Sea-level rise during the last 2000 years as recorded on the Frisian Islands (the Netherlands)

Th.A.M. de Groot
W.E. Westerhoff
J.H.A. Bosch
Rijks Geologische Dienst, P.O.Box 157, 2000 AD Haarlem, the Netherlands

De Groot, Th.A.M., Westerhoff, W.E. & Bosch, J.H.A., 1996: Sea-level rise during the last 2000 years as recorded on the Frisian Islands (the Netherlands).- Meded. Rijks Geol. Dienst, 57, p. 69-78

Key words: sea-level rise, palaeo mean high water, Holocene, sedimentology, palaeoecology, barrier islands

Manuscript: received February 1995; accepted after revision May 1995

Abstract

In view of the current serious concern about the impacts of the greenhouse effect upon the coastal zone, the understanding of sea-level trends during the last centuries has become of increasing importance. In the Netherlands, the rate of relative sea-level rise during the last 2000 years is poorly known, mainly because of the lack of well-datable material associated with sea-level markers concerning that period. The present study concentrates on data collected on the Frisian Islands in the northern Netherlands, as these are derived from well-preserved sedimentary successions and from datable material formed during the last two millennia. Cored boreholes and excavations were analysed with the use of sedimentological and palaeoecological criteria, and numerous ^{14}C datings, constraining the boundary between the marine and the terrestrial domains. A palaeo Mean High Water (MHW) trend curve covering the last 2000 years was established. The upper limit of the curve shows a marked steepening over the last 800 years. The effects of the Little Ice Age (i.e., a levelling of the trend curve) can be inferred from the data.

1 Introduction

Future accelerated sea-level rise (SLR) as a result of the greenhouse effect, is of particular concern to coastal communities around the world. Recent studies of the world climate system (Houghton et al., 1990, 1992) forecast an accelerated SLR in the near future on a decadal-to-century time scale, while the apparently high average rate of relative SLR (15-20 cm/century), derived from tidal gauge records in the Netherlands over the last century, remains unexplained. In any case, forecasting rates of sea-level change is hazardous, especially over time scales exceeding a century. An understanding of past changes is therefore of paramount importance for the explanation of present conditions and validation of prognosis of future changes. Where the changes of sea-level are concerned, little is really known for the last three millennia in the Netherlands. Instrumental records only extend back a little over 200 years and geological data are scarce, because up to now the main areas of study have been located in the western part of the country, which was formed mainly before 3000 BP.

Well-documented Holocene sea-level curves have been published during the last 30 years (e.g. Jelgersma, 1961 and 1979), based on radio carbon data obtained from Basal Peat[1] collected in the western and the northern regions of the Netherlands (Figure 1). This curve was later improved by the results of Van de Plassche (1982), based mainly on data from the Province of Zuid-Holland, and by the curve of Roep & Beets (1988) mainly based on data from the Province of Noord-Holland. More recently, curves for the southwestern part of the Netherlands (Kiden, 1995) and the Belgian coastal zone (Denys & Baeteman, 1995) not only fill in the southern geographical gap, but also complete our understanding of the complex interactions between sea-level changes, tectonics, and climate. However, almost all of the data pertain to the period prior to 2500 BP. Over the last 2000 years there has been no coastal progradation in the western part of the Netherlands and no palaeo sea-level markers were formed.

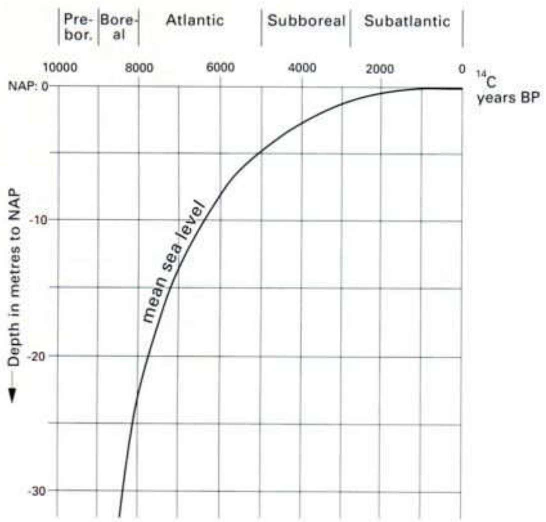

Figure 1
Holocene relative sea-level rise in the coastal plain of the Netherlands. NAP datum: circa present-day mean sea-level. After Jelgersma (1979).

In an attempt to remedy this situation and to close the gap between 2500 BP and the present, a project was carried out by the Rijks Geologische Dienst (Geological Survey of the Netherlands) between 1987 and 1990. As study location the Frisian Islands (Figure 2) were chosen, because most of these islands came into existence in their present form during the last three millennia (De Jong, 1984; Streif, 1986, 1987).

2 Methodology

Reconstruction of Holocene sea-level changes is made possible by assessment of the changes reflected by the geological, pedologic, and biological processes. Data can be used for such reconstruction when the following requirements are met:

1. A change in the lithological or sedimentological characteristics related to sea-level must be present.
2. The datum level must be datable.
3. The datum level should have undergone only a minimal amount of post-sedimentary compaction.

The datable material most commonly used in SLR studies is peat, e.g. Basal Peat (Jelgersma, 1961), or peat resting upon more or less compaction-free marine deposits (e.g. Louwe Kooijmans, 1974; Van de Plassche, 1982). A different approach was taken by Roep et al. (1975) and Roep & Beets (1988) who used sedimentological criteria establishing the height of Mean High Water (MHW) during the period of sedimentation. The latter method was used in the present study.

The study was carried out on a series of continuously cored boreholes, after a field survey of each of the five Frisian Islands. In addition, available outcrops and excavations were studied. The borehole locations were selected according to the most promising sedimentological sequences found during the initial field survey. In total, on the islands of Texel, Vlieland, Terschelling, Ameland, and Schiermonnikoog (Figure 2), seventeen boreholes and five

[1] *Basal Peat: an early Holocene peat bed in the coastal plain of the Netherlands, lying on top of the Pleistocene sands and at the base of the Holocene marine sequence (sand, clay and intercalated peat).*

excavations were studied in terms of palaeo MHW levels using ^{14}C datings. The cores were taken through the entire Holocene series, to obtain indications about problems related to post-depositional compaction and about the palaeogeographic evolution of the islands and the Wadden Sea (see also: De Jong, 1984; Van der Spek, 1996). The results deriving from the deeper parts of these cores will be published in a later phase (Bosch et al., in prep.).

For the purpose of a sea-level curve, the upper five to six metres were investigated in detail. Lacquer peels from the cores produced the sedimentological data needed for reconstructing the palaeo MHW levels in each borehole. The results were checked against the palaeoecological data (pollen and diatoms) obtained from the cores and excavations and dated by means of conventional radio-carbon dating of available organic material in the cores or excavations, as close as possible to the reconstructed palaeo MHW level.

3 Criteria for the reconstruction of palaeo MHW levels

Sedimentological criteria

As already mentioned, the reconstruction of a relative SLR curve must be based upon a number of assumptions and measurable parameters. The curves given by e.g. Jelgersma (1961 and 1979) and Van de Plassche (1982), were based upon the assumption that the oldest available peat layer found on top of compaction-free Pleistocene sand would represent the local groundwater rise, the first indication of marine influence for the period during which relative SLR was rapid, prior to about 5000 BP. The reliability and accuracy of the data used were discussed by Van de Plassche (1982) and Van de Plassche & Roep (1989). With the levelling-off of the relative SLR after 5000 BP, other environmental factors became increasingly important in addition to - and sometimes overprinting - the relative

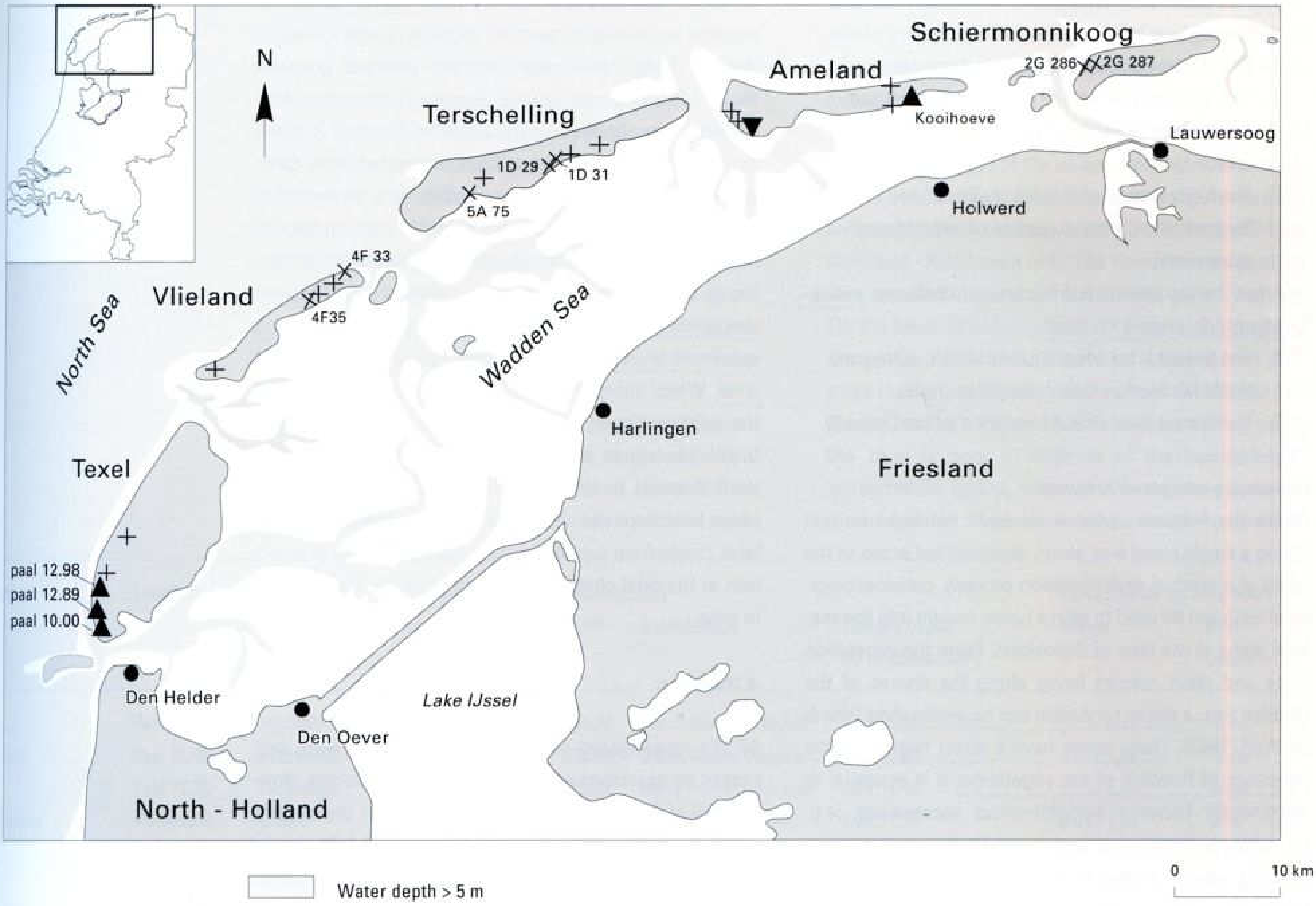

Figure 2
Location map of the Frisian Islands with the investigated sites.

SLR, e.g. the gradual increase of the local tidal range during the Holocene (Franken, 1987).
The incorporation of tidal range data in the relative sea-level curve was first attempted by Roep & Beets (1988). By the use of detailed sedimentological observations in excavations and cored boreholes, they were able to reconstruct palaeo MHW levels, and sometimes - albeit with much less accuracy - palaeo MLW (Mean Low Water) levels (Roep, 1986). From these levels a palaeo-tidal range and a palaeo MSL (Mean Sea-Level) could be reconstructed.

For the recognition of palaeo MHW levels in cores or outcrops, use can be made of several sedimentological criteria because the MHW datum determines a number of environmental responses, biological as well as sedimentological. Palaeo MHW levels can be defined using the following macroscopic features (Roep, 1986):

- From the bottom upward in cores or outcrops, indicators for deposition in water:
  1. The highest level of bioturbation.
  2. The highest level of wave-ripple lamination.
  3. The highest level of clay layers or clay drapes.
  4. The highest level of "bubble"-sand structures (beach facies).
  5. The highest level of marine shells or shell fragments (with the exception of wind-blown specimens).
- From the top downward in cores or outcrops, indicators for deposition on land:
  6. The lowest level of eolian lamination: adhesion ripple lamination (beach facies) or dunes.
  7. The lowest level of soil formation or peat growth.

Palaeoecological criteria

Where the features under study have not been formed during a single event (e.g. storm deposits) but arose as the result of a gradual sedimentation process, palaeoecological criteria can be used to gain a better insight into the sea-level stand at the time of deposition. From the vegetation types and plant species living along the shores of the Wadden Sea, a distinct zonation can be established (Vos & De Wolf, 1993). These zones have a direct relation to the frequency of flooding of the vegetation. It is essential to discriminate between autochthonous successions (e.g. salt water to fresh water species indicating a decreasing flooding frequency) and allochthonous (i.e. reworked) assemblages. The conservation potential of diatom assemblages in particular, is generally better than that of the rest of the plant community. Diatom assemblages are also more accurate for use in palaeoenvironmental reconstructions because they can be recognised on the species level, whereas pollen are indicative for the genera level. Environmental changes in vegetated salt marshes will thus be registered more accurately by the diatom populations living there, in particular by *Diploneis interrupta*.

The following palaeoecological diagnostics can be used:

- Indicators for a salt marsh (the zone at or just above MHW):
  1. A high percentage of complete (i.e. non-reworked) *Diploneis interrupta* diatoms.
  2. A high percentage of *Chenopodiaceae, Plantago maritima* and sometimes *Plantago coronopis*.
  3. A peak in the occurrence of *Foraminifera*.
- Indicators for a non-vegetated tidal flat (the zone at or just below MHW):
  4. A high percentage of *Melosira sulcata* diatoms.
  5. A relative abundance of reworked pollen material (e.g. *Calluna, Dryopteris, Sphagnum*).

Radio carbon data

To be able to place the reconstructed MHW levels and the palaeoenvironments in an adequate time frame, samples of datable material were collected, as near as possible to the interpreted MHW level. A total of 74 samples from boreholes and excavations were radio carbon dated. The material consisted of peat or rootlets, gyttja, or humic clay, or humic sand and carefully selected (juvenile) shells (*Cerastoderma edule, Spisula subtruncata, Macoma balthica, Mytilus edule, Littorina littorea*). It is evident that this material must have originated from different environments. Peat and rootlets are of terrestrial origin and occur well above the MHW level; gyttja and humic clay or sand are deposited in aquatic environments (tidal flat to salt marsh) around the MHW level; shells, especially, when they are represented by whole specimen in living position, are found below the MHW level. When interpreting the ^{14}C data from this material, the relative position of the samples in relation to the MHW level must be taken into account. The selected shell material concerns predominantly the deeper and older tidal deposits. This will be discussed further in a later publication concerning the sedimentological evolution of the tidal channels under the islands (Bosch et al., in prep.).

4 Results

All the investigated sites shown in Figure 2 were processed as described under section 2: Methodology. However, all of the sites did not yield complete or useful data, either for reconstructing palaeo MHW levels (absence of sufficient diagnostic sedimentological criteria, ambiguous or multi-interpretable sedimentological data) or gaps in the fossilized palaeoenvironments. In the end, and after detailed analysis of the data, only eleven locations (Figure 2) met the three requirements (see under section 2) for the reconstruction of the palaeo-sea-level changes on the Frisian Islands over the last 2000 years. The results of the radio carbon dating and the reconstructed paleo MHW levels from these ten locations are presented in Figure 3.

During the present study the investigations were concentrated upon the recognition of palaeo MHW levels in the lacquer peels made from the cores. No evidence pointing to palaeo MLW levels was found. This is not surprising, since this level is very poorly defined. It is therefore not possible to reconstruct the palaeo-tidal range, or the MSL trend for the Frisian Islands over the last 2000 years.

The reconstruction of the palaeo MHW level from the data of each location was derived from the following criteria:

- *Texel - Paal 10.00 (P1)*: The dated organic layer, which represents the base of a former peat layer, was exposed on the present beach, directly overlying about 2 m of dune sands. The highest possible level of MHW can thus be put at about 0.03 m +NAP.
- *Texel - Paal 12.89 (P2)*: The same lithological succession as Paal 10.00. The highest marine deposits are situated about 1.30 m +NAP. These, however, probably represent storm deposits and are not related to the fair weather MHW.
- *Texel - Paal 12.98 (P3)*: The same lithological succession is found in this excavation. The highest marine deposits occur beneath dune sands at about 1.15 m +NAP. The possibility of storm influence on this level is not excluded (see discussion below).
- *Vlieland - 4F35 (V3)*: From the lacquer peels of the borehole, the range of palaeo MHW was established through the sedimentological criteria. The best estimate (0.72 m +NAP) was inferred by constraining as much as possible the top-downward and the bottom-upward criteria. Palaeoecological criteria could not be used at this location.
- *Vlieland - 4F33 (V12)*: As for 4F35, sedimentological criteria were used to establish the range of palaeo MHW. A best estimate was inferred at about 0.94 m -NAP. However, the distance between the dated sample and the palaeo MHW range is great. This leads to problems for positioning the MHW range on the time scale (see discussion below). Palaeoecological criteria could not be used for the MHW interpretation.
- *Terschelling - 5A75 (T7)*: The range of the palaeo MHW level was determined with use of the sedimentological criteria from the lacquer peels. The top of the range was confirmed by palaeoecological data. No best estimate could be arrived at.
- *Terschelling - 1D29 (T2)*: Here too, sedimentological criteria were used for the range of palaeo MHW. The sedimentological log of borehole 1D29 is shown in Figure 4. It must be mentioned that not all of the criteria occur in this borehole, which is almost never the case in natural systems. However, the sedimentological criteria shown in Figure 4 (criteria 1, 3, 5, 6, and 7) and the ratio shift from marine planktonic diatoms (*Melosira sulcata*) to the group of marine brackish aerophile diatoms (*Diploneis interrupta*), constrain the best estimate of the palaeo MHW level at 0.10 m +NAP, within the gyttja and below the peat that forms the top of the salt-marsh deposits (see also Ameland-Kooihoeve, below).
- *Terschelling - 1D31 (T4)*: Sedimentological criteria determined the range of the palaeo MHW, but no best estimate can be given. Palaeoecological criteria were not sufficiently distinct to help determine the best estimate.
- *Ameland - Kooihoeve (A1)*: The Kooihoeve excavation was sampled in detail for diatom and pollen analysis. On the basis of palaeoecological criteria, the range of the palaeo MHW was determined and the best estimate (1.05 m +NAP) was inferred from the zonation of the diatom flora (Figure 5). Below about 1.05 m +NAP, the zone is poor in diatoms of the marine/brackish/aerophile group, whereas the marine planktonic group (mainly *Melosira sulcata*) is well-represented,

Island	**Location**	**Borehole**	**Radio carbon data (conventional)**					**Palaeo MHW (in m to NAP)**	
			Group nr.	GrN	Years BP	Sample type	Sample depth (in m above NAP)	Range	Best estimate
	Paal 10.00	excavation	P1	19427	90±70	Sand, humic (extract)	2.03 / 2.06	/ 0.03	none
Texel	Paal 12.89	excavation	P2	19160	120±30	Sand, humic (residu)	1.66 / 1.68	/ 1.30	none
	Paal 12.98	excavation	P3	19161	155±30	Sand, humic (extract)	2.06 / 2.10	/ 1.15	none
Vlieland	Vianenslid	4F35	V3	17212	268±35	Peat, sandy (residu)	1.08 / 1.10	0.41 / 1.03	0.72
	Kaap Bol	4F33	V12	17208	1530±30	Peat, sandy	0.16 / 0.20	-1.60 / -0.94	-0.94
	Dellewal	5A75	T7	17597	1260±50	Gyttja, sandy (residu)	0.51 / 0.54	-0.41 / 0.25	none
Terschelling	Paradijs 1	1D29	T2	17592	1285±30	Clay, humic (residu)	0.18 / 0.23	-0.40 / 0.10	0.10
	Paradijs 2	1D31	T4	17594	880±45	Peat, sandy (residu)	0.52 / 0.55	-0.31 / 0.31	none
Ameland	Kooihoeve	excavation	A1	16022	375±25	Peat (residu)	1.27 / 1.29	1.02 / 1.12	1.05
Schiermonnikoog	Westerplas	2G286	S2	16935	525±30	Peat, sandy (residu)	1.01 / 1.08	-0.95 / 0.90	-0.25
	Westerduinen	2G287	S4	17004	455±90	Sand, humic (extract)	1.58 / 1.67	0.12 / 0.57	0.26

Figure 3

Radio carbon dates and reconstructed palaeo MHW levels used in this study.

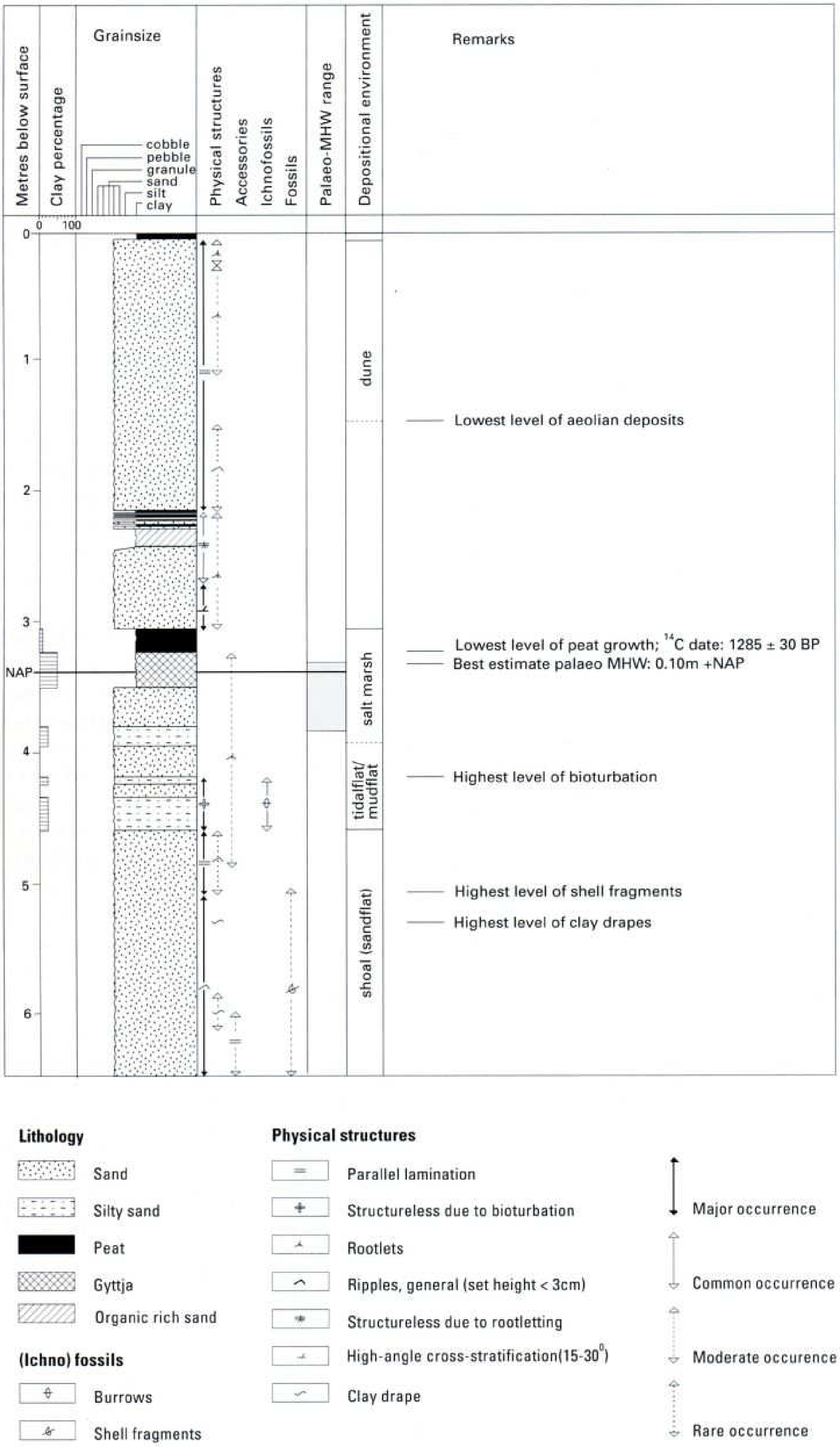

Figure 4
Sedimentological log of borehole 1D29 (Paradijs 1, Terschelling).

especially by incomplete specimens. In the upper zone, above about 1.05 m +NAP, the diatom *Diploneis interrupta* is the dominant species within the marine/brackish/aerophile group, and the marine planktonic group is significantly poor in specimen. The changes in the ratio between complete and broken tests reflects the differences in lithology. Complete tests are found more or less in situ in the fine-grained sediments; broken tests are found in sand layers and were damaged during transport by wind or water. The pollen zonation shows a similar picture with high percentages of *Gramineae*, *Plantago*, and *Triglochin* in the upper zone, which represents a salt-marsh vegetation. From the changes between the occurrence of *Melosira* and *Diploneis* and the occurrence of salt-marsh vegetation, the best estimate for the palaeo MHW level can be inferred at 1.05 m +NAP.

- *Schiermonnikoog - 2G286 (S2)*: This borehole contains a very wide range of palaeo MHW based on sedimentological criteria, probably due to a relatively slow net sedimentation rate determined by repeated local sedimentation/erosion phases. Moreover, the criteria were not clear enough to define the range limits further. The top of the range is confirmed by the palaeoecological data. Nevertheless, a best estimate palaeo MHW level could be inferred at about 0.25 m -NAP.
- *Schiermonnikoog - 2G287 (S4)*: In contrast with the preceding borehole, the palaeo MHW range is much smaller. The best estimate is inferred at 0.26 m +NAP. However, the distance between the range and the nearest radio-carbon date is much more than at the other locations. This complicates estimation of the exact position on the time scale (see discussion below).

All the radio-carbon and MHW data are shown graphically on the time/depth diagram in Figure 6. The palaeo MHW range is represented by a box. The height of the box represents the maximum range of palaeo MHW occurrence,

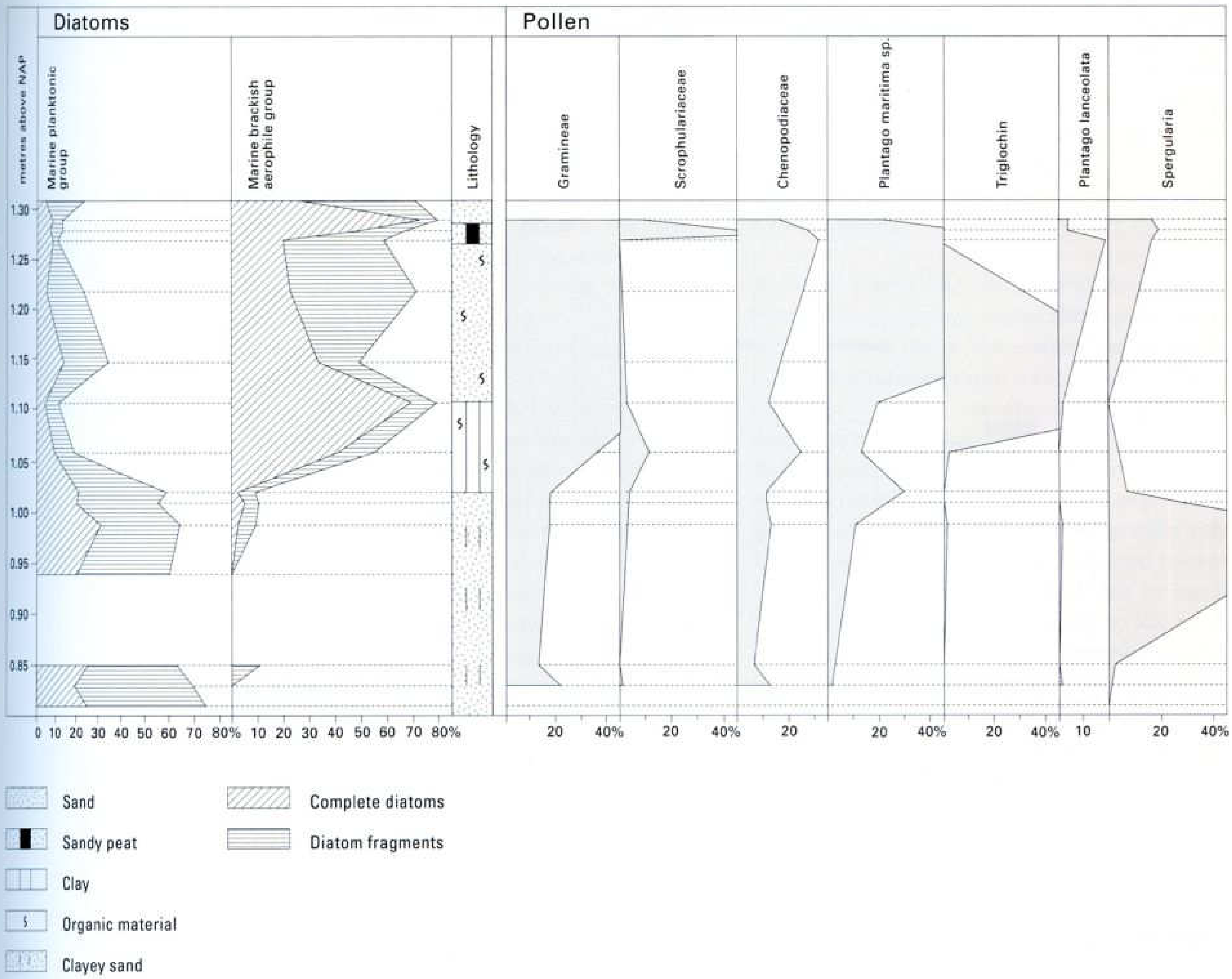

Figure 5
Palaeoecological data obtained from the Kooihoeve excavation (Ameland).

and the width of the box is related to the 2 σ range of the nearest ^{14}C dating within the core. Within each box and - where possible (see Figure 3) - a line and triangle indicate the best estimate of the palaeo MHW level. The ^{14}C box of the nearest ^{14}C date within the core, is drawn according to the 2 σ range (box width), and the sample thickness (box height).

5 Discussion

As already mentioned, all sedimentological criteria seldom occur together. The recognition of the palaeo MHW range and - increasingly so - the palaeo MHW best estimate, in the Frisian Island cores was either complicated by the lack of sufficiently clear criteria or by the poor preservation, since the cores are only ten centimetres wide. Furthermore, the preservation potential of facies types can differ widely depending on the local geomorphological position (e.g. exposed coastal high-energy domain versus a sheltered back-barrier domain).

In this context, the Late Holocene dynamics of the barrier islands, especially the migration and evolution of tidal channels, undoubtedly played a complex role that has not yet been elucidated. This is of particular importance because the facies under study were formed during the last few thousand years, a period of relatively slow sea-level rise and thus fewer chances of fossilisation (see also: Van der Spek, 1996).

The same pertains to analysis of the fossilization potential of palaeoecological data, which generally speaking, are

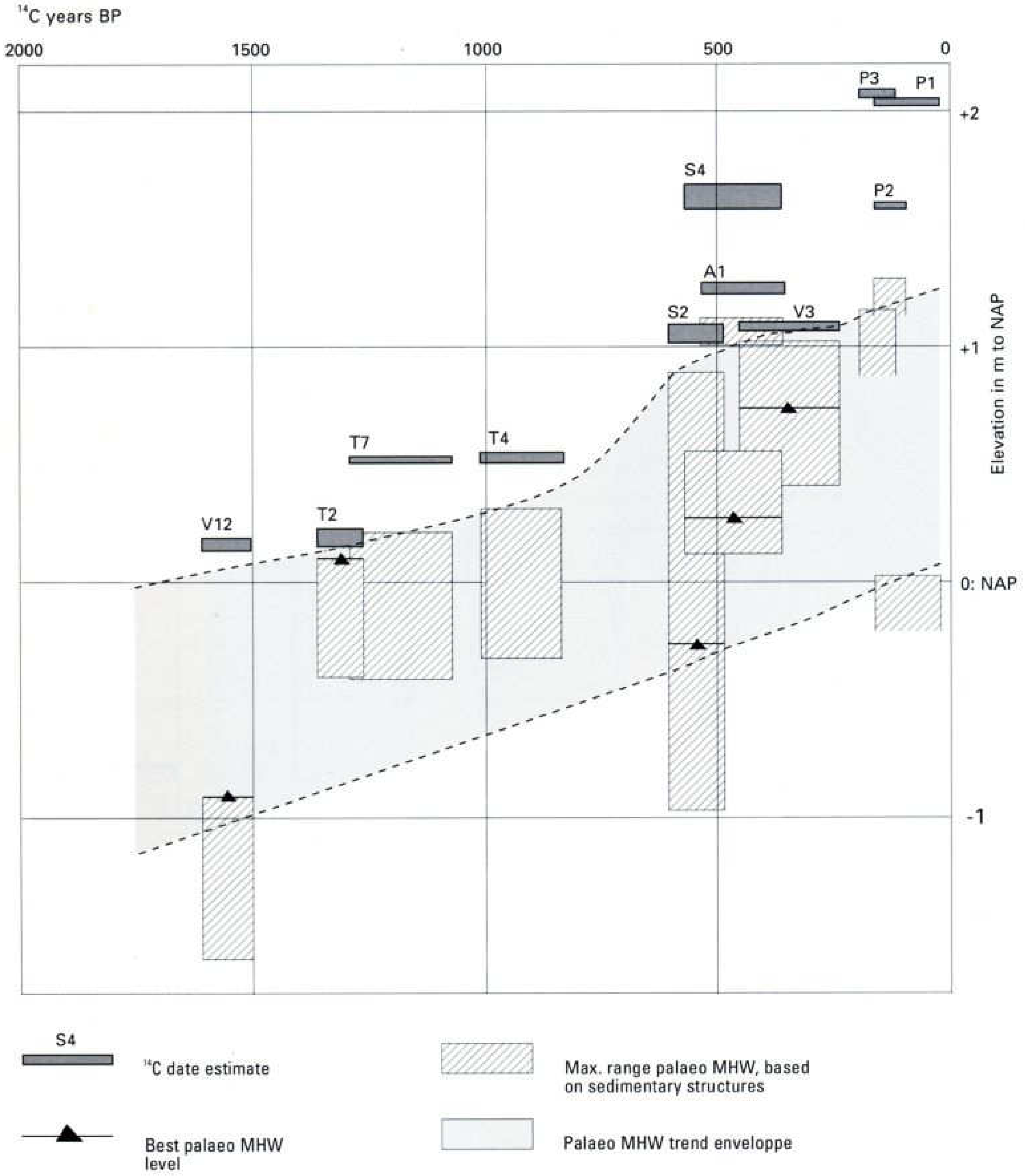

Figure 6
Time-depth reconstruction of the palaeo MHW trend over the last 2000 years on the Frisian Islands.

subject to the same preservation problems as the sedimentary facies with which they are associated.

One major problem is the temporal relationship between the palaeo MHW range and the nearest ^{14}C dating (Figure 6). In most cases, there is a depth difference varying from centimetres to several decimetres. In two cases (V12 and S4), the distance even amounts to about one metre. This implies that there can be a - sometimes significant - difference between the time of deposition of the MHW-related sediments and the earliest time of peat growth in the nearest datable material. Thus, the datings are too young and all the palaeo MHW range boxes should be shifted some distance to the left in relation to the ^{14}C boxes. However, it is impossible to infer the duration of the interval between the two boxes. This interval probably varies from several decades to even centuries. For the time being and as a working hypothesis, the palaeo MHW range boxes and the ^{14}C boxes have been related vertically to each other (Figure 6). We assume, however, that if a more precise assessment could be made, the interpreted palaeo MHW level over the last 2000 years would not be shifted significantly backward in time, whereas the shape of the trend curve will hardly change.

Around the palaeo MHW range boxes (Figure 6) a shaded zone represents the best possible interpretation of the palaeo MHW trend during the last 2000 years. The shape of the upper boundary is constrained by the upper limit of the palaeo MHW range and the lower limit of the ^{14}C samples. Three features should be noted here:

1. From about 800 BP onward, the upper boundary tends to steepen gradually.
2. Around 400 BP, this trend is temporarily interrupted by a gentle levelling of the upper boundary.
3. The steepening increases again after about 300 BP.

Obviously, the Ameland-Kooihoeve (A1) data lie somewhat above this trend curve. Since it may be assumed that the Kooihoeve data are reliable, the interpretation should be that local factors influenced the height of the MHW, e.g. differences in tidal amplitude due to bottom friction and dam-up of the tidal prism within the Wadden Sea tidal basin. In the present island configuration the variation range of the MHW in the Wadden Sea varies from 0.80 m +NAP in the tidal channel between Terschelling and Ameland and 0.95 m +NAP on the back-barrier side of Ameland.

At this stage, however, it is not clear whether the steepening of the MHW trend between 800 BP and the present is related to an accelerated sea-level rise (which seems in contradiction with the tidal gauge records as far as the period between 800 BP and 100 BP is concerned), changes in storm frequencies and storm amplitudes over the last 1000 years, or the influence of the dyke constructed in the northern part of the Netherlands since about 1000 AD. Only the last-century part of the curve may be coincident with the accelerated sea-level rise shown by the tidal gauges. It should be noted that the Texel data do not derive from locations on the back-barrier part of the island. This means that the local tidal amplitude (present MHW: about 0.65 m +NAP) is less than that of the other sites in a back-barrier position (e.g. Ameland, present MHW: about 0.95 m +NAP) where the effects of the tidal basin geometry play an important role. This also means that the relatively high level of the MHW trend on Texel in comparison with the average present level, may be influenced by storm activity on the exposed side of the island.

The levelling of the boundary around 400 BP is puzzling, but is possibly a result of the impact of the Little Ice Age[2] climatic change. However, more data are needed to allow refinement of this part of the curve before a more definite answer can be given.

Alternatively, as was postulated above for the Ameland-Kooihoeve data, the shape of the upper boundary may be related to the position of the samples at the back-barrier side of the islands. Local differences in tidal amplitude behind each barrier island are able to influence the local MHW level significantly. These questions cannot be answered adequately by the present study.

6 Conclusions

This paper presents the first results of the analysis of palaeo MHW changes over the last 2000 years as they affected the Frisian Islands. The combined use of sedimentological and palaeoecological criteria as well as a large number of ^{14}C datings, made it possible to establish a trend curve for palaeo MHW levels. In particular, the constraints determining the shape of the upper boundary of the MHW trend indicate changes in MHW level over the last 800 years, possibly related to climatic changes (Little Ice Age), and seem to confirm the accelerated sea-level rise over the last century. It is expected that the results will provide a solid basis for future work on MSL reconstructions over the last 2000 years. However, as already mentioned, some problems remain to be solved. In particular, the temporal relationship between the MHW levels and the 14C datings should be assessed in more detail.

Acknowledgements

This study was partially funded by Directorate General XII of the Commission of the European Communities (C.E.C. contract number: EV4C-0024-NL-GDF) as a contribution to the 2nd Framework Project: *"Investigation Of Past And Future Sea Level Changes And Their Impacts"*. We are in-

[2] Little Ice Age: a historical period (XVth-XIXth century) of global lower winter temperatures.

debted to Dirk Beets and Thomas Roep for lively discussions about the cores. Piet Cleveringa and Hein de Wolf are thanked for their detailed pollen and diatom analyses that were so important for the palaeo-environmental interpretations. The director of the Geological Survey of the Netherlands granted permission for publication.

References

Bosch, J.H.A., Westerhoff, W.E. & De Groot, Th.A.M., in prep.: Holocene sedimentary sequences of the Frisian Islands (the Netherlands).

De Jong, J., 1984: Age and vegetation of the coastal dunes on the Frisian Islands, the Netherlands. - Geol. Mijnbouw, 63, p. 269-275.

Denys, L. & Baeteman, C., 1995: Holocene evolution of relative sea-level and local mean high water spring tides in Belgium; a first assessment. - Marine Geology 124, p. 1-19.

Franken, A.F., 1987: Rekonstruktie van het Palaeo-Getijklimaat in de Noordzee. - Report X0029-00, Delft Hydraulics Laboratory, Delft, 74 pp.

Houghton, J.T., Jenkins, G.J. & Ephraums, J.J. (eds), 1990: Climate Change. The IPCC Scientific Assessment. - Cambridge University Press, 365 pp.

Houghton, J.T., Callander, B.A. & Varney, S.K. (eds), 1992: Climate Change 1992. The Supplementary Report to the IPCC Scientific Assessment. - Cambridge University Press, 200 pp.

Jelgersma, S., 1961: Holocene sea-level changes in the Netherlands. - Meded. Rijks Geol. Dienst, Serie C-VI(7), 100 pp.

Jelgersma, S., 1979: Sea-level changes in the North Sea basin. - p. 233-248 in: Oele, E., Schüttenhelm, R.T.E. & and Wiggers, A.J. (eds): The Quaternary history of the North Sea. - Acta Univ. Ups. Symp. Univ. Ups. Annum Quingentesium Celebrantis 2.

Kiden, P., 1995: Holocene relative sea-level change and crustal movement in the southwestern Netherlands. - Marine Geology, 124, p. 21-41.

Louwe Kooijmans, L.P., 1974: The Rhine/Meuse delta, four studies on its prehistoric occupation and holocene geology. - Analecta Praehistorica Leidensia VII, Leiden University Press, 421 pp.

Roep, Th.B., 1986: Sea-level markers in coastal barrier sands: examples from the North Sea coast. - p. 97-128 in: Van de Plassche, O. (ed.): Sea-level research: a manual for the collection and evaluation of data. - Geo Books, Norwich.

Roep, Th.B. & Beets, D.J., 1988: Sea-level rise and palaeotidal levels from sedimentary structures in the coastal barriers in the western Netherlands. - Geologie en Mijnbouw, 67(1), p. 53-60.

Streif, H., 1986: Zur Altersstellung und Entwicklung der Ostfriesischen Inseln. - Offa, vol. 43, p. 29-44.

Streif, H., 1987: Barrier islands, tidal flats, and coastal marshes resulting from a relative rise of sea level in East Frisia on the German North Sea coast. - Proceedings KNGMG Symposium 'Coastal Lowlands', Geology and Geotechnology, p. 213-223.

Van de Plassche, O., 1982: Sea-level change and water-level movements in the Netherlands during the Holocene. - Meded. Rijks Geol. Dienst, N.S. 36(1), 93 pp.

Van de Plassche, O. & Roep, Th.B., 1989: Sea-level changes in the Netherlands during the last 6500 years: basal peat vs. coastal barrier data. - p. 41-56 in: Scott, D.B., Pirazzoli, P.A. & Honig, C.A. (eds.): Late Quaternary sea-level correlation and applications. - NATO ASI Series C 256.

Van der Spek, A.J.F., 1996: Holocene depositional sequences in the Dutch Wadden Sea south of the island of Ameland. - Meded. Rijks Geol. Dienst, 57 (this volume), p. 41-68. (Also published in: Van der Spek, A.J.F., 1994: Large-scale evolution of Holocene tidal basins in the Netherlands. - Thesis, Utrecht, p. 27-73.)

Vos, P.C. & De Wolf, H., 1993: Diatoms as a tool for reconstructing sedimentary environments in coastal wetlands; methodological aspects. - Hydrobiologia, vol. 269/270, p. 285-296.