

Holocene water level development in The Netherlands' river area; implications for sea-level reconstruction

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Abstract

Plotting of radiocarbon datings of samples from the base of peat layers on the flanks of fossil river dunes results in time-depth graphs that can be interpreted as curves of the local rise of the groundwater table. Combination of data from individual sites makes it possible to reconstruct groundwater gradient lines at selected moments. All gradient lines appear to consist of a steep upper part (river dominated) and a level lower part (sea level dominated). Between 6750 and 2850 BP the knickpoint between the two wandered some 10 km upstream. During all of the Holocene the area east of Leerdam remained outside the direct influence of the sea. Irregularities in individual curves in the downstream area – if not caused by dating errors – may represent varying rates of MSL rise, varying tidal range and a varying floodbasin effect. For the pre-5000 BP period, assumed sea level dominance in the downstream area is not consistent with the general evidence on the position of the sea level in The Netherlands. This situation is possibly due to less tectonic subsidence in the southwestern coastal sector.

1. Introduction

In the central part of the Rhine-Meuse delta a relatively large number of fossil river dunes rise up to 20 m above the buried Late Glacial/Early Holocene floodplain of the rivers Rhine and Meuse (Fig. 1). The dunes consist of wind-blown medium sized sand. They were essentially formed after the Allerød Interstadial and before the Preboreal (Pons 1957, Verbraeck et al. 1974, De Jong 1981), i.e. during the Younger Dryas Stadial of the Weichselian. During the Holocene the dunes became partially or completely covered by fluvial deposits and peat. In the western part of the river area they are known as 'donken'. Where peat is resting directly on the compaction-free dune sand, radiocar-

bon dating of basal peat samples may serve to reconstruct the position of former groundwater levels. In this respect only fen (*Phragmites-Carex*) and fen-wood (mainly *Alnus*) peat, the development of which is governed by the ground water level situation, should be considered. Fen-wood peat is assumed to develop at about groundwater (= local MHW in tide-influenced situations or average (ground)water elsewhere) level; fen peat, however, may develop in water depths of up to several decimetres (Van de Plassche 1982).

Jelgersma (1961), in her study of Holocene sea level rise in The Netherlands, was the first to date basal peat samples from the flanks of buried river dunes, at Barendrecht and Brandwijk (Fig. 1). Being aware of the uncertainties involved in interpret-

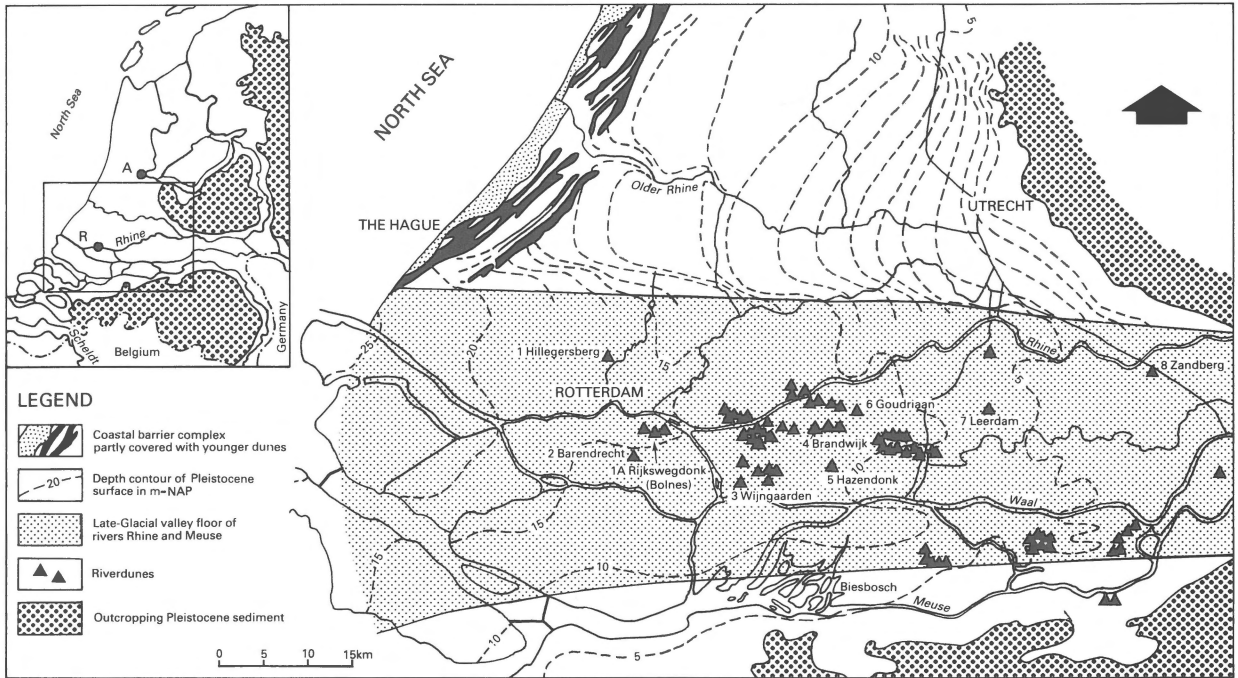


Fig. 1. Map showing the investigated fossil river dunes in the Rhine-Meuse delta.

ing former groundwater levels in the coastal area in terms of former sea levels (Jelgersma 1961, p. 20), Jelgersma especially valued fossil river dune peat samples, since the steep morphology of the dunes largely excludes the occurrence of early topogenic peat formation in local depressions. This latter situation, which involves groundwater levels that are not in a direct manner related to the position of the sea level, is difficult to avoid or recognize in areas where the gently seaward sloping Pleistocene subsurface has an essentially level topography, unless subsurface topography is mapped in much detail (see also Van de Plassche, 1982). Jelgersma (1961) was of the opinion that the rise of the ground water level as reconstructed for the western Netherlands coastal plain (including the Barendrecht and Brandwijk fossil river dunes) was directly related to the rise of coastal mean high water (MHW). In a later paper (Jelgersma 1979), however, she argued that the rise of groundwater level in the coastal area should be considered to represent the rise of mean sea level (MSL).

Since Jelgersma's publication of 1961, reconstruction of sea level history in The Netherlands

has been pursued with increasing subtlety and detail. Van de Plassche (1982), after scrutinizing existing evidence and collecting additional data, published sea level curves for The Netherlands which are to be regarded as extremely accurate with reference to the global standard. In the course of his work Van de Plassche (1982) was able to demonstrate that the isochrones of commencing basal peat formation in the coastal area show a seaward dip. This situation implies an additional uncertainty in the interpretation of the relation of former groundwater levels to the then sea level.

With regard to basal peat samples from fossil river dune flanks the situation is even more complex. Van de Plassche (1980) reasoned that time-depth curves of groundwater rise based on samples of progressively farther inland situated fossil river dunes, will tend to be situated more and more above the curve of mean sea level rise. Moreover, the curves will converge in time with the MSL curve (Fig. 2). This situation is basically explained as the result of the river gradient effect. Van de Plassche (1980) argued that other factors may be involved as well, since the convergence of the groundwater

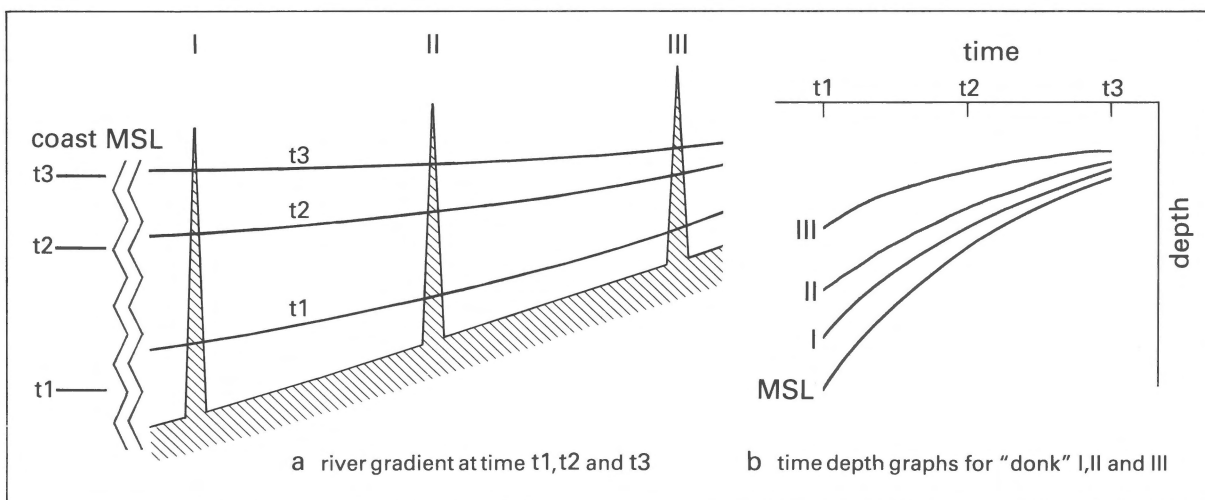


Fig. 2. River gradients (a) at three moments during the Holocene, and time-depth curves (b) for the local rise of the ground water table at three river dunes (after Van de Plassche, 1981).

level curves of the Barendrecht and Hazendonk fossil river dunes (Fig. 1) with the smooth MSL curve (Jelgersma 1979), seems to be irregular. If the assumed irregularity is real (it is not certain that all dates involved are reliable, and Jelgersma's MSL curve is based on a very limited number of basal peat data), then several factors may be involved. In the first place, the coastal tidal range may have varied over time. Jelgersma (1980) reckoned with a constant tidal range along the mid-western Netherlands coast during the last 4800 C-14 years. Coastal tidal range fluctuations have also not been regarded by Van de Plassche (1980), but recent evidence (Roep & Beets, 1988) points to a somewhat enlarged tidal range before 3000 cal BC. Secondly, variations in the degree of reduction of the tidal amplitude in the intracoastal area are to be regarded. Reduction of tidal amplitude will result from frictional dissipation of energy and from storage in the tidal basin ('floodbasin effect', Zonneveld 1959). Obviously, both the floodbasin effect and the river gradient effect may have varied in time and space, as they are related to changes in the location and the depth and/or width of former river channels and tidal inlets. On the basis of the uncertainties involved Van de Plassche (1980, p. 351) concluded that in general river dune data are less suited for sea-level studies. Berendsen (1982) men-

tioned a number of other factors which may explain possible irregularities of river dune curves of beginning peat formation: avulsion of river channels, high river discharge, storm surges, wiggles in the C-14 calibration curve, real sea-level fluctuations, seepage from higher Pleistocene grounds, local relief and lithology of the substratum.

Steenbeek (1990) has pointed to the fact that in the river area proper two different water levels are recorded: basin water level and channel water level. Average basin water level may be regarded as the general regional ground water level which governs the occurrence of initial peat formation, provided that conditions are otherwise suited. Former basin water levels are most readily reconstructed from the compaction-free upper depositional level of basin clays and related deposits. However, it is difficult to assess a precise value for the *average* basin water level, which will have been somewhat, possibly up to a few dm, beneath the highest observed depositional level of basin sediments. Contrary to basin water level, channel water level, which is represented by the upper depositional level of natural levees and fossilized streams ('stream ridges'), should be regarded as a water level of local significance only. According to Steenbeek (1990) the difference in altitude between the depositional levels of natural levees and basins (i.e. between

channel water levels and above-average basin water levels) has been some 1.5 m during the Sub-boreal and Early-Subatlantic in the central and eastern part of the Dutch river area. In the western part of the river area the difference will have been less, due to the fact that in the coastal zone ultimately only a single, sea-level induced, water level could exist.

Steenbeek's (1990) model of dual water levels makes it clear that stream ridges and levees in the river area may have stood out as topographical highs with regard to the regional water level for a prolonged period (up to several millenia) after their formation by an active channel had come to an end. On their flanks zones of initial peat formation may have crept upward in much the same manner as they did on river dune flanks.

So far, the number of published radiocarbon dates of basal peat samples from river dune flanks is very limited. It has been difficult therefore to draw final conclusions with regard to the Holocene evolution of water levels in the Rhine-Meuse delta and to assess the influence and significance of the factors mentioned above for this evolution. It is the aim of this paper to evaluate on the basis of a relatively large number of additional C-14 dates the general trend of Holocene water level changes in the Rhine-Meuse delta, and to further document and, as far as possible, explain irregularities in the evolution. By combining the new data on the general trend of water level rise in the delta with recently published evidence for the evolution of the water table in the upstream situated part of the river area (Steenbeek 1990) an attempt will be made to reconstruct the general Holocene evolution of the water table gradient between the coast and the area downstream of Nijmegen.

It will be shown that during the Holocene development of the longitudinal profile was composed of a level downstream part and a steeper upstream part. The knickpoint between the two stretches, which determines important differences in palaeohydrological and depositional conditions, wandered upstream in the course of time. Finally, it will be argued that on the basis of the evidence from the river area there is reason to suspect that the older part of Van de Plassche's (1982) curve of

sea level change in The Netherlands is not representative for the Rhine-Meuse mouth area.

2. Method

A number of river dunes were mapped in detail by borings. Also, several detailed lithological cross-sections have been constructed (Figs. 3–6). Four river dunes were selected for radiocarbon sampling, namely (3) Wijngaarden (Van Dijk); (6) Goudriaan (Van Dijk); (7) Leerdam (Berendsen) and (8) Zandberg (Berendsen); numbers refer to the river dunes indicated in Fig. 1. Data of four other fossil river dunes are available from the literature, namely: (1) Hillegersberg and (1A) Rijkswegdonk (Bolnes) (Van de Plassche 1982), (2) Barendrecht and (4) Brandwijk (Jelgersma 1961; see also Van de Plassche 1980 and 1982). Information has also been published from (5) Hazendonk-Molenaarsgraaf (Louwe Kooijmans 1974), but in this case no basal peat data are available.

Selection of the new sites for sample collection was based on the following criteria:

1. Geographical location; together the selected sites form a roughly west-east transect, parallel to the main rivers.
2. General presence of peat layers directly overlying river dune sands. In principal basal peat samples have been taken at 0.5 m vertical intervals. This comparatively high density can not be achieved at many locations, since at many river dune flanks intermittent phases of mineroclastic deposition have occurred.
3. Topography and gradient of river dune flanks. Whenever possible sampling in depressions and on flanks with low gradients has been avoided, since such samples are likely to reflect local water levels rather than regional water levels (Van de Plassche 1982).

All radiocarbon dated samples have been plotted in a time-depth diagram (Fig. 7). Age and sample characteristics are given in Table 1. In addition to Fig. 7 samples have been plotted also on a calibrated time scale. Since this plot did not reveal any new points of view it has been omitted here.

Table 1. Radiocarbon datings

| Name | Sample No. | GrN | Age (Conv. C-14 y BP) | Map sheet | Coordinates | Depth in cm below | |
|-------------|------------|-------|-----------------------|-----------|-----------------|-------------------|-------------|
| | | | | | | surface | NAP |
| Wijngaarden | 1 | 9564 | 3400 ± 70 | 38D | 110.963–426.937 | 57–61 | 171–175 |
| | 2 | 9558 | 4150 ± 60 | 38D | 110.962–426.939 | 107–111 | 246–250 |
| | 3 | 9559 | 4480 ± 70 | 38D | 110.961–426.940 | 145–149 | 288–292 |
| | 4 | 9560 | 4670 ± 70 | 38D | 110.979–426.941 | 177–182 | 325–330 |
| | 5 | 9561 | 4990 ± 70 | 38D | 110.971–426.940 | 220–224 | 366–370 |
| | 6 | 9562 | 5140 ± 100 | 38D | 110.976–426.944 | 255–260 | 415–420 |
| | 7 | 9563 | 5340 ± 80 | 38D | 110.969–426.950 | 290–295 | 450–455 |
| | 8 | 10096 | 5320 ± 80 | 38D | 110.950–426.962 | 344–349 | 505–510 |
| Goudriaan | 1 | 10872 | 5400 ± 70 | 38G | 120.532–435.861 | 336–340 | 446–450 |
| | 2 | 10884 | 3520 ± 90 | 38G | 120.526–435.880 | 74–77 | 165–168 |
| | 3 | 10873 | 3520 ± 60 | 38G | 120.527–435.875 | 105–109 | 202–206 |
| | 4 | 10874 | 4140 ± 60 | 38G | 120.527–435.875 | 127–130 | 224–227 |
| | 5 | 11532 | 4210 ± 90 | 38G | 120.527–435.875 | 137–140 | 234–237 |
| | 6 | 10876 | 4600 ± 60 | 38G | 120.527–435.875 | 166–169 | 263–266 |
| | 7 | 10877 | 4580 ± 140 | 38G | 120.529–435.870 | 240–243 | 343–346 |
| | 8 | 10878 | 4990 ± 70 | 38G | 120.529–435.868 | 287–290 | 395–398 |
| | 9 | 10885 | 5240 ± 60 | 38G | 120.530–435.866 | 324–327 | 430–433 |
| | 10 | 10879 | 5785 ± 45 | 38G | 120.534–435.856 | 430–433 | 532–535 |
| | 11 | 10880 | 6690 ± 70 | 38G | 120.531–435.799 | 704–707 | 827–830 |
| Leerdam | 1 | 11689 | 4390 ± 60 | 38H | 135.395–436.080 | 110–122 | 96–108 |
| | 2 | 11690 | 4840 ± 60 | 38H | 135.390–436.070 | 164–175 | 153–164 |
| | 3 | 11694 | 6540 ± 45 | 38H | 135.255–435.850 | 520–529 | 508–517 |
| | 4 | 11691 | 5340 ± 70 | 38H | 135.230–435.800 | 265–275 | 235–245 |
| | 5 | 11692 | 6190 ± 45 | 38H | 135.220–435.772 | 415–430 | 412–427 |
| | 6 | 11693 | 6720 ± 70 | 38H | 135.212–435.755 | 475–490 | 471–486 |
| | 7 | 10119 | 2510 ± 60 | 38H | 135.170–435.665 | 86–90 | 90–94 |
| | 8 | 10118 | 2860 ± 60 | 38H | 135.170–435.665 | 111–114 | 115–118 |
| | 9 | 10117 | 4730 ± 70 | 38H | 135.170–435.665 | 240–243 | 244–247 |
| | 10 | 10116 | 4800 ± 80 | 38H | 135.170–435.665 | 248–251 | 252–255 |
| | 11 | 10115 | 4970 ± 70 | 38H | 135.170–435.665 | 257–260 | 261–264 |
| | 12 | 10114 | 5300 ± 80 | 38H | 135.170–435.665 | 271–274 | 275–278 |
| | 13 | 10113 | 5270 ± 40 | 38H | 135.170–435.665 | 295–298 | 299–302 |
| Zandberg | 1 | 12459 | 3825 ± 40 | 39B | 152.137–440.595 | 385–389 | + 15/+ 11 |
| | 2 | 11475 | 5895 ± 35 | 39B | 152.308–440.387 | 465–475 | 66–76 |
| | 3 | 11474 | 4820 ± 70 | 39B | 152.318–440.388 | 405–410 | 11–16 |
| | 4 | 11473 | 5335 ± 40 | 39B | 152.351–440.339 | 349–355 | + 30/+ 24 |
| | 5 | 11472 | 5240 ± 60 | 39B | 152.378–440.307 | 293–300 | + 89/+ 82 |
| | 6 | 11471 | 4575 ± 40 | 39B | 152.385–440.290 | 275–280 | + 110/+ 105 |
| | 7 | 11470 | 4840 ± 70 | 39B | 152.394–440.288 | 235–240 | + 153/+ 148 |
| | 8 | 12461 | 5350 ± 40 | 39B | 152.852–439.762 | 225–230 | + 55/+ 50 |
| | 9 | 12460 | 4235 ± 40 | 39B | 152.852–439.762 | 145–150 | + 135/+ 130 |
| | 10 | 11469 | 11700 ± 100 | 39B | 152.621–440.044 | 618–623 | 219–224 |
| Ottoland | | 10853 | 6280 ± 80 | 38D | 119.294–432.919 | 632–636 | 744–748 |
| Noordeloos | | 10104 | 6310 ± 60 | 38G | 123.193–435.132 | 468–471 | 608–611 |

GrN: Groningen Radiocarbon Dates.

BP: Before AD 1950.

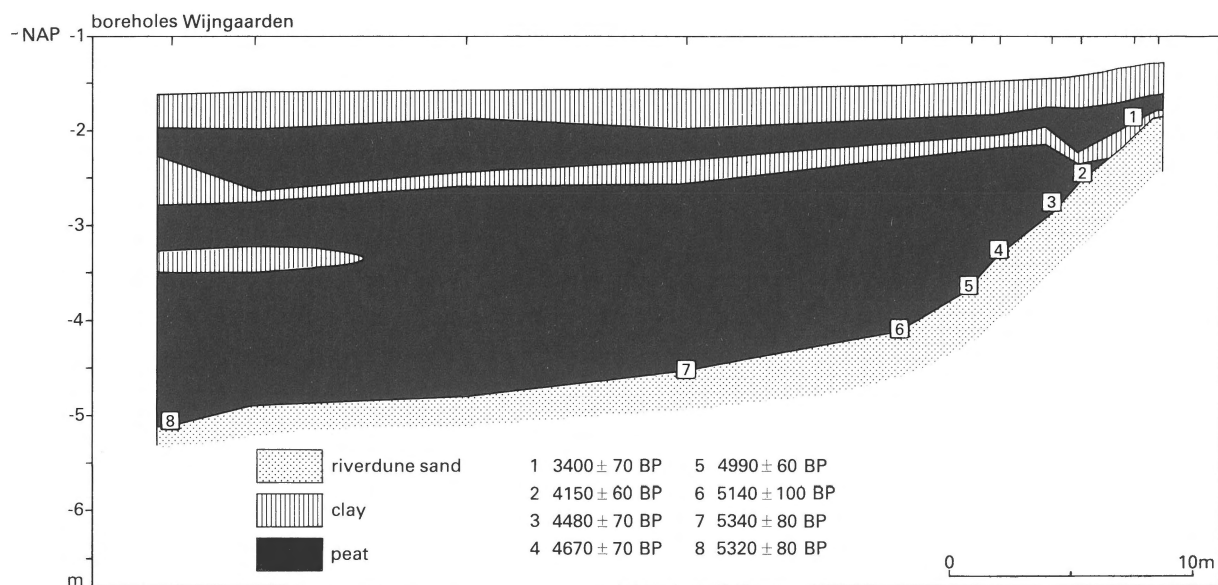


Fig. 3. Cross section Wijngaarden.

3. Cross-sections

3.1. Wijngaarden

The cross-section (Fig. 3) was made at the north-western side of the river dune, approximately 1 km west of the village of Wijngaarden. Eight basal peat samples overlying river dune sand were radiocarbon dated (Table 1 and Fig. 3). Until about 5400 BP mineroclastic sediments were deposited in the area, initially followed by the formation of a thin layer of reed (*Phragmites*) peat. Within a few hundred years the area became overgrown by wood (*Alnus*) peat. Between about 4150 and 3400 BP peat formation was interrupted at the flank of the river dune by deposition of a layer of humic clay. Sedimentation of the uppermost clay bed ended around 1000 BP. The top of this upper clay bed overlies the river dune sand at a level of 0.9 m-NAP (NAP = Dutch Ordnance Datum, viz. about MSL). Samples 1 through 7 consist of wood peat, whereas sample 8 consists of reed peat. A best fitting exponential curve has been drawn in Fig. 7 through the time-depth boxes. This curve may be regarded as an approximation of the trend of the local rise of the groundwater table (although not necessarily the best one). The curve slightly con-

verges upon the smoothed version of Van de Plassche's (1982) curve of MSL, as is to be expected in a situation with a gradually decreasing gradient effect (cf. Introduction). At 5000 BP the curve is situated about 1 m above Van de Plassche's (1982) trend curve of MSL. Compared to an adjusted curve of MSL, to be discussed further on in this paper, the Wijngaarden trend curve is situated at an essentially constant, circa 0.6 m higher level.

Sample 8 appears to be slightly too young with reference to the trend curve (Fig. 7). This may be due to the rejuvenating effect of *Phragmites* roots penetrating the sample from above (the so-called 'Streif-effect', Streif 1971; Roeleveld 1974; see also Van de Plassche 1982, par. 7.3.2.). On the other hand, the *Phragmites* peat of sample 8 may have been formed at a water depth of up to several decimetres. Although time-depth box 3 seems to be situated a little too high with regard to the curve (Fig. 7), margins of error do not allow for final conclusions on possible irregularities in the regional rise of the groundwater table. It is noteworthy, through, that a comparable steepening is suggested around 4600 BP at Goudriaan (see below).

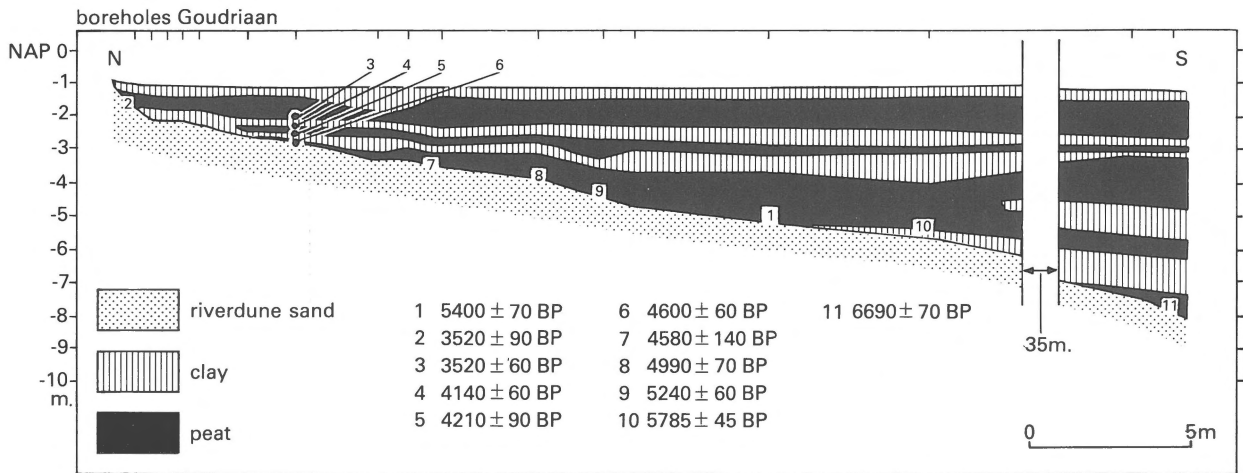


Fig. 4. Cross section Goudriaan.

3.2. Goudriaan

The cross-section (Fig. 4) was made north of Goudriaan, at the southern flank of the river dune. Eleven samples were radiocarbon dated, 7 of which were basal peat samples on river dune sand (Table 1 and Fig. 4). The remaining 4 samples were taken to elucidate the regional chronostratigraphy.

At a depth of 5.2 m-NAP a clay bed wedges out against the river dune flank. The onset of peat formation on top of this clay bed was dated at 5785 ± 45 BP (GrN-10879, Goudriaan 10 in Fig. 4). However, in the wider surroundings considerably older dates were obtained by Van Dijk (unpublished) for the base of the same peat layer: Ottoland 6280 ± 80 BP (GrN-10853), and Noordebos 6310 ± 60 BP (GrN-10104). Since peat formation is determined by the essentially horizontal groundwater table, this diachronism has to be related to differences in height of the clay bed between the basin area and the river dune flank. Such differences may partly be the result of initial compaction of clay and peat in the river basins, but most likely they may be attributed to original variations in depositional level. The last explanation implies the occurrence of significant basin water level fluctuations, with deposition of basin clays at a comparatively elevated level at the river dune flank during high water stands. In a natural fluvial dominated environment the occurrence of such

fluctuations, due for instance to seasonal variations in discharge, will have been no exception.

It is obvious from the situation described above that erroneous time-depth data would have been obtained, had the dates from the river basins been projected to the equivalent lithostratigraphic level at the river dune flank. At the Hazendonk river dune, situated about 6 km southwest of Goudriaan, this procedure was applied by Van de Plassche (1980, 1984). He projected a date of 6060 ± 80 BP (GrN-7864) at the base of a peat layer which occurred on top of a fluvial clay bed in the basin area at a depth of circa 8.25 m-NAP, to the equivalent lithostratigraphic level at the river dune flank (some 1000 m away) at a depth of about 6.8 m-NAP. Remarkably, however, in this case the projected date seems to fit quite well, especially when compared to the evidence from the nearby situated Brandwijk river dune (Jelgersma 1961; Van de Plassche, 1980). This suggests that in the Hazendonk area the clay bed that had been deposited shortly before 6000 BP did not show significant primary relief, in contrast to the situation near Goudriaan.

At a level of about 3 m-NAP in Fig. 4 two layers of fluvial clay occur, together with an intercalated peat bed. The clay beds are related to the Zijderveld and Schoonrewoerd stream ridges (De Boer & Pons 1960; Verbraeck 1970; Berendsen, 1982). They were formed between 4600 ± 60 BP

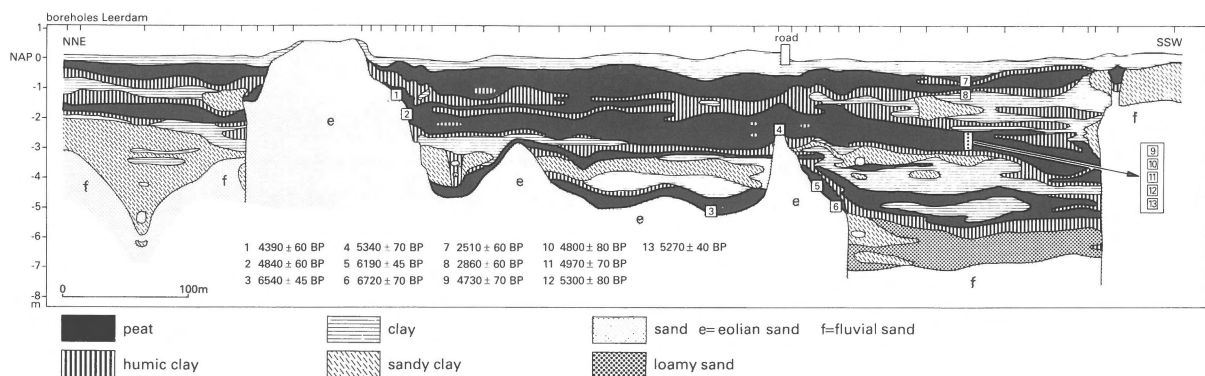


Fig. 5. Cross section Leerdam.

(GrN-108/6) and 3520 ± 90 BP (GrN-10884). The intercalated peat bed was formed between 4210 ± 90 BP (GrN-10875) and 4140 ± 60 BP (GrN-11532).

A smooth curve that is fit through the Goudriaan time-depth data, is slightly convergent with Van de Plassche's (1982) curve of MSL. At 5000 BP the curve is at approximately the same level in the time-depth graph (Fig. 7) as the Wijngaarden-curve. Compared to the adjusted curve of MSL (see further on in this paper) the Goudriaan curve is hardly convergent, except for the lower part. Sample 6 obviously is somewhat too old with respect to the curve. Time-depth boxes of samples 4 and 5 are also comparatively high in the diagram. Together with sample 6 they may suggest an accelerated rise of the groundwater level between approximately 4600 and 4500 BP. It is remarkable that both the Hazendonk and Hillegersberg data (Van de Plassche 1980, Fig. 1 and Van de Plassche 1982, Fig. 58) and to a certain extent also the situation at Wijngaarden (see above) suggest a similar effect around 4500 BP. As we suspect that at around this time the groundwater situation in this particular zone of the river area was essentially governed from the sea side (see below), the suggested steepening of the water level rise may primarily be explained by relating it either to an increased rate of rise of MSL or to an increased tidal amplitude. Van de Plassche's (1982) data do not contradict the idea of an increased rate of MSL rise just before circa 4500 BP. On the other hand, according to Roep & Beets (1988), tidal amplitude at

the coast of the western Netherlands was circa 1.50 m during the last 2000 historical years and circa 2 m between 4500 and 3000 cal BC; this difference may (partly) explain a decrease of groundwater level rise since about 4350 BP (circa 3000 cal BC), although it does not explain the suggested acceleration at around 4600 BP.

3.3. Leerdam

The cross-section (Fig. 5) was made about 3 km north of Leerdam. Thirteen samples were C-14 dated, 6 of which were taken from the base of peat on river dune sand (Table 1 and Fig. 5). The remaining samples were taken for stratigraphic reasons. In the northeastern part of the cross-section the river dune has partly been eroded away by the Middelkoop stream. No samples were collected here. Van der Woude (1982, Fig. 10) published a similar but less detailed cross-section of the river dune. According to his data the sandy stream ridge which came into existence after siltation of the Middelkoop stream, became covered by peat around 4800 ± 70 BP (GrN-8376) according to our samples 12 and 13 (Table 1) peat formation on top of the Middelkoop fluvial basin clay beds, at a distance of about 500 m south of the stream ridge, began as early as 5300 BP (GrN-10114 and GrN-10113). In the flood basin, Van der Woude (1981) found an even older date for beginning peat growth: 6090 ± 70 BP (GrN-8922). The strong diachronism of beginning peat growth suggests that

there were considerable differences in altitude in the depositional area. This may be explained by assuming that natural levees of former streams stood at a considerable height above the flood basins. According to Steenbeek (1990) the difference in altitude between the depositional levels of natural levees and flood basins may be about 1.5 m. Depositional levels of basin clays may be assumed to be related to average groundwater levels in the fluvial backswamps; they have therefore essentially the same palaeohydrological significance as the occurrence of initial peat formation on river dune flanks. Levee deposits on the other hand represent much higher situated (channel) water levels. Van de Plassche (1984) by attaching a channel water level of about 2 m-NAP to the date of 6090 BP, which is representative of a basin situation, reached a wrong conclusion on regional water level evolution in the Leerdam area. This is now evident from the plot of basal peat dates in the Leerdam area (Fig. 7), which show that around 6100 BP basin water level was only at about 4 m-NAP.

The Schaik stream ridge, another fossilized stream, occurs in the southern part of the section. According to our C-14 data it was essentially formed between 4730 ± 70 BP (GrN-10117) and 2860 ± 60 BP (GrN-10118), when the deposits became covered by wood peat. Since the last date is only a terminus ante quem, river activity may have ended earlier than 2860 BP. These data are in accordance with those of De Boer & Pons (1960, p. 26). Between 5270 ± 40 (GrN-10113) and 4730 ± 70 BP (GrN-10117) essentially clayey reed peat was formed in the area. The base of this peat layer merges with the river dune at a compaction-free level of 2.1 m-NAP. This corresponds with an approximate age of 5300 BP (Fig. 7). Below this peat layer stratigraphy is extremely complicated. Layers of clay alternate with thin humic layers, reed-peat, wood-peat, clay with pieces of wood and gyttja (Fig. 5). No samples have been collected here.

Dates from the base of peat on river dune flanks generally are consistent with local stratigraphy, although sample 6 may be somewhat too old (or alternatively, 3 may be somewhat too young). Data suggest a curve for the rise of the groundwater table that is clearly convergent with Van de

Plassche's (1982) curve of MSL. Around 5000 BP the vertical distance between the curves is approximately 3 m (Fig. 7). In relation to the adjusted curve of MSL (see below) the Leerdam-curve is still convergent, but less so.

3.4. Zandberg

The cross-section (Fig. 6) was made about 2 km south of Wijk bij Duurstede. Ten samples were C-14 dated, 6 of which were taken from the base of peat on river dune sand (Table 1 and Fig. 6).

Sample 10 was taken from a 20 cm thick layer of peat, overlying gravelly fluvial sands and underlying the river dune sand at a depth of 6.18 m below the surface. Pollen analysis, carried out by Dr. C. Bakels of the Institute for Prehistory (Leiden) suggests that the peat layer was formed during the Allerød Interstadial. This was confirmed by the radiocarbon date: 11700 ± 100 BP (GrN-11469). Since the peat layer was formed during the Allerød-Interstadial, the river dune must be younger; it probably dates from the Younger Dryas-Stadial. Pons (1957), Verbraeck (1974 and 1984), and De Jong (1981) found the same age for other fossil river dunes in The Netherlands river district.

In the southeastern part of the section, bank deposits of the Maurik stream occur. The Maurik stream ridge has been shown to be connected with the Benschop and Tienhoven stream ridges (Hofstede et al. 1989). Therefore, its terminus ante quem should be similar to that of the Benschop stream ridge: 5350 ± 35 BP (GrN-7957) (Berendsen 1982, p. 148).

This date is confirmed by sample 8 (5350 ± 40 BP, GrN-12461), taken from the base of a peat layer overlying the Maurik stream ridge. The top of this layer was dated with sample 9: 4235 ± 40 BP (GrN-12460). A vegetation horizon overlying the peat layer has been C-14 dated by Berendsen (1982, p. 162): 3000 ± 35 BP (GrN-8706). Havinga & Op 't Hof (1975) on archaeological grounds dated it between 1800–1000 BC. The uppermost layer of clay was deposited mainly by the Kromme Rijn river.

In the northwestern part of the section a thick

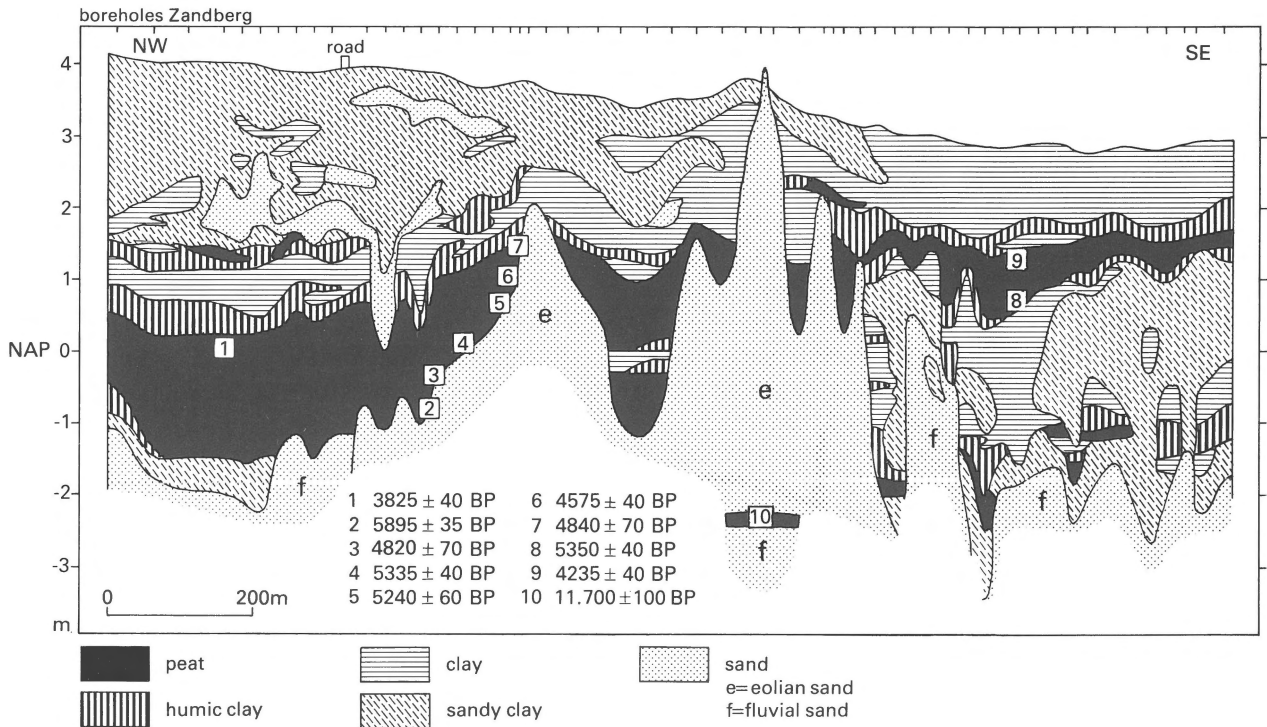


Fig. 6. Cross section Zandberg.

layer of peat occurs on the river dune flanks, between 1.5 m – NAP and 1.5 m + NAP. This layer has been compacted by the weight of the overlying sediments (Fig. 6). The top of this peat bed was dated with sample 1: 3825 ± 40 BP (GrN-12459). It was expected to be synchronous with sample 9, but appears to be some 400 years younger. As yet, no plausible explanation for the difference in age is at hand.

The uppermost layers (roughly above 1 m + NAP) belong to bank and crevasse deposits of the Kromme Rijn and Lek channels of the river Rhine (Berendsen, 1982). Because erosional surfaces are common in this part of the section no C-14 samples have been taken in this interval.

Samples taken at the base of peat on the river dune flank all were more or less clayey. Peat was rather amorphous, but *Phragmites* seemed to be the main constituent.

Dating results are quite irregular. The best fitting curve, drawn in Fig. 7, slightly converges with

a smoothed version of Van de Plassche's (1982) curve of MSL. At 5000 BP the curve is 2.5 m above the Leerdam curve, and almost 6 m above the MSL-curve. If this curve is considered to be representative of the general water level rise, then sample 3 obviously is considerably too young. Samples 5 and 7 which are slightly too old to fit the curve, may represent early local peat formation or be contaminated through the admixture of older organic material of the directly underlying A-horizon of the soil developed at the surface of the river dune. Steenbeek (1990) has reconstructed the rise of basin water level for the period between circa 4500 and circa 1500 BP for the area of the Wijk bij Duurstede (de Horden) archaeological excavation (situation about 2 km north of the Zandberg). His reconstruction is based on compaction-free depositional levels of basin clays, which are probably situated slightly above average basin water level (see Introduction). His curve, when extrapolated back in time, suggests that the curve drawn through

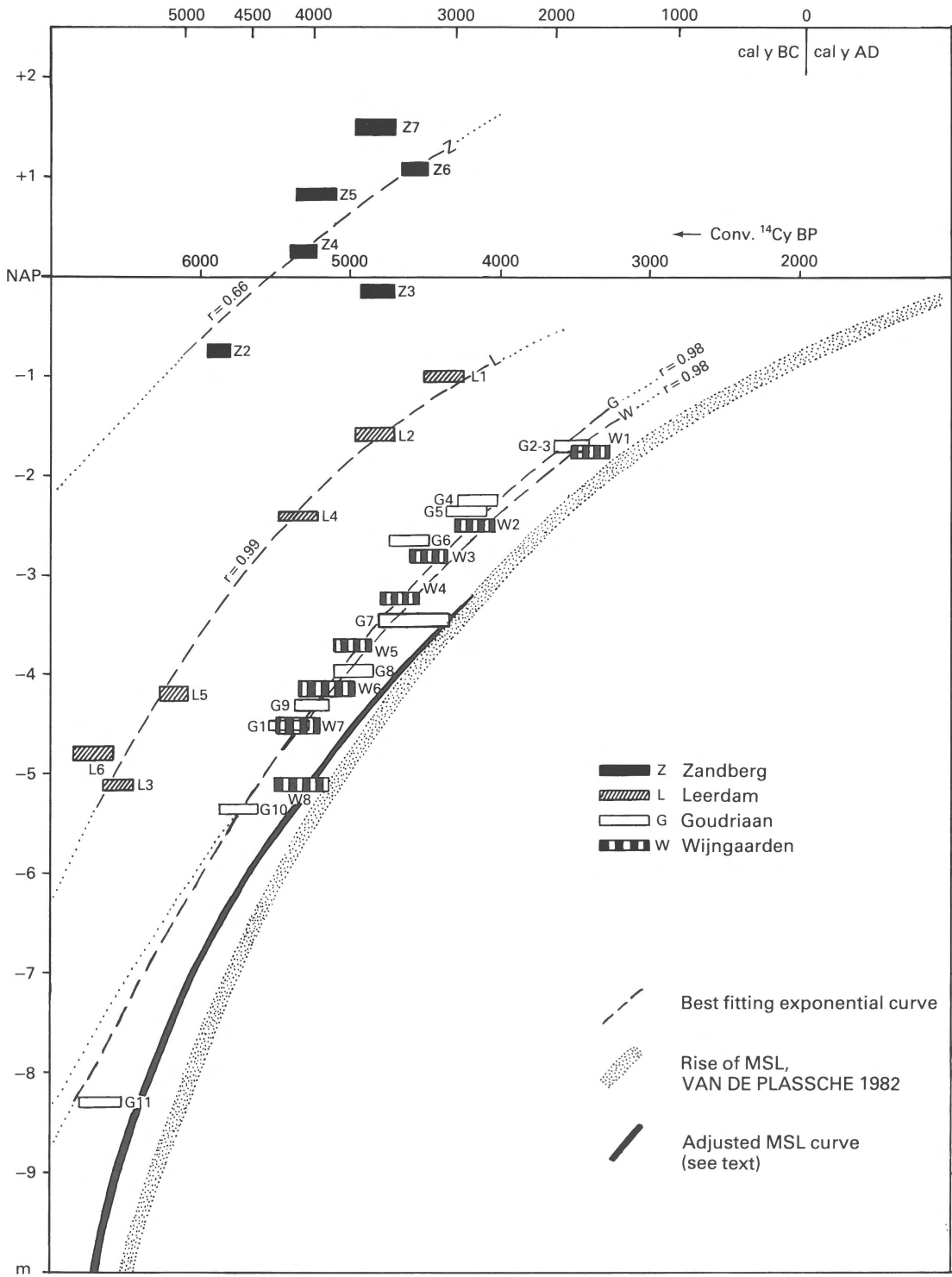


Fig. 7. Time-depth graphs of radiocarbon samples at the four investigated fossil river dunes.

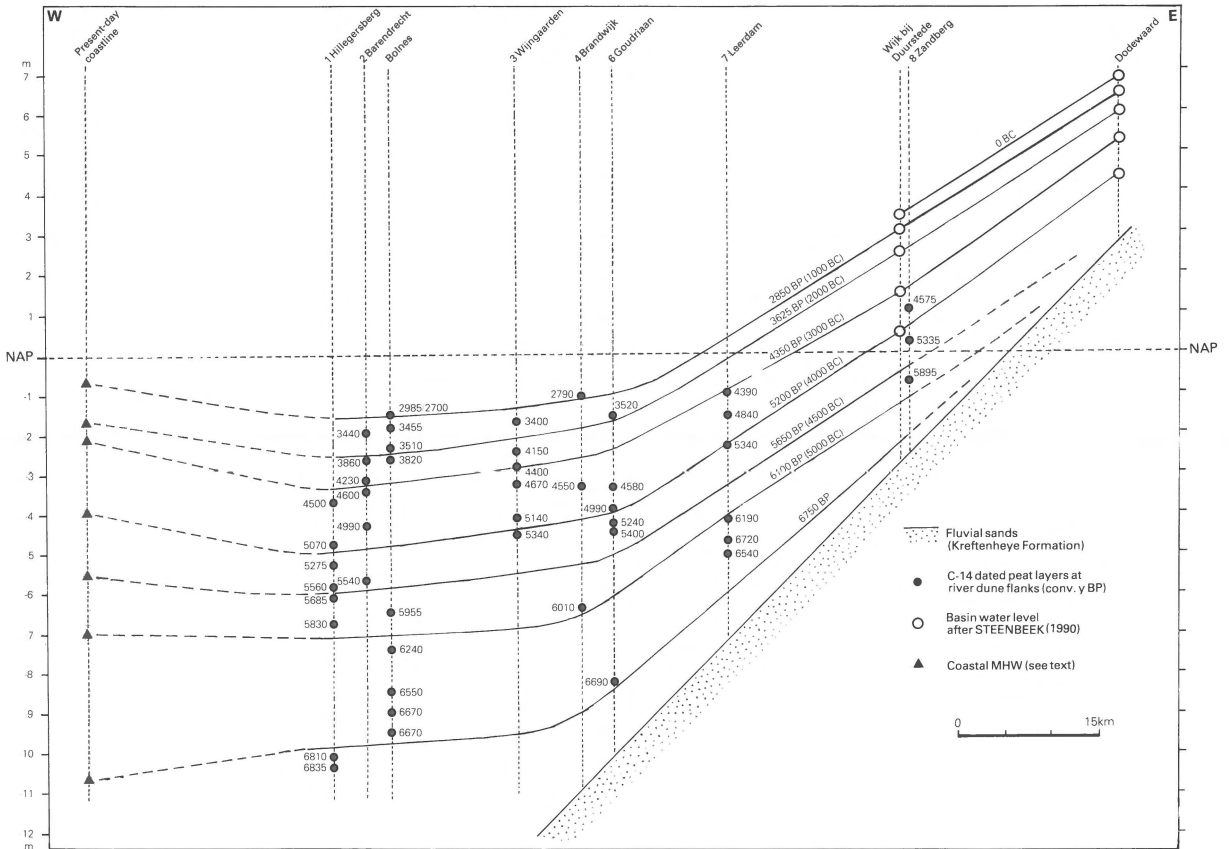


Fig. 8. Isochrones of peat formation in an east-west cross section.

our samples 2, 4, and 6 is a good approximation of the general water level rise in the area.

A major problem with the Zandberg samples is the fact that the amorphous structure of the peat does not permit to securely interpret peat formation in terms of related water levels. Also rejuvenating or ageing contaminants are difficult to detect in these samples.

4. Gradient lines

In Fig. 8 (ground)water gradient lines have been drawn for an East-West cross-section through The Netherlands river area. For the larger part of the cross-section the gradient lines are formed by the isochrones of initial peat formation on river dune sand. The isochrones were constructed through interpolation, based on the radiocarbon-dated basal

peat samples from the Wijngaarden, Goudriaan, Leerdam and Zandberg river dunes presented above. Previously published dates from the river dunes at Hillegersberg and Bolnes (Rijkswegdonk) (Van de Plassche 1982) and at Barendrecht and Brandwijk (Jelgersma 1961; ages corrected according to Van de Plassche 1980) have also been used. In Fig. 8 the relevant dates are indicated. Also, the Pleistocene subsurface, which consists of gravelly fluvial sands of the Kreftenheye Formation, is shown as far as situated above 12 m – NAP.

In the easternmost part of the cross-section Steenbeek's (1990) data on basin water level rise at Wijk bij Duurstede and Dodewaard have been used. Steenbeek's curves are based on compaction-free depositional levels of basin clays. These levels are assumed to represent slightly above-average groundwater levels in the fluvial backswamps and hence to signify a slightly higher water level sit-

uation then initial peat formation on dune sand does.

It is clear from Fig. 8 that all gradient lines show a rather clear knick point. At the seaward side gradients are very small: about 2.5 cm/km. At the landward side gradients are much greater: from about 20 cm/km around 6750 BP to about 16 cm/km around 2850 BP. Although the gradient lines have been drawn in an arbitrary manner and different interpretations are possible, there is a clear suggestion that the knick point wandered upstream in the course of time over a distance of some 10 km, from a location west of Brandwijk at 6750 BP to a location between Goudriaan and Leerdam at 2850 BP.

In order to extend the gradient lines seaward from the westernmost river dune group (Bolnes, Barendrecht and Hillegersberg), coastal MHW levels have been plotted at the location of the present-day coastline. These levels are based for 4000 cal BC and younger on Roep & Beets (1988), while for the older period, for which no independent data is available, coastal MHW has been approximated as MSL (according to Van de Plassche 1982) + 1.0 m. It appears that for the younger gradient lines, from 4500 cal BC onward, coastal MHW is situated well above the local water level at the westernmost river dunes (Fig. 8). Around 5000 cal BC/6100 BP coastal MHW and the local water level at Hillegersberg etc. are about the same, whereas at 6750 BP the local water level at the westernmost river dunes is situated about 0.80 m above the coastal Mean High Water level. Van de Plassche (1984, Fig. 2) observed the same tendency. Due to the manner in which he reconstructed his gradient lines he was tempted to explain the situation around 6700 BP as one in which the water level gradient between Hillegersberg-Barendrecht-Bolnes and the present-day coast was still rather steep and completely dominated by the river gradient effect. The gradient line at about 6050 BP, according to Van de Plassche (1984), showed the combined influence of both the river gradient effect and of lowering of the water level as a result of

the floodbasin effect. After 6050 BP floodbasin effect became dominant, with local intracoastal water levels below coastal MHW as a result.

The gradient lines as drawn in our Fig. 8 for the area upstream of the Hillegersberg-Barendrecht-Bolnes river dunes are based on much more detailed data than Van de Plassche (1984) had available. The present data suggest, as indicated above, that throughout the evolution, and already as early as 6750 BP, all gradient lines consist of a steep upper part and a much flatter lower part. It is plausible that the steep upper part reflects the river gradient effect, whereas the level lower part is likely to be determined in a direct manner by the sea level. If this interpretation is correct, then the water level in the area downstream of Wijngaarden was, even as early as 6750 BP, determined by the sea level. In that case it is hard to see how at that time the local water level at Hillegersberg-Barendrecht-Bolnes could attain a position well above coastal MHW, instead of being situated (due to the floodbasin effect) below the MHW level, as it was in younger phases. The possibility has to be envisaged therefore that the values applied for coastal MHW in Fig. 8 are not correct. There is no reason to doubt the MHW data from Roep & Beets (1988) for the period younger than about 4500 BP. However, for the older period figures had to be based on the MSL trend curve of Van de Plassche (1982).^{*} For the period older than 5000 BP this curve is based on a very limited number of time-depth data, the more pertinent ones of which come from the Zuiderzee area and from the province of Friesland, at distances of some 100 to 200 km from the river area. It is known on the other hand that time-depth data of basal peat samples from the province of Zeeland, situated some 50 km south from the Rhine-Meuse estuary, indicate much higher water levels (up to several metres) than the general MSL curve does. So far the exceptional situation in Zeeland has not been explained properly, but less tectonic subsidence has been suggested as a probable cause (Jelgersma 1961; Van de Plassche 1982). If

^{*} The possibility of a strongly increased tidal amplitude in the period before 5000 BP, which could explain elevated coastal MHW levels without challenging the MSL values for this period, is remote and will not be further considered.

this has indeed been the case, then it is plausible that also the nearby situated Rhine-Meuse estuary will have been affected to a certain extent and this effect might indeed produce higher MSL levels (and consequently higher coastal MHW levels) in the area than can be deduced from Van de Plassche's (1982) general sea level curve.

Altogether we feel justified in suggesting that on the basis of adjusted sea level data all gradient lines of Fig. 8 can be satisfactorily interpreted to consist of a sea level dominated downstream part and a river gradient dominated upstream part. The necessary adjustment of sea level history may be approximated by assuming that at 6750, 6100 and 5650 BP respectively MSL was at the same level as the local water level at the Hillegersberg-Barendrecht-Bolnes river dunes, i.e. that at this location flood basin depression of coastal MHW was complete. In this manner MSL estimates of about 9.85 m – NAP, 7.15 m – NAP, and 6.0 m – NAP respectively can be read from Fig. 8. In Fig. 7 the resultant adjusted MSL trend curve has been pictured next to Van de Plassche's (1982) original curve.

Interpreted as outlined above, Fig. 8 shows that as early as 6750 BP Wijngaarden and the area downstream were under the direct influence of sea level. In the course of time the sea level dominated realm progressed upstream; around 1000 cal BC it extended to the area just west of Leerdam. It is obvious that the eastern boundary of the perimarine area, as genetically defined by Hageman (1969), may conveniently be located at the transition from the sea level dominated part of the gradient lines to the river gradient dominated part. Over the past 3000 to 4000 years this transition has been situated somewhere between Goudriaan and Leerdam (see also Berendsen 1984). To the west of it, sea level (either MSL or MHW) fluctuations could influence the groundwater level in a direct manner. East of the knick point local fluvial features will have become increasingly important in determining groundwater fluctuations. The irregularities in the Zandberg data may be related to this.

5. Conclusions

1. Radiocarbon dating of samples taken from the base of peat layers on river dune flanks results in a number of curves that may be interpreted to represent the local rise of the ground water table near the river dunes. All curves (Fig. 7) slightly converge upon a smoothed version of Van de Plassche's (1982) curve of MSL, which is consistent with a gradually decreasing 'river gradient effect'.
2. By combining data from individual river dunes (ground)water gradient lines may be reconstructed for selected moments (Fig. 8). All gradient lines, from 6750 BP onward, appear to consist of a steep upper part and an essentially level lower part. Between 6750 BP and 2850 BP the knick point between the two stretches wandered upstream over a distance of some 10 km. It is plausible that the steep upper part of the gradient lines reflects the river gradient effect, whereas the level lower part is likely to be determined in a direct manner by the sea level. This conclusion is of relevance to the discussion on the eastern boundary of the so-called perimarine area (see also Hageman 1969; and Berendsen 1984).
3. The assumption that the level lower part of the reconstructed (ground)water gradient lines has been determined in a direct manner by the sea level is not consistent with available sea level data for the period before 4500 BC/5650 BP. There is reason to suspect that Van de Plassche's (1982) MSL curve is not representative for the study area for the pre-5000 BP period. Sea level data from the nearby province of Zeeland suggest a higher position of the MSL curve in this part of the country.
4. Compared to an adjusted MSL curve only the water level curves of the easternmost situated river dunes show the convergence which points to a decreasing gradient effect. Downstream, water level curves point to a very slight and constant gradient; they are more closely related to MSL than to coastal MHW, apparently as a result of the inland reduction of the tidal amplitude by the floodbasin effect.

5. Time-depth data at Goudriaan and possibly also at Wijngaarden suggest that there were small irregularities in the rise of the groundwater table. Data from the localities Hazendonk (Louwe Kooijmans 1974), Barendrecht and Brandwijk (Jelgersma 1961) and Hillegersberg and Bolnes (Van de Plassche 1982), which are also situated in the area in which groundwater table development was sea-level dominated, point to the same (see also Van de Plassche, 1980). Assuming that the dating results are not in error, these irregularities may be the result of various factors, including a varying rate of MSL rise, varying tidal range, and a varying flood-basin effect.

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