Environmental changes recorded in the Holocene molluscan faunas from Djursland, Denmark

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Kaj Strand Petersen. Environmental changes recorded in the Holocene molluscan faunas from Djursland, Denmark. — Scripta Geol., Spec. Issue 2: 359-369, 3 figs., 2 pls. Leiden, December 1993.
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Key words: Holocene, Denmark, marine Mollusca, radiocarbon datings, sedimentation rate, palaeoecology.
Environmental changes in the Holocene molluscan fauna are elucidated by the investigation of the Korupsø area in the central part of Djursland, Denmark, on macrofossils and ^{14}C datings of shell material. The oldest recorded stratum is a lacustrine Boreal lime gyttja which in the Early Atlantic was covered by saltwater gyttja with a rich fauna of molluscs. The fauna is characterised by *Ostrea edulis*, *Venerupis decussata*, *Macoma balthica*, and *Corbula gibba*. *Bittium reticulatum* is only found in large quantities within this older part of the sequence up to the end of the Atlantic. The disappearance of *Bittium reticulatum* in the Subboreal is explained as having been caused by a change to a more brackish environment. This explanation is supported by the decline in numbers of *Hydrobia ulvae* and the occurrence in equal numbers of *Hydrobia ventrosa* in the Subboreal. The rate of sedimentation was low during the Atlantic (1 m per thousand years) compared to the Subboreal, when a sedimentation of up to 5 m per thousand years has been observed. This change in sedimentation rate is tentatively connected with a lowering of the tidal range in the Danish waters since the Atlantic.

Contents

Introduction

Denmark is part of the subsiding area of the North Sea, where, in the central part, c. 1000 m of Quaternary sediments have accumulated. Furthermore, the area is placed within the submarginal zone of the Quaternary glaciations, and as a result of this up to 200 m of glacial sediments have accumulated during the Late Pleistocene.

The recurrence of ice caps over the Danish area during the Pleistocene, spreading from the central part of Scandinavia, contributed with a great variety of material from afar. Furthermore, the impact of the icecover has had an effect on the isostatic movements. According to Mertz (1924) the Djursland Peninsula belongs to the northeastern Danish area of isostatic uplift. The area in question is situated between the

+3.0 and the +4.5 m isobase. The Korupsø area, at a level of +3 m, has been connected with the Kattegat through the Kolindsund as figured by Jessen (1920, map 1), see Fig. 1 in this paper, and to the northwest towards Randers Fjord during the Littorina Sea fjord stage. This implies that the Kolindsund Fjord system in those days was a strait with an east-west extent of nearly 50 km, where the Korupsø, situated in the middle, formed a southward branch. The stratigraphic and spatial position of the Holocene sediments accumulated on the Djursland Peninsula show no marked change from the Late Weichselian to the Holocene. However, it must be stressed that during Late Weichselian and up to Early Holocene times the area was deeply eroded due to the low-laying erosional base during the Continental period (11,000-7500 years BP). During this period most of the Danish area, including part of the present sea territory, was above sea level (Petersen, 1985) and consequently the deeply cut part of the Kolindsund is regarded as having been formed during this period.

The history of the lake/fjord system Korupsø can be dated back to the Boreal (by pollen analyses - H. Krog pers. comm.). Freshwater deposits with *Anodonta* sp. and other lacustrine molluscs are found underlying the beds from the marine transgression during the Atlantic. The marine stage existed up to the Late Subboreal according to ^{14}C dating of the brackish water species *Cerastoderma glaucum* from the area. Subsequently, freshwater gyttja was deposited until the lake was reclaimed in the last century.

Geological setting

The question of sea-level changes in the Atlantic and Subboreal has particularly interested Danish researchers. One can point to 1937 as the publication date of these investigations by Iversen (1937), Jessen (1937) and Troels-Smith (1937, 1942).

In general these studies, especially through the work of Iversen, succeeded in showing four *Littorina* transgressions: the Early Atlantic, the High Atlantic, the Late Atlantic and the Early Subboreal.

Of the above-mentioned investigations of the *Littorina* transgressions, those of Troels-Smith are related to coastal settlements. Iversen's studies were based on diatoms, pollen and *Hystrix* in fjords, where height of the threshold is crucial for the transgressional history.

Korupsø on the Djursland Peninsula was one of the fjords Iversen investigated. The whole series of layers is marine, and according to Iversen only the quantity of *Hystrix* indicated the transgression. These *Hystrix* (hystrichosphaerids) are the remains of organisms many of which also live in Danish waters today. It was Iversen's belief that these *Hystrix* were washed out of glacial deposits during periods of transgression. As they are found in Danish waters today, however, one must go further, and to follow up Iversen's idea it is necessary to establish which of these organisms derive from the late glacial deposits. Recent investigations at Korupsø by H. Krog (pers. comm.) have also shown that the hystrichosphaerid curve is more complex than Iversen's investigations suggested.

What is at stake here is the maximum connection with open water, and thus a higher salt content in the water. Maximum values in the diversity of the molluscan fauna could therefore be used. In this connection *Ostrea edulis* appears in Korupsø around

the High and Late Atlantic transgression in a rich faunal association, which is contemporary with the data on oysters from the site of Barkær (Fig. 2) next to Korupsø (Troels-Smith, 1982).

In the faunal succession off the Dyrholm settlement on Djursland, to the northwest of Korupsø, at another branch to the Kolindsund Fjord system (Fig. 1), there is also a level with *Ostrea edulis* and *Venerupis aurea* (Gmelin, 1791) dated to the High Atlantic (Troels-Smith, 1942; Petersen, 1985).

The geobotanical investigations did demonstrate the different transgressions through the Littorina Sea stages. However, the influences of such environmental changes on the macrofauna, in casu the molluscs, were still an open question. Through time workers on macrofossils from the Danish Holocene had been aware of the high amount of halophilous species far up the former fjords that open on to the Kattegat and the Limfjord region.

In 1938 Steemann Nielsen published his paper on 'the hydrography of the Danish waters during the *Littorina* Sea period' (author's translation). In this paper Nielsen (1938: 340) suggests that the higher exchange of water was caused by a higher tidal range than nowadays. Already Spärck (1926) argued that the much wider range of *Scrobicularia plana* in Danish waters during the *Tapes*-period (the *Littorina* Sea stages) might suggest that conditions of nourishment were better then than they are now. The cause might have been that the tides then may have been considerably stronger in the Kattegat region.

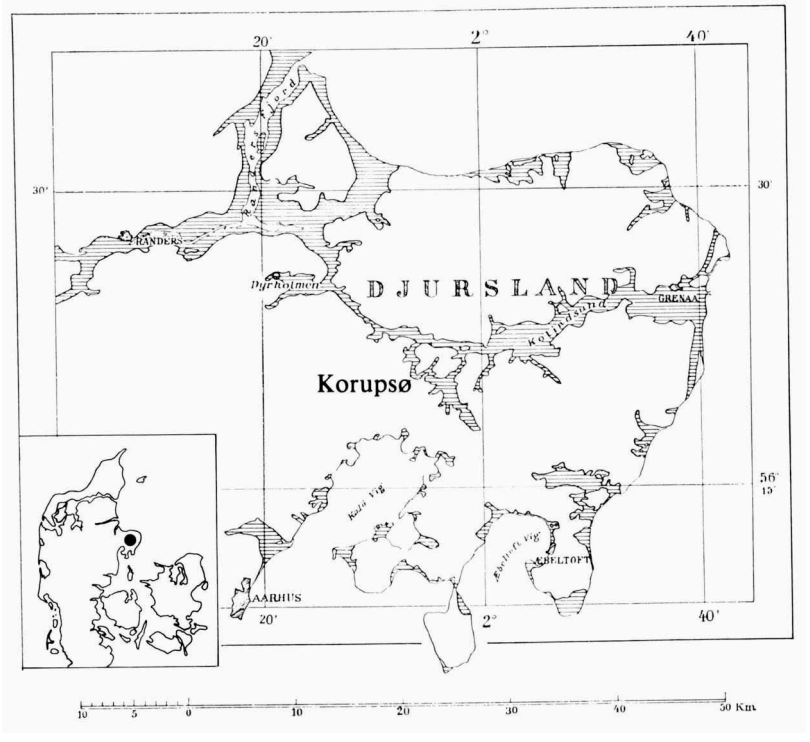


Fig. 1. Location map.

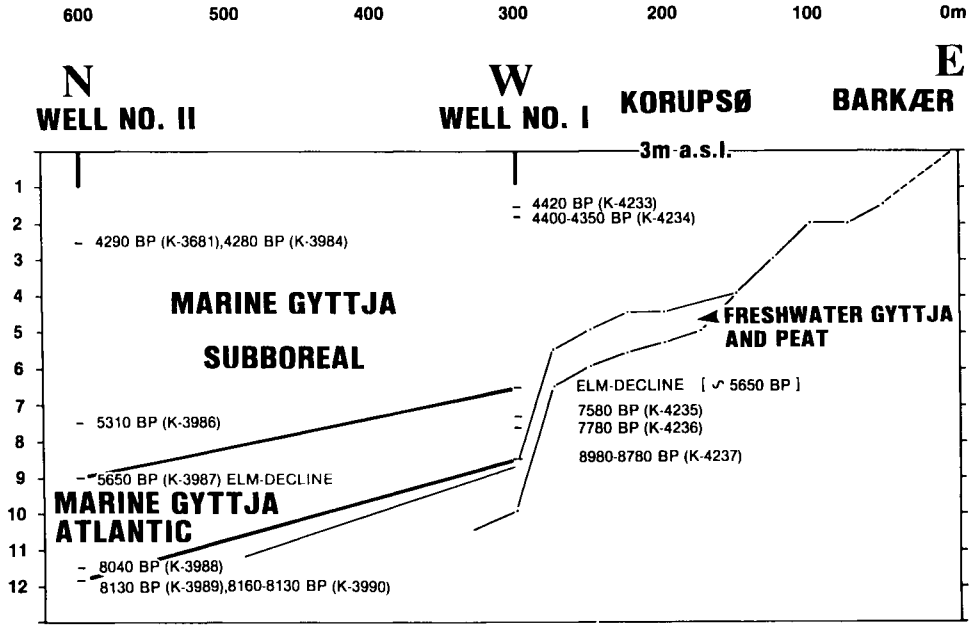


Fig. 2. Section through the drillings in Korupsø with Well no. I and II. The calibrated years BP together with their K-no. (Copenhagen ^{14}C Laboratory) are given for the strata. The siting of the Elm-decline is based on the pollenanalyses by H. Krog.

The marine molluscan assemblages in Korupsø

The investigations in the Korupsø area are based on several drillings, one of which (no. I) has been analysed in detail with quantitative analyses of the molluscan assemblages through time, see Table 1, with ^{14}C datings at certain levels.

From a nearby well (no. II), 300 m north of no. I (Fig. 2), another series of samples has been taken and a set of five ^{14}C datings has been performed which permits a correllation on dated strata between the two wells. Furthermore both wells are under pollen-investigation by H. Krog and informations on their pollen stratigraphy are kindly given by H. Krog (pers. comm.).

In the two wells the same molluscan species have been found. The list of molluscan species can be seen on Table 1 showing the development through time in well no. I. In all 26 species are recorded, 11 bivalves and 15 gastropods. From the column giving the number of molluscan species ('N. species Mollusca') in Table 1 it appears that not all the species are present within one single level or even within a section of the well. There is also a marked difference in the number of occurrences for most of the species in question.

On Table 1 is also shown the occurrences of fossilia varia, such as: ostracodes, malacostracans, barnacles, echinoderms, *Pomatoceras* sp., fishes and *Ruppia* sp., which demonstrate the high amount of organic remains found in the deeper part of

the well as reflected in the molluscan record.

The deeper part of well no. I up to 650 cm below surface belongs to the Atlantic according to the ^{14}C datings and pollenanalyses and covers the time interval from 8000 to 5000 years BP in ^{14}C years. Confined to this section are the following bivalves: *Ostrea edulis, Parvicardium exiguum, Corbula gibba* and the few finds of *Macoma balthica* and *Abra alba*. *Venerupis decussata* and *Scrobicularia plana* have a sparse occurrence in the Early Subboreal (Pls 1-2). This record might reflect changes in the salt content in the former fjord to a more brackish environment or/and show that conditions of nourishment have been reduced as pointed out by Spärck (1926) in the case of *Scrobicularia plana*.

Within the gastropods (Pls 1-2) no such marked difference is found in the occurrence of a single species, except *Nassarius reticulatus*, when comparing the Atlantic section with the Subboreal strata above. *Odostomia eulimoides*, which is an ectoparasite of *Chlamys opercularis* (L., 1758) and *Pecten maximus* (L., 1758) (compare Fretter & Graham, 1962: 405) might be connected with such species not recorded from the present investigations in Korupsø. However, the major part of the *Bittium reticulatum* individuals belong to the Atlantic section and in this case a higher saltcontent during the Atlantic must be the reason, as *Bittium reticulatum* only tolerates waters with

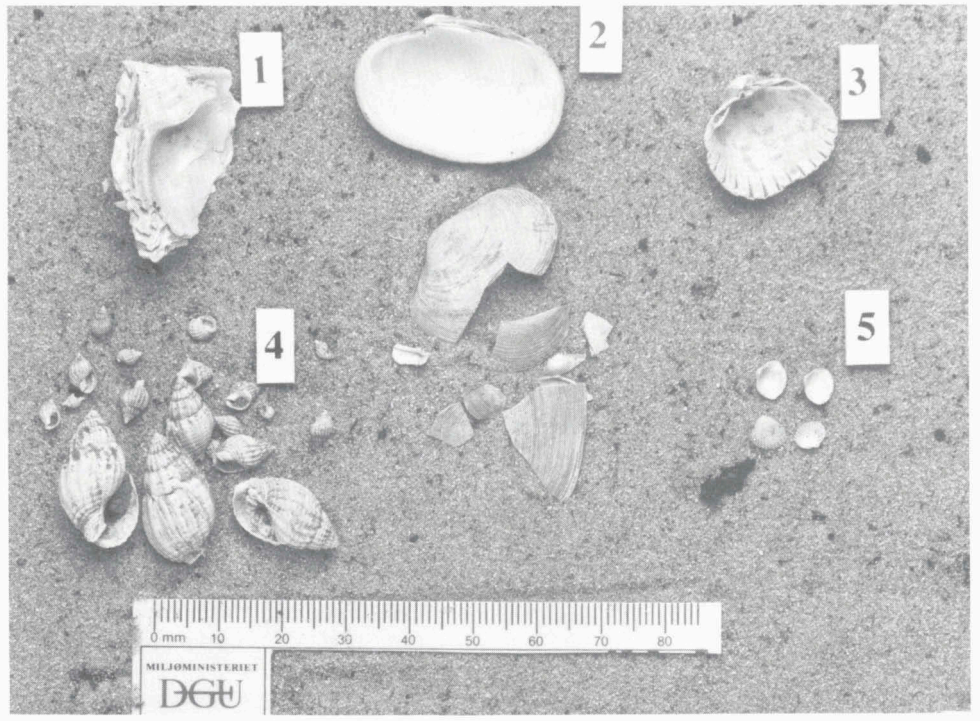


Plate 1.

Part of the molluscan assemblage from well no. I, 727 - 735 cm below surface dated to 6750 ± 100 ^{14}C years BP (K-4235). 1. *Ostrea edulis*; 2. *Venerupis decussata* ; 3. *Cerastoderma edule*; 4. *Nassarius reticulatus*; 5. *Parvicardium exiguum*.

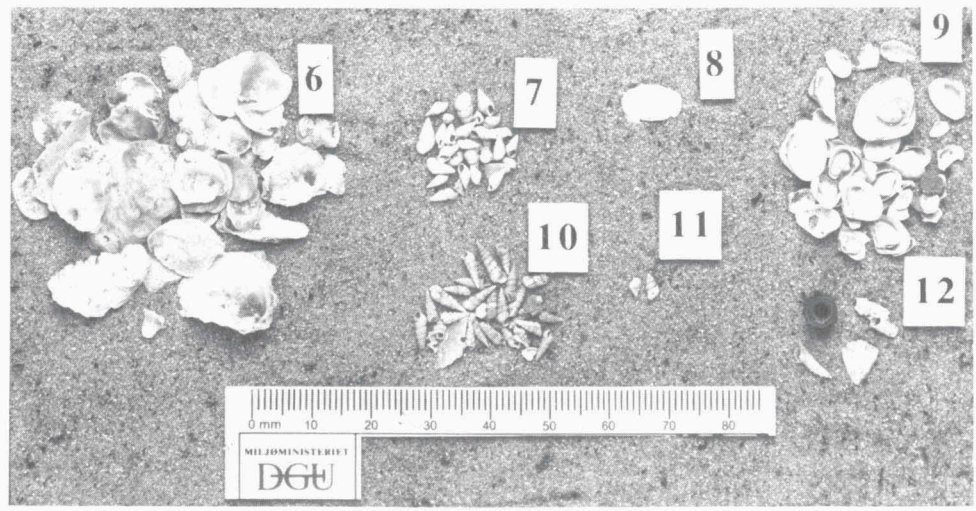


Plate 2.

Part of the molluscan assemblage and *fossilia varia* from well no. I, 727-735 cm below surface; 6. juvenile *Ostrea edulis*; 7. *Hydrobia ulvae*; 8. *Abra alba*; 9. *Corbula gibba*; 10. *Bittium reticulatum*; 11. *Rissoa albella*; 12. *fossilia varia*, as mentioned in the text.

more than 25‰ salt. The same is reflected in the occurrence of malacostracans, barnacles, echinoderms and *Pomatoceras* sp., all of which are confined to the Atlantic. Furthermore, the changes in numbers between *Hydrobia ulvae* and *Hydrobia ventrosa* as shown on Table 1, where *H. ulvae* flourishes in water with more than 20‰ salt, show that there is a change from a saltwater to a brackish water environment up into the Subboreal strata. The high number of *H. ventrosa* in the lowermost part of the Atlantic section reflects the initial part of the Early Atlantic transgression when, as the first change, the lacustrine environment was turned into a brackish water environment.

Considering the changes up through the Subboreal, which has been dated as far as around 4000 years BP in ^{14}C years, it is seen that *Littorina saxatilis tenebrosa* is the only new molluscan taxon to be recorded together with the sparse occurrence of *Onoba semicostata*. *Littorina tenebrosa* tolerates a low saltcontent around 7‰, however, in this place the occurrence should be seen also in connection with the shallowing of the water in the Korupsø area towards the end of the fjord-period. This is demonstrated by the few finds of *Littorina littorea* during the older part of the marine sequence which reflect a rapid rise of sealevel (Petersen, 1981), forming a deeper water environment soon in the Early Atlantic for the places observed during this investigation.

The change to a brackish environment during the Subboreal, however, is demonstrated both among the bivalves and the gastropods, by the high number of *Cerastoderma glaucum* and *Hydrobia ventrosa* respectively, and the disapperance of *Bittium reticulatum*. The occurrence of some of the small gastropods, such as *Rissoa membranacea*, which is found in a higher number in the upper part of the sequence, should be regarded as reflecting a flourishing epifauna on algae.

Fig. 3. Section from a ditch to the NW of Korupsø showing tidal bedding. The yardstick is 7 cm.

It appears from Table 1 that in the central part of the sequence representing the early part of the Subboreal the Mollusca both have a low number of species and of specimens. This will be discussed in the following chapter considering the rate of sedimentation as deduced from the ^{14}C dating available from wells no. I and II (Fig. 2).

Rate of sedimentation during the Atlantic and the Subboreal

When calculating geological processes, such as sedimentation rates, calendar years are necessary (Petersen & Rasmussen, in press). Nowadays it is possibly to use calibrated dates back to 10,000 ^{14}C years BP, consequently the Holocene strata recorded in this investigation can all be given in calendar years BP.

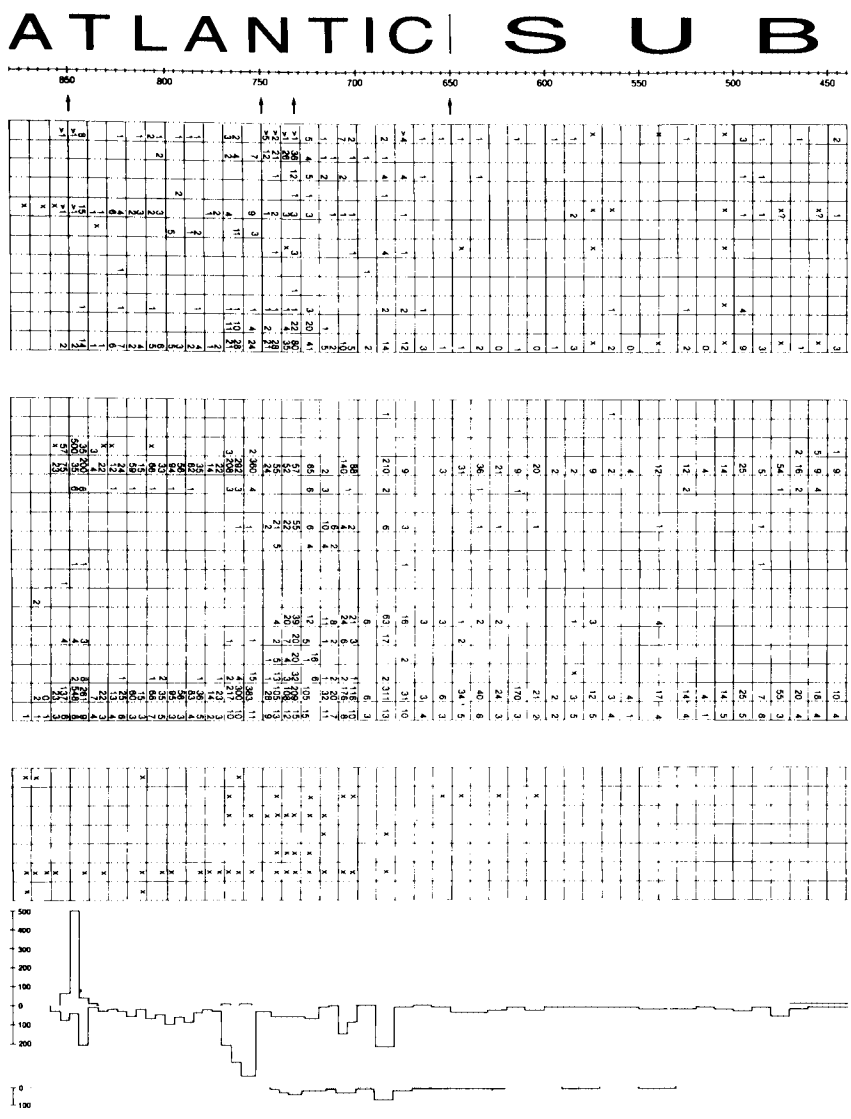
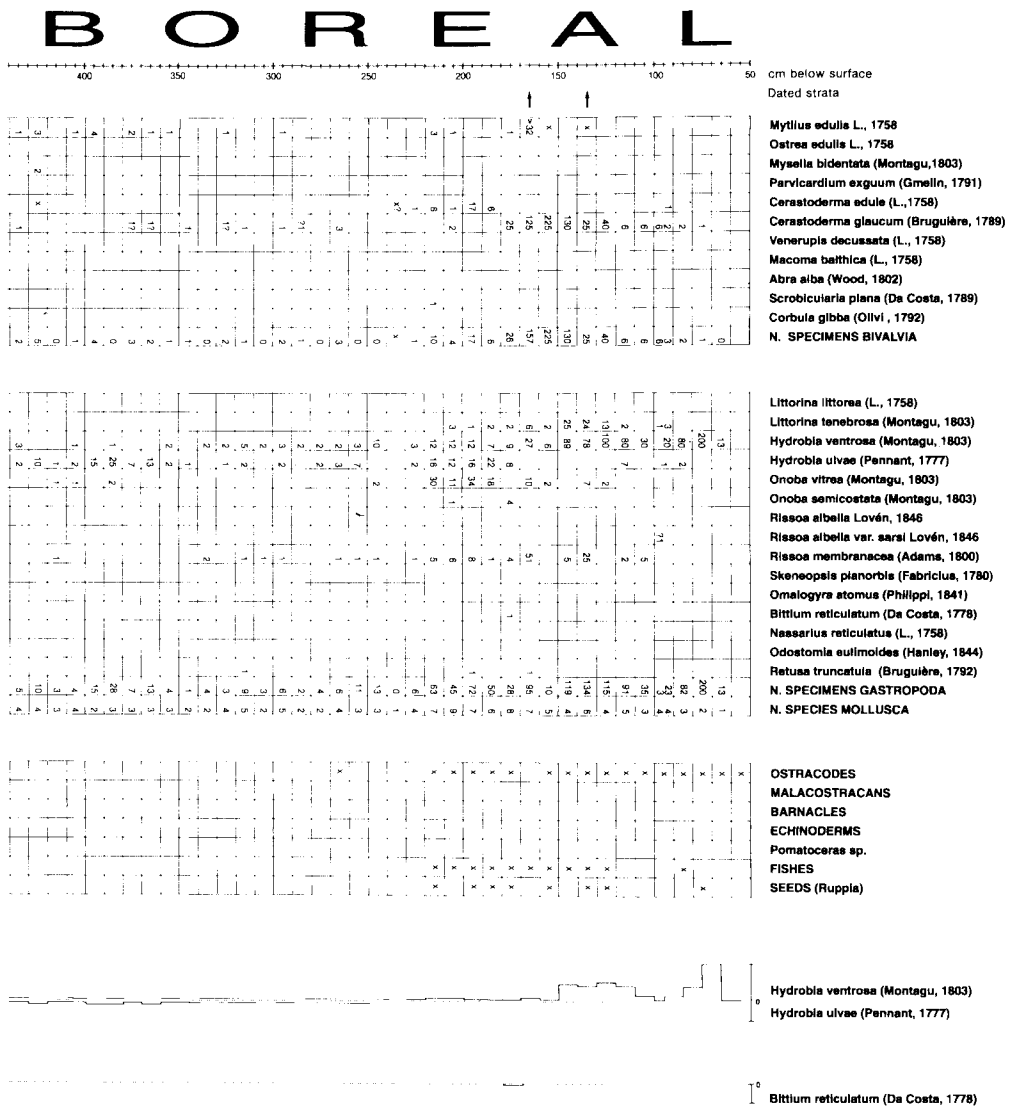


Table 1. The quantitative analyses of the Holocene marine molluscan fauna from well no. I in Korûpsø, Djursland, Denmark. The ages of the dated strata are given in Fig. 2. The surface of Korupsø is 3 ma s.l.

On Fig. 2 the calendar years BP together with their K-no. (Copenhagen ^{14}C Laboratory) are given for the strata within wells no. I and II. It is calculated that the sedimentation rate for wells no. I and II during the Atlantic has been 0.62 m and 1.01 m per 1000 years respectively. During the Subboreal wells no. I and II record a sedimentation rate of 4.07 m and 4.78 m per 1000 years respectively. The difference in sedimentation rate during the Atlantic between wells no. I and II, viz. 0.39 m is reflected



also in the Subboreal with a difference of 0.71 m, this points to the fact that well no. II to the north is situated in the deeper part of the former fjord system. However, there is a marked difference with a factor of 5 between the sedimentation rate during the Atlantic and the Subboreal. This is the background for the low number of molluscan species and specimens during the early part of the Subboreal.

Implications of the present study for the explanation of environmental changes

The evaluation of molluscan assemblages on a quantitative basis in connection with ^{14}C datings and pollen stratigraphy confirms the older view that the fauna during the *Littorina* Sea period was more prolific than nowadays. However, it does

Well No.	Lab. No.	Material	Elev.m.	^{14}C (BP)	Calibra. BP.
II	K-3681	C. edule	0.8	3860 ± 85	4290
II	K-3984	C. edule	1.0	3850 ± 85	4280
II	K-3986	M. edulis	-4.0	4600 ± 90	5310
II	K-3987	O. edulis	-5.5	4910 ± 90	5650
II	K-3988	C. gibba	-8.5	7240 ±110	8040
II	K-3989	C. edule	-8.7	7370 ±110	8130
II	K-3990	C. gibba	-8.7	7380 ±110	8160-8130
I	K-4233	C. edule	1.7	3960 ± 65	4420
I	K-4234	C. edule	1.3	3880 ± 65	4400-4350
I	K-4235	M. edulis	-4.4	6750 ±100	7580
I	K-4236	O. edulis	-4.5	6990 ±100	7780
I	K-4237	{ M. edulis C. edule }	-5.5	7990 ±100	8980-8780

Table 2. The source material, elevation and laboratory no. of the ^{14}C dates from the Korupsø wells no. I and II on Fig. 2.

demonstrate as a new point of view, that this applies only for the Atlantic.

The change in sedimentation rate from the Atlantic to the Subboreal, which has been calculated for the Korupsø area, points to a lowering of the tidal range in the Danish waters since the Atlantic. This is explained by the fact that sedimentation will stay low as far as the tidal current reaches and allows halophilous species far up the fjords according to observations on the faunal record. Furthermore, an older record of flaser bedding, tidal bedding (thinly interlayered sand/mud) seen in Fig. 3, from the mapping of the area, supports such an explanation.

In order to control the explanation given above the data on sedimentation rates in lakes during the same period were consulted in publications of Odgaard (1989, 1992). In the case that the sedimentation rates were equal during the Atlantic and the Subboreal in the lakes this would sustain the view that the changes found in the former fjord system were caused by a change in the tidal range. However, the studies by Odgaard (op. cit.) showed that many factors should be taken into account, such as the mineralogical part of the sedimentation, which has not been evaluated at present in this study. Consequently the conclusion must be that this study only tentatively points to the change in the environment of the marine fauna in the inner Danish waters from the Atlantic to the Subboreal as caused by a lowering of the tidal range at that time.

Acknowledgements

S.Th. Andersen, H. Krog and B. Odgaard from the Geological Survey of Denmark are thanked for stimulating discussions and H. Krog furthermore for communicating part of his results. K.L. Rasmussen (Department of Physics, University of Odense) is thanked for the evaluation of the ^{14}C datings.

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Manuscript received 3 September 1993, revised version accepted 13 April 1993.