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MOLLUSCAN SHELL DISTRIBUTION AND SEDIMENTS OF THE FOSSIL AND MODERN UPPER SHOREFACE OF THE COAST OF HOLLAND (HOLOCENE, W. NETHERLANDS)

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The lithology, sedimentary structures and (sub)fossil molluscan content of Subatlantic (Holocene) barrier deposits in the western Netherlands and the modern Dutch shoreface are compared. The taphonomy and depth distribution of common Recent North Sea fauna is shown to be distinctive in the interpretation of fossil sections. ^{14}C methodology is discussed in an appendix.

Key words — Coastal barrier, shoreface, molluscs, taphonomy, sedimentology, Holocene (Subatlantic), ^{14}C analysis, The Netherlands.

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Contents

Introduction

In comparison with data available on Recent benthic molluscs in the shallow North Sea (Eisma, 1966; de Bruyne, 1990), information on the distribution of (sub)fossil molluscs in this area is extremely scarce. (Sub)fossil molluscs are herein taken to be 10,000 years old or younger. In the coastal zone of The Netherlands, these molluscs can be distinguished easily from *e.g.* Eemian (the last Pleistocene interglacial stage) molluscs by their habit. Eemian molluscs are generally dull grey or white in colour and chemically leached, while Holocene molluscs generally have a much fresher appearance. Molluscs from a variety of environments that existed during the Holocene, are found in coastal deposits (van Straaten, 1965), on the bottom of the North Sea, or washed up on the beach (van Regteren Altena, 1937). Van Straaten (1957, 1965) used these remanié shells in an analysis of the geological history of the western Netherlands. Only few subsequent publications have been devoted to this subject (*e.g.* van Urk, 1970).

Recently, the subject of (living) molluscan assemblages in the coastal zone of the western Netherlands has received more attention, because of their importance in indicating environmental changes (van Ommering, 1988; Oosterbaan, 1988). The relationship between recent occurrences and (sub)fossil Holocene molluscs has lately been explored in a search for sand transport ways (van der Valk & de Bruyne, 1990).

The present-day Holland coast is characterised by a peculiar pattern of grain size and sedimentary facies distribution. Below -18 to -16 m (all depth figures in this paper being given in m with respect to the Normaal Amsterdams Peil [NAP], which is roughly equivalent to the Mean Sea Level [MSL]), a coarse-grained sand wave facies ('shore-connected ridges') predominates, the origin of which is still a matter of debate (Jelgersma, 1979). Between -18/-16 m and -7/-6 m a generally fine sandy flat surface is present, with extensive biological life. From -7/-6 m up to and including the berm on the intertidal beach a generally barred, medium- to coarse-grained sandy facies is present. An active zone usually consists of two to three subtidal bars and one intertidal longshore bar. Only few clay layers are found. Mean tidal amplitude on this coast is about 1.8 m in transition between a mesotidal and a microtidal type of coast (*sensu* Hayes, 1979).

It is the aim of this paper to indicate how an analysis of (sub)fossil molluscs may contribute to the interpretation of fossil coastal deposits and coastal environments. It is not in the usual 'biological' way that the presence or absence of molluscan species is used. Using (sub)fossil material as if it were modern and autochthonous would lead to erroneous conclusions. The interpretation presented in this paper is related to the depositional environment from which a given sample has been taken, and to energy conditions associated with this environment. This taphonomic approach has rarely been used in the study of modern subtidal deposits. In some publications, however, reference is made to this subject (Hertweck, 1971; Cadée, 1984; Frey & Dörjes, 1988). Frey & Dörjes (1988) are the only scientists to have investigated a data set which is in part comparable to the actualistic (molluscan) subject, the Egmond transect, dealt with in this paper.

For the intertidal and supratidal part of the Holland coast several attempts have been made to construct a range chart of sedimentological features, including the depth dependence of molluscs in general and of separate species in particular (van der Baan, 1978; Huyser, 1987; van Schoor, 1988). For the subtidal part of the Holland coast (between about *c.* -1 m NAP and the lower boundary of the shoreface at *c.* -18 m), no systematic attempt has been made so far to investigate the vertical distribution of sedimentary structures and/or other lithological features. Investigations are hampered by the high-energetic conditions of the wave-dominated Holland coast. Only in restricted periods of the year which cannot be predicted very well, can vessels operate in the shallow zone along the shore. This is especially so for the zone above -10 m NAP.

First, this paper fills in the data gap between the supra/intertidal North Sea beach and the lower shoreface and shallow North Sea shelf. The latter was discussed by Eisma (1966). Secondly, these data are compared with the youngest beach barrier data available for the western Netherlands. The recent depth distribution of sedimentary structures and shells (living, recent or subrecent) is used to interpret ancient parts of the coastal barrier in an approach similar to that of van Straaten (1965), but extended.

Methods

Information on sequences, structures and shell content was collected in various ways. First of all, a series of box cores was taken off the Egmond coast (Fig. 1) by means of a Reineck box corer. No other apparatus can be used in the shallow shoreface, because of practical limitations (Anonymous, 1983). The prime reason for selecting this transect was the fact that Roep (1984, 1986) had already done considerable work on the intertidal and supratidal part of the coastal profile. Of these box cores lacquer peels were made in order to study sedimentary structures. The remaining part of the box cores was used to analyse lithological and biological parameters *e.g.* grain size, live organisms and molluscan shell content.

These Egmond data were then compared with two fossil beach barrier sections, one of them, a cored borehole, situated to the south of Zandvoort (Rijks Strand Paal [RSP] 69) at the high-tide level of the beach, the other situated at IJmuiden-Haringhaven, a temporary excavation, supplemented by a bailer drilling (Fig. 1). These two sections are amongst the stratigraphically youngest that are available in the Holland beach barrier area (Roep, 1984, 1986; van der Valk, in prep.).

Generally, the hydrodynamic regime of the modern Dutch coast and the regime of the Subboreal and Subatlantic barrier coasts are referred to as being equal in character. These parts were mapped stratigraphically by the Geological Survey as (Holocene) Older Beach and Dune Sands of the Westland Formation (Zagwijn & van Staalduinen, 1975). The youngest of these barrier sands would correspond most closely to the recent coast.

In view of the way molluscan shells are treated in this paper, it was not necessary to identify all to the species level. Bivalve taxonomy follows Tebble (1976), while gastropod names are those listed by Janssen (1975). First, the fossil sections are given and secondly the recent survey will be reported upon. Finally, the results will be compared and the

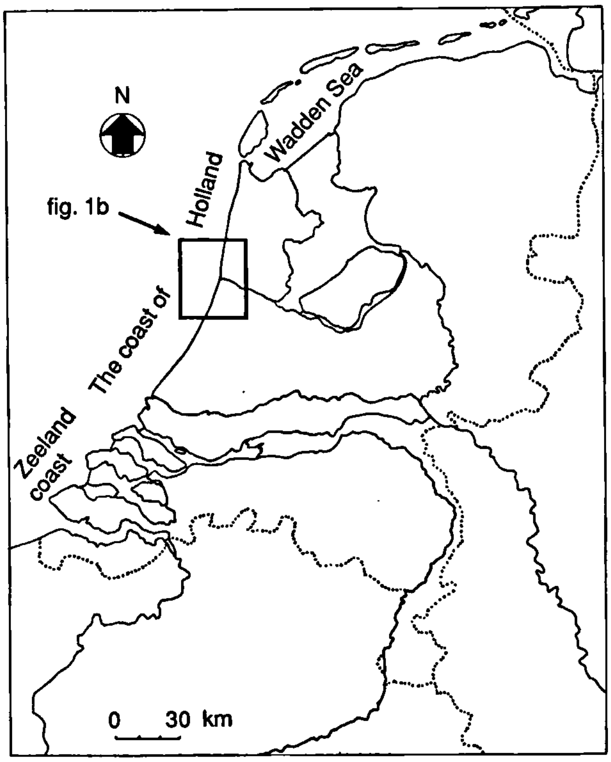

Fig. 1a. The Netherlands with the location of the study area: the middle part of the coast of Holland.

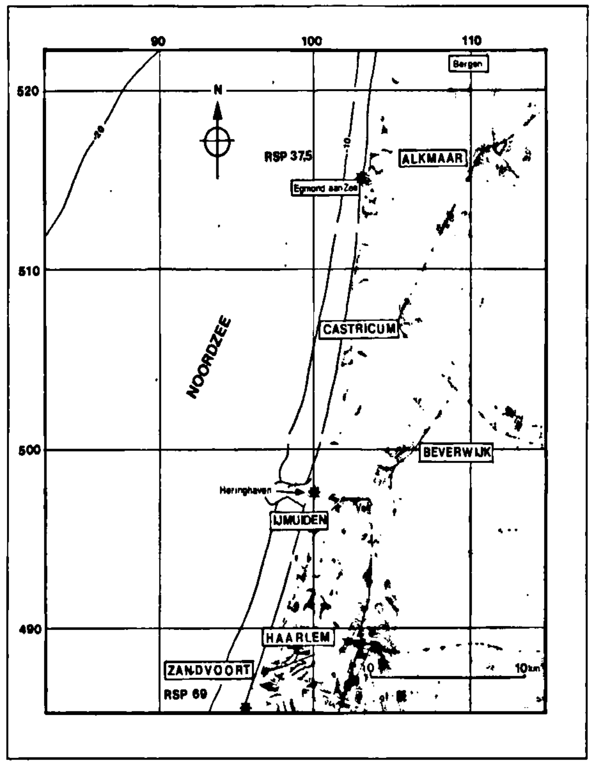

Fig. 1b. The situation of the locations in the study area, Egmond Rijks Strand Paal (RSP) 37.5, IJmuiden Haringhaven and Zandvoort RSP 69.

importance of the recent survey for the interpretation of fossil sections discussed.

Section IJmuiden-Haringhaven

General — In the autumn of 1989 an excavation at IJmuiden-Haringhaven was accessible for study (Fig. 1). Dunes covering the area had been excavated down to +3.5 m NAP during harbour construction at the start of this century. Because of its proximity to the recent coastline (500 m) and because of the geological work that had been done 1.5 km to the east of the present locality (see *e.g.* Roep, 1986), the excavation was surveyed. The information gathered from a construction pit at IJmuiden-Haringhaven was supplemented by data from a bailer drilling (by hand) down to -6.5 m NAP. In this way the separate data sets could be combined so as to form a single consistent data set covering both exposure and borehole. Figure 2 shows the section of the excavation at about right angles to the former (and also the present-day) coastline. In Fig. 3a a composite schematic section of exposure and borehole, and in Fig. 3b the results of an analysis of molluscan content are shown.

Results — In the uppermost metre of the excavation remnants of a dune soil occur at about +3 m (Fig. 2). The soil is weakly developed with shallow decalcification and some bleaching. On top of the soil a shallow lake must have been present, as indi-

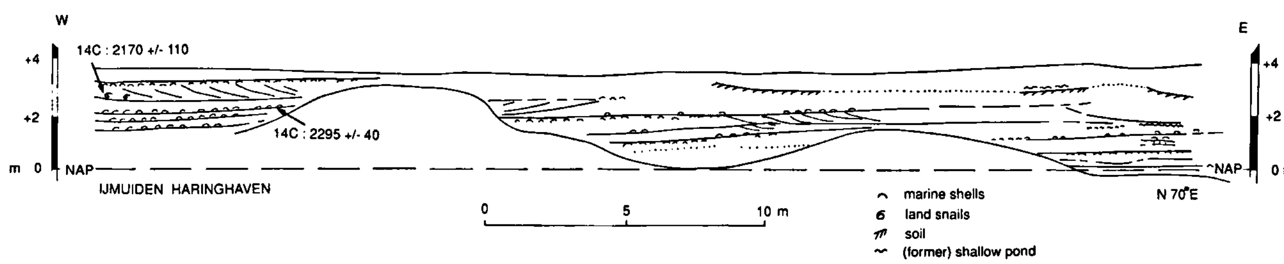

Fig. 2. The section at IJmuiden-Haringhaven. The (ancient) sea is to the left. Nearly all deposits are supratidal, intertonguing of storm planated beach and dune sands is most clearly seen in the west. For a discussion of ^{14}C data, see Appendix.

cated by the occurrence of freshwater gastropods [*Galba truncatula* (Müller, 1774)] and on top of this again some dune sand was found (unit 1). The soil partly covers a cross-bedded unit. This unit 2 consists of seaward dipping plane-bedded sets and landward directed scoop-shaped cross-bedded sets. The zone of interfingering of these two types of sets has a thickness of about 1.2 m. The seaward dipping beds contain shell material, the landward dipping beds do so only occasionally and when they do the shell material consists mostly of the terrestrial gastropod *Cepaea nemoralis* (Linné, 1758). In the seaward dipping beds shell material is marine. The landward tips of these beds curve gently upwards and carry isolated shells (mainly large specimens of several species and some isolated coarse gravel pebbles). The strata dip seawards at 1:17 to 1:40 (mean 1:27.6; n=6). Such gradients are not unusual on the modern beach (Roep, 1986). Unit 3 occurs below +1.8 m and consists of plane beds dipping seawards at very low angles and containing some shell material. The bedding in this unit is the result of swash and backwash of waves on the former North Sea beach. Some irregular bedding was observed, usually associated with bubble sand formation. Unfortunately, this unit was poorly exposed. It continued further down in the borehole. At -3 m highest cm clay flasers occur. This compares favourably with the sections described by van Straaten (1965) and by Roep (1986). The bailer drilling did obviously not yield any bedding information.

Down to -5.5 m the bivalve *Chamelea striatula* (da Costa, 1778) occurs (Fig. 3b). As in other beach barrier sections, the presence of this species indicates a relatively young age (van der Valk, in prep.), which is in accordance with the age determination discussed below (see Appendix).

Figure 3b gives the percentages of valves of a number of common molluscan species plotted against depth of excavation and borehole. Three zones are distinguished. Zone A is characterised by relatively few species and by high values for the bivalves *Cerastoderma* sp. and *Mactra corallina* (Linné, 1758) and low values for *Spisula* sp. Zone B is characterised by a large number of species, high values for *Spisula* sp., the gastropod *Euspira* sp. and the bivalve *Ensis* sp. and low values for *Cerastoderma* sp. and *Mactra corallina*. Zone C shows a decline of the number of species and of the curve of *Spisula* sp. A number of bivalve taxa show a curve rise: *Donax*, *Macoma*, *Tellina fabula* (Gmelin, 1791) and *T. tenuis* (da Costa, 1778). The boundary between zones A and B roughly coincides with the boundary between units 2 and 3 at +1 m NAP. The boundary between zones B and C is not clearly reflected in the units of Fig. 3a, but it could correspond to the median grain size minimum between -5.5 and -6 m.

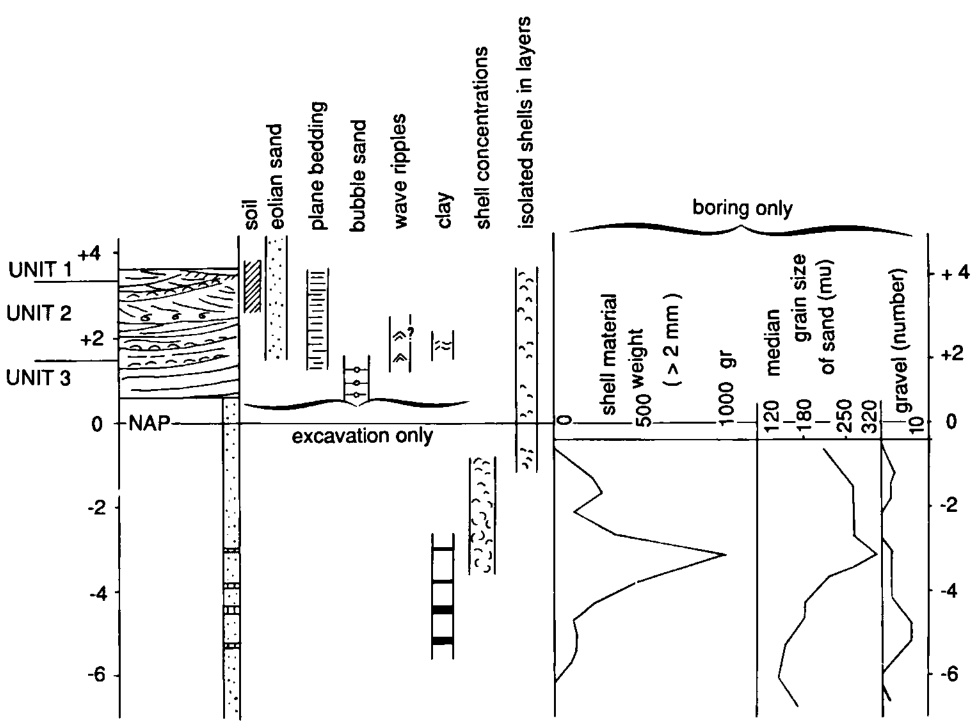

Fig. 3a. Composite schematic section in coastal barrier sands at IJmuiden-Haringhaven. Depth distribution of sedimentary features in the middle part. Inferred palaeo Mean Sea Level close to -0.5 m NAP.

Discussion — Unit 1 is purely aeolian with intermittent (wet) soil formation. Unit 2 and molluscan zone A are predominantly aeolian, but occasionally dunes must have been swept and eroded by storm waves at the high beach of the former coast. Nevertheless, the coastline is prograding. The largest break in the section occurs at +1.8 m where aeolian deflation stops. This level is not considered the deepest level of aeolian scour, however, because of the lack of good exposure. Unit 3 and molluscan zones B and C are marine intertidal for the upper part and marine subtidal for the lower part, probably lower than -2 m NAP: no reliable indication can be given for the depth of the lower-tide level. Taking the IJmuiden-Spuisluis section (Roep, 1986) into account, this boundary could be situated some 3 m lower than the highest shell material (here exceptionally high at +3.7 m) and well above the highest cm clay flaser. This leaves the lower-tide level to be situated at approximately -2 m NAP. The lower boundary of erosional activity by troughs belonging to the breaker-bar system that has supposedly been present and still is present along the Dutch barrier coast, could very well be indicated by the gravel maximum, the *Euspira* sp. and *Littorina* sp. (gastropod) maxima between -5 and -6 m. The largest amounts of bivalve shell material are also present in this zone, dominated by *Spisula* sp.

It is concluded that this section shows a well-defined distribution of molluscan species related to depth in the section. This distribution can be tied to the position on the coastal profile.

Cored borehole Zandvoort

General — As part of a coring programme in the beach barrier area, a borehole was drilled on the beach near RSP 69, 3 km south of Zandvoort (Fig. 1). A one-day operation allowed 11 m of cores with a diameter of 11 cm to be taken.

The beach characteristics on this part of the Dutch coast may be summarised as follows. Zandvoort beaches have already been surveyed several times (Doeglas, 1954; van den Berg, 1977), while Short (1990) gave an overview of Dutch beaches in general. The Zandvoort beaches are characterised by one or two intertidal ridges (bar 1 according to Short, 1990) and a backshore that is usually dry and generally subject to aeolian reworking. Only during exceptional storms and storm surges does the sea reach the dune foot at about +3 m NAP. Van den Berg (1977) reported on an eight year beach monitoring survey at RSP 70. During 71.2% of this period a one or two beach ridge profile was present, while post-storm flattened beach conditions occurred during 7.2% of the time. The remainder of 21.7% was occupied by a steep,

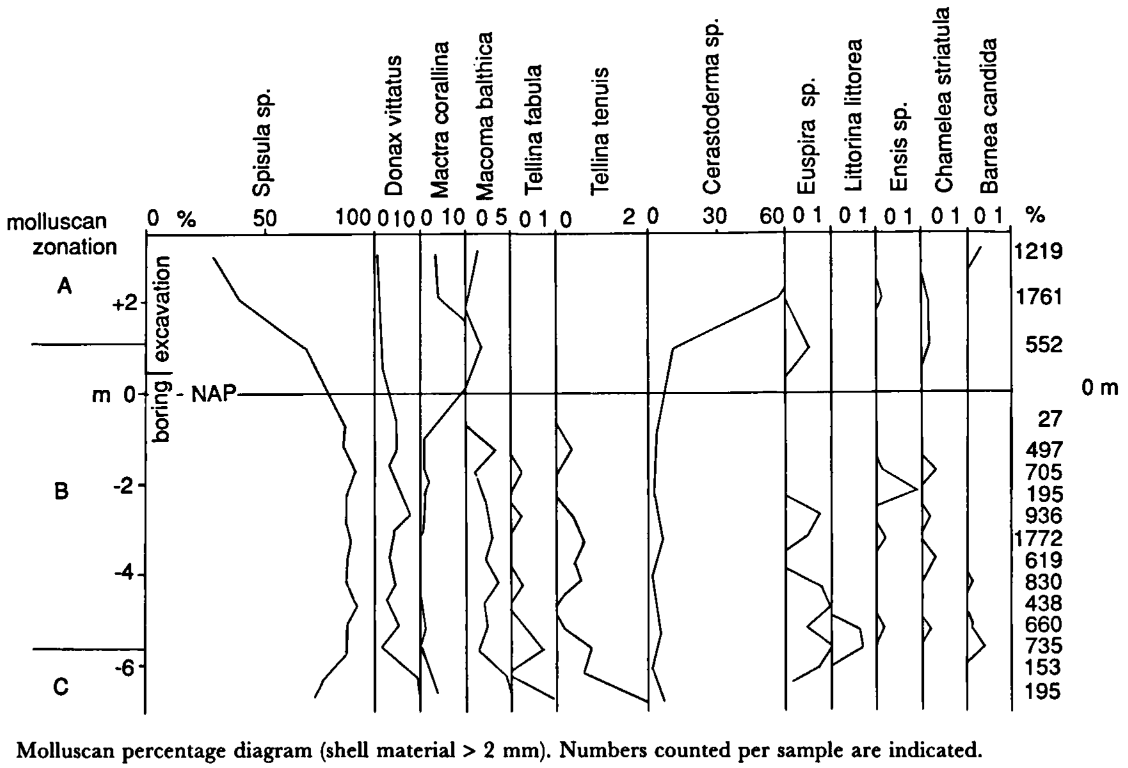

Fig. 3b. Molluscan percentage diagram (shell material > 2 mm). Numbers counted per sample are indicated.

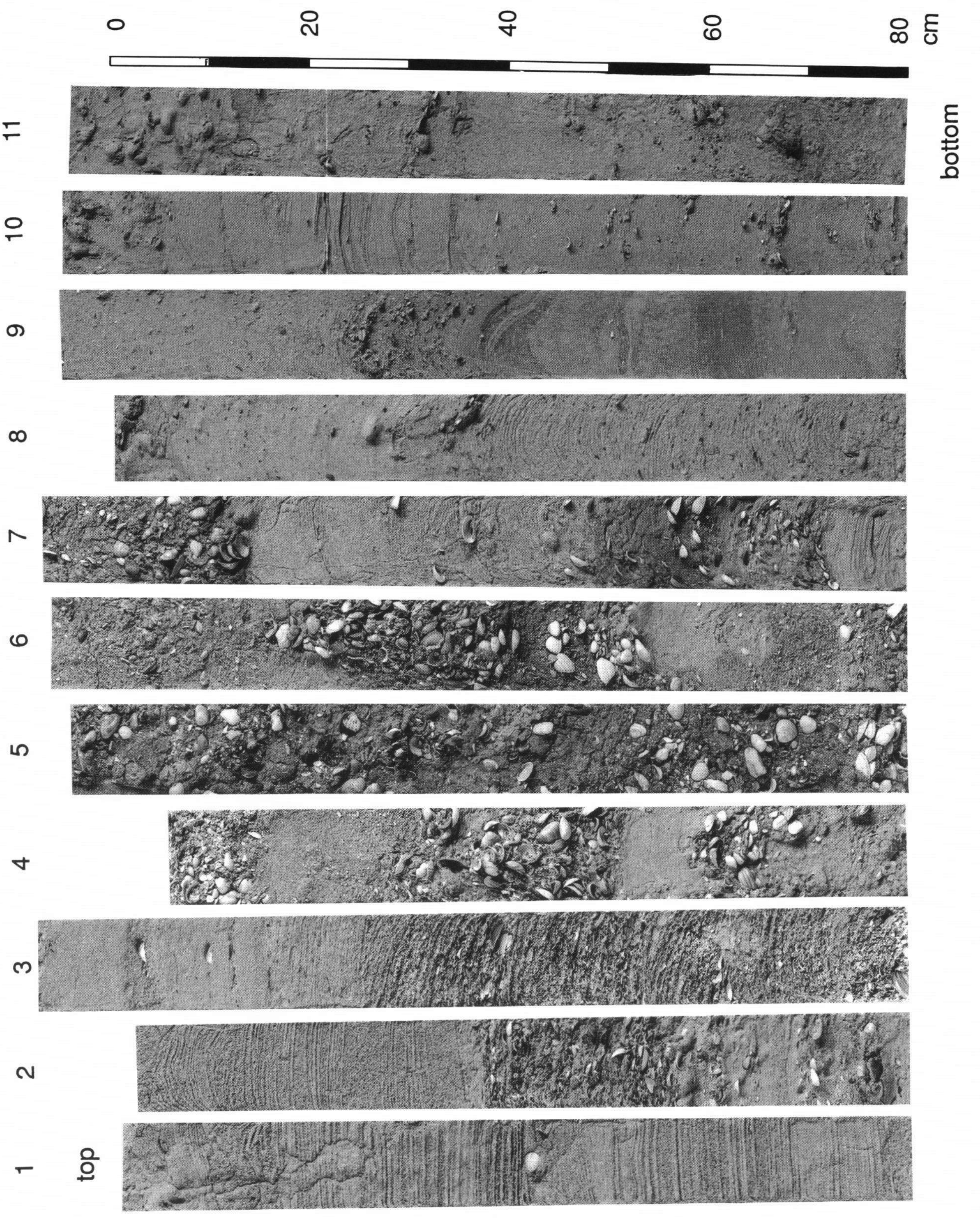

Fig. 4. Borehole Zandvoort-Rijks Strand Paal 69: lacquer peels of cores 1 to 11; one core per metre. The top of the individual cores was usually disturbed during coring. Note coarse fabric in cores 4 to 6 and thick clay layers in the lower half of core 9. Surface is at +2 m NAP. Photograph Rijks Geologische Dienst.

reflective profile. Short (1990) pointed out that two processes could account for this mobility pattern. First, beach erosion during severe storms and rapid recovery (Doeglas, 1954) and, secondly, longshore (northward) migration of points of bar attachment.

Bar 2, the first subtidal bar, is always present. According to de Vroeg (1987), this bar is usually shore attached in the area where it shows up first on the sounding profiles and is situated gradually lower seawards. When following the same morphological feature, it becomes bar 3 and finally disappears towards the offshore (Short, 1990). This is not necessarily the direction of net movement of the bars. A typical feature of this bar 2 zone is the occurrence of rip currents.

Short (1990) pointed out that due to a lack of data taken with sufficiently high frequency, no precise figures on bar migration could be given. It is clear from his data, however, that bar 2 migration is greatest in the mid-Dutch area of the coast. Bar 3 shows the highest mobility of all bars and, on the basis of available data, it proceeds predominantly offshore. According to Short (1990), an on-offshore movement accompanied by a net offshore movement contributes to bar crest mobility. Again, bar 3 migration appears greatest in the mid-Dutch coastal area.

Summarising, it can be stated that surf zone processes dominate sediment transport on the coastal profile down to bar 3 to a very large extent, showing increasing volume of sediment mobility towards the offshore (Short, 1990). This implies that sediment reworking will be largest in the zone of the breaker bars and that repeatedly all sediment particles including the shell material will change position until a high degree of stability is reached for every sediment particle, including the shells.

For a more long-term development (centuries) a very limited amount of data is available. A net progradation of 50 m for the dune foot has been reported for the period 1860-1960 (Edelman, 1967). These data are not apparent in the 1600-1990 development which was recorded by Ligtendag (1990): *i.e.* a coastal recession of some 120 m. It may be concluded that the resolution of the data for a longer period of several centuries is not very extensive and that (periodic ?) oscillations of the High Water (HW) line have a magnitude of 50 to 120 m, which can be well within the resolving power of the historical map analysis carried out by Ligtendag (1990).

The cored boring — At +2 m, close to the HW mark, a cored borehole was drilled. The purpose of this borehole was to find out whether recent backshore deposits could be distinguished from (presumable) older beach barrier deposits, which can be expected underneath the recent beach. Furthermore, the westernmost of these coastal barrier sands was sampled in order to compare on grain size, sedimentary structures, shell habit etc. with older bar-

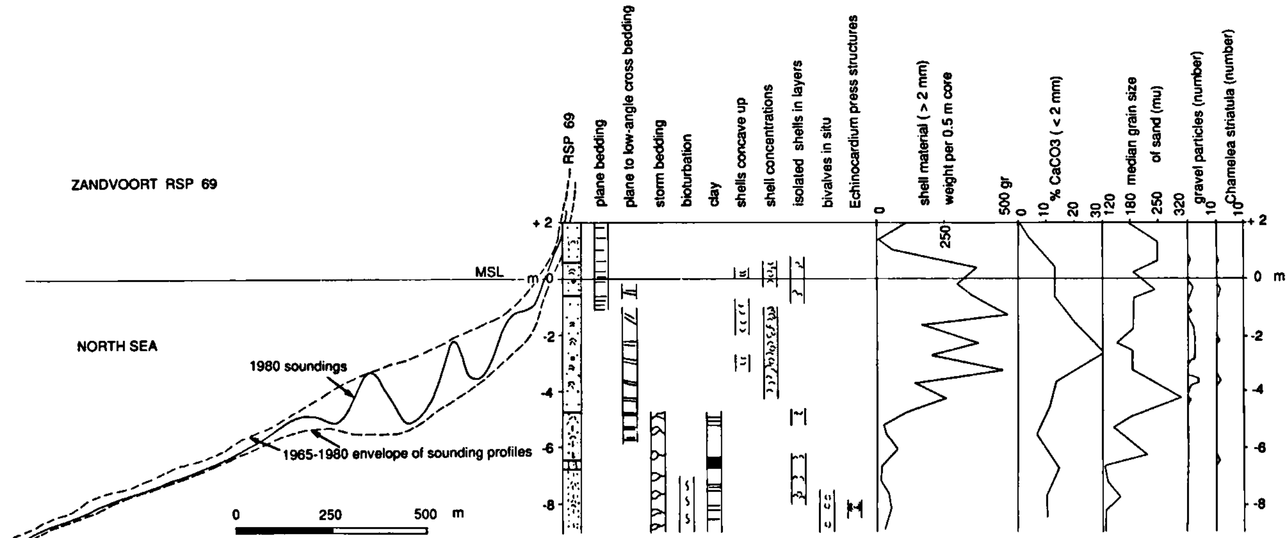

Fig. 5. Borehole Zandvoort-RSP 69, schematic section, 1965-1980 coastal longshore bar envelope and 1980 sounding profile.

rier deposits, located further to the east. Lacquer peels were made of the cores (Fig. 4); the schematised features are summarised in Fig. 5. In Fig. 5, a recent (1965-1980) envelope of coastal sounding profiles is added. The 1980 sounding profile is indicated with a solid line.

A boundary between the recent beach sands and older barrier sands was not visible in grain size trends or in sedimentary structures and could only be established on shell habit. A change of habit of the commonest bivalve shell [*Spisula subtruncata* (da Costa, 1778)] occurs at +0.2 m NAP. Freshest shell habit of *Spisula* disappears below this boundary. This depth accords rather well with the deepest scours documented in the sounding profiles of +0.5 m NAP at the location of this beach pole, which is also the location of the borehole (Fig. 5). The shell lag between +0.5 m and 0 m NAP in the borehole may very well be related to these deepest recent scours.

From the presence of bioturbation and bivalves *in situ*, together with the range of features related to sedimentary structures and the sediment itself, it is clear that a major change occurs in the depth range of -6.5 to -5 m (Fig. 5). From that zone upwards, median grain size as well as the weight of the 2 mm shell material increase. Thick clay layers occur at the boundary and bioturbation is present below -6.5 m only.

A major change in sedimentary facies, however, occurs at -6.5 m. Below this depth, (amalgamated) fining-up sequences occur, which sometimes show clay deposition at the top. These sediments are interpreted as deposits related to the wave activity associated with storms (cf. Aigner, 1985).

Bioturbation in the section is most important in the interpretation of the sedimentary sequence. Bioturbation is considered to take place below mean fair weather wave-base (see the Egmond section). From -6.5 m upwards, coarse plane-bedded and occasionally low-angle cross-bedding prevail with massive shell accumulations (Fig. 4). At a depth of -1 m these are gradually replaced by generally plane to very low-angle crossed strata. Shell concentrations disappear and median grain size is not at its maximum and subject to fluctuation.

Discussion — As is apparent from the sounding profiles, the -6.5 m depth of major change in the cored borehole is not coincident. If a similarity is accepted between the recent Dutch coastal mechanism and the 2000 BP coastal mechanism (which seems reasonable; see *e.g.* Roep, 1986), it may be assumed that the -6.5 m depth is the maximum reworking depth of the 2000 BP Dutch coastal bar profile.

No ^{14}C dates are available for this locality which means that a different method of dating of the deposits below the recent beach must be used. Immediately to the east (some 400 m and 900 m) ^{14}C dates are available (van der Valk, in press). On the basis of these ^{14}C dates and the combination of molluscan shell data of this slightly more easterly locality, it is concluded that around 2300 BP *Chame-*

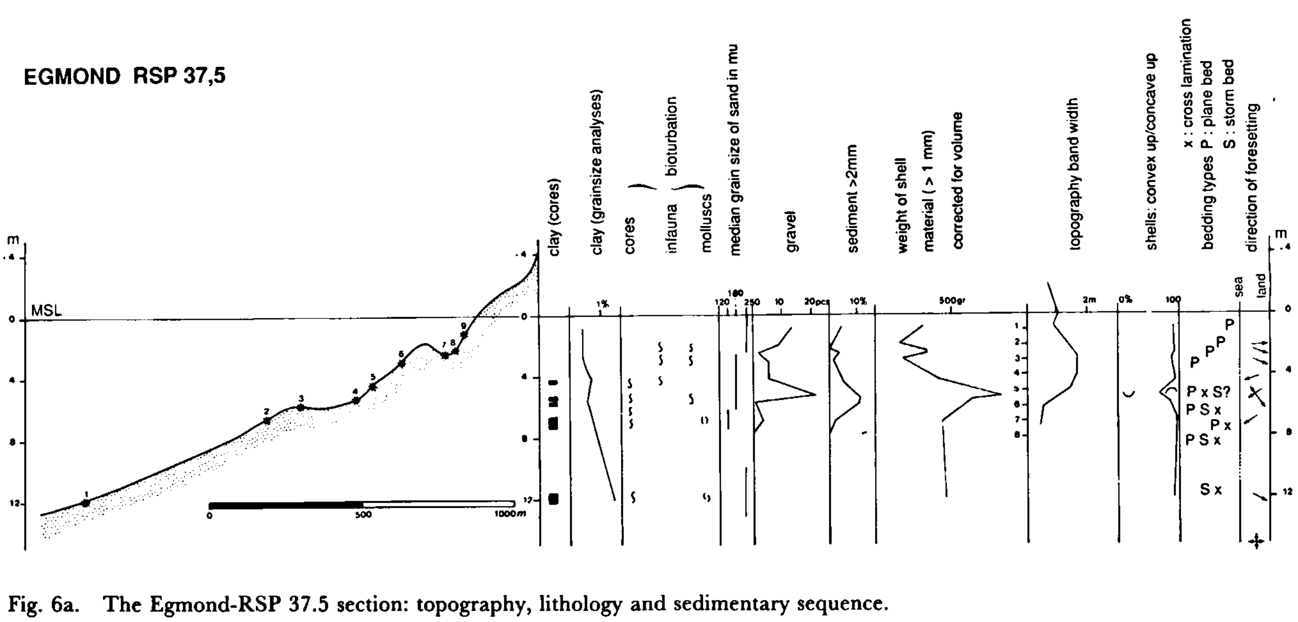

Fig. 6a. The Egmond-RSP 37.5 section: topography, lithology and sedimentary sequence.

lea striatula is present as remanié shells in the section and may be assumed to have been living on the shoreface during the Holocene for the first time. In the present borehole shells of this species were found to a depth of -6.5 m, indicating an age of 2300 BP or younger for the deposits above this level. Minimum age limits cannot be given, because no other molluscan species with later younger occurrences (*e.g. Mya arenaria* Linné, 1758 [16th century] or *Petricola pholadiformis* Lamarck, 1818 [1906]) were encountered in the samples from this borehole.

In conclusion, the Zandvoort RSP 69 core and faunal data and the implications of the recent morphodynamics lead to the following remarks which point in the same direction.

The upper 1.5 m of the borehole is seen as the active zone of the recent beach, while the deposits below 0.5 m NAP belong to the Older Beach and Dune Sands. The age difference between the recent beach deposits and underlying coastal barrier deposits is currently estimated to be some 2000 years. The bedding type of the upper part of the barrier sands is mainly plane bed. This indicates that under the coastal regime which was active during the deposition of this sequence, the preservation potential for cross-bedding was low, which bedding type is expected to fossilise according to older (Subboreal) barrier data (Beets *et al.*, 1981). This means that mainly the plane bed strata of breaking waves at the stoss sides of bars have been preserved. These strata should dip slightly seawards. The cores were not oriented, which means that further conclusions on this point are impossible.

The difference in preserved bedding type between older and younger coastal barrier sequences can be understood when the rate of coastal progradation (Roep, 1984) is considered. Fast progradation during early barrier formation implies high preservation potential for both types of bedding, cross and plane, while in the phase of low progradation rates frequent reworking in the upper shoreface allows only the plane-bed stoss sides of the longshore bars to be preserved.

The recent Egmond transect

General — The Egmond transect is situated before RSP 37.5; samples were taken between -12 m and -1 m. At the time of coring (June 1985) there had already been several days of fair weather, with mild to moderately strong easterly winds. Prior to boxcoring (by means of a Reineck box corer: Anonymous, 1983), the transect was surveyed by echosounder to determine core sites. Nine cores were recovered. From each core oriented lacquer peels were made, one parallel to the coast (N-S), the other at right angles (W-E). After removal of the peels, the rest of the cores were used for grain size analysis and collection of molluscan shells.

The shoreface at Egmond continues between -5 m and -16 m under a slope of 1:218. Below this depth, a gentler angle is present down to -20 m. At that depth, the actual North Sea bottom is reached

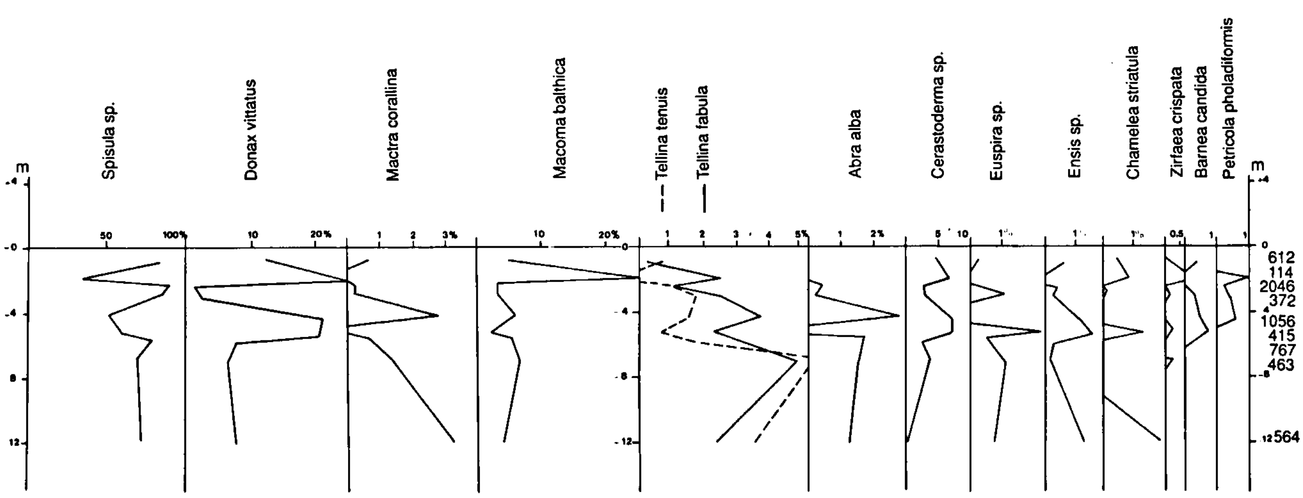

Fig. 6b. The Egmond-RSP 37.5 section: top layer molluscan relative diagram. Note horizontal scale differences between separate species. Numbers counted per sample are indicated.

(Niessen & Laban, 1987, encl. 2, section V-V'). The transect discussed here occupies the upper part of this section. The section's surface sediments are characterised by a slight variation in median grain sizes (180-260 µm) (Niessen & Laban, 1987). Long-term development of the coast at Egmond has been erosive, at least in historical time. Since 1664 the coastline has receded *c.* 250 m (Schoorl, 1968). This erosional tendency continues up to the present day: the beach has been raised artificially on several occasions. The negative coastal movement is generally correlated with the development of the Marsdiep channel, the main flood tidal channel of the western Wadden Sea. Since its beginning, tidal volumes (and currents) have steadily increased (Sha, 1990). The concomitant increase of sand transport capability and net inland transport towards the Wadden Sea has caused the coast south of the inlet to recede.

In Fig. 6 the box core information is summarised. Figure 6a shows lithological and structural features, while Fig. 6b provides some information on the relative abundance of 14 common North Sea molluscan species of the uppermost beds in box cores 1 to 9.

Lithology and structures — As may be seen from the columns in Fig. 6a, the lithological parameters change considerably between -5 and -6 m: sand median grain size, gravel and sediment coarser than 1 mm and 2 mm. Below this boundary curves are more regular. From this boundary upwards, many curves are highly irregular. This effect is even clearer when one looks at the presence of clay layers and the orientation of molluscan shells in the box core lacquer peels (Fig. 7). Again the strong -5 to -6 m change is conspicuous. This marked change has no connection with the season's mean fair weather wave base, but it is demonstrated below that the change occurs at the erosional base of the longshore bar system. It becomes clear from worm burrows that the fair weather wave base was situated very high (-3 m) in comparison with data supplied by Aigner & Reineck (1983). These authors described the shoreface of the Norderney Wadden island (Germany). They found daily wave base varying between -3 and -7 m on the basis of bioturbation, during an 18 month observation period. When one compares the molluscan and worm bioturbation at Egmond, it appears that the latter occurs higher up in the coastal profile than does the former. As the sea state of the period concerned was very quiet, the -3 m depth for the uppermost burrow is realistic. It may be concluded that the -3 to -7 m variation of fair weather wave base off the barrier island of Norderney is valid for the Dutch coastal area as well.

Clay is present below -5 m, mostly as isolated flasers. At -12 m, a thick clay layer occurs (Fig. 7). The truncation of this clay layer is very probably man-induced (fishing gear).

Some remarks as to the distribution of sedimentary structures may also be made, as far as this is possible on the basis of a sole section. All structures observed in the box cores have originated very recently. As shown from the changes in subtidal topography (Fig. 10; after JARKUS measurements, kindly supplied by Rijkswaterstaat), it is very likely that all sedimentary structures have originated in a period of years, but more probably of months.

In Fig. 7 the nine box cores are shown in two sections: one section normal to the shore and another section parallel to the shore. Smallest median grain size in this coastal section is found at -5.8 to -5.4 m (box cores 3 and 4).

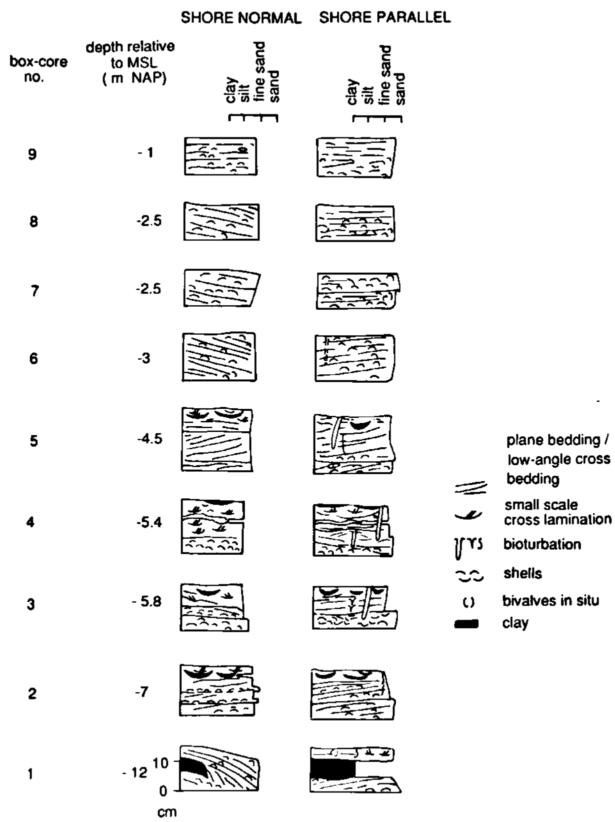

Fig. 7. The Egmond box cores, drawn from lacquer peels. The depths are indicated on the left-hand side. Peels on the left are oriented in a shore-normal direction; peels on the right in a shore-parallel direction, north being on the right-hand side.

The dominant structure is plane bed. Below -4 m, a variety of structures occurs *i.e.* low-angle cross-bedding, cross-lamination and just underneath of bar crests, beds very similar to the storm layers described by Aigner & Reineck (1983) occur (cores 2, 4 and 5). A storm layer consists of a fining-upward deposit of sand with many shells at the base with a generally fine-grained, usually bioturbated deposit at the top. As a whole, one layer is thought to be the result of waning wave conditions after a storm. For the North Sea environment the reader is referred to Aigner (1985). Cross-lamination is found only below -4.5 m.

The change of dominant bedform type at -4 m coincides with a change in sediment transport direction, as indicated by preserved sedimentary structures. As far as these observations allow generalisation, transport direction above -4 m is generally towards the beach, while below that depth direction is variable.

Molluscan shells — In Fig. 6b, molluscan shell percentages of 14 common North Sea species are presented. Of each box core every uppermost layer was analysed. The total sediment was passed through a sieve with a 1 mm mesh. Fragments were counted as far as they could be identified. Living molluscs were counted as a single specimen and incorporated into the total. As these were extremely rare, their influence on the sum total is negligible.

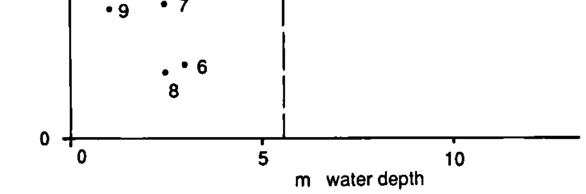

Fig. 8. Molluscan shell material weight per box core vs. water depth, corrected for volume.

Comparable to the grain size distribution indicated above, a marked change is present at -6 m. This change is reflected in various ways, not only in the species composition (see below), but also in the weight of the shell material present in the box cores. In Fig. 8 this weight per unit of core volume is plotted against depth of the cores. From core 3 upwards, a highly variable amount of shell material occurs, while cores 3 to 1 are characterised by less variable amounts (compare Fig. 6a).

The high amount of shell material present in core 4 is considered of prime importance. It is this core which is situated near the base of the zone in which longshore bars are continuously present on the Holland upper shoreface.

Shells of all species show highly variable scores (Fig. 6b), but below the -6 m boundary curves generally are less variable, at least for the commoner species. A very common species such as *Spisula* sp. equally shows strong fluctuations in its presence (above -6 m) as do less common species such as *Donax vittatus* (da Costa, 1778) and rare species such as *e.g. Abra alba* (Wood, 1802) and *Chamelea striatula.*

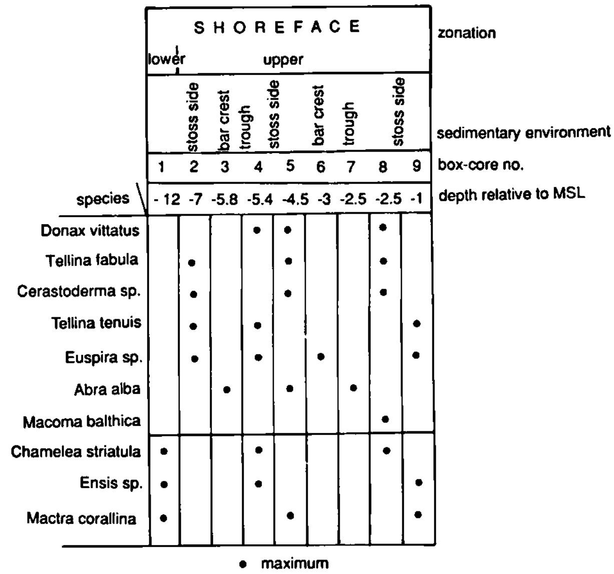

Fig. 9. Maximum occurrence of shells of ten molluscan species in the shoreface at Egmond.

In Fig. 9 the maximum distribution of 10 molluscan species is depicted. *Spisula* sp. is not incorporated because of its overall presence, and three species of low occurrences are omitted as well. Figure 9 shows that two groups of molluscan shell occurrences may be distinguished. A group of seven species shows maximum occurrences in box cores 2 to 9 and another group of three species shows maxima in cores 1 to 9. Furthermore, it shows that box cores 2, 4/5 and 8/9 carry most maxima. This distribution is due to the sedimentary environment from which the box cores were taken. Cores 2, 4/5 and 8/9 are all taken from the 'stoss sides' of subtidal (2 and 4/5) and intertidal (8/9) longshore bars. Apparently, the molluscan species showing maxima in those positions indicate greatest stability per species. At a closer look, Fig. 9 reveals that per species individual maximum occurrences are noted. Only rarely does it show equal maxima. This indicates that every molluscan species' shell lies more or less in its most favourable, stable hydrodynamic position, even when juvenile shells are not tallied separately, as is the case here. Apparently, the -6 m boundary is a very important one, since this is the depth boundary between the two groups.

A specific vertical distribution of some molluscan shell occurrences is not unknown for the inter- and supratidal part of the Dutch coast (see Roep [1986] for a recent discussion). The basic idea is that the sedimentary environment is responsible for this distribution. However, only a limited amount of species was incorporated into this discussion (*Donax*, *Cerastoderma* sp.). It must now be considered that a larger part of the (very) common molluscan species (in their maximum values) is indicative of a certain set of sedimentary (mostly hydraulic) conditions. However, the limited character of the small data set on which the conclusions discussed below are based should be kept in mind. Additional evidence in the form of more transects of a design similar to the one discussed here are certainly needed.

Discussion and conclusions

The determination of the set of sedimentary conditions may be as follows. From the JARKUS data (Rijkswaterstaat) a large number of coastal profiles are available for comparison. A 1960-1973 selection of summer profiles, augmented by a 1982 winter profile is shown in Fig. 10. Solid profile lines together form the envelope within which successive profiles have moved. Deepest scours together form the lower line of the envelope, which line is situated between -6 and -7 m. From this it is clear that in the breaker bar zone of the Dutch coast extensive erosional and depositional processes take place within relatively short timespans (in this case 22 years, the

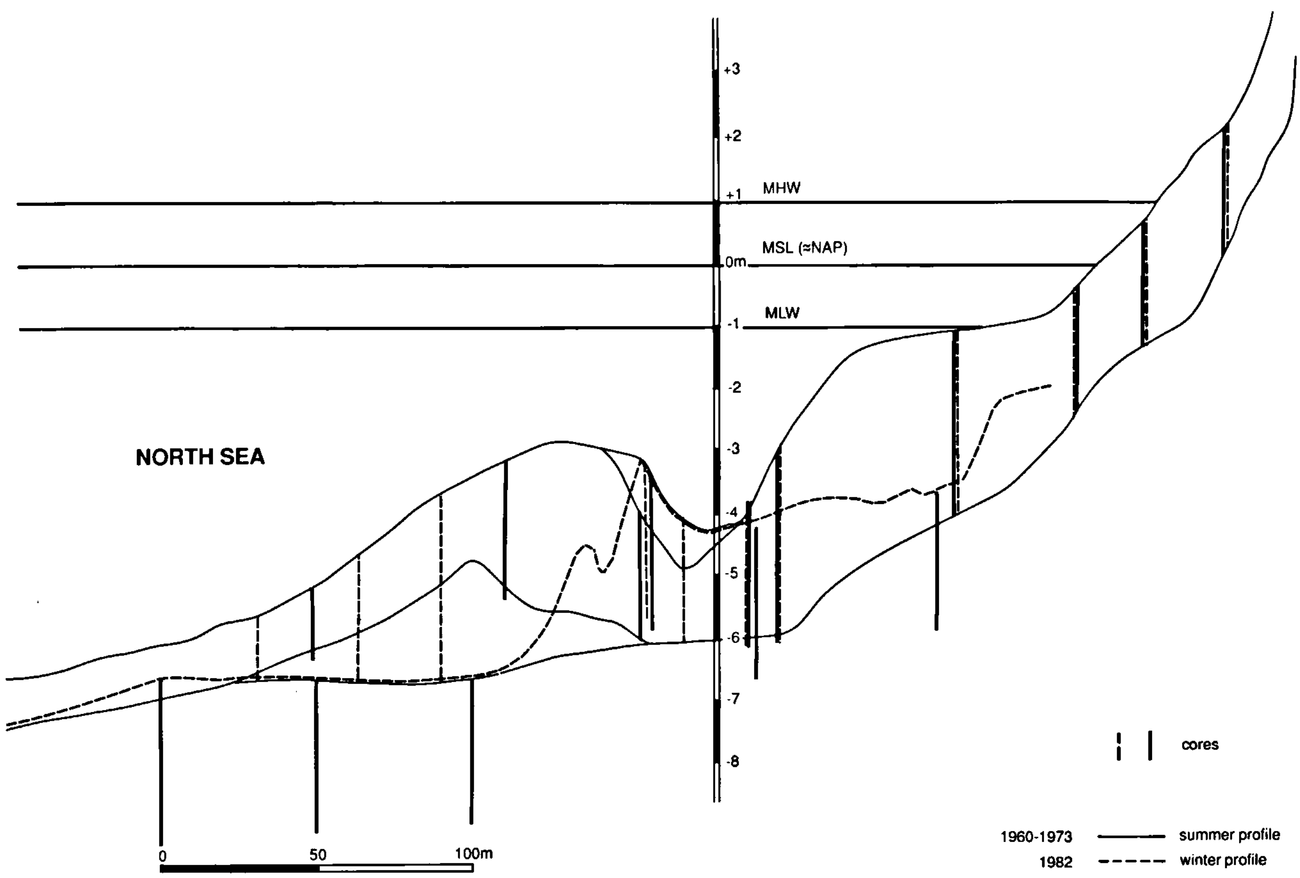

Fig. 10. Envelope of the 1960-1082 JARKUS profiles at Egmond.

zone	facies	limits (in m rel. to MSL)	bedding types	lithology	typical species
A	supra-/ intertidal beach	+3/-1	plane beds seaward dipping	medium sand few shells, thin layers	upper: Cerastoderma sp. lower: Spisula sp.
B	longshore bar/ upper shoreface	-1/-7	plane beds/ very low angle crossbeds, some storm beds	fine to medium sand, shells concentrated in layers, occasional clay layers and bioturbation	Spisula sp., highly variable numbers of: Donax vittatus, Macoma balthica, Mactra corallina, Tellina tenuis, T. fabula, Abra alba and Euspira sp.
C	lower shoreface	-7/(-17)	storm beds	medium sand, clay layers and bioturbation	Spisula sp., Mactra corallina, Tellina tenuis, T. fabula, Chamelea striatula, Ensis sp.

Fig. 11. Summary of sedimentary and molluscan features for the Holland shoreface and beach.

1982 winter profile incorporated). The winter profile is meaningful in this respect: it is only because of this winter profile that seaward erosion took place to such depth.

Short (1990) has recently discussed the morphology and dynamics of the Dutch coast. Bar mobility over the period 1976-1985 is found to have increased to the offshore from a mean of 60 m at the intertidal bar closest to the shore to 113 m for the next bar and 175 m at the deepest bar. These figures have been established over a nine year period (1976-1985). The active sweep zone, defined as the zone of movement of the bars, is some 800 m at Egmond (as it is for the larger part of the Dutch shoreface). Box cores 2 to 9 fall well within this zone. These figures indicate that sediment turnover within this 800 m zone is very high. Along with this sediment turnover, condensation of shell material takes place. Most molluscs are single valves of bivalves. No living molluscs were found in this zone. On the other hand, bioturbation by worms was found on several occasions. It may be concluded that some worm species [*Lanice conchilega* (Pallas, 1766) and *Nephthys hombergi* (Savigny, 1818)] are better adapted to this environment than are molluscs.

In view of the above data it is now considered acceptable that limited bioturbation is kept in the section and that molluscan shells in this zone of high turnover of the Dutch shoreface are moved and sorted in the way they are (compare Hertweck, 1971 for a Mediterranean example). The model presented here refers to the local conditions of the southern North Sea. In the fossil sections and the box core transect the same species were found. No influence of former or contemporary tidal inlets was noted, indicating that the sections and the recent transect were taken in representative Holland coast positions.

With regard to seasons, the results of Aigner & Reineck's (1983) survey off the island of Norderney may be interpreted as follows: every few months bioturbation is erased from the upper two to three metres in this zone. Erasion of bioturbation occurring lower takes place only during infrequent, severe storms.

A further conclusion is that for the depth range described in this paper the sedimentary environment that existed during the Subatlantic progradational phase of the mid-Dutch coast was the same as the present environment at the erosional coastline at Egmond. The depth distibution of sedimentary structures and the sedimentary behaviour of empty shells of a substantial amount of common North Sea bivalve species are similar. Median grain size distribution seems to be much less influenced by a common law.

The composition of empty bivalve shells in a sample is an indicator of the specific character of the set of hydrodynamic conditions at the sampling station on the shoreface of wave-dominated coastal deposits. It is suggested that fossil and recent sections show similar patterns in this respect in the time period covered by the data in this paper. In Fig. 11, a summary is given of the variables in the different zones. The supra- and intertidal beach is characterised by low diversity assemblages of molluscs with a marked depth-related distribution, mainly involving *Cerastoderma edule* (Linné, 1758) and *Spisula subtruncata*. The main sedimentary structure on the Holland coast beach is plane bed, dipping seawards, accompanied by bubble sand formation. The subtidal beach and barred shoreface are characterised by highly variable occurrences of a larger number of species. The mean fair weather wave base can be situated as high as -3 m in the off-storm season. The zone of high sediment turnover extends to a depth of some 6 m below MSL and is characterised by series of longshore bars. Internal structures consist mainly of plane bed and some low-angle cross-bedding. The latter has low preservation potential for the time period concerned. Clay layers and clay laminae have low preservation potential at the present-day coast. This preservation potential was much higher during the highly progradational phases of the Holland coast of the Subboreal and early Subatlantic. Large differences between summertime and wintertime coastal profiles exist. Taphocoenoses of this zone reflect depositional conditions of a highly dynamic wave-dominated environment. The amount of shell material is by far the largest and highest peaks occur near the base of this zone. Less dynamic conditions apparently existed during Subboreal barrier formation in the western Netherlands (Roep, 1986, fig. 17), judging by the preserved type of bedding in the same depth range relative to sea-level (low- and high-angle cross-bedding). Below -6 m the upper shoreface is characterised by taphocoenoses that reflect much more closely the original faunal composition (cf. Hertweck, 1971; Frey & Dörjes, 1988). Living molluscs were encountered below -6.8 m. Beds resembling storm deposits were found at Egmond below -5 m, a depth which is about equal to the older (some twenty centuries) IJmuiden and Zandvoort deposits. The same is true for the depth below which bivalve molluscs in life position were found in the Zandvoort borehole. When one ignores the effect of sea-level rise during a period of twenty centuries, the distribution of sedimentary environments of the Subatlantic beach barrier appears to be comparable with that under the recent regime on the Holland coast.

The composition of the skeletal assemblages only vaguely resembles the composition of the benthic associations present off the main Dutch coast (Eisma, 1966). The way the taphocoenoses are tentatively interpreted herein shows how they may be used in the analyses of fossil sedimentary facies, but it should be stressed that many additional structural box core data are needed before the Holland coastal regime is fully understood. As facies data for the upper shoreface are still limited, the monitoring of some beach-to-offshore transects of oriented boxcores at distinctive sites along the western Netherlands coast could prove to be very elucidating.

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APPENDIX

Dating the IJmuiden-Haringhaven section

The IJmuiden section was dated by ^{14}C analyses of two samples (Figs 2, 12). Dating results call for some comments. The 2295 ± 40 y BP is only very slightly younger than the 2310 ± 35 BP of the IJmuiden sluices exposure 1.5 km to the east. It is considered very unlikely that the coastline prograded over this distance in just 15 ^{14}C years (compare Roep, 1984). Especially in the time range within which the two samples are situated, calibration of ^{14}C results is extremely difficult (Stuiver & Pearson, 1986). This implies that it is impossible to assess the time that elapsed between the deposition of the two sections. Fortunately, there was another way to date the Haringhaven section. Terrestrial gastropods (*Cepaea nemoralis*) occurred in the shallow blow-outs at +2 m NAP; their dating yielded a result of 2170 ± 110. After calibration (using the updated version of the calibration programme by van der Plicht & Mook, 1988) this result indicates an age ranging from 370 cal BC to 110 cal BC, while the 2295 ± 40 dating is calibrated at 402 to 366 and 278 to 262 cal BC. For the Haringhaven section, the 2170 ± 110 dating is considered more realistic than the 2295 ± 40 dating, because the oldest archaeological finds on top of the dunes (unit 1) some 1.5 km to the east were dated 2250 ± 45 (Velsen-Hoogovens, GrN 4483; Jelgersma *et al.*, 1970). In addition, peat growth immediately to the north of the Haringhaven section started at 1910 ± 60 BP (Velsen-Vormenhal, GrN 5083; Jelgersma *et al.*, 1970). When one ignores the disadvantages associated with the dating of ter-

local no.	species	habitus	context	GrN	age	δ13C(‰)	Shell 14C ± SD (%)	depth (m~NAP)
1	Mactra corallina	fresh single valves, also broken	stormplanated beach surface	15157	2295±40	-1.59	-	+2
2	Cepaea nemoralis	whole shells	eolian concentrate	16185	2170±110 (after correction for δ13C)	-6.78	76.32 ±1.04	+2

Fig. 12. Radiocarbon analyses of shell carbonate of two IJmuiden samples (coordinates 62.300/436.100). Age in years BP (Present being 1950 AD).

restrial molluscan shells (the incorporation of 'old' inorganic carbon: *e.g.* Goodfriend, 1987), an acceptable age determination has been procured.

If, on the other hand, age anomalies of land snails are incorporated into the evaluation of the 2170 ± 110 dating, it would mean a further age reduction of reportedly at least 700 years (Goodfriend, 1987). In any case, this indicates a coastal progradation of 1.5 km in 140 ^{14}C years, but the period during which progradation occurred, could have been much longer, if the uptake of older inorganic carbon by land molluscs is taken into account. Extensive systematic research into this subject still remains to be carried out (Burleigh & Kerney, 1982).

However, sedimentation occurring during a much younger stage of coastal development is unlikely on the basis of the result of the 2295 ± 40 on marine shell material at the same height in the same geological sequence, but in different type of environment. This is also documented by the traces of human occupation mentioned above which immediately follow upon the deposition of the coastal sequence and the dating of the start of peat growth in the region (Pruissers *et al.*, in press).

The fact that the two radiocarbon dating results of the IJmuiden-Haringhaven section are so close may indicate that coastal dune *Cepaea nemoralis* takes up inorganic carbon that has a much more 'contemporaneous' stable isotope composition than *e.g.* in a Chalk (late Cretaceous) landscape, in which 'old' inorganic carbon is occurs profusely. The inorganic carbon in the dune landscape is provided by contemporaneous shell fragments from the beach, transported inland by wind, together with the dune-forming sand. The (delta) ^{13}C measurement of the GrN 16185 is indicative of this, when compared with the lower (*i.e.* more negative) values for *Cepaea nemoralis* of the Chalk landscape (Burleigh & Kerney, 1982). This interpretation certainly needs to be checked through studies on sections similar to that at IJmuiden, preferably in sections with mixed types of datable material and supplemented by recent monospecific snail data (cf. Burleigh & Kerney, 1982).

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