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Alder carr, growth and drowning in the IJsselmeer region, an aspect of the Dutch coastal development

D. G. VAN SMEERDIJK

Hugo de Vries-Laboratory, University of Amsterdam, Kruislaan 318, 1098 SM Amsterdam, The Netherlands

SUMMARY

A peat layer and the underlying mineral soil in a section of the Zuidelijke Flevopolder in the central Netherlands has been studied for pollen analysis. The pollen spectra from the mineral soil reflect a Late-Atlantic forest development under relatively dry soil conditions. Podzolizing has started, but as a consequence of a rise of the groundwater table the soil became wetter and an alder carr could develop. A further rise of the water table is thought to be responsible for the decline of the alder carr after 3780 ± 60 BP. Eutrophic peat growth at site OZ-43 is synchronous with the deposits belonging to the 'Cardium transgression' phase. The development in the IJsselmeer region was strongly correlated with the coastal development of Noord-Holland. The oldest 'Cardium deposits' are thought to be transported via the Oer-IJ and the youngest via tidal channels in the north near Hoorn. The clay sediments covering the peat belong to the Zuiderzee deposits and indicate a hiatus between the peat and the clay deposits of at least 3500 calendar years.

Key-words: alder carr, Cardium transgression, coastal development, palaeoecology, peat, radiocarbon dating.

INTRODUCTION

In the autumn of 1980 the wreck of a ship was recorded on parcel OZ-43 in the polder of Zuidelijk Flevoland. The ship had fallen into pieces, and lay on top of the Pleistocene sandy subsoil; its deepest parts had sunk into the sand. At some distance from the wreck there was a natural peat layer of *c.* 30 cm thick covering the sand, so that the wreck must have sunk through the peat into the Pleistocene sand. The wreck was covered with disturbed peat and clay material and overlain by humic clay. At the start of the excavation of the wreck the age of the ship was unknown, and neither was the age of the peat layer. Presumably there is a relationship between the age of the ship and the age of the peat, and in this case the peat deposit would be rather young. An alternative assumption is that the peat dates from much older times. In that case it can be of great value for dating and correlating other sediments in the IJsselmeer region, because most of the former peat deposits in the area have been eroded away.

This paper is dedicated to Professor Dr T. van der Hammen on the occasion of his 65th birthday.

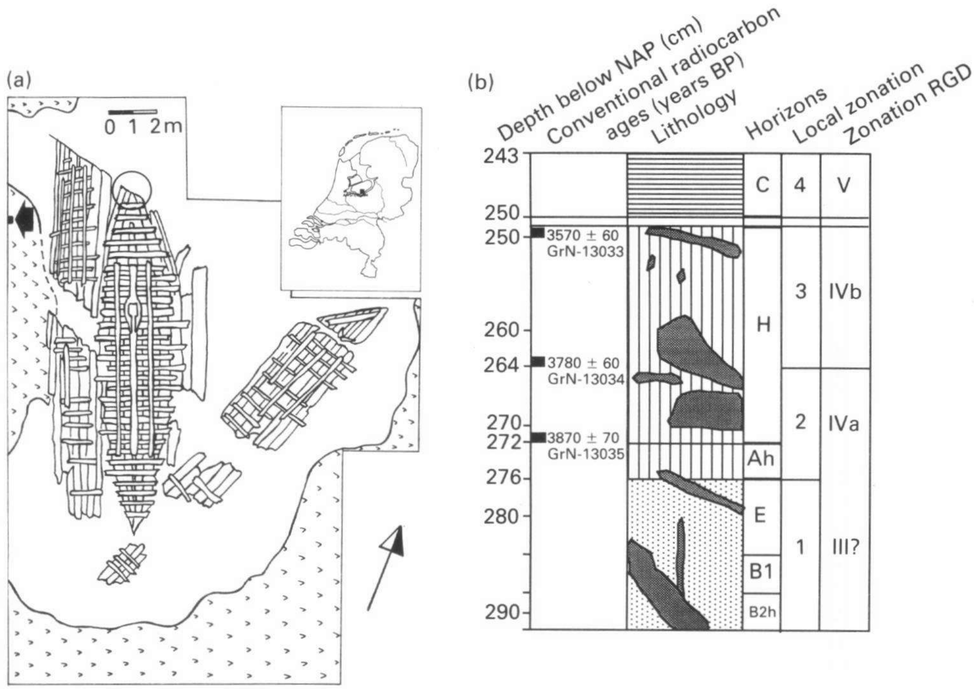


Fig. 1. (a) Excavation pit of the medieval shipwreck at parcel OZ-43 with the limits of the peat *in situ* and location of the section OZ-43. (○) sand samples, (▧) peat *in situ*, (←) location of section OZ-43. (b) Lithology, zonation, pedogenic horizons and conventional ^{14}C ages. (■) Clay, (▦) sand, (■) peat and (■) wood.

MATERIAL AND METHODS

Sampling had been done in 1981 during an excavation of a wreck, dating from the 13th or 14th century (Vlierman 1985), on parcel OZ-43 in the polder of Zuidelijk Flevoland, the Netherlands (Fig. 1a). The excavation was carried out under the supervision of the IJsselmeerpolders Development Authority (Department of Nautical Archaeology) in Ketelhaven. The samples were collected by means of a metal box, 50 × 10 × 15 cm, which was pushed into the exposed W profile of the excavation pit (on 27th May 1981) and subsequently cut out. From each centimetre, except from the top and bottom one, subsamples were taken for micro- and macrofossil analyses. From a depth of 250 cm, the clay and peat were collected separately. The exact depth of the section with regard to the Dutch ordnance Data (NAP) could not be determined, and is taken as accurate to within 15 cm (Koopstra, 1988 personal communication). The top of the Pleistocene sand was podzolized, and a description of the pedogenic horizons follows (Fig. 1b):

I C: humic grey clay with many shell fragments; 244–250 cm below NAP;
II H (histic horizon): brown peat with wood remains; 250–272 cm below NAP;
III Ah (histic A horizon): strongly decomposed black peat, with sand; 273–276 cm below NAP;
III E (=A2): humic blackish sand; 277–280 cm below NAP; dark grey sand; 281–284 cm below NAP;
III B1: grey sand; 285–288 cm below NAP; and
III B2h: brownish sand: 289–293 cm below NAP.

Pollen and other microfossils

Subsamples of known volumes for pollen analyses were treated according to the standard method of Erdmann (Faegri & Iversen 1975). The clay- and sand-containing subsamples were also treated with bromoform (sp.gr. 2·0). Subsequently the residues were treated according to the method of Middeldorp & Mijzen (1986). This is a new method for establishing pollen concentrations by embedding the total amount of microfossils of the subsample in a film of polyvinyl alcohol. The relative contributions of the microfossils are expressed as percentages of the tree pollens ($\Sigma AP \geqslant 300$). The results are shown in Figs 2 and 3 and Table 1.

Macrofossils

Subsamples of *c.* 10 cm^3 were treated with a 5% KOH solution and rinsed with tap-water over a sieve with 177 μm pores. The results are given as percentages of the residue on the sieve or as numbers (Fig. 4; Table 1). At the site several litres of sand from the inside of the wreck (see Fig. 1) were sieved and yielded a few *Pinus* cones and a handful of *Corylus* nut fragments.

Diatom analysis

Diatom analyses of the upper 6 cm of the clay deposits and of the underlying 8 cm of the peat deposits have been carried out by J.A.E. Kooyman (method according to Van der Werff 1960). At least 100 diatoms per sample were counted. The results (Table 2) have been interpreted according to the methods used by the Rijks Geologische Dienst (De Wolf 1982). The peat samples did not contain any diatoms.

Organic carbon, nitrogen, hydrogen and C/N ratio

A selection of subsamples were used for the determination of total carbon and nitrogen and the C/N ratio. The untreated material was dried at 105°C for 24 h and ground. Aliquots of 2 mg were incinerated using a Perkin-Elmer 240 element analyser. The results are shown in Fig. 5. The amounts of total carbon and nitrogen are more or less constant in the main part of the peat (44·5–46·7% C; 2·4–2·6% N) and subsequently decrease to 38·3% and 1·7%, respectively, at a depth of 272 cm.

In the Ah horizon, where sand is incorporated in the peat, both values fall off sharply but then stay at a more or less constant level (10·6–15·4% C; 0·7–0·8% N). In the deeper horizons they decline further to a very low level (1·3% C; 0·2% N). The C/N-ratio does not fluctuate very much in either the peat or the mineral soil (18–22 in the peat and 13–21 in the mineral soil). The C/N values in the peat point to a high rate of decomposition. The values in the mineral soil point to moder, a characteristic of rather dry soils.

In all diagrams, 49 spectra have been shown, namely, 48 spectra corresponding with 48 cm of sediment, and an additional one extra corresponding with the clay from depth 250 cm. The space between the two samples from depth 250 cm represents a hiatus. The scale distances in the pollen and macrodiagrams represent 5 plot units (short bars) and 10 plot units (long bars).

Radiocarbon dating

Initially the age of the peat of the section OZ-43 was unclear. Palynological dating only yields a rough estimate of the age: Late-Atlantic/Subboreal. Radiocarbon dating, carried out by the Centre for Isotope Research of the University of Groningen, placed the peat growth in the middle of the Subboreal (Table 3).

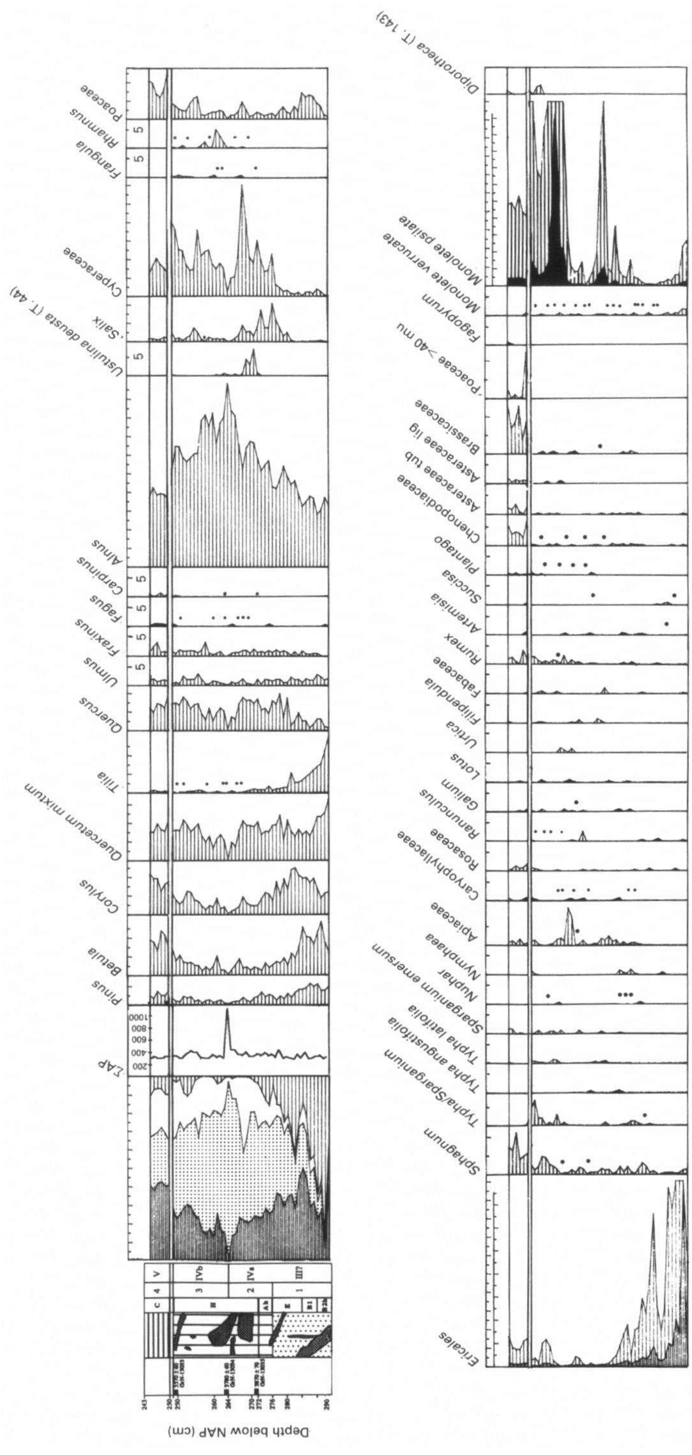


Fig. 2. Percentages diagram of pollen and spores, section OZ-43. (▦) Trees, excluding *Alnus* and *Salix*, (▦) *Alnus* and *Salix*, (☐) Podceae and Cyperacaea, (▤) *Ericales*.

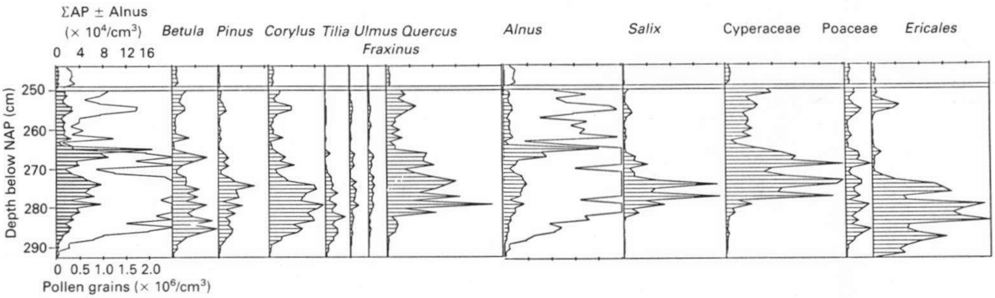


Fig. 3. Pollen concentration diagram, section OZ-43. The upper scale for ΣAP excluding *Alnus* (□), *Alnus* (□) and all other pollen types. The lower scale for ΣAP includes *Alnus* (■) and *Alnus* (⊟).

RESULTS AND DISCUSSION

Peat accumulation and pollen concentration

In this section the selection of samples for radiocarbon dating was primarily lithostratigraphical: the topmost peat sample and the first that does not contain sand from the subsoil. The third sample was taken at the point where the cumulative arboreal pollen curve plotted against depth shows a remarkable turn (Fig. 6a). The same trend, although less sharp, can be observed in the cumulative arboreal-*Alnus* pollen curve. In Fig. 6b the calibrated ^{14}C-dates are compared with the depth. On the basis of this relationship the peat accumulation rate is calculated. Figure 6c shows a slightly decreasing peat accumulation rate with decreasing depth, a mean of 0·068 cm year^{-1} between depths 272 and 264 cm, and of 0·047 cm year^{-1} between depths 264 and 250 cm.

The highest pollen concentrations (Fig. 3) were found in the top layer of the Pleistocene sand, and for peat in the samples from depths 276 to 272 cm (Ah horizon) and in the samples from depths 269 to 264 cm. In the last series these high pollen concentrations are caused by *in-situ Alnus* production (Brock *et al.* 1989). The former high concentrations point to favourable preserving conditions for the locally produced pollen, attributable to a low biological activity. This may also point to a rather high humidity of the soil, in particular of the Ah horizon where peat formation took place. In the Ah horizon, representing the initial phase of peat growth, the high pollen concentrations reflect a slow rate of peat accumulation. The decrease of the pollen concentrations in the peat from a depth of 272 cm (4302 cal. BP = 3870 BP) onward is primarily caused by the decline of the pollen production of all the forest elements. In the period from 4302 cal. BP to 4184 cal. BP (3780 BP), i.e. the depths 272 to 264 cm, the arboreal pollen production recovers somewhat, but after 4184 cal. BP a total decline of all forest elements takes place. This points to a gradual disappearance of the forests.

Reconstruction of the local vegetational succession

Zone 1: 292–277 cm below NAP (mineral soil). Pollen analyses of soil profiles have been subject to many discussions in the last 10 years (e.g. Havinga 1962; 1974; Dimbleby 1985; Gaudreau *et al.* 1989). Several processes, dependent on the local soil-forming conditions, are thought to have been responsible for the pollen content of mineral soils.

In the present study the mineral soil had a well-developed podzol profile. Pollen occurs to at least 16 cm below the top of the mineral soil and shows a characteristic distribution pattern similar to that of a peat deposit. However, it is generally accepted that once pollen

Table 1. Less frequently occurring micro- and macrofossils, restricted to water

Microfossil (m) or macrofossil (M)*	Sample number†																																			
Species	1	2	3	4	5	6	8	9	10	11	12	13	14	16	17	18	19	22	23	24	26	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
M *Mya arenarea*	++	++		+	+	+	++																													
M *Cardium glaucum*	1	1				1																														
M *Hydrobia ulvae*		2	1																																	
M Ostracoda	3		3	3	1	5																														
M *Balanus* sp.		1																																		
m *Pediastrum*	7	3	7	5	3	8																														
m *Botryococcus*	4	5	2	1	3	5																														
m Type 128	+	+		+		+		+		+																	+	+								
m *Spirogyra* (T.132)		+	+			2	+		+	2	2	+	+									+			+		+									
M *Chara*						25	48	7	3		4																									
M *Batrachium*								2																												
m *Spirogyra* (T.131)				+							+																									
m *Mougeotia*							+																	+												
M *Plumatella fungosa*						1						1																								
m *Spirogyra* (T.315)										+	+																									
m *Spirogyra* (T.130)											+																									
M *Daphnia pulex*-type (T.189C)											1				1			1		1																
M *Moina* (189B)												1						2																		
m Zygnemataceae														+	+	+	+						+				+	+				1				
M *Lophopus crystallinus* (T.192)																		2	1		1	1		1												
M *Cristatella mucedo* (T.390)																							2													
m *Debarya*																														+						
m Type 314		+			+	+																+	+	+	1	+	1	1	+	1	2	1	2	1	+	+

*Microfossils (m) given in percentages or presence (+), macrofossils (M) given in numbers or presence (+).
†Sample number 1 correlates with a depth of 245 cm, sample 49 correlates with 293 cm.

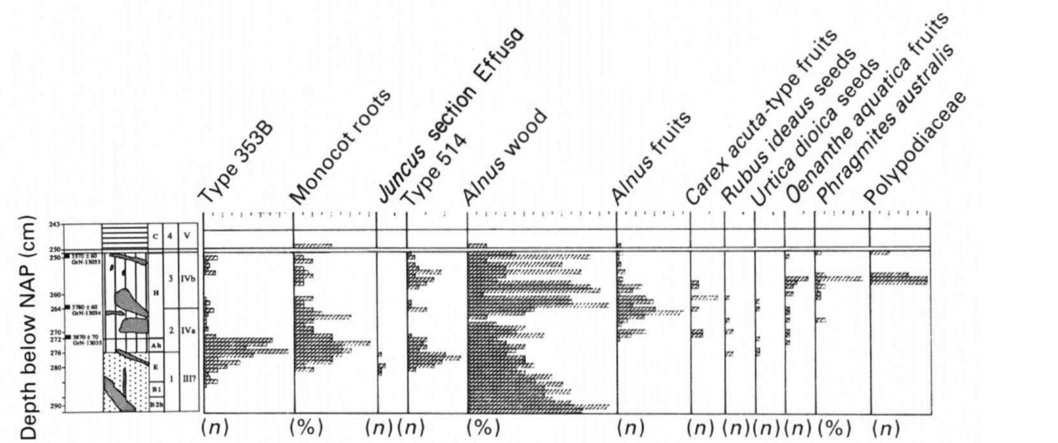


Fig. 4. Macrofossil diagram, section OZ-43. In number (*n*) or percentage (%).

has become incorporated in the deposit it moves neither upwards nor downwards. In mineral soils, on the other hand, the course of events responsible for incorporation of pollen in the soil are quite different from that in peat. Pollen diagrams from soils must therefore be interpreted in a different way.

Pollen in soils is not freely dispersed but is incorporated in fossil excrements of the soil fauna (modex). The infiltration of pollen into deeper layers of the soil is strongly related to the movement of modexial material (Van Mourik 1986). In podzols the absolute pollen frequencies are high in the topmost layer of the soil and decrease with depth. The quantities of pollen of the various taxa in the soil are not only related to the depth but also to the age. Each depth level may contain pollen of different ages.

In the mineral part of the soil several distribution patterns in the absolute pollen frequencies can be observed. (a) The pollen frequencies of *Pinus*, *Betula*, *Corylus*, *Tilia* and Poaceae increase from a depth of 292 to 284 cm and reach maximum values between 282 and 276 cm; *Corylus* is the most abundant. (b) The pollen frequencies of Ericales increase from 292 to 282 cm and reach maximum values between 282 and 278 cm and subsequently decrease rather rapidly. (c) The pollen frequencies of *Fraxinus* and *Ulmus* are low and increase very slightly to reach maximum values between 280 and 274 cm. (d) The pollen frequencies of the total arboreal pollen and of *Alnus* increase from 292 to 276 cm and attain very high values between 280 and 276 cm. (e) A sudden rise of the pollen frequencies of *Salix* and Cyperaceae from 282 cm onward. (f) The pollen frequencies of *Quercus* show low values until 282 cm and subsequently increase strongly.

It is evident that the spectra from the mineral soil are mixed. Conceivably *Quercus* is under-represented in the lowest 12 cm because of the rather high susceptibility of its pollen to corrosion (Havinga 1962; 1974; 1984). Havinga (1962) suggested that high *Tilia* pollen values may point to *in-situ* stands of *Tilia*. Keatinge (1982) has shown that a high concentration of *Tilia* pollen is found in a narrow zone around trunks of *Tilia*. This has been interpreted as follows.

The first vegetation phase was an open *Betula–Quercus* forest with local stands of *Pinus* and *Tilia* and heathers, grasses and *Pteridium* in the understorey. *Corylus* co-dominated in the shrub layer. *Alnus* was not yet an element of the local stand of vegetation so its pollen must have infiltrated from a younger horizon. The podzolizing of the relatively dry soil

Table 2. Diatoms content of 6 clay samples of sections OZ-43

Species	Depth (cm)								
	245	246	247	248	249	250	I*	II*	III*
Cymatosira belgica	7	14	1	20	20	++	1	1	0
Actinoptychus undulatus	1	2		8	8	++	1	1	0
Coscinodiscus nitidus	2						1	1	0
Podosira stelliger	2						1	1	0
Thalassionema nitzschioides		2			2	+	1	1	0
Campylosia cymbelliformis		1					1	1	0
Biddulphia rhombus				2			1	1	0
Aulacodicus argus						+	1	1	0
Plagiogramma vanheurckii		1					1	2	0
Melosira culcata				2	2	+	1	2	0
Dimerogramma minor				2			1	2	0
Diploneis bombus						+	1	2	0
Rhaphoneis surirella	1	1	1	4	2	+	1	3	0
Rhaphoneis amphiceros		5			2		1	3	0
Cyclotella striata	5						2	1	3
Coscinodiscus lacustris	1						2	1	2
Achnanthes hauckiana	2						2	3	0
Fragilaria inflata	8	3			2		3	1	0
Cyclotella menighiniana		2					3	1	2
Nitzschia hungarica	1						3	2	2
Rhopalodia gibberula				2	6		3	3	0
Navicula mutica		1					3	4	3
Fragilaria construens	2	2	1		2		4	1	2
Fragilaria virescens		1		2			4	1	2
Stephanodiscus astraea					2		4	1	1
Synedra ulna		1					4	1	3
Fragilaria pinnata	50	54	79	48	20	+	4	3	2
Fragilaria pinnata var. *lancettula*	15	6	13	4	10		(4	3	2)
Fragilaria brevistriata				2	2		4	3	2
Hantzschia amphioxys					4		4	4	3
Nitzschia debilis	1						4	4	2
Achnanthes lanceolata		1					4	4	2
Cocconeis diminuta			2				5	3	1
Navicula insociabilis			1				5	4	3
Amphora sabyii	1	3		6	8	+			
Cocconeis thumensis	1					+			
Cocconeis sp.			2	2	4				
Navicula mutica var. *nivalis*				2					
Nitzschia frustulum					2				
Licmophora abbreviata						+			

*Ecofactors.

I: Salinity: (1) polyhalobions, (2) mesohalobions, (3) oligohalobions (halophyl), (4) oligohalobions (indifferent), (5) holophobes.

II: Life form: (1) plankton, (2) benthos, (3) epiphyts, (4) aerophil, (5), eu-terrestrial.

III: pH spectrum: (1) alkalibiontic, (2) alkaliphilous, (3) indifferent, (4) acidophilous, (5) acidobiontic.

probably took place in this period. In the second vegetation phase a brook forest developed with *Alnus*, *Salix* and Cyperaceae.

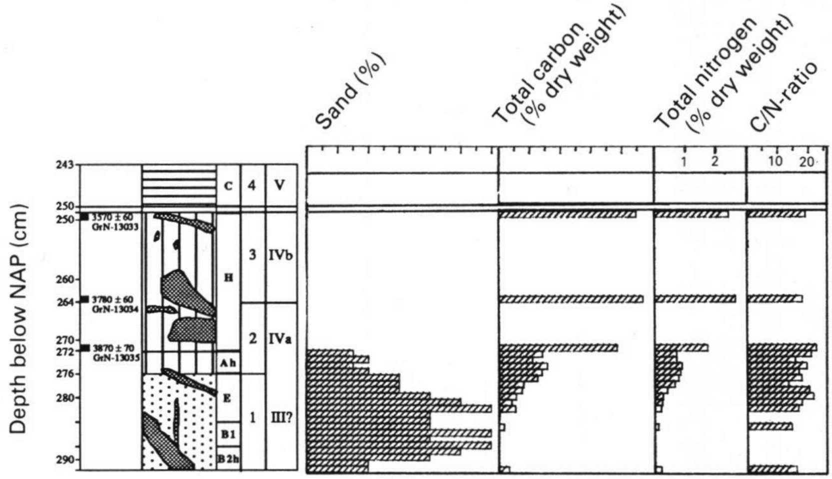


Fig. 5. Contents of sand, total carbon, total nitrogen and C/N-ratio.

The dating of pollen spectra in mineral soils does not yield satisfactory results. The pollen spectra in the mineral soil of this section are thought to have been formed in the Late-Atlantic or Early-Subboreal period. In summary, the pollen spectra from the mineral soil reflect an Atlantic/Subboreal forest development starting on a relatively dry soil. As a consequence of a rising groundwater table the soil became wetter and an alder carr could develop, which finally resulted in a peat layer on top of the mineral soil.

Zone 2: 276–265 cm below NAP (Early-Subboreal, pollen zone IVa). Subzone 2a: (276–273 cm). The sediment consists of a mixture of the mineral soil material and peat. Roots of monocots and woody material of alder are the most important macroscopic remains. This subzone is rather poorer in microfossils than in other tree pollen. The presence of pollen of *Nuphar, Nymphaea* and Typhaceae, and of algae (*Mougeotia* and Type 132, 314), Bryozoa (*Cristatella mucedo, Lophopus crystallinus*) and cocoons of flat-worms (T.353B, described by Van Geel *et al.* 1980/81) and Type 514 (described by Ran 1989) is noteworthy (see Table 1, Fig. 2) because it points to local freshwater conditions. Some of these fossils have penetrated into the underlying sand deposits. Under the influence of a rising groundwater table local pools were formed and subsequently the present forest became submerged. Simultaneously a *Carex* mire developed which later became overgrown by *Salix* and *Alnus*.

The relatively high values of *Corylus, Quercus* and Ericales point to the former vegetation cover and must have arisen from the sandy subsoil, incorporated into this peat layer.

Subzone 2b (272–265 cm; 4301–4200 cal. BP). The peat is strongly degraded and contains much woody material of *Alnus* and roots of monocots. The vegetation type is an alder carr with a predominance of *Alnus*, which reaches its maximum extension towards the end of this subzone, and with some local stands of *Salix*. Cyperaceae and ferns are the most important herbs in the understorey. The ecological conditions point to a rather eutrophic environment with the ground-water table a little above the surface, this is supported by the presence of several aquatic organisms (see Table 1).

Zone 3: 264–250 cm below NAP (Late-Subboreal, pollen zone IVb). The sediment is similar to that of subzone 2b. The pollen percentages curve of *Alnus* decreases strongly,

Table 3. Radiocarbon dating of the peat

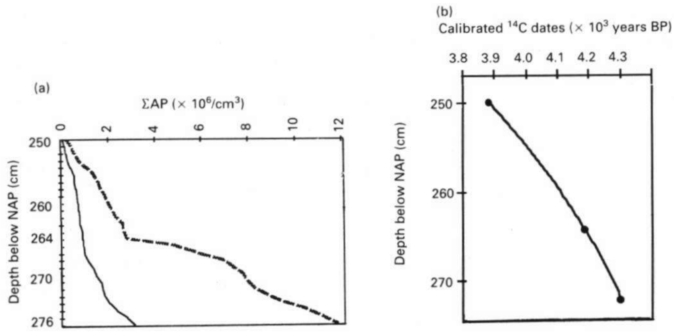
GrN-No	Depth below NAP* (cm)	Conventional ^{14}C age (years BP)	Calibrated age (years BP)†	Calibrated age (years BP)‡
13033	250	3570 ± 60	3845;3846;3870 (3780–3979)	3883
13034	264	3780 ± 60	4154;4173;4176;4206;4219 (3994–4287)	4184
13035	272	3870 ± 70	4300,4330;4346;4374;4377 (4180–4420)	4302

*Depth is approximate.

†Ages (calendar years) calibrated according to Stuiver & Becker (1986); between parentheses the upper and lower age are given at sigma one. All samples had three calibrated ages.

‡Ages (calendar years) calibrated according to Van der Plicht *et al.* (1986) at 50% probability.

The calibrated ages were used for all calculations and for final dating of the zone boundaries.



(c)

Depth (cm)	Age (cal. year BP)	Age/cm peat	Peat accumulation (cm/cal. year)
250	3881	25	0.04
251	3907	26	0.038
252	3932	25	0.04
253	3956	24	0.042
254	3980	24	0.042
255	4003	23	0.043
256	4025	22	0.045
257	4048	23	0.043
258	4069	21	0.048
259	4089	20	0.05
260	4109	20	0.05
261	4129	20	0.05
262	4147	18	0.056
263	4165	18	0.056
264	4183	18	0.056
265	4200	17	0.059
266	4217	17	0.059
267	4232	15	0.067
268	4247	15	0.067
269	4261	14	0.071
270	4275	14	0.071
271	4288	13	0.077
272	4201	13	0.077

Fig. 6. (a) Cumulative ΣAP/cm³ (- - -) and cumulative ΣAP – *Alnus*/cm³ (———) plotted versus depth for peat samples of section OZ-43. (b) Calibrated radiocarbon dates plotted versus depth. Polynomal (2°): $x = -21\,742 + 179{\cdot}20455y - 0{\cdot}30681818y^2$ ($R = 1{\cdot}0000$). (c) Calculated ages per depth in calendar years BP, age per cm peat and peat accumulation in cm/calendar year.

while the absolute frequences are more or less constant at a rather low level. In this subzone Cyperaceae and Monolete spores reach their second maximum, the fern spores in particular being very abundant. The *Carex acuta*-type, Apiaceae (such as *Oenanthe aquatica*), *Phragmites australis*, and ferns dominated the understorey. Towards the end of this zone there is some evidence for *in-situ* wet conditions, such as an increase of pollen of Typhaceae and Sparganiaceae, spores of *Spirogyra*, and the regular occurrence of oosporangia of *Chara* and other aquatic organisms (Table 1). The top of the peat is eroded and the aquatic organisms pointing to open fresh water probably date from the erosion phase and have been washed into the peat. It is also possible that they were brought into the alder carr by innundations, heralding an approaching wet phase. The arboreal pollen except that of *Alnus* and *Salix* now represents the regional forest. They occur in low quantities, and this points to a restricted forest development in the IJsselmeer region in the period between 4183 cal. BP and 3881 cal. BP.

Zone 4: 250–245 cm below NAP (Subatlantic, pollen zone Vb2). The sediment consists of a dark-grey clay with many shell fragments. Next to *Mya arenarea*, the most important among the shell fragments, *Cerastoderma glaucum*, *Hydrobia ulvae* and Ostracoda are found. *Pediastrum* and *Botryococcus* are the most frequently occurring microfossils. The clay sample immediately above the peat also contains some micro- and macrofossils (such as *Spirogyra*, *Chara* and *Plumatella fungosa*) pointing to fresh water.

Diatom analyses of the clay samples (Table 2) point to a saline or saline–brackish environment with freshwater influences. The presence of *Mya arenarea* in these sediments no doubt indicates that these sediments belong to the Zuiderzee-deposits (Ente *et al.* 1986) which were formed between 1600 AD and 1932 AD which implies that there is a hiatus of *c.* 3500 calendar years between the top of the peat and the clay deposits.

Peat growth in the IJsselmeer region

The palynological dating of this section is hampered by the predominance of alder pollen and by the scarcity of such characteristic markers as pollen of *Fagus* and *Carpinus*. Only a rough dating could be made: 'Subboreal'. This is an interesting period in the development of the Dutch coast. Radiocarbon datings of the section place it more precisely in the Subboreal time corresponding with the top of pollen zone IVa and the lower part of pollen zone IVb.

Peat deposits in the IJsselmeer region have been studied palynologically by Muller & Van Raadshooven (1947), Wiggers (1955) and Havinga (1962). Investigations of Noordoostpolder deposits show that the oldest peat on top of the Pleistocene dated from Preboreal times, but the peat is mostly of Boreal age, and there is also some Atlantic peat. These peat layers are usually 10–50 cm thick, except some studied by Muller & Van Raadshooven (1947), that were up to 5 m thick. These workers showed that there is some peat of Subboreal and Subatlantic age. The depth level of the surface of the Pleistocene is very important for the dating of the development of peat and can serve as a support for other datings. Most of the latter are palynologically estimated, and of course may have to be re-interpreted. Much of the peat is eroded away, and therefore it is hardly possible to reconstruct the Subboreal peat growth. In the south-western and north-eastern parts of the Noordoostpolder the Subboreal peat is found at a depth of 3·5–2 m below NAP. Wiggers (1955) proposed that during the Subboreal the Noordoostpolder was covered with mesotrophic and oligotrophic peat, with some eutrophic alder peat in the south along the gullies. From the other IJsselmeerpolders there is little information on peat formation available. Havinga (1962) interpreted the thin layers of peat on top of the Pleistocene (*c.* 3·2–3·0 m below NAP) to be of Atlantic age.

If we accept that eutrophic peat growth takes place at the ground-water level, and is thus directly correlated with the mean sea level (MSL) at 3780 ± 60 BP the palaeo-MSL was 264 ± 15 cm below NAP at site OZ-43. Roep and Van Regteren Altena (1988) reconstructed palaeo-tidal levels at about 3700 BP in north Holland and showed that their palaeo-MSL is *c.* 2·30 m below NAP; 10 cm higher than the one based on the MSL trend curve of the barriers.

Cardium transgression (see Fig. 7)

The peat of site OZ-43 is more or less synchronous with deposits belonging to the 'Cardium transgression', but ever since the first description of these sediments (Muller & Van Raadshooven 1947) their age has been disputed (Zagwijn 1973; Koopstra 1981; Ente *et al.* 1986). The sediments belonging to the 'Cardium deposits' partly consist of clay or clay–sand and partly of organic (detritus-gyttja) material, with a characteristic marine and brackish fauna, in particular *Cerastoderma glaucum* Poiret (*Cardium glaucum*). The shells were initially identified as *Cardium edule*, but taxanomic studies have proved that these shells have to be conceived as *Cerastoderma glaucum* Poiret (Janssen & Van der Slik 1978). Koopstra (1981) gives an overview of the radiocarbon ages of *Cerastoderma* shells from the Noordoostpolder (Tollebeek II: 3920 ± 60 BP) and Oostelijk Flevoland (G42c: 3995 ± 40 BP). De Jong (1988) studied two sections rather close to that of site OZ-43, in one, KZ-58, *c.* 10 km NW from section OZ-43, *Cerastoderma* shells were dated at 4220 + 90 BP. Palynological dating (boundary of pollen zone IVa and IVb) of the *Cerastoderma* level of this section does not fit with the radiocarbon age of the shells.

The 'Cardium deposits' in the Noordoostpolder were dated palynologically in the Subboreal, particularly at the boundary of the pollen zones IVa and IVb (Florschütz in

Wiggers 1955). This boundary is not synchronous in the Netherlands (De Jong 1982) but is assumed to be at 3800 BP. Without local ^{14}C-dating this boundary cannot be used for exact dating purposes. The radiocarbon date of section OZ-43 (3780 ± 60 BP) of the beginning of the decline of the alder carr in this area could be used for dating the transition between pollen zones IVa and IVb, although the usual marker for this transition, the first continuous occurrence of *Fagus* pollen, is not discernible in the pollen diagrams of site OZ-43. The start of the 'Cardium transgression' is usually placed at this boundary, but on the other hand the time span in which the 'Cardium deposits' are found is a global one (Ente *et al.* 1986: 3900–3200 BP; Zagwijn, 1986: 4000–3400 BP). There is little doubt about the reliability of the radiocarbon dating of the shells (Koopstra 1981; De Jong, 1988); they are thought to be too old (3920–3995–4220 BP).

Radiocarbon dating of shells in general implies more uncertainties than those of peat (Mook & Streurman 1983) and for that reason radiocarbon datings of shells are used without any reserve. In the Noordoostpolder a clay–peat layer correlating with the 'Cardium clay' (Urk: 3505 ± 120 BP) and an eutrophic peat layer, shaded off into a 'Cardium clay' layer (Schokland: 3315 ± 90 BP) were used for dating this 'Cardium clay' (Wiggers, 1955). Although these dates do not really reflect the age of the 'Cardium deposits' they are the best approximation, if no direct datings are available.

There are arguments pleading for accuracy of the older datings. Comparison of the data of site J51 (Zagwijn 1973) and G42c (Koopstra 1981) *c.* 5 km apart shows that the datings of the shell-containing layers lay very close to each other. The boundary of pollen zone IVa dn IVb in section J51 can be set at *c.* 3800 BP, the *Cerastoderma* shells found just below that boundary must then be older than 3800 BP. The *Cerastoderma* shells of site G42c were dated at 3995 ± 40 BP.

If the datings of the *Cerastoderma* shells are accepted the conclusion must be that the oldest deposits belonging to the 'Cardium transgression' phase lay in Zuidelijk Flevoland, the somewhat younger deposits lay in Oostelijk Flevoland and in the Noordoostpolder and the youngest lay in the Noordoostpolder.

The development of the IJsselmeer region is strongly correlated with the coastal development of north Holland (Ente *et al.* 1986; Zagwijn 1986; Westerhoff *et al.* 1987, Westerhoff & Cleveringa 1989). The peat growth of the IJsselmeer region in the coastal plain moved further to the east under the influence of a continuous rise of the sea level during the period 7000–3000 BP. In the beginning of this period a series of W–E orientated tidal channels developed. In the west most of these channels were filled with sediments, at *c.* 5300 BP two were left which ran eastwards into the Noordoostpolder and Flevopolders. The position of the two tidal channels were primary influenced by the relief of the Pleistocene surface (Zagwijn 1986; paleogeographical map 1).

At the start of the Subboreal (5000 BP) beach barriers developed for the first time, this means an enormous change in the coastal development. The open coast is getting closed. Since then there has been a lack of sediments to fill the more eastward plains, and in the central part of the IJsselmeer region a lagoonal system could establish. The northern tidal channel (via Heer hugowaard-Hoorn) silted up, but was active until *c.* 3200 BP, the inlet near Bergen is closed indefinitely.

In the lagoon the influence of the sea decreased, the ebb/flood movements were reduced and probably stopped, and in the lagoon a new water management system established. In view of the radiocarbon datings the Oer-IJ, as the southern-most connection to the sea, is thought to be the main transport system for sediments with *Cerastoderma* shells in the Flevopolders, and the northern tidal channel mentioned above (originated from the inlet near Bergen) was the transport system for these sediments in the Noordoostpolder. The sediments in which the *Cerastoderma* shells occur give rise to the idea that the *Cerastoderma* shells were not deposited continuously but transported as spatefall (Westerhoff *et al.* 1984). This spatefall transport could have taken place several times during the period that the lagoonal system was connected to the sea.

Eutrophic peat growth had already started before 3870 BP in the section OZ-43. The eastern limits of the eutrophic peat growth in Zuidelijk Flevoland (shown on the paleogeographical map of the Mid-Subboreal by Zagwijn 1986) should be diverted to the southeast for at least 5 km. This implies that peat growth had already taken place at a higher level on the Pleistocene surface, and that the ground-water table was also somewhat higher. The eutrophic peat growth at site OZ-43 is synchronous with the 'Cardium deposits' in the IJsselmeer region, and should have taken place at ground-water level, which is nearly the same as the water level in the lagoon. However, the deposition of the shells themselves, which is thought to have taken place during the frequent storm surges, did not influence the peat growth at site OZ-43. Flooding of this part of the IJsselmeer region was responsible for hampering peat growth and ultimately also for the decline of the alder carr. The flooding is thought to be caused by a continuous rise of the water level in the lagoon, which in turn was depending on the continuous rise of the sea level.

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