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THE BERGEN INLET, TRANSGRESSIVE AND REGRESSIVE HOLOCENE SHORELINE DEPOSITS IN THE NORTHWESTERN NETHERLANDS[1]

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ABSTRACT

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This paper deals with the sediments that have filled up the Bergen inlet. The scouring effect of the inlet caused significant erosion of the Pleistocene sandy sediments. In the deepest part of the inlet a 15 m sandy clay deposit is encountered interpreted als Regression I. This deposit was caused either by enlargment of the ebbtidal delta or by clogging of the smaller inlets situated further inland. During the deposition of the sandy clay the coastline south of the inlet is supposed to be near the present one. After that time this shoreline moved landwards to the region of Uitgeest. In the inlet itself the clay deposits were covered by sandy deposits. North of the inlet curved spits moved landwards.

Finally a significant progradation of the coastline south of the inlet and a retreat in southeastern direction of the hooked spits north of the inlet resulted in the closing of the Bergen inlet. Dating by mean of pollen analysis indicate a short 'life' of the Bergen inlet (5300-3300 B.P.).

Investigation of the underlying Pleistocene layers give evidence of a deep valley at the end of the Saalian glaciation overlain by a late Eemian estuarium.

The formation of the Bergen inlet is thought to be related to these Pleistocene erosion phenomena. The sources of the sediments in and near the Bergen inlet are discussed.

INTRODUCTION

The present study covers the coastal barrier area and concerns the deposits that have filled up the Bergen inlet.

Sixteen borings, reaching a depth of 50 m, were carried out parallel to the coastline between Petten en Egmond. In the dunes 4 borings were made to supplement data derived from existing borings of the Water Authority in the area. The information derived from the samples of these borings led to the discovery of the Bergen inlet.

This study project, financed by the Public Work Department and carried out by the Geological Survey, is mainly intended to provide information to the geological history of this part of the coastline; it could be useful in providing an explanation for the considerable coastal retreat in recent times (RIJKS GEOLOGISCHE DIENST, 1967). During the last century the coastal retreat north of Bergen amounted to 50 m, increasing in northern direction to nearly 200 m. South of Bergen the retreat is less than 50 m, changing in a small progradation of the coastline south of Egmond (BAKKER ET AL., 1979). In the hinterland a geophysical and geological investigation demonstrated the landward existence of the buried Bergen inlet, especially the clay fill. The latter was of great influence in the distribution of salt and fresh water in the subsurface (VAN DAM & JELGERSMA, 1964).

Geological setting

The present Netherlands coastal plain is underlain by Weichselian deposits of various sedimentary environments. The Rhine, Meuse and Scheldt rivers have dissected valleys and deposited coarse fluvial sediments. Local fluvial streams have eroded plateau-like areas, and deposited sands with intercalated loam and peat layers in lower areas. During the very dry and cold period of this glaciation, the ice cap did not reach The Netherlands, while eolian sands covered large areas of The Netherlands. In general it can be stated that during this glacial period a levelling took place of the pronounced topography caused by the Saalian glaciation and the following Eemian interglacial.

During the Holocene transgression this area of seaward

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sloping Pleistocene surface was gradually buried, eroded and filled up by Holocene sediments as a direct result of the relative rise in sea level (combined effect of eustatic and tectonic movements). It is evident that due to the depth of the Pleistocene surface the thickness of the overlying Holocene deposits varies considerably. In many places in the coastal area, these deposits are more than 20 m thick and reflect different depositional environments.

In an east-west section through the middle part of the Dutch coastal area, three zones of sedimentation can be distinguished: in the east a zone of peat, then a clayey zone of tidal flats, salt marshes and brackish lagoons with intercalated peat layers, and near the coast a littoral sandy zone of coastal barriers and dunes. The latter environment is well developed in the central part of the coastline; in the other two areas, the southwest and the northern part they must have been present but were for a major part destroyed by a landward moving coast after the Roman period. The clayey zone of tidal flats, salt marshes and brackish lagoons with peat present, not only at the surface but also in the subsurface, indicates that during the whole Holocene period the hinterland must have been protected from the open sea by coastal barriers or beach ridges.

As a consequence of the Pleistocene topography the shape of the coastline during Atlantic and Subboreal times must have been quite different from the present smooth course of the Dutch coastline (ZAGWIJN, 1974). The latter is the result of the significant erosion of the coast after the Roman period and the deposits of the Younger Dune sand, which closed the inlet of the Old Rhine and the Bergen inlet.

At the present time three coastal landscapes can be distinguished: the Rhine, Meuse and Scheldt estuary in the southwestern part, the coastal barriers in the central part and the Wadden Islands bordering a large tidal flat area in the

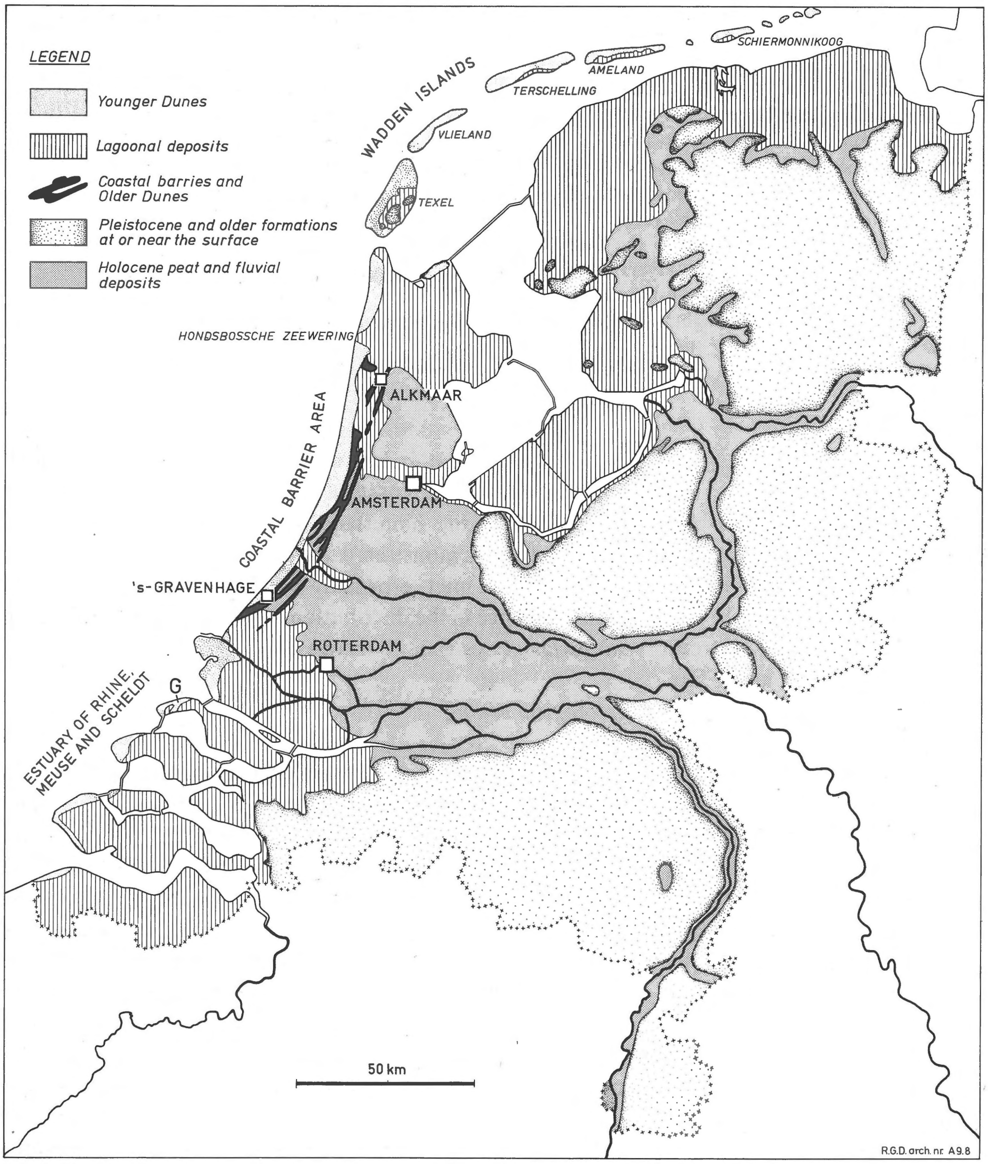


Fig. 1
Generalized geological of map The Netherlands.

northern part of the country (see Fig. 1). From the coastal barrier area the following outline can be given. In this part of the coast three coastal units can be distinguished: a series of coastal barrier ridges, overlain by dune sands of the Older Dunes, part of which is covered by the Younger Dunes. These coastal sediments have been studied i.a. by VAN STRAATEN (1961, 1965), ZAGWIJN (1965) and JELGERSMA ET AL. (1970).

The coastal barriers consist of sandy ridges separated by depressions filled with peat. The age of the barriers is Early Subboreal, and they are supposed to have developed in two phases. The first phase started shortly after 4700 B.P. and the second one after 4100 B.P. (VAN STRAATEN, 1965). This stabilization of the coastline (first phase), connected with outbuilding in a seaward direction (second phase), is most likely connected with a slowing down in the relative rise of sea level. The transgressive shoreline changed to a regressive shoreline resulting in a progradation of the coastline.

As discussed by JELGERSMA ET AL. (1970), three important inlets were present in this barrier coast. Two inlets are connected with the Rhine-Meuse and the Old Rhine rivers; they show the typical concave pattern of spits connected with river mouths (Fig. 2A). The third inlet is the estuary near Bergen with the curved spits on its north side (Fig. 2B).

On top of the coastal barriers dune sand accumulated, on the geological maps indicated as 'Older Dunes'. From excavations in this dune area it is known that eolian deposition was not a continuous process but must have been interrupted repeatedly by periods with vegetation. This is demonstrated by several soil and peat beds intercalated in the sands of the Older Dunes. (JELGERSMA ET AL., 1970).

The formation of the Older Dunes was completed before the Roman period and a more or less dense vegetation covered the whole dune area. The western part of the Older Dunes is covered by the Younger Dunes. The deposits of the Younger Dunes are related to the significant retreat of the coastline after the Roman period.

The major part of these eolian sands must have been deposited between the 12th and the 16th century. In contrast to the Older Dunes, the Younger Dunes are rather high, 20 to 50 m above sea level. Most of the Younger Dunes consist of a system of parabolic dunes, bordered on the seaward side by a fore-dune and on the landward side by a precipitation

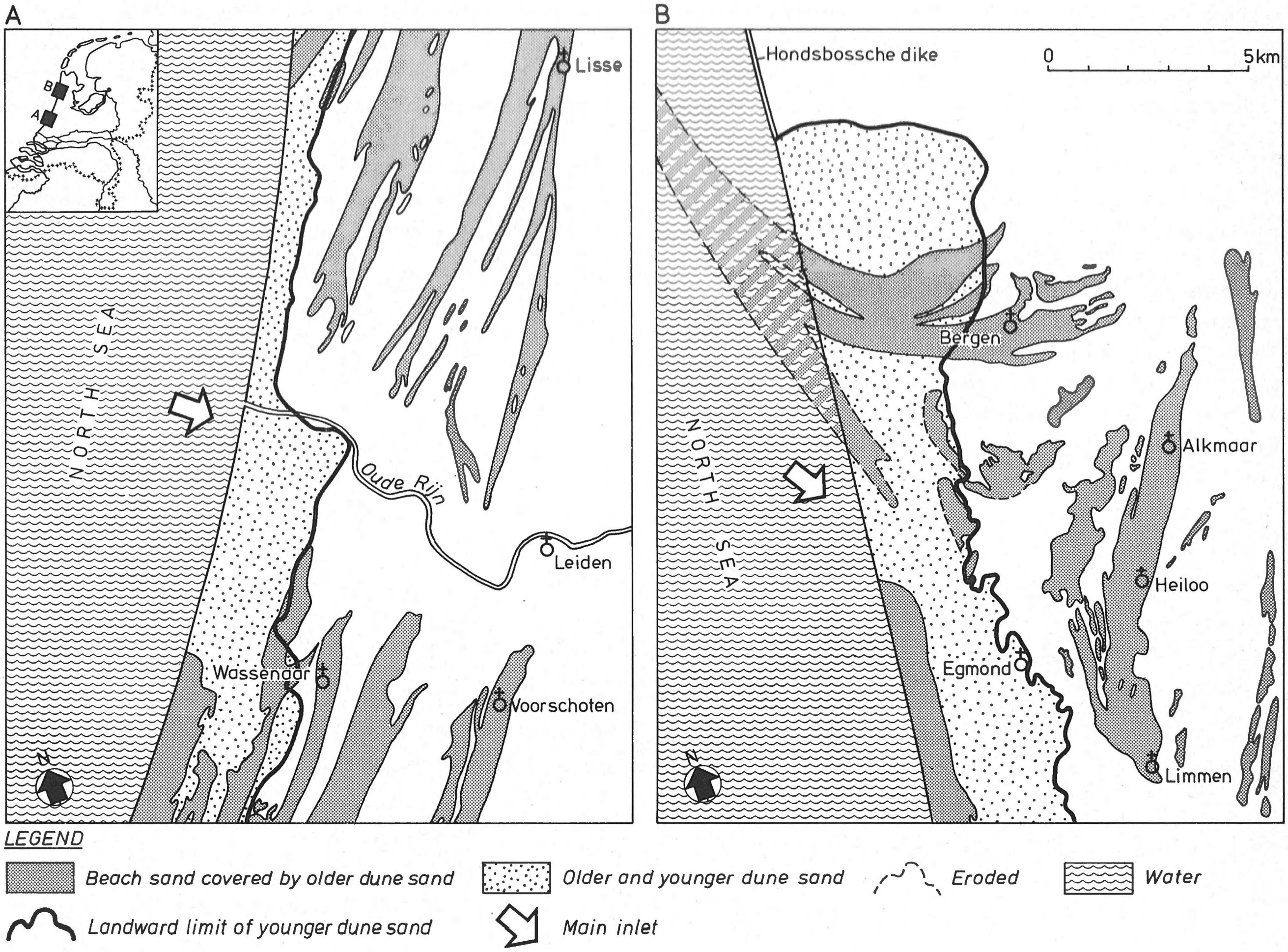


Fig. 2
Former inlets between coastal barriers: A) River mouth of the Older Rhine. B) The Bergen inlet.

ridge.

South of Bergen, the Older and the Younger Dunes consist of medium fine calcareous sand, but north of Bergen the sands are much less calcareous. Also the mineral content is different. Both factors cause differences in vegetation, which is denser in the calcareous dunes. The differences in composition of the coastal sands are related to the former Bergen inlet.

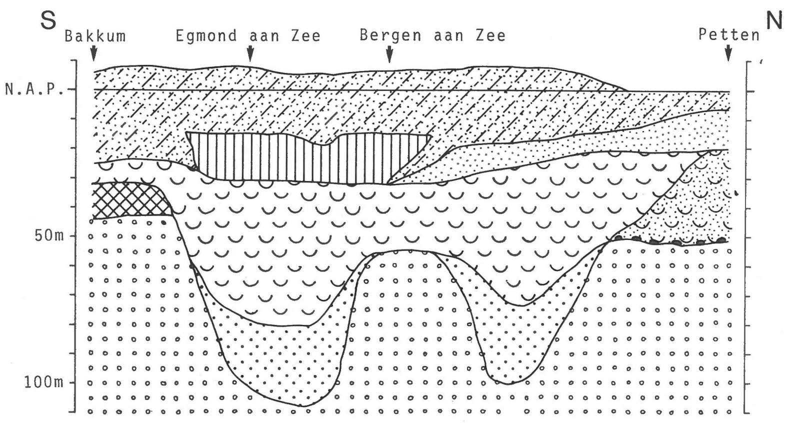
Physical environment

The tidal range along most of the Dutch coast is 1.50-2.00 m, but in the southwestern part it may be as much as 3.00-4.00 m. In the area of the former Bergen inlet the present tidal range is 1.80 m. Sand drift along the coast is of great importance along the Wadden Islands (from west to east), of lesser importance between the Belgian border and the Old Rhine (from southwest to northeast) and rather insignificant between the Old Rhine and the island of Texel (VAN STRAATEN, 1961, 1965).

Prevailing winds in the eastern part of the southern North Sea area have an onshore direction. The present coastal area is periodically subject to storms from the southwest, west and northwest. The latter direction is the most dangerous one, as the configuration of the southern North Sea causes extremely high tides during northwest storms. The whole littoral area can be classified as a micro- to meso-tidal wind-dominated clastic shoreline.

Pleistocene deposits

A north-south section through the Bergen estuary provides information about the lithology and the geological history of the underlying sediments (Fig. 3). The basal layers of the section consist of coarse fluvial sands deposited during the Early and Middle Pleistocene (Formations of Harderwijk, Enschede and Urk). On the south side of the section these fluvial deposits are overlain by a layer of boulder-clay from the Saalian glacial. North of this boulder-clay plateau the fluvial deposits are deeply eroded by meltwater streams of the Saalian glaciation. This glacial valley partly filled by fluvioglacial sandy deposits, belongs to the ice-marginal valley of the river Vecht (WIGGERS, 1955; JELGERSMA & BREEUWER, 1975). The local occurrence of great depth (more than 120 m) of this valley indicates an initial formation under the ice front by hydrostatic pressure of meltwater. During the retreat of the land ice cap these initial depressions were overlain by deposits of an ice-marginal valley. Figure 4 illustrates the different glacial deposits formed during the Saalian glacial period and its impact on the morphology in the northwestern part of The Netherlands. The glacial phenomena presented in this figure are slightly different from the map published by JELGERSMA & BREEUWER (1975). New borings have provided evidence that the glacial depression in the coastal area of Bergen does not belong to a glacial basin but should be interpreted as part of the ice-marginal valley of the Vecht. The Saalian glacial deposits are covered by marine deposits of the Eemian interglacial. These deposits consist of sandy deposits with shells and are locally intercalated with small clay horizons. The pollen analytical investigation have given indications of the age of these deposits. They are dated as having been deposited at the end of the Eemian interglacial; pollen zone E 6 (ZAGWIJN, 1961, 1983). This pollen zone can be divided into two subzones: E 6a and E 6b. Pollen analysis indicates that the marine deposits overlying the ice-marginal valley were formed during the final stage of the Eemian interglacial: pollen zone E 6b. These deposits have a thickness of more than 50 m.



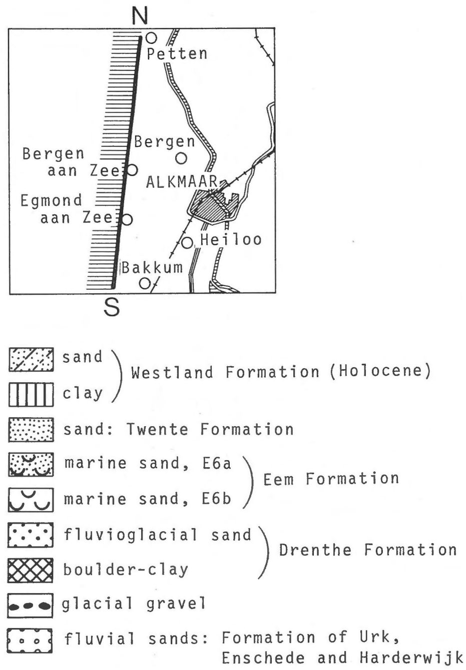


Fig. 3
Geological cross-section between Petten and Bergen.

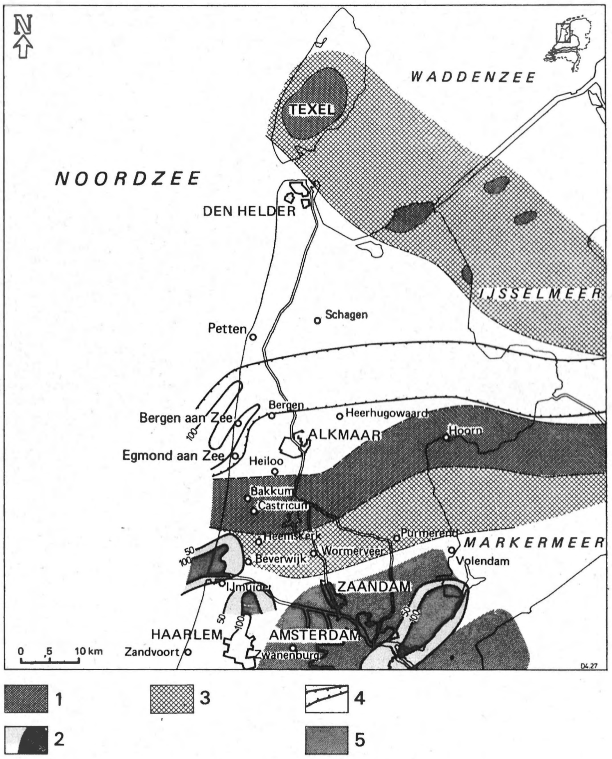


Fig. 4
Glacial phenomena during the Saalian glaciation: 1) ice-pushed boulder clay at the surface, in the region Hoorn – Bakkum covered by younger deposits. 2) depth below M.S.L. of the base of the glacial basin. 3) boulder clay covered by younger deposits. 4) ice-marginal valley of the Vecht. 5) ice-pushed ridge covered by younger deposits.

In the northern part of the section the Eemian deposits are older; they are dated as having been formed during pollen zone E 6a. These datings of the marine Eemian sediments point to a regression of the sea most likely due to climatic deterioration that resulted in the building up of land ice caps in the northern hemisphere (ZAGWIJN, 1983). It must be concluded from the dated sediment sequence that at the end of the Eemian E 6b during a period of falling sea level an estuary came into being which eroded the underlying deposits of Eemian and Saalian age and deposited about 50 m of estuarine sediments. Directly after that period the still falling sea level resulted in an emergence of the whole area of the southern North Sea (JELGERSMA, 1979; ZAGWIJN, 1983).

During the Weichselian glacial stage the Eemian deposits became covered by coase and fine sand layers intercalated by clay and peat layers. Pollen analytical investigations of the latter deposits have dated these deposits of the Formation of Twente to the beginning of the Weichselian (the Brørop and Amersfoort interstadials).

It is reasonable to assume that during the Early Weichselian erosion took place in the high-lying northern and northeastern plateau, in a fluvioperiglacial environment, resulting in a fan-like deposition of sandy material on top of the former Eemian seafloor. These deposits can be as thick as 15 m in areas not subjected to erosion by the Holocene transgression. The most important conclusion that can be derived from the cross-section presented is the erosion and deposition at the end of the Saalian glaciation and again at the end of the Eemian interglacial.

These phenomena resulted in a depression in the seaward sloping Pleistocene surface at the beginning of the Holocene. A reconstruction of the contourline on top of the Pleistocene deposits is given in figure 5. The location of the Saalian glacial depression, the late Eemian (E 6b) estuary and the area of deep scouring during the Holocene are represented in figure 6.

FACIES RELATIONS

Transgressive and regressive series

The cross-section of figure 7 indicates that during the Holocene transgression significant erosion of the Pleistocene deposits took place. This erosion is thought to have been caused by the scouring effect of tide movements in a large inlet. This inlet is completely filled up with sediments of different lithologies. Investigations of borehole samples of sediments of the buried inlet in the coastal area have given rise to the following rather hypothetical interpretation of the course of events during the silting up of the Bergen inlet. It must be mentioned that during our investigation undisturbed samples of sandy deposits were not available. The latter are of great importance for indicating the environment of sedimentation of the sediments in relation to the sedimentary structures.

The cross-section presented in figure 7 gives the following interpretation of the buried holocene sediments: The sediments of the Bergen estuary are subdivided into two transgressive and two regressive sedimentary sequences.

The basal transgressive sediments (TrI) are channel deposits consisting of coarse and medium grained sand with some marine shell fragments. These deposits are related to a large tidal inlet causing significant erosion of the Pleistocene surface.

The first regressive sequence (ReI) is thought to be represented by the thick silty clay deposit bordered by tidal flat deposits. Cored samples of the silty clay have given evidence of a lamination of dark and light coloured laminae, the latter being rich in diatoms. Analyses of the diatoms indicate a marine environment of deposition.

During the second transgressive sequence (TrII) the silty clay deposit is covered by fine grained sands with shells. The latter indicate an open marine environment. North of these fine sands coarse grained sands extremely poor in shells and lime are encountered. These deposits belong to a hooked spit formed on the North side of the inlet (JELGERSMA ET AL., 1970). On the landward side of the spit tidal flat deposits were able to develop. The second regressive sequence (ReII)

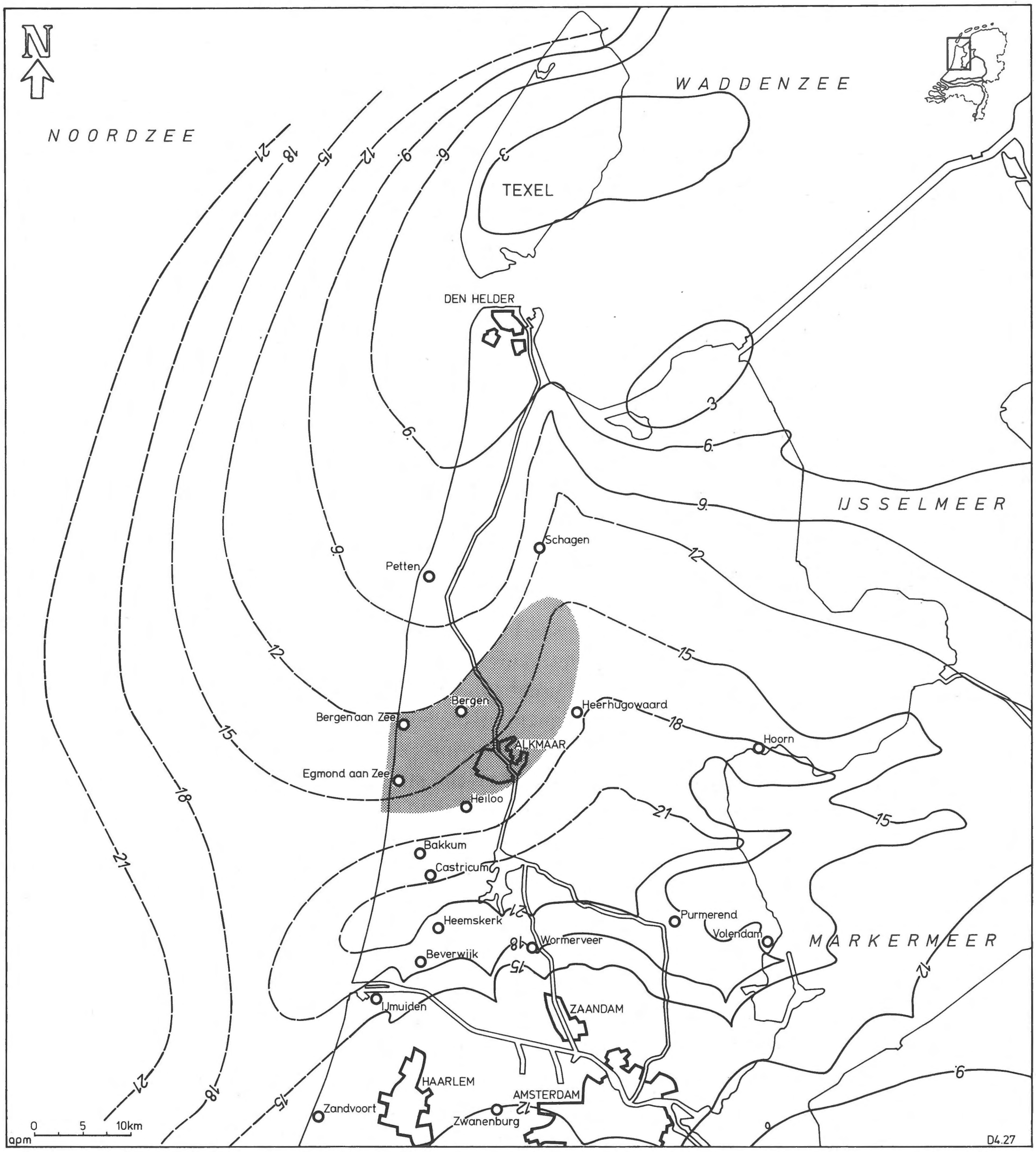


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Fig. 5
Reconstruction of the top of the Pleistocene in the Bergen area: 1) Contours of top of the Pleistocene (in metres); dotted line reconstruction. 2) Distribution of clay in the Bergen inlet.

finally closed the inlet: In the north a second phase of a hooked spit was able to develop consisting of the same coarse grained sand as in the first spit phase. Spits and coarse grained deposits cover the underlying fine grained inlet deposits. North of the hooked spits the tidal flat environment changed to a lagoonal one characterized by clay and peat layers. On the southern of the inlet beach barriers were formed more or less parallel to the present coastline.

In the area between the hooked spits and the beach barriers, for a major part covered by dune sands, the same coarse grained sands as the hooked spit sands are deposited. They are interpreted as belonging to banks related to tidal deltas. Finally the Bergen area was covered by dune sands: the Older and the Younger Dunes.

Lithology and facies of four boreholes

The above described facies relations are presented in a north-south cross-section (Fig. 7). Details of the lithology and the environment of sedimentation are presented from the samples of 4 boreholes.

Boring Bergen 65B91 is situated in the deeper part of the

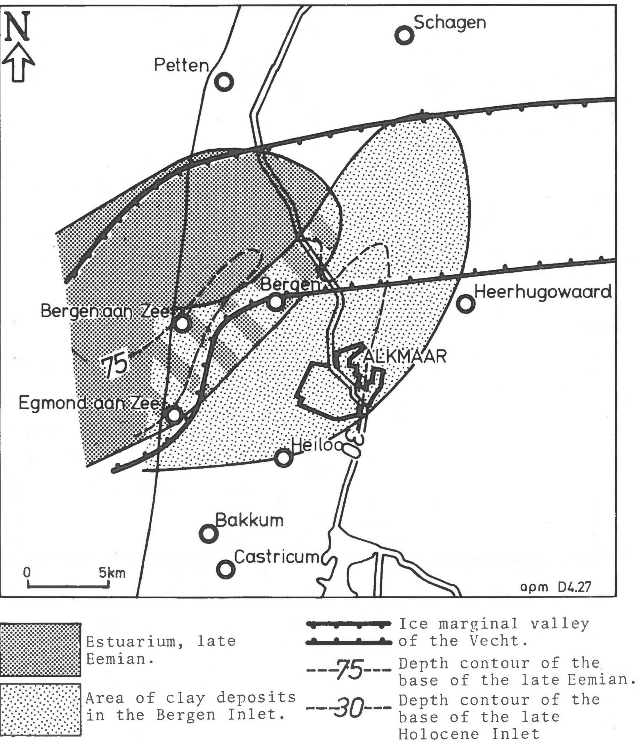


Fig. 6
Pleistocene and Holocene erosion features in the Bergen area.

inlet. The Holocene sequence presented shows a very pronounced upward increase in coarseness. Directly on top of the Pleistocene a 12 m thick silty and fine sandy clay is present; this layered clay rich in diatoms is thought to represent Regression I. The sandy clay is overlain by fine to medium fine sands with some shell fragments; in our opinion this layer represents Transgression II. The facies can be interpreted as channel deposits. The medium fine to medium coarse sands on top of the channel deposits are correlated with Regression II; these deposits represent either spits or banks of a tidal delta. The top layers of the boring represent an eolian facies: the Older Dune sand with a peat layer on top, overlain by Younger Dune sands (Fig. 8).

Boring 608 is situated on the north side of the Bergen inlet. The basal medium coarse sands are thought to represent channel deposits of Transgression I. The overlying medium fine sands are tital deposits correlated with Regression I; they are thought to be chronologically equivalent to the silty clay deposit in the deeper part of the inlet. On top of the fine sands medium fine to medium coarse sands are present. The basal part of this deposit is thought to belong to the spit platform sands of Transgression II, the top layer represents the hooked spits of Regression II. In general it should be noted that a pronounced upward increase in coarseness from −20 m MSL is present in this section (Fig. 9).

Boring Schoorl II is situated in the dune area between Bergen and Schoorl. The section consists of medium fine to medium coarse sand, extremely poor in lime, which shows an upward increase in the grain size. Below −14.50 m medium fine sands are present that are thought to be channel deposits correlated with Regression I. The relatively coarse sands overlying these deposits are interpreted as spit platforms and spit sediments belonging to Transgression II. There is a transition from these deposits into eolian sands of the Older Dunes. The border between marine and eolian is hard to ascertain as the marine spit deposits are extremely poor in shells. The upper two metres represent the Younger Dunes, the border between the Younger and the Older Dunes is represented by a peat layer, which is a well known phenomenon in the Dutch coastal area (JELGERSMA ET AL., 1970) (Fig. 10).

Boring Schoorl III is situated in the dune area north of Schoorl II. The basal part of this section represent lagoonal and tidal deposits correlated with Regression II. The lagoonal deposits became covered by eolian sands. On the basis of the grain size and the intercalated soils and peats a subdivision into Older and Younger Dune sands can be made (Fig. 11). A radiocarbon date of the base of the peat layers gives an age of 4045±40 B.P. As the lagoonal deposits are thought to have been formed behind the protection of the spit of Transgression II they indicate a minimum age of the latter.

It may be concluded that the interpretation of the 4 borings are mainly based on grain-size analysis and investigations of molluscs and diatoms. Investigations of the sediment structures by means of cored borings could lead to an improved interpretation.

HISTORY OF DEVELOPMENT

Nearly 18 000 years ago the North Sea lay about 100 m below its present level. Accordingly, the area of the present southern North Sea was then land. After that time the melting of the continental ice caps started a rise of the ocean level resulting in a transgression in the North Sea area. Hypothetical late Weichselian and early Holocene shorelines in the southern North Sea are given by JELGERSMA (1979). In this study it was cosidered that at about 7800 B.P. the shoreline approximated the present coastline of The Netherlands. From the early Atlantic period onwards sedimentation and erosion in the coastal area of The Netherlands was a direct result of the relative rise in sea level. In the Bergen area an inlet became into being, the scouring effect of which resulted in significant erosion in the Pleistocene surface. In the area of the inlet and in the hinterland the age of the eroding inlet is unknown. Only a few data are available that can be used to date the filling by the hypothetical sediment sequences of the Bergen inlet.

These data concern the thick silty clay deposits (Regression I), the time of the closing of the Bergen inlet and the age of the beach barriers of Uitgeest and Alkmaar-Heilo (ROEP ET AL., 1979; BEETS ET AL., 1981). Pollen analytical investigations of the silty clay deposit indicate an early Subboreal age;

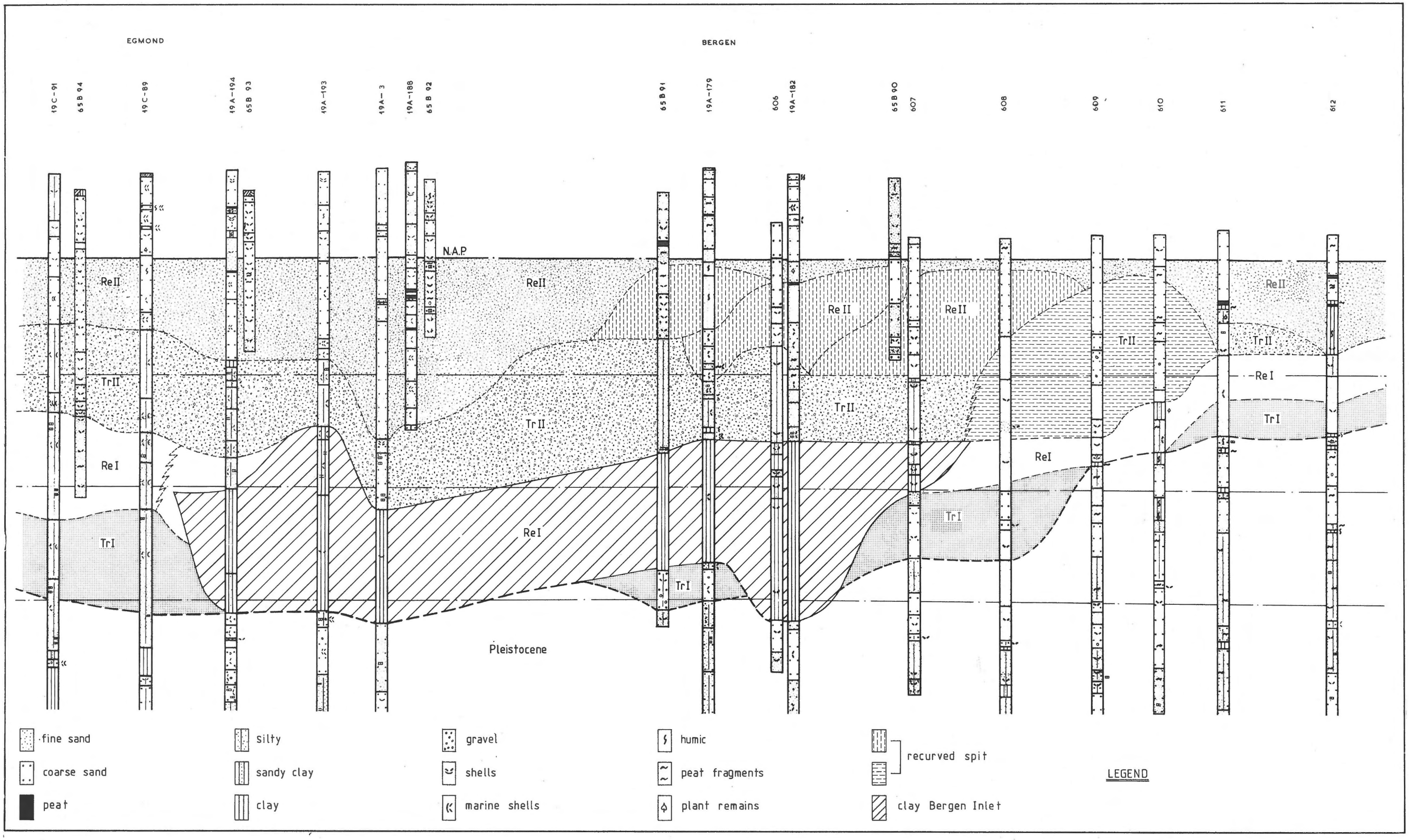


Fig. 7
North-south section through the Bergen inlet (for location see Fig. 3).

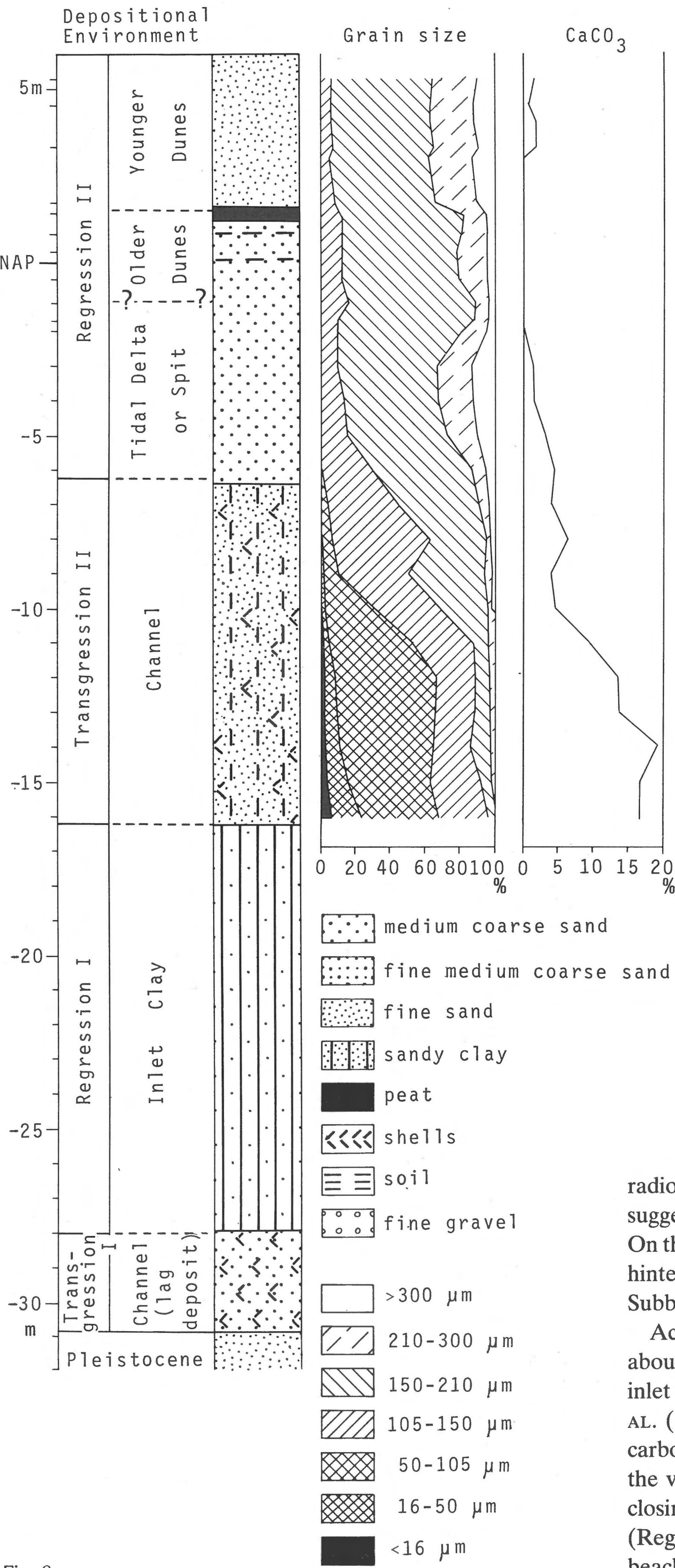


Fig. 8
Boring 65 B 91.

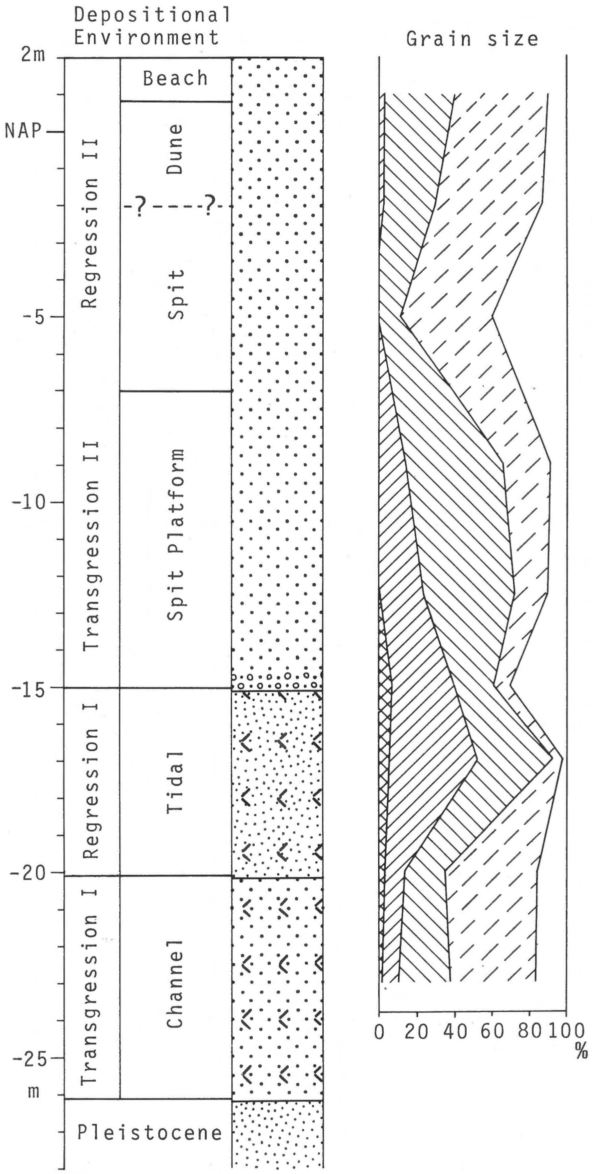


Fig. 9
Boring 608. For legend see figure 8.

radiocarbon dating of a layer rich in diatoms on the other hand suggest an origin in Atlantic age: 6135±65 B.P. (GRN5671). On the basis of investigations in sedimentary sequences in the hinterland DE MULDER & BOSCH (1983) prefer an early Subboreal age of the clay deposits.

Accordingly the later date is accepted for Regression I; about ± 5000 B.P. Data concerning the closing of the Bergen inlet are given in the study of ROEP ET AL. (1979) and BEETS ET AL. (1981). Their sedimentological studies backed by radiocarbon datings of samples from several excavations in and in the vicinity of the Alkmaar-Heiloo beach barrier indicate a closing of the Bergen inlet between 3700 and 3300 B.P. (Regression II). They also publish a radiocarbon dating of the beach barrier of Alkmaar: 3810±65 B.P. (GRN7776). A radiocarbon date of a peat layer in the hinterland of the beach

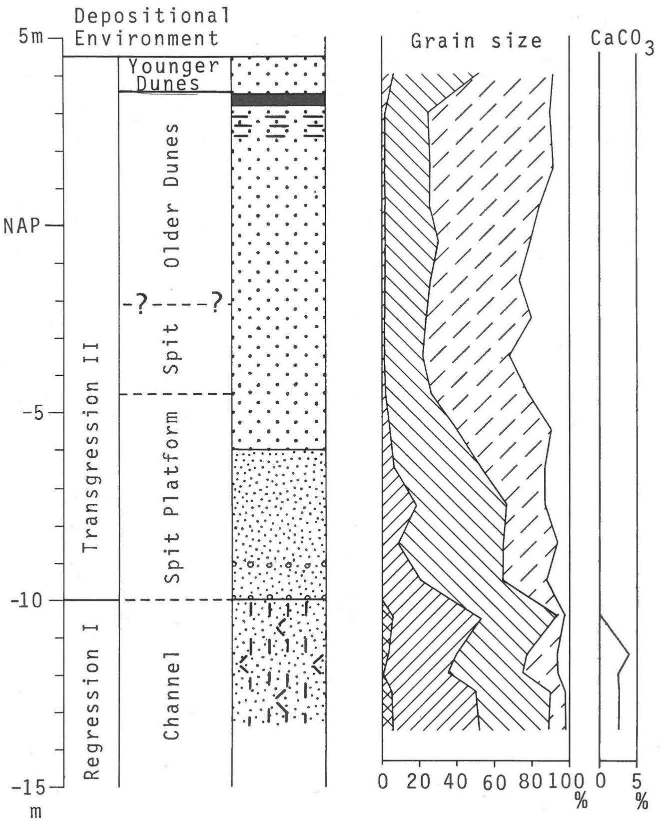


Fig. 10
Boring Schoorl II. For legend see figure 8.

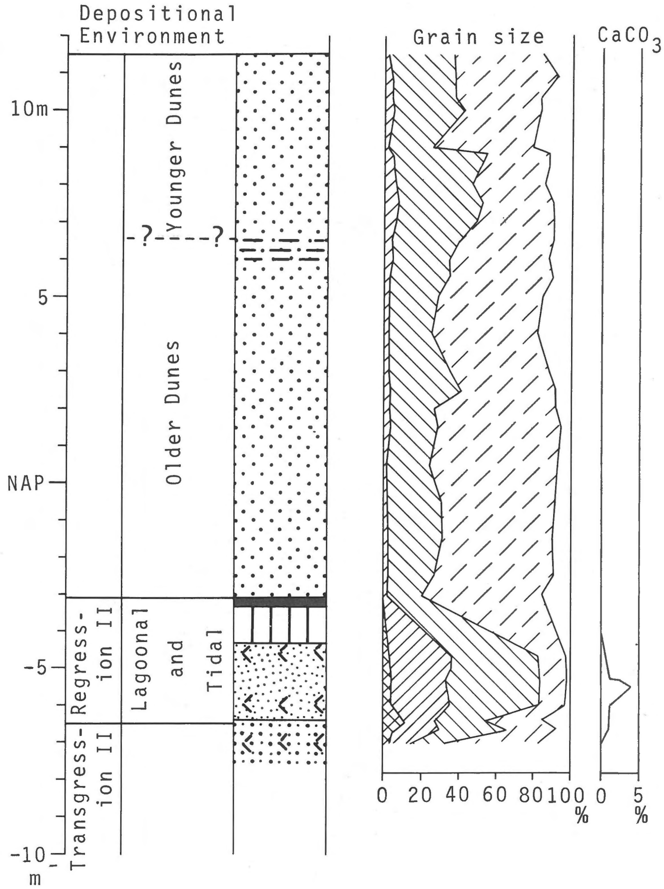


Fig. 11
Boring Schoorl III. For legend see figure 8.

barrier of Uitgeest indicates that this barrier had been formed before 4500 B.P. (JELGERSMA, 1961).

In relation to the above mentioned data we accept that the Bergen inlet was able to develop in the Late Atlantic (Transgression I, ± 5300 B.P.). After the rather turbulent period of the inlet, with its channel deposits, clay sedimentation occurred in the deeper part of the inlet. This significant change in hydrodynamics of the inlet is interpreted by us as a regression (Regression I: early Subboreal, ± 5000 B.P.).

As the curve of the sea-level rise does not give indications of any temporary fall in sea level the changes in sedimentation must be explained by other phenomena. In our opinion the deposition of sandy clay in the inlet was caused either by enlargement of the ebb delta or by clogging of the smaller inlets, situated further inland. The latter could have been caused by large sediment transport, during the turbulent phase (Transgression I), from the main inlet to the smaller branches. In the present tidal flat area of the Wadden Sea it is well known that blocking of an inlet some way inland, by means of dikes, results in deposition of mud in that part of the inlet further towards the sea. Measurements in such a closed inlet indicate a mud layer of 10 m thick to be deposited in 30 years. The explanation of the clay deposition as being due to clogging of the creeks further inland seems a rather attractive hypothesis. During the time of the deposition of clay in the Bergen inlet a more southerly situated inlet, the 'Oer Y', became more active (ZAGWIJN, 1971). It is most likely that the shoreline in the Bergen area during Regression I was situated much further to the west than the present one.

The continued rise of sea level caused a landward shifting of the coastline after the clay deposition. In the inlet itself fine grained sands were deposited on top of the clay (Transgression II) while on the north side hooked spits were able to develop. During this Transgression II sedimentary sequence the beach barriers of Akersloot and Uitgeest are thought to have developed. If the assumption is correct that during Transgression II the beach barrier of Uitgeest was formed then Transgression II can be dated to about 4700 B.P. This age is indicated by data derived from peat layers in the hinterland formed behind the protection of the barrier.

During the Regression II sequence the Bergen inlet was filled with sands of either tidal deltas or spits. South of the Bergen inlet the progradation of the coast resulted in the beach barriers of Alkmaar-Heiloo . According to ROEP ET AL. (1979) the final closing of the Bergen inlet should be dated between 3700 and 3300 B.P. During this Regression II an important progradation of the coastline south of the Bergen

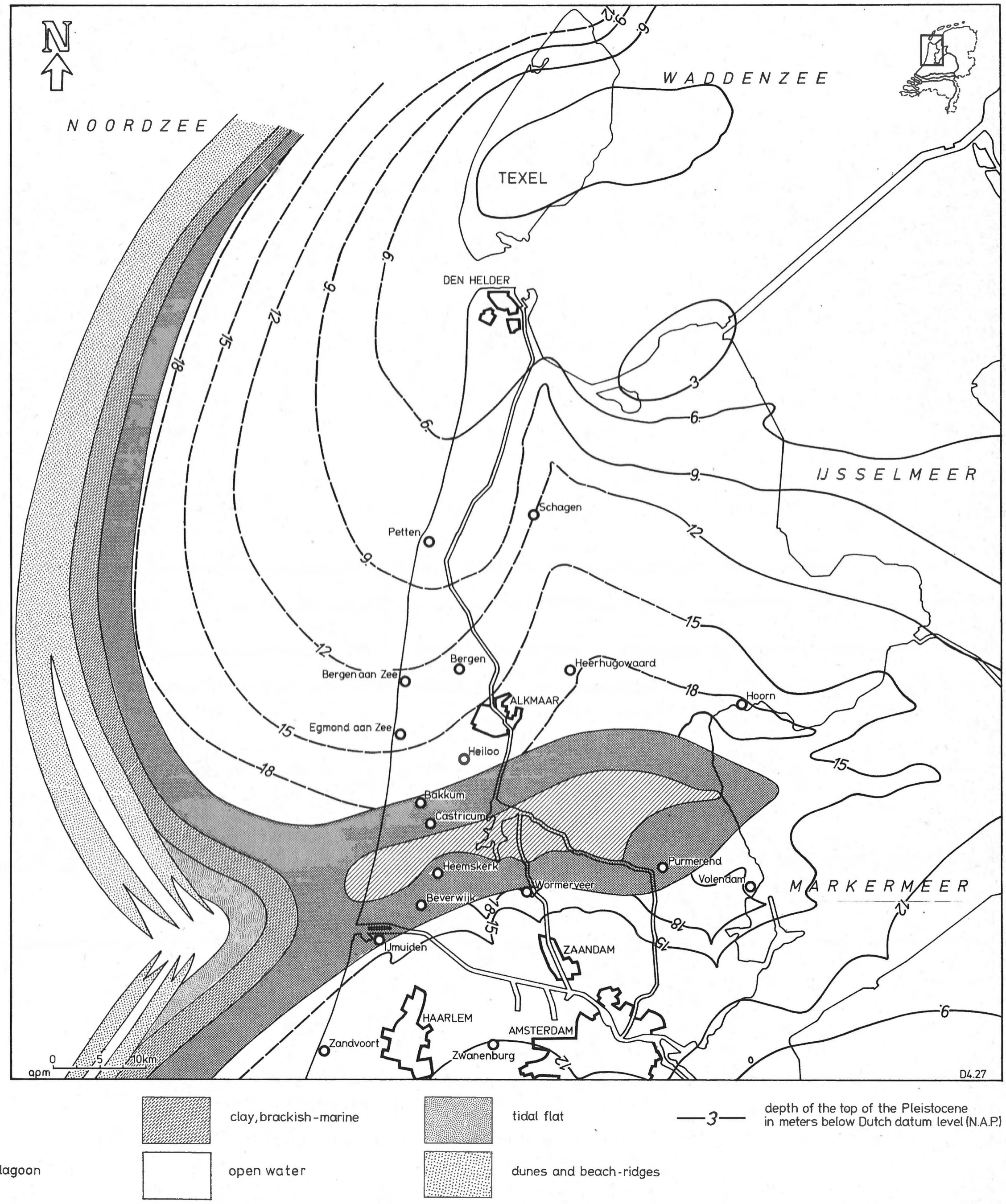


Fig. 12
Palaeogeographical map of the northwestern Netherlands at about 7700 B.P.; sea level about −21 m M.S.L.

inlet took place. In the area north of the inlet and bordered by a second series of curved spits, a progradation in western direction is less likely.

During the sanding-up of the Bergen inlet another inlet further south, in the region of Egmond, remained where the 'Oer Y' estuary was still important. This 'Oer Y' estuary has shifted northward, forced by a beach barrier that developed due to longshore transport in a northward direction. Shortly before Roman times the small 'Oer Y' inlet near Egmond became closed (JELGERSMA ET AL., 1970).

Finally the whole area of the Bergen inlet was covered by Older and Younger Dune sands. During the latter period the coastline must have retreated considerably. Especially the coast north of the Bergen inlet, which was situated much further west than the present one, was eroded severely. From the data presented it may be concluded that the Bergen inlet

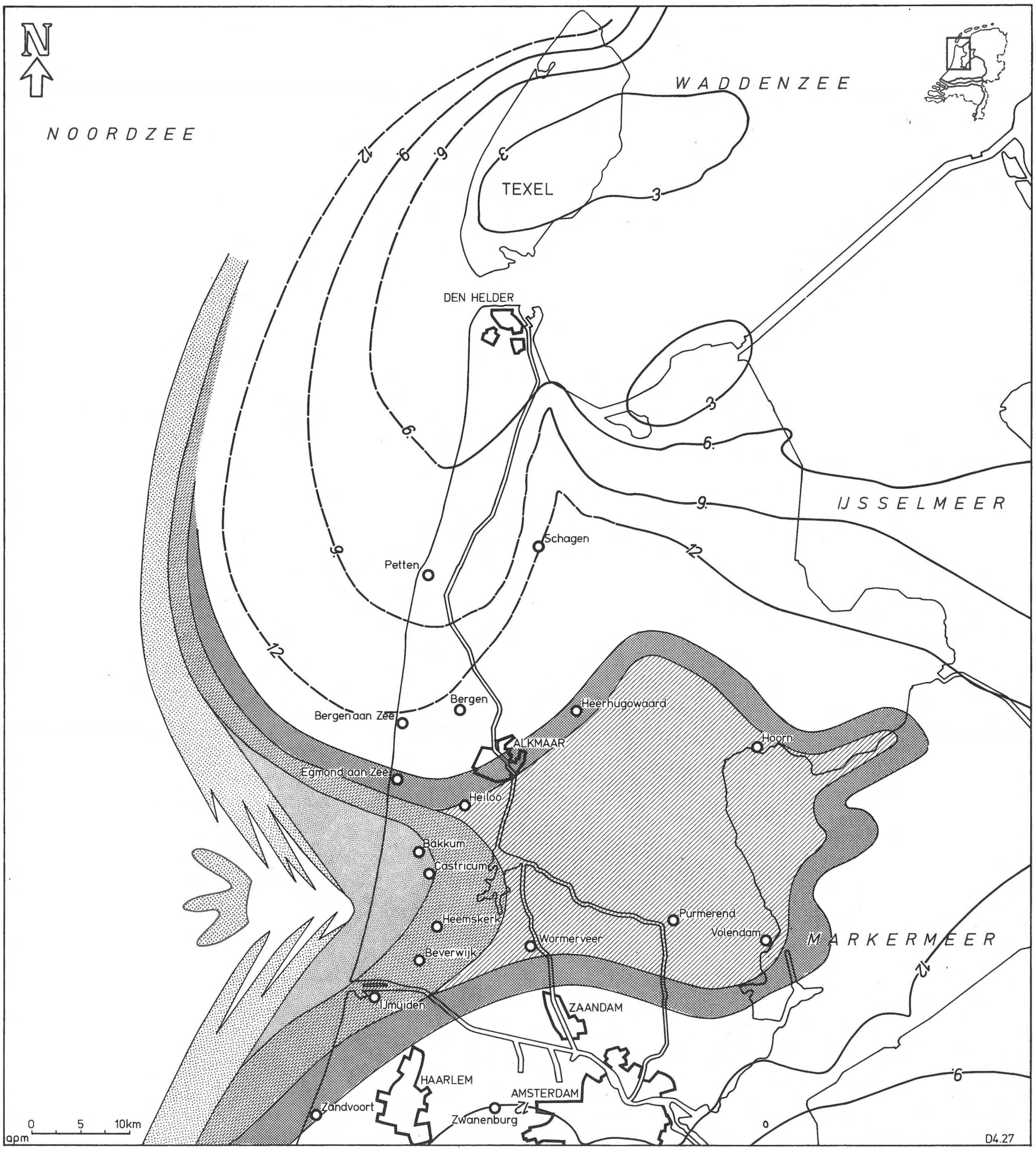


Fig. 13
Palaeogeographical map of the northwestern Netherlands at about 7000 B.P.; sea level about −14 m M.S.L.

silted up in a relatively short time. If the acceptance of the age of the sedimentary sequences is correct, it took place between 5000 and 3300 B.P., i.e. in less than 2000 years. It must be mentioned that the discrepancy between radiocarbon age and chronological age increases in the interval between 4000 and 5000 B.P. If the data of FERGUSON ET AL. (1966) are accepted then the amount of time involved in the silting up of the Bergen inlet should be about 2400 years. BEETS ET AL. (1981) give a rough estimate of the mean progradation rate of the Alkmaar-Heiloo beach barrier of 238 m/100 year. However, between 3610 and 3560 B.P. the progradation should amount to a minimum value of 500 m/100 year. The curved spits north of the Bergen inlet could have a much higher progradation rate.

Historical evidence is available of the development of the curved spits in the southwestern part of the island of Texel, as follows. At the beginning of the 18th century a concealment of the 'Hors' shoal of the ebb tidal delta resulted in a progradation of the southwestern coastline of 1400 m between 1750 and 1840. The concealment of the 'Onrust' shoal in 1914 resulted in the formation of another series of spits (± 1 km wide) bordered on the seaward side by a sand shoal of 1.5 km lying above mean sea level. This situation came into being in 1967. Figures 12, 13, 14, 15, 16 and 17 illustrate the supposed history of development.

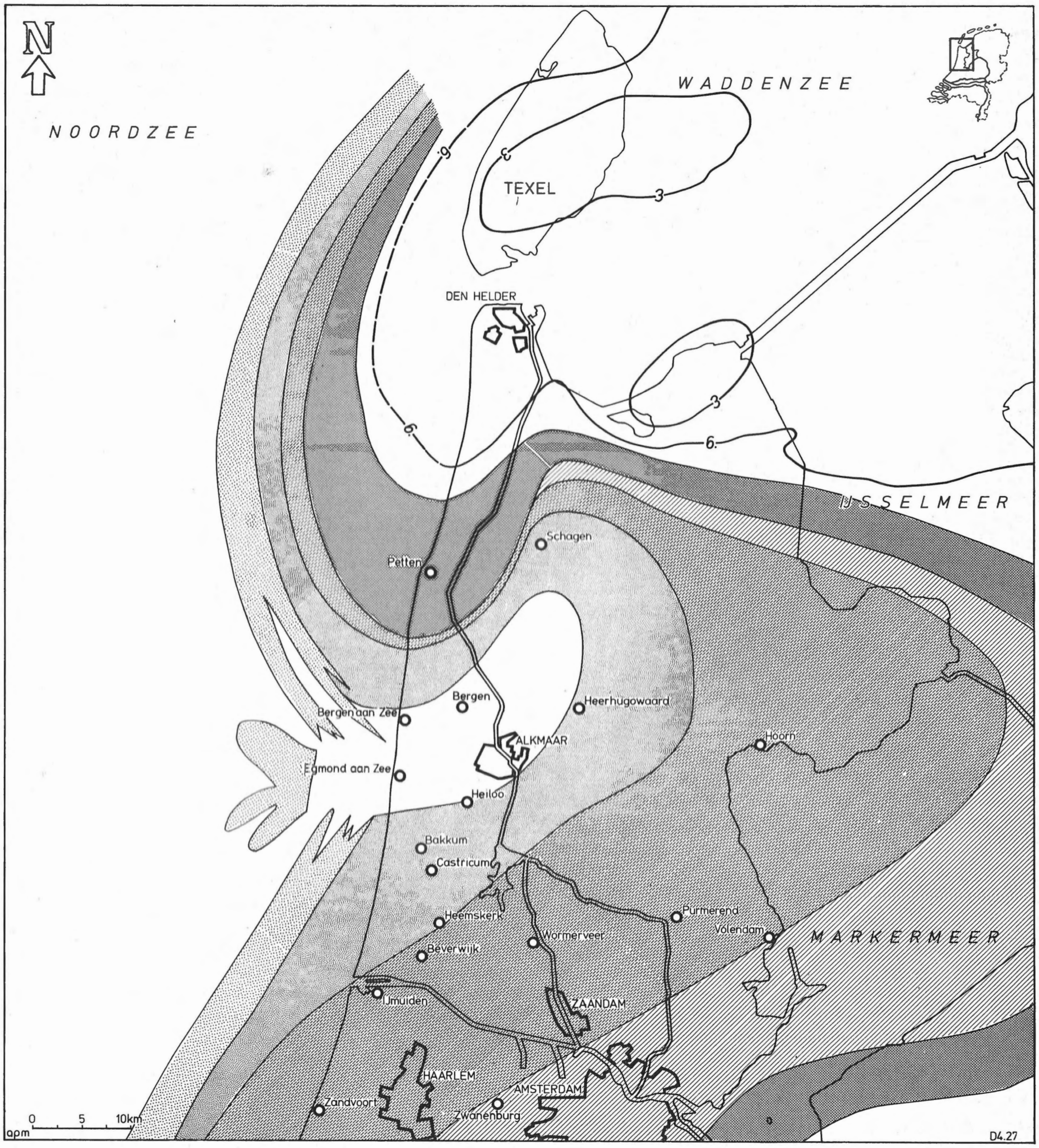


Fig. 14
Palaeogeographical map of the northwestern Netherlands at about 5300 B.P.; sea level about −6 m M.S.L. Eroding phase of the Bergen inlet.

SOURCES OF SEDIMENTS

In general it can be stated that the sediments filling the Bergen inlet have been derived from the North Sea and mixed by eroded Pleistocene material in the off- and onshore zone. The action of waves and tidal currents eroded, sorted and accumulated the sediments. Erosion and accumulation took place during a period of active relative rise in sea level. The extent of this rise can be calculated from the sea-level curve to be at least 4 m (JELGERSMA 1979).

The clay in the Bergen inlet must be derived from the North Sea, as no important river was present to supply mud in the inlet. Only a drainage system of the peat landscape in the hinterland could discharge into the inlet. POSTMA (1961) in his study of sedimentation of clay in the Wadden Sea gives evidences that the net transport and deposition are landward. The latter phenomena is related to the assymetric tidal cycle in the inlet channels, the time between maximum ebb and flood has a shorter duration than between maximum flood and ebb. This results in a consequent transport landwards. In our opinion the clay sedimentation in the Bergen inlet occurred under the same tidal regime as described in the recent Wadden Sea.

The sandy deposits can be divided into two types. North of Bergen relatively coarse grained sands extremely poor in lime are present; south of Bergen finer sands relatively rich in lime

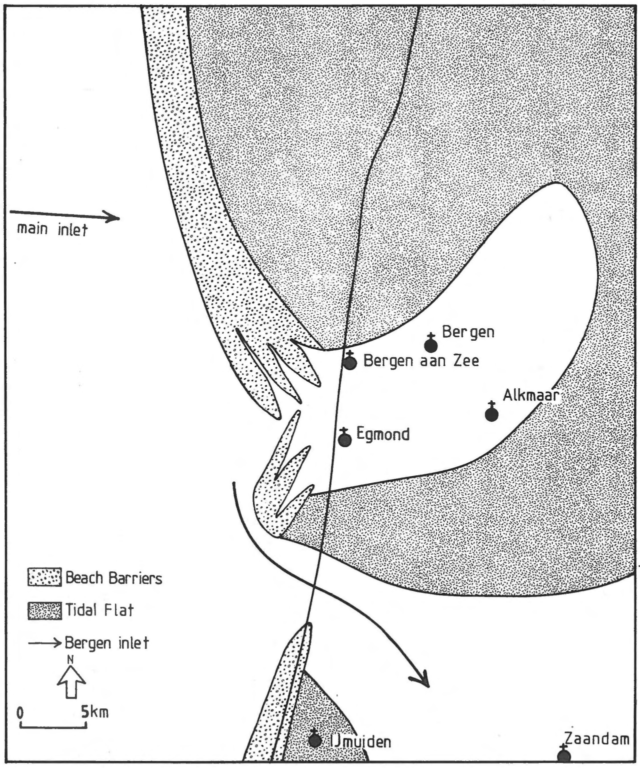


Fig. 15
Palaeogeographical map of the Bergen area about 5000 B.P.; sealevel about −5 m M.S.L. Sedimentation of clay in the deepest part of the Bergen inlet.

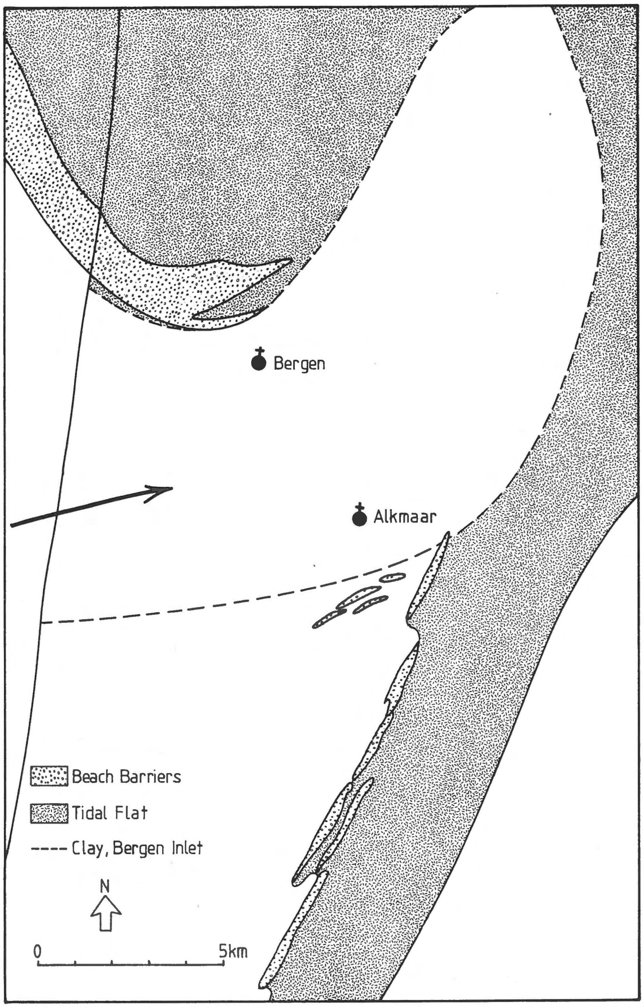


Fig. 16
Palaeogeographical map of the Bergen area about 4700 B.P.; sealevel about −4.50 m M.S.L. Sedimentation of sand in the Bergen inlet, arisen of curved spits north of the Bergen inlet and arisen of the beach barrier of Uitgeest – Akersloot.

are encountered. The latter are derived from the bottom of the North Sea, sorted by waves and accumulated in coastal barriers and dunes. They originate from Pleistocene deposits of the River Rhine (rich in lime).

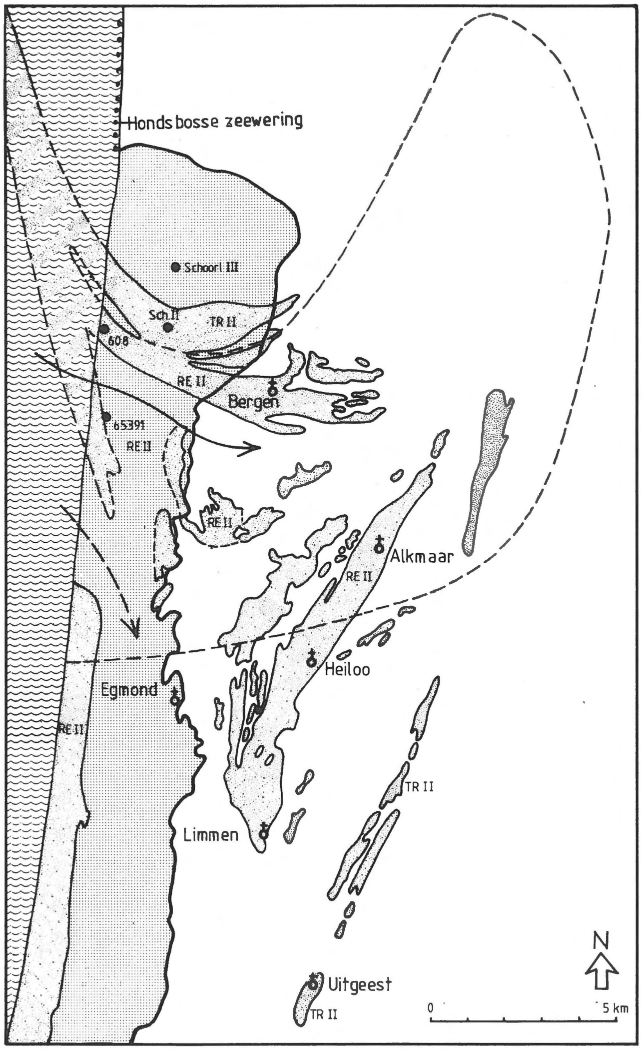
The coarse sands poor in lime are eroded material from the fan-like deposits of the Early Weichselian. This material eroded by waves and currents of the transgressing North Sea was sorted by waves and currents and accumulated in hooked spits and coastal dunes. As mentioned above the source of the Early Weichselian deposits are the Middle and Late Pleistocene deposits, poor in lime, from the north and northeast.

CONCLUSIONS

At the end of the Atlantic a large tidal inlet formed in the Bergen area. The inlet is about 10 km wide. It penetrated deep inland, eroding the underlying Pleistocene deposits. The shoreline north of the inlet was situated much more to the west than the present one; south of the inlet the shoreline is thought to be near the present coast. The origin of the inlet seems to be related to the Pleistocene topography of the area. The inlet has been filled up with sandy clay in the deeper part, overlain by littoral sands and dune sands.

The deposition of the sandy clay in the inlet is thought to have taken place when the shoreline was situated much more to the west than the present one. During the time of deposition of the littoral sands in the inlet the southern shore retreated first far inland followed later by an important progradation in westwards direction. North of the inlet the coast line retreated continuously. The retreat of the coast in this area is going on at the present time with rates varying between 50 and 200 m per century. South of the former inlet coastal recent retreat is less severe; the coastline seems to be more or less stable.

The closure of this large inlet must have had important consequences for the shoreline. During periods of high storm frequency the storage capacity was reduced resulting in high tides and coastal erosion. In the area north of the inlet the erosion and retreat of the shoreline resulted in the formation of several inlets in historical time. The closing of these inlets succeeded after great human effort. The differences in lime



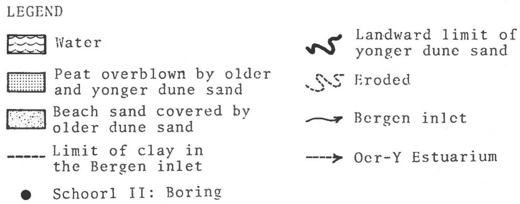


Fig. 17
Compilation of the course of events in the coastal area near Bergen.

and mineralogy of the dune and coastal sands north and south of the Bergen inlet are contributed to the high lying Pleistocene deposits in the area north of the inlet that became subject to erosion during the Holocene transgression. These sediments have a northeastern origin in contrast to the Pleistocene sediments south of the inlet which originated from Pleistocene Rhine-Meuse deposits.

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