DATING LITTORINA SEA SHORE LEVELS IN DENMARK ON THE BASIS OF DATA FROM A MESOLITHIC COASTAL SETTLEMENT ON SKAGENS ODDE, NORTHERN JUTLAND

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Abstract. The Mesolithic settlement site of Yderhede on Skagens Odde is interesting because it lies on Denmark's highest Littorina coastline, 13 m above present-day sea level. The settlement was founded on peaty ground on the shore of a sheltered fjord. Pollen-analytical investigations have been carried out on marine/brackish gyttja deposits containing refuse from the settlement. These marine sediments were formed as a result of a transgression starting around 5300 cal. BC, reaching a maximum of 13 m above present sea level. Settlement took place during a subsequent regression and ceased in connection with a new Atlantic transgression. Subsequently, the lagoon silted up partly due to isostatic land upheaval of the area. The settlement lies on flat ground below the marked raised coastal cliff that runs from Frederikshavn to Hirtshals, see figure 1. The formation of this cliff has previously been assigned to the time of the Littorina Sea, but it is now suggested that it was formed in Late Glacial times.

The two transgressions demonstrated here have been fitted into the overall pattern for sea-level change in Denmark. Subsequently, on the basis of well-dated sea-level curves for Southern Scandinavia, dates are given for the highest shore levels of the Littorina Sea. As a result of the interaction between increasing upheaval in a north-easterly direction and the general sea-level rise during the Littorina transgression, the maximum in the Gothenburg area (23 m-isobase) occurs as early as 6300 cal. BC, whereas the maximum at the 0m-isobase in Southern Denmark first occurs around 3600 cal. BC.

Key words: Littorina transgression, sea-level change, shorelines, Mesolithic coastal cultures, pollen analysis, Holocene.

INTRODUCTION

The Yderhede settlement was excavated by Per Lysdahl and Torben Nilsson of Vendsyssel Historical Museum. VHM case no. 190/1987, Yderhede, Tolne Parish, National Museum, Environmental Archaeology Department No. A7684.

Its location in the northernmost part of Denmark, at the root of Skagens Odde (Fig. 1) makes the site interesting both with regard to vegetation history (Denmark's northernmost pollen diagram) and shoreline studies (Denmark's highest Littorina shorelines). On the basis of five dates for cultural remains from the settlement, see later list of radiocarbon dates, the site was occupied between 5450 and 4850 cal. BC. This coincides with the earliest Ertebølle culture, corresponding to the Trylleskov phase (P.V. Petersen, 1984).

The site was located on the flat ground below the marked, now raised, coastal cliff, 300–400 m to the north of the cliff. This cliff has always been perceived as having been formed by the Littorina Sea. Accordingly, it was to be expected that the settlement had been sited on a newly-formed beach ridge on an exposed marine coast. This proved, however, not to be the case. On the contrary, the settlement had been established over peat deposits and had a refuse zone extending out into gyttja, a deposition environment well known from sheltered fjords or lagoons. There were good preservation conditions for wood and animal and fish bones – the finds included a whole dug-out boat. The site is important in connection with establishing the initiation date for the growth of Skagens Odde, one of the world's largest beach-ridge complexes.

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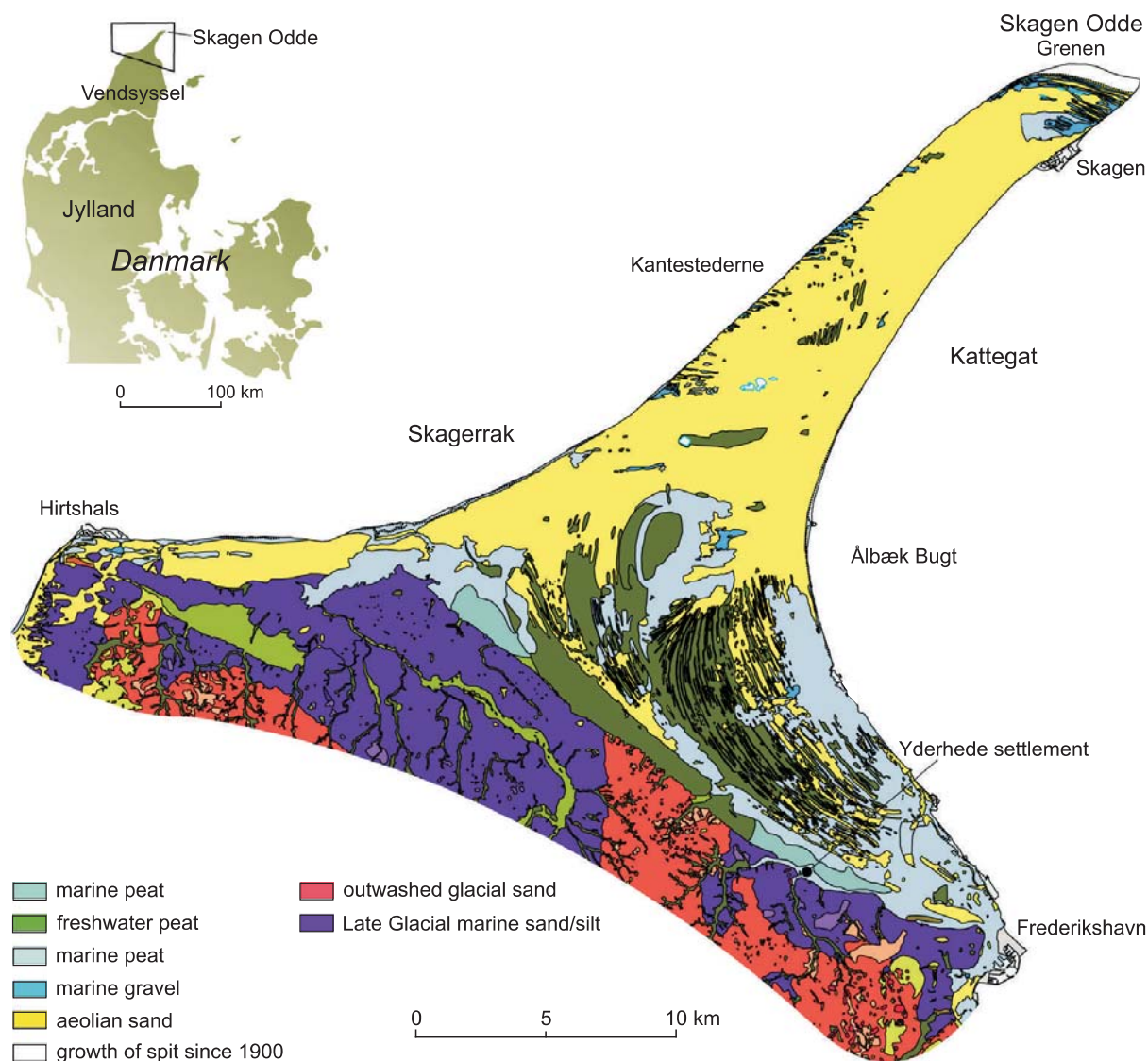
Fig. 1. Geological map of northernmost part of Jutland, showing the location of the Yderhede settlement, from Nielsen, Johannesen (2004, with English translation)

STRATIGRAPHY

METHODS

The geological fieldwork was carried out in 1995 by the 1st author. Series of pollen samples were taken from the section running north-south through the excavation, at two points, P1 and P2 (P1 northernmost), lying 15 m apart. At the same points the sediments were investigated and described and sample columns were removed for possible plant macrofossil analysis and radiocarbon dating. It was intended that the archaeologists subsequently should record the intervening section but this was never done. It remains the intention of Vendsyssel Historical Museum to carry out further excavations at the site, including recovery of the dug-out boat which was left *in situ*.

The stratigraphy at the two sampling points, based on the subsequent investigations and description of the constituent layers, is shown as sediment columns denoted by geological signatures in Figure 2. The layers are numbered differently at the two positions, but an attempt at correlation is shown on the figure. The sediment descriptions for P1 also include the excavator's layer codes, layers H, G, F and E, which are also used in the list of radiocarbon dates. In the majority of cases, the sediment descriptions include a Troels-Smith diagnosis (Troels-Smith, 1955).

Sediment descriptions at P1
(All heights are above Danish Normal Zero)

Layer 10 (layer H). Up to 11.44 m (only the uppermost 15 cm was exposed). Grey sand with gravel and stones. Upper few cm brown-coloured. Contains stones up to 2–3 cm. With penetrating herbaceous roots. Lim. s. 1–2, slightly undulating.

The Geological Institute of the University of Aarhus has cored down to 8 m below the ground surface at a position about 2.5 m NW of P1. The approximately 6m thick sediment sequence under the peat and gyttja deposits comprised well-sorted, very silty fine sand. Towards the base there were occasional marine mollusc shells.

Layer 9. 11.44–11.52 m. Chocolate brown, slightly sandy degraded peat. Matrix infiltrated by a fine root mat along with a good quantity of larger herbaceous fragments. Scattered twigs. It could not be established whether the layer contained gyttja. Lim. s. 1.

T-S diagnosis: Th^3 4, Ga + (lowermost), Tl^2 + (or Dl +).

Layer 8 (layer G). 11.52–12.195 m.

Description for 11.59–11.69 m: Chocolate-brown fen peat, apparently without gyttja. Occasional penetrating (from above) rhizomes of reed (*Phragmites*). Fine root mat is the main component. Occasional seeds of bogbean (*Menyanthes)*. Rather coarse, splits along horizontal planes.

T-S diagnosis: Th^{2-3} 4, [*Phragmites*: Th^{1-2} ++]. Between 11.69 and 11.84 m there is an horizon with numerous *Menyanthes* seeds

Description for 11.84–11.94 m: As 11.59–11.69 m but a little coarser. Includes a quantity of greenish horizontal *Phragmites* rhizomes which presumably penetrated later from above. In section these form greenish horizontal stripes.

Description for 12.09–12.195 m: As 11.84–11.94 m but with clearly more numerous green *Phragmites* rhizomes. Also more coarse herbaceous fragments. Presumably a brackish fen peat. Lim. s. 1–3.

Layers 8 and 9 are in total 0.75 m thick and completely lacking a visible layer boundary in that layer 9 is only distinguished by its slight sand content.

Layer 7 (layer F). 12.195–12.315 m. Olive green, slightly sandy, marine detritus gyttja. Fine-grained and smooth and shining in the section wall. Includes some *Phragmites* rhizomes and a little root mat. A quantity of fruitstones of pondweed (*Potamogeton)*. With scattered cultural remains. The lower part with rounded lumps of very fine, dark peat, presumably from a underlying layer. Lim. s. 1–2.

T-S diagnosis: Ld^1 3, Dg 1, Th^1 ++, Ga +, Dh (+), [rud. cult. (+)].

Layer 6 (layer E). 12.315–12.455 m. Mottled olive green to grey, containing gyttja, marine sand and many cultural remains. Very variable gyttja content. The layer contains a large number of cultural remains comprising sharp-edged, un--patinated flint, nutshells, worked wood, charcoal and fish bones. Lim. s. 1–2.

T-S diagnosis: Ga 3, Ld^1 1, Th^1 ++, [rud. cult. +++].

Layer 5. 12.455–12.59 m. Olive green, slightly sandy, containing fen peat, marine detritus gyttja. Very much like
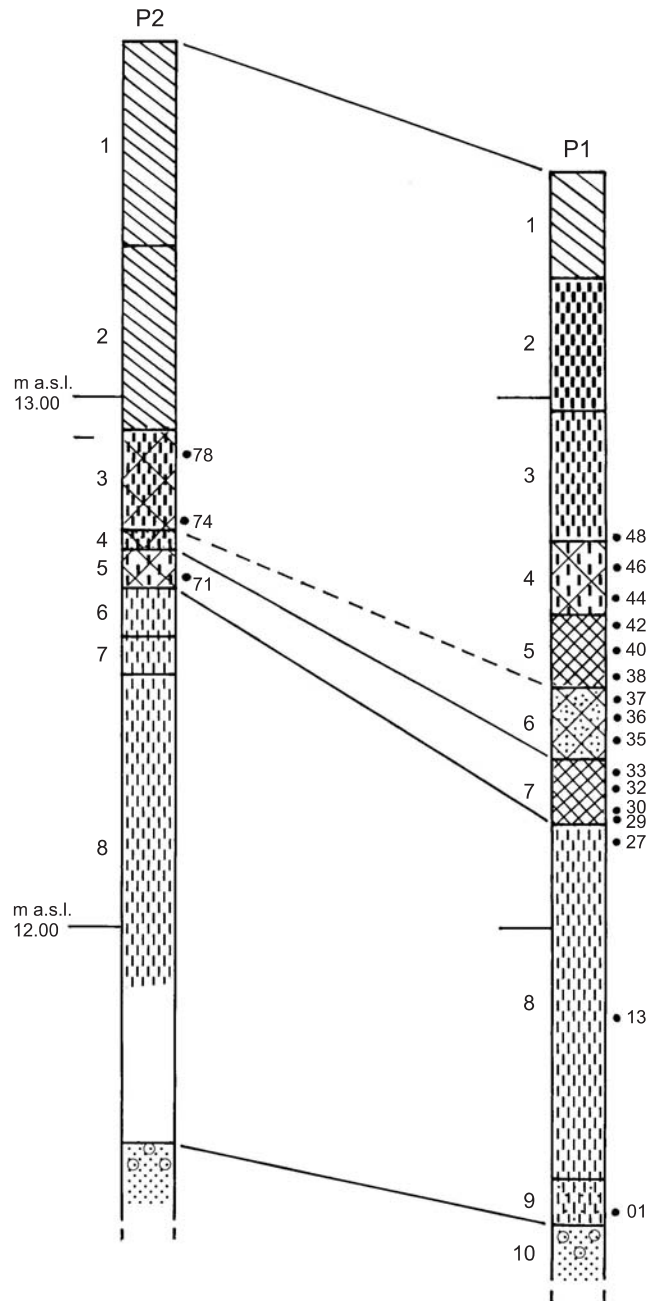

Fig. 2. The stratigraphy at Yderhede

In the sample columns at the two sampling points, P1 and P2, simplified symbols from Troels-Smith (1955) has been used. The lines between the two join up layers or layer boundaries which can more-or-less securely be connected. To the right of each sample column the position and number of the analysed pollen samples is given. For further information see text.

layer 7, but with a somewhat greater content of fen peat, especially *Phragmites* rhizomes and roots. Scattered cultural remains in the form of wood, bark and nutshells. No seeds or fruits observed. Lim. s. 1–2.

T-S diagnosis: Ld^1 3, Dg 1, Th^1 +++, Ga +, Dl +, [rud. cult. +].

Layer 4. 12.59–12.72 m. Mottled brown to green fen peat with gyttja. Consists of dense, middle-coarse root mat with a black-brown matrix of gyttja. No seeds or fruits observed. Lim. s. 1–2.

T-S diagnosis: Th^2 3, Ld^3 1.

Layer 3. 12.72–12.97 m. Black-brown degraded peat, consisting of fine and coarse root mat in an almost black matrix. A few large roots of alder (*Alnus*). Lim. s. 1.

T-S diagnosis: Th^3 4, $[Tl^2$ +].

Layer 2. 12.97–13.22 m. Black-brown, slightly sandy degraded peat with recent *Alnus* roots. Lim. s. 1.

T-S diagnosis: Th^4 4, Tl^0 +, Ga +.

Layer 1. 13.22–13.42 m. As layer 2 but mixed by ploughing, dry and disintegrating.

Sediment description at P2
(All heights are above Danish Normal Zero)

Below 11.60 m sand corresponding to layer 10 at P1 was encountered using metal prod.

Layer 8. 11.60–12.48 m. This layer is very much like layer 8 at P1, only seen in the upper part are some layer boundaries which make it possible to separate out layers 7 and 6. In the lower part, around 12.12 m, a seed of *Menyanthes* was found. Lim. s. 2.

Description around 12.37 m: Brown, slightly greenish fen peat, possibly containing gyttja, perforated by numerous pale yellow *Phragmites* rhizomes and roots from above. Fine root mat woven throughout the matrix.

T-S diagnosis: Th^{2-3} 4, Ld ?, Dg ?, [Th^1 (*Phragmites*) +++].

Layer 7. 12.48–12.55 m. As layer 8 but appears lighter in colour in the section wall. Some *Phragmites* rhizomes are faintly greenish. Lim. s. 1.

Layer 6. 12.55–12.64 m. As layer 8. Appears darker than layer 7. With greenish horizontal *Phragmites* rhizomes. Lim. s. 1.

Layer 5. 12.64–12.71 m. Greenish-brown marine detritus gyttja with a major content of fen peat. In section it appears greener and finer than layers 8, 7 and 6. Lim. s. 1.

T-S diagnosis: Th^2 2, Ld^2 2.

The layer is not particularly conspicuous and probably disappears only a few metres to the south. Is without doubt identical with layer 7 at P1.

Layer 4. 12.71–12.74m. Sandy, coarse marine gyttja with cultural remains. Heterogeneous layer of sandy coarse detritus gyttja containing wood, bark fragments, twigs and cultural remains (charcoal, nutshells and worked wood). Only a slight root mat observed, but a quantity of *Phragmites* rhizomes. It is in this layer that the dug-out boat occurred. Lim. s. 1–2.

T-S diagnosis: Ld^2 2, Dg 1+, Th^2 1–, Ga ++, Dl ++, Dh +, [rud. cult. ++].

The layer is by all accounts the southern continuation of layer 6 at P1.

Layer 3. 12.75–12.94 m. Sandy, somewhat degraded peat with gyttja. The layer changes character and composition from bottom to top, in that the lower part is the most sandy with the least content of fen peat and cultural remains and is the wettest. The colour changes from grey-brown lowermost to a warmer dark brown at the top. The upper 5 cm in particular contains a great deal of cultural remains, mostly charcoal but also significant quantities of flint. In the long profile running north-south, 2–3 cm thick sand layers, 30–50 cm in length and sloping down towards the north, are apparent in places within this layer. Lim. s. 1–4.

T-S diagnosis: Ld^3 1, Th^3 3, Ga +++ (lowermost) to Ga+ (uppermost), Dg ?, [rud. cult. + (lowermost) to +++ (uppermost].

The genesis of this layer is difficult to establish. On the face of it, it appears that this was wet peat which was habitable during dry periods, but it could possibly be a somewhat degraded coarse drift gyttja.

Layer 2. 12.94–13.29 m. Previously re-ploughed peat. Lim. s. 4.

Layer 1. 13.29–13.67 m. Fill and present plough layer.

List of radiocarbon dates

All dates are AMS dates from the AMS Laboratory, Aarhus. Calibrated (Stuiver, Reimer, 1993).

AAR-1222. Charred wood. Gyttja layer.
^{14}C age (BP): 6,500 ±80. Cal. age, ±1 st. dv.: BC 5,450–5,330

AAR-1999. Bone, antler axe. Recovered from settlement.
^{14}C age (BP): 6,100 ±80. Cal. age, ±1 st. dv.: BC 5,200–4,920

AAR-2460. Plant material. Taken from the lowermost 5cm of peat layer G, corresponding to layer 9 at P1.
^{14}C age (BP): 10,050 ±90. Cal. age ±1 st. dv.: BC 9,910–9,090

AAR-2461. Wood, bark fragment. Taken from the lowermost part of layer F, corresponding to Layer 7 at P1.
^{14}C age (BP): 6,440 ±80. Cal. age ±1 st. dv.: BC 5,440–5,280

AAR-2462. Bone, antler. Taken from the middle of layer E, corresponding to layer 6 at P1.
^{14}C age (BP): 6,060 ±80. Cal. age ±1 st. dv.: BC 5,060–4,850

AAR-2463. Wood, dug-out boat. From layer E, corresponding to layer 6 at P1.
^{14}C age (BP): 6,210 ±65. Cal. age ±1 st. dv.: BC 5,240–5,060

AAR-2464. Charcoal from layer rich in cultural remains lying over the dug-out boat, corresponding to layer 3 at P2.
^{14}C age (BP): 6,080 ±100. Cal. age ±1 st. dv.: BC 5,200–4,850

INTERPRETATION OF THE STRATIGRAPHY

Figure 2 shows the stratigraphy at the two sampling points.

Underneath the organic sediments there is sand with stones and gravel, layer 10 at P1. Coring carried out by the Geological Institute in Aarhus shows that these deposits are

more that 6 m thick and comprise fine silty sand. Stones and gravel are apparently only present at the top. These deposits must be Glacial or Late Glacial in origin, see later.

Over this minerogenic "natural subsoil" is an approximately 1m thick sequence of peat, layers 9 and 8 at P1 and layers 8, 7 and 6 at P2. These deposits are very homogeneous, comprising brown to chocolate brown fen peat with a fine herbaceous root mat. Towards the top, the peat is permeated by olive-green rhizomes of *Phragmites*, which have grown down from above and should, therefore, chronologically be linked with the overlying marine sequence. An AMS date from the lowest 5cm fixes the start of peat formation at the transition between the Late Glacial and the Preboreal (AAR-2460, see list of radiocarbon dates). Preservation conditions for pollen in the peat were extremely poor; in samples 01, 13 and 27 from P1, see Figure 2, only very few pollen grains were observed and an actual pollen count was quite impossible. In sample 13, i.e. in the middle of the peat layer, a few pollen grains of oak (*Quercus*) showed that the peat at this level was formed in the Atlantic period. There is, however, unlikely to have been continuous peat formation throughout the Preboreal, Boreal and Early Atlantic times.

At some point the continuing Atlantic rise in sea level exceeded the level of the upper boundary of the peat at 12.20 m at P1 and 12.64 m at P2. The peat layer was transgressed and subsequently a marine sequence of sandy or fen peat mixed with detritus gyttja was deposited: layers 7, 6 and 5 at P1 and layers 5, 4 and possibly 3 at P2. Several of these layers contain cultural remains from settlement at the site. The marine transgression of the site is usually marked by a sharp boundary to the underlying peat. Similarly, the lowermost part of layer 7 contains embedded clumps of peat. The time of the transgression is dated by way of a piece of bark from the lowermost part of the gyttja to around 5400–5300 BC (AAR-2461). A charred piece of wood from the gyttja layer containing refuse gave the same age (AAR-1222), and also dates the earliest settlement on the site. The latest date for settlement on the site is for antler from the sandy gyttja, corresponding to layer 6 at P1: 5000–4900 BC (AAR-2462). There are no dates from the latest marine deposits, layer 5 at P1, but pollen analysis shows that the whole of the marine sequence lies within the Atlantic period.

Layer 7 at P1 comprises olive-green detritus gyttja deposited under calm conditions in a fjord protected by beach ridges, see later section on shorelines. The layer can readily be correlated with layer 5 at P2, which just has a greater content of fen peat. Only a few metres to the south of P2 the layer can no longer be recognised. At P1, layer 6 is a marked sand layer with gyttja in the otherwise almost sand-free marine sequence. This layer can, with its somewhat variable proportions of sand and gyttja, be followed everywhere in the refuse zone and it is in this layer that most of the cultural remains are found. The layer is correlated, although not quite unequivocally, with layer 4 at P2. It must have been deposited under shallower water than the underlying layer 7, i.e. settlement took place during a period of regression. The flat peat surface, lacking in particular areas of higher ground, presumably excluded the possibility of settlement of the site under the previous period of higher sea level.

Over layer 6 at P1 lies layer 5, very like layer 7 but with a greater content of fen peat. The layer was formed under a renewed transgression which did not quite reach P2. Layer 5 contains only very few cultural remains and for this reason the settlement must be assumed to have ceased or been moved during the transgression. Layer 4 at P1 consists of fen peat with only a slight gyttja content and the layer was deposited during the final silting up of the fjord. There is a marked occurrence in this layer of freshwater algae, and the common presence of marsh plants linked with freshwater, shows that the fjord closed up in its last phase and was transformed into a lake, see subsequent section on pollen analysis. After silting up was complete, the overlying totally gyttja-free peat layers 3 and 2 were formed at P1.
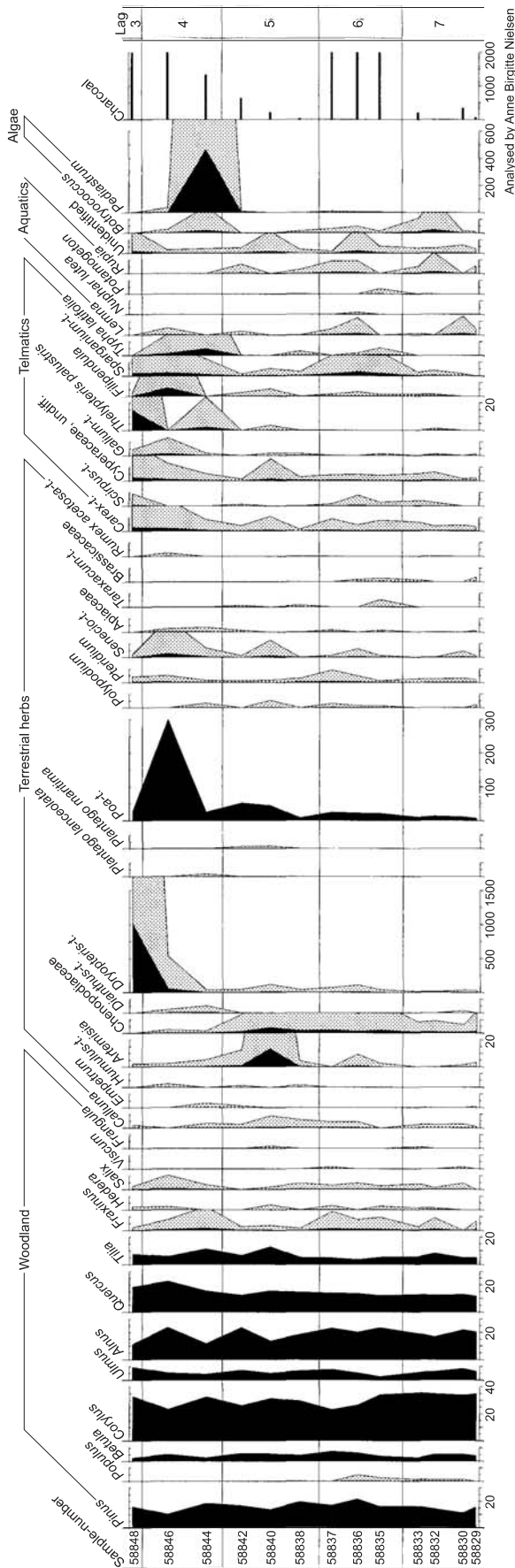
The results of the investigations into the marine deposits can be summarised as follows: A transgression has been demonstrated at the site with a maximum shortly after 5400–5300 BC, during which the shoreline must have lain at a minimum height of 13 m (gyttja, layer 5, up to 12,71 m at P2, cf. Figure 2). A subsequent transgression with a minimum around 5000 BC and a shoreline around 12.5 m made settlement at the site possible. The settlement ceased again, apparently due to a subsequent transgression which almost reached the same level as the previous one, i.e. around 13 m. The latter transgression is undated, but judging from the thickness of the layers it occurred a maximum of 200–300 years after the regression minimum mentioned above. On the basis of the pollen analysis we can be certain that the transgression was completed in Atlantic times. The sea-level changes and shoreline heights are put into a regional context below.

POLLEN ANALYSIS AND VEGETATION HISTORY

METHODS

The pollen counting was carried out by A. B. Nielsen (Nielsen, Christensen, 1999). The analysed pollen samples are identified in this report by the last two digits of the laboratory's original sample number. In the pollen diagram the full numbers are used. Samples 01, 13 and 27 at P1 were analysed from the lower peat, see Figure 2, but an apparently very aggressive environment has, as mentioned earlier, destroyed virtually all the pollen. Similarly, samples 71, 74 and 78 from the marine sediment sequence at P2 were without preserved pollen. Only samples from the marine and limnic layers at P1, layers 7–4, were countable and 13 samples were analysed from these layers. Here the state of preservation was, in contrast, often very good. The samples were prepared using stan-

Fig. 3. Pollen diagram P1

Percentage diagram with the trees and shrubs as the pollen calculation sum. No corrections have been made for differences in pollen production. The hatched curves show the percentages × 10. For further information see text.

Analysed by Anne Birgitte Nielsen

dard methods (KOH, HF, acetolysis, tertiary butyl alcohol and embedding in silicone). On average, 600 tree pollen were counted per sample. In addition to this was the herb pollen which in several samples was very abundant.

The resulting pollen diagram is presented in Figure 3. It is a percentage diagram with the combined totals for trees and shrubs being as the sum used in the calculations (pollen sum). The hatched curves for less common pollen types show a 10× exaggeration of the percentage values. No correction has been carried out for the varying pollen production of the tree species. The individual pollen types have been grouped according to the plant's/plants' ecological requirements. The sample numbers are given to the left of the diagram, the layer numbers, corresponding to P1 in Figure 2, are shown to the right. The curve for unidentifiable pollen can be more-or-less taken as the curve showing pollen destruction. In addition to pollen and spores, the freshwater algae *Botryococcus* and *Pediastrum* have also been identified. In addition, charcoal dust greater than around 25μ has also been recorded. In samples 35, 36, 37, 46 and 48 the charcoal was not actually counted as the values here exceeded 2000% of the pollen sum.

INTERPRETATION

Regional vegetation history

The whole of the analysed sediment sequence at P1 lies within the Atlantic period, pollen zone VII (Jessen, 1935). This conclusion is primarily based on radiocarbon dating of the lower part of the sequence, the absence of pollen of agricultural indicator species, along with the high levels of elm (*Ulmus*) pollen. In view of the site's special location it could be expected that there was some deviance in the composition of the vegetation relative to the well-known very stereotype picture from the Atlantic period. This is not, however, the case. In the case of trees and shrubs, the pollen curves follow a very gentle course and the occurrence of the individual species is very like that seen at other Danish sites lying further to the south and east.

The high percentage values for trees relative to herbs (apart from the uppermost three samples) show that the woodland must have been very close to the site, i.e. it had spread out on to the flat land below the marked coastal cliff. Had part of the flat land not occupied by the fjord been covered with fen vegetation, this would probably have been apparent in the form of higher values for grasses (*Poaceae*), sedges (*Cyperaceae*), reed mace/club rush, bulrush (*Typha*) etc. The diagram for layers 7, 6 and 5 is very regional in nature; it is first in layer 4 that the local vegetation begins to dominate.

Local vegetational history and environment

The marine environment is unequivocally confirmed by the occurrence of tassel pondweed (*Ruppia*) throughout layers 7, 6 and 5. This plant can tolerate brackish water, down to a salt concentration of about 3 parts per thousand and does not grow in fresh water. In the same layers, pollen of goosefoot family (*Chenopodiaceae*) is common and prior to the introduction of agriculture this must be seen as indicative of a marine environment. High values of *Artemisia*-type in layer 5 are presumably due to sea wormwood (*Artemisia maritime*).

Layer 6 must, as mentioned above, have been deposited under shallower water than the layers above and below it. The only evidence from the pollen diagram in support of this is the occurrence of high values in layer 6 of *Sparganium*-type, which includes lesser bulrush (*Typha augustifolia)* and bur-reed (*Sparganium*).

With the deposition of layer 4, fen peat with gyttja, there is decisive change in the deposition environment. *Ruppia* disappears completely, whereas *Artemisia* and *Chenopodiaceae* are virtually absent. In contrast, the fresh-water algae *Pediastrum* and *Botryococcus* reach very high and high values respectively in sample 44, lowermost in layer 4. Bulrush (*Typha latifolia*) also becomes common. It is clear that

the fjord has become closed off from the sea and subsequently enters a freshwater phase.

The subsequent "silting up" of the resulting lake, probably accelerated by the continuing land upheaval, is beautifully illustrated by the two subsequent pollen samples. In sample 46 *Pediastrum* falls to very low values, while in particular wild grasses, probably *Phargmites*, along with the fern *Thelypteris*, presumably marsh fern (*Thelypteris palustris*), increase dramatically. Other fen plants also increase; *Senecio*-type, most probably hemp-agrimony (*Eupatorium*), sedge (*Carex*-type), *Cyperaceae* undifferentiated, bedstraw (*Galium*-type), meadowsweet (*Filipendula*) and *Sparganium*-type, all plants that grow in reed swamp.

Sample 48, lowermost in the gyttja-free fen peat, layer 3, is completely dominated by *Thelypteris*. By this time there was no longer open water at the site.

To the right of the pollen diagram is the curve for charcoal dust. The marked occurrence of charcoal dust in layer 6 is in complete compliance with the appearance of macroscopic cultural remains in this layer. However, layers 4 and 3 also have high values for charcoal. This could suggest renewed settlement in the area in the lake and a silting-up phase after the second of the two transgressions which have been demonstrated. Re-deposition of older charcoal is, however, also a possibility.

SHORELINES

PREVIOUS INVESTIGATIONS OF THE EXTENT OF THE LITTORINA SEA IN NORTHERN JUTLAND

Jessen (1899, 1920, 1936) has mapped the extent of the Littorina Sea in Northern Jutland. The very obvious former coastal cliff running from Frederikshavn to Hirtshals, which separates the old highland lying to the south from the later formed spit, Skagens Odde (see Figs. 1, 4), is described by Jessen as a coastal cliff formed at the highest level of the Littorina Sea. All of the great beach-ridge complex to the north of the coastal cliff is thought to have been formed after the Littorina Sea maximum. The formation of Skagens Odde, according to Jessen, began with the laying down of a sand bar from Frederikshavn to Tversted, see figure 4. The spit was then built up beyond this bar by continuing beach-ridge formation.

Jessen does, however, highlight some of the problems with this model for the beginning of the formation of the spit, in that he writes (Jessen, 1899) that: "Deposition of the great sand bar from Frederikshavn to Tversted must, however, have already begun at the end of the Late Glacial or the beginning of the Post Glacial and the bar may have formed the northern limits of the land in the Continental period. In the low-lying area between the bar and the highland, peat layers have been observed in many places which are covered by layers of marine, shell-containing clay and silt deposited in Littorina times. The peat, with its numerous trunks of pine apparently originates in the Continental period and shows that the land

extended this far out to the north at that time. During the maximum of the Littorina subsidence the sand bar was covered by the sea such that the shoreline ran along the foot of the highland; it was first during the subsequent land upheaval that the bar obtained its present form, and after it had been raised above the sea a lagoon appeared between it and the highland, in which saltwater clay and gyttja was deposited on top of the peat bogs of the Continental period."

With knowledge of the stratigraphy at the Yderhede settlement, this description seems familiar. The Yderhede settlement lies between the slope to the highland and the above-mentioned sand bar, see figure 4. As already mentioned, the settlement is located on 1m of peat deposits, the formation of which began at the transition between Late Glacial and Post Glacial times. The area was partially covered by the sea during the first transgression demonstrated above, which peaked around 5200 BC with a sea level a little above 13 m. It is, however, very difficult to imagine that the sea, at the aforementioned time, as Jessen writes, transgressed the sand bar off Yderhede and eroded the great coastal cliff south of the site. Such exposed conditions would undoubtedly have removed the peat layers at Yderhede, or at least have left behind minerogenic deposits in the stratigraphy; nothing of this nature is at all apparent. The peat layers are overlain by fine detritus gyttja and the transgression must have taken place in a calm depositional environment, protected by the above-mentioned sand bar.

Another factor which contradicts the conclusion that the Littorina Sea formed the slope is the relative elevation. With
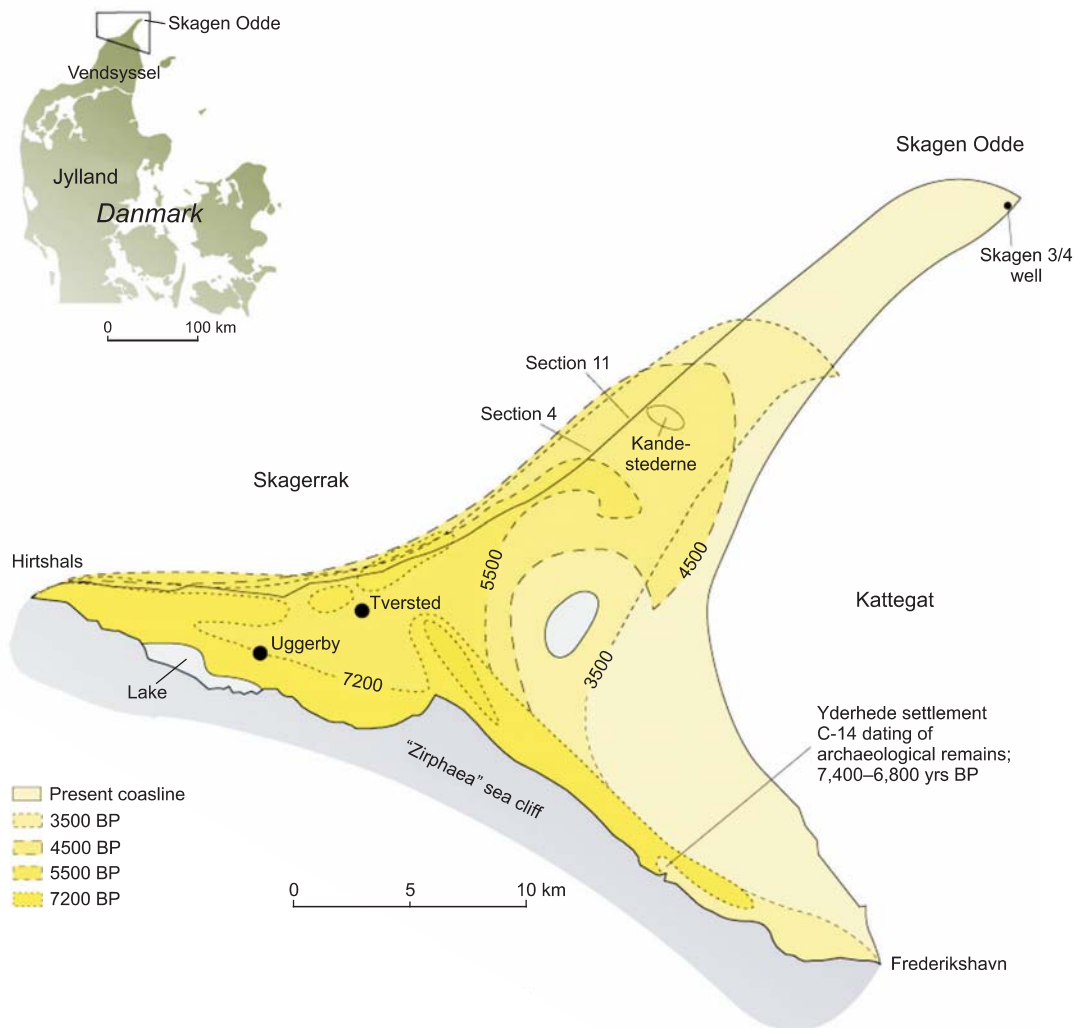
Fig. 4. The development of Skagens Odde

The Yderhede settlement lies on the shore surface below the Late Glacial coastal cliff. The coastline shown, 7200 BP, has been established on the basis of the investigations at Yderhede. From Nielsen, Johannesen (2004, with a few changes and English translation)

a sea level not much higher than 13 m, the sea would hardly have reached the foot of the cliff at Yderhede and certainly no further towards Tversted, where the boundary to the flat land at the foot of the cliff lies as high as 19 m. Jessen also emphasises that the marine deposits have not been demonstrated extending up to the cliff, the foot of which is characterised by slumped sand. Judging from the elevations, the Littorina Sea could have contributed to the formation of the cliff between Yderhede and Frederikshavn, but it is unlikely to have been a major factor.

All in all, the marked coastal cliff between Frederikshavn and Hirtshals appears to have been formed in Late Glacial times. The maximum transgression by the Yoldia Sea,

60 m at Frederikshavn, occurred around 13500 BP (uncalibrated), after which there was a regression. During the so-called Zirphea Sea, 12500–12000 BP (uncalibrated) it has been demonstrated that there was a balance between sea-level rise (caused by the higher temperature in the Bølling period) and land upheaval, after which the relative sea level fell again through the Younger Dryas and the beginning of Post Glacial times (K.S. Petersen, 1984; Richard, 1996; Nielsen, Johannesen, 2004). Zirphea deposits have been demonstrated up to a minimum height of 16 m and terrace formation linked to the Zirphea Sea at 22 m. It is presumably to this phase that the formation of the coastal cliff should be assigned. Accordingly, the Littorina coastal cliff

shown on many maps between Frederikshavn and Hirtshals should be changed to a Late Glacial coastal cliff and the extent of the Littorina Sea at the root of Skagens Odde should be corrected correspondingly.

Even though the local natural conditions at the Yderhede settlement can be described as a sheltered fjord environment, the undoubted proximity of the site to the sea is nevertheless apparent from its content of fish bones. And as such it is the only locality in Denmark from where bones of three shark species (tope, piked dogfish and porbeagle) have been recovered (Enghoff, 1995).

An account will not be given here of the subsequent development of the great spit – Skagens Odde. This has been described in many publications, most recently by Nielsen, Johannesen (2004), from which Figure 4 is taken. Mention will, however, be made of the fact that in 1936 samples were taken from a 1.5 m thick gyttja/peat sequence from a freshwater basin at the site of Studeli Klit directly south of Kandestederne (see Figure 4). New pollen analyses (Christensen, unpubl.) show that sedimentation in the lake began at the end of the Atlantic period and the tree pollen spectrum is virtually identical with that at Yderhede. This shows that wooded islands existed then to the north of the contemporary coast prior to the formation of Skagens Odde. Account is also taken of this in the latest study of the development of the spit (Nielsen, Johannesen, 2004).

SHORELINES DURING OCCUPATION OF THE YDERHEDE SETTLEMENT

As mentioned above, a marine transgression was recorded in the stratigraphy above the peat layer, with a maximum occurring between 5300 and 5200 BC at a sea level a little above 13 m. This Early Ertebølle settlement was associated with a subsequent regression which apparently made habitation possible on this flat peat-covered area. The dates for the settlement cluster around 5100 BC (see list of radiocarbon dates). A subsequent later Atlantic transgression did not quite reach the same height as the first, as the settlement area itself was not transgressed. Following the closing of the lagoon, a lake phase began, after which silting up, overgrowth and the associated consequent growth of peat filled the lake, presumably accelerated by the continuing land upheaval.

At Dybvad, innermost in a Littorina fjord around Voersaa (Jessen, 1920), about 25 km south of Yderhede, Iversen (1943) has demonstrated two Atlantic transgressions which, by all accounts, are contemporary with Yderhede. The site lies on isobase 10.5 m (Mertz, 1924). The first transgression, termed by Iversen the Early Atlantic, reached an elevation of about 9.5 m, the subsequent regression had a minimum at

about 9 m, after which the so-called High-Atlantic transgression reached a minimum of 10 m. This is in very good agreement with the situation at Yderhede where, due to its more northerly location, it is the first transgression which is the highest. It has therefore been possible, by way of the Yderhede investigation, to date two of the well-documented transgressions demonstrated by Iversen.

Figure 5 shows the changes in sea level at Yderhede (curve 1) inserted into a diagram for shoreline displacement
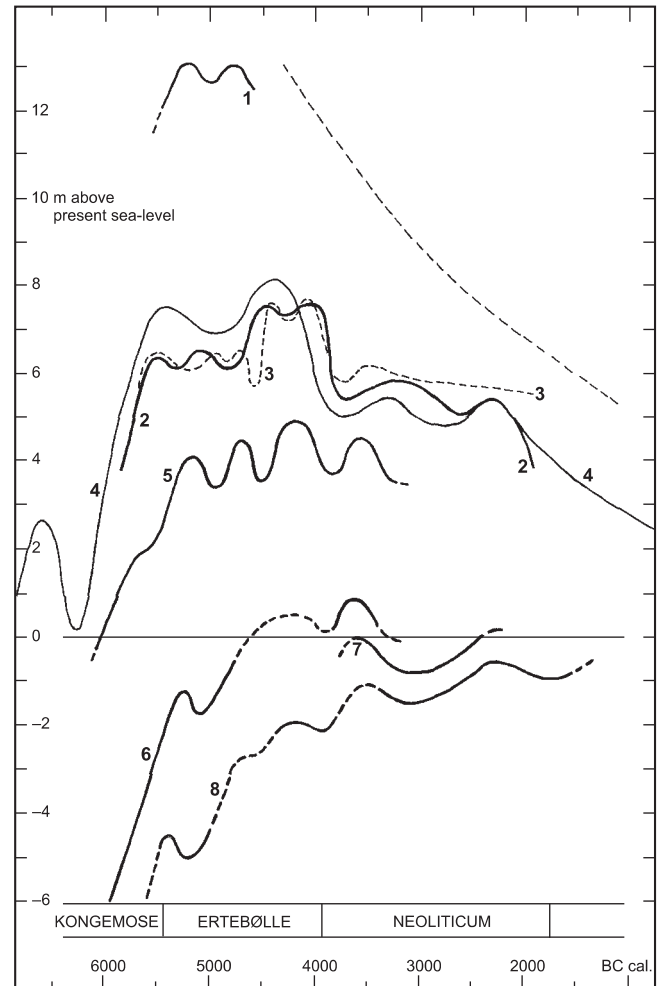

Fig. 5. Shoreline displacement curves for Denmark and Blekinge for the period 6,000–1,000 BC

The positions for the eight curves are shown in Figure 6: **curve 1** – Yderhede (this investigation), stippled line after Tanner (1993); **curve 2** – Blekinge (Berglund, 1971), calibrated by the authors; **curve 3** – Spjälkö, Blekinge (Liljegren, 1982), calibrated by the authors; **curve 4** – Blekinge (Yu, 2003; Berglund *et al.*, 2005); **curve 5** – Vedbæk (Christensen, 1982, 1995); **curve 6** – Halsskov (Christensen *et al.*, 1997); **curve 7** – Langeland (Christensen, 1998); **curve 8** – Western Baltic (Christensen, 1998). The archaeological division into main periods is given lowermost. For further details see text. Construction and drawing: Charlie Christensen, 2005.
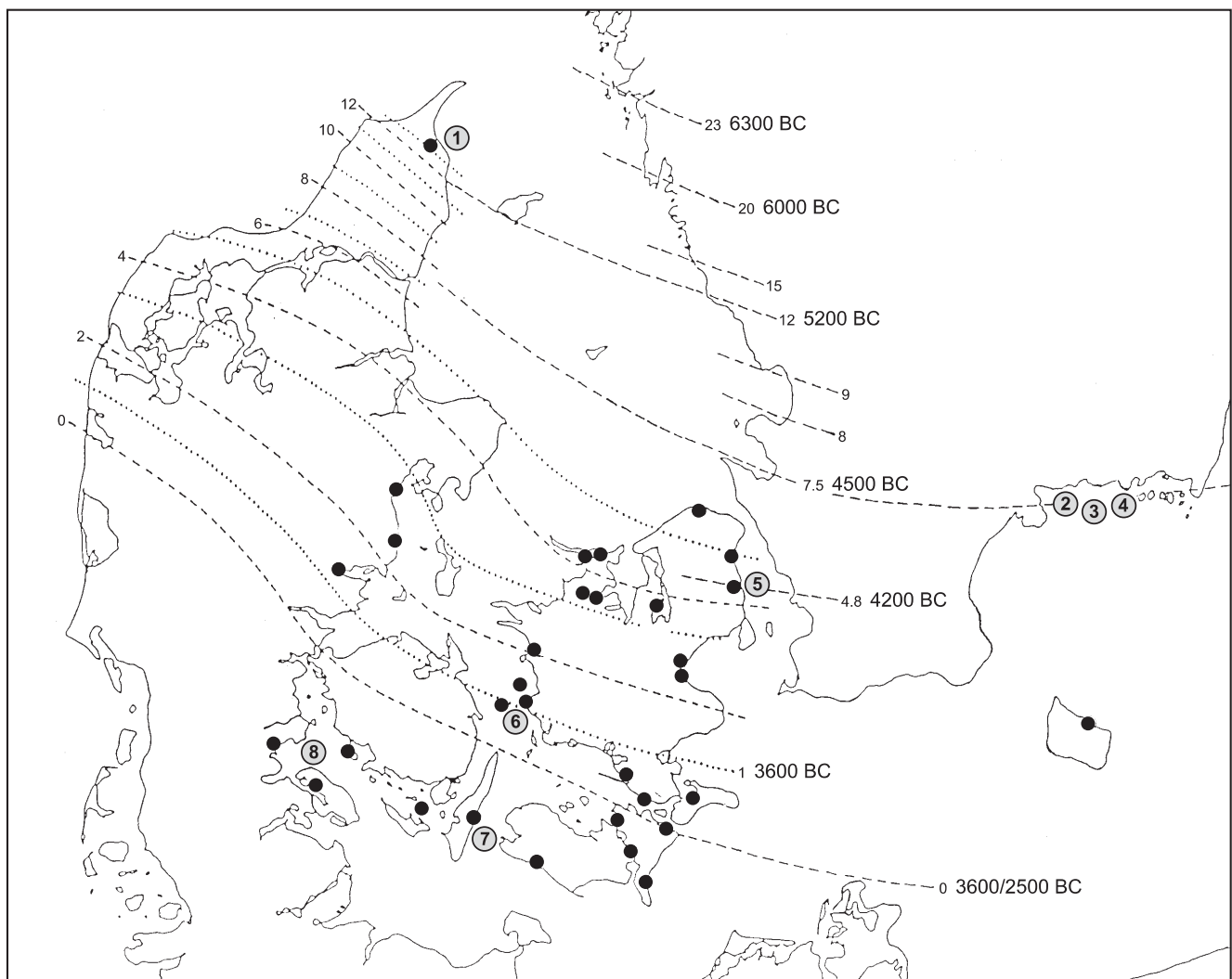
Fig. 6. Isobars for the highest shorelines of the Littorina Sea in Denmark (Mertz, 1924) and Sweden

Localities investigated by Charlie Christensen are shown with solid circles. The numbers 1–8 show the positions of the shoreline displacement curves in figure 5. On the west coast of Sweden the course of the isobases has been sketched on the basis of the following localities, starting from the north: Gothenburg – 23 m, Sandsjöbacka – 20 m, Varberg – 15 m, Falkenberg – 12 m, Halmstad – 9 m and Bjäre – 8 m, primarily after Påsse (1996). The authors' suggested isobase course across the Kattegat is shown with a stippled line. Isobase 7.5 m between Blekinge and Vendsyssel has been moved further north than in Mertz (1924), where it follows the north coast of Zealand. The age of the highest shoreline is given where reliable dates are available. Construction and drawing: Charlie Christensen, 2005.

for Southern Scandinavia for the period 6000–1000 BC. The stippled continuation of the Yderhede curve is after Tanner (1993) who has investigated the beach-ridge complex in the Jerup area northeast of Yderhede. The Yderhede site is exceptionally important as previously there were no comprehensive shoreline studies from Denmark at isobases higher than 5 m (i.e. Vedbæk, see Figure 6).

HEIGHT AND DATE OF THE LITTORINA SEA'S COASTLINES IN SOUTHERN SCANDINAVIA

Figure 5 shows a combination of five selected shoreline displacement curves from localities from the northernmost and highest to the southernmost and lowest Littorina isobases in Denmark. These were chosen on the basis of the first author's involvement in investigations of a large number of Southern Danish localities, see Figure 5 and Christensen (2001). The location of the selected curves is shown in Figure 6. Between Yderhede on isobase 13 m and Vedbæk on isobase

5 m, there are no detailed shoreline displacement curves available, which is why the three curves from Blekinge in Sweden on isobase 7.5 m have been included. Figure 5 illustrates differences in both the level and the course of the curves from Northern to Southern Denmark. It is apparent that there is, in this small country, nevertheless a difference in height of about 14 m between the highest shoreline of the Littorina Sea in Northern and Southern Denmark. Furthermore, it is appar-

ent that the highest shoreline level is dated later the further to the southwest the locality lies, but this will be explained in more detail later. A brief overview is given below of the investigation which have provided data enabling construction of the eight selected curves.

Curve 1 – Yderhede, Frederikshavn (Nielsen, Christensen, 1999), stippled: Tanner (1993). Described above.

Curve 2 – Blekinge, Sweden (Berglund, 1971), calibrated by the present authors.

Curve 3 – Spjälkö (Liljegren, 1982), calibrated be the present authors.

Curve 4 – Blekinge (Yu, 2003; Sandgren *et al.*, 2004; Berglund *et al.*, 2005).

The three Blekinge curves are based on detailed stratigraphic investigations of basins with thresholds along the Blekinge coast. The sea-level fluctuations have been established by way of several methods of palaeoecological analysis applied to cores taken from the basins, whereas the transgression maxima have been recorded *via* investigations of beach ridges.

Curve 5 – Vedbæk (Christensen, 1982, 1995).

The shoreline displacement studies were carried out in conjunction with archaeological excavations at ten settlements located on the shore of a small fjord. The sea-level fluctuations have been established through detailed recording and cross-correlation of numerous sections, while the precise height of the shoreline through the Atlantic and Subboreal has been established by way of numerous radiocarbon dates for tree stumps and archaeological features in the settlement areas and for discarded wooden artefacts from gyttja deposits formed offshore from the settlements.

Curve 6 – Halsskov (Christensen *et al.*, 1997).

The methods used were identical to those used at Vedbæk.

Curve 7 – Langeland (Christensen, 1998).

This short but well-dated curve was constructed around a Middle Neolithic wooden structure at a coastal settlement lying around present-day sea level.

Curve 8 – Western Baltic (Christensen, 1998).

The whole curve lies under the present-day sea level and is based on dates arising from archaeological investigations on the seabed or in dammed and now dried-out fjords. Use has also been made of dates for stumps of trees that were drowned by the progressive rise in sea level.

It lies beyond the scope of this article to attempt a correlation between the individual fluctuations in the selected curves shown in Figure 5. The three curves from Blekinge demonstrate that correlation is not always easy done. Reference is therefore made to the concise discussion in Christensen (1995). It is the maximum transgression levels which are of primary interest in this instance. Figure 5 shows that the highest sea level at Yderhede occurs about 5200 BC (during the earliest Ertebølle culture), in Blekinge around 4500 BC, in Vedbæk around 4200 BC (during the latest Ertebølle culture), at Halsskov around 3600 BC (Early Neolithic), on Langeland around 2200 BC (Late Neolithic) and, finally, in the Western Baltic around the birth of Christ. That is to say, the highest sea level occurs later the further to

the southwest a locality lies. The situation is, therefore, as is to be expected with a combination of a general, albeit slightly, rising sea level throughout the period in parallel with a isostatic upheaval which varied from large in the north to almost nothing in the southwest and which also decreased throughout the period.

Figure 6 is the classic illustration of the highest shoreline of the Littorina Sea (Mertz, 1924). This figure has been misused and misunderstood. The raising of the shorelines of the Littorina Sea is, as a result, often over-simplified and wrongly presented as a tilting process about the 0-isobase. But the position of this tilting axis was not stationary throughout the Littorina period as shown, for example, by Petersen (1985). The basis for the figure was, however, reliable geological fieldwork. During a long term programme of geological mapping, various traces of the Littorina Sea's raised shorelines were observed in the landscape. These could be in the form of beach ridges, coastal cliffs, terraces, the height of marine shell layers etc. Unfortunately the age of the raised shoreline was generally not known and the term "Littorina Sea" covers a period of 5,000–6,000 years. It has, however, always been clearly stated that the isobars shown in Figure 6 are not synchronous.

With the aid of the shoreline displacement curves shown in Figure 5, an attempt has been made in Figure 6 to allocate dates to some of Mertz' isobases. Furthermore, attempts have also been made to extend these isobases to the Swedish west coast and to Blekinge in order to place Denmark in a comprehensive Southern Scandinavian context. In drawing the isobases for the Swedish west coast extensive use has been made of the compilation of shoreline displacement curves in Påsse (1996). Yderhede's important position is immediately apparent from Figure 6.

There is a long-running geological discussion as to whether it is permissible to correlate shorelines across the Øresund and Kattegat as two marked geological fault lines run through these areas, the Sorgenfrei–Tornquist zone and the Fennoscandinavian marginal zone (Hansen, 1994). There is, however, nothing to indicate significant divergences in the age, direction and distance between the Danish and Swedish isobases. Accordingly, it can be presumed that there have been no movements along these zones in later Post Glacial times. The only break in pattern is the 7.5 m isobase which in Mertz (1924) follows the northeastern coast of Zealand. This isobase is difficult to transfer to the coast of Blekinge where it is securely fixed. However, marine layers have never been demonstrated above 4.5 m in the Stone Age fjords along the northeastern coast of Zealand (Rørdam, 1892). It would therefore be more correct to let the 6m-isobase follow this coast and, at the same time, it would correspond better to the Swedish situation if the 7.5 m-isobase were moved north of Kullen peninsula as has been done in Figure 6.

After inclusion of the Swedish data, Figure 6 shows how the time of the highest level of the Littorina Sea is displaced from 6300 BC at Gothenburg (isobase 23 m) to 3600/2500 BC at the 0-isobase in Southern Denmark. To the south of

the 0-isobase, in the Western Baltic, the present sea level was first reached around the birth of Christ, cf. Figure 5.

From time to time in Denmark examples have been presented of Post Glacial tectonic movements which have either locally or regionally influenced the height of the observed shoreline. In the authors' opinion no convincing local or regional deviations from the overall upheaval pattern as shown in the classic presentation of the course of the Littorina isobases (Mertz, 1924) have been documented. Only on Bornholm, in the Baltic, and on Læsø, in the Kattegat, both of which lie on the preciously mentioned fault lines (Hansen, 1994), have such phenomena possibly taken place.

Translated by David Robinson and Anne Block Jørgensen

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