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QUANTITATIVE ANALYSIS OF RADIOCARBON DATES OF THE PERIMARINE AREA IN THE NETHERLANDS[1]

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ABSTRACT

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Until recently it was thought that sedimentation in the perimarine area of the Netherlands occurred synchronously with sedimentation in the marine area. The observed alternation of clastic sediments and peat in both areas was attributed to an alternation of transgressions and regressions. Quantitative analysis of available radiocarbon dates of the perimarine area leads to the following conclusions: 1–It is impossible to establish a chronology of periods of sedimentation and periods of sedentation (peat formation) which corresponds with any of the existing chronologies in the marine area. The observed alternation of clastic sediments and peat in the perimarine area is determined by avulsion rather than by an alternation of transgressions and regressions; 2–Peat formation in residual channels west of a line from Utrecht to Den Bosch is determined to a high degree by the general rise of mean high water in the Netherlands; 3–Peat formation in residual channels in the perimarine area starts mainly during periods of regression; 4–Avulsion occurred almost exclusively during periods of transgression.

INTRODUCTION

Part of the Dutch subrecent coastal plain is referred to as the 'perimarine area', which is defined by HAGEMAN (1969) as 'the area where sedimentation or sedentation (peat formation) took place under the direct influence of the relative sea level movements but where marine or brackish sediments themselves are absent'.

The Geological Survey of the Netherlands assigns all Holocene mineral deposits and peat in the marine as well as in the perimarine area to the Westland Formation (ZAGWIJN & VAN STAALDUINEN, 1975). The Westland Formation is subdivided into members on the basis of the alternation of clastic sediments and peat. The clastic marine deposits comprise essentially the lower Calais Deposits and the upper Dunkirk Deposits (Fig. 1). The clastic perimarine deposits comprise the lower Gorkum Deposits and the upper Tiel Deposits. In both areas peat layers are included in the Holland Peat (member).

Most authors assume that during the Holocene clastic sedimentation in the marine area was especially favoured by transgressions that occurred more or less synchronously along the coasts of Northern Germany, the Netherlands, Belgium and Northern France (BAKKER, 1954; BENNEMA, 1954; JELGERSMA, 1961; GEYH, 1966; HAGEMAN, 1963; 1969; ROELEVELD, 1974; ENTE ET AL., 1975; GRIEDE, 1978). A period of transgression is defined by ROELEVELD (1980) as a period in which, in a rather large area, the influence of the sea increased relative to the preceding period. The beginning of peat formation is assumed to take place at the onset of periods of decreasing marine influence ('regressions').

There is little agreement about the cause of the alternation of transgressions and regressions; BENNEMA (1954), HAGEMAN (1969) and LOUWE KOOYMANS (1974) suggested that fluctuations of sea level may be involved while ZAGWIJN & VAN STAALDUINEN (1975) were of the opinion that transgressions might be related to an increased frequency of storm surges. According to HAGEMAN (1969) the rivers swelled in their lower courses during periods of transgression as a result of the rising

marine area	perimarine area
Dunkirk Deposits	Tiel Deposits
Holland Peat	Holland Peat
Calais Deposits	Gorkum Deposits
Holland Peat (Basis peat)	

Fig. 1
Lithostratigraphic subdivision of the Westland Formation in the marine and perimarine area of the Netherlands.

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sea level, thus giving rise to overbank deposition of clay. Marine transgressions therefore would lead to clastic sedimentation in the river area, synchronously with clastic sedimentation in the marine area. Regressions in the coastal district proper would be characterized by decreasing sedimentation of clastics and an increase of peat formation in the lower river area.

On the basis of this assumed genetic relationship ZAGWIJN & VAN STAALDUINEN (1975) included the deposits in the so-called perimarine area in the Westland Formation. However, it will be shown here that on the basis of available radiocarbon datings it is impossible to corroborate the presumed synchronism of periods of sedimentation in the perimarine area with those in the marine area.

METHOD

To determine to what degree peat formation occurred simultaneously in the marine and the perimarine area, 89 radiocarbon datings of the base and the top of peat layers within the perimarine area (as areally defined by HAGEMAN, 1969) have been plotted in frequency histograms (Figs 3 and 5) by graphical superposition. Each date is represented by a Gaussian distribution of equal area. The width of each Gaussian curve is four times the standard deviation of the ^{14}C date: a date with a large standard deviation is represented by a Gaussian distribution with a low height and thus contributes less to the histogram peaks. A date with a standard deviation of ± 45 years has been chosen to represent the frequency 1. All dates are expressed in conventional radiocarbon years BP.

To distinguish between beginning and ending periods of peat formation, dates of the base and the top of peat layers have to be separated. Therefore dates of the top of peat layers have been plotted under the horizontal time axis, dates of the base of peat layers above it. A table which contains all the details of the dates used in the histograms is given by BERENDSEN (1982).

INTERPRETATION OF ^{14}C FREQUENCY HISTOGRAMS

Peaks in the upper histogram are considered to represent maxima in the occurrence of beginning peat formation, while peaks in the lower histogram are considered to represent maxima in the occurrence of ending peat formation. A period of clastic sedimentation thus lies between a peak in the lower histogram and the next peak on the time axis in the upper histogram. If the perimarine area is characterized by a general alternation of periods of sedimentation (interpreted as transgressions) and periods of peat formation (interpreted as regressions) peaks in the upper and lower histogram should alternate in time, as illustrated schematically in Fig. 2a.

THEORETICAL SHAPES OF THE HISTOGRAMS

For a marine area which is characterized by a clear alternation of transgressions and regressions the frequency histogram will have the shape of Fig. 2a. In theory the frequency histogram of datings in the perimarine area could have any of the shapes indicated in Fig. 2.

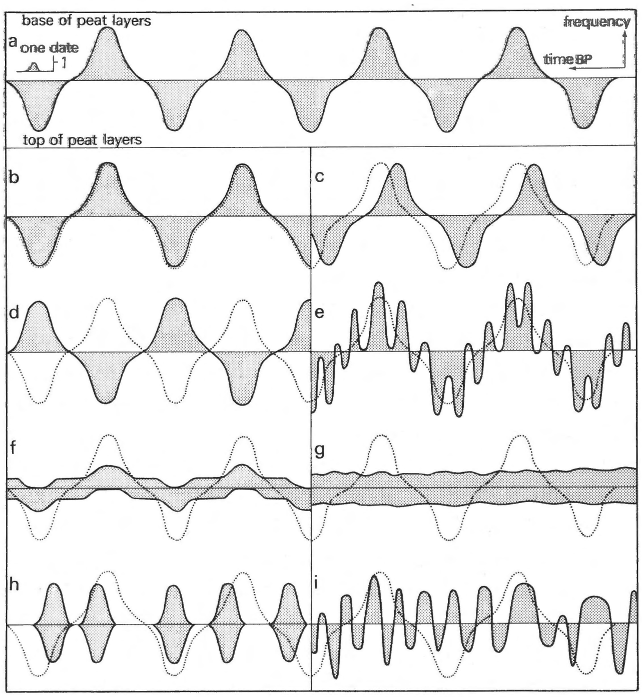
Fig. 2b is identical to Fig. 2a. In this case a perfect synchronism exists between periods of sedentation in the marine and the perimarine area.

Fig. 2c shows a shift of phase compared to Fig. 2a. In both areas the same mechanism may control the geological development, but the registration of periods of sedentation in the perimarine area is retarded.

In Fig. 2d the shift of phase is 180°, which means that periods of sedimentation in the marine area would occur simultaneously with periods of sedentation in the perimarine area.

Fig. 2e shows a rapid alternation of periods of sedimentation and periods of sedentation. The periodicity is superimposed on that of Fig. 2a. In this case only the intensity of the alternation can be correlated to the development in the marine area.

In Fig. 2f there is synchronism with Fig. 2a, the intensity of the peaks, however, is lower.



a shape of the histogram of the marine area
b-i theoretical shapes of the histogram of the perimarine area
The dotted line in fig. b-i represents the shape of fig. a

Fig. 2
Theoretical shapes of frequency histograms of radiocarbon datings at the base and the top of peat layers.

In Fig. 2g peat development is random; there is no alternation of periods of sedimentation and periods of sedentation.

In Fig. 2h the peaks above and below the horizontal time axis coincide. This may seem a contradictory situation, because it means that a maximum of beginning peat formation coincides with a maximum of ending peat formation. This may be explained by:

– a clustering of radiocarbon dates on random peat development, due to the non-linearity of the radiocarbon calibration curve (DE JONG & MOOK, 1981).

– shifting of rivers, which may cause an alternation of clay and peat beds of only local significance. It is feasible that sedimentation stops and development of peat starts near an old river branch, while the reverse happens near a river branch that just came into existence. It will be shown that the influence of shifting of rivers on the frequency histograms of the perimarine area in the Netherlands is very important.

Fig. 2i shows a clear alternation of periods of sedimentation and periods of sedentation, but there is no synchronism with Fig. 2a.

Finally it is possible that the shape of the histogram is a mixture of the examples in Fig. 2 or a combination of two or more examples in time.

NUMBER OF DATINGS REQUIRED

It will not be easy to ascertain the 'real' shape of the histogram of the perimarine area. To obtain reliable results a large number of datings should be scattered over a large area. A computer simulation by SHENNAN (1979) showed that a very small number of datings may result in small peaks that do not have any statistical significance.

In his simulation, about 115 datings were enough for reliable results: an increasing number of datings changed the shape of the histograms only slightly. It should be stressed, however, that small peaks that lack statistical significance may well have geological significance. At present it is therefore hard to say how many radiocarbon datings are really needed. When the so-called lithostratigraphic Calais, Dunkirk and Holland deposits were formally introduced by DE JONG & HAGEMAN (1960), only a few radiocarbon datings were available. ROELEVELD's (1974) scheme of transgressions and regressions – which seems to be generally accepted – was based on 59 radiocarbon datings only (Fig. 5a). Although the now available 89 ^{14}C datings in the perimarine area may not solve the problem once and for all, it still seems possible to identify at least the shape of the histogram of the perimarine area, because the histogram shows some striking characteristics that cannot be overlooked.

COMPARISON WITH FREQUENCY HISTOGRAMS OF THE MARINE AREA

ROELEVELD (1974) and GRIEDE (1978) have shown that in the marine area of the northern Netherlands there indeed seems to be an alternation of transgressions and regressions, as illustrated in Fig. 5a.

ROELEVELD's (1974) chronology of transgressions and regressions for the northern Netherlands is based upon 59

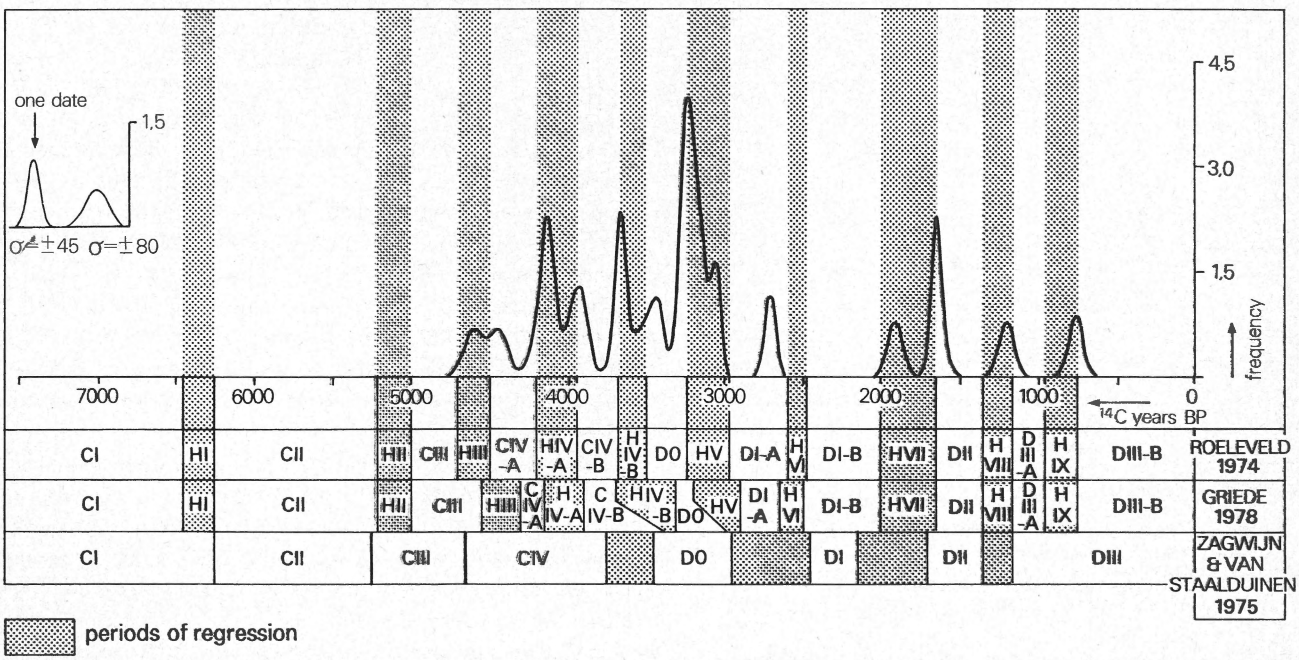


Fig. 3
Frequency histogram of 24 radiocarbon dates at the base of peat layers in residual channels in the perimarine area of the Netherlands.

radiocarbon datings. However, his chronology has never been proven to be valid for the western Netherlands; a quantitative analysis of radiocarbon dates of the marine district of the western Netherlands is yet to be made.

ZAGWIJN & VAN STAALDUINEN (1975) claim that one chronology is valid for the whole Netherlands' coastal area, but their chronology is not based upon a quantitative analysis of radiocarbon dates.

At present, the only possibility is to compare our histograms with ROELEVELD's (1974) histograms, assuming that his chronology of transgressions can largely be applied to the western Netherlands.

FREQUENCY HISTOGRAM OF DATINGS AT THE BASE OF PEAT LAYERS IN RESIDUAL CHANNELS

In Fig. 3 24 datings of the base of peat layers in residual channels have been plotted. Samples were taken only in residual channels that are easily recognized in the field. Since older residual channels are increasingly difficult to find, no channels older than 4700 BP have been dated. The number of 24 datings is too low for a purely statistical treatment. It is doubtful, however, if ever enough data will become available

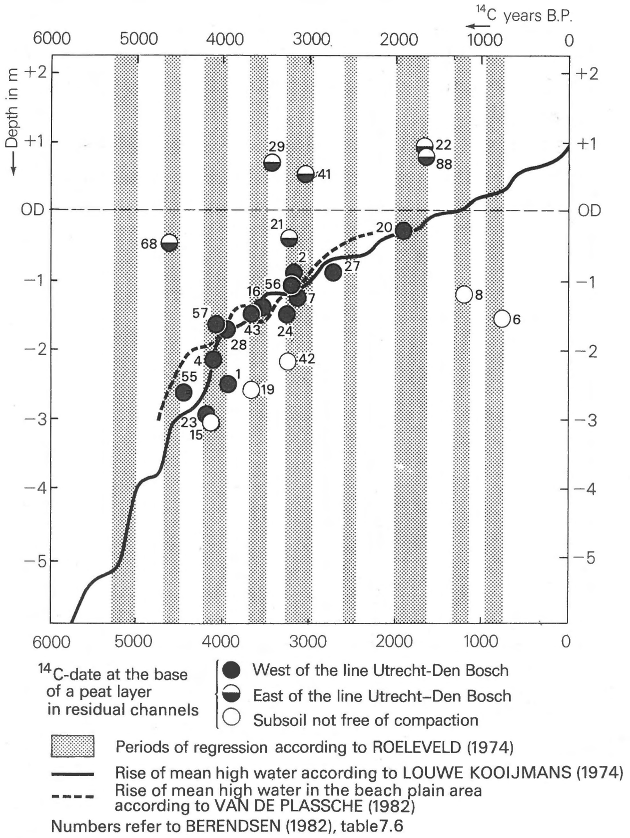


Fig. 4
Time-depth graph of the rise of mean high water in the Netherlands according to Louwe Kooijmans (1974), with radiocarbon dates from the base of peat layers in residual channels in the perimarine area.

(from a statistical point of view) since there simply is a limited number of residual channels of which dates can be obtained.

Fig. 3 shows high peaks around 4150 BP, 3650 BP, 3250 BP and 1675 BP, that lie either at the beginning or at the end of ROELEVELD's (1974) periods of regression. Only one date (2700 BP) definitely lies in the middle of ROELEVELD's D I-A period of transgression. If also the smaller peaks are taken into consideration, it shows that ten out of thirteen peaks lie mostly within ROELEVELD's (1974) periods of regression. It may therefore be concluded that as far as data are available they suggest that the beginning of peat formation in residual channels started mainly during periods of regression in the northern marine area. Fig. 4 leads to the same conclusion.

In addition it can be seen from Fig. 4 that samples taken west of a line drawn from Utrecht to Den Bosch cluster around the MHW (Mean High Water) curves of LOUWE KOOIJMANS (1974), and VAN DE PLASSCHE (1982). Because of compaction, all samples taken in stream ridges with no solid foundation on Pleistocene sand lie under the MHW curve. Samples taken east of a line drawn from Utrecht to Den Bosch lie above the MHW curve, but in general still fall within periods of regression.

Summarising it may be concluded that the beginning of peat formation in residual channels west of a line drawn from Utrecht to Den Bosch is somehow linked with: 1–the rise of MHW, according to LOUWE KOOIJMANS (1974), and 2–the occurrence of periods of regression in the northern marine area.

FREQUENCY HISTOGRAM OF DATINGS AT THE BASE AND THE TOP OF PEAT LAYERS IN BACKSWAMPS

In Fig. 5b 65 datings of the base and the top of peat layers in backswamps in the perimarine area have been plotted. Datings of the top of peat layers have only been used if no signs of erosion could be detected. For comparison, ROELEVELD's (1974) histograms of the marine district of the northern Netherlands are given in Fig. 5a.

Three peaks in the lower histogram of Fig. 5b (4950 BP, 3950 BP and 2900 BP) coincide with the end of ROELEVELD's (1974) Holland II, Holland IV-A and Holland V periods of regression respectively. This however is the only resemblance with his histograms.

It is clear that in Fig. 5b there is no evidence whatsoever for an alternation of periods of transgression and periods of regression. Instead of alternating, the peaks in the lower und upper histogram of Fig. 5b often coincide. Although some peaks are made up of only one or a few dates, it is striking that within the standard deviation of a date at least eleven coincident peaks can be observed. In other words, (a maximum of) beginning peat formation coincides with (a maximum of) ending peat formation. Minima in the upper

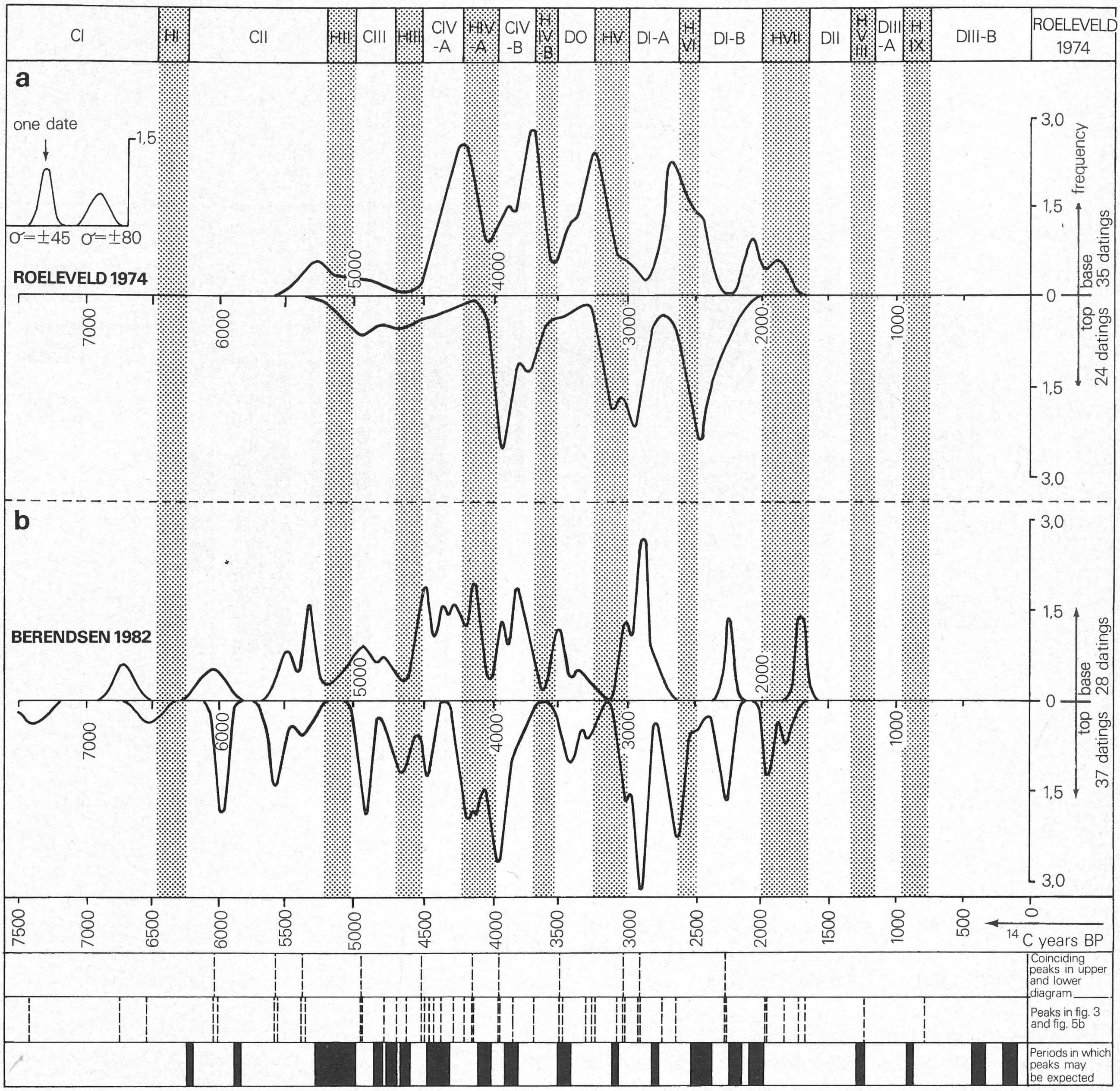


Fig. 5
Comparison of frequency histograms of ^{14}C dates at the base and the top of peat layers from the marine district of the northern Netherlands (Roeleveld, 1974) and the perimarine area (Berendsen, 1982).

and lower histograms of Fig. 5b coincide 8 times. It may be concluded therefore that Fig. 5b shows in essence the characteristics of Fig 2h (and possibly Fig. 2i). This means that no synchronism exists between the periods of sedentation in the marine and the perimarine area. The question whether ROELEVELD's (1974) chronology of transgressions and regressions for the northern marine area is also valid for the western Netherlands – although important in itself – is hardly relevant in this respect.

The conclusion that no synchronism exists between the sedimentation in the marine and the perimarine area is further supported by Fig. 6, in which the lithology of several borings in an E-W section through the perimarine area has been plotted against time.

It is obvious that peat formation was not governed by periods of regression.

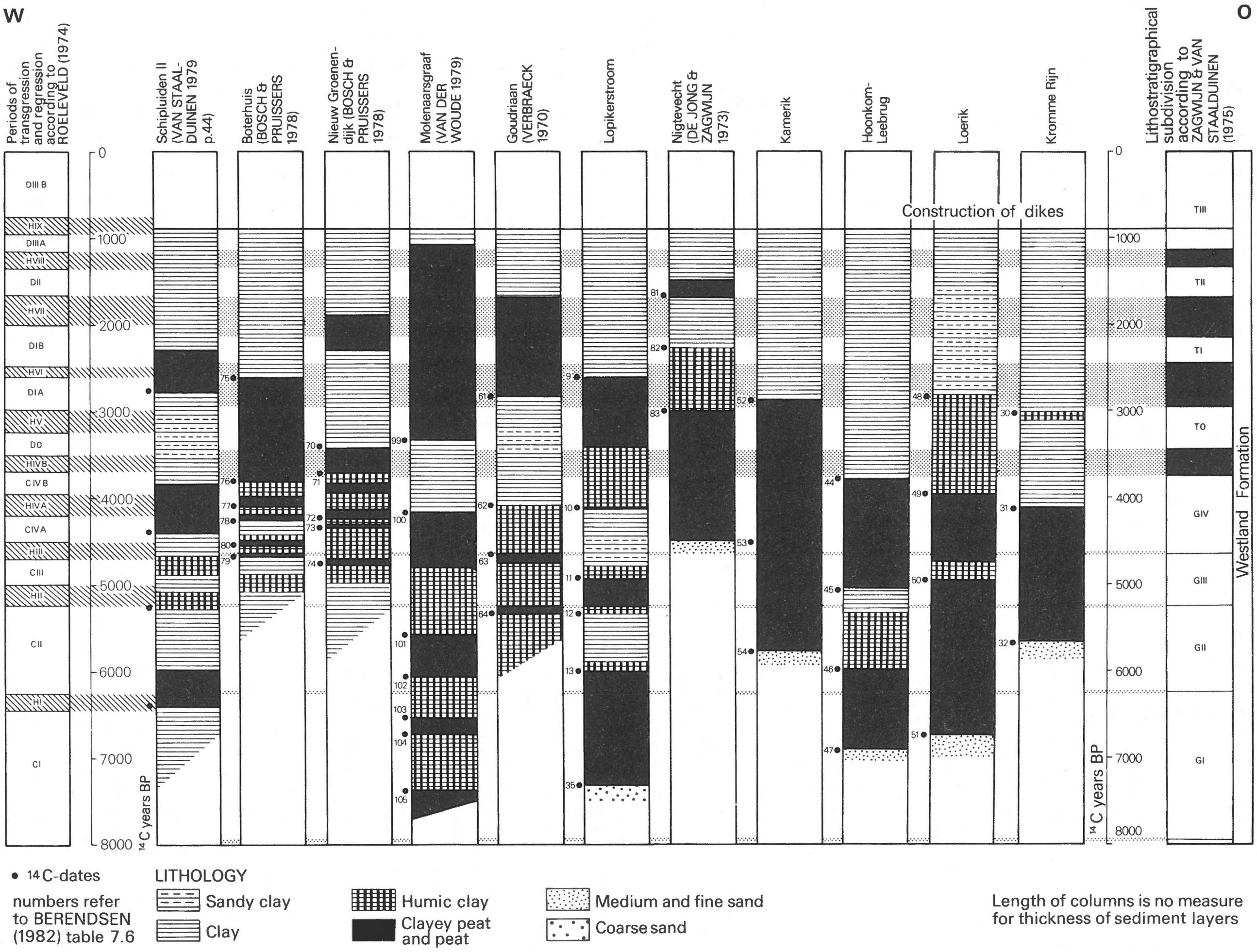


Fig. 6
Lithology of borings in the perimarine area of the Netherlands plotted against time.

THE INFLUENCE OF THE NON–LINEARITY OF THE RADIOCARBON CALIBRATION CURVE ON THE FREQUENCY HISTOGRAMS

Because the atmospheric ^{14}C content has not been constant over the past 10,000 years, radiocarbon ages expressed in years on the basis of a halflife of ^{14}C of 5568 years are different from astronomical ages (solar years). By carrying out radiocarbon datings on dendrochronologically dated wood a radiocarbon calibration curve could be made (SUESS, 1970; DAMON ET AL., 1972; RALPH ET AL., 1973). Due to the non-linearity of this radiocarbon calibration curve the possibility exists that clustering of radiocarbon dates occurs in the frequency histograms (DE JONG & MOOK, 1981). This effect is schematically presented in Fig. 7. The left curve is a histogram, constructed by assuming that each historical year presents a sample which is ^{14}C dated with a standard deviation of ± 40 years. Obviously the chance of obtaining radiocarbon ages around P and Q is higher than for the other radiocarbon time periods. Radiocarbon dates from different areas will therefore give rise to synchronous maxima in the histograms,

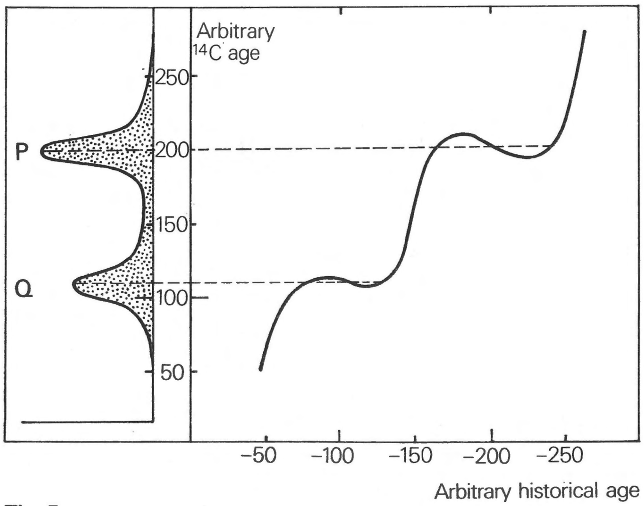


Fig. 7
The effect of clustering of radiocarbon dates upon frequency histograms. The left curve represents a histogram with peaks, that are caused by the non-linearity of the arbitrary radiocarbon curve on the right (after De Jong & Mook 1981).

provided that peat development is random and evenly distributed over the historical time scale. Various attempts have been made to investigate this effect (GEYH, 1980; DE JONG & MOOK, 1981). However, no conclusive quantitative solution to the problem is available yet. Therefore at present the influence of the non-linearity of the radiocarbon calibration curve on the histograms can only be estimated in a qualitative way.

The black bars at the bottom of Fig. 5 represent periods in which a clustering of radiocarbon datings may be expected, according to the calibration curves presented by SUESS (1970) and RALPH ET AL. (1973). Dotted lines represent maxima in Fig. 3 and Fig. 5b.

It can be concluded for three reasons that the influence of clustering of ^{14}C datings on the histograms of Fig. 3 and Fig. 5b may be considered small:

1–Only 11 out of 48 peaks lie within periods in which a clustering of ^{14}C datings may be expected, while only 1 out of the 11 coincident peaks in Fig. 5b lies within a period in which clustering may be expected.

2–MOOK ET AL. (1979) showed that a smoothed calibration curve should be used for samples covering 50 or 100 years. Since only peat samples (that easily cover 50 – 200 years) are included in the histograms, the influence of wiggles in the calibration curve on the histograms will be small.

3–The coincidence of peaks in the upper and lower histograms did not occur in the investigations of ROELEVELD (1974) and GRIEDE (1978), see Fig. 5a. If it is accepted that the influence of the wiggles in the calibration curve is not strong enough to explain the coincidence of peaks in the upper and lower histograms of Fig. 5b it has to be concluded that there are several instances in which beginning peat formation and ending peat formation occurs simultaneously.

THE INFLUENCE OF THE SHIFTING OF RIVERS (AVULSION) ON HISTOGRAMS

The influence of avulsion (the abandonment of a meander belt by a stream for a new course) on the frequency histograms is schematically illustrated in Fig. 8. As soon as sedimentation near river A stops peat may start to develop. Meanwhile peat development near B stops because sedimentation near B begins. In this case samples 2 and 3 are of the same age, which means that dating these samples will result in a peak in the upper as well as in the lower histogram.

In the period between the ages of sample 1 and sample 4 both peat formation and sedimentation occurred, depending only upon the distance to the river that existed at any given moment. If a situation like that shown in Fig. 8 occurs frequently and many samples at the top and at the base of peat layers are dated over a large area, more and more peaks in the upper and lower histograms will coincide. The coincidence of

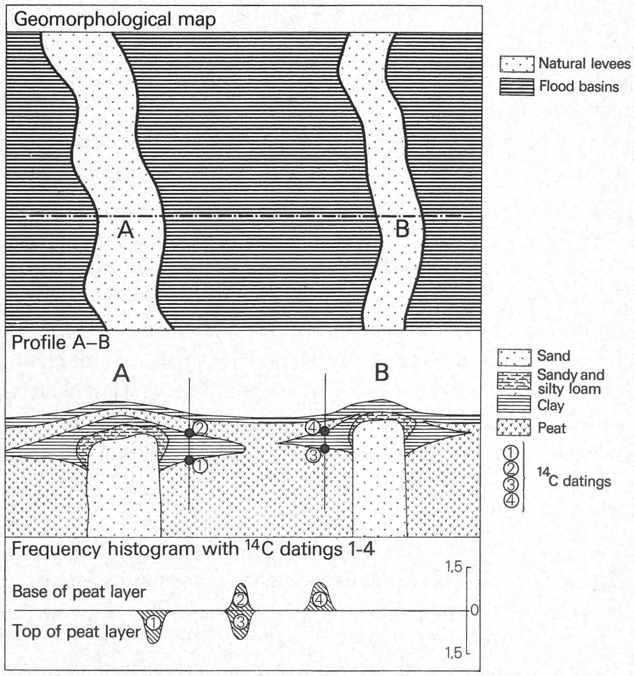


Fig. 8
The influence of avulsion (the abandonment of meander belt A and the development of a new course in meander belt B) upon frequency histograms.

peaks therefore can simply be explained as a result of avulsion. It is a well-known fact that avulsion occurred many times in the Dutch perimarine area, and it can be shown by an independent line of reasoning that the coincidence of peaks in Fig. 5b can be attributed to traceable avulsions (see BERENDSEN, 1982).

It is striking that 9 out of 11 coincident peaks in Fig. 5b lie within ROELEVELD's (1974) periods of transgression. In one case the coincident peaks fall at the end of the H V period of regression, and once they fall in the middle of a period of regression (H IV-A). In 6 out of 11 cases the coincident peaks fall at the very beginning of a period of transgression. If avulsion is the main cause for the coincidence of the peaks in Fig. 5b it can be concluded that avulsion occurred almost exclusively during periods of transgression in the northern marine area.

Finally it should be noted that a very limited number of datings in a small area might give the impression that the development of peat in the perimarine area occurs synchronously with regressions in the marine area. Because 6 out of 11 avulsions occurred at the very beginning of a period of transgression, datings at the top and at the base of peat layers near the rivers involved will result in dates that cluster around the beginning of a period of transgression and the end of a period of regression. The idea that periods of sedentation in the marine and the perimarine area generally occur synchronously is wrong and can be attributed to ignorance of this effect.

CONCLUSIONS

Since HAGEMAN (1969) introduced his concept of synchronous sedimentation in the marine and the perimarine area, the number of radiocarbon datings has increased at least tenfold. At present there are still too few datings available from the perimarine area to permit purely statistical treatment, but a few conclusions can be drawn:

1–In the perimarine area it is impossible to establish a chronology of periods of sedimentation and periods of peat formation which is synchronous with any of the existing chronologies in the marine area. The peaks above and below the horizontal time axis in Fig. 5b do not alternate; they often coincide. This coincidence can hardly be explained by a clustering of radiocarbon dates as a result of the non-linearity of the radiocarbon time scale. Instead, it can easily be explained as being the result of avulsion.

2–West of a line from Utrecht to Den Bosch the beginning of peat formation in residual channels is determined largely by the general rise of MHW in the Netherlands, as given by LOUWE KOOIJMANS (1974) and VAN DE PLASSCHE (1982).

Assuming that ROELEVELD's (1974) chronology of transgressions and regressions can largely be applied to the western Netherlands, the following provisional conclusions can be drawn:

3–Peat formation in residual channels in the perimarine area starts mainly during periods of regression in the marine area.

4–Avulsion occurred almost exclusively during periods of transgression in the marine area.

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