A synthesis of early and middle Holocene coastal changes in the western Belgian lowlands

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ABSTRACT
A large-scale pattern of Holocene coastal evolution of the western Belgian coastal plain has been reconstructed by means of a series of palaeogeographical maps at 9 time slices between 9.5 and 6 cal. ka BP together with schematical cross-sections of the vertical sediment accumulation. The time-depth estimate and the spatial extension of the palaeo-environments is based on the relative sea-level (RSL) curve and radiocarbon dates of (basal and intercalated) peats and shells. This paper describes the methodology of reconstructing the pre-Holocene surface and asserts that the morphology of the flooded surface is a controlling factor in the distribution of the Holocene sediments. For a better visualization of the rather weak relief, a 3D terrain model is presented. The coastal evolution is further controlled by the changes in the rate of RSL rise and sediment budget. The period before ca. 7.500 cal BP is marked by a rapid RSL rise and consequently by a progressive rapid landward migration of all depositional environments as well as a major vertical sediment accretion. In the period following the first substantial decrease in the rate of RSL rise, the direct impact of the latter is subordinate to the effect of sediment budget which is in balance with the creation of accommodation space. This resulted in the sedimentary infilling of the tidal basin and the deposition of tidal clastic sediments with peat accumulation.

KEY WORDS: coastal plain development, palaeogeography, pre-Holocene surface, 3D terrain model, relative sea-level rise, tidal environment, radiocarbon dates

SAMENVATTING
VROEG EN MIDDEN HOLOCENE KUSTEVOLUTIE VAN DE WESTELIJKE BELGISCHE KUSTVLAKTE - EEN SYNTHESE
Een groot-schalige reconstructie van de Holocene kustevolutie voor het westelijke deel van de Belgische kustvlakte wordt voorgesteld door middel van 9 paleogeografische kaarten voor de periode tussen 9.5 en 6 cal ka BP, samen met schematische doorsneden van de vertikale sediment accumulatie in de tijd. De tijd en plaats bepaling van de paleomilieus is gebaseerd op de relatieve zeespiegelcurve en radiokoolstof dateringen van veen (basis- en verlandingsveen) en schelpen. Deze studie beschrijft uitvoerig de methodologie voor de reconstructie van het pre-Holoceen oppervlak. De morfologie van dit oppervlak is een bepalende factor bij de verspreiding van de Holocene sedimenten. Een 3D terrein model geeft een duidelijk beeld van het tamelijk zwakke reliëf van het oorspronkelijke Pleistocene oppervlak. De kustevolutie is mede bepaald door de snelheid van de zeespiegelstijging en het sediment budget. De aanvankelijk

vlugge zeespiegelstijging in de periode voor ca. 7500 cal BP veroorzaakte een vlugge verschuiving van de sedimentaire afzettingsmilieus landinwaarts samen met een belangrijke vertikale opvulling. Een vertraging van de snelheid van de zeespiegelstijging in de daaropvolgende periode resulteerde in een verminderde invloed van de relatieve zeespiegelstijging ten opzichte van de invloed van het sediment budget dat in evenwicht was met de bergingsruimte. Daardoor kon het getijdengebied volledig opgevuld worden met clastische sedimenten afwisselend met verlandingsvenen.

SLEUTEWOORDEN: kustvlakte evolutie, paleogeografie, pre-Holoceen oppervlak, 3D terrein model, relatieve zeespiegelstijging, getijde-afzettingsmilieus, radiokoolstof dateringen

INTRODUCTION

The aim of this paper is to present a broad scheme of coastal evolution in the western part of the Belgian coastal plain throughout the Holocene (Fig. 1). Emphasis is put on the period prior to 6000 cal BP because this period shows major changes and illustrates the mechanism of infill of a tidal basin. Moreover, coastal evolution during this period apparently is not well understood in Belgium since in the literature it is frequently written that the coastal plain formed as from 5500 cal BP.

Since the beginning of the marine inundation of the area in the early Holocene, clastic tidal sediments and peat beds have accumulated. The Holocene sequence attains thicknesses of up to 25 m at the coast and thins to the south where Pleistocene deposits are outcropping (Fig. 2). The infill of the area and the associated coastal evolution will be discussed in relation to the controlling factors, i.e. the morphology of the Pleistocene surface prior to marine inundation, the rate of relative sea-level (RSL) rise, sediment supply and accommodation space (Baeteman, 1998, 1999; Beets et al., 1992; Beets and van der Spek, 2000).

This contribution summarizes the present knowledge on coastal evolution by means of palaeogeographical reconstructions and schematical cross-sections through the Holocene accumulation wedge at various times. This paper is concerned with large-scale development of coastal evolution and not with detailed reconstructions of the sedimentary infilling requiring much more detailed maps.

STUDY AREA

The study area is located in the western part of the coastal plain of Belgium (Fig. 1). The latter belongs to the lowlands of the southern North Sea extending from the cliffs of northern France to Denmark in the North. The coastal plain was created through embankment and is separated from the North Sea by a closed coastal barrier and seawalls. Its elevation varies from +2 to +5 m TAW, thus well below high water level (cf. Fig. 2) since the Belgian TAW datum refers to mean lowest low water spring which is about 2 m below mean sea level. The coast of the study area is presently characterized by a mean tidal range of 4.08 m, and a mean spring tidal range of 4.85 m (Van Cauwenberghe, 1993). In the west, the plain is drained by the IJzer, a small river which is canalized and flows into the North Sea at the town of Nieuwpoort (Fig. 1). The river, together with its tributaries, drains a small and relatively low-lying basin to the south and south-west of the coastal plain.

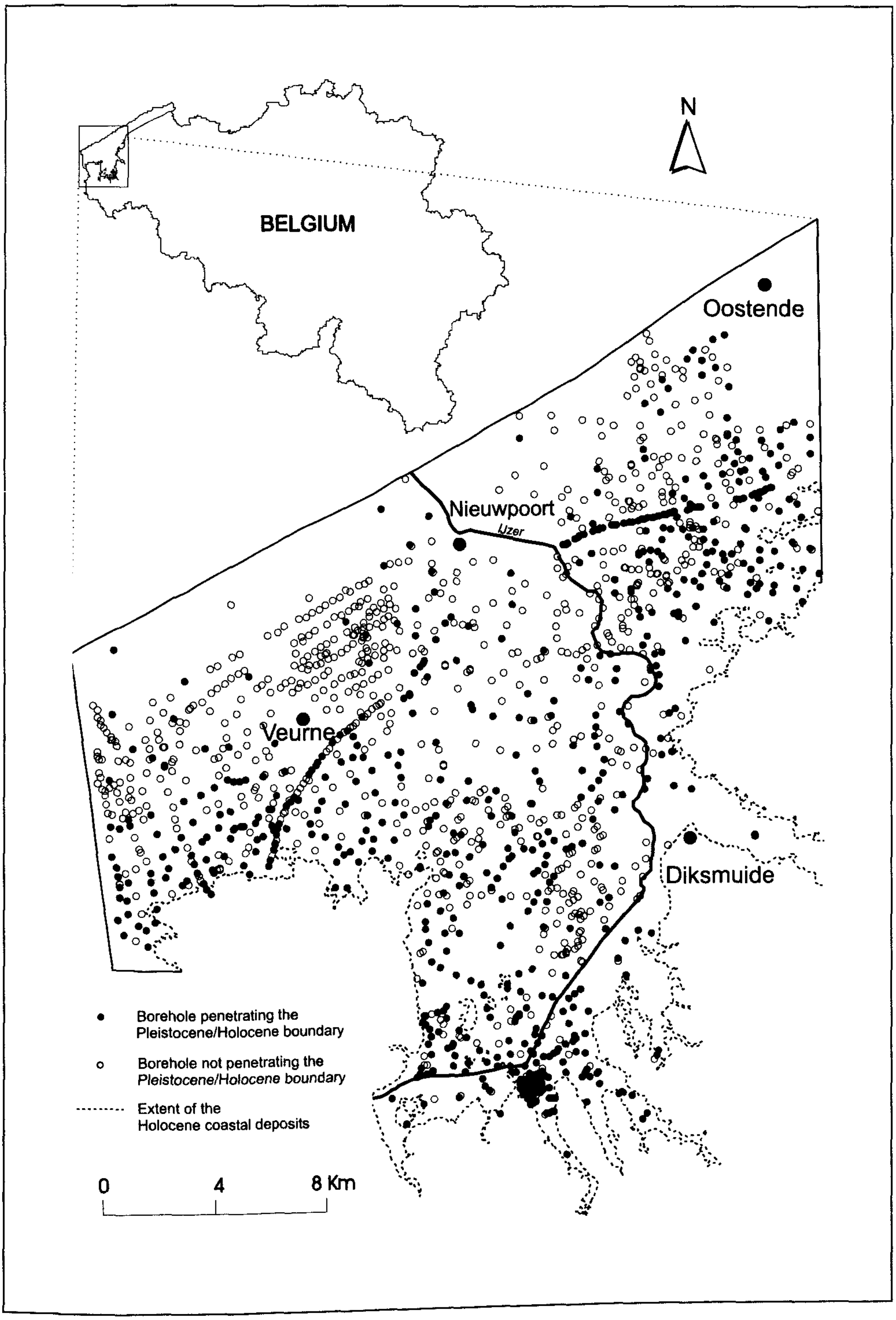


Figure 1. Map of the western coastal plain of Belgium with location of the boreholes.

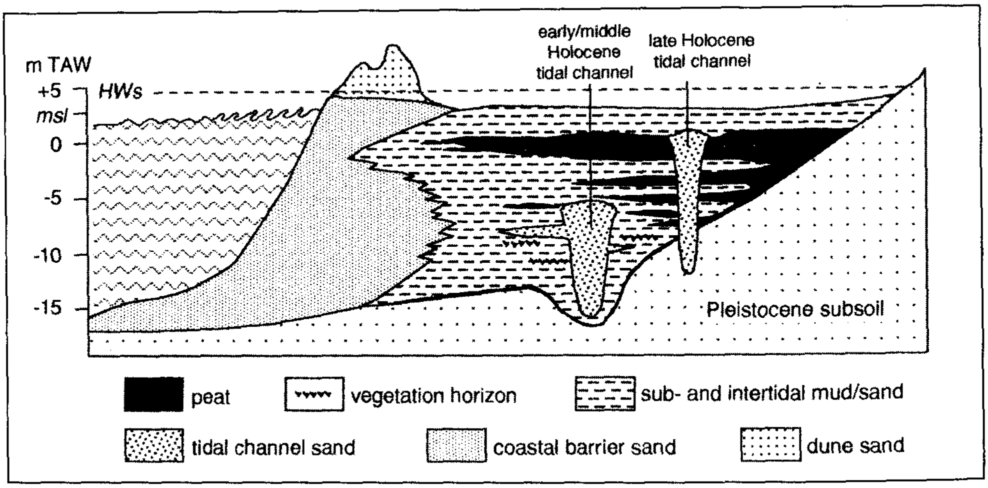


Figure 2. Schematic cross-section through the sedimentary sequence of the coastal Holocene.

PREVIOUS WORK

Research on the Holocene sedimentary sequence in the Belgian plain began mainly with the Soil Survey (e.g. Tavernier, 1938; Ameryckx, 1959) describing only the late Holocene sediments and putting forward hypotheses about coastal evolution. The invalidity of the hypotheses has been argued in many publications (e.g. Baeteman, 1983, 1985, 1991, 1999; Denys, 1993; Ervynck et al., 1999) and therefore will not be discussed here, although they still remain in the recent literature (e.g. Maréchal, 1992; De Moor and Pissart, 1992; Jacobs and De Ceukelaire, 2002).

Baeteman (1981) provided a first attempt at palaeogeographic reconstructions, however on the basis of a sparse borehole coverage supported by few radiocarbon dates. Thanks to the ongoing systematic mapping and survey of temporary outcrops in the western coastal plain since the early 1980s, a rather extensive geological data set of Holocene deposits and radiocarbon dates is available. Besides, several cores of the data set were analysed for diatoms in great detail in order to permit environmental interpretation and sea-level research (Denys, 1985, 1990, 1991, 1993, 1994, 1995, 1999). De Ceunynck (1985) provided palynological data for the dune area in the very western part. This new data resulted in a better understanding of sedimentary environmental interpretation and depositional history of the coastal plain, chronology of the Holocene deposits and sea-level reconstruction (Baeteman, 1985, 1991, 1993, 1999; Baeteman et al., 1999; Baeteman et al., 2002; Baeteman and Denys, 1995; Denys and Baeteman, 1995; De Ceunynck and Denys, 1987).

Only recently have new palaeogeographical reconstructions been presented, for example the extension of the tidal inundation for various time slices between 9450 and 6000 cal BP (Baeteman, 1999); four schematic palaeogeographic maps of respectively ca 5500-4000, ca 3000, ca 1500 cal BP and 7th-8th century AD (Ervynck et al.,1999) and a series of detailed palaeogeographical maps of the very western part of the plain (east of Veurne, Baeteman, 2001a).

DATABASE

The research methodology is based on core drilling supported by absolute age determination by radiocarbon. The data set consists of over 1150 boreholes carried out over the past 25 years in the framework of the systematic mapping of the coastal plain providing a good coverage of the area (Fig. 1). About 650 boreholes reach the Pleistocene/Holocene boundary. As Fig. 1 demonstrates, there is a local paucity of borehole coverage along the coast because of the sand deposits of the coastal barrier. The poor distribution in the central part of the southern extension of the plain (WSW of Diksmuide) reflects the high position of the Pleistocene subsoil as inferred from the pedological map.

The boreholes were carried out using a hand-operated gouge auger giving undisturbed cores. About 100 boreholes were drilled mechanically covering the entire Quaternary sequence. In addition, several series of borings carried out by the Geotechnical Institute have been incorporated in the data set taking into account the lower quality of the stratigraphic data because the method of coring produced disturbed samples. The database of the Geological Survey was not used because of its low quality of sample description in that area and because most of the boreholes are too shallow.

All sedimentary sequences were described and analysed using the same criteria for facies identification which is based on lithology, sedimentary structures and macro fossils. Diatom analyses of several cores (Denys, 1993) confirmed the field interpretation of the different facies units. The elevation of the handborings is inferred from the topographic map. All other boreholes together with those handborings sampled for age determination, were levelled to TAW.

140 radiocarbon dates from peat and shells were used for the palaeogeographical reconstructions (Table 1). Most of the samples were analysed by the IRPA-laboratory and a few of them by the Antwerpen and Hannover Laboratories using the convential method referred to as IRPA, ANTW, Hv, respectively, and the AMS method referred to as UtC, KIA and NZA. All ages are quoted in calendar years before present (cal BP) with a two sigma age range. All dates are calibrated (Stuiver and Pearson, 1993; Stuiver and Reimer, 1993) taking into account a reservoir age of 400 ± 40 BP for the shells.

METHODOLOGY

A prerequisite for the reconstruction of the Holocene palaeogeography is a reliable model of the original Pleistocene relief, i.e. the morphology of the pre-transgressional surface. It is against this surface that the surface indicating RSL at any particular time is intersected, so giving the form of the tidal basin (Brew et al., 2000). The original Pleistocene relief is known when the basal peat is present (see Fig. 3), and in the areas along the landward limit of the coastal plain, where it is near to the present-day surface although basal peat never formed there just because the position of the Pleistocene subsoil is too high (see Fig. 2). Data for the original surface, however, is missing in the areas where late Holocene tidal channels eroded deeply and, in the seaward part, where in the middle Holocene, tidal scour removed most of the previously deposited Holocene sequence as well as the upper part of the Pleistocene deposits. Data is also missing at sites where the Holocene sequence is too thick or sandy and the Pleistocene/Holocene boundary is beyond hand auger reach. So for those areas, the original surface must be reconstructed. Figure 1

N°	Site	Sample altitude m TAW	Age ^{14}C yrs BP	Calibrated age yrs BP
1	Schoudervliet	-16.97	9940±110	11550
2	Schoudervliet	-16.64	8440±130	9440
3	Allaerts	-11.27	8250±95	9220
4	Oostkerke	-15.60	8170±90	9010
5	Woestijn	-15.20	8120±100	8990
6	B 5B	-14.21	8210±40	8700
7	Suikerfabriek	-5,45	7760±80	8491
8	N. Gasthuis	-13.75	7620±90	8397
9	Kerkwijk	-11.70	7530±60	8356
10	B5B	-9.01	7835±40	8315
11	Veurne	-9.62	7490±130	8260
12	Moerhof	-11.02	7420±190	8160
13	Suikerfabriek	-5.25	7350±45	8110
14	Orth. Kerk	-5.23	7230±85	8035
15	bh 363	-7.05/-6.95	7171±275	7974
16	Westende 4	-5.14/-5.19	7160±85	7970
17	Waterhoek bis	-7.62	7150±65	7960
18	Orth. Kerk	-5.13	7110±90	7927
19	bh A 64	-4.90	7080±60	7900
20	3-Grachten	-6.85	7030±85	7854
21	Suikerfabriek	-5.29	7030±55	7823
22	Oostkerke	-7.48/-7.44	7000±80	7789
23	Oostkerke	-7.37/-7.34	6750±80	7584
24	Waterhoek bis	-6.50/-6.45	6940±60	7780
25	Westende 4	-5.19/-5.03	7160±85	7759
26	Suikerfabriek	-5.19	7340±55	7750
27	Suikerfabriek	-5.29	6975±55	7748
28	Dijk	-5.10	6870±70	7681
29	Suikerfabriek	-5,20	6840±90	7626
30	Oostkerke	-7.37/-7.34	6750±80	7584
31	bh A78	-5.97	6730±35	7583
32	Waterhoek bis	-5.40/-5.35	6620±60	7540
33	Dijk	-4.90	6680±80	7516
34	Suikerfabriek	-4,49	7060±70	7507
35	Spoorweg	-3.67	6665±60	7506
36	Suikerfabriek	-7,94	6990±55	7434

Calibrated age 2s range	Dated material	Laboratory number	Ref.
12100-11150	base basal peat	IRPA 680	3
9781-9041	top basal peat	IRPA 681	3
9442-8964	top basal peat	IRPA 566	3
9379-8733	base basal peat	IRPA 734	3
9370-8652	top basal peat	IRPA 616	3
8881-8550	*Cerastoderma*	KIA 12252	7
8720-8350	humic horizon	UtC 4173	5
8621-8136	base basal peat	IRPA 678	3
8406-8277	basal peat (mean)	UtC 8802	12
8381-8173	*Scrobicularia*	KIA 12253	7
8492-7967	top basal peat	UtC 2625	7
8546-7820	basal peat (mean)	UtC 2626	11
8180-8000	base basal peat	UtC 3732	5
8164-7909	base basal peat	IRPA 533	3
8426-7472	basal peat (mean)	Hv8797	1
8080-7780	base intercalated peat	IRPA 615	3
8057-7824	intercalated peat (mean)	NZA 11948	12
8070-7690	top basal peat	IRPA 534	3
7980-7755	basal peat (mean)	KIA 12243	12
8029-7669	basal peat (mean)	IRPA 520	3
7920-7700	top basal peat	UtC 3733	5
8029-7599	base intercalated peat	IRPA 536	2
7709-7429	top intercalated peat	IRPA536	3
7867-7665	base gyttja	NZA 11947	12
8121-7766	top basal peat	IRPA 614	3
7890-7620	*Scrobicularia*	IRPA 1096	5
7860-7660	base basal peat	IRPA 1163	5
7881-7536	base basal peat	IRPA 542	2
7830-7500	top basal peat	UtC 3449	5
7709-7429	top intercalated peat	IRPA 535	3
7664-7562	base basal peat	KIA 12247	12
7586-7424	top gyttja	NZA 11946	12
7631-7388	top basal peat	IRPA 541	2
7630-7370	*Hydrobia*	UtC 4175	5
7599-7429	top basal peat	IRPA 927	3
7550-7320	*Cerastoderma*	IRPA 1115	5

N°	Site	Sample altitude m TAW	Age ^{14}C yrs BP	Calibrated age yrs BP
37	bh A78	-5.80	6470±50	7420
38	3-Grachten	-4.35/-4.29	6500±95	7375
39	Suikerfabriek	-3.94	6480±95	7359
40	Wolvenest	-2.77/-2.73	6420±80	7296
41	bh 755	-2.53/-2.48	6380±115	7278
42	Spoorweg	-2.65/-2.51	6375±60	7276
43	bh 1074	-5.04	6410±60	7276
44	Suikerfabriek	-3,34	6770±55	7239
45	Veurne	-4.62	6300±200	7210
46	Suikerfabriek	-7,94	6700±80	7189
47	bh 363	-2.70/-2.50	6340±110	7185
48	Wolvenest	-2.67/-2.63	6200±80	7164
49	Orth. Kerk	-3.38/-3.33	6190±65	7159
50	bh 999	-4.68/-4.65	6110±60	7140,7008
51	bh 1050	-4.08	6240±90	7100
52	Suikerfabriek	-3,47	6590±60	7087
53	Mil. Vliegveld	-4.14	6550±50	7021
54	bh 1004	-3.70/-3.67	6130±100	7005
55	Suikerfabriek	-3,32	6110±50	6967
56	Waterhoek bis	-3.60/-3.50	6100±60	6947
57	Westende 1	-2.68	6040±80	6890
58	bh 362	-2.00	6015±65	6885
59	bh 742	-2.25	5970±120	6846
60	Vliegveld	-2.39/-2.33	5960±55	6828
61				
62	bh 363	-2.50	6340±110	6828
63	Suikerfabriek	-2,35	6330±70	6776
64	Suikerfabriek	-3,42	5900±45	6733
65	Spoorweg	-2.14/-2.09	5850±55	6723
66	bh 407	-2.25	5830±115	6670
67	Orth. Kerk	-3.01/-2.95	5810±75	6668
68	B5B	-3.17	6215±35	6654
69	Noordhoek	-2.37/-2.30	5770±100	6581
70	Noordhoek	-2.37/-2.30	5770±100	6570
71	Jacobs	-2.70/-2.58	5715±75	6526
72	Waterhoek bis	-2.45/-2.43	5740±60	6500

Calibrated age 2s range	Dated material	Laboratory number	Ref.
7440-7271	top basal peat	KIA 12246	12
7568-7189	base intercalated peat	IRPA 515	3
7510-7200	vegetation horizon	UtC 3722	5
7449-7179	base intercalated peat	IRPA 561	2
7479-7018	base intercalated peat	IRPA 724	12
7429-7179	base intercalated peat	IRPA 871	3
7382-7219	base basal peat	UtC 5637	6
7380-7150	*Cerastoderma*	IRPA 1095	5
7479-6746	intercalated peat (mean)	UtC 2637	6
7360-7000	*Ostrea*	UtC 4168	5
7289-6898	intercalated peat (mean)	Hv 8795	1
7279-6857	top intercalated peat	IRPA 559	2
7260-6889	base intercalated peat	IRPA 831	4
7175-6884	base intercalated peat	UtC 2294	4
7283-6891	base basal peat	UtC 5636	6
7210-6910	*Cerastoderma*	UtC 4174	5
7169-6888	*Scrobicularia*	UtC 4862	12
7210-6781	base intercalated peat	UtC 2627	6
7130-6850	top second peat	IRPA 1074	5
7098-6791	base gyttja	NZA 11945	12
7169-6729	base intercalated peat	UtC 1537	8
7149-6729	base intercalated peat	HV 8799	3
7161-6494	base basal peat	IRPA 725	3
6984-6677	base intercalated peat	IRPA 849	8
7289-6898	intercalated peat (mean)	HV 8796 + HV 8795	3
6980-6610	*Cerastoderma*	UtC 3941	5
6860-6640	base second peat	IRPA 1189	5
6846-6535	top intercalated peat	IRPA 834	3
6892-6357	basal peat (mean)	ANTW 136	12
6846-6449	top intercalated peat	IRPA 612	3
6771-6520	*Scrobicularia*	KIA 12254	7
6845-6316	base basal peat	IRPA729	8
6790-6360	base intercalated peat	IRPA 729	3
6729-6315	basal peat (mean)	IRPA 617	3
6666-6406	top gyttja	NZA 11944	12

N°	Site	Sample altitude m TAW	Age ^{14}C yrs BP	Calibrated age yrs BP
73	Spermalie 2	-1.04	5650±70	6445
74	Dijk	-2.59/-2.54	5550±75	6314
75	Vliegveld	-1.96	5540±55	6312
76	bh 746	-0.56	5490±100	6299
77	bh 1004	-2.74/-2.70	5480±80	6290
78	bh 1074	-3.43	5885±35	6287
79	Waterhoek	-2.31/-2.25	5400±90	6195
80	bh 1057	-0.55	5395±40	6195
81	Jacobs	-0.82/-0.80	5360±70	6184
82	B 71	-1.25	5310±190	6100
83	3-Grachten	-2.22/-2.16	5220±70	5982
84	Suikerfabriek	-0,67	5610±55	5980
85	Violon	-0.45/-0.40	5160±70	5937
86	Suikerfabriek	-7,00	5430±55	5822
87	Orth. Kerk	-0.49/-0.46	5130±70	5923
88	B 71	-0.85	5100±140	5906
89	Westende 1	-0.80/-0.75	5125±55	5890
90	Suikerfabriek	-7,00	5420±50	5766
91	bh 747	+0.99	4990±70	5732
92	Wolvenest	-0.53/-0.49	4970±70	5729
93	Spoorweg	+0.56/+0.49	4920±55	5713
94	bh 747	+0.99/+0.89	4990±70	5710
95	Waterhoek bis	-1.86/-1.84	4915±60	5630
96	B14 Bulskamp	-0.02	5280±35	5622
97	Spermalie 2	-0.39/-0.29	4860±70	5610
98	Moerhof	+0.95/+0.90	4830±70	5588
99	Vliegveld	-1.68/-1.64	4820±70	5570
100	Suikerfabriek	-2,77	5170±45	5555
101	Suikerfabriek	-2,65	5160±50	5546
102	bh 363	+0.10	4800±80	5509
103	Suikerfabriek	-7,00	5140±50	5493
104	Oostkerke	+1.08/+1.05	4750±70	5472
105	bh 990	+0.14	4720±100	5460
106	Vliegveld	-1.56/-1.52	4700±70	5453
107	Vliegveld	-1.56/-1.52	4700±70	5400
108	Gracht 2	+2.70	4660±50	5400

Calibrated age 2s range	Dated material	Laboratory number	Ref.
6632-6298	top basal peat	IRPA 519	1
6523-6194	*top intercalated peat*	IRPA 613	3
6449-6279	base intercalated peat	IRPA 924	3
6479-5995	base basal peat	IRPA 722	3
6456-6170	top intercalated peat	UtC 2291	6
6399-6192	*Scrobicularia*	UtC 5999	6
6406-5951	top gyttja	IRPA 875	4
6288-6167	base gyttja	UtC 5539	6
6299-5951	base intercalated peat	IRPA 538	3
6479-5652	base basal peat	ANTW 251	1
6189-5770	base intercalated peat	IRPA 531	3
6160-5880	*Scrobicularia*	IRPA 1078	5
6170-5739	base intercalated peat	IRPA 562	2
5930-5650	*Spisula*	UtC 3719	5
6163-5729	base intercalated peat	IRPA 532	3
6189-5589	top basal peat	ANTW 250	1
6000-5730	base intercalated peat	IRPA 846	3
5910-5650	*Cerastoderma*	UtC 4178	5
5929-5589	base basal peat	IRPA 723	12
5919-5589	base intercalated peat	IRPA 560	3
5858-5494	base intercalated peat	IRPA 848	3
5900-5600	base intercalated peat	IRPA 723	3
5754-5578	base intercalated peat	NZA 11943	12
5753-5543	*Scrobicularia*	KIA 12255	7
5720-5430	base intercalated peat	IRPA 518	3
5729-5330	base surface peat	IRPA 564	3
5680-5390	top intercalated peat	IRPA 866	3
5650-5380	*Barnea*	UtC 3725	5
5630-5340	*Barnea*	UtC 4176	5
5728-5319	base intercalated peat	HV 8794	3
5610-5320	*Cerastoderma*	UtC 4171	5
5649-5309	base intercalated peat	IRPA 868	3
5652-5253	base basal peat	UtC 2636	6
5589-5299	base intercalated peat	IRPA 865	8
5580-5280	base intercalated peat	IRPA 865	3
5488-5287	base basal peat	UtC 4143	12

Table 1. Radiocarbon ages and calibration dates from the western coastal plain.

N°	Site	Sample altitude m TAW	Age ^{14}C yrs BP	Calibrated age yrs BP	Calibrated age 2s range	Dated material	Laboratory number	Ref.
109	Suikerfabriek	+0.18	4610±40	5314	5450-5250	base intercalated peat	IRPA 1180	5
110	Dam 5	+3.25	4600±50	5307	5336-5241	base basal peat	UtC 4144	12
111	Wale 2	+3.40	4560±60	5293	5330-5029	base basal peat	UtC 4145	12
112	Leffinge	+1.80	4465±220	5049	5649-4457	base basal peat	IRPA 282	1
113	Waterhoek	-0.70/-0.66	4460±60	5048	5299-4869	clayey peat	IRPA 873	4
114	Suikerfabriek	-2,46	4790±50	5027	5240-4870	*Cerastoderma*	IRPA 1114	5
115	Adinkerke Autostr.	+0.93	4435±40	5000	5079-4869	base intercalated peat	IRPA 1151	7
116	Lekebek 2	+3.82	4270±70	4838	4989-4790	base basal peat	UtC4142	12
117	Nieuwpoort 2	+0.19/+0.12	4220±65	4743	4964-4563	base intercalated peat	IRPA 726	3
118	GBV	+1.40	3970±35	4415	4524-4343	base intercalated peat	UtC 8247	7
119	GBV	+1.60	3760±35	4100	4231-4052	top intercalated peat	UtC 8248	7
120	Kromfort	+1.60	4065±35	4083	4238-3925	*Scrobicularia*	UtC 5386	7
121	Kromfort	+2.00	4060±50	4077	4261-3894	*Hydrobia*	UtC 5527	7
122	Lekebek 4	+3.25	3640±40	3931	4052-3850	base basal peat	IRPA 1173	12
123	Nieuwpoort 2	+0.61/+0.57	3580±60	3885	4082-3709	top intercalated peat	IRPA 727	3
124	Wolvenest	+0.18/+0.15	3550±60	3844	4065-3689	base intercalated peat	IRPA 860	3
125	Adinkerke Autostr.	+1.58	3550±40	3835	3919-3702	top peat	IRPA 1165	7
126	Wulpen	+1.83	3490±60	3787	3961-3629	base intercalated peat	IRPA 527	3
127	GBV	+2.25	3395±35	3631	3702-3548	base peat	IRPA 1237	7
128	bh 363	+1.75	3290±80	3554	3699-3379	top intercalated peat	HV 8793	3
129	GBZ	+2.35	3270±40	3469	3579-3380	base reed peat	IRPA 1231	7
130	Kromfort	+2.50	3055±35	3260	3355-3201	vegetation horizon	UtC 5122	7
131	GBV	+3.20	3055±45	3259	3360-3143	peat/humic sand	UtC 5651	7
132	Adinkerke Autostr.	+1.78	3030±40	3244,3223,3217	3280-3107	base peat	IRPA 1153	7
133	GBV	+2.80	3020±40	3211	3275-3077	top peat bed (erosive)	UtC 6743	7
134	Wulpen	+2.00	2970±60	3170	3349-2959	top intercalated peat	IRPA 528	3
135	De Panne Stort 1	+1.85	3260±60	3089	3299-2879	*Cerastoderma*	IRPA 793	8
136	Wolvenest	+0.68/+0.63	2710±60	2792	2949-2749	top intercalated peat	IRPA 859	3
137	Orth. Kerk	+1.10/+1.05	2690±45	2782	2871-2749	top intercalated peat	IRPA 832	3
138	De Panne DO2	+1.95	2970±70	2740	2860-2607	*Scrobicularia*	IRPA 792	8
139	GBZ	+2.70	2560±40	2734	2678-2479	top peat	UtC 6730	7
140	Vliegveld	-0.26/-0.23	2580±60	2720	2800-2450	top intercalated peat	IRPA 512	3

Ref.: 1. Baeteman, 1981; 2. Baeteman, 1985; 3. Baeteman and Van Strydonck, 1989; 4. Baeteman, 1993; 5. Baeteman et al., 1999; 6. Baeteman, 1999; 7. Baeteman, 2001a; 8. Denys, 1993; 9. De Ceunynck, 1985; 10. De Ceunynck et al., 1986; 11. Denys and Baeteman, 1995; 12. this publication.

shows the borehole distribution with an indication of the known and unknown original surface (the boreholes from the Geotechnical Institute not penetrating the Pleistocene subsoil are not indicated).

Thus the reconstruction of the original surface is based partly on exact data, partly on interpretation. Although the interpretation involves a certain measure of subjectivity (cf. Streif, 1998; Vos and Van Heeringen, 1997), certain points are taken into consideration from which data can be inferred indirectly. Boreholes with a thick Holocene sequence, but not yet reaching the Pleistocene/Holocene boundary, give information that the boundary is at least deeper than the depth of the borehole. Missing points were also inferred from borehole correlation in cross-sections. It has been observed that the late Holocene tidal channel incisions reoccupied the same location as the palaeovalleys (Baeteman, 1999) or older tidal channels (Baeteman et al., 1999). In some cases, the sedimentary record of the

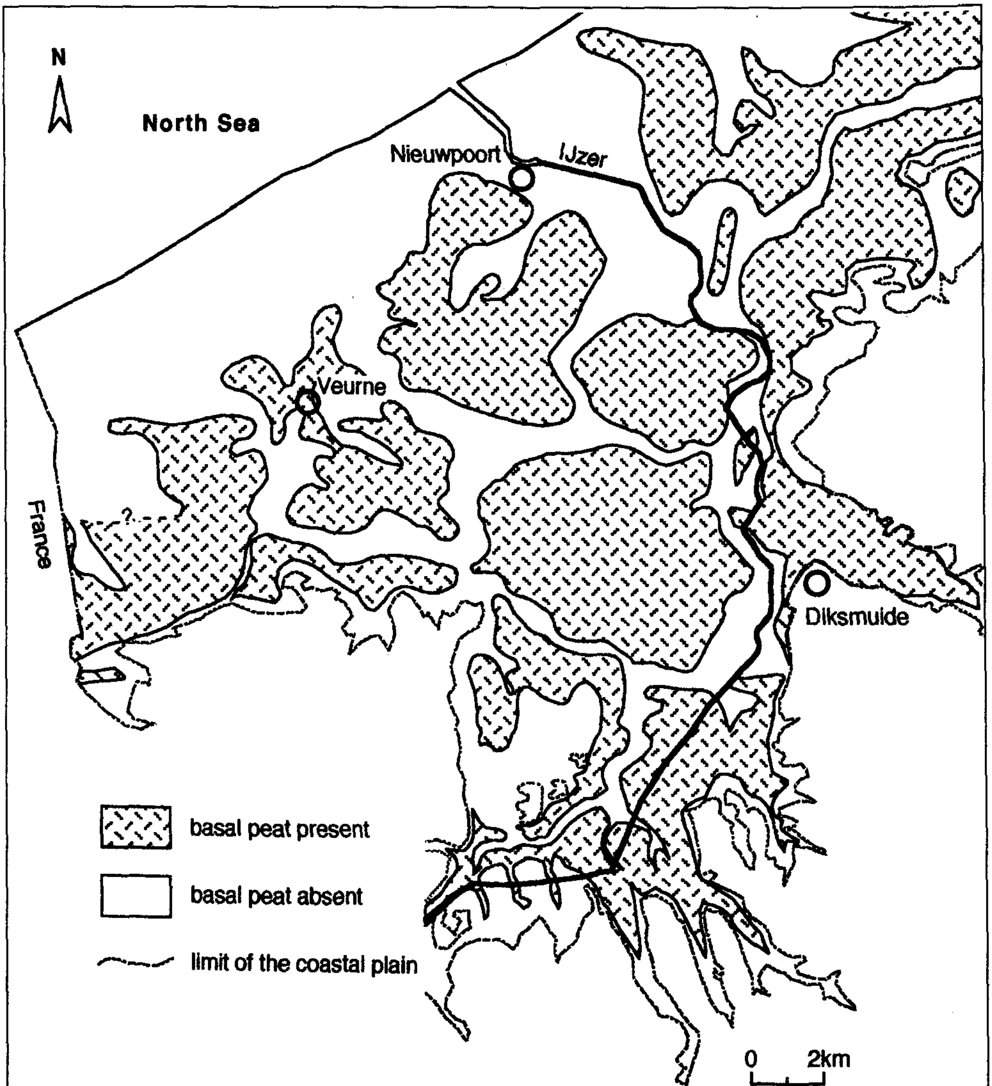


Figure 3. Distribution of the basal peat.

palaeovalley fill escaped from later erosion in restricted parts, providing valuable information about the existence of a valley in the original surface. Fig. 4 shows such an example of late Holocene channel incision (boreholes 867 and 540) in a palaeovalley fill leaving a small portion of the initial mud and peat layers (borehole 203). The remaining part of the palaeovalley was filled by sand of an early Holocene tidal channel, impossible to penetrate with the handauger. The palaeovalleys in the southern part of the plain in particular show such a favourable situation (Fig. 5). However, it is more a question of being lucky rather than the rule to find these «small portions» by means of boreholes and in many cases only sand-filled channels are found. In this case, the sedimentary record adjacent to the location of the late Holocene sand-filled channel must be analysed in detail. Sand deposits within a mud and peat sequence can represent sand flats, sand bars or crevasse splays which are associated with migrating tidal channels (Van der Spek and Beets, 1992; Cleveringa, 2000; Baeteman et al., 1999). So the sand deposits indicate the proximity of an early and/or middle Holocene tidal channel which most of the time occupied a palaeovalley, thus indirectly indicating the presence of a deeper Pleistocene surface.

Because of these constraints, the isohypse map (Fig. 6) of the original Pleistocene relief has been constructed manually and not by geostatistical software. It is self-evident that in areas with a low coverage of known data points, the isohypse map is more schematic than in areas with a dense data set. The morphology of the pre-Holocene surface contrasts with the contour map showing the real top of the Pleistocene deposits previously published (Baeteman, 1993, 1999).

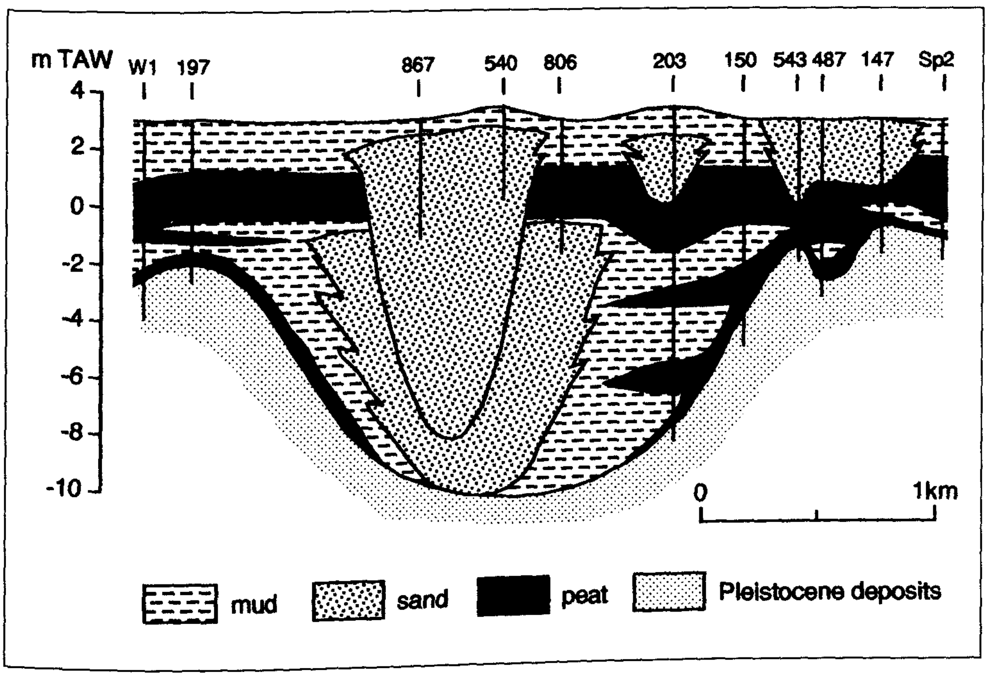


Figure 4. Cross-section through the palaeovalley east of Nieuwpoort showing a late Holocene tidal channel incision (boreholes 867 and 540) and a portion of the mud and peat palaeovalley fill (borehole 203) indicative for the existence of a depression in the pre-Holocene surface.

The timing of the marine inundation is recorded from dating the basal peat. In general, the basal peat is formed due to the rising groundwater level which is dependent on sea level. The post-glacial RSL rise induced the groundwater level to rise and freshwater marshes developed with peat accumulation. However, as will be demonstrated at some locations, basal peat was formed independently from the contemporary position of the sea level under the influence of local hydrological conditions. The start of the basal peat corresponds approximately to local mean highwater level (Van de Plassche, 1982; Vos and van Heeringen, 1997). The basal peat is a time-transgressive unit shifting landward and upward with the rising sea level. Thus basal peat provides a time-depth relationship. Age and elevation of the basal peat are used to construct a curve of relative sea-level rise, which in turn can be used to infer the onset of basal peat formation. So where the basal peat is missing, the contour lines of the original Pleistocene surface have been used as guidelines for time boundaries on the basis of this time-depth relationship (Vos and van Heeringen, 1997).

The contact of the basal peat with the overlying clastic unit used to construct the RSL curve, was only dated when it was not showing erosion or reworking as determined by diatom analysis (Denys, 1993; Denys and Baeteman, 1995). For the time-place estimate for the onset of marine inundation, dates of intercalated peat beds were not used because their original elevation altered due to consolidation and compaction. Only dates from sites where compaction is considered to be negligible, were used. On the other hand, the dates of the intercalated peat beds form the basis for the chronology of the sedimentary infilling of the area.

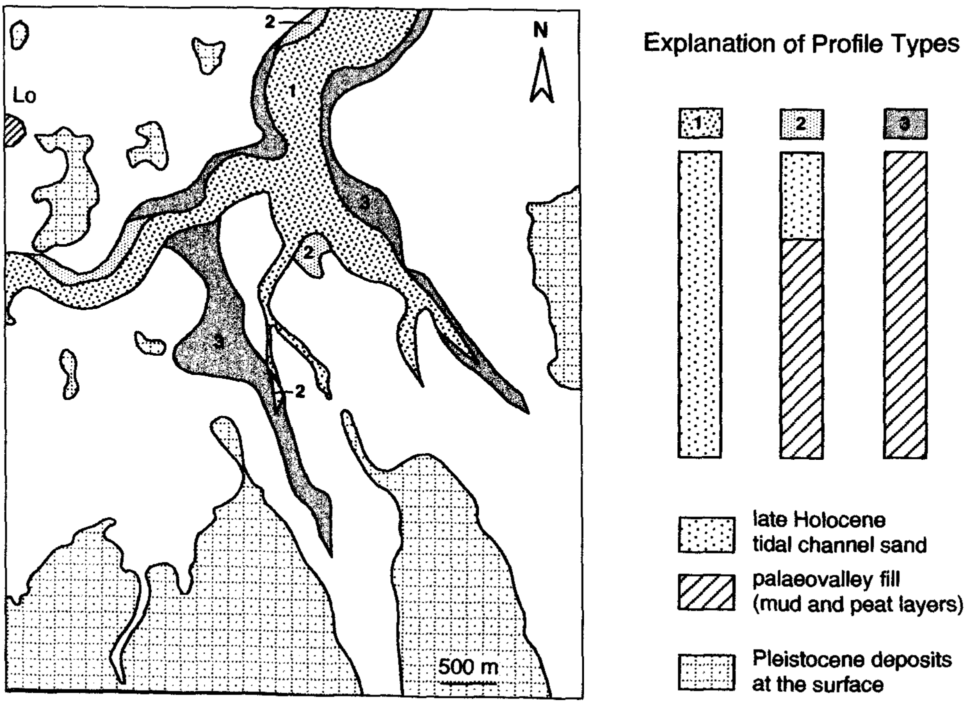


Figure 5. Simplified sequence map to illustrate a late Holocene channel incision (profile type 1 and 2) leaving a portion of the original palaeovalley fill in restricted zones (profile type 2 and 3). Redrawn from Baeteman (1999).

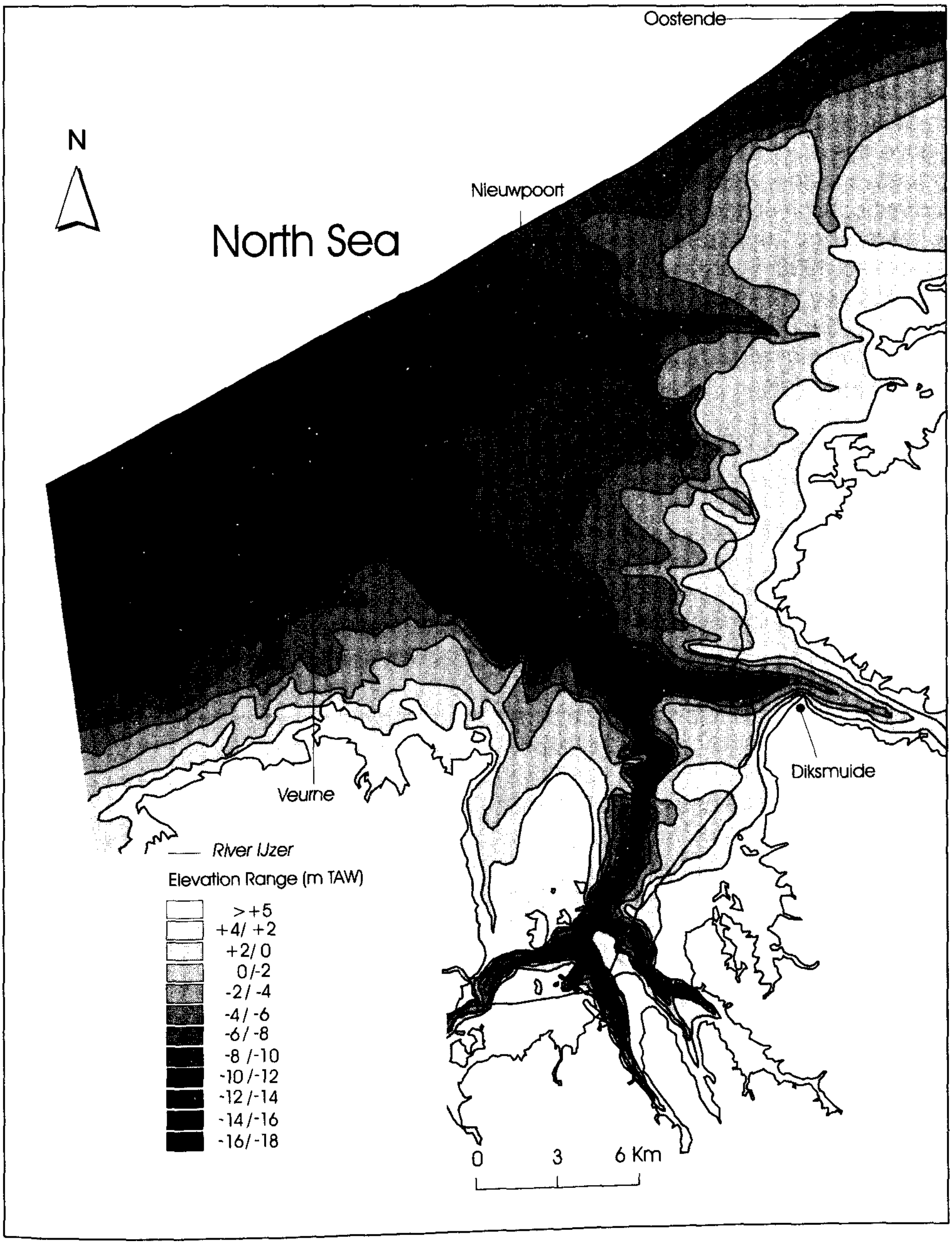


Figure 6. Isohypse map of the pre-Holocene surface at a 2 m interval relative to TAW. Due to the (inevitable) vertical exaggeration the map gives a wrong impression of the relief of the river valleys. In reality, they are shallow with gentle slopes.

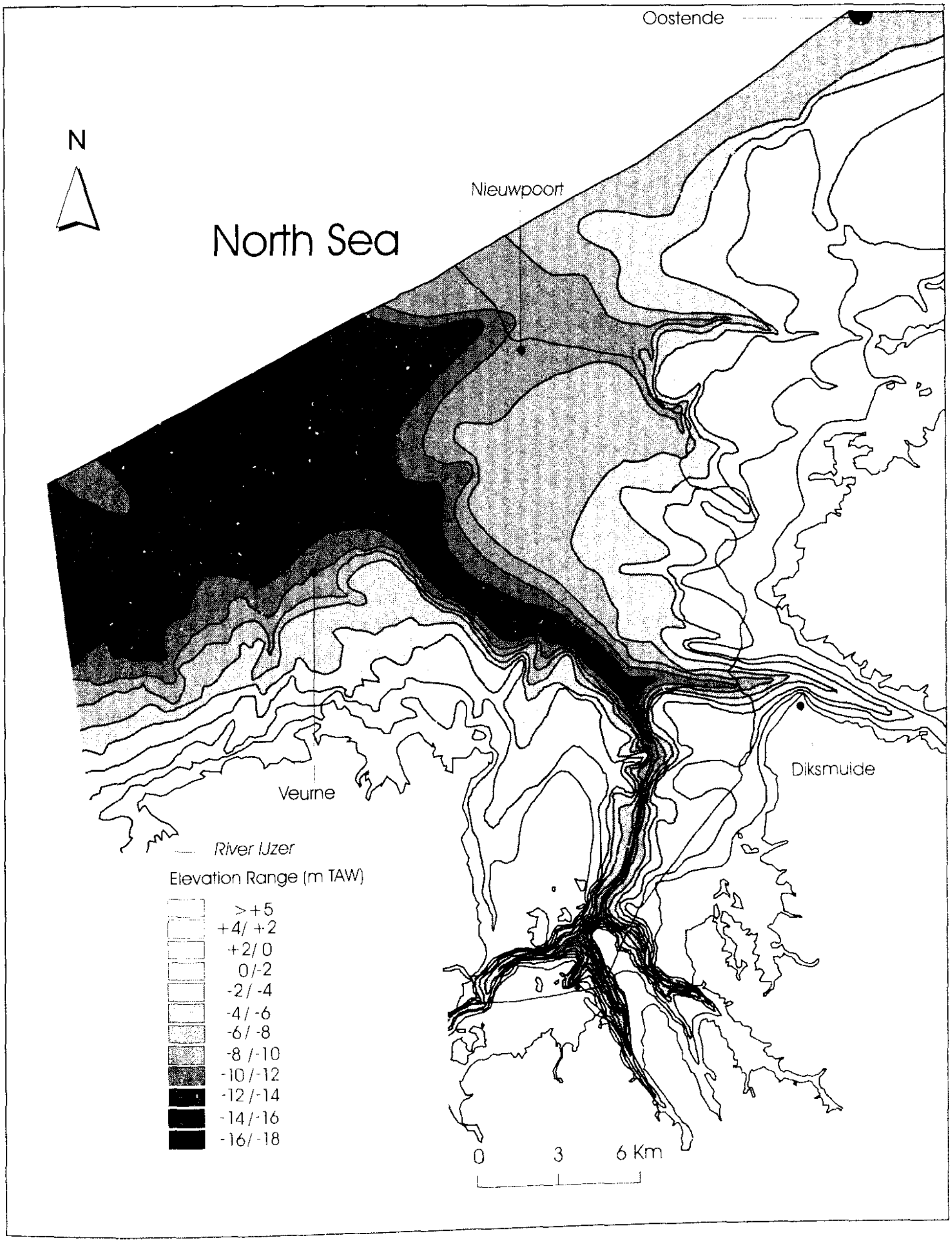


Figure 6. Isohypse map of the pre-Holocene surface at a 2 m interval relative to TAW. Due to the (inevitable) vertical exaggeration the map gives a wrong impression of the relief of the river valleys. In reality, they are shallow with gentle slopes.

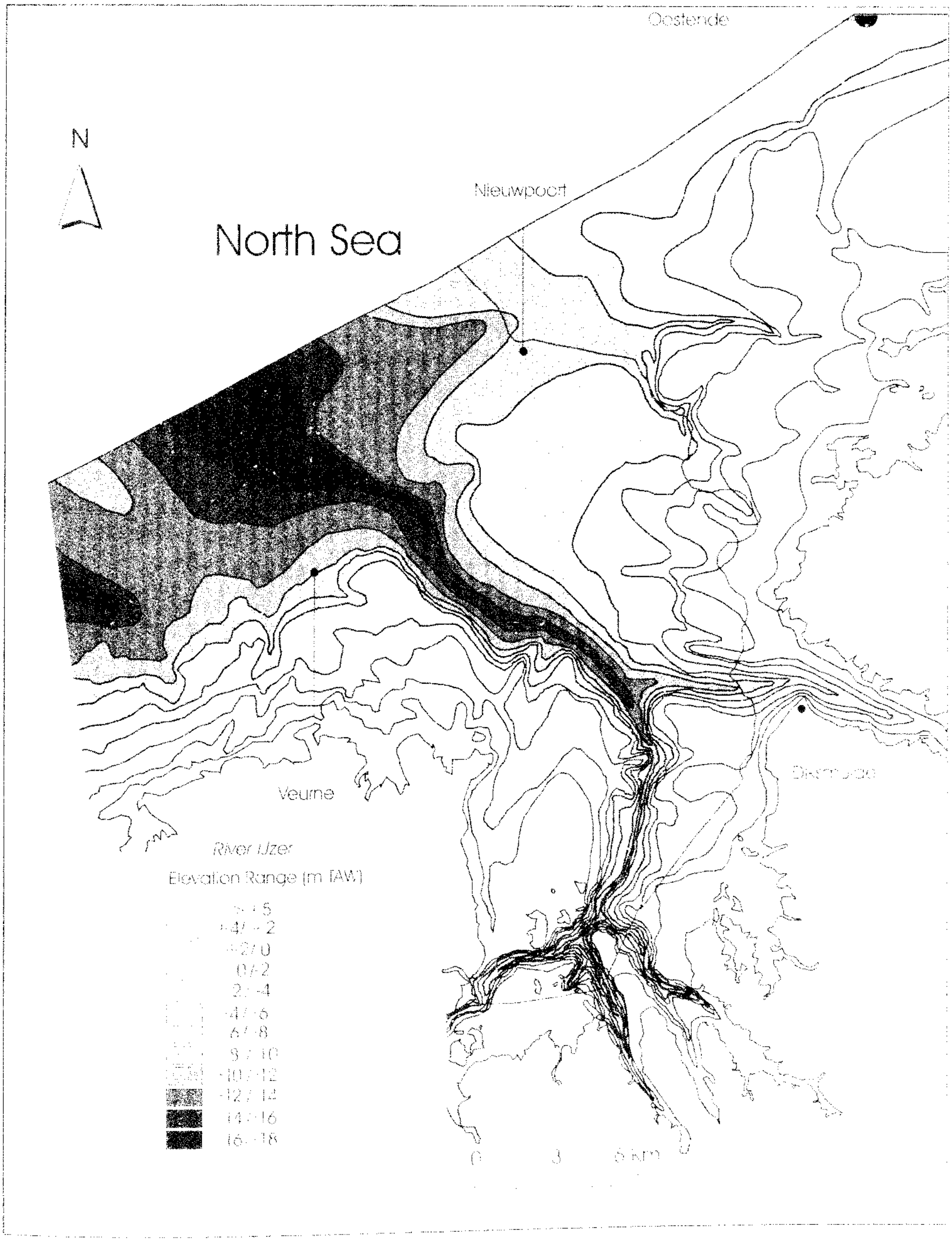


Figure 6. Isohypse map of the pre-Holocene surface at a 2 m interval relative to TAW. Due to the (inevitable) vertical exaggeration the map gives a wrong impression of the relief of the river valleys. In reality, they are shallow with gentle slopes.

The development of a coastal plain is a function of the following factors: rate of relative sea-level rise, morphology of the flooded surface, sediment budget and accommodation space, the latter effected by sediment and peat compaction (Baeteman, 1998; Beets and van der Spek, 2000). During the infill of the area, initially caused by the RSL rise, the relative importance of the individual factors changes in the course of time.

RELATIVE SEA-LEVEL RISE AND SEDIMENT BUDGET

The RSL rise in the western part of the Belgian coastal plain is recorded as from ca. 9500 cal BP. This contrasts the general view in the literature where sea level starts to rise as from 5000 BP (ca. 5500 cal BP, e.g. Maréchal, 1992; Jacobs and De Ceukelaire, 2002). As will be discussed below, the depositional history of the area is mainly a function of changes in the rate of RSL rise.

The sea-level curve generated for this area (Fig. 7, Denys and Baeteman, 1995; Baeteman 2001a, 2001b) shows that the rate of RSL rise prior to ca. 7500 cal BP was in the order of 7 m/ka. At this high rate, the area was flooded rapidly and tidal environments shifted landward towards a position close to the present-day limit of the coastal plain. The rapid RSL rise created plenty of accommodation space so that little to no erosion occurred. Since no lagoonal environments were ever encountered, but on the contrary, vegetation horizons originating on supratidal flats, it is assumed that supply of sediment was suf-

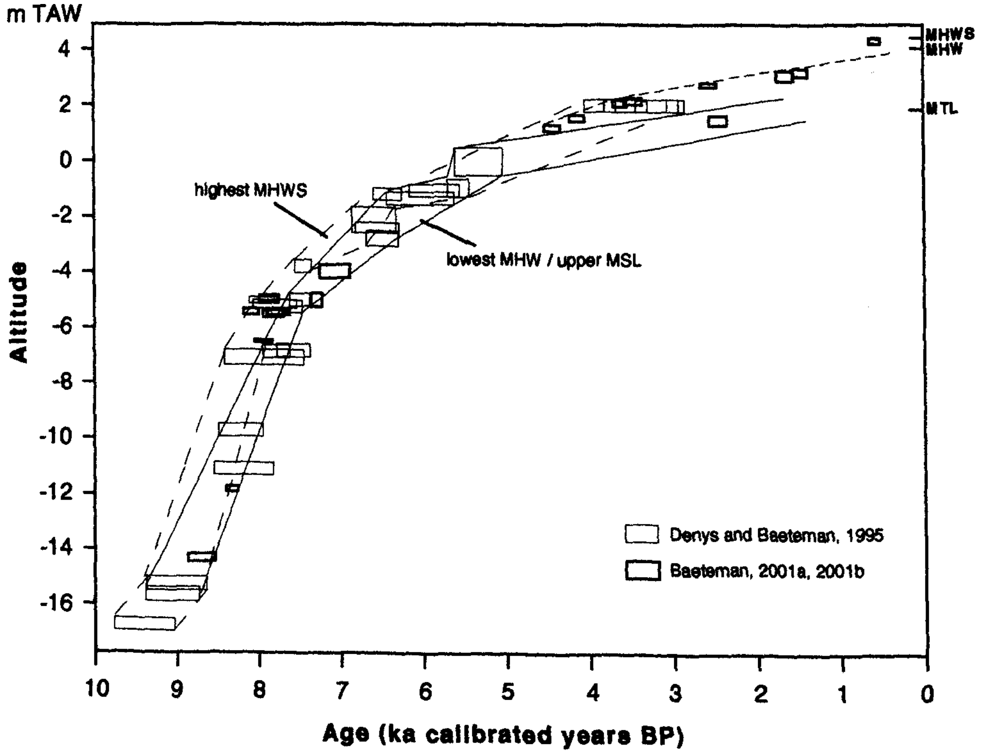
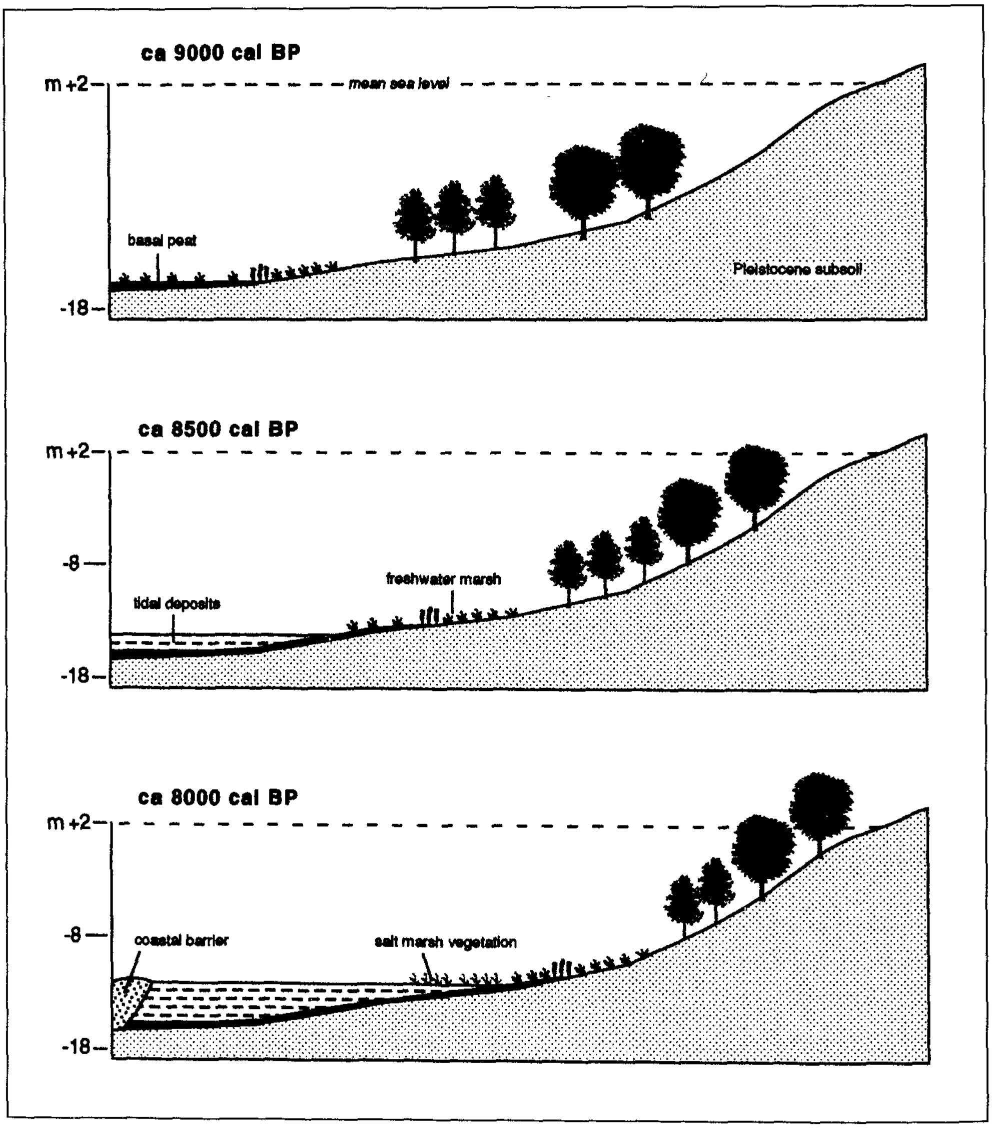


Figure 7. Relative sea-level curve for the study area (from Denys and Baeteman, 1995 completed with data from Baeteman 2001a, 2001b). The 2 sigma standard deviations were used in constructing the error boxes. MHWS: mean high water spring tide, MSL: mean sea level, MTL: mean tide level.

ficient. This is in contrast with the situation in The Netherlands where sediment supply was insufficient to compensate for the accommodation space created by the rapid RSL rise (Beets and van der Spek, 2000). In Zeeland, on the other hand, intertidal and supratidal sediments of this period were found in many places in the tidal basin implying that sedimentation rate was able to keep up with RSL rise (Vos and van Heeringen, 1997). In the study area, sediment accumulation in an intertidal and supratidal environment kept pace with the rate of RSL rise and vertical sediment accretion was dominant for the period prior to ca. 7500 cal BP (Fig. 8). However, erosion did occur at the shoreface. At the onset of the RSL rise, most of the fluvial sediments were trapped within the estuary, reducing to nearly zero the volume of sand supplied to the adjacent shorelines (Allen and Posamentier, 1994). This resulted in coastal erosion by waves and a landward shift of the coastal barrier. The definition of a coastal barrier as described by Roy et al. (1995) will be used here, i.e. elongated, shore-parallel sand bodies, extending above sea level and consisting of a number of sandy lithofacies including beach, dune, shoreface, tidal delta, inlet and washovers. To clarify certain misconceptions, the presence of a coastal barrier does not necessarily imply the existence of well developed aeolian deposits decorating the barrier.

The rate of RSL rise dropped to ca. 2.5 m/ka after about 7500 cal BP. Consequently, the rapid landward shift of the tidal environments stopped and the position of the coastal barrier became more or less stable (Fig. 8). Sediment supply was now in balance with the accommodation space created by RSL rise. Periods of emergence lasted much longer and freshwater conditions prevailed for short periods (in the order of about 200 years, Baeteman et al., 1999). Salt marsh vegetation evolved into reed growth resulting in peat accumulation (Fig. 8). These freshwater marshes developed locally in the relatively higher silted-up areas which, for a certain time, were out of the reach of daily tidal flooding and consequently deprived of sediment. However, sand and mud accretion supplied by channels, continued in the nearby areas. When the latter were in turn silted up sufficiently high, meander cut-offs and crevasse splays resulted in a lateral shift of the position of the channel (Baeteman, 1998, 1999; Baeteman, et al., 1999). This happened during storm events when the water stored in the channel reached far above normal high-water level and produced ebb-flow accelerations during discharge (Cleveringa, 2000). Due to the lateral shift, the marsh area changed again into intertidal flat. The area abandoned by the channel, filled with sediment in a relatively short period (months to years, Oost and de Boer, 1994; van den Berg, 1982) and in turn evolved into salt marsh followed by freshwater marsh with peat accumulation. This process happened repeatedly and is the origin of the alternation of mud and peat beds in the sedimentary record. This sedimentary process is governed by the position of the tidal channels and thus by sediment budget and not by sea-level fluctuations such as Gullentops and Broothaers (1996) claimed in their sea-level curve whereby the sea level drops by about 1 m every time an intercalated peat bed occurs. This process, however, implies that the channel network is still migrating landwards, but at a reduced rate. The shift of the channels alternately serving and abandoning a particular part of the tidal flat continues only as long as new accommodation space is steadily being created by a sea-level rise, so that the entire channel network can continue to migrate landwards and upwards. Sediment supply must also balance the creation of accommodation space, otherwise silting up in the channel would not occur, nor would the flats silt up each time to the upper intertidal and supratidal level (Baeteman, 1999).

In the period following the first substantial decrease in the rate of the RSL rise, the direct impact of the RSL rise is subordinate to the impact of sediment budget and the effect of local variations in the distribution of sediments.


ca 9000 cal BP
m +2
mean sea level
basal peat
Pleistocene subsoil
-18
ca 8500 cal BP
m +2
-8
freshwater marsh
tidal deposits
-18
ca 8000 cal BP
m +2
-8
coastal barrier
salt marsh vegetation
-18

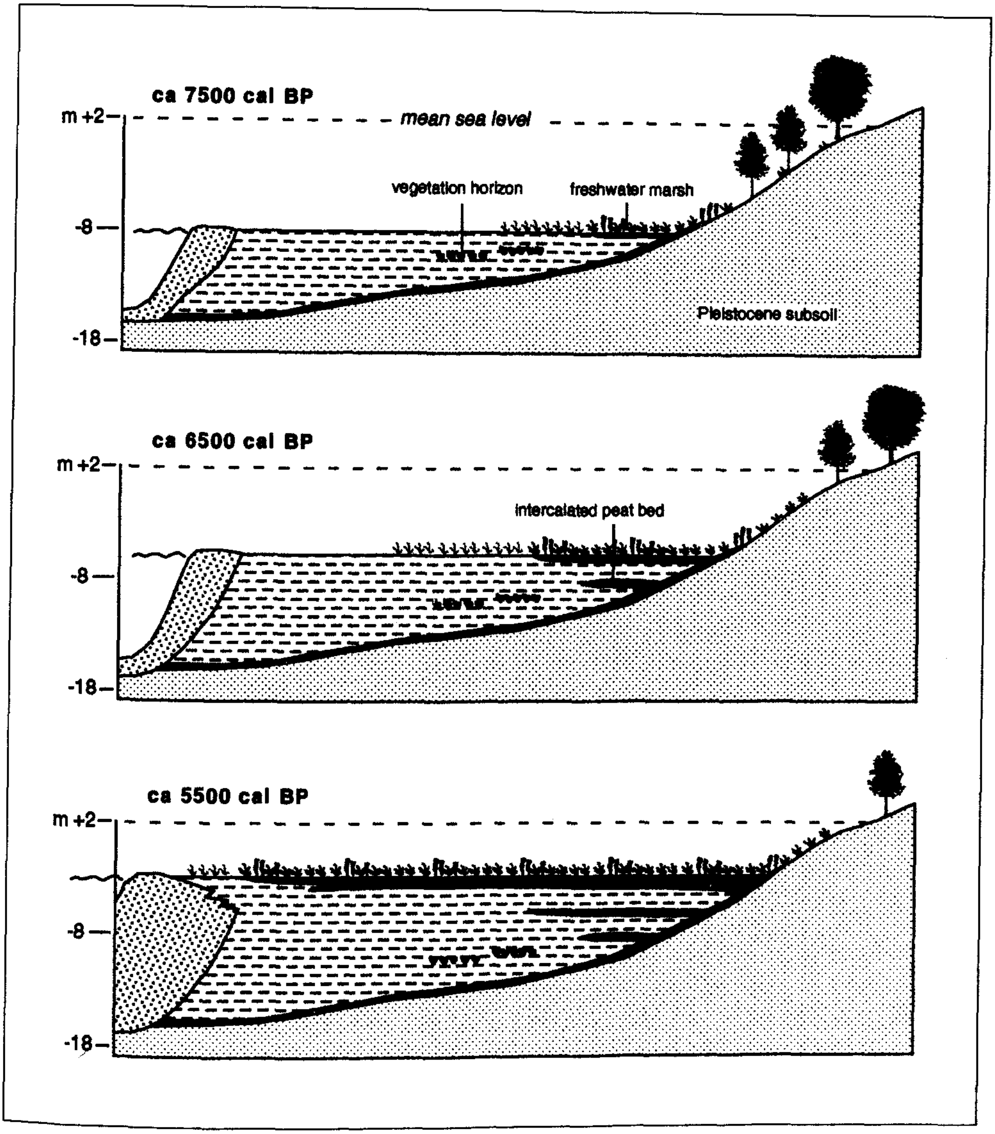


Figure 8. Schematical cross-sections from sea to land illustrating the vertical sediment accretion, the lateral expansion and the evolution of the various environments through time. In order to simplify the evolution, a tidal channel is not incorporated. (Note that the depth is relative to mean sea level and not to TAW.)

RSL rise continued to decrease to reach an average of 0.70 m/ka after ca. 5500-5000 cal BP. This is about the same average RSL rise as measured nowadays (Van Cauwenberge, 1993). From 5500-5000 cal BP, sea level has been close to its maximum and sediment supply has exceeded the creation of accommodation space. Landward migration of the tidal sedimentary environments has stopped completely, the stabilization of the shoreface has shifted to shoreface accretion and the shoreline has prograded beyond the present-day one (Fig. 8). Periods of peat growth have lasted longer and the lateral extension of the freshwater marshes has became more widespread. Between about 5500 and 4500 cal BP, almost the entire coastal plain was changed into a freshwater marsh with peat accumulation. In the very western and seaward parts of the study area, however, tidal sedimentation went on (Baeteman, 2001a). This peat accumulation which lasted almost 3000 years, could keep pace with the slow RSL rise. No substantial coastal changes are observed for that period. Traces of tidal influence in the thick peat bed in the landward areas (Denys, 1993) suggest that the major tidal channels remained open, although they mainly served as drainage for the peat swamp. Mud intercalations in the peat bed in the seaward areas originated from local floodings in different periods ranging between about 4000 and 2500 cal BP (Baeteman and Van Strydonck, 1989). Denys (1999) however, tends to interprete these local floodings as short periods of regional significant positive tendencies in the marine influence, at least those which occurred at about 4200 cal BP and 2100 cal BP. It is believed that the local floodings herald the end of the progradation and the re-entrance of the tidal system which led to the final fill of the plain (Baeteman, 1999; Baeteman et al., 1999). As mentioned above, this period will not be considered here. The mechanism and timing of the re-entrance of the tidal system is discussed in Baeteman et al. (2002) and is beyond the scope of this paper.

THE PRE-HOLOCENE SURFACE

The lithology of the Pleistocene substratum

The Pleistocene deposits in the western part of the coastal plain generally consist of clay, silt and fine sand of fluvial origin dating from the Late Pleistocene. In the seaward part, marine and coastal deposits from the Last Interglacial underlie the Holocene deposits, the fluvial portion being eroded during the middle and late Holocene (Baeteman, 1993). In the western part of the study area, the Pleistocene deposits, consisting most probably of slope deposits, are very thin and Tertiary deposits (Eocene, Kortrijk Formation, formely Ieper Clay, Jacobs and De Ceukelaire, 2002) are found in the shallow subsurface. In general, periglacial aeolian coversands from the Late Pleistocene are absent in this area.

The morphology of the flooded surface

The landscape prior to marine flooding consisted of a drainage pattern of 4 relatively small and shallow rivers joining in the central part of the plain and forming a southeast-northwest depression (Fig. 6). This depression is interpreted as a former palaeovalley of an ancient IJzer river. Note that in the coastal plain, the present-day course of the river is located outside the palaeovalley. The small southeast-northwest running valleys in the South reach a depth of about -8 m. The palaeovalley has a very gentle slope with depths of -12 m and -18 m in the central and seaward part, respectively. The relief of the pre-Holocene surface contrasts greatly between the western and eastern part. The eastern part has a flat morphology, while the slope is rather steep in the west. A low and small devide in the northwest separates the palaeovalley from an elongated depression. From the data available, it is difficult to ascertain whether this depression also belongs to a valley of an ancient river system, but the presence of basal peat indicates that the depression was not formed by tidal scour processes during the Holocene flooding.

As will be shown in the palaeogeographical maps, the valleys and depression were important as conduits (in the form of tidal channels) for water and sediments of the Holocene flooding the area, and have had a significant control on the distribution of the sediments. The devide developed into a headland, but as it was low, it was eventually also flooded and the entire area was transformed into a tidal basin.

Elevation model of the pre-Holocene surface

To better visualize the relief of the palaeovalley, a 3-dimentional digital terrain model was constructed on the basis of the manually-made isohypse map. Following this, the isohypse map was georegistered in a geographical information system (GIS) and the contour lines were digitized manually. Each polygon represents an elevation range (e.g. -2 to -4 m). A mean value was attributed to each polygon (e.g. -3 m) so that the entire surface of the polygon is fixed at the same elevation. As a result the surface appears as a staircase. This irregular surface made of polygons was then input into a TIN (Triangulated Irregular Network). A TIN is an object used to represent a surface (Ianko, 2002). In this case, the TIN is similar to a DEM (Digital Elevation Model). Since representation of a surface can be done in different ways (e.g. Delaunay triangulation), TIN also implies a specific storage structure of surface data. TIN divides a surface into a set of contiguous, non-overlapping triangles. A height value is recorded for each triangle node. Heights between nodes can be interpolated thus allowing for the definition of a continuous surface. TIN can accommodate irregularly distributed as well as selective data sets. With this method it is possible to represent a complex and irregular surface with a small data set, which is the case here.

A network of triangles allows the staircase aspect to be eliminated and the elevation variation can then be represented in three dimensions in a GIS (Fig. 9A). Note that the vertical exaggeration is at least 50 (10 being generally the maximum admitted) due to the weak elevation difference between the highest and lowest point (weakness of gradient). Some artifacts result from the conversion into the TIN representation, such as the connection between the two depressions in the NW part. The depressions are actually quite distinct, but the size of the most western polygon, the distance between the two depressions, and the difference in elevation are all too small to completely separate them. So the algorithm behind the TIN links the two depressions and allocates the same value to the new unit. In the smoothed version (Fig. 9B), the vertical exaggeration is changed to 100 for a better visualization.

PALAEOGEOGRAPHIES OF THE IJZER TIDAL BASIN

In this palaeogeographical study, the following environments have been used: tidal flat, tidal channel, coastal barrier and freshwater marshes or coastal peat bogs (cf. Fig. 8). The tidal flat as considered here, comprises subtidal shallow shoals, intertidal sandflats and mudflats, and supratidal salt marshes. Only the major tidal channels are represented.
We are aware that their spatial and temporal distribution is far from complete. This would require an even denser boring grid and, moreover, the pattern would still not be realistic. In the reconstruction of the earliest stages of coastal evolution, the course of the tidal channels is chosen arbitrarily because of the scarcity of sufficiently deep boreholes. The reconstruction of the position of the coastal barriers in the present-day offshore area is impossible since they dissappeared as a result of erosion. Therefore, no attempt was made to show them on the maps for the early Holocene, which does not imply that they did not exist. For the younger time slices however, few data for the coastal barrier

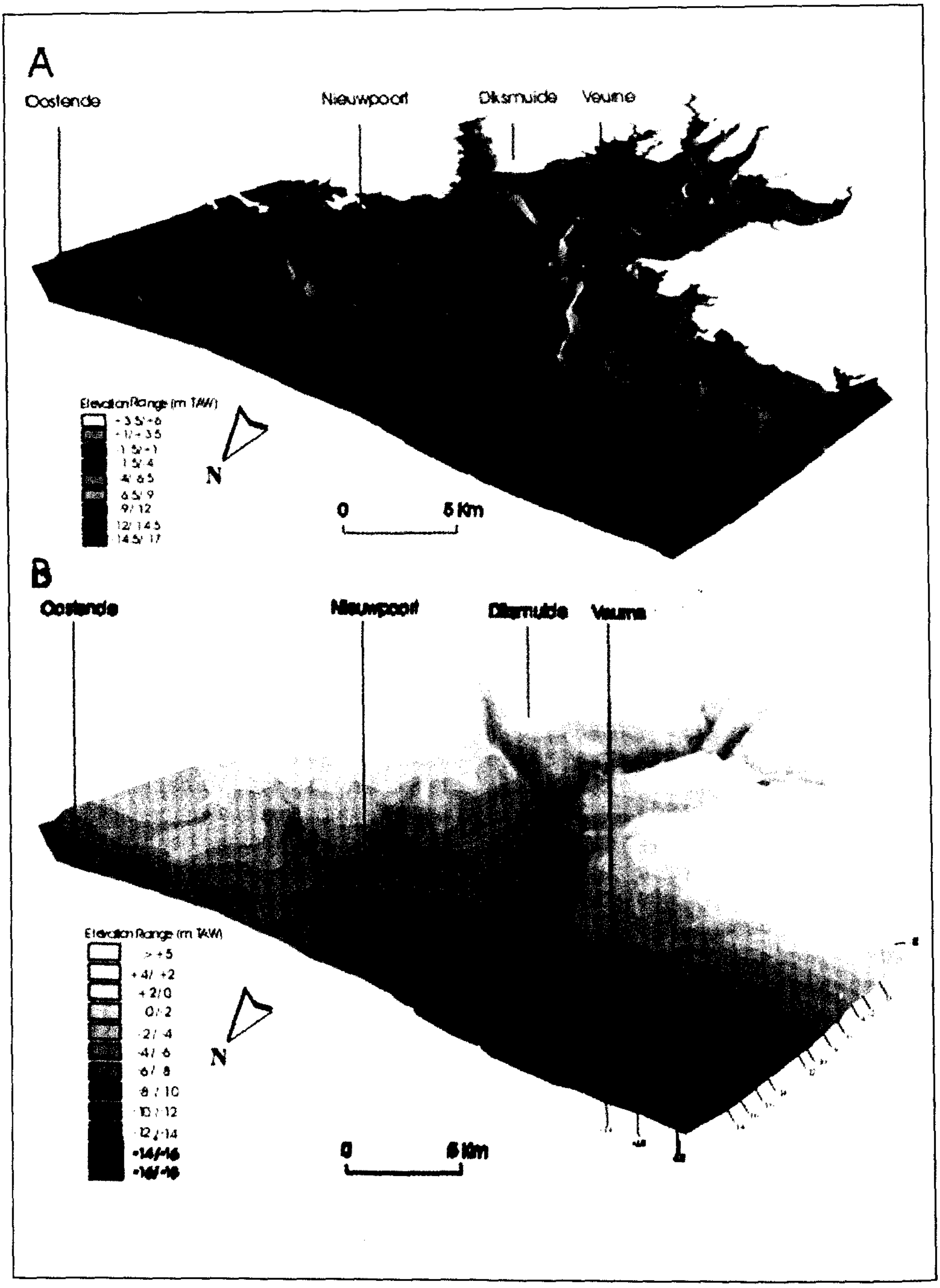


Figure 9. Three dimentional elevation model of the pre-Holocene surface. Fig. 9A: TIN representation; Fig. 9B: smoothed representation. The present-day coastline is the seaward boundary of the model.

are available (for the area around Nieuwpoort and the western part of the study area, Baeteman, 1999; Baeteman, 2001a). However, the presence and position of the coastal barrier was also inferred from associated sedimentary environments, although the major part of the position is chosen arbitrarily. The present-day shoreline is shown on the maps for reference.

This palaeogeography aims at a reconstruction of a large-scale pattern of coastal development, i.e. the progressive landward extention of the tidal basin in the course of time and the silting-up phases with peat accumulation. Therefore, short periods when tidal sedimentation prevailed, and which are recorded in the sedimentary sequence as an alternation of mud and peat, are not represented. Moreover, the presentation of the latter would require much more detailed maps.

The different time slices are chosen according to the available radiocarbon dates and to the major changes in the coastal development. Where the density of data points is low, the reconstruction is more schematical. The borehole data and cross-sections which form the basis for the reconstructions, are not presented in this paper. The significant ones can be consulted in the papers mentioned above. The reconstructions for the western part are redrawn from Baeteman (2001a). The ^{14}C dates are presented in Table 1 and the numbers in the text refer to the site numbers in the Table.

9400-9000 CAL BP RECONSTRUCTION (Fig. 10A)

The tidal system invaded the palaeovalley together with the western depression when relative sea level was at about -18 m. A headland came into being between the depressions. A tidal channel was installed while at the landward edge of the tidal flat, freshwater marshes with peat accumulation developed. For this period, only one borehole with a deep seated basal peat was found (n°1). The immediately overlying clastic sediments are fine-grained and indicative of low energy environments.

9200-9000 CAL BP RECONSTRUCTION (Fig. 10B)

Although RSL rise was rapid, the lateral extension of the tidal flat was not yet substantial because of the presence of the valley. This illustrates the effect of the morphology of the flooded surface on the distribution of the sediments. However, freshwater marshes in the palaeovalley have been found as far as the central part of the plain (n°4). One borehole (n°3) east of the tidal basin indicates that peat developed locally on higher ground, possibly enhanced by seepage since RSL was at about -15 m.

8700 CAL BP RECONSTRUCTION (Fig. 10C)

The RSL was at about -14 m and the tidal flat and channel continued slowly to extend into the palaeovalley and the western depression. The presence of *Scrobicularia plana* (n°6) indicates that in the tidal basin a low energy environment, i.e. mudflat, prevailed. The belt of freshwater marsh, shifting upland and inland, was still narrow because the relief prevented it from lateral expansion.

8400 CAL BP RECONSTRUCTION (Fig.10D)

About 1000 years after the tidal system encroached the area, and after a rise of the RSL of about 6 m, a first substantial lateral and landward expansion of the tidal flat and channels is seen, in particular in the western part. However, the headland in the NW was not yet flooded. Since no tidal flat can exist without a tidal channel, a channel has been drawn arbitrarily in the eastern extension of the tidal flat. The relatively flat relief of the Pleistocene surface resulted in a broader belt of freshwater marshes which also began to develop in two of the small rivers.

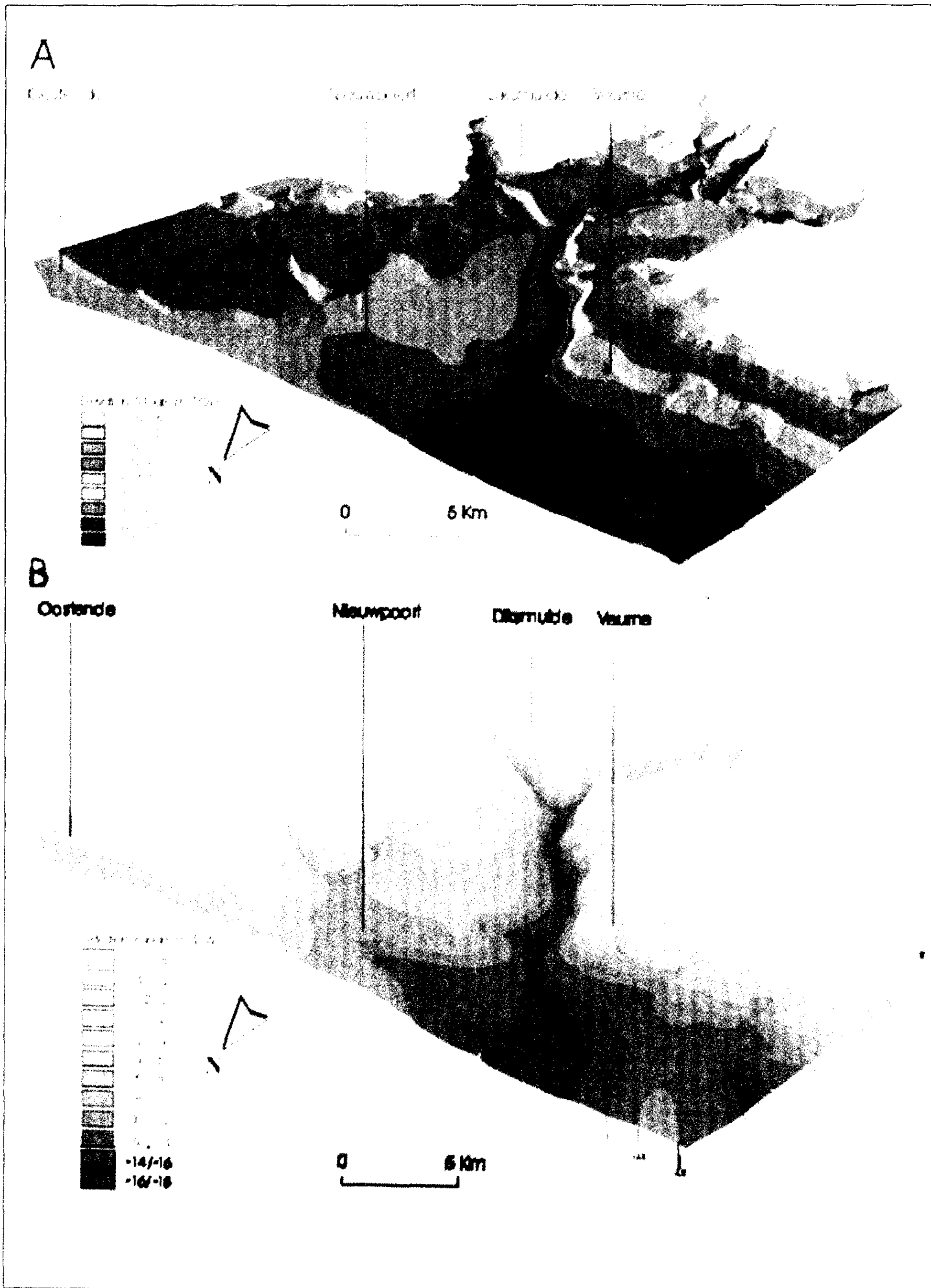


*Figure 9. Three dimentional elevation model of the pre-Holocene surface.
Fig. 9A: TIN representation; Fig. 9B: smoothed representation. The present-day coastline is the seaward boundary of the model.*

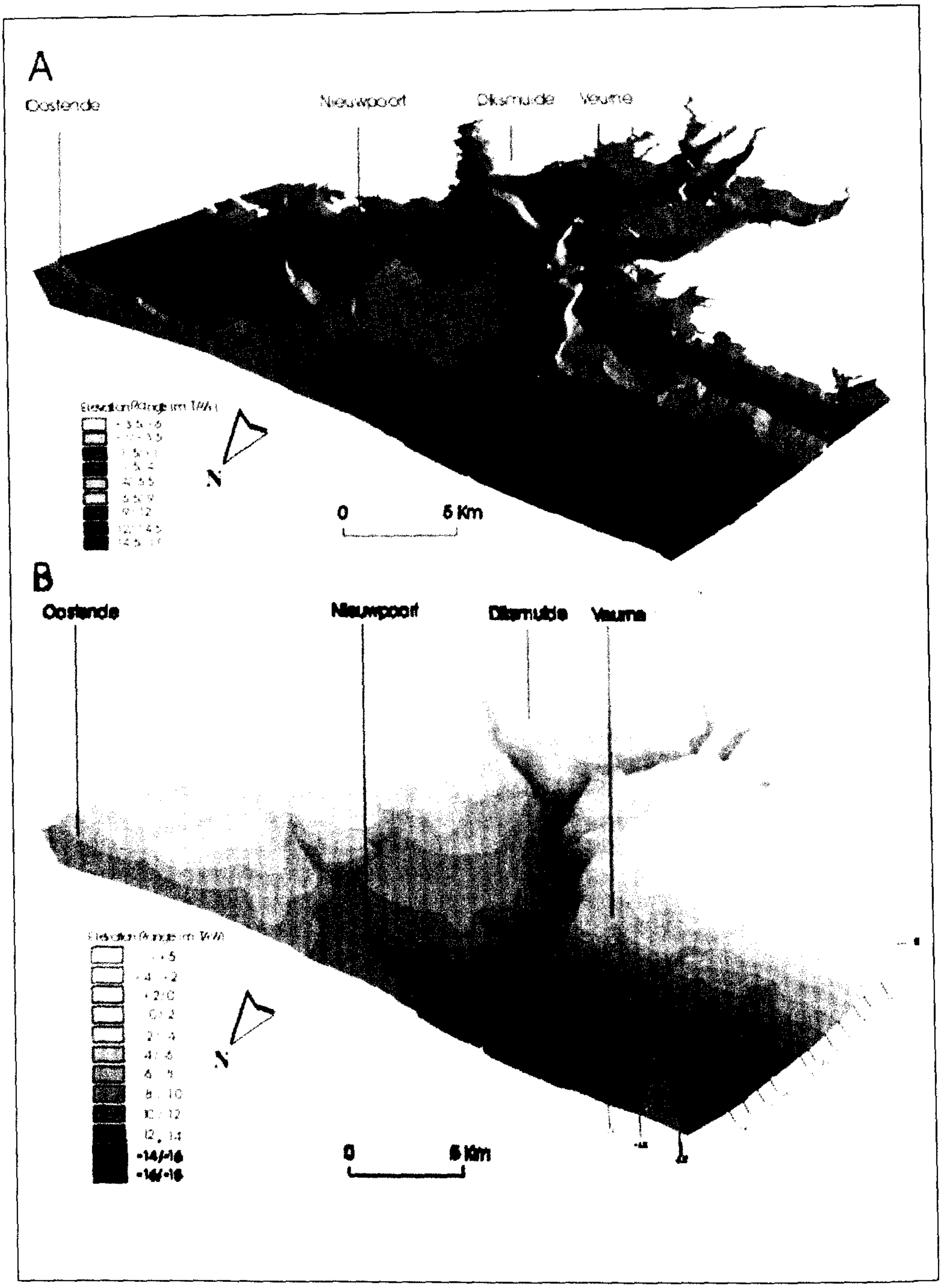


Figure 9. Three dimentional elevation model of the pre-Holocene surface.
Fig. 9A: TIN representation; Fig. 9B: smoothed representation. The present-day coastline is the seaward boundary of the model.

8300-8100 CAL BP RECONSTRUCTION (Fig. 10E)

RSL was at about -10 m. The tidal flats extended further inland and the freshwater marshes were pushed upstream due to the RSL rise. The small river valleys, in particular, were characterized by peat growth. The coastal peat bog which developed locally east of the tidal basin has been encroached by the tidal flat, as well as the headland in the NW.

8000-7800 CAL BP RECONSTRUCTION (Fig. 10F)

RSL was between -8 and -7 m. As the map shows, a substantial expansion of the tidal basin towards the west happened together with the tidal channel. Numerous cores record the development of a mudflat on the basal peat at this elevation. The tidal flat now also invaded the small river valleys far south which resulted in poor (freshwater) drainage since most of the freshwater marshes changed into permanently flooded depressions with accumulation of gyttja. In this period, the coastal barrier reached the position of the present-day coastline in the west. It is most likely that during this period the tidal scour processes began in that area. Cores show that the mudflat deposits are erosively overlain by fine sand, but on the other hand, in the area just NW of Veurne, a mudflat developed between -8 and -3 m overlaying sandflat deposits, indicating low energy environments and this for a quite long period, since a *Scrobicularia plana* in the upper part of the mudflat deposit was dated at about 7000 cal BP (n°53).

7750-7500 CAL BP RECONSTRUCTION (Fig. 10G)

RSL was at about -5 m. Sedimentary records in the area of Nieuwpoort (cf. Baeteman, 1999) show that by this period, the coast had receded far inland. The eastern part of the study area was eventually flooded. This period was characterized by a decrease of the rate of RSL rise resulting in some significant changes. The landward shift of the tidal flat was much reduced, but the tidal channel now occupied the IJzer valley, even far south. This most probably resulted in an improvement of the drainage in view of the alternation of gyttja and peat in the valley fill. The channel also brought the tidal flat far south in the eastern small valley, while in the western ones, freshwater marshes developed over the tidal flat (salt marsh). Because of the reduced rate of RSL rise, peat growth at the outer edge of the tidal flat could last for a much longer time and developed over broader areas. Similar dates of basal peat are found at locations with elevation ranges between -6 and -4 m. The tidal flat itself must have been silted up to a supratidal level for its major part because local peat growth developed. Even the tidal channel gives evidence of silting up and of a short period of peat accumulation (n^{os} 22, 23) in the area where it bifurcates into the small river valleys (not shown on the map).

7500-7000 CAL BP RECONSTRUCTION (Fig. 10H)

RSL reached -5 to -4 m. The shoreline stabilized and the extension of the tidal flat hardly changed, except in the area south of Veurne. The reduced rate of RSL rise did not create accommodation space any longer and vertical accumulation in the plain dominated. The areas with local peat growth, recorded as intercalated peat beds in the cores, became larger and more widespread. These intercalated peat beds very often merge with the peat at the landward edge of the tidal basin (the basal peat). The tidal channels expanded only a little landward. On the other hand, the channels are drawn much wider on the map. Because of lateral migration, their sand bodies were much broader, although the size of the channel itself did not change. Most probably their size was slightly reduced because of the general silting up since the cross-section of a channel is related to its tidal prism. Lateral migration became possible in this period because substantial accommodation space was not created any longer due to the reduced rate of RSL rise (van der Spek and Beets, 1992).

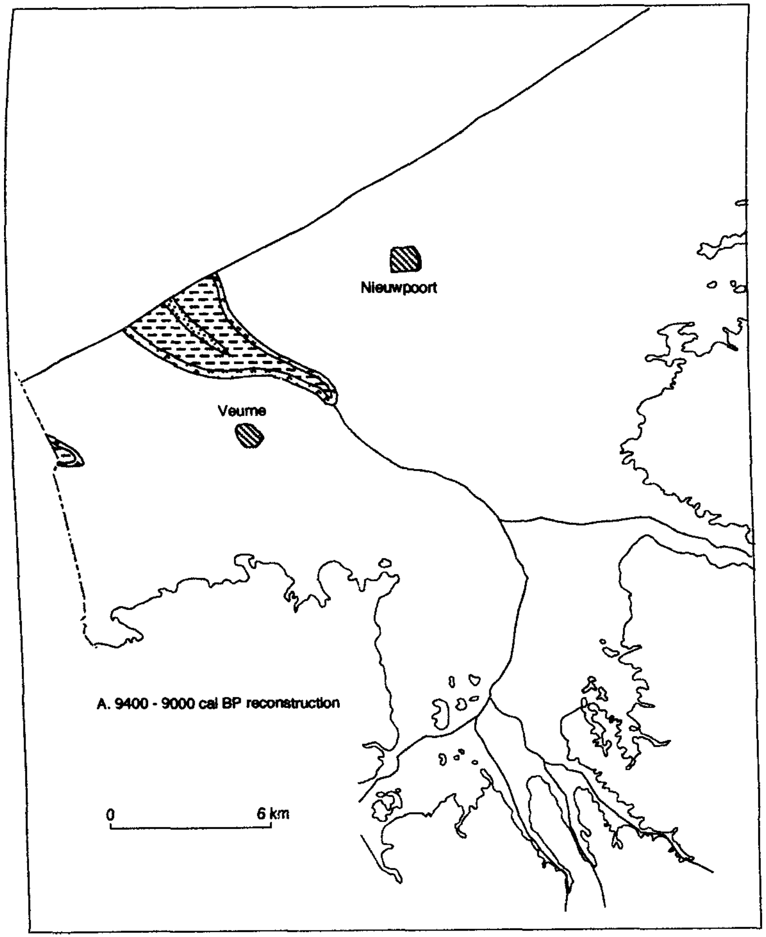


Figure 10A

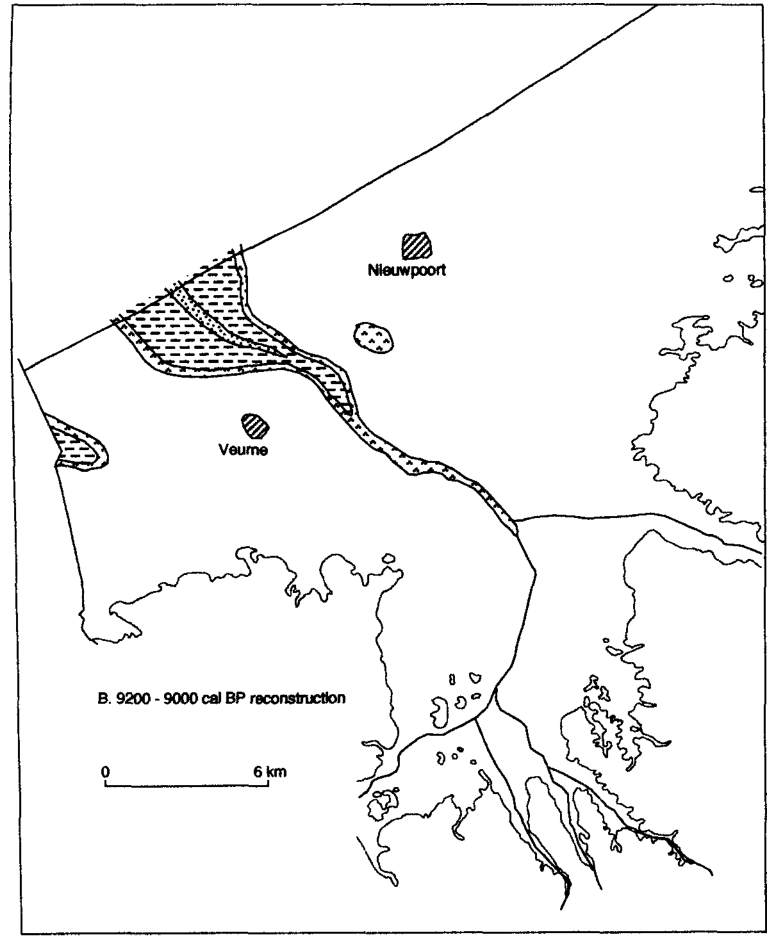


Figure 10B

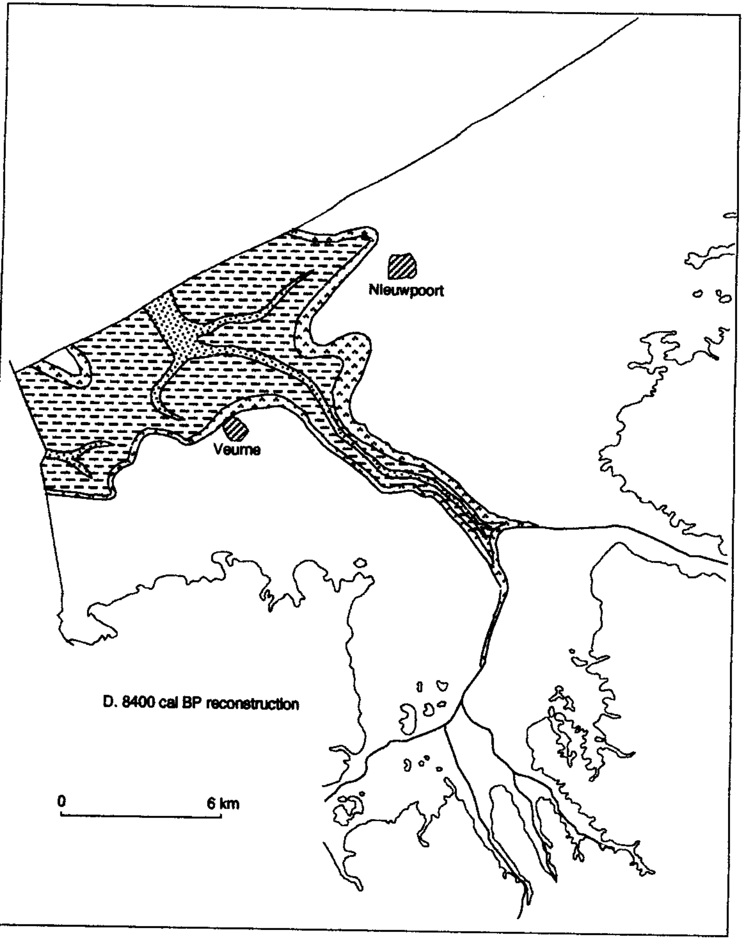


Figure 10D

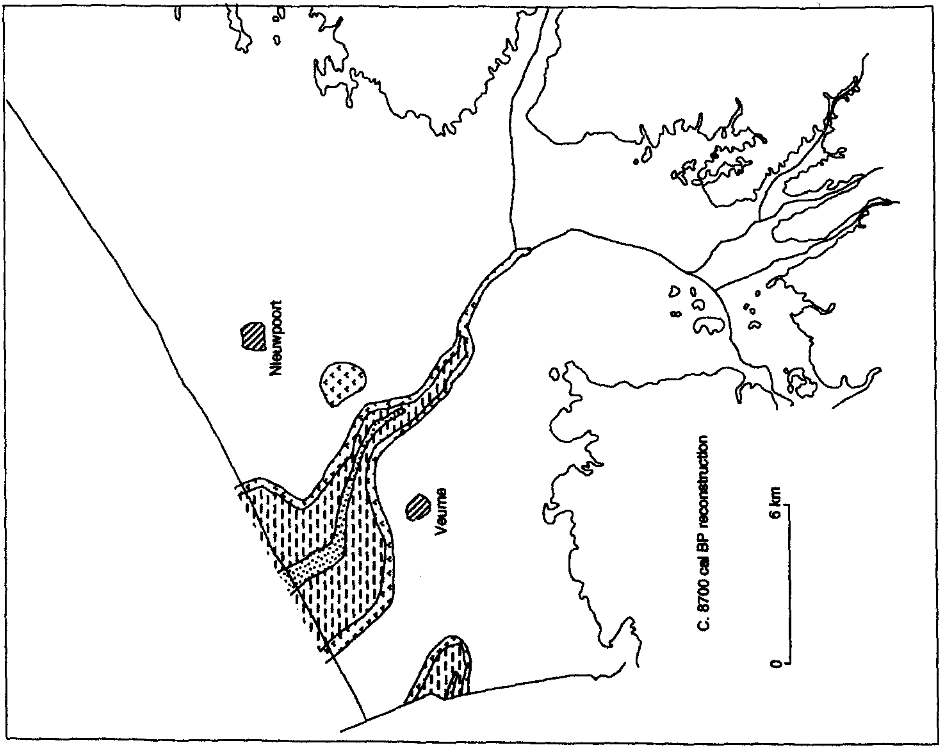


Figure 10C

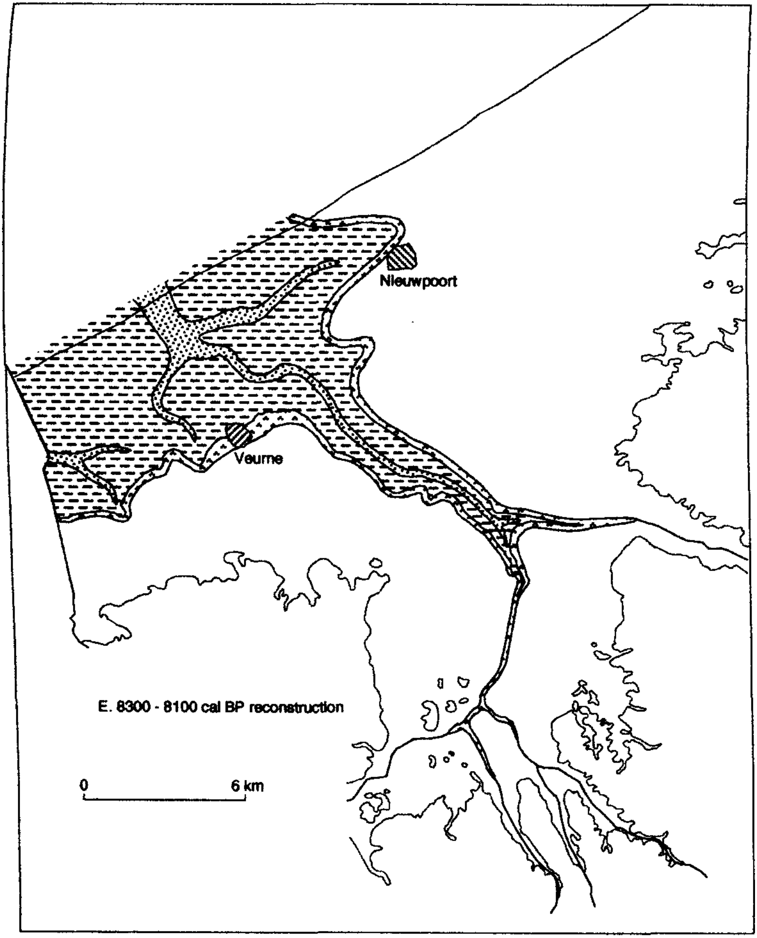


Figure 10E

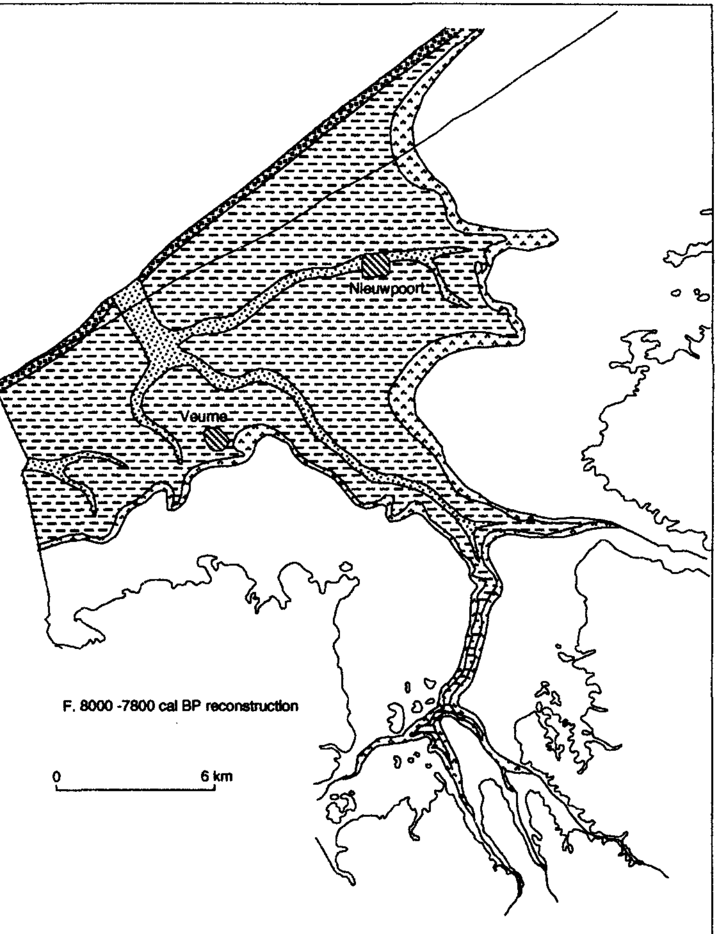


Figure 10F

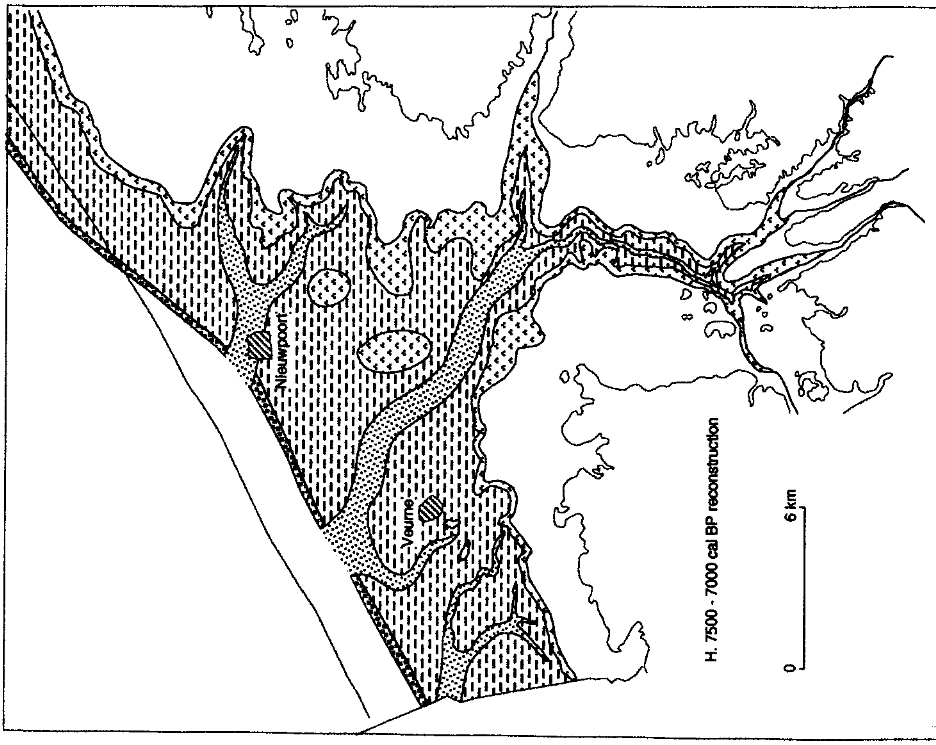


Figure 10H

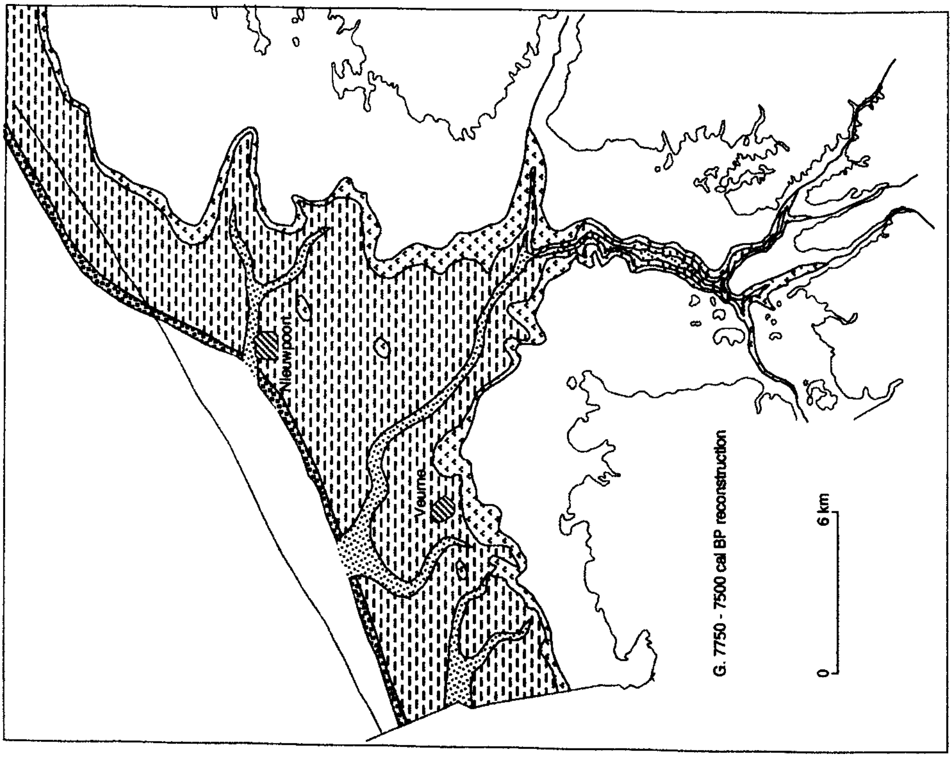


Figure 10G

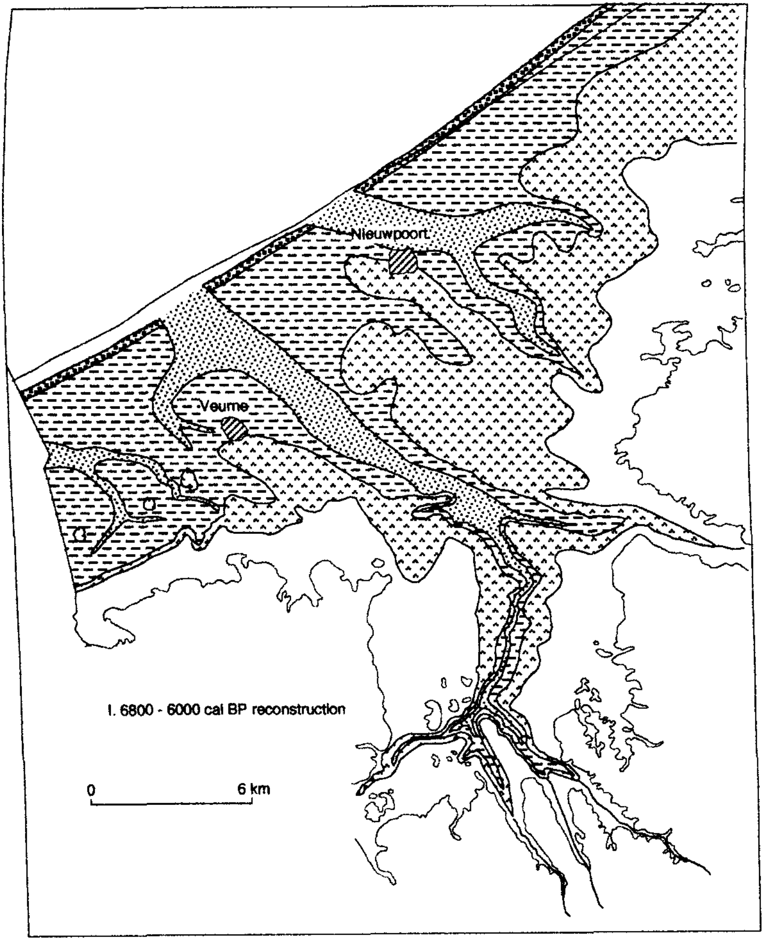


Figure 10l

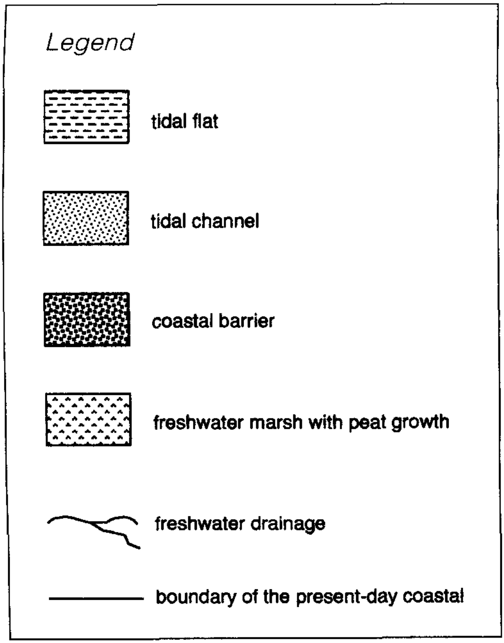


Figure 10. Palaeogeographical maps of the IJzer palaeovalley from 9500 to 6000 cal BP.

6800-6000 CAL BP RECONSTRUCTION (Fig. 10I)

RSL was at about -2 m, and the shoreline had prograded, at least in the western part where the tidal basin was completely filled and sediment supply outran the creation of accommodation space through RSL rise. Freshwater marshes with peat accumulation prevailed over the major part of the area, except in the west.

As mentioned above, the further evolution of the coastal plain is one of very little change. The freshwater marshes became more widespread in both landward and seaward directions (cf. Fig. 8), except in the area west of Veurne. Tidal channels were also covered with peat accumulation (cf. Fig. 4). The major channels of the plain, however, remained open, most probably very much reduced in size. They acted as freshwater drainage for the peat swamp and only temporarily, tidal waters entered the channels. This situation lasted until about 2500 cal BP when the tidal system re-entered the plain. The detailed palaeogeographical reconstruction of this re-entrance is the subject of research in progress.

FINAL CONSIDERATIONS

Although this paper deals with a Holocene palaeogeographical reconstruction of the infill of the western Belgian coastal plain, its depositional history is not only of local significance. Regional comparisons with tidal basins or estuaries showing a different infill and reflecting difference in the impact of the rate of RSL rise, the relief of the pre-Holocene surface and the balance between the creation of accommodation space and the sediment supply, should allow to filter the relative importance (and their regional or local significance) of the various factors controlling the infill and consequently contribute to a better understanding of coastal evolution.

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