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Coastal development, sea-level change and settlement history during the later Holocene in the Clay District of Lower Saxony (Niedersachsen), northern Germany

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Abstract

This paper focuses on the last 4000 years of coastal evolution and settlement in Niedersachsen (Lower Saxony). Due to a decrease in the rate of sea-level rise during the later Holocene, regressions took place, which included calmer phases, during which intercalated peat developed. The first marked regression started at ca. 1500 BC (calibr.). As a result, peats formed which can be traced into the tidal flats far beyond the present coastline. During the following Dunkirk I transgression period, several bays were created and the coast took on its present-day outline. Shortly before the Birth of Christ, a second pronounced regression occurred, which resulted in soil formation and led to a far-reaching human occupation in the Clay District, i.e. the so-called *Marsch*. For this time, and also for the period around AD 800 as well as for around AD 1500, the entire coastlines have been reconstructed. Increase in storm-flood level from the 1st century AD onwards was responded to by the local population by the construction of dwelling mounds, i.e. *Wurten*. Diking started in the 11th century and by the 13th century a continuous system of winter dikes had been created. The cutting-off of the hinterland by diking resulted in higher storm-flood levels. Severe breaches of the Medieval dikes led to the formation of large bays such as the Dollart, Ley Bay, and Jade Bay as a result of higher storm-flood levels which, in turn, were caused by diking. The formation of these new bays resulted in large-scale changes in hydrographic conditions in the hinterland and, as a consequence, existing bays sometimes silted up. The consequences of short-term storm flood events are compared with the long-term effects of the changing drainage system.

Keywords: North Sea; Germany; Lower Saxony; Holocene; Sea-level changes; Former coast lines; Occupation history; Diking history

1. Introduction

The history of coastal development is a research topic with a long tradition in Lower Saxony. In the early stages, i.e. in the first decades of the 20th century, it was mainly the field of amateur scientists such as H. Schütte and D. Wildvang. They carried out thousands of corings in the Clay District (*Marsch* as opposed to *Geest*, i.e. the higher Pleistocene sandy ground) and also collected many observations in order to draft a first picture of the coastal history. Though an early stage in the research, they combined information on the geological record as well as evidence for human occupation.

There are few areas in Europe where habitation is so dependent on developments in the natural landscape as in the Clay District of the southern North Sea. Both landscape changes and settlement history were determined by sea-level changes. During the early decades of research in this new field, the opinion prevailed that it was the land that subsided, due to tectonic crustal movements. It was only in the 1930s that the view changed as a result of comparisons with sea-level change in other regions and also repeated levelling in the coastal region. Now it is generally accepted that tectonic decline contributes only a very small part compared with that ascribable to sea level rise.

In 1938, the Niedersächsisches Institut für historische Küstenforschung (Lower Saxony Institute for Historical Coastal Research) was founded by W. Haarnagel in Wilhelmshaven, with the object of carrying out coastal research in a professional way. From its foundation, the Institute was concerned not only with Holocene geology but also settlement archaeology and environmental history informed by botanical/palaeoecological research. Together with the Niedersächsisches Landesamt für Bodenforschung (Geological Survey) in Hanover

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and other institutes, the modern view of the coastal history of Niedersachsen which is presented here, has been elaborated. The outlines of the research area and the locations of the sites mentioned in the text are depicted in Fig. 3.

The main features of the present-day coastal area are as follows. Pleistocene ground (*Geest*) is exposed mainly in the hinterland, reaching the sea at only two points in Lower Saxony, at Dangast in the inner part of the Jade Bay and at Cuxhaven between the Weser and Elbe rivers. To the seaward side of the Pleistocene ground, the Holocene Clay District has resulted from deposition by marine and brackish waters, and with a transitional backswamp area between it and the Pleistocene deposits. The Clay District is bordered nowadays by dikes, outside which some salt marshes still exist. Outside these and below the mean high water level lies the Wadden Sea, a large sheltered tidal flat area.

Along the edge of the tidal flats there is a chain of small barrier islands, formed by mobile sand bodies. This is the geographic continuation of the Dutch coastal barrier system. This system ends in the west at Alkmaar in the Netherlands where the tidal range exceeds 1.5 m, while to the east in begins at Blåvandshuk in Denmark, where the tidal range is again below 1.5 m. In between, in the German Bight, the tidal range reaches 4.0 m. This large tidal range has severe consequences for the barrier islands. With increasing tidal range, the islands became more unstable and mobile so that some were merely shoals of a temporary nature. Because of the permanently changing shipping channels on the seaward side of the present coast and also on account of the soft (and difficult) building ground in the Clay District a large amount of applied research has been done which provided considerable contributions to our present knowledge.

2. Coastlines and deposition in the marine area before the Birth of Christ

While in the North Sea itself, the Holocene deposits are generally thin and the sequence often incomplete, there are many areas in the Wadden Sea and especially in the Clay District behind the present-day dikes where the entire sequence of sedimentation can be observed. The record normally extends not further back than the last 8000 years and starts with the infilling of valleys in the Pleistocene surface. During this time, the early Holocene rapid rise in sea level had slowed down to less than 50 cm per century. Under these conditions, deposition of clastic marine sediments did not take place immediately on the Pleistocene surface but was preceded by peat formation. Due to a rise in groundwater table level, large-scale paludification of the low-lying area close to the coast occurred. Further rise in sea level led to the transgression of these peats, and deposition of marine clay and sand on the peats. The elevation of the peat/clastic deposits boundary is used to establish the sea-level curve while the peats, which are usually at the base of the Holocene sequence, are used for radiocarbon dating. However, only those peats which are linked to the eustatic sea-level rise, may be used for establishing sea levels. Peats of other origin, which are generally older, should not be used for this purpose. Recognising this, Lange and Menke (1967) proposed that the term basis peat (*Basistorf*) be used to designate the former peats while the general term basal peat (*Basaltorf*) should be used only in those cases where a causal relation between peat formation and sea-level rise cannot be proved. This proposal is followed here.

The age of the basis peat depends on its depth. In the coastal zone, it is overlain by mainly clastic deposits. Different transgression phases can be distinguished. For the subdivision of the Holocene marine sequence, the detailed scheme of Brand et al. (1965), which has been in use in Germany for some time, has been abandoned in favour of the widely used general form of the Belgian-Dutch terminology of Calais I–IV and Dunkirk I–IIIb, which has been further developed (Table 1).

In the late Holocene with low rates of sea-level rise, there were calm phases during which fresh water conditions were re-established and peat formation took place in parts of the coastal zone. These peat layers extend from the landward side more or less far into the brackish and marine areas (Fig. 1). These intercalated peats are important for dating and subdivision of the Holocene sequence. A particularly favourable period for the formation of such intercalated peat layers occurred between 3000 and 2400 BC (ages are in calibrated/calendar years). Later, between 1500 and 1000 BC, another retardation in sea-level rise ended in a lowering

Table 1
Calais- and Dunkirk transgressions and their ages (uncalibrated ^{14}C-dates BP)

Transgression	Age	Transgression	Age
	3250		500
Calais IV		Dunkirk IIIb	
	3900		850
	4400		1100
Calais III		Dunkirk IIIa	
	5100		1250
	5300		1600
Calais II		Dunkirk II	
	6400		1950
	6400		2100
Calais I		Dunkirk I	
	7800?		2850

The dates given are averages from Lower Saxony and Schleswig-Holstein.

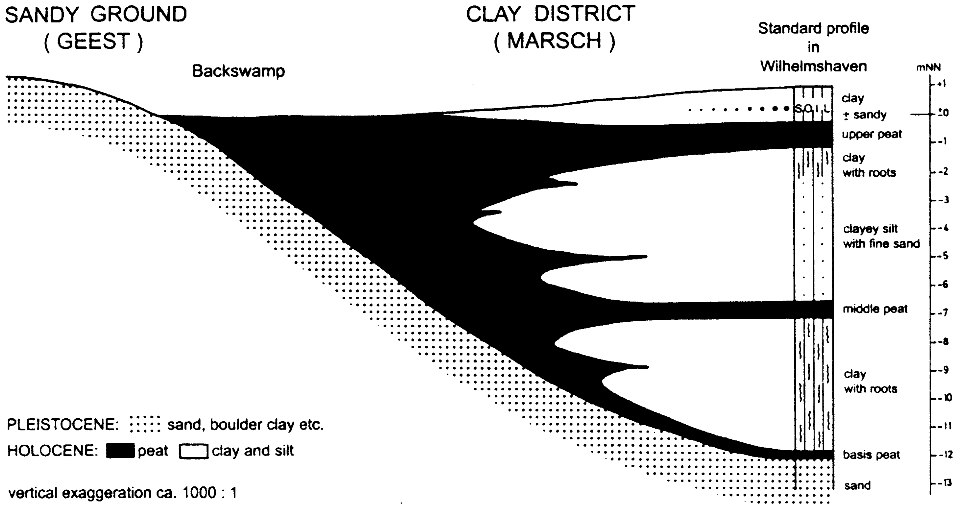

Fig. 1. Schematic representation of Holocene deposits in the Wilhelmshaven area showing a typical sequence of marine and brackish deposits with intercalated layers of peat, formed under freshwater conditions.

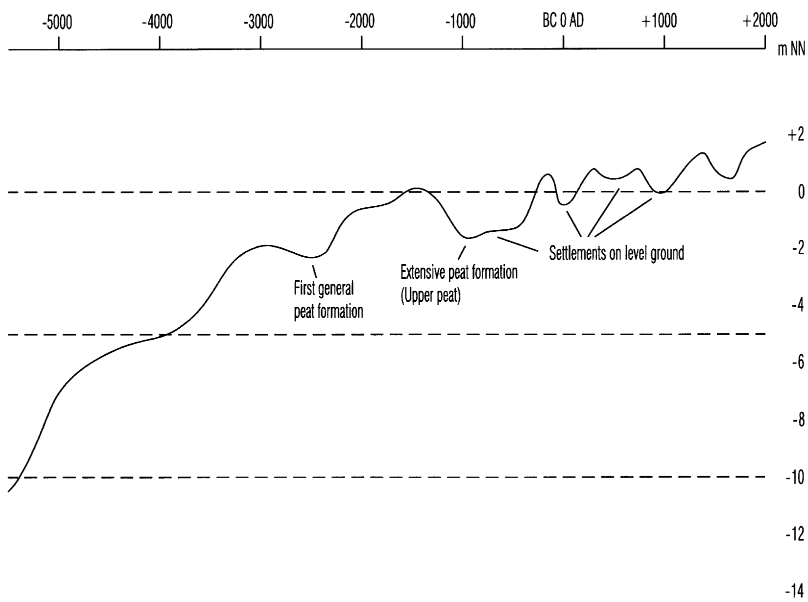

Fig. 2. Sea-level curve (mean high water level) for the middle and late Holocene in the North Sea coastal region of Germany. Age in calendar years.

of the sea level and a large-scale regression of the North Sea took place (Behre, 2003). In this time, the so-called Upper Peat was formed over extensive areas in the German coastal region (Fig. 1).

The formation of the Upper Peat (Figs. 1, 2 and 4) is an important feature in the landscape history and the corresponding sea-level decline has also consequences for the history of habitation. Below the Upper Peat there is, according to the diatom flora, a transitional zone from salt and brackish to freshwater conditions during which clay was still deposited. Here rhizomes are encountered, which come from the *Phragmites* peat above. This reedswamp peat is another part of the regressive development and in typical successions it is followed by sedge and carr peats (Fig. 4). The beginning of the Upper Peat formation dates to ca. 1500 BC with somewhat earlier dates in landward areas (ca. 1700 BC).

In many places, the formation of fen peat stopped and was succeeded by raised bog vegetation which resulted in the formation of *Sphagnum* peat (Fig. 4). This strongly suggests that the initial lowering of sea level has taken place which lead to a decline of groundwater level in the coastal area. This had consequences for mire development insofar as fens are dependent on groundwater, while raised bogs are ombrotrophic, i.e. rainwater dependent.

The extent of the Upper Peat is well known because its upper surface is only 1–2 m below the present-day clay surface and is often encountered in field investigations as well as during construction of buildings and

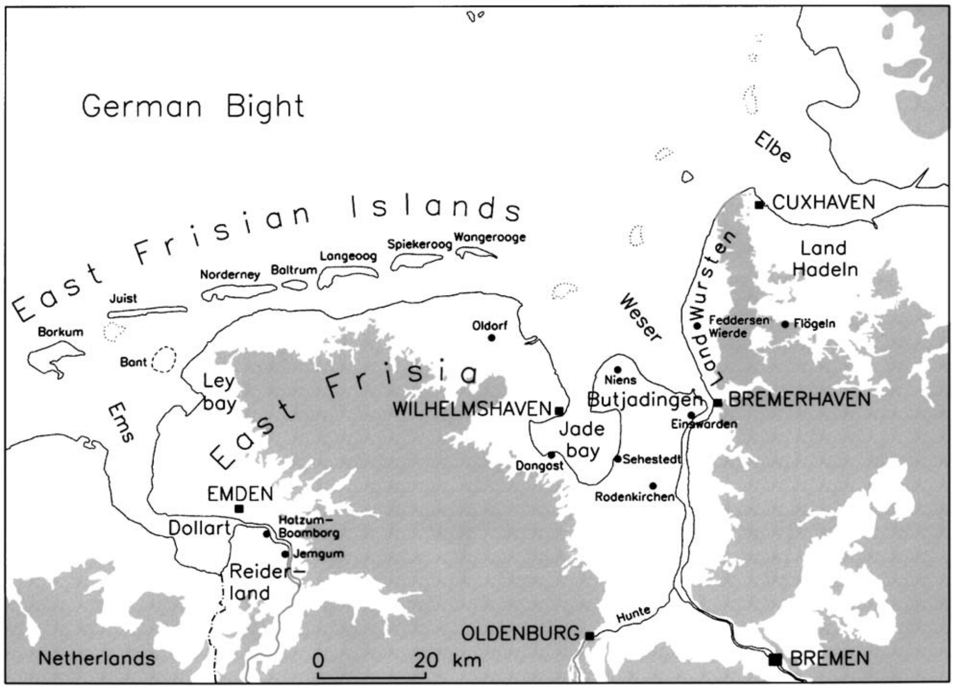

Fig. 3. Location of the names mentioned in the text. Former bays are indicated in Fig. 14.

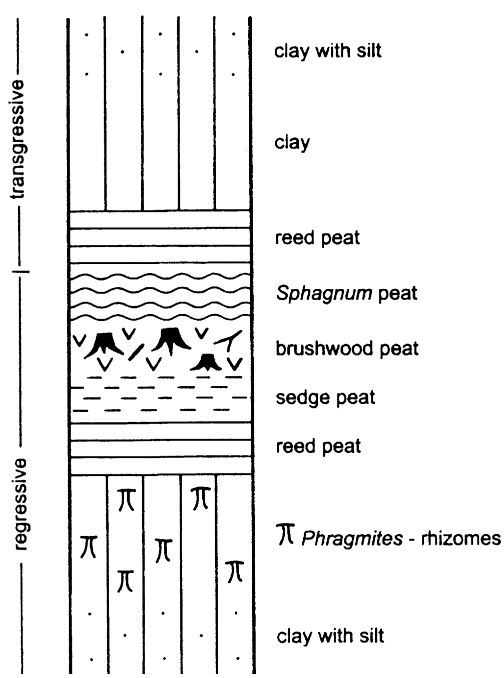

Fig. 4. Schematic section through an intercalated upper peat layer, showing a complete hydrosere succession (regressive) followed by transgressive development to wetter conditions.

roads. It stretched far beyond the present coastline and has been recorded in cores from the tidal flat area west of Cuxhaven (Linke, 1979) and in many places between the mainland and the East Frisian Islands (see e.g. Haarnagel, 1953; Sindowski, 1957). Because of erosion during later periods, its original northern delimitation is not known.

The regressive trend which is recorded in the Upper Peat was followed by another transgressive trend. This led to new flooding and to the deposition of clay and sand on top of the peat. In most cases, the peat surface has been eroded to some extent. In some places where calmer conditions prevailed, the transitional development from freshwater to a saline environment can be demonstrated. Here, the *Sphagnum* peat (if present) gave way to *Phragmites* peat and then gradually to clay deposition.

This new transgression phase–Dunkirk I–is perceptible from ca. 1000 BC and, after an interruption, reached its maximum between 400 and 150 BC. In this period, the coastline shifted southwards and it changed shape considerably. Sediments from this time are found everywhere: they cover peats and settlements, and even coarse gravel was transported as in the well-known submerged beach ridge that stretches north–south in the Clay District of Land Wursten, north of Bremerhaven. This transgression, which is sometimes referred to as the prehistoric catastrophe, formed a new coastline, which remained more or less unchanged until the severe floods in the Middle Ages. Deep bays, such as those of Sielmönken and Kampen in the western part of Ostfriesland, and Crildum and the Maade in the area north of Wilhelmshaven were scoured out during this time. Sea incursion often followed the pattern of the streams and gullies of the existing fluvial systems. Along the coastline and around the bays, new elevated levees were created which later served as favourable areas for the establishment of settlements. Following the general principles of coastal morphology, there is a backswamp area behind the levees, where clastic deposits are lacking and consequently huge mires developed. Deposition of clay and sand in an area where peat had previously been eroded led to the formation of a rather extensive island in front of the north-west coast of East Frisia, the former island of Bant.

3. The perimarine area and the earliest settlements in the German Clay District

3.1. The geological setting and the vegetation of the perimarine area

According to the definition of Hageman (1969) (see also van der Woude, 1981) the term 'perimarine area' signifies "the area where the sedimentation or seditation took place under the direct influence of the relative sea level movements but where marine or brackish sediments themselves are absent". This is mainly the backswamp area and the lower part of the fluvial system where river levels rise with rising sea level. Here deposition kept pace with the relative sea-level rise.

These river landscapes in the Clay District have a special structure that reaches far beyond the river margins and determines to a large extent the vegetation as well as settlement pattern and land use (Fig. 5). As along the sea coast, the natural accumulation on the riverbanks due to the rising water level created elevated levees that lined the large rivers and also the smaller gullies and creeks. These levees consist of clay or sand and were deposited during high storm floods, when the rivers overflowed their banks and resulted in extensive flooding. Due to the rapid decrease in flow velocity with increasing distance from the riverbed, the transport capacity of the water decreased and sediments were deposited. In the freshwater to slightly brackish river-clay areas, this process was also favoured by the existence of wide reedbeds along the rivers which further slowed down the water flow and acted as filters. Consequently, the deposition of sediment was restricted largely to the levees which rose continuously with the rising water level.

These elevated levees have an average width of 1.5 km along the lower Ems and are even wider along the lower Weser and Elbe. Along tributaries and creeks, they are much less extensive. Behind these elevated levees there was a permanent deficit of sediments while the water still penetrated far into the interior parts. As a consequence, vast mires developed which characterize the so-called 'backswamp area'. Clay was deposited in these areas only in some old and often overgrown creeks where it has been recorded during coring.

Detailed palaeoecological investigations have been carried out in the backswamp areas of the main rivers in the German coastal area using botanical macro-remains as well as pollen (Grosse-Brauckmann, 1962, 1963; Menke, 1968, 1988; Behre, 1970, 1979; Schwaar, 1978). The sea-level fluctuations are reflected in the peat sequences. At certain times, hydroseral succession appears, as it were, in reverse, starting with wood peat and then giving way to sedge peat and reed peat. This reflects the rise in watertable levels and, at later stages, successional patterns that reflect decreasing or stagnant water levels are indicated by a normal hydroseral succession or *Verlandung*. Such patterns of reverse and normal successions may alternate repeatedly in a particular area.

On a regional scale, these tendencies have the same direction, although recorded in different facies. With respect to terminology, Menke (1968) introduced the terms autogenic and allogenic series. The former represents the normal hydrosere with decreasing moisture and often leading to more oligotrophic conditions which is sometimes expressed by raised bog development, while the latter, which usually indicates increase in wetness and is often connected with eutrophication and sometimes brackish influence, is always influenced primarily by external factors. The different facies can

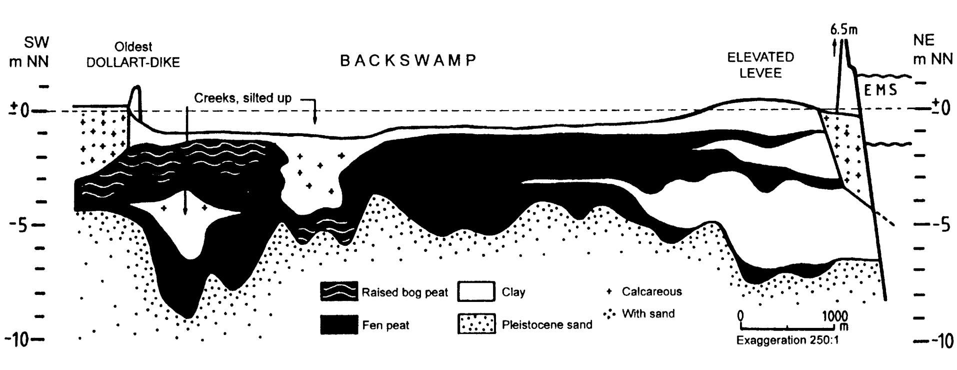

Fig. 5. Schematic cross-section through the riverine clay area west of the river Ems. It shows an elevated levee with several transgression layers along the river, behind which lies a backswamp area with mainly fen peat. The expansion of the Dollart Bay (to the left) at ca. AD 1500 led to extensive flooding and deposition of clay over the entire region.

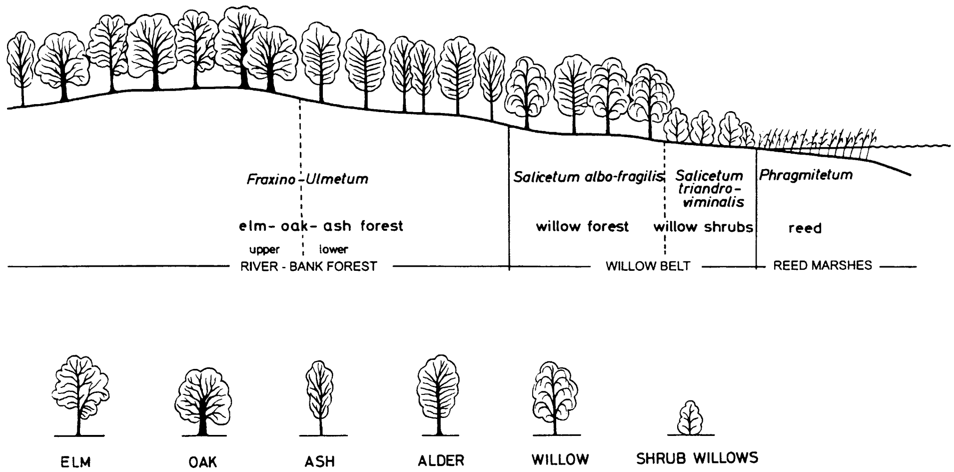

Fig. 6. Zonation of riverbank forests (*Auenwälder*) according to their elevation above the river water level as reconstructed for early Subatlantic times (ca. 800 BC) in the lower Ems area (Reiderland).

be distinguished on the basis of the plant species composition of the peat.

The huge backswamp areas were treeless for millennia, apart from temporary phases of brushwood vegetation. This is in sharp contrast to the elevated levees which were covered with woodland from the beginning (Figs. 6 and 7). The first reconstructions of these forests were made for the lower Ems area (Behre, 1970, 1985). The archaeological excavations of the riverside settlements from the Early Iron Age yielded thousands of wood samples not only from buildings, etc., but also many tree stumps, i.e. remnants of the clearings during the occupation phase. The composition of the wood samples allowed a reliable reconstruction of the riverbank forests. The low-lying willow belt, i.e. the *Weichholzaue*, was composed of so-called softwood species and included willow shrubs and willow forest. This was followed on the more elevated natural levees by the upper riverbank forests or *Hartholzaue* which were composed of so-called hardwood species, and included mainly *Fraxinus* and in the highest parts *Quercus* and *Ulmus*. *Acer campestre* and *A. platanoides* were also present in these woods (Behre, 1999a). A Fraxino-Ulmetum occupied the highest parts of the elevated levees and was cleared first by the colonizing settlers who wanted to have safe places for their houses and dry areas for their fields. Already in the Roman period, the Fraxino-Ulmetum of this area was almost completely cleared and became extinct in the early Middle Ages.

Since the above investigations of wood from archaeological contexts, much new information has come to light. Corings by the Geological Survey of Niedersachsen (J. Barckhausen and H. Streif) provided many wood samples of various age from the riverbanks of the Ems, Weser and Elbe, while exposures on the Weser (Rade, 1410–900 cal. BC) gave additional evidence (Behre, 1985). Summarizing the results it can be stated that, at least from 3000 BC and probably much earlier, the major lowland rivers were accompanied by the Fraxino-Ulmetum (*obere Hartholzaue*). This woodland vegetation type became extinct about AD 1000.

For millennia, the natural physiognomy of the river areas in the Clay District was similar to the river forests in African savannahs, where, behind a gallery of forests along the rivers, a landscape without woodland exists. In the coastal parts of Central Europe, because of the different ecological conditions, extensive treeless bogs bounded the riverbank forests (Fig. 7).

3.2. The first human occupation

The regression phase, during which the Upper Peat was formed, also offered possibilities to settle in the Clay District. From this period, the first habitation in the German Clay District is registered (Fig. 13). This is in contrast to the Netherlands, where older settlements have been recorded from this environment, which may also be expected in Germany. To date, the oldest known settlements in the German area are Jemgum/Ems (Haarnagel, 1957) and particularly Rodenkirchen on the lower Weser river (Strahl, 1998). The latter, situated on the landward slope of the elevated levee at an altitude of -1.50 m NN (German ordnance datum), was occupied in the 10/9th century BC. Several three-aisled farmhouses have been excavated, and botanical investigations by D. Kučan (in preparation) have shown that arable farming was practised and that the settlement was situated in the upper part of a *Weichholzaue*, dominated by *Alnus*. Several habitation phases have been recorded at Rodenkirchen and the occupation spanned the Late Bronze Age to the beginning of the Iron Age when the site was abandoned.

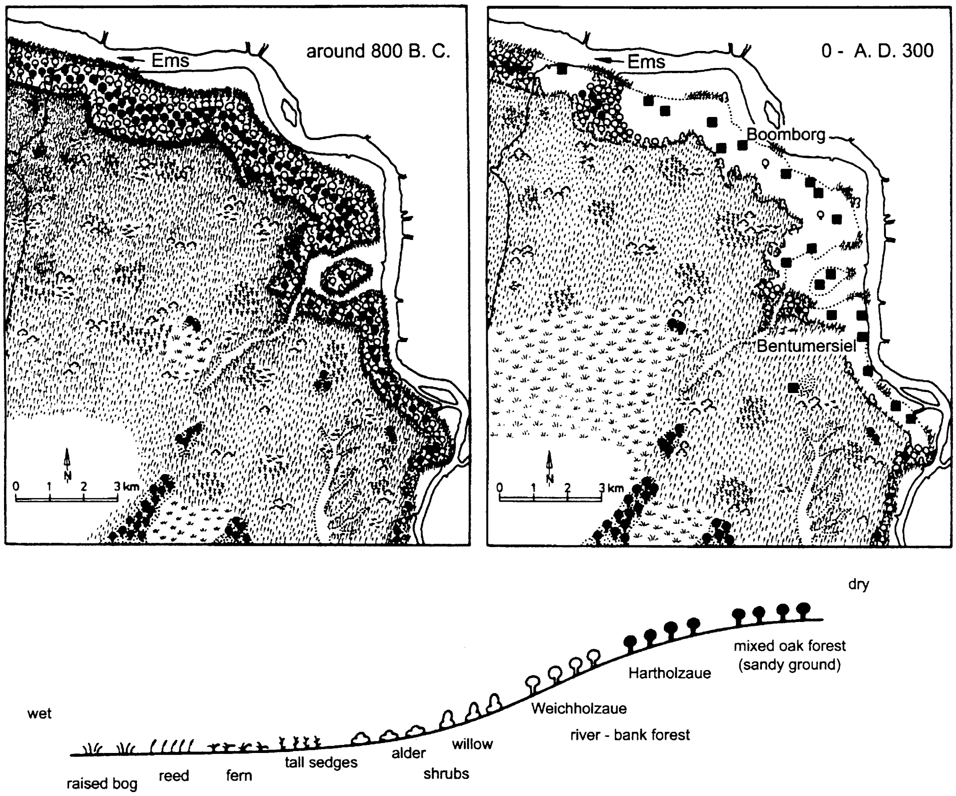

Fig. 7. Maps showing major environmental change in the lower Ems region, a riverine area in the clay region. Left: Natural riverbank forests on the elevated levees, backswamp areas behind them (around 800 BC). Right: the same area during the Roman Iron Age after destruction of the forests (settlements are indicated by squares).

In the beginning of the Pre-Roman Iron Age, between 700 and 660 BC, early settlers penetrated also into the uppermost parts of the riverbank forests, i.e. the Fraxino-Ulmetum, along the river Ems. They cleared the forest and established several hamlets. Large-scale excavations by Haarnagel (1969) at Hatzum-Boomborg unearthed remains of 37 buildings from five habitation layers (Fig. 8). The excellent preservation of organic matter in these waterlogged sites facilitated the identification of thousands of wood samples from posts, wattles, etc. Abundant remains from wild and cultivated plants enabled the reconstruction of the environment that existed in a freshwater context, as well as the nature of the arable farming which involved growing of horse bean, flax, gold of pleasure and also the cereals barley and emmer (Behre, 1970). Animal husbandry, however, was the main basis of this rural economy.

The oldest Iron Age settlement layers occur at an altitude of −0.70 m NN (modern mean high water level is +1.35 m NN). At ca. 300 BC, the settlements along the Ems river were abandoned due to the Dunkirk I transgression which resulted in destruction of the villages and widespread deposition of clay.

Settlements of the early Pre-Roman Iron Age have also been traced in other parts of the river system in the Clay District, but there have been no excavations. Först (1991) mentions several sites along the Weser and Hunte rivers and Schmid (1957) has compiled ceramic records from the banks of the Medem, a tributary of the Elbe river, which obviously come from several settlements of this period.

Fig. 8. Excavation Boomborg-Hatzum/Ems with three-aisled farmhouse of early pre-Roman Iron Age (from Haarnagel).

4. The extensive regression around the Birth of Christ and its consequences

The most active phase of the Dunkirk I transgression lasted in northern Germany for only about two and a half centuries, i.e. 400–150 BC. As already mentioned, the clastic deposits from this period are encountered in most parts of the marine and perimarine areas. On the surface of these deposits, a black layer is often observed which indicates that soil formation took place. This layer is well known to farmers who frequently encounter it when they clean the ditches, and in some areas it is so common that special expressions are used such as *Blauer Strahl* (blue ray) or *Schwarze Schnur* (black string). Independent confirmation of the age of such deposits is essential. Radiocarbon dating of mineral-rich soils is difficult but there are several dates available, particularly from places where the soil is rather peaty. The available ^{14}C dates suggest that soil formation started in Niedersachsen and also in Schleswig-Holstein and the Netherlands at ca. 100 BC (Behre, 1986).

As soil formation does not occur below the mean high watertable level, this phenomenon may be regarded as a certain indication of a decreasing watertable level. It is highly unlikely that this is caused by a reduction in the tidal range. The general configuration of the coast around the German Bight, which is mainly responsible for the tidal range, did not change substantially and this view is supported by the fact that the phenomenon of soil formation was common along the whole southern North Sea coastal area (e.g. Hoffmann, this volume). The decline in mean high watertable levels implies also a decline in mean watertable levels. As will be shown later, storm flood levels also declined.

The decrease in watertable levels was probably considerable since almost no peat formation occurred as happened in the previous regressions. In only a few places, humic layers or small areas of peat have been observed. This suggests that conditions in the Clay District changed rapidly from salt to freshwater and much drier conditions prevailed.

The decline in groundwater table level had also considerable consequences for the perimarine backswamp area. Over extensive areas, the formation of fen peat stopped and raised bogs, which gave *Sphagnum* peat, resulted. Good examples are the Reiderland area west of the Ems, the area east of the Jade Bay at Sehestedt and in Schleswig-Holstein the island Nordstrand (see compilation in Behre (1986) and Fig. 9). The change to raised bog formation must have been very fast, because the normal development of a hydrosere which leads to carr vegetation was interrupted and in many places reedswamp peat is overlain directly by *Sphagnum* peat. This synchronous sudden change in watertable levels corresponds exactly with developments in the marine area. Low groundwater levels must have persisted for a considerable time as is indicated by the substantial thicknesses of *Sphagnum* peat that accumulated in several places. The growth of the raised bogs outpaced the later increase in watertable levels which is connected with sea-level rise. Thus, the raised bogs remained uninfluenced by rising sea and watertable levels until late Medieval times.

The most recent ^{14}C date for the switch from fen to *Sphagnum* peat in Niedersachsen is from Sehestedt in the Jade Bay. This gave the date 2180$\pm$75 BP (Behre and Kučan, 1999), which compares well a previously obtained date of 1915$\pm$65 BP from the same bog (Streif, 1984) and other dates (pollen and ^{14}C-based) from Niedersachsen and Schleswig-Holstein (mainly around the Birth of Christ).

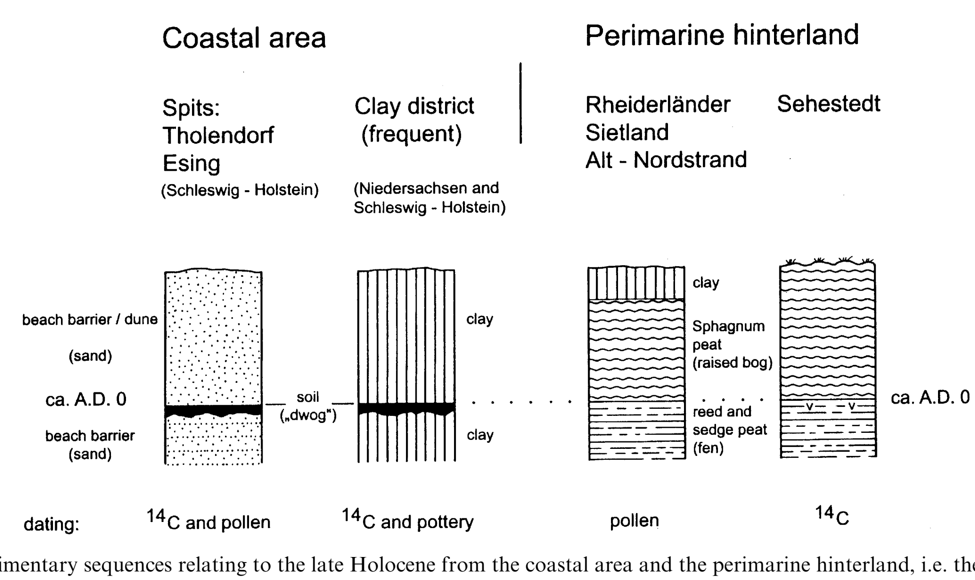

Fig. 9. Typical sedimentary sequences relating to the late Holocene from the coastal area and the perimarine hinterland, i.e. the backswamps, in the German North Sea coastal region. Left: area close to the coast. Right: backswamp area.

Another important consequence of the regression dating to around the Birth of Christ is the start of the formation of the East Frisian barrier islands of to day. These barrier islands are mobile bodies of sand. According to the *Platentheorie* (shoal theory; Barckhausen, 1969) which is based mainly on observations from the island of Langeoog (cf. also Ehlers, 1988; Streif, (1990) for other islands), these islands developed on tidal flat deposits as a shoal was created above mean high water level through sand supplied by the sea. This shoal is to be regarded as the initial stage of the island. Continuing sand accumulation, as a result of sea and later by wind action, results in the present-day islands. Earlier stages are documented by organic layers and horizons rich in plant remains which serve as fossil sea-level indicators. Such deposits on the island of Juist have recently been investigated by Freund and Streif (2000) with a view to reconstructing sea-level change. On top of these organic-rich horizons, sand dunes formed.

Movement of the barrier islands has resulted in the destruction of the earliest of these organic-rich horizons or at least they have yet to be found. To date, the oldest ^{14}C date from such an organic horizon is from the island of Juist, i.e. 1965 ± 130 BP, cal. AD 39 (BC 109 to AD 213), while other ^{14}C dates from Juist and Wangerooge are 400–500 years younger (Streif, 1986, 1989; Freund and Streif, 2000). This supports the view that the formation of the East Frisian barrier islands started during the regression phase that dates to about the Birth of Christ and was favoured by the particular hydrological conditions of that time. Once in existence, these islands withstood the later increase of the sea level, though the shape and number of islands changed in later periods. The first known occupation of these islands dates to the 14th century.

The most important consequence of this large-scale regression was the possibility for settlement in the Clay District. Settlers penetrated the area where fresh and calcareous soils offered excellent conditions for farming. Many settlements were established and, within a short period, the whole Clay District along the coast of Niedersachsen, as well as along the lower parts of the rivers in the Clay District, was colonized. All these settlements from before and around the Birth of Christ were erected on level ground without any artificial elevation of ground level, i.e. the so-called *Flachsiedlungen* (Fig. 13). The settlers chose, however, the naturally elevated levees for their houses. Because these levees follow the coast and the riversides (cf. Chapter 2), the distribution of the settlements indicates the configuration of the coastline during this period (Fig. 14). Good examples of this include the many settlements around the Bay of Sielmönken in western East Frisia, the inner row of settlements on the peninsula of Butjadingen between Jade und Weser, and the north-south alignment of settlements in Land Wursten, north of Bremerhaven. Due to further coastal development, all these sites nowadays lie inland.

In the Wadden Sea, north-west of East Frisia, there was an island which has been documented in written sources and which was lost in the 18th century. It was called Bant, but Haarnagel, (1980) has argued convincingly that this island was identical with an island referred to as Burcana by Roman authors and that the name was later switched to the adjacent island of Borkum. According to Plinius, Burcana was the largest offshore island in Germania. Strabo states that the island was besieged and conquered by Drusus which suggests a considerable population. That farming was important is supported by another Roman name for this island, namely Fabaria, which points to the cultivation of the horse bean, *Vicia faba*, the most important crop plant in the Clay District during that period.

It should be noted that the settlement remains from this period lie directly on the surface of the Dunkirk I sediments. The settlements were permanent and included animal husbandry and arable farming. This indicates that, even during winter, there was no danger of inundation, so that the storm flood level must have been considerably lower than in the preceding period. In summary, the geological sources, as well as evidence from habitation, which reflect the important indicators of sea-level change, i.e. mean sea-level, mean high water level and storm surge level, all point to a sharp and substantial decline in sea-level around the Birth of Christ.

Additional dates for the beginning of this favourable period are provided by the archaeological dating of the settlements. In Niedersachsen, most settlements start around the Birth of Christ, their pottery characterized by strongly thickened facetted rims. New investigations at the best known settlement from this period, the Feddersen Wierde north of Bremerhaven, show that habitation started there in the latest phase of the Pre-Roman Iron Age, approximately in the middle of the first century BC (based on a dendrochronological date from a house plank as *terminus post quem;* Schmid and Schuster, 1999). Indications of somewhat earlier habitation come from the settlement Einswarden on the left bank of the lower Weser river, which was excavated as early as 1938. Here, the pottery points to the onset of habitation at ca. 100 BC (Schmid, 1993).

The available records show that at ca. AD 0 most of the settlements in the Clay District of Niedersachsen had been established (Behre, 1986). To the west, in the northern Netherlands, the occupation history is rather different. In the Clay District of the provinces Friesland and Groningen, continuous habitation dates back to ca. 600 BC and with a large increase in the number of settlements at about the Birth of Christ (Waterbolk, 1967). On the other hand, the start of settlement history to the northeast in Schleswig-Holstein is somewhat delayed. In the Clay District along the west coast of Schleswig-Holstein, the oldest settlements do not commence before AD 100. While the available geological dates show that the regression phase was synchronous from the northern Netherlands to Schleswig-Holstein, the settlement history was different. This is the result of population movements, which occurred later in Schleswig-Holstein compared with Niedersachsen.

5. The first millennium AD: further rise of sea level and human responses

Already, in the first century AD, an increase of storm flood level is evident. Some of the *Flachsiedlungen* were abandoned, and others continued to be occupied. The remaining inhabitants now protected themselves against the storm floods by constructing their dwelling places on artificially raised mounds. These mounds were further raised in succeeding years to cope with the continuously rising storm-flood levels. In this way, the *Wurten* (singular: *Wurt*) or dwelling mounds were created, some of which reached an altitude of more than +5 m NN (even +7 m NN have been recorded). These village mounds of the first *Wurten* phase in Germany are widely distributed over the Clay District. They include several habitation layers (Figs. 10–12).

One of the numerous *Wurten* from the Roman Iron Age, Feddersen Wierde, was completely excavated in the late 1950s and 1960s (Haarnagel, 1979). It is situated in the Clay District north of Bremerhaven. The wealth of evidence from the excavation and associated palaeoecological investigations enables detailed reconstructions of the settlement and its palaeoenvironmental contexts. This *Wurt* started as a *Flachsiedlung* on level ground at ca. 50 BC. At the end of the first century AD, the dwelling place was raised by creating a low mound in response to a rise in storm flood level. This was continued and at the end there were seven settlement layers in the *Wurt* separated from each other by clay layers, which had been brought in to increase the height of the *Wurt*. The clear separation of the individual habitation horizons in the *Wurt* provides a unique chance for the archaeologists to distinguish between the consecutive settlement patterns as well reconstructing the ground plans of the buildings from the various phases.

A remarkable feature of these *Wurten* is the excellent preservation of the associated organic remains, as a result of the permanent moist conditions of the soils in the Clay District. Thus, in the settlement layers intact posts, wattles, as well as other wooden parts of houses are found. It could be demonstrated that the farmhouses from the Feddersen Wierde as well as from other *Wurten* of this period were arranged radially in a circle, the living quarter being always towards to the centre of the *Wurt* where there was an open space.

Animal husbandry constituted the economic basis of these settlements. More than 50 000 bones of domestic animals were unearthed and identified during the excavation of the Feddersen Wierde (Reichstein, 1991). Cattle prevailed, followed by sheep, horse, pig and dog. Only 2% of the mammal bones came from wild animals.

Another important characteristic of the *Wurten* of the Roman period as well as the early Middle Ages is the presence of large quantities of so-called manure in the

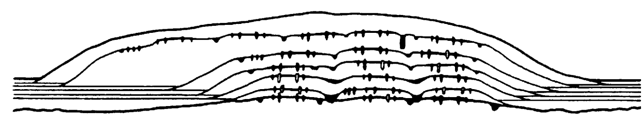

Fig. 10. Schematic representation of a Roman Iron Age *Wurt* (settlement mound). It shows the natural levee of a creek bearing a *Flachsiedlung* (settlement on level ground), above which lie several clay layers of human origin, each with a habitation layer containing the foundations of houses and other remains of human settlement.

Fig. 11. Cross-section through the Roman Iron Age *Wurt* Feddersen Wierde, showing several habitation layers with large amounts of dung and each horizon separated by clay layers that were deposited by the farmers to raise the dwelling mound (from Haarnagel).

Fig. 12. Excavation of the Roman Iron Age *Wurt* Feddersen Wierde, part of the village of the 2nd century with three-aisled farm houses, their lower parts preserved in wood (from Haarnagel).

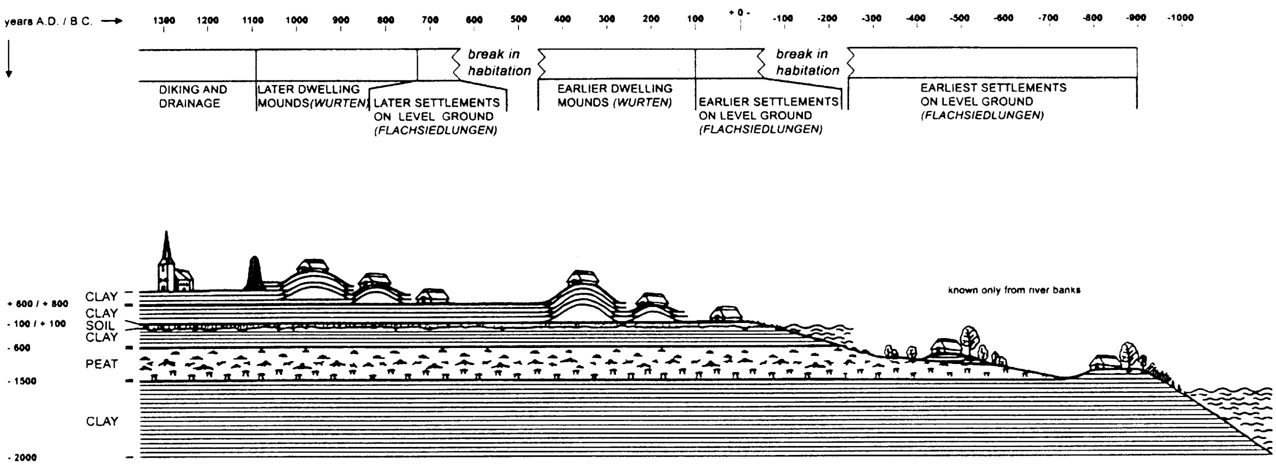

Fig. 13. Schematic illustration of deposition and occupation in the German Clay District ("*Marsch*").

habitation layers. This term is used not only for animal dung but includes a wide variety of plant debris such as litter from the stables, remains of fodder and threshing and hay, as well as remains of thatched roofs. As a result, most plant species that grew around the settlements are represented in the macrofossils which provide an excellent archive for palaeoecological investigations aimed at reconstructing the former environment as well as of the prehistoric farming economy. Also, important insights into the elevation of the settlement in relation to mean high water (MHW) level can be deduced from the plant macrofossil data. Körber-Grohne (1967), who carried out the botanical investigations at the Feddersen Wierde, was the first to present a detailed reconstruction of the palaeoenvironment associated with such a settlement. She confirmed, what had been anticipated, that this *Wurt* was established in a saltmarsh environment. The most important plant community relates to the Juncetum gerardii, which is composed of halophyte species. The former saltmarsh vegetation has been described in detail and also subdivided into subassociations which reflect small differences in elevation above MHW level. Trees were absent. Inland, there was a wide transitional zone to brackish and fresh conditions which is also registered in the botanical record.

Even under these unfavourable conditions in these salt marshes, small-scale arable farming was possible. Arable activity was confined to the elevated levees of small gullies and limited to a few cultivated plants. The most important was horse bean (*Vicia faba*), accompanied by barley (*Hordeum vulgare*), oats (*Avena sativa*), sometimes emmer (*Triticum dicoccon*) and, as sources of oil, flax (*Linum usitatissimum*; also for fibres) and gold of pleasure (*Camelina sativa*) were cultivated.

In the meantime several other *Wurten* have been investigated with respect to plant remains. It has been shown that all settlements grew cultivated plants, which were summer sown as could be demonstrated by the associated weeds. The weed flora, together with the remains of threshing, which are recorded in the *Wurten,* also confirm that cultivation took place in the saltmarshes close to the settlements and that there has been no exchange of food plants with settlements on the adjoining Pleistocene (*Geest*) areas.

The *Wurten* which were erected to protect the inhabitants against storm floods, can in turn be used as fossil tide-gauges. It can be assumed that the various settlement horizons, which are securely dated on the basis of archaeology and ^{14}C-determinations, lay above the maximum level of storm floods. Thus, they provide a series of indicators of storm-flood levels. However, as the settlement area often extended somewhat downwards on the slopes of the mounds, only the level of the lowermost houses can be used for this purpose (Behre, 2003). On the other hand, *Wurten* sometimes provide indicators of other water levels including even MHW levels. At Feddersen Wierde, for instance, a narrow bridge was excavated, that dated to the first half of the first century AD. The bridge crossed a small gully and lay at -0.15 m NN. It can be assumed that the bridge indicates a MHW level of -0.25 m NN. The associated settlement layer in the *Wurt* had an elevation between $+0.50$ and $+1.25$ m NN, which means that the difference between MHW and storm-flood level was only about 1 m, compared with 3.5 m today (Haarnagel, 1979; Brandt, 1980). This is in agreement with other dates from the period before diking.

In the middle of the 5th century AD, the Feddersen Wierde and all the other *Wurten* were abandoned (Fig. 13). It was previously assumed that a huge storm surge caused the end of these settlements. However, new evidence for the habitation history of the nearby high and safe sandy grounds of Pleistocene origin (*Geest*) such as the *Siedlungskammer* Flögeln, close to Fedder-

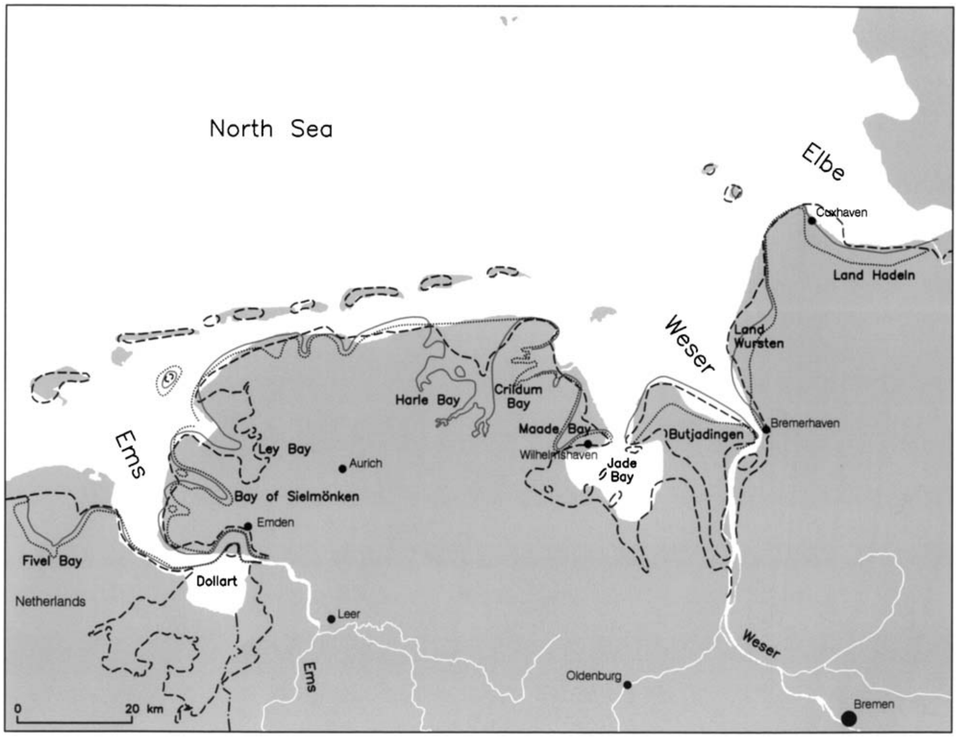

Fig. 14. Former coastlines in Lower Saxony (*Niedersachsen*). Dotted line: ca. AD 0; solid line: ca. AD 800 (before diking); broken line: ca. AD 1500, when the bays had reached their maximum extent.

sen Wierde (Zimmermann, 1992), indicates that most settlements in the wider region were abandoned at about the same time. This coincides with population movement in the Migration period, when the Saxons emigrated from Lower Saxony to England. Extensive areas, in particular along the North Sea coast, were abandoned at that time.

During the interruption in habitation, which lasted around two centuries, the sea level declined, i.e. at least the storm flood level. This is suggested by the fact that the next occupation of the Clay District began again with *Flachsiedlungen* on level ground. The Frisians, coming from the west, now entered the German Clay District. The beginning of these settlements, is dated dendrochronologically at Oldorf, north of Wilhelmshaven, to AD 630 (Schmid, 1994). In the course of the 7th and 8th centuries, a new colonization took place in Niedersachsen as well as in Schleswig-Holstein. Many of the earlier *Wurten* were again settled, but where there was new land with fertile soils to the seaward side, this was settled in preference. In the initial phase, settlements did not require protection from the sea. However, the numerous settlements on level ground were raised as reaction to the storm-flood level which began to increase. These dwelling mounds represent the second *Wurten* phase in Germany. On several of these *Wurten,* excavations were carried out accompanied by palaeobotanical investigations with a view to reconstructing the palaeoenvironment and farming economies, e.g. at Niens between Jade and Weser (Behre, 1991; Brandt, 1991) and Elisenhof in Eiderstedt/N. Friesland (Bantelmann, 1975; Behre, 1976). Farming was based on cattle breeding, but crop plants were also sown, so that conditions were rather similar to those in the first *Wurten* period, and the environmental context of the settlements was also similar in that saltmarshes dominated. Sometimes, rather exposed areas were occupied in this period, e.g. Elisenhof in Eiderstedt. This is reflected in the botanical analyses which suggest particularly low-lying salt marsh communities and only four species of cultivated plants, the horse bean (*Vicia faba*) being the most important. Here also the relative importance of cattle and sheep changed in favour of the latter (bone ratio of 25:50, compared with 50:25 at Feddersen Wierde). Most of the *Wurten* of the second *Wurten* phase in Germany remained occupied throughout the Middle Ages and Modern times and became the centres of many of the present-day villages.

Using the geological and archaeological evidence, an attempt has been made to reconstruct the coastline for the period at ca. AD 800 (Fig. 14). This configuration remained more or less unchanged until diking started in the 11th century. Between the Birth of Christ and 800, two new bays were formed, the smaller being the forerunner of the Ley Bay, which probably came into existence in this period. Its formation was probably triggered by the reduction of the size of the Bant Island (Clay origin) which sheltered this exposed part of the coast.

Another very severe breach formed the Harle Bay. Geological as well as archaeological records indicate that formation of this large bay was completed by ca. AD 800 (Behre, 1999b). The reason is not clear but it is probable that the eastward shift of the island of Wangerooge resulted in diminished protection for this part of the coast. During storm surges, the tidal inlet between the islands of Spiekeroog and Wangerooge allowed high energy currents to impact on this part of the coast resulting in a breach through the elevated coastal levee so that floods scoured the low lying backswamp area.

The formation of Harle Bay had severe consequences for the neighbouring Crildum Bay. The hydrological system was destroyed in that the creeks that drained this area to the east were cut off and after that drainage was northwards through Harle Bay. Without flowing water to keep Crildum Bay open, it rapidly silted up and was reclaimed and used for farming until the 13th century. This connection between formation and infill of bays demonstrates that the pattern of drainage waters may have an importance for coastline formation equal to that of short-time events such as storm floods followed by marine incursions.

In other areas, new land had formed seaward of the older coastline. This was particularly the case in Butjadingen between Jade and Weser, in Land Wursten north of Bremerhaven and along the river Elbe, east of Cuxhaven. Similarly, new land has formed in Dithmarschen on the west coast of Schleswig-Holstein (Meier, 1995). All these new areas were ready for occupation in the early Middle Ages.

6. Diking and its consequences for coastal evolution and occupation

6.1. From ring dikes to winter dikes

Until the high Middle Ages, the inhabitants of the Clay District protected themselves against storm floods by dwelling mounds. Protection for the farmland, which was regularly inundated in winter, did not exist. At the end of the 11th century, the settlers in the coastal marshes started dikes construction for the first time. These earliest dikes, called ring dikes, were built around the arable fields and meadows to keep out the occasional spring and summer floods. They were too low, however, to withstand higher floods and were no protection against winter floods. These ring dikes are difficult to trace because of their low elevation and also many have been dug away or levelled out by ploughing in later periods. However, some have been traced, e.g. in the Wilhelmshaven area (Reinhardt, 1979; Nitz, 1984), in Butjadingen (Krämer, 1984) and Land Wursten (Schmid, 1988), as well as in Schleswig-Holstein (Kühn and Panten, 1989).

In the 13th century, these ring dikes were connected and raised, and since this time we have a continuous line of dikes, which protects the area behind against winter storm floods. Consequently, the raising of the height of the *Wurten* ceased in the 13th century. It is remarkable that the younger layers of the *Wurten*, i.e. after AD 1000, consist only of clay material in contrast to the large amounts of manure, alternating with clay, which had been used to increase the *Wurten* before AD 1000. The dung was now being used for fertilizing in order to compensate for the lack of fertilizer in the form of freshly deposited sediments which were no longer being deposited as a result of diking.

Along the lower Elbe and lower Weser rivers, diking took another form. Since the early 12th century, Dutch colonists had been enlisted who diked this area, section by section, using a rectangular pattern of diking.

The completion of the winter dikes had several important consequences with regard to the natural environment as well as to habitation. Before diking, the coastal area showed a great variety of vegetation cover from saltmarsh to freshwater communities and with many intermediate forms. Diking resulted in a dramatic change in this transitional zone and its ecology. The dikes sharply divided the marine and brackish area outside from the freshwater-dominated area inside. The protection of the region was also of importance for the settlement pattern. New settlements were established in the Clay District, but now mainly as single farms outside the villages (Reinhardt, 1979). The construction of *Wurten* was no longer necessary and houses were erected on slight elevations only. Drainage of the inland areas commenced, and in this way new areas for arable farming and pastures were created.

6.2. The formation of new bays in the Middle Ages

The most severe consequence of diking was the increase in storm-flood level as a result of reduction in the space that could be inundated during storm floods. Now the flood waters rose against the dikes and, particularly in the estuaries of the Ems, Weser and Elbe rivers, this had severe consequences due to the bay effect which magnified the increase in flood levels. The northwest storms especially forced water into the German Bight and the estuaries, and breaches of the dikes were common. In response to this, the dikes were elevated and new areas were cut off thus leading to further rise of the storm floods.

Once the floods had overcome the natural elevated levees along the coast or the rivers, they invaded the low lying backswamp areas and these were exceedingly difficult to subsequently drain. Due to the draining as consequence of the diking, their surface had been lowered by compaction. Several catastrophic storm floods created new bays and caused terrible loss of people and cattle. These flood events started in the 13th century corresponding to the time of completion of the main dikes.

Before the Middle Ages the Dollart Bay of today did not exist. The relatively narrow Ems river was bordered by natural elevated levees, on which numerous *Wurten* were situated. It was probably during the Lucia flood of 1287 that the first irreversible breach in the dike took place and the sea invaded the backswamp area (Behre, 1970, 1999b). During the next 200 years, consecutive storm floods destroyed huge areas of land including many villages on both sides of the Dutch/German border until, during the Cosmas and Damian flood in 1509, the Dollart reached its maximum extension, i.e. ca. six times its modern size. In the 16th century reclamation started, several times interrupted by setbacks caused by severe storm floods. For reasons of nature protection, what remains of the bay is being conserved as it is now.

In the western part of East Frisia, Sielmönken Bay reached far inland (Fig. 14). It had been formed during the pre-Roman Dunkirk I-transgression and was also bordered by natural elevated levees. The bay was kept open by waters draining from the higher Pleistocene ground in the eastern hinterland. These waters were cut off when, to the north, Ley Bay developed probably in the 12/13th century and extended far to the south. In the absence of flowing water, the narrow Sielmönken Bay silted up rapidly. Because sedimentation in the outer parts of the bay was faster than in the inner part, drainage in the bay was impeded. As a consequence, an artificial draining canal was dug to the south in the 14th century, which led the water into the Ems river.

The formation and extension of Ley Bay was probably triggered by the reduction in size and hence protection afforded by Bant Island. This reduction was largely due to the salt making activities on this island, which are well known in written sources and resulted in the final destruction of Bant around 1780. A good example for the history of the embankment of a former tidal bay is offered by the Harle Bay which has been progressively reclaimed from late Medieval until Modern times (Fig. 15).

The largest medieval intrusion by the North Sea took place in the Jade area. Until the Middle Ages the Jade Bay did not exist, but there was another small bay, the Maade Bay, which also was created during the Dunkirk I-transgression phase. East of Wilhelmshaven lay the mouth of a tidal channel that drained the large backswamp area in the south. This outlet became the entrance for the first incursions of the sea into this area, probably during the Marcellus flood in 1219 and the

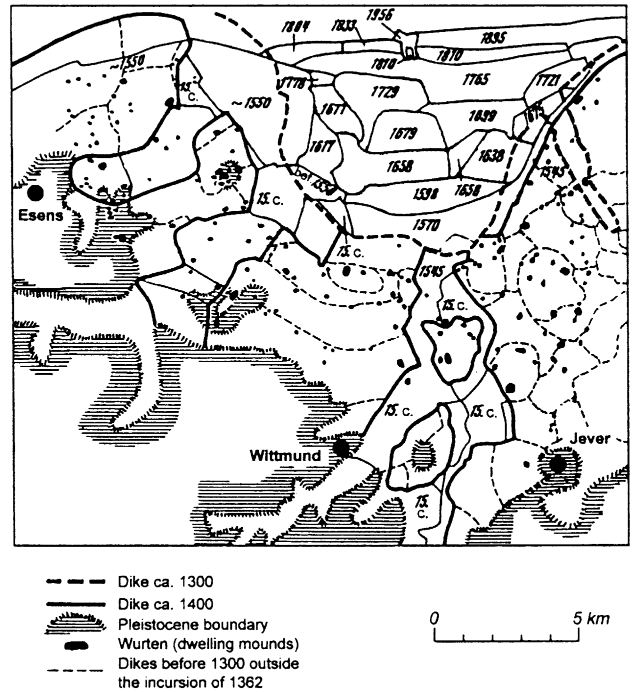

Fig. 15. A good example of the reclamation history of former tidal bay offers the Harle Bay, north-west of Wilhelmshaven, which has been embanked from late Medieval into Modern Times (after Homeier, 1969).

Lucia flood in 1287 (Reinhardt, 1979; Behre, 1999b). Once the gate was open, further floods enlarged the bay in that they eroded the soft peat in the backswamp area. In several places, there was the unusual phenomenon of bog floated on the seaward side during high storm tides and thus protecting the landward parts. As the peat floated, thin layers of clay were deposited in the gap between fen peat and raised bog peat, i.e. the point where the bog usually open-up as it began to float. This floating, which includes ‘inner sedimentation’ of clay occurred in former times in many parts of the North Sea coast and has frequently been documented in corings. Nowadays, there is still one locality left in Europe, where this unique phenomenon can be observed. This is the Sehestedter Außendeichsmoor, a small raised bog, situated outside the dike on the Eastern Shore of the Jade Bay and the last remnant of the huge bogs that once occupied this area. Recent studies by Behre and Kučan (1999) show that in this bog up to 40 cm of clay were deposited 3.10 m below the bog surface and pollen analyses confirmed that this clay layer is younger than the bog above it (Fig. 16).

The destruction of the peaty backswamp area in the Jade Bay continued and it was in particular the devastating second Marcellus flood of 1362 which caused huge damage all along the German North Sea coast and led to a considerable extension of the Jade Bay. In the east it broke through to the Weser river and created a connection between Jade and Weser which

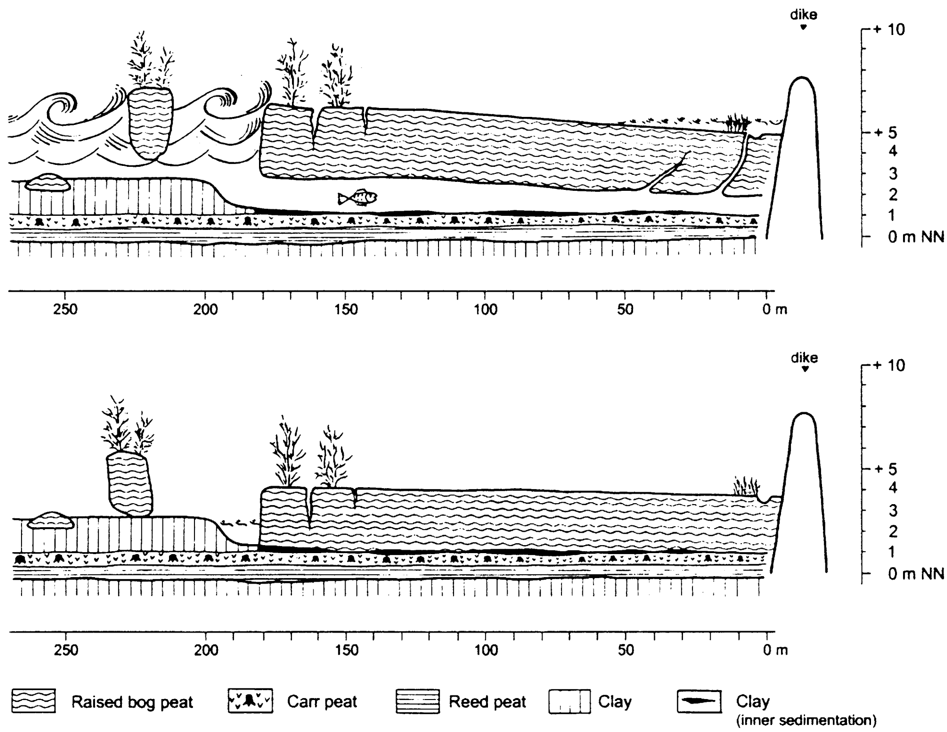

Fig. 16. Fragmentation of the Sehestedter Moor and deposition of intercalated clay (formation of *Klappklei*). Above: peat floating at high-tide storm surge. Below: normal situation.

remained open about 150 years. The same flood formed a large side bay in the west. Here, too, the drainage system was disturbed in that the new bay cut off the small river Maade which had drained the area to the north into the Maade Bay. During the subsequent years things happened as already described at other examples: without water runoff the Maade Bay rapidly silted up. While the Jade Bay still expanded, the Maade Bay was reclaimed by diking, and when the Jade Bay had reached its largest extension, the Maade Bay was closed in AD 1520 (Behre, 1999b). Also, large parts of the Jade Bay were reclaimed between the 16th and 19th century. Still today (and much more in the configuration around AD 1500, see Fig. 14) the geological background can be seen in the form of the Jade Bay. The bay itself occupies the former backswamp area, while along the coast the firm elevated levees composed of clay withstood the floods much better and so there is only a relatively narrow bottle-neck as an inlet east of Wilhelmshaven.

As was shown before, the Frisian coast between the rivers Ems and Weser had been completely reshaped in the late Middle Ages due to storm floods, the height of which increased considerably as a consequence of diking. Although the eastern part of the coast of Niedersachsen between the Weser and Elbe rivers has a similar geomorphology, i.e. the elevated levees along the coast and the lower Elbe river, as well as a wide and low-lying backswamp area, bays have not been formed here, neither in the pre-Roman Iron Age nor in the Middle Ages. This is probably due to the special conditions created by the wide mouth of the Elbe river. Here, water pressure resulting from storm floods is partly dissipated by the broad Elbe river, which absorbed some of the excess water. Upstream, where the river is narrower, the floods caused major damage and changes to the river banks.

In northern Friesland/Schleswig-Holstein, on the other hand, developments were similar to those to the west of the Weser river. Here a wide coastal area, between Eiderstedt and the island of Sylt, was devastated during the Marcellus flood of 1362 and again in 1634, and so was transformed into an extensive tidal-flat area with some islands. Considerable additional destruction was caused by lowering of the ground level through large-scale salt-making activities in the Middle Ages and early Modern times (Bantelmann, 1966; Hoffmann, 1988).

Since the 16th century, the technique of diking has been improved and reclamation of new land has prevailed. Polder after polder has been embanked. Because the natural drainage was interrupted by the dikes, an artificial drainage system had to be established. Draining of the Clay District presents a severe problem. As has already been described, the most elevated parts of the Clay District are those close to the sea and to the rivers, with the hinterland being lower. In a series of adjoining polders, the younger ones are always higher than the older ones due to the increase of the storm-flood level and hence increasing deposition (Fig. 17). Furthermore, in the backswamp area drainage leads to

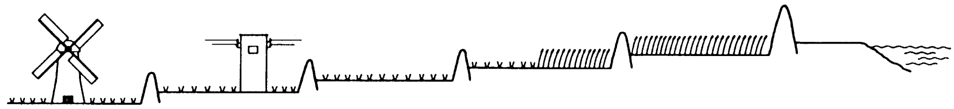

Fig. 17. Schematic representation of a polder landscape showing differences in elevation, drainage and land-use with the oldest polders (at greatest distance from the coast) on the left-hand side.

strong compaction which may result in subsidence of up to –2 or even –3 m NN, i.e. considerably below mean low-water sea level. This process still continues and the lowest parts of Germany, which lie in these areas, are still subsiding.

This typical morphology makes it very difficult to get the water out of the low hinterland across the elevated areas along the coast. In earlier times the water was lifted by windmills, sometimes several times, while in modern times electric pumping stations are employed for this task. A very sophisticated drainage system has been established in the Clay District with ditches and channels at different levels which lead the surplus water to the floodgates that are constructed within the dikes.

Acknowledgements

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