

UPPER CENOZOIC OF THE SOUTHERN NORTH SEA BASIN: PALAEOCLIMATIC AND PALAEOGEOGRAPHIC EVOLUTION

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ABSTRACT

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An outline is presented of Neogene and Quaternary biozonation and lithostratigraphy of the southern North Sea Basin. The maps showing the thickness distribution of the Upper Miocene deposits and the depth contours of the base of the Quaternary depict the basin evolution. The pattern of basin development in the Quaternary differs distinctly from that in Neogene times; resemblance with the pattern in Mesozoic times is ascribed to reactivated downwarping in areas of much earlier, namely Mesozoic, basin development.

Considerably greater amounts of sediments were accumulated per time unit in the southern North Sea Basin during the Quaternary as compared to the Neogene.

INTRODUCTION

The southern part of the North Sea Basin, which is the area covering the present mainland of The Netherlands and the adjacent part of the southern North Sea, has experienced a long and complicated evolution. The latest part of this evolution, taking place in the Neogene and the Quaternary, will be discussed.

The main structural elements relevant to the mentioned period are shown in figure 1 (sources have been AHORNER, 1962; VAN MONTFRANS, 1975). The area with pre-Tertiary rocks under a thin cover of Quaternary sediments is shaded. This area was structurally high during Tertiary and Quaternary times. The NW-SE fault system, extending into the Lower Rhine Embayment, delimits the deep Central Graben, the Peel Horst and the shallow Venlo Graben. This fault system was active in the Oligocene and movements along the faults have, according to some authors, resulted in the formation of the Upper Rhine Valley Rift Graben (ZIEGLER, 1975). Towards the NW, the faults fade away and instead of

horst and graben structures, basins and swells are present. The Zuiderzee Basin, which is located in the NW extension of the Venlo Graben, was subsiding in the Neogene as well as in the Quaternary. Three other basins, indicated as West Netherlands Basin, Broad Fourteens Basin and Vlieland Basin, developed in the Quaternary as a result of re-activated subsidence of much older, namely Jurassic-Lower Cretaceous tectonic lows.

The Upper Cenozoic sediments of the southern North Sea Basin have been deposited in marine and continental facies. A correct stratigraphical correlation between the deposits of the two facies is an essential requirement for an understanding of the basin development.

BIOSTRATIGRAPHIC ZONATION

Foraminiferal, molluscan and palynological studies executed at the Geological Survey of The Netherlands (DOPPERT, 1975; SPAINK, 1975; ZAGWIJN, 1960) have permitted biostratigraphical zonations of the marine and continental beds. Palynology in particular, has proved to be useful for correlations between sedimentary rocks in continental and marine facies.

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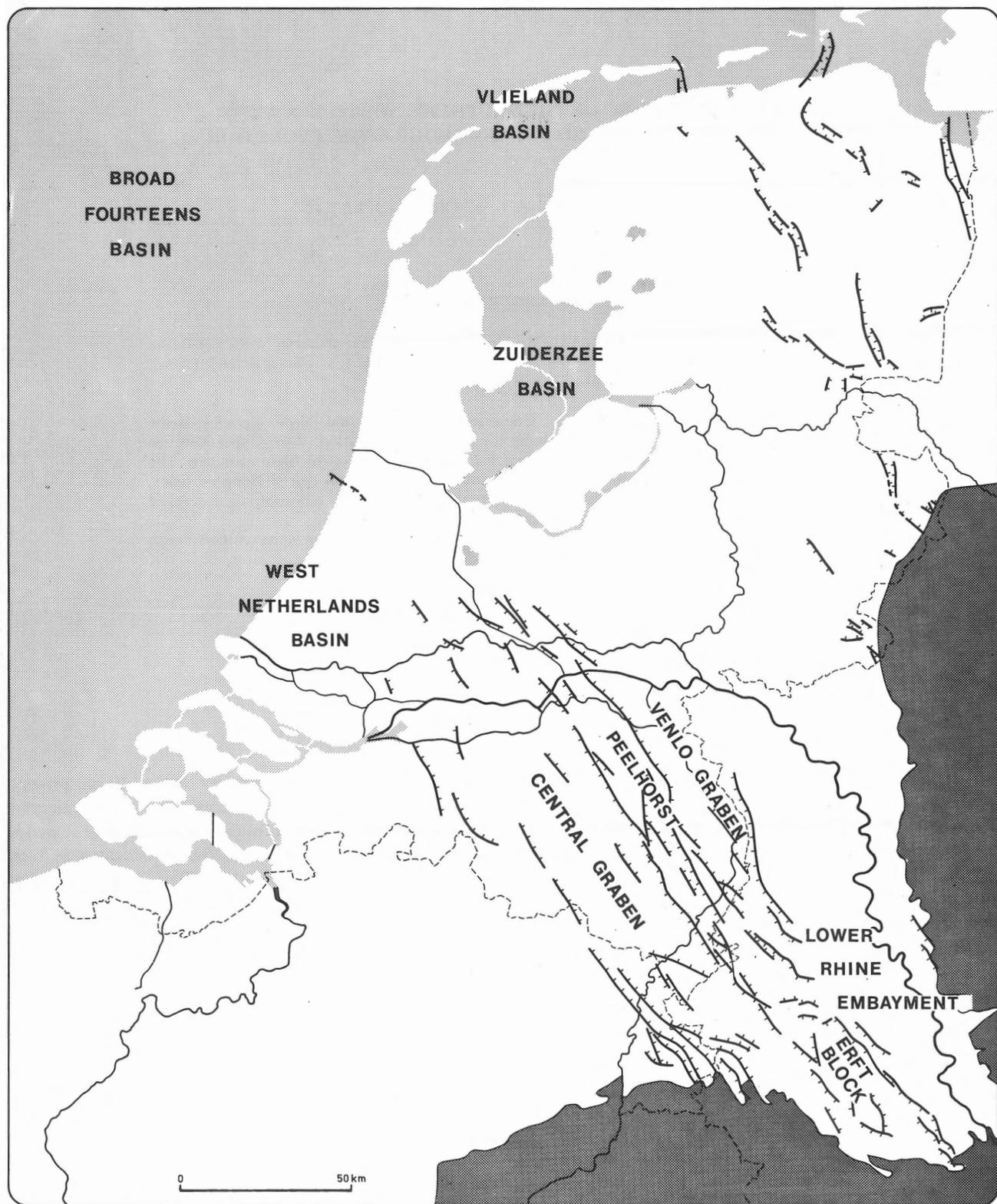


Fig. 1
Tectonic units of the southern North Sea Basin active in Neogene and Quaternary times.

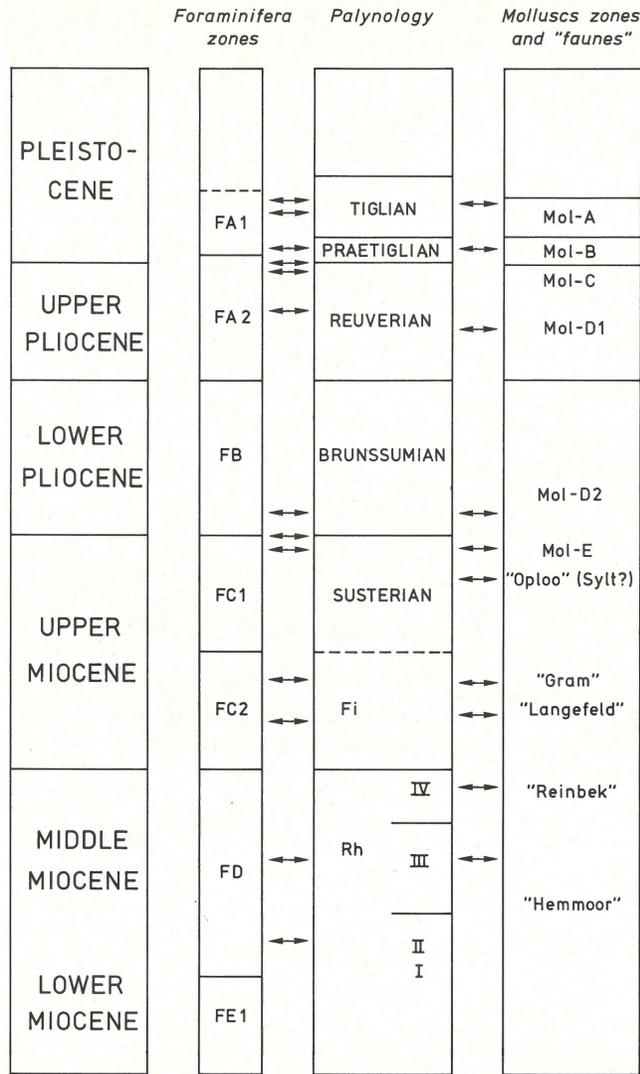


Fig. 2 Biostratigraphic zonations of the Neogene and Early Quaternary in The Netherlands (according to Doppert, Spaink & Zagwijn, 1975; with modifications).

In figure 2 the biozonations of the Neogene and Lower Pleistocene beds are compared. The arrows indicate direct (first order) correlations between the zoning-systems by means of palynology. Foraminiferal data have proved to be useful in correlating marine sediments throughout the basin, whereas results of molluscan studies have appeared to be most suitable for correlations in former nearshore regions.

The age assignments presented in the table are conventional, but it has to be pointed out that correlation with the Thethys area is in various instances doubtful or impossible. Therefore terms as Middle Miocene, Late Miocene etc. in this paper should be regarded as substitutes only for zonal names in the actual biostratigraphic classification.

Biostratigraphic subdivision of the Quaternary in The Netherlands is mainly based on pollen-analytical studies,

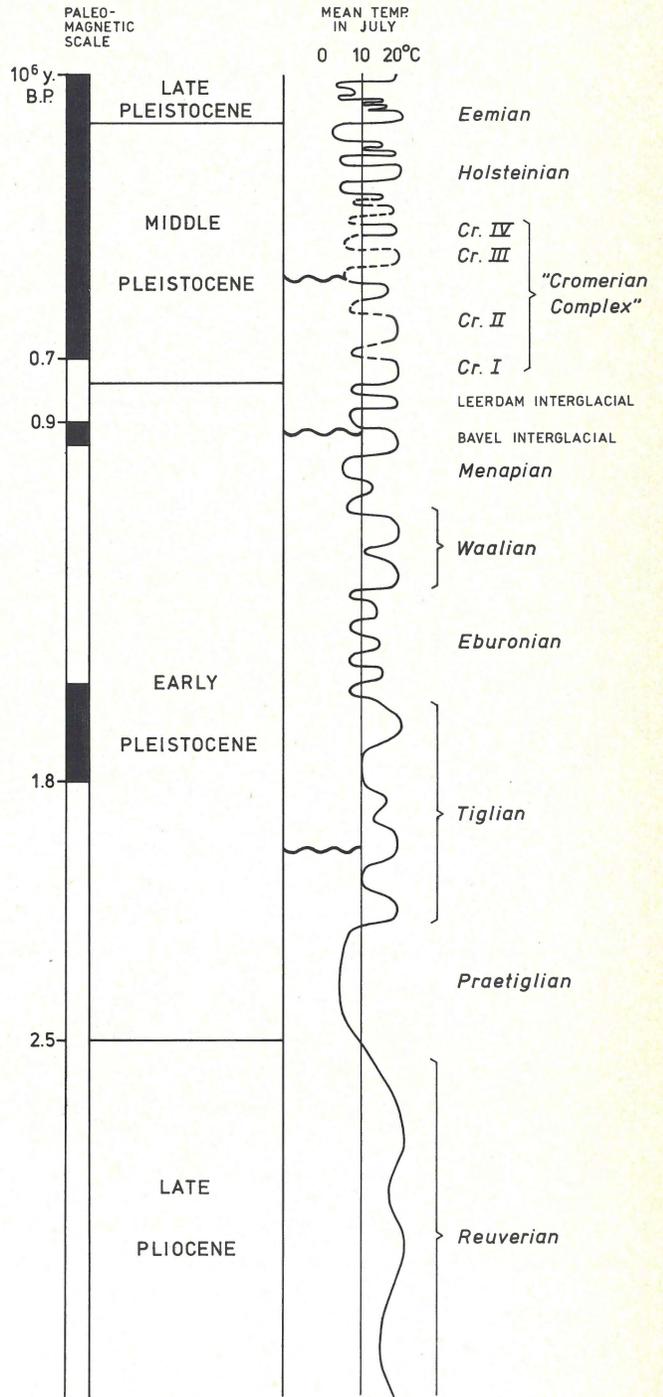


Fig. 3 Palaeoclimatic curve of the Pleistocene (from Zagwijn, 1975; with modifications).

which have revealed many details on the palaeoclimatic evolution (e.g. ZAGWIJN, 1975). A set of formal stage names related to warm-temperate (interglacial) and cold (glacial) climatic episodes has been established (VAN DER VLERK, 1957; VAN DER HEIDE & ZAGWIJN, 1967). Since more data have been obtained from palaeobotanical research it has become evi-

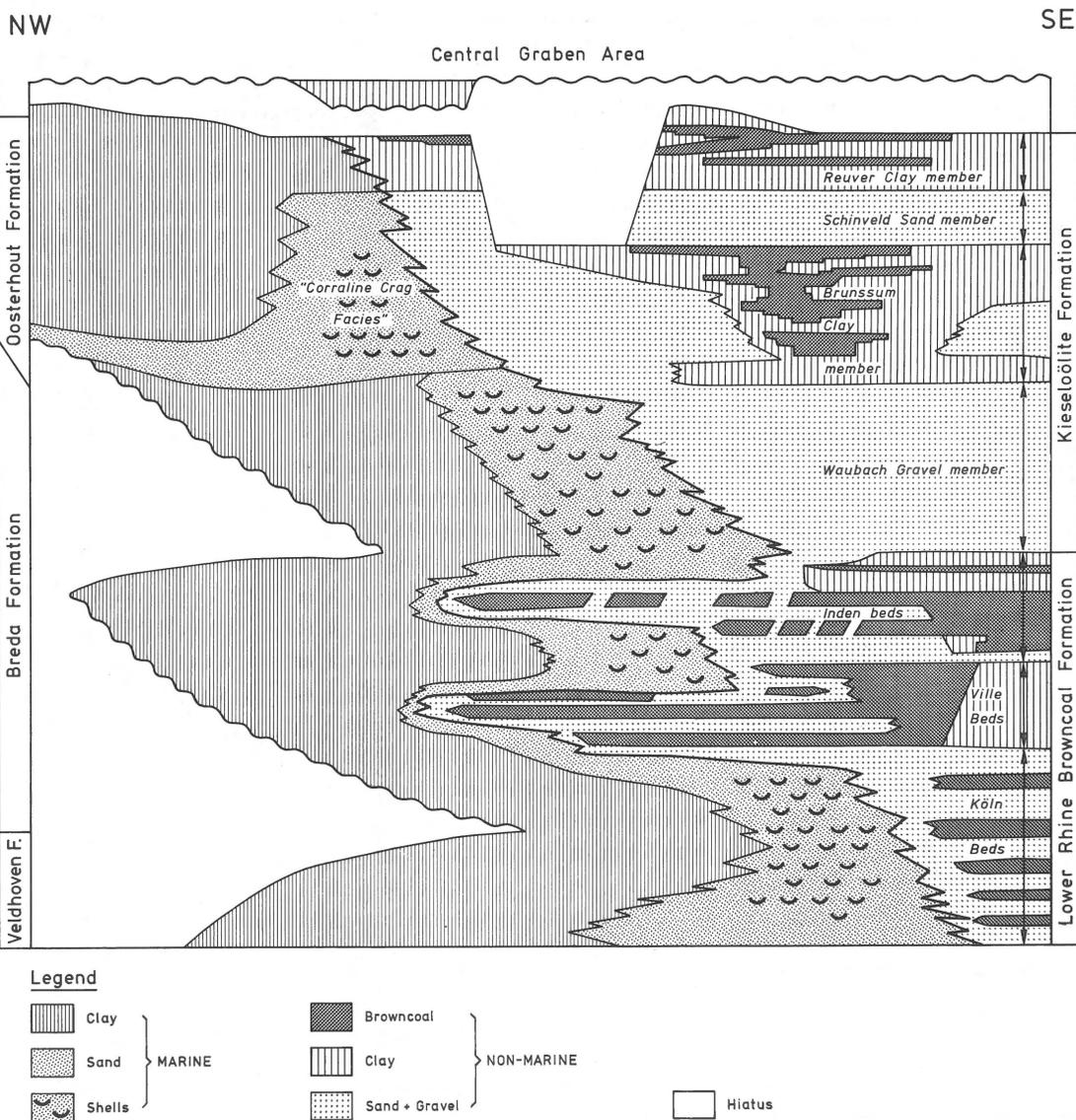


Fig. 4
Lithostratigraphy of the Neogene beds in the Central Graben area of The Netherlands and the adjacent Lower Rhine Embayment in Germany.

dent that the climatic evolution is more complex than initially thought. Several of the stages originally established, are actually complexes of several alternating cooler and warmer episodes. This holds especially true for the so-called 'Cromerian-complex', which to date is assumed to comprise four warm-temperate episodes of the same character as true interglacials of later Pleistocene times. Recently it has become apparent, that also in the upper part of the Early Pleistocene, at least two additional warm-temperate stages are present, characterized palaeobotanically by the same assemblage of exotic species, hitherto considered indicative only of the

Tiglian and Waalian temperate stages. The deposits in which exotic species occur clearly overlie deposits of Waalian age. For the time being, no stage names have been assigned to these newly found interglacials but they are indicated provisionally as Bavel interglacial and Leerdam interglacial.

Figure 3 presents the climatic curve as constructed on the basis of data from The Netherlands. Basically it is very similar to the curves reflecting changes in the ratio of the oxygen isotopes ^{16}O and ^{18}O as obtained from the study of deep-sea cores (SHACKLETON & EMILIANI, 1974; SHACKLETON & OPDYKE, 1976).

NEOGENE AND QUATERNARY LITHOSTRATIGRAPHY

The main lithostratigraphic relations between and characteristics of the Neogene sediments in the Central Graben area are shown in figure 4. In the southeast the sequence is completely continental, in the northwest the beds are entirely marine. Upper Oligocene to Middle Miocene continental beds consist of sands, clays and several lignite horizons and are included in the Lower Rhine Browncoal Formation. Subdivisions of these beds have been discussed extensively in published articles (ref. HAGER, 1966; and this volume).

Of particular interest is the presence of the so-called Main Seam or Ville Member, which reaches a maximum thickness of nearly 100 metres in the Erft region of the Lower Rhine Embayment. This seam splits into a number of smaller individual seams towards the NW, some of which can be traced as far to the west as in The Netherlands, where they interdigitate with marine beds of Middle Miocene age (foraminiferal zone FD). Below as well as above these browncoal seams, marine beds of Early to Middle Miocene age are found as far east as the area of Straeten, i.e. east of the present German-Dutch frontier.

In general these marine beds consist of very glauconiferous shelly sands deposited in former nearshore areas, and glauconiferous clays laid down in offshore regions. In the extreme west, beds of Early and Middle Miocene age are absent due to a sedimentary gap.

The marine beds of Late Miocene age are lithologically similar to those of the Early and Middle Miocene and are therefore included in the same formation, i.e. the Breda Formation.

Late Miocene beds are also absent in the extreme west due to a sedimentary gap; deposits of this age consist more to the east of glauconiferous clays or shelly greensand of a nearshore facies. Contemporary with these marine beds are two series of continental beds in the southeast, namely clays and lignites of the upper part of the Lower Rhine Browncoal Formation (Inden Member or part of it), overlain by a thick series of fluvial gravels. These gravels (Waubach gravels of The Netherlands, Main Gravel of Germany) are considered to constitute the basal member of the Kieselöölite Formation, which was laid down by an ancient River Rhine; the upper course of this river did not reach yet into the Alpine foreland (BOENIGK, 1978).

In Late Miocene times continental sedimentation progressed gradually to the northwest, resulting in regression of the sea.

At the transition from the Miocene to the Pliocene the sediments deposited by the River Rhine changed from coarse grained to predominantly fine grained. A thick series of clays with interbedded lignites and some beds of sand and gravel was laid down in Early Pliocene times. These beds are included into the Brunssum Clay Member of the Kieselöölite Formation.

The above mentioned Waubach Gravel and the Brunssum Clay represent a major sedimentary cycle. At stratigraphically higher levels more such sedimentary cycles occur in the sequence deposited by the River Rhine (Schinveld Sand overlain by Reuver Clay of Late Pliocene age; Belfeld Gravel and Belfeld Clay; Tegelen Gravel and Tegelen Clay of Early Pleistocene age). ZAGWIJN (1963) assumed these sedimentary cycles to be related to tectonic movements intermittently resulting in uplift of the Central European hinterland.

The above mentioned Pliocene fluvial deposits interfinger with a series of marine deposits grouped together in the Oosterhout Formation. The lower part of the latter formation is generally sandy, the upper part consists of clay. The glauconite content is distinctly lower than in the underlying Breda Formation, and therefore the deposits of the Oosterhout Formation are less greenish: predominantly greyish to white. The beds laid down in previous near-coastal environments are very shelly and at present known as 'Coralline Crag'. This 'Coralline Crag' which contains abundant shells and bryozoans, is similar to the Coralline Crag of East Anglia, and has appeared to be of the same age according to biostratigraphic correlations. The topmost clay of the Oosterhout Formation is the marine equivalent of the Reuver Clay deposited in a fluvial environment and is therefore likewise of Late Pliocene age. A wide-spread hiatus at or close to the Plio-Pleistocene transition is noticeable in marine as well as fluvial sedimentary sequences. This hiatus probably resulted from erosion subsequent to tectonic uplift in the basin, possibly in addition to glacio-eustatic sea-level changes related to the first glacial episode of the Quaternary. The exact age of the gap varies strongly from place to place.

In the Quaternary sequence many formations have been established and described in detail some years ago (DOPPERT ET AL., 1975). The scheme presented here in figure 5 is based on these data, though all names of formations have been omitted for convenience' sake. The following outline may be given.

In the beginning of the Pleistocene marine beds were deposited in the same depositional areas as those in Neogene times. A swift regression took place in the Late Tiglian and marine influence remained absent until far in the Middle Pleistocene. In the later part of the Middle Pleistocene and during the Late Pleistocene, tongues of marine deposits related to interglacial marine transgressions were formed. Fluvial sedimentation became predominant. Lithologic examinations and sedimentary petrographic studies (mainly by heavy mineral and gravel analysis) have made possible a detailed lithostratigraphic subdivision of these fluvial beds. This subdivision is among others based on the provenance of deposits. They may have been supplied by the River Rhine (which reached into the Alpine molasse area since the latest part of the Pliocene: BOENIGK, 1978), the River Meuse, other smaller southern rivers such as the River Scheldt and its predecessors, or in the Early Pleistocene and earliest Middle Pleistocene by rivers from the east and northeast, including

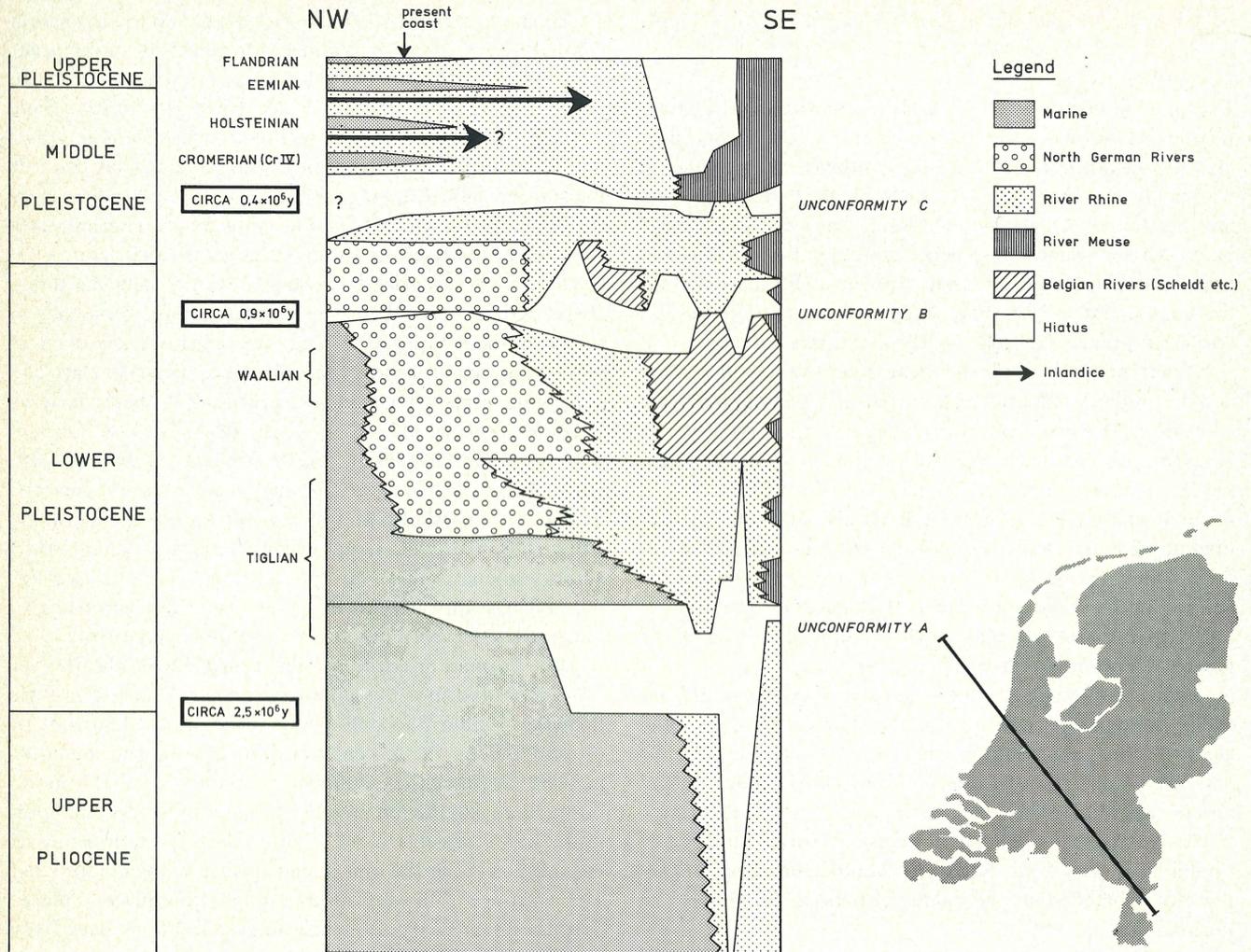


Fig. 5
Lithostratigraphy of the Quaternary in The Netherlands.

predecessors of the present North-German rivers Elbe and Weser, but probably mainly by a large river system draining the Baltic region.

Except for the Plio-Pleistocene unconformity discussed earlier, two more regional unconformities were formed in the Quaternary. One at the transition of Early to Middle Pleistocene times and another formed in a later phase of the Middle Pleistocene. Beds above the latter unconformity contain elements indicating the presence of inland ice from Scandinavia close to or partly covering the area under discussion.

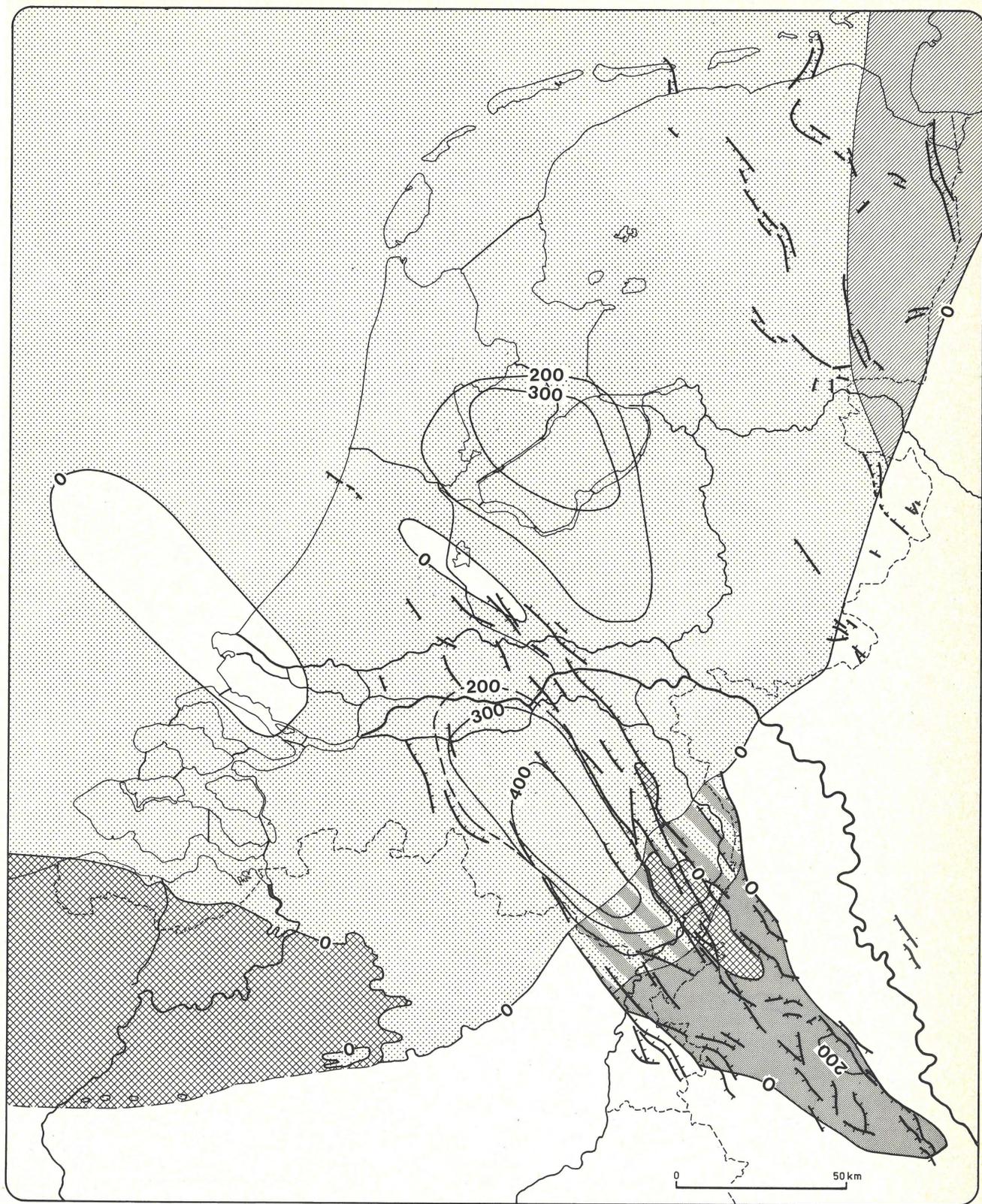
BASIN DEVELOPMENT AND PALAEOGEOGRAPHY

A brief account of the basin development in the Neogene and Quaternary is presented, and illustrated by two maps, selected from a series of maps available.

The first map shows the thickness distribution of Upper Miocene deposits (Fig. 6). The patterns of thickness distribution of the deposits of most of the Neogene stages are similar to that of the Upper Miocene. In the Lower Rhine Embayment and adjacent parts of the Central Graben and the Venlo Graben a fan of fluvial sediments is present in the Late Miocene. During this stage the boundary between the fluvial and the marine sedimentation areas shifted to the NW. The sequence of marine Upper Miocene sediments in the Western Netherlands and the adjacent offshore area is

Fig. 6
Upper Miocene: isopachs and facies distribution (Zones FC and Fi + Su).

- 1: marine facies.
- 2: fluvial facies.
- 3: marine facies overlain by fluvial facies.
- 4: marine facies overlain by brackish facies.
- 5: Upper Miocene removed by later erosion.



LEGEND



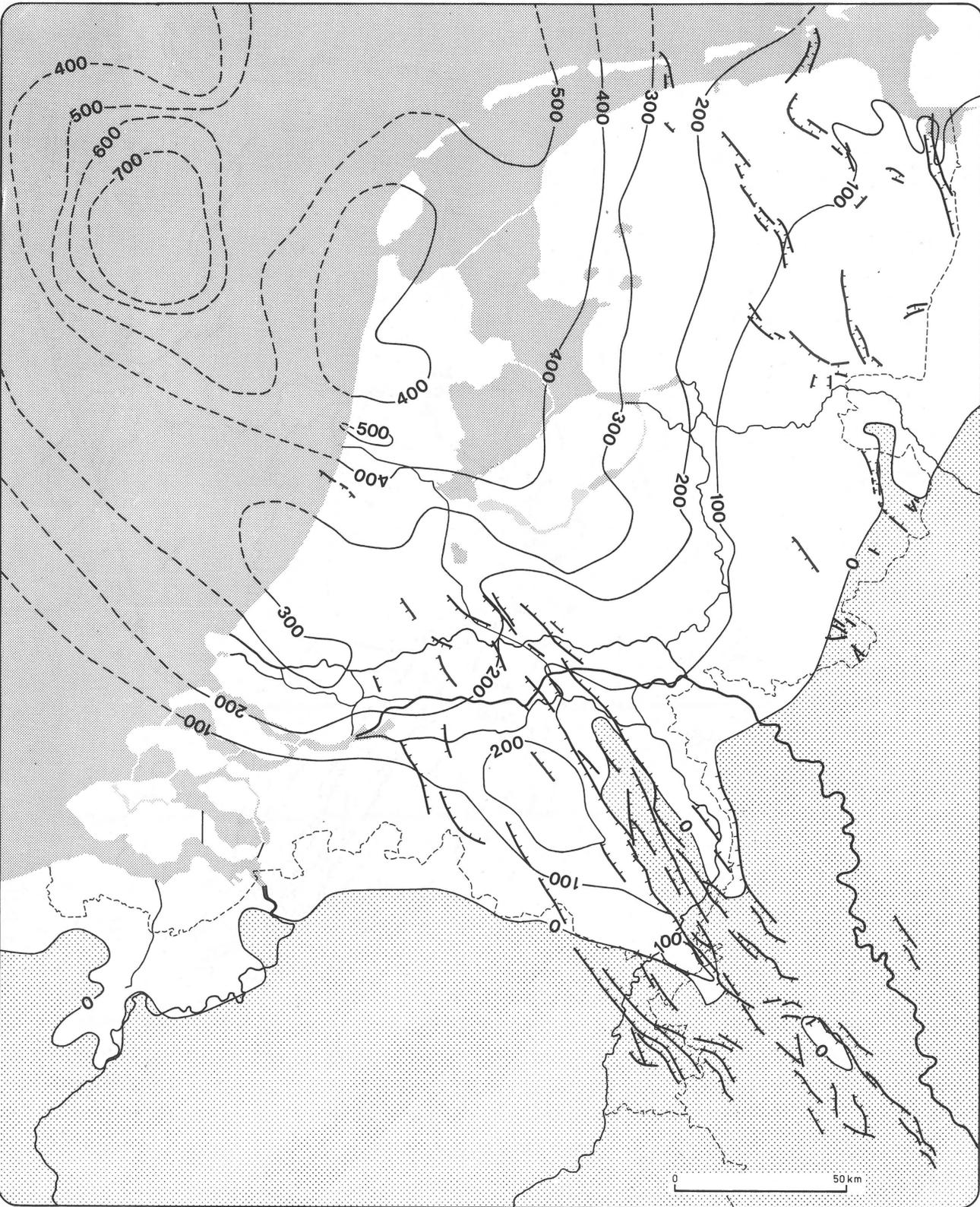


Fig. 7
Depth contours of the base of the Quaternary (offshore area according to Caston, 1977; with modifications).
1: base Quaternary above present sea level.

very thin or even absent. Of particular interest is the presence of erosion remnants of Upper Miocene beds in Southern Flanders which has led to the assumption of a southward transgression of the North Sea during the Late Miocene; however, the sediments deposited by this sea between the hills of South Flanders and the southern part of The Netherlands have apparently been removed by later erosion.

The two hundred metre isopachs encompass two areas of strong accumulation, one in the Central Graben and one in the Zuiderzee Basin. Also in the Erft Block a relatively strong accumulation area is present. Areas of strong accumulation were also present in the Central Graben and in the Zuiderzee Basin during the Early to Middle Miocene and during the Early Pliocene. Detailed observation, however, shows that the centres of strong accumulation shifted since Middle Miocene time to the northwest in the same direction as the shift of coastlines in the Central Graben and in the Venlo Graben since that time.

From the observed phenomena it is apparent that the strongest accumulation of sediment has taken place in the nearshore marine environment in front of former deltas in subsiding areas. The waterdepth in which the marine beds were deposited during the Neogene was less than about one hundred metres, and in nearshore areas even considerably less. For this reason it is evident that the areas of excessive accumulation in the two areas mentioned were also areas of considerable subsidence.

According to data at present available, the pattern of accumulation and subsidence began to change during the Late Pliocene; unfortunately it is not yet possible to present maps illustrating this phenomenon.

The pattern of subsidence and sediment accumulation changed during the Quaternary as depicted on the map showing the depth contours of the base of the Quaternary below present sea level (Fig. 7). This map has been constructed on the basis of onshore well information available, and data on the offshore area of CASTON (1977) supplemented with some other information.

Thicknesses of over 200 metres are present over a large, even considerably larger area than in corresponding stages of the Neogene.

The following tectonic lows stand out clearly:

- (1) Erft Fault Block.
- (2) Central Graben area near Eindhoven.
- (3) Zuiderzee Basin and Vlieland Basin, which are in the southern extension of the Central North Sea Graben.
- (4) West Netherlands Basin, apparently a new feature.
- (5) Broad Fourteens Basin, also a new feature.

The basins mentioned under (4) and (5) were tectonically quiet areas in Neogene times; they were areas of subsidence during Jurassic and Early Cretaceous times (HEYBROEK, 1974). Inversion of the two basins took place at the end of the Mesozoic and the beginning of the Tertiary and they resumed subsidence in the Quaternary.

The Quaternary sediments are of a shallow marine or continental facies; consequently, the thickness of accumulated sediments is commensurate with the amount of subsidence. In view of the relatively short duration of the Quaternary (about 2.5 million years) as compared to the stages of the Neogene, rates of subsidence were much higher during the Quaternary than in the preceding period.

Since the Neogene until the end of the Middle Tiglian part of the present mainland of The Netherlands was covered by sea. In a relatively short time span, however, the sea retreated, and in the Late Tiglian and Waalian the coastline was in the present offshore area more or less parallel to the present coastline, and the mainland consisted of a huge delta built up by the rivers Rhine and Meuse and rivers from the northeast. During that time the Broad Fourteens area witnessed particularly strong accumulation of marine sediments. It has appeared that in Quaternary time, as also in Neogene times, the strongest accumulation and subsidence took place in nearshore areas in front of deltas.

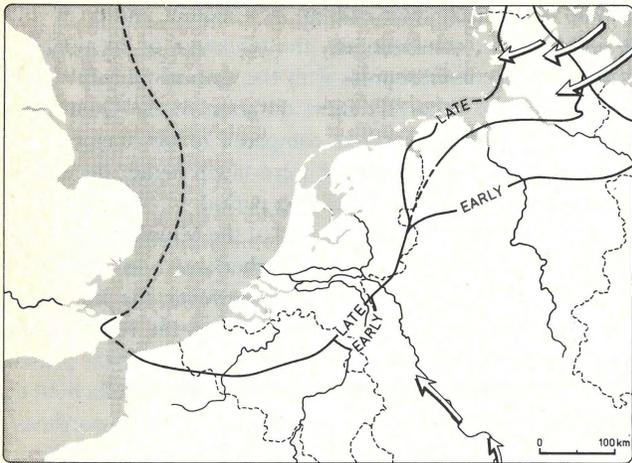
In the Middle Pleistocene the sea withdrew completely from the area under consideration and marine deposits were, as far as known to date, only laid down to the north of the southern North Sea Basin. Possibly during that time the Quaternary sediments in the central North Sea area, as reported by CASTON (1977), accumulated to a thick sequence.

In figure 8 the evolution of the coastlines and main areas of fluvial sedimentation in the southern North Sea Basin and adjacent areas is summarized in a number of selected maps representing the changing palaeogeography since the Late Miocene. In the beginning of the Late Miocene the sea extended over large areas of Northern Germany (HINSCH, 1970, 1974; RASMUSSEN, 1961; SPIEGLER, 1974), The Netherlands (VAN VOORTHUYSEN, 1963) and Belgium (TAVERNIER, 1954). In Southeastern England also some marine deposits of this age occur (Lenham Beds: EDMUNDS, 1954).

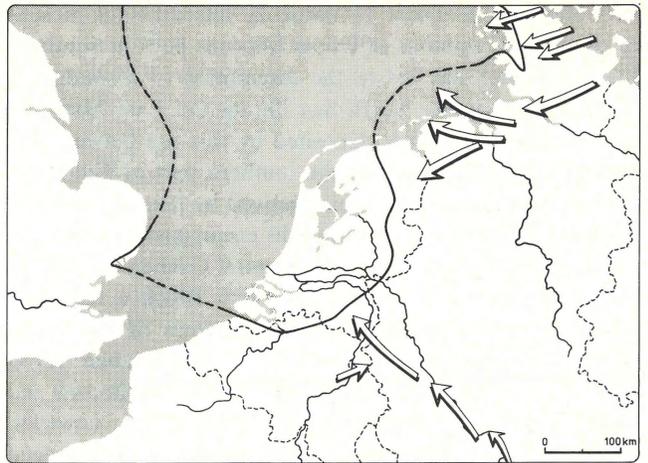
During the Late Miocene the sea regressed, in particular from the area bordering the present German Bight, until in the Early Pliocene marine conditions persisted only in the surroundings of Sylt (HINSCH, 1974). In Northern Germany marine sedimentation discontinued and mainly fluvial deposits (so-called kaolin sands) of northeastern provenance were laid down. These deposits, also present in the northeastern part of The Netherlands have been dated Early Pliocene (Brunssumian) by means of pollen analyses; the same age was obtained from datings of the deposits from Sylt (WEYL ET AL., 1955). The palaeogeographic reconstruction presented shows that these fluvial deposits probably occur as a deltaic fan in the subsurface of the present German Bight.

In the Southeastern Netherlands and the adjacent part of the Lower Rhine Embayment fluvial deposits of the River Rhine were laid down, whereas in Belgium the sea regressed and covered a more restricted area than during the Late Miocene (TAVERNIER, 1954).

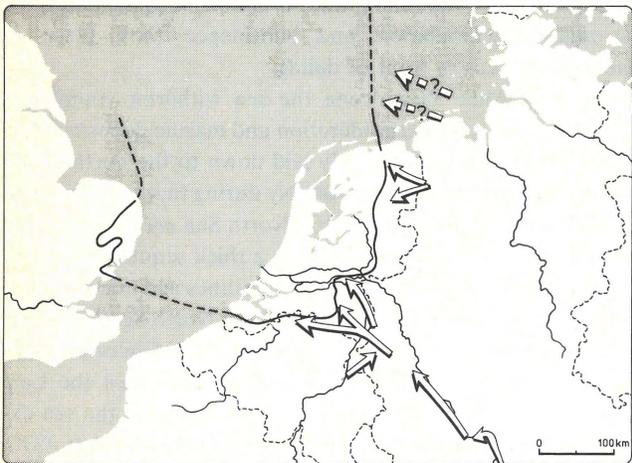
In England, finally, beds of Early Pliocene age showing



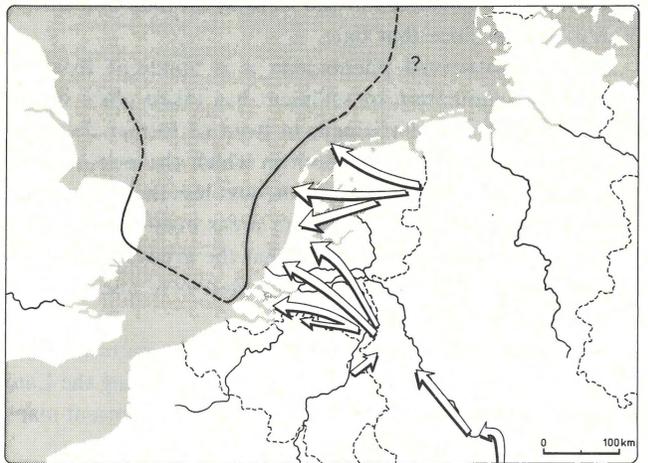
Late Miocene (FC)



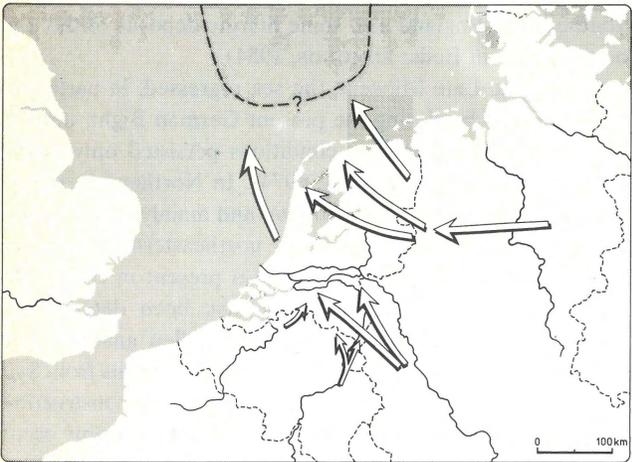
Early Pliocene (FB)



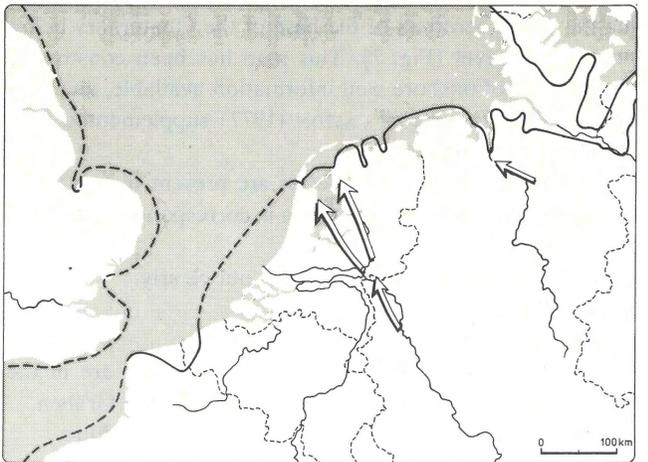
Early Pleistocene I (Middle Tiglian)



Early Pleistocene II (Late Tiglian)



Middle Pleistocene I (Early 'Cromerian')



Middle Pleistocene II (Holsteinian)

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- 2

Fig. 8 Evolution of coastline and fluvial sedimentation in the southern North Sea area and adjacent regions from Late Miocene to Middle Pleistocene.
1: coastline.
2: main flow direction of rivers.

the characteristic Coralline Crag facies occur in East Anglia and adjacent areas (CHATWIN, 1961). This facies extends into the area of near-coastal marine sedimentation during the Early Pliocene in The Netherlands.

In the earliest part of the Early Pleistocene the palaeogeography remained similar to that of the Pliocene, with the exception of the North German Lowland and the North-eastern Netherlands, where fluvial deposits of northeastern provenance occurring in the subsurface suggest a more westward shifting of the large deltaic fan since the Early Pliocene. In East Anglia the area of sediment accumulation shifted to the north at the beginning of the Pleistocene. In the Late Tiglian, about 1.8 to 1.6 million years ago, the palaeogeography changed rather drastically; a large deltaic fan was formed by the combined northeastern rivers and the rivers Rhine and Meuse and this fan extended over the entire mainland of the present Netherlands. Only in East Anglia marine sediments of this age occur at present (WEST, 1968). Delta fan building during the Early Pleistocene resulted in narrowing of the southern part of the North Sea until in the earlier part of the Middle Pleistocene (interglacials I and II of the 'Cromerian complex') the sea had withdrawn completely and could not, even during interglacial high sea-level stands penetrate into this part of the North Sea Basin. In a later phase, however, the southern part of the basin could be flooded again during interglacial high sea-level stands. In the Holsteinian the sea transgressed over parts of the German lowland which had not been flooded since the Late Miocene. During the last mentioned interglacial an initial connection with the open ocean through the Straits of Dover may have existed (Sommé and Paepe & Baeteman in: OELE ET AL., in press).

CONCLUSIONS

The palaeogeographic evolution discussed above, showing gradual narrowing of the southern part of the North Sea since Late Miocene time until complete retreat of the sea in the early part of the Middle Pleistocene, may be assumed to be the result of epirogenetic uplift or tilting of the Central European hinterland, and the changing pattern of subsiding areas in the basin proper. Epirogenetic uplift of the hinterland increased in intensity particularly during the early Middle Pleistocene (ZAGWIJN, 1963). Probably the enlargement of deltas in the later part of the Early Pleistocene may be attributed to increased sediment supply by the rivers draining the hinterland of Central Europe. One of these rivers, the River Rhine, enlarged its source area progressively (BOENIGK, 1978). In the Middle Miocene the Rhine was a local river draining the Rhine Slate Plateau; during Late Miocene and Pliocene times the upper reaches migrated to the Upper Rhine Graben area and were in the Alpine molasse foreland since latest Pliocene time; finally in the Middle Pleistocene the upper course of the Rhine had reached the inner Alpine

region. Another river system, draining the Scandinavian shield and running through the Baltic area to the North Sea, existed since the Pliocene until the early part of the Middle Pleistocene. In a later phase this drainage system vanished and was replaced by the present North German rivers, which previously may have been only tributaries of the larger north-eastern river system.

A feature of particular interest is the increased supply of sediments per time unit to the basin during the Quaternary as compared to that in the Neogene. This increase is roughly estimated to have been in the Early Pleistocene ten times the sediment supply in the Neogene.

In the Neogene the main sedimentation area was in a marine nearshore environment in front of deltas in tectonically subsiding areas, and during at least the earlier part of the Quaternary the data available indicate similar phenomena; during the latter time, however, areas of basin subsidence had shifted to the west and to areas of much earlier namely Mesozoic basin development which were tectonically quiet areas during the intervening Neogene.

Inland ice from Scandinavia did not reach the area discussed prior to the later part of the Middle Pleistocene.

The particular character of the southern North Sea Basin in the Quaternary as compared to that in the Neogene has been evidently the result of epirogenetic uplift of the hinterland together with increased subsidence in a narrowing basin in the present western part of The Netherlands and the adjacent offshore area.

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