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The Holocene Marine Sequence in the Løkken Area of Vendsyssel, Denmark

DAVID NORMAN PENNEY *)

Shorelines, borehole sections, marine sequence, land barrier, paleoenvironmental reconstruction, C14 dating, Foraminfera, Ostracoda, Lower Holocene, sea level changes.
Denmark, Vendsyssel, Loekken Area, Skagerrak

Abstract: JESSEN (1918, 1920, 1936) proposed the existance of a land barrier separating the Løkken area from the Skagerrak during the Holocene and MÖRNER (1969) suggested that this area had been invaded by three successive positive movements of sea-level, corresponding to his PTM-2, PTM-3 and PTM-4 shorelines.

Recent evidence based largely on a collation of the microfossil (Diatomaceae, Foraminifera and Ostracoda) data, supports JESSEN's view. Marine conditions penetrated into the Løkken area from the south between 8,000 BP and 5,300 BP and there was no input of more saline waters from the west. No incontrovertable evidence for a fluctuating sea-level has however, been found.

[Die holozäne marine Schichtenfolge im Løkken-Gebiet von Vendsyssel, Dänemark]

Kurzfassung: JESSEN (1918, 1920, 1936) postulierte die Existenz einer Landbrücke, die das Løkken-Gebiet während des Holozän vom Skagerrak trennte, und MÖRNER (1969) deutete an, daß drei aufeinanderfolgende positive Seespiegel-Verschiebungen, die seinen PTM-2, PTM-3 und PTM-4 Strandlinien entsprechen, das Gebiet überflutet haben.

Neue Befunde, die sich weitgehend auf einen Vergleich von Mikrofossil-Daten (Diatomaceae, Foraminifera und Ostracoda) stützen, bestätigen JESSENS Ansicht. Marine Verhältnisse breiteten sich zwischen 8000 v. h. und 5300 v. h. von Süden her vordringend im Løkken-Gebiet aus, und es erfolgte kein Zustrom von stärker salzhaltigen Wässern aus dem Westen. Widerspruchsfreie Beweise für Seespiegelschwankungen wurden jedoch nicht gefunden.

1. Introduction

Holocene marine sediments exposed in the cliffs north of Løkken in northern Denmark (figs. 1 and 2) have been the subject of several previous investigations. The deposits at Kodals Rende, Løkkens Blånæse and Furreby Å (fig. 2) were originally dealt with in detail by JESSEN (1899, 1918, 1920, 1931, 1936). At Løkkens Blånæse he

*) Address of the author: Dr. D. N. PENNEY, Laboratoriet for Palæontologi og Stratigrafi, Geologisk Institut, Aarhus Universitet, 8000 Århus C, Denmark.

described a 6 m section of marine clay and shelly organic mud which contained mollusc assemblages comparable to the "fjord" faunas found at present in shallow, brackish water Danish embayments (NORDMANN 1905). JESSEN concluded that some form of land barrier must have existed to the west of Løkken, and that marine inundation had occurred from the Limfjord to the south, via the Store Vildmose (fig. 1).

Subsequent workers in the area (CHRISTENSEN 1973; KNUDSEN 1971, 1973; MÖRNER 1969; VORK 1979) have in general supported JESSEN's view. Marine conditions penetrated up into the inner ramifications of a fjord system between 8,000 and 5,000 BP. The environment was essentially both shallow and brackish throughout this period, except where the presence of freshwater sand and peat suggested intermittant exclusion of the sea from certain localities. MÖRNER (1969) proposed that at least three marine transgressions had occurred here. This interpretation was supported by CHRISTENSEN's (1973) diatom work. In addition she found evidence for occasional marine inundation from the west. The other microfossils (Foraminifera and Ostracoda: KNUDSEN 1971, 1973; PENNEY 1984; VORK 1979) however, do not support either of these suggestions, agreeing instead with JESSEN's (1918, 1920, 1936) findings. Two conflicting opinions have therefore arisen. These may primarily have resulted from the different methodologies used, even on the same samples. A collation of the evidence was therefore felt necessary in order to obtain an overview of the palaeoenvironmental and Holocene sea-level history of the area. To this end much of the original material was reanalysed and is compared here with the results obtained from a new section at Løkkens Blånæse. This site is described in more detail elsewhere (PENNEY 1984) and only a short summary is included below. The material was processed following the procedure of MELDGAARD & KNUDSEN (1979) and PENNEY (1983). An examination of the Foraminifera and Ostracoda

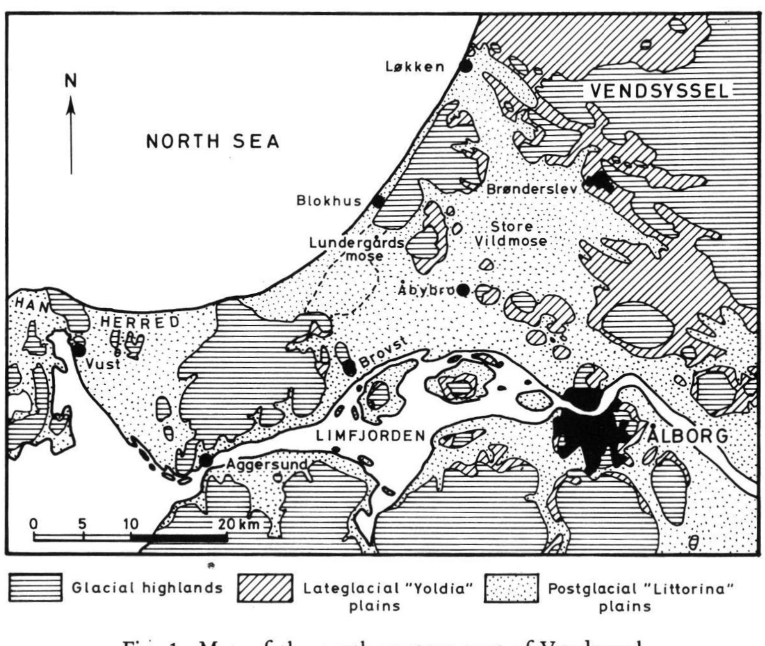

Fig. 1: Map of the south-western part of Vendsyssel.

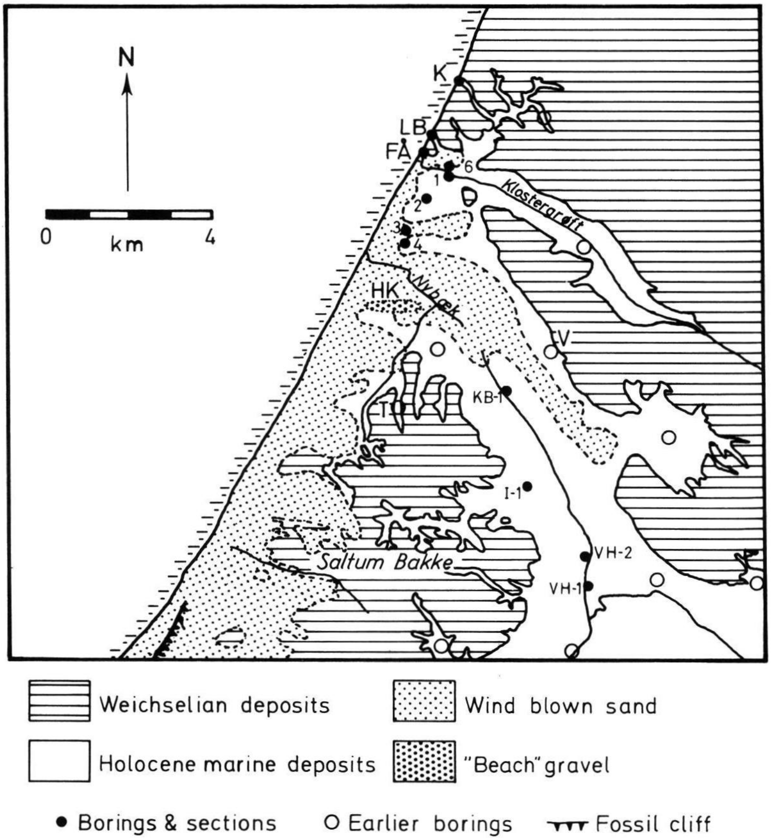

Fig. 2: Map of the Løkken area showing the sites discussed:
K = Kodals Rende, LB = Løkkens Blånæse, FÅ = Furreby Å, HK = Hvorupklit.

resulted in the erection of assemblage zones reflecting palaeoenvironmental changes in the depositional history of the site (fig. 3). These will be discussed in more detail at a later date.

2. Løkkens Blånæse

Marine conditions were first established here above a freshwater sandy gyttja (Zone OA: fig. 3) at —1.68 m. The environment was initially very shallow (< 1 m) and brackish (3—10 ppm). A progressive increase in both water depth and salinity was apparent up through zones FB, FC, OC, OD and OE (fig. 3) until a protected, shallow (< 5 m), mixopolyhaline (< 20—25 ppm) environment possessing *Zostera marina* on a hard bottom was established (Zones FD, FF & OF: fig. 3). This correspond approximately with a shift from biogenic to minerogenic sedimentation at + 0.15 m. Three radiocarbon dates have been obtained from a little above the base of the biogenic sediments (PENNEY 1984). Two of *Quercus* wood gave ages of 7,810 ± 115 BP (K-2451) and 7,950 ± 120 BP (K-3316). The third, a sample of shells (*C. edule* and *M. edulis*)

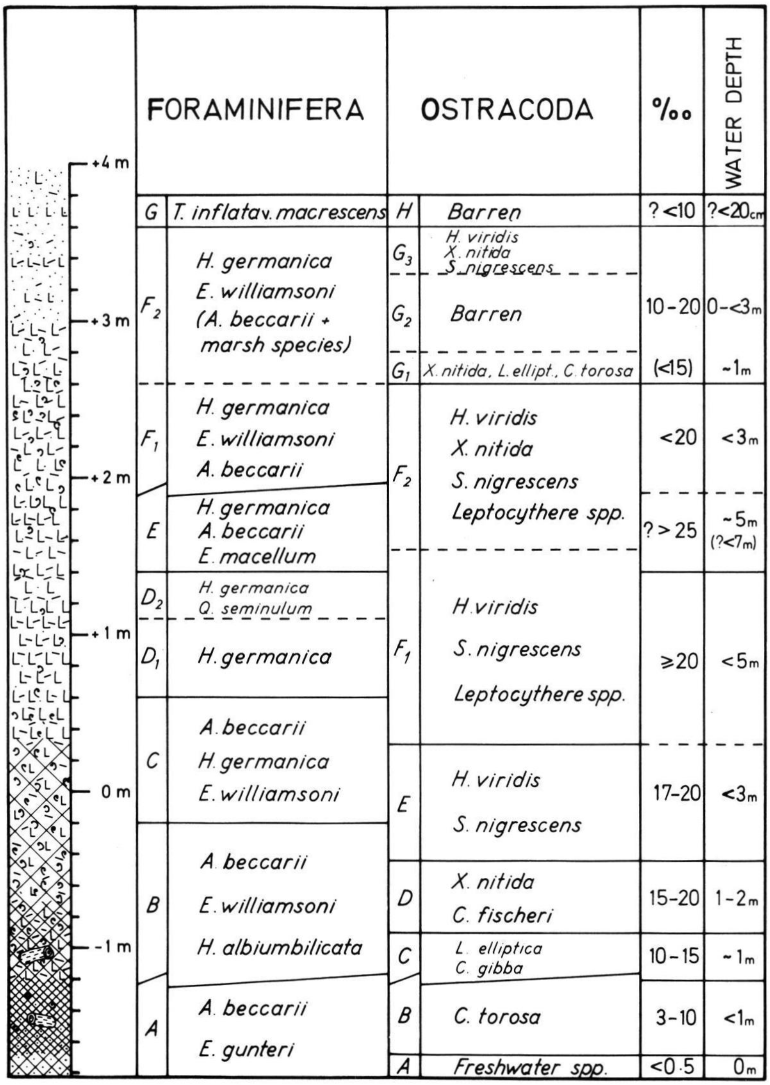

Fig. 3: Summary of Palaeoenvironmental data for Løkkens Blånæse.

from the same horizon, was considered too old (8,870 ± 125 BP: K-3317) as there was evidence for recrystallization (PENNEY 1984). The two wood dates cannot be used as sea-level index points owing to their allochthonous condition, but do suggest a minimum age for marine inundation at about 8,000 BP.

Slightly deeper (perhaps up to 7 m), more saline conditions (? > 25 ppm) were picked out in Zone FE (fig. 3), corresponding to a sea-level high of about + 9.0 m. A shallower (< 3 m), mixomesohaline (< 20 ppm) environment returned above + 1.9 m and above + 2.6 m salinity may have fallen below 15 ppm and water depth dropped to around 1 m. Laminated sands containing shell and clay laminae were found above

+ 3.0 m (fig. 3). It is probable that much of this sand was irregularly supplied to the inlet by aeolian transport. The microfossil evidence (Zones FF_2 & OG: fig. 3) indicated an environment fluctuating between 0 and 3 m in depth and from 10 to 20 ppm. A 1—2 cm thick silty clay horizon at + 3.84 m contained a very distinctive assemblage of Foraminifera (Zone FG: fig. 3), resembling the faunas which characterize the upper saltmarsh zone of intertidal estuaries (CULVER & BANNER 1978; SCOTT & MEDIOLI 1978; 1980). In microtidal environments these faunas are found in isolated localities at water depths of less than 25 cm where salinity can range from 5 to 20 ppm (LUTZE 1968; JENSEN 1983). This clay horizon must therefore represent the final stage of marine inundation at Løkkens Blånæse, corresponding to a sea-level of about + 4.0 m.

There is no microfossil evidence to support the suggestion of any opening between the Skagerrak and the Løkken area via Løkkens Blånæsee. The assemblages resembled the faunas found at the present time in protected Danish lagoons and inlets throughout the marine succession, even when the water depth attained its maximum in Zone FE (fig. 3). Neither can any indication of a sea-level fall be extracted from the data.

3. Kodals Rende

MÖRNER (1969: 381) dated both the arrival (7,065 ± 135 BP: carbonate removed) and withdrawal (5,315 ± 100 BP) of marine conditions from this site (fig. 2) and correlated the sequence with his PTM-2, PTM-3 and PTM-4 shorelines for the Kattegat. He did not however, carry out a comprehensive examination of the deposits between the dated levels. CHRISTENSEN (1973) found oligohalobion diatom floras both a little above and below MÖRNER's dated horizons. She identified two periods of marine inundation in the intervening sediments, separated by a peak in the *Fragillaria* curve at + 5.4 m, which was considered evidence for a regression. In addition, the appearance of "North Sea" diatoms in the floras at + 5.05 m and + 6.25 m was interpreted as indicating the presence of an opening to the west on at least two occasions. These conspicuous floras were not complemented by reciprocal changes in the Foraminifera and Ostracoda. KNUDSEN (unpubl.) examined the Foraminifera from the same samples as CHRISTENSEN and found mixomesohaline/mixopolyhaline faunas throughout, with no evidence for either an opening to the west or a fall in sea-level. The former must therefore have been of such an ephemeral nature as to have caused no alteration in the sediments and microfaunas. In addition, the possibility that "North Sea" diatoms were occasionally blown in cannot be overlooked. The *Fragillaria* peak may have resulted from increased freshwater runoff rather than from a fall in sea-level.

4. Borehole Data

South of Løkken the marine sequence is buried by aeolian sand and there are no coastal exposures. Palaeoenvironmental data has however, been collected from several boreholes to the east and south (CHRISTENSEN 1973; KNUDSEN 1971, and unpubl.; VORK 1979). Figure 4 depicts the stratigraphy of these boreholes (locations shown on fig. 2), together with a curve of marine influence which was based on a collation of the microfossil data.

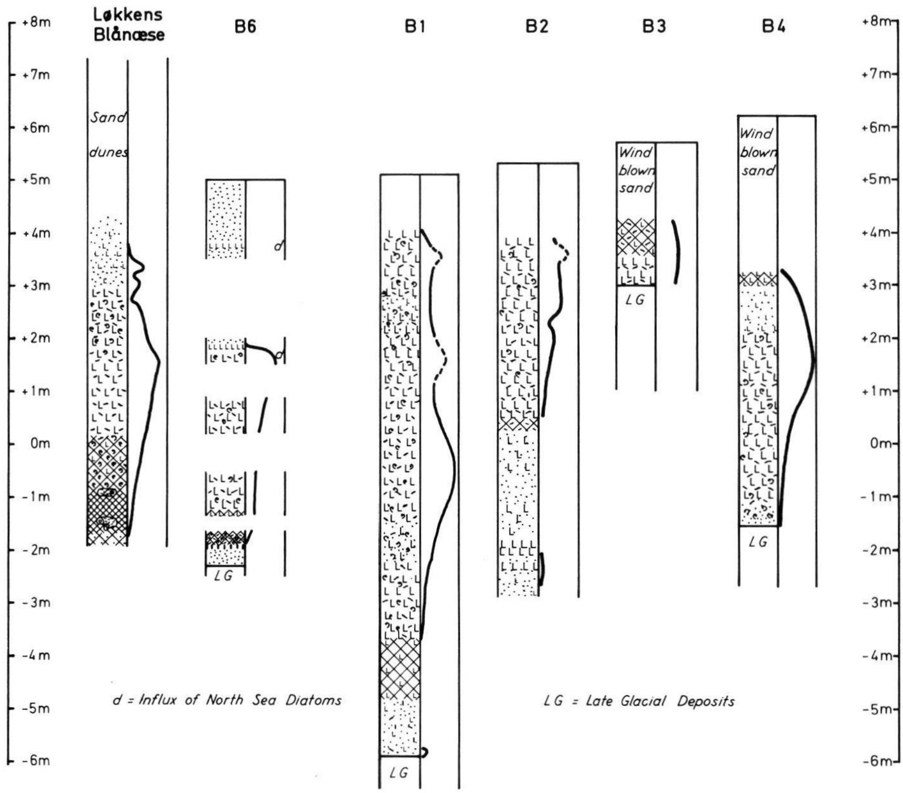

Fig. 4: Stratigraphy of the Holocene deposits in the Løkken area. The curves to the right of the stratigraphic columns depict the intensity of marine influence (less intense to the left = shallower, less saline; more intense to the right = deeper, more saline) on the basis of the microfossil data.

A mixooligohaline environment was first recorded in B. 1 above —6.0 m (fig. 4). This was overlain by freshwater sand and clayey gyttja. The latter was originally described as a peat and interpreted as indicating a regression (KNUDSEN 1971: 133). This reversion to non-marine deposition could however, have resulted from the rapid build-up of a sand bar and subsequent shift of stream-course at the mouth of a river, and may not therefore, have required a fall in sea-level.

Marine conditions returned to B. 1 at —3.4 m and thereafter reached the remaining boreholes (fig. 4). This must be the same event as was recorded at Løkkens Blånæse and dated to 8,000 BP. The sea had reached Kodals Rende by about 7,000 BP (MÖRNER 1969). The same progression of palaeoenvironments as was recorded at Løkkens Blånæse occurred in the boreholes and there was a corresponding succession of diatom floras in B. 6 (CHRISTENSEN 1973). Eventually a typical "fjord" environment was established over the whole area, inferring shallow waters (< 5 m), mixomesohaline-mixopolyhaline salinities ($\simeq$ 17—20 ppm) and a hard bottom of sandy mud on which grew a thick sward of *Zostera marina.* Although this area was evidently less isolated than the inlets to the west, no conclusive evidence could be found for any direct connection to the Skagerrak. That slightly deeper (5—10 m), more saline (> 25 ppm) conditions occasionally existed was apparent from the microfossil content of certain levels. This was noted at —1.0 to 0.0 m in B. 1, + 1.0 to + 2.0 in B. 4, B. 6 and at Løkkens Blånæse and between + 3.0 and + 4.0 in B. 3. The sea never exceeded about + 9.0 m.

Shallower conditions returned in the upper part of the marine sequence. Here the palaeoenvironmental picture was unfortunately blurred by a fluctuating input of wind-blown sand. B. 6 was completely smothered shortly after water depths attained their maximum (fig. 4), whereas marine deposition continued up to at least + 4.2 m in B. 1 and B. 3. This resulted in a complicated discordancy of microfossil assemblages in each borehole — as it did Løkkens Blånæse.

A clay lamination at + 3.75 m in B. 6 contained a "North Sea" diatom assemblage and was interpreted by CHRISTENSEN (1973) as a storm surge deposit. This horizon was devoid of Foraminifera. A few normal marine microfossils (i. a. *Ammonia beccarii batava* and *Callistocythere littoralis*) were observed at + 3.6 m in B. 1 and B. 2. Their presence might be interpreted as corresponding to the same event. These two species were however, noted at several levels in the boreholes, particularly where water depths peaked (fig. 4), whilst other marine species (i. a. *Cibicides lobatulus* and *Pontocythere elongata*) which would have been introduced if any breach to the west had occurred, were absent. Their presence here cannot therefore, be considered incontrovertable evidence for an opening to the Skagerrak. Moreover, the aforementioned variability in sediment input in the upper part of the marine sequence may render this altitudional similarity coincidental. Radiocarbon and pollen dates have not been attempted on any of the borehole material. It is nonetheless apparent from the microfossil data (curve of marine influence on fig. 4), that sedimentation rates were not consistant over the area under question. In addition, localized erosion and aerial discrepancies in post-depositional compaction could have occurred. The resultant palaeoenvironmental picture did not therefore, allow for direct cross-correlation between the boreholes on either an altitudional or zonal basis.

5. Discussion and Conclusions

MÖRNER (1969) constructed shoreline and shoreline displacement diagrams for Vendsyssel based largely on his own observations. Fitting this data into his model for Holocene sea-levels in the Kattegatt, he postulated that three transgressions (i. e. positive movements of sea-level) had occurred across the area (PTM-2, PTM-3, PTM-4). The data presented above does not support this interpretation. There are no clear trends in the marine intensity curves on fig. 4 which might imply a fluctuating sea-level. If these did occur, factors such as sediment supply, local accretion rates, erosion and consolidation as well as the tolerance ranges of the individual species, all combined to obliterate the evidence. More importantly, evidence for minor fluctuations in sea-level was not forthcoming from the more isolated localities (eg. Kodals Rende and Løkkens Blånæse) where the microfossil faunas would have been more sensitive to minor changes in both water depth and salinity. There is therefore no incontrovertable evidence to support MÖRNER's (1969) proposal for a fluctuating sea-level in the Løkken area. Both JESSEN's (1899, 1936) and MÖRNER's (1969) estimates for a maximum sea-level high of between + 9.0 m and + 9.5 m can however, be ratified.

Another important point arising from the microfossil data is the lack of evidence for any major opening to the Skagerrak, thus supporting JESSEN's (1918, 1920, 1936) postulated land barrier. Some evidence for the latter can in any case, be extracted from JESSEN's (1899) original work in the area. To the south-west of Løkken, the former Holocene shoreline which occurs inland of Blokhus (fig. 1), is truncated by the present Skagerrak coast south of Nybæk Å (fig. 2). North of this point subsequent coastal recession has removed much of the evidence for a coastal barrier. JESSEN (1899) however, observed a 0.3—0.5 m thick Oyster bank near the mouth of the Nybæk Å at + 4.0 m. This rested directly on Younger Yoldia Clay. The mollusc assemblages here had a much greater affinity to the present-day Limfjord bios than to that of the North Sea. One kilometre south at Hvorupklit (HK on fig. 2), he found beach gravels infilling an undulating terrain of Lateglacial clay, such that the impression obtained was one of east-west-alligned beach ridges. VORK (1979) implied that this feature could indicate an open connection to the west via a sound, but the mollusc assemblages did not support this suggestion. In addition, the gravels cannot be considered as beach ridges as their form is controlled by the underlying topography. A tongue of land must therefore have extended out in a northerly direction from Saltum Bakke (fig. 2) towards Løkken, and more than likely continued offshore, thus forming JESSEN's barrier.

South-east of Nybæk Å (fig. 2), up to 8—10 m of Holocene marine sediments are present in the valley between Løkken and the Store Vildmose (JESSEN 1899; VORK 1979). The sequence here comprises organic shelly clays and sandy silts which have been subdivided into three units based on their ostracod content (VORK 1979): a lower brackish water unit which often rested on freshwater sand and gyttja (or peat), sandier sediments of more marine (Limfjord) affinity and an upper brackish water deposit. These three units possessed considerable aerial and altitudional variability. In I-1 for example, brackish water deposits between —4.5 m and + 1.0 m were capped by 3 m of more marine sandy silts. The upper brackish unit was absent here. In KB-1, VH-1 and VH-2 (fig. 2) the lower brackish water unit was either absent or very thin (< 2 m) and more marine sediments often directly overlay the freshwater deposits. These passed upwards gradually into a 2—8 m thick upper brackish water unit. VORK (1979) suggested that a deep channel may have been scoured out of the lower brackish water unit at about the same time as more marine sediments were being deposited, perhaps as sea-level approached its maximum level. This channel was subsequently infilled as sea-level fell and progressively more brackish water conditions returned. The I-1 borehole penetrated deposits on the flanks of this channel where little or no erosion had occurred, whereas KB-1, VH-1 and VH-2 were located near its centre. This channel more than likely extended right up into the Løkken area, and acted as a transport route for many of the more marine microfossil species found there. The faunas found in the Store Vildmose deposits (JESSEN 1899, 1905, 1920; KNUDSEN 1971, 1973; VORK 1979) are comparable to those found today in the Limfjord (HVIID 1984; JENSEN 1983; KJEMTRUP 1982) and both contain these more-marine species. Their presence in small amounts in the Løkken area does not therefore necessitate the existance of an opening with the Skagerrak at any time.

6. Acknowledgements

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