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THE FORMATION OF THE YOUNGER DUNES ON THE WEST COAST OF THE NETHERLANDS (AD 1000-1600)[1]

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ABSTRACT

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The formation of the Younger Dunes on the west coast of The Netherlands is discussed in some detail. The onset of overblowing along the beach can be placed around AD 1000. Around AD 1600, the general outline of today's dune morphology was already present except in areas close to the coast. The behaviour of the water table and the sedimentary processes of the Younger Dune formation are dealt with.

INTRODUCTION

In the western part of The Netherlands two dune systems are known, the Older and the Younger Dunes. Older Dunes are found between The Hague and Schoorl and on the island of Schouwen (Fig. 1); the Younger Dunes along the entire coast. Both systems consist of calcareous sediments south of Bergen, but are lime-free to the north of it. The two systems differ in age, the Older Dunes are essentially pre-Roman although locally, and in particular in areas near the present shoreline, dune activity continued until the onset of Younger Dune formation. According to JELGERSMA ET AL. (1970), Younger Dune formation began in the twelfth century, but on historical grounds an earlier date was subsequently put forward by RENTENAAR (1977). KLIJN (1981) pointed out that since it must have taken at least several centuries for dune sand to migrate inland, the formation of Younger Dunes along the beach must have started earlier than the twelfth century.

As will be discussed below, overblowing by Younger Dunes did not happen synchronously along the entire coast. Hence, the dates mentioned are valid for certain areas only.

There is a striking difference in morphology between the two systems. The Older Dunes form low elongated ridges that are separated by peat-filled depressions, they lie subparallel to the coastline and reflect the pattern of older underlying beach-barriers. The Younger Dunes have a much greater height (20-50 m), show series of parabolic dunes with a SW-NE direction and, in many places, have a high ridge with a steep east-facing slope on their landward side. These ridges

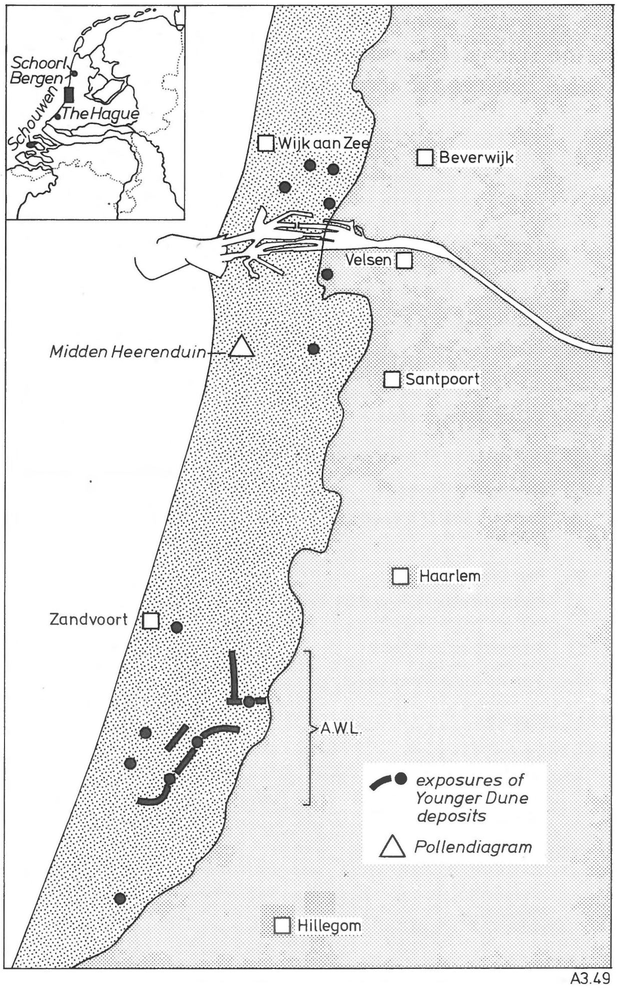

Fig. 1
Map showing sites investigated in the Zandvoort-Velsen area. Scale: 1 cm = 2 km.

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must be regarded as precipitation dunes, indicating that the Younger Dune system may have originally been a migrating barren dune system. As will be discussed below, this assumption has been confirmed by observations in exposures.

The sands that compose the Younger Dunes south of Bergen are remarkably rich in fine shell debris, a component that is lacking in the upper part of the Older Dunes. During the long process of soil formation between the two dune systems shell debris was partly leached from the Older Dunes. However, it must also be said that the upper Older Dune sands have never been rich in shell material, even during deposition.

These observations have led to the conclusion (VAN STRAATEN, 1965; ZAGWIJN, 1969; JELGERSMA ET AL., 1970; ROEP, 1984, this issue) that the material of the Younger Dunes came from the shore-face at a time when coastal erosion increased the depth of the sea, making large amounts of material with a high shell content available. The pattern of the Older Dunes indicates that the former coastline was less straight than it is now. Near the old estuaries of the Meuse and the Rhine and the tidal inlet near Bergen in particular, the coastline must have protruded several kilometres. It is interesting to note that the Younger Dunes are narrower in just these places than in areas between the former tidal inlets. The most obvious explanation is that the Younger Dunes are youngest in the areas where coastal erosion was strongest, their older parts having been swept away by the sea. In areas where coastal erosion was limited, the original width of the Younger Dune belt was preserved. The observations made in the area of The Hague (next paragraph) seem to confirm this view.

THE ONSET OF FORMATION OF THE YOUNGER DUNES

I. *Velsen-Zandvoort area*

One date is available which rather accurately determines the time when the westernmost part of the Older Dune landscape, at the site of Midden Heerenduinen, was overblown by Younger Dune sand, (Fig. 1; see also ZAGWIJN, 1984). The top of a peaty bed gave a conventional ^{14}C age of 970 ± 45 BP (GrN-6447), which is between about AD 1000 and 1150 in dendroyears (Fig. 4).

Further to the east, in both the dune area of Zandvoort-Amsterdamse Waterleiding (AWL) and the Velsen area, a few radiocarbon dates (JELGERSMA ET AL., 1970) indicate overblowing between AD 1150 and 1250 (in dendroyears; see Fig.

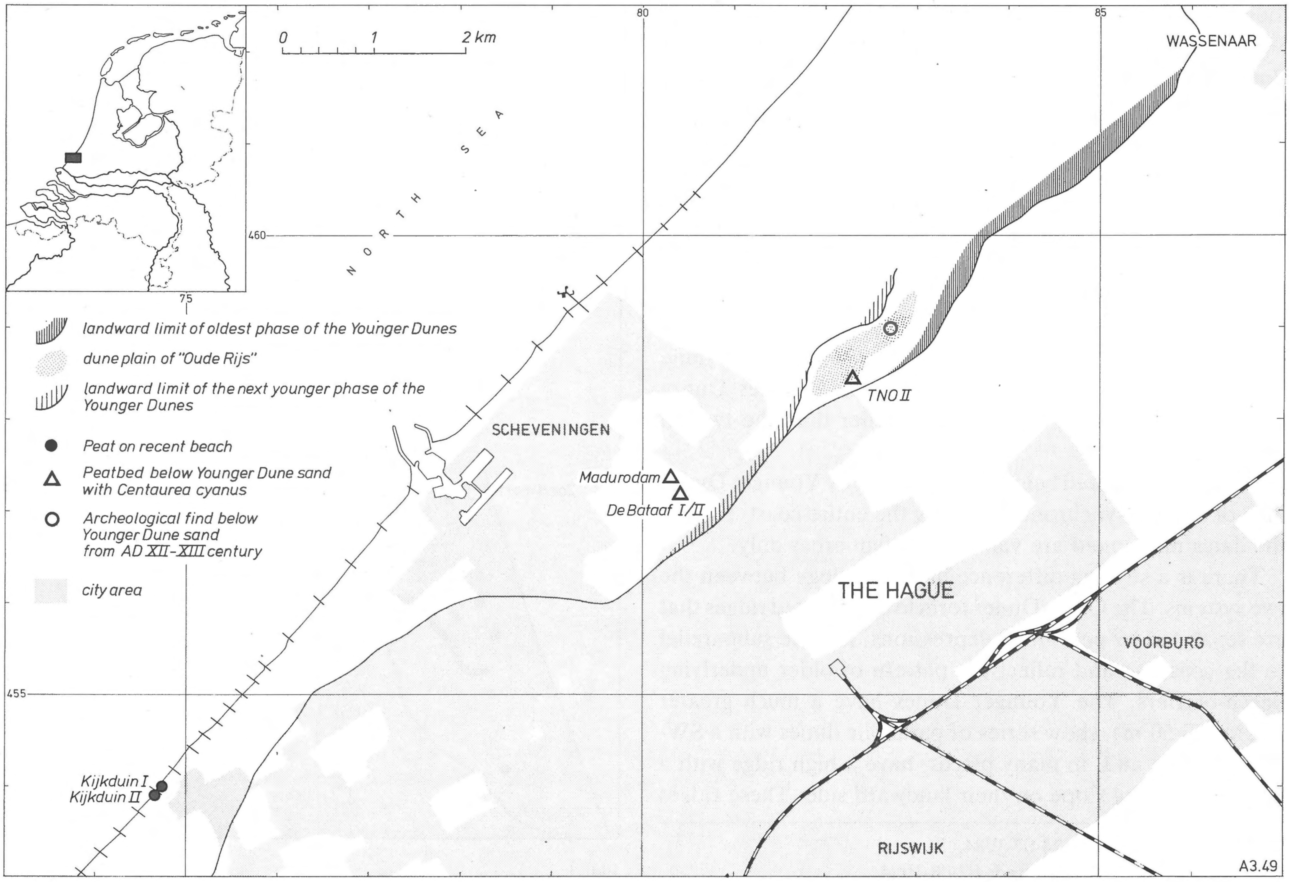

Fig. 2
Map showing sites investigated in the The Hague-Wassenaar area.

4). The most reliable of these radiocarbon datings are from the outer zone of the trunk of an oaktree found in the Zandvoort-AWL area (860 ± 40 BP, GrN-4642) and from moss found along the boundary between Older and Younger Dunes in the same area (880 ± 45 BP, GrN-12092, AWL XXIII). It should be mentioned that, according to radiocarbon datings, peat formation ended earlier, namely between AD 900 and 1000, which might reflect a temporary fall of the water-table.

Archaeological datings provided twelfth-century dates in both the Velsen and the Zandvoort areas (JELGERSMA ET AL., 1970).

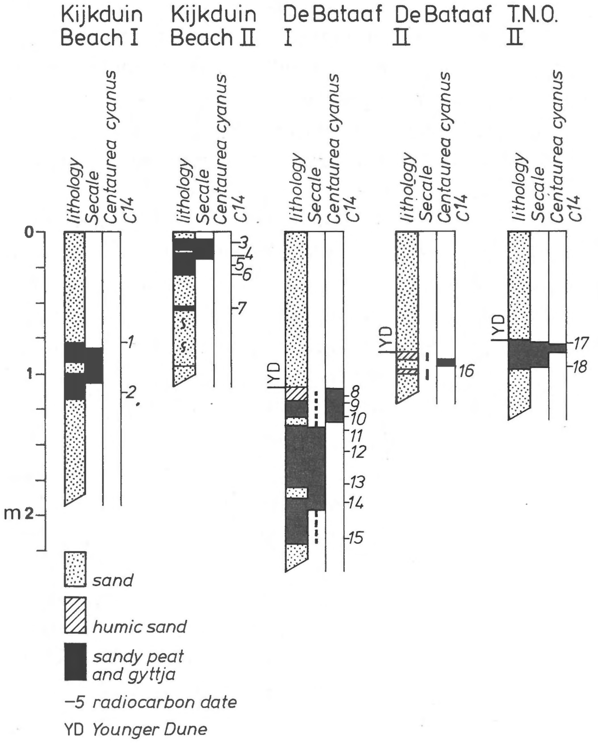

Fig. 3
Sections near The Hague (for location, see Fig. 2).
The radiocarbon dates (in ^{14}C years BP) read as follows:

1	1105 ± 35	GrN-12085
2	1460 ± 100	GrN- 631
3	1250 ± 30	GrN-12086
4	1385 ± 30	GrN-12102
5	1575 ± 30	GrN-12103
6	1605 ± 25	GrN-12104
7	1970 ± 30	GrN-12087
8	905 ± 30	GrN-12089
9	1035 ± 40	GrN-12106
10	1030 ± 35	GrN-10947
11	850 ± 20	GrN-10948
12	1020 ± 30	GrN-12107
13	1135 ± 25	GrN-10949
14	1455 ± 30	GrN-10950
15	1905 ± 30	GrN-10951
16	1125 ± 30	GrN-10952
17	1090 ± 45	GrN-12088
18	1130 ± 35	GrN-12105

II. *The Hague-Wassenaar area*

For this area, there are a few data concerning the onset of the formation of the Younger Dunes. Unfortunately, the exposures have not yet revealed details that could serve as a basis for a stratigraphic subdivision of the Younger Dune sand, as was the case in the Velsen-Zandvoort area.

At Kijkduin (Figs. 2 and 3) a peat bed is exposed at the beach, two sections of which have been investigated by pollen analysis and sampled for radiocarbon dating. The upper parts date from medieval times, as indicated by the relatively high percentages of *Secale* (rye). *Centaurea cyanus* (cornflower) is absent, indicating an age before AD 1300. This is corroborated by the radiocarbon dates, of which the youngest one (1105 ± 35 BP, GrN-12085) puts the date in dendroyears between AD 900 and 1000 (see also time table in BERENDSEN & ZAGWIJN, 1984, this issue, p. 228). The peat bed lies in the Older Dune landscape in an elongated depression which is cut at an angle by the present coastline. This indicates that both coastal erosion and the onset of the Younger Dune formation must have occurred after about AD 1000.

The De Bataaf I and II sites (Figs 2 and 3) are in an excavation less than 500 m from the landward boundary of the Younger Dunes, which is here developed as a relatively high dune ridge. Medieval peat beds occurred at both sites, as indicated by the frequencies of *Secale* in the pollen diagrams. The regular occurrence of *Centaurea cyanus* in the upper part of the sections (Fig. 3) is striking, and corroborates an earlier find made at the Madurodam site, which is situated in the immediate vicinity (BOERBOOM & ZAGWIJN, 1966; DE JONG & ZAGWIJN, 1984). This indicates formation of the top part of the peaty beds around AD 1300 or later and therefore the same date applies to the time of overblowing of the Younger Dune sand. The radiocarbon dates are, however, at variance. Those of the uppermost peat bed in Bataaf I are older than that of the top of the peat bed below (dated at 850 ± 20 BP, GrN-10948). Presumably, the dates for the upper peaty bed are aberrant because older organic material was incorporated into it, perhaps as a result of human activity.

Another find of *Centaurea cyanus*, also indicating an age around AD 1300, was made in the top part of a thin peat bed exposed while digging an excavation for a building (TNO II) (Figs 2 and 3). This peat bed was cut by a sand-filled ditch related to a surface representing old arable land. The whole assemblage was overblown by Younger Dune sand. The radiocarbon date (1090 ± 45 BP, GrN-12088) does not agree with the pollen data, probably also due to human interference.

From these data it appears that in the area of The Hague overblowing by Younger Dune sand took place around AD 1300. This is definitely later than in the Zandvoort-Velsen area, where *Centaurea cyanus* was only found once and then only as a stray grain (pollen diagram for Midden Heerenduinen, in ZAGWIJN, 1984). It is also later than another archaeological date from the same area, i.e. in the northern part of the Oude Rijs dune plain, which indicates overblowing in the twelfth to thirteenth centuries (VAN DER ROEST & WAASDORP, 1983). To the northeast of this site, near Wassenaar, the landward limit of the Younger Dunes is developed as a ridge, which VAN HOUTEN recognized as a typical precipitation dune as early as 1939. As can be seen in Fig. 2, this ridge must be older than the ridge that borders the Younger dunes in The Hague. The precipitation dune at Wassenaar duplicates the situation in the area further north, near Zandvoort-AWL and Haarlem. It therefore seems likely that in the Wassenaar area overblowing took place in the twelfth century as well, and that only near The Hague the Younger Dunes were blown over at a later time. Additional relevant data for the Wassenaar area are required to test this assumption.

STRATIGRAPHY OF THE YOUNGER DUNE DEPOSITS IN THE ZANDVOORT-VELSEN AREA

The stratigraphy of the Younger Dunes was studied in the areas of Zandvoort and Velsen in numerous excavations during the Sixties (JELGERSMA ET AL., 1970) and later (ZAGWIJN, 1984; DE JONG & ZAGWIJN, unpublished data). Fig. 1 shows the investigated sites.

The stratigraphy can be summarized as follows (Fig. 5). The lowest unit (YD Ia) has been found in many places, although only in depressions of the Older Dune morphology. This unit is composed of dune sand with shell debris, showing mega cross-bedding (slip-face lamination), of which one set comprises the cross-section of the depression-fill. These deposits belong to a phase of barren dune migration under dry conditions. During this process the crests of the Older Dunes were blown off down to the water-table producing a large flat deflation plain at the end of YD Ia. This plain extended across the entire area under discussion and coincided with the water-table at that time. On the inland side, in the area west of Haarlem, the Younger Dunes are bordered by a high ridge with a steep landward slope at an angle of about 30°. This ridge must have originated as a precipitation dune (see also DOING, 1963) stacked by migrating dunes.

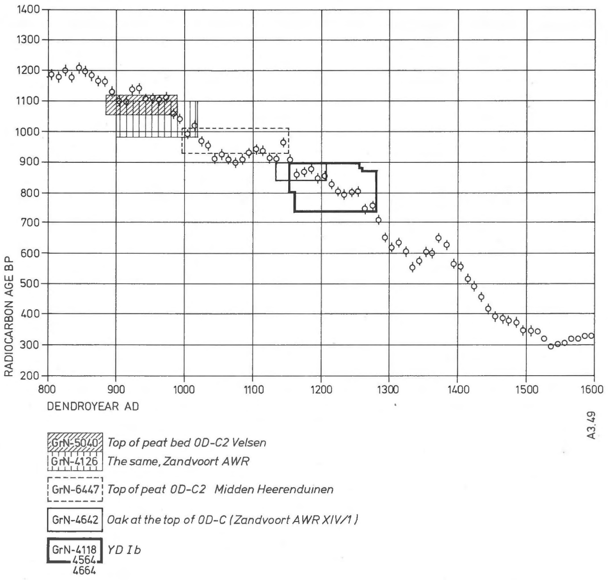

Fig. 4
Conversion of radiocarbon dates into dendrochronologically calibrated years for the period AD 800-1600 (from Stuiver 1982), including some dates with relevance for Younger Dune formation. For these dates the conversion was based on one standard deviation. BP means before present (AD 1950).

The next wind-blown sand unit (YD Ib) is characterized by a remarkably horizontal bedding with a rather uniform thickness of about 1.0 – 1.5 m. This unit occurs throughout the area. Adhesion ripple lamination is frequently found in this unit, which indicates overblowing of moist sand surfaces. Intercalated are three, in some places even more, peaty bands that are locally replaced by calcareous gyttja. According to palynological and malacological studies these peaty horizons originated in wet dune slacks. Generally, the peat bands are strikingly parallel over large distances, their height above sea level increasing very gradually toward the centre of the dune area, which means that these peat bands mark time horizons.

In one excavation in the Zandvoort-AWL area, that cuts the inner slope of the precipitation dune, these bands diverge to leeward of the ridge. This indicates that stacking of the ridge continued during the formation of unit YD Ib. In the sand-sheet area, sediments of this unit must have accumulated under wet conditions, which means that the groundwater table rose steadily. The alternating peaty bands represent even wetter stages during which sand transport and deposition diminished.

The next unit (YD II) consists of several series of parabolic dunes with mega-trough cross-bedding. These dunes form the recent topography of the greater part of the Younger Dune area under discussion (except for the precipitation dune along its landward boundary). This topography was fixed by vegetation and a thin soil was formed. Later, during another period of overblowing which only slightly changed the topography, unit YD III was formed; this sediment exhibits “flowing” low-angle lamination.

According to radiocarbon datings and archeological findings (JELGERSMA ET AL., 1970), the age of unit YD Ib is roughly 700 BP. More precisely, three reliable radiocarbon dates from peaty bands intercalated in unit YD Ib fall within the range of dendroyears 1150 to 1280 AD (Fig. 4).

In view of the dates obtained for the end of the Older Dune formation, unit YD Ia must have been deposited very fast. This question is discussed in more detail in the last section of this paper.

Because the general topography of the parabolic dunes of unit YD II can be seen on 17th century topographic maps (and in some cases on somewhat earlier documents), formation of this unit must have come to an end around 1600 AD at the latest. An archeologic find has corroborated this assump-

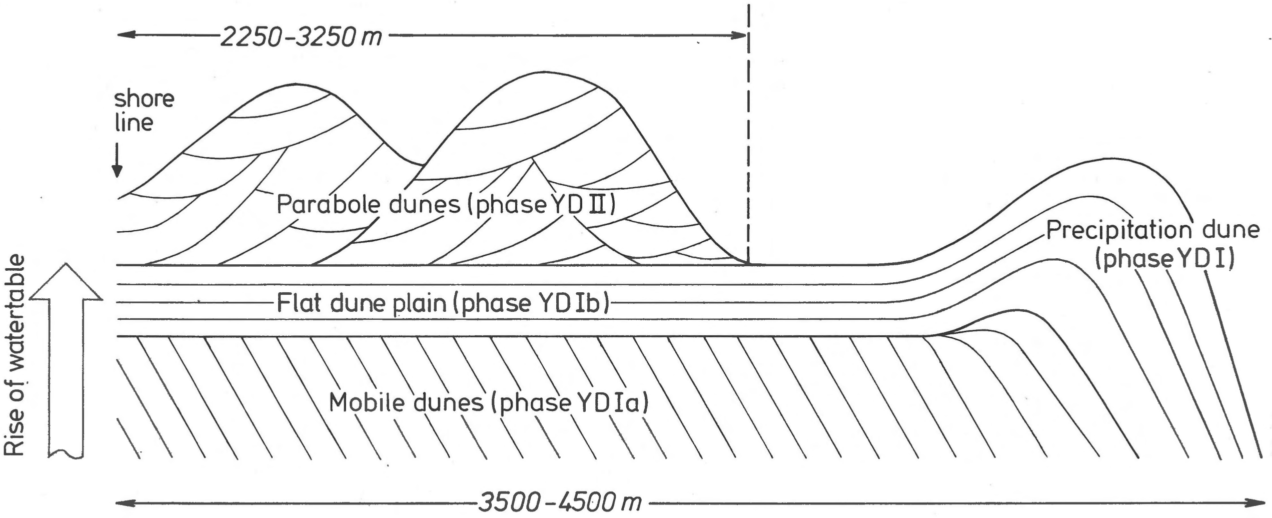

Fig. 5
Summary of the lithostratigraphy of the Younger Dunes in the Zandvoort-Velsen area.

tion (JELGERSMA ET AL., 1970, p. 146). Unit YD III possibly dates from the first half of the eighteenth century (JELGERSMA ET AL., 1970). Table I summarizes the conclusions drawn in this and preceding sections.

WATER-TABLE CHANGES IN THE ZANDVOORT-VELSEN AREA

Under the coastal dunes there is a freshwater lens which is in dynamic equilibrium with the surrounding salt and brackish groundwater. The hydrological properties of this body of fresh water can be described with the help of mathematical models originally developed by BADON-GHIJBEN (1889) and others. Recently, BAKKER (1981) published a detailed study on the geohydrology of the coastal dunes of The Netherlands which has provided many details on the behaviour of the water-table in the area. The following factors are mentioned as being of importance in the formation of a freshwater lens under these dunes: precipitation surplus (P), the hydrogeological conditions of the subsoil, and the width of the

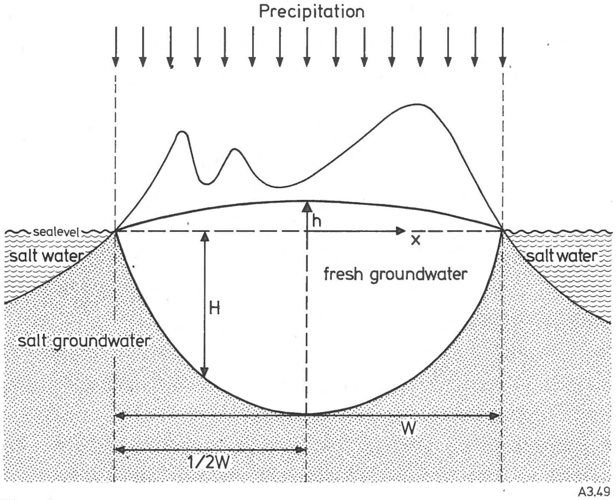

Fig. 6
Scheme for a mathematical model describing hydrological behaviour of fresh water lens under coastal dunes. (adapted from Bakker, 1981).
H = depth of fresh water body, h = height of water-table above sea level, x = distance from centre of dune area, W = width of dune area.

Table I

	Beginning of overblowing by Younger Dunes		Dating of units of Younger Dunes		
	West	East	YD Ia	YD Ib	YD II
Velsen-Zandvoort	AD 1000-1150	AD 1150-1250		AD 1150-1280	
		XIIA	XII	XII-XIII	XIV-XVI
The Hague	after AD 900-1000	after AD 1150-1250			
	AD 1300				
Wassenaar	XII-XIII				

Summary of datings of the Younger Dunes. Radiocarbon dates (in dendroyears AD) are in arabic numerals, archeological dates (in centuries) are in roman numerals, and palynological dates are in italics.

dune zone (W) (Fig. 6). For the discussion of past changes in the water-table, one factor must be added, namely sea level, because in the coordinate system used in the mathematical models this level is the horizontal axis.

Due to the formation of a freshwater lens (which is lighter than the surrounding salty groundwater) the water-table in a dune belt rises above the level of reference, which here is sea level. In a dune belt with a homogeneous subsoil the water-table will reach its maximum height in the centre and it will fall to its reference level towards the boundaries of the dune belt. In reality, the maximum height of the water-table is not always found in the centre of the dune area, because geological and topographical irregularities will tend to shift it.

The height of the water-table (h) depends on the three factors mentioned. In the case of a homogeneous sandy subsoil the following equations apply (BAKKER, 1981): $h = C_1 P^{1/2}$ (in which C_1 is a constant depending on the geohydrological conditions and the width of the dune belt) and $h_c = C_2 W$ (in which h_c is the height of the water-table in the centre of the dune belt and C_2 a constant depending on the hydrogeological conditions and the precipitation surplus). For places where the subsoil is not homogeneous the equations are slightly different, but discussion of this point would take us beyond the scope of the present paper.

Because sea level has been gradually rising during the last 5000 years, albeit not uninterruptedly (JELGERSMA, 1961; VAN DE PLASSCHE, 1982), a corresponding rise of the water-table in the dune area may be safely assumed. Other changes can be ascribed to changes in either the precipitation surplus or the width of the dune belt. With respect to the latter, reference is made to Fig. 7 (after BAKKER, 1981), which indicates that an increase in the width of a dune belt may lead to a considerable rise of the water-table and a horizontal shift of the position of its highest level. Changes in the precipitation surplus are related to changes in the amount of precipitation or the degree of evaporation (governed predominantly by changes in the vegetation) or a combination of these factors. Variations in evaporation affect the height of the water-table more than known variations in precipitation do.

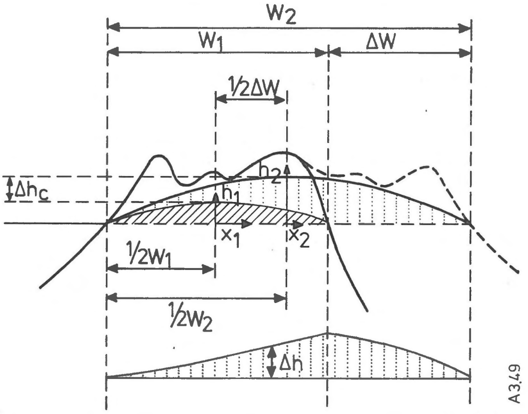

Fig. 7
Influence of the widening of a dune area on the height of the water-table above sea level (adapted from Bakker, 1981); h_c = height in the middle of the dune area.

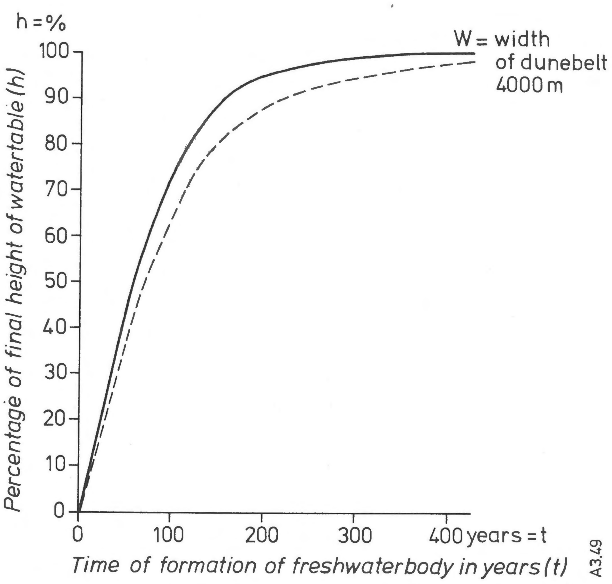

Fig. 8
Rate of the rise of the water-table as a result of the formation of a freshwater lens under a dune belt 4000 m wide (after data in Bakker, 1981; p. 11 and 12). The full line was drawn according to the method of Brakel (1968), the dashed line according to a numerical model discussed by Bakker (1981).

Finally, the time necessary for the formation of a freshwater lens under a dune area of a given width must be discussed. According to BAKKER (1981, pp. 9-12), this problem can be approached mathematically in two ways. For the geohydrological conditions that exist in the coastal areas of The Netherlands, the results of calculations by these two methods do not differ essentially, and are shown graphically in Fig. 8 for a dune area that is 4000 m wide. In such an area it will take several centuries to complete the formation of a freshwater lens, which means that the water-table will continue to rise for several centuries. However, by far the greatest rise (75% of the total) will take place within 106 to 128 years and half of the rise in no more than 60 to 70 years. As we shall see. this phenomenon is important for an understanding of the sedimentological conditions under which units YD Ia and YD Ib of the Younger Dunes came into being.

It proved possible to construct curves representing the changes in water-table during the last few thousand years for various places in the dune area between Zandvoort and Velsen. Two of these, for the Zandvoort-AWL region, are given as examples in Fig. 9, one of them (Droge Kom) showing a site near the inner limit of the dune belt, the other (AWL-section II) closer to the centre of the belt. The latter curve of course lies above the former (Fig. 9). The original data are taken from JELGERSMA ET AL., (1970). (It should be mentioned that the depths indicated in the pollen diagram for the Droge Kom in Fig. 25 of that paper are erroneous; those for the section in Fig. 18 are correct).

Both curves show a gradual increase between 2500 and 1000 BP, mainly reflecting the rise in sea level during that period. The more detailed curve shows some steep rises

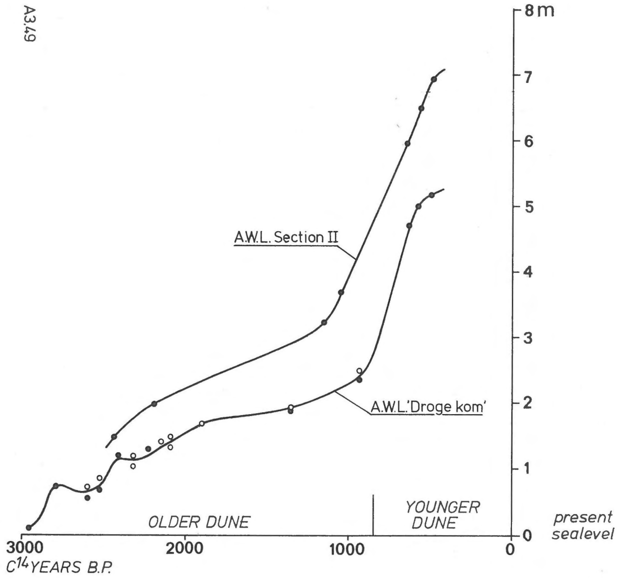

Fig. 9
Curves of the change in the water-table in the area of Zandvoort-Amsterdamse Waterleiding Duinen (AWL). Former heights of the water-table have been reconstructed from the measured heights of wedging out of dated wet soils in dune sand (solid circles) and from dated peat levels corrected for compaction (open circles). AWL-Section II is situated near the centre of this dune area, AWL Droge Kom closer to the eastern limit.

(around 2900 and around 2500 BP). These might be related to changes in the precipitation surplus as a result of changes in the vegetation. A closer inspection of the pollen diagram for this site (JELGERSMA ET AL., 1970; Fig. 25) shows that the changes in the vegetation at those times would instead have led to increased evaporation and therefore to a fall of the water-table. There is, however, a clear link with overblowing, since these two rises occurred shortly after the cessation of sand deposition during two active dune phases, i.e., OD IIa and OD IIb. It is therefore concluded that these accelerations in the rise of the water-table were probably caused by successive broadening of the dune belt.

The steep rise of the water-table at the onset of the Younger Dune formation is particularly prominent. This change cannot be fully accounted for by a change in precipitation surplus only. Even a change from a completely overgrown to a completely barren dune landschape would only account for about half the observed rise of the water-table. Moreover, subsequent restoration of the vegetation cover would have led to a lowering of the groundwater-table, which did not happen (see below). A more plausible explanation is that the observed rise of the water-table is at least partially due to a widening of the dune area by overblowing of the Younger Dune sand. This is the more likely because the dunes of the Older Dune landscape formed groups of low dune ridges with intervening lows that were arranged in a pattern that reflected the older beach barriers morphology. Each such group of the Older Dunes can be regarded as a dune area having its own width and its own water-table. The overblowing Younger Dune sands connected several of these Older Dune belts to form a single belt with a width of 4 to 5 km.

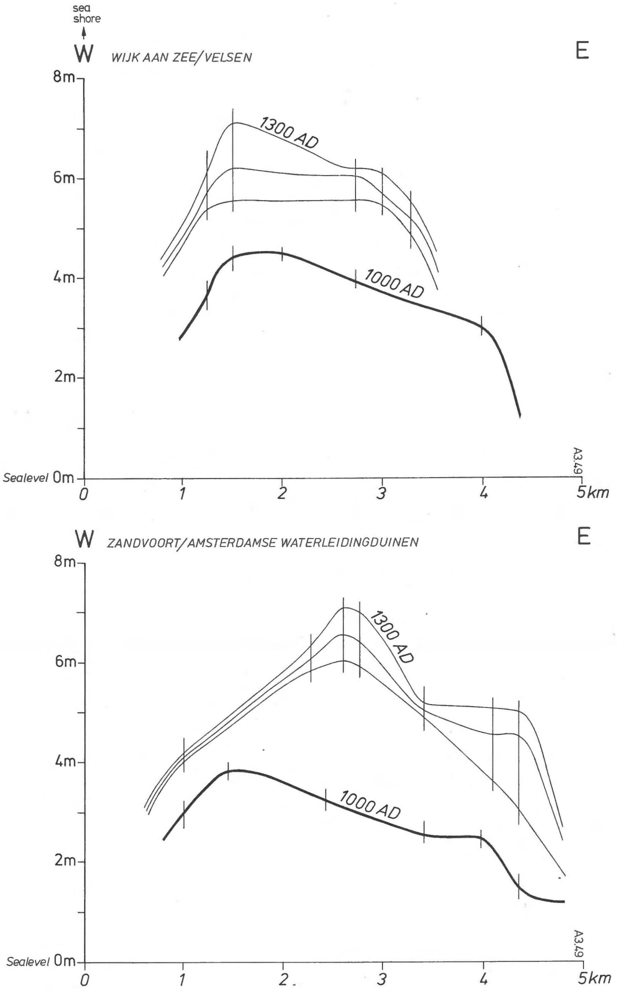

Fig. 10
Transects in the Velsen and Zandvoort areas (location: Fig. 1), that show the changes in the height of the water-table from the end of the Older Dune formation (about AD 1000) to the end of the formation of unit YD Ib of the Younger Dunes (about AD 1300).

Signs of the strong rise of the water-table at the onset of the formation of the Younger Dunes have been found in other places as well. Fig. 10 shows two transects, one in the Velsen area, the other in the Zandvoort-AWL region. In both transects the bulge in the palaeo-water-table across the dune area is very clear. These transects clearly reflect a strong rise of the water-table between about AD 1000 (end of Older Dune formation) and about AD 1300 (end of the formation of unit YD Ib). Moreover, it is evident that the position of the maximum height of the water-table shifted inland, which is consistent with a rise of the water-table, due to broadening of the dune area (compare Fig. 7).

No sign of a temporary drop of the level has been found, although this might have been expected as a result of coastal erosion at this time. Two phenomena could account for this,

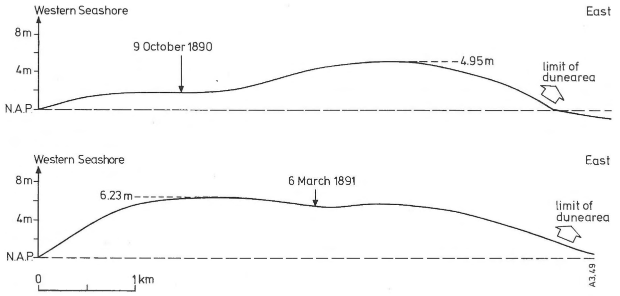

Fig. 11
Water-table in the dunes west of Haarlem at the end of the nineteenth century (from Bakker, 1981).

i.e., the coast did not recede far in this area (ZAGWIJN, 1984), and the effect of widening of the coastal dune area outweighed that of coastal erosion. The occurrence of three synchronous peaty levels in unit YD Ib, make it possible to draw lines that indicate the water-tables during the deposition of this unit. They show that after the first strong rise during phase YD Ia there was a further rise of the water-table during phase YD Ib.

Finally, the water-table reached roughly the level of the large flat depressions (interdune areas) that are found in both regions. These depressions are known to have been at approximately groundwater level before the construction of water-supply systems and the digging of the North Sea Canal in the second half of the last century which caused a drastic lowering of the watertable in the two areas under discussion.

In the intervening area, west of Haarlem, the water-table was measured at the end of the last century (Fig. 11). At that time, this area was still unaffected by water-extraction, but the water-table had probably already been lowered somewhat as a result of the removal of a larger part of the innermost dune ridge near Santpoort and the construction of the North Sea Canal.

These data also indicate that the water-table reached a height similar to that which prevailed at the end of Younger Dune phase YD Ib. This means that after the completion of YD Ib, in about AD 1300, there was no further substantial rise of the groundwater level. This cessation can be understood from the calculation results presented in Fig. 8. During the mobile dune phase YD Ia the dune area became wider and a rapid rise of the water-table took place. Since the water-table in the Older Dunes had already risen, it is evident that the further rise to about 75% of the final value must have taken place in no more than 40 to 50 years. The further rise to about 95% during phase YD Ib was, according to the model used, much slower and in the Zandvoort-AWL area may have lasted another 150 to 250 years. The same mechanism provides a satisfactory explanation for the remarkable subhorizontal bedding and the relatively constant thickness of unit YD Ib, as well as for its formation under moist conditions.

SEDIMENTARY PROCESSES IN THE YOUNGER DUNE FORMATION

The migration rate of moving dunes, such as existed during the formation of unit YD Ia, varies under the influence of wind force, precipitation, and the height of the individual dunes. In a desert region of California the average rate of migration of barchans in two periods. one of 15 and the other 7 years, was 24.6 m and 15 m, respectively. Barchans with a height of 3 m showed displacements amounting to as much as 39 m per year, and 6 m high barchans were displaced more than 24 m per year (LONG & SHARP, 1964). A similar average value, i.e., 27 m per year, has been reported from Peru (HASTENRATH, 1967; LETTAU & LETTAU, 1969). In The Netherlands a dune on the island of Terschelling is reported to have migrated at an average rate of 25 m per annum (VAN DIEREN, 1934).

Because in the Velsen-Zandvoort area unit YD Ia is found in depressions, only the lower parts of the mobile dunes have been preserved; these are up to 3 m thick. An original height of between 3 and 6 m does not seem improbable for these dunes. Therefore, a migration rate of 25 m per year was taken as the most acceptable value for dune migration during the formation of unit YD Ia.

As mentioned in the introduction, the sand of the Younger Dunes, came as fresh material from the shore-face and was subsequently blown inland. If we assume that in medieval times the shoreline in the Zandvoort-Velsen area was in the same position as the present one (in reality it lay slightly further west), the distance to be crossed was 3500 m in the Velsen area and 4500 m in the Zandvoort area, which means that in these places the formation of unit YD Ia took at least 140 years and 180 years, respectively. If we take AD 1000 as the earliest date for the beginning of overblowing of the Younger Dunes in the west, the end of phase YD Ia must have been around AD 1180. Toward the end of this dune phase, when the dune area was reaching its greatest width, the water-table rose swiftly within a period of a few decades. At the same time, a huge flat deflation plain developed.

Table II
Summary of datings of the Younger Dunes based on hydrological and sedimentary processes.

	Migrating dunes YD Ia	Flat dune plain YD Ib	Parabole dunes YD II
assumed migration rate	25 m/y		10 m/y
rise of water-table	quick, during 40-50 years	slow, during 150-200 years	little or none
duration (Zandvoort area)	180 (AD 1000-1180)	a minimum of 150 (AD 1180-1330)	(325) (AD 1330-1600)

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During deposition of unit YD Ib, sand was transported inland from the beach, without dune accumulation. This means that sand was rapidly blown inland over the huge sandy plain, which in many places was bordered by a precipitation dune. The absence of a dune ridge in the Velsen region, where the easternmost part of the Younger Dunes is flat, is almost certainly explained by the presence of an adjacent inland lake, the IJ, where wind-borne sand did have no chance to accumulate and pile up.

As discussed above, the formation of unit YD Ib most likely occurred at a time when the water-table was still rising, albeit progressively more slowly. The formation of unit YD Ib would have required at least 150 years, which puts the date of its formation between AD 1180 and at least 1330. This then leaves only 270 years for the completion of the parabolic dune phase YD II, of which the main pattern must have been completed around AD 1600. The distance from the eastern limit of this unit to the present coast is 2250 m in Velsen and 3200 m in the Zandvoort area. The migration rate of vegetation-covered parabolic dunes is 5 to 10 m per year (VAN DIEREN, 1934). If we take the highest rate, the calculated time available was adequate in the Velsen area but too short for the other region. Probably at the beginning of phase YD II, when vegetation cover was less dense or even absent, the migration rate of the dune ridges was higher and in fact they would have been mobile dunes. In any case, it is clear that the period during which the main part of the Younger Dunes must have been formed, was a short one, i.e., 600 years. One must accept therefore rather high, but certainly not impossible, sedimentation rates. The data in Table II summarize the foregoing discussion.

CONCLUSIONS

1 – Around AD 1000, large-scale dune formation began along the west coast of The Netherlands. The material for this new dune building phase came from the submarine part of the barrier, which must have been eroded continuously since that time.

2 – The new dune formation started in the Zandvoort-Velsen area – but probably elsewhere as well – with a mobile phase which lasted from about AD 1000 to 1180. At the end of this phase (YD Ia), after a quick rise of the water-table due to the substantial widening of the dune area, a flat deflation plain was formed.

3 – The sand-sheet stage lasted about 150 years. During this phase (YD Ib) a subhorizontally bedded unit 1-1.5 m thick with three subparallel humic horizons, was formed. During the formation of these peaty beds the environment was too wet to permit large-scale transport of sand across the plain. On the inland side of the Younger Dunes a precipitation dune was piled up in many places, reaching heights of 30 to 50 m. The flat-bedded unit YD Ib was formed between about AD 1180 to 1330, during a slow rise of the water-table, an after-effect of the widening of the dune belt.

4 – The sedimentary succession of large-scale cross-bedding followed by subhorizontal parallel bedding can be taken as a typical succession in a quickly widening mobile coastal dune belt.

5 – This succession was followed in turn by a parabolic dune phase, which began under a vegetation increasing in density and was essentially completed around AD 1600. After that, new dune-sand accumulations were formed only in a 1-1.5 km wide belt parallel to the shore and by deformation of existing dunes.

6 – The causes of the renewed dune building are complex. Since a supply of fresh material from the shore-face was essential, the main cause must have been the change in the coastal pattern, the origin of which is not yet well known. Climatic change seems to be just one possibility. Certainly the fact that man had deforestated the coastal hinterland promoted large-scale wind transport inland. This process may have led to a shortage of material on the beach and hence to further coastal erosion. Analysis of the palaeohydrological changes in the dune system does not support the assumption of a strong semi-permanent climatic change (less precipitation) as a cause of the onset of dune building. The changes in the water-table can be understood as an aftermath of the widening of the dune area.

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REFERENCES

Badon-Ghijben, W. & J. Drabbe 1889 Nota in verband met eene voorgenomen putboring nabij Amsterdam - Tijdschr. Kon. Inst. Ing., Verh. 1888-1889: 8-22

Bakker, T. W. M. 1981 Nederlandse Kustduinen; Geohydrologie - Thesis, Wageningen: 189 pp.

Berendsen, H. J. A. & W. H. Zagwijn 1984 Some conclusions reached at the symposium on geological changes in the western Netherlands during the period 1000-1300 AD. In: Berendsen, H. J. A. & W. H. Zagwijn (eds): Geological changes in the western Netherlands during the period 1000-1300 AD - Geol. Mijnbouw 63: 225-229.

Boerboom, J. H. A. & W. H. Zagwijn 1966 Pollen-analytical investigations in the coastal dune area near The Hague (The Netherlands) - Acta Botanica Neerl. 15: 376-388.

Brakel, J. 1968 De vorming van een zoetwaterlens in een duingebied ten gevolge van de nuttige neerslag als functie van de tijd - Doctoraal studie, T. H. Delft.

De Jong, J. & W. H. Zagwijn 1984. De vegetatiegeschiedenis van 's-Gravenhage en omgeving - in: De Bodem van 's-Gravenhage - Meded. Rijks. Geol. Dienst 37 (1): 44-62.

Doing, H. 1963 Eine Landschaftskartierung auf vegetationskundlicher Grundlage im Maszstab 1:25.000 in den Dünen bei Haarlem - Bericht Int. Symp. f. Veget. Kart. 23-26/3 1959, Stolzenau/Weser: 297-312.

Hastenrath, S. L. 1967 The Barchans of the Arequipa Region, Southern Peru - Geomorphol 11 (3): 300-331.

Jelgersma, S. 1961 Holocene Sea Level changes in The Netherlands - Meded. Geol. Stg. C-VI-7: 1-50.

Jelgersma, S., J. De Jong, W. H. Zagwijn & J. F. Van Regteren Altena 1970 The coastal dunes of the western Netherlands; geology, vegetational history and archeology - Meded. Rijks Geol. Dienst NS 21: 93-167.

Klijn, J. A. 1981 Nederlandse kustduinen; geomorfologie en bodems - Thesis, Wageningen: 188 pp.

Lettau, K. & H. Lettau 1969 Bulk transport of sand by the barchans of the Pampa de la Joya in Southern Peru - Geomorphol 13 (2): 182-195.

Long, J. T. & R. P. Sharp 1964 Barchan-dune movement in Imperial Valley, California - Geol. Soc. Am. Buil. 75 (2): 149-156.

Rentenaar, R. 1977 De Nederlandse duinen in de Middeleeuwse bronnen tot omstreeks 1300 - KNAG Geogr. Tijdschr. 11: 361-376.

Roep, Th. B. 1984 Progradation erosion and changing coastal gradient in the coastal barrier deposits of the western Netherlands. In: Berendsen, H. J. A. & W. H. Zagwijn (eds): Geological changes in the western Netherlands during the period 1000-1300 AD - Geol. Mijnbouw 63: 249-258.

Stuiver, M. 1982 A high-precision calibration of the AD radiocarbon time scale - Radiocarbon 24: 1-26.

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

Van Der Roest, J. & J. A. Waasdorp 1983 Proefopgravingen op de Waalsdorpervlakte - Report: 62 p.

Van Dieren, J. V. 1934 Organogene Dünenbildung - Thesis, Amsterdam: 304 p.

Van Houten, J. 1939 De oppervlaktevormen van het Haagsche duinlandschap - Tijdschr. Kon. Ned. Aardr. Gen. 51: 1-50.

Van Straaten, L. M. J. U. 1965 Coastal barrier deposits in South- and North-Holland, in particular in the areas around Scheveningen and IJmuiden - Meded. Geol. Stg. N.S. 17: 41-75.

Zagwijn, W. H. 1969 Geologie en vegetatiegeschiedenis van de Nederlandse Kustduinen - Jaarb. 1968/69 Kon. Maatsch. Natuurkunde "Diligentia": 167-176.

—— 1984 Pollenanalytische Untersuchung einer mittelalterlichen Ablagerung in den Küstendünen westlich von Haarlem, Niederlande - Diss. Bot. 72 (Festschrift Welten): 359-376.