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Sea level rise and paleotidal levels from sedimentary structures in the coastal barriers in the western Netherlands since 5600 BP

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Abstract

A trendcurve for the rise of mean sea level (MSL) since 5600 BP is given based on ^{14}C-dated coastal sequences. Mean High Water level (MHW) is inferred from the deepest occurrence of dry eolian scour and the highest marine burrow-level and small-scale cross-lamination. Estimates of Mean Low Water levels (MLW) are based on the level of thickest shell beds, the range of structureless sand or bubblesand, the range of low-angle bars and the occurrence of cm-thick clay intercalations. Estimates of MHW have an error of a few decimetres. Those of MLW somewhat more. All data are presented in a ^{14}C time-depth graph and also in a historical time-depth graph (calibrated years BC). MSL is drawn halfway MHW and MLW estimates. The MSL trendcurve indicates a rise of ca. 2 m between 4500 cal BC and 3000 cal BC and ca. 3.5 m during the last 5000 historical years. Our data suggest a tidal amplitude of ca. 2 m between 4500 cal BC and 3000 cal BC and of ca. 1.50 m during the last 2000 historical years.

Introduction

This article is the result of observations over 15 years in man-made trenches and pits in the coastal barriers of the W Netherlands (Roep et al., 1975; Roep et al., 1979; Beets et al., 1981; Roep et al., 1984; Roep, 1986). These pits gave the opportunity to study the sequence of sedimentary structures in relation to paleo-Mean High Water (MHW) and Mean Low Water (MLW). In addition, the vertical distribution of sedimentary structures on the recent beach have been studied in relation to present-day tide levels (cf. Roep, 1986). These data combined with ^{14}C-dated paired shells may be used to construct a curve of sea level rise. Most sea level curves for the Netherlands are trendcurves based on time-depth plots of ^{14}C-dated peat and saltmarsh deposits indicating changing groundwater levels and high water levels respectively (a.o. Jelgersma, 1961; Van de Plassche, 1982). A comprehensive evaluation of all published SL-curves for the Netherlands since 1954 is given by Van de Plassche (1982). The preliminary results of our present paper have been published elsewhere in abstract form (Roep & Beets, 1986).

Time-depth data and curve construction

Figure 1 indicates the position of 19 sites used for the reconstruction of our MSL-trendcurve. In Table 1 all relevant data and references are given for each site. Age indications and levelled sedimentological features of this table have been used in Figs 3 and 4. All heights are measured in metres in relation to Dutch Ordnance level (NAP), which is

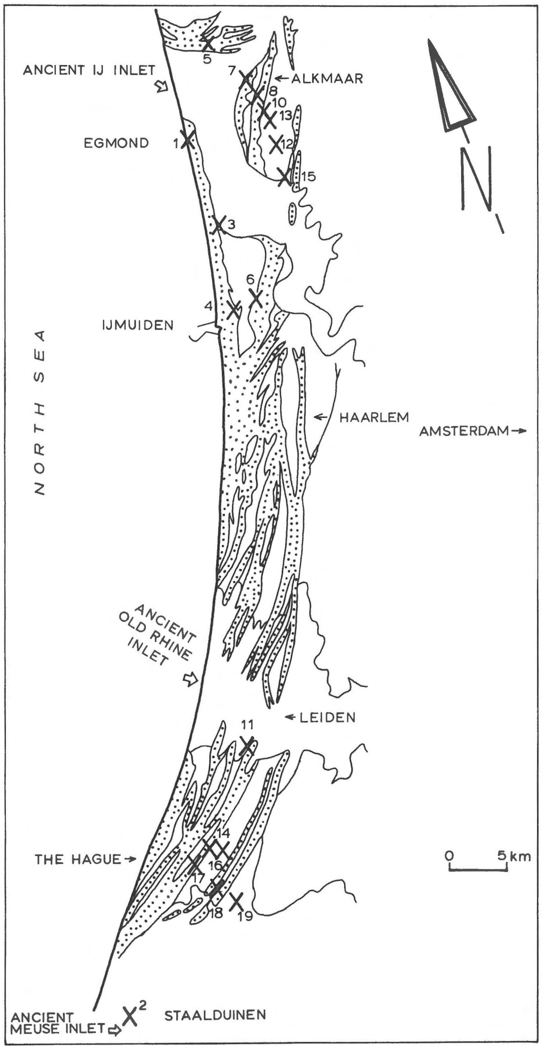

Fig. 1. Coastal barrier complex of W Netherlands (modified after Jelgersma et al., 1970) with position of localities 1–19.

roughly present MSL. Except for sites 1 and 2 all the data were obtained in deep reconstruction pits and trenches. Site 1 indicates the position of the recent Egmond beach and site 2 the position of Staalduinen. For the latter site the height of eolian sand is measured from a published cross-section (Van Staalduinen, 1979). All radiocarbon data in Table 1 are from paired shells of marine or brackish pelecypods, except for the age indications of site 2 (historical data); 5 (charcoal); 9 (interpolation between 8a and 10) and 18 (peat and pollen-zonation). The ^{14}C ages of Table 1 have also been converted into calibrated years BC or AD using the tables and graphs in Stuiver & Kra (1986). Calibrated ages are calculated from ^{14}C dated tree rings with ages derived from dendrochronologic methods.

The levelled sedimentological data in our table are derived from two main types of sandy sequences encountered (examples are shown in Fig. 2, plotted in a time-depth diagram). The first type (IJmuiden, site 4) is characterized by horizontal or very low-angle seaward dipping lamination in the intertidal part that is covered by a relatively thick sequence of eolian sand. The other type (Starting, site 15) is characterized by thin clayey intercalations, marine burrow levels and low-angle landward dipping and flattening-upward longshore bar lamination in the intertidal part that is covered by a thin veneer of eolian sand. The first type formed during slow coastal progradation with a relatively steep nearshore gradient, the other type during more rapid progradation with flatter gradients (Beets et al., 1981; Roep, 1986). Sites 7, 8, 13, 15, 16 and 19 (Fig. 1) belong to the latter type and sites 4, 9, 17 and 18 to the former. Some sequences show somewhat more intermediate characteristics or could not be classified because of insufficient exposure.

The most important feature for SL-studies in the IJmuiden type sequences (Fig. 2) is the deepest level of dry eolian scour or dry eolian sand (above high-tide level). Important furthermore is the level of the highest high-angle longshore bar (here preserved as complex high-angle landward oriented cross-bedding). Such bars at the recent beach (site 1) may climb up to a level of −0.7 m (occasionally even up to +1.6 m above MSL during quiet weather). During a storm, however, they are wiped out in the intertidal part of the beach and give way to low-angle seaward dipping parallel swash lamination. There is therefore a better chance of preservation of longshore bar lamination in the subtidal parts of the sequence. Important also is the presence of cm-thick clay layers in the IJmuiden type sequence. Along the recent coast such layers are only found subtidally.

In the Starting type sequences cm-thick clay lay-

Table 1. Age and depth data for 19 localities with references. Depth data are in m in relation to Dutch Ordnance Level (NAP). ^{14}C ages have been converted into calibrated years BC or AD (Stuiver & Kra, 1986). The abbreviations S & P; P & S and P & al. refer to respectively Stuiver & Pearson; Pearson & Stuiver; and Pearson et al., all in Stuiver & Kra (1986).

Locality and reference	^{14}C age BP	Calibrated age and range (Stuiver,1986) cal BP=1950-cal AD cal BP=1949+cal BC 0 cal BP=AD 1950	Position ^{14}C sample	Deepest dry eolian sand	Highest marine burrow	Range low-angle bars	Range structureless sand (adhesion ripples; bubble sand)	Highest high-angle bar	Highest cm-clay or thicker	Highest ripples or micro-cross-bedding
1.Egmond Roep(1986);De Weerd (1983); Mier & De Ruig (1986)	30-36 yr past 1950	1980-1986		+1.60		+1.80 -0.90	+2.80 -1.10	(+1.60) and-0.70	(-8.25)	+1.80
2.Van Staalduinen(1979)		1242-1421 AD		+0.60						
3.Castricum Van Deelen & Schermer (1963);De Jong(1982)	2180±35 GrN-8661	340-200 cal BC (360-197 cal BC)	-1.55	0	-0.52					
4.IJmuiden Roep et al.(1975);Roep (1986);Ruegg(1975); & unpubl. data	2310±35 GrN-6445	395 cal BC (385-400 cal BC) S&P	+0.38 +0.35	+0.5		-0.35	+1.20 -1.10	-1.95	-2.76	+0.10
5.Bergen, Komlaan De Jong(1980; 1983); & unpubl. data	3340±70 GrN-10244	1635 cal BC (1738-1520 cal BC) P&S max.range	-1.01	-1.16			-0.66 ≥-1.47			-2.26
6.Velzen, PEN Jelgersma et al.(1972); & unpubl. correction	3400±55 GrN-4566	1735-1695 cal BC (1850-1650 cal BC) P&S	+0.57 to -0.18	-0.80						
7.Alkmaar,v.d.Veldelaan Roep et al.(1979); & unpubl. data	3560±40 GrN-6309	1910 cal BC (1830-2010 cal BC) P&S	-2.00		-2.10	-1.79 -3.40			(-4.93)	
8a.Alkmaar, Spoorwegtunnel, W randweg	3615±90 GrN-7281	2015-1975 cal BC P&S (2130-1880 cal BC)	-2.76	-1.25	-1.66	-1.66 -3.33	-1.20 -1.50	-3.33 to -4.00		
8b.idem Beets et al.(1981); Roep(1986)	3755±55 GrN-7282	2140-2190 cal BC (2280-2045 cal BC) P&S	-4.07							
9.Alkmaar, tunnel Zandersloot,Roep(1986); & unpubl. data	older than 8a younger than 10	interpolated age ca.2370-2176 cal BC P&S		-1.39	-2.15			-3.75 to (-5.10)	-5.10	
10.Heiloo HOS De Mulder & Bosch(1982)	3880±30 GrN-9042	2450-2370 cal BC P&S (2455-2335 cal BC)	-1.45 to -1.55							
11.Wassenaar Van de Plassche(1982)	4140±40 GrN-8411	2860-2670 cal BC P&al (2870-2620 cal BC)	-1.80	-1.20			-1.20 -1.50		(-2.43)	
12.Heiloo, Kooiburg Roep et al.(1979); De Jong(1987,pers.comm.)	4190±70 GrN-10170	2875-2710 cal BC P&al (2620-2900 cal BC)	-2.70 to -3.50		-2.41					
13.Heiloo, Nijenburger brug, De Jong(1987,pers. comm.); Meyboom(1985)	4300±40 GrN-10169	2910 cal BC (2900-3000 cal BC) P&al	-4.00		-2.02	-2.80 -3.50	-1.60 -3.10	3.75 to (≥-5.00)		
14.Den Haag, Bezuidenh. Weg, Roep et al.(1984)	4380±60 GrN-7721	3015-2915 cal BC P&al (3095-2905 cal BC)	-4.19 to -4.70	-2.17	-2.50				-4.95	-2.35
15.Starting Beets et al.(1981)	4420±70 GrN-10168	3070-3040 cal BC P&al (3300-2920 cal BC)	-2.60 to -2.80	-1.31	-2.20	-2.80 -4.47	-1.75 to -2.20	-4.47		(-1.60)
16.Den Haag, Schenkkade Roep et al.(1984)	4510±60 GrN-7720	3320-3140 cal BC P&al (3345-3045 cal BC)	-3.00 to -3.20		-3.00	-3.24 to -4.78	-3.28 to -5.05			
17.Den Haag, Westeinde Roep et al.(1984)	4560±60 GrN-7722	3320 cal BC P&al (3370-3110 cal BC)	-2.10	-2.05		-3.00 -3.78	-3.78		-5.27	
18.Rijswijk, Haagweg Roep et al.(1984); Jelgersma(1961; Zagwijn(1965)	older than peat 4670±65 GrN-2267 probably ±4870 to ±5000 BP (Ulmus pollen fall)	P&al 3690 cal BC 3880-3780 cal BC (range taken: 3690-3880 cal BC)		-1.25				-3.30	-4.50	
19.Rijswijk, Plaspoelpolder, 1.2 km SE of oldest beach barrier Van der Valk et al. (1985); De Jong(1985); unpubl.data	a)5350±80 GrN-12846 b)5610±70 GrN-128348 c)5390±80 GrN-13490	a)4230-4165 cal BC (4335-4040 cal BC) b)4460 cal BC (4515-4360 cal BC) c)4290-4240 cal BC (4340-4045 cal BC) inaccurate age conversion (De Jong & Mook, Fig.1, 1981)	-5.05 -5.45 -7.50	-4.10	-4.50	-5.20 -6.50	(-5.00 to -6.75)		-7.30	

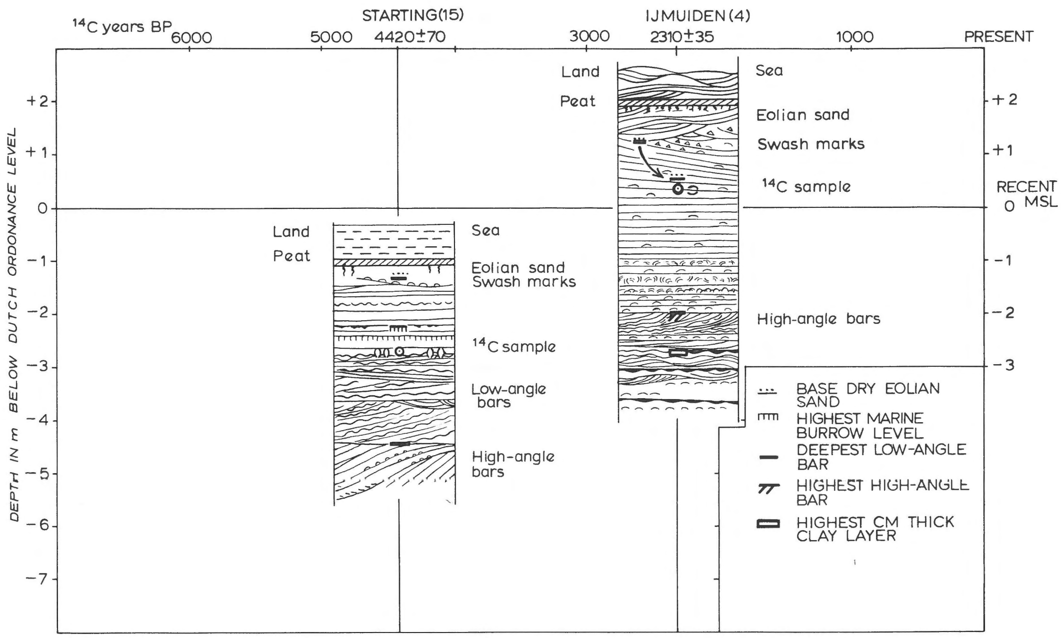

Fig. 2. Example of a time-depth diagram with two types of coastal sequences (sites 4 and 15) and the sedimentary structures, that are relevant for paleotide level reconstruction. Note that in the measured section of site 4 the deepest eolian scour (at +0.5 m) was observed elsewhere in the construction pit.

ers may occur also in the intertidal part. In these sequences the feature has not been plotted in Figs 3 and 4. In the Starting type sequences the most important parameter for paleo-tide reconstruction is the combination of the position of deepest eolian scour or dry eolian sand and highest level of marine burrows. MHW is between these and probably nearer the latter level, because similar marine burrows occur up to the high tide mark on the recent beach of the island of Texel (about 35 km N of the map area of Fig. 1). Typical for Starting sequences are low-angle longshore bars within the intertidal reach. The flattening upward trend of such bars (see Fig. 2, Starting sequence) has also been observed in the top part of recent beaches, where sometimes two berms developed. For a more complete description of these bars one is referred to Beets et al. (1981) and Roep (1986). Important for the intertidal character of the low-angle longshore bars in the close association with burrow levels, structureless sand and bubble sand. Bubble sand is produced by the escape of air from beach sand washed over by waves during rising tide. Structureless sand is not easily explained and is probably due to many causes. Structureless sand is found exclusively in the top part of both IJmuiden type and Starting type sequences, never in deeper parts. It is not produced by burrowing because on lacker peels often a sharp top and lower surface is seen that is intercalated in normal laminated layers. One may think of wet beach adhesion ripples, hail imprints etc. Structureless sand with a more blurred lower surface may be due to original snow-sand intercalations or may be found in combination with bubble sand. A more complete discussion of the use of sedimentary structure of beach sequences to ascertain SL-data is given by Roep (1986).

All the features that indicate tide-level (see example Fig. 2) are plotted on time-depth diagram Fig. 3, above or below the level of the corresponding ^{14}C samples. The lithologic symbols have been given the width of the standard deviation in years at each side of the ^{14}C age. Per site the symbols have been plotted vertically above each other. No correction has been made for the older age of lower parts of the sequence because of the incertitudes of

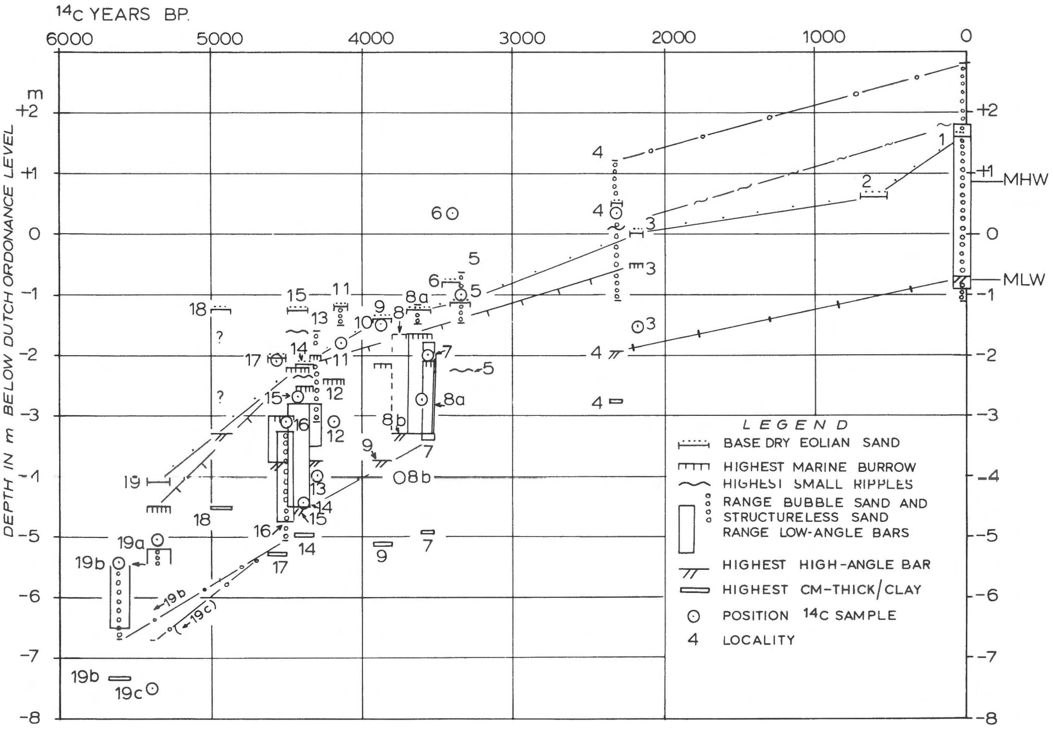

Fig. 3. ^{14}C-Time-depth diagram for all 19 sites.

gradient and speed of progradation of the ancient coasts. However, from an example given by Roep (1984) one metre of vertical section in the intertidal zone represents ca. 20 to 30 years (given a reasonable rate of progradation of 200 m/100 yr and using recent gradients of 1 : 44 to 1 : 64).

After plotting the lithologic symbols the deepest occurring eolian scours and highest burrow levels in the graph have been connected. It can be seen from the vertical separation of the mentioned lithologic trendlines that estimates of MHW have an error of a few decimetres at most. Most deviating is site 18 (see next section). In order to breach the data gap between 2300 BP (site 4) and the Present (site 1) we also connected the highest occurring levels with bubble sand or structureless sand and small scale aquatic ripples. This data gap is due to the retarded progradation or even to erosion in that period (Roep, 1984) and the absence of pits available for study in these most seaward parts of the barrier system.

Estimates of MLW have a much greater error than those of MHW. We connected the highest occurring high-angle longshore bars (loc. 4 and 1). This indicator is not very reliable as can be seen in older parts of the barrier (loc. 18, 17, 15, 13 and 9). The same holds true for the cm-thick clay layers in the IJmuiden type sequence (18, 17, 4). Better estimates for MLW (based on two intertidal features) are obtained with the deepest structure-less sand and low-angle bars in the Starting type sequences (loc. 19-16 and 16-7). The steepness of the curve connecting 19 and 16 depends on the choice between ages 19b or 19c. The curves have not been combined in order to show the effects of ^{14}C variations in this type of time-depth diagram.

A calibrated version of Fig. 3 is given in Fig. 4 by converting the ^{14}C-data into calibrated BC or AD years (Table 1). This conversion is necessary because of the increasing difference in years with age, between ^{14}C age and true age. This difference may become as large as 800 years (cf. Table 1). In Fig. 4 the width of each lithologic symbol corresponds to the maximum range of calibrated BC-AD ranges

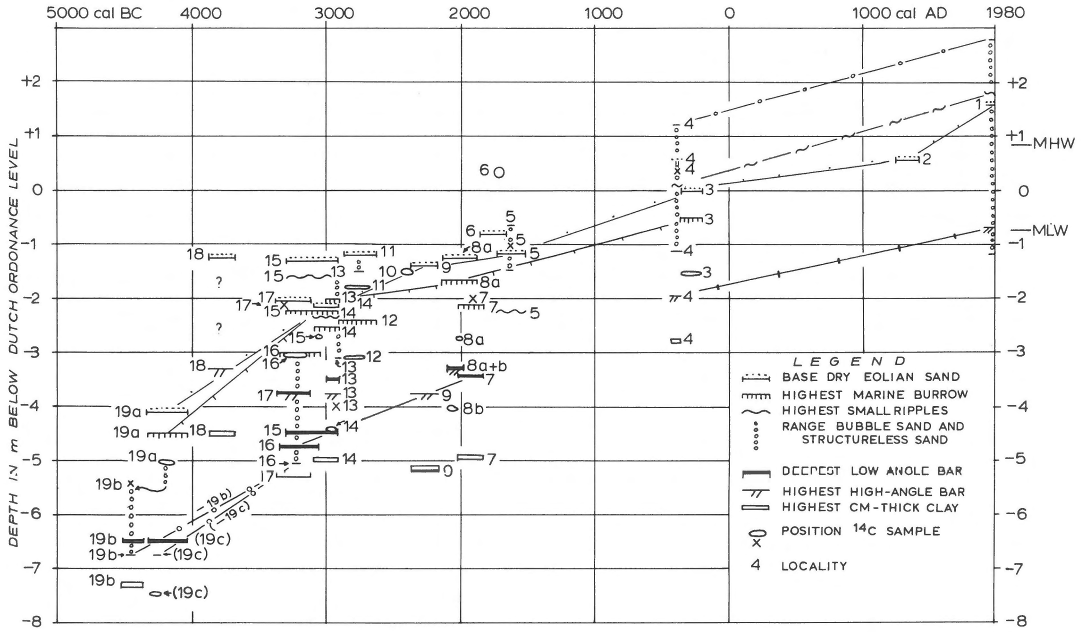

Fig. 4. Calibrated time-depth diagram for all 19 sites.

(without possibly occurring time gaps).

In Fig. 5 the inferred MHW and MLW curves have been plotted by combining different lithologic trendlines of Fig. 4. In drawing these MHW and MLW curves the data points of sites 19, 16, 15, 8a, 7 and 4 have been given somewhat more weight because of the quality of the exposures.

As to the MLW curve the trendlines of structureless sand (19-16) and low-angle bars (19-16-15-8a-7) have been combined and connected with the trendline of the high-angle bars (4-1) and present MLW. The problem of the dating of site 19 and its influence on the position of the trendlines has been discussed above.

As to the MHW curve, this curve is drawn nearer to the trendline of the highest marine burrow levels than that of deepest eolian excavation or dry eolian sand levels, as explained above. The data from sites 2 and 3 have been given less weight: those of site 2 because they were derived from a published cross-section and not from an outcrop and those of site 3 because the quality of the data from site 4 is better.

The MHW position indicated in site 4 is based on a more detailed comparison of this site and the recent coast, taking also other features into account, such as shell beds and swash marks with driftwood at the dunefoot (Roep, 1986). Inferred MHW of site 4 is connected with present MHW of site 1 by making use of the orientation of the trends of highest bubble sand, small-scale ripples and high-angle bars.

The MSL trend curve in Fig. 5 is drawn as half-tide level between the inferred MHW and MLW curves.

Discussion and conclusions

In conclusion three trendcurves have been constructed (MHW, MLW and MSL, see Fig. 5). Most accurate is the MHW trendcurve because it is based on two reliable SL-indicators (deepest eolian scour or dry eolian sand and highest marine burrows). This curve has an accuracy of a few decimetres. Less accurate is the MLW trendcurve. Apart from site 18 (see below) errors are possible in the order of 0.5 m. In combination with other sites of the graph the error is probably less. The MSL trend-

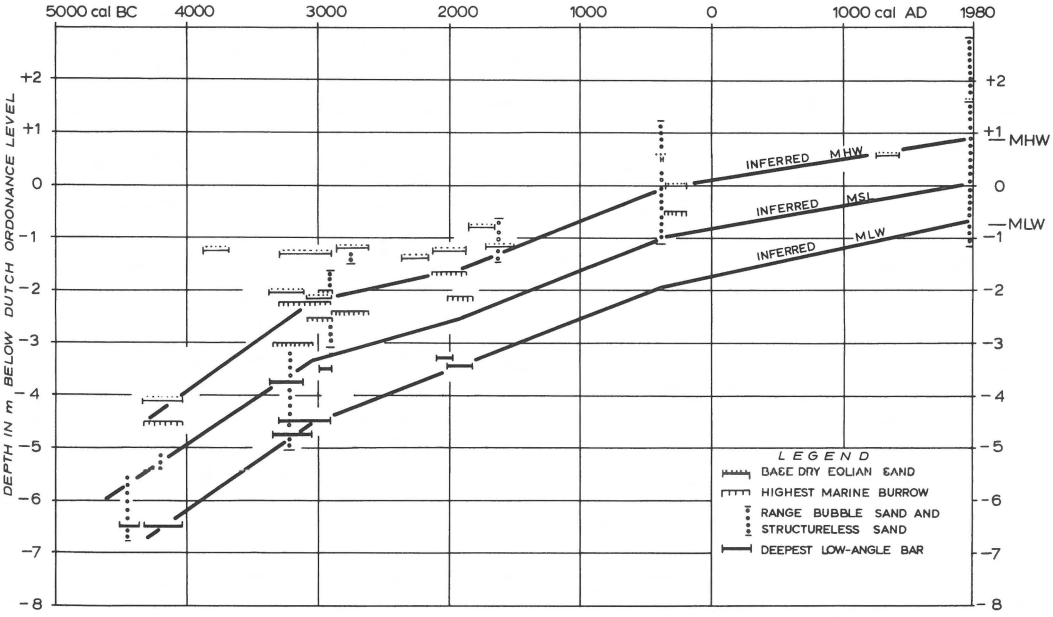

Fig. 5. Calibrated time-depth diagram for all 19 sites with trend curves of mean sea-level and paleotidal levels (slightly schematized version of Fig. 4).

curve (half-tide level) is thought to be accurate within a few decimetres.

An important question bears on the problem of SL-oscillations. Our data set (Fig. 4) is too small to detect these. The only exception to this statement are the data of site 18. Roep et al. (1984) discussed the information of this pit and the difficulties of interpretation. They concluded that there is a possible wiggle in the SL-curve. However, as this paper was written a pit quarried in the oldest barrier east of the town of Haarlem (Fig. 1) showed the MHW to be situated at a depth of about −3.50 m NAP. Although no ^{14}C dates are as yet available the sequence of this barrier is roughly of the same age as that of site 18. Therefore, the data of this latter site must be considered unreliable and have to be reevaluated.

In the time-depth graph deepest eolian scour always occurs above the highest marine burrow levels, with one exception, where eolian scour (site 14) occurs 0.15 m below the highest recorded burrows in site 13. This difference is too small to be explained by a temporary SL-drop and could be explained just as well by a slight variation in tidal amplitude. Only in one case (not represented in our graphs because of insufficient dating) a deep reaching eolian scour (down to −2.38 m NAP) was found between burrow levels at −1.73 and −2.23 m NAP in a 750 m long trench a few km's S of pits 8 and 9. Along the same trench an irregular variation was observed in the heights of burrow levels between −1.73 and −2.38 m NAP.

Pressing questions, brought forward by such observations are, what is the effect of a temporary SL-lowering, of tidal variation, of preservation differences of mean or extreme processes? For the time being such questions are difficult to answer. Our trendcurves, however, do not seem to be much affected by such problems.

Our data indicate a more rapid rise of MSL between 4500 and 3000 cal BC (of ca. 2 m in 1500 yr or ca. 1.3 m/1000 yr) and a slower rise since then (ca. 3.5 m in 5000 yr or ca. 0.7 m/1000 yr). Our data furthermore suggest a tidal amplitude of ca. 2 m between 4500 and 3000 cal BC and of 1.50 m during the last 2000 years. Recent tidal amplitude varies between 1.40 m and 1.70 m along the uninterrupted barrier coast of the W Netherlands. Between 3000 and 2000 cal BC a tidal reduction seems to have taken place in the order of half a metre.

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