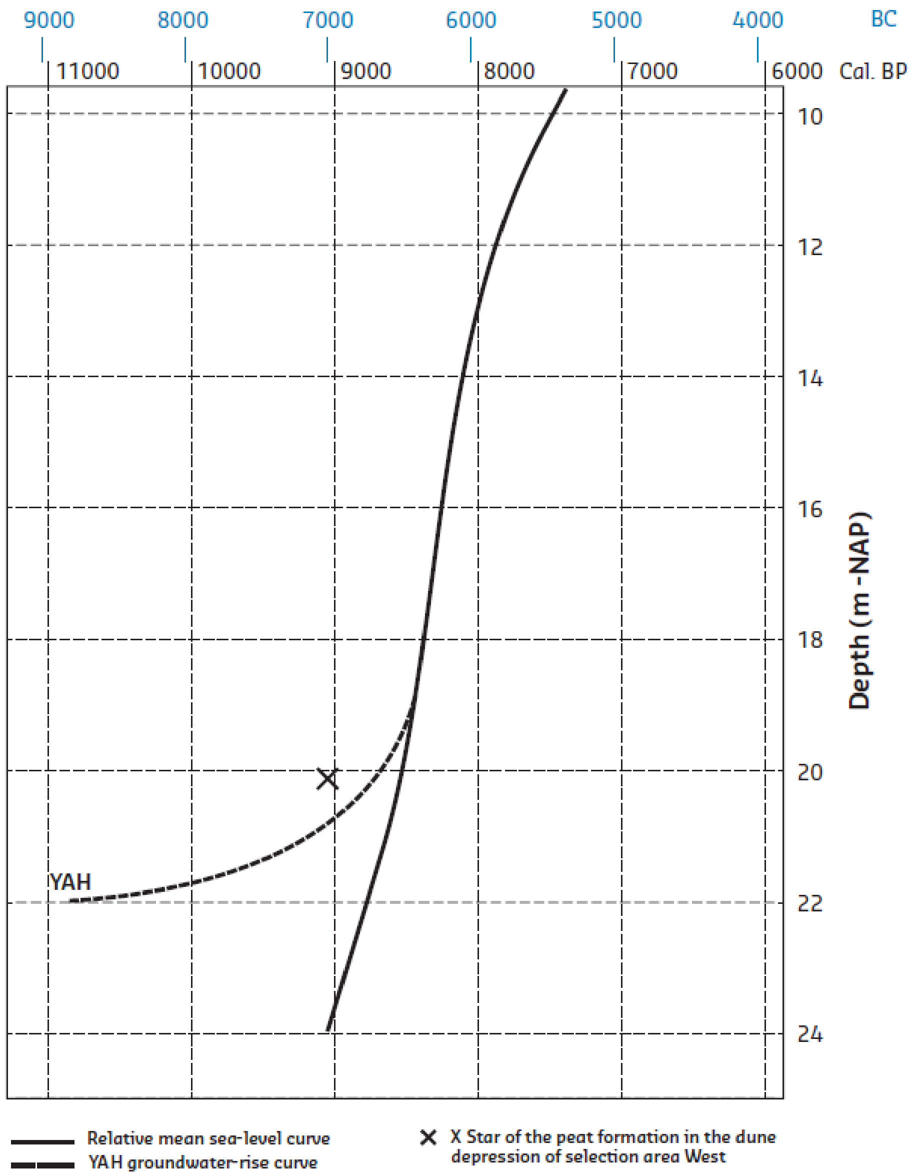


Figure 3N51: Time –depth curves of the Early Holocene sea-lever and groundwater table rise. Afer Hijma & Cohen, 2010 and data of the Yangtze harbour area (groundwater curve).

At ca. 6500 BC, a marked change in deposition occurred in the study area. This had been postulated from dates and sea-level index points obtained 30 km upstream (Hijma and Cohen, 2010) and attributed to an event of accelerated sea-level rise (Figure 3N51). The collected data for the top of the Basal Peat in the study area reproduces the 6500 BC age multiple times and confirmed the event-like timing of the drowning. Just as sea level had been rising before the 6500 BC 'jump', it also continued to rise after at a rate decelerating from 1 m/century to dm/century. This made that waters continued to deepen for millennia after. The region transformed into an estuarine delta and eventually became offshore area (Van Heteren et al., 2002; Rieu et al., 2005; Hijma et al., 2010). These transgressive developments based on sedimentary-geological mapping and dating of organics, can be further detailed using the palaeo-environmental information contained in pollen and diatom palynology.

Landscape reconstructions

With the help of the geological and palaeo-environmental data, the Early Holocene landscape evolution of the study could be reconstructed in relative high detail. Around 9000 BC the study area was situated in a mostly dry river plain of the rivers Rijn and Maas.The lower parts (below 22 m –NAP) were occasionally flooded during periods of extremely high water and a thin layer of silty clay was formed (KRWY-2 layer) there. Vegetation in the river plain was still scarce and as regards the pollen, it is dominated by pine. The floodplain lay dry for long periods of the year. Locally sand drifts occurred, the inland dunes to form. By 8400 BC, the dune in Area West is estimated to have reached a height of 15 m –NAP (6 meters above the surrounding plain). Absence of palaeosol B-horizons in the core of the dune complex below the younger marine truncation surface, indicate at least 1 m of dune top to have been eroded. The estimate for the top of the dune is a projection of similar dune morphologies of better preserved examples more inland in the delta plain. The highest occurences of a clay cover on the dune flank indicate (one or two dm thick; KRWY at highest encountered positions) occasional high water levels in the delta plain, due to floods of the river. The time span of this unit is long, more than 1000 years (i.e. sedimentation rates less than 1mm per year) and also its pedogenic ripening indicates the floodplain to have been dry land, and suitable for occupation, for most time of the time year round. With this respect, the Phase 3 and 4 findings confirmed the presence of such a landscape at the time of the early Mesolithic and early middle Mesolithic age, that had been the reason to do detailed investigations in Area East. An archeological site, however could not be confirmed in Area East.

The landscape situation changed after 7250 BC, when a large part of the area became wetland. Assuming that Mesolithic man did not stop visiting the study area but altered its use of it to the wetland situation, this palaeogeographical change would predict the potential area where archeological sites (e.g. places where fire was used) to have shrunk and find concentrations to have increased in the remaining suitable zone.

As evidenced by the Basal Peat, the water table rose at rate of 0.2 to 0.3 m per century (7250 to 6500 BC). Peat formation and distal clay sedimentation together could generally keep pace with the provision of accommodation space by the groundwater rise, but local lakes formed in the places receiving too little sediment and not able to grow enough organic matter. The landscape diversified greatly. Shallow ponds and lakes developed reed-sedge marsh rims. The higher river dune area maintained terrestrial and with woody vegetation cover. The tree vegetation on top of the dune shows the immigration of broad leaved tree species around 7000 BC, marking the Boreal / Atlantic transition. The proportion of *Pinus* reduced strongly and the thermophilic tree species such as *Alnus*, *Corylus*, *Quercus* and *Ulmus* increased greatly in numbers. Around the dune reed-sedge marsh vegetation, riparian vegetation and open water vegetation gain importance from this time. Around 6500 BC, with wetland sedimentation up to 18.75 m –NAP, the habitable area on the dune was at its smallest.

The hydrological and palaeo-environmental changes in the river plain mean that, while dry habitable areas became smaller and smaller, conditions for hunting and gathering may have diversified and improved. The new environment of the late boreal and earliest Atlantic of the area improved the pallet of food resources available in the direct surroundings. Therefore, at remaining high-and-dry locations in the wetland, one may consider the odds of encountering Mesolithic archaeology to have been raised relative to earlier situations.

In Figure 3N52 and Figure 3N53 the drowning history of Area West is visualized in a map and profile reconstruction. The figures show both the run up to the 6500 BC drowning of the area, and the aftermath. At the critical moment, the drowning was very fast (sea-level jumping, in a few months or a year, possibly in two events of about a meter each (Hijma and Cohen, 2010) and thereafter drowning and deepening continued.

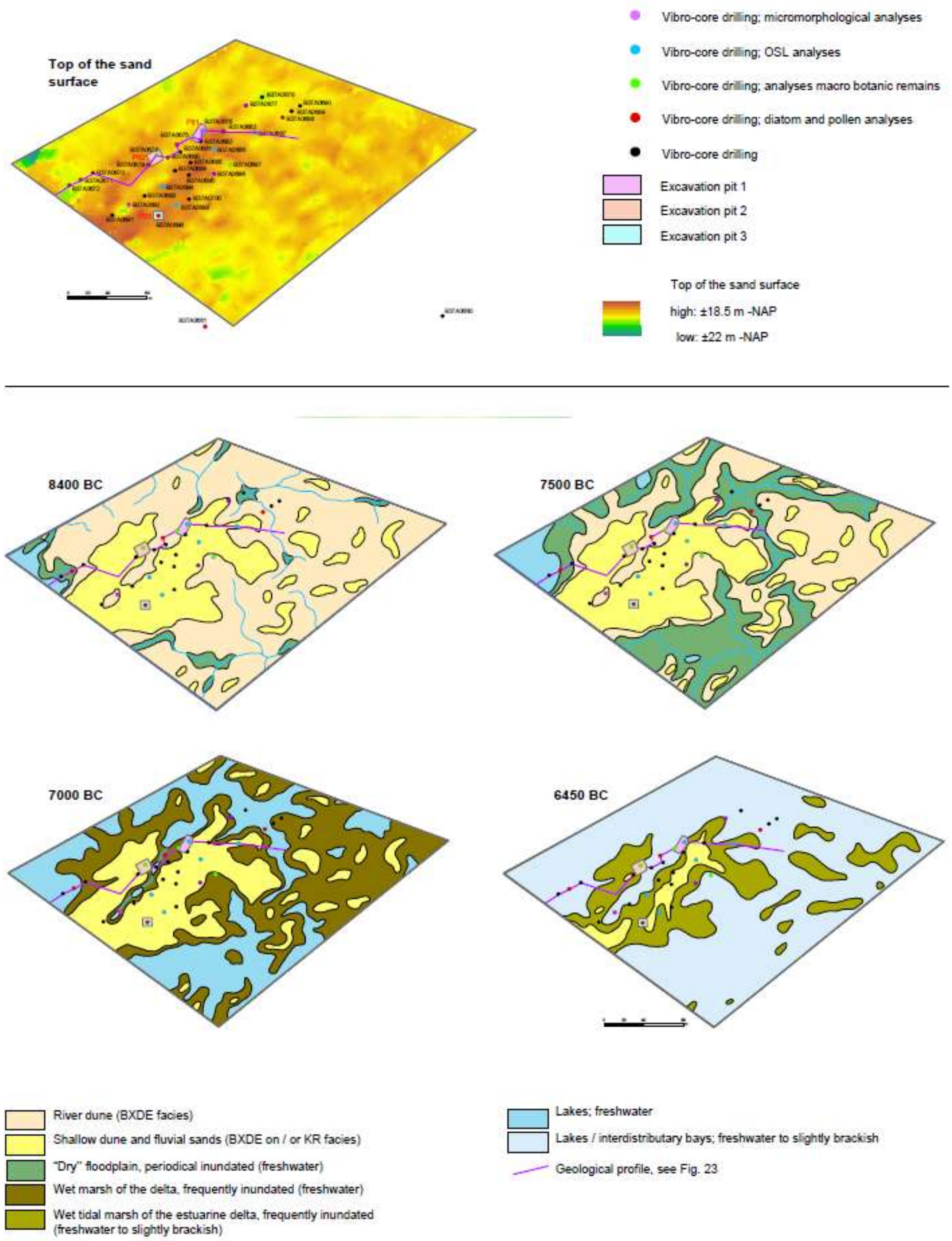


Figure 3N52: Map reconstruction of the drowning of the landscape of selection area West for the time steps: 8400, 7500, 7000 and 6450 BC

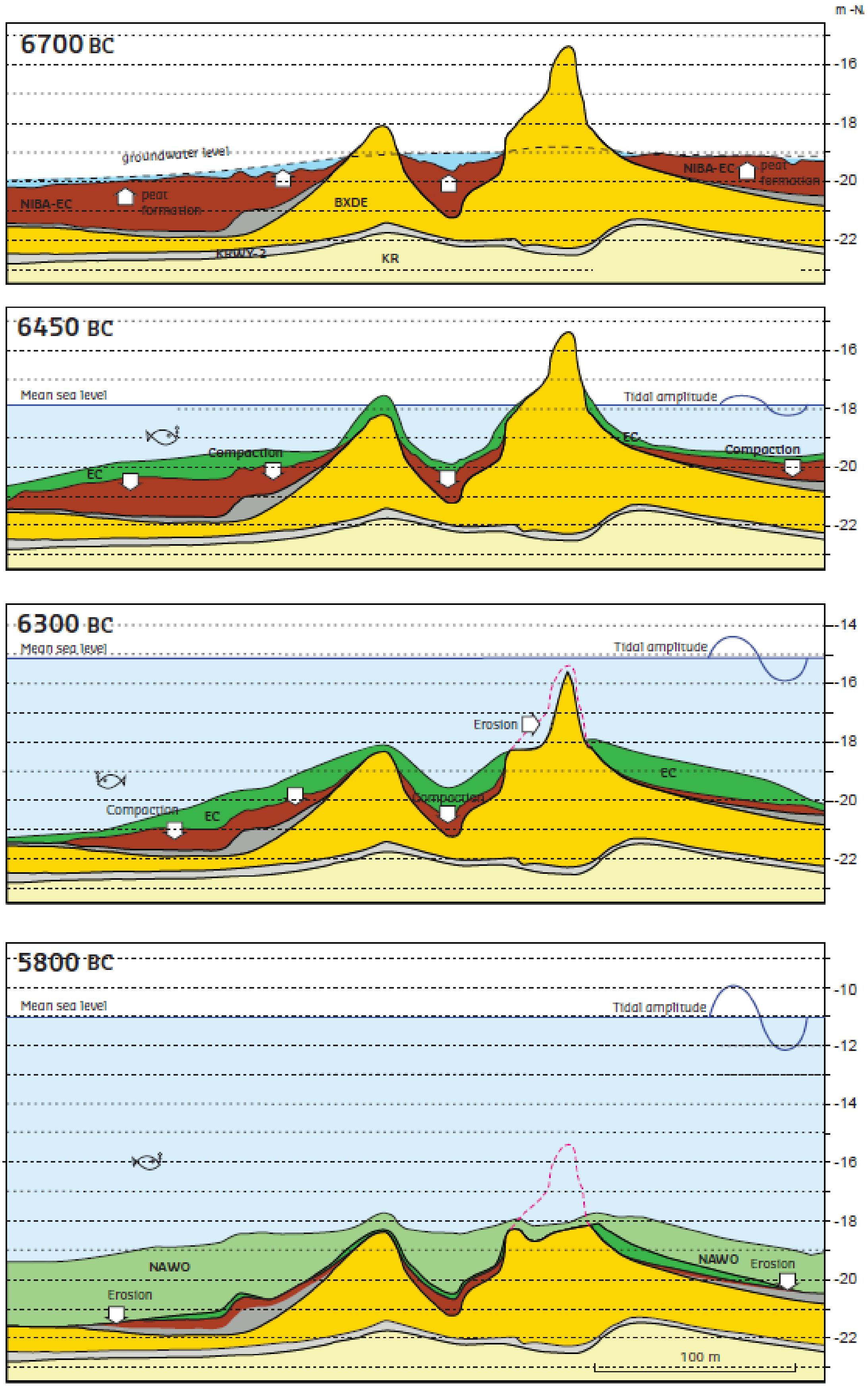


Figure 3N53: Profile reconstruction of the drowning of the landscape of selection area West for the time steps: 6700, 6450, 6300 and 5800 BC. Legend profile see Figure 3N38.

The 6500 BC event transformed the river plain wetland (zone 1 in Figure 3N33) into shallow subaqueous river mouth wetlands (zone 2 in Figure 3N33): 'upper-estuarine' or 'fluvial deltaic' freshwater floodbasin environment, part subtidal and part intertidal. Thereafter the environment became brackish, deepened further and became subtidal everywhere, and eventually became saline. In this environment the top of the dune was drowned and washed out by marine erosion. The would-be dune top at 15 m –NAP would have beend drowned at 6300 BC, based on sea-level data collected 20-30 km inland (Hijma and Cohen, 2010).

Coincidently and conveniently, the 6500 BC transgressive event matches the boundary between the Middle and Late Mesolithic in archaeological time division as has been used on inland sites (Louwe Kooijmans, 2005). In the coastal Netherlands, the transgressive event(s) of 6500-6300 BC may have been instrumental in causing a change in Mesolithic site patterns. From 6500 BC, the dune site Yangtze Harbour West rapidly became inhabitable. Successors of Middle Mesolithic people that had been visiting the area for its specific resources and hunting habitats, would have find these environments shifted to more inland positions (e.g. Rotterdam and Alblasserwaard), where indeed Late Mesolithic occupation is present and was exploited (Louwe Kooijmans, 2005; Brouwer-Burg, 2013). From a palaeogeographical perspective, we recommend detailed archeological intercomparison of these deltaic Late Mesolithic sites and the submerged Middle Mesolithic equivalents. In such comparisons and evaluations, it should be considered that the inland shifting of environments not only considers fluvial and estuarine wetlands, but also (embryonic) coastal barrier and spit systems at the estuary mouth (at the boundary of zones 3 and 4 in Figure 3N33). These environments may have been part of the Mesolithic land use strategies too, but these structures are not preserved because of coastal erosion.

3N. 4 Conclusions and Recommendations

3N.4.1 Vergulde Hand West: Regional significance of the VHW in the landscape reconstruction

The area of the VHW belongs to the best-studied geo-archaeological sites in the Rijn-Maas delta area of the Maasmond. This case study puts the history of this region over the last 3500 years in a different light. On the base of the VHW study data, the regional paleogeographic maps from 2008 and 2011 (Vos and Zeiler, 2008; Vos et al., 2011) have been adjusted significantly as compared to those from 2002 (Vos, 2002). The changes regards the peat distribution and the courses of the main drainage channels in the delta in the map reconstructions.

An important regional signal, which was derived from the VHW research, was that after 250 BC a large influx of fresh river water occurred from the hinterland of Rijn and Maas. The increase of the river discharge is indicated by extreme high flood water levels in the VHW area. The increase of the water level during floods did not directly led to the drowning of the peat area of the VHW location. Initially the upper part of the peat of the VHW was not submerged during periods of extreme high water levels because the upper part of peat became buoyant and tear loose of the peat in the deeper part of the subsurface. The alder vegetation in the peat and clay layer on top indicated that at that period of drowning the water was predominantly fresh; however, the diatoms examined in the intrusion clays and cover layer indicate that there was tidal influence in the area (influx of coastal allochthonous diatoms). The combination of alder vegetation and marine diatoms in the clays indicate that between 250 and 1 BC, the VHW location had become part of a freshwater tidal area.

The increase of discharge of freshwater from the hinterland is explained by the formation of new tributaries of the Rijn towards the Maasmond area. This interpretation implicates that the channel migration of the river Rijn - from the Oude Rijn area towards the Maasmond area - was older than those described by (Berendsen and Stouthamer, 2001) which dated these Rijn avulsions in the Roman period. After the time that Maasmond area became the main outlet of the Rijn - Maas river system (again), this Oude Rijn estuary lost gradually their discharge function and diminished in size from the Roman period onwards (Van Dinter, 2013).

Another interesting feature which was observed on the VHW location, was the expansion of the Early Medieval peat, of which the existence was proven in the peat depressions of sector West (Figure 3N28a), whereas the main channel of the Rijn-Maas system was located immediately south of the VHW area (Nieuwe Maas channel). The expansion of the peat – immediately along the main channel, indicates that the flow rate of this channel had been reduced. This is remarkable because in that period of the Oude Rijn decreased more and more and the discharge through the IJssel only began to play an important role after 800 AD (Makaske et al., 2008). From this observation at the VHW site it has been concluded that other southern channels took over the discharge of the Oude Maas. In the map reconstruction of 800 AD has been assumed that those were the channels of the later Hollandsch Diep, Bernisse and Binnenbedijkte Maas / Oud-Beijerlandsche Kreek. These watercourses could find a shorter route to the sea because after 350 BC the peat areas of Zeeland and the islands of Zuid-Holland Holland were flooded and new openings to the sea were created in this area (e.g. Vos and van Heeringen, 1997).

3N.4.2 Yangtze Harbor

From findings in the Western Netherlands (Louwe Kooijmans, 2005), and also from offshore dredged sands used to further extend made land of the Maasvlakte, the presence of Mesolithic archaeology in the region had been known (e.g. Louwe Kooijmans, 1975; Verhart, 1988; Verhart, 2005). It was reason to dedicate archaeological prospection efforts to surfaces from the Mesolithic period in the Yangtze Harbour area in the Port of Rotterdam too, which was carried out using 'the geogenetic approach'.

As a result, this case study report can present the relation between 1) early and middle Holocene landscape development, 2) potential Mesolithic use of the reconstructed landscapes and 3) understanding what localities in the landscape would have the highest chance to find the archaeological proof for human presence. For the Yangtze Harbour area, the insights are:

1. Up to 7250 BC the whole floodplain and inland dune complex in it was suitable for (seasonal) settlement (i.e. make use of fire to cook food, make tools). Locations along local drainage are regarded to have been frequented most, but in the rest of the floodplain suitable locations will have existed too. It is hard to differentiate and chances of actually finding archaeology are to be considered low.

2. Between 7250 and 6500 BC, the area suitable for settlement was reduced to the higher parts of the inland dunes. The surrounding wetlands (swamps, marshes, lakes) were part of the rich habitat, but not good settlement location. It is easy to differentiate and the chances of finding archaeology on the top of the dune sediment is large. Chances are equally high on the dune foot and the fringe of swampland surrounding dunes. The state of preservation and the opportunities to also collect contextual palaeo-environmental information are even better. Finds at the dune foot may have been colluvially been displaced a few meters.

3. After 6500 BC, the study area had submerged. No Mesolithic archaeological sites are expected, also because of further sea level rise of many meters in later millennia.

The contrast between the period before and after 7250 BC is the result of the connection between the drowning due to groundwater rise (in advance of sea-level rise) and habitat changes with the altered hydrology (besides climatic developments and vegetation succession). In combination, this creates a Mesolithic 'prospection optimum' centred on inland dunes that have wetland deposits capping their feet. For the study area, this relation is visualized in Figure 3N54, together with trend lines of groundwater and sea-level rise, decline of available land.

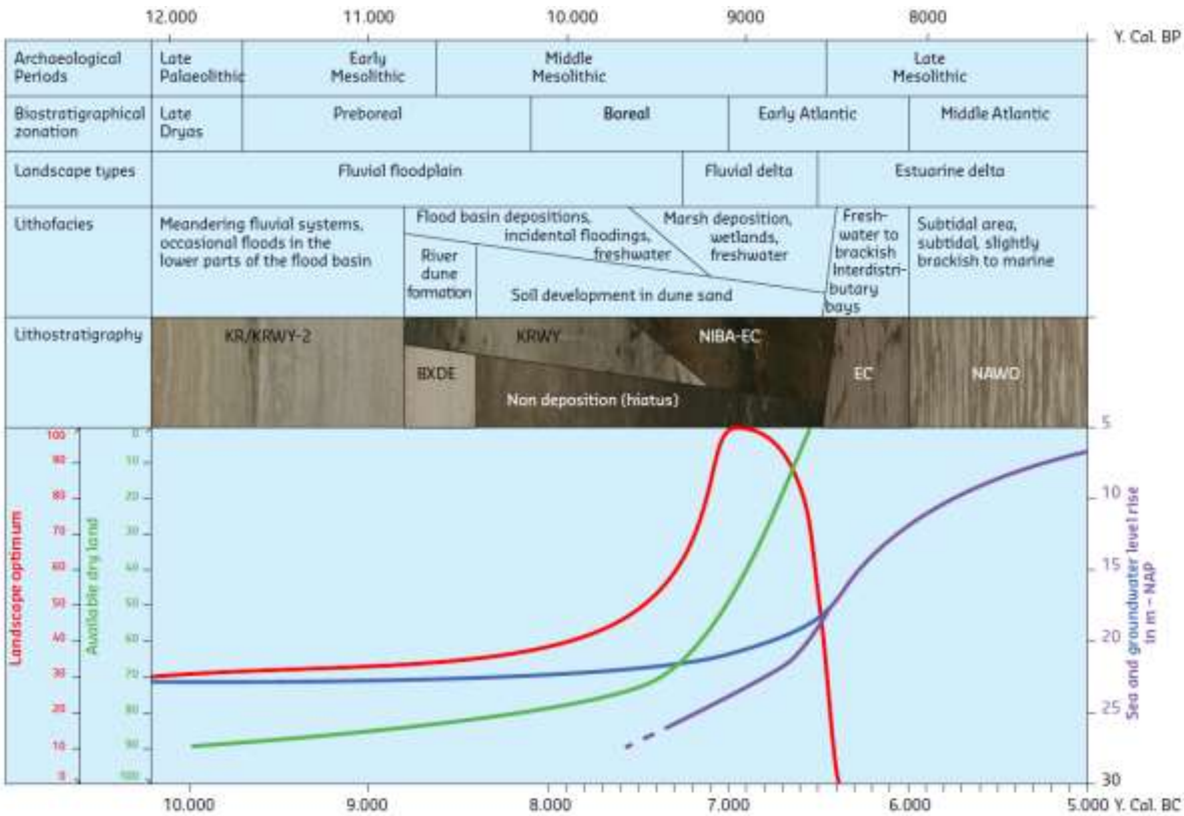


Figure 3N54: Synthesis of the lithostratigraphy, sedimentary environments, and dry / ''optimal'' land surface in time, related to ground- and sea-level rise. Stratigraphy, Figure 3N38, Figure 3N39 and Figure 3N44; sea- and groundwater-level curves, see Figure 3N51; salinity reconstruction, Figure 3N45 and Figure 3N46; available dry land / ''landscape optimum'' reconstruction, see Figure 3N52.

The geogenetic approach (targeting specific sediment layers and surface contacts), stepwise deployed, provided the insights needed to do targeted high-resolution research, at locations optimal for prehistoric habitation, and to select the best methods and techniques for mapping the palaeolandscape and proofing human presence in it. Suitable habitats for hunting and gathering in the fluvial delta were widespread. At site Yangtze Harbour West, archaeology of this period was indeed found at depth of 18,5 – 20 m -NAP. It shows that an extensive drilling program in inland dune sands will have a large change of success in finding archaeological proof by sieving the sediments of the sampled cores. The geogenetic approach also makes sure that sufficient material is collected to support detailed palaeo-environmental reconstructions to place excavated archeological sites in context. The geogenetic approach also makes sure that the obtained results feed back to the regional paleogeographical knowledge.

The stepped geogenetic approach can be applied in comparable underwater areas elsewhere in the world where large engineering projects are taken place. It is difficult to proof the effectiveness of the methodology on the single case of this study, but at least future underwater archaeological investigations can base their approach on ours. Especially for underwater areas where thick sediment layers cover up the palaeolandscapes – which is the case in the coastal zones of many of the world's present-day deltas, it is a promising approach. In this study, the information after each phase of the survey was used for planning the next phase. The stepped strategy makes anticipating, flexible project planning within the larger engineering operations feasible, and made adjustments to the outset concept of the project possible (methods, disciplines to consult specialist from). The stepped strategy also is more efficient than an overall project plan in which the budgets for the various activities (in time and money) are allocated in advance.

The geoarchaeological investigation benefited of the geotechnical data of the engineering work. The reverse can also be the case: an improved geological model, made for archaeological reasons, can be valuable for the design of the infrastructural work and the operation activities. In the case of the Yangtze harbour project, during phase 1 (desk study) the geotechnical CPT data constituted the base of the first conceptual geological model. During phases 2 – 4, the geoarcheological field survey had much benefit that the – from a (prehistoric) archaeological point of view - irrelevant sea sand deposits up to 17 m – NAP were dredged away, so that the relevant deltaic deposits were much easier to investigate with geophysical and coring technics. Because the geoarchaeological investigations were incorporated, the overall impact on the harbour engineering works itself was negligible and the cost for the archaeological research reduced.

One may wonder if the here deployed methods were the most optimal ones. A better alternative method to proof the presence of archaeology in floodplain deposits such as in Area West and Area East, could have been to take large ''bulk samples'' instead of corings ' already in Phase 3 instead of Phase 4. Such methods have been piloted for palaeolithic and paleontological (e.g. Mammoth bones) surveys of sand nourishments to beaches.

Like other elements of the geogenetic approach, bulk sampling can be fit in to the works that engineers are executing anyway to deepen the harbour, i.e. 'controlled dredging'. The means exist to obtain large grab samples for which it can be confidently known from which geological layer they were coming (the eventual Phase 4 archaeological dig has demonstrated this). After Phase 2, optimal locations for taking bulk samples can be decided on, and part of the coring activities in Phase 3 can be replaced by bulk grab sampling. For age control and palaeo-environmental control and geological context, cores will have to be taken prior to the dredging. Especially for the non-cohesive units such as dune sands and tidal silt-laminated clays and sands, in grab samples the sedimentary sequence will be disturbed when the slush is brought to the surface for inspection. Surely, bulk sampling is a 'rough' way of underwater archaeological prospection (and / or excavation). However, for the North Sea area in most cases there is no alternative considering the depth and cost of the investigation. Important is that before the sampling of the seafloor subsurface the geology of area is investigated with geophysical techniques and boreholes and the palaeo-environment of the area of investigation can be determinate.

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3N.5 Annexe: description of the samples.

KRWY layer: 4.10–3.98 m below HB (Harbour Bottom during springtime 2011. (21.26–21.14 m –NAP)

Diatoms:

The diatoms in this layer are particularly dominated by four ecological groups (Vos & De Wolf, 1993): freshwater epiphytes, freshwater plankton, brackish- and freshwater tychoplankton and freshwater epipelon / epipsammon. At the species level, the following freshwater species have been found most commonly: *Epithemia adnata* (epiphyton), *Aulacoseira crenulata*, *Aulacoseira subarctica* (both plankton), *Staurosira venter*, *Pseudostaurosira brevistriata* (both tychoplankton), *Cocconeis placentula* (epiphyton) and *Amphora pediculus* (epipelon). The only marine-brackish diatom species which occurs is a small number of *Gyrosigma attenuatum* which, however, also tolerates freshwater conditions. Marine diatoms are not present.

Pollen

The pollen sample from this layer belongs to pollen Zone A. This zone is characterized by high values of the *Pinus* pollen. Apart from *Pinus* small percentages of pollen of thermophilic species such as *Corylus*, *Quercus*, *Ulmus* and *Tilia* are present. In addition, pollen of marsh vegetation (reed-sedge vegetation) and a number of pollen from freshwater plants occur. A common type of spores in this zone is *Ophioglossum vulgatum*, a small species of fern which during the Early Holocene often occurred in relatively high percentages in near coastal sediments. Currently, this species is found mainly in wet dune valleys. Marine indicators such as pollen of salt-tolerant plants, dinoflagellates and foraminifera are absent. The high values of *Pinus* and the still relatively low values of the thermophilic species indicate a Boreal age of the KRWY layer.

Palaeo-environment

The KRWY layer in borehole B37A0705 lies relatively low and along the edge of a trench-like depression (palaeo-brook system). The humid conditions account for the fact that the diatoms have been preserved relatively well there. In higher-level samples of the same KRWY layer of other cores the diatoms have often been dissolved by soil formation. The KRWY deposits were formed in a fresh water environment, which probably was permanently submerged for long periods of time. The co-occurrence of the planktonic, tychoplanktonic, epipsammic and epiphytic habitats are indicative thereof. The site was outside the sphere of influence of the sea.

NIBA-EC group: 3.98–3.50 below HB (21.14–20.66 m –NAP)

Diatoms

In this layer mainly species of freshwater planktic and freshwater epiphyton habitats have been found. Brackish-freshwater tychoplankton occurs only in relatively small quantities. In the groups mentioned *Aulacoseira crenulata*, *Aulacoseira islandica*, *Aulacoseira subarctica* (all plankton) and *Epithemia adnata* (epiphyton) are most commonly found. Marine diatoms are not present.

Pollen

The pollen samples from the NIBA-EC group belong to pollen Zone B. In this zone, the percentage of pollen of *Pinus* clearly decreases and the percentages of thermophilic tree species such as *Corylus*, *Quercus* and *Ulmus* increase. *Hedera helix* is also found in this zone. In this zone a strong expansion of pollen types of marsh and open water vegetation can be observed. Species indicating marsh fern-reed-sedge vegetation are, apart from Cyperaceae and *Dryopteris* types, *Typha latifolia*, *Sparganium* and *Alisma plantago-aquatica*, but also tall forbs from wet habitats such as *Filipendula*, *Lythrum salicaria*, *Valeriana oficinalis*, *Iris pseudocorus*, *Euphorbia palustris*, *Calystegia sepium* and Tubuliflorae. Also pollen of *Brassicae* species are present, in this context, probably originating from the marsh plants *Nasturtium* and / or *Rorippa*. Other species from wetland- and riparian vegetation are of the type *Polygonum persicaria* type – here probably originating from *P. hydropiper*, *P. minus* or *P. mite*.

In this zone the flora of open water is present in a great diversity with relatively high percentages. Nymphaeoide vegetations are represented by pollen of *Nymphaea alba* and *Nuphar luteum*, often with large numbers of basal hair cells and trichosclereids of these species, indicating a very local origin. *Oenanthe aquatica* type, *Butomus umbellatus*, *Cicuta virosa*, *Berula erecta*, *Apium inundatum* type, *Myriophyllum verticilatum* and *M. spicatum*, *Potamogeton* and *Ceratophyllum demersum* play a role alongside algae such as *Pediastrum*, *Botryococcus*, Zygnemataceae and *Spirogyra*. Noteworthy is the regular occurrence of *Salvinia natans* (a free floating water fern) and a single find of *Trapa natans* (water chestnut, a potential food plant for Mesolithic man). Both species are known from the mid-Holocene of the Netherlands (Zandstra, 1966; Out, 2010; Van Haaster & Brinkkemper, 1995).

Palaeo-environment

The diatoms in the NIBA-EC group include species that thrive in a freshwater depositional environment. The species composition, with much plankton, but also epiphyton and epipelon/epipsammon, is indicative of a predominantly permanently submerged environment with littoral vegetation of aquatic plants. The pollen species assemblage confirms this. This indicates the presence of eutrophic, relatively deep, stagnant open ponds with littoral vegetation and wet brushwood at the edges. The clayeyness of this unit fits within this type of aquatic environment.

EC layer: 3.50–2.80 below HB (20.66–19.96 m –NAP)

Diatoms

In this layer, for the first time diatoms are found, originating from the marine environment. The environmental groups which occur in the layer are – in addition to the marine habitats of marine tychoplankton, marine epipsammon and plankton – the groups of brackish-fresh tychoplankton, freshwater epiphyton and freshwater epipelon /epipsammon. At the species level these are: *Staurosira venter*, *Pseudostaurosira brevistriata*, *Staurosira construens* (all brackish-fresh tychoplankton), *Fragilaria sopotensis* (marine epipsammon) and *Cymatosira belgica* (marine tychoplankton). In the upper sample of this layer, the number of marine species increase slightly, including *Thalassiosira decipiens* (marine plankton).

Pollen

The samples from the EC layer belong to the pollen Zone C. In this zone – as is the case with the diatoms – the first marine elements are found, such as pollen types of salt-marsh vegetations (Chenopodiacea, *Armeria*) and further foraminifera and dinoflagellates. Characteristic of the zone C is the marked increase in pollen of *Alnus* and the occurrence of *Tilia*, in relatively low percentages. Further *Fraxinus*, *Viburnum opulus*, *Humulus lupulus*, *Frangula alnus* and *Myrica occur*, and in addition *Hedera helix* and pollen grains of *Ilex*, also in very low percentages. Also in this zone marsh vegetations and those of open freshwater play a major role. But, the percentages decrease sharply whenever the first marine elements do occur in the deposits. The decrease in the spores of ferns is clearly connected with this. The fact is that marsh ferns (*Thelypteris palustris*) – probably the major part of the present spores of *Dryopteris* type – is a very halophobic species. Therefore the reed beds rich in marsh ferns decrease in size during the deposition of the EC layer. Also the continuing drowning of the landscape during this deposition period may have brought about the further decrease in this type of vegetation.

The picture of the pollen of this zone falls in the Atlantic which is consistent with the ^{14}C datings in the top of the NIBA-EC unit.

Palaeo-environment

The diatoms and also the pollen spectrum show that the EC layer was formed within the sphere of influence of the sea. Relatively many diatoms of the allochthonous coast group (marine plankton and tychoplankton), foraminifera and dinoflagellates were found in the samples of this layer. These elements were supplied from the sea by tidal movements. This caused the depositional environment to become slightly salty. The clays of the layer were deposited largely in a submerged environment (interdistributary bay environment). The water in these deltaic lakes was still predominantly fresh to brackish, given the large amount of fresh and brackish-fresh pollen types and diatom species. In light of the lacustrine nature of the deposits many pollen may have been supplied from elsewhere through water currents. This also applies to the marine diatoms (allochthonous coastal group). The increase in these coastal allochthonous diatoms in the upper sample from the layer EC indicates a continuous increase in the tidal influence and salinity within the study area.

NAWO layer: 2.80–1.47 below HB (19.96–18.63 m –NAP)

Diatoms

In this layer mainly diatoms of groups of marine plankton and tychoplankton occur. In addition, also brackish-fresh plankton is frequently found. Ecological groups that are observed less frequently are freshwater epiphyton and marine-brackish epipelon. At the species level the most commonly diatoms are: *Thalassiosira proschkinae* (marine plankton), *Cymatosira belgica* and *Delphineis minutissima* (both marine tychoplankton), *Thalassiosira pseudonana* (brackish-freshwater plankton) and *Nitzschia frustulum* var. *inconspicua* (freshwater epiphyton).

Pollen

The pollen samples from the NAWO layer fall, like those of the EC layer, in pollen Zone C. Many pollen will have been supplied from the fluvial hinterland which explains why the pollen zones of the EC and NAWO layers are very similar.

Palaeo-environment

The increasing dominance of marine plankton and tychoplankton in this layer indicates that the site was under the increasing influence of the sea. The eastern tidal channel deposits of the NAWO layer also point thereto. Freshwater diatoms are still present although only in minor amounts. The occurrence of brackish-fresh, salt tolerant plankton (mainly *Thalassiosira pseudonana*) is indicative of the brackish nature of the depositional environment of the NAWO layer. That still a relatively large freshwater supply from the hinterland took place, is evidenced by the freshwater pollen assemblage which is still strongly present in the pollen spectrum.

SBBL layer: 1.47–0 below HB (18.63–17.16 m –NAP)

This layer was not investigated on pollen and diatoms. Deposits were formed in an open marine environment and for the major part during the Subatlantic.

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