SEA LEVEL, GROUNDWATER, AND BASAL PEAT GROWTH –
A REASSESSMENT OF DATA FROM THE NETHERLANDS

O. VAN DE PLASSCHE[1]

ABSTRACT

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An analysis is made of the relative time-depth positions for published data from the base of the so-called Lower Peat in The Netherlands. Development of this peat is generally linked with the Holocene sea-level rise. Emphasis is placed on the location of samples with respect to pre-existing subsurface topography. This factor is thought to govern the moment at which peat formation commenced at a given site. However, in those cases where topographical influence has been small, it becomes apparent that other (dynamic) factors, such as seepage and local tides, in fact control the initial time-depth position of Lower Peat growth.

INTRODUCTION

Peat that occurs at the base of the Holocene coastal sequence in The Netherlands is generally referred to as Lower Peat or basal peat. It overlies the gently seaward dipping surface of mostly permeable, late Pleistocene deposits (HAGEMAN, 1969; JELGERSMA ET AL., 1979). In more detail, the Lower Peat generally covers a low, irregularly undulating (aeolian) topography of Late-glacial material which is locally of early Holocene age (e.g. VEENENBOS, 1954). Pollen analyses by VERMEER-LOUMAN (1934) have shown the age of this Lower Peat to decrease with decreasing depth of underlying deposits. Like BENNEMA (1954), JELGERSMA (1961) assumed that development of the Lower Peat on top of permeable aeolian and fluvial sediments was caused by a rise in the groundwater table, which was in turn controlled by a rising sea level. By radiocarbon dating samples from the base of the Lower Peat a reconstruction could be made of changes in groundwater level with time, and thus indirectly of sea-level changes. On the basis of this assumption JELGERSMA (1961) collected several tens of samples from the base of the Lower Peat. The time-depth points thus obtained and the two curves derived from these data

(JELGERSMA, 1966) are shown in figure 1. In addition, the time-depth position of five samples collected at random from the base of the Lower Peat in north-eastern Friesland (GRIEDE, 1978) have also been plotted on the same figure. It has been noted (VAN DE PLASSCHE, 1979) that the two Friesland points which coincide with Jelgersma's curve I have been obtained from elevated, well drained parts in the former landscape, whereas each of the remaining Friesland samples were collected at sites which were favourable for the concentration of surface and/or seepage water. This could explain the early onset of peat growth at these locations.

The close relationship found to exist between time-depth position of the five samples from Friesland and their location with respect to substrate morphology, raised the question, investigated in this paper, to what extent can the relative time-depth position of the basal peat samples collected by Jelgersma be explained in similar terms.

TERMINOLOGY

The Lower Peat, which is considered here to be part of the Holland peat Member, can only be recognized as such where its thickness is limited by the presence of an overlying

[1] Instituut voor Aardwetenschappen, Vrije Universiteit, De Boelelaan 1085, 1081 HV AMSTERDAM, The Netherlands.
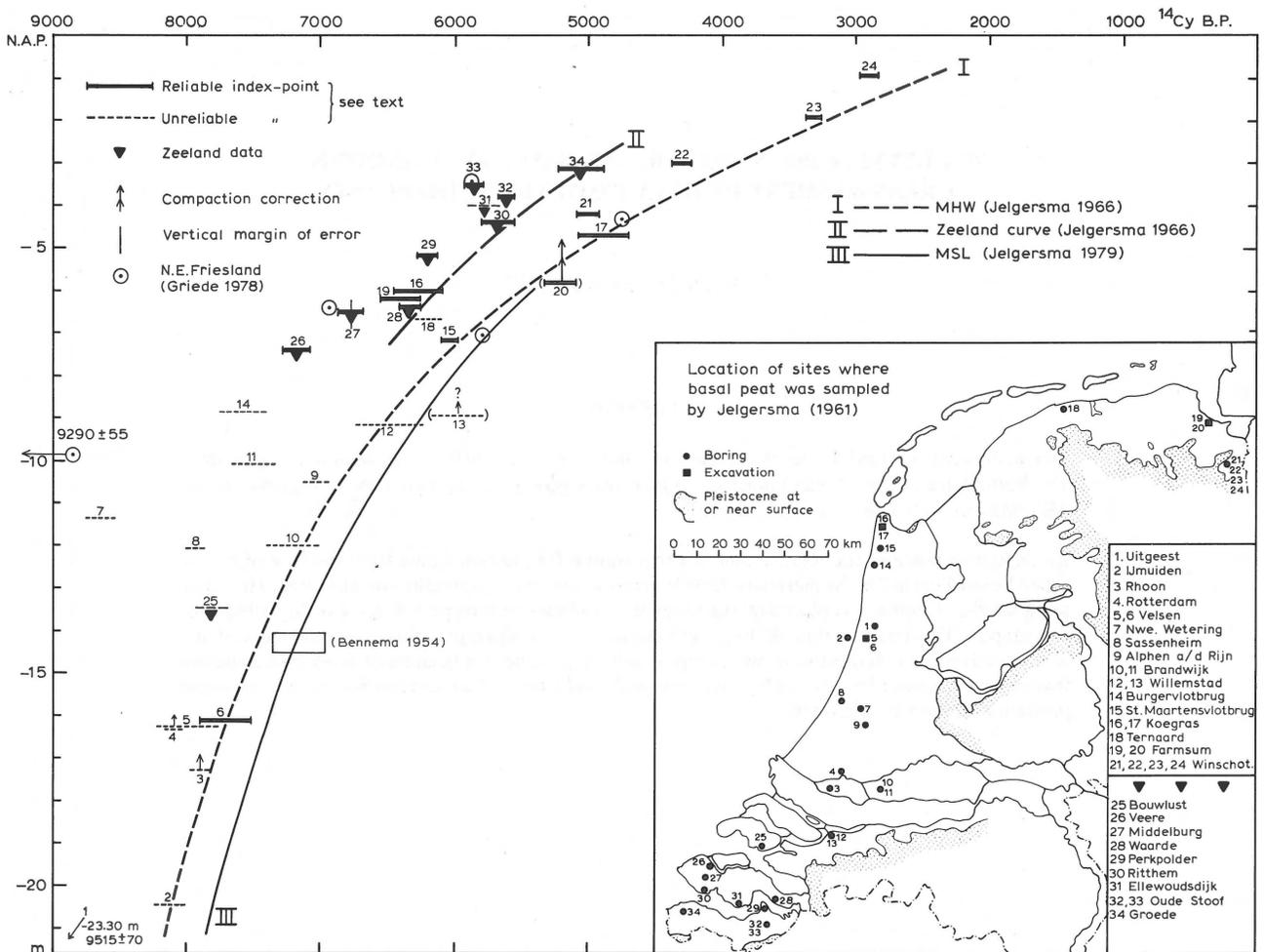
Fig. 1

Time-depth plot of basal peat data published by Jelgersma (1961, 1966) and Griede (1978). Criteria for determining suitability of the index points 1-34 for estimating former sea-level stands are discussed in the text. Curve III, which merges with the younger part of curve I, is not mentioned, but is included for comparison.

minerogenic bed of the Calais Member of the Westland Formation (DOPPERT ET AL., 1975). In a landward direction these clastic beds taper out into the main body of the Holland peat Member, called Holland peat. The time-depth points under discussion all derive from the base of either the Lower Peat or the Holland peat and are collectively referred to as basal peat data: i.e. data from the base or the basal part of the Holland peat Member. The underlying deposits are generally of aeolian origin (the so-called cover sands) and belong to the Twente Formation.

COLLECTION OF BASAL PEAT DATA

Jelgersma's principal concern was to avoid sampling peat that might have grown independently of the sea-level-controlled groundwater level. Care was taken to ensure that most samples consisted of eu-/mesotrophic peat (fen or fen-wood), collected at sites where the Pleistocene subsurface was known to be sloping and underlain by a permeable soil. The slope of

the substrate was studied by borings which varied from several hundred metres to occasionally a few kilometres apart. The Pleistocene relief was known in more detail in the province of Zeeland, where the Geological Survey had carried out extensive mapping. The best insight into local subsurface features was obtained from excavations at Velsen, Koegras, and Farmsum (for location see Fig. 1). Thirteen samples were taken from isolated borings.

The 34 basal peat time-depth data obtained by Jelgersma are listed in table I and have been numbered in figure 1.

EVALUATION OF THE BASAL PEAT DATA

Jelgersma considered index points 3, 4, 7, 8, 9, 10, 13, 25, and 31 (see Fig. 1) to be less suitable for estimating the former sea-level since the samples were obtained from isolated borings. The possibility cannot be excluded, therefore, that the peat was formed in a local depression independent of the regional groundwater level. Moreover, she pointed out that in the case

Table I
Time/depth data plotted in figure 1/radiocarbon dates used in the text.

no.	Location/name of sample	GrN	14C-age 1)	altitude in m below NAP	dated material
1	Uitgeest	1054	9515+70	23.25-23.30	gyttja with Phragmites
2	IJmuiden	2274	8130+100	20.40-20.50	fen peat
3	Rhoon	2180	7900+ 75	+17.22-17.28	fen wood peat
4	Rotterdam	2177	8090+ 70	+16.23-16.26	fen peat
5	Velsen	165	8000+230	16.23-16.24	sandy peat
6	Velsen	161	7705+200	16.10	Alnus roots
7	Nwe. Wetering	1618	8660+110	11.34-11.38	fen peat
8	Sassenheim	792	7930+ 60	12.02-12.07	fen peat
9	Alphen	2619	7030+100	10.48-10.51	fen peat
10	Brandwijk 8	186	7200+210	11.96-11.98	fen wood peat
11	Brandwijk 6	201	7500+170	10.04-10.08	fen wood peat
12	Willemstad II	240	6485+250	9.11- 9.15	detritus
13	Willemstad I	228	6000+130	8.89- 8.92	peat
14	Burgervlotbrug	1123	7570+ 65	+8.88- 8.91	peat (oligotrophic ?)
15	St.Maartensvlotbrug	1633	6040+ 60	7.17- 7.22	fen peat
16	Koegras I	455	6280+185	+6.00- 6.02	fen peat
17	Koegras II	476	4885+190	+4.70- 4.72	fen peat
18	Ternaard 14	606	6255+140	6.62- 6.65	Sphagnum-Eriophorum
19	Farmsum B1	621	6420+145	6.17- 6.20	fen wood peat
20	Farmsum B2	637	5210+150	+5.77- 5.80	peaty clay
21	Winschoten 518	1091	5010+ 80	4.19- 4.23	fen peat
22	Winschoten 515	1088	4310+ 75	2.98- 3.03	fen peat
23	Winschoten 513b	1090	3310+ 65	1.87- 1.92	fen peat
24	Winschoten 512	1089	2910+ 70	0.90- 0.94	fen peat
25	Bouwlust	2283	7810+100	13.48-13.55	sandy humified peat
26	Veere	1580	7170+ 90	7.43- 7.46	fen peat
27	Middelburg	1626	6760+ 85	+6.49- 6.52	fen peat
28	Waarde	1121	6330+ 85	6.38- 6.40	fen peat
29	Perkpolder	1045	6200+ 70	5.20- 5.25	fen peat
30	Ritthem	405	5680+120	4.40- 4.44	fen peat
31	Ellewoudsdijk	1571	5780+ 70	+4.05- 4.09	peat
32	Oude Stoof 4	1048	5850+ 55	3.50- 3.54	fen peat
33	Oude Stoof 3	1042	5615+ 65	3.77- 3.80	fen peat
34	Groede	187	5060+180	3.13- 3.15	fen peat

Top of Lower Peat dates

Koegras II (Jelgersma 1961)   GrN 1060 4920+ 80 fen peat
Velsen   (Bennema   1954)   GrN   75 7100+200 wood

1) All ages have been corrected for δ 13C by subtracting 40 years (Mook, pers. comm.).

Official (previously published) ages are obtained by adding 40 years.

of index points 3 and 4 the samples were underlain by clay and sandy clay respectively, which may not only have caused some lowering of the peat due to compaction, but may also be responsible for local peat growth. Furthermore, index points 7, 8, and 9 are located in an area where the Pleistocene surface is subhorizontal, and drainage conditions were probably very poor. Also, according to Jelgersma (pers. comm.), the samples Willemstad II and I (points 12 and 13) consisted respectively of peat and an admixture of sand, wood and clay and not of wood and fen-wood peat as stated in her thesis (JELGERSMA, 1961, p. 35). Sample Willemstad I was probably disturbed during coring operations due to high groundwater pressure (Zagwijn, pers. comm.).

Index point 1 was considered unreliable for estimating the former sea level since the sample came from a broad depression in which peat growth which was unrelated to sea level, may have occurred. This, according to Jelgersma, is supported by the absence of diatoms indicative of a brackish environment. For the same reason she discarded sample Burgervlotbrug (no. 14).

Index point 18 was also regarded as unsuitable since the peat consisted of *Eriophorum* and *Sphagnum* sp. remains.

With respect to point 5 she argued that the given date is probably too old due to contamination by material from the top of the underlying soil.

The following time-depth points were thus considered to be sufficiently reliable: 6, 19, 20, 21, 22, 23, 24, 26, 27, 28, 29, 30, 32, 33 and 34. Jelgersma made no special remarks concerning samples 2, 15, 16 and 17.

Some additional comments

Sample IJmuiden (no. 2) was obtained from an isolated

boring and therefore should also be considered less reliable for former sea-level stand derivation.

It is invalid to reject index point 14 solely on the ground that brackish diatoms were absent in the sample since the diatom content of other reliable samples has not been investigated. DU BURCK (1959, p. 67), however, mentions that the Lower Peat at Burgervlotbrug contains many remains of oligotrophic species.

Index point 20 does not represent a basal peat sample; it is in fact a humic clay sample taken 0.4 m above the base of the Lower Peat (JELGERSMA, 1960).

In summary, the following time-depth data can in principle be considered suitable: south-western sector: 26, 27, 28, 29, 30, 32, 33 and 34; western and northern sectors: 6, 15, 16, 17, 19, 21, 22, 23 and 24.

METHOD OF CURVE CONSTRUCTION

Curve I (Fig. 1) is based on the assumption that peat growth (on the gently seaward sloping Pleistocene surface) may have taken place locally above MHW; hence, ' . . . only the points located in the lowest places for a given age, or even slightly lower, represent a groundwater table which coincides with high tide level' (JELGERSMA, 1961 p. 45). From this line of reasoning, which can be exercised without consideration of the earlier evaluation of the individual time-depth data, it follows that ' . . all aberrations are considered as errors and not as fluctuations of sea level'. This statement can also be considered to apply to the position of the Zeeland data relative to curve II. From figure 1 it can be concluded that, in terms of this method of curve construction, index points 21,

31 : - 4.09 m NAP

26 : -7.76 m NAP

30 : -4.44 m NAP

28 : −6.40 m N.A.P.

3 = 3-4 m below NAP
4 = 4-5 m „ „
etc.

□ eroded by marine gullies

✗ Position of sample
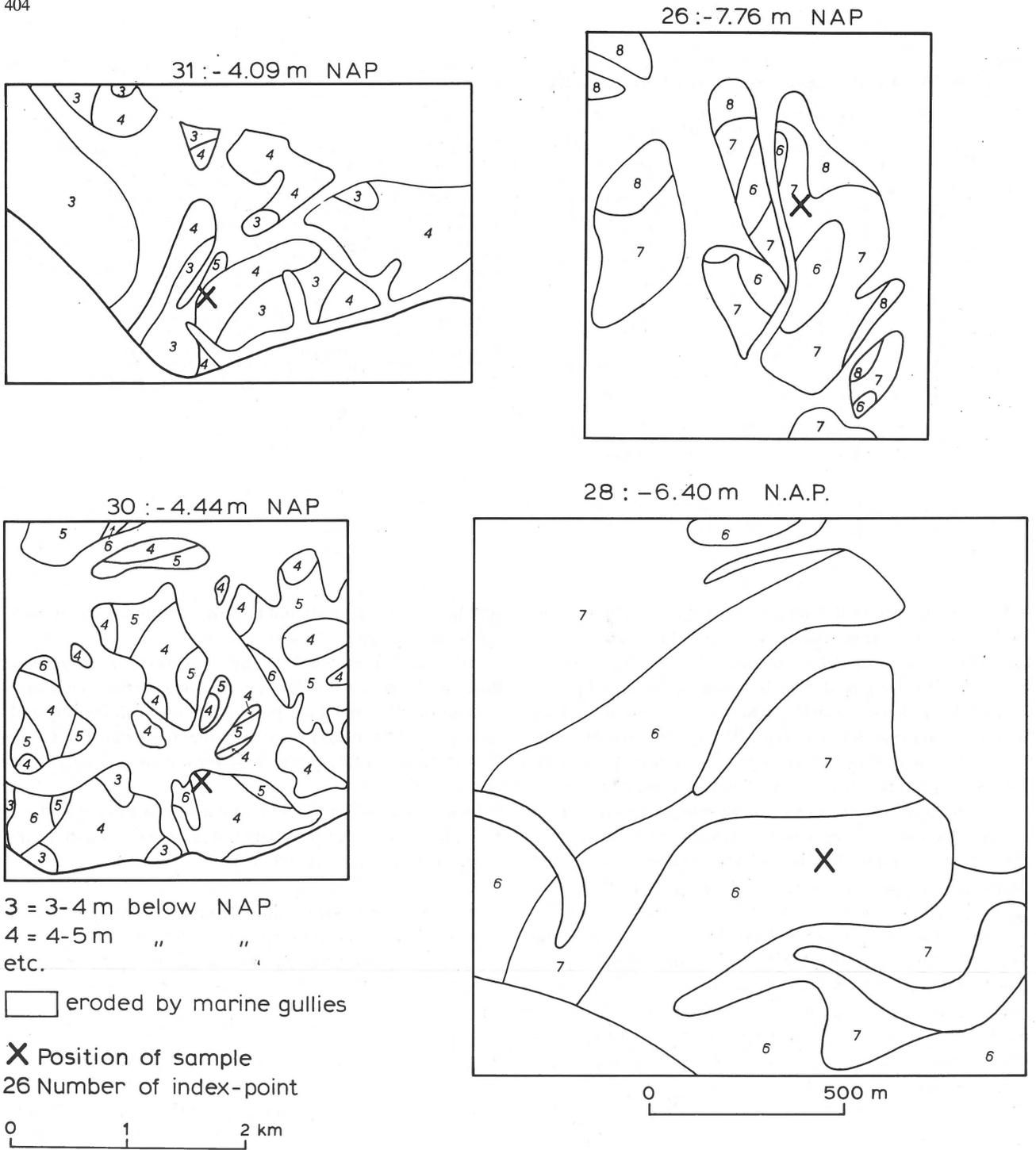26 Number of index-point

0   1   2 km

Fig. 2

Maps showing location of some of the basal peat samples from Zeeland with respect to surrounding substrate topography (depth contours from maps produced by the Geological Survey).

0   500 m

22, 24 and 26, 27, 29, 32 and 34, which were all considered as suitable for sea-level height reconstruction in principle (see above), must now be considered in 'error'. As the peat composition of the samples is the same, it seems that the explanation of this discrepancy should be sought in the location of samples with respect to (local) topography of the substrate.

FACTORS WHICH DETERMINE THE RELATIVE TIME-DEPTH POSITIONS OF THE BASAL PEAT DATA

South-western sector

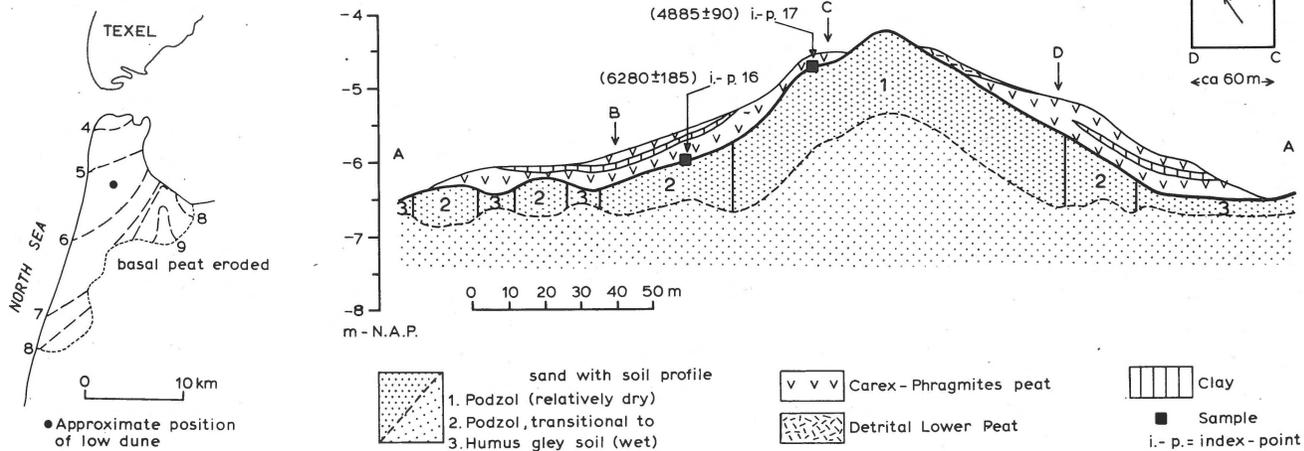VAN RUMMELEN (1965, 1970, 1972, 1978) published 1m-interval

Fig. 3
Schematic cross-section representing in one plane the four faces of a building pit near Julianadorp, North-Holland. The section shows a low dune largely covered by Lower Peat (After Du Burck, 1959).

depth-contour maps (scale 1:100,000) of the Pleistocene sub-surface relief in the province of Zeeland. Locations where basal peat samples were collected by Jelgersma have been plotted on these maps (examples are shown in Fig. 2). It appears that all index points which do not lie on curve II (26, 27, 29, 32 and 33) are located in topographic positions which are relatively favourable for the concentration of surface and/or seepage water. The opposite holds true for index points 28, 30 and 34. It is concluded, therefore, that there is a remark-ably close relationship between relative time-depth position of the index points and the general topographic situation of the sample localities. Even if for one or two index points (e.g. no. 31) this relationship is coincidental, it suggests again a strong influence of existing (general) relief on the height of the (local) groundwater table, and probably therefore, also on the time of basal-peat growth commencement.

Western Netherlands

No evaluation of the St. Maartensvlotbrug sample (no. 15) is attempted because of insufficient detailed data on the sur-rounding Late-glacial/early Holocene relief.

Points 16 and 17 have been obtained from a building pit at Koegras, for which detailed information is available on the local cover-sand morphology and former soil-hydrological conditions (DU BURCK, 1959). A schematic cross-section of the pit is given in figure 3. The main features shown by the section are a low dune overlain by a peat bed, containing an interca-lated clay bed of fresh-water origin, and overlain by marine sediments. The local topography is superimposed on a sloping Pleistocene surface which dips from -4 m NAP (Dutch Ord-nance Datum) in the NW to -7 m NAP in the SE over a dis-tance of about 10 km (PONS & WIGGERS, 1958; ENTE ET AL., 1975; Fig. 3). Wet conditions already existed before the onset of peat accumulation at the foot of the dune, as indicated by soil profiles in the sand, and explains the position of index point 16 at about 2.5 m above curve I. However, this sample does not

come from the lowest part of the relief but from the sloping foot of the dune 0.35-0.7 m above the base of local depres-sions. This suggests that the time-depth position of the sample cannot be understood in terms of local peat growth alone (see below). In the case of index point 17, height of the groundwa-ter level was certainly not influenced by existing relief. It must therefore have been a function of the local tidal range and/or (if that tidal range was nil) the slope of the regional groundwa-ter table. At the sites of index points 16 and 17 the *top* of the Lower Peat has been dated as 4830 ± 100 and 4950 ± 50 years B.P. respectively (JELGERSMA, 1961, p. 29); the mean of these dates is 4920 ± 80 years B.P. (GrN-1060, Table I). Therefore, at the time that the (basal) peat of sample 17 was formed (4885 ± 90 years B.P.), clay deposition took place nearby. It can thus be assumed that peat growth began at a level which was between about MHW and MSL dependent on the amplitude reduction of the tidal wave on its passage from the open coast to the site under discussion. (Palaeogeographic evidence for the region (ENTE ET AL., 1975) suggests that an increase in tidal amplitude in a landward direction is not probable.)

A large excavation at Velsen supplied the only reliable index point at a depth greater than -8 m NAP (no. 6). It also provided detailed data on the irregular topography of the Twente Formation and the closely related distribution of dry, wet and intermediate soil profiles (PONS, 1959; Fig. 4). In the north-eastern corner of the pit a sample of *Alnus* roots preserved in the cover sand was collected (VAN STRAATEN, 1954). Since only wet and intermediate soil profiles occur in that part, it is possible that the *Alnus* trees grew above the lowest possible level of peat growth in the surrounding area at that time, given also the evidence of index point 16. Pollen diagrams (DOPPERT, 1957) indicate that the site had a high groundwater table at an early stage and that in local, shallow depressions peat growth had already taken place in the late Boreal.

A pollen section of the Lower Peat sampled 5 km west of IJmuiden harbour (site IJmuiden V) demonstrates a clear Boreal-Atlantic transition at a depth of about -20.25 m NAP,
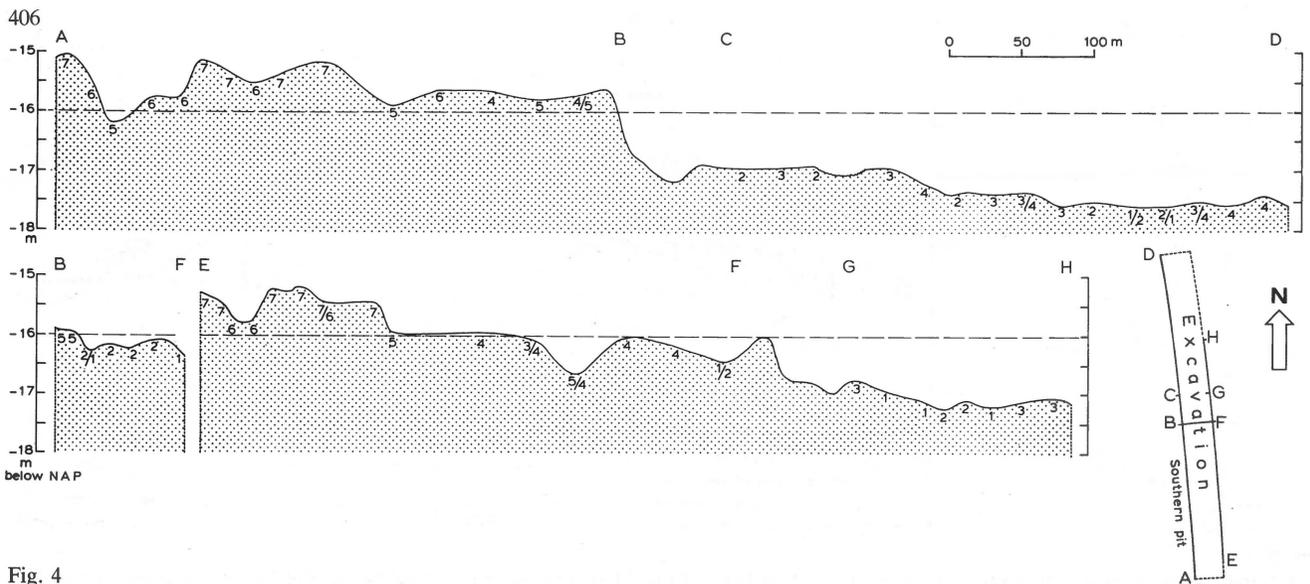
Fig. 4
Sections showing the irregular cover-sand morphology near Velsen. Numbers refer to different types of soil-profiles: 1 = low AC-soil with iron pan; 2 = low eutrophic AC-soil; 3 = low, mesotrophic (oligotrophic) AC-soil; 4 = low mesotrophic humus podzol with iron containing humus B layer; 5 = low oligotrophic humus podzol; 6 = medium high oligotrophic humus podzol on iron containing B layer; and 7 = high mesotrophic humus iron podzol (from Pons, 1959).

about 0.25 m above the cover sand (JELGERSMA, 1961, Plate I). Assuming 87.5-89% compaction, the altitude of the Lower Peat surface at that time (about 8000 years B.P.) and location is thus estimated to be at about -18.25 to -18 m NAP. It is evident from the pollen diagram that the peat at that time was formed in very shallow water. Thus local water level cannot have been much higher than -18 m NAP.

The -18 m NAP contour line of the Pleistocene subsurface approaches the excavation site at Velsen to within 500 m due to the presence of a former natural drainage channel in the sandy substrate (Fig. 5). The proximity of the Velsen site to the drainage channel, in which early peat growth may have taken place, has probably influenced the height of the local groundwater table, thus explaining the late Boreal peat growth in shallow depressions. By about 8000 years B.P., however, the entire excavation site, except for parts higher than about -16.3 m NAP, had turned into a peat swamp (FLORSCHÜTZ, 1944; DOPPERT, 1957). Yet, at the sampling site 5 km from IJmuiden harbour the surface of the Lower Peat cannot have been much above -18 m NAP at that time. Since this height difference cannot be explained in terms of water depth, it is concluded that in this region the 8000 years B.P. surface of the Lower Peat was sloping gently upwards in the direction of the land. It is not certain to what extent this slope can be connected with the above-mentioned drainage channel. In our opinion this has been of secondary importance, since it can be argued that the origin and maintenance of a sloping peat surface is primarily a function of sufficient supply of fresh (seepage) water. The presence of fresh-water clay in the basal part of the Lower Peat at Velsen suggests that this condition has been amply fulfilled. A tentative palaeogeographic reconstruction of the IJmuiden-Velsen area at the beginning of the Atlantic is given in figure 5.

The consequence of a sloping Lower Peat surface at about 8000 years B.P. on the interpretation of index point 6 is

difficult to determine; firstly, because of the large standard deviation of the date (± 200 years), and secondly, because it is not known how the configuration of the surface slope changed with the continuing sea-level rise and the accompanying landward migration of the belt of peat formation. However, the hypothesis of a sloping peat surface maintained by seepage is adequate reason to consider the possibility that the *Alnus* tree grew above contemporaneous MHW level. It is equally clear that the altitude of index point 2 (base of Lower Peat at IJmuiden V) may also demonstrate a sloping-peat-surface effect.
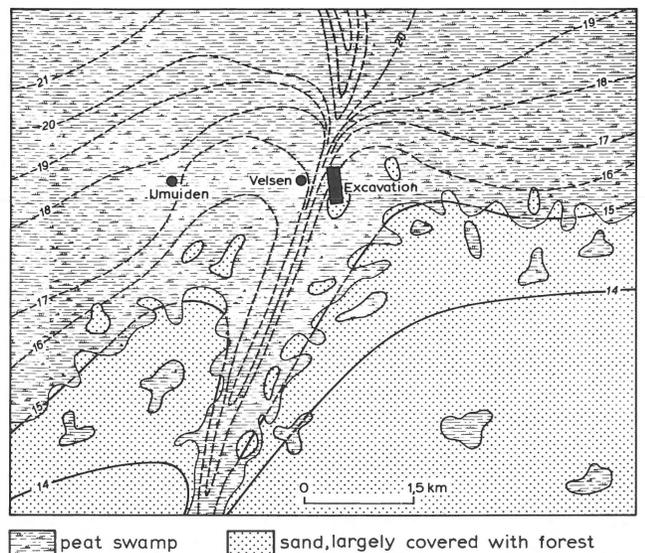

Fig. 5
Tentative palaeogeographic reconstruction in the IJmuiden-Velsen area at about 8000 years B.P. Five kilometres to the west of IJmuiden the top of the peat swamp cannot have reached much higher than about -18 m NAP, which is about 1.5 m lower than at Velsen (depth contours of the top of the sandy substrate (in m below NAP) from Pons, 1959).
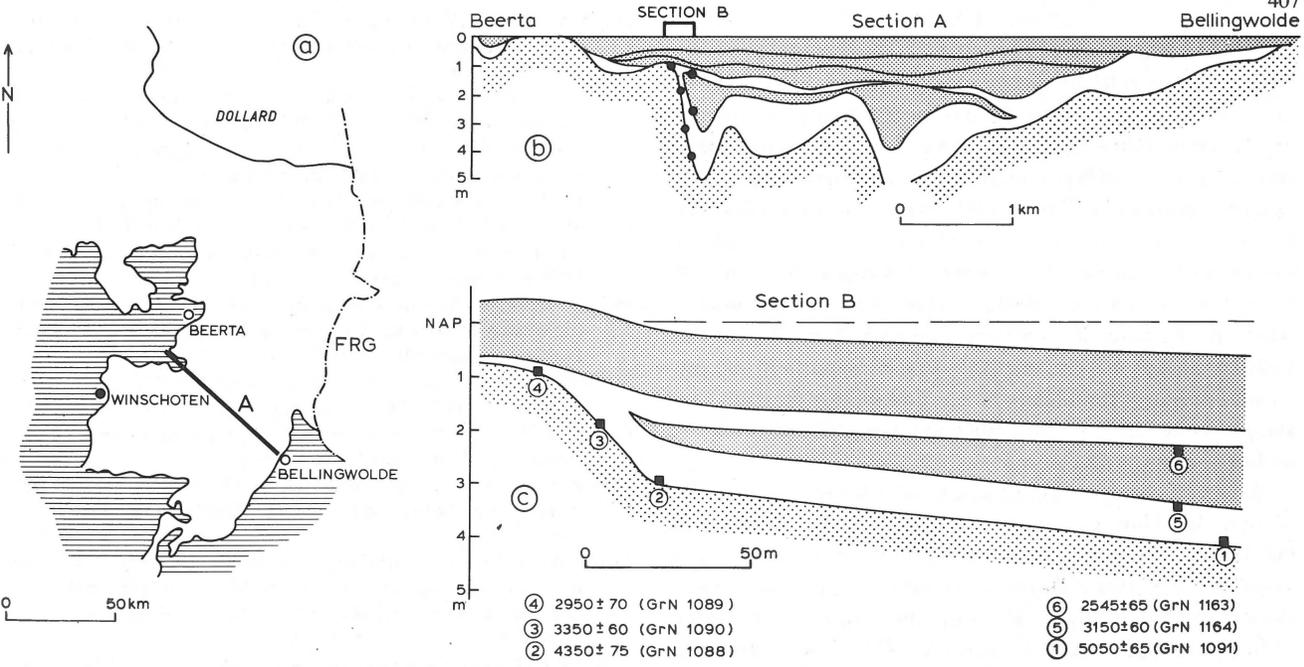
Fig. 6

(a): Location of cross-section A through topographic depression in Pleistocene sediments (horizontal hatching), N.E. Netherlands; (b): lithostratigraphy of Holocene deposits and position of radiocarbon dated samples (after De Smet, 1962); (c): detail of section A (after Jelgersma, 1961); note that at the time of peat growth at the spot of sample 3 (index point 23 in Fig. 1) the embayment constituted an extensive peat marsh, whereas during the onset of peat growth at the site of sample 4 (index point 24 in Fig. 1) open-water conditions occurred nearby.

To complete the discussion of data from the Velsen-IJmuiden area one further point should be mentioned. BENNEMA (1954) published a radiocarbon date from the top of the Lower Peat at Velsen. The sample consisted of a piece of wood taken 0.05 m below the slightly eroded top of the Lower Peat at a depth of -16.05 m NAP, and was dated at 7100 ± 200 years B.P. (GrN-75, Mook pers. comm.; in Bennema's publication the figure 7200 ± 200 years B.P. was used). The original altitude of the sample was -14.25 ± 0.25 m NAP, computed by Bennema using two different methods. According to him MSL at that time occurred within the lower half of this interval. Even if MSL is placed at -14 m NAP, MHW cannot have been much higher than -13 m NAP, which is still about 1 m below curve I (Fig. 1).

The time-depth position of index point 16 could not be satisfactorily explained in terms of sample location alone (see above) and may perhaps also be attributed to a previously sloping (basal) peat surface.

Northern coastal sector

The sample at index point 19 has been taken from a broad drainage depression, judging from the Pleistocene depth map for the north-eastern Netherlands (ROELEVELD, 1974), and this may account for the early peat growth there.

The question may now be raised with regard to the four Winschoten samples (21-24) as to why three of the four plot above curve I. All four samples have been taken from the flank of a north-east dipping depression in the Pleistocene

subsoil which was moderately deep and several kilometres wide (Fig. 6a and b). Within this embayment there are two smaller valleys and the two deepest Winschoten samples were collected at the foot of the northern slope of the northernmost valley (Fig. 6b). This, combined with the limited width of the valley and the receipt of run-off and seepage from several directions, may explain peat growth at a relatively high elevation.

By the time peat formation had commenced at the level of index point 23 most of the embayment had become an extensive reed swamp or fen marsh in which the Pleistocene morphology exerted little influence on the height of the groundwater table. The same situation also applies to index point 24, but in the meantime a wide gully had penetrated the embayment to beyond the sampling site (DE SMET, 1962; Fig. 6c). The time-depth position of the two younger Winschoten samples may be explained on the basis of this difference in palaeogeography, which can also be expected to have influenced the local tidal range. In the case of no. 23 it is assumed that local tidal range was small because of the presence of a fen marsh in front of the sampling site, which must have had a strong frictional effect on the progression of the tidal wave. Local tidal amplitude will have increased again when an arm of the sea broke into the peat area and open-water conditions occurred very near the spot concerned. Thus, in the absence of other disturbing factors and provided the smooth character of curve I is accepted, one may interpret the two younger Winschoten samples as: index point 23 representing commencement of peat growth close to MSL and index point 24 indicating a former (local) MHW level.

CONCLUSIONS

The introduction to this paper reflects our preoccupation with pre-existing subsurface topography as the principal explanatory factor in understanding the time-depth position of basal-peat data. This emphasis originated when it appeared that the time-depth position of five basal peat samples randomly collected in north-eastern Friesland (GRIEDE, 1978) could be satisfactorily explained in terms of sample location with respect to substrate morphology. It was further strengthened when, in the case of data from Zeeland, it was found that samples collected from relatively low lying parts in the pre-existing relief occur higher in the time-depth diagram than samples collected from sites much less likely to receive surface and/or seepage water.

However, examination of available information from the Velsen-IJmuiden area now suggests that the influence of subsurface topography may explain only part of the relationships. It is clear that in this area at least the prime condition for development of a coastal peat-formation zone was the supply of fresh (seepage) water (cf. DE VRIES, 1974), such that the peat crept up the sandy subsoil resulting in the development of a sloping peat surface. This surface may intersect both convex and concave parts of the drowning relief at the same time. If, therefore, the basal peat in Zeeland also possessed a sloping surface, the close relationship between sample location with respect to subsurface topography and time-depth position may be largely accidental.

It is concluded from the discussion of index points 17, 23 and 24 that if topography plays a subordinate or negligible role and supply of fresh-water is moderate or small, the main factor which determines the level of initial peat growth is the local tidal range.

Basal peat may develop a local or regional slope, implying that peat growth may commence well above coastal MHW without being independent of the sealevel. In the case of index point 7, 8 and 9, and probably of no. 14, basal peat growth occurred unrelated to the sealevel.

ACKNOWLEDGEMENTS

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