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HOLOCENE WATER-LEVEL CHANGES IN THE RHINE-MEUSE DELTA AS A FUNCTION OF CHANGES IN RELATIVE SEA LEVEL, LOCAL TIDAL RANGE, AND RIVER GRADIENT[1]

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ABSTRACT

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Published time-depth data from peat-covered slopes of early Holocene river dunes in the Rhine-Meuse delta are reviewed in the light of a new sea-level graph by Jelgersma. It is argued that the irregular convergence of the river-dune data on this curve with time can be explained in terms of a gradually decreasing gradient of the (tidal) rivers and a variable reduction – both in time and space – of the tidal range behind the coastline.

A curve is constructed for the Brandwijk-Hazendonk area and shows the decrease of the raising effect of the river gradient on the local mean high-water level or groundwater level with time. For each time-depth point from the Brandwijk-Hazendonk area this gradient-effect reduction curve allows an estimate of the extent to which the decrease in tidal amplitude behind the coastline has compensated the gradient effect.

INTRODUCTION

With the aim of reconstructing the Holocene relative sea-level rise in The Netherlands, JELGERSMA (1961) collected compaction-free samples from (1) the base of the so-called Lower Peat, the peat that occurs at the base of the Holocene coastal sequence and directly overlies the seaward sloping surface of the Pleistocene subsoil; and (2) the base of organogenic deposits on the slopes of two high river dunes – known as 'donken' – that rise from the former Late Glacial/early Holocene floodplain of the rivers Rhine and Meuse. In figure 1a curve I and curve II indicate respectively the groundwater-level rise based on the base-of-Lower-Peat data and on the data from the base of the peat on the river dunes (hereafter referred to as 'donken' data). According to JELGERSMA (1961, 1966) curve I represents the rise of coastal mean high water (MHW). However, she deduced that the peat sampled on the 'donken' also formed at the level of coastal MHW (JELGERSMA 1961, p. 21). Until now the discrepancy between theory and observation that is apparent from the position of curve II above curve I (Fig. 1a) has not been resolved. On the contrary, with the modification by JELGERSMA (1979) of curve I to curve III (Fig. 1a) this contradiction has even been enlarged, in particular for the older part of the curves. Compared to her former curve (I) the new one (III) represents the rise of mean sea level (MSL) instead of MHW and, still more important, has a steeper trend for the period before 5000 years BP. Figure 1a shows that, whereas curve II and curve I are more or less parallel, the vertical distance between curve II and the new MSL curve (III) markedly diverges with increasing age. This latter point is clearly brought out in figure 1b where the height of curve II has been plotted relative to curve IV, which is a slightly corrected version of curve III (in her 1979 publication JELGERSMA slightly misplotted the new Lower Peat time-depth point (GrN 8098: 6980±40, -12.58-12.60 m NAP = Dutch Ordnance Datum) that obliged her to revise the original curve. As a result the older part of curve III was drawn somewhat too low. In figure 1a the 1979 curve has been redrawn according to the correct position of the time-depth point concerned: curve IV).

Accepting curve IV as a fair approximation of the MSL rise and assuming a constant tidal range during the last 7200 years (see below), this paper attempts to explain the conse-

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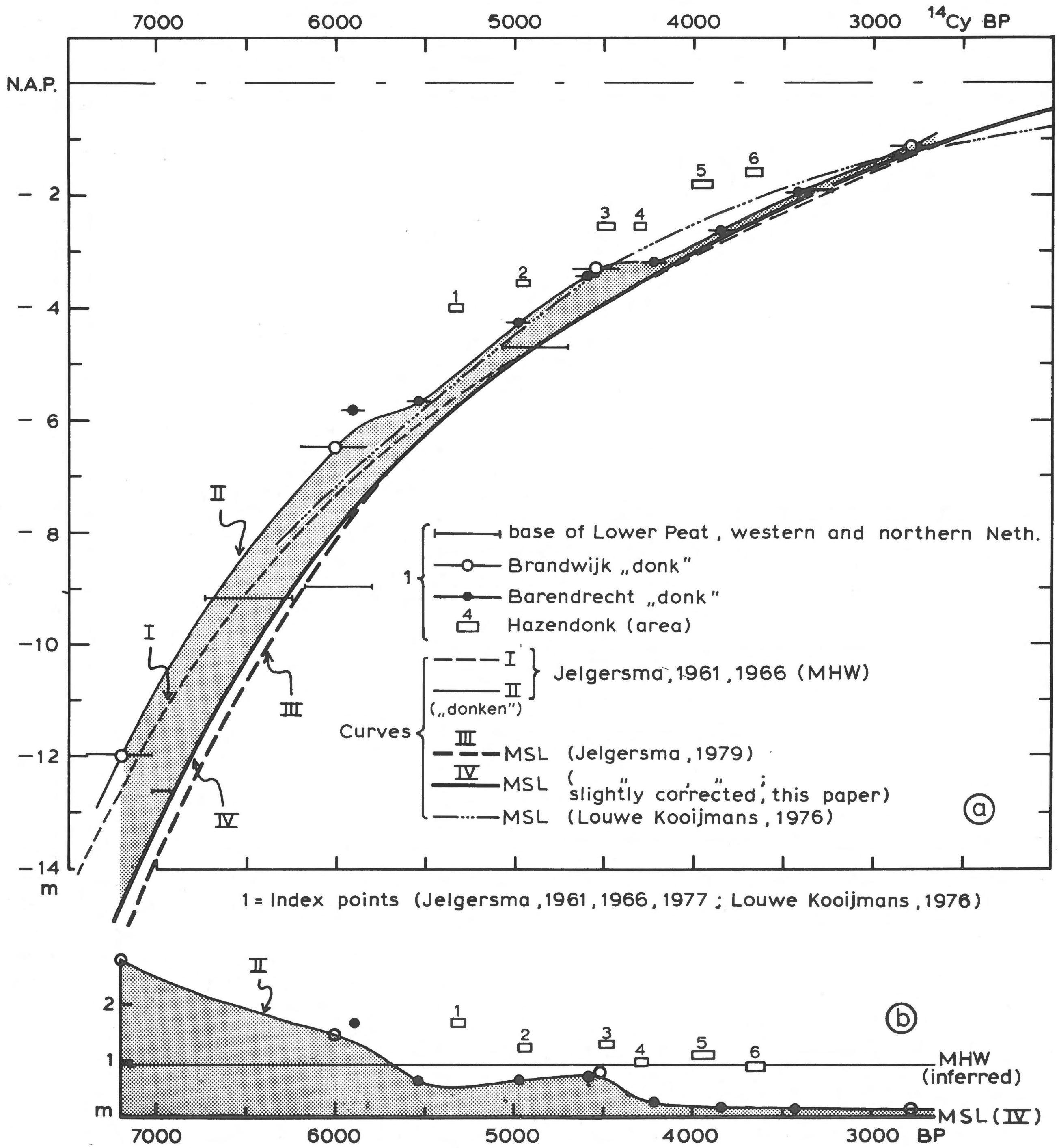

Fig. 1
(a): Time-depth diagram showing several published sea-level graphs for The Netherlands: (I) Jelgersma's former (base-of-Lower-Peat) graph (MHW, 1961, 1966); (III) Jelgersma's modified graph (MSL, 1979); (IV) graph III, but slightly corrected for the older part (this paper); and (II) line connecting time-depth data obtained from the base of organogenic deposits on the slopes of an early Holocene river dune near Barendrecht and near Brandwijk (see 1 and 2 in Fig. 2). The time-depth boxes 1-6 represent former water levels near another river dune, the Hazendonk (Louwe Kooijmans, 1974, 1976; see 3 in Fig. 2). The MSL curve that Louwe Kooijmans (1976) largely derived from these data is also depicted.
(b): Plot of the vertical distance above curve IV of (1) the Brandwijk and Barendrecht data, together with curve II (see stippled areas); and (2) the Hazendonk data. The time-depth data clearly converge upon the MSL curve (line) with time. Based partly on field evidence (Roep et al., 1975; Jelgersma, 1980), partly on the assumption of constancy of tidal range, a line representing MHW has been inserted at 0.9 ± 0.1 m above the MSL line.

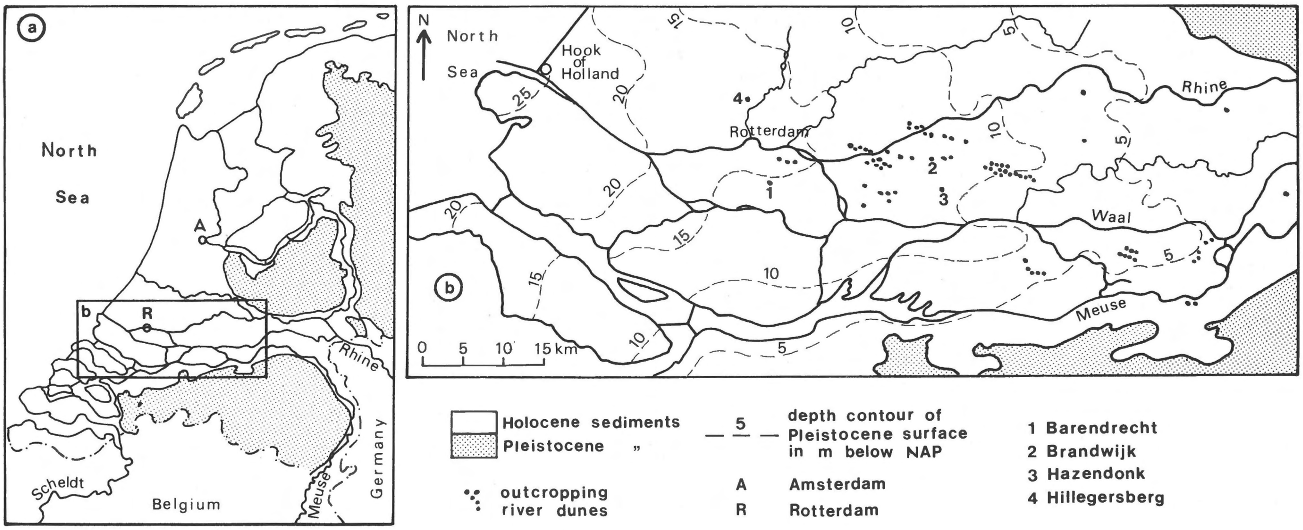

Fig. 2
Map of the Rhine-Meuse delta, showing location of sites mentioned in text. Contour lines after Oele & Pruissers (1975).

quence of Jelgersma's revision of meaning and gradient of curve I for the significance of the 'donken' data. As can be read from figure 1b the consequence is that in the Rhine-Meuse delta[3] at about 7000 years BP peat growth apparently occurred almost 2 m above the contemporaneous MHW level, while by about 4000 years BP it took place 0.8 m below that level.

The position of the two river dunes investigated by JELGERSMA (1961), the 'donk' of Brandwijk and the 'donk' of Barendrecht, is indicated in figure 2. Four kilometres SSE of the Brandwijk 'donk' lies a small river dune called Hazendonk, from (the vicinity of) which LOUWE KOOIJMANS (1974, 1976) collected fossil groundwater-level data. These time-depth data have also been plotted in figure 1a and 1b. One notes that the vertical distance between the Hazendonk data and curve IV decreases with time too.

AIM

The area in which the 'donken' under consideration are located was transitional to the fluvial area in the east and the lagoonal-estuarine area in the west during most of the middle and late Holocene (HAGEMAN, 1969). The two main factors which can be expected to have determined the water level in this region are therefore (1) the effect of the river gradient, and (2) the local tidal range.

The aim of this paper is to explore the extent to which the irregular convergence of the 'donken' data on the MSL curve (IV) (Fig. 1b) can be explained in terms of these two factors, and to estimate the change in magnitude of their effect in the course of the middle and late Holocene development of the region.

[3] In this paper the term 'delta' is used in a morphological-geographical sense, rather than in a strictly sedimentological one.

BRIEF DISCUSSION OF THE 'DONKEN' DATA

The time-depth data on which JELGERSMA (1961) based curve II (Fig. 1a) all derive from samples taken at the base of fen wood peat that began to grow on the Brandwijk and Barendrecht 'donken'. It may be assumed that in the tide-influenced part of the Rhine-Meuse delta the upper limit of fen wood peat growth about coincided with local MHW; in the non-tidal part this limit will have been set by an average groundwater level. The assumption is made that all samples represent fen wood peat accumulations at this upper limit and not at various depths below it.

The Hazendonk time-depth boxes 1, 2, 3, and 4 (Fig. 1a) all pertain to moments of inhabitation on or near that river dune (LOUWE KOOIJMANS, 1974, 1976). The altitude of each box relates to the juncture on the dune slope of occupation layers present in the fen wood peat that surrounds the dune. For the first three boxes the time of inhabitation was established by dating a sample from those intervals of a pollen-analytically investigated core taken near the 'donk', that exhibited the presence of human influence on the local vegetation and correspond with the respective occupation layers. The sample that gave the age for Hazendonk datum 4 consisted of mixed material from the occupation layer concerned. According to LOUWE KOOIJMANS (1976) the occupation layers were situated just above the local groundwater level. As such they can also be interpreted to indicate former upper limits of fen wood peat growth.

The altitude of time-depth box 5 concerns the top of a backswamp clay deposited by the Schoonrewoerd stream, the sandy filling of which occurs 1 km north of the Hazendonk. The top of this clay reaches a height of -1.8 m NAP on the Hazendonk. From radiocarbon-dated samples of charcoal and bone (GrN 6216: 3795±55; GrN 6384: 3820 ± 45; Table I) collected on the Schoonrewoerd stream ridge, LOUWE

KOOIJMANS (1974, 1976) concluded that the clay must have been deposited before 3800 years BP. It is assumed here that the clay attained its highest level on the Hazendonk between 4000 and 3875 years BP. Louwe Kooijmans stressed the point that the clay shows little or no signs of physical ripening. Consequently, it may indicate a level somewhat below the average groundwater table.

Finally, box 6 gives height and age of the approximate groundwater level or local MHW in a gully transversing the Schoonrewoerd stream ridge (LOUWE KOOIJMANS, 1974, p. 179 and further).

Table I lists the 'donken' data plotted in figure 1a.

RIVER GRADIENT-EFFECT

Due to the river gradient, MHW and other tidal levels tend to be raised in an upstream direction. LOUWE KOOIJMANS (1974) called this the river gradient-effect.

The fact that peat growth on the three 'donken' under consideration has occurred under strong influence of river water is indicated by the peat composition: fen wood. This is only formed in an eutrophic fresh-water environment. The rivers in the early Holocene must have had a distinct seaward slope which, for a given stretch, decreased in time as a result of the Holocene sea-level rise and simultaneous landward

Table I

Age, altitude, and meaning 1) of the "donken" data used in figure 1a

symbol	name of sample	dated material	GrN No.	age in conv. 14C y BP corrected for δ13C 3)	compaction-free altitude in m below NAP	altitude is related to:
0	Brandwijk 8	fen wood peat	186	7200±210	11.96-11.98	base of peat on dune slope
0	,, 5	,,	203	6010±200	6.45-6.47	,,
0	,, 4	,,	191	4550±150	3.29-3.31	,,
0	,, 2	,,	192	2790±135	1.11-1.15	,,
●	Barendrecht I	fen wood peat	1160	5920±60	5.80-5.85	base of peat on dune slope
●	,, V	,,	1151	5540±60	5.65-5.72	,,
●	,, VI	,,	1140	4990±70	4.28-4.30	,,
●	,, VIII	,,	1144	4600±70	3.40-3.46	,,
●	,, VII	,,	1146	4230±55	3.19-3.24	,,
●	,, X	,,	1147	3860±70	2.63-2.67	,,
●	,, XII	,,	1148	3440±50	1.92-1.97	,,
box 1	Molenaarsgraaf-Hazendonk	fen wood peat	6215	5320±40	4.00±0.08	juncture of occupation layer to dune slope
box 2	,,	,,	6214	4935±40	3.55±0.08	,,
box 3	,,	,,	6213	4480±40	2.55±0.08	,,
box 4	,,	mixed material from peaty occ. layer	5175	4290±40	2.55±0.08	,,
box 5	Ottoland-Kromme Elleboog I & II	charcoal bone 2)	6216 6384	3795±55 3820±45	1.80±0.08	highest level of backswamp clay on dune slope
box 6	Molenaarsgraaf no. 58	charcoal	5176	3640±30	1.60±0.08	boundary between gully filling and occupation layer on Schoonrewoerd stream ridge

1) Meaning: with the exception of box 5 all time-depth data are assumed/interpreted to indicate former local MHW or local mean groundwater level. Time-depth box 5 may indicate level somewhat below ground-water level.

2) Assumed by Louwe Kooijmans to post-date final phase of activity of Schoonrewoerd stream.

3) Ages for the Brandwijk and Barendrecht samples have been corrected for δ13C by subtracting 40 years (Mook, pers. comm.). Previously published ages are obtained by adding 40 years.

Sources: archive Groningen radiocarbon laboratory, Jelgersma 1961, Louwe Kooijmans 1974, 1976 displacement of the coastline until about 5000 years BP. Because at the same time the rivers were forced to deposit much of their load upstream (HAGEMAN, 1969) there was a tendency for the gradient to maintain itself. It is expected, therefore, that the raising effect of the river gradient will have decreased more gradually than would have been the case otherwise. Figure 3 schematically illustrates the basic effect of a decreasing river gradient on the upper limit of fen wood peat growth on three 'donken' located at increasing distance from the coast: the time-depth graph for each dune converges upon the coastal MHW curve with time, and the greater the distance from the coast, the higher is the position of the graph in the time-depth diagram. By plotting the time-depth graphs for the three dunes relative to the coastal MHW curve (Fig. 3c) one obtains for each of the three localities a *gradient-effect reduction curve.*

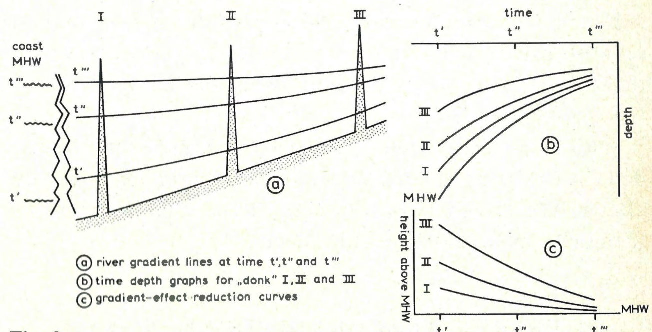

Fig. 3
(a): Diagram illustrating the decrease in river gradient near three river dunes as a result of the rising sea level and simultaneous raising of the river bed due to fluvial deposition.
(b): time-depth graphs for the rise of coastal MHW and the water-level rise at each of the three river dunes.
(c): curves showing the decrease in river gradient-effect with time for each of the three localities.

LOCAL MEAN HIGH WATER

It has been established from the study of sedimentary structures in coastal barrier deposits (ROEP ET AL., 1975, in prep.; JELGERSMA, 1980) that during the last 4800 years mean tidal range along the mid-western Netherlands coast has not differed significantly from that at present. A value of 1.8 ± 0.2 m is accepted here for the mean tidal range in the mouths of the rivers Rhine and Meuse, and this value is also assumed to have been constant throughout the period 7200-4800 years BP. In figure 1b coastal MHW is indicated by a line 0.9 ± 0.1 m above the MSL line.

The fact that sample Barendrecht VII (4230 ± 55, -3.20 m NAP) plots well below the contemporaneous coastal MHW level (Fig. 1b), can only be ascribed to a reduction of the tidal amplitude behind the coastline. This, in turn, can be explained by frictional dissipation of energy as the tidal wave moved into the lagoons, estuaries and/or tidal gullies and creeks, and by the so-called floodbasin (or flood depression) effect (VAN VEEN, 1950; ZONNEVELD, 1959). The last-mentioned effect refers to the lowering of MHW within a smaller or larger area due to an increase in storage capacity within the tidal basin. Apparently, any increase in coastal tidal amplitude due to, for example, the geometry of inlets or basins, has been overruled by the friction and/or floodbasin effect(s).

Summarizing the above it can be said that in the Rhine-Meuse delta the altitude (with respect to coastal MHW) of the upper limit of fen wood peat growth at a given 'donk' has been the sum of the gradient effect (+), and the friction and floodbasin effects (-,-). In the non-tidal area the latter two are nil and the height of the forementioned limit above coastal MHW represents the full local gradient effect. In the tide-influenced area the floodbasin effect may be absent (Fig. 4a) or present (Fig. 4b), but a smaller or greater friction effect is always involved. This implies that in the tidal part of the delta the potential value of the river gradient-effect is nowhere reflected in the altitude of former upper limits of fen wood peat growth (this would be the case if the landward reduction in tidal amplitude was solely due to transformation of kinetic into potential energy). Thus, although the MHW line in figure 4a clearly reflects a river gradient-effect, it is impossible to tell how much higher it would have been with a different pattern of energy loss due to friction.

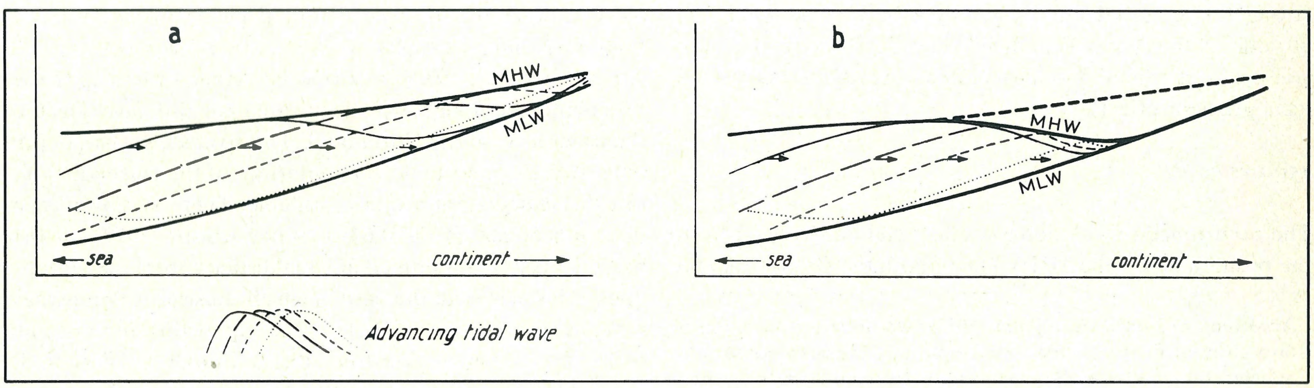

Fig. 4
Schematic illustration of the tidal wave progressing in a river gradient-influenced water body (after Zonneveld, 1959). (a) without floodbasin effect; (b) with floodbasin effect.

Figure 4b illustrates how a floodbasin effect may cause a seaward extension of the non-tidal zone. It is clear, however, that there too no data representative of the full gradient-effect can be obtained.

With the available time-depth data from the Rhine-Meuse delta it is not possible to seperate floodbasin from friction effects. The former term will therefore be used synonymous with or to include the friction effect.

INTERPRETATION OF THE 'DONKEN' DATA

As the 'donk' of Brandwijk is situated about 20 km to the east of the Barendrecht 'donk' (Fig. 2), curve II, the line connecting the 'donken' data collected by Jelgersma (Fig. 1a), has to be seperated – because of the upstream increase in gradient-effect – into two curves, one for each 'donk' (Fig. 5a). Figure 5b shows the height of these two curves and of the Hazendonk time-depth boxes above curve IV, the slightly corrected MSL curve by JELGERSMA (1979) (Fig. 1a). The general convergence in time of the time-depth graphs for the Brandwijk and Barendrecht 'donken' and of the Hazendonk data on the MSL and MHW lines respectively (Fig. 5b), can be interpreted to reflect a gradual decrease in river gradient-effect.

Since the 'donk' of Brandwijk and the Hazendonk are located at comparable distances from the coast, it can be concluded from figure 5b that if the Hazendonk time-depth data contain a floodbasin effect, it is clearly less than in the case of the Brandwijk data. This conclusion implies that the convergence of the time-depth boxes from the Hazendonk area on the inferred coastal MHW line (Fig. 5b) may rather closely approach the decrease in local river gradient-effect with time. It is possible to elaborate this point by further examining the available data.

7200 years BP

In view of the relatively low sea-level stand at that time and consequently a more westerly position of the coastline and stronger river gradient, it can safely be assumed that the altitude of the oldest Brandwijk time-depth point does not contain even a small floodbasin effect (i.e. represents the full local gradient-effect).

4500 years BP

The occurrence of a floodbasin effect can be deduced from the position below the MHW line of both the Brandwijk and Barendrecht time-depth points (Fig. 5b). As suggested by the markedly higher position of Hazendonk time-depth box 3, the water level surrounding this dune was not, or was much less affected by a reduction of the tidal amplitude. It is tentatively concluded that the altitude of this Hazendonk datum closely approximates the full local gradient-effect of that time[4].

Gradient-effect reduction curve for the Brandwijk-Hazendonk area

Assuming the difference in gradient effect between the Brandwijk 'donk' and the Hazendonk to have been negligible (comparable distances to the coast), one obtains, by connecting the two previously discussed time-depth data in a slightly concave fashion, a curve that approximately indicates the reduction in river gradient-effect in the Brandwijk-Hazendonk area (Fig. 5b). With this curve it is now possible to specify for each of the Brandwijk or Hazendonk time-depth data the extent to which the floodbasin effect has (over)compensated the gradient effect. The height above coastal MHW of the second oldest Brandwijk datum, for example, is the sum of the gradient-effect and the floodbasin effect: 0.56 m = 1.08 m – 0.52 m. In view of the approximative nature of the gradient-effect reduction curve, the fact that Jelgersma's MSL curve is assumed to provide a reliable line of reference, and that constancy of tidal range before 5000 years BP remains to be proved, the given example illustrates the principle rather than the quantitative truth.

THE GRADIENT-EFFECT REDUCTION CURVE AND THE FURTHER INTERPRETATION OF FIGURE 5b

From the position of the second oldest Brandwijk time-depth point below the gradient-effect reduction curve it is concluded that at about 6000 years BP a floodbasin effect was present there. As the area bounded by the 'donken' of Barendrecht and Hillegersberg (Fig. 2) in the west and by the Brandwijk 'donk' and Hazendonk in the east at or just before 6000 years BP apparently constituted a wide body of more or less open water (JELGERSMA, 1961; VAN DE PLASSCHE, 1979; VAN DER WOUDE, 1979), it would be rather surprising if the forementioned floodbasin effect would not also have affected the water level at the Hazendonk. Unfortunately, time-depth data from the peat/dune-sand interface of the Hazendonk to test this expectation are not available. There is, however, a date of 6060±80 (GrN 7864: VAN DER WOUDE, 1979) for the base of a peat bed sampled at 1 km distance from the Hazendonk. This peat bed, the base of which consists of *Phragmites* remains, overlies a fluvial clay. The top of this minerogenic bed attains a compaction-free altitude of -6.8 ± 0.2 m NAP on the Hazendonk (Van der Woude, pers. comm). This value must have been reached before the onset of peat growth 1000 m from the dune. The question is: how much before? If the

[4] According to Louwe Kooijmans (1976, whose sea-level graph is also given in figure 1a, the water level near the Hazendonk was affected by a full floodbasin effect. In correcting the measured altitude of time-depth box 3 for the remaining gradient-effect in order to arrive at a figure for MSL, he applied, in our interpretation, too low a value (0.5 ± 0.2 m).

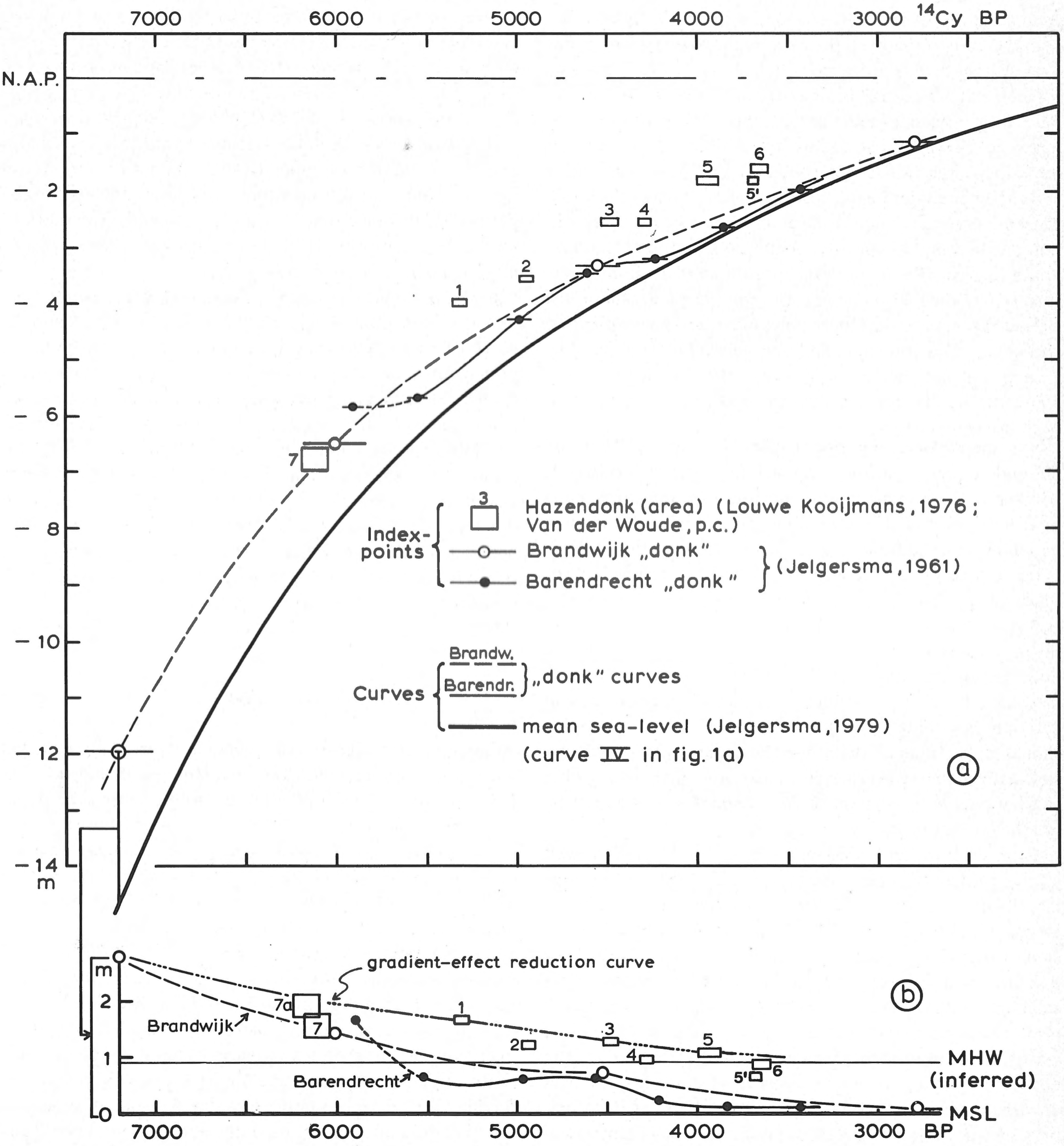

Fig. 5
(a): Time-depth diagram showing the slightly corrected (1979) MSL curve by Jelgersma, the curves based on data from the 'donken' of Barendrecht and Brandwijk, and the Hazendonk data (boxes).
(b): Plot of the vertical distance above the MSL curve of the graphs and time-depth data mentioned sub (a). Convergence of the Brandwijk and Barendrecht curves upon MSL, and of the Hazendonk data upon coastal MHW reflects the decrease in river gradient-effect. In the text it is argued that a line connecting the oldest Brandwijk datum and Hazendonk datum 3 in a slightly concave fashion yields a gradient-effect reduction curve for the Brandwijk-Hazendonk area. With the help of this curve it is possible to estimate the local floodbasin effect(s).

age of the top of the clay is assumed to be 100 years older than the base of the peat, then the upper half of a hypothetical time-depth box (6160±80, -6.8 ± 0.2 m NAP) would coincide with the gradient-effect reduction curve (box 7a in Fig. 5b), suggesting (near) absence of a floodbasin effect at that time. However, in that case one is obliged to account for the rather large time gap between the end of sedimentation and the beginning of peat growth, which is difficult without invoking a considerable drop in water level causing conditions to become too dry for peat formation. We therefore prefer to accept the more simple possibility that within a time span of less than 40 years after the end of sedimentation the clay surface was colonized by *Phragmites* and peat formation had begun. The corresponding time-depth box (no. 7 in Fig. 5a and 5b) plots below the gradient-effect reduction curve and confirms that the expected floodbasin effect at the Hazendonk is indeed present.

It is noted above that around 4500 years BP MHW in the Hazendonk area was lowered much less than in the Brandwijk area. This can be accounted for in two ways: either the tidal wave reached the Hazendonk without much dampening of amplitude additional to that caused by frictional dissipation of energy; or, the Hazendonk had come to lie beyond reach of the floodbasin effect due to a more or less local, seaward, shift of the tideless fluvial zone. The latter possibility is favoured here since the occurrence of a floodbasin effect in both the Barendrecht and Brandwijk areas suggests it to have been of more than just a local nature and would certainly also have been felt at the Hazendonk (mapping should prove that at that time the Brandwijk 'donk' was situated on the seaward side of the so-called lung-system (HAGEMAN, 1969), whereas the Hazendonk was situated on the fluvial side of it).

From the position of time-depth box 1 on the approximate gradient-effect reduction curve it follows that the above-mentioned seaward shift of the fluvial zone occurred in the course of the period 6000-5500 years BP. A westward extension of the tideless area can result from an increase in river discharge and sediment transport and/or a lowering of either sea level or the intracoastal MHW level. In this connection it is interesting to note that according to VAN DER WOUDE (1979) clastic deposition in the Hazendonk area recommenced at about 5600 years BP after a period of 400 years of peat growth, and that data collected from the 'donk' of Hillegersberg by VAN DE PLASSCHE (1980) permit the reconstruction of a period of reduced (local?) water-level rise between 5650-5500 years BP.

With respect to time-depth box 5 the following is remarked. Its position on the gradient-effect reduction curve is somewhat contradictory to the interpretation given above (see brief discussion of the 'donken' data) that it might indicate a level (of deposition)slightly below mean groundwater. This contradiction is resolved if the age of the top of the clay would be younger than 3800 years BP and not older as LOUWE KOOIJMANS (1974) argued. That the sedimentation may indeed have ended later is indicated by the age of a sample, taken near the dune, from the base of the peat overlying the backswamp clay: 3630±35 (GrN 6212: LOUWE KOOIJMANS, 1974). Since the very low degree of physical ripening precludes the possibility of a dry period, it can be concluded that sedimentation near the Hazendonk did not end before 3800 years BP, but continued to about 3675±25 years BP. In figure 5a and 5b box 5 may thus be replaced by box 5'. The position of this new time-depth box below the groundwater level indicated by time-depth box 6 corresponds well with the low consistency of the backswamp clay.

In the Barendrecht area the floodbasin effect can be seen to have been quite large, except in the period 5250-4500 years BP. The fluctuating Barendrecht curve can be interpreted to reflect changes in the width and/or depth of the former inlets of the rivers Rhine and Meuse, and/or in the degree to which the creeks and water courses connected to the inlets allowed the tidal wave to migrate inland. For example, the wide inlet that, around 4500 years BP, extended from Hook of Holland (Fig. 2) to at least 20 km inland in the direction of the Barendrecht 'donk' (VAN STAALDUINEN, 1979; pers. obs.), had been reduced to a much narrower tidal creek bordered by well developed natural levees by about 4200 years BP (MODDERMAN, 1953; VAN REGTEREN ALTENA ET AL., 1962).

DISCUSSION

Although it has been shown in the previous paragraph that the gradient-effect reduction curve for the Brandwijk-Hazendonk area can be successfully confronted with time-depth data and geological information, the curve should be regarded as preliminary. Firstly, because the 'donken' data have been considered relative to JELGERSMA's (1979) *smooth* MSL curve. As her graph is based on only a limited number of widely spaced (Lower Peat) time-depth points (Fig. 1a), additional data may in due course reveal the presence of fluctuations in the sea-level rise. This may alter the relative position of Hazendonk datum 3 and other time-depth points and, consequently, oblige a change in the gradient-effect reduction curve. In the second place, because the mean value of the radiocarbon age for the lowest Brandwijk sample and for the Hazendonk-3 sample have been assumed to be correct (i.e. the statistical nature of the dates has not been taken into consideration). A third reason is that either or both of these two time-depth points may not fully represent the upper limit of fen wood peat growth.

Two more arguments for stressing the preliminary character of the curve under discussion can be given. One is that the gradient effect may have temporarily increased, namely during periods of prolonged increase of river discharge and sedimentation. If such events have been recorded in the fen wood peat growth, the gradient-effect reduction curves will show fluctuations. The second, and final, reason is that all radiocarbon dates will have to be converted into calender years when a definite dendrochronological calibration curve is available (this includes the problem of ambiguity of convertion posed by short-term fluctuations in the atmospheric 14C concentration).

A check on any gradient-effect reduction curve is that the floodbasin effect cannot become greater than half the tidal range at the coast. In this connection it may be remarked that if it is accepted that the 0.65 m difference in water level between the 'donk' of Brandwijk and the Hazendonk is real, the two time-depth points concerned will always put an important constraint on the ultimate position of the gradient-effect reduction curve for the area.

CONCLUSIONS

The irregular convergence of age-altitude data from the Brandwijk and Barendrecht 'donken' and the Hazendonk upon the smooth curve for MSL or MHW can largely be explained in terms of (1) a gradually decreasing river gradient-effect and (2) a floodbasin effect, the magnitude of which varied both in time and space.

The first effect renders 'donken' data in themselves less suitable for sea-level studies than previously held; the second is a disturbing factor in distinguishing true from apparent variations in sea-level rise.

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