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A DIATOM AND RADIOCARBON PERSPECTIVE OF THE PALAEOENVIRONMENTAL HISTORY AND STRATIGRAPHY OF HOLOCENE DEPOSITS BETWEEN OOSTENDE AND NIEUWPOORT (WESTERN COASTAL PLAIN, BELGIUM)

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(12 figures and 3 tables)

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ABSTRACT. Diatom and radiocarbon data of two cores from the north-eastern part of the western Belgian coastal plain are discussed. The palaeoenvironmental reconstruction of these sites and additional stratigraphic and geochronological information, allow an assessment of the general development of this region throughout the Holocene. Prior to *c.* 7500 yrs cal. BP a rapidly transgressing coast exists. Basal peat development may have been fairly widespread. Extensive erosion channels form towards the interior once the volume of the developing tidal basin has increased sufficiently. In spite of very high rates of sediment accumulation, high-intertidal environments remain poorly developed due to the high rate of RSL rise and the relatively steep slope of the transgressed terrain. Diatom taphocoenoses of this period consist primarily of coastal tychoplankton (mainly *Cymatosira belgica*), deposited in association with flood transported sediment, and some epipsammon. Hereafter, the incidence of negative tendencies in marine influence increases, culminating between *c.* 6300 to 5600 yrs cal. BP. Diatom assemblages are now more varied with an improved representation of tidal flat and salt marsh communities. The marine species *Paralia sulcata* and *Pseudopodosira westii* become abundant in high intertidal deposits, which may involve selective transport, sedimentation and preservation mechanisms. In general, the environmental changes reflect the development of a broad intertidal sedimentation zone in which sediment supply remained high, combined with a gradual slowing down of the RSL rise. Coastal progradation finally leads to sufficiently sheltered conditions for long-lasting peat growth in the intracoastal area up to perhaps c. 2100 yrs cal. BP. Presumably a coastal barrier, which remains intersected by some inlets, also develops during this period. At places, peat growth is interrupted at about 4200 yrs cal. BP by a marked but short-lived period of marine sedimentation. Within the general framework of a return to a transgressive setting and a destabilisation of the barrier system due to a decreasing sediment supply, climatic conditions and human interference may have played a role in the final termination of peat growth and the resumption of tidal activity. So far, the exact chronology of the return of tidal sedimentation in the study area remains unclear. No general sedimentation cycles, or so-called Dunkerque transgressions, are identified during the deposition of the upper tidal deposits, which are again characterized by a high representation of *Cymatosira*, reflecting a more open coastal setting. A tentative chronology of regional tendencies in the marine influence is derived from both bio- and lithostratigraphical indications and compared with the assumed chronology of transgressive and regressive phases in the northern Netherlands. Points of agreement are discussed in terms of possible supra-regional processes.

KEYWORDS: Belgian coastal plain, Holocene, diatom data, radiocarbon data, sea-level rise, tendencies in marine influence.

SAMENVATTING. De resultaten van het diatomeeënonderzoek van twee door middel van ^{14}C-analyse gedateerde boorkernen uit het noord-oostelijke deel van de westelijke Belgische kustvlakte worden besproken. Op basis van de paleomilieureconstructie van beide sites en stratigrafische en geochronologische gegevens wordt de algemene ontwikkeling van het gebied tijdens de Holocene periode geschetst. voor *c.* 7500 jaren cal. BP vindt een snelle transgressie van de kustzone plaats, waarin initieel basisveenvorming optrad. Naarmate het bergingsvolume van het getijdengebied toeneemt, breiden de geulen zich landinwaarts uit. Niettegenstaande een zeer aanzienlijke sedimentaccumulatie, blijft de ontwikkeling van hoog-intertidale milieus zeer beperkt tengevolge van de sterke relatieve zeespiegelstijging en de sterke helling van het pre-Holocene bodemreliëf. Diatomeeëntafocoenosen uit deze periode bestaan voornamelijk uit marien-litoraal tychoplankton (vooral *Cymatosira belgica*) dat geassocieerd met sediment door de getijden is aangevoerd en enig epipsammon. Door de hieropvolgende ontwikkeling van een brede getijdenzone, waarin nog steeds grote hoeveelheden sediment worden afgezet en een geleidelijke vertraging van de zeespiegelstijging, kan plaatselijk de mariene invloed gaan afnemen. Dit gebeurt in toenemende mate en komt vooral tussen *c.* 6300 to 5600 jaren cal. BP tot uiting. De mariene soorten *Paralia sulcata* en *Pseudopodosira westii* worden talrijk in hoog-intertidale afzettingen, wat door selectieve transport-, sedimentatie- en bewaringsmechanismen verklaard kan worden. Doordat de kustlijn inmiddels ver in zeewaartse richting verschoven is, wordt langdurige veengroei in het opgeslibde achterliggende gebied mogelijk. Wellicht wordt in deze periode tevens een kustbarrière gevormd, weliswaar met enkele open blijvende zeegaten. Plaatselijk vindt rond *c.* 4200 jaren cal. BP een kortstondige periode van mariene sedimentatie plaats in het veengebied. Hoewel de terugkeer naar een transgressieve situatie en de remobilisatie van de kustbarrière wellicht in de eerste plaats het gevolg waren van een verminderde sedimentaanvoer, kunnen klimatologische factoren en menselijke invloed een rol gespeeld hebben bij de uiteindelijke beëindiging van de veengroei door toenemende getijdenwerking. De juiste chronologie hiervan blijft evenwel nog onduidelijk voor het studiegebied. Algemene sedimentatiecycli of zogenaamde Dunkerque transgressies kunnen bij de vorming van de afdekkende afzettingen niet worden aangetoond. Deze getijdenafzettingen zijn opnieuw gekenmerkt door een hoog aandeel van *Cymatosira*, wat de terugkeer naar een meer open kust weerspiegelt. Uit zowel litho- als biostratigrafische aanwijzingen is een voorlopige regionale chronologie van positieve en negatieve tendenzen in mariene invloed afgeleid. Deze wordt vergeleken met de veronderstelde afwisseling van transgressieve en regressieve fasen in Noord Nederland. Enkele punten van overeenkomst worden besproken in het kader van mogelijke supra-regionale processen.

SLEUTELWOORDEN: Belgische kustvlakte, Holoceen, diatomeeën, radiokoolstof dateringen, zeespiegelstijging, tendenzen in mariene invloed.

1. Introduction

Implicitly, palaeoenvironmental interpretations have played a key role in the development of a stratigraphic framework for the Holocene deposits in the Belgian coastal plain. In the classification scheme of Tavernier (1948), and later e.g. Tavernier and Moormann (1954) and Ameryckx (1959), which has been the standard for several decades, paramount importance was attributed to the punctuated and alternating occurrence of large-scale transgression and regression events. These were tied to corresponding lithosomes in the field, yielding the so-called Calais and Dunkerque deposits of marine origin. The wide-spread upper peat layer was considered to represent a sea-level stand-still or even a negative sea-level oscillation separating the two major periods of transgression and was therefore used as a stratigraphic marker horizon as well. As details on the deeper deposits were still quite limited, the Dunkerque deposits received most attention and four beds of different extent were distinguished within them, again corresponding to an equal number of transgressive phases.

Considering the absence of visible marker horizons for the stratigraphic delimitation of these beds, such as regional vegetation horizons, peats or soils, one might expect that the concept of Calais and Dunkerque transgressions would have resulted in a broad application of sensitive techniques for palaeoenvironmental reconnaissance, in order to detect and eventually map the different sedimentation cycles which were assumed to have occurred. Surprisingly though, this was never the case; the theories and maps developed with regard to the Belgian coastal plain were hardly supported by any reliable palaeoenvironmental evidence of transgressive or regressive events at all. With exception perhaps of the peat beds (e.g. Stockmans and Vanhoorne, 1958), palaeontological aspects that could have been helpful in this respect were largely left unconsidered. Instead, different lithological field characteristics were attributed to the deposits of the Calais and the multiple Dunkerque phases. Nowadays, it is, however, quite impossible to perceive how these should be matched with the intense lateral and vertical variation of lithological facies that actually occurs in the coastal plain (*cf.* Baeteman, 1999). At the same time, little notice was paid to the development of a geochronological framework based on data from the area itself, other than from historical sources. Consequently, ruling opinions on coastal development and sea-level history were largely determined for quite some time by personal "reworking" of existing viewpoints, rather than by the elaboration of original scientific evidence (Baeteman, 1983).

Since the late seventies, however, research in the area revived, and it rapidly became clear that the established ideas on coastal development and architecture were too simplistic for practical application, although some apparently have not been completely abandoned yet (see e.g. Houthuys *et al.*, 1992; Marechal, 1992; Gullentops and Wouters, 1996). More recent studies (e.g. Baeteman, 1981a; 1985; 1991) clearly showed that local facies variations resulting from changes in marine influence, such as the occurrence of peat, are highly variable in space and time and were controlled by interacting variables operating at different time scales. Consequently, an alternation of general transgressions and regressions can not be used as a stratigraphic basis, even in areas where peat formation occurred. A more explicitly lithologic method is preferred now for mapping purposes and as a basis for deciphering the Holocene history of the area (see Baeteman, 1981a, 1981b, 1987, 1991; De Ceunynck, 1984; Mostaert, 1985; Baeteman and Denys, 1995, 1997). Here also, unequivocal palaeoenvironmental inferences remain of utmost importance to explain the origin and relations of the various lithofacies.

Diatom assemblages have provided a very useful means to assess Holocene coastal palaeoenvironments and events in a wide variety of situations (see reviews by Palmer and Abbott, 1986 and Denys and de Wolf, in press), and have also contributed to palaeoecological reconstructions in the Belgian coastal plain and Schelde Estuary (Denys *et al.*, 1983; Denys, 1985, 1989, 1993a, 1993b, 1993c, 1994, 1995; De Ceunynck and Denys, 1987; Denys and Verbruggen, 1989; Verbruggen and Denys, 1995), as well as to biostratigraphy (de Wolf and Denys, 1993) and sea-level history in this area (Denys and Baeteman, 1995). Especially rewarding for coastal stratigraphic studies may be -next to the general identification of palaeoenvironmental conditions- the inferences that can be made from these microfossils with regard to even minor changes in the proximity of marine conditions and the intensity or source of sediment supply, as well as on the significance of stratigraphic overlaps (e.g. detection of hiatuses). Combined with litho- and chronostratigraphic evidence, such information may be used advantageously to obtain a more detailed picture of former developments in local conditions and the general palaeosetting.

In this paper, the environmental history of the north-eastern part of the western coastal plain -the region between Nieuwpoort-Oostende (Fig. 1)- is discussed by reference to the diatom record, and additional information presently available. New data are presented on two cores that cover the Holocene sequence and represent complementary palaeoenvironmental archives of the infilling process. Previous studies on cores from this area (Denys, 1985, 1995) have demonstrated local variations in marine influence which are not reflected by marked lithological changes. Moreover, a certain degree of synchrony in the timing of local transgressive and regressive events was suggested, presumably resulting from the strong control of marine activity and sedimentation processes by a large NW to SE directed tidal-channel system intersecting the area close to Nieuwpoort (Fig. 1 and next section). The changes in marine influence recorded at the most exposed site, Wolvenest, situated W of this channel, were considered especially significant in this respect (Denys, 1995). Further details on the sedimentation history of the eastern part of the area, away from the main channel system, and their integration with available radiocarbon data on the chronology of peat allows a further exploration of the controlling factors that have been at work. To this aim, the chronology of local "sea-level tendencies" (Shennan, 1982a, 1986; Shennan *et al.*, 1983), or in this case more appropriately named "marine influence tendencies", in the area is explored and a working model for regional developments is derived. Possible causal mechanisms are discussed and the model is compared with the chronology of Calais and Dunkerque phases proposed for the northern Netherlands (Roeleveld, 1974; Griede, 1978; van de Plassche, 1985). Vos and van Heeringen (1997) have adequately demonstrated that the Dunkerque chronologies which have been proposed for the more nearby province of Zeeland (e.g. Bennema and Van der Meer, 1952; Van Rummelen, 1972) are highly questionable and for this reason they are not considered here.

2. Study area and general set-ting during the Holocene

At present, the coast along the study area has a (marginally) macrotidal tide-dominated regime (*cf.* Hayes, 1979), with amplitudes of semidiurnal tides reaching 4.12 m at Nieuwpoort and 3.94 m at Oostende (Van Cauwenberghe, 1977). The study area itself is a polder extending almost 7 km inland, more or less parallel to the coastline.

The topography of the pre-Holocene subcrop, consisting of Eocene and Pleistocene deposits, and the location of all sites mentioned in the text are shown in Fig. 1. In general, the pre-Holocene surface dips rather gradually towards the present coastline. Along the coast, a broad depression which is delimited more or less by the -5 m depth contour extends from Nieuwpoort to the north-east. This depression presents a series of NW to SE oriented indentations protruding inland. The deepest and broadest of these is situated just NE of Nieuwpoort, reaching a depth of more than 15 m near the coastline and shallowing rapidly towards the southeast. Contrary to the former, the less extensive protrusions further to the NE do not extend more than halfway across the coastal plain. Here, the main ones are situated on either side of the Pleistocene mound ("donk") of Leffinge. To the W of Nieuwpoort, outside the area considered here, the coastal plain broadens considerably due to the presence of a large

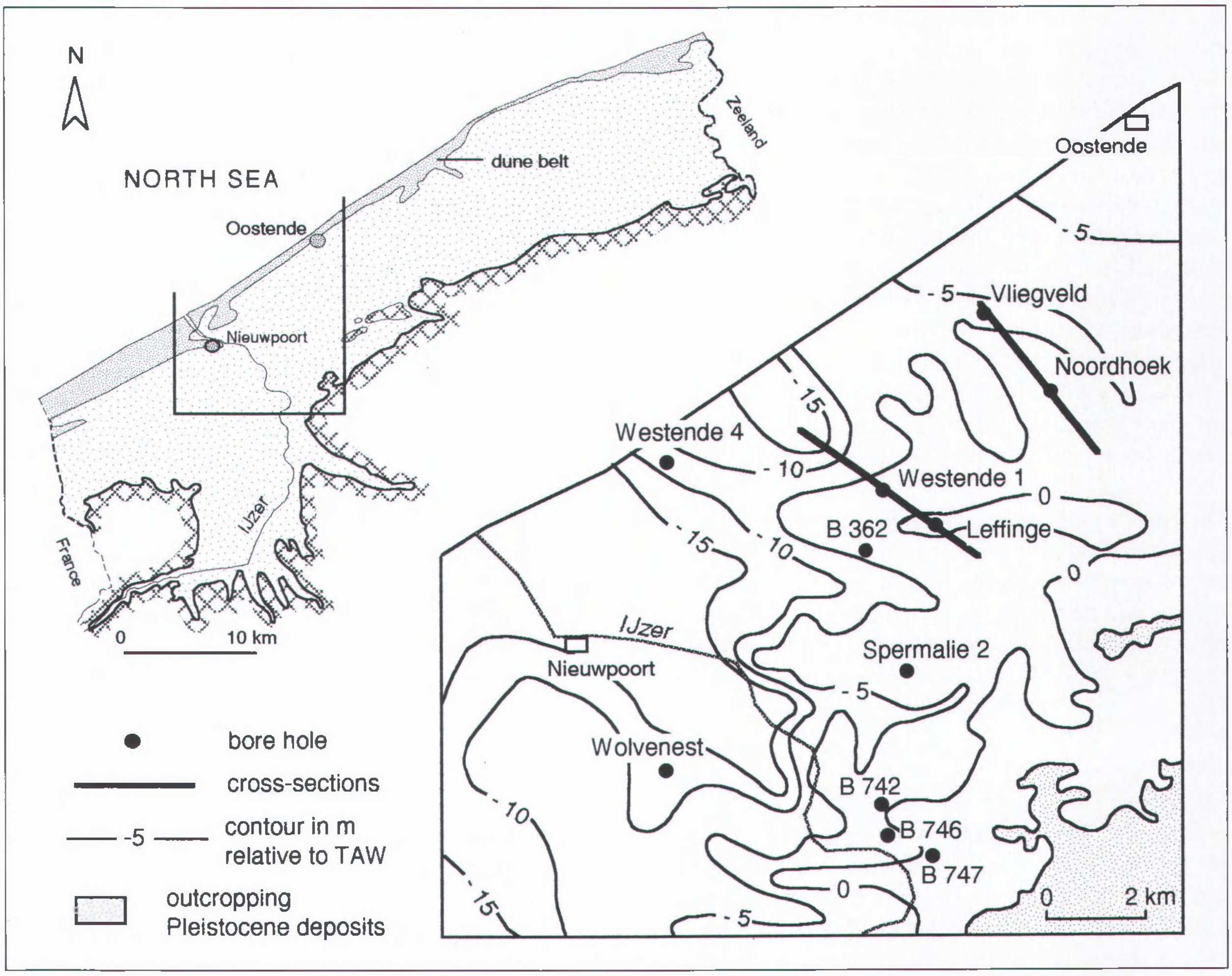

Figure 1. Map of the coastal plain between Nieuwpoort and Oostende with indication of the sites mentioned in the text, stratigraphic cross-sections (Figs 2 and 4) and depth contours of the pre-Holocene surface.

palaeovalley system of pre-Holocene age. Baeteman (1999) discusses the stratigraphy and development of this part of the coastal plain.

The Holocene infill of the study area consists largely of more sandy sediments in the most seaward part, grading towards the interior into the typical interfingering complex of siliciclastic and organogenic deposits occurring in many coastal plains of the Southern North Sea (Baeteman, 1991). In general, peat development becomes more extensive inland, and where the pre-Holocene subcrop reaches above *c.* -1.5 m, the stratigraphy usually consists only of a thick basal peat, covered by a few meters of clay. Close to the polder border the basal peat is lacking again.

Considering the time-depth relation of relative sea-level (RSL; Denys and Baeteman, 1995; Baeteman, 1999) and the temporal distribution of peat (Baeteman and Denys, 1997; Table 1), the onset of marine activity in the study area dates somewhere between about 9000 and 7500 cal. yrs BP. As a result of the extremely rapid rise of RSL during the early Holocene (approximately 7 m/ka; Denys and Baeteman, 1995) major tidal-channel systems developed in the area. Tidal ravinement resulted in the depression of the pre-Holocene surface along the coast and its multiple protrusions stretching inland. By *c.* 7200 yrs cal. B.P. marine sedimentation attained the -5 m level, and some 1000 years later intertidal environments reached almost to the present limits of the coastal plain (Baeteman and Denys, 1997). The accommodation space created by the RSL rise and locally by scouring was filled with sediment supplied by the channels running through the tidal basin. As the rate of RSL rise slowed down after c. 6000 yrs cal. BP, the area silted up, tidal volume decreased and conditions became sufficiently wave-sheltered for peat growth to occur more generally. The coastline, which had been transgressive up to this time, now prograded considerably. Mud and sand flats, as well as peat marshes, developed in a seaward direction, and at some point, a sandy barrier island chain presumably developed here. Throughout this period, the channels in the intracoastal area remained active, however, reaching

Reference number	Site	Altitude (cm TAW)	Age (^{14}C yrs BP)	Calibrated age intercept (yrs cal. BP)	Calibrated age 1σ (yrs cal. BP)	Calibrated age 2σ (yrs cal. BP)	Stratigraphic context	Tendency
Utc 1344	Westende 1	+61/+68	2570±70	2710	2770-2640	2810-2420	top intercalated peat	+
IRPA 846	Westende 1	-91/-86	5125±55	5890	5950-5820	6000-5730	base intercalated peat	-
Utc 1537	Westende 1	-2.9/-268	6040±80	6870	6970-6790	7100-6710	top basal peat	+
IRPA 512	Vliegveld	-28/-23	2580±60	2720	2770-2670	2800-2450	top intercalated peat	+
IRPA 864	Vliegveld	-103/-.99	3800±60	4170	4260-4070	4360-3990	clayey part of intercalated peat	+ → -
IRPA 865	Vliegveld	-156/-152	4700±65	5400	5520-5360	5580-5280	base intercalated peat	-
IRPA 866	Vliegveld	-168/-164	4820±70	5570	5640-5510	5680-5390	top intercalated peat	+
IRPA 924	Vliegveld	-200/-195	5540±55	6340	6380-6280	6430-6240	base intercalated peat	-
IRPA 849	Vliegveld	-253/-248	5960±55	6790	6830-6740	6920-6690	entire intercalated peat	- → +
IRPA 614	Westende 4	-508/-503	6780±80	7580	7640-7520	7710-7460	base basal peat	+ (groundwater)
IRPA 615	Westende 4	-519/-514	7160±85	7970	8020-7880	8080-7780	top basal peat	+?
IRPA 730	Noordhoek	+17/+21	2220±55	2230	2290-2130	2340-2070	top basal peat	+
IRPA 729	Noordhoek	-237/-230	5770±100	6570	6710-6450	6790-6360	base basal peat	+ (groundwater)
Hv 8799	B 362	-203/-197	6015±65	6830	6940-6780	7000-6720	base intercalated peat	-
IRPA 859	Wolvenest	+68/+72	2710±60	2810	2850-2770	2910-2730	top intercalated peat	+?
IRPA 860	Wolvenest	+15/+18	3550±60	3830	3900-3740	3980-3660	base intercalated peat	-
IRPA 825	Wolvenest	+5/+ 8	3830±70	4220	4330-4090	4430-4000	top intercalated peat	+
IRPA 560	Wolvenest	-53/-49	4970±70	5690	5780-5650	5870-5580	base intercalated peat	-
IRPA 559	Wolvenest	-265/-261	6200±80	7100	7180-6970	7250-6870	top intercalated peat	+?
IRPA 561	Wolvenest	-277/-273	6420±80	7300	7370-7230	7440-7170	base intercalated peat	-
Hv 8800	Leffinge	+217/+223	2960±50	3120	3190-3030	3270-2950	top basal peat	+?
IRPA 283	Leffinge	+217/+223	3140±165	3340	3520-3140	3720-2880	top basal peat	+?
IRPA 337	Leffinge	+217/+223	3340±185	3550	3790-3360	4030-3130	top basal peat	+?
Antw 227	Leffinge	-	3520±60	3790	3860-3700	3930-3630	top basal peat	+?
IRPA 282	Leffinge	+177/+183	4465±220	5050	5390-4840	5650-4480	base basal peat	+ (groundwater)
IRPA 518	Spermalie 2	-39/-29	4860±70	5610	5660-5540	5720-5430	base intercalated peat	-
IRPA 519	Spermalie 2	-109/-1.4	5650±75	6430	6500-6360	6630-6300	top basal peat	+
IRPA 725	B 742	-225/-210	5970±120	6790	6940-6690	7110-6510	base basal peat	+ (groundwater)
IRPA 722	B 746	-56/-46	5490±100	6290	6380-6200	6470-6060	base basal peat	+ (groundwater)
IRPA 723	B 747	+89/+99	4990±70	5710	5810-5660	5900-5600	base basal peat	+ (groundwater)

Table 1. Radiocarbon dates from the Belgian coastal plain between Nieuwpoort and Oostende and corresponding tendencies in marine influence.

the open sea by inlets situated a few km offshore from the present-day coastline. Lasting peat growth, with formation of the so-called surface peat, occurred in the intracoastal area from about 6000 to 2200 yrs cal. BP (Baeteman, 1991). Hereafter, tidal sedimentation regained predominance again for another millenium, until the final polder reclamation.

Two cores are discussed in detail here. The first one, Vliegveld, is situated at about 1.5 km from the present coastline in the most north-eastern extension of the depression in the pre-Holocene surface (51°11'45" N, 2°52'20" E; Fig. 1). The second one, Westende 1, was taken some 4 km more to the SW, close to the central Pleistocene mound (51°09'47" N, 2°50'44" E; Fig. 1). Together with data from geological studies (e.g. Baeteman *et al.*, 1981; Baeteman and Van Strydonck, 1989; Baeteman, 1991, 1993), and diatom results from cores from the more inland part of the area (Spermalie 2, Fig. 1; Denys, 1985), and on the western slope of the major depression near Nieuwpoort (Wolvenest, Fig. 1; Denys, 1995), their records allow a consideration of the general evolution of the area between Nieuwpoort and Oostende.

3. Methods

Cores were recovered in 10 cm diameter PVC tubes by hydraulic augering. Surface altitude at the coring sites relative to TAW (the Belgian ordnance datum corresponding to LLWS and *c.* 2 m below MSL) was levelled to the nearest cm. After the tubes were cut in half length-wise, the lithological facies were described in detail. Samples for sediment analyses were taken at regular intervals of 10 cm, with closer spacing across lithological and diatom-inferred boundaries. A number of peat samples were also taken for radiocarbon dating, which was carried out by the Koninklijk Instituut voor het Kunstpatrimonium (Brussel). The radiocarbon chronology is based on conventional (lab code IRPA) or AMS dating (lab code Utc) of untreated bulk samples. Dates have been calibrated with CALIB 3.0.3 (Stuiver and Reimer, 1993), using the bidecadal dataset and method A. For peat samples a 200 year smoothed curve was used, as recommended by Törnqvist and Bierkens (1994). Results are given as intercepts and rounded to the nearest decade.

Organic matter content was determined as loss on ignition (L.O.I.) according to Dean (1974) and presence of carbonates was tested with hydrochloric acid. For diatom analysis, 0.1 g of dried sediment was treated with hydrogen peroxyde and hydrochloric acid. Tablets with *Lycopodium* spores (Stockmarr, 1971) were added to estimate valve concentrations. Only coarse sand was removed from the spiked samples by decanting. Permanent slides for microscopy were prepared using pleurax as mountant. With exception of a very poor sample, more than 500 and usually over 600 valves were counted at 1250 x magnification along random transects, using a Leitz Orthoplan with Nomarski interference optics. Taxa were identified according to literature listed by Denys (1993a, p. 4.14-4.15) and grouped into ecological and taphonomic categories according to Denys (1991). Nomenclature follows the latter checklist, with exception of some cases where the classification of Round *et al.* (1990) has been followed. Only relative abundance diagrams with the more abundant taxa and total valve concentrations are reproduced here. Estimated standard errors on the latter follow Stockmarr (1971), whereas 95 % confidence limits on relative abundances are calculated according to Mosimann (1965, p. 643). Zonation into local (= core specific) diatom assemblage zones was established by visual inspection of relative abundance data, stratigraphically constrained clustering (Grimm, 1987), DCA ordination (ter Braak, 1987), and calculation of the distance measures SIMI and D between samples (see McIntire and Moore, 1977; Patrick, 1977). Full details are given by Denys (1993a).

4. Core descriptions and chronology

4.1. Vliegveld

The surface elevation at the Vliegveld coring site was levelled at + 3.26 m TAW. The lithological composition of the core is given in Table 2. Contrary to the more inland region, where basal peat occurs and marine deposition was limited to the latest millenia (Fig. 2), the Holocene sequence starts here with marine sediments. A lag deposit, indicating an active channel setting, occurs at the base of the sequence (955 cm below the surface), corresponding to the depth were diatoms remained preserved. From 923 to 585 cm the sediments are mainly silty, but layers of sand or clay are frequent; channel lags are noted around 915, 911 and 880 cm. Paired valves of *Scrobicularia plana* start to occur from 910 cm, and above 870 cm the deposits are intensively bioturbated. From 585 cm the silt becomes more and more clayey, leading to a first thin bed of rather amorphous reed peat at 579 cm, which is dated at about 6790 yrs cal. BP (Table 1). A decalcified mud separates this peat from the next at 526 to 489 cm depth. This stratum is dated at *c.* 6340 to 5570 yrs cal. BP and consists of *Phragmites* peat at the base, turning into amorphous fen peat higher up. The second peat is covered by 5 cm of mud, which appears to have been deposited within a period of about 2 centuries (Table 1). At 484 cm the third and final peat bed

Depth (cm)	Lithology	Main colour	Lower limit
0-70	slightly crumbly muddy clay, strongly rooted, dispersed brick fragments and pebbles	greyish dark-brown	very gradual
77-88	muddy clay, some small peat lumps	grey, pale-brown mottles	gradual
88-96	clay with much detrital peat	brown	gradual
96-102	slightly humic clay with thin irregular more sandy laminae,		
	many small peat lumps and brick fragments	dark-grey, lower part blackish	abrupt
102-144	slightly crumbly clay, rooted, much decalcified debris of gastropod shells below 115 cm	brown-grey, rusty mottles	gradual
144-155	muddy clay with few thin silt laminae and lenses, some small peat lumps	grey, dark-grey mottles	gradual
155-205	slightly humic muddy clay with many oblique lenses of peat detritus		
	and few silt lenses, Hydrobiidae at 173 cm	greyish dark-brown	gradual
205-225	muddy clay, some thin silt lenses, rooted	brownish grey	gradual
225-247	muddy clay, lower part more humic, thin laminae of peat detritus, some horizontal silt lenses	brown-grey	gradual
247-406	peat (mainly monocotylodonous), upper part *Sphagnum*, *Phragmites* below 400 cm,		
	strongly humified at 297-300 cm	brown, black at 297-300 cm	gradual
406-510	muddy reduced clay, slightly humic and many *Phragmites* remains above 425 cm	blue-grey, black mottles	very gradual
(excl. 450-500)	(below this mostly rhizomes)		
510-580	muddy clay with thin wavy silt laminae, bioturbated, slightly rooted, some decalcified shell debris	blue-grey, black mottles	abrupt and oblique
580-583	*Phragmites* peat, lower part clayey	brown	gradual
583-587	muddy clay, many *Phragmites* remains	blue-grey	gradual
587-592	peat, upper part clayey	brown	gradual

Table 2. Lithology of the core Westende 1 (simplified).

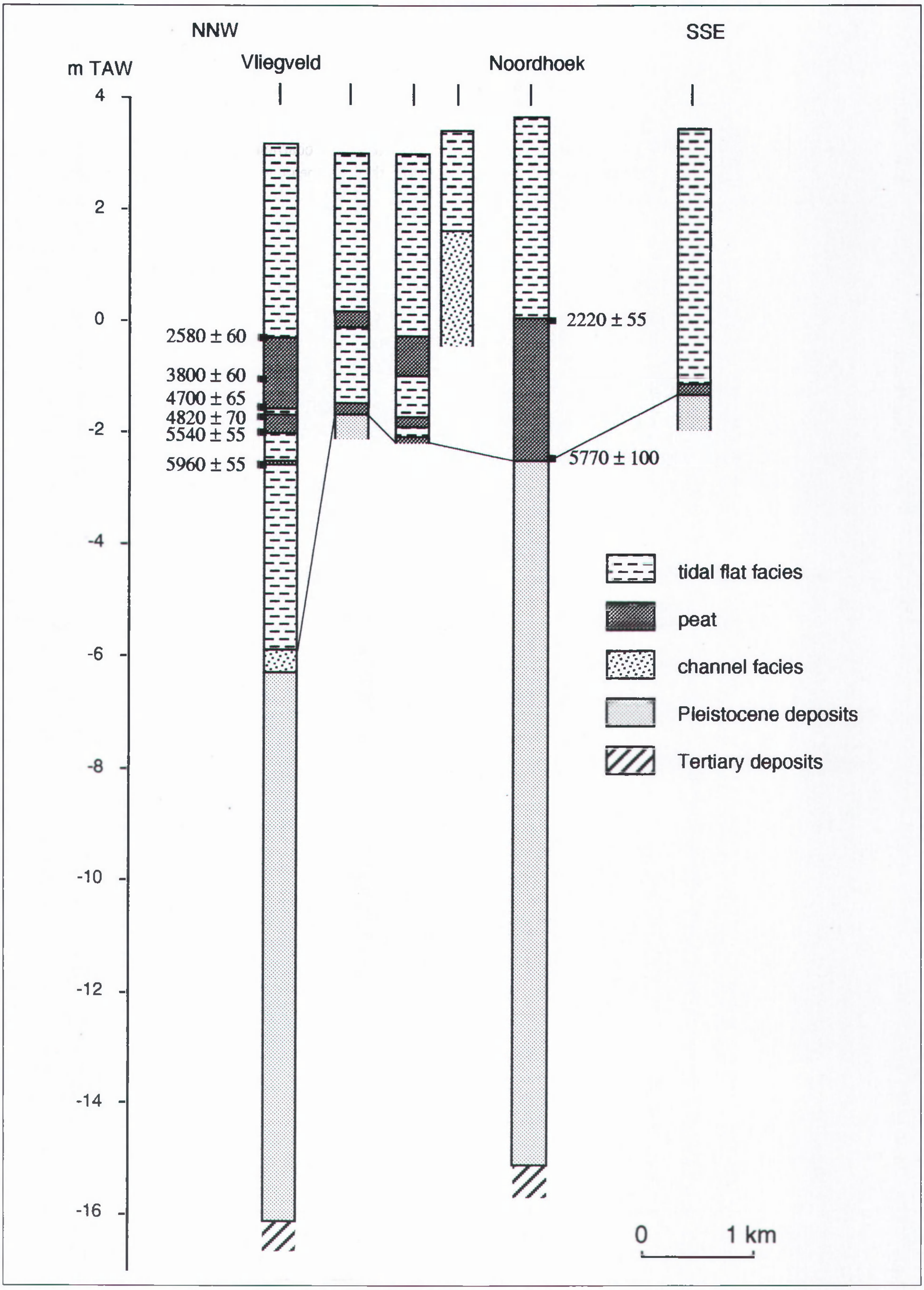

Figure 2. General lithological transect (position indicated on Fig. 1) perpendicular to the coastline with the sites Vliegveld and Noordhoek (radiocarbon dates in yrs BP).

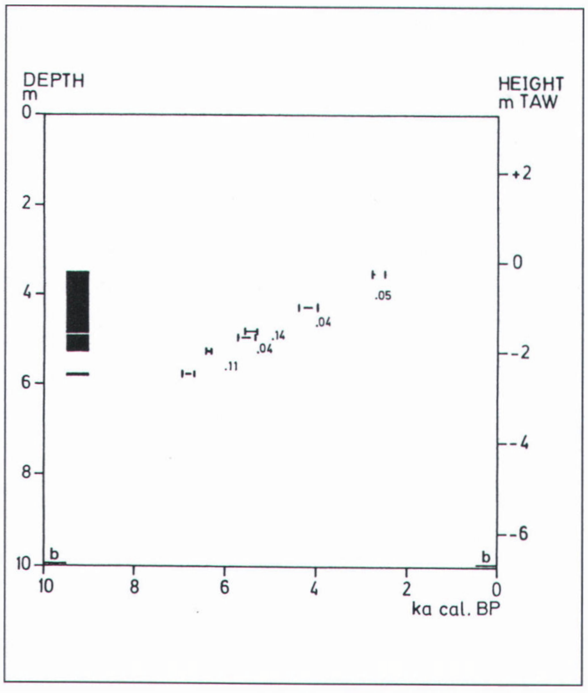

Figure 3. Time/depth plot of the radiocarbon dates for the core Vliegveld (horizontal lines indicate 1s range, vertical lines delimit 2s range) with interpolated mean accumulation rates (cm/cal. year). Black squares at the left show peat occurrence; b indicates base of Holocene deposits.

starts. This peat is rich in *Phragmites* at the base, then turns into amorphous fen peat and finally into *Sphagnum* peat at the top. Some clay admixture is observed at 427-426 cm, which was dated at *c.* 4170 yrs cal. BP. The top of the peat yielded a date of approximately 2720 yrs cal. BP. At 350 cm it is covered abruptly by sticky clay and more fine-sandy deposits. The upper part of the core consists of clay. Some thin wedge-like structures extending downward from 40 to 70 cm are considered to represent former mud cracks.

Fig. 3 gives an age-altitude plot for the radiocarbon dates obtained from the core, together with mean accumulation rates calculated by linear interpolation between adjacent dates. Since the base of the sequence could not be dated, such a figure is lacking for the lower part. If one assumes that the pre-Holocene surface was not too strongly eroded, tidal conditions would not have reached the site earlier than *c.* 8000 yrs cal. BP, leaving only about 1200 yrs for the accumulation of 3.75 m of sediment which experienced some compaction. This amounts to a minimum rate of roughly 0.3 cm/yr. Although quite crude, this exercise shows that mean accretion rates were highest prior to the formation of the first peat bed.

4.2. Westende 1

The Westende 1 core (surface at + 3.15 m TAW) presents a succession of fine siliciclastic sediments and organogenic deposits (Fig. 4, Table 3). The base of the Holocene sequence, at 592 cm below the surface, is delimited by a thin basal peat. This is covered by 5 cm of mud and a few cm of reed peat. The base of this latter peat is dated at about 6870 yrs cal. BP (Table 1); its top appears eroded. From 580 to 510 cm the sediment consists of a bioturbated and reduced mud with thin silt laminae. The silt content decreases substan-

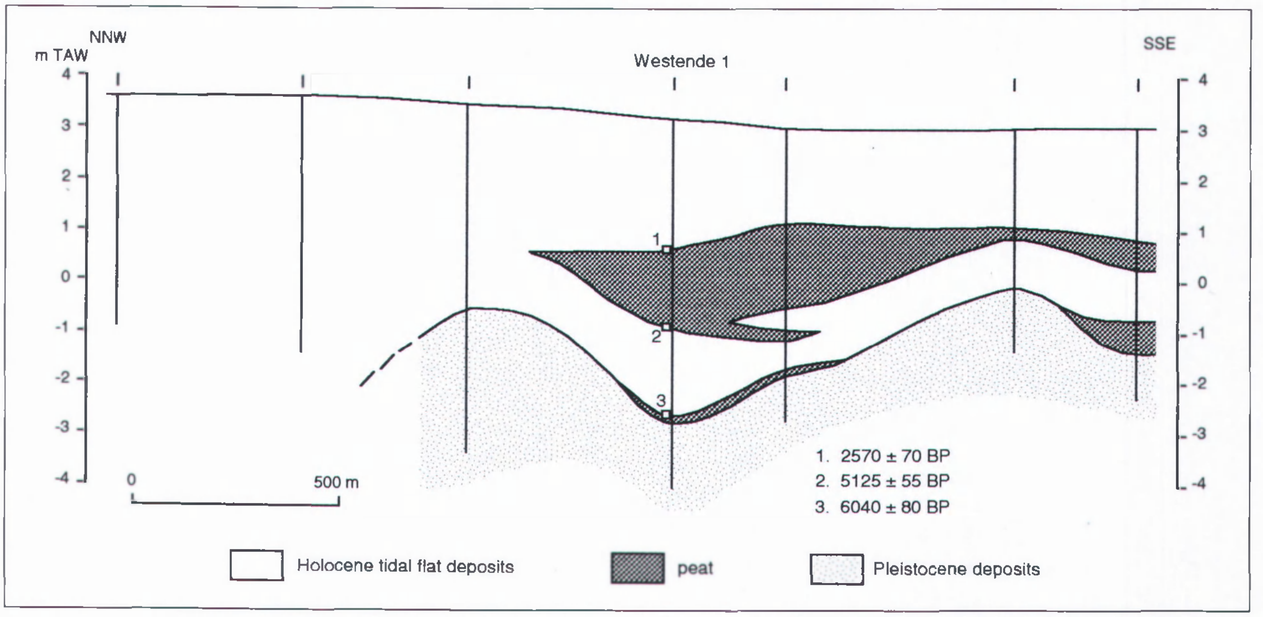

Figure 4. General lithological transect (position indicated on Fig. 1) perpendicular to the coastline with the site Westende 1 (radiocarbon dates in yrs. BP).

Depth (cm)	Lithology	Main colour	Lower limit
0-26	slightly crumbly clay with oblique silty laminae, small brick fragments	grey-brown	abrupt and oblique
26-100	compact slightly crumbly clay, silt laminae above 80 cm, rooted, slightly humic at 92-96 cm, narrow darker vertical wedges from 40 to 70 cm	yellowish brown	not observed
100-120	sticky clay with diffuse more humic laminae, more peat detritus towards the base	brown	gradual
120-140	muddy clay, many diffuse more humic laminae, some thin silt lenses, rooted	dark-brown	gradual
140-205	muddy clay, many laminae of detrital peat, some silt laminae (max. 0.5 cm thick), slightly rooted, remains of Cyperaceae and *Phragmites*	dark-grey to brown-grey	gradual
205-303	regularly alternating laminae of muddy clay and very fine sand or silt, laminae of coarser sediment closer and thicker below 270 cm, thin laminae and lenses of detrital peat, strongly bioturbated, more humic at 237-240, 242-245 and 247-258 cm	brown-grey	rather gradual
303-327	strongly clayey fine sand, some laminae and lenses of clay, lenses of detrital peat, some fine shell debris	grey-brown	abrupt
327-335	alternating laminae of muddy clay and silty fine sand, laminae of peat detritus	brown-grey	abrupt
335-350	sticky clay with much detrital peat, laminae and lenses of peat detritus, fragments of gastropod shells	dark blue-grey	rather abrupt, oblique
350-484	rather amorphous peat, upper part with *Sphagnum*, clayey at 426-427 cm, *Phragmites* from 470 to 484 cm	dark-brown	gradual
484-489	muddy clay with *Phragmites* remains and peat detritus	grey-brown	gradual
489-510	amorphous peat	dark-brown	gradual
510-526	*Phragmites* peat, lower part clayey	brown	very gradual
526-528	muddy reduced clay with many *Phragmites* rhizomes	brown	gradual
528-574	muddy reduced clay with *Phragmites* rhizomes and decalcified Hydrobiidae shells, small peat lumps below 568 cm	blue-grey	rather abrupt
574-579	rather amorphous compact peat	brown	rather abrupt, wavy
579-585	strongly silty muddy clay with *Phragmites* rhizomes and more humic streaks	brown-grey to blue-grey	gradual
585-627	reduced silt with many irregular laminae and lenses of muddy clay, many *Phragmites* remains	blue-grey	gradual
627-700	obliquely and rather irregularly interlayered silt and muddy clay, detrital peat in the clay, thicker clay laminae (max. 1 cm) from 652 to 661 cm, partly bioturbated	blue-grey	rather abrupt
700-728	muddy clay and silt with irregular clay lenses, some detrital peat in the clay, some fine shell debris and fragments of *Scrobicularia plana*, strongly bioturbated	blue-grey	abrupt
728-842	thinly laminated silt and muddy clay, reduced, clay lump with peat detritus at 745 cm, clay laminae up to 1 cm thick from 764 to 767 cm, strongly oblique lamination and numerous laminae of peat detritus below 825 cm, partly bioturbated below 744 cm, some fragments of *Scrobicularia plana*	blue-grey	rather abrupt
842-872	very clayey fine silt with irregular clay laminae and lenses, some lenses of fine sand and dispersed peat detritus, oblique layering at the top, strongly bioturbated, some shell debris	blue-grey	abrupt, oblique
872-882	very clayey fine sand with many entire (some paired) and broken valves of *Scrobicularia plana*, small peat lump at 882 cm, at the base a 1 cm thick clay layer	blue-grey	abrupt, oblique
882-891	very fine silt and muddy clay in cm-thick lamination, thin laminae of fine sand, peat detritus and shell debris within the clay layers, valves of *Scrobicularia plana* at 883 and 885 cm	grey	rather abrupt
891-900	slightly clayey very fine silt, some diffuse clay lenses with peat detritus	grey	not observed
900-910	clayey silt with many horizontal clay laminae and lenses, thin laminae of peat detritus at 900-903 cm, paired valve of *Scrobicularia* at the base	grey	abrupt
910-912	small quartz and silex pebbles, fragments of *Scrobicularia* valves and shells of Hydrobiidae	grey to white	abrupt
912-914	very clayey silt with diffuse more humic laminae, several large *Scrobicularia* valves at 914 cm	grey	abrupt
914-920	fine to medium fine sand with clay lumps and lenses, many Hydrobiidae and fragments of *Scrobicularia*, lense of strongly humic clayey sand with small pebbles at 914-916 cm	grey	abrupt
920-923	very clayey silt with diffuse more humic laminae, numerous Hydrobiidae	grey	very abrupt
923-935	wood lump	brown	very abrupt, oblique
935-955	heterogenous; clayey, slightly fine-sandy silt with lumps of peaty clay and many Hydrobiidae, oblique 1 cm thick layer of humic clay at 945 cm, wood fragment at 949-952 cm, at the base coarse quartz grains, shells (*Scrobicularia*, Hydrobiidae) and a lump of wood peat	grey	abrupt

Table 3. Lithology of the core Vliegveld (simplified).

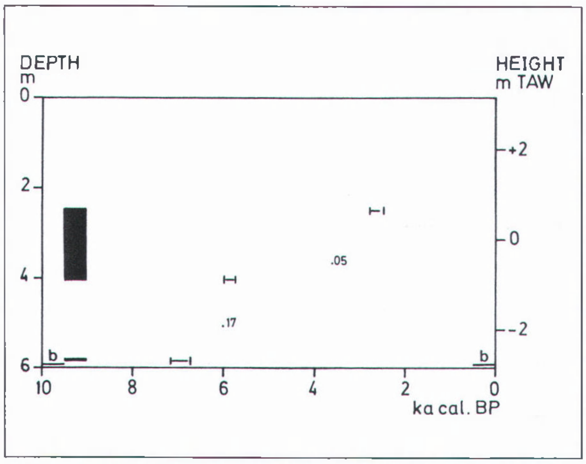

Figure 5. Time/depth plot of the radiocarbon dates for the core Westende 1 (horizontal lines indicate 1s range, vertical lines delimit 2s range) with interpolated mean accumulation rates (cm/cal. year). Black squares at the left show peat occurrence; b indicates base of Holocene deposits.

tially above the 510 cm level, leaving mud only. A significant part of the sequence -from 500 to 450 cm- was not retreived, presumably because of its too fluid nature. Notable is the increased LOI at the 500 cm level (Fig. 6), immediately below the break in sampling, suggesting the onset of a phase with more organogenic deposition. The mud grades into a *Phragmites* peat at 406 cm. The base of this bed is dated close to 5890 yrs cal. BP. Already within a few cm, the reed peat is succeeded by fen peat and only near the top a final transition to moss peat occurs. According to the radiocarbon date from the top, peat growth continued at least until *c.* 2710 yrs cal. BP. The upper 250 cm of the core is entirely clayey. For this core also, the time/depth profile is steepest for the oldest sediments (Fig. 5).

5. Results

5.1. Basal peat

Westende I: diatom zone 1 (588-584 cm)

Only Westende 1 presents a basal peat, which apparently developed in the deeper part of a sizeable bowl-shaped depression of the pre-Holocene surface at the foot of the "donk" of Leffinge (Fig. 4). It is therefore quite likely that the waterlogging of the Pleistocene substrate, which induced the peat growth, resulted initially from drainage and seepage, rather than from a strictly sea-level related rise of the groundwater table. The peat itself contains no diatom remains, which is not unusual for basal peats and probably relates to low diatom productivity and poor preservation due to insufficiently moist conditions. In analogy, surfaces at elevations above extreme high waters bordering estuarine marshes on the Atlantic coast of the U.S. were found to be devoid of diatom populations (Nelson and Kashima, 1993; Hemphill-Haley, 1995a). The further development of the basal peat is rather unusual, however, as it is subdivided by a thin bed of organic clay. This clay contains a diatom assemblage of mainly *Cymatosira belgica* and *Nitzschia navicularis* (Fig. 6, diatom zone 1). Especially the latter species, an epipelic diatom from brackish water, together with species of similar ecology such as *Caloneis westii*, *Diploneis didyma*, and *D. smithii*, characterises local conditions. These represent a typical flora from the higher mud flats and lower salt marsh (e.g. Brockmann, 1950; Round, 1960; Hendey, 1964; Colijn and Dijkema, 1981; Vos and de Wolf, 1988), indicating a temporary extension of such low-energy conditions over the peat marsh. Some reed-marsh diatoms with even lower salinity optima, such as *Diploneis interrupta* and *Navicula peregrina* (Brockmann, 1940), are represented as well. A complete absence of autochtonous plankton or even epiphytes indicates that the site was flooded only at high tide and that a more permanent water body did not develop. The high abundance of marine tychoplankton, i.e. *Cymatosira*, *Rhaphoneis amphiceros*, *Delphineis minutissima* and *Paralia sulcata*, clearly indicates the flood-tidal origin of the sediment, which was provided by nearby channels. No diatom remains have been preserved in the overlying peat either, suggesting that tidal flooding was absent or extremely rare.

5.2. Lower siliciclastic deposits and intercalated peat beds

Vliegveld: diatom zones 1-7 (955-527 cm); Westende I: diatom zones 2-5 (578-410 cm)

In both cores, laminated silty sediments rest on the underlying deposits with erosive contacts (Tables 2, 3). In spite of the difference in age, the lower siliciclastic deposits show rather similar diatom assemblages initially, having *Cymatosira belgica* as the most abundant species, accompanied by a number of other tychoplanktonic taxa (*Delphineis*, *Rhaphoneis*, *Paralia*, *Thalassiosira decipiens*) and some smaller epipelic or epipsammic forms (e.g. *Navicula flanatica*, *N. microdigitoradiata*, *N. perminuta* complex, *N. phyllepta*, *N. salinicola*, *Nitzschia frustulum*, *Opephora marina* complex; Figs 6, 7). In agreement with lithological features, the latter testify of rather energetic hydrodynamic conditions. This is especially evident in the Vliegveld core, which is actually from within a channel area. On the whole, however, there is little *in situ* diatom development at both sites and the bulk of the assemblages consists of species which are

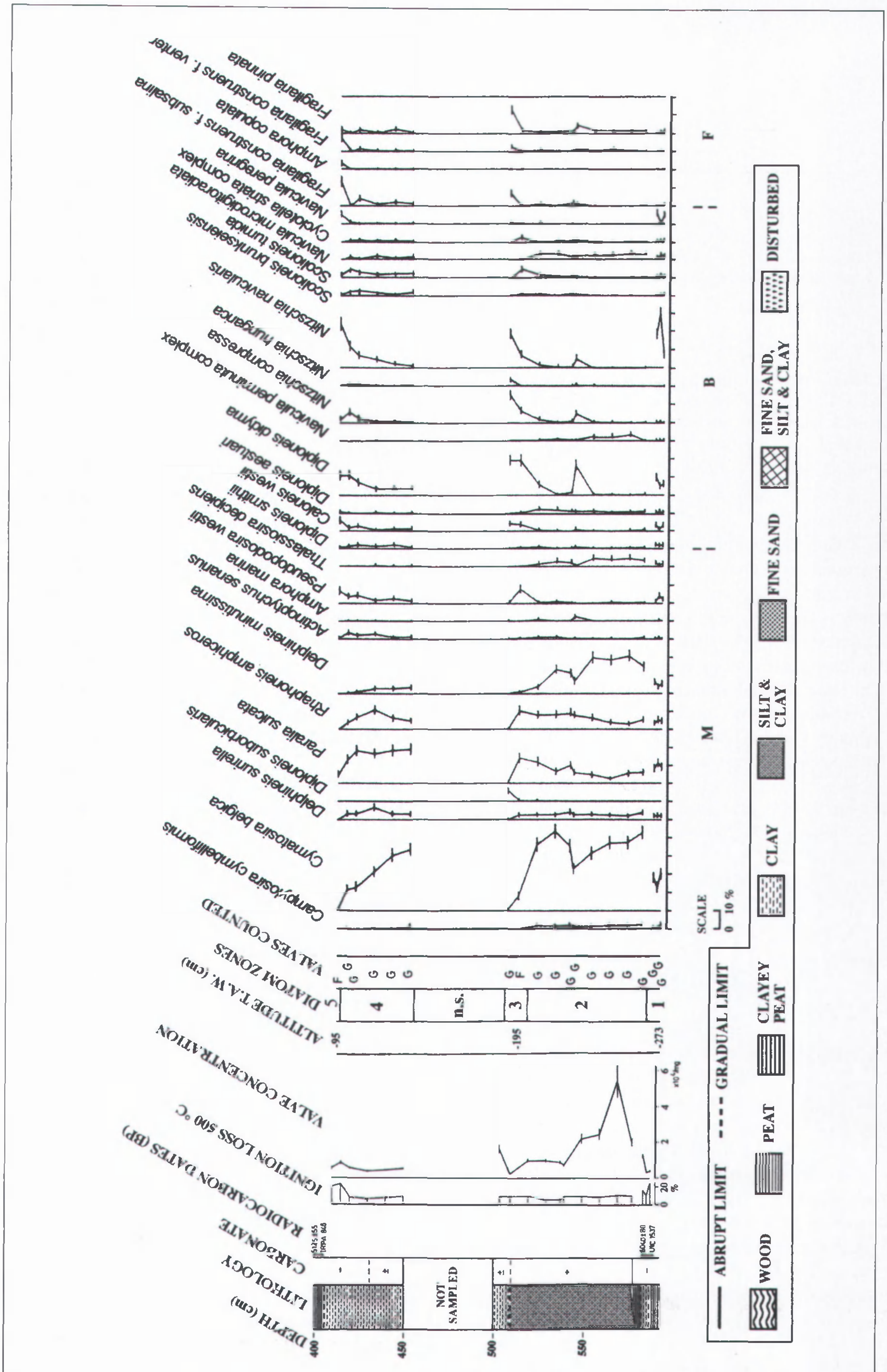

Figure 6. Lithological characteristics, radiocarbon dates, diatom valve concentration and percentage abundance of most important diatom taxa for the lower siliciclastic sediments of the core Westende 1 (diatom zones 1 to 5; number of valves counted: F - 500-599, G - 600-799; M - marine, B - brackish, F - fresh).

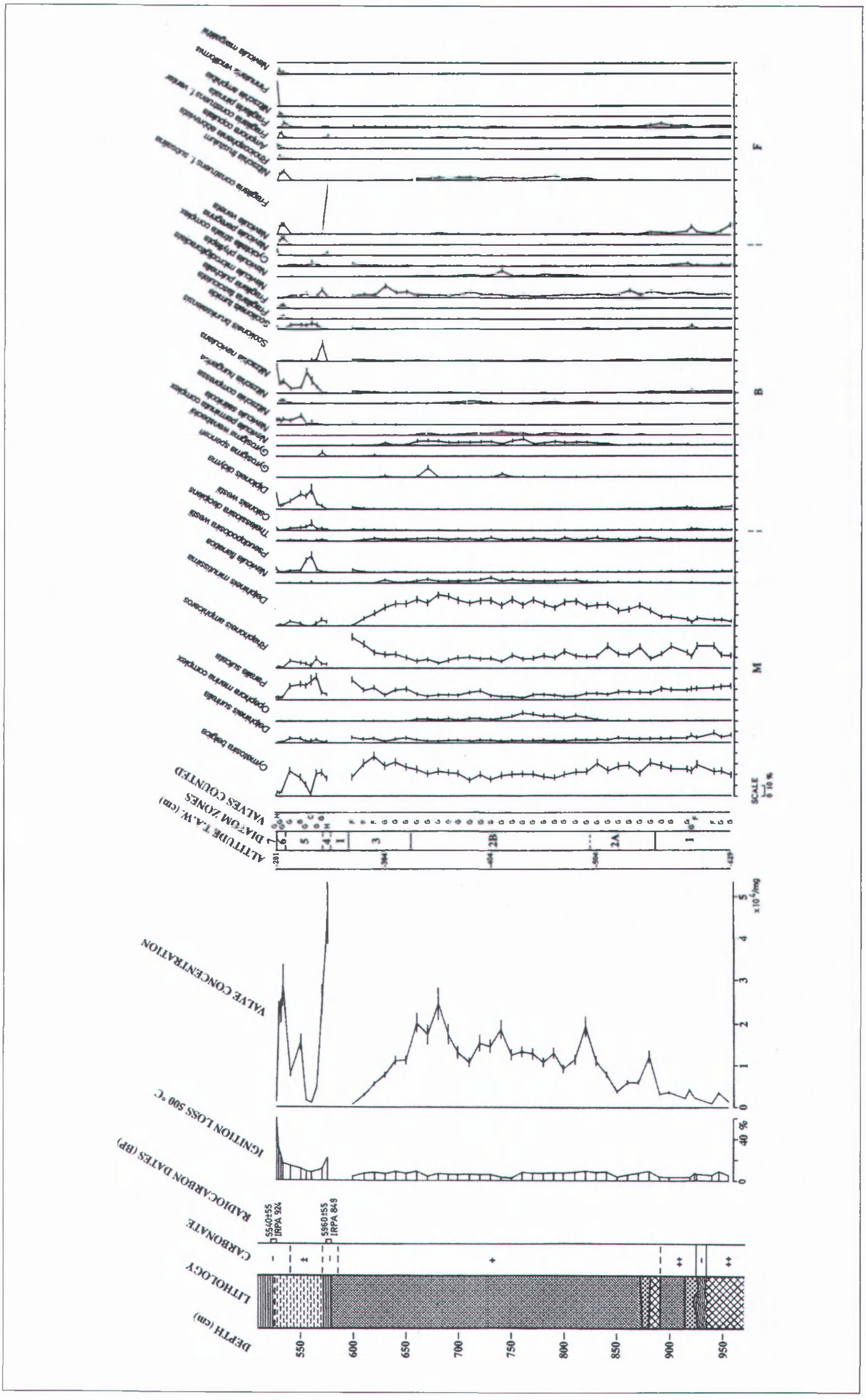

Figure 7. Lithological characteristics, radiocarbon dates, diatom valve concentration and percentage abundance of most important diatom taxa for the lower siliciclastic deposits with intercalated peat layer of the core Vliegveld (diatom zones 1 to 7; number of valves counted: F - 500-599, G - 600-799, H - 800-999; I - interzone, M - marine, B - brackish, F - fresh). See Fig. 6 for lithological legend.

transported in association with sediment particles and flocs (e.g. Hasle *et al.*, 1983; Vos and de Wolf, 1994; Denys, 1995), suggesting rapid accretion. Although the distinction of subtidal from intertidal deposits is difficult in such cases, there are no indications favouring subtidal sedimentation. Underwood (1994) identified *Cymatosira belgica*, *Delphineis minutissima* and *Navicula flanatica* as characteristic taxa for the lower intertidal zone of the Severn estuary where the sedimentation regime is highly dynamic.

5.2.1. Vliegveld

In the Vliegveld core (Fig. 7), the presence of a fair amount of reworked *Fragilaria construens* f. *subsalina* and *F. construens* f. *venter* in the lowermost samples (zone 1) indicates that sediments from nearby slightly brackish ponded marshes (see Denys, 1989, 1990) were eroded and transported to the site. Pieces of wood in this part of the core, as well as slightly higher LOI values than at succeeding levels (Fig. 7), suggest that organic deposits, probably basal peat, have been reworked. The former presence of such peat is not unlikely since lithostratigraphic investigations indicate that erosive conditions only developed after basal peat formation at comparable depths (personal communication C. Baeteman, 1997).

There is hardly any environmental differentiation noticeable up to zone 3, which again supports the idea of rather dynamic conditions and abundant sediment supply. In view of the better development of the epipelic species *Gyrosigma spenceri*, *G. wansbeckii*, *Navicula flanatica*, *N. phyllepta* and *Nitzschia hungarica*, which also present more brackish affinities, slightly calmer conditions and/or a somewhat more gradual accretion regime are established from zone 2B onwards. This also appears from the more regular sediment lamination and less variable valve concentrations. Obvious indications of the development of a brackish high tidal flat or salt marsh in zone 3 are lacking, although such environments are likely to have preceded the formation of the first intercalated peat. However, together with the slight increases of *Pseudopodosira*, *Diploneis didyma*, *Nitzschia compressa*, *N. navicularis* and *Scolioneis* spp., the pronounced expansion of *Paralia* can be considered as a marker for this progressive silting-up (Denys, 1989, 1994, 1995). The very poor representation of autochthonous diatoms from high tidal levels reflects a high rate of sediment input. Furthermore, the environmental evolution prior to peat initiation, the lack of any diatom remains within the peat itself, and its obvious humification, suggest that peat growth occurred in a fairly well-drained situation, such as could be imagined to have existed on a levee for instance.

Fresh-brackish *Fragilaria* spp. are abundant in zone 4, indicating the establishment of shallow water conditions of low salinity towards the end of peat formation. After this period of rapid water logging, the marsh gave way to a brackish tidal flat again, as reflected by the assemblage of zone 5. The peak of *Scolioneis brunkseiensis* near the base of this zone, a species which reaches its highest numbers near the flood seam (Hendey, 1964), is quite conspicuous. This time, mesohaline intertidal conditions prevailed for a short time only, and the rapid decrease of marine tychoplankton in the upper part of zone 5 indicates that sediment influx hampered. Hereafter, the diverse epipelic and epiphytic diatom communities of zone 6 (*Fragilaria* spp., *Navicula margalithii*, *N. veneta*, *Nitzschia amphibia*, *N. frustulum*, *N. hungarica*, *Rhoicosphenia*) clearly show the development of a slightly brackish shallow pool environment. Within a few cm of sediment, however, the abundance of epiphytes decreases sharply, indicating a decline of submerged macrophyte stands. The assemblage remaining in zone 7 has an epipelic character, including species such as *Amphora copulata*, *Anomoeoneis sphaerophora* and its f. *sculpta* (3%), *Navicula peregrina*, and especially *Pinnularia viridiformis*, which is often abundant in temporary waters. Together with the abundant production of chrysophyte stomatocysts (*cf.* Brockmann, 1940), these developments testify of the withdrawal of open water and marsh development. From valve concentration data of individual taxa (not shown) it can be deduced that the improved relative abundance of *Diploneis didyma* and *Nitzschia navicularis*, which accompanies this change in assemblage, is only an artefact of the demise of the limnic community. A strongly decreased concentration of all marine-littoral diatoms indicates that even regular spring tides could no longer influence the site, allowing further fen peat development.

5.2.2. Westende 1

In Westende 1 (Fig. 6), the palaeoenvironmental succession is somewhat less complicated. Although only partly resolved because of the sampling difficulties mentioned above, the development of high mud flat to salt marsh conditions can be identified at three successive moments. A first time, at about 540 cm depth, the extent of marsh development appears to have been limited and did not include the site, which remained a brackish mud flat. Apparently, only a limited lateral shift of the sedimentation pattern was involved. The ephemeral character of this event is also highlighted by the abrupt return of polyhaline tidal flat conditions. A more significant trend is observed in zone 3. *Cymatosira* regresses and is replaced by the more transport resistant *Paralia* and *Pseudopodosira*, as well as brackish epipelon (*Caloneis westii*, *Diploneis didyma*, *Nitzschia compressa, N. navicularis, Scolioneis tumida*) and salt-marsh indicators such as *Navicula peregrina, Nitzschia hungarica*, and *Fragilaria* spp. (further taxa in this group, not shown in Fig. 6, include *Navicula veneta* and the epiphytic *Rhopalodia acuminata*). Although classified among the polyhalobous and subtidal taxa in the Baltic area (Simonsen, 1962; Edsbagge, 1968; Pankow, 1976), *Diploneis suborbicularis*, which occurs here with 5 %, is probably also indicative of a less well-drained salt-marsh environment (*cf.* de Wolf, 1984). After a return to full tidal-flat conditions in the lower part of zone 4, a very similar species succession development is once again observed above 430 cm, this time preceding the development of a *Phragmites* marsh.

5.3. Upper intercalated peat

Westende I: diatom zone 6 (249-247 cm); Vliegveld: diatom zones 8-11 (489-353.5 cm)

In general, diatoms are completely absent in the uppermost peat in most parts of the coastal plain with exception of horizons evidencing some marine influence. In the Vliegveld core two such horizons are present, both marked by a higher clay content. The lower and most developed one, situated between 489 and 482 cm and corresponding to diatom zones 8 and 9 (Fig. 8), evidences the local installation of a brackish salt marsh, as indicated by forms of *Fragilaria construens, Caloneis westii, Diploneis didyma and D. interrupta*. In the uppermost levels of the intercalation, the development of *Navicula peregrina* and *Pinnularia viridiformis* marks the recession of tidal influence and a return to increasingly fresher and dryer conditions. Diatom assemblages comparable to those present in the intercalation, nowadays occur close to spring tide levels (e.g. Haynes *et al.*, 1977). To a large extent, the accompanying decline of diatom valve concentration follows from the exclusion of salt-marsh taxa from the site as it became revegetated and flooding frequency decreased. Interestingly, *Actinoptychus splendens* appears for the first time in this intercalation. According to de Wolf and Denys (1993), this species immigrated into the North Sea between 4400 and 4100 yrs BP (*c.* 5000-4600 yrs cal. BP), becoming very widespread hereafter. At 427 to 426 cm diatom remains are also present (Fig. 9, zone 10), but this time only as an entirely allochthonous assemblage of mainly polyhalo-bous taxa. This horizon clearly testifies of a short-lived wash-over event, resulting from perhaps only one or a few extremely high floods which hardly disturbed the fen peat development.

In both cores, the top of the upper peat, presents an assemblage in which tide-transported tychoplankton (*Cymatosira, Paralia, Pseudopodosira*) predominates (Figs 10, 11). Since diatom concentrations are quite low, however, they only point to a very restricted tidal influence, i.e. limited to the very highest of spring tides. The representation of taxa from the muddy high-intertidal zone (*Caloneis westii, Diploneis didyma, D. interrupta, Nitzschia compressa, N. navicularis, Scolioneis* spp., *Navicula microdigitoradiata, N. peregrina*) -salt marsh and mud flat- is also consider-

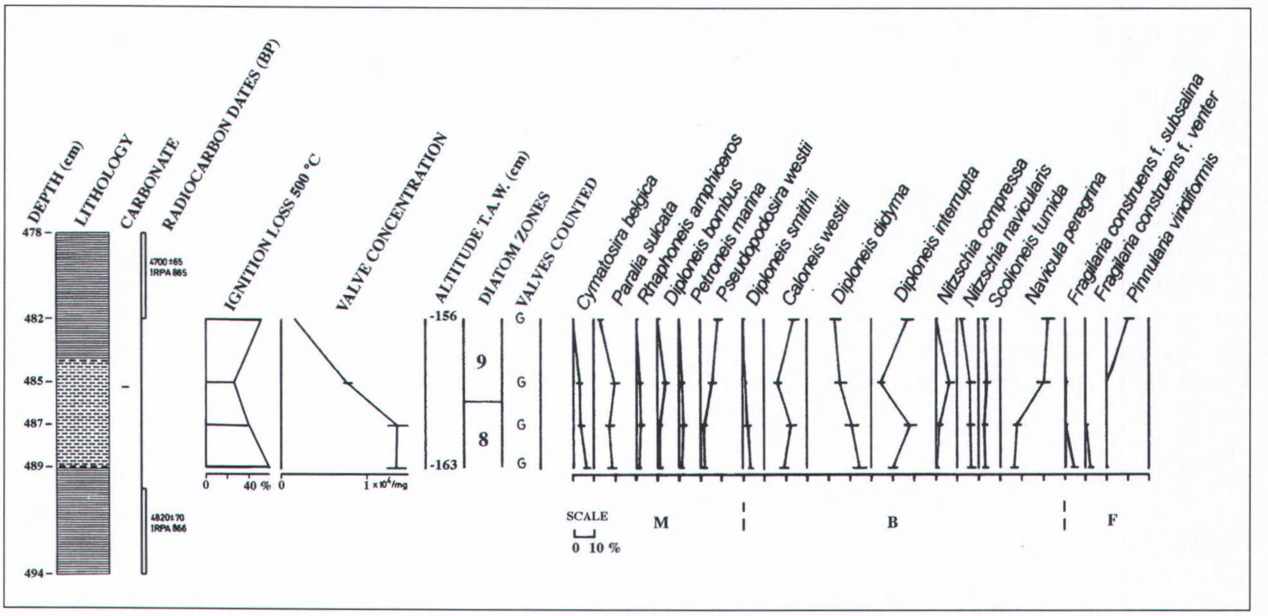

Figure 8. Lithological characteristics, radiocarbon dates, diatom valve concentration and percentage abundance of most important diatom taxa for the lower clayey intercalation in the upper peat of the core Vliegveld (diatom zones 8 and 9; number of valves counted: G - 600-799). M - marine, B - brackish, F - fresh). See Fig. 6 for lithological legend.

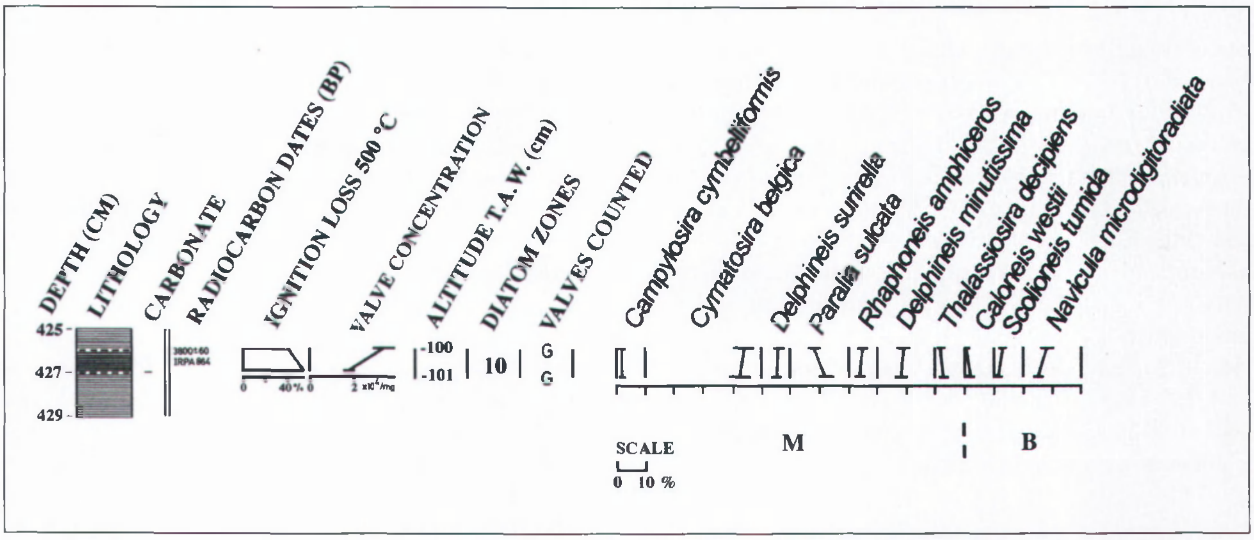

Figure 9. Lithological characteristics, radiocarbon dates, diatom valve concentration and percentage abundance of most important diatom taxa for the upper clayey intercalation in the upper peat of the core Vliegveld (diatom zone 10; number of valves counted: G - 600-799; M - marine, B - brackish). See Fig. 6 for lithological legend.

able, especially in the Westende core (Fig. 10, zone 6), and points to the local establishment of such conditions. Intermingled with these are lower proportions of a number of taxa which typically occur in fresher, subaerial conditions and even soils. These include *Caloneis bacillum*, *Diploneis ovalis*, *Hantzschia amphioxys*, *Diadesmis gallica* var. *perpusilla*, *Luticola mutica*, *L. nivalis*, *Navicula cincta*, and *Pinnularia silvatica* in the Westende core (Fig. 10, zone 6), and *Hantzschia amphioxys*, *Diadesmis gallica* var. *perpusilla*, *Luticola mutica*, *L. nivalis* and *Navicula cincta* in the Vliegveld sediments (Fig. 11, zone 11). As these more xerotolerant taxa prefer relatively alkaline and minerogenic conditions (Lund, 1946; Jörgensen, 1948; Hustedt, 1957; Cholnoky, 1968; Germain, 1981; Van der Werff and Huls, 1957-1974), they cannot be associated with the acid and nutrient poor environment of a living *Sphagnum* bog, indicating that such peat growth had already stopped. The strong humification of the upper part of the peat, which is of more regular occurrence in this area according to observations on hand-augered cores, also suggests that the peat formed a rather well drained soil surface for some time before the resumption of tidal inundation.

5.4. Upper siliciclastic deposits

Westende I: diatom zone 7 (245-205 cm); Vliegveld: diatom zones 12-14 (353-30 cm)

In both cores the assemblages related to the upper tidal limit occurring at the top of the upper peat are succeeded by full-intertidal assemblages with euryhaline brackish epipelon, next to a predominant quantity of polyhaline tychoplankton (Fig. 10, zone 7A; Fig. 11, zone 12). Whereas the latter merely reflects the flood-tidal origin of the deposited sediment, characteristic species such as *Caloneis westii*, *Scoliopleura brunkseiensis* and *S. tumida* reflect the shift to low-energy mud-flat conditions as tidal influence increases. As the hydroperiod lengthens further and the contact with the organic substrate is lost, these rapidly wane altogether. Interestingly, *Paralia* and *Pseudopodosira* follow the same trend. In the deposits of the Belgian coastal plain, these heavily silicified and chain-forming marine species are generally related to high-intertidal conditions in the proximity of channel systems (Denys, 1989, 1993a, 1994), and similar behaviour has been observed in comparable settings elsewhere also (Vos and de Wolf, 1993). This seems to conflict with studies of recent intertidal diatom distributions where the highest abundance of *Paralia* is often found on tidal flats and channel banks below mean high water (e.g. Nelson and Kashima, 1993; Hemphill-Haley, 1995b). The apparent discrepancy between both distribution patterns might be due to a more effective displacement of these chain-forming diatoms by flood than by ebb currents (e.g. settling and scour-lag effects; Postma, 1967) and/or efficient trapping mechanisms occurring in the higher tidal zone (e.g. ingestion by benthic fauna, effects of vegetation) combined with the considerable resistance of the valves to breakage during transport. An abundant occurrence in plankton communities during the gale season is also likely to be of further importance. The alternative explanation of an abundant autochthonous occurrence of these species in the higher intertidal is much less likely. Even though it has been

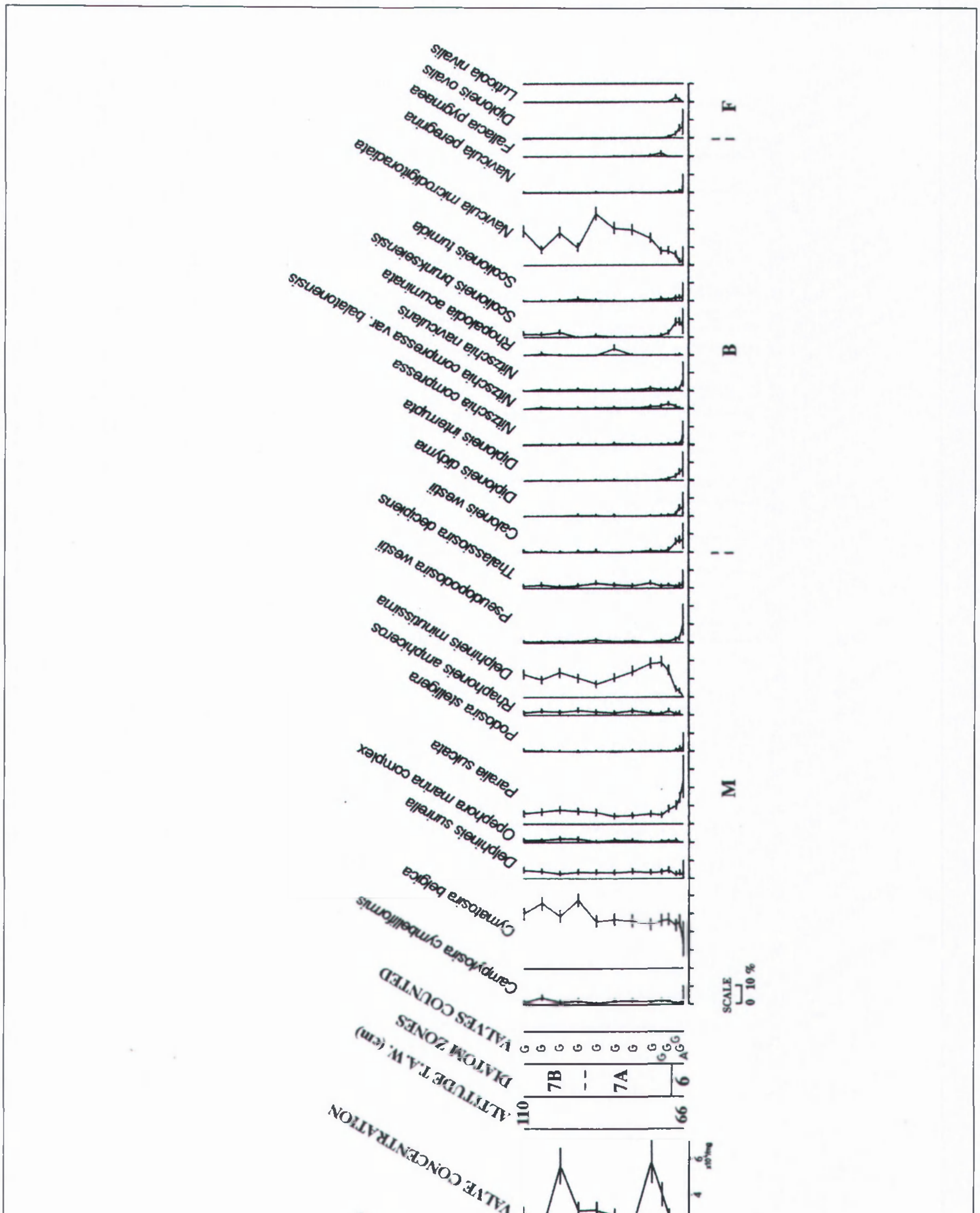

Figure 10. Lithological characteristics, radiocarbon dates, diatom valve concentration percentage abundance of most important diatom taxa for the upper siliciclastic sediments of the core Westende I (diatom zones 6 and 7; number of valves counted: A - < 100, G - 600-799; M - marine, B - brackish, F - fresh). See Fig. 6 for lithological legend.

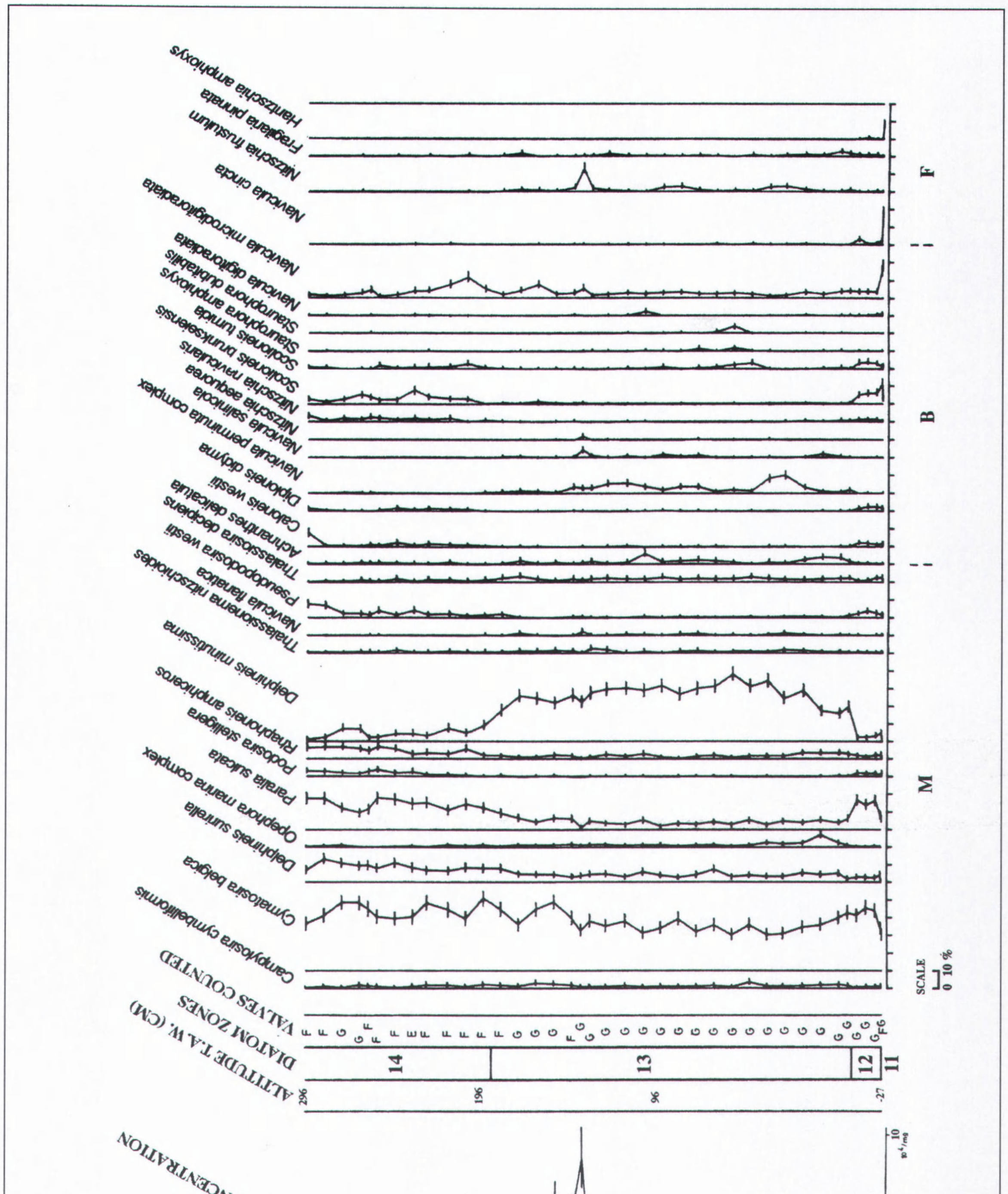

Figure 11. Lithological characteristics, radiocarbon dates, diatom valve concentration and percentage abundance of most important diatom taxa for the upper siliciclastic deposits of the core Vliegveld (diatom zones 11 to 14; number of valves counted: E - 400-499, F - 500-599, G - 600-799; M - marine, B - brackish, F - fresh). See Fig. 6 for lithological legend.

suggested that *Paralia sulcata* may be able to bloom at low salinities (Zong, 1997), whereas a small morphotype of *Pseudoposira westii* -which is also represented in the deposits considered here- is known to live in brackish water (Brander, 1935), more appreciable water depths appear to be required for this. In both cores, the expansion of *Paralia* appears short-lived, as the relative proportion of *Cymatosira belgica* and *Delphineis minutissima* increases further within a few cm of sediment.

In the Westende core (Fig. 10), *Navicula microdigitoradiata* remains an abundant representative of the epipelon throughout. Its gradual increase in the lower part of zone 7 could indicate that the rate of sediment deposition slowed down somewhat, especially as it is accompanied by decreasing values of *Delphineis minutissima*. Near the top of subzone 7A, a small peak of the brackish epiphyte *Rhopalodia acuminata* is noticed, followed by a very slight increase of *Fragilaria construens* f. *subsalina* and *Navicula cincta* at 225 cm depth. Although obviously transported, this could point to some salt-marsh development in the environs. Above this level, the higher tychoplankton proportion seems to indicate that sediment supply has increased once more, before the halting of diatom preservation.

Contrary to the only partial occurrence of diatom remains in the uppermost part of Westende 1, a much fuller record is offered by Vliegveld, which presumably comprises the complete sedimentation history up to the final retreat of regular marine influence (Fig. 11). Here a co-dominance of *Cymatosira* and *Delphineis minutissima*, with a notable abundance of epipsammon (*Achnanthes delicatula*, *Navicula perminuta* complex, *Nitzschia frustulum*, *Opephora marina* complex) develops (zone 13), pointing to more energetic tidal flat conditions. Diatom concentrations are low in these more sandy deposits, of which the contact to the underlying clay appears to be erosive. Near 270-280 cm some larger epipelic species make their appearance (*Scoliopleura tumida*, *Staurophora* spp.), possibly suggesting a transient phase of increased sediment stability. The final stage in sedimentation (zone 14) corresponds to a decrease in the silt content and is characterised by the replacement of *Delphineis minutissima* (a species adhering to sand grains and larger particles as well as to detritus and fines), by larger and more heavily silicified attached or tychoplanktonic taxa, such as *Delphineis surirella*, *Paralia sulcata*, *Podosira stelligera*, *Pseudopodosira westii*, *Rhaphoneis amphiceros*, as well as a modest increase of more brackish epipelon (*Navicula microdigitoradiata*, *Nitzschia navicularis*, *Scoliopleura brunkseiensis*, and markedly in the uppermost sample *Caloneis westii*). Clearly this transition corresponds to a more advanced silting-up and a return to higher mud-flat conditions, albeit still with sediment aggradation continuing at a considerable pace. The establishment of a salt marsh is no longer recorded because of anthropogenic disturbance of the profile, but filled-in mud cracks still provide some evidence of the conditions hereafter. From the fills of these cracks, two samples at 45 and 65 cm depth were analysed for diatoms. Although this revealed assemblages that were similar to those from samples taken at corresponding levels adjacent to the cracks, a slightly better representation was noted for some subaerial taxa (*Caloneis bacillum*, *Diploneis ovalis*, *Hantzschia amphioxys*, *Navicula atomus* var. *asellus*, *N. cincta*), as well as for a number of planktonic and epiphytic species from eutrophic fresh waters (e.g. *Achnanthes lanceolata*, *Cyclostephanos dubius*, *Rhoicosphenia abbreviata*, *Stephanodiscus hantzschii*). These diatoms were apparently washed down from the surface, and the occurrence of the latter suggests the formation of pools after salt-marsh emergence.

6. Chronology of tendencies in marine influence

In Fig. 12, the radiocarbon chronology of peat growth and estimated timing (by linear interpolatation) of diatom-inferred variations in local marine influence for the region between Nieuwpoort and Oostende have been combined. In comparing these different types of data, one should bear in mind that no degree of uncertainty is indicated for interpolated ages. Interpolations will inevitably suffer from unknown variations in sediment accumulation rates and compaction, as well as deficiencies of the bracketing dates (e.g. from eroded or contaminated peats). Presumably, the possible age offset from the actual time of occurrence increases with the time lapse between the radiocarbon dates. For radiocarbon dates as well, prudence should be taken, although in this case the possible errors can be grasped a little better. Moreover, it is likely that the response of both data types to a same event will differ due to their different sensitivity. Local environmental changes of lesser amplitude will be registered more adequately by the diatom record than by lithological overlaps. Lags will equally differ. It is essential to acknowledge that both only record local sedimentation conditions, which are not necessarily to be equalled with vertical sea-level variations. Although relations to such processes will exist, these are likely to be more complex than anticipated (see for instance Allen, 1995). In view of this and the relative scarcity of data, preventing frequency analysis (*cf.* Geyh, 1980; Shennan, 1982b, 1987; Stolk *et al.*, 1989), any interpretation in regional terms, such as the one attempted in Fig. 12, remains tentative for the time being.

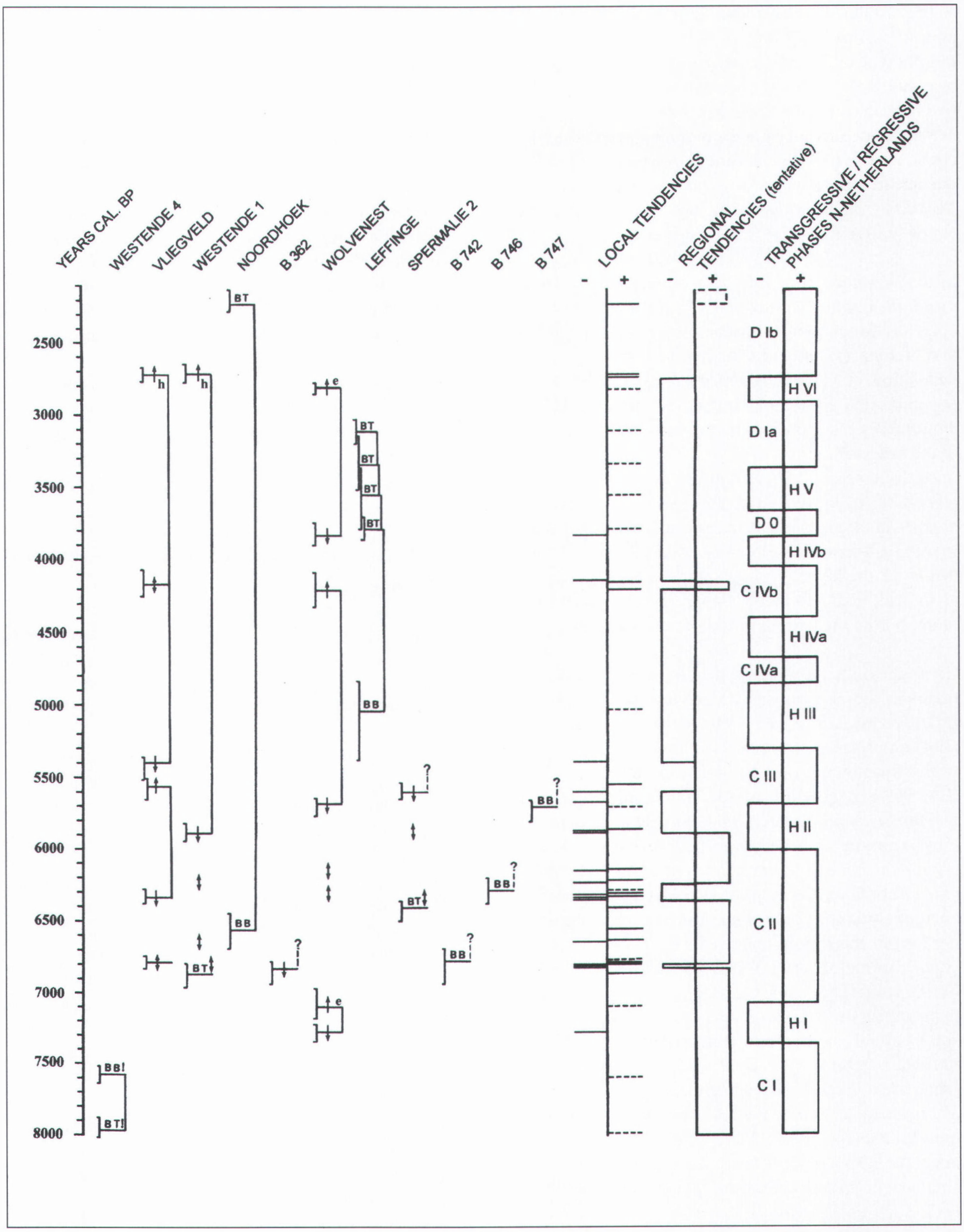

Figure 12. Radiocarbon dates of stratigraphic overlaps (intercepts with calibration curve; brackets represent 1s range) and interpolated ages for diatom-inferred tendencies in marine influence for different sites from the coastal area between Nieuwpoort and Oostende, local tendencies (dashed lines for radiocarbon-dated indications reflect uncertainty in timing or tendency of the event), tentative regional tendiencies for the study area and the Dutch chronology of Calais/Dunkerque phases for the northern Netherlands (Griede, 1978; van de Plassche, 1985). Upward arrows indicate positive tendency, downward arrows indicate negative tendency. Vertical connections between radiocarbon dates indicate continuous peat growth at the site. BB - base of basal peat, BT - top of basal peat (note inversion for core Westende 4), e - eroded, h - humified.

At least up to 7300 yrs cal. BP conditions were unfavourable for the occurrence of negative tendencies in the marine influence. In spite of the rapid sediment accumulation, some time was clearly required before the accommodation space created by the very swift rise of RSL, and enlarged further in the initial erosive phase, became sufficiently infilled to allow more extensive development of high-intertidal environments. Concentrations of negative tendencies, however, seem to occur at about 6800, 6300, and 5900-5600 yrs cal. BP. Only at Wolvenest, the most south-western location (Fig. 1), did an intercalated peat form as early as *c.* 7200 yrs cal. BP (Table 1; Denys, 1995). With exception of the first period, which is indicated exclusively by events at sites north of the main tidal channel, both other periods include registrations of decreasing marine activity spread throughout the area. This suggests that, in general, marine activity decreased earlier in the north-eastern part of the tidal basin. Infilling was completed more rapidly here because of the higher elevation of the subsoil. By about 6300 yrs cal. BP the tidal volume of the basin was reduced considerably and channels filled up. More sheltered conditions became established across the region and intermittent salt-marsh emergence or even more permanent peat growth (e.g. Vliegveld) occurred.

From about 5900 yrs cal. BP positive tendencies became infrequent as the area was now more and more dominated by peat marshes and marine conditions were progressively excluded. Although the continuing landward extension of basal peat development implicates a further rise of the ground-water table in the area beyond immediate marine influence and mean RSL kept rising, the predominant tendency in marine influence was negative during almost the entire period from *c.* 5900 to 2700 yrs cal. BP, as indicated also by autogenic bog development.

The renewal of intertidal sedimentation at Vliegveld around 5500 yrs cal. BP is not recorded at any of the other sites, where peat growth continued without interruption. No regional tendency is assumed for this period. In contrast, marine activity is recorded at Vliegveld and Wolvenest near 4200 yrs cal. BP. At both sites the onset appears to be coeval, but tidal inundation prevailed considerably longer at Wolvenest. This suggests that the event which actually caused the extension in marine influence was short-lived, occurred close to 4200 yrs cal. BP, and was of more regional significance. Actually, the very same event is also registered by beds of marine clay in the peat S of Nieuwpoort, and possibly in the pollen stratigraphy of the peat at Leffinge (see Baeteman and Van Strydonck, 1989; Baeteman, 1991; Denys, 1993a, 1993b, 1994). A short period of positive tendency of regional significance is therefore considered to have occurred at *c.* 4200 yrs cal. BP.

Dates for the final termination of peat growth show rather large discrepancies. Dates from the archaeological site of Leffinge, where salt making was practised in Roman Times, are 1000 to 300 yrs older than those from all other sites. According to Baeteman *et al.* (1981), peat growth ended here due to impeded drainage rather than by marine flooding. Also, the radiocarbon dates may have been affected by human disturbance of the peat surface. The results from Vliegveld, Westende 1 and Wolvenest are in very close agreement with each other (*c.* 2800-2700 yrs cal. BP). However, no other dates were obtained from the Belgian coastal area for peat termination near 2700 yrs cal. BP (Baeteman, 1991; Denys, 1993a). At Westende 1 and Vliegveld, peat accumulation appears to have been hampered by drier conditions prior to the onset of intertidal sedimentation, resulting in a strong humification of the peat. Such conditions will enlarge the offset between the dating result and the actual time of tidal inundation. At Wolvenest the upper part of the peat appears to have been removed by peat digging (Denys, 1995). A dry phase and more oxidised layer may have occurred originally in the peat here as well, so the apparent coincidence in dates might result from the practice to extract only the upper layer of *Sphagnum* peat, and leaving the peat of lesser quality untouched. The considerably younger date obtained from the more inland site Noordhoek, *c.* 2100 yrs cal. BP, is more in line with results from elsewhere in the coastal plain (Denys, 1993a; Baeteman and Denys, 1997), but has not been validated by micropalaeontological analyses. In view of the dating uncertainties involved with the resumption of marine conditions, no attempt is made to indicate regional tendencies after 2700 yrs cal. BP, except for the possibility of an increasing marine influence at about 2100 yrs cal. BP.

Fig. 12 also allows a comparison of the assumed regional tendencies with the chronology of Holland (peat) and Calais/Dunkerque phases for the northern Netherlands. In comparing these models the relative subsidence of The Netherlands relative to Belgium during the first half of the Holocene (Denys and Baeteman, 1995; Kiden and Denys, 1995) must be considered, as this is likely to result in a somewhat higher frequency of negative tendencies in the Belgian area. Positive tendencies, resp. transgressive phases, predominate prior to *c.* 6000 yrs cal. BP when RSL rise was most rapid. Hereafter, a switch towards more negative tendencies, resp. regressive phases, takes place up to the start of the so-called Dunkerque Ib transgression. Next to this general correspondence due to a broadly similar coastal development (*cf.* below), however, agreement remains limited to a few periods only, indicating that eventual supra-regional phenomena are subordinate to regional developments. Possible exceptions include the redrawal of the marine influence which apparently occured in both areas at about 5900-5700 and 5400 yrs cal. BP and the resume which took place around *c.* 4200 yrs cal. BP.

7. Discussion

Sedimentation during the initial phase of infilling -up to *c.*7500 yrs cal. BP- is controlled entirely by the rapid RSL rise in relation to the topography of the existing terrain, partly modified by tidal ravinement. Basal peat development prior to tidal inundation was probably widespread, but much of it was eroded quite rapidly in the seaward part of the area as the tidal volume of the developing channels increased. In the diatom record this may result in a significant admixture of taxa with lower salinity requirements. The diatom results from the older sediments of the Vliegveld core are entirely comparable with those from Wolvenest (Denys, 1993a, 1995). The assemblages from these deposits consist mainly of marine tychoplankton, *Cymatosira* especially, with a smaller contribution of species adapted to more energetic conditions. Their prevalence indicates that conditions in the tidal area are characterised by very high sediment accumulation rates under an open coastal configuration. Due to the steep gradient of the transgressed terrain and the rapid rate of RSL rise, the lateral extension and continuance of high-intertidal environments remain very limited. Consequently, stratigraphic transitions including such facies are poorly developed (*cf.* Vliegveld). Furthermore, erosion may have affected their occurrence.

As the rate of RSL rise decreases and tidal conditions occupy a larger area, additional factors start to play a role. From about 7200 yrs cal. BP the incidence of phases of local silting-up and peat development increases as sediment supply starts to balance the RSL change. Also, more complex transitions occur at certain overlaps, with fresh conditions and peat growth resuming after the initial onset of tidal influence, indicating a certain degree of resilience to change. Although the influx of considerable amounts of sediment through the channels continues, the progressive infilling of the tidal basin and seaward development of the tidal flats slow down tidal currents. Next to an improved representation of epipelic tidal-flat diatom communities this is accompanied by a higher abundance of the sturdy tychoplankton species *Paralia sulcata* and *Pseudopodosira westii* in the marine and brackish deposits, presumably reflecting changes in sedimentation/resuspension conditions mainly.

From now on, certain periods of a more general negative tendency in marine influence may be tentatively suggested, but their relation to particular causative factors largely remains obscure and it cannot be determined whether they result purely from autocyclic processes, *i.c.* sedimentation (Baeteman *et al.*, 1999; Baeteman, 1999), or have more general causes, such as RSL variations, as well. Detailed comparison with other areas may provide an indication of the relevant scale or process operating. For example, the negative tendencies observed in the study area between *c.* 6800 and 6600 yrs cal. BP have no apparent counterparts in the rest of the Belgian coastal plain (Denys, 1993a) and most likely can be attributed to local phenomena only. Conversely, some negative tendencies in the more western part of the Belgian coastal plain apparently coincide with the first formation of peat at Wolvenest (*c.* 7300 yrs cal. BP; Denys, 1993a). This suggests that a relation to the Holland I phase in the Netherlands might be possible, even though a clear "regional phase"is missing in the study area itself. In this respect, it should be noted that the northern Netherlands were still subsiding considerably relative to Belgium during this period due to isostatic adjustment (Denys and Baeteman, 1995; Kiden and Denys, 1995). Hence, the coincidence of negative tendencies in both areas at this time of rapid RSL rise might be particularly meaningful. Also, for the periods at about 6300 and, especially, 5900-5600 yrs cal. BP evidence for comparable tendencies of marine influence elsewhere in the western coastal plain of Belgium is more widespread. For the latter period, the apparent chronological correspondence to the Holland II regressive phase of the northern Netherlands, which appears to be represented in Schleswig-Holstein as well (Menke, 1988), is notable (Denys, 1993a). Presumably, the increased frequency of such negative tendencies can be related to the interplay of a high sediment supply and a decrease in the rate of RSL rise (to *c.* 2.5 m/kyr; Denys and Baeteman, 1995). However, at about the same time, extensive coastal barriers begin to develop along the coast of western Holland (Beets *et al.*, 1992; van der Valk, 1992). For the Belgian coast, extensive progradation and development of a very wide tidal-flat zone, possibly even the initial emergence of coastal barrier structures, can also be assumed to be taking place.

Although it was sometimes claimed that the upper peat started to grow in brackish lagoons (e.g. Blanchard, 1906; Paepe, 1960; Allemeersch, 1995), the absence of lagoonal diatom assemblages at the transition to peat clearly shows that this was not the case. As argued by Denys (1989), aggradation of siliciclastic sediment continues under intertidal conditions up to the point in the tidal frame where organogenic accumulation can take over. Local conditions control the tidal level and moment at which this switch may occur. The more generally observed succession from tidal flat to reed marsh or fen (Denys, 1985, 1989, 1993a), seems more in line with a reduction of the marine influence through silting-up and (reed)marsh development, than with the complete closure of the inlets by the chaining of proximal barrier islands, which would have impeded the evacuation of freshwater. The development of more limnic conditions always remains limited to very shallow and short-lived pools, at the most (*cf.* Vliegveld). Undoubtedly, however, the cross-section of the inlets was reduced considerably as the volume of the tidal basin decreased. The later resurgence of marine activity at certain times during the period of general peat formation also indicates that a fully closed barrier may not have developed.

Baeteman (1999) envisages the positive tendencies registered in the surface peat as "precursors of the eventual landward migration of the tidal system"; an explanation favouring a more hap-hazard and mutually unrelated occurrence of inundation phenomena. For the events at *c.* 4200 yrs cal. BP, however, it should be taken in account that these are in very strong chronological agreement, even though pertaining to sites that are influenced by different tidal channel systems. The positive tendencies at *c.* 4200 yrs cal. BP in the Belgian area also correspond rather neatly to the Calais IVB interval in the Netherlands (Fig. 12). A common mechanism was therefore suggested to be operating here (Denys, 1993a, 1994), such as a slightly increased rate of sea-level rise (van de Plassche, 1982), and/or a switch to increased continentality (Beyens, 1985; Dupont, 1985; Dubois, 1987; Bohncke, 1991; Magny, 1992) resulting in slower peat growth or even peat shrinkage, or a stronger tidal pull (Lamb, 1980). Schoorl (1980) and Bohncke (1991) explicitly suggest a link between the Calais IVB and dry/warm climatic conditions.

The radiocarbon dates of the top of the upper peat at Westende 1 and Vliegveld are almost identical (*c.* 2580 yrs BP); an agreement which is quite striking since the period between *c.* 2750 and 2450 BP corresponds to no more than *c.* 90 sidereal years. This interval is marked by an abrupt change from relatively warm continental conditions to an oceanic climate (van Geel *et al.*, 1996). Prior to the final inundation phase, conditions appear to be rather unfavourable for peat formation at Westende 1 and Vliegveld and possibly even some peat wastage may have occurred, which agrees well with the prevalence of a continental climate. The occurrence in the uppermost peat levels of diatom taphocoenoses with an appreciable abundance of taxa tolerating dry conditions indicates that drainage remain quite good up to the end.

In line with its stratigraphic importance, the final, more lasting and extensive return of tidal conditions in the area has been the subject of more considerable debate, but the mechanism which induced the inundation of the peat has not been clarified yet. A general destabilisation and retreat of the barrier system may be assumed, resulting primarily from sediment depletion as the RSL rise declines and an erosive coast develops (*cf.* Van der Valk, 1992). Furthermore, the consequent steepening of the shoreface and higher susceptibility to breaching (Beets *et al.*, 1992, Long *et al.*, 1996) may have interacted with increased storminess during the Subatlantic (Lamb, 1977, 1980). A persistent idea, inspired by historical accounts, is that severe storm surges devastated the coastal barrier, causing dramatic inundations of the peat area (Gottschalk, 1980; Augustyn, 1992). However, the diatom-inferred environmental conditions at the end of upper peat growth for Westende 1 and Vliegveld, as well as for a number of other sites (Denys, 1993a), do not support this. Although occurring swiftly, the extension of tidal sedimentation takes place gradually, with salt-marsh conditions and low energy mud flats preceding more dynamic environments; eventual erosion of the peat post-dates its termination (see also Baeteman, 1999). Baeteman and Denys (1995) consider drainage of the peat bogs by reactivated tidal channels or other causes to have been of importance. Vos and van Heeringen (1997) have recently emphasized the interaction of natural and anthropogenic drainage in causing the inundation of Zeeland after 300 AD. In the study area as well, peat exploitation took place during the Roman Period (possibly 3rd century) as evidenced by the archeological sites of Leffinge and Raversijde (Pieters, 1993; Pieters *et al.*, 1998). Furthermore, the drier climatic conditions at the end of the Subboreal may have affected the vulnerability of the peat landscape, either directly by causing slower peat growth and compaction or by improving the accessibility of the bogs for peat diggers. The inundations were already under way well before the 1st century AD (Baeteman and Van Strydonck, 1989; Denys, 1993a; Baeteman and Denys, 1995, 1997; Baeteman *et al.*, 1999; Baeteman, 1999), the date assumed by Tavernier and Ameryckx (1970) for the onset of the Dunkerque inundations. Yet, the chronology of peat termination in this part of the Belgian coastal plain needs to be elaborated further by means of high-precision dating before causal mechanisms can be indicated more precisely.

In general, the diatom assemblages occurring in the upper siliciclastic deposits strongly resemble those of the Atlantic period in their high representation of *Cymatosira belgica* and *Delphineis minutissima*. This parallel relates to the more open coastal configuration existing during both periods, allowing a high sediment influx into the coastal area by turbid tidal waters.

Classically, three successive Dunkerque transgressions (DI, D II, D IIIA) are assumed to have occurred in the study area (Tavernier and Ameryckx, 1970; De Moor and Ozer, 1985). If so, up to three phases of salt-marsh or soil development might be expected to be present in the uppermost sediments. Denys (1995) identified a single transient phase of somewhat reduced marine influence in the silts of the Wolvenest core, but a clear salt-marsh horizon was absent. Rather similar observations are made on the Westende 1 core where, although resolution is limited by the disturbance of the soil profile, it appears that the deposition of more than 2 m of clay above the brackish mud flat sample at the top of the sequence involves a later resumption of tidal activity. At the archaeological site of Raversijde, evidence was found for three periods of positive tendency after Roman peat extraction, the latest one being of Late Medieval age (Pieters *et al.*, 1998). Conversely, the sediments at Vliegveld, spanning the entire final period of tidal sedimentation, show no trace of negative tendencies until the uppermost levels. It appears, therefore, that tidal activity continued at this site without interruption from the termination of the upper peat growth until perhaps as late as the medieval polder reclamation. The absence of apparent soil development over large areas indicates that the terms "regression" or "transgression" are not applicable here, but rather that sedimentation was influenced in some areas by at least one phase of channel reactivation, as also suggested by Mostaert (1989) for the eastern part of the coastal plain. For human occupation, the consequences of such events may, nevertheless, have been significant. More permanent land-use was probably restricted to the better drained levees and highest salt-marsh areas. Renewal of tidal activity would have forced their abandonment, thus affecting the accessibility of the entire coastal region. On the other hand, it is possible that conditions were less favourable for the preservation of intercalated salt-marsh horizons at some places, perhaps because of intensified lateral channel migrations promoted by a slower RSL rise (Beets *et al.*, 1994).

8. General conclusions

Up to *c.* 7500 yrs cal. BP the development of the western coastal plain to the east of Nieuwpoort was determined by the rapid RSL rise. The existence of an open coast allowed a high sediment influx into the tidal basin, yet the high-intertidal zone remained poorly developed. Hereafter, the interplay of a high sediment supply and a decrease in the rate of RSL rise allowed local silting-up and peat growth as extensive coastal progradation occurred and a wide tidal-flat zone developed. The frequency of negative tendencies in the marine influence increased progessively and conditions became more and more favourable for peat growth, leading towards extensive peat development from *c.* 5900 to, perhaps, 2100 yrs cal. BP. During this period tidal sedimentation was local and short-lived, until coastline retreat started. The occurrence of successive large-scale Dunkerque inundations is not supported by micropalaeontological and lithostratigraphic data.

Although diatom data extend considerably on the lithostratigraphic evidence for tendency changes of the marine influence, only a tentative chronology of regional tendencies can be proposed for the study area so far. Even though this shows some points of agreement with the presumed alternation of transgressive and regressive phases in the northern Netherlands, causal relations cannot yet be established with confidence. This will require more comprehensive data as well as tendency chronologies based on a common operational methodology.

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10. References

ALLEMEERSCH, L., 1995. Peat in the Belgian eastern coastal plain. *In*: GULLENTOPS, F. (ed.), *Wetlands in Flanders. Contributions to palaeohydrology of the temperate zone in the last 15000 years. Aardkundige Mededelingen*, 6, pp. 1-54.

ALLEN, J.R.L., 1995. Salt-marsh growth and fluctuating sea level: implications of a simulation model for Flandrian coastal stratigraphy and peat-based sea-level curves. *Sedimentary Geology*, 100, 21-45.

AMERYCKX, J., 1959. *De ontstaansgeschiedenis van de zeepolders*. Biekorf, 60, 1-26.

AUGUSTYN, B., 1992. *Zeespiegelrijzing, ecologische en klimatologische studie in historisch perspektief.* Brussel, Algemeen Rijksarchief.

BAETEMAN, C., 1981a. *De holocene ontwikkeling van de westelijke kustvlakte (België).* Doctoral thesis, Vrije Universiteit Brussel.

BAETEMAN, C., 1981b. An alternative classification and profile type map applied to the Holocene deposits of the Belgian coastal plain. *Bulletin van de Belgische Vereniging voor Geologie*, 90, 257-280.

BAETEMAN, C., 1983. De holocene sedimenten van de westelijke kustvlakte: een analyse van de Belgische literatuur. *Professional Paper Belgische Geologische Dienst*, 204, 1-45.

BAETEMAN, C., 1985. Development and evolution of sedimentary environments during the Holocene in the western coastal plain of Belgium. *Eiszeitalter und Gegenwart*, 35, 23-32.

BAETEMAN, C., 1987. Mapping a coastal plain, problems concerning mapping units. *Geobound*, 1, 3-9.

BAETEMAN, C., 1991. Chronology of coastal plain development during the Holocene in West Belgium. *Quaternaire*, 2, 116-125.

BAETEMAN, C., 1993. The western coastal plain of Belgium. *In*: BAETEMAN, C. and W. DE GANS (eds), *Quaternary shorelines in Belgium and The Netherlands. Excursion guide INQUA Subcommission on Shorelines of Northwestern Europe Fieldmeeting 1993.* Brussel, Belgian Geological Survey, pp. 1-24, 43-55.

BAETEMAN, C., 1999. The Holocene depositional history of the palaeovalley of the IJzer (western Belgian coastal plain) with reference to the factors controlling the formation of intercalated peat beds. *Geologica Belgica*, 2, 39-72.

BAETEMAN, C., BEETS, D.J. and VAN STRYDONCK, M., 1999. Tidal crevasse splays as the cause of rapid changes in the rate of aggradation in the Holocene tidal deposits of the Belgian coastal plain. *Journal of Quaternary International*, 56, 3-13.

BAETEMAN, C., CLEVERINGA, P and VERBRUGGEN, C., 1981. Het paleomilieu rond het Romeins zoutwinningssite van Leffinge. *Professional Paper Belgische Geologische Dienst*, 186, 1-33.

BAETEMAN, C. and DENYS, L., 1995. Western coast of Belgium. *In*: SCHIRMER, W. (ed.), *Quaternary field trips in Central Europe. Vol. 2. Field trips on special topics.* München, Verlag Dr. Friedrich Pfeil, pp. 1010-1014.

BAETEMAN, C. and DENYS, L., 1997. Holocene shoreline and sea-level data from the Belgian coast. *Paläoklimaforschung*, 21, ESF Special Issue 14, 49-74 (in press).

BAETEMAN, C. and VAN STRYDONCK, M., 1989. Radiocarbon dates on peat from the Holocene deposits in West Belgium. *In*: BAETEMAN, C. (ed.), *Quaternary sea-level investigations from Belgium.* Professional Paper Belgische Geologische Dienst, 241, pp. 59-91.

BEETS, D.J., VAN DER SPEK, A.J.F. and VAN DER VALK, L., 1994. *Holocene ontwikkeling van de Nederlandse kust.* RGD-rapport 40.016 - Projekt Kustgenese. Haarlem, Rijks Geologische Dienst.

BEETS, D.J., VAN DER VALK, L. and STIVE, M.J.F., 1992. Holocene evolution of the coast of Holland. *Marine Geology*, 103, 423-443.

BENNEMA, J. and VAN DER MEER, K., 1952. De bodemkartering van Walcheren. *Verslagen van Landbouwkundige Onderzoekingen*, 58, 4, 1-171.

BEYENS, L., 1985. On the Subboreal climate of the Belgian Campine as deduced from diatom and testate amoebae analyses. *Review of Palaeobotany and Palynology*, 46, 9-31.

BLANCHARD, R., 1906. *La Flandre.* Paris, Librairie Armand Colin, 530 p.

BOHNCKE, S.J.P., 1991. Holocene lake-level fluctuations and climatic evolution as recorded in the sediments of the Mekelermeer, The Netherlands. *In*: BOHNCKE, S.J.P., *Palaeohydrological changes in The Netherlands during the last 13.000 years.* Doctoral thesis, Vrije Universiteit Amsterdam, pp. 109-175.

BRANDER, G., 1935. Die baltische Diatomeen-Succession des Balen-Beckens. *Geologiska Föreningen i Stockholms Förhandlingar*, 57, 318-340.

BROCKMANN, C., 1940. Diatomeen als Leitfossilien in Küstenablagerungen. *Westkuste*, 2, 150-181.

BROCKMANN, C., 1950. Die Watt-Diatomeen des schleswig-holsteinischen Westküste. *Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft*, 478, 1-26, 6 pl.

CHOLNOKY, B.J., 1968. *Die Ökologie der Diatomeen in Binnengewässern.* Vaduz, J. Cramer Verlag, 699 p.

COLIJN, F. and DIJKEMA, K.S., 1981. Species composition of benthic diatoms and distribution of chlorophyll a on an intertidal flat in the Dutch Wadden Sea. *Marine Ecology Progress Series*, 4, 9-21.

DEAN, W.E., 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. *Journal of Sedimentary Petrology*, 44, 242-248.

DE CEUNYNCK, R., 1984. A contribution to the study of dune deposits of the Belgian coastal plain. *Bulletin van de Belgische Vereniging voor Geologie*, 93, 251-254.

DE CEUNYNCK, R. and DENYS, L., 1987. Geologisch en paleoecologisch onderzoek van de laatholocene afzettingen langsheen de Veurnestraat te De Panne (Duingebied - Belgische Westkust). *De Duinen*, 17, 5-31.

DE MOOR, G. and OZER, A., 1985. Belgium. *In*: BIRD, E. and SCHWARTZ, M. (eds), *The world coastlines*. New York, Van Nostrand Reinhold, pp. 353-358.

DENYS, L., 1985. Diatom analysis of an Atlantic-Subboreal core from Slijpe (western Belgian coastal plain). *Review of Palaeobotany and Palynology*, 46, 33-53.

DENYS, L., 1989. Observations on the transition from Calais deposits to surface peat in the western Belgian coastal plain - results of a paleoenvironmental diatom study. *In*: BAETEMAN, C. (ed.), *Quaternary sea-level investigations from Belgium*. Professional Paper Belgische Geologische Dienst, 241, pp. 20-43.

DENYS, L., 1990. *Fragilaria* blooms in the Holocene of the western Belgian coastal plain. *In*: SIMOLA, H. (ed.), *Proceedings 10th International Diatom Symposium*. Koenigstein, Koeltz Scientific Books, pp. 397-406.

DENYS, L., 1991. A check-list of the diatoms in the Holocene deposits of the western Belgian coastal plain with a survey of their apparent ecological requirements. I. Introduction, ecological code and complete list. *Professional Paper Belgische Geologische Dienst*, 246, 1-41.

DENYS, L., 1993a. *Paleoecologisch diatomeeënonderzoek van de holocene afzettingen in de westelijke Belgische kustvlakte*. Doctoral thesis, Universitaire Instelling Antwerpen.

DENYS, L., 1993b. The diatom record of Holocene deposits near Oostkerke and the development of the Avekapelle gully. *In*: BAETEMAN, C. and W. DE GANS (eds), *Quaternary shorelines in Belgium and The Netherlands. Excursion guide INQUA Subcommission on Shorelines of Northwestern Europe Fieldmeeting 1993*. Brussel, Belgian Geological Survey, pp. 25-42.

DENYS, L., 1993c. Holocene valley fills at the southern limit of the western Belgian coastal plain - general palaeoecological outline. *In*: BAETEMAN, C. and W. DE GANS (eds), *Quaternary shorelines in Belgium and The Netherlands. Excursion guide INQUA Subcommission on Shorelines of Northwestern Europe Fieldmeeting 1993*. Brussel, Belgian Geological Survey, pp. 56-73.

DENYS, L., 1994. Diatom assemblages along a former intertidal gradient: a palaeoecological study of a Subboreal clay layer (western coastal plain, Belgium). *In*: BAKKER, C., VAN DAM, H., DAVIDS, C. and DE WOLF, H. (eds), *Memorial volume A. Van der Werff. Netherlands Journal of Aquatic Ecology*, 28, pp. 85-96.

DENYS, L., 1995. The diatom record of a core from the seaward part of the coastal plain of Belgium. *In*: MARINO, D. and MONTRESOR, M. (eds), *Proceedings of the thirteenth International Diatom Symposium*. Bristol, Biopress Ltd., pp. 471-487.

DENYS, L. and BAETEMAN, C., 1995. Holocene evolution of relative sea level and local mean high water spring tides in Belgium - a first assessment. *Marine Geology*, 124, 1-19.

DENYS, L. and DE WOLF, H., in press. Diatoms as indicators of coastal paleoenvironments and relative sea-level change. *In*: STOERMER, E.F. and SMOL, J.P. (eds), *The diatoms. Applications for the environmental and earth sciences*. Cambridge, Cambridge University Press.

DENYS, L., LEBBE, L., SLIGGERS, B.C., SPAINK, G., VAN STRYDONCK, M. and VERBRUGGEN, C., 1983. Litho- and biostratigraphical study of Quaternary deep marine deposits of the western Belgian coastal plain. *Bulletin van de Belgische Vereniging voor Geologie*, 92, 125-154.

DENYS, L. and VERBRUGGEN, C., 1989. A case of drowning - the end of Subatlantic peat growth and related palaeoenvironmental changes in the lower Scheldt Basin (Belgium) based on diatom and pollen analysis. *Review of Palaeobotany and Palynology*, 59, 7-36.

DE WOLF, H., 1984. Diatom analyses on two profiles from the Schildmeer area (Province of Groningen, The Netherlands). *In*: SCHOUTE, J.F.T. (ed.), *Vegetation horizons and related phenomena. A palaeoecological-micromorphological study in the younger coastal*

Holocene of the northern Netherlands (Schildmeer area). Dissertationes Botanicae, 81, pp. 257-264.

DE WOLF, H. and DENYS, L., 1993. *Actinoptychus splendens* (Shadbolt) Ralfs (Bacillariophyceae): a biostratigraphic marker for the later part of the Holocene coastal deposits along the southern North Sea. *In*: VAN DAM, H. (ed.), *Twelfth International Diatom Symposium. Hydrobiologia*, 269/270, pp. 153-158.

DUBOIS, A.D., 1987. *De deuterium/waterstof-verhouding in cellulose als indicator voor klimaat-veranderingen*. Doctoral thesis, Universitaire Instelling Antwerpen.

DUPONT, L.M., 1985. *Temperature and rainfall variation in a raised bog ecosystem. A palaeoecological and isotope-geological study*. Doctoral thesis, Universiteit Amsterdam.

EDSBAGGE, H., 1968. Zur Ökologie der marinen angehefteten Diatomeen. *Botanica Gothoburgensis*, 6, 1-153, 7 pl.

GERMAIN, H., 1981. *Flore des diatomées. Diatomophycées. Eaux douces et saumâtres du Massif armoricain et des contrées voisines d'Europe occidentale*. Paris, Boubée, 444 p.

GEYH, M.A. , 1980. Holocene sea-level history: case study of the statistical evaluation of ^{14}C dates. *In*: STUIVER, M. and KRA, R.S. (eds), *Proceedings 10th International Radiocarbon Conference 1979. Radiocarbon*, 22, pp. 695-704.

GOTTSCHALK, M.K.E., 1980. Subatlantische transgressiefasen en stormvloeden. *In*: VERHULST, A. and GOTTSCHALK, M.K.E. (eds), *Transgressies en occupatiegeschiedenis in de kustgebieden van Nederland en België*. Gent, Belgisch Centrum voor Landelijke Geschiedenis, pp. 21-27.

GRIEDE, J.W., 1978. *Het ontstaan van Frieslands Noordhoek*. Doctoral thesis, Vrije Universiteit Amsterdam.

GRIMM, E.C., 1987. CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computers & Geosciences*, 13, 13-35.

GULLENTOPS, F. and WOUTERS, L., 1996. *Delfstoffen in Vlaanderen*. Brussel, Ministerie van de Vlaamse Gemeenschap - Afdeling Natuurlijke Rijkdommen en Energie, 198 p.

HASLE, G.R., VON STOSCH, H.A. and SYVERTSEN, E., 1983. Cymatosiraceae, a new diatom family. *Bacillaria*, 6, 9-156.

HAYNES, J.R., KITELEY, R.J., WHATLEY, R.C. and WILKS, P.J., 1977. Microfaunas, microfloras and the environmental stratigraphy of the Late Glacial and Holocene in Cardigan Bay. *Geological Journal*, 12, 129-158.

HAYES, M.O., 1979. Barrier island morphology as a function of tidal and wave regime. *In*: LEATHERMAN, S.P. (ed.), *Barrier islands, from the Gulf of St. Lawrence to the Gulf of Mexico*. New York, Academic Press, pp. 1-27.

HEMPHILL-HALEY, E., 1995a. Intertidal diatoms from Willapa Bay, Washington, application to studies of small-scale sea-level changes. *Northwest Science*, 69, 29-45.

HEMPHILL-HALEY, E., 1995b. Diatom evidence for earthquake-induced subsidence and tsunami 300 yr ago in southern coastal Washington. *Geological Survey of America, Bulletin*, 107, 367-378.

HENDEY, N.I., 1964. An introductory account of the smaller algae of British coastal waters. Part V: Bacillariophyceae (diatoms). London, Her Majesty's Stationery Office, 315 p., 45 pl.

HOUTHUYS, R., DE MOOR, G. and SOMME, J., 1992. The shaping of the French-Belgian North Sea coast throughout recent geology and history. *In*: HILLEN, R. and VERHAGEN, H.J. (eds), *Coastlines of the Southern North Sea*. New York, American Society of Civil Engineers, pp. 27-40.

HUSTEDT, F., 1957. Die Diatomeenflora des Fluszsystems der Weser im Gebiet der Hansestadt Bremen. *Abhandlungen des Naturwissenschaftlichen Vereins zu Bremen*, 34, 181-440.

JØRGENSEN, E.G., 1948. Diatom communities in some Danish lakes and ponds. *Biologiske Skrifter*, 5, 1-117, 3 pl.

KIDEN, P. and L. DENYS, 1995. Late Quaternary isostatic and tectonic movements in the southern North Sea (Belgium and The Netherlands). *TerraNostra*, 2/95, 135.

LAMB, H.H., 1977. *Climate: present, past and future. Vol. 2. Climatic history and the future*. London, Methuen & Co., 835 p.

LAMB, H.H., 1980. Climatic fluctuations in historical times and their connection with transgressions of the sea, storm floods and other coastal changes. *In*: VERHULST, A. and GOTTSCHALK, M.K.E. (eds), *Transgressies en occupatiegeschiedenis in de kustgebieden van Nederland en België*. Gent, Belgisch Centrum voor Landelijke Geschiedenis, pp. 251-284.

LONG, A.J., PLATER, A.J., WALLER, M.P. and INNES, J.P., 1996. Holocene coastal sedimentation in the Eastern English Channel: new data from the Romney Marsh region, United Kingdom. *Marine Geology*, 136, 97-120.

LUND, J.W.G., 1946. Observations on soil algae I. The ecology, size and taxonomy of British soil diatoms. Part 2. *New Phytologist*, 45, 56-110.

MAGNY, M., 1992. Holocene lake-level fluctuations in the Jura and the northern subalpine ranges, France: regional pattern and climatic implications. *Boreas*, 21, 319-334.

MARECHAL, R., 1992. *Kwartairgeologie. Lithologie van de oppervlakkige lagen. Commentaar Blad II.3.* Tweede Atlas van België. Brussel, Belgische Geologische Dienst, 25 p.

MCINTIRE, C.D. and MOORE, W.W., 1977. Marine littoral diatoms: ecological considerations. *In*: WERNER, D. (ed.), *The biology of diatoms*. Berkeley, University of California Press, pp. 333-371.

MENKE, B., 1988. Die holozäne Nordseetransgression im Küstengebiet der südöstlichen Deutschen Bucht. *In*: *Norderhever-Projekt. 1. Landschaftsentwicklung und Siedlungsgeschichte im Einzugsgebiet der Norderhever (Nordfriesland)*. Neumunster, Karl Wachholtz Verlag, pp. 117-137.

MOSIMANN, J.E., 1965. Statistical methods for the pollen analyst. *In*: KUMMEL, B. and RAUP, D. (eds), *Handbook of paleontological techniques*. San Francisco, W.H. Freeman & Co., pp. 636-673.

MOSTAERT, F., 1985. *Bijdrage tot de kennis van de Kwartairgeologie van de oostelijke kustvlakte op basis van sedimentologisch en lithostratigrafisch onderzoek*. Doctoral thesis, Rijksuniversiteit Gent.

MOSTAERT, F., 1989. Holocene sea-level indicators in the eastern part of the Belgian coastal plain. *In*: BAETEMAN, C. (ed.), *Quaternary sea-level investigations from Belgium*. Professional Paper Belgische Geologische Dienst, 241, pp. 44-58.

NELSON, A.R. and KASHIMA, K., 1993. Diatom zonation in southern Oregon tidal marshes relative to vascular plants, foraminifera, and sea level. *Journal of Coastal Research*, 9, 673-697.

PAEPE, R., 1960. La plaine maritime entre Dunkerque et la frontière belge. *Bulletin de la Société belge d'Etudes Géographiques*, 29, 47-66.

PALMER, A.J.M. and ABBOTT, 1986. Diatoms as indicators of sea-level change. *In*: VAN DE PLASSCHE, O. (ed.), *Sea-level research, a manual for the collection and evaluation of data*. Norwich, Geo Books, pp. 457-489.

PANKOW, H., 1976. Algenflora der Ostsee II. Plankton (einschl. benthischer Kieselalgen). Stuttgart, Gustav Fischer Verlag, 493 p.

PATRICK, R., 1977. Ecology of freshwater diatoms - diatom communities. *In*: WERNER, D. (ed.), *The biology of diatoms*. Berkeley, University of California Press, pp. 284-332.

PIETERS, M., 1993. Archaeological research in Raversijde (municipality Oostende, province West-Flanders). *In*: BAETEMAN, C. and W. DE GANS (eds), *Quaternary shorelines in Belgium and The Netherlands. Excursion guide INQUA Subcommission on Shorelines of Northwestern Europe Fieldmeeting 1993*. Brussel, Belgian Geological Survey, pp. 88-93.

PIETERS, M., BAETEMAN, C., DEMIDDELE, H. and A. ERVYNCK, 1998. The polder area of Raversijde (Ostend, Belgium): a complex parent material affected by intense human interventions. Archaeology as a tool in geopedology. *Proceedings World Congress of Soil Science,* Monpellier, Summaries, vol. 1, 10 p..

POSTMA, H., 1967. Sediment transport and sedimentation in the estuarine environment. *In*: LAUFF, G.H. (ed.), *Estuaries*. Washington, A.A.A.S., 83, pp.158-179.

ROELEVELD, W., 1974. The Holocene evolution of the Groningen marine-clay district. *Berichten Rijksdienst voor Oudheidkundig Bodemonderzoek*, 24, Supplement, 8-132.

ROUND, F.E., 1960. The diatom flora of a salt marsh on the River Dee. *New Phytologist,* 59, 332-348.

ROUND, F.E., CRAWFORD, R.M. and MANN, D.G., 1990. *The diatoms. Biology and morphology of the genera*. Cambridge, Cambridge University Press, 747 p.

SCHOORL, H., 1980. The significance of the Pleistocene landscape of the Texel-Wieringen region for the historical development of the Netherland coast between Alkmaar and East Terschelling. *In*: VERHULST, A. and. GOTTSCHALK, M.K.E (eds), *Transgressies en occupatiegeschiedenis in de kustgebieden van Nederland en België*. Gent, Belgisch Centrum voor Landelijke Geschiedenis, pp. 115-153.

SHENNAN, I., 1982a. Problems of correlating Flandrian sea-level changes and climate. *In*: HARDING, A.F. (ed.), *Climatic change in later prehistory*. Edinburgh, University Press, pp. 52-67.

SHENNAN, I., 1982b. Interpretation of sea-level data from the Fenland, England. *Proceedings Geologists' Association*, 83, 53-63.

SHENNAN, I., 1986. Flandrian sea-level changes in the Fenland. II: Tendencies of sea-level movement, altitudinal changes, and local and regional factors. *Journal of Quaternary Science*, 1, 155-179.

SHENNAN, I., 1987. Global analysis and correlation of sea level data. *In*: Devoy, R.J.N. (ed.), *Sea surface studies*. London, Croom Helm, pp. 198-230.

SHENNAN, I., TOOLEY, M.J., DAVIS, M.J. and B.A. HAGGART, 1983. Analysis and interpretation of sea-level data. *Nature*, 302, 404-406.

SIMONSEN, R., 1962. Untersuchungen zur Systematik und Ökologie der Bodendiatomeen der west-lichen Ostsee. *Internationale Revue der gesammten Hydrobiologie, Systematische Beihefte*, 1, 8-144, 4 pl.

STOCKMANS, F. and VANHOORNE, R., 1958. Etude botanique du gisement de tourbe de la région de Pervijze (Plaine Maritime belge). Mémoires de l'Institut royale des Sciences Naturelles de Belgique, 130, 1-144, 4 pl., app.

STOCKMARR, J., 1971. Tablets with spores used in absolute pollen analysis. *Pollen et Spores*, 13, 615-621.

STOLK, A., HOGERVORST, K. and BERENDSEN, H., 1989. Correcting ^{14}C histograms for the non-linearity of the radiocarbon time scale. *Radiocarbon*, 31, 169-178.

STUIVER, M. and REIMER, P.J., 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration. *Radiocarbon*, 35, 215-230.

TAVERNIER R., 1948. De jongste geologische geschiedenis der Vlaamsche kustvlakte. *Handelingen Maatschappij voor Geschiedenis en Oudheidkunde, Gent*, 3, 107-115.

TAVERNIER, R. and AMERYCKX, J., 1970. *Kust, duinen, polders. Atlas van België, Blad 17*. Brussel, Commitee Nationale Atlas, 32 p.

TAVERNIER R. and MOORMANN, F., 1954. Les changements du niveau de la mer dans la plaine maritime flamande pendant l'Holocène. *Geologie en Mijnbouw*, 16, 201-206.

TER BRAAK, C.J.F., 1987. *CANOCO a FORTRAN program for canonical community ordination by (partial) (detrended) (canonical) correspondence analysis, principal components analysis and redundancy analysis (version 2.1)*. Wageningen, ITI-TNO, 95p.

TÖRNQVIST, T.E. and BIERKENS, M.F.P., 1994. How smooth should curves be for calibrating radiocarbon ages? *Radiocarbon*, 36, 11-26.

UNDERWOOD, G.J.C., 1994. Seasonal and spatial variation in epipelic diatom assemblages in the Severn estuary. *Diatom Research*, 9, 451-472.

VAN CAUWENBERGHE, C., 1977. Overzicht van de tijwaarnemingen langs de Belgische kust (periodes 1941/1959-1970). *Tijdschrift voor Openbare Werken*, 4, 1-12.

VAN DE PLASSCHE, O., 1982. Sea-level change and water-level movements in the Netherlands during the Holocene. *Mededelingen Rijks Geologische Dienst*, 36, 1-93.

VAN DE PLASSCHE, O., 1985. Time-limit assessment of some Holocene transgressive and regressive periods in the northern Netherlands. *Eiszeitalter und Gegenwart*, 35, 43-48.

VAN DER VALK, L., 1992. *Mid- and late-Holocene coastal evolution in the beach-barrier area of the western Netherlands*. Doctoral thesis, Vrije Universiteit Amsterdam.

VAN DER WERFF, H. and HULS, H., 1957-1974. *Diatomeeënflora van Nederland*. Reprint 1976. O. Koenigstein, Koeltz.

VAN GEEL, B., BUURMAN, J. and WATERBOLK, H.T., 1996. Archaeological and palaeoecological indications of an abrupt climate change in The Netherlands, and evidence for climatological teleconnections around 2650 BP. *Journal of Quaternary Science*, 11, 451-460.

VAN RUMMELEN, F.F.F.M., 1972. *Toelichtingen bij de geologische kaart van Nederland, 1:50000, blad Walcheren*. Rijks Geologische Dienst, Haarlem.

VERBRUGGEN, C. and DENYS, L., 1995. Early tidal influence on the Lower Schelde. *In*: GULLENTOPS, F. (ed.), *Wetlands in Flanders. Contributions to palaeohydrology of the temperate zone in the last 15000 years. Aardkundige Mededelingen*, 6, pp. 167-169.

VOS, P.C. and DE WOLF, H., 1988. Methodological aspects of paleo-ecological diatom research in coastal areas of the Netherlands. *Geologie en Mijnbouw*, 67, 31-40.

VOS, P.C. and DE WOLF, H., 1993. Reconstruction of sedimentary environments in Holocene coastal deposits of the southwest Netherlands; the Poortvliet boring, a case study of palaeoenvironmental diatom research. *In*: VAN DAM, H. (ed.), *Twelfth International Diatom Symposium. Hydrobiologia*, 269/270, pp. 297-306.

VOS, P.C. and DE WOLF, H., 1994. Palaeoenvironmental research on diatoms in early and middle Holocene deposits in central North Holland. *In*: BAKKER, C., VAN DAM, H., DAVIDS, C. and DE WOLF, H. (eds), *Memorial volume A. Van der Werff. Netherlands Journal of Aquatic Ecology*, 28, pp. 97-115.

VOS, P.C. and VAN HEERINGEN, R.M., 1997. Holocene geology and occupation history of the Province of Zeeland. *In*: FISCHER, M.M. (ed.), *Holocene evolution of Zeeland (SW Netherlands)*. Mededelingen Nederlands Instituut voor Toegepaste Geowetenschappen TNO, 59, pp. 5-109.

ZONG, Y., 1997. Implications of *Paralia sulcata* abundance in Scottish isolation basins. *Diatom Research*, 12, 125-150.

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