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THE QUATERNARY GEOLOGY OF THE SOUTHERN AREA OF THE DUTCH PART OF THE NORTH SEA.[1)]

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ABSTRACT

A map of the southern area of the Dutch part of the North Sea is presented. The geological history of the Quaternary can be summarized as follows.

During the Late Tertiary and Early Pleistocene sedimentation of fine sands and clays took place in a marine environment. Gradually the westwards progradation of the "Rhine-Meuse" delta caused these sediments to be covered by a veneer of fluviatile sediments of about the same grain size. In the Middle Pleistocene the sediments became coarser, but were still of fluviatile origin.

Meltwater clay of the Elsterian glaciation, present in the north, marks the first observed interruption of the fluviatile sequence. After the Holsteinian interglacial, the Saalian glaciation reshaped the topography, creating ice-pushed and morainic ridges.

During the Eemian interglacial a marine environment persisted, whilst the marine sedimentary series was closed by the deposition of a fresh water clay in the Early Weichselian.[3)] Later during this cold phase the coversands were formed in the north, the Kreftenheye Formation being deposited by the Rhine in the south.

The Holocene sea level rise resulted in the deposition of the Lower Peat Bed and a cover of tidal flat sands on top of which, after a period of non-deposition, the young seasand was deposited.

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1) With colored map.

2) Netherlands Geological Survey, P.O. Box. 157, Haarlem.

3) Although the term Würmian is preferred in this issue, the term Weichselian is maintained in the present paper to be in harmony with the map, the legend of which was printed before (editor).

INTRODUCTION

In close co-operation with the Department of Harbour Entrances of the Rijkswaterstaat the Netherlands Geological Survey is carrying out an extensive geological investigation of the North Sea area. The results of the investigations in the area north of the Frisian Isles were presented earlier (O e l e, 1969, 1970). The data collected in the southern half of the Dutch part of the North Sea has lead to a geological map of that area, the discussion of which is presented in this paper.

The sampling equipment used consists of two types of vibracorers, which have produced undisturbed samples up to 6 metres long and disturbed samples up to 10 metres long. In addition samples from rig-site investigations have been placed at our disposal by the various oil companies.

Various surveys have also been made by means of a sonic profiler, the Sonia. The sampling stations as well as the lines surveyed with Sonia are shown on fig. 1.

The pollen dating of the various deposits by Zagwijn has been of fundamental value and the determination of sedimentary environments from diatom and ostracod analyses by du Saar was important for the interpretation of the results.

Since the most recent layer of sediments, the young seasand, varies greatly in thickness (0-10 metres), the geologic map (Plate I) shows only the deposits underlying this horizon.

Because the investigation is still going on, publications of the interpreted data are to be considered as progress reports.

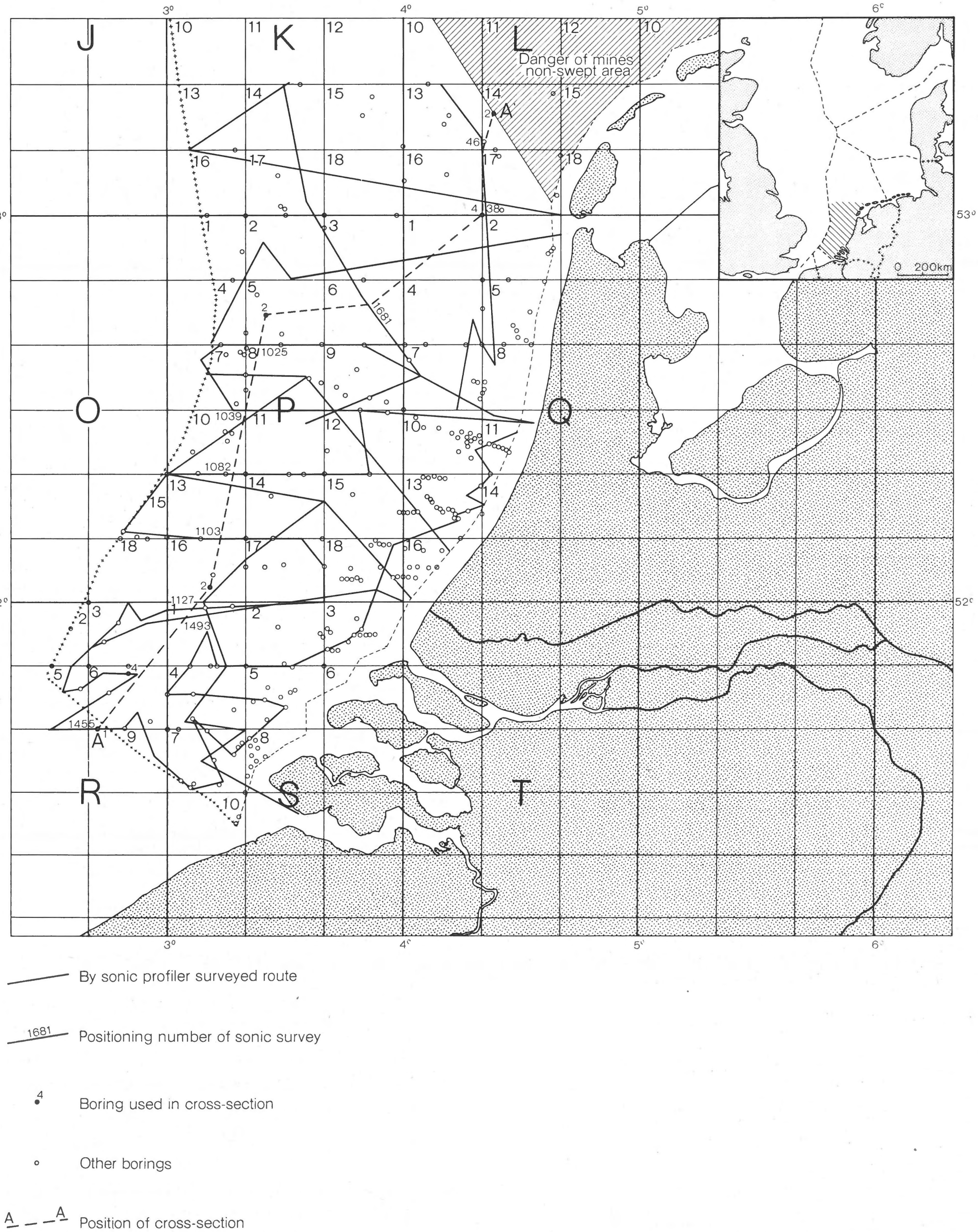

Fig. 1
Area of investigation with location of borings and lines surveyed by sonic profiler.

THE QUATERNARY GEOLOGY OF THE WESTERN NETHERLANDS

Already from the geology of the western Netherlands we know, that most of the Quaternary formations are likely to extend beyond the present coast line into the area under investigation. Therefore, a short review of the geological history of the western Netherlands from the Tertiary onwards will be given. More detailed information on this subject is presented in a publication of de Jong (1967) and in the explanations of the recently published geological maps of Zeeuwsch-Vlaanderen and Schouwen-Duiveland (van Rummelen, 1965 and 1970). The coastal development is dealt with in a paper by Pons et al. (1963).

During the *Tertiary* sedimentation of mainly fine-grained deposits took place in a marine environment. The Tertiary sediments settled in a tectonic basin, bounded in the south by the Brabant Massif. Due to tectonic movements the Tertiary formations are slightly folded. The top of the Tertiary occurs at a depth of appr. 20 metres below mean sea level in the southwestern Netherlands and dips progressively northwards until north of the Isle of Goeree it is found at over 100 metres in depth.

After the onset of the *Pleistocene* sedimentation of marine sands and clays proceeded unchanged. They settled on top of the Tertiary deposits increasing in thickness from the northern flank of the Brabant Massif towards the centre of the subsiding basin in the north. The marine Lower Pleistocene[4] comprises the "Merksem Formation" and the younger "Icenian Beds". In particular the fauna of the latter indicates that the climate was rather cool at the time of deposition.

During the formation of the Icenian deposits, rivers deposited the Formation of Tegelen in the eastern Netherlands. Gradually the coast line prograded in a westerly direction until eventually fluviatile sediments covered the marine Lower Pleistocene deposits. The fluviatile Lower Pleistocene comprises the "Tegelen and Kedichem Formations", both of them consisting predominantly of fine sands and clays.

The Middle Pleistocene rivers brought coarser material to The Netherlands, which was the result of a tectonic uplift of the source area. Their deposits consist of medium to coarse-grained sands. In the southwestern part of The Netherlands deposits of Middle Pleistocene age are unknown and the Upper Pleistocene directly overlies the Lower Pleistocene.

Although it is known that several glacial advances occurred after the beginning of the Pleistocene, they apparently did not affect the fluviatile sedimentation until the Elster glaciation. Then the glaciers probably reached the northern part of The Netherlands and gave rise to the deposition of fluvioglacial clays (Peelo Formation), which are present for example in the subsoil of the Isle of Texel.

Marine sediments of the Holsteinian interglacial have only been encountered in one locality in the province of Friesland. Although therefore little is known about the distribution of the marine deposits fluviatile sedimentation will have predominated at this time.

The subsequent Saale glaciation strongly affected the area north of the present E-W course of the river Rhine, not least by reshaping the topography. The glaciers reached the line running from Düsseldorf through Nijmegen, Arnhem and Amersfoort to the coast, the line being marked by the occurrence of ice-pushed ridges, situated along glacial tongue basins. Northwards, a series of boulder clay elevations and ice-pushed ridges indicates stationary periods of the retreating glaciers. Best known is the terminal moraine running from Gaasterland through Wieringen to Texel (Zonneveld, 1958; ter Wee, 1962), whilst an older phase might be represented by boulder clay occurrences in the subsoil near Hoorn, Alkmaar and Bergan aan Zee.

The glacial deposits of the Saale glaciation, consisting of boulder clay and fluvioglacial sediments, are grouped in the Drente Formation. South of the ice-covered area the rivers Meuse and Rhine flowed westward, the latter acting as a main drainage channel. In the province of Noord-Brabant an extensive deposit of coversands, intercalated with eolian and fluviatile loams was laid down during that time.

Like the Holsteinian interglacial, the Eemian interglacial resulted in the deposition of marine sediments in the coastal areas. As a result of the existence of glacial valleys the sea penetrated locally for considerable distances inland. The Eem Formation as well as the more or less contemporaneous fluviatile sediments (Kreftenheye Formation) present in the

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[4] For a definition of the terms Lower-, Middle- and Upper-Pleistocene as used in this paper is referred to Zagwijn (1959).

western Netherlands consist of medium to coarse-grained sands. At the end of the Eemian interglacial and in the beginning of the Weichselian glaciation the marine Eemian sediments in the province of North-Holland were reworked by rivers.

The Weichselian glaciers did not reach The Netherlands, but these latitudes experienced periglacial conditions. The most important deposits are the eolian coversands (Twente Formation), that settled all over the country.

In the central part of The Netherlands the Rhine continued the deposition of the Kreftenheye Formation, which has only a limited distribution, confined as it is to the zône of the present great rivers.

The rising sea level at the beginning of the *Holocene* and the amelioration of the climate initially led to the formation of a peat bed (Lower Peat Bed), on top of which clay settled. The clay shows a transition from a fresh-water to a marine environment, thus marking the Holocene transgression. A series of tidal-flat sands are found to have been deposited on top of this marine clay. This series of sediments is known as "Calais Deposits".

A retardation in the rate of sea-level rise resulted in the deposition of a peat bed, on top of which further tidal-flat deposits were formed. The complex is called "Dunkirk Deposits". A synchronous event with the formation of the tidal-flat deposits was the building of the Old Coastal Barriers (de Jong, 1971), which have been covered by the younger dunes in Late Medieval times (Jelgersma et al., 1970).

RESULTS OF THE INVESTIGATION

Tertiary deposits. Samples of Tertiary sediments have been collected only incidentally. They consist of fine, glauconite-bearing sands and tough clays. It has been difficult to determine the age of the sediments because of the lack of fossils. The presence and distribution of the Tertiary is deduced from the Sonia records, which clearly show the folding and faulting of these beds. Since the strike lines, which on the land run E-W, bent to the NW in the coastal region, it is not yet clear in which way the recorded beds must be connected with those on the land.

Merksem Formation. Since these deposits have not been sampled and no correlation between their distribution on land and reflections on the sonograms could be established, it is not known, if the Merksem Formation is present.

Deposits of the marine Icenian. Icenian deposits have been sampled in one locality only. Near the western border of the investigated area, directly underlying the young seasand, a coarse-grained sand was found which contains shells indicating an Icenian age: *Nucula cobboldiae, Yoldia myalis* and *Yoldia lancelata* (Spaink, 1969). It has not always been possible to discern the Icenian deposits from the Tertiary by means of the Sonia. In the area west of the Isle of Schouwen a reflecting horizon on the sonograms is interpreted to represent the Icenian deposits because of a correlation with their occurrence on that island.

The Tegelen/Kedichem Formations. Sediments belonging to these fluviatile formations have been sampled in two borings reaching a greater depth than the vibracorer borings. Near the light vessel "Goeree" the fine sands occur at a depth of about 40 metres below mean sea level, while in a boring in block P5 made on behalf of the Petroland oil company the formation is found at a depth of nearly 70 metres below mean sea level. These observations permitted an interpretation of a reflecting layer in the sonograms, from which it could be deduced that the surface of the fluviatile Lower Pleistocene deposits gradually slopes to the north. Such an interpretation is in accordance with the observations made on land.

The samples of the P5 boring have been dated from pollen analyses. According to Zagwijn (1970a) the presence of *Tsuga, Eucommia, Carya* and *Azolla filiculoides* indicates a Lower Pleistocene age. Most probably the age is Waalian, though an Upper Tiglian age cannot be completely excluded.

Beneath a cover of young seasand in block Q4 the Kedichem Formation was encountered at a depth of 27 metres below mean sea level. The pollen of a peat bed was dated by Zagwijn (1970b). The relatively high position of the sediment is probably the result of ice-pushing.

Pre-Holsteinian Middle Pleistocene fluviatile deposits. In the above mentioned boring P5-2 fine-grained sands occur below dated Holsteinian sands. Unfortunately only a few samples of this series, which has a thickness of 14 metres, were available. The absence of shell debris, foraminifera and diatoms indicates a non-marine deposit. The mineralogical composition, investigated by Z a n d s t r a (1970), does not allow a correlation with known fluviatile formations, but the sediment is nevertheless most probably fluviatile in origin because the absence of glacial components excludes a fluvioglacial origin.

Z a g w i j n (1970a) investigated two samples from this series of sands, one of the samples was suggested to represent a cold phase of the Middle Pleistocene and the other a Middle Pleistocene interglacial, which cannot be dated more closely.

It will be clear from the sparsity of samples that nothing can be said about the distribution of those deposits.

The Peelo Formation. The fluvioglacial clay, present in the northern part of the North Sea over such a vast area, is found in only a few borings in the southern part. The clay was sampled west of the Isle of Texel at a locality, where according to the Sonia records, it appears to occur in an elevated position due to ice-pushing. This is in agreement with recent finds on the Isle of Texel itself. The surface of the clay dips rather steeply in a southerly direction, being traceable over a short distance only.

The clay is brownish in colour, is very stiff and sometimes shows lamination.

The deposits of the Holsteinian. In two borings, made on behalf of the N.A.M. and Petroland oil companies in the blocks K17 and P5 resp. the presence of deposits belonging to the Holsteinian interglaciation has been established by means of pollen analysis. In boring K17B the thickness of the Holsteinian deposits is over 20 metres i.e. from 56 – > 78 metres below mean sea level, the base of the deposits not having been reached. In boring P5-2 the Holsteinian sediments have a thickness of only 7 metres i.e. from 49.80-56.80 metres below mean sea level.

The sediments in boring K17B consist of fine grey sands, a clay bed being intercalated from 58-70 metres below mean sea level. The sands do not contain shell fragments, diatoms or ostracods. In boring P5 too the sediments are predominantly fine sands, becoming somewhat coarser to the base of the series, where fossils are also found.

According to Z a g w i j n (1969, 1970a) the sediments, present in boring K17B were deposited during the second half of the interglacial, whereas those of boring P5-2 span the whole interglacial.

It is remarkable that both of the borings contain unmistakably marine beds, but that the beds are of different ages. D u S a a r (1968a, 1970a) investigating the diatom and ostracod content of the samples, concluded a marine environment for the Early Holsteinian deposits of boring P5-2, the younger beds not containing fossils. In boring K17B the upper part of the clay appeared to be marine, thus representing a marine intercalation not present in boring P5-2. The abundance of Chenopodiaceae in the samples of P5-2 led Zagwijn to conclude that the sea was not far away during the whole interval.

The Drente Formation and the glaciogenic morphology of the Saalian glaciation. Deposits of a glacial origin have not yet been recorded in the investigated area. However, their presence is inferred from the interpretation of sonograms and extrapolations of the geology of the western Netherlands. The Sonia in blocks Q7 and Q8 recorded isolated occurrences of material projecting as mounds above the interface. This shape and the intensity of the reflections, show that the material composing these mounds must be very stiff and difficult to erode. Since the same forms have only been found heretofore in association with glaciogenic deposits (in the northern part of the North Sea), they are considered to be boulder clay elevations. Their presence in blocks Q7 and Q8 would be in agreement with known boulder-clay occurrences at the same latitude between Alkmaar and Hoorn, where the boulder-clay is present in isolated patches at about the same depth (ca 30 metres below mean sea level).

Besides depositing boulder clay the Saalian glaciers transformed the topography by the formation of ice-pushed ridges. These could be anticipated offshore from the presence of such ridges in The Netherlands. At various localities the Sonia records show disturbances in the bedding, that most probably must be ascribed to ice-pushing. Such irregular forms notably occur below the Brown Bank in blocks P7 and P10 (fig. 3). The sediments of the Eemian interglacial wedge out against an inclined horizon, which is interpreted as the surface of Pre-Saalian deposits.

In block P6 inclined bedding was recorded by the Sonia. Due to the vertical exaggeration of the sonograms, the inclination is in reality less than it appears on the records. Nevertheless the bank containing the inclined bedding is considered to be an ice-pushed ridge and is, as such, comparable to the

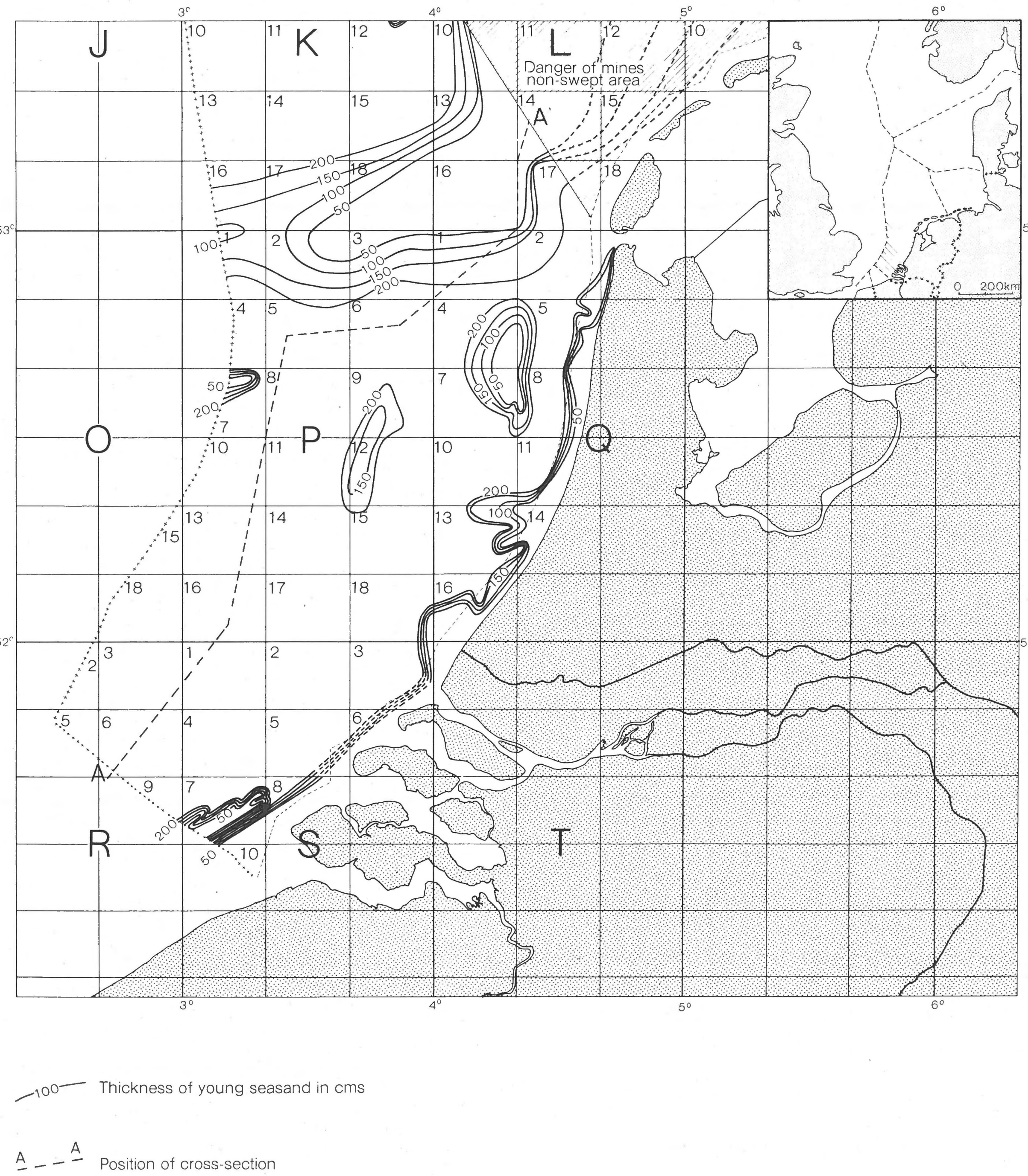

Fig. 2
Thickness of young seasand as far as it is less than 2 metres.

Archemer berg, having the same type of internal structure as described by de Jong (1952, 1955). Favouring this view is the deep valley directly east of the bank considered as an ice-marginal valley. The base of the valley was not reached by the Sonia, for its depth was over 70 metres below mean sea level. The infilling material shows a parallel layering, the layers wedging out against the valley flank. To the north the same valley has been recrossed several times with the Sonia. The valley is thought to be glaciogenic. The matter will be discussed in the next paragraph dealing with the interpretation of the results.

West of Texel Elsterian fluvioglacial clay, which was sampled in block L14 near the seabed is observed on the Sonia records to dip steeply southwards. The elevated position marks the westward continuation of the previously-mentioned terminal moraine from Gaasterland to Texel.

The Eem Formation. At various localities samples have been collected, which according to their pollen content and their fossils represent the marine Eemian deposits (Eem Formation). In this respect again boring P5-2 discussed above, gives at the moment the best information as far as the southern part of the Dutch area of the North Sea is concerned.

The marine series has a thickness of about 7 metres ((39.00-46.00 metres below mean sea level), and consists of coarse-grained sands, only the upper part being clayey. According to Zagwijn (1970a) the series ranges from the Quercus Zone (E3) to the Pinus-Picea Zone (E6) i.e. Middle to Late Eemian.

The clayey part is fairly rich in ostracods which were examined by du Saar. The ostracods indicate a shallow marine environment with a water depth of less than 30 metres (du Saar, 1970a). The sands were barren of diatoms or ostracods, but the shell debris present points to a marine environment.

In various vibrocorer borings Eemian sands with marine shell fragments have been found. West of Texel the vibrocorer sampled clays covered by a thin layer of young seasand at a depth of 30 metres below mean sea level. Pollen from the samples was dated by de Jong (1970a) who resolved the age as Late Eemian. Du Saar (1970b) deduced from the ostracods that the environment was still marine, although littoral.

The Brown Bank Bed. In the area around the Brown Bank a very tough clay is found at a depth of about 38 metres below mean sea level, although its surface, according to the sonograms, varies from 33 to 42 metres below mean sea level. The clay has a brownish gray colour and has some thin laminae of fine sand. The overlying sand is also often present in cracks in the clay.

Various pollen diagrams of the clay have been drawn which indicate sedimentation during a subarctic phase of a glacial advance (large amounts of herbs and Calluna percentages of over 100%). The clay, overlying the Eemian beds in boring P5-2, was dated by Zagwijn (1970a) as Early Weichselian. The samples obtained and the Sonia records show, that the clay is widely distributed. Because of its distribution over such a vast area it seemed to merit being named. As a similar deposit of the same age is not present in The Netherlands a new name is proposed for this fresh-water clay: the Brown Bank Bed, comprising the fresh-water clay, which is of Early Weichselian age i.e. pollen zone EW1a as defined by Zagwijn (1961).

The Kreftenheye Formation. Borings made in 1967

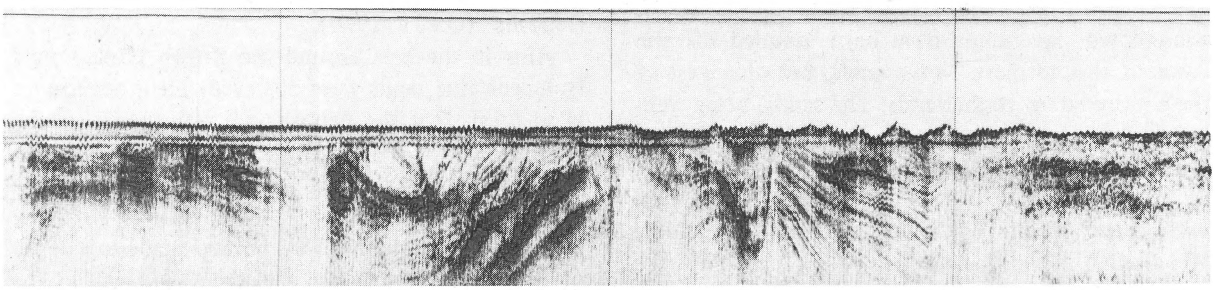

Fig. 3
Inclined bedding due to ice-pushing; to the left and right gully infilling material. Lower horizontal reflections represents Early Weichselian fresh-water clay. Waterdepth: 36 metres below mean sea level. Hor. Scale appr. 1:16.000. Vert. Scale appr. 1:1.000

on behalf of Rijkswaterstaat in the shipping route to the Hook of Holland demonstrated the extension of the Formation of Kreftenheye in a westerly direction. Due to a reworking of the marine Eemian the fluviatile sediments contain shells and shell fragments, which hampers a distinction of the two types of sediments. Based on the content of diatoms and ostracods a division of the sediments was given by d u S a ar (1967), which more or less coincides with that suggested by S p a i n k (1967) based on the molluscs.

The surface of the formation occurs at a depth of about 22 metres below mean sea level at the Hook of Holland and slopes to a depth of 37 metres below mean sea level in block P16, which confirms the suggestion of P o n s (1954) concerning the equilibrium profile of the Rhine at that time. The formation has a thickness of about 8 metres and consists of medium-grained sands. The mineralogical composition according to Z a n d s t r a (1967) shows a heavy-mineral association characterized by relatively high amounts of augite and of the minerals garnet, epidote and hornblende. Some samples have a fine-grade gravel fraction, which incidentally contains rounded, white pumice pebbles. The sands did not yield pollen, so a detailed age determination is extremely difficult. According to F r e c h e n (1959) the presence of pumice would indicate a post-Allerød deposit.

In the province of North-Holland a series of sands bearing marine Eemian molluscs is widely distributed. It is thought that the sediments are marine deposits, which were reworked and redeposited by rivers at the end of the Eemian or the beginning of the Weichselian. Most likely the same holds for a part of the so-called marine Eemian sands in the North Sea area, but too little is known to make a distinction between the autochthonous and allochthonous sediments.

The Twente Formation. As could be expected, wind-blown coversands have been sampled off the coast of the northern Netherlands, but also west of the southwestern Netherlands. The sands, being well-sorted, have a median value of about 150 microns and are intercalated with loamy laminae.

In a boring west of the Isle of Goeree a peat seam intercalated in the coversand was dated as Middle Weichselian (Pleniglacial) by pollen analysis. (d e J o n g, 1970a).

The Lower Peat and Elbow/Calais Deposits of the Holocene. The peat of the Holocene sequence has been collected at various places. Its presence is established by borings around the Goeree lightvessel, near the harbour entrance of Hook of Holland, off the coast at Scheveningen, IJmuiden, Petten, Den Helder and Texel. It is known to be absent in the old river mouth of the Rhine near Katwijk and in a gully, which runs in a south-north direction west of Hook of Holland.

Normally the peat overlies the coversands, and is itself overlain by a brackish-water clay (Velsen Layer). In area around Hook of Holland the peat is observed to overlie a fresh-water clay.

The age of the Lower Peat near the Goeree lightvessel was dated by d e J o n g (1970a) as Boreal. The peat was collected at a depth of 24.5 m below mean sea level. It is remarkable that the peat of this age occurring at the adjoining Isle of Schouwen lies at a depth of only 15 metres below mean sea level. As to the distribution of the clay overlying the peat, the information is still rather scarce. It seems, that the Velsen Layer is present only off the coastal area between IJmuiden and Goeree.

After deposition of the clay in the western Netherlands the transgression of the sea resulted in the deposition of fine sands with thin clay laminae. In the North Sea area the same kind of deposit settled on top of the Velsen Layer, but the percentage of the particles < 16 microns and the number of clay laminae are much smaller. From their fossil content they are considered to be some tidal flat deposits. As a result of their being covered by young seasand more than 3 metres in thickness, the old tidal-flat deposits have been sampled only occasionally. Their distribution is mainly deduced from the Sonia records. From the depth of their occurrence it can be concluded that the sediments must have been formed partly during the Boreal and partly during the Atlantic. Therefore, the series is grouped in the "Elbow/Calais Deposits" (O e l e, 1969).

Also in the area around the Brown Bank Lower Holocene fine sands were observed. Their occurrence is so local, that the deposits are not shown on the map.

The Brown Bank itself appeared to consist of fine sands, being well-sorted and containing a small amount of shell debris. Two borings made to a depth of 6 metres on the top and the flank yielded the material, which according to S p a i n k (1970) represents a warm period of the Holocene (Boreal or the Atlantic). Since the Sonia registered a somewhat concave, inclined bedding, it is possible that the Brown Bank is an old beach barrier.

Connected with the deposition of the tidal-flat sands was the formation of tidal gullies. Such gullies occur near Katwijk and were infilled at the beginning of the Subboreal, as is established by pollen analysis (d e J o n g, 1970b). Deep gullies are also observed West of Texel and an important gully is present west of Hook of Holland. The existence of the latter was demonstrated during boring operations made on behalf of the Rijkswaterstaat. Sands with an Holocene fauna infill the valley, which locally eroded the Lower Peat Bed and extended deep into the Pleistocene fluviatile sediments.

The Dunkirk Deposits. The above mentioned deposits are overlain by a layer of yellowish brown sand. Those oxidized sands contain a Young Holocene fauna. Among the molluscs the most diagnostic is *Angulus pygmaeus.*

The thickness and grain size of the sand varies markedly. In the southern part of the North Sea the investigation carried out by Van Veen revealed that the young seasand had a thickness of over 10 metres, the sand being rather coarse. To the north, west of the Hook of Holland the thickness is generally about 5 metres. Megaripples are very common in this area (v a n V e e n, 1935; C l o e t, 1954; H o u b o l t, 1968). Fig. 2 shows the areas, where the cover young seasand is less than 2 metres.

By means of pollen analyses it has been established, that in the northern part of the North Sea a stratigraphic hiatus exists between the old tidal-flat deposits and the young seasand, the latter being dated as Late Medieval. Unfortunately the young seasand of the area under investigation does not contain pollen, and hence an age determination is difficult. However, some suggestions can be put forward, to indicate a relatively young age for the sediments.

A thin layer of the young seasand is commonly present on top of the ridges west of the province of Zeeland in the SW part of The Netherlands. As described earlier by H o u b o l t (1968) the sand overlies fine-grained, grey sediments. Datings of the latter reveal ages which range from ca. 2000 BP to as young as less than 500 BP. Most of them belong to the Dunkirk III transgression i.e. postninth century, implying the young seasand is even younger.

Evidence for a rather recent deposition of the young seasand is given by the presence of *Mya arenaria* in these sands to a depth of 3 metres below the sea bottom. According to Spaink the mollusc Mya arenaria was reintroduced in the North Sea area by man after 1600. This evidence is, as yet, not entirely conclusive as, owing to limitations of the drilling equipment the shells may not have been sampled in situ.

The mineralogy of the young seasand as far as analyzed has not allowed any new conclusions. The sands clearly are Rhenisch in origin, as shown by previous workers (B a a k, 1936; T e r w i n d t et al., 1963; H o u b o l t, 1968). In the southwestern part of the area of investigation flint gravel was present in very small amounts. This is in accordance with the observations, made by V e e n s t r a (1964), who, like the present author, did not notice the presence of Rhine – Meuse gravel as reported by T e s c h and R e i n h o l d (1946).

INTERPRETATION OF THE RESULTS

Late Tertiary to the Saalian glaciation. The data collected at sea confirm that the geological history of the area during this period was similar to that of the western Netherlands. The sedimentation of marine fine sands and clays, which took place during the Late Tertiary, continued after the beginning of the Pleistocene. Subsidence of the sedimentary basin as well as an uplift of the northern flank of the Brabant Massif in the south proceeded. Due to a regression the westward prograding fluviatile delta resulted in the marine deposits being covered by fluviatile fine sands and clays. Although in the North Sea the base of the Lower Pleistocene fresh-water deposits has not been observed, it is probable that its age will be about the same as that established on land (Late Tiglian).

The deposition of the fluviatile fine sands and clays continued until the end of the Lower Pleistocene. The position of the coast line is still not clear. According to Z a g w i j n (1970a) the relatively high amounts of Chenopodiaceae indicate a deposition close to the sea. This would mean that the coast at this time was some distance from its present position.

The presence of Eemian sediments on top of the Lower Pleistocene deposits, as found in the boring near the Goeree lightvessel proves the existence of the stratigraphical hiatus recorded in the southwestern Netherlands, which was caused by a northward shift of the southern boundary of the fluviatile delta i.e.

north of Hook of Holland. The samples of the P5-2 boring prove the westward extension of the Middle Pleistocene fluviatile sediments present in The Netherlands.

The data collected do not yield information on the effects of the climatic changes in the period under consideration. The influence of the Elster glaciation which brought the glaciers to the northern boundary of the area of investigation, is not known at all. One might expect that coversands would have been deposited in our area, which most probably was a periglacial zone at this time.

Also, the results of the restoration of the sea level in the subsequent Holsteinian interglacial are not understood, since only two borings contained sediments of this age.

The Saalian glaciation and the subsequent Upper Pleistocene. The renewed extension of the glaciers during the Saalian glaciation led to a land-ice cover over the northern half of the investigated area. The glaciers altered the topography, building ice-pushed and morainic ridges. Evidence of such events has not only been observed at several localities, but it also seems possible to connect the phenomena observed with those on land.

The evidence of ice-pushing around the Brown Bank is the southernmost, and is present at the latitude of the maximum extension of the glaciers in the western Netherlands. Therefore it is assumed, that the ridges in block P8 mark the location of the ice front during its maximum extension (phase A of Maarleveld (1953) and ter Wee (1962).

The evidence of glacial action in the blocks P6 and Q4 which comprises the observed inclined bedding in a bank bordering a deep valley, the elevated position of Lower Pleistocene sediments and the presence of boulder-clay mounds strongly supports the suggested continuation of the glaciogenic ridge running from Hoorn to Egmond aan Zee. The ridge consists of elevated boulder-clay mounds (Zonneveld, 1958) and ice-pushed older deposits (Jelgersma, 1967). The valley which is present on the northern side of the ridge at Egmond aan Zee and which is most likely glacial in origin has tentatively been connected by the present author with the observed glacial valley in block P6. The latter can be traced as far north as the observed continuation of the Gaasterland-Wieringen-Texel glaciogenic ridge in block L14. According to ter Wee (1962) the ridge, marking the ice front of phase D, is a terminal moraine of a glacier, which was younger than the earlier-mentioned glaciers and had a separate source area.

It is most likely, that in addition to the deposition of boulder clay, fluvioglacial material settled from the meltwaters, especially in the glacial valleys. Since such deposition is known to have occurred in the northern Netherlands, it is assumed to have taken place in the area of investigation as well.

The same holds true for the supposed continuation of sedimentation in the valleys during the Eemian interglacial. During that period sedimentation would have been terrestrial and later marine. Even during the Weichselian glaciation the Saalian glacial valleys still formed depressions in which still streams flowed and fluviatile small material was deposited.

The Eemain sea covered the whole area and gave rise to the deposition of marine sands, which to a certain extent consist of reworked fluviatile deposits. The time of transgression shown by the datings of the P5-2 boring coincides with the dated transgression level on the main land (Amersfoort, Amsterdam), namely the junction of the pollen zones E3-E4. It is noted that even the uppermost Eemian deposits are marine: West of Texel the diatoms present, show that the sediments were deposited in a tidal-flat environment, whereas in boring P5-2 the environment was fully, though shallow, marine (du Saar, 1966, 1970a).

Due to the continued lowering of the sea level the investigated area eventually fell dry, fresh-water deposits being formed from then onward. In an extremely wide area around the Brown Bank a fresh-water clay settled (Brown Bank Bed), which can be classified as the topmost regressional bed of the Eem Formation. Desiccation phenomena as mud cracks demonstrate that the clay underwent subaerial exposure during the last glaciation. In addition to the wide distribution, the persistent presence of the clay in that area and the very limited number of small gullies in the clay and the presence of water plants suggest the existence of a vast lake fed probably by small streams coming down from the ice-pushed ridges in the north and the east.

The clay now dated as Early Weichselian was earlier supposed to have an age of Late Eemian or Early Weichselian. In some places it underlies the Brown Bank (at a depth of ca. 40 metres below mean sea level), but it does by no means form a part of the bank itself. Hence the view held by earlier workers (v a n E e r d e, 1964; H o u b o l t, 1968; D u j o n, 1969) must be discarded.

The distributaries of the river Rhine probably reworked outside the present coast line the Eemian deposits in the same way as it is known to have occurred in the Province of North-Holland. The main stream will have debouched into the Atlantic Ocean.

The contribution of the rivers to sedimentation must have decreased rapidly as a result of the smaller discharge and the formation of the cover-sands started. It is not yet understood why those sands are absent in the central part of the North Sea.

The Holocene. The climatic amelioration, as well as the rise in sea level, resulted in the western Netherlands in the deposition of a sediment series in a gradually changing environment and led to a similar sequence of sediments in the area of study. At first the rivers Rhine and Meuse deposited a clay layer in the then rather restricted area through which they flowed. So the clay is present for instance near Hook of Holland. Then the conditions favoured the growth of a fen-peat, the Lower Peat, over the whole coastal area. The sea then invaded the area and caused the deposition of the tidal-flat sands. The preponderance of sandy sediments might be explained by the rapid rate of sea-level rise (cf. d e J o n g, 1967, p. 381). As can be seen on the map (plate I) the distribution of the Lower Holocene sediments is rather striking in its parallelism to the present coast line. However, until more datings are available, it is not possible to draw any conclusions from this feature. It is rather unfortunate, that the present investigation does not yield information on the Holocene coastal development, especially because the extensive studies on the subject by a.o. P o n s et al. (1963) and v a n S t r a a t e n (1965) need supplementary evidence from the sea area.

The most important gully formed by the transgressing sea is located west of the Hook of Holland. Most likely it is to be connected with the gully running through the Isles of Schouwen-Duiveland and Goeree in a northerly direction (v a n R u m m e l e n, 1970).

The gullies west of the Isle of Texel had possibly already been formed at the end of the Eemian as a drainage system of the ice-pushed ridge debouching in the broad glacial valley, after the sea level had started falling. This is suggested by their sharp V-shape. The Holocene sea would have used these existing depressions to invade the land. It is still doubtful whether deposition of the tidal-flat sediments took place behind a series of barrier islands or not. In the area near the present coast no indications for the existence of such barriers has been found. As previously stated the author is strongly inclined to assume the Brown Bank to be an old beach barrier. Since the Brown Bank has been proved to overlie the Early Weichselian fresh-water clay, the presence of marine fossils, also mentioned by H o u b o l t (1968) means that the bank was formed during the Holocene. The inclined bedding, as well as good sorting of the material sampled and the presence of fine shell debris, are taken as evidence that the Brown Bank can only represent a beach barrier.

After a period of non-deposition the Zeeland ridges were formed, the origin of which is probably related to the development of a new Scheldt mouth, south of Walcheren. Most likely, erosion of the ridges took place in the transgressive phase of Late Medieval time, when the sea invaded far into the main land.

The sedimentation of the young seasand closes the sedimentary sequence. Because of the datings of the material building the Zeeland ridges, the young seasand will have been deposited in Late and Post Medieval times.

The material of the young seasand layer is supplied by the rivers Rhine and Meuse. Because of the presence of Cretaceous elements south of the area of investigation a northern transport of material from the Straits of Dover occurred as well. T e s c h (1942) suggested, that the Rhine and Meuse brought their sediments into the Britisch Channel during the last glaciations. The material was swept to the north again during the Eemian and Holocene transgressions. It explains the mixture of Cretaceous and Rhine - Meuse elements.

The transport of the young seasand in a unidirectional sense from the Channel to as far north as the Dogger Bank as suggested by K r u i t (1963) and S t r i d e (1965) is unlikely because of a.o. the variation in thickness of the young seasand.

CONCLUSIONS

The investigations carried out revealed the expected similarity between the geological history of the western Netherlands and that of the adjoining part of the North Sea. The pre-Saalian deposits do not lead to new points of view. However, concerning the

Saalian glaciation, there is some new evidence suggesting a stationary phase of the inland-ice front between the phases B and C (Maarleveld, 1953; ter Wee, 1962).

Although the sedimentary sequence deposited in the subsequent periods is fairly well understood, the reasons for the distribution of the various sediments are less clear. Neither the position of the boundary of the Brown Bank Bed nor that of the coversands can be accounted for from present evidence. The same holds for the deposits of the lower part of the Holocene which occur in a zone parallel to the present coast.

The presence of a stratigraphic hiatus between the Lower Holocene deposits and the Subatlantic young seasand seems to be established. The problems concerning the source area and the origin of the banks of young seasand are not yet solved. It is, however, thought, that the young seasand consists of material, supplied by the Rhine and Meuse with an admixture of Cretaceous and Tertiary elements derived from the Channel area. It is assumed, that the young seasand as formed in post-Medieval times.

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