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DIACHRONISM OF THE *DEFLANDREA OEBISFELDENSIS* ACME TOWARDS THE SOUTHERN MARGIN OF THE BELGIAN BASIN

by

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ABSTRACT

The biostratigraphic significance of the *Deflandrea oebisfeldensis* acme is lost near the southern margin of the North Sea Basin where it is recorded in higher dinoflagellate zones within the lowermost Ypresian deposits. A tentative explanation of the diachronism of the *D. oebisfeldensis* acme is based on certain changes of palaeogeography and palaeohydrography of the North Sea Basin during the Early Ypresian.

RESUME

La signification biostratigraphique de l'acme de *D. oebisfeldensis* se perd vers les limites méridionales du Bassin de la Mer du Nord, où on l'observe plus haut dans les zones à dinoflagellés des dépôts de base de l'Yprésien. Nous tentons d'expliquer le diachronisme de l'acme de *D. oebisfeldensis* par certains changements paléogéographiques et paléohydrographiques du Bassin de la Mer du Nord au cours de l'Yprésien inférieur.

KEY WORDS

Ypresian, Dinoflagellates, biostratigraphy, Belgium.

MOTS CLE

Yprésien, dinoflagellates, biostratigraphie, Belgique.

1. THE POSITION OF THE *DEFLANDREA OEBISFELDENIS* ACME IN THE WETZELIELLACEAE ZONES

The biostratigraphical significance of the relatively high frequencies of *Deflandrea oebisfeldensis* and related forms observed in the Late Paleocene deposits in the North Sea Basin indicated as the *D. oebisfeldensis* acme Zone, has to be restricted.

The position of the *D. oebisfeldensis* acme in the Wetzeliellaceae Zones (figure 2) can be deduced from information found in Knox and Harland (1979), Heilmann-Clausen (1985), Nielsen *et al.* (1986), Heilmann-Clausen and Costa (1989) and my own published work ; information about the presence of *D. oebisfeldensis* in Lessines, St. Omer and Château de la Bruyère is not yet published. In the central North Sea Basin (Forties field, Well 39/2-1) in East Anglia (Harwich), in Denmark (Store Baelt borehole), and in North Germany (Wursterheide borehole), one encounters the *D. oebisfeldensis* acme in the upper part of the *Apectodinium hyperacanthum* Zone. The species attains a frequency between 5 and 7 % in Knokke from -288 m up to -284 m (Member X) and of about 3 % in Kallo at -377 m ; this occurs a few meters below the level in

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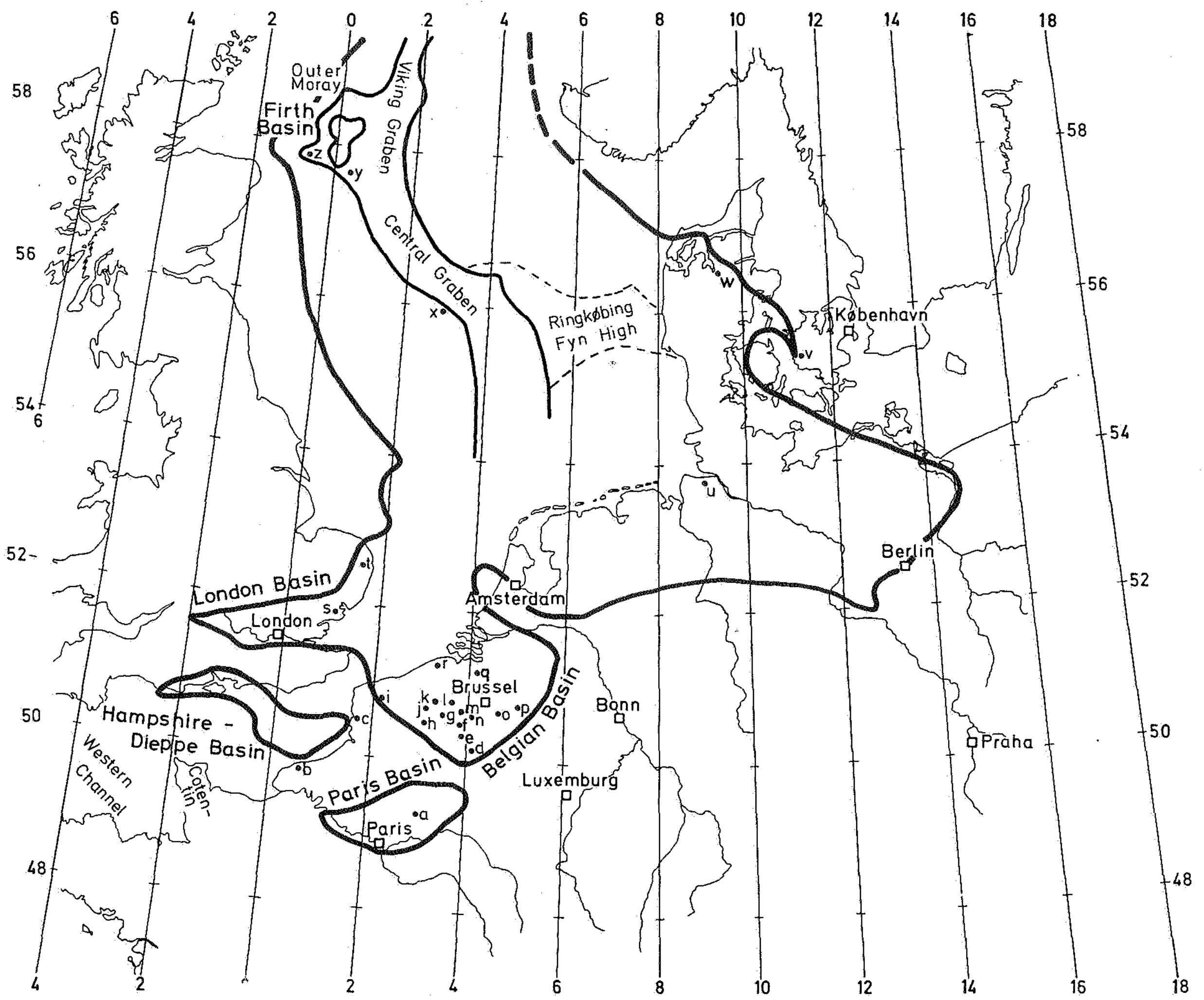

Figure 1. Location of the commented boreholes and outcrops.
bold line : approximate limit of areas with Early Eocene deposits.

Localities in alphabetical order

Château de la Bruyère	c	Marke	j	Saint Maur	g
Cuise-la-motte	a	Mons-Ghlin	f	Saint Omer	i
Erquelinnes	d	Mont Héribu	e	Steenhuize-Wijnhuize	l
Forties Field	y	Orchies	d	Store Baelt	v
Harwich	s	Ormesby	t	Varengeville	b
Kallo	q	Outer Moray-Firth Basin	z	Viborg	w
Knokke	r	Overijse	o	Well 39/2-1	x
Lessines	m	Quenast	n	Wursterheide	u
Linter	p	Ronse-Waaienberghe	k		

which *Wetzeliella lobisca* appears for the first time (at - 282.26 m in Knokke where it was recorded as *W. meckelfeldensis* in Dupuis *et al.* (1990, table 1 and p. 40) and at -374.5 m in Kallo recorded as *W.* aff. *symmetrica* and *W.* aff. *symmetrica* ? in De Coninck (1969, pp. 8, 9 and 21, Pl. IV, figs. 1-8). According to Jolley and Spinner (1989, fig. 3), *W. lobisca* appears already at the base of the *Wetzeliella astra* Zone but its frequency is higher in the upper part of that zone. At Lessines, *D. oebisfeldensis* is relatively frequent in the lowermost level of the deposits resting upon the microdioritic intrusion. Among the accompanying species we regularly note several *Apectodinium* spp. and a few *Phthanoperidinium crenulatum*. One *Wetzeliella astra* was found, indicating that the deposits can be situated in the *W. astra* zone. *P. crenulatum* is probably not as significant for biostratigraphy of the Lower Ypresian as was suggested in De Coninck (1991, fig. 2, p. 291). At St. Omer, northwestern France, *D. oebisfeldensis* attains its highest frequency in company of *W. astra* and *W. lobisca*, thus possibly a little higher in the dinoflagellate zonation. At Que

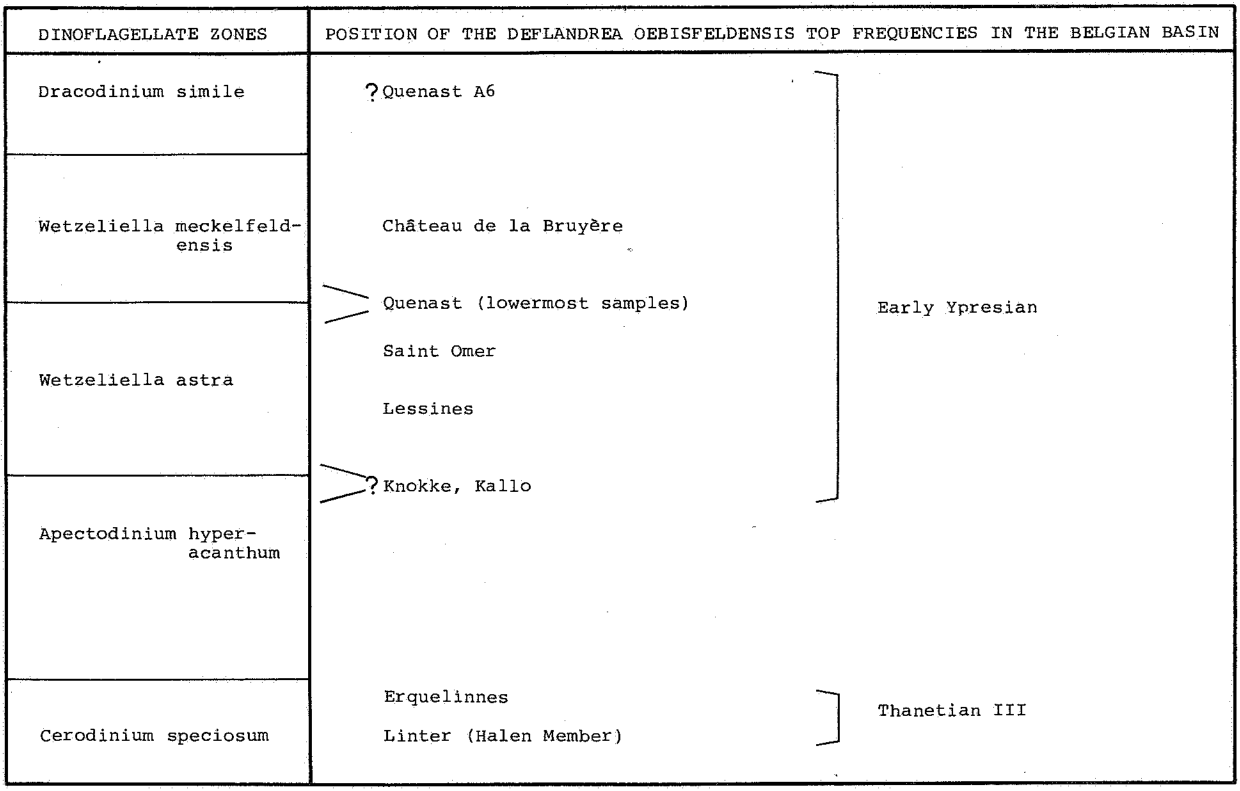

Figure 2. Position of the *Deflandrea oebisfeldensis* top frequencies in the Belgian Basin.

nast, Belgium, relatively high frequencies (up to 6 %) of *D. oebisfeldensis* are observed in the clay matrix from the conglomerate (Quenast A_1 in De Coninck, 1986) found in a cleft in the microdiorite and also in the base of the Ypresian deposits overlying the intrusive rocks. Among the accompanying species, we encounter *W. lobisca* (recorded as *W.* sp. A in De Coninck 1986, pp. 10, 21 and 44), *W. meckelfeldensis* and again *Phthanoperidinium crenulatum*. As the presence of *P. crenulatum* is probably not very relevant, the other species suggest that the acme is situated in the top of the *W. astra* Zone (Quenast A_1) and in the *W. meckelfeldensis* Zone for the deposits directly overlying the microdiorite. Higher in the deposits (Quenast A_6 in De Coninck, 1986) just below the level with some gravel, the species makes up 5% of the assemblage which contains only one specimen of Wetzeliellaceae (*W.* sp. cf. *D. varielongitudum*). The biostratigraphic position of A_6 remains uncertain : it cannot be younger than our *Dracodinium simile* Zone because several significant species from higher zones are missing. Elsewhere, near the border of the Belgian Basin *D. oebisfeldensis* has also been recorded in the *W. meckelfeldensis* Zone, namely in the lowermost Ypresian in the Overijse boring (0.1 %) (De Coninck 1981, table 1), at Mont-Héribu (1%) and at Mons-Glin (1%) (De Coninck *et al.* 1983, table 3), and at Orchies (less than 1%) (De Coninck 1976, p. 18). These percentages are not really acme frequencies and it remains uncertain whether laterally at the same levels higher frequencies occur. Finally, beyond the Belgian Basin, near the northeastern border of the Hampshire-Dieppe Basin, at Château de la Bruyère up to 35 % of *D. oebisfeldensis* are found together wit *W. lunaris* an *W. meckelfeldensis*, i.e. in the *W. meckelfeldensis* Zone. *D. oebisfeldensis* has not been recorded in Ypresian deposits from further in the Hampshire-Dieppe Basin or from the Paris Basin.

2. QUESTIONS ARISING FROM THESE OBSERVATIONS

1. How can we explain the appearance of the acme of *D. oebisfeldensis* and related forms in higher zones within the southern Ypresian deposits of the Belgian Basin and in the adjacent northeastern part of the Hampshire-Dieppe Basin, while in the northern part of the Belgian Basin and further north in the North Sea Basin the acme was already over ?
2. Why is the species never recorded in corresponding deposits in the Paris Basin or in the Hampshire-Dieppe Basin ?
3. Why does *D. oebisfeldensis* disappear ultimately above the *Dracodinium simile* Zone ?

3. TENTATIVE EXPLANATION

At the meeting of the R.C.N.P.S. in September 1991, R. Knox and C. King made some remarks about the conditions in the North Sea Basin during the Early Ypresian. The hypothesis that follows puts forward that certain environmental conditions may have been necessary for the flourishing of *D. oebisfeldensis* and very related forms, and takes into account the remarks and suggestions.

During the time corresponding to the uppermost part of the *Apectodinium hyperacanthum* Zone up to the final *Dracodinium simile* Zone, relatively anoxic water was probably stagnating in the deeper parts of the North Sea Basin. Towards the border of the basin, and also during some regressive phases the sea became shallower and the interface between the anoxic, stagnating bottom water and the surface water gradually was more often disturbed probably by increased tidecurrents reaching the interface. At such depths the phytoplankton (and among them the dinoflagellates) must have suffered repeatedly very stressing conditions of a different kind than those near the watersurface. Certain dinoflagellate species such as the one which generated the cyst *Deflandrea oebisfeldensis*, may have reacted by massive cyst production, when anoxic bottom water was contaminating their environment.

Maybe that such an environmental situation existed already within the Paris Basin and the Belgian Basin earlier in the Late Paleocene. Indeed, *D. oebisfeldensis* was recorded by Gruas-Cavagnetto (1976, p. 14 & 20, pl. 1, fig. 13) in the boring at Cuise-la-Motte, in Thanetian III deposits only. These correspond to the upper part of the *Cerodinium speciosum* Zone. At the time of sedimentation of the Thanetian III deposits, the northern sea had invaded the adjacent part of the Paris Basin and the eastern part of the London Basin (Cavelier, 1987, pp. 263 & 265; Siesser *et al.*, 1987, p. 86 & fig. 6; Gramann & Kochel, 1988, p. 429). In the Belgian Basin, the species and related forms are encountered in a corresponding stratigraphic position. In the uppermost level of the Bois Gilles Formation (top of the *C. speciosum* Zone) at Erquelinnes, the frequency of '*Deflandrea* sp. cf. *D. speciosa* - *D. oebisfeldensis*' attains 3 % (De Coninck *et al.*, 1981, Table 2). In the Halen Member (*C. speciosa* Zone) at Linter, 1.3 % was recorded in the boring at -21.50 m, where *C. speciosum* becomes very frequent (12.5 %) (Vlerick, 1987, table 1). No information is available about an eventual presence of *D. oebisfeldensis* in the same stratigraphic position in the southeast of England. After the Thanetian III episode, a regressive phase took place in the North Sea Basin. According to Knox (1989, p. 26), the lowering of the sea level (top-Lista event) left only a restricted marine area and sedimentation became limited to the Central Graben in which the Forties Sands were deposited. These Forties Sands correspond to the lower part of the *Apectodinium hyperacanthum* Zone (Knox & Harland, 1979, pp. 464 & 465). Apparently fully marine conditions remained confined to the central North Sea Basin (Viking Graben, Outer Moray Firth Basin and Central Graben) (Knox *et al.*, 1981, p. 276; Gramann & Kochel, 1988, p. 430) during most of the time of the *A. hyperacanthum* Zone. In this central part, the tide or convection currents were probably only rarely able to reach stagnating lower watermasses, while in the very shallow remaining parts of the North Sea Basin such a waterstratification could not develop. Therefore, the particular conditions which we suppose to be required for the production of *D. oebisfeldensis*, were generally lacking during that time in the whole North Sea Basin. This can explain the low frequencies of *D. oebisfeldensis* in the central deposits and its absence in the Woolwich Beds and equivalent deposits in the border region of the North Sea Basin. A hiatus probably coinciding with the NP9/NP10 Zones boundary separates the Woolwich Beds from the oldest representative of the London Clay transgression, the Hales Clay Member (Knox, 1990, pp. 59-62 ; Knox, this volume). This member is well developed in the area of Norfolk (Ormesby boring) and corresponds to the Knudeklint Member which forms the lower part of the Danish Fur Formation and which corresponds to the negative ash-series-deposits in that area. It is in the upper levels of this oldest representative of the London Clay transgression that *D. oebisfeldensis* reappears, becoming sometimes frequent again in the assemblages. The species was indeed recorded in the upper part of the negative series in the Viborg 1 borehole by Heilmann-Clausen (1985, p. 28) and also in the upper part of the equivalent subunit E2 in the Outer Moray-Firth Basin in the central North Sea (Knox *et al.*, 1981, p. 278). Its increase in frequency possibly indicates that, already during the earliest phase of the London Clay transgression, water stratification had developed again and that some shallowing of the sea towards the end of this first transgressive-regressive phase can be held responsible for the increased disturbance of the interface between anoxic, stagnant bottom waters and surface waters. Acme frequencies are further observed in the succeeding ash bearing Harwich Member in the north-eastern London Basin, in the positive series in Denmark (Viborg 1 borehole and Store Baelt borehole) and in northern Germany (Wursterheide borehole), and also in the lowermost Member X in the Knokke borehole (Belgium) between -288 and -284 m. Later occurrences have already been given (see introduction).

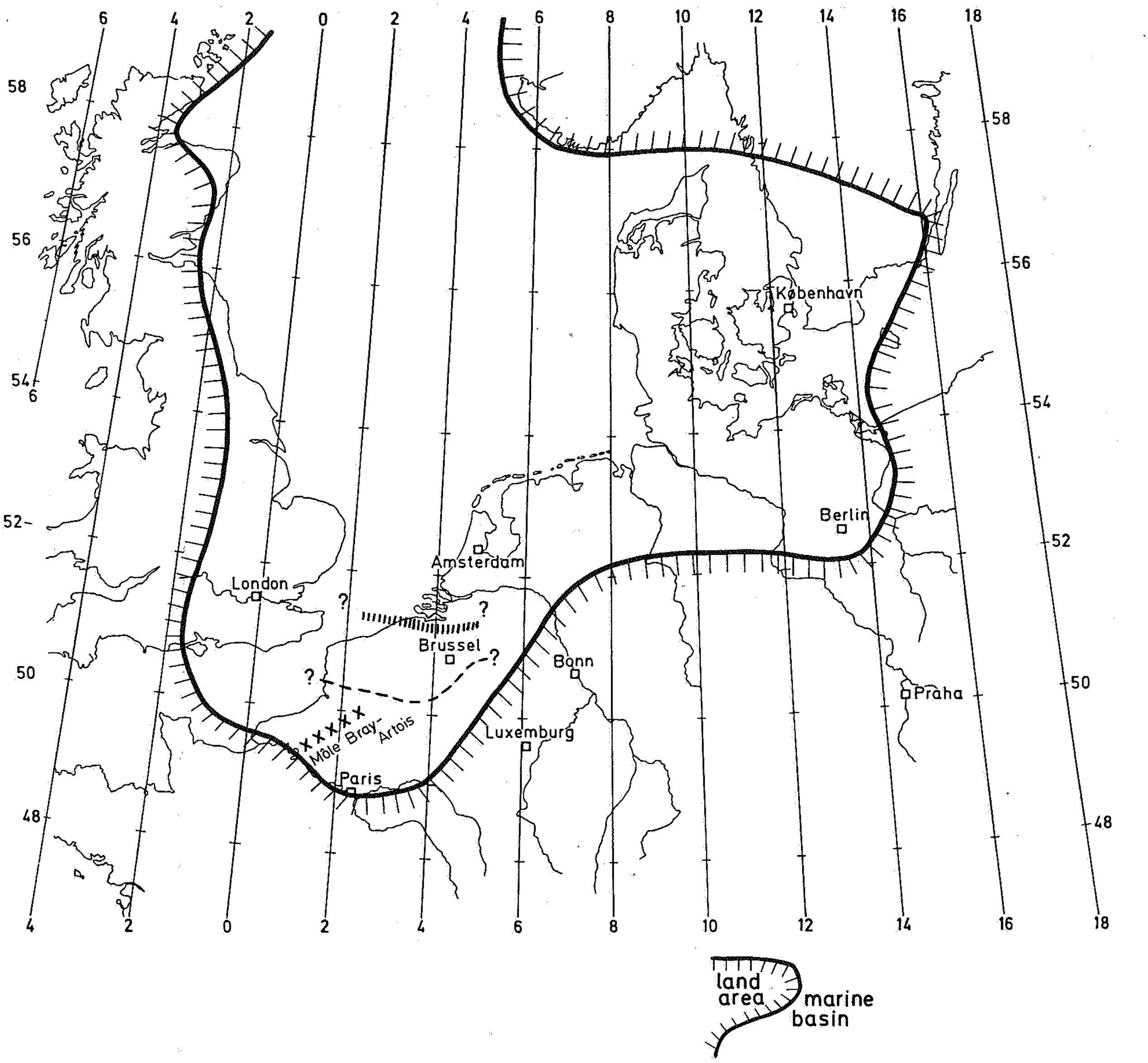

Figure 3. Southern limit of stagnant, anoxic bottom waters during sedimentation of :

1. The uppermost part of the *Apectodinium hyperacanthum* Zone. IIIIIII
2. *Wetzeliella meckelfedensis* Zone. Up to the *Dracodinium simile* Zone. - - - -

The Ypresian transgression was a major one as was the Late Paleocene one during which the Thanet Beds (London Basin) and the Sables de Bracheux (Paris Basin) etc. were deposited. During sedimentation of the *W. astra* up to the *D. simile* Zone, the transgression was certainly important enough to allow water stratification to progress further south in the Belgian Basin where near the margin it was frequently disturbed leading to *D. oebisfeldensis* production (figure 3). The anoxic bottom water could probably not advance further into the Paris Basin because of the Bray-Artois Môle (Dupuis *et al.* 1984, pp. 53-56), behind which very shallow sea and several areas with brackish conditions occurred. Apart from its extreme northeastern region, the Hampshire-Dieppe Basin too became very shallow in its eastern part preventing a further penetration of anoxic waters. Indeed, extremely shallow conditions are suggested there by increased frequencies of *A. homomorphum* and *A. parvum* in the levels above the deposits containing *W. meckelfeldensis* (Chateauneuf & Gruas-Cavagnetto, 1978, p. 75). Locally in the Varengeville Formation, *W. meckelfeldensis* itself is very frequent (up to 22 %) (Gruas & Bignot, 1985, p. 120). Such high percentages too are indicative of shallow, near-shore conditions. The absence of anoxic waters in the areas discussed would hence explain why *D. oebisfeldensis* is never recorded in the Lower Ypresian from the Paris and Hampshire-Dieppe Basin.

Why does *D. oebisfeldensis* become very rare near the end of sedimentation of our *Dracodinium simile* Zone in the shallow areas near the margin of Belgian Basin, where the species was still more or less flourishing ? The answer is probably to be found in a major hydrographic change affecting especially the southern North Sea Basin. The Ypresian transgression attained then its maximal extension in the Paris Basin and in the Hampshire-Dieppe Basin. Already near the beginning of the sedimentation of our *Eatonicysta ursulae* Zone, when calcareous benthonic and planktonic foraminiferids appear in the Belgian Basin, a connection was created between the Anglo-Paris-Belgian Basin and the Western Channel. Boillot and Le Calvez (1961, p. 29) indicate that such a connection must already have existed for a certain time in the Ypresian. A regular water flow from the Western Channel, the Loire atlantique and the Aquitaine Basin may have penetrated the Anglo-Paris-Belgian Basin by the Cotentin region. Indeed, Bignot, Hommeril and Larsonneur (1968, p. 411) think that parts of the old surface of the Col du Cotentin, which is situated at an altitude of 35 to 40 m, may have been formed by marine abrasion during Cretaceous and Eocene times. The steady flow of oceanic waters into the southern, extended North Sea Basin started probably together with the sedimentation of our *E. ursulae* Zone, at the base of which the sudden arrival of many calcareous benthonic and also planctonic foraminiferids (= base of BF IV association zone in Willems & Moorkens, 1991, p. 238, pl. 3; Event I1 in King, 1991, p. 352, fig. 4) reveals a major change in the hydrography of the basin. Other arguments in favour of a supply of oceanic water from the Western Channel are found higher in the *D. varielongitudum* Zone *sensu* Costa and Downie (1976). In this zone corresponding with the transition between our *E. ursulae* Zone and *D. varielongitudum* Zone *sensu* De Coninck (1981, p. 292), accumulations of *Nummulites planulatus* are found in the Sands of Mons-en-Pévèle or in their lateral equivalents, the Roubaix Clay and the Sands of Forest from the southwestern and southeastern Belgian Basin, for instance at Steenhuize-Wijnhuize and Ronse-Waaienberghe (Vanhove & De Coninck, 1992, pp. 356-357) and at Marke (Steurbaut, 1988, p. 343). This species arrived a first time in the Paris-Belgium Basin through the penetration of southern oceanic water into the basin (Gramann, 1988, pp. 413-414). In the Hampshire Basin, it appears only from the time of deposition of Fisher Bed IV of the Bracklesham Group, i.e. significantly later than in the Paris and Belgian Basin. The counter clockwise hydrographic system of the southwards enlarged North Sea Basin certainly caused this difference and was also responsible for the contrast between the "boreal" sharks found in the London Clay division B up to E and the "Tethyan" species in the partly equivalent Roubaix Clay and Mons-en-Pévèle Sands from the Belgian Basin (Ward, 1990, unpublished information). *Turritella* beds are also observed in the Roubaix Clay and lateral equivalents. These concentrations result from rather strong currents near the bottom. Reworked species of organic walled phytoplancton from the *W. meckelfeldensis - Charlesdowniea crassoramosa* Zone have been recorded in the nummulite and *Turritella* bearing Mons-en-Pévèle Sands at Steenhuize-Wijnhuize and at Ronse-Waaienberghe (Vanhove & De Coninck, 1992, pp. 358 and 359). Very probably they indicate local erosion of the seabottom in the eastern shallow area of the Hampshire-Dieppe Basin and further in the direction of the Belgian Basin. Together with the flow of southern oceanic water northeast, sediment particles and among them microfossils brought in suspension again, could very well have settled after arriving in the southern Belgian Basin.

The connection of the North Sea Basin with the Western Channel changed the whole hydrography in the Belgian Basin, where the particular conditions favouring the production of *D. oebisfeldensis* cysts disappeared. Maybe in the western part of the London Basin, the change was less pronounced and did not yet affect the water stratification. *D. oebisfeldensis* is indeed recorded at Enborne in the upper part of the Stiff Clays (= London Clay Division B) (Davey *et al.*, 1966, p. 233 and Table I) corresponding to our *E. ursulae* Zone (De Coninck 1991, fig. 4).
As a conclusion, we can say that the *D. oebisfeldensis* acme Zone lost some of its biostratigraphic importance in the southern marginal areas of the North Sea Basin. Instead, it may have acquired more significance for the environmental history of the Early Ypresian in the southern North Sea Basin.

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PLATE 1

All figures : *Deflandrea oebisfeldensis* Alberti 1959.

magnification : 500 X

Figure 1. Linter boring 105W345, - 21.5 m, slide 2.

Figure 2. Linter boring 105W345, - 21.5 m, slide 2.

Figure 3. Linter boring 105W345, - 21.5 m, slide 2.

Figure 4. Erquelinnes Sablière du Bois-Gilles, M7, slide 2.

Figure 5. Knokke boring 11E138, - 284.1 à - 284.2 m, slide 1.

Figure 6. Knokke boring 11E138, - 284.1 à - 284.2 m, slide 1.

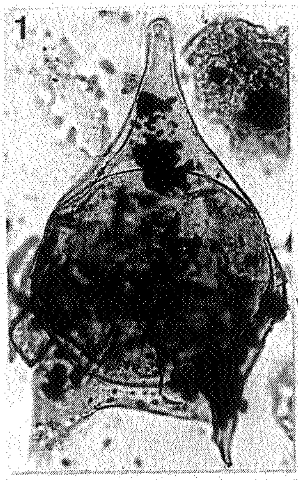
Figure 7. Erquelinnes Sablière du Bois-Gilles, M7, slide 5.

Figure 8. Erquelinnes Sablière du Bois-Gilles, M7, slide 1.

Figure 9. Knokke boring 11E138, - 284.1 à - 284.2m, slide 1.

Figure 10. Knokke boring 11E138, -284.1 à -284.2m, slide 1.

Figure 11. Kallo boring 27E148, -377m, slide 9.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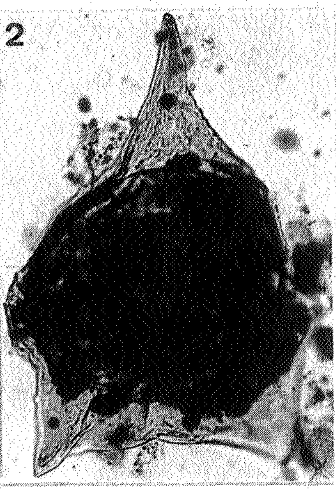
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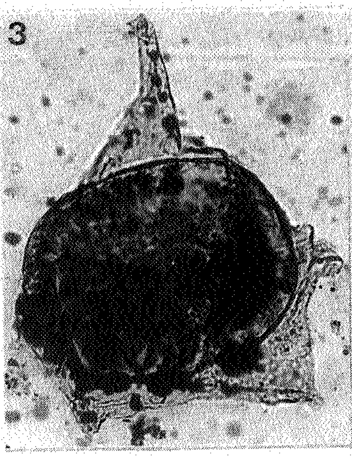
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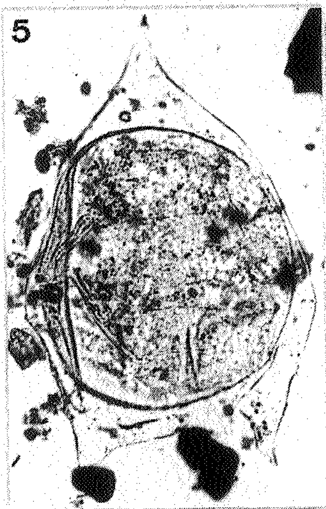
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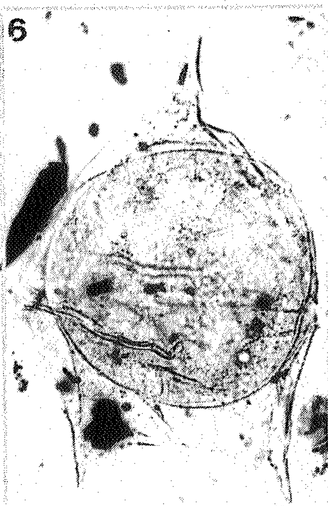
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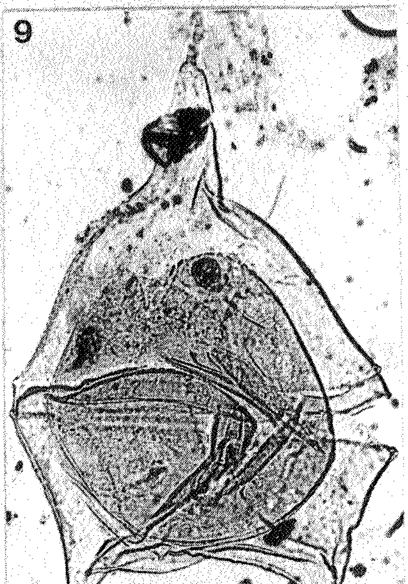
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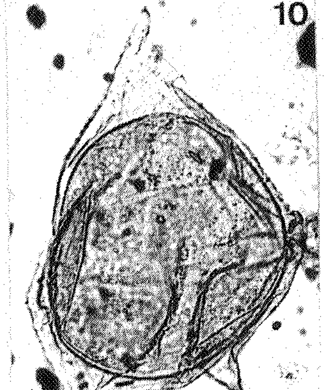
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PLATE 2

Figures 1, 2, 5, 6, 7, 8, 9 and 10. *Deflandrea oebisfeldensis* Alberti 1959.

Figures 3 and 4. *Wetzeliella lobisca* (Williams and Downie 1966) Jolley and Spinner 1989.

Figures 11 and 12. *Wetzeliella lunaris* Gocht 1969.

magnification : 500 X

Figure 1. Kallo boring 27E148, -377m, slide 1.
Figure 2. Kallo boring 27E148, -376.5m, slide 8.
Figure 3. St. Omer - Helfaut, 12, slide B.
Figure 4. St. Omer - Helfaut, 12, slide A.
Figure 5. St. Omer - Helfaut, 14, slide A.
Figure 6. St. Omer - Helfaut, 12, slide A.
Figure 7. Château de la Bruyère boring SA 62, about -12m, slide 3.
Figure 8. Quenast Carrière CGCP, A1b, slide 4.
Figure 9. Château de la Bruyère boring SA 62, about -12m, slide 1.
Figure 10. Overijse boring 103W145, -70.9m, slide 3.
Figure 11. Château de la Bruyère boring SA 62, about -12m, slide 3.
Figure 12. Château de la Bruyère boring SA 62, about -12m, slide 1.

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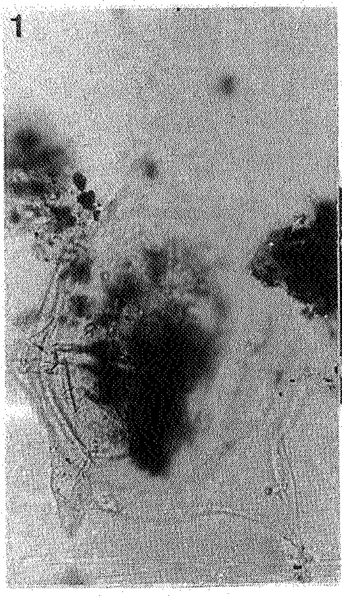

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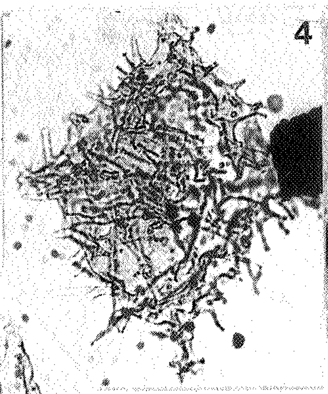

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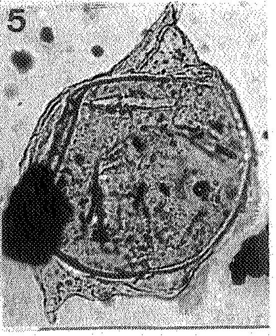

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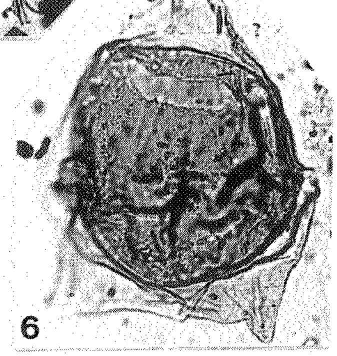

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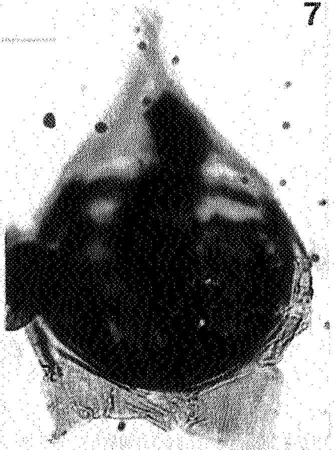

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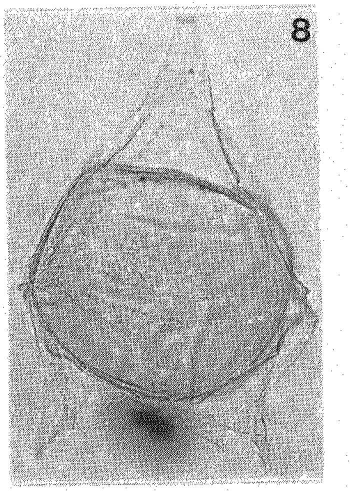

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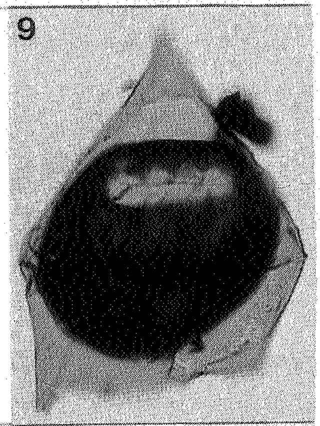

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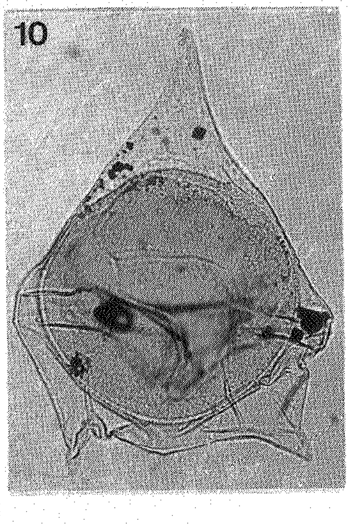

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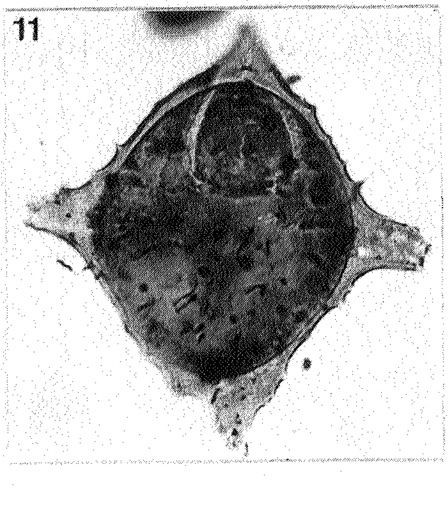

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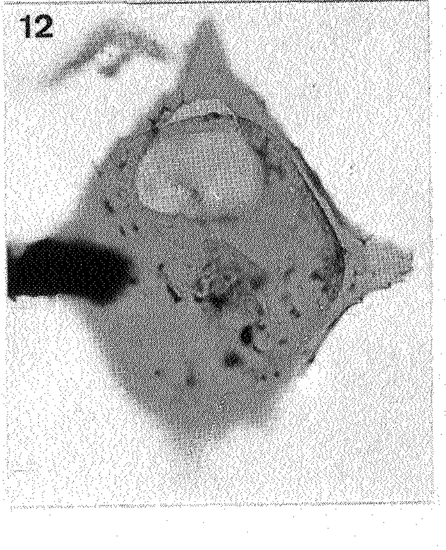

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Bulletin van de Belgische Vereniging voor Geologie. Ed. 1994

BIOSTRATIGRAPHY AND PALEOGEOGRAPHY OF VIERLANDIAN AND HEMMOORIAN (EARLY MIOCENE) IN THE FLENSBURG-SCHLESWIG AND NORTH FRISIA REGION

by

Winfried HINSCH[1]

ZUSAMMENFASSUNG

Biostratigraphie und Paläogeographie des Vierlandium und Hemmoorium (Untermiozän) im Raum Flensburg-Schleswig-Nordfriesland.

Durch die Korrelation biostratigraphischer Befunde unter chronostratigraphischen wie biofaziellen Aspekten mit der lithostratigraphischen Untergliederung vermessener Bohrprofile des Hemmoorium und Vierlandium im Raum Schleswig-Flensburg-Nordfriesland konnte die Paläogeographie der Zeitabschnitte : Vierlandium, Unteres Behrendorfium, Mittleres Behrendorfium bzw. Frörup, Oberes Behrendorfium, Unteres Oxlundium und Oberes Oxlundium rekonstruiert werden. Die marinen Äquivalente der "Braunkohlensande" der Ribe-Formation und der Odderup-Formation zeigen unterschiedliche Abfolgen der Biofaziesbereiche vom fluviatil-terrestrischen Milieu im Osten bis zur euhalinen Fazies des tieferen Wassers im Westen, was in Profilen und Kartenskizzen dargestellt wird.
Die Sande der Ribe-Formation zeigen einen direkten Kontakt der fluviatilen Fazies zu euhalinen Milieu. Damit wird ein relativ steiler Abfall des vorgelagerten Schelfs von der Küste in tiefere Wasserbereiche belegt. Während der Ablagerung der Odderup-Formation entstehen hingegen weite Flachwasserbereiche vor der Küste mit brachyhaliner bis intertidaler Fazies. Die D-*Lembulus*-Biofazies kommt vom oberen Behrendorfium bis ins untere Oxlundium vor. Die *Ervilia*-Biofazies ist (abgesehen von einer kurzen Episode am Kopf des Frörup Member in Flensburg-Nord) vor allem im Oxlundium gut entwickelt, während *Lentidium*-Horizonte wie auch eine weit nach W reichende Sandschüttung im oberen Odderup auf das späte Oxlundium beschränkt sind.
Die drei Ingressionen des Vierlandium, des Frörup-Horizont und des Reinbekium dringen mit euhaliner A- und B-Biofazies weit nach Osten vor. Wegen des diachronen Beginns der brachyhalinen Biofazies innerhalb des Hemmoorium wird das Aussetzen (LOD = Last Occurrence Date) von *Tritonella cimbrica* der phylogenetischen Reihe *T. cimbrica* → *T. voorthuyseni* für die Abgrenzung Behrendorfium/Oxlundium vorgeschlagen.
Die durch Biofazies, Lithofazies und die Paläogeographie definierten miozänen Unterstufen von Untermiozän- und Nordelbe-Zyklus des östlichen Nordseebeckens werden mit den globalen Meeresspiegelschwankungen und den Zyklen dritter Ordnung von Haq *et al.* (1988) korreliert.

ABSTRACT

By the correlation of bio- and chronostratigraphic results, the lithostratigraphic subdivison, and molluscan associations found in well sections in the Schleswig-Flensburg-North Frisia region, the paleogeography for the time-spans of the Vierlandian, the Early Behrendorfian, the Middle Behrendorfian or the Frörup niveau, the Late Behrendorfian, the Early and Late Oxlundian is reconstructed.
The "Braunkohlensande" fo the Ribe Formation and the Odderup Formation show a quite different pattern of the off-shore biofacial succession ranging from fluviatile-terrestric facies in the East, into deeper euhaline environment in the West. The Ribe sands show direct contact of fluviatile facies to an euhaline milieu, thus pointing to a steep coastal slope.
During Odderup deposition wide belts of shallow sea with several brachyhaline or intertidal marine associations, are developing in front the coastline. Of these the D-*Lembulus*-association appears first in the Late Behrendorfian. The

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Ev-*Ervilia*-biofacies, with a first episode at the Frörup top of Flensburg North, is mainly developed in the Oxlundian, whereas special *Lentidium* horizons are restricted to the Late Oxlundian.

Three marine ingressions can be distinguished in this area, showing prograding of the euhaline A- and B-biofacies, far to the E in the Vierlandian, in the Frörup Member (Behrendorfian), and in the Reinbekian (basal Middle Miocene). Because of the diachronic start of brachyhaline biofacies within the Hemmoorian the LOD of *Tritonella cimbrica* is proposed as marker for the Behrendorfian/Oxlundian boundary.

The substages of both the Early Miocene Cycle and the Nordelbe Cycle of the eastern North Sea Basin are dated by correlation of biofacies, lithofacies, and paleogeography. They are correlated to the sequence chronostratigraphy and to the eustatic sea level changes of Haq *et al.* (1988).

KEY WORDS

biostratigraphy, paleogeography, Miocene, Germany, molluscs.

1. INTRODUCTION

A survey of the chronostratigraphical, biostratigraphical, and lithostratigraphical Units of the Neogene in the eastern part of the North Sea basin, and their juxtaposition to the global stratigraphical scheme is given in table 1.

In the chronostratigraphic part (columns 1-5) a correlation is made of the regional North sea stages to the series, to the global stages, and tentatively also to the regional stages of the Paratethys. This chronostratigraphic correlation is based on biostratigraphical zones (columns 6-8). The zones of benthic molluscs (BM),

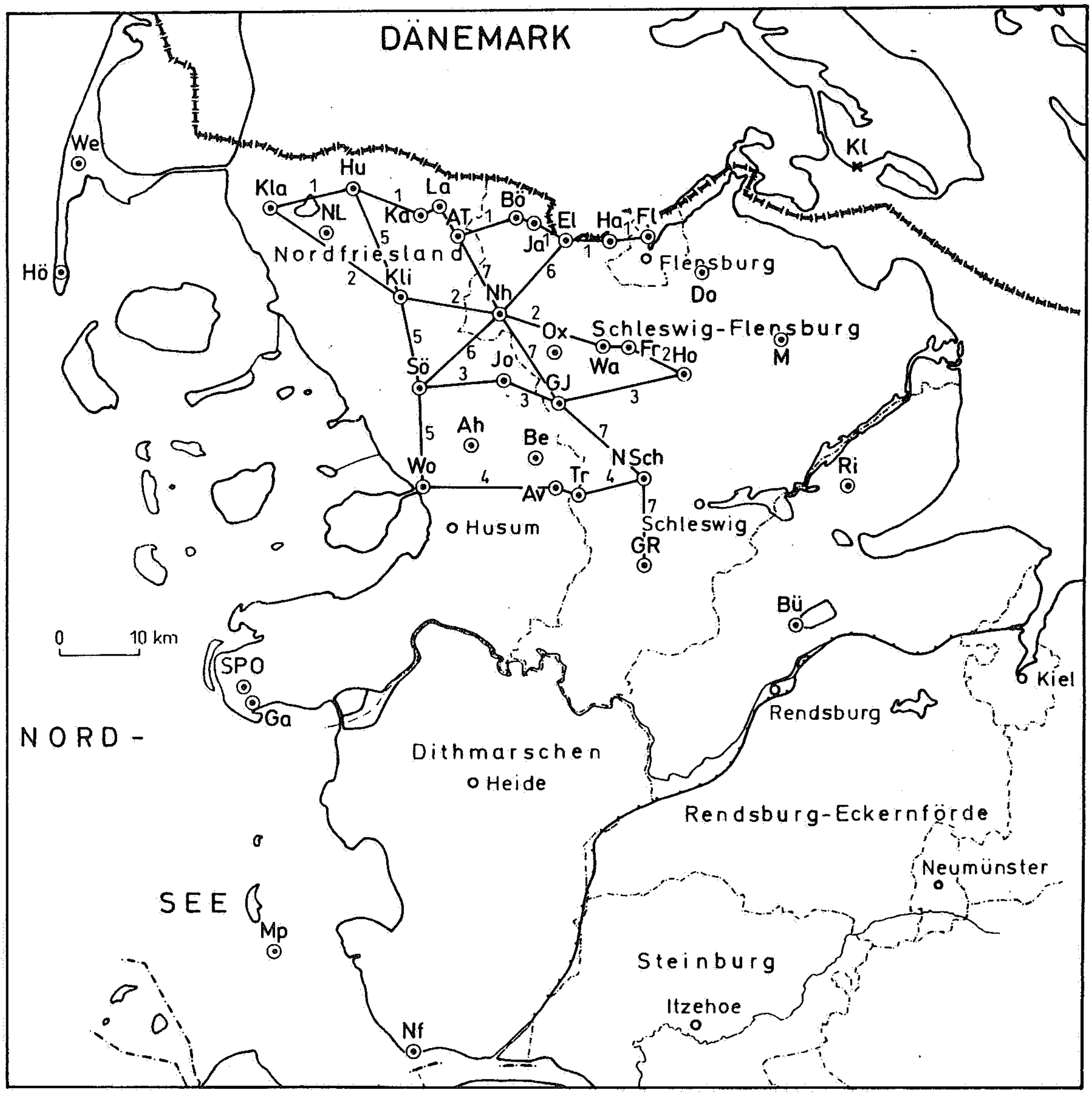

Figure 1. Location maps and draft lines.

calcareous nannoplancton (NN) and planktonic foraminifera (N) are selected here, whereas the zones of other fossil groupes can be found in Hinsch, 1986d.

The lithostratigraphy of the Neogene of the region studied here comprises three sedimentary cycles generally starting with a rather rapid sea level rise, with an eastward transgression, and gradual regression in the upper part of the cycle : Early Miocene Cycle, Nordelbe Cycle, and Crag Cycle (column 9). The lithostratigraphic units are sorted according to their environment of deposition from W to E into a) deeper marine mica clay facies (column 10) b) shallower marine mica sand facies (column 11), and c) fluviatile-terrestric "Braunkohlensand"-Formation (column 12).

For the upper part of the Nordelbe-Cycle the successive shifting of biofacies has been documented by Hinsch (1990). Now the gradual change of biofacies marked by benthic molluscs and of lithofacies has been studied for the Early Miocene Cycle. In this paper the Miocene succession of the Vierlandian and Hemmoorian stages, that means Aquitanian and Burdigalian is studied in the region of Flensburg-Schleswig and North Frisia.

In the nearshore regions of the eastern North Sea Basin the successions are - in contrast to the central and western parts of the basin - nearly complete, and therefore they give good hints for sea level changes. At the base of the Early Miocene Cycle of the area studied, a transgressive hiatus occurs between the Vierlandian and the Early Eochattian as youngest bed below it to be observed. As this hiatus occurs between sediments of deeper marine environments it appears to be caused by reduced sedimentation rates and subsequent erosion. Generally the extent of the hiatus between Neogene and Paleogene increases towards the west.

A good marker is the sea level rise of the Frörup Member-event, which is even invading the terrestrial environment. The top of the Early Miocene Cycle is very clearly defined by the Middle Miocene or Reinbekian transgression with a sudden rise of sea level.

2. WELL SECTIONS

During the last two decades twenty-two hydrogeological research wells have been sunk in the districts of Schleswig-Flensburg and North Frisia mainly for the Geologisches Landesamt Schleswig-Holstein. The well section used are (abbreviation as given on the map) :

22 wells in profiles :

Kla	Klanxbüll
Hu	Humptrup
Ka	Karlum A 14
La	Ladelund
AT	Tettwang
Bö	Böxlund B 4
Ja	Jardelund
El	Ellundfeld
Ha	Harrislee
Fl	Flensburg A 1/85 and 1/88
Kli	Klintum
Nh	Nordhackstedtfeld
Sö	Sönnebüll
Jö	Joldelund
GJ	Jörl
Fr	Frörup
Ho	Holmingfeld
Wo	Wobbenbüll
Av	Ahrenviölfeld
Tr	Treia
NSch	Nordschubyfeld
GR	Groß Rheide

3 wells of 1991 (not in profiles) :

M	Mühlenholz
NL	Niebüll-Langstoft
Ah	Ahrenshöft

2 wells of Dittmer (1959) :

Be	Behrendorf
Ox	Oxlund

These wells have also been used in the profile section 1-7 in chapter 6. This list can be extended by 6 wells located farther to the W and SW (Sylt, Eiderstedt, Southern Dithmarsia) and 2 wells from the Rendsburg-Eckernförde area :

We	Westerland, Seedeich
Hö	Hörnum, Graues Tal
SPO	St. Peter 1
Ga	Garding 1
Mp	Mittelplate 1
Nf	Neufelderkoog
Ri	Rieseby, Sonderbyhof
Bü	Bünsdorf

The wells of Wanderup (Wa) and Dollerup (Do) yielded no Hemmoorian (only Vierlandian) fauna. Table 2 lists the coordinates and the main boundaries of the sections of 30 wells and in the map of the area (Fig. 1). These wells are marked together with the 7 profile lines of fig. 2-8.

Chronostratigraphy				Biostratigraphy			Lithostratigraphy			
Series	global stages	regional stages Para-tethys	regional stages North sea basin	benthic molluscs BM	standard planctonic zones NN	standard planctonic zones N	Sedimentary cycle	deeper marine mica clay facies	marine mica sand facies	terrestric fluviatile
Pleistocene		Dacian					Crag Cycle			
Pliocene	Piacentian		Merxemian	22 C	18 to 12	22		▨	▨	Oldesloe- Fm.
			Scaldisian	22 B		21		▨	▨	
				22 A		20 to 18		▨	▨	
	Zanclean		Morsumian	21 C				▨	Morsum Mbr.	
Late Miocene	Messinian	Pontian	Syltian IV III II I	21 B	11	17	Nordelbe-Cycle	▨	Pinneberg Fm.	
	Tortonian	Pannonian						Gram Fm.		▨
			Gramian II I	21 A	10	16			Saed Mbr. Pinneberg Mbr.	▨
Middle Miocene	Serravallian	Sarmatian	Langenfeldian s.l. Langenfeldian S.S. IV	20 B	9 to 6	15		Eidelstedt Fm.	▨	▨
			III			14 to 11			▨	▨
		Badenian: Kosovian	Lüneburgian II	20 A					▨	▨
		Wielician	Levensauian I	19 B					▨	▨
		Moravian	Reinbekian	19 A	5	10 to 8b		Hodde Fm.	▨	▨
	Langhian	Karpatian							Katzheide Mbr.	▨
Early Miocene	Burdigalian	Ottnangian	Hemmoorian: Oxlundian	18 B	4	8a	Early Miocene Cycle	▨		Trittau Fm. Etz Mbr. Hamburg Mbr.
						7				
		Eggenburgian	Behrendorfian	18 A	3	6		Elmshorn Fm.	Arnum Fm.	Odderup Fm.
					2	5		Frörup Mbr.	Frörup Mbr.	
	Aquitanian				1				Arnum Fm.	Ribe Fm.
		Egerian	Vierlandian	17		4		Klintinghoved Fm.	Wanderup Mbr.	▨
Late Oligocene	Neochattian		Neochattian	16 C	NP 25	3 = P22		▨	▨	
	Eochattian		Late Eochattian	16 B	NP 24					
			Early Eochattian	16 A						

Table 1. Chrono- bio- and lithostratigraphical correlation.

Table 2. Location and litho- and chronostratigraphical boundaries (around Early Miocene) of 30 well section.

							Top Level	Level 5	Level 4	Level 3	Level 2	Level 1	Base level		
well sections	abbreviations	TK 25/5	Rechtswert Lang.	Hochwert Lat.	über NN	base qp	base tmir XX	base tmihx Late XVII	base tmihx Early XIII	base tmihb Late VIII	base tmihbF V	base tmihb Early III	base tmiv I	below tmiv-transgression	profiles
Klanxbüll	Kla	1118	^{34}80 040	^{60}78 910	+ 1	57	198	207	235	260	275	309	325	teom S	1/2
Humptrup	Hu	1119/11	91 025	81 820	+ 3	58	151	157	176	191	210	274	288	teom S	1/5
Karlum A 14	Ka	1119	99 650	78 300	+ 12	122	127	138	155	186	202	228	248	teom S	1
Ladelund	La	1120	^{35}01 710	79 500	+ 22	47	131	140	163	187	204	223	228 FD	-	1/7
Tettwang	AT	1120/27	03 825	75 530	+ 11	79	121	129	153	175	189	214	219 FD	-	1/7
Böxlund B. 4	Bö	1121/19	11 233	78 343	+ 42	85	-	87	117	152	168	216	245	teom S	1
Jardelund	Ja	1121/26	13 300	77 630	+ 37	65	72	82	111	155	181	230	240 FD	-	1
Ellundfeld	El	1121/34	16 885	75 212	+ 23	76	-	85	105	139	162	210	253	teom S	1/6
Harrislee	Ha	1122	22 695	75 330	+ 37	54	-	60	85	127,5	147,5	193	220 FD	-	1
Flensburg 1/85 (1/88)	FL	1122	27 200	75 100	+ 31	30	87	139	161	-	225	282	300 FD	-	1
Klintum	Kli	1219/14	^{34}96 975	68 115	+ 9	144	151	154	179	203	217	253	272	tolm	2/5
Nordhackstedt	Nh	1220/20	^{35}09 355	66 190	+ 8	92	106	124	146	176	196	251	263	teom S	2/6/7
Sönnebüll	Sö	1319/20	^{34}99 737	56 116	+ 28	180	187	193	225	252	277	301	315	tolm	3/5/6
Joldelund	Jo	1320	^{35}09 870	57 725	+ 21	99	105	121	153	183	199	243	260	teom S	3
Jöri	GJ	1321/28	16 480	54 900	+ 25	67	77	96	115	147	173	208	210 FD	-	3/7
Frörup	Fr	1322	24 700	62 230	+ 28	96	133	158	191	248	275	312	330 FD	-	2
Holmingfeld	Ho	1322	32 015	58 540	+ 39	50	94	108	132	179	207	240	250 FD	-	2/3
Wobbenbüll	Wo	1420	00 290	43 845	+ 11	107	140	146	163	179	183	219	235	teom S	4/5
Ahrenviölfeld	Av	1421/22	16 435	44 065	+ 14	32	82	96	129	160	189	226	251	teoo S	4
Treia	Tr	1421/29	19 135	43 444	+ 16	43	117	135	158	192	202 FD	-	-	-	4
Nordschubyfeld	NSch	1422/18	27 610	45 680	+ 14	42	283	307	365	429	465 FD	-	-	-	4/7
Groß Rheide	GR	1522/18	27 245	34 525	+ 11	118	134	150	191	244	268	317	360	toloe	7
Westerland	We	1015	^{34}56 040	^{60}85 950	+ 2	0	345	359	382 FD	-	-	-	-	-	-
Hörnum	Hö	2125	54 420	71 570	+ 4	12 qh	348	356	400	402 FD	-	-	-	-	-
St. Peter 1	SPO	1617	77 920	19 575	+ 1	110	1262	1290	1335	1417	1480	1532	1662	tolon	-
Garding 1	Ga	1718	78 927	17 225	+ 2	65	1656	1686	1753	1935	2195	2456	tolon	-	-
Mittelplate	Mp	1919	82 382	^{59}88 404	± 0	75	295	317	338	374	397	422	434	toloe	-
Neufelderkoog	Nf	2119	99 070	74 005	+ 2	63	215	258	296	321	330 FD	-	-	-	-
Rieseby	Ri	1424	^{35}52 260	^{60}44 860	+ 26	45	48	ho	ho	106	132	162	230	toloe	-
Bünsdorf	BÜ	1624	46 900	27 450	+ 12	126	-	-	-	129	161	201	261	toloe	-

3. CHRONOSTRATIGRAPHY

The stratigraphical interval considered in this paper corresponds to the Aquitanian and the Burdigalian. In the present paper the regional stages of the Vierlandian and the Hemmoorian are used.

3.1. Vierlandian

The Vierlandian is represented by the mica clay of Klintinghoved Formation (perhaps, according to the microfauna, including some Neochattian deposits), and the more silty-sandy Wanderup Member. In the E to the S and the W the mica-clays of Elmshorn-Formation occur. The Vierlandian is transgressive :

a) upon the Middle Eocene Søvind-Formation at Klanxbüll, Humptrup, Karlum, Böxlund, Ellundfeld, Nordhackstedt, Joldelund, Wobbenbüll,
b) upon the Late Eocene to Latdorfian Søvind-Formation at Ahrenviölfeld,
c) upon marly clays of the Rupelian at Sönnebüll,
d) upon marly clays of the Early Eochattian at Groß Rheide, St Peter, Garding, Mittelplate, Bünsdorf, and Rieseby.

In the E a fairly rich Vierlandian molluscan fauna has been described from the Klintinghoved type locality (Sorgenfrei, 1940), and from the Wanderup Member (Dittmer, 1959b). To the W there is both a reduction of thickness from more than 50 m to 15-20 m in North Frisia and a reduction of faunal content which is probably caused by sedimentation at greater depth, and at a greater distance from the coast. The poor remnants of molluscan fauna of this interval are in most cases difficult to assess as they are hidden by caving in the very fossiliferous overlying Behrendorfian beds. Therefore only in 2 of our wells a faunistical proof of the Vierlandian was possible :

Ellundfeld 198 - 202 m *Hinia meyni* (Beyrich)
Klintum 270 - 273 m *Stenomphalus wiechmanni* (Koenen)

3.2. Hemmoorian

The Hemmoorian stage occurs between the Vierlandian and Reinbekian stages. Whereas the underlying Vierlandian and overlying Reinbekian are completely represented by deeper marine facies, the Hemmoorian comprises the full range of environments from terrestrial-fluviatile, via diverse brachyhaline and intertidal settings to the euhaline deeper environment. The index fossils of the Hemmoorian occurring in euhaline environment of the region studied here are for example :

Pecten brummeli Nyst LOD (= Last Occurrence Date)
Solariella miosuturalis (Kautsky)
Arsenia belgica Glibert
Haustator eryna (Orb.)
Architectonica carocollata (Lam.)
Miohinia coronata (Mostafavi)
Tritonella serraticosta (Bronn)
Aquilofsus siebsi Kautsky (Joldelund 198 - 204 m)
Elaeocyma diensti (Kautsky)
Glyphostoma borealis (Kautsky)
Glyphostoma elatior (Koenen)

Some other index fossils restricted to an brachyhaline environment are found among the species of the groups 14 and 15, of table 3a, for example : *Microloripes niveus* (Eichwald), *Dosinia basteroti* (Agassiz), *Donax stoffelsi* (Nyst), *Dorsanum boreobaccatum* (Kautsky), *Phrontis pölsensis* (H. & A.), and *Aurelianella wolffi* (Kautsky) as LOD's.

3.3. Behrendorfian/Oxlundian boundary

Generally the brachyhaline environments are confined to the upper part of the Hemmoorian and the euhaline milieu abounds in the lower part ; therefore tentatively the boundary between the substages Behrendorfian and Oxlundian was placed by Hinsch (1972, 1973, 1977) at the biofacial boundary of the euhaline to brachyhaline environment. From the results of the type-region of both the Behrendorfian and the Oxlundian stages as studied in this paper, it is evident that this biofacial boundary is a diachronic one. Looking for a phylogenetic lineage occurring in the Hemmoorian of this region, usable for a Behrendorfian/Oxlundian boundary, only the lineage of *Tritonella cimbrica* (Ravn) → *Tritonella voorthuyseni* (Janse & Janssen) could be detected. Hinsch (1988) used this lineage for the separation of the benthic mollusc zones BM 18 A for the Behrendorfian stage and BM 18 B for the Oxlundian stage. The last occurrence of *Tritonella cimbrica* was observed in the lithostratigraphical units XI and XII. Below it this species is rather common in the central part of the region (without its eastern and western outskirts). The LOD of *Tritonella cimbrica* in the units XI/XII was observed in the wells : Ahrenviölfeld and Treia (in XII), Ladelund, Tettwang, Böxlund, Jardelund, Nordhackstedt, Joldelund, Jörl (in XI). The LOD's in IX were observed at Humptrup, Karlum, Ellundfeld, Wobbenbüll. Much too deep (? by caving) *T. cimbrica* was found at Klintum. This species is missing in the E at Harrislee, Flensburg, Frörup, Holmingfeld probably because of the occurrence of fluviatile facies and in the W it is missing at Klanxbüll and Sönnebüll because of a too great water depth in the complex VIII-XII.

Higher than this unit only occasional specimens of *T. voorthuyseni* were found. This younger species is very abundant in the Katzheide Member of the Early Reinbekian.

I therefore propose to put the boundary Behrendorfian/-Oxlundian between the lithostratigraphic units XII and XIII of this region. For the well Nordhackstedt this boundary nearly coincides with the change from euhaline to brachyhaline environments. At Tettwang, Karlum, Ladelund this environmental limit is somewhat higher, at Joldelund and Ahrenviölfeld it occurs somewhat deeper than the newly defined Behrendorfian/Oxlundian boundary. Towards the W the brachyhaline enivronment is restricted to the youngest part of the Oxlundian, whereas in nearshore areas to the E the brachyhaline milieus appear earlier. The first occurrence of brachyhaline environment occurs at the top of the Frörup Member as observed in the well Flensburg 1/85.

3.4. Top of the Oxlundian

The Oxlundian/Reinbekian boundary is best characterized by the LOD of *Haustator eryna*, often accompanied by some brachyhaline species. In 12 of 22 wells the LOD of *Haustator eryna* was observed less than 4 m below the Reinbekian ingression. This species is only missing from Klanxbüll and Klintum of the W, and because of fluviatile facies from Harrislee towards the E. The first appearance of *Haustator eryna* was observed in the Frörup Member at Flensburg.

3.5. Reinbekian

The Reinbekian deposits overlying the Oxlundian sediments show an ingression of a rather deep sea, and the depositional environment is euhaline in contrast to the underlying brachyhaline or fluviatile Oxlundian. In 26 of 30 wells the Reinbekian was encountered on top of the Oxlundian, only in 4 wells this contact was removed by Quaternary. In 23 wells the Early Reinbekian is developed as Katzheide Member with abundant *Tritonella voorthuyseni*, only at Groß Rheide *Bittium obsoletum* is also present. The heavy mica clay of the Hodde Formation overlies the Katzheide Member. Only at Neufelderkoog, Mittelplate, and Rieseby the Hodde Formation was found directly above the Oxlundian.

The index fossil *Scalaspira festiva* (Beyrich) was encountered at Klanxbüll, Klintum, Wobbenbüll, Treia, Nordschubyfeld and Groß Rheide. The species *Streptodictyon abruptus* (Beyrich) was found at Wobbenbüll and Groß Rheide.

4. LITHOSTRATIGRAPHICAL AND SEQUENCE STRATIGRAPHICAL SUBDIVISION

The lithostratigraphic subdivision into units I-XX follows a sequential sedimentation scheme of alternating sediment packet of more sandy/silty and more clayey beds. This scheme can be pursued by considering the lithology, the fauna and the log correlations, especially in marine milieu. By comparing the chronostratigraphic markers it can be concluded that also the "Braunkohlensande" of the Ribe Formation and the Odderup Formation are to be considered as equivalents of the marine Hemmoorian and are thus well fitting in this system of lithostratigraphical units.

The units I and II are Vierlandian equivalents, III-XII belong to the Behrendorfian, XIII-XIX ot the Oxlundian, and XX, XXI are of Reinbekian age including the Katzheide Member and the Hodde Formation.

The main marine ingressions are that of I = basal Vierlandian, V = basal Frörup, and XX = basal Reinbekian. Within the Hemmoorian the maximal continental influence of the W is marked by IV for the Upper Ribe Formation and by XVII for the Upper Odderup Formation. To the E the Ribe Formation comprises III and IV, and the Odderup Formation at last extends from VIII to XVII followed successively by thin equivalents of the Hamburg Member XVIII and the Trittau Formation XIX.

In the western area the marine milieu of the Hemmoorian including the Arnum Formation, the Elmshorn Formation and the Frörup Member, comprises an alternation of more sandy and more clayey complexes : relatively clayey units of low energy regime are III, V, VII, IX, XI, XIII, XV and XVIII. The more sandy or silty units as deposited in higher energy environment are IV, VI, VIII, X, XII, XIV, XVI increasing to XVII, and XIX. In the profiles and facies maps (figs. 2-14) not every unit is marked, because in some areas with reduced thickness not every unit can be clearly distinguished in the well logs.

Therefore only the following six stratigraphical units could be discerned by litho- and biofacies given in the figs. 2-14 in all profiles :

XVII - XIX	Late Oxlundian
XIII - XVI	Early Oxlundian
VIII - XII	Late Behrendorfian
V - VII	Middle Behrendorfian or Frörup Member
III - IV	Early Behrendorfian
I - II	Vierlandian

Therefore only the following stratigraphical levels of the Lower Miocene Supercycle are used in the profiles and paleogeographical maps :

Top level	base of the Reinbekian ingression or transgression
Level 5 (between XVI/XVII)	base of the maximal extension of the Odderup Formation in the E and sandy Arnum Formation towards the W,
Level 4 (between XII/XIII)	last occurrence of *Tritonella cimbrica* and rare appearance of *Tritonella voorthuysensi,*
Level 3 (between VII/VIII)	top of the Frörup Member, first appearance of the brachyhaline environment and base of the Odderup Formation in the E
Level 2 (between IV/V)	ingression of marine Frörup Member above the top of Ribe Formation in the NE and E, very rich Behrendorfian in the mica clay in the W,
Level 1 (between II/III)	first Hemmoorian fauna in the W, basal "Braunkohlensande" of Ribe Formation in the E,
Base level (=I)	transgressive Vierlandian.

The stratotypes for the substages of Behrendorfian and Oxlundian described in Dittmer (1959a) correspond to two horizons with rich molluscan fauna in the two stagename giving wells :

1. Behrendorfian in well Behrendorf
   TK25 Viöl 1421
   R 14120
   H 47 530
   + 11,3 m NN
fossil sample from depth 132-144 m.

2. Oxlundian in well Oxlund
   TK25 Jörl 1321
   R 16 000
   H 60 950
   + 18 m NN
compound fossil sample from depth 105-128 m.

For these two boreholes no well logs are available. A correlation can be made by the modern fully-logged exploration wells of Ahrenviölfeld, Groß Jörl, Joldelund, Nordhackstedt, and Ellundfeld in the neighbourhood. By its fossil content and thickness of lithological units the stratotype of the Behrendorfian can be correlated with the Frörup Member between its Levels 2 and 3. This member was introduced by Hinsch, 1972a for a marine horizon in the Flensburg area, occurring between the Ribe-Formation and the Odderup-Formation. But the Frörup Member is recognizable in the whole region, also between marine strata by its rich fauna and deeper marine environment as caused by the high sea-level stand during that period.

The first appearance of *Haustator eryna* has been observed in the Frörup Member at Flensburg, whereas *Haustator goettentrupensis* was not encountered in the Behrendorfian. It was erroneously reported by Dittmer (1959a) in that unit. The most common turritellid in the Frörup Member is *Torculoidella subangulata* (Brocchi).

The Oxlund samples of the interval 105-128 m comprise to a great extent fauna from the earliest brachyhaline environment between Levels 3 and 4 and therefore below the LOD of *Tritonella cimbrica.* But there are also indications of fauna from beds higher than Level 4 with abundant *Ervilia.* In the modern wells located in the adjacent area around the original type-locality some samples taken in intervals of 3 m or at least 6 m, show the presence of younger horizons above Level 4 with a brachyhaline fauna. Therefore it seems legitimate to restrict the Oxlundian to the sequence above Level 4 and the LOD of *Tritonella cimbrica* as it was proposed by Hinsch (1988) as boundary between BM 18 A (=Behrendorfian) and BM 18 B (=Oxlundian).

In the profiles of chapter 5 and the paleogeography of chapter 6 the following six time-spans are considered :

between Top Level and Level 5 (XVII-XIX)	Late Oxlundian
between Level 5 and Level 4 (XIII-XVI)	Early Oxlundian
between Level 4 and Level 3 (VIII-XII)	Late Behrendorfian zone BM 18 A (=Earliest Oxlundian of Dittmer)
between Level 3 and Level 2 (V-VII)	Middle Behrendorfian = stratotype of he Behrendorfian = Frörup Member
between Level 2 and Level 1 (III-IV)	Early Behrendorfian (= Ribe Formation in the E)
between Level 1 and Base Level (I-II)	Vierlandian

	A_0	A_1	B	C	D	E
1. *Cardiomya costellata*-Gruppe						
Cardiomya costellata (DESHAYES, 1832)	II					
2. *Limopsis aurita*-Gruppe						
Limopsis aurita (BROCCHI, 1814)	V	V				
Elaeocyma diensti (KAUTSKY, 1925)	I	III				
Tornatina bellardii (KOENEN, 1882)	I	II				
3. *Boreodrillia hosiusi*-Gruppe						
Boreodrillia hosiusi (KOENEN, 1872)		III				
Cylindrophyllia duncani (REUSS, 1871)		II				
Stephanophyllia nysti (M.E. & H., 1851)		II				
Ceratocyathus granulatus (GOLDFUSS, 1826)		I				
Solariella miosuturalis (KAUTSKY, 1925)		I				
Aquilofusus siebsi (KAUTSKY, 1925)		+				
Apnanitoma gleibiergensis (SORGENFREI, 1958)		+				
4. *Astarte goldfussi*-Gruppe						
Astarte goldfussi (HINSCH, 1952)	V	V	IV			
Cyclocardia orbicularis (SOWERBY, 1825)	V	V	II			
Astarte (Nicaniella) radiata (NYST & WEST, 1839)	I	V	IV			
Goodallia angulata (LEHMANN, 1885)	II	III	+			
Thracia ventricosa (PHIL., 1844)	II	+	I			
Terebra acuminata (BORSON, 1820)	I	-	+			
5. *Astarte gracilis convexior*-Gruppe						
Astarte gracilis convexior (ANDERSON, 1959)		II	+			
Asthenotoma pannus (BAST, 1841)		II	I			
Giyphostoma elatior (KOENEN, 1872)		+	+			
Costoanachis terrebralis (GRAT., 1834)		r	+			
Favriella sinuosula (SORGENFREI, 1958)		r	+			
6. *Pectunculina lamellata*-Gruppe						
Pectunculina lamellata (LEHMANN, 1885)	II	III	III	I		
Babylonella fusiformis (CANTRAINE, 1835)	II	III	II	I		
Gemmula boreoturricula (KAUTSKY, 1925)	II	III	III	I		
Parvicardium straeleni (GUBERT, 1945)	I	II	-	I		
Borsonia uniplicata (KOENEN, 1872)	I	II	-	+		
Arsenia belgica (GUBERT, 1945)	II	+	I	+		
7. *Leionucula haesendoncki*-Gruppe						
Leionucula haesendoncki (NYST & WEST, 1837)		III	II	I		
Hemiacirsa lanceolata (BROCCHI, 1814)		II	III	+		
Tahusyrinx corneti (KOENEN, 1872)		III	+	+		
Nannodiella hannoverana (KAUTSKY, 1925)		II	+	I		
Pecten brummeli (NYST, 1864)		I	+	I		
Pleurotomella mioweberi (NORDSIECK, 1972)		r	+	+		
8. *Phos decussatus*-Gruppe						
Phos decussatus (KOENEN, 1872)		r	II	I		
9. *Torculoidella subangulata*-Gruppe						
Torculoidella subangulata (BROCCHI, 1814)	II	IV	III	+	II	
Michinia turbinella fuchsi (KOENEN, 1872)	IV	IV	+	I	I	
Thyasira hanseata (KAUTSKY, 1925)	II	+	I	+	I	
10. *Lamellinucula cromata*-Gruppe						
Lamellinucula cromata (SORGENFREI, 1958)		I	I	+	II	
Pitar rudis (POLI, 1795)		I	-	-	I	
Uromitra acicula (NYST, 1861)		II	-	-	I	
Balcis alba eichwaldi (HÖRNES, 1856)		+	-	-	I	
Leucotina nordmanni (SORGENFREI, 1958)		r	-	+	I	
11. *Tritonella woodwardi*-Gruppe						
Tritonella woodwardi (HARMER, 1913)			II	I	II	I
Strioterebrum basteroti (NYST, 1845)			II	II	II	III
Splendrillia selenkae (KOENEN, 1872)			II	I	-	II
Michinia pseudoturbinella (MOSTAFAVI, 1978)			II	I	-	I

	A_0	A_1	B	C	D	E
12. *Tritonella voorthuyseni*-Gruppe						
Tritonella voorthuyseni (JANSE & JANSSEN, 1983)			-	III	II	III
Glyphostoma simplex (SORGENFREI, 1958)			+	I	II	II
Calyptraea chinensis (LINNE, 1758)			+	+	-	+
13. *Circulus subcirculus*-Gruppe						
Circulus subcirculus (COSSMANN & PEYROT, 1916)					I	
Starkeyna hanseata (KAUTSKY, 1925)					I	
14. *Lembulus emarginatus*-Gruppe						
Lempulus emarginatus (LAMARCK, 1819)					V	III
Asthenotoma festiva (HOERNES, 1854)					III	II
Dosinia basteroti (AGASSIZ, 1845)					II	II
Ensis hausmanni (GOLDFUSS, 1841)					I	I
15. *Ervilia pusilla*-Gruppe						
Ervilia pusilla (PHILIPPI, 1836)						IV
Acanthocardia hanseata (KAUTSKY, 1925)						III
Lentidium donaciformis (NYST, 1836)						III
Dorsanum boreobaccatum (KAUTSKY, 1925)						II
Phrontis polsensis (HÖRNES & AUINGER, 1879)						II
Actaeocina lajonkaireana (BASTEROT, 1825)						II
Clavatula boreointerrupta (KAUTSKY, 1925)						II
Microloripes niveus (EICHWALD, 1830)						I
Laseina degrangei (COSSMANN & PEYROT, 1912)						I
Donax (Cuneus) stoffelsi (NYST, 1845)						I
Tesseracme sp.						I
Aurelianella wolffi (KAUTSKY, 1925)						I
Partnenina cimbrica (KAUTSKY, 1925)						I
Moerella donacina (L., 1758)						+
Spaniorinus cimbricus (KAUTSKY, 1925)						r
Solenocurtus sp.						r
Cirsope saucatsensis (C. & P.)						r
Perrona pseudoduchasteli (KAUTSKY, 1925)						r
Ringiculocosta cancellarioides (SEGUENZA, 1879)						r

Table 3a. Groups of characteristic "Trennarten" of mollusc associations in hte Hemmoorian stage in Südschleswig.

	A_0	A_1	B	C	D	E
Varicorbula gibba (OLIVI, 1792)	IV	IV	IV	IV	V	V
Yoldia glaberrima (MÜNSTER, 1837)	V	V	V	IV	IV	V
Saccella westendorpi (NYST, 1839)	III	V	V	III	II	II
Dentalium dollfusi (KOENEN, 1882)	IV	V	IV	II	IV	III
Yoldiella pygmaea (MÜNSTER, 1837)	II	III	V	IV	IV	IV
Haustator eryna (ORB., 1852)	-	II	V	III	V	IV
Nucula nucleus (L., 1758)	III	III	II	III	IV	IV
Spisula trinacria (SEMPER, 1861)	I	IV	III	II	IV	V
Aporrhais alata (EICHWALD, 1830)	IV	V	IV	III	IV	II
Gemmula denticula borealis (GLIBERT, 1954)	II	IV	III	III	IV	III
Miohinia schlotheimi (BEYRICH, 1854)	-	III	III	III	IV	IV
Anadara diluvii (LAM., 1805)	-	IV	III	II	IV	IV
Ringicula buccinea (BROCCHI, 1814)	III	III	III	II	IV	IV
Bittium tenuispina (SORGENFREI, 1958)	-	II	III	III	IV	IV
Leionucula laevigata (SOWERBY, 1818)	-	III	II	II	IV	III
Vaginella austriaca (KITTL, 1886)	-	III	IV	II	III	III
Strioterebrum hoernesi (BEYRICH, 1854)	II	III	III	II	IV	III
Streptodictyon sexcostatus (BEYR., 1856)	I	III	IV	II	IV	II
Neoguraleus tenella (MAYER, 1858)	-	III	II	II	IV	III
Fusiturris flexiplicata (NYST, 1836)	III	IV	IV	II	II	II
Amyclina facki (KOENEN, 1872)	II	II	IV	II	II	II
Ringicula striata (PHIL., 1843)	-	II	II	II	IV	III
Megastomia conoidea (BROCCHI, 1814)	II	III	III	II	II	II
Roxania utriculus (BROCCHI, 1814)	I	II	III	II	IV	I
Tritonella cimbrica (RAVN, 1907)	-	III	III	II	IV	I
Syrnola hoernesi (KOENEN, 1882)	II	IV	II	II	III	I
Tritonella tenuistriata (BEYRICH, 1854)	I	III	III	II	IV	I
Cylichna pseudoconvoluta (ORB., 1852)	I	II	-	II	III	III
Gemmula zimmermanni (PHILIPPI, 1846)	IV	III	+	I	-	II
Crassispira borealis (KAUTSKY, 1925)	II	III	II	II	I	II
Murex (Haustellum) inornatus (BEYR., 1854)	III	III	III	II	II	I
Ventricoloidea multilamella (LAM., 1818)	II	II	II	I	II	II
Laevidentalium sp.	-	II	+	II	III	III
Pseudolatirus rothi (BEYRICH, 1856)	II	III	III	I	-	II
Miohinia coronata (MOSTAFAVI, 1978)	I	IV	III	I	-	r
Abra sorgenfreii (ANDERSON, 1965)	II	II	II	II	II	II
Lyrotyphis sejunctus priscus (RUTOT, 1876)	-	II	II	I	II	II
Cadulus (Gadila) gadus (MTG., 1803)	-	I	II	I	II	III
Pyrgolampros pseudoterebralis (SACCO, 1892)	II	III	II	I	II	I
Brachytoma obtusangula (BROCCHI, 1814)	II	III	III	I	-	I
Bittium spina (HÖRNES, 1854)	-	IV	III	+	-	+
Euspira helicina (BROCCHI, 1814)	II	II	I	I	I	II
Gemmula stoffelsi (NYST, 1845)	-	II	I	+	II	II
Rhizorus acuminatus (BRUG., 1792)	-	II	II	II	II	II
Tritonella serraticosta (BRONN, 1831)	-	I	II	II	II	II
Brachytoma pannoides (KOENEN, 1872)	-	II	+	I	II	II
Acteon semistriatus (FERUSSAC, 1822)	-	I	II	I	II	II
Hiatella arctica (L., 1758)	-	II	II	I	I	I
Neverita olla (SERRES, 1829)	-	I	I	II	II	I
Glyphostoma borealis (KAUTSKY, 1925)	-	II	I	I	II	I
Conolithus dujardini (DESH., 1845)	I	I	III	I	II	I
Gonimyrtea droueti (NYST, 1861)	-	II	II	I	-	r
Tectonatica miopusilla (KAUTSKY, 1925)	-	II	II	I	II	I
Zygochlamys lilli (PUSCH, 1837)	-	II	+	-	II	I
Strephona dufresnei (BAST., 1825)	-	II	+	-	II	I
Aequipecten seniensis (LAM., 1819)	-	II	II	I	II	+
Habecardium subturgidum (ORB., 1852)	I	II	+	I	-	r
Gouldia minima (MTG., 1803)	-	II	II	-	I	I

Table 3 b (continued)

	A_0	A_1	B	C	D	E
Siphonodentalium sp.	II	-	II	+	II	I
Ancilla obsoleta (BROCCHI, 1814)	-	II	II	+	II	I
Teretia anceps (EICHWALD, 1830)	-	II	-	-	I	I
Peronaea fallax (LEHMANN, 1893)	II	+	-	-	II	II
Columbellopsis attenuata (BEYR., 1854)	-	II	I	+	-	+
Pyrgulina pygmaea (GRAT., 1838)	I	II	I	-	I	r
Niso acarinatoconica (SACCO, 1892)	I	II	+	-	I	+
Cylichnina elongata (EICHWALD, 1830)	-	II	+	-	-	+
Mangelia calais (KAUTSKY, 1925)	-	+	-	I	II	I
Turricula steinvorthi (KOENEN, 1872)	I	-	II	I	-	I
Bathytoma jugleri (PHIL., 1846)	-	II	I	I	I	I
Gemmula coronata (MÜNSTER, 1844)	I	I	+	+	I	I
Fusiturris aquensis (GRAT., 1832)	-	I	+	+	-	I
Xenophora deshayesi (MICH., 1847)	-	+	-	I	-	I
Genota ramosa (BAST., 1825)	-	I	-	-	I	I
Architectonica carocollata (LAM., 1822)	-	I	+	+	I	I
Circulus hennei (GLIBERT, 1952)	-	+	-	-	I	I
Ditrupa cornea (L.)	II	II	III	I	IV	IV
Balanus sp.		r	-	+	-	r

		total Hemmorian	A_0	A_1	B	C	D	E
Number of molluscan species	Korallen	5	-	5	1	-	-	-
	Bivalvia	57	21	37	30	27	20	28
	Scaphopoda	6	2	5	4	5	4	5
	Gastropoda	140	38	119	81	73	63	93
		208	71	157	116	105	87	136

Steadiness of presence (Stetigkeit)		
	V	80,1 - 100 %
	VI	60,1 - 80 %
	III	40,1 - 60 %
	II	20,1 - 40 %
	I	10,1 - 20 %
	+	5,1 - 10 %
	r	0,1 - 5 %

Table 3b. Molluscan Fauna (except "Trennarten") of Hemmoorian stage in Südschleswig. both Table 3a and 3b with steadiness of presence (Stetigkeit).

Klanxbüll KL	198	- 235 C	Ellundfeld El	(76)	- 85 K	Jörl GJ	77	- 102 Ev
1/2		- 325 A	1/6		- 126 J	3/7		- 108 AV (+J)
					- 139 D			- 115 Ev
Humptrup Hu	151	- 161 Et			- 145 C			- 145 D
		- 184 C			- 150 B			- 150 B
		- 193 B			- 162 A	(173 - 175		- 173 A
		- 288 A			- 180 K	? K)		-(210)B
					- 201 C			
Karlum Ka	127	- 138 Ev			- 204 B	Frörup Fr		- 248 K
1		- 162 C			- 210 C	2		- 255 B
		- 174 B			- 253 B		133	- 275 A
		- 186 C					ca.	- 312 K
		- 192 B	Harrislee Ha	(54)	- 60 K			-(339)B
		- 202 A	1		- 120 J			
		- 203 K			- 127,5 YSp	Holmingeld		- 179 K
		- 248 A		ca.	- 140 ?C	Ho		- 207 B
					- 147,5 A	2/3	94	- 240 K
Ladelund La 1/7	131	- 150 Ev			- 168 K			-(250)B
(168-171 Ev by					- 174 YSp			
caving)		- 183 C			- 193 J	Wobbenbüll		- 153 Et
		- 192 B			-(220) A	Wo		- 175 C
		- 204 A				4/5	140	- 179 B
		- 206 K	Flensburg 1/88 +	94/	- 200 K			- 235 B
		-(228)A	1/85 Fl	87	- 220 Ev			
			1		-225/232A	Ahrenviöl-		- 96 Ev
Tettwang AT 1/7	121	- 145 Ev			- 282 K	feld Av		- 114 Av
(150 -162 D/Ev by					-(300) B	4	82	- 160 D
caving)		- 168 C						- 165 C
		- 183 B	Klintum Kli	(151)	- 154 Et			- 170 B
		- 189 A	2/5		- 168 C			- 226 A
		- 195 K			- 179 B			- 245 B
		- 204 V			- 272 A			- 251 A
		-(219)B						
			Nordhackstedt Nh	106	- 146 Ev	Treia Tr		- 145 Ev
Böxlund Bö	(85)	- 87 J	2/6/7		- 150 B	4		- 156 AV
1		- 97 Av			- 156 D		117	- 192 D
		- 102 Ev			- 176 B			-(202)C
		- 117 Av	(196 - 197 ? K)					
		- 152 D			- 251 A	Nordschu-		- 365 K
		- 162 B			- 263 B	byfeld		- 373 J
		- 168 A				NSch 4/7	283	- 429 K
		- 180 K		183	- 193 Et			- 447 C
		- 216 C	Sönnebüll Sö		- 215 C			-(465)B
		- 245 B	3/5/6		- 225 B			
					- 315 A	Groß Rheide		- 205 K
Jardelund Ja	72	- 76 J				GR 7		- 244 C
1		- 82 K		111	- 150 Ev		134	- 268 B
		- 92 J	Joldelund Jo		- 156 D			- 318 K
		- 96 Av	3		- 162 C			- 366 B
		- 111 J			- 168 D			
		- 150 D			- 174 C			
		- 162 C			- 180 B			
		- 181 A			- 243 A			
		- 192 K			- 260 B			
		- 230 C						
		-(240)B						

Table 4. Environmental subdivision of Hemmoorian and Vierlandian in 22 well sections used in profiles 1-7.

5. ENVIRONMENT CLASSIFICATION BY BIOFACIES

5.1. Diagnostic "Dividing Species" and mollusc associations

The Hemmoorian of Schleswig-Flensburg-North Frisia gives us the opportunity to observe the transition from continental fluviatile delta top sediments via the near-shore marine environment, to the deeper euhaline milieu. This depositional setting is reflected in the rich molluscan fauna observed in well sections. Directly from this material, analysed according to the Braun-Blanquet method, 15 groups of "dividing species" (="Trennarten") are discerned in table 3a.

In this list for the dividing species groups (and also for the species not belonging to these groups) the steadiness of their presence in the samples occurs in steps of generally 20 %.

Among the "dividing" species the groups n° 1-8 are restricted to the euhaline environment, n° 9-12 are appearing in both euhaline and brachyhaline milieus, whereas n° 13-15 are confined to the brachyhaline environment. Using the species of the "Trennarten"-groups the following biofacies units are distinguished :

A_O *Limopsis-Astarte-Caridiomya*-association, A 1 *Limopsis-Astarte*, B *Astarte* clay (without *Limopsis*) C shallow euhaline milieu, D *Lembulus*-association, E with Et *Lentidium* and Ev *Ervilia*-horizon, AV *Acanthocardia-Varicorbula* association, YSp poor *Yoldia-Spisula*-biofacies, J unfossiliferous sideritic sand, and K fluviatile "Braunkohlensande".

5.2. The A-*Limopsis* biofacies

For the A_O facies, which is only observed at Klanxbüll in units VII/VIII, the "Trennarten"-group 1 is characteristic, but also species from the groups 2, 4, 6 and 9, are present. The A_1 *Limopsis-Astarte* biofacies (without *Cardiomya*) comprises the dividing species from the groups 2.-10. For practical purposes in the profiles and maps the biofacies A_O and A_1 are summarized to the A-*Limopsis*-association as the deepest euhaline environment of the region. This A-association is present in the eastern part of the region in the Vierlandian and the Behrendorfian lithostratigraphical units I-XII, whereas to the W it is ranging upwards into the Oxlundian up to unit XVI. The Reinbekian again shows in most cases an A-biofacies. For this euhaline environment a water depth of 100-150 m is estimated.

5.3. B-*Astarte* biofacies

This B-biofacies, an *Astarte-Cyclocardia*-association without *Limopsis*, shows the "Trennarten"-groups 4.-12., and is present in the euhaline milieu of the Vierlandian to Oxlundian, in units I-XIX. For this low-energy euhaline environment a water-depth of 50-100 m is estimated.

5.4. C-biofacies

This association is less characteristic and mainly defined by the missing of both the deeper euhaline *Astarte*-clay-species and also the brachyhaline indicators. The C-association with the "Trennarten"-groups 6-12 is appearing first in the marine equivalent of the Lower Ribe Formation (= unit III) and it is present up to the Late Oxlundian (unit XIX). It is considered here as a shallow euhaline environment of ca. 20-50 m water depth.

5.5. D-*Lembulus* biofacies

This brachyhaline environment with species from the "Trennarten"-groups 9-14 appears first in the Behrendorfian (VIII) and has its main distribution in this period (VIII-XII) ; it is extending into the Early Oxlundian and ranges upwards into unit XV at the S of Joldelund.

For the D and E (Et and Ev) brachyhaline environments water depths of 0-20 m are estimated.

5.6. Et *Lentidium* horizon (and It)

From the strongly brachyhaline or intertidal E environment, with many rapid burrowers among the bivalves, the *Lentidium* association with some species of the "Trennarten"-group 15., (for example *Lentidium* in great abundance and also *Acanthocardia*, but without *Ervilia*) had to be separated. This specialized brachyhaline association appears first at Wobbenbüll and Humptrup in unit XVI and it is present up to the top of the Oxlundian (XIX) in the western outer belt of brachyhaline environment, where the thick-shelled and somewhat worn preservation of shells points to a higher energy regime (outer surf area) than in the inner *Ervilia*-biofacies. In Holstein the *Lentidium*-association was found both in the western brachyhaline outskirts and in the inner estuarine of the Etz Member covering Hamburg Member and of the Itzstedt Member (It) covering the Trittau Formation (Ehlers & Hinsch, in press). The state of preservation also points to a higher energy regime, occurring here in an estuarine milieu.

5.7. Ev *Ervilia* biofacies

The first appearance of an *Ervilia* horizon has been observed in the well Flensburg 1/85 at the top of the Frörup Member (units VII/VIII). It consists of a rather thick shelled assemblage with worn shells pointing to a higher energy milieu. In the Later Oxlundian this depositional setting will be inhabited by a *Lentidium* fauna. After this first episode the *Ervilia*-biofacies starts with a normal (lower energy) brachyhaline biotope in the Oxlundian. It was observed in the unit XIII at Joldelund and Jörl ; in the unit XIV at Ladelund and Tettwang ; and in the unit XV at Nordhackstedt. This biofacies persists up to the Late Oxlundian (unit XIX) in a N-S belt from Ladelund to Farnewinkel/-Burg/Gribbohm (East Dithmarsia and Western Steinburg). An *Ervilia*-Acme is much better developed in the brachyhaline Oxlundian of Schleswig than in that of Holstein.

The *Ervilia* biofacies has species of the "Trennarten"-groups 11.-15. and points to a brachyhaline environment because the greatest number of the species present is specialized to this environment.

5.8. *Yoldia-Spisula* and *Acanthocardia-Varicorbula* biofacies

Nearshore from the characteristic Ev-association there are some impoverished molluscan faunas in which the characteristic forms of the "Trennarten"-group 15. are missing. Nevertheless these associations, covering a much narrower belt than the *Ervilia*- or *Lentidium*-biofacies, have to be related to a brachyhaline or intertidal milieu.

A poor *Yoldia*-association was observed in the units VIII-X of the Upper Behrendorfian of Harrislee and Groß Rheide between D-*Lembulus*-biofacies in the W and fluviatile Odderup-Formation in the E.
The *Acanthocardia-Varicorbula*-association with *Varicorbula*-Acme (= AV biofacies) is restricted to the units XIII-XVI of the lower Oxlundium between the *Ervilia* biofacies in the W and either sideritic fine sand of facies J, or the K facies (= fluviatile Odderup Formation) in the E. From Böxlund-Jardelund in the N, the AV-biofacies can be followed in a narrow belt via Jörl and Treia to the Wacken area in western Steinburg/Holstein (Hinsch, 1972b).

5.9. Unfossiliferous facies (J + K)

The fine sands, locally indurated with sideritic cement (which may be weathered to limonitic cement) are occurring in unit III of the Lower Behrendorfian (Harrislee). They appear again from the Late Behrendorfian to the Oxlundian (units VIII-XIX) and are intercalated between the brachyhaline environments in the W, and the fluviatile Odderup Formation in the E, and thus they may be considered as a nearshore marine lithofacies of 0-5 m water depth.

At last the "Braunkohlensand"-lithofacies (= K facies) of the Ribe-Formation and of the Odderup Formation, which contains only fossil plant remains is considered as a terrestrial-fluviatile deposit, observed in this region in the units III and IV and from unit VIII up to unit XIX of the Hemmoorian stage;

6. PROFILES 1 - 7

Seven profiles have been constructed through the Vierlandian-Hemmoorian sequence of the Schleswig-Holstein-North Frisia region belonging (with exception of the easternmost part) to the geotectonical unit West-Schleswig block (see Hinsch, 1986c). As reference Level the boundary Behrendorfian/Oxlundian is used with the Oxlundian above the straight line and the Behrendorfian to Vierlandian below it. The base of the units I, III, V, VIII, XIII, XVII and XX are marked by full lines with indication of drilled depth in the wells, whereas the boundaries of the biofacial units are connected by interrupted lines.

6.1 Profile 1 is a W-E section from Klanxbüll to Flensburg (fig. 2). The Vierlandian stage shows an A- and a B-biofacies. The Ribe-Formation is overlying the Vierlandian with the units III and IV at Flensburg, and it ranges into the uppermost IV unit in Karlum in the W. The base of the Ribe Formation, prograding to the W, is observed to covering the sideritic J-facies and the *Yoldia-Spisula* association. Further westward it overlies in the greatest part the euhaline C-biofacies and at last, at it outskirts even the A-*Limopsis*-association. The basal Frörup Member shows again an invasion of deeper euhaline A-biofacies far to the E, where in Upper Frörup it grades into the B- or C-biofacies. Only near Flensburg the A-biofacies is directly overlain by an *Ervilia* horizon. The fluviatile Odderup Formation in this northern profile is not reaching so far to the W as the Ribe Formation does. Near Flensburg the whole complex from IX to XIX has a fluviatile facies, but already at Harrislee and Ellundfeld the lower fine sands show sideritic J-facies. The fluviatile maximum of unit XVII ends to the W between Jardelund and Böxlund. The Odderup Formation is underlain at Flensburg 1/85 by an *Ervilia* horizon, but for the largest part it is bordered during the Late Behrendorfian by a sideritic J-facies. The *Lembulus*-D-biofacies between J-facies and C-biofacies is confined to the Behrendorfian. During the early Oxlundian the J-facies is changing to the W into a small belt of AV-

Legend of figures 2 -14

Biofacial classification :

A	*Limopsis*-biofacies, deeper euhaline (100 -150 m)	
B	*Astarte-Cyclocardia*-association without *Limopsis* (euhaline 50-110 m)	
C	Shallow euhaline environment (20 - 50 m)	
D	*Lembulus*-biofacies, slightly brachyhaline	
Ev	*Ervilia*-biofacies	
Et	*Lentidium*-biofacies	= strongly brachyhaline
Av	*Acanthocardia-Varicorbula*-association	to intertidal
YSp	*Yoldia-Spisula*-association	
J	unfossiliferous sand, partly siderite cements, ? brackish	
K	fluvial-terrestric environment ("Braunkohlensande")	

tmihO = Odderup Fm. KhD = *Lembulus*-Karzheide Mbr.
tmiHR = Ribe-Fm. hH = Hamburg Mbr. Fig. 14

Levels

Top Level	Oxlundian/Reinbekian
Level 5	Base Late Oxlundian
Level 4	Base Early Oxlundian
Level 3	Base Late Behrendorfian
Level 2	Base Middle Behrendorfian and Frörup
Level 1	Base Early Behrendorfian
Base Level	Base Vierlandian

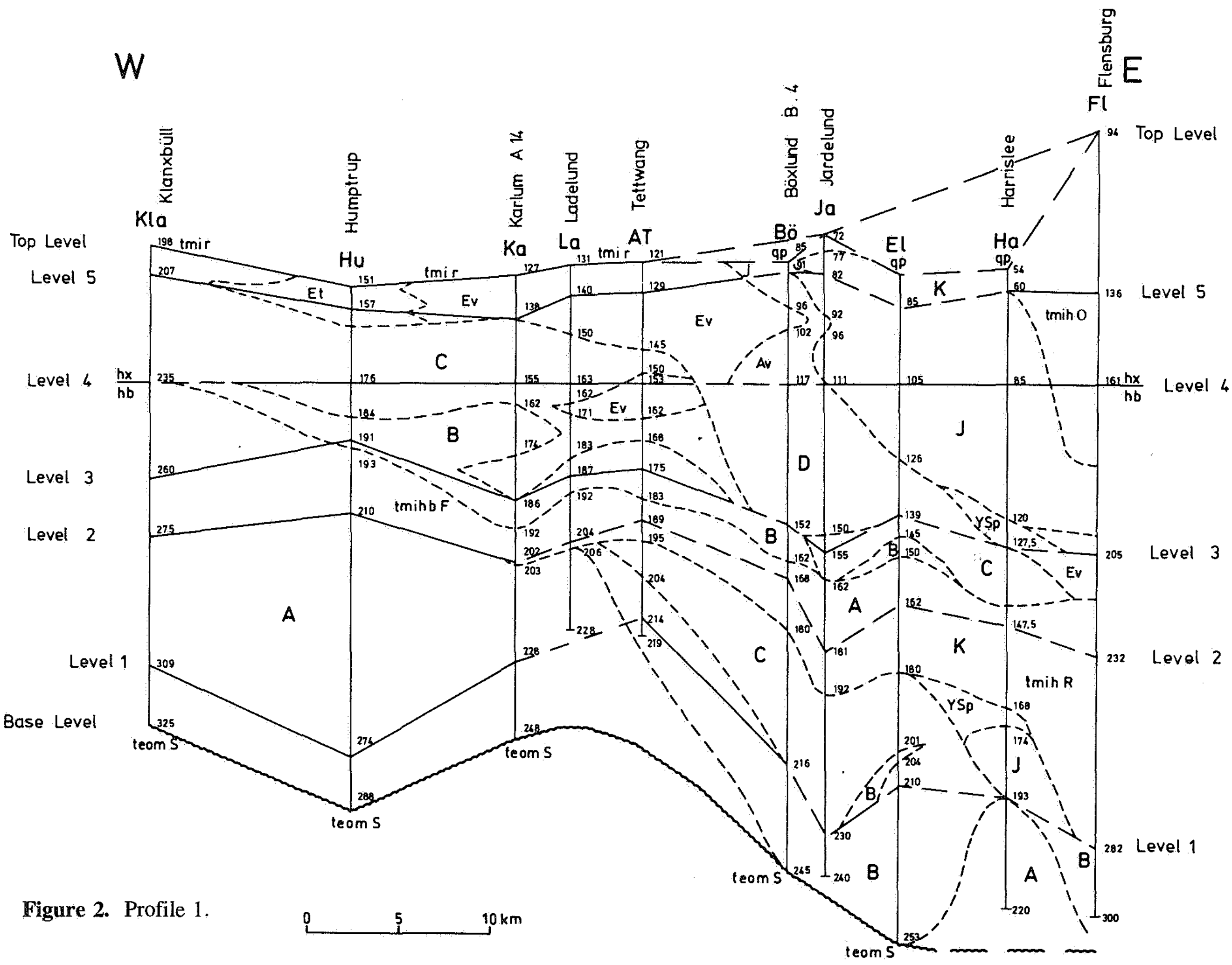

Figure 2. Profile 1.

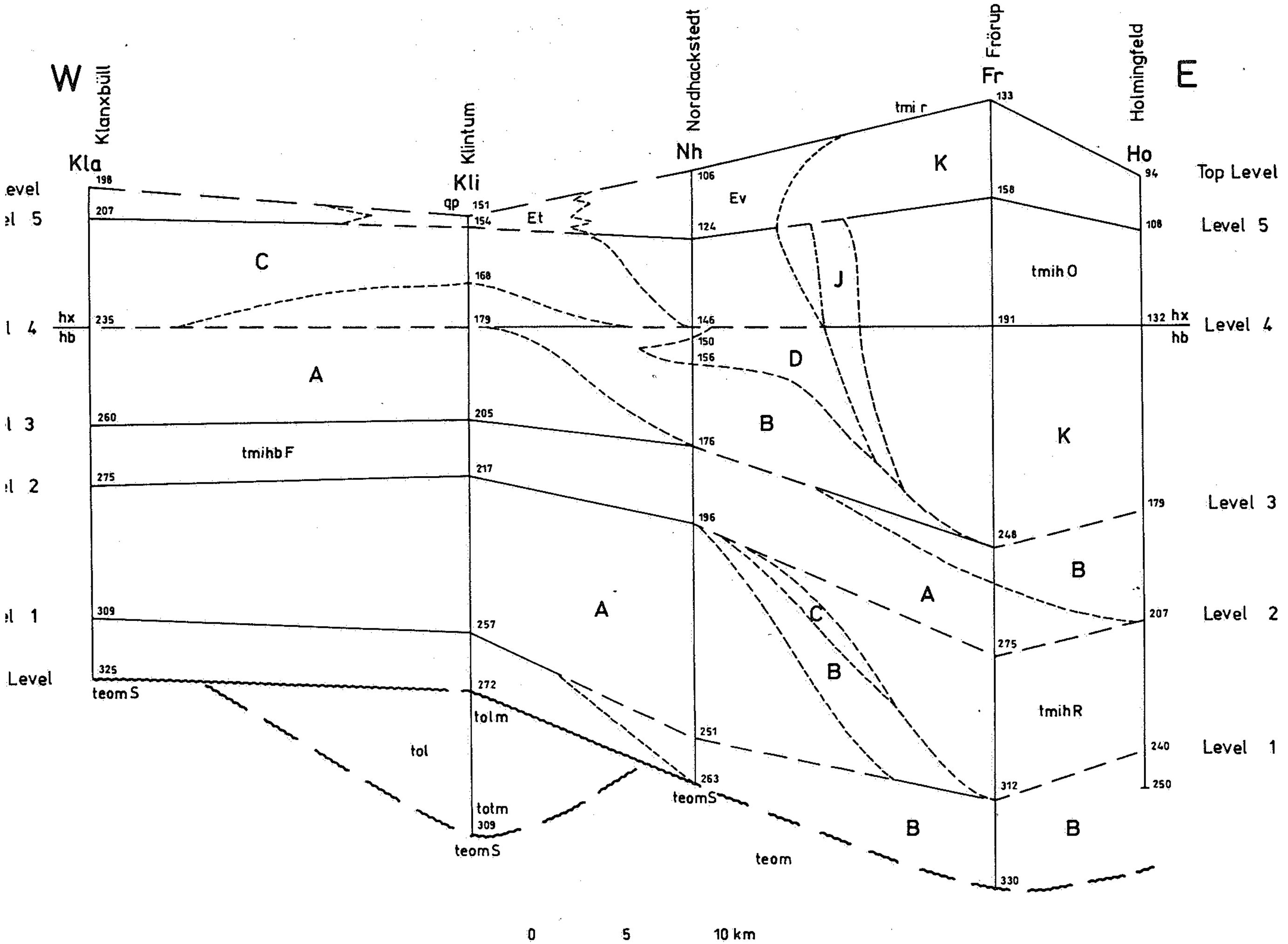

Figure 3. Profile 2.

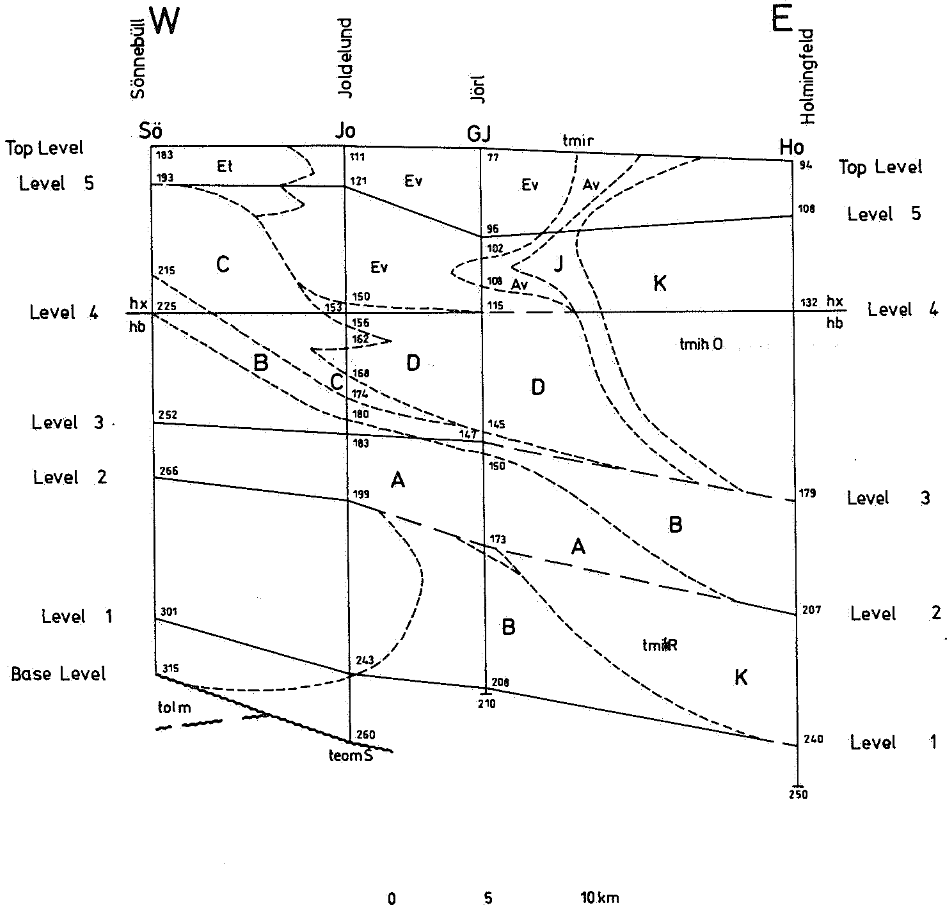

Figure 4. Profile 3.

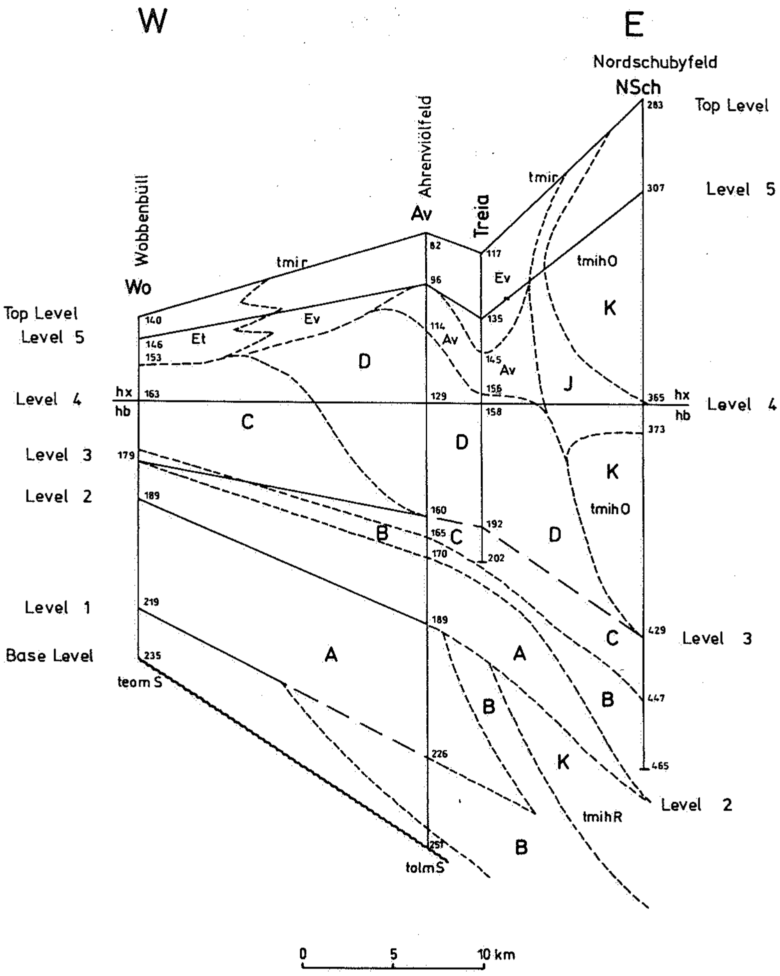

Figure 5. Profile 4.

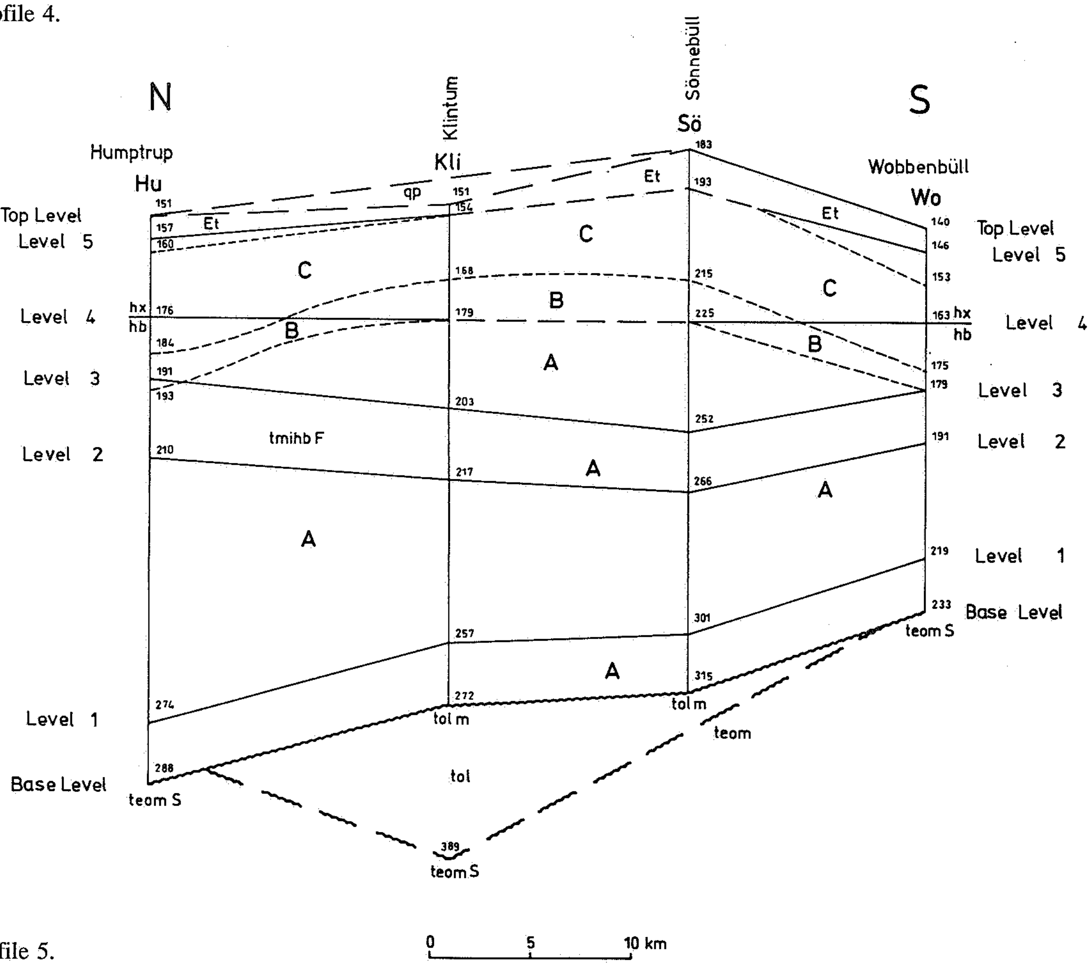

Figure 6. Profile 5.

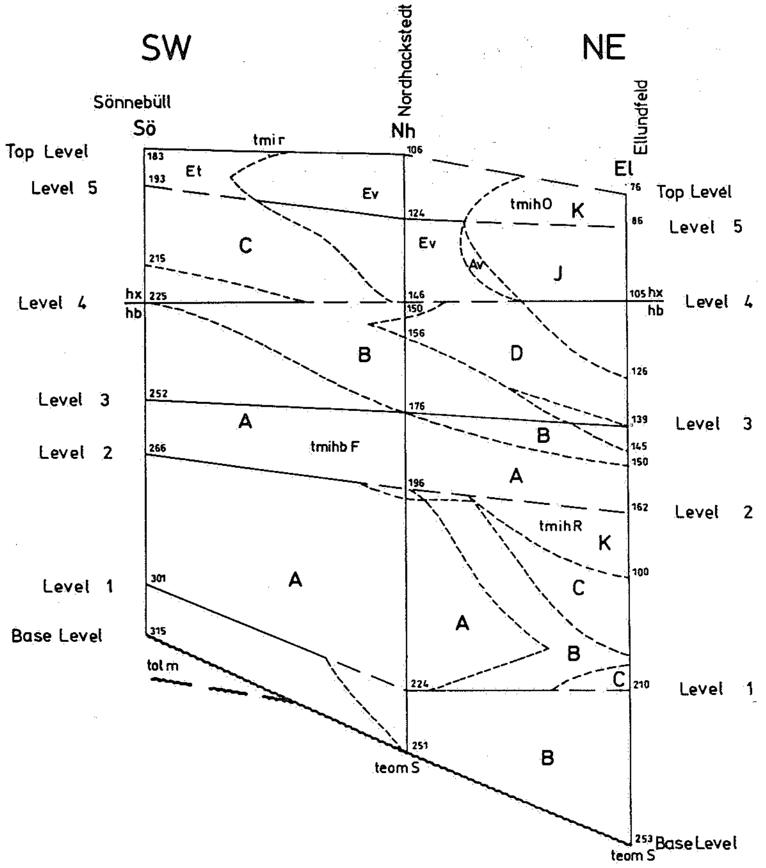

Figure 7. Profile 6.

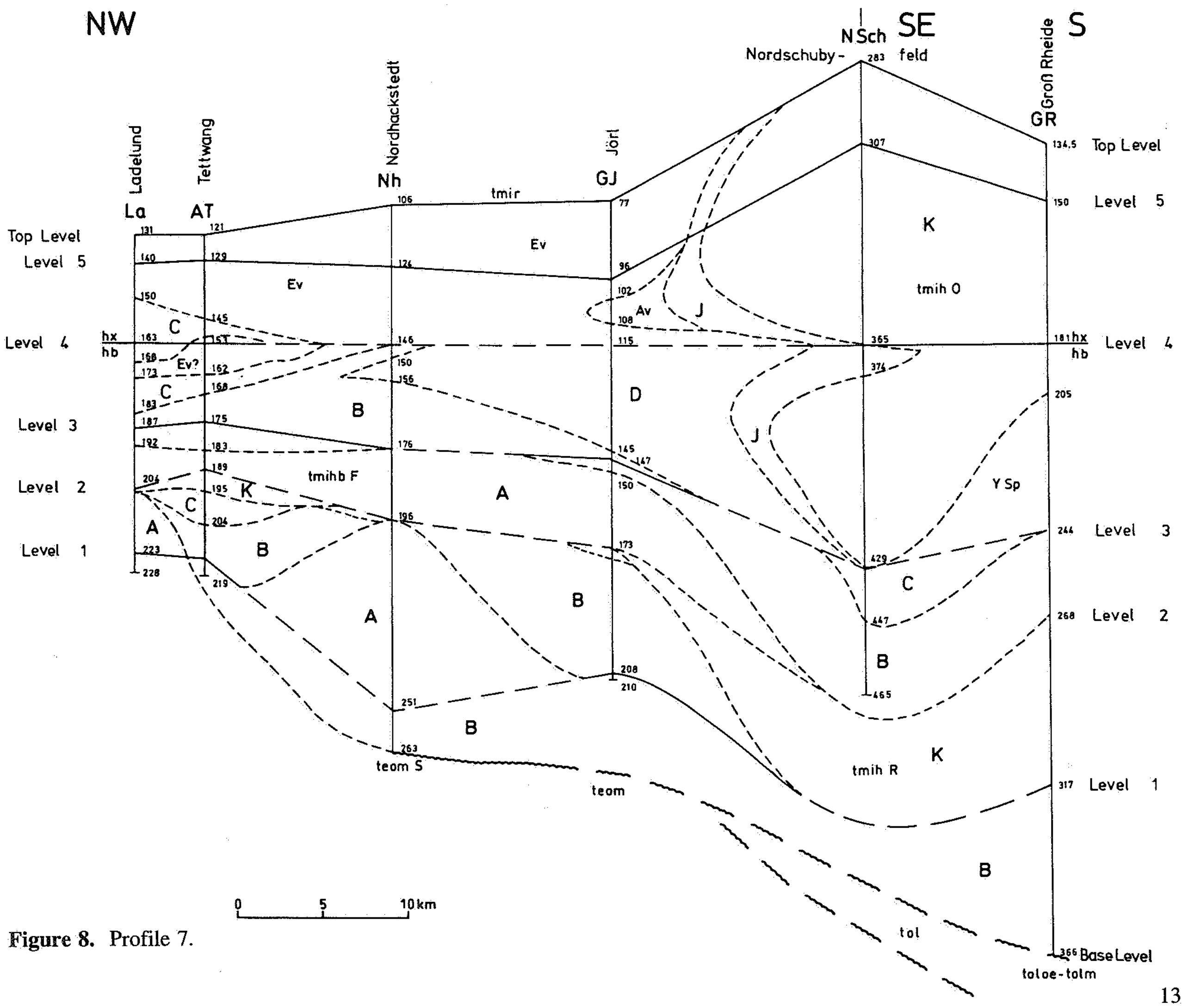

Figure 8. Profile 7.

biofacies, followed by a nearly 20 km wide belt of Ev-Ervilia-biofacies, framed by a ca. 10 km wide belt of Et-*Lentidium*-biofacies in the outer surf region. The D, Ev and Et brachyhaline association form the border to an euhaline C-biofacies, underlain by a B-biofacies of small thickness in the Behrendorfian, and thick A-biofacies in the W below it.

6.2 The profile 2 (fig. 3) is a W-E-profile from Klanxbüll to Frörup-Holmingfeld, S of Profile 1. The Vierlandian has an A-biofacies in the W and a B-biofacies in the E. The Ribe-Formation and the Odderup-Formation show nearly the same extension to W. The Ribe Formation base is bordered by a B- and a C-biofacies rapidly grading into a deeper A-biofacies. The Ribe Formation is overlain by the Frörup Member, with an A-biofacies extending farther to the E than in the Vierlandian stage. The Odderup Formation overlies the euhaline Frörup Member. To the W the Odderup Formation is bordered in the Late Behrendorfian first by a B-biofacies and later by a D-*Lembulus*-biofacies, which is replaced during the Oxlundian by the *Lentidium*-biofacies. In the western region with a complete euhaline sequence the deeper A-*Limopsis*-biofacies dominates in the Behrendorfian, whereas the Oxlundian shows a basal B-biofacies, and for the larger part a C-biofacies. This can be considered as a far reaching influence of the Odderup delta sedimentation in the euhaline pro-delta environment.

6.3 The profile 3 (fig. 4) representing a W-E-profile from Sönnebüll to Holmingfeld, again shows the direct contact of the Ribe-Formation to the A- and B-euhaline environment. The Odderup-Formation is bordered by a narrow belt of the J-facies and the AV-association. The main brachyhaline milieus occurs in the Behrendorfian D-*Lembulus*-biofacies. In the Oxlundian the wide belt of the Ev-*Ervilia*-biofacies is replaced to the W in the Upper Oxlundian by an Et-*Lentidium*-biofacies overlying the euhaline C-biofacies.

6.4 The profile 4 (fig. 5) is the most southern W-E-profile from Wobbenbüll to Nordschubyfeld showing again the Ribe Formation surrounded by the A- and B-biofacies. The Odderup Formation is accompanied by a wide belt of brachyhaline or intertidal environment. In this profile the D-*Lembulus*-biofacies persists from the Late Behrendorfian into the Early Oxlundian. The nearshore *Lembulus*- and *Ervilia*-biofacies are divided by layers with AV-association. To the W the Ev-biofacies is replaced by an Et-*Lentidium* horizon.

6.5 The profile 5 (fig. 6) is a N-S profile in North Frisia ranging from Humptrup to Wobbenbüll. In all four wells the Late Oxlundian shows an Et-*Lentidium*-biofacies of the outer surf region ranging from a brachyhaline to an intertidal shallow sea, and overlying the euhaline C-biofacies deposited in the Early Oxlundian. Below the C facies the B facies is rather thin, and the greatest part of Behrendorfian shows a deeper water A-*Limopsis*-biofacies.

6.6 The profile 6 (fig. 7) is a SW-NE-profile from Sönnebüll to Ellundfeld connecting the Profiles 1, 2 and 3. Profile 7 (fig. 8) is a NW-SE-profile from Ladelund to Groß Rheide crossing the profiles 1, 2, 3, 4 and 6.

Both profiles show the direct contact of the fluviatile Ribe Formation to the euhaline environment, whereas the Odderup Formation is accompanied by an *Ervilia*-biofacies, replaced towards the W in the Late Oxlundian, by an Et-*Lentidium*-biofacies. The different facies regions of the Late Oxlundian are overlain by the marine ingression of the Early Reinbekian with a deeper euhaline A-biofacies in the Katzheide Member and the Hodde Formation.

In the well Groß Rheide of profile 7, the beds above the Frörup Member i.e. the lower Odderup Formation is replaced by an impoverished *Yoldia-Spisula*-association, probably deposited in an intertidal environment.

7. PALEOGEOGRAPHY

Six time-spans can be distinguished when reconstructing the paleogeographic evolution of the area : (1) the Vierlandian, (2) the Early Behrendorfian, (3) the Middle Behrendorfian or Frörup event, (4) the Late Behrendorfian, (5) the Early Oxlundian, and (6) the Late Oxlundian.

For each of these time spans the regional extent of facies belts, ranging from the (deep marine) euhaline to the (non marine) fluvial-terrestrial environment can be reconstructed from the above mentioned paleontological and lithostratigraphical data. In the well sections considered, the thickness of the different units are marked for each locality separately, leading to the profiles as given in the sketches. Moreover these results, based on the well sections, allow to map the different facies belts for each of the six considered periods.

7.1. The Vierlandian stage (I + II) (fig. 9)

Only the euhaline biofacies of the soft bottom sediments is observed in the whole region. The deeper euhaline A-biofacies is distributed from the Sylt region in the W to Rieseby and Bünsdorf in the E. Only in an area from Tettwang-Flensburg in the N to Groß Rheide in the S the B-biofacies has been encountered. At Ahrenviölfeld the B-biofaces is overlying the A-biofacies. In the eastern part of the region the thickness of the Vierlandian stage generally exceeds 50 m comprising the fossiliferous Klintinghoved-Formation (Sorgenfrei, 1940) and the Wanderup Member (Dittmer, 1959b) with a rather rich fossil content. Towards the W it probably was deposited at greater water-depth and the thickness of the Vierlandian ranges there between 15-20 m ; only a sparse fauna is observed at Ellundfeld and Klintum allowing a chronostratigraphic assessment of these deposits.

Probably the Vierlandian transgression was somewhat younger in the W of the region studied, than in the E, because there is a general trend to a greater hiatus between the Neogene and the Paleogene towards the W - with the exception of the very deep subsidence areas, like the Garding Trough with well St. Peter in table 2 - in the North Sea Basin.

7.2. The Early Behrendorfian stage (III + IV) (fig. 10)

In the southern part of the map there is a simple model with the A-biofacies occurring from the Sylt area in the W, to the Ahrenviölfeld well in the E thus comprising only a narrow belt of the B-biofacies directly bordering the area of the (fluviatile) Ribe Formation in the E. In the northern part of the map one observes a more complex situation with progradation of the Ribe Forma-

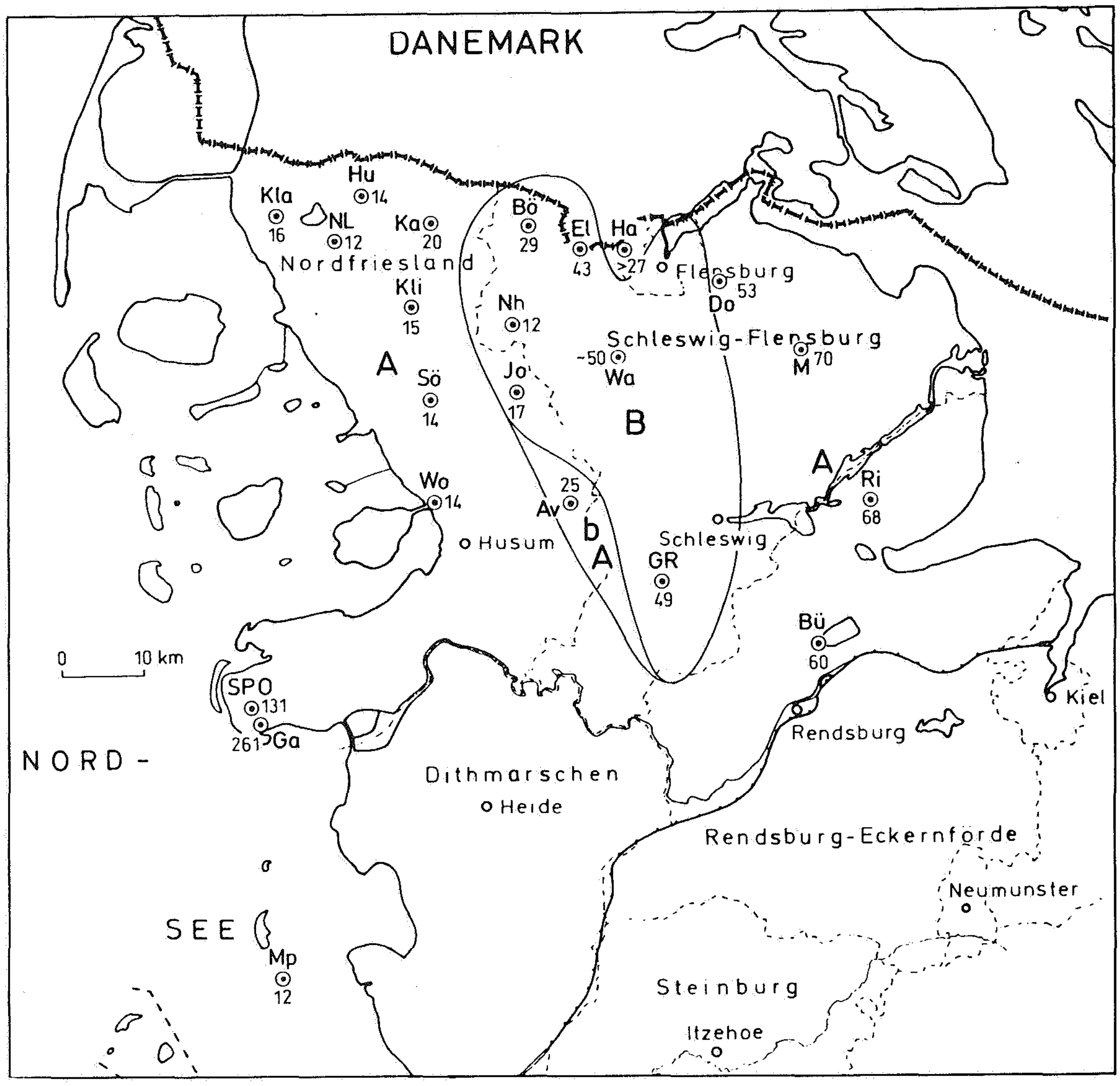

Figure 9. Paleogeographic map. Vierlandian.

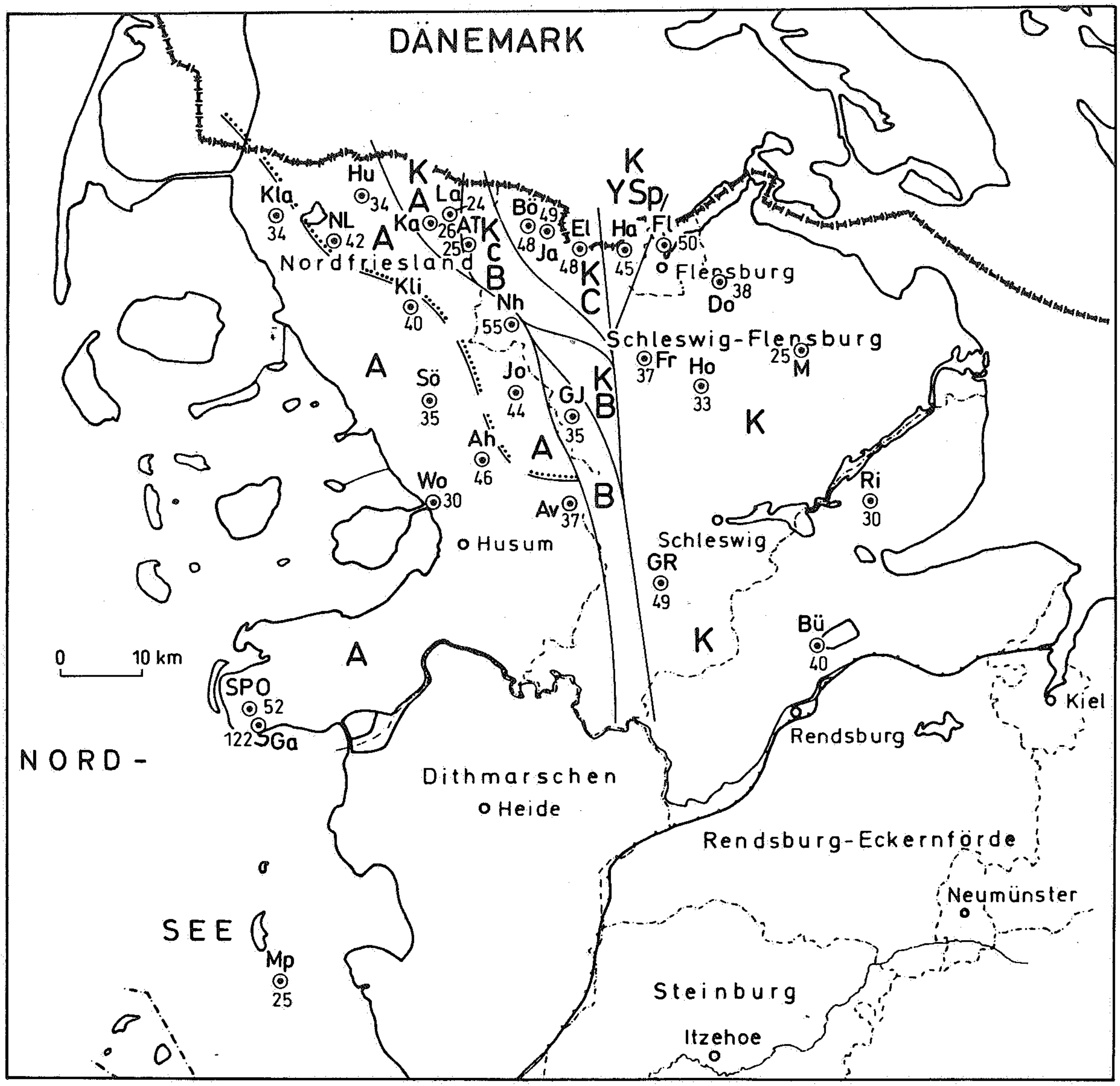

Figure 10. Paleogeographic map. Early Behrendorfian.

tion (especially in the upper unit) towards the W, and by the intercalation of C-biofacies between A-biofacies and fluviatile K-facies. The upper Ribe Formation overlies the *Yoldia-Spisula*-association at Harrislee and it overlies the C-biofacies at Ellundfeld, Jardelund, and Böxlund. At Tettwang the B- and C-biofacies underly the uppermost Ribe, which at Ladelund and Karlum directly overlies the A-biofacies. The direct contact of the fluviatile to deeper euhaline biofacies points to a steep coastal slope that did not allow the formation of a brachyhaline environment in the shallow water nearshore zone. In this depositional setting the quartz gravel directly slid into deeper water, extending even further to the S and the Ribe Formation itself. This phenomenon was observed in the wells Humptrup, Nordhackstedt, and Joldelund. The area of distribution of these quartz gravels in silty marine environment is marked in figs. 10 and 11 by a dotted line.

7.3. The Frörup or Middle Behrendorfian stage (V - VII) (fig. 11)

The lower Frörup Member comprises a simple facies scheme of A-biofacies extending from the Sylt area to Frörup followed by a B-biofacies (Holmingfeld, Groß Rheide, Bünsdorf) and a C-biofacies at Rieseby in the E. The fluviatile facies has completely disappeared from the region.

In the upper Frörup Member there is a complication by the facies differentiation, as observed from N to S, and forming a sort of undulation in the biofacies areas :

1. brachyhaline influence occurred in the N of Flensburg (Ev) and a shallower facies ranged up to Jardelund (C),
2. a deeper marine facies prograded from Joldelund to Holmingfeld (A and B),

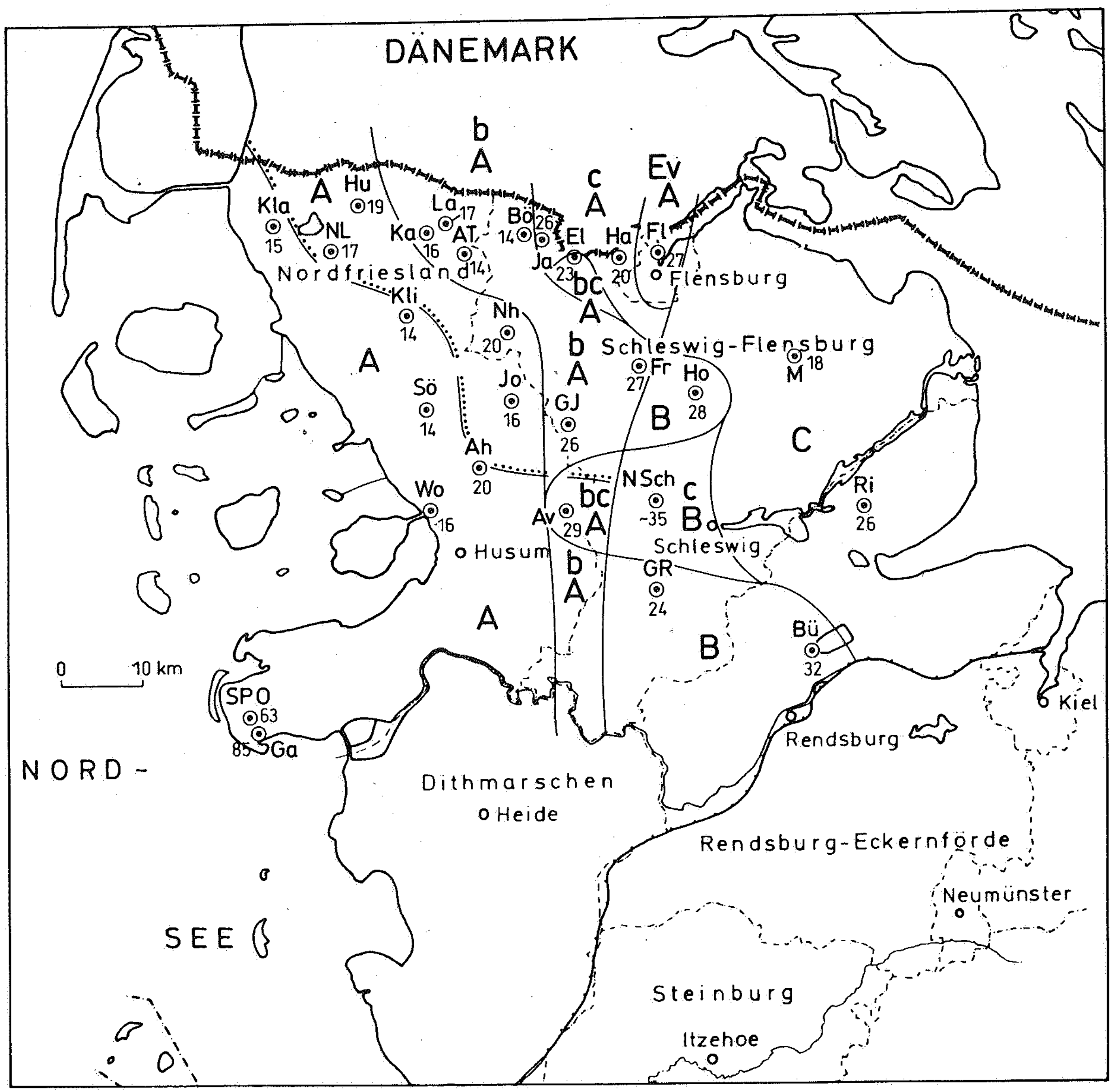

Figure 11. Paleogeographic map. Middle Behrendorfian (Frörup).

3. a shallower marine facies (C) occurred from Ahrenviölfeld to Rieseby, and
4. a deeper marine facies existed at Groß Rheide and Bünsdorf (B).

7.4. The Late Behrendorfian stage (VIII - XII) (fig. 12)

In the lower part of this complex the A-biofacies, occurring from the Sylt area to Klintum-Sönnebüll in the W, is accompanied by a belt with B-biofacies, overlain by C-biofaces observed at Humptrup. Towards the E we observe a belt of D-(*Lembulus*)-biofacies, which had its widest extent in the Upper Behrendorfian. At Nordhackstedt this biofacies overlies the B-biofacies. At Joldelund A-, B- and C-biofacies were found below the brachyhaline D-biofacies. The most characteristic feature of this map is a N-S belt with the wells Böxlund, Jardlund, Jörl, Ahrenviölfeld and Treia, where the complete Late Behrendorfian is developed in the D-*Lembulus*-biofacies. At Ellundfeld the upper part is replaced by the sideritic J-facies. Towards the E it follows the fluviatile K-facies of the Odderup Formation. At Harrislee and Groß Rheide the *Yoldia-Spisula*-association was found at the base of Odderup, whereas the *Ervilia* horizon (with robust *Ervilia* shells) has to now its only occurrence at the Frörup/Odderup boundary.

7.5. The Early Oxlundian stage (XIII - XVI) (fig. 13)

The most intricate pattern of marine and especially of brachyhaline biofacial units is observed during this time-span.

In the W (Sylt and Eiderstedt area) the A-biofacies is mostly overlain by the B-biofacies. Only the B-biofacies was observed at Mittelplate and Neufelderkoog. At Klintum and Sönnebüll the B-biofacies is overlain

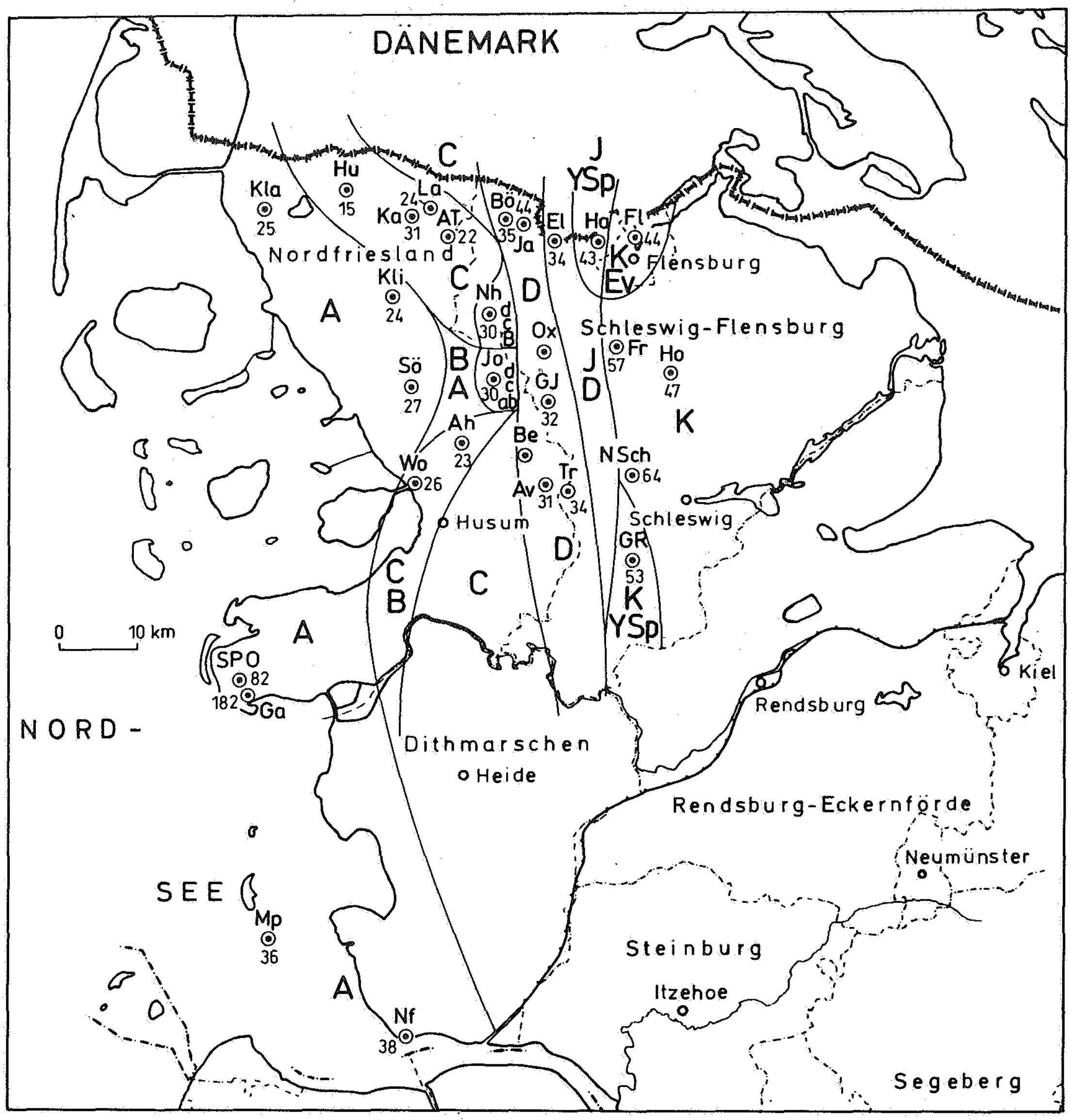

Figure 12. Paleogeograhic map. Late Behrendorfian.

by a C-biofacies extending further towards the E than to the N of it ; at Klanxbüll and Karlum only the C-biofacies is present.
The first appearance of a *Lentidium* horizon overlying the C-biofacies was observed at Humptrup and Wobbenbüll.

The most characteristic feature of this period is the brachyhaline *Ervilia*-biofacies. Only in the wells Nordhackstedt and Joldelund the complete Early Oxlundian has an *Ervilia*-biofacies Ev, whereas at Ladelund and Tettwang the Ev-biofacies is overlying the C-biofacies in the lower part. Therefore the Ev-biofacies with an *Ervilia*-Acme is better developed in Schleswig than in Holstein. Towards the coast-line the Ev-biofacies is replaced by a narrow belt with *Acanthocardia-Varicorbula*-association AV, as best recorded from Böxlund. At Jörl and Treia the B-biofacies is intercalated between strata of the Ev-biofacies or it separates the D-biofacies and the Ev-biofacies from each other. The AV-biofacies is replaced towards the coast by a sideritic J-facies. In the eastern part of the region, from Flensburg-Frörup-Groß Rheide towards the E, it is covered by the fluviatile K-facies of the Odderup Formation.

7.6. The Late Oxlundian stage (XVII - XIX) (fig. 14)

This complex comprises the maximal extent of the Odderup Formation (unit XVII and the equivalents of Hamburg- and Trittau- Formations).

In the W the deepest euhaline environment is the B-biofacies in the Sylt area, followed towards the E, by the C-biofacies at Klanxbüll and Mittelplate. Among the brachyhaline associations the Et (= *Lentidium* horizon) has its greatest extent in the Late Oxlundian. In our region, it is observed in a broad N-S-belt of ca. 20 km, as observed in the wells Humptrup, Klintum, Sönnebull, Wobbenbüll, St. Peter (only indicated by

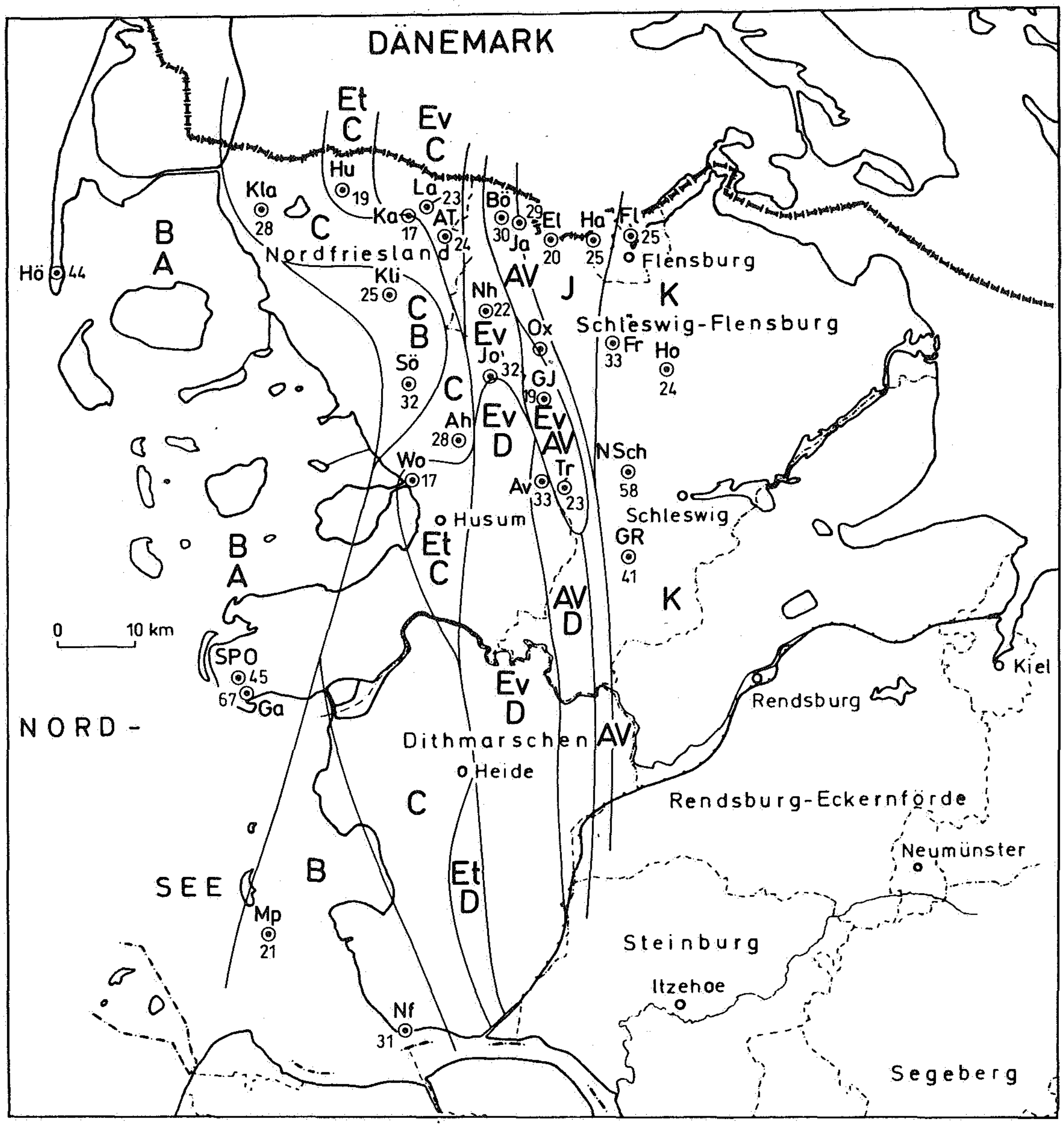

Figure 13. Paleogeographical map. Early Oxlundian.

Acanthocardia), and Neufelderkoog. This facies indicates the outer rim of the brachyhaline shallow sea, with a higher surf energy. During the Oxlundian the Ev-association inhabited the areas with a lower energy environment occurring behind the Et-*Lentidium* belt, as observed in the wells Karlum, Ladelund, Tettwang, Nordhackstedt, Joldelund, Jörl, Ahrenviölfeld and Treia. The Ev-biofacies is directly bordering the fluviatile Odderup or the reduced Trittau-Formation occurring in K-facies. Only at Böxlund-Jardelund the sideritic J-facies replaces first the thin Hamburg and Trittau equivalents and finally the Unit XVII of the Odderup-Formation.

In North Frisia and western Holstein the *Lentidium*-Et-biofacies occupies the western outskirts of the brachyhaline or intertidal region. Another type of the *Lentidium* horizons are the Etz Member, overlying Hamburg Member, and the Itzstedt Member overlying the Trittau-Formation in the region of S-Holstein-Hamburg-Lüneburg. In this area relatively narrow belts of bay deposits are intercalated between fluviatile environments. These sediments were apparently deposited in an estuarine environment, also corresponding to a high energy regime (Ehlers & Hinsch, in press).

7.7. General paleogeographical results

There are great differences in the facies zonation of the coastal or marine nearshore environment between the Ribe-Formation and its marine equivalents at the one hand, and the Odderup-Formation and its marine equivalents at the other. Indeed, in the Ribe-Formation a direct contact is observed of fluviatile and deeper euhaline environments, pointing to a steep coastal slope with delta-top sediments bordering a prodelta with the omission of shallow delta-slope environment.

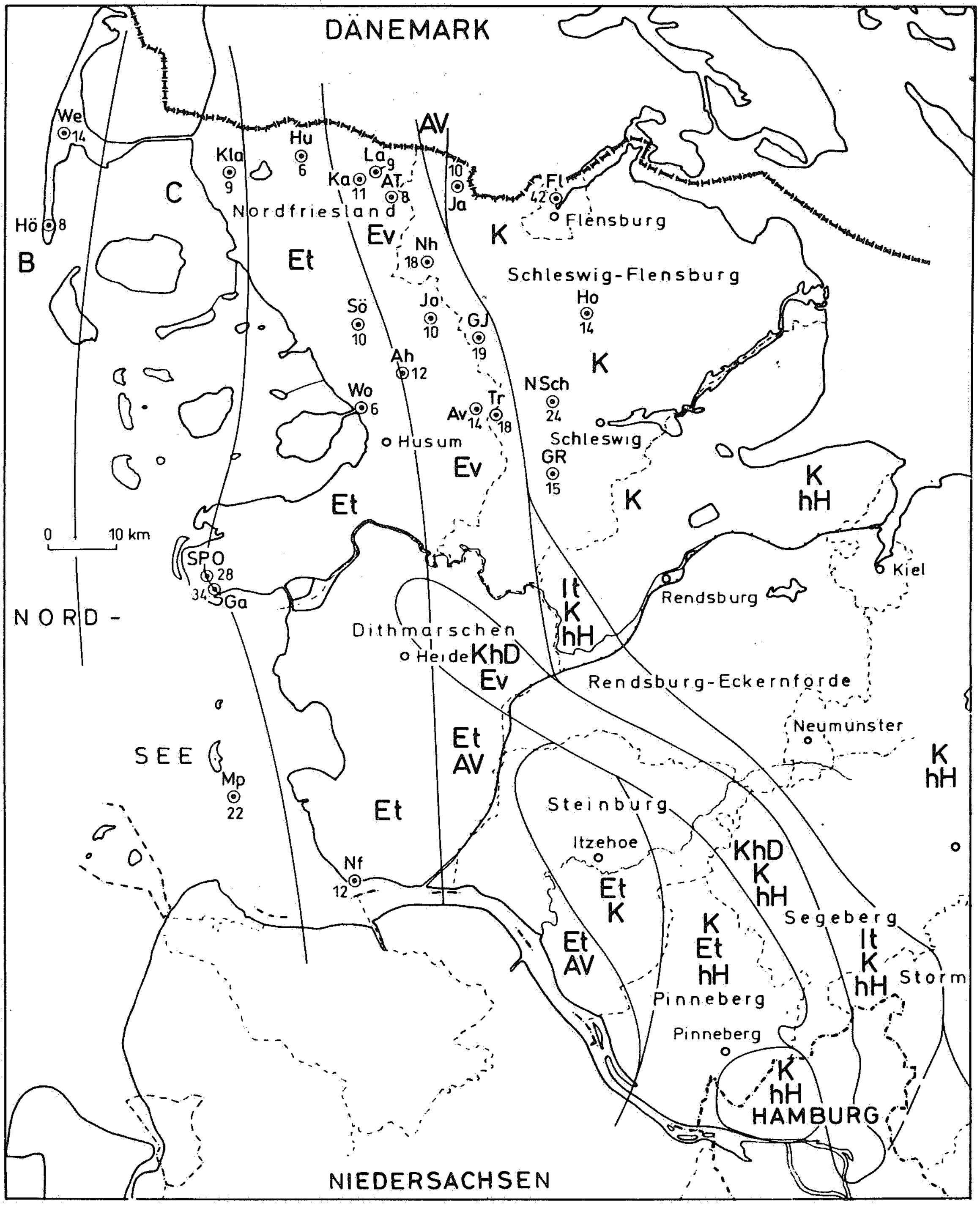

Figure 14. Paleogeographic map. Late Oxlundian.

Khd	Katzheide Mbr. (with *Lembulus*).
It	Itzstedt Mbr. (with *Lentidium*).
hH	Hamburg Member.

In the Odderup Formation the nearshore sedimentation is well represented by wide belts of brachyhaline or intertidal deposits. The D-*Lembulus*-biofacies has its main extent during the Late Behrendorfian, the Ev-*Ervilia*-biofacies abounds in the Oxlundian. The *Yoldia-Spisula*-association and the *Acanthocardia-Varicorbula* are only observed in a narrow nearshore facies belt. The brachyhaline biotopes corresponding to higher energy milieus are represented by the Ervilia horizon at the top of the Frörup, the Et-*Lentidium*-biofacies of the Late Oxlundian in the western brachyhaline outskirts, and the diverse Lentidium horizons in Holstein (Etz Member, Itzstedt Member) of partly estuarine milieu.

During the three marine ingressions of the Vierlandian, the Frörup, and the Reinbekian respectively, the fluviatile environment disappeared from the region studied, and it was replaced by a deeper euhaline milieu ; during the deposition of the Odderup sand the nearshore marine region was rather shallow and partly intertidal. During the Reinbekian and the Vierlandian, only marine beds of water depths greater than 50 m were encountered in the region of the paleogeographical sketch maps.

The belt of marine environment of 0 - 50 m water depth had the following width during the Hemmoorian stage :

Late Oxlundian	45 - 60 km
Early Oxlundian	20 - 50 km
Late Behrendorfian	15 - 40 km
Frörup Member	10 - 30 km
Early Behrendorfian	0 - 25 km

Similarly, it appears that the brachyhaline to intertidal part, corresponding to the shallow water belt, had the following width :

Late Oxlundian	30 - 45 km
Early Oxlundian	15 - 30 km
Late Behrendorfian	10 - 20 km,

whereas this environment is totally missing in the Lower Frörup Member and the Early Behrendorfian substage.

7.8. Correlation of the Miocene substages in the North Sea basin to the global sequence chronostratigraphy and eustatic sea level changes of Haq *et al.* (1988)

The changes of the paleogeography during the Miocene reconstructed by study of mollusc associations and lithology allow to correlate the sea level changes in the eastern North Sea basin to the Cenozoic Cycle chart of Haq, Hardenbol & Vail in its most recent version of 1988. To give a survey of the complete Miocene, the results of this paper concerning the Early Miocene, have been completed by the paleogeography of the stages of the Nordelbe Cycle as given by Hinsch, 1987, 1990. To fill the hiatus at the base of the Vierlandian in the Schleswig area, the paleogeographic sketches of Ehlers and Hinsch, 1992 for the Hamburg area, where the sedimentation from Oligocene to Miocene is continuous, are also used for a synopsis of the sea level changes in all parts of Schleswig-Holstein during all substages of the Miocene. Generally the correlation of the Nordelbe Cycle is less problematic than that of the Lower Miocene Cycle, when an important elevation of Scandinavia, leading to great sand supply appeared mainly all during the Hemmoorian, with the effect of compensating the sea level changes.

Substages characterised by transgressive tendencies, or by the rise of the sea level are : Morsumian, Syltian III, Syltian I, Gramian I, Lüneburgian, Reinbekian, Late Oxlundian around Hamburg Member, Frörup or Middle Behrendorfian, and Vierlandian. The highest sea levels are observed in the Vierlandian, Frörup, Reinbekian, and Lüneburgian, whereas in the Late Oxlundian (Hamburg Member and Etz Member), Syltian III and Morsumian, the rise of sea level was less strong than in the global chart. The Langenfeldian III shows no observable rise, but rather a slight fall of the sea level. A regressional tendency with fall of the sea level occurs in the substages : Syltian IV, Syltian II, Gramian II, Langenfeldian IV, Levensauian, uppermost Oxlundian (Trittau-Formation or unit XIX), and from the Late Behrendorfian (unit VIII) a decreasing water depth occurred up to the Oxlundian (unit XVII), the Early Behrendorfian of Ribe equivalents (units III/IV), and the Late Neochattian of the Ratzeburg Member. Compared with the global scheme the regression is less intensive in the Langenfeldian IV of the North Sea Basin. The deposition of the Braunkohlensand Formation, caused by the uplift of Scandinavia and causing intensified sand supply alters or even overcompensates the influence of sea level changes. Table 5 gives a correlation of the substages of the North Sea Basin substages (especially those used in Schleswig-Holstein) to the sequence chronostratigraphy and eustatic sea level changes represented in the Cenozoic Cycle Chart of Haq, Hardenbol and Vail, 1988. From the correlations of table 5 the following main features of the Early Miocene Cycle in the Schleswig region can be derived :

The Oligocene/Miocene boundary, as occurring between the Ratzeburg Member and the Elmshorn Formation is present within a continuous sedimentary succession only E of the line Kiel-Hamburg. Therefore in the Schleswig region, there is a hiatus, and the Vierlandian ingression (without hiatus) changes into a transgression with a hiatus below it. The Miocene base has according to the K-Ar-dates of Kreuzer *et al.* (1980), an age of 23 m.y., whereas Haq, Hardenbol and Vail (1988) assume 25 m.y. In table 5 the value of Kreuzer is used, and thus the time-span of the Vierlandian appears to be reduced.

The sea level rise of the Frörup ingression at 21 m.y. is, in its whole extent, comparable to that of the Vierlandian. It is divided from the Vierlandian by a short sea level fall at 22 m.y. corresponding to the Ribe Formation. Characteristic for this short regression, occurring between the periods of high sea level stands, is the abrupt change from an euhaline to a fluviatile environment. In contrast to the lower part of the Early Miocene Cycle, the upper part shows only small sea level rises. Especially during the deposition of the Odderup Formation the global sea level rises are overcompensated by regressive tendencies caused by the elevated Scandinavian shield combined with the supply of sandy material into the North Sea Basin. Therefore the global rise of sea level, with its maximum at 18,5

	North sea substages HINSCH 1992 (selected Litho-stratigraphical Fm. and Mbr.)		Cycles of 3rd order HAQ, HARDENBOL, VAIL
	Morsumian/Kattendijkian		Upper TB 3.4
	Syltian IV		Lower TB 3.4
	Syltian III		Upper TB 3.3
	Syltian II		Lower TB 3.3
	Syltian I		Upper TB 3.2
	Gramian II		Lower TB 3.2
	Gramian I		Upper TB 3.1
	Langenfeldian IV		Lower TB 3.1
	Langenfeldian III		TB 2.6
	Lüneburgian = L II		Upper TB 2.5
	Levensauian = L I		Lower TB 2.5
XXI	Reinbekian	(Hodde Fm.)	TB 2.4
XX	Earliest Reinbekian	(Katzheide Mbr.)	Upper TB 2.3
XIX		(Trittau-Fm.)	Lower TB 2.3
XVIII	Late Oxlundian	(Etz Mbr.) (Hamburg Mbr.)	Upper TB 2.2
XVII		(Odderup-maximum)	Lower TB 2.2
XVI XV XIV XIII	Early Oxlundian		Upper TB 2.1
XII XI X IX VIII	Late Behrendorfian		Lower TB 2.1
VII V	Middle Behrendorfian	(Frörup Mbr.)	TB 1.5
IV III	Early Behrendorfian	(Ribe-Fm.)	boundary TB 1.5/TB 1.4
II I	Vierlandian		middle part of TB 1.4
	Neochattian	(Ratzeburg Mbr.)	Lowest TB 1.4
			TB 1.3
	Eochattin		TB 1.2 TB 1.1

eustatic curve
HAQ, HARDENBOL,
VAIL (1988)
revised by HINSCH 1992
for the eastern North sea basin

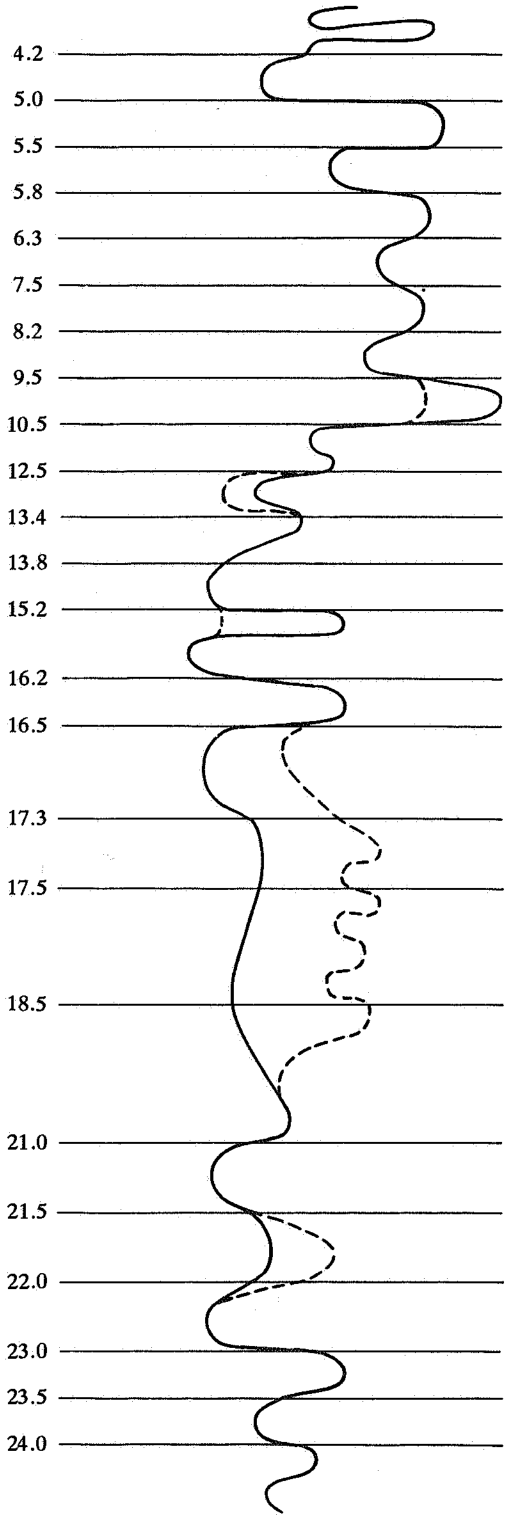

Table 5. Eustatic curve of Haq, Hardenbol, Vail (1988), revised for the eastern North Sea Basin and correlation of North Sea Basin and Correlation of North sea stages to cycles of 3rd order in the Cenozoic Cycle Chart.

m.y., is completely suppressed. Furthermore in the Cycle TB 2.1 the global tendency is inverted. Therefore in the Schleswig region, the sea level curve shows the lowest sea level stand at the top and not in the lower parts of the Cycle TB 2.1.

The sea level rise at 17 m.y. is traceable by the lagoonal Hamburg Member and its brackish to brachyhaline companions, such as the Etz Member and the *Ophiomorpha* Member in eastern Holstein and southwestern Schleswig. The sea level rise is unimportant because only shallow or intertidal environments have been observed beside the fluviatile facies. In the northern part of Schleswig the uppermost Oxlundian, including the regressive phase at 16,5 m.y. with the Trittau Formation, is strongly reduced and partly even missing below the Reinbekian transgression.

The Reinbekian (or Langhian) sea level rise has its greatest extent during the Miocene of the North Sea Basin. There is an euhaline biofacies of deeper water all over Schleswig-Holstein and towards Mecklenburg in the E. The regressive interruption at 15 m.y. is in most cases not distinguishable, because of the occurrence of deeper water environments. In the western Schleswig region the boundary between the Katzheide Member and the Hodde Formation could be an indicator of this event.

Generally there is a good coincidence between the changes of water depths during the Miocene in the eastern North Sea Basin and the global eustatic curve. Greater deviations are only observed during the cycles TB 2.1 and TB 2.2 of the sequence chronostratigraphy. These are caused by the elevation of the Scandinavian shield during the sedimentation of the "Braunkohlensande" formations, especially that of the Odderup Formation. By these regional events the transgression, culminating in a sea level rise of 18,5 m.y. is inverted into a gradual and fluctuating shallowing of water depth. The next sea level rise at 17 m.y. can still be observed, but it is considerably subdued.

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