Veget Hist Archaeobot (2009) 18:351–369
DOI 10.1007/s00334-009-0214-x

ORIGINAL ARTICLE

Vegetational and environmental history during the Holocene in the Esbjerg area, west Jutland, Denmark

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Received: 18 August 2008 / Accepted: 17 December 2008 / Published online: 14 February 2009

Abstract A pollen diagram from a site in the Esbjerg area, western Denmark, is used for reconstruction of the Holocene vegetational and environmental history there. During the Atlantic there was a parallel development of the landscape to that of other areas in Jylland (Jutland). From the late Neolithic onwards the development took its own course related to the approaching North Sea, which periodically inundated parts of the Esbjerg area. The record reflects landscape development in a formerly marine valley where sediments seem to be missing from parts of the Bronze Age and the early Iron Age. Consequently the landscape development during these times is only reflected in glimpses in the vegetation record, which shows gradually more open woodland and increasing human impact. During the late part of the Iron Age, Viking period and Middle Ages, the woodland was diverse in taxa but became increasingly open, finally reaching a stage during which there may have been too little wood even for daily use. At the same time the use of the land intensified. During the Sub-Atlantic, the Esbjerg area offered good natural resources with extensive grazing areas in the marine marshes in addition to good possibilities for farming and use of the woodland on higher ground, but devastating floods occurred.

Keywords Holocene · West Denmark · Vegetational history · Sea level · Human impact

Communicated by K.-E. Behre.

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Introduction

Holocene vegetational history based upon pollen investigations is known from several localities around the southern North Sea. From Denmark, the records include northern west Jutland (Odgaard 1994) and southern Jutland (Aaby 1986; Kolstrup, in press), and from northwestern Germany there are several records (Dörfler 1989; Behre and Kučan 1994; Wiethold 1998). However, from a large part of western Jutland no detailed pollen records exist, but there is a general overview from Filsø c. 25 km north of Esbjerg (Jonassen 1957). The Esbjerg area, which is located within this palaeo-vegetationally relatively unknown area, is today generally regarded as a relatively infertile part of Denmark mainly because of its sandy soils (Jessen 1925), but also owing to occasional floodings by salt water into low lying areas along the southern part of the Danish North Sea coast. In spite of this, archaeological investigations by Esbjerg Museum have shown that during the late part of the Atlantic period the Esbjerg area seems to have been fairly densely populated, and even more so during the following early Sub-Boreal (P. Siemen, personal communication). Furthermore, in many parts of the area, especially near the Præstesti valley northwest of Esbjerg (Fig. 1), there have been rich late Iron Age and Viking Age finds (Siemen 2000; Robinson 2000).

To remedy the gap in palaeoenvironmental information in the area, palynological investigations were begun in the early 1990s with the main aim of reconstructing the Holocene vegetational history and relating it to the natural landscape development and cultural impact. The best place for the purpose was found to be the Præstesti site (55°31′N, 8°23′E), which is located c. 7 km northwest of Esbjerg and forms part of a low-lying formerly marine valley, that extends into the Esbjerg Bakkeø (hill-island) from the Ho

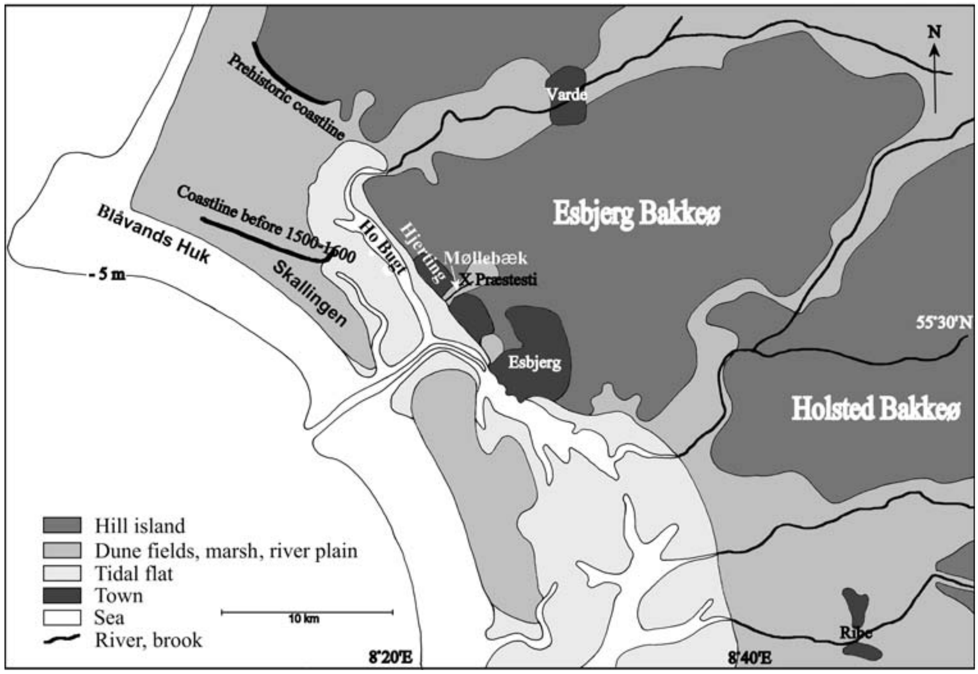

Fig. 1 Map of the Esbjerg area with the Præstesti site in relation to the surrounding geomorphology. Data from Jessen (1922, 1925), Smed (no year), Binderup (2004), Suadicani and Binderup (2004)

Bugt (bay) tidal flat in the southwest (Fig. 1). In the southern part of that area the difference between high and low tide levels is c. 1.5 m (Jacobsen 1969).

Geological setting

The Esbjerg area forms part of a *bakkeø*, a relatively high lying moraine landscape, which was formed during the Saalian glaciation. During the Weichselian the area was ice free and owing to the cold climate conditions and relatively open vegetation during parts of the Weichselian, mass movement, slope wash and aeolian processes created a relatively smoothed surface topography. Sandy soils are common in the area but clayey areas also exist, and in some depressions and valleys there are accumulations of organic material (Jessen 1922, 1925).

During the early part of the Holocene, the Esbjerg area was located relatively farther inland than now because of the lower sea level, which initially left most of the North Sea dry. During the Holocene, the sea level gradually rose so that at the transition from the Atlantic to the Sub-Boreal the mean high tide level in the southern North Sea was about 5 m below present mean sea level (Behre 2005, 2007). From around that time and later, the sea level rise became slower and finally stagnated, yet, from some time during the Bronze Age and later there seem to have been fluctuations in the order of ±1–2 m superposed on the general trend (Behre 2007). Geomorphological investigations in this western part of Denmark show that there are old beach ridges at an altitude of up to between 4.5 and 5 m above present sea level (Jessen 1925). Even during extreme storm events this height is well above the level at which beach ridges can be formed along this coast today (Jessen 1925). The geomorphological investigations have further shown that the southwest extending corner of Blåvands Huk and a large area to the northeast, east and southeast of it make up a very young landscape (Jessen 1925) and its southern part, the flats of Skallingen, were formed after A.D. 1500–1600 (Suadicani and Binderup 2004), which is around or after the time reflected in the upper part of the pollen diagram. As a consequence of this land–sea configuration, once the sea level was sufficiently high that the water could reach the coast between Esbjerg and Hjerting, the Møllebæk valley, in which the Præstesti site is located, would have been open to inundation from the sea. In the beginning, inundation would presumably have taken place during storm events, but later the sea intrusion became permanent as indicated by the sediments around Ho Bugt, including those in the Møllebæk valley. In the Ho Bugt area deposits of marine clay are located up to 1.6 m above present sea level and locally up to 2.2 m (Jessen 1925). According to Jessen, the top level of the marine clay layer is higher than that at which such deposits can be expected to accumulate today, so there must have been periods in the past when the relative sea level was higher than now. According to Jessen (1922) a maximum was reached during the Bronze Age when marsh development started in the higher areas. According to Shennan (1987), a relative sea level maximum was reached in the Fenland in England around 2500 B.P., a little out of phase with the outline by Behre (2003, 2007) who suggests a number of maximum high water levels after c. 300 cal B.C. along the German coast. According to Mertz (1977), marsh clay in the Ribe area south of Esbjerg does not accumulate above the height of the high-tide wave, which is c. 0.8 masl in the area, and there has been a relative rise of the land or lowering of the sea level in the order of 1.2–1.5 m in the area around Ribe since the high water maximum, provided the maximum height of the tidal wave has not changed through time. In contrast, based upon a large dataset, Behre (2003) came to the conclusion that marsh clay can accumulate 0.6 m or higher above the mean high tide level. Behre (2003) carefully adapted a mean marsh surface level of +0.4 m above the high tide level for a reconstruction of prehistoric, pre-dike, sea levels.

Another characteristic of this part of Denmark is the widespread occurrence of dunes. The aeolian dune-building activity seems to have had its first major phase around or after 3800 ^{14}C B.P. after which there were three other major phases starting around or after 2600 ^{14}C B.P., 1900 ^{14}C B.P. and 1000 ^{14}C B.P. respectively (Clemmensen et al. 2008). The sand drift continued until it was artificially stabilized by extensive planting during the 1800s (Clemmensen et al. 1996).

Today large areas along the coast form tidal flats with extensive clay districts that are artificially protected from the sea by dikes. The southwest–northeast oriented formerly marine Møllebæk valley, in which the Præstesti site is found, is more than 2 km long and 300–500 m wide and is drained into the shallow Ho Bugt through a c. 100 m wide opening in the higher ground along the coast. In the valley, organic and clayey sediments have accumulated through time so that the surface of the meadows is presently around 2 m above mean sea level in its central part. The inland part of the valley is sheltered from the sea towards the south by higher lying moraines along the coast except for the c. 100 m wide, low lying area around the outlet of the Møllebæk. This low area is now artificially closed off by dikes. During the last few hundred years the North Sea water in the Esbjerg area is known to have reached around or more than 4 m above mean sea level on several occasions, for example in 1981 and 1999 when the levels there were 4.33 m (and more than 5 m further to the south) and 3.98 m respectively above normal sea level (http://www.dmi.dk/dmi/index/viden/stormflodstema-2/historiske_stormfloder.htm (19 November 2008). During earlier extreme events it could well have been higher although older records are less specific (see the overview in Gram-Jensen 1991). For example, according to Siemen (2000) the storm level during a major flood in 1634 was up to 6 m above normal sea level, a figure that might be regarded as reliable, when compared with later events such as a flood level of c. 5.7 m in Hamburg in 1916; and in 1362 there was a historically major devastating flood, the “Grote Mandranke” (Gram-Jensen 1991). Clearly, through time there must have been regular inundations into the low lying areas along the coast including the area of investigation here.

The Præstesti pollen diagram presented below is from an excavation east of a higher area with abundant archaeological finds from the Iron Age and Viking Age, and the site is located almost 2 km from the present coast. The valley is more than 100 m wide at this place and along its centre it has a recently dug straight canal which has lowered the local ground water level. An about 5 m high and ca. 30 m long slope with a midway step of 2–3 m forms the transition between the higher area and the valley.

Materials and methods

During the summer of 1990 extensive investigations including visual inspection and hand coring with an Edelman auger were undertaken in almost all moist and wet depressions within a distance of c. 20 km from the city of Esbjerg. During the field work it was noted that most organic deposits were thin or there were visible traces of former peat digging. From 13 sites a total of 62 samples were collected for pollen analytical survey, prepared in the laboratory and summarily investigated under the microscope; but the preliminary analysis revealed that most of the sites represented short and fragmentary records.

In 1991 the best section, the Præstesti site northwest of Esbjerg, was chosen for further study. Before the sampling it was realized that the presence of a drainage system and former inundations in the valley present a risk for erosion and redeposition of sediment through time. To minimize this uncertainty it was first decided to make an open southeast–northwest oriented profile through the organic deposits because it was hoped that the most complete section for pollen analysis could be selected in this way, and that lateral changes of sediment might be detected. In practice this turned out to be impossible owing to collapse of the sediments. Instead three open profiles, which represent the central, midway and near-shore deposits along a transect of the valley west of the new, straight drainage trench, were dug by means of an excavator. During the work, water had to be pumped away from these holes, but in spite of this the sediments remained unstable and collapsed repeatedly especially in the most central part of the valley, which was also the wettest. As a consequence, it was not possible to carry out profile descriptions in the field, but continuous sample series could be collected in 4 cm wide, 4 cm deep and 50 cm long aluminium boxes inserted into the open profiles. During the sampling the uppermost loose fibrous sedge peat was not included in the series. In the field it was noted that the lower part of the series contained peat, probably alder peat, and that there was a horizontal clayey layer of lighter colour, presumably marine marsh clay, at a

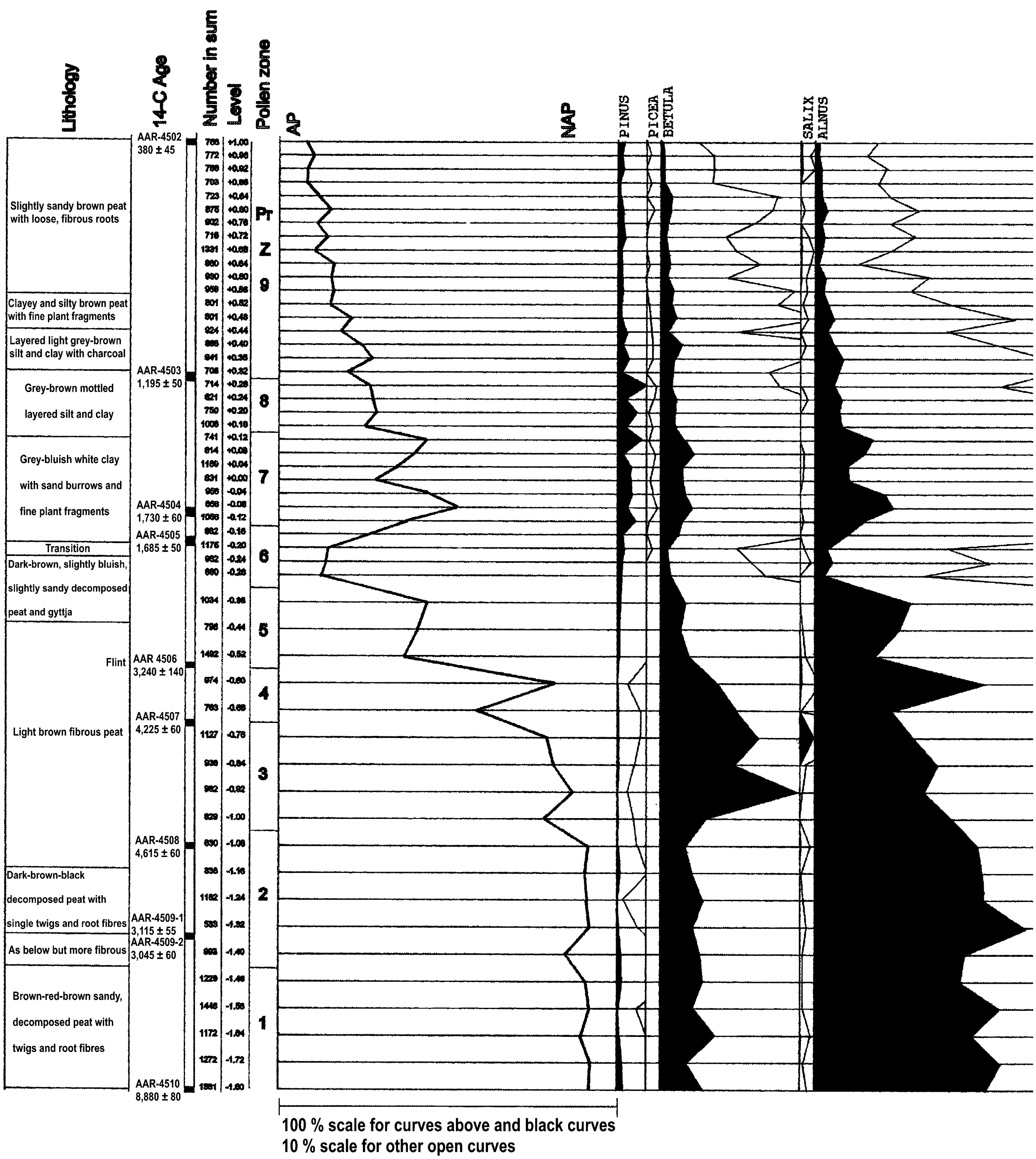

Fig. 2 Pollen percentage diagram from the Præstesti site. General information is given in the *left hand columns*. The proportion of dry arboreal versus non-arboreal pollen is given in the left part of the main diagram, followed by pollen percentages of individual tree taxa. The dry herb pollen is arranged alphabetically according to family name. In the right hand part of the diagram the percentages of water plants and identified microscopic non-pollen and spore elements are shown. *P-3* represents an unidentified 3-porate pollen type. For further explanation, see text

certain depth. This grey-bluish-white clay layer, which corresponds to the upper part of pollen Zones Pr 6 and Pr 7 in the diagram (Fig. 2), was a good marker for visual correlation from one excavation to another.

Overall, the sediments in the Præstesti valley are relatively poor in organic material, which is probably the reason that the accumulations had become preserved as they might otherwise have been used as fuel.

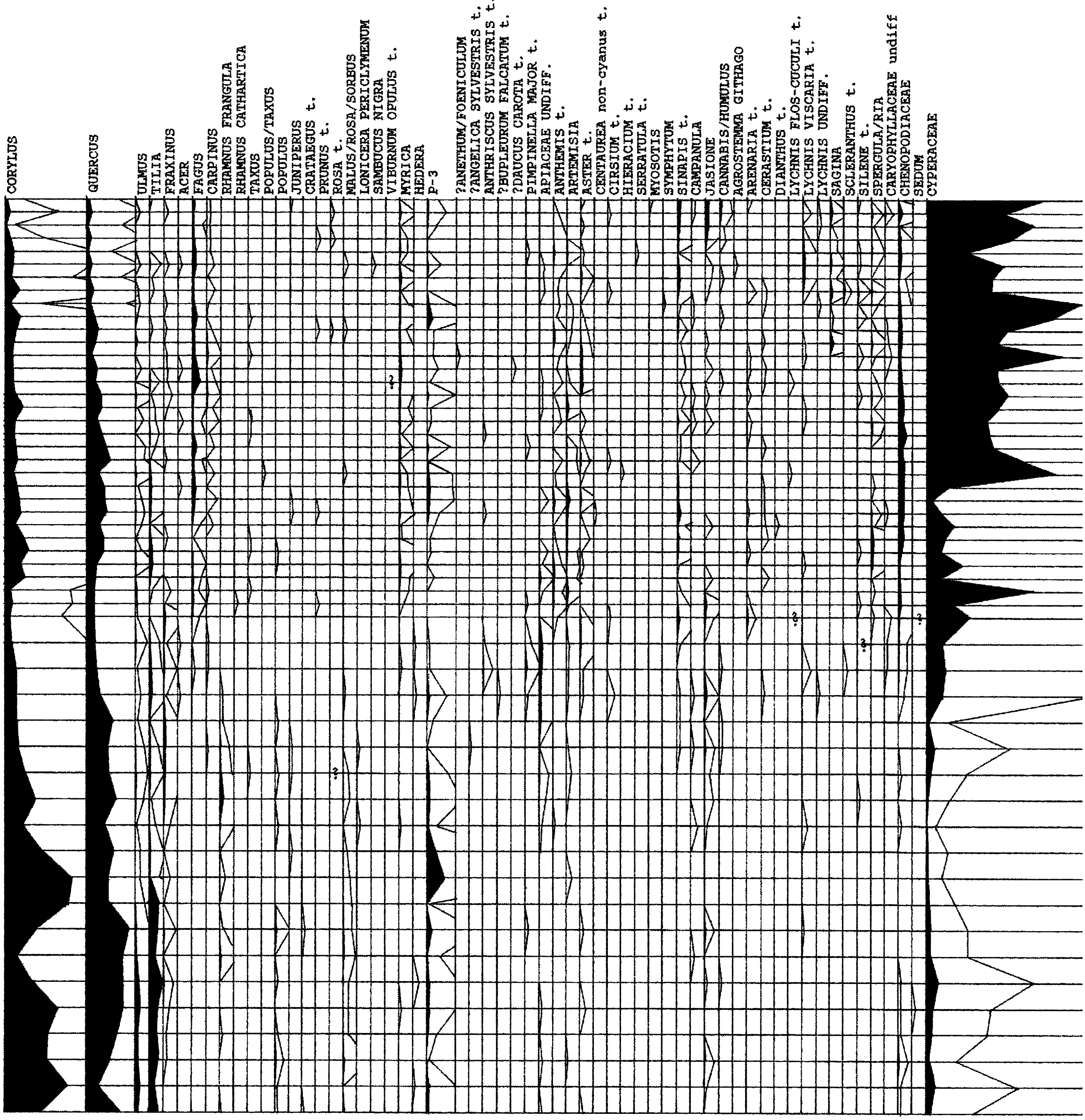

Fig. 2 continued

In the laboratory the sampled sediments from the deepest and midway sections in the Præstesti site, sections 1 and 2 respectively, were described and sub-samples collected. In section 1, which is presented in this paper, 0.5 cm^3 sub-samples (0.8 cm × 0.8 cm × 0.8 cm) for pollen analysis were collected at 8 cm intervals first. To these samples were added four tablets, each with 12,100 *Lycopodium clavatum* spores (purchased from the Department of Quaternary Geology, University of Lund, Sweden) for calculation of the pollen concentrations according to the method of Stockmarr (1971). Small particles were eliminated by sieving on 10 µm gauze (Kolstrup 2005) and all samples were treated with 10% HCl, 10% KOH, sieved through 224 µm gauze and

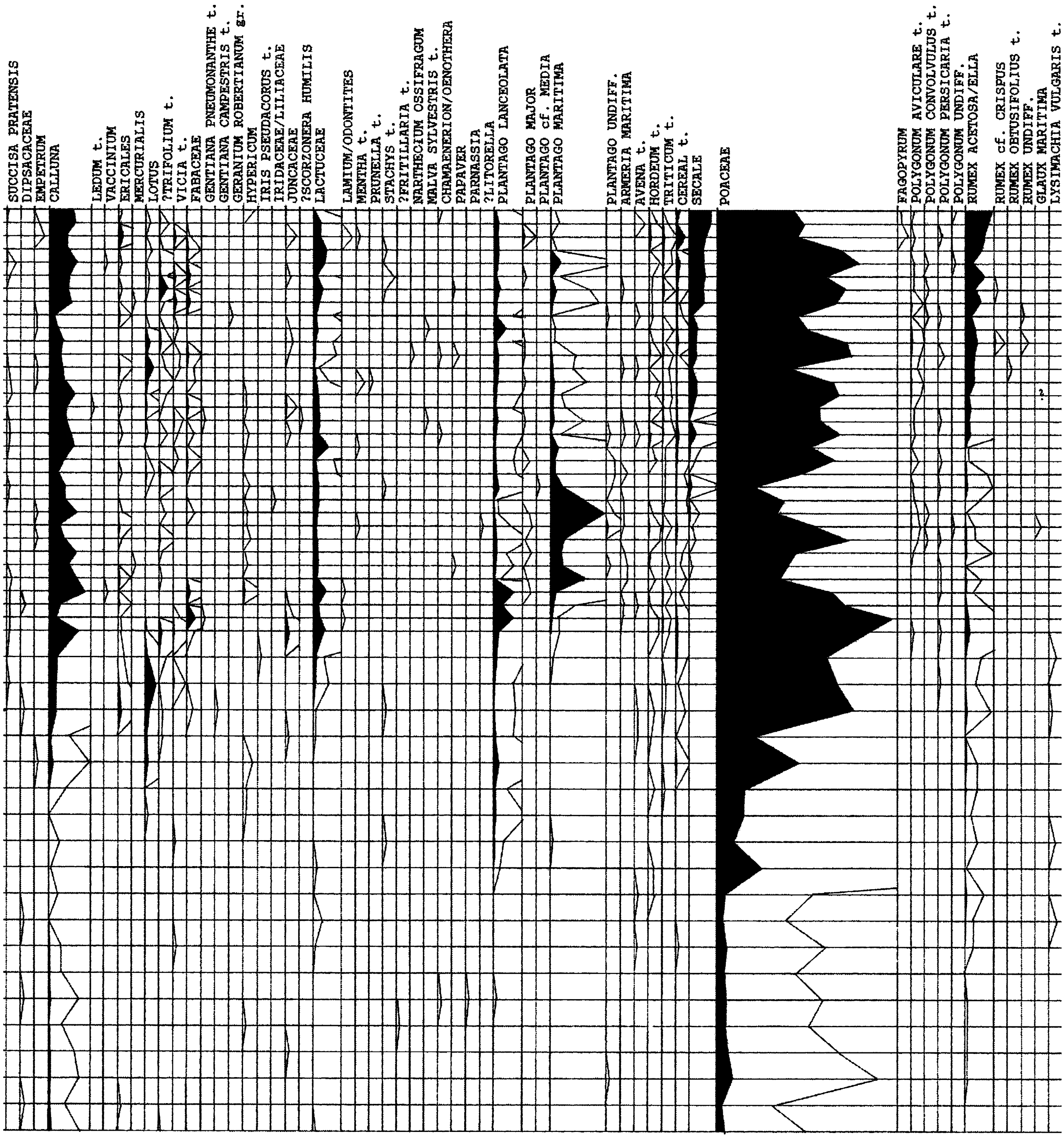

Fig. 2 continued

underwent Erdtman acetolysis (Moore et al. 1991). The samples were then treated with $ZnBr_2$ (specific gravity 2.0) and washed in mild KOH before they were embedded in glycerol and stained with basic fuchsine (Kolstrup 2005). From the upper half of the series intervening samples were selected, so that the distance between consecutive pollen spectra in this part is 4 cm. No *Lycopodium* tablets were added to these samples.

In the microscopic determination work a pollen and spore reference collection of c. 1,000 slides was used in addition to a number of determination keys (Fægri and Iversen 1966; Moore et al. 1991; Punt et al. 1976–1991) as

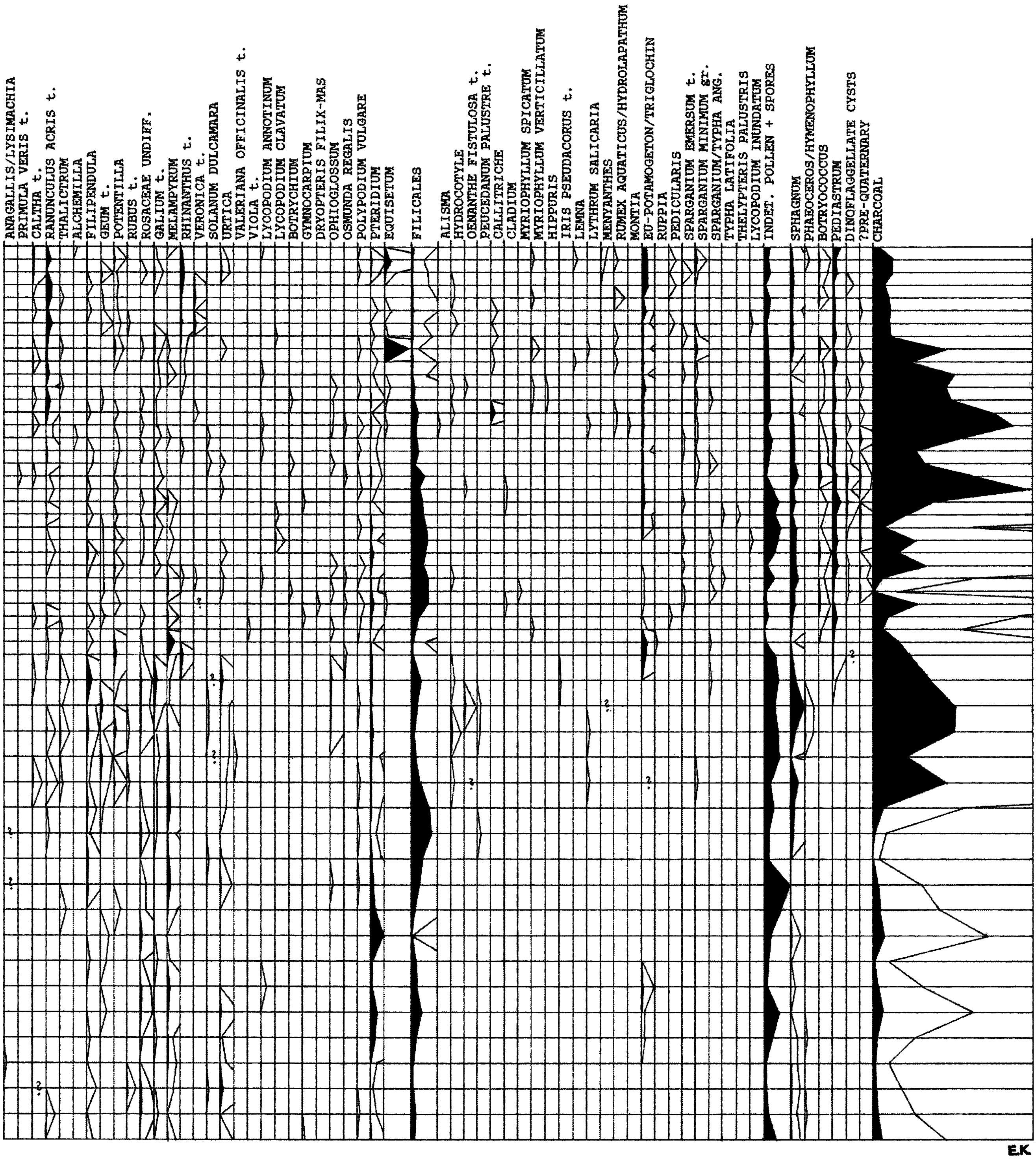

Fig. 2 continued

well as other, more specialized works. For cereal type pollen, Andersen (1979) was consulted.

In almost all samples a sum of more than 600 palynomorphs from arboreal (AP) and non-arboreal (NAP) terrestrial plants was counted. For all samples the percentages are calculated based on this dry AP + NAP sum and are presented in the percentage diagrams of Fig. 2. Further, on the basis of the added *Lycopodium* spores in the Præstesti samples, the total number of selected pollen types was calculated for each cm^3 of sediment at 8 cm intervals (Fig. 3).

The samples for radiocarbon dating were collected from the sample boxes and were initially submitted to the

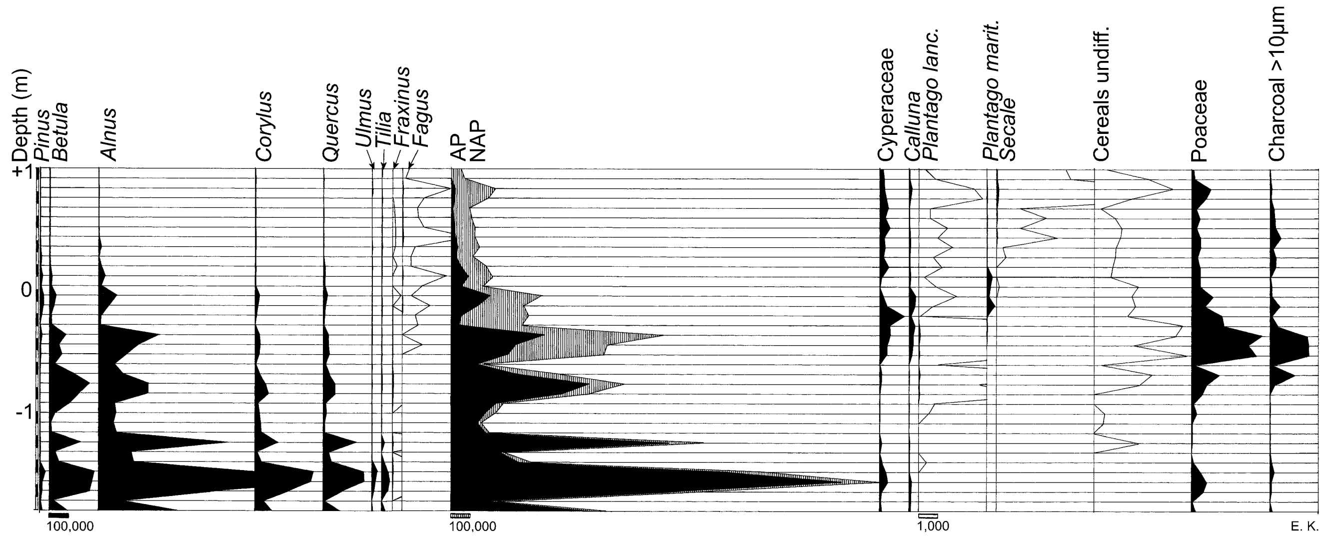

Fig. 3 Pollen concentration diagram showing selected taxa as well as charcoal particles >10 μm from the Præstesti site

Radiocarbon dating laboratory at the National Museum in Copenhagen where they were left for a few years, during which time some had partly dried out and others had got a whitish cover of fungi. In 1998, fungal coverings and hair roots were removed from them and the samples were transferred to the AMS ^{14}C Dating Laboratory at the University of Aarhus for AMS dating. There the samples were treated with 1 M HCl for 4–5 h and with 1 M NaOH for 2–3 h, in both cases at room temperature. Samples AAR 4502 and AAR 4506 were so small that only 0.5 M NaOH was used.

The pollen percentage diagram (Fig. 2) (drawn by hand) is organized with the general sediment description on the left followed by radiocarbon ages, the number of pollen and spores from terrestrial plants included in the sum, the preliminary level in relation to mean sea level as noted with the sediment description and finally, the pollen zones.

In the diagrams the pollen types are arranged with the percentages of terrestrial arboreal and non-arboreal pollen (AP–NAP) to the left followed by various tree and shrub pollen taxa and subsequently pollen from terrestrial herbs organized alphabetically according to their Latin family names. Spores from terrestrial Pteridophytes are followed by pollen and spores from ferns and water plants, unidentifiable (usually damaged) pollen and spores, identifiable microscopic plant fragments and finally *Sphagnum* spores, algae and charcoal particles more than 10 μm long.

Results

Sediments

The sample identifications follow the original field depth measurements from 1991 (Table 1). In October 2007 the site where the sample series was collected was not accessible, but a GPS measurement c. 80 m to the south of it gave +0.33 masl for the top of the marine clay, a few centimetre higher than in the series here. This means that the depths in the Præstesti diagram need to be regarded as tentative.

Description of the pollen diagrams

The curves are not clustered according to ecological requirements or anthropogenic relevance as sometimes seen in pollen diagrams related to archaeological investigations. There are two reasons for this:

- First, even if an ecological presentation to some extent facilitates an overview of the former human uses of the plants shown in the diagram, it may at the same time limit the openness to and discovery of alternative possibilities. A consultation of the comprehensive ethnobotanical work of Brøndegaard (1987) can clearly illustrate numerous former, now almost forgotten uses of plants, and once such added knowledge is included it might cause revision of the grouping of taxa, and might even need to record changes of these uses with time. In addition, one could speculate how to classify the trees, of which some might also be grouped in accordance with anthropogenic uses if the system is to be consistent. A classification according to present-day knowledge and uses might therefore need repeated revision and still possibly not be satisfactory.
- Second, only a few pollen types can be identified to species level. This means that some pollen types can represent species that were cultivated or used as well as species which were not. For example the Apiaceae curve could include celery, parsley, caraway, parsnip,

Table 1 Sediment stratigraphy at the Præstesti site northwest of Esbjerg

Depth (m)	Sediment description
+1.36 to +1.01	Top soil. Surface tentatively put at 1.36 m
+1.01 to +0.59	Brown, slightly sandy peat of loose, fibrous root mat. Only herb fragments and no wood fragments. Moss fragments at +0.92
+0.59 to +0.44	Brown clayey and silty peat with many fine plant fragments including ?*Phragmites*. Upwards it gradually becomes almost pure peat with a very low content of sand. Downward the transition is gradual
+0.44 to +0.32	Light grey-brown, layered silt and clay with black dots of charcoal. Very fine and thin plant fragments. Indistinct wavy lamination
+0.32 to +0.12	Grey-brown, layered silt and clay with white dots. Very fine and thin plant fragments. Indistinct wavy lamination
+0.12 to −0.19	Grey to bluish-white clay with vertical concentrations of sand (burrows) in particular between −0.10 and −0.14. Above +0.02 the sediment contains single fine plant fragments which gradually increase in number upwards and the sediment becomes browner upwards. Laterally, at c. 0.00 there was an arrangement of large, flat (stepping) stones
−0.19 to −0.23	Transition
−0.23 to −0.43	Dark-brown to slightly bluish, slightly sandy, "greasy" decomposed peat or possibly gyttja with fine plant fragments. Upwards the deposits become lighter in colour due to an increasing content of marine clay
−0.43 to −1.15	Light brown fibrous peat with twigs and possible *Phragmites*. The transition from the underlying layer is gradual. At −0.55 there is a c. 1 cm piece of flint, which seems retouched
−1.15 to −1.35	Dark-brown to black, decomposed peat with a few twigs and a little root "felt"
−1.35 to −1.44	As below but somewhat more fibrous
−1.44 to −1.82	Brown to red-brown, sandy (medium sand) decomposed, slightly granular peat, with pieces of twigs and some fine root fibres. The sand content decreases upwards and from −1.77 there is almost none. Between −1.42 and −1.57 there are pieces of ?alder wood, c. 2 cm in diameter

dill and carrot as well as wild species. Other families such as Asteraceae, Chenopodiaceae, Lactuceae, Lamiaceae and Rosaceae and many more could also represent plants belonging to more than one group of classification.

The concentration diagram from the Præstesti site in Fig. 3 shows the values of a few selected pollen types and groups calculated as concentration per cm^3.

Pollen content and zonation

Præstesti 1 is a percentage pollen diagram from the central part of the Møllebæk brook valley (53 m from a N-S oriented path and 9 m from an artificial drainage trench), and Præstesti 2 is a concentration diagram from the same section, but with greater intervals between consecutive samples in the upper part. In the concentration diagram only selected pollen types and charcoal particles are included.

PrZ 1 −1.80 to −1.44. The zone covering the lower part of the percentage diagram is characterized by high tree pollen percentages, notably of *Alnus*, *Betula, Corylus*, *Quercus* and, considering its low pollen production and dispersal, also of *Tilia*. *Ulmus* forms a continuous curve of 1–2%, and *Populus* and *Malus/Rosa/Sorbus* are represented. Amongst the non-arboreal taxa there is low representation of *Calluna*, Poaceae and Cyperaceae. *Urtica, Melampyrum* and, especially in the upper part, *Pteridium* are also present as well as a small percentage of charcoal particles. The pollen concentrations in this part fluctuate strongly, and in some parts of the zone they reach high values indeed. The transition to the succeeding zone is placed at the decrease of *Ulmus* and just at the start of this decline is a single pollen grain of *Plantago lanceolata*.

PrZ 2 −1.44 to −1.04. The percentage representation of trees is similar to that in Zone PrZ 1, except for *Ulmus*, which has almost disappeared. There are single Cereal type pollen grains in this part, as well as low percentages of Cyperaceae and Poaceae, and there is continued presence of *Melampyrum* as well as of *Pteridium* and charcoal particles, while *Urtica* has disappeared. Except for a clear maximum at one level, the concentration values for this zone are lower than in Zone PrZ 1 and generally decreasing, but there is still dominance of pollen from arboreal taxa. The transition to the following zone is marked by a decrease in *Tilia* and an increase in Poaceae and Filicales.

PrZ 3 −1.04 to −0.72. In this zone there is a maximum of *Betula*. The percentages of *Alnus* and *Corylus* decrease, whereas *Quercus* remains the same. *Fraxinus* and *Rhamnus frangula* are present and the percentages of Poaceae, Filicales and *Melampyrum* have increased, and those of Cyperaceae and *Pteridium* have decreased. *Plantago lanceolata* is present continuously, and *Urtica* and *Polypodium vulgare* are represented, as are *Filipendula* and some other herbs. There is a slight change in the relationship between AP and NAP percentages. The concentration values are low in the lower and high in the upper part. The transition to the overlying zone is placed at a decrease in the percentages of *Corylus* and increases in the percentages of Cyperaceae, *Calluna*, Poaceae and charcoal.

PrZ 4 −0.72 to −0.56. This zone is characterized by decreasing *Betula* values and a maximum of *Alnus*. Poaceae and charcoal have higher percentages and there is increased representation or appearance of various cereal types as well as of many herbs. The concentration values show a minimum. At the transition from PrZ 4 to PrZ 5, a piece of retouched flint was present in the peat.

PrZ 5 −0.56 to −0.32. The transition to this zone is gradual over 8 cm and shows decreases in the percentages of *Betula*, *Quercus* and *Fraxinus*. *Rhamnus frangula* disappears. Furthermore, at this transition there is an increase of *Tilia* and further increases of Cyperaceae, *Calluna*, *Lotus* and Poaceae. *Fagus* and *Ophioglossum* become represented in this part. *Sphagnum* has a maximum and there are single occurrences of *Hydrocotyle* and *Oenanthe*. Charcoal particle values are high. The most striking feature in this zone is that here and further up, pollen from non-arboreal plants is dominant compared to arboreal pollen. The concentration values are relatively high and show a maximum.

PrZ 6 −0.32 to −0.14. At the transition between PrZ 5 and PrZ 6, the percentages of *Alnus* and *Betula* decrease. Many pollen curves show changes at this level either as a decrease or increase or as first or last presence for a while. Both percentages and concentration values of arboreal pollen are relatively low in this zone. Cyperaceae, Poaceae, *Plantago lanceolata*, Lactuceae, Fabaceae, *Rumex* and *Melampyrum* have maxima. *Potamogeton–Triglochin* type is present and there are low values of the algae *Botryococcus* and *Pediastrum*. There are low percentages of *Plantago maritima* and *Armeria maritima* type and there is a single pollen grain of *Ruppia*. *Spergula/Spergularia* and *Sinapis* are present from now on. In the sediment there is increasing content of clay upwards.

PrZ 7 −0.14 to +0.14. The transition to this zone is placed at an increase in most woodland elements and especially at the increase of *Plantago maritima*. *Betula*, *Alnus*, *Corylus*, *Quercus*, *Tilia* and *Pinus* have higher percentages than in the preceding zone, and *Fagus* reaches higher percentages in the upper part of the zone; the first pollen grains of *Carpinus* are found. There are very high percentages of *Plantago maritima* while those of *Plantago lanceolata*, Cyperaceae and charcoal particles have decreased. *Calluna* and Filicales are well represented. Overall, there is a wide range of different herb pollen with low percentages, but single groups such as Chenopodiaceae and Lactuceae are better represented. The first pollen grains of *Secale cereale* are found in this part and also *Plantago major*. There is a low representation of *Sparganium* and the percentages of charcoal particles are relatively low. In part of the zone there are algae and Dinoflagellate cysts and a low admixture of pre-Quaternary pollen types. The sediment in this part is marine clay.

PrZ 8 +0.14 to +0.30. The transition to this zone is marked by a decrease in the percentages of *Plantago maritima* and an abrupt rise in those of Cyperaceae. In this zone there are no major changes in the tree pollen composition and percentages. There is a high diversity of taxa and even if *Plantago maritima* has decreased it is still well represented. There is presence of *Cladium*, and Dinoflagellate cysts form a continuous curve.

PrZ 9 +0.30 to +1.00. This upper part of the diagram is considered as one zone. At the transition to it there is a further decrease in the *Plantago maritima* percentages and an increase in the percentages of *Secale* and *Rumex*. Throughout the zone there are gradual changes in some of the pollen curves while others remain generally unchanged, yet with some fluctuations. The herb pollen diversity is relatively high and in the upper samples there is *Fagopyrum esculentum*. *Plantago maritima* is present in some parts as are Dinoflagellate cysts. In addition to *Sparganium* and *Potamogeton/Triglochin* there is an increase in the representation of other hygro- and helophytes. Charcoal particles have high percentages in the lower part to become more modest in the upper. The pollen concentration values have decreased further, especially those of the tree pollen.

Correlation and age of the series

In the following section, the Præstesti series is palynologically compared to other pollen series and tentatively dated in this way. Besides, several radiocarbon ages are presented and discussed.

Tentative biostratigraphic correlation

In Zone PrZ 1 there is presence and dominance of various trees including *Ulmus*, *Tilia* and *Fraxinus*. This, together with the decrease of *Ulmus* at the transition from PrZ 1 to PrZ 2 after which the pollen percentages from this tree remain low, suggests that PrZ 1 belongs to the Atlantic and includes its upper part. The *Ulmus* percentages are rather low for this zone compared to standard diagrams from eastern Denmark, but the situation is parallel to that in northern west Jutland (Odgaard 1994). The overlying zone with cereal type pollen could consequently represent part of the Sub-Boreal. The *Tilia* percentages in the Præstesti pollen diagram are high at this level compared to the percentages at the start of the Sub-Boreal in diagrams from sites further to the north and east (Odgaard 1994), and are in better agreement with the representation of *Tilia* after the elm decline in some northwest German sites (Dörfler 1989; Behre and Kučan 1994; Wiethold 1998) and to some extent also with sites on the island of Fyn in Denmark (Rasmussen 2005) as well as in southeastern Jutland at the transition between the Saalian and the Weichselian landscapes (Aaby 1986). From Zone PrZ 2 and above, the palynological correlation to other pollen diagrams from Denmark (Mikkelsen 1949; Odgaard 1994; Rasmussen 2005) and northern Germany (Dörfler 1989) is less clear. This is partly because a correlation to a transition from the Sub-Boreal to the Sub-Atlantic, which is normally based upon an increase in the *Fagus* percentages (compare for example Jonassen 1957) is unclear owing to continuously low *Fagus* percentages throughout. Likewise, the percentages of *Carpinus* remain very low in the Esbjerg area compared to those in other diagrams, so this taxon only helps to mark the Sub-Boreal to Sub-Atlantic transition in the Præstesti site to a limited extent. This transition might possibly be placed within Zone Pr Z 7 around level +0.04 m from where *Fagus* and *Carpinus* form almost continuous curves, but it is to be noted that the immigration of these trees is time transgressive (Wiethold 1998). *Secale* appears with very low values at this level in the Præstesti site and similar first finds are found at this level elsewhere (Behre and Kučan 1994) and might thus support this transition, yet in some diagrams it is found later (Dörfler 1989; Behre and Kučan 1994).

Radiocarbon ages

The AMS ^{14}C Dating Laboratory at the University of Aarhus notified that the ^{14}C ages are reported in conventional radiocarbon years (B.P. = 1950) and that calibrated ages in calendar years are given as obtained from the tables in Stuiver et al. (1998) using version 4.0. In Table 2, the ages are given as provided by the laboratory in 1999.

−1.80 to −1.81 m, 7950 B.C.: The sediment in the lower part of the sequence is sandy and there could perhaps be an admixture of older material especially because there is a fair consistency in the palynological composition and succession in pollen diagrams from other areas for the corresponding part of the biostratigraphic record. There is thus no reason to assume a very different vegetational history in the Esbjerg area and consequently the radiocarbon age at the start of the series is regarded to be at least 1,000 years too old.

−1.35 to −1.36, 1400 and 1370–1320 B.C.: The two dates, done on the same piece of wood, were expected to date the elm decline, which is dated to around 5000 years B.P. elsewhere (Innes et al. 2006). Even though it appears that there may have been up to four elm declines, of which the first and last are some hundred years in age apart (Andersen and Rasmussen 1993), the ages from the Præstesti locality are clearly much too young, which is why the dating procedure was repeated after AAR-4509-1 had been done. It cannot be decided if something had happened to the sample during the long storage or if the sample was from a younger root that had penetrated down into older sediment. In spite of the ^{14}C results, the age of the level of the elm decline is regarded as being c. 5000 B.P. in accordance with the general age for the elm decline in other sites.

−1.08 to −1.09 m, 3360 B.C.: The age at −1.08 represents the end of the relatively high *Tilia* and *Pteridium* percentages and the start of the continuous curve of *Plantago lanceolata.* It does not have a clear Danish palynological parallel for comparison, because in northwestern Jutland the *Tilia* decline takes place around the same time as the *Ulmus* decline rather than after it, but in a northwest German record a *Tilia* decline and the simultaneous start of an almost continuous *Plantago lanceolata* curve has been radiocarbon dated to 4670 ± 90 B.P. (Dörfler 1989). Behre and Kučan (1994) found a coincidence of the decline of *Tilia* and an increase in Poaceae, which might parallel the development in the present diagram. According to these authors, the northwest German *Tilia* decline is time-transgressive with ages around 4500 B.P. and locally later. Against this background, the Præstesti age is regarded as being reasonably correct.

−0.72 to −0.73 m, 2880 B.C.: The age at −0.72 m is difficult to check because the *Betula* maximum which is the most conspicuous change in this part does not have parallels in other diagrams. However, the age would fit in with a reasonably constant sedimentation rate from c. 5000 B.P. (the elm decline level) through 4600 B.P. until c. 4200 B.P. and could therefore be acceptable.

−0.545 to −0.555 m, 1510 B.C.: The level with the age of 3240 B.P. of −0.55 m has a parallel with diagrams from northwestern Jutland in the now almost equal AP/NAP proportions as well as in a decrease of *Quercus* percentages, and the ^{14}C dates from elsewhere overlap with the one in the Præstesti pollen diagram, thus giving a fair degree of confidence in this result although this sample was very small, which is the reason for the relatively high uncertainty.

−0.18 to −0.20 m, A.D. 390; −0.09 to −0.11 m, A.D. 270–330: These two ages date the levels of −0.18 and −0.10 m for the marine influence and the first *Secale* respectively. The first results can to some extent be assessed against the background of the development in the southern North Sea (Behre 2007), where the sea level seems to have been relatively high between around A.D.

Table 2 Results of ^{14}C-dating, calibrated with Calib 4.0 according to Stuiver et al. 1998

Depth (m)	Lab-code (AAR-)	^{14}C age (B.P.)	Cal. age (1 σ-range)	δ^{13}C (‰) PDB	Dated material	Remarks
1.005–0.995	4502	380 ± 45	A.D. 1485 (1450–1630)	−26.5	Moss fragments, Polygonaceae seeds	Top of the sampled sequence
0.31–0.29	4503	1195 ± 50	A.D. 880 (780–890)	−27.2	Seeds and plant fragments	Increase of *Secale*
−0.09 to −0.11	4504	1730 ± 60	A.D. 270–330 (240–410)	−26.5	Plant fragments	First *Secale*, recent fungi removed
−0.18 to −0.20	4505	1685 ± 50	A.D. 390 (270–420)	−27.1	Plant fragments	Increase in marine influence and herb pollen diversity
−0.545 to −0.555	4506	3240 ± 140	1510 B.C. (1680–1330)	−27	Pieces of wood, cf. Chenopodiaceae seed fragment	Piece of flint; single sand grains, decomposed peat; many hair roots and some recent fungi removed
−0.72 to −0.73	4507	4225 ± 60	2880 B.C. (2890–2700)	−28.4	Pieces of wood	Decrease in AP pollen percentages; single sand grains, almost black, strongly humified, woodland peat; hair roots removed
−1.08 to −1.09	4508	4615 ± 60	3360 B.C. (3500–3340)	−28.2	Pieces of wood, beetle fragments	Start of cultural influence, crossing pollen values of *Tilia* and *Betula*; decomposed woodland peat, hair roots and some recent fungi removed
−1.35 to −1.36	4509-1	3115 ± 55	1400 B.C. (1430–1310)	−28.6	Piece of wood	Elm decline
−1.35 to −1.36	4509-2[a]	3045 ± 60	1370–1320 B.C. (1400–1130)	−29.7	Piece of wood	Elm decline
−1.8 to −1.81	4510	8880 ± 80	7950 B.C. (8020–7750)	−24.6	Piece of charcoal	Recent fungi removed

[a] Same sample as AAR-4509-1, but exposed to a particularly harsh pre-treatment with 1 M NaOH for 24 h at 80°C

200 and 400. The start of the almost continuous occurrence of *Secale* pollen is dated to before A.D. 270 elsewhere and *Secale* is known to have been cultivated in southern Denmark around A.D. 400 (Henriksen 2003). These two radiocarbon ages are therefore accepted as being reasonably correct, but with the comment that there might have been redeposition of sediment in this part.

+0.31 to +0.29 m, A.D. 880: The age at +0.30 is more difficult to check palynologically. Trees had decreased significantly and *Secale* had become common in the area, so by comparison with other areas the level could be somewhat later than A.D. 400 (Henriksen 2003; Kolstrup, in press). The marine influence seems to have decreased but had not stopped at this level. A sea level curve constructed from a compilation of data from the southern North Sea area shows that there was a relatively low sea level from around A.D. 800 and for a few hundred years on (Behre 2007). It is possible that the age of A.D. 880 for this level is correct, but from the rye pollen curve it may also be suggested that the age is a little too young.

+1.005 to +0.995 m, A.D. 1485: This radiocarbon age dates the top of the sampled series and gives a late age of A.D. 1485. The level can also be tentatively dated by pollen owing to the presence of *Fagopyrum*, which is thought to have been introduced in Sjælland, Denmark during the first half of the 1300s and it was commonly cultivated in Denmark around A.D. 1500 (Brøndegaard 1987, vol 2, p. 136). This radiocarbon age is therefore taken to be correct.

Sedimentation series and hiatuses

From the combined information derived from the radiocarbon ages, the palynological correlations and the relation to former sea levels, it is clear that the pollen diagram from the Præstesti site does not represent an uninterrupted sequence of vegetational history for the area. The lower part up to c. −0.70 m seems to be without major gaps, although some redeposition of older material could have taken place in the lowermost sample. The upper c. 1.3 m of sediment also seems to be reasonably continuous, but in the intervening part of the diagram, longer time spans seem to be missing.

Vegetational and environmental developments and human activity

The pollen composition from the time represented by the lower part of the Præstesti section, Zone PrZ 1, which is from the late part of the Atlantic, suggests that there was a widespread woodland cover in the area at that time, as was also the case elsewhere in Jutland (Odgaard 1994) and in northwest Germany (Dörfler 1989; Behre and Kučan 1994). The woodland composition was diverse and on high ground there may have been *Quercus*, *Ulmus*, *Tilia*, *Fraxinus, Rhamnus* and probably also *Corylus*, *Betula* and *Populus*, while the relatively moister valley could have been dominated by *Alnus* with *Salix* as an accessory element.

The presence and preservation of peat in this part indicates locally moist to wet conditions, but since there is no pollen from aquatic plants there may not have been permanent open water at the site. Instead there was local herb vegetation with modest representation of Cyperaceae, Poaceae and Filicales as well as representation of various other plants including *Melampyrum*, *Pteridium*, *Urtica* and *Filipendula*. Some of these may also have grown on higher and dryer ground together with *Jasione* and *Rumex*; and *Plantago lanceolata* is represented by a single pollen grain at the level just before the elm decline. The two last mentioned taxa as well as *Melampyrum* and *Pteridium* might be taken as indicators of human activity (Behre 1981). According to P. Siemen (personal communication) the Esbjerg area was fairly densely populated during the late part of the Atlantic period and at the transition to the Sub-Boreal, so the presence of these plants may possibly be related to human activity in the area, as could also have been the case in northwest Germany as proposed by Behre and Kučan (1994).

In the early part of the Sub-Boreal in Zone PrZ 2, the vegetational picture is very similar to that of the late part of the Atlantic with presence of a mixed deciduous woodland with a fairly high species diversity, the exception being the reduced presence of *Ulmus*. Also, herbs seem to have been present with about the same diversity and density as previously, at least in as far as the limitations in pollen production and dispersal and the microscopic identifications allow one to conclude, so no major changes may have occurred to this part of the vegetation either. Locally or periodically there could now have been open water present in the valley, as suggested by the presence of pollen of *Eu-Potamogeton*. The presence of single cereal type pollen grains suggests cultivation of cereals even if it cannot be ruled out that the *Hordeum* pollen type may represent a wild grass. It is not clear from the diagram what other vegetational food sources there could have been for the Neolithic people at that time, but the representation of *Corylus* indicates the continued presence of hazel, which is known to have been present and used during the Neolithic (Jensen 1985a, b), and in early excavations in Esbjerg harbour, charred fragments of hazelnut shells have also been found in Atlantic peat (Hartz 1902). *Malus/Prunus* and Rosaceae could represent the presence of edible fruits. Pollen from *Rubus idaeus* is not identifiable, but it is known to have been present in the Esbjerg area already from an early part of the Holocene (Hartz 1902). *Galium* and other plants may also have been of use though not necessarily all as food sources. Overall, in the Præstesti results it seems that the influence of Neolithic people on the vegetation is detectable but relatively slight. This development fits in well with that in Norfolk in England, on the other side of the North Sea (Bennett 1983) as well as that in northwestern Jutland (Odgaard 1994), central Denmark (Rasmussen 2005) and northwest Germany (Dörfler 1989; Behre and Kučan 1994). In the upper part of this zone *Pteridium* has a maximum at the level from which *Tilia* decreases, and according to Göransson (1986) young shoots of this fern could have formed a useful food source. From a comparison with other pollen diagrams (Iversen 1967; Behre 2000) it is proposed that the coincidence of a maximum of *Pteridium* with the *Tilia* decline represents a landnam (land use) in the area, in parallel with that found with the *Tilia* decline elsewhere in Denmark and northwest Germany.

Zone PrZ 3 shows that *Tilia* had become rarer by then, and on high ground there could have been some unwooded areas from now on. Alternatively, the woodland could have become more open as suggested by the increase in the light demanding *Betula,* which had become relatively more common, possibly as regrowth in previously cleared areas. Also, *Rhamnus frangula* and *Fraxinus* are relatively well represented during this time and may also have occupied the higher and dryer areas, whereas alder was still common, although decreasingly so, on moist ground, probably mainly in the valley where *Salix* had become more common in the upper part of the zone. With regard to pasture areas, it is possible that the expansion of grasses here could show that local grazing areas included the Møllebæk valley and that *Alnus* had decreased as a consequence. It is uncertain whether a single pollen grain of *Taxus* indicates the growth of yew in western Jutland at that time, but for comparison, it was present from 4500 B.P. on the other side of the North Sea (Bennett 1983). Even though peat accumulated at the site during that time, pollen from aquatic plants is too scarce to indicate an area of open water, at least permanently. But there is a gradual, relative increase in pollen from Poaceae and Filicales as well as Campanulaceae, *Filipendula* and other herbs, which may not have been restricted to the valley and its sloping sides, but could also have grown in the surrounding higher areas within an increasingly open woodland, as was also the case in the northwest German area (Behre and Kučan 1994). The presence of these herbs in combination with the continuous presence of pollen from *Plantago lanceolata* and the regular occurrence of pollen from self-pollinating cereal types makes it clear that the openness of the vegetation was probably mainly caused by increased agriculture with pastures and cultivated fields in the area during this part of the Neolithic. Rasmussen (2005) found a similar coincidence of high *Betula* percentages, cereal pollen and *Plantago lanceolata* pollen on the island of Fyn and suggested that the development there might be related to the first traces of cultivation using the ard plough, so it is possible that a similar agricultural development may be part of the explanation for the vegetation changes in the Esbjerg area.

Until the time represented by the upper part of Zone PrZ 3 there is only a little *Calluna* and charcoal in the Præstesti samples which suggests that the various human activities, including those related to agriculture, were very limited. From this zone and onwards, the Præstesti vegetational and environmental patterns differ from those at sites further inland.

Zone PrZ 4 represents a clear change in the development in the area in more than one way. Provided that the radiocarbon ages are reasonably reliable, this includes a major hiatus, which covers the late part of the Neolithic or the early part of the Bronze Age or probably both.

At the start of the zone, the trees are still well represented both with regard to their abundance and the diversity of species, but subsequently birch and hazel show decreased percentages while alder became temporarily relatively more abundant. The latter may still have been favoured by moister conditions in the valley, but all trees including alder show reduced pollen concentrations. There is a clear decrease in the proportion of arboreal pollen in this zone. Therefore, a real clearance or thinning of the woodland is indicated, probably in part caused by burning, because at this level there are strongly increased percentages of charcoal. In addition there is an increase of Poaceae and *Calluna* so heathland probably expanded in the surroundings after the fires. A recent study of heather sods in an early Bronze Age burial mound east of Esbjerg shows that there was heathland pasture management with burning in that area (Karg 2008). The combined presence of *Calluna*, sedges, abundance of grasses and the high content of charcoal particles indicates that a similar land-use system could also have existed in the Præstesti area. The pollen percentages from cereals increase but only modestly, then decreasing again, so it seems that the clearance did not result in a major permanent expansion of the area for crop cultivation. It is therefore more likely that the occupants in this area had adapted a system of land use with the main emphasis on grazing, for which the heath areas provided extensive pastures, maybe especially for sheep. The opening up of the landscape seems to mainly have been at the cost of areas previously with *Betula* and *Corylus*.

The valley seems to have become wetter as suggested by presence of *Caltha* type, *Hydrocotyle*, *Lythrum* and a few other taxa that depend on moister and wetter growing conditions. This change could possibly be related to an increasing sea level. At this level in the diagram there are no direct indications of marine influence, but the hiatuses suggest either that sediment was removed or that there was no accumulation for a long time. The former possibility is regarded as the more likely one, because the wetter environment could be expected to have made accumulation and preservation of organic sediments more likely than during the previous periods.

When the changes in this zone are seen against the continued rise in sea level, as outlined in the geological background above, one can speculate that the sea had by now extended to areas so close that it seriously affected the settlements in the area. Even if such a rise may still not have reached the area directly, it could have impeded the ground water flow and the water courses that drained the hinterland by decreasing the run-off gradient, and may thus have caused the increased wetness in the valley that is reflected in the local vegetation there. The rise in sea level could also have forced people to move from flooded areas to higher parts of the land, which would then have become more densely populated. It is easy to envisage that such a situation could have imposed increased pressure on the natural resources with associated increased intensity of human activities.

In Zone PrZ 5 there is a further reduction in the proportion of AP/NAP suggesting continued and increasing woodland clearance in the surroundings. If the ^{14}C dates are correct, the radiocarbon ages suggest that this zone should cover a time span of almost 2,000 years, which would suggest either a very slow sedimentation rate or one or more hiatuses. The absolute pollen diagram shows fairly high pollen concentrations for most of this part, which could hint at a slow sedimentation rate for most of the zone. On the other hand there is a change in the sediment composition around −0.43 m which might point to changed local conditions during the formation of this sediment. It is most probable that this part of the diagram does not represent a continuous vegetational sequence, and the abrupt change in the palynological picture at the transition between Zones PrZ 5 and PrZ 6 almost certainly points to a major gap in the record at that level. According to Barber et al. (2004) northwest Europe seems to have experienced a phase of a few centuries with a more unstable, cooler and possibly wetter climate during a period around 2800 cal B.P. This period falls within PrZ 5 so it is possible that the climatic change could have contributed to erosion along the coast of Jutland especially because it can be envisaged that the temperature/moisture change was associated with a change towards more windy conditions following altered cyclonic tracks.

In accordance with the geological outline given above, there would have been a high sea level during the deposition of the sediments in Zone PrZ 5, so it is very probable that erosion took place during extreme high water events. Also, the start of the *Plantago maritima* curve at −0.36 m followed by *Armeria maritima* and the possible marine indicators Chenopodiaceae and *Potamogeton/Triglochin* show that marine surges had entered the valley at least with a more than annual frequency (compare Mikkelsen 1969). Since hiatuses are possible in this part of the sequence, the following vegetational outline can only be seen as general, because it cannot be decided how much of the upper part of the Bronze Age and the lower part of the Iron Age are represented in the pollen diagram.

Even if the proportion of trees has decreased compared with herbs and shrubs, it nevertheless seems as if the diversity of trees has not changed and it can be noted that *Fagus*, *Carpinus* and *Acer* are now present, so possibly these trees now grew closer to the area. In moist areas *Myrica* could have formed an accessory element, and *Hedera* is present.

Pollen from helophytes such as *Hydrocotyle*, *Oenanthe fistulosa* type, *Peucedanum palustre* type, *Iris pseudacorus* and possibly also others suggest that fresh water was present in the depression during those times that are represented in the pollen record, but it is possible that open water was not permanently present (compare Gaillard 1984).

Areas with grasses and sedges must have been widespread not only in the occasionally inundated valley, but also on higher ground where areas with heather seem to have increased, providing extensive pastures and meadows; so it is probable that the heathland pasture management with burning (Karg 2008) had intensified in the Præstesti area. Also, on the dryer areas there was an increased variety of herbs, including types that are traditionally included with the categories of apophytes (native plants in habitats created by humans) and anthropochores (plants introduced by humans) (Behre 1981), for example various Apiaceae, *Sinapis* type and Chenopodiaceae as well as Lactuceae, various Fabaceae, *Rumex*, *Galium* and *Urtica*, but others might also have belonged to the list of useful plants from that time. Such presence probably reflects a diverse and, when seen in combination with the high charcoal percentages, intensified use of the resources in the environment. Pollen from various cereal types, including the self-pollinating *Triticum* type, shows that cultivation of cereals continued. In addition, it is possible that local metal production began in the area during the Iron Age, and this activity would have further increased the need for wood and added to the charcoal dust.

Zones PrZ 4 and PrZ 5 differ from contemporary diagrams from Jutland and northern Germany, but also have enough features in common with them for general comparisons between the areas, even if the Præstesti record may not be continuous. From the pollen series and the sediment record it is not clear what the reason for the possible discontinuity(ies) might be, but as noted above, inundation and erosion by the sea during extreme events of above-flood sea water levels seems to be a likely explanation even though there are only a few marine indicators so far in the diagram. Yet, in spite of the lack of halophytes (salt-tolerant, usually maritime, plants) in the pollen record proper, the effects of the raised sea level upon the surrounding areas are almost certainly indirectly reflected through the increased human impact as reflected in the vegetation.

The transition from PrZ 5 to PrZ 6 indicates a marked change for the Præstesti area with the major impact at −0.32 m. The sediment becomes more clayey with an admixture of sand, the over- and underlying radiocarbon ages differ relatively much and there are so many changes in the pollen composition of the diagram that a hiatus can be postulated. It is quite possible that the gap in the sedimentary record includes erosion of older sediments. The increasing content of clay in Zone PrZ 6 in combination with the presence of the halophytes *Plantago maritima*, *Armeria maritima* and *Ruppia* as well as Chenopodiaceae, *Spergula* or *Spergularia* and *Eu-Potamogeton/Triglochin* shows that there was marine tidal water in the Møllebæk valley. The decrease in the *Alnus* and possibly also *Betula* pollen content in Zone PrZ 6 could be an indication that these trees, especially the former, had grown in the valley until the permanent marine inundation, when they were destroyed by the salt water. Zone PrZ 6 can be said to represent the direct vegetational reaction of the environment in the valley to the influence of the salt water. The exact timing of the start of the deposition of marine sediments is not clear, but to judge from the radiocarbon ages it can be suggested to have been around or shortly before A.D. 400, which is in agreement with the relatively high sea level in the southern North Sea at that time (Behre 2007). It can be hypothesized that the initial inundation took place during an extreme event that broke through the outlet of the Møllebæk, reaching into the hinterland and widening this passage.

At the zone transition the pollen concentration values decrease markedly, especially for trees of dryer habitats, thus pointing towards decreasing tree growth density around the valley, but the diversity does not seem to have been reduced, and *Fagus* may now have formed part of the flora. Grasses and *Plantago lanceolata* have clearly increased percentages suggesting a further expansion of dry pastures (compare Behre 1981) and meadows (Groenman-van Waateringe 1986). *Calluna* on the other hand is relatively reduced, so possibly there was now a different type of land management. There are maxima of Cyperaceae, Fabaceae, Lactuceae, *Rumex*, *Potentilla* and *Rhinanthus*. These pollen groups include plants that benefit from presence of open soil surfaces and light open patches such as for example after harvesting or mowing (Behre 1981; Groenman-van Waateringe 1986), and it is also possible that there are cultivated plants amongst the species represented by these taxa. Juncaceae could have grown in the swampy areas of the depression.

In Zone PrZ 7 marine clay is present in the elongate, relatively sheltered valley. Today the tidal range in the Esbjerg area is c. 1.5 m and the presence of marine clay indicates that the valley formed part of the tidal flat area. An arrangement of flat stones aligned across the valley suggests that it could be crossed dry-footed and without getting clayey feet, at least during low tide. The good representation of *Plantago maritima* as well as the presence of *Armeria* type pollen and *Glaux maritima* with a possible addition of Dinoflagellate cysts also suggest that the marine influence had intensified and that marine surges above the level of the tidal flat were of an elevation and a frequency to create a system of a salt marsh and above that a marine grassland zone, so floods would have taken place a few times weekly in the lower part of the valley and up to once a year in the higher reaches (compare Van Zeist 1974; Mikkelsen 1969). The indicator value of the Dinoflagellate cysts in the diagram may be queried because this curve corresponds to some extent with the presence of pre-Quaternary pollen and could thus also represent redeposited material. However, since the curves do not fluctuate in parallel, the Dinoflagellates are taken to be predominantly primary.

Considering the poor production and dispersal of *Armeria* pollen, the plant was probably rather common in the area, but the difficulty of identifying various taxa to species level from their pollen makes it difficult to pinpoint other plants of the halophytic community. It is probable that *Spergula*, *Spergularia* and some of the Chenopodiaceae belong in this environment and the same could be the case with some grasses and sedges as well as species within the Asteraceae including possibly *Aster tripolium*, *Artemisia* and others related to the tidal salt marsh regime (Van Zeist 1974; Mikkelsen 1969) and the beach grassland zone, which could have provided high quality grazing areas (compare also Groenman-van Waateringe 1999).

Fresh water algae are also represented in this part of the diagram. Seen together with the marine influence they could represent the inflow of fresh water from further inland.

The relative proportion of trees seems to have increased as seen from their increased pollen percentages, which reach up to 50%, and the tree pollen concentrations also increase, so trees probably expanded in the area. *Alnus*, especially, became more frequent again and together with *Myrica* it may have re-occupied moist parts of the valley that were out of reach of salt water influence. *Betula* also became more common and might have taken over parts of the surrounding higher ground where it could have grown together with *Corylus*, *Quercus* and the insect pollinated *Tilia*. Herbs, on the other hand do not show an increase, so there was probably a shift towards regrowth of woodland in some areas. *Fagus* is also represented, but the pollen percentages are low and its flowering and especially seed production could have been hampered in the windy coastal environment, as is the case today in the Esbjerg area.

There are relatively low Cyperaceae values, but there are again fairly high *Calluna* percentages, while Poaceae and *Plantago lanceolata* are also relatively abundant, so there may have been a return to the earlier grazing system, with both fields and heath pastures in the surroundings.

Cereal type pollen is continuously represented and may represent oats and hulled barley as well as emmer, because seeds of these have been found in the area and dated to the early Roman Iron Age (Robinson 2000). The wind-pollinated *Secale*, which spreads many times more pollen than other cereals, is encountered in the pollen record for the first time. As suggested by Behre (1992) for northern Germany, low percentages could be a hint that rye was not yet cultivated in the area, but rather occurred as a weed among other cereals, or alternatively its pollen could have blown in from afar. Between the first and fifth century A.D. rye was, together with hulled barley, the most important crop plant in the northeastern part of Netherlands (Van Zeist and Palfenier-Vegter 1991/1992) as well as in northwest Germany (Behre 1992). In southern and central Jutland, rye cultivation seems to have started around or before A.D. 400 (Henriksen 2003; Kolstrup, in press). However, in spite of the low pollen representation in the Esbjerg area, presence of seeds indicate that collection (and cultivation?) of rye took place there during the early Roman Iron Age (Robinson 2000).

The diversity of herbs in the area had further increased, and the traffic indicators *Plantago major* and *Polygonum aviculare* type point to trampling near the site. The charcoal values are fairly low, and in combination with the increase in pollen from woodland elements, the particles may mainly represent dust from heating and cooking.

At +0.12 m there is a striking coincidental maximum of tree pollen percentages, mainly *Alnus*, and an almost complete absence of charcoal particles as well as a decrease of some anthropogenic indicators, and it can be wondered if the area had been abandoned during a period of the late Iron Age during which the trees were able to spread. This would fit in with a marked marine influence upon the area as suggested by the pollen and sediment records here and it would also be in line with changes in the settlement patterns at some other sites in Denmark (Kolstrup, in press) and in northern Germany (Wiethold 1998), from around the same time. Partly using published literature, Barber et al. (2004) point to a possible relationship between a deteriorating climate and reduced human activity in northern Germany from A.D. 500, yet, as far as can be estimated from the Præstesti record, this development might be slightly later than the age of the AP maximum and charcoal minimum on the Danish west coast. Another change that might have affected the Møllebæk area and its surroundings is the spread of dunes within a few kilometres to the northwest from c. A.D. 300 (Clemmensen et al. 1996).

Zone PrZ 8 reflects an increasingly open, culturally influenced landscape. From the zone transition and upwards, the tree pollen percentages and concentrations decrease gradually. There was still a diverse composition of woodland trees, but the woodland cover must have been modest, possibly even more so than the pollen percentages suggest, because free standing trees can flower more freely (Bennett 1983) and can therefore disperse their pollen better than in more dense woodland.

The content of organic matter in the sediment has increased, but clay is still present and taken together with the continued but fluctuating presence of *Plantago maritima*, presence of *Cladium* and the low content of Dinoflagellate cysts this indicates continued inundation of the Møllebæk valley by the sea. Also, the presence of *Armeria maritima* points to continued influence of salt.

In this zone there is a high diversity of herbs including plants which are well known to be found often in relation to human influence. Apart from cultivated cereals there is presence of Chenopodiaceae, possibly mainly from the saline species, *Calluna*, *Trifolium* type and other Fabaceae as well as Lactuceae, *Plantago lanceolata* and *Galium*, and the percentages of charcoal particles increase markedly. The area was almost certainly densely populated at this time.

In Zone PrZ 9, which covers the relatively warm Viking period and Middle Ages and continues up to and possibly into the Little Ice Age in the seventeenth and 18th century, the marine influence upon the valley seems to have further decreased, which is in tune with the generally decreased high tide water level in the southeastern part of the North Sea around this time (Behre 2007). In addition, the locally accumulated sediments would have raised the level of the valley floor, thus further decreasing the possibility of marine influence; however, some marine impact can still be detected both in the slight clayey component in the sediment and in the fluctuating representation of *Plantago maritima*, *Armeria maritima* and Dinoflagellate cysts.

In addition to the marine influence, this part of the sediment is slightly sandy and it is possible that sand particles were blown into the area from the growing beach bar systems and dune areas to the northwest.

The vegetation during the Middle Ages as represented by this pollen zone is dominated by a high floristic richness of cultural elements in an increasingly open landscape. The maritime vegetational element mentioned above is related to the occasional inundations of the valley. There is an increased intensity of cereal cultivation and it is especially noteworthy that *Secale* has become very well represented, and rye must have been cultivated extensively in the surroundings of the valley. There are also some weeds possibly related to the cornfields, such as *Polygonum aviculare* and *P. convolvulus* type, *Scleranthus*, *Rumex* and possibly also *Spergula*. *Fagopyrum* was cultivated in the very latest part represented by the diagram and *Cannabis/Humulus* may also have been cultivated. Pastures might be represented by the presence of Cyperaceae, *Calluna*, Ranunculaceae, *Plantago lanceolata* and other more accessory elements, as well as by the abundance of grasses. More indirect hints of human presence are provided by the families of Lactuceae, Asteraceae and Fabaceae which include many useful and possibly cultivated plants.

There was still a high diversity of trees which is very similar to the composition in the German marsh area (Behre 1991), so apart from *Alnus*, *Quercus*, *Corylus*, *Betula* and *Fagus*, there may also have been present *Acer*, *Salix*, *Taxus*, *Sambucus nigra*, *Prunus* type and *Malus/Rosa/Sorbus*.

Conclusions

The pollen diagram from the Esbjerg area shows the vegetational and environmental development in the westernmost part of Denmark from the Atlantic period until the end of the Middle Ages. Initially, the vegetational composition and the woodland density and diversity were similar to those of other parts of Jutland as well as northwest Germany. During the time of the rising sea level, the North Sea came closer to the site and the vegetation and environment in the area reacted to this, so that their development took a different trend here, compared with areas further inland. The differences are especially seen in the sediments, once the sea had started to inundate neighbouring coastlands to finally reach the Esbjerg area during the Bronze Age and the Iron Age. Marine influence is detected in the vegetation records from this point all the way to the top of the sampled sequence, although with decreasing impact during the Middle Ages. When the sea level was at its highest, low lying sheltered bays, now above high tide level, were inundated and formed tidal flat areas, with associated communities of various beach zone vegetations which could have formed good pastures. In the higher areas there was crop cultivation and grazing areas existed there as well as increasingly open woods through time. Owing to the influence of the sea, and maybe also for other reasons, there are interruptions in the sediment deposition, so for some parts of the Holocene the vegetational history is only shown in glimpses.

From the late Neolithic and later it seems that there was increasing human population density as expressed by increasingly extensive, yet fluctuating, uses of the natural resources and burning of woodland and heathland. The pressure on the environment may have exceeded the natural supply of wood for burning, as this resource seems to have come to an end during the phase from the late Middle Ages to the early part of the Little Ice Age. Through time, the area would have offered the natural vegetational resources and possibilities for cultivation and farming that are also found in areas further inland, with the addition of the marsh areas that formed extensive grazing areas probably from some time in the Bronze Age and the Iron Age. At the same time the floods and erosion along the coast influenced the settlements, and forced populations to move, and periodically the coastal area might have been almost abandoned. The present landscape with its open vegetation can be seen as a result of human impact through time, and possibly even of medieval over-exploitation, and the influence of the sea.

Acknowledgements Palle Siemen, Esbjerg Museum, was very helpful with the search for suitable sites, with the fieldwork, as well as with discussions on the area and archaeological information. The geological investigations and the pollen analysis were financially supported by the Danish Research Council for the Humanities (SHF) through grants J. nr. 15-7500 (1990), 15-8034-1 (1991) and 15-8842-1 gj (1993) to Esbjerg Museum. The radiocarbon dates were funded by SHF, grant of 24th February 1995, Sagsnr. 9500977, and were performed by the AMS ^{14}C Dating Laboratory at the University of Aarhus under the supervision of Jan Heinemeier and Niels Rud. The constructive comments of an anonymous reviewer and especially of K.-E. Behre on a previous version of the manuscript are highly appreciated, as is the editorial work of K.-E. Behre. I am also grateful to the editor F. Bittmann for his help with the paper and to the copy editor J. Greig for thorough editing and upgrading of the English text.

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