Prehistoric settlements and Holocene relative sea-level changes in north-west Sjælland, Denmark

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The topographic and geographic distribution of the Mesolithic and Neolithic habitations seen today in the Saltbæk Vig area, north-west Sjælland are directly related to relative sea-level changes of the Littorina Sea. The archaeological data indicate that the settlements changed their topographic positions from lower to higher ground. This pattern is explained by a rising relative sea-level during the Atlantic and early Subboreal period. Geological investigations of this phenomenon focused on changes in relative sea-level documented by the sedimentary record. At Smakkerup Huse, a late Mesolithic site, a sequence of stacked transgressive and regressive sediment deposits confirmed that the occupation coincided with a slowing rate of relative sea-level rise and beginning of relative sea-level fall during the late Atlantic period. The timing of the changes in relative sea-level was obtained by radiocarbon measurements of wood and bone fragments together with implements retrieved from contemporaneous sediment deposits. A rise in relative sea-level during the early Subboreal forced the inhabitants at Smakkerup Huse and in the Saltbæk Vig area to relocate to higher grounds.

Key words: Holocene, relative sea-level changes, Littorina transgressions, Sjælland, Denmark, sequence stratigraphy, Mesolithic and Neolithic settlements.

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The focus of this paper is a discussion of the prehistoric habitation pattern in the Saltbæk Vig area, north-west Sjælland, Denmark. It is suggested that the topographic distribution of the late Mesolithic (5400–3900 BC) and early Neolithic (3900–2800 BC) sites reflects a response to a rising relative sea-level during the Atlantic and early Subboreal period. In an area like Saltbæk Vig, with shallow offshore gradients, land was flooded at a rate that may have reduced the low lying land areas and forced the inhabitants to settle on higher ground. This behavior is confirmed by the habitation pattern in the Saltbæk Vig area recorded during archaeological field surveys and excavations at the late Mesolithic site Smakkerup Huse. The geological transects demonstrate a sediment succession of land and shallow marine deposits reflecting the repeated changes in relative sea-level. Sequence stratigraphy is used to explain the sediment distribution during each succesive phase of relative sea-level rise and fall. Radiocarbon measurements provided a time scale for the relative sea-level changes interpreted from the sedimentary record. All quoted ages are calibrated radiocarbon years BC (for uncalibrated radiocarbon years, see Table 1). In this paper the relative sea-level changes documented in the sedimentary record are used as an explanation for the late Mesolithic and early Neolithic settlement pattern in the Saltbæk Vig area.

Geological setting

Saltbæk Vig is a small inlet in north-west Sjælland located north-east of the town of Kalundborg (Fig. 1). The inlet developed as an outwash plain from a large meltwater drainage system controlled by the last deglaciation, approximately 15,000 years ago (Milthers 1943, 1948; Berthelsen 1978; Houmark-Nielsen 1980, 1987; Noe-Nygaard 1995). The stream in the area today, Bregninge Å (see Fig. 2), runs in a former meltwater channel. The topographic map with 2.5 m contour intervals (Fig. 2) shows the outlet into Saltbæk Vig. Gravel quarries at the east end of Saltbæk Vig marks the place where boulders and glaciofluvial deposits accumulated in a high-energy environment

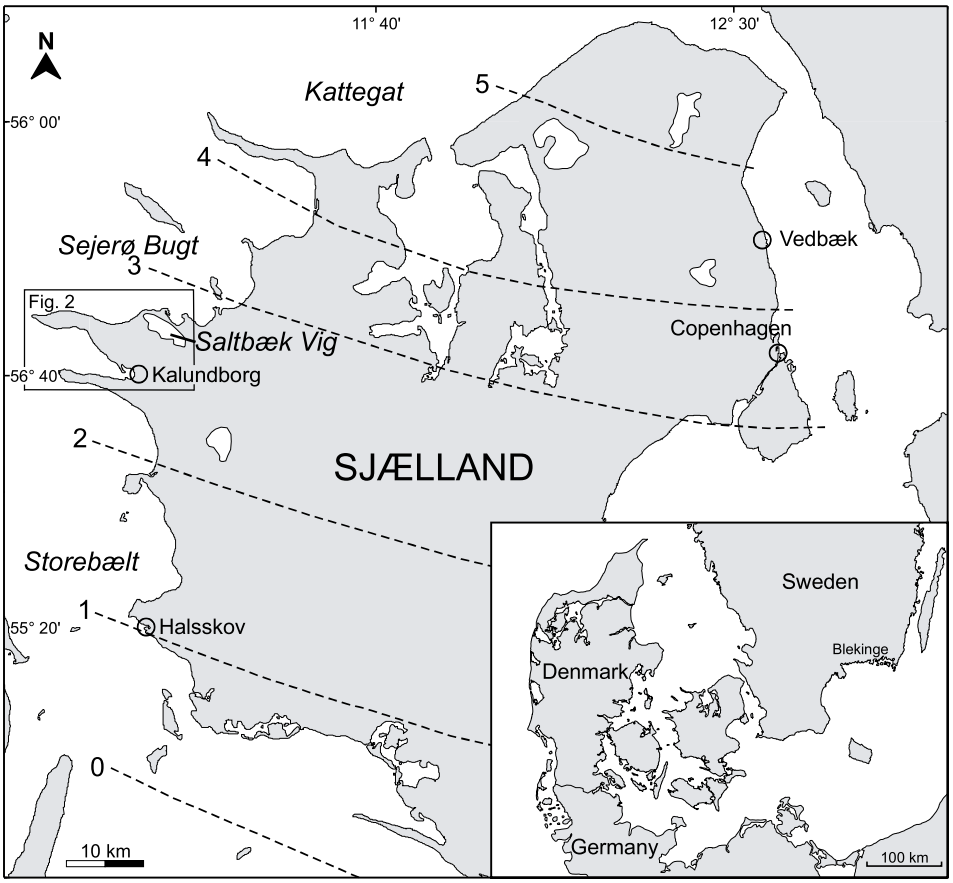

Fig. 1. Map showing the localities mentioned in the text together with the isobases of the total land uplift since the time of the Littorina Sea. The isobases are given in metres above present day sea level (Mertz 1924).

as they poured out from the meltwater channels (Humlum 1983). Clastic, more fine-grained delta sediments were deposited in Sejerø Bugt in front of Saltbæk Vig (Andersen 1998). The dead ice landscape left by the melting of stagnant ice and dead ice masses marks the southern and western drainage area of Saltbæk Vig. The many lakes and bogs in the present day landscape developed in the depressions left when remaining blocks of inactive ice finally melted. The arch-shaped terminal moraine at Røsnæs stands as a pronounced ridge to the west of Saltbæk Vig. It marks the recessional position of the receding ice sheet. Today, moraine material eroded from the cliffs at Røsnæs by the northward flowing current in Storebælt and accumulated as offshore barriers has separated Saltbæk Vig from Sejerø Bugt (Miljøministeriet 1984).

Table 1. ^{14}C dates of remains from the Smakkerup Huse site

Lab. no.	Bone	#Square	^{14}C age BP	Calibrated age BC
AAR-3316 [1]	Cow	412/502 (bed 3)	5040 ± 65	3950–3770
AAR-3317 [1]	Cow	413/496 (bed 2)	5040 ± 60	3950–3770
AAR-3318 [1]	Dog	411/501 (bed 11)	5300 ± 65	4230–4000
AAR-3782 [1]	Wood	416/500 (bed 1)	6140 ± 60	5060
AAR-3783 [1]	Peat	416/500 (bed 1)	6495 ± 60	5430
WG-2574 [2]	Bone point	412/502 (bed 13)	6100 ± 60	4993
WG-2575 [2]	Lamp residue	403/538 (bed 12)	5650 ± 70	4466

[1] AMS ^{14}C dates performed by the AMS Laboratory, Institute of Physics and Astronomy, University of Aarhus, Denmark.
[2] NEC ^{14}C dates performed at the University of Wisconsin-Madison, USA.

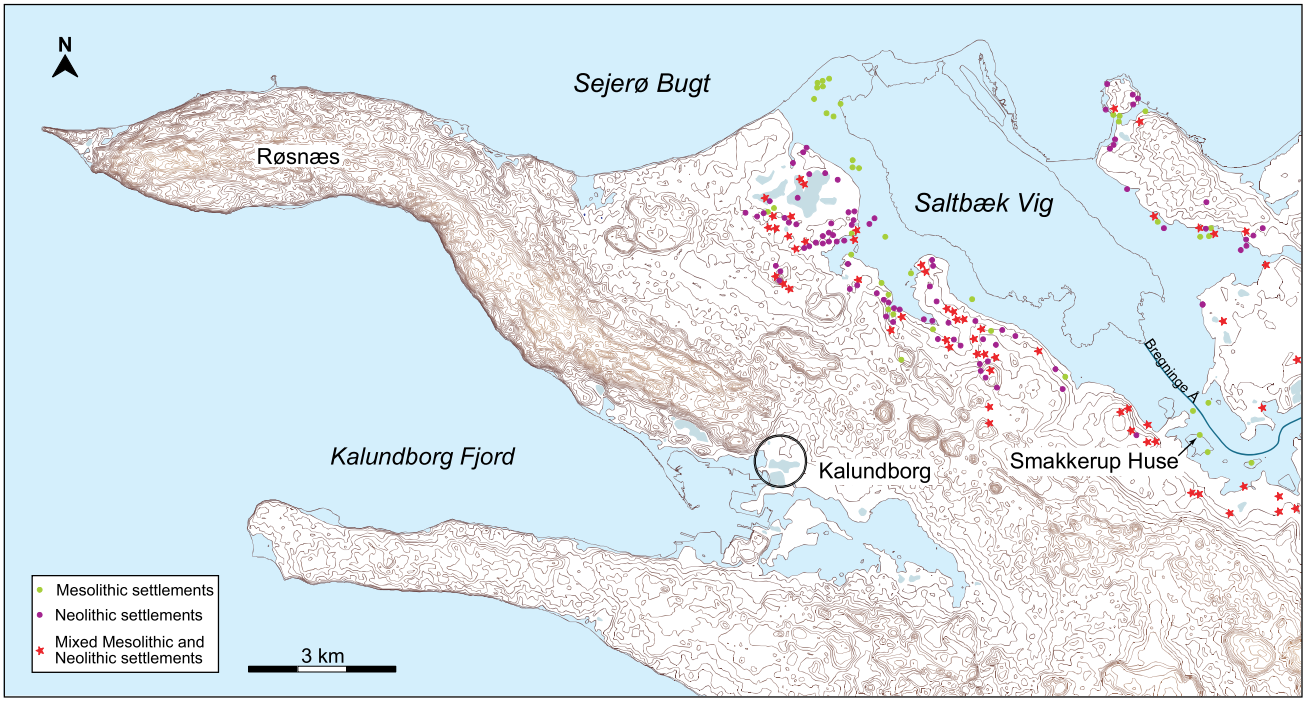

Fig. 2. Contour map of north-west Sjælland with recorded archaeological sites (modified from Gebauer & Price 1990). The contour interval is 2.5 m. The approximate sea level during the late Atlantic to early Subboreal is indicated in blue. Note the location of Smakkerup Huse near the mouth of Bregninge Å. Map copyright of Kort & Matrikelstyrelsen G 15-99.

The habitation pattern in the Saltbæk Vig area

Since the 1870s, water level in Saltbæk Vig has been maintained 1.20 m below present day sea-level by drainage and pumping at the mouth of Saltbæk Vig due to a failed attempt to drain the inlet and turn it into farmland. As a result of this, the sediment deposits and the prehistoric settlements, most of which would otherwise be covered by the sea, are now accessible. The archaeological surveys of the agricultural fields along Saltbæk Vig resulted in a registration of approximately 150 archaeological single finds together with actual settlements (Gebauer & Price 1990). The settlements are primarily from the late Mesolithic and early Neolithic cultural periods. The late Mesolithic settlements were found exclusively at or below the 2.5 m contour, while early Neolithic settlements were found at or above that elevation contour (Gebauer & Price 1990; see Fig. 2). The average elevation of the late Mesolithic settlements is 1.74 m; the average elevation of the early Neolithic settlements is 3.16 m. These results imply that there is a connection between the topographic distribution of settlements and position of sea-level. The late Mesolithic and early Neolithic settlements occur together along the irregular south-western shore of the inlet clustered toward the mouth of Saltbæk Vig (Fig. 2). They tend to be concentrated at sheltered locations on points of land and peninsulas at or close to the former coastline. A relative sea-level curve based on the position of archaeological sites in relation to shoreline displacements during the Atlantic (7000–3800 BC) and Subboreal (3800–550 BC) period in north-east Sjælland has been compiled by Christensen (1982, 1993, 1995). In the present study, geological transects reveal a series of minor transgressions (known as the Littorina transgressions) and regressions superimposed on the eustatic sea-level rise. Similar observations have been made by Christensen (1982, 1993, 1995). The sediment distribution observed in the study area shows that the early Atlantic Littorina transgression never flooded the Saltbæk Vig area but it resulted in a rising ground water level and thus growth of lakes and bogs in the area. Marine deposits did not accumulate until later in the Atlantic; the maximum relative sea-level of approximately 2.5 m (see Fig. 1) above present day sea-level was probably first reached during the early Subboreal period (Christensen 2001).

The Smakkerup Huse settlement site

Smakkerup Huse is the name given to a small area defined by the 2.5 m elevation contour. The topography drops from south to north towards the outwash plain and to a lesser extend from east to west (Fig. 3). This area would have been an island during periods of high relative sea-level in the late Atlantic and early Subboreal. Archaeological investigations and excavations carried out in 1989 and from 1995 through 1997 (Price *et al.* 2001) exposed coarse-grained sedimentary deposits with stones and redeposited artifacts to the south and gyttja with *in situ* artifacts to the north. The actual settlement is gone due to erosion. The implements were recovered from the refuse dumped in the nearshore marine environment adjacent to the settlement. The Smakkerup Huse site belongs to the middle (Stationsvejfase, 4800–4300 BC) and late (Ålekistebrofase, 4300–3900 BC) Ertebølle culture by the typology in accordance with the ^{14}C datings (see Table 2). Finds of dugout canoe fragments and fish weir posts evidenced that the people lived and worked close to the sea. Further, the place name Smakkerup indicates that the area must have been accessible by boat at least until the Viking age (a smakke is a type of Viking ship; Gebauer & Price 1990).

Table 2. Lithological description of beds in profiles 1 (Fig. 4) and 2 (Fig. 5A)

Bed	Lithology	Cal age (yr BC/yr BP)	Cultural phase
1	Freshwater peat with *in situ* tree trunks on top Underlies the sequence in profile 1.	Tree 5060/6140 Peat 5430/6495	
2	Organic rich, coarse-grained sand. Grades seaward into marine coarse-grained sandy shell gyttja (bed 10).	Cow 3950/5040	
3	Organic rich, coarse-grained sand with pebbles. Grades seaward into marine, very coarse-grained sandy shell gyttja (bed 11).	Cow 3950/5040	
4	Organic rich, medium- to coarse-grained sand with pebbles and shells in the lower part. The top is rusty, penetrated by roots.		
5, 6	Nearshore, very coarse-grained structureless sand with pebbles and cobbles. The lower boundary is erosional and cuts into older sandy deposits (bed 4).		
7	Nearshore, very coarse-grained sand with pebbles and cobbles. Fines in a seaward direction and grades into bed 8.		
8	Organic rich, medium-grained sand. Tree trunk on top. Cultual layer.		
9	Coastal, structureless coarse-grained sand.		
10	Coarse-grained sandy shell gyttja. *Cardium* shells.		Ålekistebro
11	Very coarse-grained sandy shell gyttja. *Cardium* shells.	Dog 4000/5300	Ålekistebro
12	Marine shell gyttja. Mainly oysters. Dug out canoe fragments.	Lamp residue 4466/5650	Stationsvej
13	Sandy shell gyttja. Mainly oysters. Cultural layer. Charcoal.	Bone point 4993/6100	Stationsvej
14	Brownish sandy gyttja with no cultural remains. Wedges out landward.		
15	Wavy laminated silt and organic rich silty clay.		
16	Plow zone.		
17	Modern fill, railway cutting.		

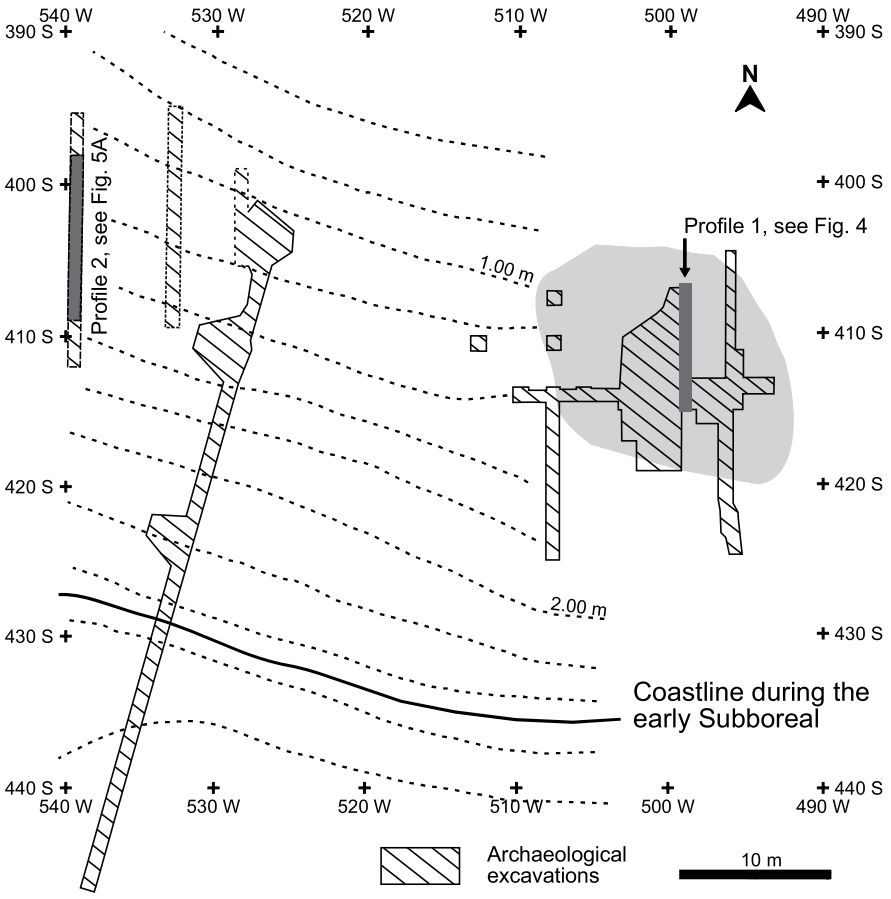

Fig. 3. The archaeologicial excavation plan of the Smakkerup Huse site. Note the location in relation to topography. The palaeocoastline during the late Atlantic to early Subboreal is based on the archaeological data and the geological investigations of profile 1 (Fig. 4) and profile 2 (Fig. 5A). Shaded: area

Changes of relative sea-level documented by the sedimentary record

The geological profiles (Fig. 4, 5A) show a composite sediment succession from peat (bed 1), upper shore face sand (beds 2–4), beach ridges (beds 5–7), coastal coarse-grained sand (beds 8–9) to dark silty, marine shell gyttja (beds 10–14). Profile 1 (Fig. 4) is similar to profile 2 (Fig. 5A) but extends further inland. The sediments are described in Table 2. The sediment distribution and type observed at Smakkerup Huse is a response to changes in accommodation space. In this nearshore environment relative sea-level (here a combination of eustasy and isostasy) is the predominant factor in determining sediment accommodation space. The primary period of concern for the present discussion extends from 5400 BC to 3300 BC, encompassing the middle and late Atlantic and the early Subboreal periods (see Fig. 6). The first sign of the Littorina transgressions at Smakkerup Huse is marked by a drowning surface separating the peat (bed 1) from the overlying transgressive deposits (beds 7–8 and beds 12–13; Figs 4, 5A). The drowning surface indicates an abrupt increase in relative sea-level (HA/LA–TS). The peat is dated to 5430 BC (Table 1), and an *in situ* oak trunk from the top of that level has been radiocarbon dated to 5060 BC. The oak tree probably died due to a rise in base level and ground water level following the transgression, which began during the middle Atlantic. The overlying transgressive deposits consist of coarse-grained beach ridge sediments (bed 7) accumulated in a nearshore, high-energy environment, probably the swash zone. The beach ridge grades seaward into coastal, coarse-grained sand (bed 8) and marine, silty shell gyttja deposited in a low-energy or deeper-water environment below fair-weather wave-base (Fig. 5A). The marine shell gyttja (beds 12–13) contains oysters indicating fully marine conditions and exchange of warm and oxygenated seawater. The fine-grained shell gyttja (bed 12) was deposited at the time when the rate of relative sea-level rise was at its highest (Fig. 5B). A lamp residue from bed 12 is dated to 4466 BC (~ late Atlantic period). Beds 1, 7–8 and the lower part of 12 were deposited just before the settlement was established (Fig. 5B). The cultural remains, which occur in bed 13 and in the top of bed 12, are dated to Stationsvejfasen 4800–4300 BC (see Table 2). A bonepoint from bed 13 is ra-

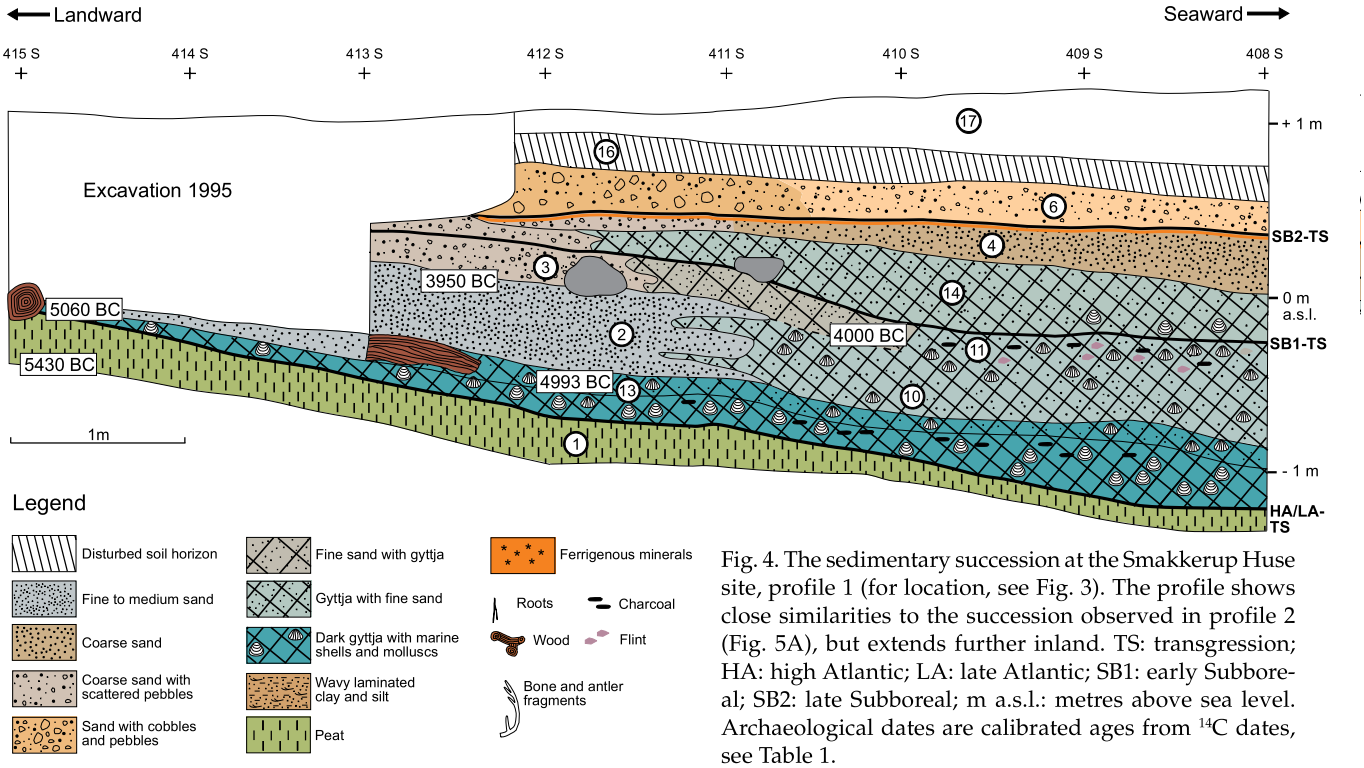

Fig. 4. The sedimentary succession at the Smakkerup Huse site, profile 1 (for location, see Fig. 3). The profile shows close similarities to the succession observed in profile 2 (Fig. 5A), but extends further inland. TS: transgression; HA: high Atlantic; LA: late Atlantic; SB1: early Subboreal; SB2: late Subboreal; m a.s.l.: metres above sea level. Archaeological dates are calibrated ages from ^{14}C dates, see Table 1.

diocarbon dated to 4993 BC. This age seems too old and suggests that the bonepoint is redeposited. Towards the top of bed 13 and in close proximity to the coast (beds 2–3) the marine shell gyttja becomes sandier and looses the content of marine molluscs (Fig. 4). The coarsening upward trend reflects deposition during the subsequent period of relative sea-level fall (Fig. 5B). The accommodation space was reduced, followed by progradation of the shoreline. As the shoreline prograded seaward, marine sandy gyttja with fewer and more fragmented molluscs shells was deposited (beds 3, 11; Fig. 4). This indicates deposition in a more high-energy environment close to the coast. The changes between coarse-grained, brackish bay deposits (beds 10–11; Fig. 4) interfingering with upper shoreface sand (beds 2–3; Fig. 4) are a result of the interplay between transgression, regression and sediment discharge. Beds 10–11 are dated to Ålekistebrofasen 4300–3900 BC by means of the cultural remains. Radiocarbon measurements of bone fragments correspond to the archaeological dating. Two cows (*Bos domesticus*, beds 2–3) are radiocarbon dated to 3950–3700 BC and a dog (*Canis familiaris*, bed 11) is radiocarbon dated to 4230–4000 BC (Table 1; Hede 1999). The datings show that the stacked sequence of regressive deposits (beds 2–3 and beds 10–11) was deposited during a relative sea-level fall between the late Atlantic and early Subboreal period (Fig. 5B). The transition between bed 11 and bed 14 is a transgressive surface interpreted to correspond to the early Subboreal Littorina transgression (Fig. 4; SB1–TS). A maximum relative sea-level of 2.5 m. is supposed to occur at Smakkerup Huse in early Subboreal time (Christensen 2001). The early Subboreal Littorina transgression should therefore be easily identified in the sediments at Smakkerup Huse. During the following sea-level highstand (early Subboreal HS; Fig. 5B) and maximum regression (occuring at the inflection point towards relative sea-level fall, see Fig. 5B) the relative sea-level started to fall and finally caused subaerial exposure of the depositional surface (bed 4). Medium- to coarse-grained sand was deposited and a reed swamp (*Phragmites australis*) developed at the time when relative sea-level was at its lowest, at some time during the Subboreal. The onset of the renewed rise in relative sea-level (SB2–TS) started with a transgressive surface of erosion (Fig. 5). The lower boundary is erosional and cuts into the older sandy deposits (bed 4). This reflects deposition in a high-energy environment and reworking of the substrate by wave action. Formation of beach ridges and sand barriers finally closed Saltbæk Vig. Wavy laminated clay and silt (bed 15, Fig. 5A) were deposited in the low-energy environment of the Saltbæk Vig lagoon, which formed an efficient trap for sediment to accumulate. Due to modern ploughing, sedimentary deposits younger than Subboreal are not represented at Smakkerup Huse.

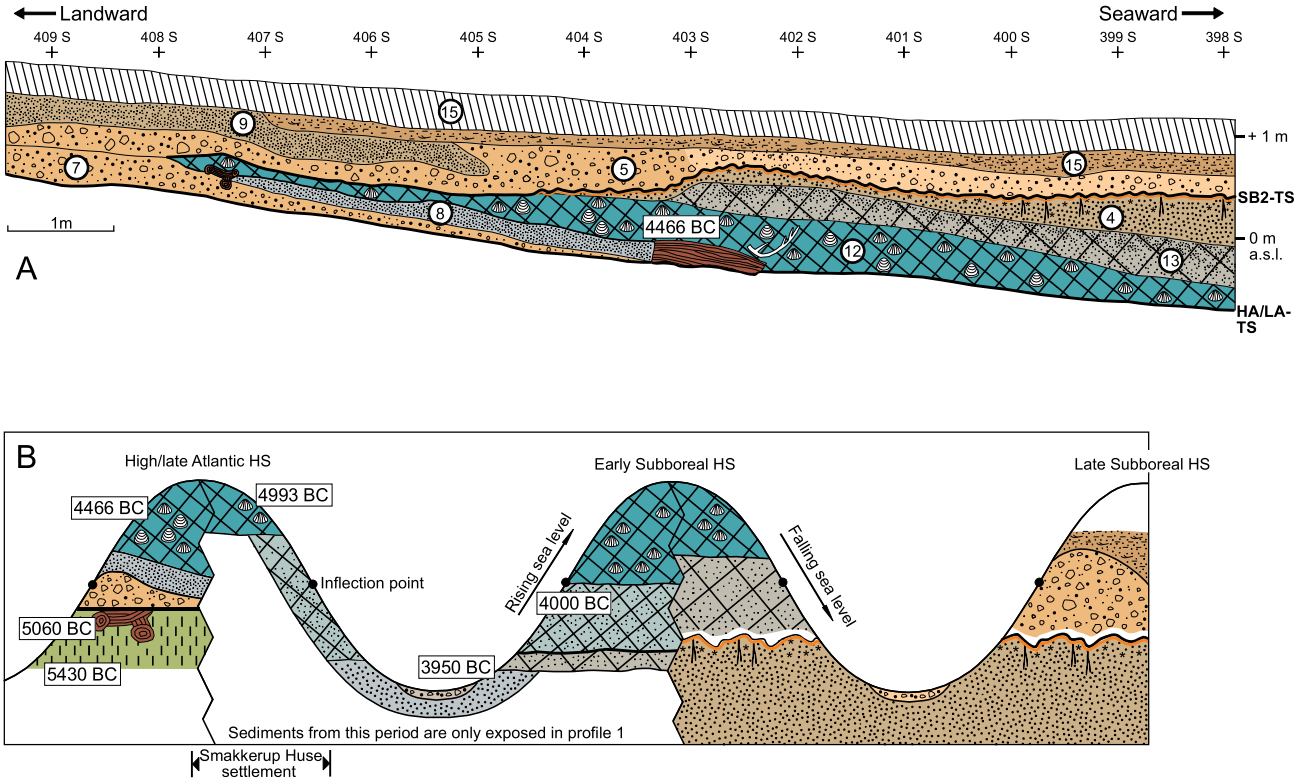

Fig. 5. A: The sedimentary succession at the Smakkerup Huse site, profile 2 (for location, see Fig. 3; for legend, see Fig. 4). TS; transgression; HA: high Atlantic; LA: late Atlantic; SB1: early Subboreal; m a.s.l.: metres above sea level. B: Relationship between development of sedimentary facies and relative sea level fluctuations deduced from the successions shown in profiles 1 and 2. HS = high stand of sea level. Archaeological dates are calibrated ages from ^{14}C dates, see Table 1.

Conclusion

The fluctuating relative sea-level of the Littorina Sea had a major influence on the habitation pattern of people living in the coastal Saltbæk Vig area. In Figure 6 a comparison is made between the length of the transgressive periods observed at Smakkerup Huse and at other localities on Sjælland and in southern Sweden. At Smakkerup Huse the first Littorina transgression began at the end of middle Atlantic (5060 BC) and continued into the late Atlantic (~ 4300 BC). The Littorina transgression (HA/LA–TS) is represented by a marine shell gyttja. In southern Sjælland (Halsskov; see Fig. 1) the HA/LA–TS corresponds to a relative sea-level rise, which began around 4800 BC and was followed by a relative sea-level fall around 4000 BC (Christensen 2001; Christensen & Andreasen 1999; Christensen *et al.* 1998; see Fig. 6). A reevaluation of the investigation at Vedbæk, north Sjælland (Christensen 1982) suggests that the two transgressive events during the late Atlantic period can be merged into one event (Charlie Christensen personal communication 2003; marked by a dotted line in Fig. 6), which began around 4800 BC and ended just before the Subboreal period, 4000 BC. The transgression could then be correlated with the HA/LA–TS at Smakkerup Huse. In Blekinge, southern Sweden, one transgression also dominated throughout the late Atlantic (4600–3800 BC; Fig. 6). At Vedbæk the time of maximum transgression occurred at the end of the Atlantic period (4200 BC) and at Halsskov it occurred in the beginning of the Subboreal (3600 BC; see shoreline displacements curves in Fig. 6). This indicates that the time of maximum transgression becomes progressively later towards the southwest (see Fig. 1 for position of the localities). At Smakkerup Huse the most extensive marine flooding, corresponding to SB1–TS in Figure 4, probably occurred during the early Subboreal, somewhere between 4200 BC and 3600 BC. The rise in relative sea-level (SB1–TS) caused the cessation of the late Mesolithic habitation at the Smakkerup Huse site. Archaeological data from the Saltbæk Vig area indicate that a new foundation for rehabitation on higher ground was established. Late Mesolithic sites show a maritime preference both in terms of elevation and location on nearshore sediments. Early Neolithic sites are located in the same areas, but generally these sites are found at higher elevations and more inland in relation to the coastline.

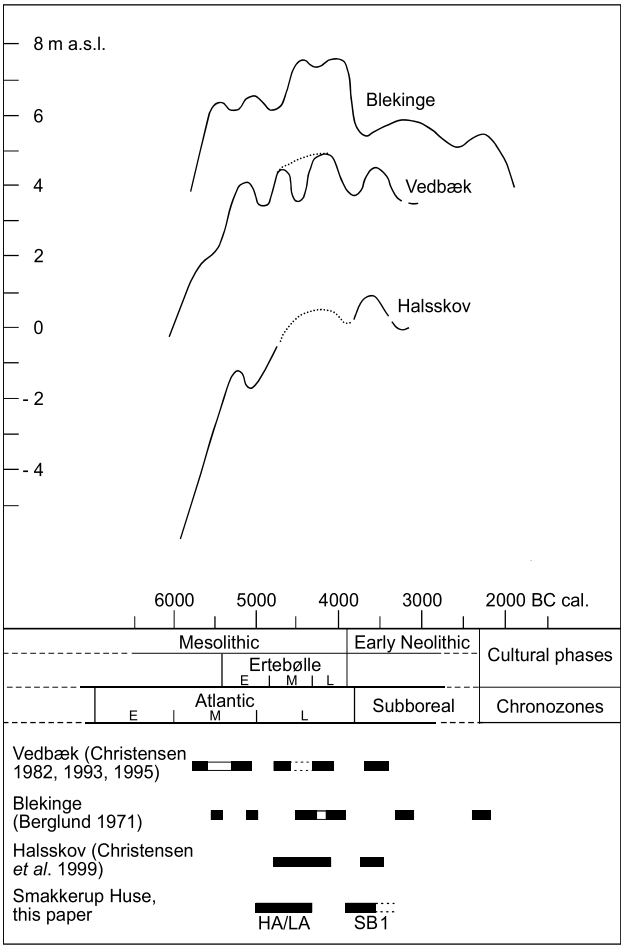

Fig. 6. Shoreline displacement curves and investigations of the Littorina transgressions (for location, see Fig. 1). The black horizontal bars show the duration of periods with high relative sea level (Littorina transgressions). HA/LA: high Atlantic to late Atlantic; SB1: early Subboreal; m a.s.l.: metres above sea level. Modified after Christensen (1995, 2001).

Acknowledgements

All colleagues who participated in the Saltbæk Vig Archaeological Project are thanked. I am deeply indebted to T. D. Price and A. B. Gebauer for their help and support during fieldwork. The ideas presented here benefited from stimulating discussions with Nanna Noe-Nygaard whose help in correcting this manuscript is greatly acknowledged. The referees Björn Berglund and Charlie Christensen are thanked for their critical and constructive comments on the manuscript.

Dansk sammendrag

I artiklen beskrives resultaterne af et studie over relative havniveauændringers indflydelse på den geografiske beliggenhed af sen mesolitiske og tidlig neolitiske bopladser i et område omkring Saltbæk Vig nord for Kalundborg (Fig. 1). Vandstanden i Saltbæk Vig holdes kunstigt 1,2 m under nuværende havniveau. Den kunstige lave vandstand har betydning for udforskningen af bopladsernes beliggenhed, idet det betyder, at de kan undersøges på tørt land. I Atlantikum varierede det relative havniveau i Saltbæk Vig området fra ca 1 m til ca 2–3 m over det nuværende havnivau. I topografisk set flade områder som Saltbæk Vig har sådanne ændringer i det relative havniveau betydet store forskydninger af kystlinien. Dette afspejles af de mange fund af bopladser og deres placering i forhold til højdekoter og aflejringstyper. Tilsammen giver disse oplysninger et billede af, hvor datidens befolkning foretrak at bosætte sig. Både de mesolitiske og neolitiske bopladser viser en kystnær beliggenhed (Fig. 2). Størstedelen af de mesolitiske bopladser er beliggende på strandvoldsaflejringer og har således været placeret i havstokken. De neolitiske bopladser er beliggende på moræneaflejringer samtidig med, at de viser en langt større spredning ind i landet. Sekvenstratigrafi bygger på det koncept, at distinkte sedimentationsskift afspejler ændringer i energiniveau og dermed ændringer i det relative havniveau. Dette er forsøgt anvendt på de sedimentære aflejringer med henblik på at fastslå, hvordan og hvornår det relative havniveau varierede. Disse oplysninger giver en bedre forståelse af bopladernes placering i Saltbæk Vig området. ^{14}C dateringer af egestammer og vedstykker udgravet på kystbopladsen Smakkerup Huse viser, at en begyndende grundvandsstigning og forsumpning af området som følge af en relativ havniveaustigning i mellem atlantisk tid forårsagede egetræernes død. Dette er det første marine indslag i Saltbæk Vig området. Det høje relative havniveau gjorde det ikke længere muligt for befolkningen at opholde sig på bopladsen Smakkerup Huse, og den blev derfor flyttet længere ind i landet. Fra denne boplads er der kun gjort fund af udsmid placeret i umiddelbar tilknytning til bopladsen ud for strandbredden (lag 12–13); selve bopladsen er borteroderet af havet. Herover følger en lagserie, der indeholder udsmid og udvasket materiale fra højereliggende kulturlag. Øverst findes en strandvoldsaflejring, der ligesom rekognoseringerne på marken vidner om fortsat bebyggelse ind i Subboreal tid. Ved Smakkerup Huse indtræder tidspunktet for den højeste transgression først i tidlig Subboreal tid. Littorina transgressionerne, som de er observeret ved Smakkerup Huse, er sam-

menlignet med strandforskydningskurver fra Halsskov, Vedbæk og Blekinge (se Fig. 6).

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