Meded. Werkgr. Tert. Kwart. Geol.	Vol. 20(2)	pp. 51-66	3 figs., 2 tabs., 1 pl.	Leiden, juni 1983

SUBATLANTIC (HOLOCENE) TIDAL FLAT AND MARSH DEPOSITS AT KATWIJK AAN ZEE (PROVINCE OF ZUID-HOLLAND, THE NETHERLANDS)

by

J.G.M. Raven
Leidschendam

Raven, J.G.M. Subatlantic (Holocene) tidal flat and marsh deposits at Katwijk aan Zee (province of Zuid-Holland, The Netherlands). Meded. Werkgr. Tert. Kwart. Geol., 19(2): 51-66, 3 figs., 2 tabs., 1 pl. Leiden, June 1983.

In a construction pit at Katwijk aan Zee deposits were studied which were formed during the late Holocene. The lower deposits were formed on a muddy tidal flat near the mouth of the river Oude Rijn. A coastal barrier protected the area and only storms disturbed sedimentation in this quiet environment. Molluscs, ostracods and foraminifera lived in clayey deposits at the highest part of the flat. These clayey deposits pass into marsh deposits which complete the Duinkerke Ib Deposits. Later, eolian deposits formed on the marsh (Older Dunes). Romans settled on these deposits. A transgression (Duinkerke II) led to their departure. The area was occupied also during the Middle Ages but man was driven away when the formation of the Young Dunes started during the late Middle Ages.

Layers consisting of sand-clay laminae, which occur in the intertidal flat deposits and containing particular structures, are compared with structures in a comparable Recent environment and interpreted as formed due to the presence of algal mats.

The faunas from the tidal flat deposits were studied. Storms transported a *Spisula* fauna coming from the North Sea beach over the barrier onto the tidal flats and marsh. The autochthonous *Scrobicularia* fauna consists of few euryhaline species but there is no proof for the occurrence of lower salinities since species from brackish water and freshwater environments are lacking.

J.G.M. Raven, Binnenweg 46, Leidschendam, The Netherlands.

Contents:

SAMENVATTING

In een bouwput op de noordoever van de uitwatering van de Oude Rijn te Katwijk aan Zee (Fig. 1) werd een profiel (Fig. 2) opgenomen door de jonge afzettingen aldaar, aan de hand waarvan de afzettingsgeschiedenis in dat gebied vanaf enige eeuwen vóór het begin van de jaartelling gereconstrueerd kan worden.

De onderste afzettingen werden gevormd op een ondiep, vrij beschut wad dat van open zee werd afgeschermd door een strandwal. Slechts door een aantal stormen werd de sedimentatie in dit milieu verstoord, merkbaar aan laagjes schoon zand mét of zonder veel getransporteerde schelpen en erosief liggend op de onderliggende afzettingen. Op het hoogste deel van het wad werden kleien afgezet waarin een autochtone fauna werd aangetroffen. Deze afzettingen gaan over in boven het gemiddeld hoog water gevormde kwelderafzettingen die worden gekenmerkt door een afwisseling van kleilaagjes en laagjes plantenresten, gevormd door het afsterven van de vegetatie tijdens de winter. Al deze afzettingen behoren tot de Afzettingen van Duinkerke Ib. De vorming van de kwelder hield na enkele tientallen jaren op en door verstuiving van zand werden lage duintjes gevormd (Oude Duinen). Daarop vestigden zich romeinen die een versterking aanlegden op de zuidoever van de Rijn (de Brittenburg). Rondom deze versterking was een kampement waarvan door archeologen een heel klein gedeelte is opgegraven. De romeinen werden verdreven door een kleine transgressie (Duinkerke II) maar later, tijdens de Middeleeuwen, werd het gebied opnieuw bewoond. Rond 1150 AD vond

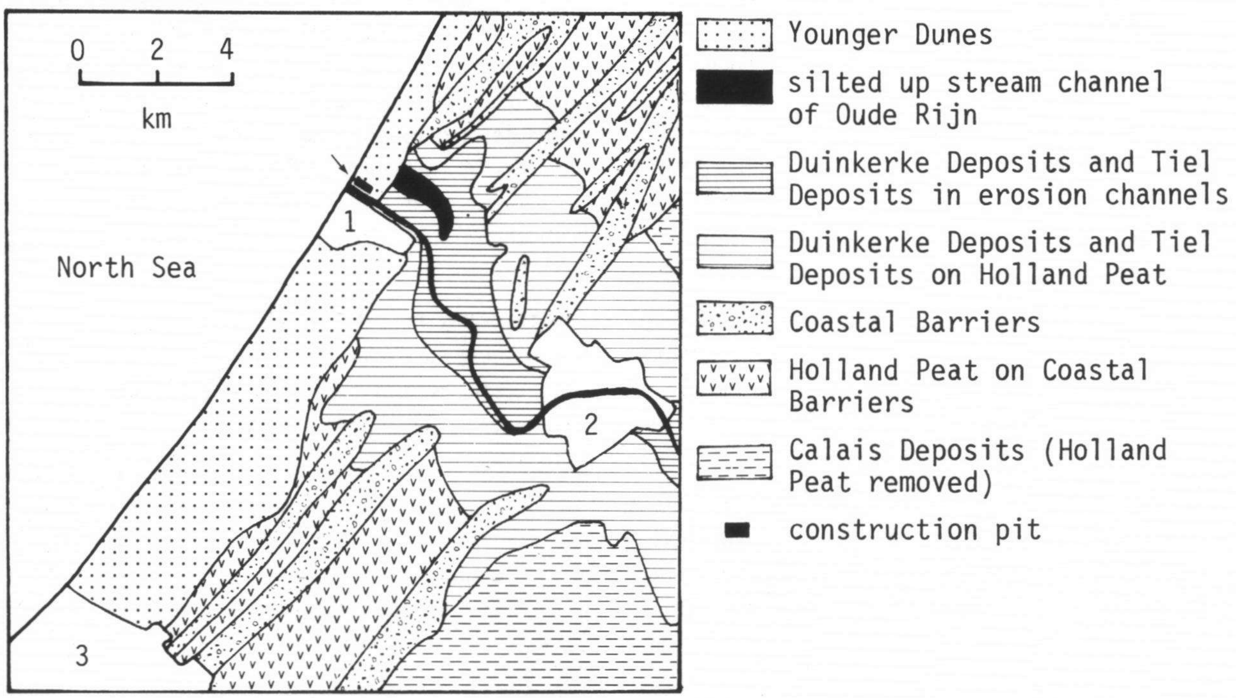

Fig. 1. Geological sketch map of the neigbourhood of the construction pit (based on Anonymous). The white areas are the villages Katwijk aan Zee (1), Leiden (2) and Den Haag (3). The last part of the actual course of the river Oude Rijn is artificial.

Fig. 1. Geologische schetskaart van de omgeving van de bouwput (gebaseerd op Anoniem). De witte plekken zijn de plaatsen Katwijk aan Zee (1), Leiden (2) en Den Haag (3). Het laatste deel van de huidige loop van de Oude Rijn is aangelegd.

sterke afslag van de kust plaats en werd de zee vóór de kust uitgediept. Het vrijgekomen zand verstoof en werd langs de kust afgezet in de vorm van duinen (Jonge Duinen). Daardoor werden de middeleeuwse bewoners verdreven en raakte de monding van de al verzande Oude Rijn verstopt.

Lagen bestaand uit klei en zand laminae, die voorkomen in het onderste deel van de sektie en opmerkelijke strukturen bevatten (Fig. 3a en b) worden na vergelijking met afzettingen in het Verdronken Land van Saeftinge (Fig. 3c) geïnterpreteerd als ontstaan onder een algenmat. Op zulke door algen verstevigde afzettingen konden zich later hogere planten vestigen wat leidde tot verlanding van het gebied.

In de fauna van de wadafzettingen worden een *Spisula*-fauna en een *Scrobicularia*-fauna onderscheiden. De Spisula-fauna komt alleen voor in de zandige stormafzettingen en is op het wad terechtgekomen doordat tijdens stormen zand en schelpen van het strand aan de onbeschutte kant van de strandwal over de strandwal heen het achterliggende beschutte gebied in werden getransporteerd, zelfs tot over de kwelder. De *Scrobicularia*-fauna leefde in de kleiige wadafzettingen direkt naast de kwelder en bestaat uit slechts enkele soorten die alle een verlaagd zoutgehalte verdragen. Het is echter opmerkelijk dat de invloed van de nabijgelegen Oude Rijnmonding zich niet manifesteert door de aanwezigheid van soorten kenmerkend voor brakwater- of zoetwatermilieu's.

INTRODUCTION AND ACKNOWLEDGMENTS

At the end of 1981 Mr C.P. Barnard (Rijksmuseum van Geologie en Mineralogie, RGM, Leiden) called attention to an excavation at Katwijk aan Zee (province of Zuid-Holland). The 23rd of November 1981 Mr C.P. Barnard, Mr A.W. Janssen (RGM), Mr H.J.M. Pagnier and the author (both Geologisch en Mineralogisch Instituut, GMI, Leiden) visited the excavation. During the visit a section was measured, sediment samples and mollusc samples were taken and some lacquer peels were made. The samples and the lacquer peels are in the RGM. The section was measured by Mr Pagnier and myself, Mr Janssen added some observations. It is situated about 50 m from the beach (Fig. 1), coordinates x=87.525 y=469.700, topographical map 1:25.000, sheet 30E Katwijk aan Zee). At the top of the marine deposits a settlement layer was found, containing numerous fragments of pottery. This was reported to the provincial archaeologist Mr D. Hallewas (Rijksdienst voor Oudheidkundig Bodemonderzoek, Amersfoort) and lead to excavation by the Instituut voor Prae- en Protohistorie (IPP, Amsterdam). During several later visits some more details were studied. At 26-3-1982 Prof. Dr J.H.F. Bloemers (IPP) invited several archaeologists and geologists to the excavation leading to useful discussions with Mr A.P. Pruissers (Rijks Geologische Dienst, Haarlem) and Mr Th.B. Roep (Geologisch Instituut, Universiteit van Amsterdam). Thanks are due to Charles Barnard, Arie Janssen and Henk Pagnier for their help in the field and the processing of the samples to Mr R. van Schooten (Hoogheemraadschap Rijnland, Leiden) for the permission to visit the excavation and to study the section and who kindly measured the altitude of a layer, and to Mr Pruissers, Mr Roep and Mr W.J. Kuijper (Instituut voor Prehistorie, Leiden) for the discussions, and Dr P.A.M. Gaemers (Leiden) for critically reading the manuscript and the identification of the otoliths.

THE MEASURED SECTION (Fig. 2)

In the section 4.3 m of predominantly marine deposits were exposed, covered by dune sand (reported to be about 11 m thick). That sand was covered up by mats to prevent the sand from

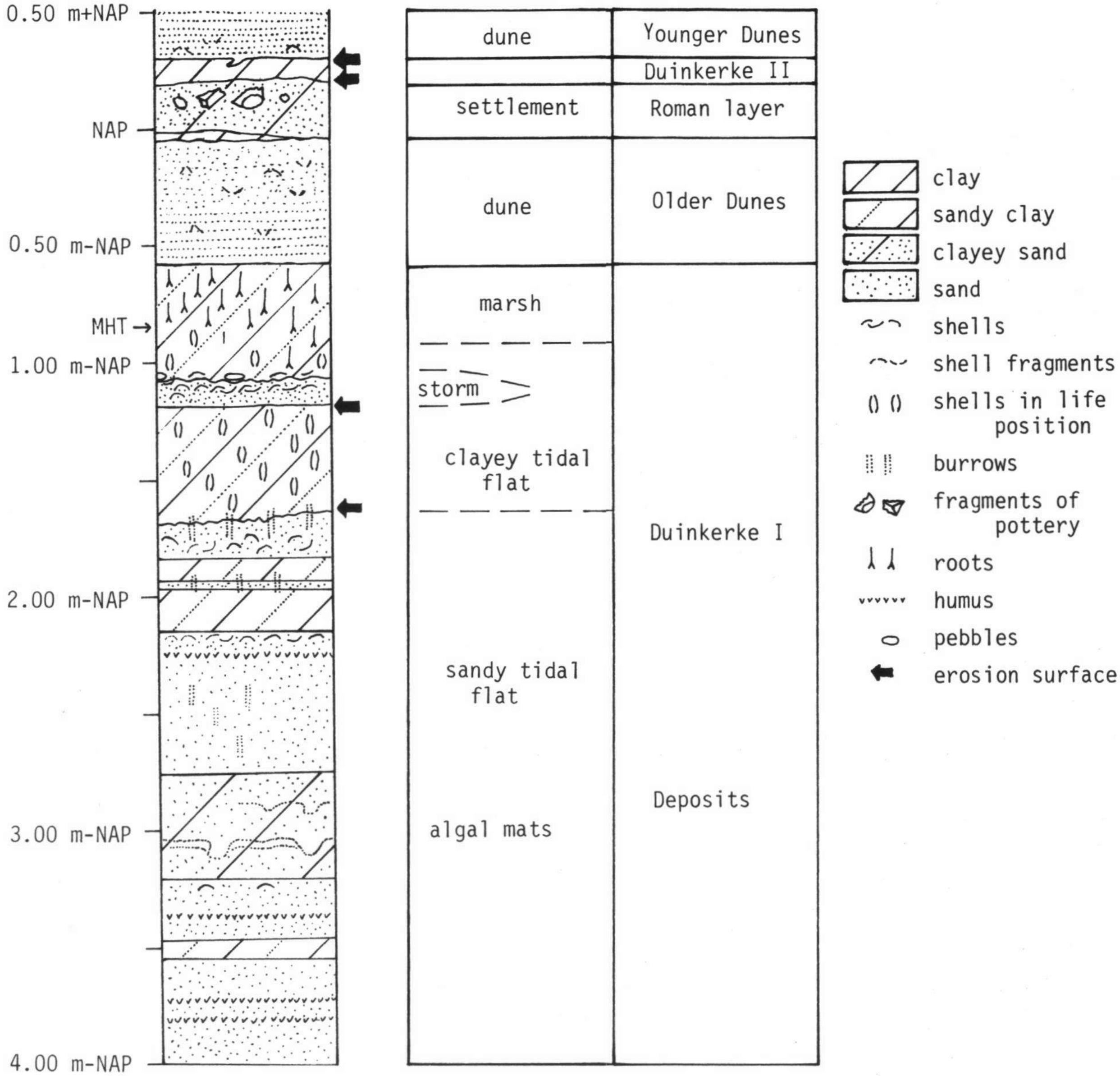

Fig. 2. **The section measured in the construction pit (MHT=palaeo-Mean-High-Tide level deduced from the distribution of bivalves in the clayey tidal flat deposits).**

Fig. 2. **De sektie die werd opgenomen in de bouwput (MHT=paleo-Gemiddeld-Hoog-Water niveau dat werd afgeleid uit de verspreiding van tweekleppigen in de kleiige wadafzettingen).**

being blown away. Therefore only the lower deposits were studied. The boundary between the lower deposits and the dunes was measured as 0.3 m+NAP.

to 0.3 m+NAP (only the lowermost 0.5 m studied) nearly horizontally laminated, light yellow to dark yellow, well sorted, medium grained quartz sand with fine shell fragments and some larger shells (*Cerastoderma*). The lower boundary is sharp and generally straight but irregular lobes may penetrate into the underlying layer (fill up structures).

0.30-0.22 m+NAP	disturbed clay layer, the lower half bluish grey, the upper half black. The lower boundary is very irregular due to later disturbance.
0.22 m+NAP to 0.05 m-NAP	disturbed layer of brownish grey, clayey sand with many fragments of pottery and roofing-tiles, charcoal, tuffite, fine gravel, some larger quartz pebbles (to 5 cm), mammalian bones, few glass fragments and some shells (*Mytilus edulis* Linné, 1758 and *Ostrea edulis* Linné, 1758). At the base an irregular, 0 to 5 cm thick layer of greenish grey clay. Due to later disturbance the lower boundary is irregular and not sharp.
0.05-0.58 m-NAP	dark grey, medium grained sand with many fine shell fragments. Towards the base more greenish. The sand is well sorted. The layer carries much water. The lower boundary is sharp.
0.58-1.08 m-NAP	black (after exposure rapidly oxidizing to dark grey), slightly sandy clay with numerous vertical root structures and about each 0.7 cm a thin layer (few mm thick) of plant remains. Due to the vegetation the clay is mottled. Towards the base more *Hydrobia* spec. occur and few *Scrobicularia plana* (Da Costa, 1778) in (vertical) life position. The base contains many reworked bivalves and a few sandstone pebbles (to 5 cm). The lower boundary is not sharp what appears to be due to bioturbation. A row of vertical wooden piles reached into this layer.
1.08-1.18 m-NAP	grey, medium frained sand, in the lower part with some thin humus layers and in the upper part with numerous transported shells (mainly *Spisula subtruncata* Da Costa, 1778). Generally the lower boundary is sharp and straight but bioturbation made it locally irregular. Due to small differences in compaction of the underlying deposits the entire layer locally shows slight undulations.
1.18-1.68 m-NAP	black (after exposure rapidly oxidizing to dark grey), clay, in the upper part sandy, in the lower part less sandy, with few plant remains. The sediment is rather strongly bioturbated by bivalves which are present in (vertical) life position: numerous *Scrobicularia plana* and few *Macoma balthica* (Linné, 1758). The lower boundary is sharp but irregular due to bioturbation.
1.68-4.00 m-NAP	horizontally layered alternation of sand and clay layers. Generally the sand is light grey and the clay dark grey. Towards the base of the exposure the amount of clay decreases. Both light grey sand layers with an admixture of clay and humus, and white sands layers without these components are present. From 1.68-1.83 m the sand contains numerous molluscs (mainly *Spisula subtruncata* but also few *Cerastoderma, Donax vittatus* (Da Costa, 1778), *Buccinum undatum* Linné, 1758 and *Euspira poliana* (Della Chiaje, 1830)). Between 1.83-1.93 m sandy clay. From 1.93-1.97 m the sand contains numerous vertical burrows with a diameter of 1 cm. From 1.97-2.15 m sandy clay. From 2.15-2.76 m sand with in the upper part a shell layer (mainly Spisula subtruncata) and at 2.255-2.27 m a humus layer. From 2.76-3.20 m an alternation of sand and clay with irregular structures. From 3.20-3.46 m sand with peat pebbles and some *Spisula subtruncata* and at 3.37-3.38 m a humus layer. From 3.46-3.53 m a clay layer. From 3.53-4.00 m sand with two humus layers at 3.725-3.73 m and 3.81-3.815 m.

INTERPRETATION OF THE SECTION

The lower interval

In the interval below 1.68 m-NAP several structures occur which deserve a further description. In many beds of this interval there is an alternation of sand and clay laminae, forming lenticular bedding. Frequently these are disturbed by vertical burrows, generally with a diameter of about 1 cm but also some thicker burrows occur. Further there is an alternation of white sand layers and grey laminated layers. In this interval shells occur only in the white layers and all the shells have been transported. These white layers are composed of clean sand in contrast to the grey laminated layers with clay and humus which were deposited under normal (quiet) circumstances. A very regular alternation of such deposits was recorded from a channel fill in the mouth of the Oosterschelde and was interpreted as alternating summer layers (grey, clayey and humose) and winter layers (white, clean sand) (van den Berg, 1981; Raven, 1982). The differences are due to the frequent occurrence of storms during the winter interval when also organic production is lower than during summer. The sequence at Katwijk is interpreted in the same way, but contrary to the subtidal channel in the Oosterschelde mouth the deposits at Katwijk were eroded during storms. Therefore only part of the sequence was preserved and the alternation of layers is less regular. Only during the heaviest storms numerous shells were transported, leading to the formation of a shell layer.

Although horizontal layers are predominant, low angle crossbedding occurs too, interpreted as tens of cms deep intertidal gullies. These occur mainly in the lower part of the exposure. In the eastern part of the pit some of the layers in the interval with the gullies are slightly convolute. Convolute bedding is generally well-developed in fine-grained noncohesive sediment such as fine sand or silty sand. It occurs due to liquefaction of the sediment (Reineck & Singh, 1975). The presence of humose layers and the absence of an autochthonous mollusc fauna indicate that the deposits were formed in a shallow environment. The structures indicate that the deposits were formed on the shallow part of a tidal flat which was now and then affected by storms.

In a few levels in the tidal flat deposits rather large deformations occur. In layers which consist of alternating sand and clay laminae structures occur which in vertical cross-section are wedge-shaped or truncated (Figs. 3a, b). At first sight these structures closely resemble water escape structures, Fig. 3a showing a pocket structure and Fig. 3b showing several pillar structures (compare Postma, 1983). There are, however, several arguments against the interpretation of the structures as water escape structures. First the laminated layers in which the structures formed may be cut off, indicating erosion from above. Secondly the sand which fills the depressions has an internal lamination which does not show disturbance by passing water but indicates that the structures formed at the sediment-water interface and were later filled in with sand, levelling-off the pre-existing palaeo-microrelief. The laminae in the sand follow the irregularities in the top of the underlying layer (Figs. 3a, b). Thus the underlying layer was deformed before deposition of the sand. Where the laminated layer is cut off this seems to be due to erosion. Where the laminated layer is deformed internally this appears to be due to another process. Locally even steep upward lobes are present within this layer (Fig. 3a). It is improbable that such structures form in unconsolidated clay or sand at the sediment-water interface (the convolute structures form within the sediment). A solution to this problem was obtained from a comparison with Recent deposits in a comparable environment. The Verdronken Land van Saeftinge (Drowned Land of Saeftinge, province of Zeeland) is an area consisting of marshes and intertidal channels and shoals. The marshes were deposited rapidly during

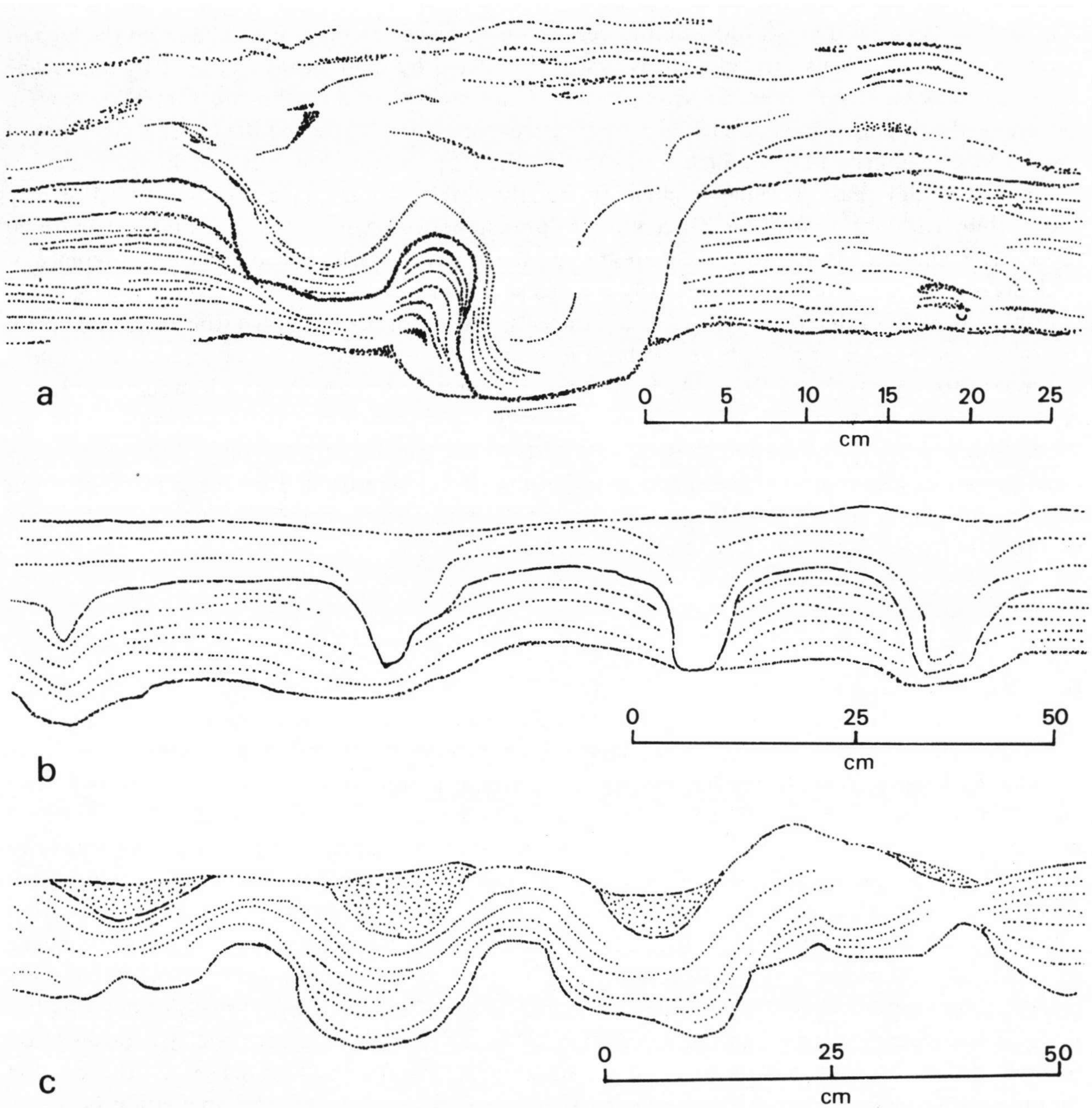

Fig. 3. Vertical cross-sections through sand and mud filled depressions in sand-clay laminated layers of tidal flat deposits (after photographs). (a) Sand filled depressions at Katwijk (2.76 to 3.20 m-NAP). (b) As (a) but here the depressions occur at regular distances. The lower surface of the laminated layer is undulating. The laminae in the sand follow the depressions. (c) Mud filled depressions at the Verdronken Land van Saeftinge (Recent). The laminated layer was formed thanks to the presence of green algae forming an algal mat which protected the underlying sediment from being washed away. The entire layer is undulating but immediately below and above it the layers are flat. Within the laminated layer disconformities occur.

Fig. 3. Vertikale dwarsdoorsnedes door met zand en slijk opgevulde kommen in zand-klei gelamineerde lagen van wadafzettingen (naar foto's). (a) Met zand opgevulde kommen te Katwijk (2.76 tot 3.20 m-NAP). (b) Als (a) maar hier komen de kommen op regelmatige afstanden voor. Het ondervlak van de gelamineerde laag is golvend. De laminae in het zand volgen de kommen. (c) Met slijk gevulde kommen in het Verdronken Land van Saeftinge (Recent). De gelamineerde laag werd gevormd door de aanwezigheid van groene algen die een algenmat vormden welke het onderliggende sediment beschermde tegen wegspoelen. De hele laag is golvend, maar onmiddellijk eronder zijn de lagen vlak. Binnen de gelamineerde laag komen disconformiteiten voor.

this century (van den Berg, 1980). Before vegetation of higher plants starts to grow on the highest parts of intertidal shoals the sediment is first consolidated by diatomeans and later by algae. The algal mats may be very resistent to strong currents, thus preventing the sediment from being eroded. Generally the upper surface of such algal mats is very irregular. Therefore the internal structure of the sand-clay laminated layer which forms due to the algae is also very irregular. In vertical cross-sections (Fig. 3c) these irregular laminae are clearly visible. The laminae may be parallel or may show internal disconformities. Such layers may be present between completely undisturbed horizontal layers. The laminated layers at Katwijk are interpreted as having been formed due to the presence of such algal mats. The sand which generally burried such laminated layers in the exposure at Katwijk may have been consolidated by algae or diatomeans. The deformations at Saeftinge and at Katwijk are of the same order of magnitude. At both locations the depressions may occur at rather regular distances (30-40 cms, Figs. 3b, c). At Saeftinge the depressions were filled with muddy sediment. At Katwijk may be the depth of the depressions increased by erosion due to water running off the shoal during ebb which followed these lowest parts of the shoals. At least some of the depressions have a more or less conical shape. These may be pits which were formed by the pecking of worm and shrimp eating birds. At Saeftinge large parts of the shoals are covered by such pits which are scoured out by water currents due to changing tides.

The upper interval

The clay deposits of 0.58 to 1.68 m-NAP were formed in an even shallower environment than the sandy tidal flat deposits immediately below it. The lower part of the clay represents the highest part of the tidal flat. An autochthonous fauna is preserved in that layer (see below). The uppermost occurrence of the bivalve *Scrobicularia plana* in life position (at 0.85 m-NAP) gives a good estimate for the palaeo-mean-high-tide (Th.B. Roep, pers. comm.). Above this level clay layers alternate with horizontal layers of plant remains. The clay has intensely been bioturbated by roots, indicating a dense vegetation. These deposits are typical for marshes. The sand layer at 1.08 to 1.18 m-NAP represents a high-energetic event as is indicated by the coarser sediment with numerous transported shells (*Spisula*-fauna) and even a few sandstone pebbles. This layer occurs all over the construction pit and has a sharp lower boundary. It is interpreted as a storm deposit (compare fig. 206 in Reineck & Singh, 1975 showing a storm deposit with shells on a Recent marsh). Comparable but thinner layers occur also at other levels within the marsh deposits and the clayey tidal flat deposits but were not indicated separately in the description of the section. The base of the clay deposits (1.68 m-NAP in the section) is an erosive and undulating surface, sloping towards the sea. At the location of the section in only one m the height of the boundary varied 5 cm. The undulation is due to differences in erosion before deposition of the clay.

In the exposure the sandy deposits of 0.05 to 0.58 m-NAP seemed to lack internal structures but in the lacquer peel a nearly horizontal lamination is visible, deformed after sedimentation. The structures and the sorting of the sand indicate that these are eolian deposits.

The sandy deposits of 022+ to 0.05 m-NAP contain the remains of a temporary settlement by man. The numerous objects are interpreted as the remains of a military settlement around a fortification forming part of the Roman defence line along the Oude Rijn (then called Rhenus). Due to the situation of the construction pit at the eastern extreme of the settlement, occupation lasted only shortly (from 160 to 240 A.D.) representing the maximum flourishing of the settlement. Also in the clayey deposits of 0.30 to 0.22 m+NAP remains of human activities were found, amongst others Medieval plough traces and ditches. The thickness of these disturbed deposits is highly variable.

Locally eolian sand is present between the dark clay and the plough traces. A detailed study was made by students and staff of the IPP. The description of these deposits between 0.30+ and 0.05 m-NAP is based on their results presented in a lecture at Leiden (J.H.F. Bloemers, 30-11-1982).

The sands present above 0.30 m+NAP are eolian deposits forming dunes. The presence of large shells, thin clay layers and plough traces in the base of these deposits indicates occupation by man even after the formation of dunes had started (Bloemers, lecture).

Stratigraphy

The lower part of the section was formed during a regression terminating with the foundation of a human settlement. The palaeo-mean-high-tide at 0.85 m-NAP indicates formation of the deposits at maximally a few hundred years before the settlement by the Romans (compare fig. 1 in van de Plassche, 1981). Therefore these lower deposits (below 0.05 m-NAP) are interpreted as Duinkerke Ib Deposits (also Pruissers, pers. comm.) and Older Dunes (0.05 to 0.58 m-NAP). The tidal flat and marsh must have been protected by a coastal barrier. The marsh was very low: in the end not more than 25 cm above MHT at the section, which height was attained after a few tens of years. The yearly accretion was less than a centimeter (estimated from the laminae with plant remains, which form during winter). Maybe this slow vertical accretion of the marsh must be explained with a rapid extension of the marshes over a broad area with a very gentle dip towards the sea. Therefore accretion of the marshes also stopped soon. Then dunes formed on the marshes (Older Dunes). The Romans settled on these eolian deposits. Later on a transgression flooded the area, leading to the departure of the Romans. The deposits which evidence this transgression were interpreted as Duinkerke II Deposits (Bloemers, lecture). Eolian deposits were formed at the marshes before the Roman occupation but thin laminae of eolian sand are present also in the deposits between 0.30+ and 0.05 m-NAP. When coastal barriers were forming (during the Subboreal) also dunes were being formed on top of these deposits. Both processes came to an end since insufficient quantities of sand were available on the foreshore. During the Roman occupation only near the former coast some dunes were formed (Jelgersma et al., 1970). The thick eolian deposits above 0.30 m+NAP in the section at Katwijk form the Younger Dunes, the formation of which is considered to have started after about 1150 A.D. (Jelgersma et al., 1970). Preceding the formation of these dunes erosion lead to an eastward shift of the coast, thus providing large quantities of sand with which the dunes were built (van Straaten, 1965). Due to the formation of the dunes the Medieval inhabitants were driven away. The Oude Rijn had already silted up as is evidenced amongst others by the Duinkerke III Deposits which are not present at the section at Katwijk but which form a thin layer of grey sand with an allochthonous mollusc fauna of predominating marine elements (*Spisula* fauna) and some brackish water snails (*Hydrobia*) in the mouth of the Oude Rijn itself, between 1 and 2 km North of the construction pit (W.J. Kuijper, pers. comm.). Due to the dune formation the mouth of this branch of the river Rhine which was hardly in use anymore was blocked.

FAUNA

It is remarkable that in the tidal flat deposits below 1.68 m-NAP no autochthonous molluscs were found at all. These could be expected to occur at least in the clayey deposits, as is the case with the clay above 1.68 m-NAP. In the interval below 1.68 m-NAP only worm burrows are preserved.

Most of the fauna is preserved in the sandy storm layers and is allochthonous. The fauna of a sample from the uppermost storm layer below the clay interval (1.68 to 1.74 m-NAP) was studied and the contents are listed in Table 1. The shells in the sample are badly preserved. The colours of the shells (bluish, brownish, or greyish) indicate that at least a part of the fauna was reworked from older deposits. The shells are strongly worn which must be due to prolonged to and fro transport in the surf zone. The fauna is dominated by the bivalve *Spisula subtruncata*: about 90% of the fauna consists of this bivalve which is still the dominant species on the actual North Sea beaches where also most of these shells are reworked fossils. Besides *Spisula subtruncata* also other species occur, mainly *Abra alba, Donax vittatus* and *Macoma balthica*. This fauna resembles the *Spisula* fauna described from the Coastal Barrier Deposits at Leidschendam (Raven, 1979) but is poorer in species and much worse preserved. The *Spisula* fauna from Leidschendam is supposed to have lived in a beach plain behind a submarine bar and probably the *Spisula* fauna at Katwijk originated from the unprotected sea in front of a barrier. A small part of the fauna at Katwijk has a different conservation, being better preserved. This part of the fauna consists of *Peringia ulvae, Scrobicularia plana, Macoma balthica* and *Mysella bidentata*. These species occur as autochthonous fauna in the clayey deposits which in the construction pit are present immediately above the storm layer. Certainly such clayey deposits were already present further landward when the storm layer formed. Therefore these shells are supposed to have been derived from such clayey deposits which were eroded during the storm. Only a very small part of the sieve fraction between 0.4 and 1 mm was studied. There are marked differences with the microfauna from the clayey tidal flat deposits (see below). Numerous are juvenile shells of *Peringia ulvae*. Ostracods are scarce but foraminifera are abundant, being represented by a varied fauna of reworked specimens of Miliolidae, *Streblus* species and *Elphidium crispum* with a few fresh specimens of *Protelphidium anglicum* and *Elphidium williamsoni* which may have been derived from clayey tidal flat deposits.

The fauna of a sample from the clayey tidal flat deposits (1.48–1.68 m-NAP) was studied (Tabel 2). *Scrobicularia plana* is by far the most striking species, occurring mainly as adult, double-valved specimens which were in life position. Juvenile specimens are remarkably scarce, probably almost all specimens became adult. The much smaller *Peringia ulvae* is more numerous, adult as well as juvenile specimens occur in large numbers. Juvenile specimens of the mussel, *Mytilus edulis*, are also numerous but only a single transported fragment of an adult shell was found, indicating that the spat died soon after settling. In lower numbers also the bivalve *Macoma balthica* occurs, pre-

Table 1. Fauna preserved in the storm layer between 1.68 and 1.74 m-NAP. Of the sieve fraction > 1 mm not all the fragments were identified and counted. Of the sieve fraction between 0.4 and 1 mm only a very small part was studied. An asterisk indicates well preserved specimens which probably were derived from clayey tidal flat deposits. The material was counted as follows: ≤ three specimens = 1; > three to ten specimens = 2; > 10 to 100 specimens = 3; > 100 specimens = 4; two valves of bivalve molluscs were counted as one specimen. The following abbreviations were used: a = adult specimens, j = juvenile specimens, f = only fragments. The material between 0.4 and 1 mm is indicated with an x.

Tabel 1. Fauna bewaard in de stormlaag tussen 1.68 en 1.74 m-NAP. Van de zeeffraktie > 1 mm werden niet alle fragmenten gedetermineerd en geteld. Van de zeeffraktie tussen 0.4 en 1 mm werd slechts een zeer klein gedeelte bestudeerd. Een sterretje geeft aan dat het materiaal goed geconserveerd is en waarschijnlijk afkomstig is van de kleiige wadafzettingen. Het materiaal werd als volgt geteld: ≤ drie exemplaren = 1; > drie tot tien exemplaren = 2; > 10 tot 100 exemplaren = 3; > 100 exemplaren = 4; twee kleppen van tweekleppige mollusken zijn geteld als één exemplaar. De volgende afkortingen zijn gebruikt: a = volwassen exemplaren, j = juveniele exemplaren, f = alleen fragmenten. Het materiaal tussen 0.4 en 1 mm is aangeduid met een x.

	> 1 mm	< 1 mm
Phylum Protozoa		
Classis Sarcodina		
Miliolidae, div. gen. et spp.		x
Streblus spp.		x
Protelphidium anglicum Murray, 1965		x *
Elphidium crispum (Linné, 1767)		x
Elphidium williamsoni Heynes, 1973		x *
Phylum Bryozoa (colony)	1	
Phylum Mollusca		
Classis Bivalvia		
Mytilus edulis Linné, 1758	1af, 1j*	
Ostrea edulis Linné, 1758	1a	
Mysella (Mysella) bidentata (Montagu, 1803)	2a*	
Cerastoderma edule (Linné, 1758)	2a	
Cerastoderma glaucum (Poiret, 1789)	1af (?)	
Mactra (Mactra) corallina cinerea Montagu, 1803	2af	
Spisula (Spisula) elliptica (Brown, 1827)	1a	
Spisula (Spisula) subtruncata (Da Costa, 1778)	4aj	
Ensis sp. indet.	1af	
Angulus (Fabulina) fabulus (Gmelin, 1791)	2af	
Angulus (Macomangulus) tenuis (Da Costa, 1778)	1af	
Macoma (Macoma) balthica (Linné. 1758)	3a, 2ja*	
Donax (Cuneus) vittatus (Da Costa, 1778)	3aj	
Scrobicularia plana (Da Costa, 1778)	2aj*	
Abra (Abra) alba (Wood, 1802)	3af	
Chamelea gallina striatula (Da Costa, 1778)	1a	
Turneria jeffreysi (Winckworth, 1930)	1a	
Barnea (Barnea) candida (Linné, 1758)	1af	
Classis Gastropoda		
Lacuna sp. (?)	1a	
Peringia ulvae (Pennant, 1777)	3aj*	x *
Bithynia (Bithynia) tentaculata (Linné, 1758) (operculum)	1a	
Epitonium (Clathrus) clathrus (Linné, 1758)	1af	
Euspira poliana (Della Chiaje, 1830)	2ja	
Buccinum undatum Linné, 1758)	1a	
Phylum Arthropoda		
Sunphylum Crustacea		
Classis Cirripedia		
Balanus sp.	3f	
Classis Ostracoda		
Cyprideis torosa (Jones, 1850)		x
Pontocythere elongata (Brady, 1868)		x
Phylum Echinodermata		
Classis Echinoidea		
Echinocardium cordatum (Pennant, 1777) (spines)		x
Phylum Chordata		
Classis Pisces		
Merlangius merlangus (Linné, 1758) (otolith)	1	
Pomatoschistus sp. (*P. minutus* or *P. microps*) (otolith)	1	

dominantly as juvenile specimens. Most of the adult specimens were in life position but some were transported. *Macoma balthica* generally passes its youth in muddy environments near the high-water mark but later most specimens move towards sandy environments near the major tidal inlets (Wolff, 1973; Raven, 1982), therefore the number of adult specimens is relatively low. Transported shells of adult specimens of some bivalve species were found, mainly *Spisula subtruncata* (Tabel 2). These shells have the same preservation as those in the storm layer just below the clayey deposits and were also transported during storms. It is remarkable that *Spisula subtruncata* is less dominant among these transported shells than in the storm layer below the clayey deposits. Further numerous juvenile shells of many species of bivalves were found (Table 2, Pl. 1) which partly may have been transported as dead specimens but most probably most of them reached the area during their planctonic life-stage and died soon after settling. The clayey tidal flat was not a suited environment for these species, most of which live in open marine environments. Among the foraminifera there are two species which probably lived on the clayey tidal flat: *Protelphidium anglicum* and *Elphidium williamsoni*, the first of which is the most numerous species (Table 2). Hofker (1977) mentions *Protelphidium anglicum* as a common species, occurring in most of the samples from Dutch tidal flats and salt marshes, also occurring in brackish water. *Elphidium williamsoni* is a very common species, occurring mostly on tidal flats but also in brackish water and on salt marshes (Hofker, 1977). *Cyprideis torosa* dominates the ostracod fauna (Table 2). It is an euryhaline species being most numerous in mesohaline water. In water with low salinities part of the specimens may have knobs on the outer side of the shell (Wagner, 1957). All the specimens at Katwijk, however, have smooth valves. Of the other fossils transported spines of the echinoid *Echinocardium cordatum* are most common, skeleton fragments were not found.

There are marked differences between the fauna in the storm deposits and the autochthonous fauna which indicate that the fauna in the storm deposits originated from another environment. The tidal flat deposits were formed in a generally low-energetic environment with a very weak gradient as is indicated by the rapid extension of the low marsh. High-energetic conditions occurred only during storms. The fauna in the storm deposits, however, evidences prolonged reworking in the high-energetic surf zone. This is explained by the presence of a coastal barrier separating a high-energetic beach with a *Spisula* fauna from a low-energetic tidal flat and marsh with a *Scrobicularia* fauna behind it. The storm layers are interpreted as wash-over deposits: during storms sediment (including shells) from the North Sea beach was transported over the barrier onto the tidal flat and marsh. This implies that a barrier protected the area near the mouth of the Oude Rijn. Since the present beach is very close to the construction pit the barrier must have been removed by later erosion which is also supported by other geological and archaeological data.

Table 2. Fauna preserved in the clayey tidal flat deposits between 1.48 and 1.68 m-NAP. The sieve fraction > 1 mm was studied entirely; of the sieve fraction < 1 mm only a part was studied. For the ostracods (234 valves) and foraminifera (149 specimens) the percentage of each species is given, for the molluscs absolute numbers of specimens are indicated and for the other fossils only the presence is indicated with x. An asterisk indicates reworked adult bivalves. The following abbreviations were used: a = adult specimens, j = juvenile specimens, f = only fragments.

Tabel 2. Fauna bewaard in de kleiige wadafzettingen tussen 1.48 en 1.68 m-NAP. De fraktie > 1 mm werd geheel bestudeerd; van de fraktie < 1 mm werd slechts een deel bestudeerd. Voor de ostracoden (234 kleppen) en foraminiferen (149 exemplaren) wordt het percentage van elk soort gegeven, voor de mollusken worden absolute aantallen van elke soort gegeven en voor de andere fossielen wordt alleen de aanwezigheid aangeduid met een x. Een sterretje geeft geremanieerde volwassen tweekleppigen aan. De volgende afkortingen zijn gebruikt: a = volwassen exemplaren, j = juveniele exemplaren, f = alleen fragmenten.

	> 1 mm	< 1 mm
Phylum Protozoa		
Classis Sarcodina		
Quinqueloculina sp.		1% *
Lagena cf. *semistriata* Williamson, 1857		1% *
Guttulina sp.		1% *
Streblus beccarii (Linné, 1767)		2% *
Protelphidium anglicum Murray, 1965		73%
Elphidium williamsoni Heynes, 1973		22%
Elphidium sp.		1% *
Phylum Porifera (sponge spicules)		x
Phylum Bryoza (colonies)	x	
Phylum Mollusca		
Classis Bivalvia		
Nuculacea gen. and sp. indet.		5/2j
Mytilus edulis Linné, 1758	1af*, 239/2j, 2/1j	172/2j, 2/1j
Aequipecten opercularis (Linné, 1758)	1/2j	2/2j
Ostrea edulis Linné, 1758		6/2j
Mysella (Mysella) bidentata (Montagu, 1803)	1/2a	49/2j
Cerastoderma edule (Linné, 1758)	3/2a*, 9/2j	4/2j
Spisula (Spisula) subtruncata (Da Costa, 1778)	106/2aj*	67/2j
Phaxas (Phaxas) pellucidus (9Pennant, 1777)		3/2j
Angulus (Fabulina) fabulus (Gmelin, 1791)		9/2j
Macoma (Macoma) balthica (Linné, 1758)	6/2a*, 10/1a, 73/2j	42/2j
Donax (Cuneus) vittatus (Da Costa, 1778)	6/2a*, 4/2j	36/2j
Scrobicularia plana (Da Costa, 1778)	112/1a, 1/2j	13/2j
Abra (Abra) alba (Wood, 1802)		32/2j
Turneria jeffreysi (Winckworth, 1930)		6/2j
Barnea (Barnea) candida (Linné, 1758)	1af*	
Classis Gastropoda		
Peringia ulvae (Pennant, 1777)	375/1	172/1j
Succineidae gen. and sp. indet.	1af*	
Phylum Annelida		
Classis Polychaeta		
Nereis sp. (jaws)	x	x
Phylum Arthropoda		
Subphylum Crustacea		
Classis Ostracoda		
Cyprideis torosa (Jones, 1850)		97%
Pontocythere elongata (Brady, 1868)		2%
Urocuthereis distinguenda (Neviani, 1928)		1%
Phylum Echinodermata		
Classis Echinoidea		
Echinocardium cordatum (Pennant, 1977) (spines)		x

Although the tidal flat deposits were formed close to the mouth of the river Oude Rijn (1-2 km farther north, Fig. 1) in a restricted area where fresh water of the river and seawater were mixed no species were found which occur only in brackish water or freshwater environments, except an operculum of the freshwater-brackish water snail *Bithynia tentaculata* and two fragments of reworked shells which may belong to the brackish water bivalve *Cerastoderma glaucum* (Table 1). One would expect to find at least several fresh, juvenile shells of freshwater species. That these are lacking completely indicates that the influence of the Rhine in this southern area was not very great, maybe due to the strong longshore current from the South. All the species of the autochthonous fauna tolerate lower salinities, thus the salinity may have varied. That would also explain the extremely low number of species in the autochthonous fauna: three molluscs (*Peringia ulvae, Scrobicularia plana* and *Macoma balthica*), two foraminifera (*Protelphidium anglicum* and *Elphidium williamsoni*) and one ostracod (*Cyprideis torosa*). There is, however, no proof for variable salinities.

CONCLUSIONS

The Duinkerke Ib deposits near the mouth of the Oude Rijn are tidal flat and marsh deposits which were formed behind a coastal barrier which was later eroded. On the tidal flat the influence of the nearby river is marked only by the occurrence of an euryhaline *Scrobicularia* fauna; typical species for brackish water or freshwater environments are lacking. On the flat sand-clay laminated layers formed below algal mats, during winter interrupted by storm layers of clean sand with a *Spisula* fauna originating from the North Sea beach at the exposed side of the barrier. At the landward side the flat bordered a low marsh which gradually extended over the flat and became covered by a thin layer of eolian sand (Older Dunes) later on. The area was inhabited twice by man. First by Romans which were driven away by the Duinkerke II transgression and later by Medieval inhabitants which were driven away by the formation of the Younger Dunes.

EXPLANATION OF PLATE 1

All specimens are from the clayey tidal flat deposits. The scale bar indicates 1 mm. The molluscs are all very juvenile specimens.

Alle afgebeelde exemplaren zijn afkomstig van de kleiige wadafzettingen. De lengte van de maatstreep bedraagt 1 mm. De mollusken zijn allemaal zeer kleine juvenielen.

Fig. 1 Nunulacea gen. et spec. indet., coll. RGM 225 379.
Fig. 2, 3 *Mytilus edulis* Linné, 1758, coll. RGM 225 380, 225 381.
Fig. 4 *Aequipecten opercularis* (Linné, 1758), coll. RGM 225 382.
Fig. 5, 6 *Mysella (Mysella) bidentata* (Montagu, 1803), coll. RGM 225 383, 225 384.
Fig. 7 *Cerastoderma edule* (Linné, 1758), coll. RGM 225 385.
Fig. 8a, b *Turneria jeffreysi* (Winckworth, 1930), coll. RGM 225 386.
Fig. 9 *Peringia ulvae* (Pennant, 1777), coll. RGM 225 387.
Fig. 10 *Elphidium williamsoni* Heynes, 1973, coll. RGM 225 388.
Fig. 11 *Protelphidium anglicum* Murray, 1965, coll. RGM 225 389.
Fig. 12 *Cyprideis torosa* (Jones, 1850), coll. RGM 225 390.

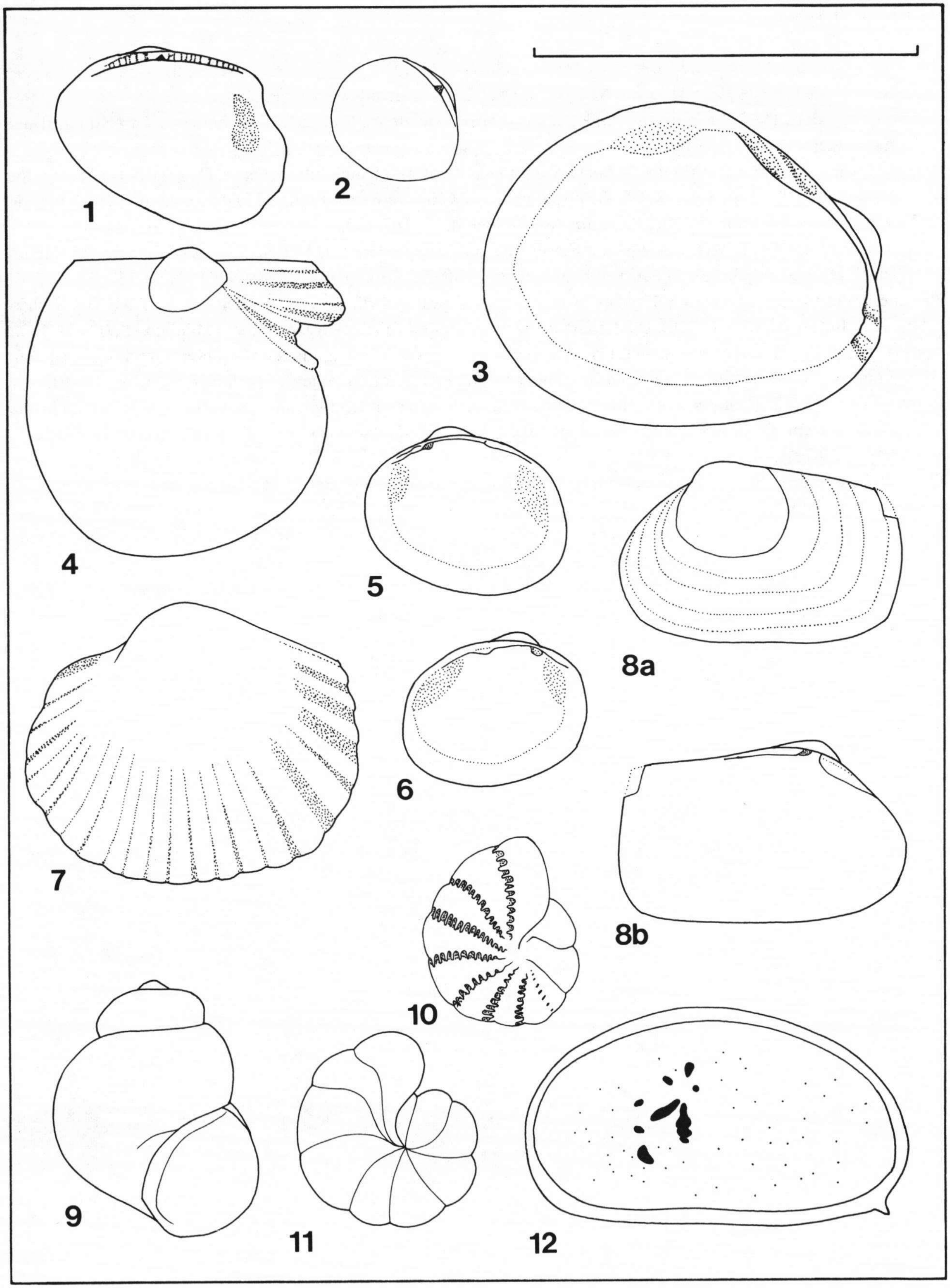

Plate 1

REFERENCES

Anonymous. Bodemkaart Zuid-Holland, Utrecht, schaal 1:200.000. In: Stichting Wetenschappelijke Atlas van Nederland, 1963-1977. - Atlas van Nederland, Den Haag (Staatsuitgeverij), blad IV-6.

Berg, J.H. van den, 1980. Field course guidebook on clastic tidal deposits in the SW Netherlands. Utrecht (Instituut Aardwetenschappen), 67 pp.

Berg, J.H. van den, 1981. Rhythmic seasonal layering in a mesotidal channel fill sequence, Oosterschelde Mouth, the Netherlands. In: Nio, S.-D., R.T.E. Schüttenhelm & T.C.E. van Weering (eds.). Holocene marine sedimentation in the North Sea Basin. - Spec. Publ. int. Ass. Sediment., 5: 147-160.

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, (N.S.) 21: 93-167.

Plassche, O. van de, 1981. Sea level, groundwater and basal peat growth - a reassessment of data from The Netherlands. In: Loon, A.J. van (ed.). Quaternary geology: a farewell to A.J. Wiggers. - Geol. Mijnbouw, 60: 401-408.

Postma, G., 1983. Water escape structures in the context of a depositional model of a mass flow dominated conglomeratic fan-delta (Abrioja Formation, Pliocene, Almeria Basin, SE Spain). - Sedimentology, 30: 91-103.

Raven, J.G.M., 1982. Changes in the macrofauna of a shallowing subtidal channel (Subatlantic, Holocene) in the mouth of the Oosterschelde (province of Zeeland, the Netherlands). - Meded. Werkgr. Tert. Kwart. Geol., 19(2): 59-78.

Reineck, H.-E. & I.B. Singh, 1975. Depositional sedimentary environments. Berlin, Heidelberg, New York (Springer), XVI+ 439 pp.

Straaten, L.M.J.U. van, 1965. Coastal barrier deposits in South- and North-Holland, in particular in the areas around Scheveningen and IJmuiden. - Meded. geol. Stichting, (N.S.) 17: 41-75.

Wolff, W.J., 1973. The estuary as a habitat. An analysis of data on the soft-bottom macrofauna of the estuarine area of the rivers Rhine, Meuse and Scheldt. - Zool. Verh., 126: 1-242.