

# DIATOM ANALYSIS OF AN ATLANTIC-SUBBOREAL CORE FROM SLIJEPE (WESTERN BELGIAN COASTAL PLAIN)

LUC DENYS

*University of Antwerp (RUCA), Department of Botany, B-2020 Antwerp (Belgium)*

## ABSTRACT

Denys, L., 1985. Diatom analysis of an Atlantic-Subboreal core from Slijpe (western Belgian coastal plain). *Rev. Palaeobot. Palynol.*, 46: 33-53.

Diatom analysis of a clayey Atlantic-Subboreal sequence from the western part of the Belgian coastal plain revealed the existence of intertidal conditions throughout, with the exception of a swampy lagoonal stage at the top of the basal peat. Several transgressive events were shown to have influenced the local palaeoenvironment. The possible relationship of these events to the Calais II and Calais 111 transgressions is discussed.

## INTRODUCTION

Classically the Holocene sequence along the Belgian coast is subdivided into the Calais deposits of Atlantic-Subboreal age (overlying the Pleistocene surface directly or separated from them by a basal peat), the Subboreal-Subatlantic surface peat and the Subatlantic Dunkerque deposits<sup>1</sup>. While the soilmapping in the fifties led to a detailed examination of the youngest deposits, the underlying Calais member received relatively little attention. In contrast to the Dunkerque deposits wherein three transgressions were distinguished, the Calais sediments were generally considered to have been deposited in the course of one single transgressive event: the Flandrian transgression (Ameryckx, 1960; Maréchal et al., 1964; Tavernier and Ameryckx, 1970; Paepe, 1971; Ozer, 1976). Nevertheless, Halet (1931), Moormann (1951) and Tavernier and Moormann (1954) had already mentioned that this sea level rise was probably not continuous, but may well have been interrupted by standstills or even small regressions. In the opinion of Baeteman et al. (1974) and Baeteman (1978) the Belgian Calais member should be subdivided into a series of consecutive transgressive and regressive intervals similar to those distinguished in neighbouring North Sea countries. Consequently a lithostratigraphical subdivision into four units was proposed, based on the occurrence of peaty intercalations. Moreover, in most of the literature dealing with the Belgian coastal plain the main depositional environment of

---

<sup>1</sup> Although this tripartition has recently been criticised strongly (Baeteman, 1981a, b), we refer to it here for ease of comparison with the existing literature.

the Calais deposits is considered to have been an intertidal sand flat. Hence the names "sables pissards" and Atlantic "wadden" deposits. Some recent publications, however, stress the importance of low energy flats, marshes and even lagoons in some parts of the area during certain periods (Baeteman, 1978, 1981a; see also Blanchard, 1906; Moormann, 1951).

In order to obtain more precise information on the formation of the Calais deposits in the western part of the coastal plain and to trace possible sea-level oscillations, several cores from the area are being investigated for their diatom content. Since diatom associations are known to be very sensitive to changes in certain environmental factors such as salinity, tidal stress, hydrogen-ion concentration, trophic conditions, etc., diatom analysis, especially when combined with other techniques, may be one of the most valuable methods to determine alterations in the local sedimentary environment of coastal deposits.

This paper is concerned with the analysis of a sequence of uninterrupted fine-grained clastic sediments belonging to the Calais member from Slijpe in the western coastal plain.

#### MATERIAL AND METHODS

The sequence was obtained by means of an undisturbed mechanical coring. The boring, known as Spermalie 2, was located some 6 km inland from the present shore line and about 4 km from the Pleistocene outcrops (Fig.1). The entire Holocene sequence reaches a thickness of 4.32 m of which the Calais deposits, resting upon a basal peat and covered by the surface-peat, represent only 65 cm. Their lithology and chronology are displayed in Fig.2.

Some granulometric data indicate an upward fining of the sediment (Table 1). Estimations of the content of organic matter, sedimentary carbonates and biogenic opaline silica are given in Fig.3. Organic matter was determined as the percentage weight loss of dried sediment after heating to 550°C in a muffle furnace, while carbonate CO<sub>2</sub> was estimated as the weight loss hereafter by ignition at 950°C (Wetzel, 1970; Dean, 1974). By multiplying by 2.27 the CO<sub>2</sub> content was converted into CaCO<sub>3</sub>. Biogenic opaline silica was digested by boiling with 0.5 N NaOH (Bradbury and Winter, 1976). The organic matter content decreased rapidly above the basal peat to a level of about 10%. From -373 cm on a gradual increase up to 19% just below the surface peat was observed. The carbonate content was highest just above the basal peat ( $\pm$  12%) and generally lower than 5% throughout the remaining part of the sequence. The biogenic silica content varied from 1 to 8% and showed no general agreement with the apparent corrosion of the diatom frustules. Investigation of digested sediment showed that nearly all diatom material was dissolved with exception of some highly resistant central nodules of *Diploneis bombus*. Sponge spicules appeared visibly unaffected, while silicoflagellates were too scarce in the material to affect the percentages. Incomplete dissolution of diatom frustules using this method was also observed by Digerfeldt (1975).

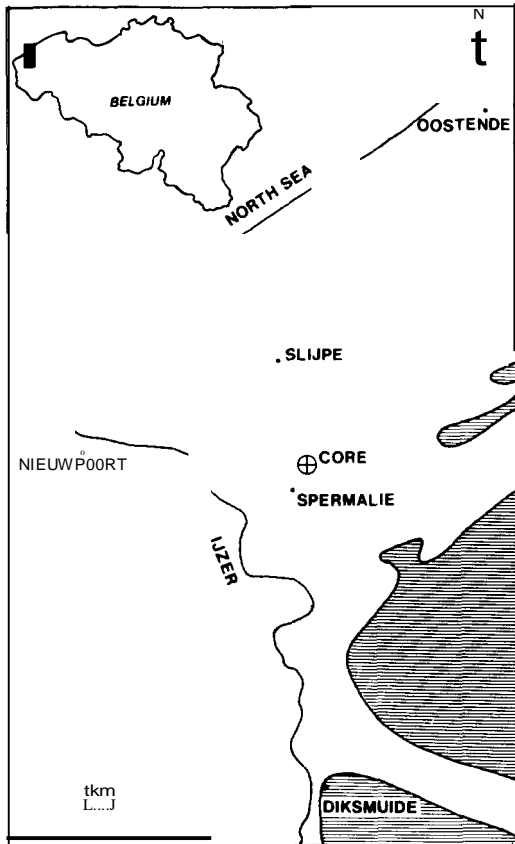


Fig.1. Situation of the coring site. Area with outcropping Pleistocene coversands shaded.

For diatom analysis the core was sampled in thin slices every three to four cm. Organic matter was removed following the method of Van der Werff (1955). Carbonate particles were dissolved using 1 N HCl. Only the coarser sand grains were removed by decanting carefully, the risk of altering the fossil assemblages being otherwise substantial (Mölder, 1943; Simonsen, 1962; Schrader, 1973). Permanent slides were made from the residue using the mounting medium Cumaron (nrD: 1.65) and 40 X 24 mm cover glasses. A Leitz Orthoplan microscope equipped with differential interference optics according to Nomarski was used for their examination. Following a qualitative survey, counts of at least 400 valves were made under high power magnification. Fragments were counted using the method described by Denys (1984). Percentage frequencies were calculated for the distinguished taxa (Table II, Fig.4). Similarity between assemblages from successive levels was calculated by means of Stander's index of similarity, SIMI (McIntire and Moore, 1977, p.358; Fig.4). Groups of taxa were made according to their ecological

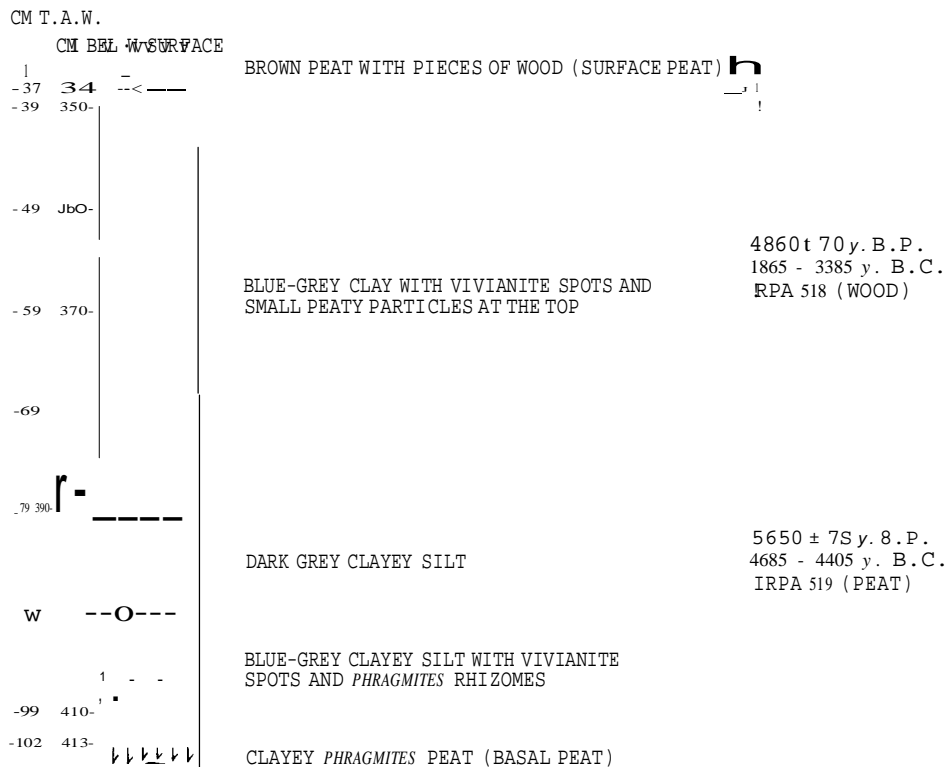


Fig.2. Lithology and <sup>14</sup>C chronology of the Calais deposits.

TABLE I

Results of the granulometric analysis (% d.w.)

Grain size (µm)	Depth (cm)		
	-360	-381	-400
2000-55	1.1	0.4	1.6
55-40	1.7	10.2	14.7
40-20	7.2	32.4	19.9
20-10	11.1	13.7	12.2
10-5	13.1	8.3	14.7
5-2	14.1	7.3	11.8
2-0	42.1	27.8	25.1

preferences to obtain a number of ecological spectra. Hereby the percentages of taxa belonging to several groups at the same time were divided evenly among these groups. The halobion system of Van der Werff and Huls (1957-1974) was applied to reconstruct the palaeosalinity (Fig.4). A generalised salinity curve was constructed using the formula:  $S = 7pM + 6pMB + 5p_8M +$

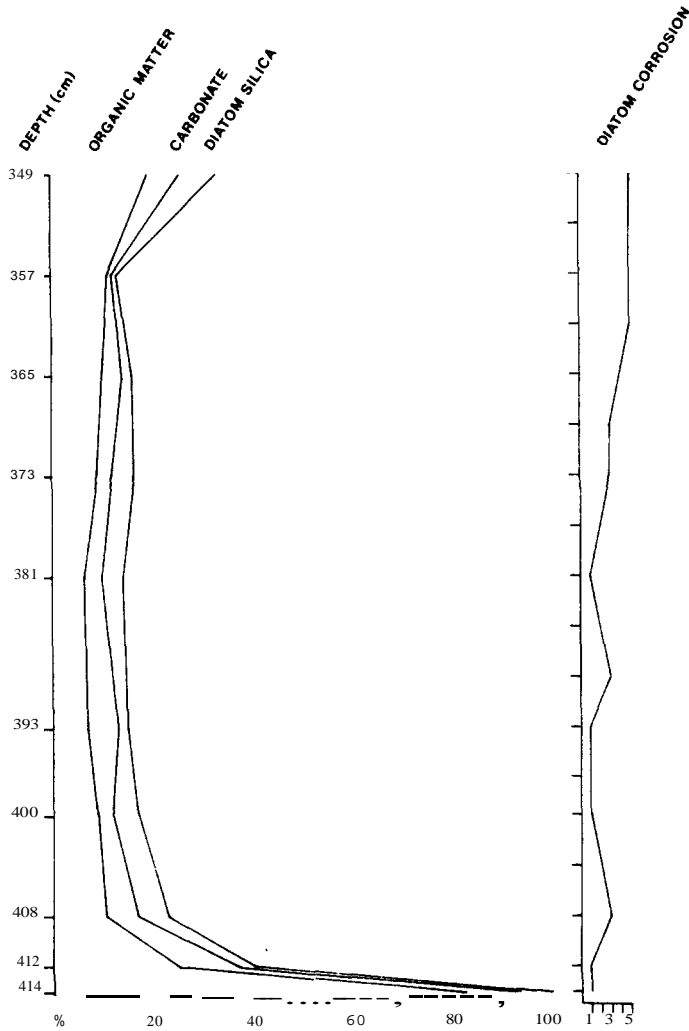


Fig.3. Sediment composition and apparent relative diatom corrosion (1 = little, 5 = marked).

$4p_8 + 3p_{8F} + 2p_{FB} + PF$  wherein  $PM$  = the relative frequency of the group of marine taxa (M = marine; B = brackish; F = fresh-water), etc. Depending on the extent of the salinity range of the taxa, the categories euryhaline,  $\pm$  euryhaline and others were applied (Fig.4). Planktonic, epontic and benthic diatoms were distinguished, while *Fragilaria* and *Paralia* were considered separate (Fig.5). The ratios of assumed allochthonous to autochthonous components were calculated as in Beyens and Denys (1982): F-value = % allochthonous fresh-water component/% autochthonous salt-water component; M-value = % allochthonous salt-water component/% autochthonous fresh-water component (Fig.4). Following the classification of Simonsen (1962), pseudampotiphilous (intertidal), ampotixenous (subtidal) and tide-indifferent

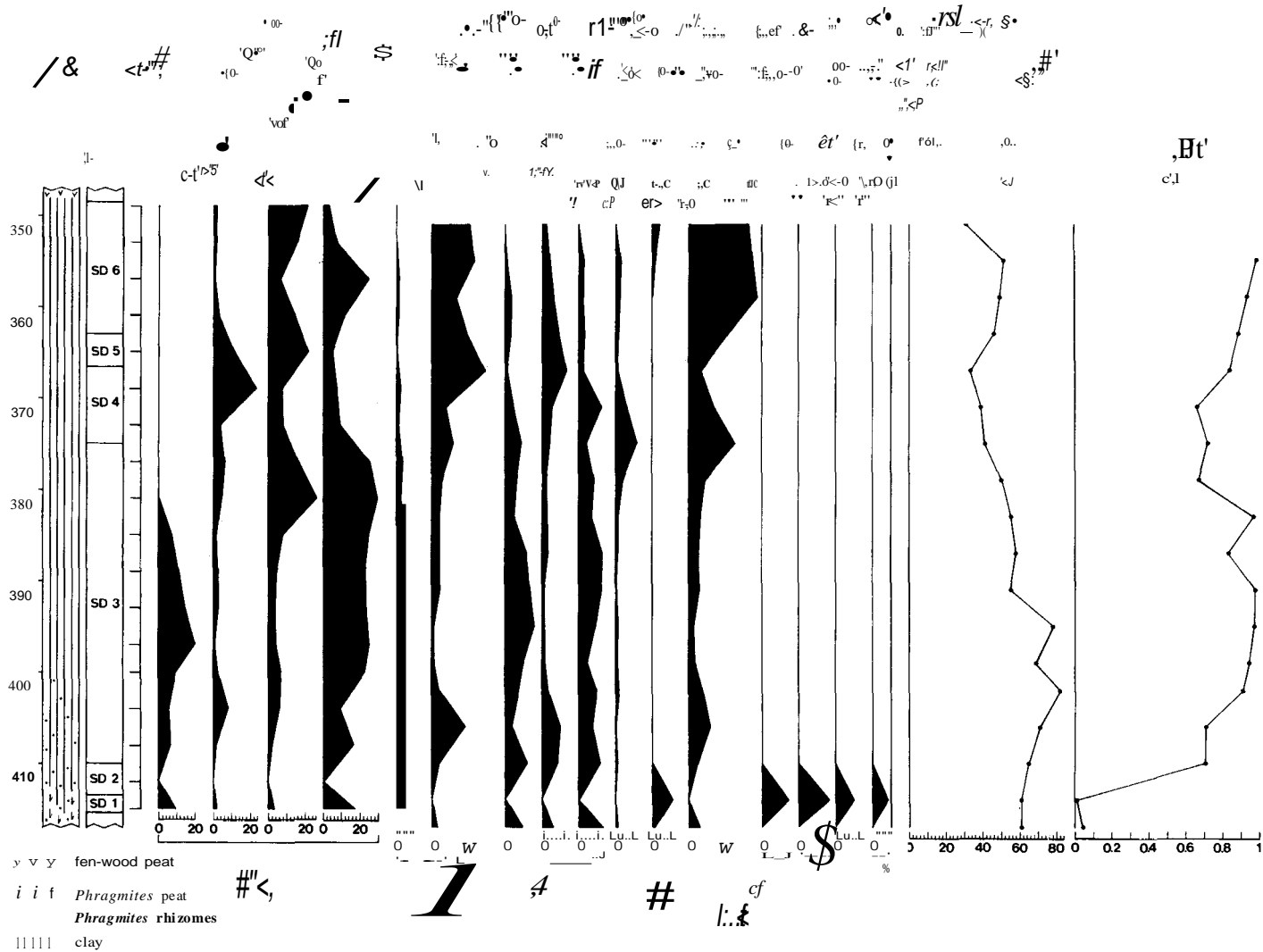




TABLE II (continued)

DEPTH (ao below surface)	349	353	357	361	365	369	373	377	381	385	389	393	397	400	404	408	412	415
NUMBER OF VALVES COUNTED	400	480	480	570	470	440	420	470	510	410	470	410	411	510	480	479	559	540
---																		
<i>-hala</i> *****																		
Nat>. aau.U'loidss *****																		
<i>Illrid. aff. var. Ollf&gt;hil'h.</i> . -																		
<i>Rit. acuntinata</i> ***** -												0.2	0.5	0.4		1.3		0.6
<i>Ntt. oonst. var. suboonet.</i> -																		
<i>Rit. fl"Z'U'ata</i> *****	0.2	1.3	0.9	1.5	0.7	1.4	1.1	1.0	0.5	1.1	1.5	0.5	1.2	0.4	2.1		0.9	
<i>Nit. i...udtiana</i> *** ***** -												0.5	1.0	0.2		0.6		
<i>!H.t. naoicutaris</i> ***** 33.0	34.3	37.2	21.2	6.2	13.2	25.0	8.3	6.1	5.4	5.7	2.4	3.2	7.6	11.5	5.0		5.7	
<i>Nit. obtusa var. saaZ.pel.</i> .																		
<i>Rit. panduzoif"iis</i> ***** -						0.2				0.4		0.2				0.2		0.6
<i>Nit. pinotata</i> ***** 2.2	4.1	s.1	9.3	la.o	s.4	4.o	t.9	2.4	2.9	o.a	i.2	1.7	a.3	9.6	a.e		s.s	
<i>Nit. saalari.s</i> ***** -																4.7	0.2	
<i>Nit. signa</i> ***** -																0.2		
<i>Rit. teybUonsZu</i> ***** -								0.2										0.2
<i>Nit. oitrea</i> ***** -																		
<i>Nit. sp. 1</i> ***** -																		
<i>Od. az&amp;l"i'a</i> ***** -				0.2								0.2						
<i>. martyi</i> ***** -				0.3	0.2		0.5			0.4						0.2		
<i>Op. eohalai</i> ***** -																		
<i>Pa&gt;-. sulcata</i> ***** 3.0	7.2	14.4	11.4	4.:	7.3	8.8	25.1	28.9	24.4	22.3	23.2	24.6	22.2	9.2	16.7		17.4	
<i>Pi"***** e 14gans</i> ***** -																		
<i>Pinnul. bN:oiastata</i> ***** -																	7.0	
<i>Pinnul. wmsriata</i> ***** -																		
<i>Pinnul. oal'dinata</i> ***** -																		
<i>Pinnul. LS-</i> ***** -																		
<i>Pinnul. majw</i> ***** -																	0.5	
<i>Pinnul. miol'ostaii'On</i> *****																		
<i>Pi;...;Z. MgLB'ta</i> ***** -																		
<i>Pinnal. ncbllie</i> ***** -																		0.2
<i>Pinnul. 'Oil'idi.s</i> ***** -											0.2		0.2		0.2	0.1j	0.1j	
<i>Pinnat. v. var. Z.ptong.</i> . -																	0.2	
<i>Pi;...;Z. sp. 1</i> ***** -																	5.0	1.1
<i>Pinnul. sp. 2</i> ***** -																		
<i>Plag.-a pul. var. PNI1'</i> ***** -																		
<i>Plag.-a stal'D'ophojom</i> ***** -																		
<i>Plag.-s U</i> ***** -												0.2						0.2
<i>Pad. suitigt</i> ***** 3.2	1.1	1.7	3.0	4.3	1.1	2.6	5.3	3.1	2.2	0.8	1.2	0.5	1.8	5.4	1.3		2.2	
<i>Rhaph. Ollf'ht</i> ***** 0.2	0.9	5.6	3.3	1.3	3.9	8.6	6.0	is,5	11.5	12.8	15.6	9.5	7.5	3.7	11.7	0.2	9.3	
<i>Rhaph. ....uá.ima</i> ***** -								0.2	1.0	2.7	0.5	4.1	1.2	0.0	0.0		2.2	
<i>RhDio. "1'0ata</i> ***** -																	0.2	
<i>RhtIp. dubia</i> ***** -	0.2															0.2		
<i>RhtIp. gibba</i> *****																		
<i>RtUp. g. var. on:t'iooa</i> ***** -																		
<i>Rhop. gibbel'Ula</i> ***** -		0.2		0.2	0.2													0.4
<i>Rhop. musoulas</i> ***** -													0.2					0.4
<i>Sool. tvniâa</i> ***** 0.2	1.7	2.0	3.3	2.1	11.8	4.0	7.9	6.7	12.7	11.9	9.0	4.6	9.6	7.6	11.5		13.3	
<i>Staw-. Ollf&gt;hUlq/B</i> ***** -								0.2	0.5									
<i>S-</i> ***** -																		
<i>Stawo. phooni...u...;</i> *****																	0.7	0.2
<i>Stauzo. aalina</i> ***** -																		
<i>Steph. 2'0illa</i> ***** -																		
<i>SilJ. faetiroea</i> ***** 0.2	0.4								0.6	0.2	0.2	0.2		0.2				0.9
<i>S... ..Z:; .</i> ***** -										0.2								
<i>SilJ. t'Fi&lt;ZuIZa</i> ***** 3.2			0.2															
<i>s.p. 02\^talUna</i> ***** -							0.2							0.2				
<i>'fab.</i> ***** -																		
<i>Tha:Z...''fm rrlhao'lrlol.be</i> ***** -											0.2	0.5	0.2					0.2
<i>Thal.-N iâoipüM</i> ***** -													0.7	0.8				0.9
<i>Thacz...N'aa.ntnoa</i> ***** -			0.2		0.2	0.2			0.7	0.4	0.5	0.5	0.4		0.4			0.7
<i>Thal.-N parri4a</i> ***** -									0.2									
<i>n..oh.</i> ***** 0.2	0.4	1.1	0.5	0.2		2.1	0.0	0.2	0.2	0.0	0.5		0.4	0.2	0.4			0.6
<i>TPW fallua</i> ***** +												0.2	0.2	0.2				





**Fig. 4.** Relative abundance of the most important taxa, number of taxa and similarity (SIMI) between successive assemblages.



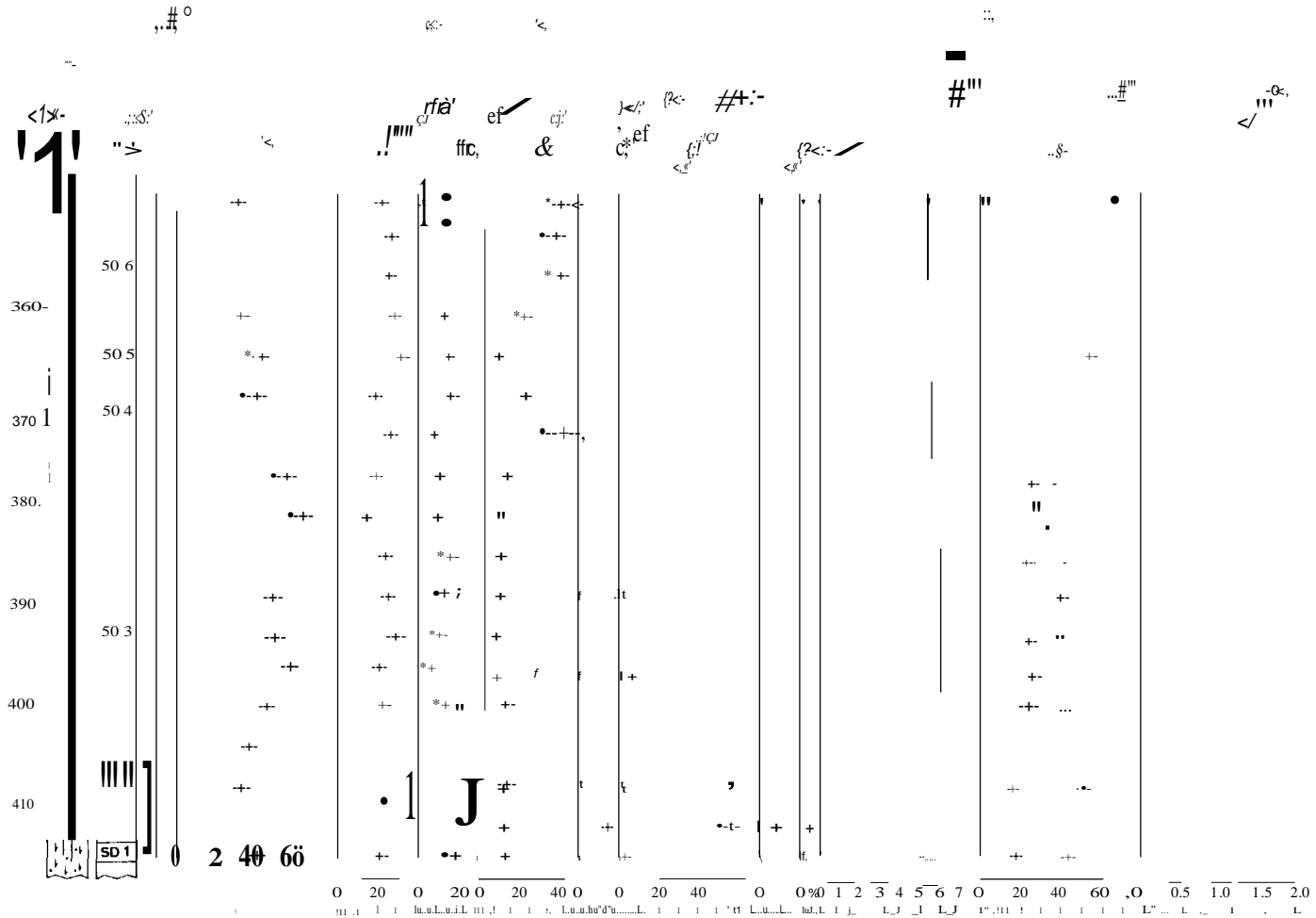


Fig.5. Salinity spectra, generalised index  $S$ , percentages of euryhaline (+-) and  $\pm$  euryhaline taxa (--+),  $M$ - and  $F$ -values (• =  $M$ , , =  $F$ ). Asterisks mark groups with highest percentage of benthic forms.



taxa were considered ( Fig.6). The pH spectrum was based on Hustedt's classification (Hustedt, 1939a), while in the spectrum reflecting the trophic conditions the categories eutrophic, mesotrophic and oligotrophic were used (Fig. 7). On the percentage data 95% confidence limits were calculated according to the formula of Mosimann (1965, p.643). A data coding method (Denys and Lodewijckx, 1984) and a Minc/Declab 23-RT system were used to facilitate the calculations.

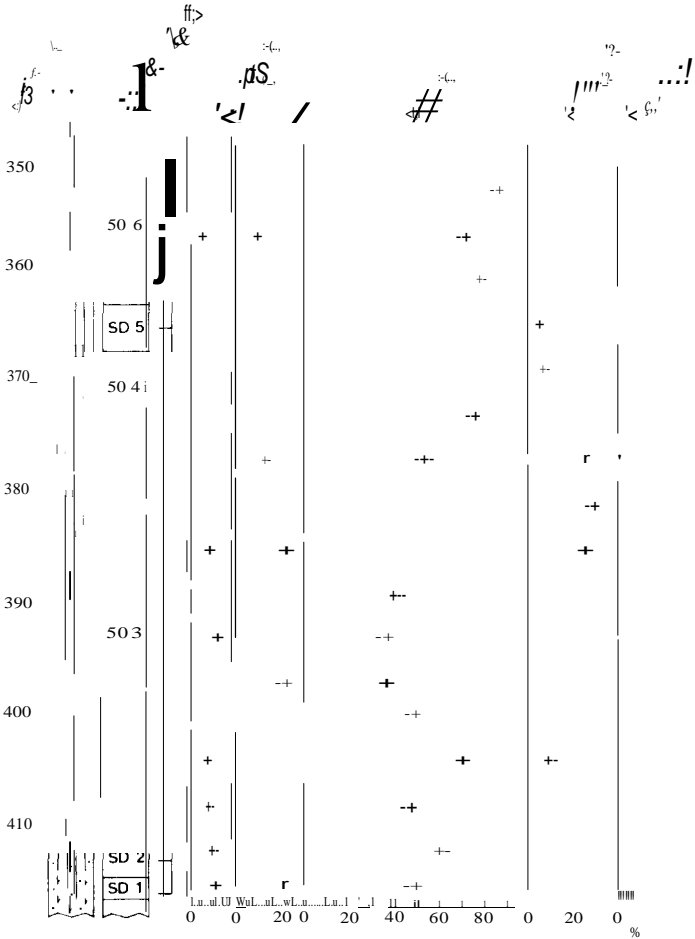


Fig.6. Life form spectra.

<sup>1</sup> The taxonomical list and the autecological data used, can be requested from the author.

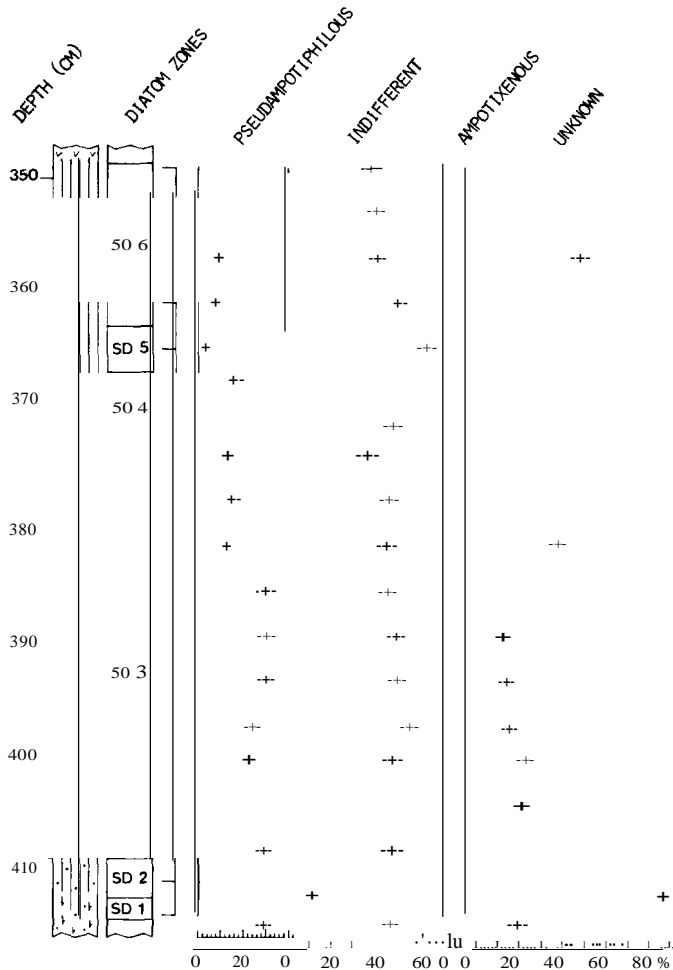


Fig. 7. Tide sensitivity spectra.

## RESULTS

### *Diatom zones*

To facilitate the presentation, discussion and future comparison of the results, the diagram was zoned as follows:

– SD1, -415 to -413 cm: Assemblage of mainly marine and marine-brackish taxa. *Paralia sulcata* dominant, *Scolioptleura tumida*, *Cymatosira belgica* and *Rhaphoneis amphiceros* abundant.

–SD2, -413 to -410 cm: Taxa from fresh and brackish water predominate. *Amphora libyca* and *Nitzschia scalaris* are codominant.

– SD3, -410 to -375 cm: Mostly marine and marine-brackish diatoms. *Paralia sulcata* generally dominant. *Scolioptleura tumida* and *Rhaphoneis*

*amphiceros* frequently abundant. The lower part of the zone is characterised by *Nitzschia punctata*, the middle by *Cymatosira belgica* and the upper part by *Melosira westii*.

-SD4, -375 to -367 cm: Increase of brackish-water diatoms. High percentages of *Nitzschia navicularis*. *Diploneis didyma*, *D. bombus* and *Scoliopleura tumida* reach important values. More than 5% *Caloneis westii*.

— SD5, -367 to -363 cm: Increase of taxa favouring a somewhat higher salinity. *Diploneis didyma* dominant. More than 20% *Melosira westii*. *Nitzschia punctata* acme.

— SD6, -363 to -349 cm: Increase of brackish-water taxa. *Nitzschia navicularis* dominant, *Diploneis didyma* and *Melosira westii* subdominant.

### *Diatom assemblages and palaeoenvironment*

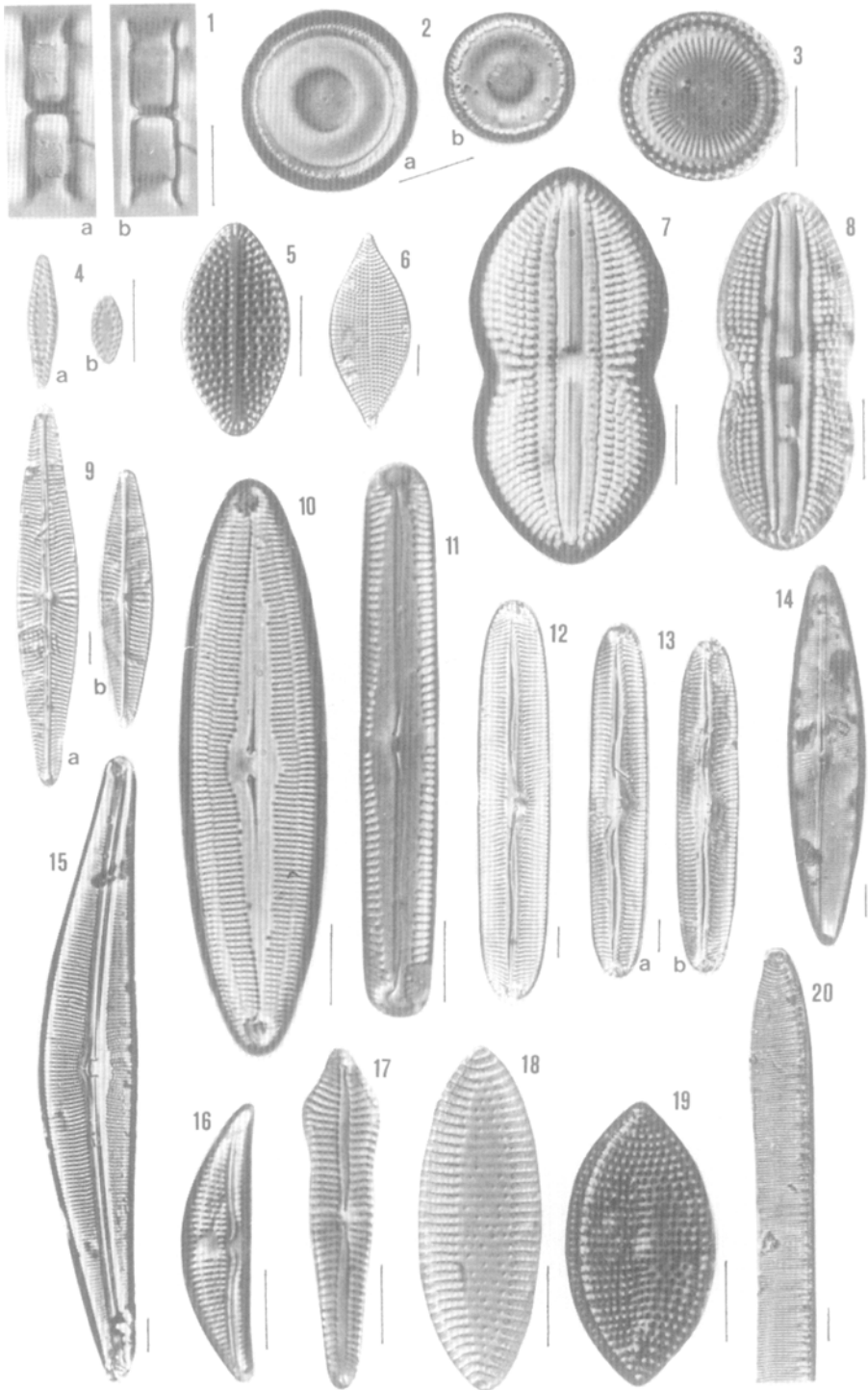
#### *Zone SDJ*

Marine diatoms are most abundant ( $\pm 40\%$ ). *Paralia sulcata* is the most important species belonging to this group. This diatom, although normally benthic, may also form important planktonic populations (cf. Louis et al., 1974). For this reason it was kept separate in the life form spectra (cf. Miller, 1964). The species is euryhaline but optimal growth occurs at salt concentrations of 2.5-3‰ (Mölder and Tynni, 1967). Marine-brackish and brackish-marine taxa are rather well represented ( $\pm 20\%$  each) with the epipsammic *Rhaphoneis amphiceros* and the epipelagic *Scoliopleura tumida* respectively as their most important species. Both taxa are reported to have a rather large salinity range. In general the salinity during this phase was situated in the marine to marine-brackish region, which explains the halt in the formation of the *Phragmites* peat; in the temperate zones the growth of *Phragmites australis* is limited by soil chlorinities above 1.2‰ (Ranwell et al., 1964). The dominance of benthic forms indicates a shallow water environment. Moreover, the assemblage points to deposition between the tidal limits; amphotixenous diatoms are scarce, tide-indifferent taxa are dominant ( $\pm 47\%$ ), while pseudamphotiphilous diatoms, such as *Scoliopleura tumida* and *Rhaphoneis amphiceros*, are quite common ( $\pm 25\%$ ). A tidal flat environment therefore seems very plausible.

#### *Zone SD2*

The tidal flat phase which is represented by only a very thin layer of sediment, was succeeded by a much less saline environment. The marine and marine-brackish taxa disappear almost completely and fresh-brackish diatoms in particular become abundant ( $\pm 58\%$ ). *Amphora libyca*, *Nitzschia scalaris*, *Navicula peregrina*, *Aulacosira ambigua* and *Gomphonema acuminatum* varieties are the main constituents of the assemblage. Some large *Pinnularia*, such as *P. brevicostata* and a taxon most probably belonging to *P. viridis* are rather numerous. *Cymbella aspera* is also fairly common, while chrysophycean cysts are abundant. Some of the taxa (*Navicula peregrina*, *Nitzschia scalaris*)

PLATE 1





prefer slightly brackish water. In coastal areas, however, the latter species in particular is often found in quite fresh but mineral- and nutrient-rich inland waters, where it can flourish rather well (Eronen, 1974; Germain, 1981). The bulk of the assemblage consists of benthic diatoms ( $\pm 62\%$ ). Epontic as well as planktonic taxa are much less important, indicating very shallow conditions. The marked fragmentation of the *Nitzschia scalaris* valves is probably due to wave action. Macrophytes are believed to have been rather scarce. The epiphytes present (*Cymbella*, *Epithemia*, *Gomphonema*) probably lived mainly on the remaining reed stems. The spectra for hydrogen-ion concentration (Fig.8a) and nutrient content (Fig.8b), indicate the slightly alkaline and eutrophic nature of the water. Judging from the pH-optima of some of the important species (pH 8.2-8.4 for *Amphora libyca*, pH 7-8.5 for *Cymbella aspera* according to Cholnoky, 1968), the pH was probably between 7.5 and 8.5 most of the time. The acidophilous species were mainly washed in from the nearby surroundings. The most likely sedimentary environment is a very shallow swampy lagoon or pool with nearly fresh water. Desalination proceeded rapidly due to precipitation and inflow of fresh drainage water. Only sporadically did some salt water reach the basin.

### Zone SD3

This zone represents a period of increasing marine influence. Although the diatom succession corresponds to a more or less gradual salinity increase, important and abrupt shifts in the abundance of separate taxa occur throughout the zone, giving it a somewhat heterogeneous aspect. The evolution of SIMI clearly visualises this phenomenon and indicates that the major changes

---

### PLAT I

1. a-b. *Aulacosira ambigua* (Grunow) Simonsen
  2. a-b. *Melosira westii* W. Smith
  3. *Paralia sulcata* (Ehrenberg) Cleve
  4. a-b. *Cymatosira belgica* Grunow
  5. *Deiphoneis surirella* (Ehrenberg) Andrews
  6. *Rhaphoneis ampiceros* Ehrenberg
  7. *Diploneis bombus* Ehrenberg
  8. *Diploneis didyma* Ehrenberg
  9. a-b. *Navicula peregrina* (Ehrenberg) Kützing
  10. *Caloneis westii* (W. Smith) Hendey
  11. *Pinnularia brevicostata* Grunow
  12. *Pinnularia viridis* (Nitzsch) Ehrenberg
  13. a-b. *Pinnularia* sp. 1 (cf. *P. viridis*)
  14. *Scoiopeura tumida* (Brébisson) Rabenhorst
  15. *Cymbella aspera* (Ehrenberg) Cleve (narrow specimen)
  16. *Amphora libyca* Ehrenberg
  17. *Gomphonema acuminatum* Ehr. (intermediate between var. *brebissonii* (Kützing) Grun. and var. *clavus* (Brébisson) Grunow)
  18. *Nitzschia navicularis* (Brébisson) Grunow
  19. *Nitzschia punctata* (W. Smith) Grunow
  20. *Nitzschia scalaris* (Ehrenberg) W. Smith (apex)
- Scales indicate 10  $\mu$ m)

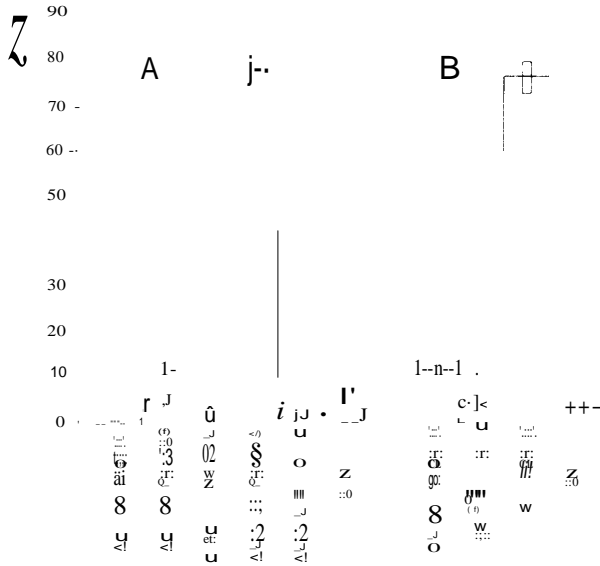


Fig.8. pH- and nutrient spectra of the assemblage from SD2.

in the assemblage composition are found at the beginning and at the end of the sedimentary phase. In the lower part of the zone the brackish-marine *Nitzschia punctata* and the brackish *Nitzschia navicularis* remain relatively important. The marine-brackish, euryhaline, *Diploneis didyma* reaches almost 20% at the -404 cm level. Above this level these species are rapidly replaced by taxa requiring more marine conditions. To start off with, *Paralia sulcata* and *Cyrtosira belgica* proved to be successful, while at the top the assemblage is characterised by *Paralia sulcata* associated with *Melosira westii*. According to Mölder and Tynni (1967) the optimal salinity of the latter species is about 3‰. The gradual rise in salinity is not only reflected by the salinity spectra, where the marine group increases in importance, but also in the behaviour of the groups euryhaline and ± euryhaline and in the M-values. The index *S* gives, by its very nature, only a limited idea of this rather subtle change. All by all it appears that the salinity increased from brackish-marine to marine-brackish (below -400 cm) through a marine to marine-brackish stage (between -400 and -385 cm) to a fully marine environment (-389 to -377 cm). Throughout the water remained shallow. The slight rise in planktonic diatoms at about the middle of the zone may well be more closely related to somewhat altered sedimentary conditions than to an actual increase in the mean water level. Intertidal deposition is indicated by pseudampotiphilous species such as *Rhaphoneis amphicerus*, *Scoliopleura tumida* and *Delphineis surirella*. The decline in typical intertidal diatoms at the top of the zone is caused mainly by the increase of *Melosira westii*, a species not yet classified in Simonsen's system. Hustedt (1939b) mentions this *Melosira*, together with, e.g. *Paralia sulcata*, as one of the quantitatively more important members of the German tidal flat flora.

#### Zone SD4

A sudden drop in the salinity follows the fully marine period. *Nitzschia navicularis* becomes the most important taxon and *Caloneis westii*, another brackish euryhaline species, reaches its acme. The brackish group represents about 40% of the assemblage at the beginning of the phase. In this case it is clearly autochthonous. According to Brockmann (1950) *Nitzschia navicularis* and *Caloneis westii* are most common on the higher silted-up parts of the tidal flat. Round (1960) also found *Nitzschia navicularis* to be most abundant on the upper and middle parts of the salt marsh he studied. When at the -369 cm level the marine group exceeds the brackish taxa quantitatively, the beginning of yet another salinity rise is indicated. *Diploneis bombus*, a marine euryhaline species, becomes the most important diatom.

#### Zone SD5

Taxa from brackish water have become scarce (*Nitzschia navicularis* for instance is represented by no more than  $\pm 4\%$ ), while marine-brackish (*Diploneis didyma*) and marine species (*Melosira westii*) are most prevalent. *Nitzschia punctata* reaches  $\pm 13\%$ . The F-value is low. The salinity increase which had already started in the previous zone has now reached its full expression. Benthic euryhaline diatoms which are indifferent to tides predominate while no increase in planktonic taxa is observed. Therefore it seems probable that the actual depth of the water did not increase very much. In any case the tidal flat remained.

#### Zone SD6

Again the brackish euryhaline group increases. *Nitzschia navicularis* rapidly becomes the dominant species. The F-value is very low while an important quantity of marine and marine-brackish diatoms remains present. *Cymatosira belgica* is considerably reduced but *Paralia sulcata* still shows a peak at -357 cm, at which point *Melosira westii* and *Diploneis didyma* decrease. *Navicula peregrina* reappears at the top when the salinity is at its lowest. The dominance of benthic forms and the quasi-absence of planktonic taxa is striking. The SIMI values illustrate the gradually changing composition. The silting-up of the area from a high tidal flat to a salt-marsh environment near the upper tidal limit is clearly reflected. The fresh-water influence remained rather unimportant and the process of infilling apparently determined the environmental change. The abrupt end of clay deposition might indicate that the area was cut off from the marine influence quite rapidly. Curiously enough the clay is overlain directly by fenwood peat. A transitory *Phragmites* peat, as is commonly found in the area (Belpaire, 1855; Stockmans et al., 1948; Moormann, 1951; Stockmans and Vanhoorne, 1954), is lacking. Nevertheless the appearance of numerous *Poaceae* phytoliths in the last few cm of clay suggest a local grassland vegetation. Moreover, the diatom valves in the upper part of the core are rather badly corroded (see Fig.3). Such corrosion may result from a more or less prolonged period of exposure of the sediment to the air (Brockmann, 1940;

Pals et al., 1980). Extraction of diatom silica from the sediment by the vegetation may have also occurred but is not apparent from the biosilica measurements. Perhaps this was obscured by a silica contribution from the phytoliths. Nevertheless, it seems probable that the fen-carr did not develop immediately after the substrate became available. Rather it only started to grow when conditions became more favourable.

## CONCLUSIONS

The diatom analysis of the core clearly shows a much more differentiated succession of palaeoenvironments than one would expect on the basis of the rather uniform lithology.

The growth of the basal peat came to an end as a result of a sudden inundation by highly saline water giving rise to marine-brackish flat conditions. This first inundation had an ephemeric character and only a little sediment was deposited before a marshy lagoonal environment with nearly completely fresh water evolved. Apparently the area was still effectively sheltered from the marine influence. The following incursion of the sea however was of greater importance. A major sediment accretion occurred under increasingly more saline tidal flat conditions. The complete change in salinity was not effected from the start, but happened in the course of two not very pronounced steps. After this marine-brackish to marine period an abrupt reversal to much more brackish conditions followed. In the transitional period only a few cm of sediment accumulated, while indications of erosion are lacking. Therefore it seems improbable that this evolution resulted from a mere local silting-up of the area. More likely changes in the morphology of the seaward area, possibly the development of a barrier system, played an important role here. Once again an increase in the marine influence occurred and this time its traces are quite well marked. Indeed at the -369 cm level a return to marine-brackish conditions can be observed. Hereafter a gradual evolution to a brackish situation took place which can be accredited to the further silting-up of the already rather highly infilled area. Notable is the observation that no indications were found for a truly lagoonal environment. In our opinion the tidal influence remained. Finally a salt marsh with some grass cover existed for some time, after which a fen-carr developed as a result of a rise in the water table.

The evolution of the sedimentary environment as discussed above was strongly influenced by several marine incursions. The first two, situated at the top and just above the basal peat respectively are probably to be considered as belonging to a single larger event. Peat from immediately below the corresponding level (-1.04 m T.A.W. <sup>1</sup>) was dated at about 5650 B.P. Taking into account the low-energy environment involved and the good

---

<sup>1</sup> T.A.W.: Tweede Algemene Waterpassing = Second General Levelling. The Belgian Ordinance Datum. The T.A.W. zero-level corresponds with -2.32 m N.A.P.

correspondence with other age determinations of the top of the basal peat in the area, this date is believed to represent the termination of the peat growth at the site. Nevertheless contamination with younger plant remains (e.g. *Phragmites* rhizomes) might have influenced the result. Chronologically this event can be situated during the Calais II transgression as dated by Roeleveld (1974), Griede (1978) and others. The second transgressive event of some importance is situated at the -0.58 m T.A.W. level, but no radiocarbon dating proved possible in this case. As the renewed peat growth may be correlated with the end of the Calais 111transgression in the region (Baeteman, 1981a), it is possible that we are dealing here with the onset of this transgression. This phase is dated to about 5000 B.P. in the northern Netherlands (Roeleveld, 1974; Griede, 1978).

It should be stressed that the data presented here are derived from one single core and that the record will be representative for only a very limited part of the quite heterogeneous western coastal plain. A more holistic reconstruction of the Holocene development of this area will require the examination of substantially more material. Achieving this goal will largely depend on a critical interdisciplinary evaluation of all the available data. It is believed that the information which the diatom record can yield will prove to be particularly valuable.

#### ACKNOWLEDGEMENTS

The author is much obliged to Prof. Dr. R. Vanhoorne, whose dedication to the coastal Quaternary made this contribution possible. Dr. L. Beyens (R.U.C.A.) is thanked for his introduction to the subject and guidance throughout this study. The Belgian Geological Survey willingly supplied the core and Dr. C. Baeteman (B.G.S.) critically read and discussed the manuscript draft. Mrs. B. Marin (B.G.S.) provided the granulometric data, while Prof. Dr. D. Ferguson (R.U.C.A.) kindly corrected the final draft of the manuscript. Sincere thanks are due to them all.

#### REFERENCES

- Ameryckx, J., 1960. De jongste geschiedenis van de Belgische zeepolders. *Tech. Wet. Tijdschr.*, 29(1): 2-10.
- Baeteman, C., 1978. New evidences on the marine Holocene in the western Belgian coastal plain. *Bull. Belg. Ver. Geol.*, 87(1): 49-54.
- Baeteman, C., 1981a. De Holocene ontwikkeling van de westelijke kustvlakte (België). Thesis, Vrije Univ. Brussel, 297 pp.
- Baeteman, C., 1981b. An alternative classification and profile type map applied to the Holocene deposits of the Belgian coastal plain. *Bull. Belg. Ver. Geol.*, 90(4): 257-280.
- Baeteman, C., Lambrechts, G. and Paepe, R., 1974. Autosnelweg Brugge-Calais. Boringen en geologisch profiel. Sectie Veurne-Franse grens. *Belg. Geol. Surv. Prof. Pap*" 2 : 1-55.
- Belpaire, A" 1855. De la Plaine maritime depuis Boulogne jusqu'au Danemark. 1. ière Partie. *Konink. Anvers*, 143 pp.
- Beyens, L. and Denys, L., 1982. Problems in diatom analysis of deposits: allochthonous valves and fragmentation. *Geol. Mijnbouw*, 61: 159-162.

- Blanchard, H., 1906. La Flandre. Familia et Patria, Handzame, 530 pp. (reprint 1970).
- Bradbury, J.P. and Winter, T.C., 1976. Area! distribution and stratigraphy of diatoms in the sediments of Lake Sallie, Minnesota. *Ecology*, 57: 1005-1014.
- Brockmann, C., 1940. Diatomeen als Leitfossilien in Küstenablagerungen. *Westküste*, 2(2/3): 150--181.
- Brockmann, C., 1950. Die Watt-Diatomeen des Schleswigholsteinischen Westküste. *Abh. Senckenb. Naturforsch. Ges.*, 478: 1-26.
- Cholnoky, B.J., 1968. Die Oekologie der Diatomeen in Binnengewässern. *Cramer, Vaduz*, 699 pp.
- Dean, W.E., 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. *J. Sediment. Petrol.* 44(1): 242-248.
- Denys, L., 1984. Diatom analysis of coastal deposits: methodological aspects. *Bull. Belg. Ver. Geol.*, 93(3): 291-295.
- Denys, L. and Lodewijckx, E., 1984. An improved method of coding diatom data for computer utilisation. *Bull. Belg. Ver. Geol.*, 93(3): 297-299.
- Digerfeldt, G., 1975. The post-glacial development of Ranviken Bay in Lake Immeln. III. Palaeolimnology. *Geol. Fören. Stockholm Förh.*, 97: 13-28.
- Eronen, M., 1974. The history of the Littorina Sea and associated Holocene events. *Commentat. Phys. Math.*, 44(4): 79-195.
- Germain, H., 1981. Flore des Diatomées. Diatomophycées. Eaux douces et saumâtres du Massif armoricain et des contrées voisines d'Europe occidentale. *Boubée, Paris*, 444 pp.
- Griede, J.W., 1978. Het ontstaan van Friesland's noordhoek. Thesis, *Vrije Univ. Amsterdam*, 186 pp.
- Halet, F., 1931. Contribution à l'étude du Quaternaire de la plaine maritime beige. *Bull. Soc. Belg. Géol.*, 41: 141-166.
- Hustedt, F" 1939a. Systematische und ökologische Untersuchungen über die Diatomeen-Flora von Java, Bali und Sumatra. III. Die ökologischen Faktoren und ihr Einfluss auf die Diatomeenflora. *Arch. Hydrobiol.* 16: 274-344 (Supplement).
- Hustedt, F" 1939b. Die Diatomeenflora des Küstengebietes der Nordsee vom Dollart bis zur Elbemündung. I. Die Diatomeenflora in den Sedimenten der unteren Ems sowie auf den Watten in der Leybucht, des Memmert und bei der Insel Juist. *Abh. Naturwiss. Ver. Bremen*, 31(3): 572---677.
- Louis, A" Petes, J., Ramboer, T. and Vanderveken, L" 1974. La végétation phytoplantonique de l'Océan Atlantique N-E et de la Mer du Nord. *Stud. Algal. Lovan*" *Story Scientia, Louvain* , 370 pp.
- Marl!chal, R" De Breuck, W" De Moor, G. and Verheye, W" 1964. Survey West-Vlaanderen. *Geologie. Geol. Inst., Rijks Univ. Gent* , 54 pp.
- McIntire, C.D. and Moore, W.W., 1977. Marine littoral diatoms: ecological considerations. In: D. Werner (Editor), *The biology of Diatoms. Univ. California Press, Berkeley Los Angeles, Calif.*, pp.333-371.
- Miller, U., 1964. Diatom floras in the Quaternary of the Göta River valley (western Sweden). *Sver. Geol. Unders. Ser. Ca.* 44: 1-67.
- Mölder, K., 1943. Studien über die Ökologie und Geologie der Bodendiatomeen in der Pojo-Bucht. *Ann. Bot. Soc. Zool. Bot. Fenn. Vanamo*, 18(2): 1-204.
- Mölder, K. and Tynni, R., 1967. Über Finnlands rezente und subfossile Diatomeen. *I. C.R. Soc. Gol. Fini.*, 39: 199-217.
- Moormann, F" 1951. De bodemgesteldheid van het Oudland van Veurne Ambacht. *Natuurwet. Tijdschr.*, 33(1/4): 3-124.
- Mosimann, J.E., 1965. Statistical methods for the pollen analyst: multinomial and negative multinomial techniques. In: B. Kummel and D. Raup (Editors), *Handbook of Paleontological Techniques. Freeman, San Francisco, Calif., London*, pp.636-673.
- Ozer, A., 1976. La morphologie des polders. Les dépôts cotiers Holocènes. In: A. Pissart (Editor), *Geomorphologie de la Belgique. Lab. Géol. Géogr., Univ. Liège*, pp.17-27.
- Paepe, R., 1971. Autosnelweg Brugge-Calais. Boringen en geologisch profiel. *Belg. Geol. Surv. Prof. Pap.*, 9: 1-59.

- Pais, J.P., Van Geel, B. and Delfos, A" 1980. Paleocological studies in the Klokkeweel Bog near Hoogkarspel (prov. of Noord-Holland ). *Rev. Palaeobot. Palynol.*, 30: 371-418.
- Ranwell, D.S" Bird, E.F.C" Hubbard, J.C.E. and Stebbings, R.E" 1964. *Spartina* salt marshes in southern England. V. Tidal submergence and chlorinity in Poole Harbour. *J. Ecol.*, 52(3): 627-642.
- Roeleveld, W" 1974. The Groningen coastal area: a study in Holocene geology and low-land physical geography. *Ber. Rijksdienst Oudheidkd. Bodemonderzoek*, 24: 5-132.
- Round, F.E" 1960. The diatom flora of a salt marsh on the river Dee. *New Phytol*" 59: 332-348.
- Schrader, H.J" 1973. Proposal for a standardized method of cleaning diatom-bearing deep-sea and land-exposed marine sediments. *Beih. Nova Hedwigia*, 45: 403-409.
- Simonsen, R" 1962. Untersuchungen zur Systematik und Oekologie der Bodendiatomeen der westlichen Ostee. *Int. Rev. Gesamten Hydrobiol. Syst. Beih*" 1: 1-144.
- Stockmans, F. and Vanhoorne, R" 1954. Etude botanique du gisement de tourbe de la région de Pervijze (plaine maritime beige). *Verh. K. Belg. Inst. Nat. Wet*" 130: 1-144.
- Stockmans, F., Vanden Berghen, C. and Vanhoorne, R" 1948. Het veenonderzoek in de streek van Lampernisse-Pervijze. *Natuurwet. Tijdschr*" 31: 154-160.
- Tavernier, R. and Moormann, F" 1954. Les changements du niveau de la mer dans la plaine maritime flamande pendant l'Holocène. *Geol. Mijnbouw*, 16: 201-206.
- Tavernier, R" Ameryckx, J" Snacken, F. and Farasyn, D" 1970. Kust, duinen, polders. *Atlas van België, Blad 17, Nat. Comm. Geogr*" Brussel, 32 pp.
- Van der Werff, A" 1955. A new method of concentrating and cleaning diatoms and other organisms. *Verh. Int. Ver. Limnol.*, 12: 276-277.
- Van der Werff, A. and Huls, H" 1957-1974. *Diatomeënflora van Nederland*. Otto Koeltz, Koenigstein, (reprinted 1976).
- Wetzel, R.G" 1970. Recent and postglacial production rates of a marl lake. *Limnol. Oceanogr*" 15(4): 491-503.