

Quaternary
Research Association

FIELD GUIDE

Easter Meeting 1982,
Soesterberg, The Netherlands

QUATERNARY RESEARCH ASSOCIATION

Easter Field Meeting, 1982

SOESTERBERG, THE NETHERLANDS

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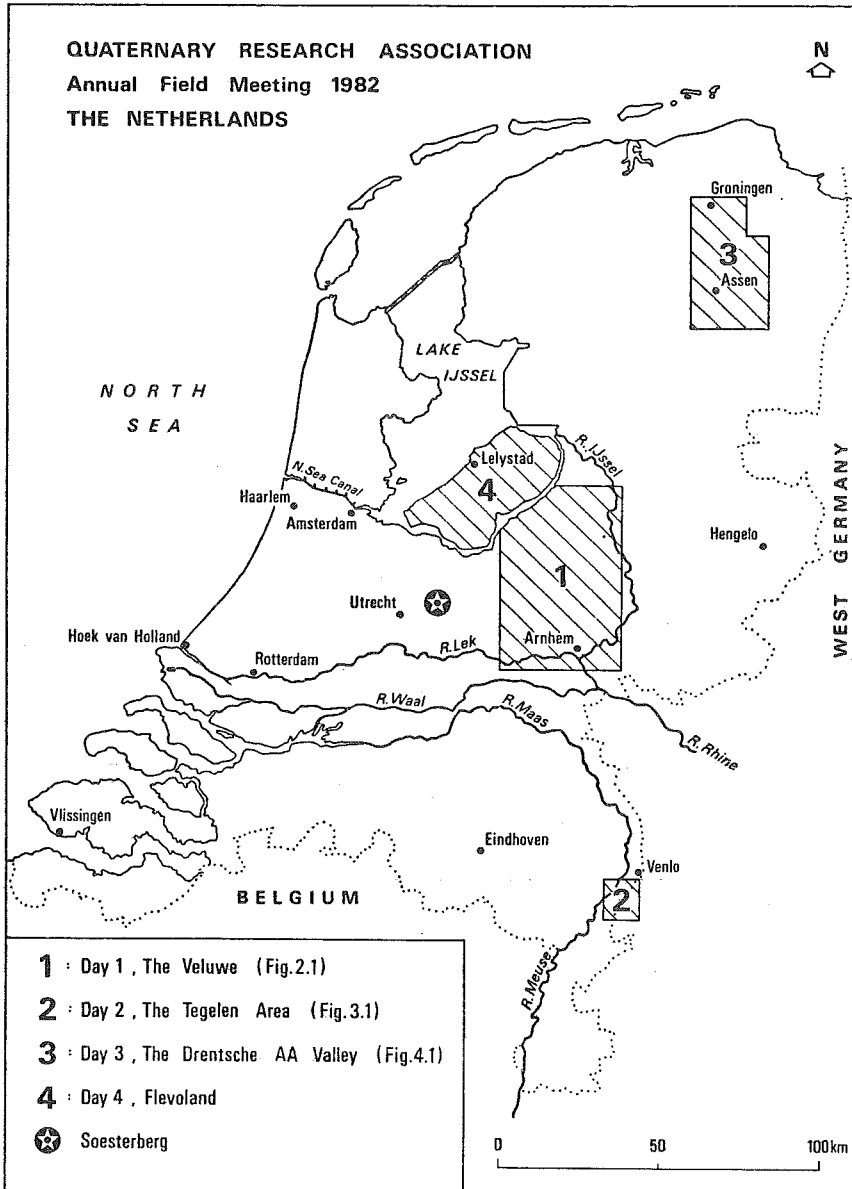
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QUATERNARY RESEARCH ASSOCIATION
Annual Field Meeting 1982
THE NETHERLANDS



INTRODUCTION TO THE QUATERNARY OF THE NETHERLANDS

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THE GEOLOGY OF THE NETHERLANDS

C.J. van Staalkuinen, H.A. van Adrichem Boogaert, M.J.M. Bless,
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5. QUATERNARY

Tertiary strata are in the greater part of The Netherlands in general conformably overlain by Quaternary deposits, varying in thickness from a few to more than 400 metres on-shore, and even more offshore (Fig. 39). These deposits are of marine and continental origin, the latter prevailing in particular in the upper part of the sequence.

During the Quaternary The Netherlands formed part of the subsiding basin of the southern North Sea (ZAGWIJN & DOPPERT 1978). The rates of subsidence and sedimentation were higher in the Quaternary than in the Neogene.

The basin may be subdivided in areas of major and minor subsidence. Some Neogene tectonic trends continued to be active into the Quaternary, in particular the SE - NW running fault-system in the southeastern part of The Netherlands. In addition some apparently new sub-basins came into existence, which are rejuvenations of much older, pre-Tertiary basins.

The Quaternary deposits have been grouped into various formations, which form part of the Upper North Sea Group. In the classification of these lithostratigraphic units the origin (marine, fluvial, River Rhine, River Meuse, etc., periglacial and other local deposits, glacial), the overall lithology and in some cases the sedimentary-petrology have been used (Fig. 24).

Chronological control is by reference to paleoclimatic changes as deduced in particular from palynological studies (Fig. 25) (ZAGWIJN 1975).

From the palynological data a number of cold and warm phases has been established. Cold phases have open vegetation, warm phases temperate forest. The cold phases are called glacials, the warm phases interglacials. However, continued research has shown that several interglacials, in particular those from Early Pleistocene times, are complex, as they have been interrupted by cooler periods. In a similar way nearly all glacials have warmer intervals, called interstadials. Moreover, as the number of pollen analytical investigations increased, the lower part of the Middle Pleistocene, initially considered as one interglacial ("Cromerian"), proved to contain at least four interglacials and three glacials. Hence today the term "Cromerian complex" is used for this time-interval. Even more recently the existence of two more interglacials was established between the Menapian glacial and the "Cromerian complex" (Fig. 25). These two interglacials have a pollenflora distinct from that of later interglacials and resembling that of the two Lower Pleistocene interglacial complexes Tiglian and Waalian. Therefore these new interglacials are considered to belong to the upper-

most part of the Lower Pleistocene (ZAGWIJN & DOPPERT 1978).

A particular point is the Plio-Pleistocene boundary as reflected in the nonmarine and marine beds.

Mollusc zones Mol B (arctic) and Mol A (temperate) coincide with the cold Praetiglian and the warm-temperate Tiglian (lower part) respectively (Fig. 21).

The foraminiferal subzone boundary FA2-FA1 is generally found a few tens of metres above the palynologically established boundary Reuverian-Praetiglian. However, both levels reflect the same distinct cooling, expressed more in the vegetational than in the faunal record.

Some available paleomagnetic data (VAN MONTERANS, 1971) may be used to calibrate the Lower-Middle Pleistocene by means of absolute age. The 0.7×10^6 years level has been found between the two lowermost interglacials of the "Cromerian complex". The Jaramillo event (about 0.9×10^6 years ago), until recently believed to fall within the Waalian interglacial, is now related to the "Bavel Interglacial", which postdates the Menapian glacial phase. The Tiglian-Eburonian boundary is within the Olduvai event (appr. 1.8×10^6 years ago) and the Plio-Pleistocene boundary is estimated at about 2.5×10^6 years. Radiocarbon dating has contributed very much to the understanding of age relations in the uppermost Pleistocene and the Holocene. The Pleistocene-Holocene boundary has been determined to date from about 10,000 years ago.

5.1. PLEISTOCENE

5.1.1. LOWER PLEISTOCENE

5.1.1.1. Stratigraphy

The Lower Pleistocene sedimentary rocks are of marine and continental facies in the lowermost part, whereas the upper part is entirely continental. A detailed correlation of the two facies has been established mainly by palynological studies (e.g. ZAGWIJN 1974). One marine formation is distinguished in the Lower Pleistocene sequence on the present mainland: the Maassluis Formation.

It should be mentioned, however, that the uppermost beds of the Oosterhout Formation (4.4.1; Fig. 21) locally extend into the very beginning of the Pleistocene.

The Maassluis Formation (Fig. 26) lies concordantly on top of the Oosterhout Formation. The extensions of both formations are about the same. The Maassluis Formation consists of coarse and fine shelly sands, with intercalated clay beds or clay lenses. The top is placed in practice at the uppermost occurrence of marine shells in Lower Pleistocene sediments. The age is Praetiglian to Tiglian. In the Middle Tiglian, there was a rather abrupt regression of the sea from the area that now forms The Netherlands.

Hence the lower part of the Tegelen Formation and the Maassluis Formation are of the same age, as is confirmed by interdigitations between the two formations in some places.

Chronostratigraphy			Deposits related to glaciations	Deposits of local origin	Fluvial deposits	Marine, estuarine and lagoonal deposits
Quaternary	Holocene		N	S N	S N	S N
	Late	Weichselian *		Kootwijk F. EO Singraven F. B Griendtsveen F. P	Betuwe F. R + M	Westland Formation
		Eemian		Twente F. EO + P + PG + B Asten F. P	Kreftenheye Formation R + M	Eem Formation
	Middle	Saalian *	Drenthe F.			
		Holsteinian		Emmiken F. EO + PG B + P	Urk Formation R	Veghel F. ***
		Elsterian *	Piedra F.			
		Cromerian complex **				
	Early	Menapian *			Enschede Formation E	Sterksel F. R + M
		Waalian		Keldchem F. (partly) B + PG + P	Keldchem Formation R + M	
		Eburonian *			Haarlem Formation E	
		Tiglian			Tegelen Formation R + M	Maassluis Formation
		Praetiglian *				
Neogene	Pliocene	Reuverian			Scheemda F.	
		Brunssumian			Kieselkolk Formation E	Oosterhout Formation
	Miocene	Susterian				
				Huizenberg F.		Breda Formation

EO = Eolian deposits
PG = Periglacial deposits
B = Brook deposits
P = Peat

R = Rhine
M = Meuse
E = Eastern supply
(N. German rivers)

* Cold
** Complex unit
composed of at least
4 interglacials
and 3 glacials

*** Unnamed, provisionally part
of the Urk Formation

Fig. 24. Table of Upper Tertiary and Quaternary formations with references to chronostratigraphic position and to genesis.

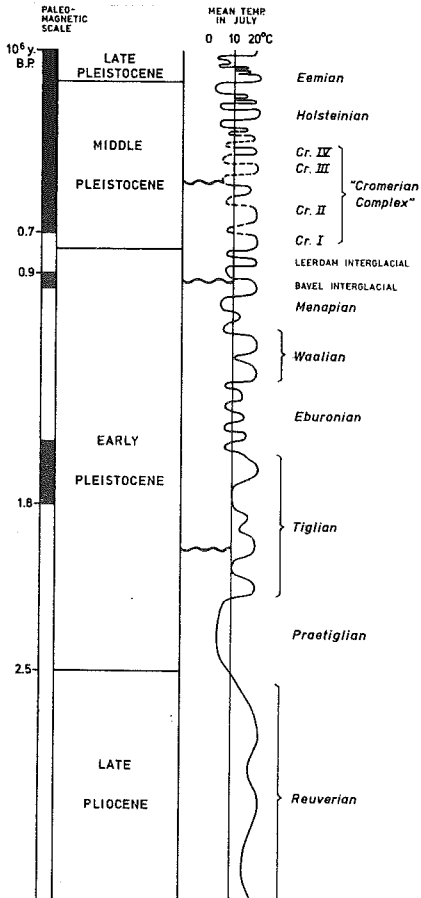


Fig. 25. Paleoclimatic curve of the Pleistocene (modified after ZAGWIJN 1975).

The continental deposits of the Lower Pleistocene constitute the Tegelen, Kedichem, and Harderwijk Formations.

The Tegelen Formation (Fig. 27) comprises, where it is complete, from the bottom upwards, coarse-grained beds with gravel (Belfeld Gravel), beds of mainly clay (Belfeld Clay), beds of mainly coarse-grained sands with gravel (Tegelen Gravel), and beds with mainly clay (Tegelen Clay). This holds especially true for part of the Central Graben area in the southeastern part of the country.

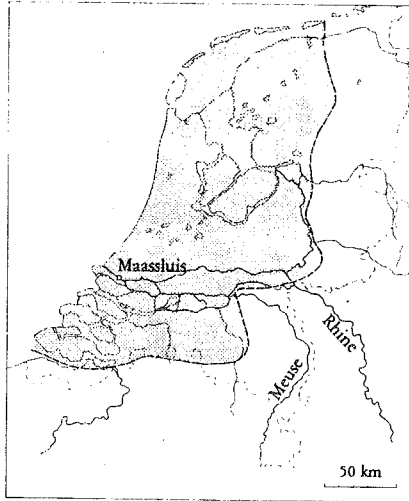
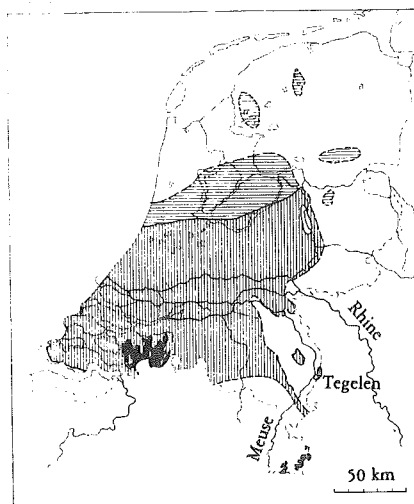


Fig. 26. Extension of the Maassluis Formation.

Elsewhere the upper part of the Tegelen Gravel and the Tegelen Clay are present on top of marine beds of the Maassluis Formation. Sedimentpetrological investigations prove a Rhine origin (in South-Limburg a Meuse origin) for the Tegelen Formation. The heavy-mineral association contains much garnet, the gravel has much quartz. The clay have been dated as Tiglian to Lower Eburonian by means of pollenanalysis.

The next younger formation is the Kedichem Formation. These sediments also have a Rhine and Meuse origin, apart from beds of local provenance. The area in which they occur is somewhat smaller than that of the Tegelen Formation area (Fig. 28). The sediments are mainly finegrained sands and clays. In the southeastern part of the country these deposits are partly periglacial; eolian deposits have also been proved. In the southeastern part of The Netherlands the formation is of local provenance and has a stable heavy-mineral association, which is contrasted to that of the underlying Tegelen Formation and that of the overlying Sterksel Formation, both showing instable assemblages supplied by the River Rhine. In the central part of The Netherlands, however, the heavy mineral assemblage indicates a Rhine provenance with components of eastern origin in the northern part of the area in which the formation occurs. In the uppermost part there is generally a stable association of metamorphic minerals. The age is Eburonian to Menapian.

The Harderwijk Formation contains riverlaid sediments that were transported from the northeast and the east. The area of occurrence onshore is roughly complementary to the Tegelen and Kedichem areas (Fig. 29). The deposits






-  Tegelen Formation
-  Tegelen Formation near the surface
-  Area with claybeds of Harderwijk Formation which are in many respects similar to Tegelen Clay

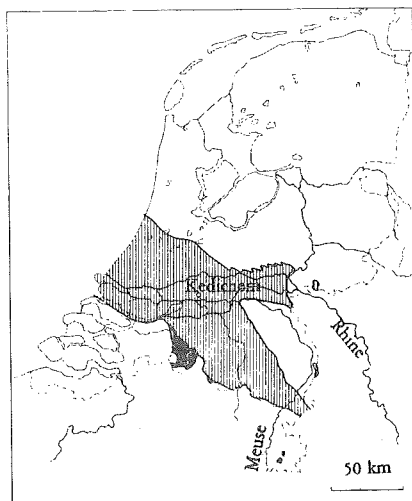
Fig. 27. Extension of the Tegelen Formation.

are mainly grey-white, coarse grained sands that contain fine gravel. There is little clay, except for the lower part of the formation in the central part of the country. Both the sand and the gravel contain much transparent quartz, and the upper part has also feldspar. In the middle and the south of the country there is some Rhine influence, with higher values for white quartz and somewhat coarser gravel. The formation interdigitates with the upper part of the Tegelen Formation and the greater part of the Kedichem Formation. The age is Tiglian to Waalian.

Until lately it was believed that palynological assemblages, considered characteristic for Lower Pleistocene, did not occur in deposits younger than Menapian. As stated before this assumption has proved to be incorrect. Actually the Early/Middle Pleistocene boundary is found within the Sterksel Formation in the Central Graben area, and within the Enschede Formation in the northern part of The Netherlands. "For convenience" sake, however, these formations will be dealt with together with the other Middle Pleistocene deposits.

5.1.1.2. Geological History

The boundary between the marine and continental lowermost Pleistocene, representing the coastline of that





-  Kedichem Formation
-  Kedichem Formation near the surface

Fig. 28. Extension of the Kedichem Formation.



Fig. 29. Extension of the Harderwijk Formation.

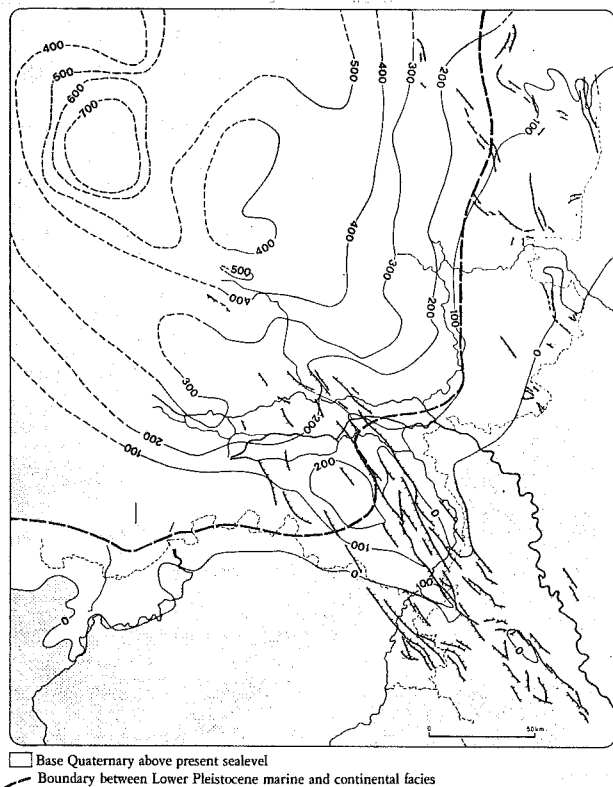


Fig. 30. Depth contours of the base of the Quaternary (offshore area modified after CASTON 1977).

time, is indicated on Fig. 30, together with depth contours of the base of the Quaternary. Sedimentation took place in a shallow sea, material was brought in by two river systems, the Rhine-Meuse river system in the southeast and another system, related to rivers draining the Baltic Shield and the northern lowland of Germany, in the northeast. There were only minor changes in this picture up to the middle of the Tiglian. Then a relatively rapid regression of the sea took place, resulting in a shoreline that was somewhat seawards of the present one. A large deltaic fan was formed by junction of the individual delta's of the two river systems mentioned above. A contour map of the top of the marine Lower Pleistocene deposits was published by VAN MONTERFANS (1975).

The paleogeographic situation stayed more or less unchanged during the rest of the Lower Pleistocene.

Fluviatile sediment was transported from the east and northeast (ancient Baltic stream, Rivers Elbe, Weser, Ems) and from the southeast (Rivers Rhine and Meuse). The boundary between these two sedimentation areas runs in an east-west direction in about the middle of the present area of The Netherlands. In the southernmost part of the country, sediments from the south were deposited by the River Meuse and other rivers draining the present area of Belgium, especially so during the Eburonian-Menapian.

The subsidence in Quaternary times may be deduced from Fig. 30. Areas of major subsidence were in the Central Graben, the Zuiderzee basin and in the area north of it, in the western part of The Netherlands and in the present North Sea (in the Broad Fourteens Basin). In particular in the three last mentioned areas Lower Pleistocene

sediments attain a considerable thickness. Synsedimentary normal faulting occurred especially in the central and in the southeastern parts of the country. Important hiatuses in the fluvial succession have been found in the Lower Tiglian and Praetiglian (this is at the transition from Pliocene to Pleistocene) and in the Menapian (between the Kedichem and Sterksel Formations, at the transition from Lower to Middle Pleistocene).

5.1.2. MIDDLE PLEISTOCENE

5.1.2.1. Stratigraphy

Marine deposits are present in the upper part of the sequence as tongues only, wedging in from the north in the northernmost part of The Netherlands.

The lower part of the Middle Pleistocene sequence consists of fluvial deposits of the Rivers Rhine and Meuse in the south and of ancient eastern rivers in the north. They belong to two formations.

The Sterksel Formation occurs in a wide SE-NW running band between South-Limburg and the northwestern part of The Netherlands (Fig. 31). The sediments are coarse grained sands with gravel, sometimes gravel only. Clay is only found near the edge of the area of distribution

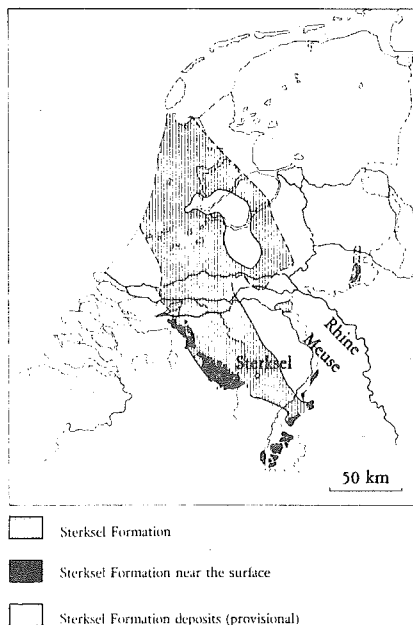


Fig. 31. Extension of the Sterksel Formation.

and as scattered lenses among the sands and gravels. They are mainly deposits of the River Rhine, partly also of the River Meuse. Sediment-petrological studies in the Central Graben area have allowed to make a subdivision into four zones (ZONNEVELD 1947). The paleobotanical age is Upper Menapian-Lower "Cromerian Complex".

The Enschede Formation is confined to the middle and the northern part of The Netherlands (see Fig. 32). It contains grey white, mainly coarse sands with gravel. In the lower part of the formation this gravel is locally very

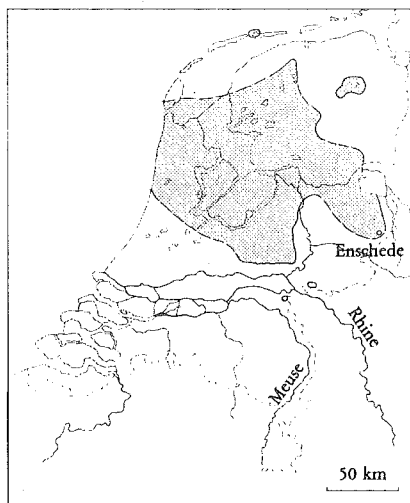
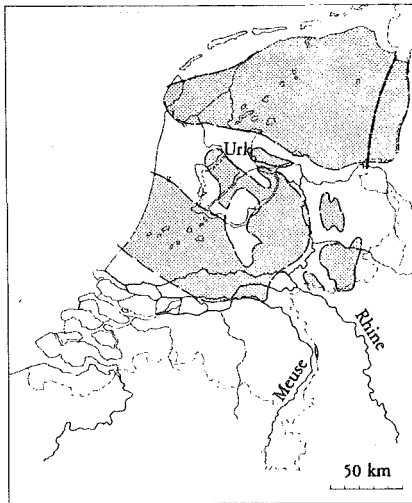


Fig. 32. Extension of the Enschede Formation.

coarse, up to boulder size. The sediment is of eastern provenance. In the upper part the topaz percentage is relatively high in the heavy-mineral assemblages. The gravels contain indicators from Central German areas, such as Thuringia. The age is Menapian to Lower "Cromerian Complex".

Overlying the two former mentioned formations are deposits of the River Meuse in the southeastern part of The Netherlands (Veghel Formation Fig. 34) and of the River Rhine in the whole area of the central and northern part of The Netherlands (Urk Formation Fig. 33). Both consist of coarse-grained sands with gravels and in many places horizons of boulders. In the upper part of the Urk Formation from the northern part of The Netherlands an interglacial clay horizon is present, which grades into marine deposits. In the same area, and locally also in the western part of The Netherlands, another interglacial marine horizon occurs intercalated in the lower part of the Urk Formation. In the northern part of The Netherlands glaciogenic deposits of the Peeloo Formation (Fig. 35) are



✓ Eastern boundary of high values of augite in the northern part of The Netherlands

Fig. 33. Extension of the Urk Formation.

found sandwiched between the afore-mentioned interglacial marine horizons.

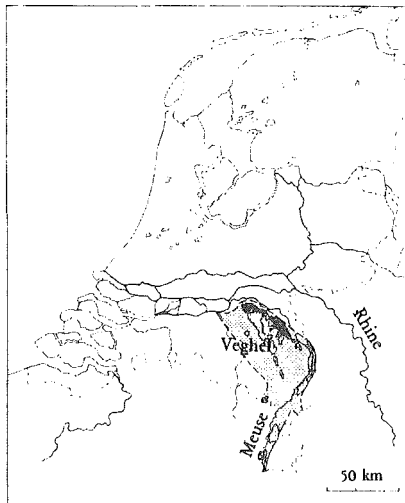
The Veghel Formation contains a heavy-mineral and gravel assemblage with indicators from the Meuse drainage area (such as Vosges hornblende). The Urk Formation has in general heavy-mineral assemblages characteristic of the River Rhine, containing more or less elevated percentages of augite. The presence of this mineral is the result of increased volcanic activity in the Eifel region, starting approximately 0.4×10^6 years ago.

The age of the Veghel and Urk Formations is Upper "Cromerian Complex" to Holsteinian. The Veghel Formation continues into the Saalian.

In the Middle Pleistocene, two formations of glacial origin can be recognized, one mainly at depth and one often at the surface, at least in the northern part of The Netherlands.

The former is the Peelo Formation (Fig. 35). It is a complex unit consisting of fine sands, some coarse sands and highly characteristic compact dark brown clays (so-called "pottery clay" or "pot"-clay). The "pot"-clay is present in gully-like depressions eroded into the subsoil and attains in many places thicknesses of up to 100 metres. The genesis of the formation is not fully understood, but certain indications for a glacial origin have been found. The age of the Peelo Formation is Elsterian.

In the Drente Formation are grouped the tills and fluvioglacial deposits related to the main Saalian glacial advance of the Scandinavian inland-ice.



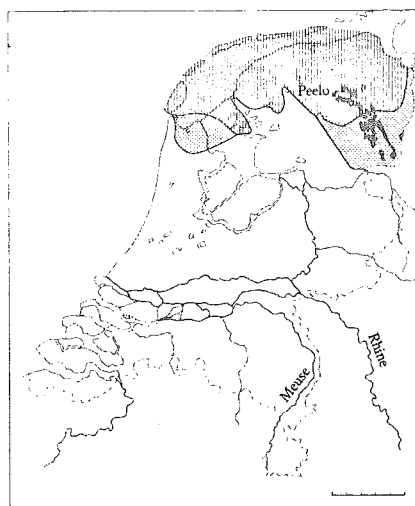
Veghel Formation
 Veghel Formation at the surface
 Krettenheye and Veghel Formation at the surface

Fig. 34. Extension of the Veghel Formation.

This glaciation had a considerable impact on the topography of the central part of The Netherlands. Here, deep glacier-tongue basins and ice-pushed ridges were formed.

In some places the resulting relief exceeds over 200 metres. The basins may reach a depth of over 100 metres below present sea level and may have a width of as much as eight kilometres. The features have been observed on land as well as in the offshore area. Lodgement tills are associated with the elongate depressions. Fig. 36 shows the distribution of the basins and the ridges as summarized by OELE & SCHÜTTENHELM (1979). In the central and eastern part of The Netherlands the present-day topography is still dominated by these glacial features.

Tills occur along the flanks and at the base of the basins. In the northeastern part of The Netherlands boulderclay is found as a more or less continuous layer close to the surface. The area, therefore, is often referred to as the "boulderclay plateau". The fluvioglacial sediments consist of a wide range of material: fluvioglacial that settled in front of the ice lobes (sandur- and kame deposits) consists of fine and coarse sands, whereas in the basins varved clays have been sampled. The clays have been deposited in lakes, which developed in the basins after the withdrawal of the ice. To the glaciogene deposits belong the huge er-



- Peelo Formation at the surface
 Fine and medium coarse sands; "Pot"-clay present
 Fine and medium coarse sand; absence of "Pot" clay

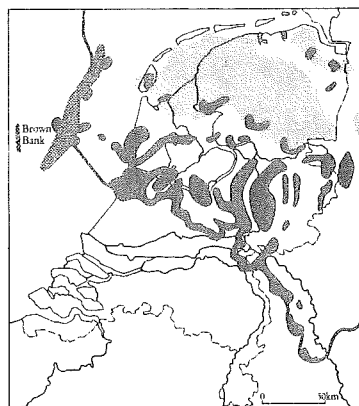
Fig. 35. Extension of the Peelo Formation.

raties, which prehistoric man used to build megalithic tombs.

5.1.2.2. Geological History

In the earlier part of the Middle Pleistocene the North Sea had withdrawn to the northwest, and the coastline probably was rather distant from the present onshore area of the country. A large alluvial fan was built up by the combined Rivers Rhine and Meuse and the eastern river-system. Generally a sedimentary hiatus is found between these and younger sediments. This hiatus may be related to a period of tectonic activity, which may in turn be compared with the period of major uplift during the Middle Pleistocene of the Rhenish Massif and the Ardennes.

After this period volcanic activity increased in the Eifel region since about 0.4×10^6 years ago. In The Netherlands an essential shift in pattern of fluvial sedimentation took place, as eastern rivers were not present any more in the area. During interglacial IV of the "Cromerian Complex" and during the Holsteinian, the sea invaded the northern part of The Netherlands, obviously as a result of eustatic rise of sea-level. Between these two interglacial periods, inland-ice reached the nor-



- Maximum extension of the Scandinavian inland-ice
 Ice-pushed ridges
 Glacial tongue basins
 Till plateaus
 Glacial valley of Saalian age or older

Fig. 36. Glacial basins during the Saalian.

thern part of the country for the first time during the Elsterian. Deep erosion channels were formed, probably as subglacial tunnelvalleys. They were subsequently filled by glacial lake-sediments, mainly clays. After the Holsteinian, in early Saalian times, eolian periglacial deposits were formed both in the southern and the northern part of The Netherlands. Two warmer, interstadial intervals interrupted the cold conditions during this time interval. The main Rivers Rhine and Meuse continued to supply material to the delta, although with some interruption. Whereas eolian and fluvial sedimentation continued in the southern part of The Netherlands, inland-ice covered the northern half of the country. This glaciation had a most important impact on the topography and on the course of the geologic events in The Netherlands. At its maximum extension the inland ice reached the central part of the country, extending even further southward in the adjoining German area (DUPHORN et al. 1973). The westward continuation of the maximum ice-front is less clear, although there is much evidence that the present North Sea area was partly covered by inland-ice. Whereas most of the ice originated from Scandinavia, data from the North Sea point to a British origin as well, the two inland-ice masses having met in the North Sea area (OELE 1971; OELE & SCHUTTENHELM 1979). In The Netherlands the glaciation may be subdivided into five phases (MAARLEVELD 1953; TER WEE 1962), the second of which brought the ice to its southernmost limit (JELGERSMA &

BREEUWER 1975). The topography as mentioned before, consists in the formation of deep glacier-tongue basins and ice-pushed ridges.

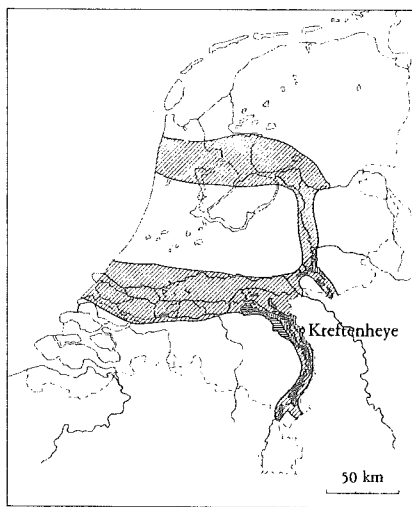
The southward extension of the inland-ice obstructed the original passage of the River Rhine and the river had to flow along the ice margin. The change in course had the effect that the Rivers Rhine and Meuse joined in the eastern part of The Netherlands. The deposits of the joined rivers are comprised in the Kreftenheye Formation, (see 5.1.3.1.).

During the retreat of the inland-ice, lakes were formed in the deep basins of the central part of The Netherlands, which were partly filled by glacial lake-sediments. The Rivers Rhine and Meuse continued their courses, the former, however, soon regained part of its former course to the northwest in the deglaciated area (VAN DE MEENE & ZAGWIJN 1978).

5.1.3. UPPER PLEISTOCENE

5.1.3.1. Stratigraphy

Four formations may be recognized in the Upper Pleistocene.







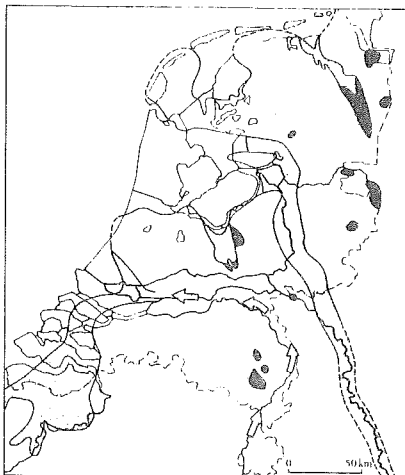
-  Kreftenheye formation
-  Kreftenheye formation near the surface
-  Kreftenheye and Veghel formations near the surface
-  Riverdunes

Fig. 37. Extension of the Kreftenheye Formation.

The fluvial deposits of the rivers Rhine and Meuse overlying the glacial deposits of the Drente Formation belong to the Kreftenheye Formation (Fig. 37). The formation consists of generally very coarse sands and gravels. In the eastern central part of The Netherlands a thick clay bed of mainly Eemian interglacial age is intercalated. The coarse deposits date from the Late Saalian and the Weichselian. At the very top a clay bed is widespread, dating from Late Weichselian to Early Holocene.

Marine and other deposits related to eustatic rise in sea-level after the retreat of the Saalian inland-ice belong to the Eem Formation. They were formed in two areas: In the southwest of the country, outside the previously ice covered area, marine and estuarine deposits are related to the river mouths of Rhine - Meuse and Scheldt. The most complete sections of the Eem Formation, however, may be found in the depressions formed by the inland ice during the Saalian. The distribution of the Eem Formation is represented on Fig. 38, which clearly shows how the sea could penetrate far beyond the present coastline in the northwest part of the country due to the presence of the









-  Depositional area of the North Sea
-  Area of peat deposits
-  Intertidal and brackish depositional area
-  Depositional area of the river Rhine
-  Depositional area of the rivers Meuse, Scheldt, a.o.
-  Direction of Main flow of the river Meuse

Fig. 38. Extension of Eemian facies.

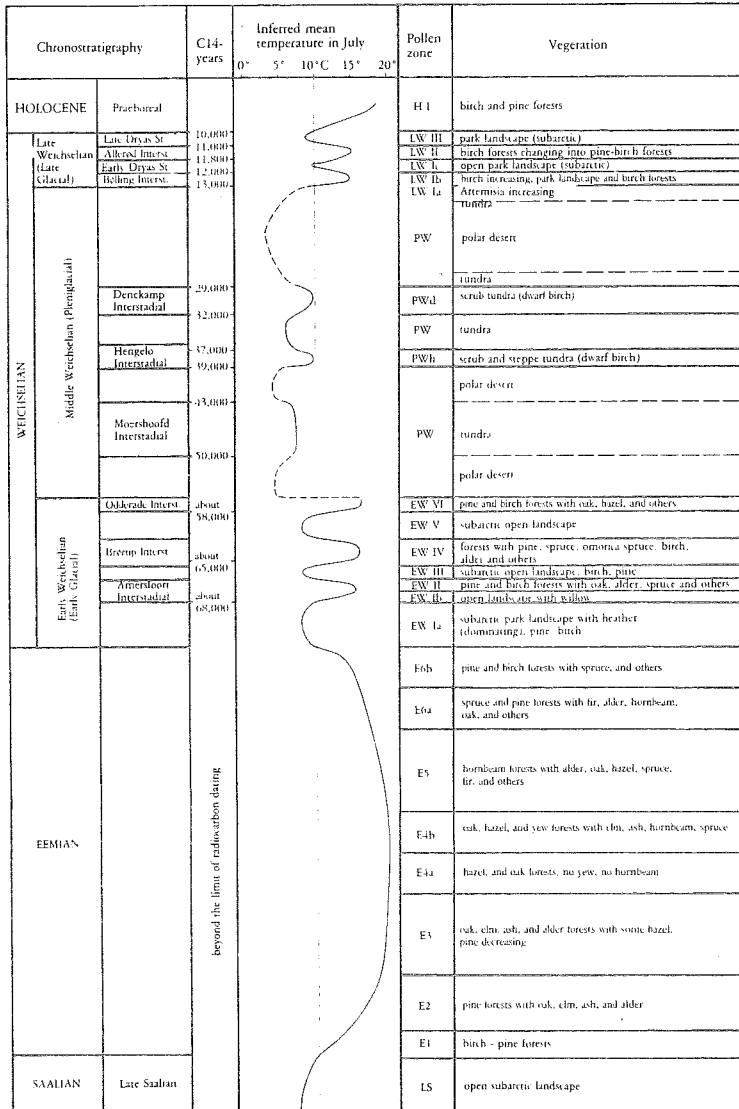


Fig. 39. Chronostratigraphy, climatic curve and pollenzones of the Late Pleistocene.

glacial valleys. The type locality, too, is located in such a valley. The base of the Eem Formation may be found in the basins at a depth of 70 metres below sea-level.

Despite the deep position of the base of the Eem Formation in the glacial basins, sediments of the oldest Eemian age have not yet been observed. This may be explained by the fact that the basins are closed features to which the sea had entrance only after its level had risen sufficiently to overflow the walls. Apparently the sea remodeled to some extent the shape of the basins during its transgression.

Clay layers may be intercalated in the coarse marine sands. In the North Sea area the transition of marine Eem deposits into fresh-water sediments (of Weichselian age) may be observed in a clay bed: the "Brown Bank Bed". On land the marine beds are underlain and overlain by peat.

Inland peat and brook deposits of Eemian age belong to the Asten Formation.

The fourth Upper Pleistocene formation is the Twente Formation. Dominant are eolian deposits, which were laid down over the country as a blanket. The windblown sands are named "coversands". Because of the horizontal lamination the sands are assumed to have been transported by storms. Thin loam layers may be intercalated in the well sorted material. Deposition of the coversands resulted in further smoothing of the Saalian topography. Other sediments, settled outside the zone of the main rivers are deposits from minor local streams fed by meltwater, and slope deposits. In South-Limburg a thick layer of loess was formed, covering all older sediments. Elsewhere, peat could locally develop. Stratigraphically the age of the Twente Formation is Weichselian.

5.1.3.2. Geological history

The Eemian geological history is mainly controlled by the sea-level rise after the Saalian glaciation and the subsequent sea-level fall due to the last, the Weichselian glaciation. These movements as well as their causes, i.e. climatic variations (Fig. 39), are clearly reflected in the Eemian sediments, especially those that settled in the marine and coastal areas. More inland the sedimentation pattern was rather monotonous. Along the course of the great rivers, material of the Kreftenheye Formation was laid down. The meandering river system shifted to the north, and took a course through the present IJsselvalley. Outside the area through which the rivers were flowing, sedimentation took place in small lakes and backswamps, resulting in the development of peat and clay layers up to a few metres thick.

In the Weichselian inland-ice did not reach The Netherlands or its off-shore area. Due to the fall in sea-level, the sea had completely withdrawn from the region, where sedimentation and erosion took place now under periglacial conditions. Temporarily climatic ameliorations occurred, leading to some expansion of the tree or shrub vegetation in the tundra-like landscape. At the moment eight interstadials may be distinguished. Cryoturbations, frost wedges and involutions indicate a periglacial climate,

in which a permafrost zone could develop. In some parts of the country pingo's, also related to the same climatic conditions, occurred.

In the central part of the country the Rivers Rhine and Meuse continued the building-up of the coarse-grained Kreftenheye Formation. Fig. 40 shows the paleogeographic situation in The Netherlands according to ZAGWIJN (1974). In the offshore area a similar depositional environment existed. A widely distributed lacustrine clay, which settled in the central part of the present North Sea area, must be mentioned separately. The clay reflects the transition of marine to fresh-water conditions at the Eemian-Weichselian transition.

In the later part of the Weichselian, deposition of eolian sand was extremely widespread, giving rise to coversand areas with low dunes, which at present characterize most of the topography of the Pleistocene part of The Netherlands.

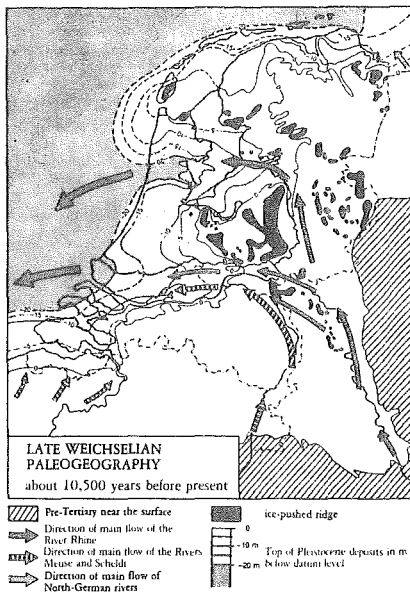


Fig. 40. Late Weichselian paleogeography.

5.2. HOLOCENE

The climatic changes after the Weichselian glaciation resulted in a sea-level rise with a subsequent rise of the groundwater table on land. Consequently, the Holocene sedimentation started with peat formation: the basal peat. The peat is not only widely distributed in the western and northwestern part of The Netherlands, but also in the adjoining North Sea area, Northwest Germany and

Belgium. In various places its growth could continue uninterrupted until the Late Holocene.

The continued sea-level rise caused a flooding of the peat. In many places a fresh-water clay is found on top of the peat, but generally a brackish influence is already apparent. Often the brackish sediments pass into marine deposits. The sea-level rise has been intermittently retarded which is at present expressed by intercalations of peat.

The oldest Holocene brackish marine deposits found in the area are the Elbow deposits in the North Sea. They date from the Praeboreal to Boreal (ca. 9000 BP). It was not before the Early Atlantic that the sea reached the present land area (ca. 7500 BP), its level being about 15 metres below present sea-level (Fig. 41). The marine deposits from the Atlantic period are the Calais deposits, which consist mainly of fine sands and clays. The transgressive phases of the sea during the Boreal and Early Atlantic have not been erosive, as is the case with the younger phases during the Atlantic, which resulted in deep channels of over 40 metres.

In the Atlantic a coastal barrier system started developing. In The Netherlands the oldest known barriers date from 5300 to 4700 BP. Various authors assume that the linear ridges in the North Sea, too, represent former beach barriers, dating from the Early Atlantic or even the Boreal. In the coastal area of the western part of The Netherlands the oldest barriers are found on the east side,

the barriers becoming younger towards the west (Fig. 42). Such a succession is explained by a seaward movement of the coastline due to a retardation in the sea-level rise. Since about 5000 BP the retardation is expressed by the development of a thick peat layer behind the coastal barriers as an extension to the west of the Holland peat, which was still growing along the eastern margin of the tidal flat zone. The peat is an important stratigraphic marker, intercalated as it is between the underlying marine Calais deposits and the overlying marine Dunkirk deposits in the coastal area from northern France to the northwestern part of The Netherlands.

Since about 3500 BP, but especially since about 2500 BP a renewed transgression, related to another eastward shift in the coastline, which culminated as late as the 12th century BC. The sea flooded parts of the peat area and created there a cover of the marine Dunkirk deposits on top of the peat. Again local or worldwide retardations resulted in the formation of thin peat layers between the marine sediments. The various Dunkirk phases differed in intensity and erosive influence from region to region. It is thought that the Dunkirk 0 phase especially was erosive in the northeastern part of the country, whereas the Dunkirk phase III apparently was strongly erosive in the western part of the country. Due to these transgressions the paleogeographic pattern changed rapidly (compare Figs. 41 and 42).

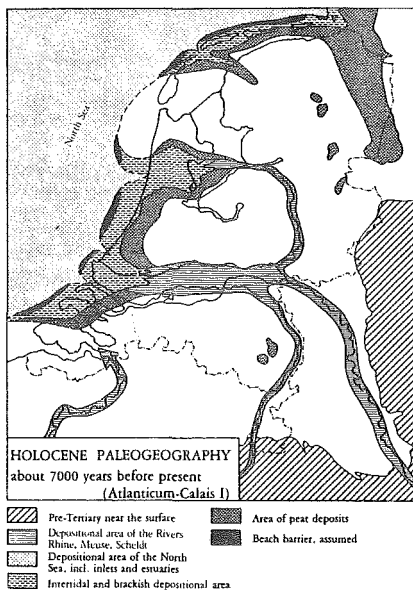


Fig. 41. Holocene paleogeography about 7000 years before present (Atlanticum-Calais I).

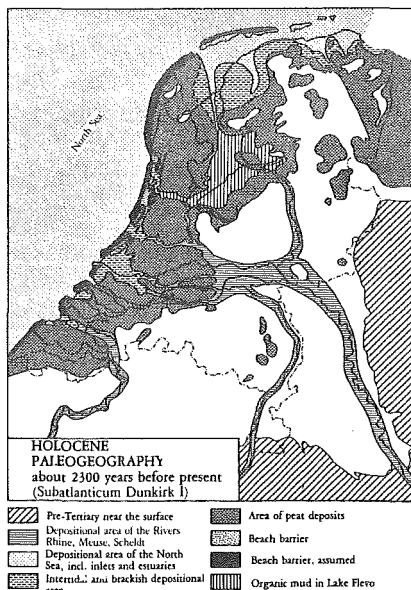


Fig. 42. Holocene paleogeography about 2300 years before present (Subatlanticum-Dunkirk I).

In the meantime the formation of the earlier mentioned barriers was completed by the deposition of windblown sand, known as Older Dunes. The formation of the Older Dunes continued until Roman times, the sea having access to the area behind the barriers through a limited number of tidal inlets and river outlets. In the central part of The Netherlands a large lake existed since about 1000 BC which after the Middle Ages was connected with the sea to form the Zuiderzee. It is now partly reclaimed. The sub-marine barrier-foot material, which came available during the afore mentioned coastal erosion in mediaeval times, yielded the material which was later blown inland from the fore-shore, and gave rise to the Younger Dunes. The formation of the Younger Dunes on top of the older barrier system marks the end of the geological coastal history. Due to human influence, large-scale changes occurred in particular in the western and northern part of The Netherlands, through dike-building, peat-digging and reclamation of lakes which had originated in the peat areas, partly through natural causes, partly as a result of peat-digging.

In the hinterland the rivers contributed mainly fine material, depositing only some sand in the vicinity of the rivers themselves, which hardly changed their courses any more. The fluvial deposits are named Tiel or Gorkum deposits depending on the correlation with either Dunkirk or Calais deposits. These deposits determine the landscape in the area of the rivers Rhine and Meuse.

Extensive formation of peat took place in The Netherlands during the last 10,000 years. Climatic conditions were temperate and moist and highly favourable for peat accumulation, both in low moors as well as in raised bogs. Raised bogs, or high moors are elevated morphological features resulting from peat formation independent of the water table and mainly dependant on the supply of rain water. Accumulation of peat occurred in many places outside the area influenced by the sea and the river-systems, in particular in the western and northern part of The Netherlands. Due to human activity it has been almost entirely removed in various places.

Human intervention also resulted in deforestation with subsequent eolian erosion, and deposition giving rise to development of dunes. The rather recent dunes are particularly present in the central part of the country.

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MONDAY 29th MARCH

THE VELUWE (J J M Van der Meer)

The Veluwe is the central part of the Netherlands and the name is generally used to indicate the high lying woods and nature reserves of this area. No exact boundaries can be given for this area as it is bounded on all sides by a transitional zone to low lying areas.

The geomorphology of this area has most recently been studied by Maarleveld and de Lange (1977), who also published a geomorphological map (1:100,000) of the Veluwe. More detailed maps of parts of the Veluwe are presented by sheets 32 (Amersfoort) and 40 (Arnhem) of the Geomorphological Map of the Netherlands (scale 1:50,000; publication by Stichting voor Bodemkartering, Wageningen and Rijks Geologische Dienst, Haarlem; see also Ten Cate et al., 1981).

The Ice-pushed Ridges

The backbone of the Veluwe is formed by a number of large crescentic ridges, consisting of ice-pushed deposits. In general these have a flat, plateau-like surface that is bounded on both sides by a steep flank. The ice-contact flank is the steeper in most cases. It has been known for some time that these ridges are the result of ice-pushing by glacier lobes during the Saalian. For a historical review see Teunissen (1961) who described the different views that have been held regarding the origin of, and relations between the ice-pushed ridges. Crommelin and Maarleveld (1949) were the first to systematically measure the strike and dip of the ice-pushed deposits, first on the S Veluwe and later on the N Veluwe and on other ice-pushed ridges as well. Through these measurements they were able to trace the orientation of the ice-pushed deposits. It was found that the strike of the deposits is parallel to the length of the ice-pushed ridges and that the dip decreases with increasing distance from the ice-contact flank. This study also revealed that some ridges cut off others and that they could be placed in a stratigraphic order. For the central part of the Netherlands Maarleveld distinguished three phases (a, b and c) of ice-pushing (Maarleveld, 1953; 1981). For the Veluwe these phases are indicated in figure 2.1. It must be stressed however that these phases do not necessarily represent different glaciations. Most probably they indicate a highly mobile ice front. It is not known how far the ice retreated between the different phases of pushing. As indicated in figure 2.1 the ice reached farthest south in phase a, which means that the phases b and c must be regarded as retreat stages. In a number of places, till remnants are found on top of the ridges, indicating that they have at least partly been overrun by the glacier lobes or by the main ice-sheet (see also De Zanger, 1980).

The deposits that have undergone pushing are mainly sandy and gravelly fluvialite deposits of Early and Middle Pleistocene age. These contain so-called "brown sands", deposited by the Rhine and the Meuse as well as

"white sands", deposited by (German) eastern rivers (Zandstra, 1971; see also Zandstra, 1981). Lithostratigraphically the former belong to the Urk Formation (possibly also Sterksel Formation) while the latter belong to the Harderwijk and Enschede Formations (see the general introduction in this field handbook and Koster (1980)). Zandstra (1971) even found clayey deposits belonging to the Tegelen Formation involved in the pushing in the northern Veluwe. No Saalian glacial sediments are involved in the ice-pushed deposits, although in the Utrechtse Heuvelrug (an ice-pushed ridge west of the Veluwe) deposits of Saale age were found to be pushed. In the northern Veluwe and east of the IJssel River older deposits containing northern erratics (the Hattum Complex) were found in an ice-pushed position (Luttig & Maarleveld, 1961). These may represent older fluvioglacial deposits.

As for the process of pushing it is generally assumed that by the time the ice arrived, the Meuse had incised a valley west of the Veluwe and the Rhine likewise east of the Veluwe. Incision was the result of the already much lower sea-level (Maarleveld, in press). The ice lobes used these valleys to penetrate inland, forcing their walls and pushing them into ridges. Presumably (local) permafrost existed in this area (Maarleveld, in press) although the coarse grained deposits were probably not cemented by ice (dry permafrost). The former valleys of the Rhine and the Meuse are difficult to recognize because positions are now occupied by deep glacial basins. The deepest parts of these basins reach to more than 100 m below NAP (Dutch ordnance datum) (Jelgersma & Breeuwer, 1975) while adjacent parts of the ice-pushed ridges reach to about 100 m above NAP (on the eastern Veluwe). This indicates a (Saalian) postglacial amplitude of relief of over 200 m.

There are still a number of problems concerning these ice-pushed ridges that remain to be solved, for instance:

- 1 Did the pushing occur in front (lateral and frontal) of the glacier or did it occur subglacially? Moran et al (1980) indicate a subglacial origin for similar features in Canada, while in the Netherlands it is generally assumed that the pushing occurred in front of the glacier.
- 2 Up to now it has been taken for granted that the pushing occurred under permafrost conditions, meaning that the deposits involved were cemented by ice. The reason for this was the assumption that loose materials would deform chaotically rather than form imbricated slabs of undisturbed sediments, and also that small scale models only worked when the material was frozen. Maarleveld (in press) indicates that dry permafrost can have existed in this area at the onset of glaciation, while Van der Wateren (1981) indicates on theoretical grounds that pushing can occur under dry permafrost conditions as well as in ice-cemented deposits.
- 3 It has been proposed that ice-pushed ridges are the result of glacier surges (Zagwijn, 1974, 1975; Jelgersma & Breeuwer, 1975). As ridges of this kind have never been found along present day surging glaciers (see eg, Can J Earth Sci., Vol. 6, No. 4, 1969) it is not very probable that this process is responsible for the formation of ice-pushed ridges. Muller (1969) even showed a glacier, that was probably surging, to overflow an existing ice-pushed ridge.

Fluvioglacial Deposits

Several types of fluvioglacial deposits can be recognized in the Veluwe. A large sandur is found in its southern part, enclosed by four ice-pushed ridges. As the measured directions of transport point WSW-SW (Crommelin & Maarleveld, 1949) in this area, it must be deduced that at least the upper part of the sandur was deposited by meltwater from the ice-lobe occupying the IJssel Valley. Depending on the distance the meltwater travelled over the ice-pushed ridge, the (sandy) sandur deposits contains few to very few glacial components (De Jong & Maarleveld, in press). In the northern part of the Veluwe extensive kame-terraces are found, lying between ice-pushed ridges (Maarleveld, 1955; 1962). These kame-terraces are characterized by a highly irregular surface, in the shaping of which dead-ice played an important role (Smit Sibinga, 1944/45). The deposits found in the kame-terraces contain much more glacial components than the sandur deposits. In addition they contain till pebbles, armoured clay balls and angular sand blocks. The latter were supposedly transported in a frozen state. In the kame-terraces some localities with laminated clays have been found (Crommelin & Maarleveld, 1952), but it is doubtful if they can be regarded as real varves (see also Castel et al., 1982). Recent, unpublished, results of geophysical research by the Free University, has shown that this clay is widespread in this valley.

Within the area occupied by the kame-terraces a number of isolated hillocks is found. Because of their different geomorphology and a higher percentage of glacial components these are interpreted as kames (Wilms, 1981). A small number of isolated hillocks on the eastern Veluwe ice-pushed ridge are also regarded as kames (Maarleveld, 1955)

Weichselian Morphological Changes

A second phase of strong morphological changes occurred during the Weichselian. During this stage, permafrost was present at least during the Lower and Upper Pleniglacial, with mean annual temperatures of -7°C (nowadays $c.+9^{\circ}\text{C}$; Maarleveld, 1976). During the Weichselian two processes were mainly responsible for the changes in the morphology of the Veluwe. The first process was the formation of valleys, associated with solifluction deposits, and the second was the deposition of coversands.

Although many of the large valleys may have originated as meltwater valleys during the Saalian, their main development took place during the Weichselian. Because of the permafrost, snow meltwater could not infiltrate into the sandy subsoil, and the resulting surficial drainage resulted in an extensive network of valleys, now dry. Due to differences in snow cover in these valleys, solifluction, and the deposition of coversand and loess, many of these valleys have an asymmetric cross-section (Edelman & Maarleveld, 1949).

Four types of valleys can be discerned. Many of the valley systems start as shallow "dellen", changing into either U-shaped or V-shaped valleys, which often combine to form large funnel-shaped valleys. The latter are of such size that only a topographic map gives a good outline of their shape, whereas in the field they are very hard to recognize. At the mouths of these valleys large alluvial fans are found, especially in the IJssel Valley. Sections in these fans give a great deal of information about the stratigraphy of the Weichselian, because intercalated in the fluvial deposits are loamy and/or organic layers, while large parts of the deposits are disturbed by periglacial activity (figure 2.2). Deposition

of the coversands started during the Upper Pleniglacial. Four different lithostratigraphic units can be recognized: Older Coversands I and II and Younger Coversands I and II (see table below). These coversand beds are separated by respectively, the Beuningen Complex, a coarse niveofluviatile deposit characterized by the occurrence of large wedges; the Lower Loamy Bed (Bjelling); and the Usselo layer (Allerød). The latter two are thin paleosol remnants of bleached appearance, while the Allerød is sometimes represented by a thin peat bed. In general it can be said that the Younger Coversands are coarser than the Older Coversands. The latter are characterized by loamy beds, while the former often contain strings of coarse sand or gravel up to 1 cm thick. This is especially true for the pseudo-osar, which are part of the Younger Coversands II. On the older geologic maps of the Netherlands these pseudo-osar are indicated as real eskers formed during the Saalian. However, Edelman & Maarleveld (1944) and Maarleveld (1951) indicated that the winding ridges must be regarded as long inland dune systems of Late Dryas age. There are two good reasons for this re-interpretation: first they are found to cross valleys which are of Weichselian age and second an Usselo layer of Allerød age is often found at their base. A detailed morphological map of a large pseudo-osar system in the Northern Veluwe had been prepared by the author (detail in figure 2.3).

CHRONOSTRATIGRAPHY	LITHOSTRATIGRAPHY	WIND DIRECTION	AGE BP
Late Dryas Stadial	Younger Coversand II	±WSW	10.100 (10.600) ¹
Allerød Interstadial	Usselo Layer		10.900 (11.000) ¹
Earlier Dryas Stadial	Younger Coversand I	±WNW	11.800 (11.800) ¹
Bjelling Interstadial	Lower Loamy Bed		12.400 (12.000) ¹
Upper Pleniglacial	Older Coversand II (Loamy older coversand)	±NNW	13.300 (13.000) ¹
	Beuningen Complex		(14.000) ²
	Older Coversand I (Non loamy older coversand)	±NW	(22.500) ²
			±30.000 (29.000) ¹

Table 1

Sequence of cover sand deposits and prevailing wind directions during the later part of the Weichselian in The Netherlands (acc. to data publication list Maarleveld nr. 44, 56, 59, 63 and 83). Radiocarbon dates in parenthesis acc. to recent data (1) of the Geological Survey of The Netherlands and (2) of Kolstrup (1980) (From Ten Cate et al, 1981).

The Holocene

During the Holocene the geomorphology of the Veluwe has been influenced mainly by eolian activity. Since the beginning of the Neolithic local redistribution of well-sorted sandy deposits has occurred in areas with a very deep groundwater level, due to the devastation of the vegetation cover by man (Koster, 1973). This process was especially active from the Late Medieval period onwards. It resulted in an area of about 230 km² of inland dunes on the Veluwe (figure 2.4). Since the end of the last century this area has been stabilized by the planting of conifers. At the moment about 5% of the area is still active, an area which is highly valued for recreation purposes.

EXCURSION

- 1 Sandpit on the northern Veluwe showing the imbricated structure of the ice-pushed Eastern Veluwe ridge. Locality: Gemeentegroeve, Wapenveld.
- 2 Geomorphology of a large pseudo-osar system as exemplified by the Renderklippen near Epe.
- 3 Kame-terrace near Vierhouten: view over the undulating terrace and visit of a small pit in varvelike deposits intercalated in the kame-terrace.
- 4 Uddelermeer. Waterfilled depression which is interpreted as a pingo-remnant of Weichselian age. This lake and the nearby Bleeke Meer are both partly filled by organic deposits of Late glacial and Holocene age.
- 5 Active inland dune area near Kootwijk.
- 6 Sandpit near Rheden/de Steeg. Imbricated ice-pushed deposits with overlying banded loess.
- 7 The Posbank area is a heavily dissected part of the Eastern Veluwe ridge. Many of the dry valleys are asymmetric in cross section.
- 8 View from the Ede ice-pushed ridge over the central sandur of the southern Veluwe. This sandur is surrounded by the Ede ridge in the west, the Oud Reemst ridge in the north, the Eastern Veluwe ridge in the east and the Arnhem ridge in the south.
- 9 Sandpit in the apex of the junction of the Ede and the Oud Reemst ridges. A complex sequence of deposits is exposed in this pit (figure 2.5). Unit A represents ice-pushed deposits and unit B is a glaciolacustrine deposit. Unit C consists of two till beds, which up to now were regarded as a flowtill. Detailed studies by Rappol and Van der Meer (publication in preparation) indicate that it must be interpreted as a lodgement till which has gained its peculiar basin shape by pushing. Unit D is a thick fluvioglacial deposit, in which syngenetic ice wedges have been observed (Van der Meer & Smeijjn, 1981). Finally, Unit E is a coversand deposit of Weichselian age.

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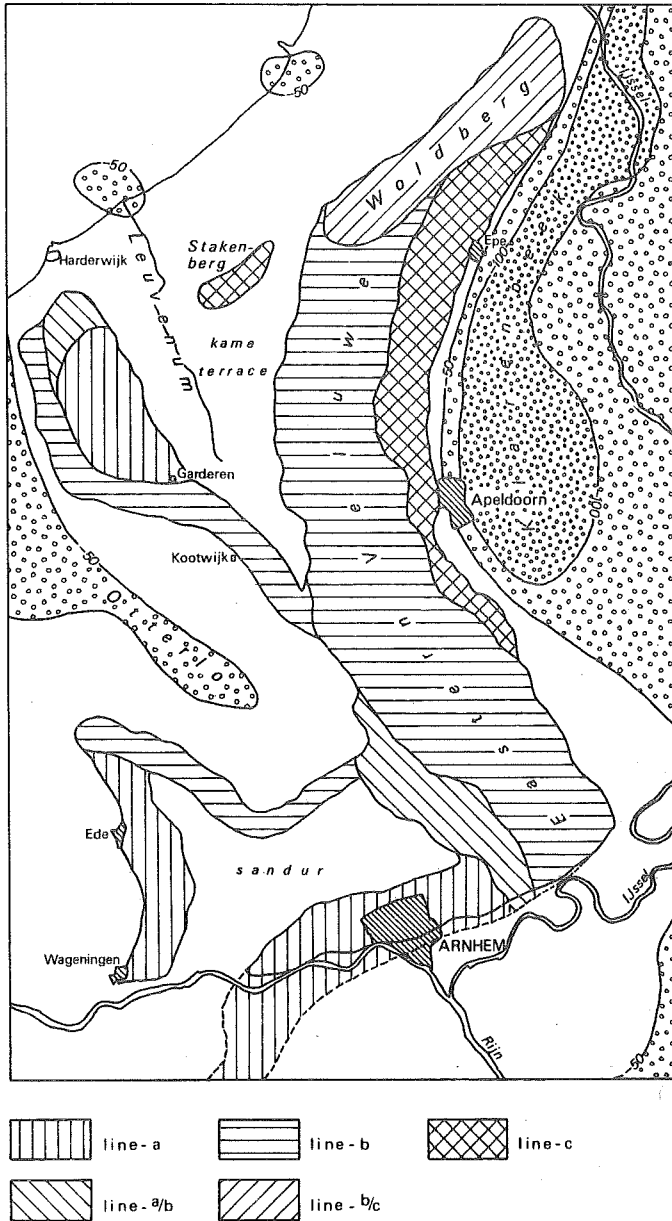


Fig. 2.1 The ice-pushed ridges of the Veluwe and the position of the over-deepened basins (after: Maarleveld, 1981).

Sandpit Heideroos, Eerbeek

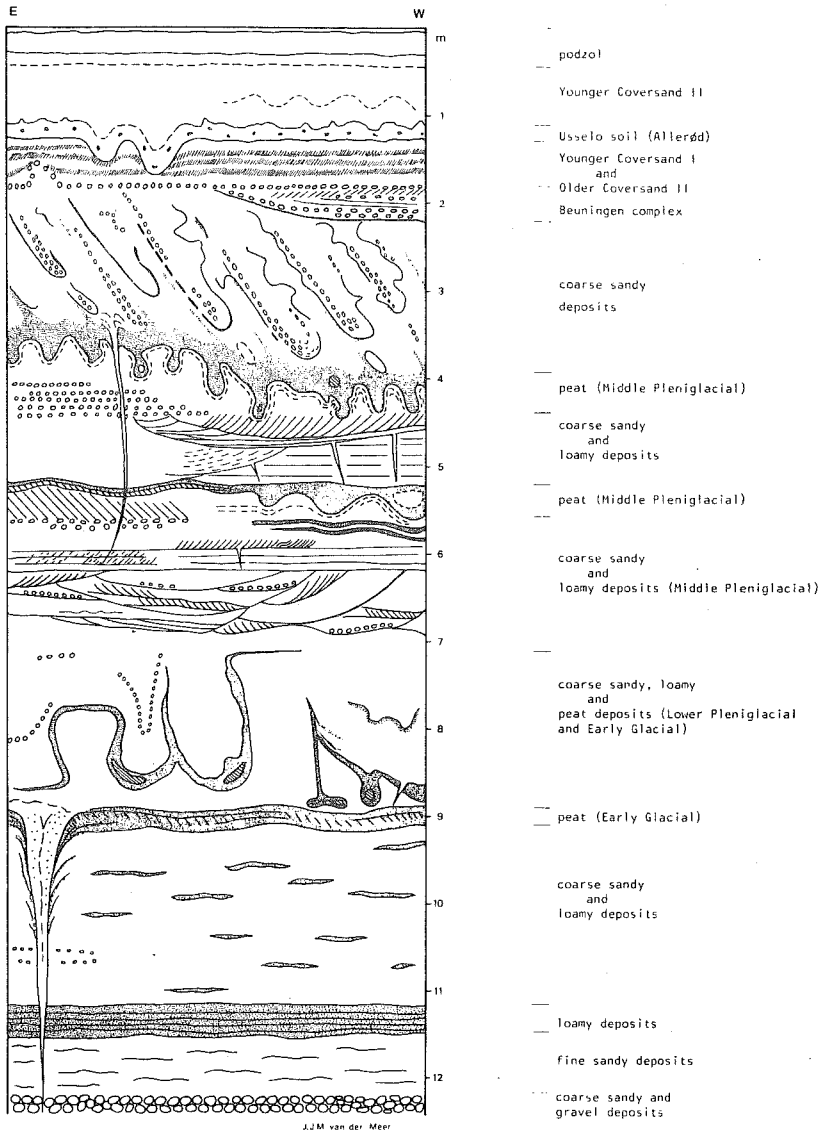


Fig. 2.2 Schematic stratigraphy of the alluvial fan near Eerbeek.

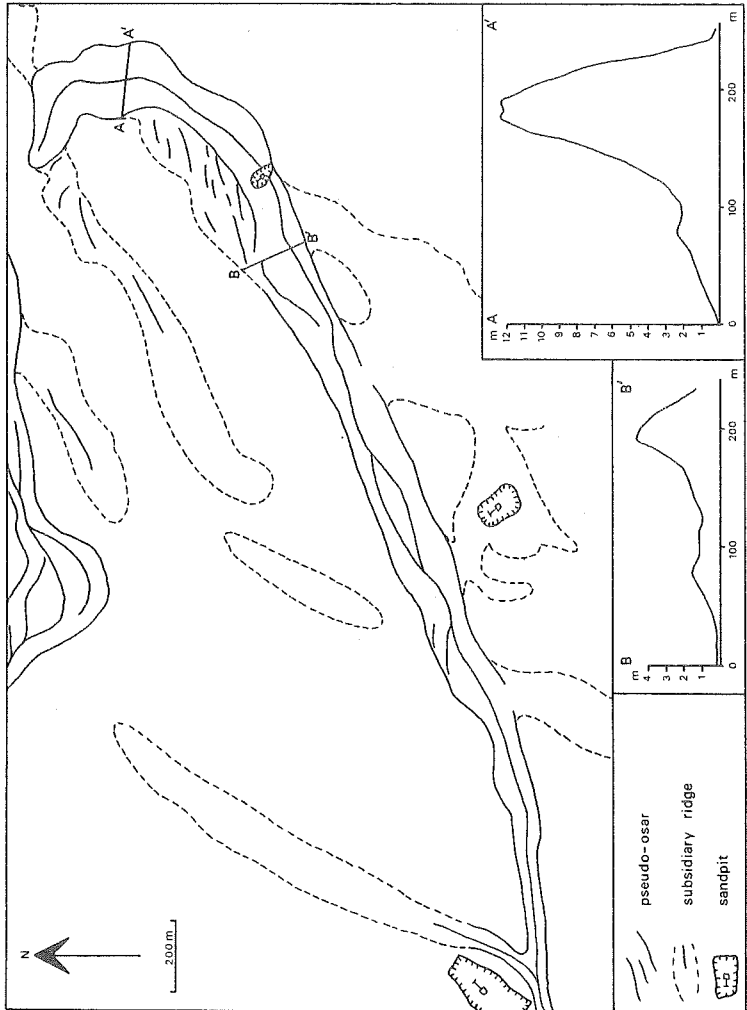


Fig. 2.3 De Renderklippen, part of a large pseudo-osar system on the Northern Veluwe.

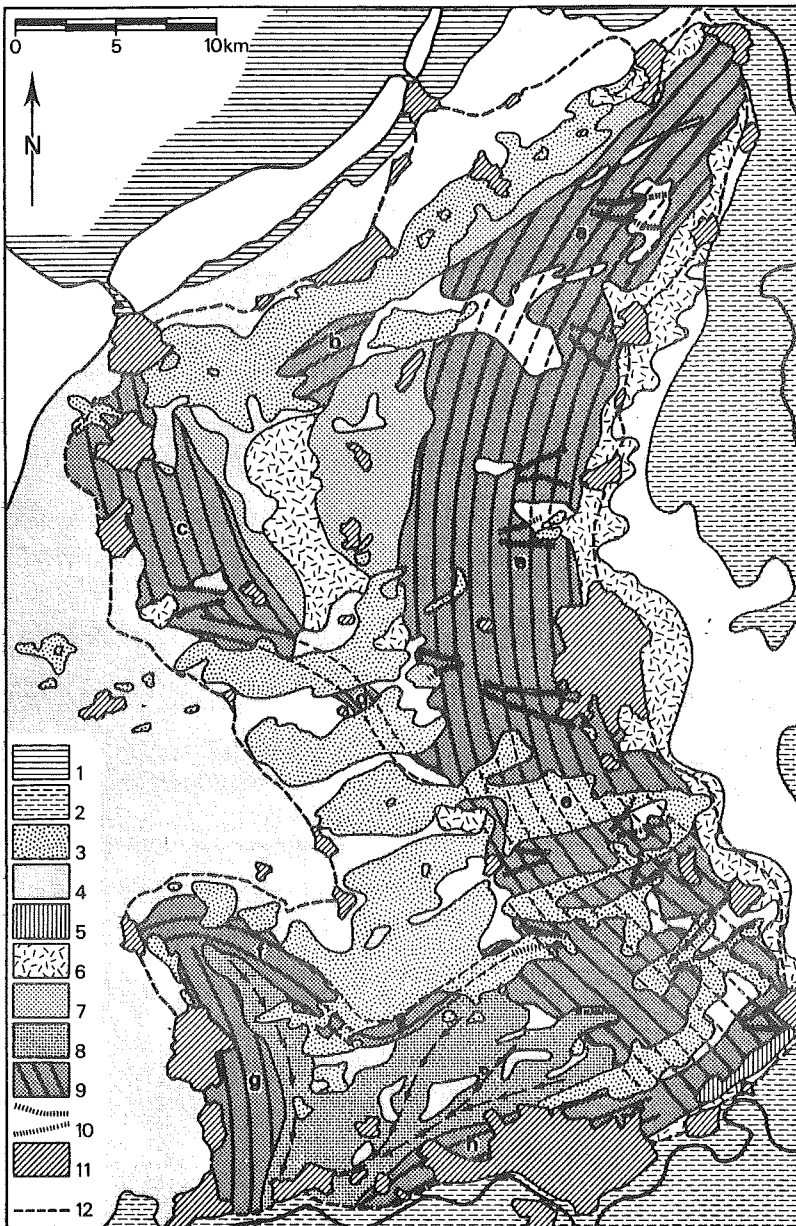


Fig. 2.4 Geomorphological map of the Veluwe (from: Koster, 1978).

Legend to Figure 24

- 1 Predominantly flat, marine deposits.
- 2 Predominantly flat, fluvial deposits.
- 3 Hills associated with drift sands.
- 4 Flat to gently undulating relief with very short steep slopes in cover sands and other aeolian deposits. Partly on the ice-pushed ridges.
- 5 Ice-pushed pre-Saalian deposits with a loess cover.
- 6 Flat and fan-shaped low rises, fluvioglacial deposits.
- 7 Gently to steeply sloping fluvioglacial deposits (kame terraces).
- 8 Flat to gently sloping fluvioglacial deposits (sandy, with valley directions).
- 9 Gently to steeply sloping ice-pushed ridges with strike directions, containing pre-Saalian deposits:
 a: Woldberg; b: Stakenberg; c: Garderen; d: Kootwijk;
 e: the eastern Veluwe; f: Oud-Reemst; g: Ede; h: Arnhem.
- 10 Funnel shaped, ice/snow meltwater dry valleys.
- 11 Built-up areas.
- 12 Boundary of the Veluwe.

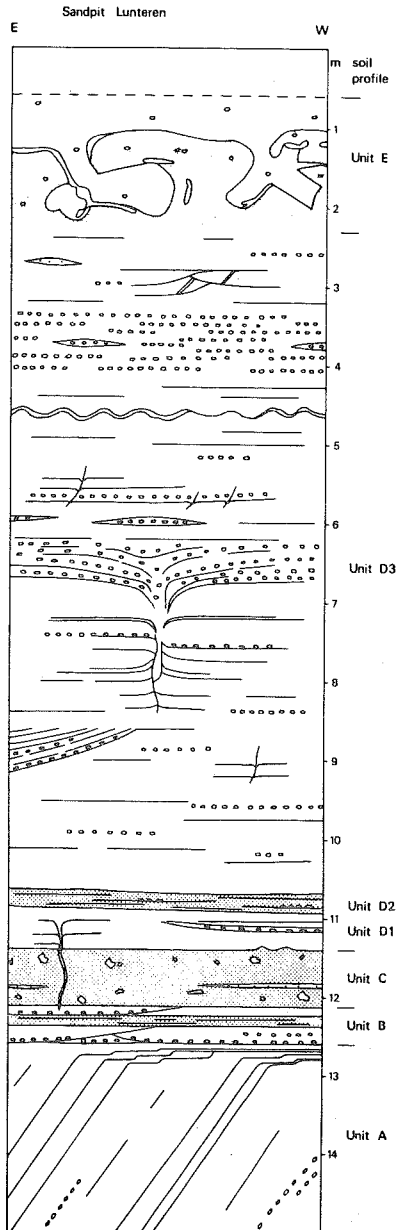


Fig. 2.5 Schematic stratigraphy of a sandpit near Lunteren (from: Van der Meer & Semeijn, 1981).

3 TUESDAY 30th MARCH

TEGELEN-REUVER AREA (W H Z and J de J)

The pits are partly on Dutch territory, partly on the German side of the frontier (figure 3.1) They are often dug in the escarpment of the Main Terrace on the eastern flank of the river Meuse valley.

From north to south one proceeds by a series of faults from the Venlo Graben to the Peel-Horst (= Horst of Bruggen-Erkelenz) (figure 3.2). In all pits we will encounter the fluvial gravels and coarse sands of the "Weert-zone" of the Sterksel Formation (so-called Younger Main Terrace Gravels of German authors), which unconformably overlies Lower Pleistocene and Pliocene beds, some of which are well-known from their fossil molluscs, wood, fruits and seeds; Reuver Clay: fruits and seeds, leaves, wood, molluscs.

Since Cl. and E M Reid's memoir of 1915 the Tegelen flora (now: Lower Pleistocene) and the Reuver flora (now: Upper Pliocene) form landmarks in the stratigraphy of the Upper Neogene non-marine beds of Europe.

In the Reuver flora many forms are still found (eg, Sequoia, Taxodium, Nyssa, Aesculus, Liquidambar, Fagus and many others) which are lacking in Tegelen. Here only some relics of the Tertiary flora element survive (Tsuga, Pterocarya, Carya, Eucommia, Phellodendron, Actinidia). The eradication of so many of the warmth-loving elements was assumed to have been caused by the first cold phase at the onset of the Pleistocene (Pretiglian). Some years ago it became possible to prove this assumption in more detail by means of pollen-analyses by which it could be shown that two temperate forest phases, the lower of Reuver type, the upper of Tegelen type, were separated by a cold-subarctic phase of open landscape (Zagwijn, 1960).

At present, exposures are not nearly as good as they used to be, mainly because of changes in the way of exploitation. Especially at Tegelen conditions are bad and only one good exposure remains (Pit Laumans), though it will also disappear within a few years. Unfortunately no beds rich in fossils are exposed at the time either.

In the Tegelen area, beds of Upper Lower Pleistocene and Upper Tiglian age are found below the Sterksel Formation (figure 3.6). In the transitional area towards the Horst at Oebel and near Belfeld (both on German territory) we find Lower Tiglian and Upper Pliocene beds, whereas on the Horst proper the Sterksel Formation caps the Upper Pliocene Reuver Clay and in some places even older beds (Miocene and Oligocene glauconiferous sands).

1 Pit Peter van Eijck (figure 3.3)

At the base a Pliocene (Upper Reuverian) clay bed is found (pollen-diagram figure 3.4). Lately W Boenigk (1970) found that the heavy

mineral composition of this clay and underlying sand was a garnet-epidote-saussurite association (figure 3.3). Therefore he assumed a Pleistocene age, as this association up till then was assumed to be of Pleistocene age exclusively. In fact, however, the combination of the pollen-data and the mineralogical data now clearly proves, that the big change in heavy mineral composition in the sediments of the river Rhine (from stable to unstable assemblages) had already occurred in the uppermost Pliocene.

There then follows in the succession the Belfeld Gravel and some clay beds which are of Tiglian age. In the pollen-assemblage of the clay bed found at this level in the adjoining pit Janssen-Dings, which is called the Belfeld Clay, *Fagus* is still present (figure 3.11). This clay is therefore placed in the Lower Tiglian. This tree disappeared later in the Tiglian for a long time from this part of Europe, to return only in the Holocene. It should be noted, that the Tiglian is not a simple interglacial but a complex of alternating temperate and cool phases of which none of the latter is at the present state of knowledge cold and long enough to use the term "glacial".

It is, however, well possible that increased knowledge in the future will change this situation and that one or perhaps some of the "cool phases" will turn out to represent longer and colder stages, which would induce a splitting up of the Tiglian into some glacials and interglacials.

In pit Peter van Eijck several clay beds of Middle to Upper Tiglian age and referred to as Tegelen Clay, are present. The pollen assemblages are vary in their composition, but *Fagus* is absent in all of them.

2 Obel (figure 3.5)

The lowermost clay member has the characteristic features of the Reuver Clay at the type-area. The blue clay especially, sandwiched between peat-horizons in the upper part, is highly characteristic from the lithostratigraphic point of view (compare figure 3.9).

In this part of the Reuver Clay there begins, according to W Boenigk (1970), for the first time a heavy mineral assemblage dominated by garnet-epidote-hornblende-saussurite. It seems likely that this part of the Reuver Clay correlates with the basal clay and sand in the Peter van Eijck pit.

The remainder of the section is similar to that in the Peter van Eijck pit. In a gully of the Tegelen Clay a very humic clay filling of Upper Tiglian age (pollen-zone TC3) occurs (figure 3.12). The Sterksel Formation caps the underlying beds unconformably.

3 Pit Russel-Tiglian Egypte (figure 3.13)

This pit has been abandoned now, after having been in exploitation for about 20 years. In the last decennium excavation was done by draglines, this resulting in bad exposures. Lately an excavation was undertaken by the State Museum of Geology and Mineralogy (Leiden) for the purpose of washing small mammal remains.

The pit is directly adjacent to the former pit of Canoy-Herfkens, from which Dubois and Cl. and E M Reid collected many fossils in the beginning of this century. This pit showed about the same succession as the pit of Egypte. Therefore this latter can serve as a substitute for the stratotype of the Tiglian as well as of the Tegelen Clay. Two sedimentary cycles are present. Cycle I consists of lake-clay filling an ancient oxbow about 200 metres broad. Cycle II consists of a narrow gully incised in the top beds of the lake-clay with levees at each side, and further away backswamp clay. This latter bed in most other pits of the Tegelen area forms the Tegelen Clay *sensu stricto*. The lower clay of cycle I has been found only in the direct vicinity of pit Egypte. A block-diagram (figure 3.13) may give an impression of the conditions in this pit as they were about 10 years ago. In the filling of the gully at the base of cycle II many fossils have been collected. It contains fossil wood, fruits, seeds, mammal remains. Among the latter *Elephas meridionalis* deserves to be mentioned. Since 1970 a large amount of material has been washed by Dr Freudenthal of the Rijksmuseum van Geologie en Mineralogie in Leiden, in order to collect remains of small mammals. A list of the plant remains found in this level, follows below (Table 3.1). A pollen-diagram from the Russel-Tiglian Egypte pit is also given (figure 3.10). It shows the fossil rich gully sand to date from pollen-zone TC5. The wood remains have been studied by van der Burgh (1974) (table 3.2). Furthermore lists of the smaller mammals and molluscs found are presented (tables 3.3 and 3.4) according to Freudenthal et al. (1976).

Table 3.1

Fossil fruits and seeds etc, collected from the Tegelen Clay in pit Russel-Tiglian Egypte at Tegelen

Sample: Sandy and clayey filling of gully at the base of the cycle IIa. Pollen-zone TC5.

f = fruit; s = seed; + = new for Tegelen

+	<i>Rossenilites areolatus</i> (Fres.) MEY	1
	<i>Picea Florschutzi</i> VAN DER HAMMEN	2 cones
	<i>Potamogeton acutifolius</i> LINK	1 f
+	<i>Sparganium minimum</i> FR	1 f
	<i>Scirpus</i> sp	1 f
	<i>Carex</i> sp	18 f
	<i>Pterocarya limburgensis</i> REID	1022 f
	<i>Carpinus betulus</i> L	21 f
+	<i>Corylus avellana</i> L	1 f
	<i>Rumex maritimus</i> L	1 f
	<i>Pilea pumila</i> A. GR	1 s
+	<i>Nuphar luteum</i> SMITH	17 s
	<i>Euryale limburgensis</i> REID	1 s
	<i>Magnolia kobus</i> DC	60 s
	<i>Ranunculus sceleratus</i> L	98 f
	<i>Eucommia europaea</i> MADLER	69 f
+	<i>Rosa</i> sp	1 thorn
	<i>Dendrobenthamia tegelensis</i> MAI	129 f
	<i>Prunus maximoviczii</i> RUPR	35 f
	<i>Prunus</i> sp	1 f
+	<i>Mercurialis cf. annua</i> L	4 s

Phellodendron elegans REID	38 s
Staphylea pinnata L	63 s
Acer campestre L	f
Acer limburgensis REID	f
Acer cf. opulifolium VILL	f
Acer sp. div. (total)	96 f
Vitis cf. silverstris GMEL	318 s
Vitis sp	tendrils
+ Parthenocissus sp	4 tendrils
Menispermum crassicaipum (REID) nov.	3 s
Actinidia faveolata REID	2 s
+ Actinidia sp	1 s
Viola sp. div.	64 s
Trapa natans L	1 f
Araliaceae/Cornaceae (REID 1910)	1 f
Cornus mas L	3 f
+ Ajuga reptans L	4 s
+ Viburnum opulus L	1 s
+ Sambucus pulchella REID	2 s

4 Pit Laumans (Tegelen)

A survey of the stratigraphy and lithology will be found in figure 3.14. Here we see only the topmost beds of the Tegelen Clay; more complete sections of which have been found in the Russel-Tiglian Egypte pit (figure 3.13). A simplified pollen-diagram from the latter pit is shown in figure 3.10, showing the transition of the temperature conditions of the main part of the Tegelen beds to cool and even cold-subarctic conditions when the top part of the Tegelen Clay was formed. Cold conditions persisted during the formation of the fine sands of the Kedichem Formation which are found on top (locally called "pap-zand" = porridge-sand, because of its quickening habit) as witnessed by small frost-wedge casts in the middle of the beds. All these cold deposits are placed in the Eburonian glacial. Some soils on top (partly with peat-horizons from which pollen-data have been obtained) point to temperate conditions again (probably during the Waalian interglacial). The soils are overlain by fine sands showing very clearly frost-wedges and involutions. They are considered to date from the Menapian glacial.

Table 3.2 Comparison between the fossil wood-flora of Tegelen and related taxa in some Recent floras.

	European flood- plain forest	Manchurian deciduous forest	Hokkaido deciduous forest	mixed mesophytic forest of eastern Asia	eastern North American flood- plain-forest and upland forest	Pontic forest	number of samples	percentage of samples
<i>Pinus</i> sp	-	+	+	-	+	-	4	3.1
<i>Picea</i> spp	-	-	-	+	+	+	15	11.5
<i>Abies alba</i>	-	-	-	+	+	+	1	0.8
<i>Chamaecyparis</i> cf. <i>thyoides</i>	-	-	-	-	-	-	2	1.5
<i>Magnolia</i> sp	-	+	+	+	+	-	4	3.1
<i>Ulmus</i> sp	+	+	+	+	+	+	3	2.3
<i>Celtis</i> sp	-	+	+	-	-	+	5	3.8
<i>Tilia</i> sp	+	+	+	+	+	+	1	0.8
<i>Phellodendron</i> sp	-	-	+	+	+	-	1	0.8
<i>Acer campestre</i>	+	+	+	+	+	+	8	6.2
<i>Vitis sylvestris</i>	+	+	+	+	+	+	1	0.8
<i>Cornus mas</i>	+	+	+	-	+	+	2	1.5
<i>Crataegus</i> sp	+	-	+	+	+	+	2	1.5
<i>Sorbus aucuparia</i>	-	-	+	+	+	+	3	2.3
<i>Prunus</i> sp	+	+	+	+	+	+	7	5.5
cf. <i>Cytisus</i> sp	-	-	-	-	-	-	1	0.8
<i>Fraxinus excelsior</i>	+	+	+	+	+	+	37	28.3
<i>Populus nigra</i>	+	+	+	-	-	-	2	1.5
<i>Carya</i> sp	-	+	+	-	-	-	2	1.5
<i>Pterocarya</i> sp	-	-	+	+	-	+	28	21.6
Indet	-	-	-	-	-	-	1	0.8
Percentage of taxa	45	60	80	75	75	70		
Percentage of samples	48	60	85	89	70	88		

Table 3.3. Smaller mammals from the clay-pit Egypte.

Insectivora

- Talpa fossilis* Petenyi, 1864
Desemana tegelensis Schreuder, 1939
 * *Desmana* sp. (small species)
 * *Sorex* sp
 * *Sorex* cf. *praeearaneus* Kormos, 1934
 * *Petenyia* cf. *hungarica* Kormos, 1934
 * *Beremendia fissidens* (Petenyi, 1864)
Lagomorpha
Hypolagus sp
Rodentia
 * *Sciurus* cf. *vulgaris* Linnaeus, 1758
 * *Muscardinus* cf. *avellanarius* (Linnaeus, 1758)
 * *Ungaromys* nov. sp
 * *Clethrionomys*? sp

Mimomys pliocaenicus (Major 1889)
 * *Mimomys reidi* Hinton, 1910
Mimomys newtoni Major, 1902
 * *Apodemus* cf. *sylvaticus* (Linnaeus, 1758)
 * *Micromys* sp

* New for the assemblage from Tegelen.

An unconformity comprising the top of the Lower Pleistocene and the lower part of the Middle Pleistocene separates the Kedichem Formation and the overlying uppermost zone ("Weert-zone") of the Sterksel Formation. Higher in the Sterksel Formation some large intraformational frost-wedge casts have been observed. Therefore this part of this Sterksel Formation dates from a Glacial Stage, yet unnamed, which is part of the so-called "Cromerian" complex. The presence of (ice-rafted) large blocks likewise indicates cold conditions.

5 Pit Maalbeek

In this now abandoned pit below the Sterksel Formation, part of the Kedichem Formation is found (the latter with a heavy mineral assemblage predominantly consisting of stable minerals), which overlies the Tegelen Clay (with a garnet-epidote-saussurite-hornblende assemblage). The pollen-diagram of the latter indicates a cold climate, during its deposition. The deposit dates from the Eburonian and lithostratigraphically it represents the top of the Tegelen Clay (figure 3.7).

The site is remarkable for the find of a molar of *Anancus* (*Mastodon*) *arvernensis*.

6 Pit east of Cancy-Herfkens

In this pit the fine sands of the Kedichem Formation display some fine cryoturbations of Eburonian and Menapian age very similar to

	pit Egypte			previous records for Dutch Tiglian
	clay	gully basis	sand	
<i>Cochlostoma (Obscurella) sp.</i>	—	—	x	—
<i>Viviparus viviparus</i> (L., 1758)	x	—	x	—
<i>Viviparus contectus</i> (Millet, 1813)	x	—	—	—
<i>Viviparus diluvianus</i> (Kunth, 1865)	x	—	x	x
<i>Viviparus glacialis</i> (Wood, 1872)	x	—	—	x
<i>Valvata piscinalis</i> (Müller, 1774)	x	—	x	x
<i>Valvata goldfussiana</i> Wüst, 1900	x	—	—	x
<i>Neumayria crassitesta</i> (Brömme, 1885)	x	x	—	x
<i>Bithynia tentaculata</i> (L., 1758)	—	x	—	x
<i>Bithynia leachi troscheli</i> (Paasch, 1842)	—	x	x	—
<i>Lithoglyphus naticoides</i> (Pfeiffer, 1828)	x	—	—	x
<i>Tanousia stenostoma</i> (Nordmann, 1901)	x	—	—	x
<i>Carychium sp.</i>	—	—	x	—
<i>Lymnaea palustris</i> (Müller, 1774)	?	—	x	x
<i>Lymnaea peregra</i> (Müller, 1774)	?	—	x	x
<i>Planorbis planorbis</i> (L., 1758)	—	—	x	x
<i>Planorbis corneus</i> (L., 1758)	?	—	x	x
<i>Acroloxus lacustris</i> (L., 1758)	—	—	x	—
<i>Succinea elegans</i> Risso, 1826	—	—	x	x
<i>Succinea oblonga</i> Draparnaud, 1801	—	—	x	x
<i>Cochlicopa sp.</i>	—	—	x	?
<i>Vertigo cf. alpestris</i> (Alder, 1838)	—	—	x	—
Chondrinidae	—	—	x	—
<i>Pupilla muscorum</i> (L., 1758)	—	—	x	x
<i>Pupilla cf. sterri</i> (Voith, 1838)	—	—	x	—
<i>Vallonia pulchella</i> (Müller, 1774)	—	—	x	x
<i>Vallonia costata</i> (Müller, 1774)	—	—	x	x
<i>Ena montana</i> (Draparnaud, 1801)	—	—	x	—
<i>Discus ruderatus</i> (Studer, 1820)	—	—	x	—
<i>Discus perspectivus</i> (Megerle von Mühlfeldt, 1816)	—	—	x	—
(?) <i>Aegopinella sp.</i>	?	?	x	x
<i>Aegopinella cf. nitidula</i> (Draparnaud, 1805)	—	—	x	—
<i>Retinella (Riedeliella) sp.</i>	—	—	x	—
<i>Vitrea crystallina</i> (Müller, 1774)	—	—	x	—
<i>Vitrinobrachium breve</i> (Férussac, 1821)	—	—	x	x
<i>Eucobresia diaphana</i> (Draparnaud, 1805)	—	—	x	—
<i>Limax sp.</i>	—	x	—	—
Limacidae	—	x	x	—
Clausiliidae	—	—	x	?
<i>Perforatella sp.</i>	?	?	x	x
<i>Perforatella dibothryon</i> (von Kimakowicz, 1884)	—	—	x	—
<i>Sieklovia cf. koehnei</i> Schlickum & Strauch, 1972	—	—	x	—
<i>Trichia hispida</i> (L., 1758)	—	—	x	x
<i>Trichia cf. striolata</i> (Pfeiffer, 1828)	—	—	x	—
<i>Soosia sp.</i>	—	—	x	—
<i>Helicigona sp.</i>	—	—	x	—
<i>Arianta arbustorum</i> (L., 1758)	x	—	x	x
Helicidae	—	—	x	—
<i>Unio tumidus</i> Philipsson, 1788	x	—	—	—
<i>Anodonta cf. cygnea</i> (L., 1758)	x	—	—	—
<i>Sphaerium corneum</i> (L., 1758)	x	—	x	x
<i>Pisidium amnicum</i> (Müller, 1774)	x	—	x	x
<i>Pisidium clessini</i> Neumayr, 1875	x	—	x	x
<i>Pisidium moitessierianum</i> Paladilhe, 1866	x	—	x	x
<i>Pisidium henslowianum</i> (Sheppard, 1823)	x	—	x	x
<i>Pisidium supinum</i> Schmidt, 1850	x	—	x	x
<i>Pisidium subtruncatum</i> Malm, 1855	x	—	x	x

Table 3.4. Molluscs from the Dutch Tiglian.

those described here (site 4). Furthermore, a clay seam, filling a shallow gully in the basal part of the gravelly sands of the "Weert-zone" (Sterksel Formation) has yielded a pollen-diagram. This pollen-diagram shows spectra with a fair amount of NAP, much Pinus, and few thermophilous trees. It indicates cool to cold conditions at the onset of the formation of this part of the Sterksel Formation.

Palaeomagnetism

According to van Montfrans (1971) the top beds of the Tegelen Clay, which date from the transition of the Tiglian to the Eburonian, probably date within the Olduvai event, 1,600,000 years ago. The results obtained from various pits to be visited during this excursion, are given below.

- Pit Laumans: normal plarity for the upper part of the section,
 reversed polarity for the lowermost part.
- Pit Maalbeek: reversed polarity
- Pit Egypte: normal polarity.

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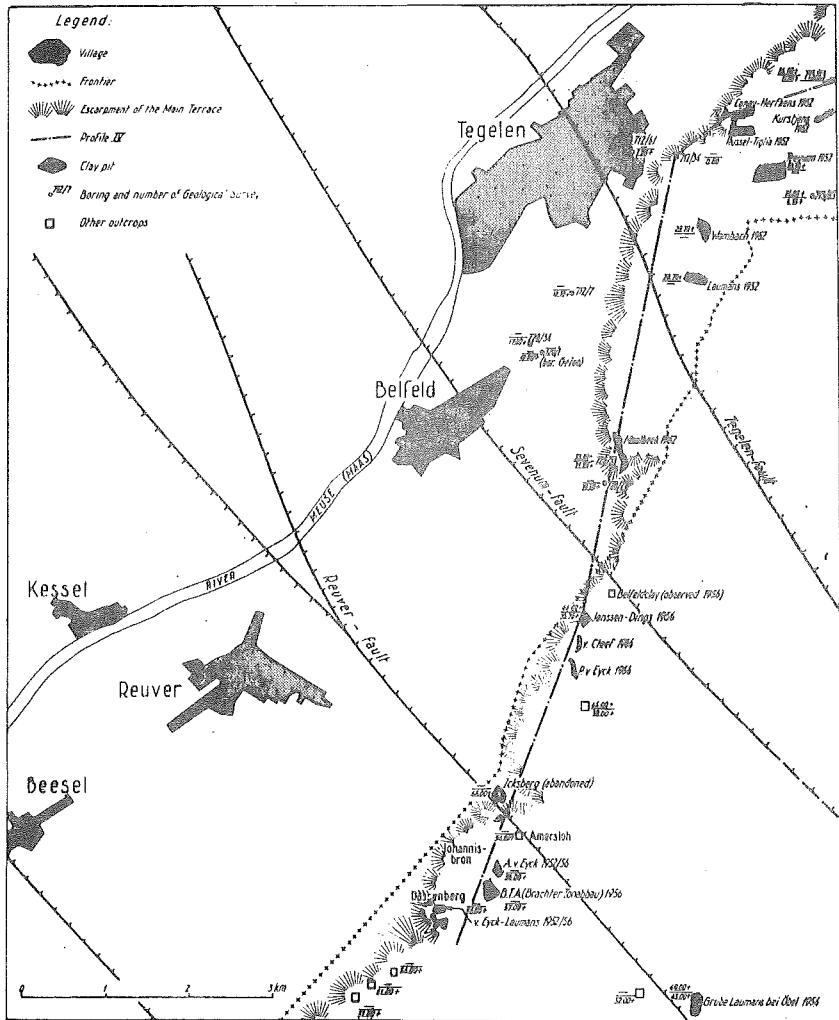


Fig. 3.1

REUVER **BELFELD** **MAALBEEK** **TEGELEN**

60 m
50 m
40 m
30 m
20 m
10 m
0
10 m
20 m
30 m
40 m

LEGEND

PLEISTOCENE (non marine)

- STERKSEL FORMATION
- KEDICHEM FORMATION
- TEGELEN CLAY
- TEGELEN GRAVEL
- BELFELD CLAY
- BELFELD GRAVEL

PLIOCENE (non marine)

- REUVER CLAY
- REUVER SAND
- REUVER CLAY
- REUVER SAND
- VENLO CLAY
- VENLO SAND

MIOCENE (marine)

- GLAUCONIFEROUS SANDS

TEGELEN FORMATION









UPPER PLIOCENE

LOWER PLIOCENE

BELFELD-Pit "Peter van Eyck"

September 17

LEGEND

	GARNET		OTHER MINERALS
	EPIDOTE		STAPHILITE
	ALTERITE		METAMORFIC MIN.
	HORNBLFENDE		TOURMALINE

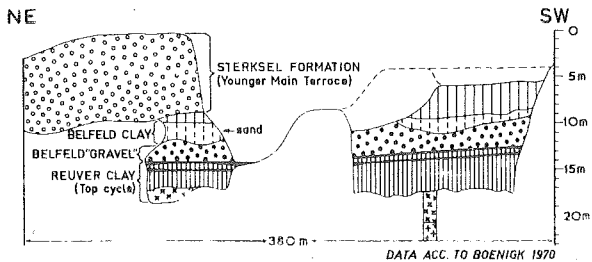
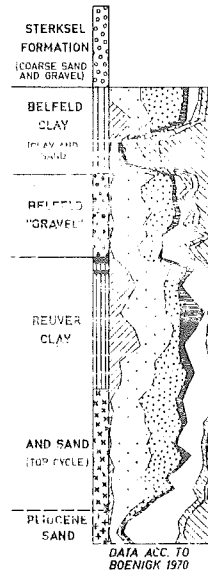
Rijks Geologische Dienst-Haarlem-A8.3ⁱ

Fig. 3.3

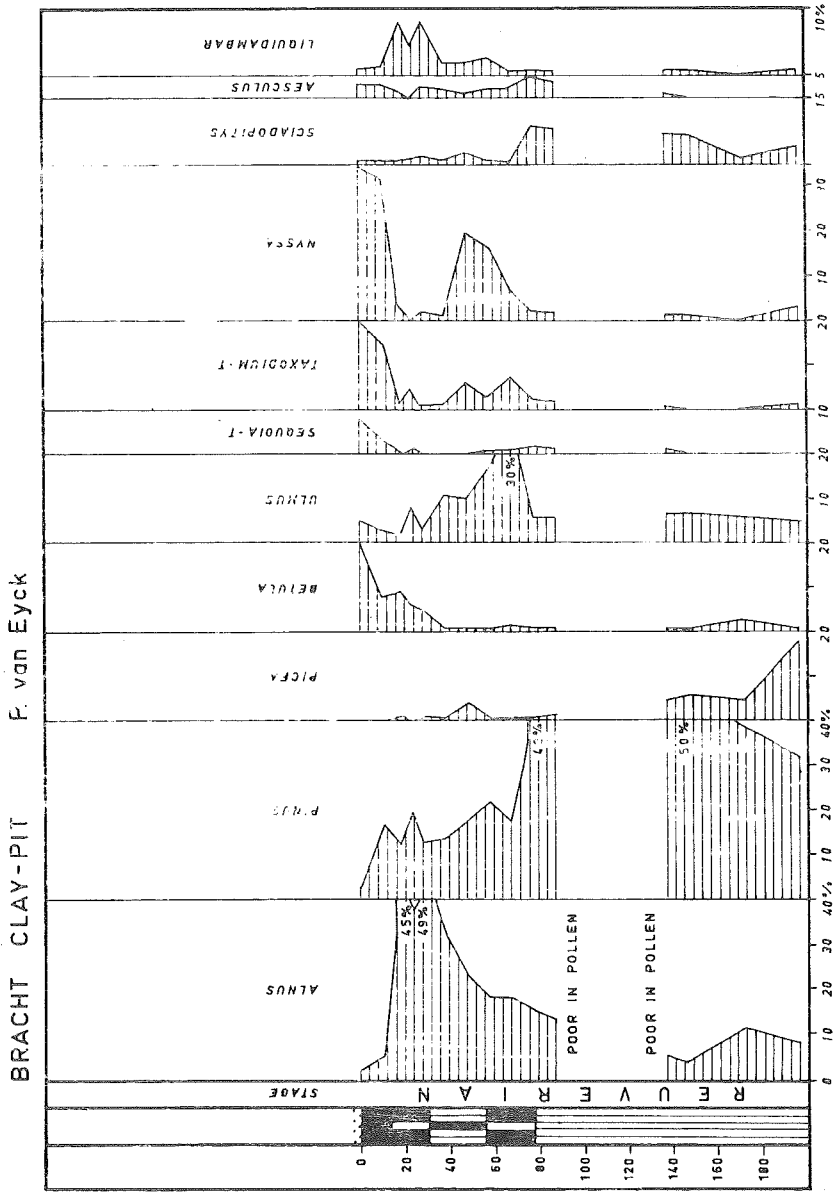










Fig. 3.4

FIGURE 7

ÖBEL

September 17

LEGEND

	GARNET		OTHER MINERALS
	EPIDOTE		STAUROLITE
	ALTERITE		METAMORFIC MIN.
	HORNBLende		TOURMALINE

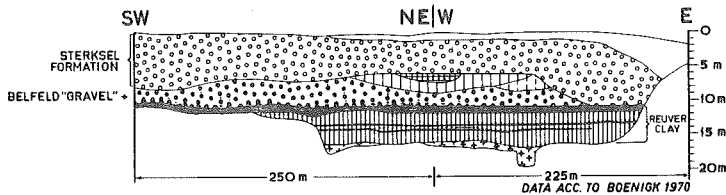
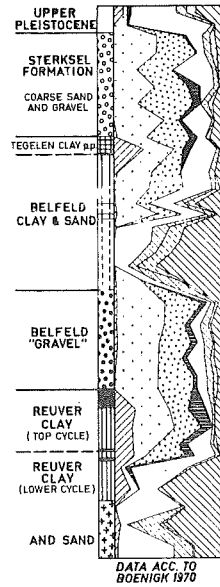


Fig. 3.5

	Stage	Pollenzones	Estimate of mean temperature in July 10° 20°	Range of Azolla	Venlo Graben and Peel Horst	Central Graben	W. and Central Netherlands (area of marine lower Pleistocene)			
					Tegelen-area	Belfeld-Reuver area	Meinweg-Merkenbosch	Eindhoven	Rosmalen	W. Netherlands
MIDDLE PLEIST.	"CROMERIAN"				Sterksel Formation			Sterksel Formation	Sterksel Formation	
	MENAPIAN									Various deposits
	WAALIAN	C W-C B W-B A W-A			Fine white sand (only local) Soil: some peaty clay at the top			Kedichem Formation	Kedichem Formation	not considered in this table
	EBURONIAN	EB VII EB VI EB V EB IV EB III EB II EB I YC 6			Fine sand with 11 in layers of loam					
		TC 5 TC 4 TC 3 TC 2 TC 1			Tegelen Clay (cycle II) Tegelen Clay (cycle I) Tegelen G-gravel			Tegelen Clay	Tegelen Clay	
	TIGLIAN	B TD A TA				Belfeld Clay Belfeld Gravel				
	PRÆTIGLIAN									
LATE PLEIST.	REUVERIAN	C B				Deuver Clay	Kiesloblitz Formation Meinweg Clay (Zagwijn 1960)			
										"ICENIAN" (littoral)
										"AMSTELIAN" (in part neritic)
										Marine deposits (in part neritic)

4.5

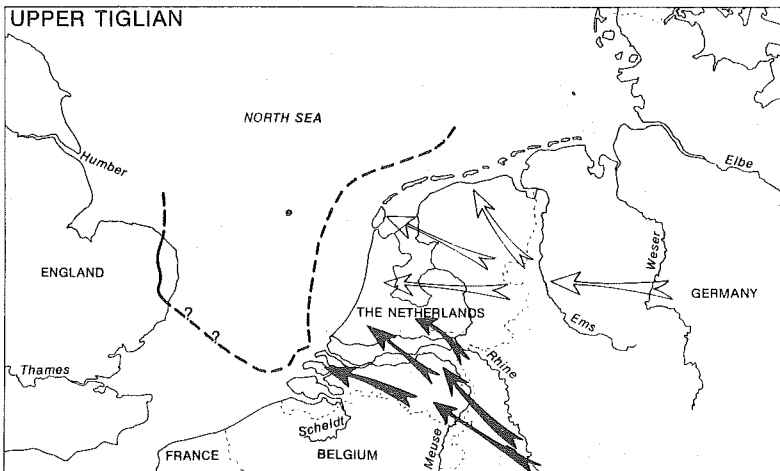
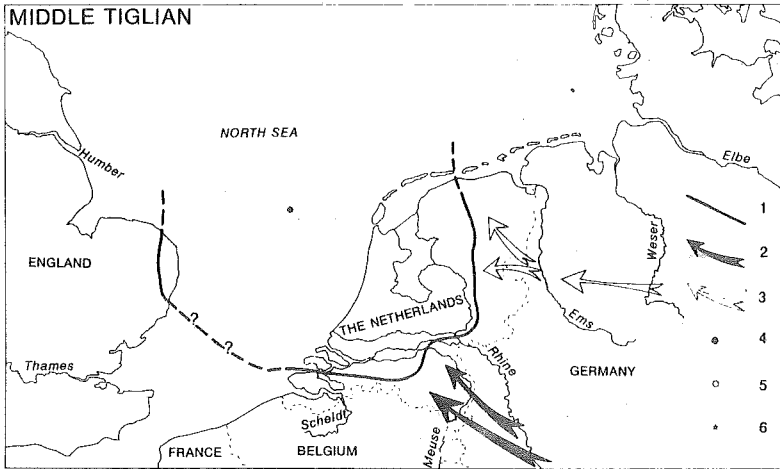
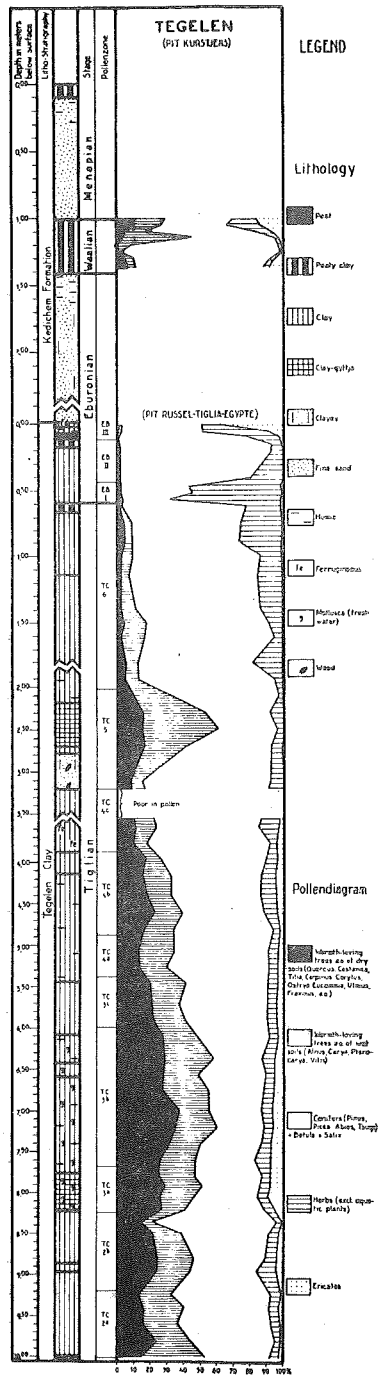


Fig. 3.8



Pollen-diagram from the Tegelen Clay in the Russel-Tiglin-Egypte pit and from the Kedichem Formation in the Kurstjens pit (according to ZAGWIJN, in the press).

Fig. 3.10

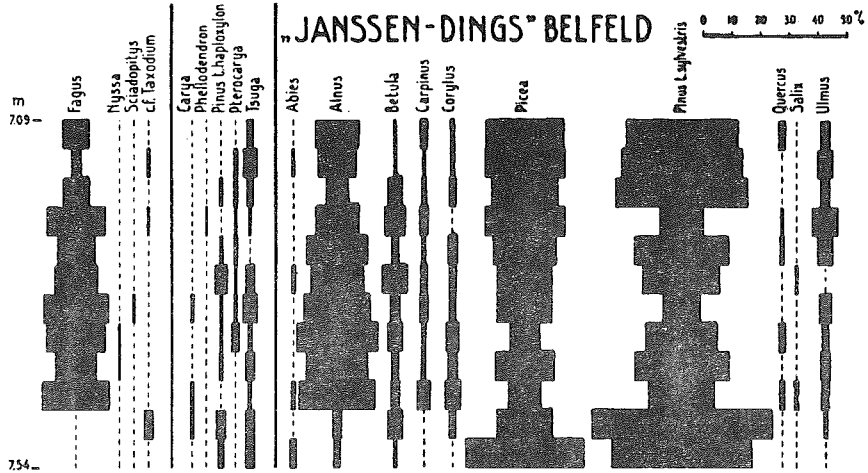


Fig. 3.11

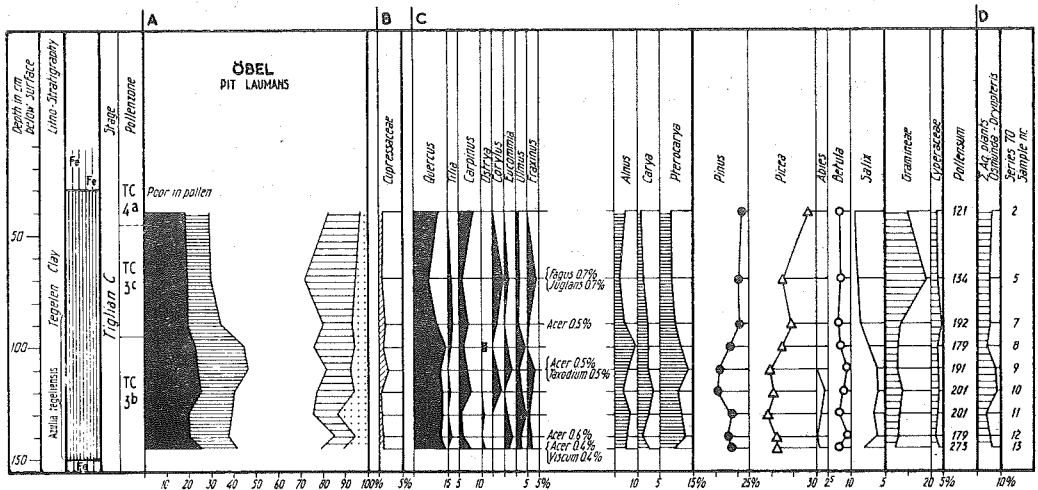
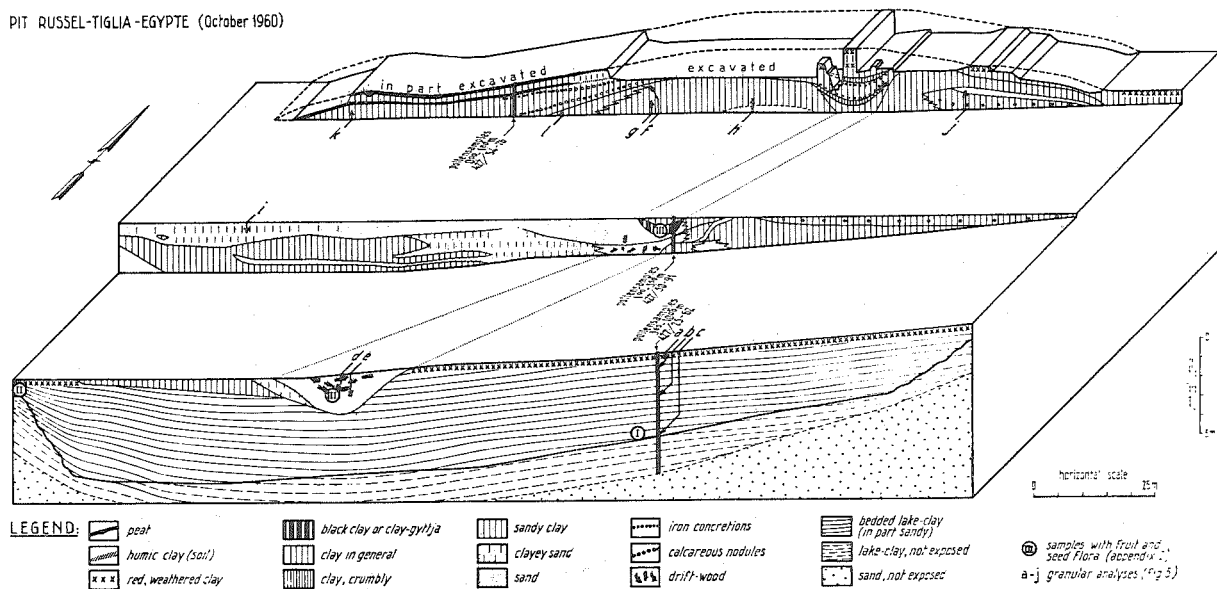


Fig. 3.12



Block-diagram of Tegelien Clay in Russel-Tiglia-Egypte pit.

The clay has been dug from three faces. The lowest chiefly consists of lake-clay deposited in an abandoned meander (cycle I). Subsequently a smaller stream cut across the lake-clay, leaving its own deposits (cycle IIa). The incision made is just visible at the top of the lowest face. The two higher faces show in section the filled-up bed of this stream, with its natural levees and back-swamp deposits on either side. At the left-hand top two peat-beds are noticeable and a clay-bed in between (cycle IIb, cp. fig. 6) (according to KORTENBOUT and ZAGWIJN 1962).

STRATIGRAPHY OF PIT LAUMANS (TEGELEN)

		FORMATION	climate	LITHOLOGY/SEDIMENTOLOGY	cryoturbations	MINERAL ZONE AND PROVENANCE	HEAVY MINERALS
UPPER PLEISTOCENE	WEICHSELIAN	TWENTE FORMATION	cold	COVERSAND (ABOUT 1m)			
MIDDLE PLEISTOCENE		STERKSEL FORMATION	cold	ABOUT 15 m OF COARSE SAND AND GRAVEL SOME LARGER BLOCKS MEANDERING RIVERS p.p.	frostwedge casts	"WEERT ZONE" (RHINE)	EPIDOTE HORNBLende SAUSSURITE
LOWER PLEISTOCENE	MENAPIAN	KEDICHEM FORMATION	cold	FINE SANDS	(large) frostwedges and involutions	"LOWER FINE ZONE" (LOCAL)	TOURMALINE STAUROLITE ZIRKONE METAMORPHIC MIN.
	WAALIAN (pp.)			SOILS			
	EBURONIAN		cold	FINE SANDS PARTLY FLUVIATILE PARTLY PERIGLACIAL-EOLIAN (ABOUT 3m)	small frostwedge casts (in other pits)		
	TIGLIAN (top)	TEGELEN FORMATION	cool- temp.	CLAY FLUVIAL (MEANDERING RIVERS) (ABOUT 2-3m)	in other pits: involutions	"TEGELEN ZONE" (RHINE)	GARNET EPIDOTE HORNBLende SAUSSURITE

Fig. 3.14

WEDNESDAY 31st MARCH

THE DRENTSCHE AA VALLEY AREA (W de G and P C)

The Drentsche Aa valley system is located in the eastern part of the so-called Drente till-plateau in the northern part of the Netherlands. The valley system runs parallel or perpendicular to four parallel ridges and is tentatively explained as being adjusted to a faultline pattern (figure 4.1).

Fluvial Sediments

The basal part of the fluvial deposits in the valley is composed of sorted sand with fine gravel and is characterised by intercalations of organic layers with a mor-like appearance (figure 4.2). These layers are correlated with former floodplain levels and are palynologically dated to the Eemian Interglacial and the Brörup and Odderade Interstadials of the Early Weichselian (Table 1). The pollen diagram derived from the fourth and topmost mor-like level is tentatively designated the Papenvoort pollen zone (figure 4.5). Surprisingly no pollen zones can be distinguished which might be compared with those of the Amersfoort Interstadial as described by Zagwijn (1961). This absence of pollen zones datable to the Amersfoort Interstadial is also described by Averdick (1967) and Stremme and Menke (1980) in north Germany, Andersen (1961) in Denmark and by Paris et al. (1981) in the Drentsche Aa area.

By definition, the fluvial sediments in the Aa valley comprise both the Asten Formation (continental Eemian deposits) and part of the Twente Formation (Weichselian fluvio-periglacial deposits) as described by Zagwijn & Van Staalduinen (1975). However, on lithological criteria these cannot be mutually discriminated in the Aa valley. For this reason a lithozone designated "Aa Deposits" is introduced to comprise all Weichselian and older fluvial deposits in the Aa valley system. The fluvial deposits which are intercalated with mor-like levels are referred to as "Lower Aa Deposits" (Table 1; figure 4.2). The Middle Aa Deposits are characterised by intercalations of humic loam layers in the top level of this sequence (figure 4.2). These humic loam layers are interpreted as thaw-like deposits. They can be traced laterally as far as the slopes of the valley system where they pass into loamy peat layers which are interpreted as the A1 horizons of former organic cryosols as described by Tedrov (1977). The pollen diagrams which are derived from these organic levels have a pollen association characterised by low percentages of arboreal pollen and high percentages of herbs with a dominance of Cyperaceae (figures 4.9, 4.8 and 4.12). Following Zagwijn (1975), Van der Hammen and Wymstra (1971) and Kostrup and Wymstra (1977) these levels are dated to the Middle Pleniglacial. However, because all the Drente diagrams are very similar and the radiocarbon data from these thawlake deposits are thought to be unreliable the Pleniglacial pollen diagrams from the Aa valley system cannot be correlated satisfactorily with the standard Middle Pleniglacial biozonations, namely the Moershoofd, Hengelo and Denekamp Interstadials (De Gans and

Cleveringa, 1981). Consequently the pollen diagrams derived from the Middle Pleniglacial organic levels are tentatively classified as pollen diagram types LT1-LT4 (table 4.1).

The Upper Aa Deposits are composed of coarse sand which overlies the Middle Aa deposits in an erosive position (figure 4.2). The Upper Aa Deposits are generally overlain by a pebble band (desert pavement). This sequence of coarse sand succeeded by a pebble band (PB2) is correlated with the Beuningen Gravel Bed as described by Kolstrup (1980) and Van Van der Hammen & Wymstra (1971) and consequently dated to the Upper Pleniglacial.

The youngest fluvial deposits in the Aa valley are assigned to the Singraven Formation and are dated palynologically as Holocene. The Singraven Formation is divided into three lithozones. A basal "sand bed" is located in the downstream part of the valley and dated as Preboreal and Boreal. The overlying "detritic gyttja bed" was formed in the Atlantic and Subboreal under the influence of the Holocene sea level rise. In the upstream part of the valley a "peat bed" was formed (figure 4.2), commencing in the Boreal. It extended after the Atlantic and eventually covered all the lower areas of the former valley system. On the evidence of the palynological data and certain cross sections three major phases of fluvial erosion have been established.

- 1 The initial incision of the valley system is dated to the transition of the Saalian to the Eemian, and is attributed to the then low local base level of erosion in the Hunze ice-marginal valley (figure 4.1).
- 2 A second, and probably more intensive erosional phase, occurred at the beginning of the Pleniglacial after the Pepenvoort pollen zone (figure 4.2). This phase may have been influenced by the presence of permafrost.
- 3 A third phase of fluvial erosion is dated to the Late Dryas Stadial (Late Weichselian) and is tentatively explained as a biogeomorphic adjustment of the river channel to climatic and hydrologic changes. Minor phases of fluvial erosion have been registered also in the Upper Pleniglacial and at the transition from the Boreal to the Atlantic in the Holocene.

Pebble Bands

In the Aa area, so far three pebble bands (PB1, PB2 and PB3) or desert pavements have been found (figures 4.2, 4.3 and 4.4). Slope processes acting under periglacial conditions probably preceded the formation of desert pavements and are thought to be responsible for the asymmetry of the Aa valley slopes (De Gans, 1981). The pebble bands are respectively dated to the Lower Pleniglacial (PB1), Upper Pleniglacial (PB2) and Late Glacial (PB3) and are composed of gravel, containing wind-faceted stones. After deposition of PB2 (the upper part of the Beuningen Gravel Bed) large areas of the valley system were covered by aeolian sand (figure 4.2 and 4.4) and the drainage system became disintegrated.

Pingo Remnants

The pingo remnants in the Aa area are all located in former Pleniglacial valleys (figure 4.3). The distribution of the depressions which are

thought to be pingo remnants suggests that the Pleniglacial drainage patterns was more dense than the present one.

The ramparts of the pingo remnants are locally located upon humic loam layers of thaw-lake deposits of the Middle Aa Deposits (figure 4.4). From these deposits a LT1 or LT2 pollen diagram type was derived. The radiocarbon data of these levels show a substantial difference between the insoluble fraction and the extract data. The extract data are tentatively choosen as being the more reliable. The melting of the pingos is assumed to be synchronous with the deposition of the Beuningen Gravel Bed and is dated between 19,000 BP and 14,000 BP. The growth of the pingos is tentatively dated between 25,000 and 19,000 BP. (Paris et al, 1979; De Gans, 1981).

The Aa valley pingos are interpreted as closed-system or hydrostatic types. The initial organic infilling of the pingo remnants investigated so far occurred between the Upper Pleniglacial and the Allerød. This means that the earliest infillings are not synchronous but may have been variously retarded until the middle of the Late Glacial, depending the thickness of the ice-core and overburden.

EXCURSION

1 Cores from the cross-section at Papenvoort

The cross section at Papenvoort is located in the upstream part of the Andersche Diep valley (figure 4.1). The section (figure 4.2) shows that the valley is eroded into glacial till and sand of the Drente and Peelo Formations respectively (table 1).

The fluvial deposits in this section consist of fining upwards sequences of fine gravel and sand with organic layers locally occurring on top. Organic layer Dra4 is the uppermost mor-like layer and indicates the top of the Lower Aa Deposits. From this level pollen diagram 2 (figure 4.7) and two radiocarbon dates are available; GrN8386: > 42,400 BP and GrN9387: 41,100⁺⁴⁶⁰⁰₋₂₉₀₀ BP.

Pollen diagram 2 is tentatively classified as Papenvoort pollen zone. From the underlying mor-like layer, pollen diagram 1 (figure 4.6) is derived. It is comparable with the Odderade Interstadial diagrams as described by Averdieck (1967).

The basal part of the overlying fluvial deposits occurs in a relatively narrow erosion valley which is incised, through organic layer Dra4, into the Lower Aa deposits and the Peelo Formation deposits. It consists of sorted fine sand and gravel containing debris up to 10 cm in diameter from the mor-like levels. The upper part of these Middle Aa Deposits comprises two humic loam layers (And1 and And2) which locally show a thin lamination of fine sand and loam with organic detritus. From both levels a pollen diagram and radiocarbon data are available. From level And1: pollen diagram 3 (type LT1) and GrN8952: 38,750⁺⁷⁵⁰ BP; and from level And2: pollen diagram 4 (type LT2) and GrN8953: 42,450⁺⁹⁰⁰ BP. The undulating depth of the layers And1 and And2 may indicate cryoturbation. The extension of layer And2 indicates that during deposition of the thaw-lake deposits of the Middle Aa Deposits the valley floor was much wider than during sedimentation of the Lower

Aa Deposits.

Organic layer And2 is overlain by a thin layer of sorted coarse sand which is assigned to the Upper Aa Deposits. On top of this deposit a pebble band (PB2) occurs, containing some small gravel. This sequence of coarse sand with a pebble band (desert pavement) on top is correlated with the Upper Pleniglacial Beuningen Gravel Bed.

Pebble band PB2 is, in its turn, overlain by well-sorted aeolian sand (Younger Coversand) which contains thin intercalations of coarser sand in its basal part. In this aeolian sand an unstratified humic loam layer (And3) is located, from which pollen diagram 5 (figure 4.10; Allerød) is derived. This organic layer is overlain by a second pebble band (PB3) which is dated to the Late Dryas. The top of the section is composed of a peat layer, which according to its position and lithology is assigned to the Singraven Formation. From this layer, pollen diagram 6 (figure 4.11) is derived. The cross section shows that the Singraven Formation is slightly eroded into the underlying deposits.

From the cross-section at Pepenvoort the cores C98, XXV and PII will be demonstrated.

2 Gasselterveld pingo remnant

This pingo remnant is located near the Andersche Diep valley (figure 4.1) on a very slight slope ($< \frac{1}{2}^{\circ}$) towards the west. A detailed cross section of this depression (figure 4.3) shows that it is located in a former valley filled with fluvial sediments which have a peaty humic loam layer on top. Pollen diagram 7 (figure 4.12) which is derived from this level is comparable with pollen diagram 3 (type LT1). Because of their lithology, stratigraphic position and palynological data these fluvial sediments are assigned to the Middle Aa Deposits. The depression is filled with sand and gravel, gyttja and peat successively. The organic infilling material has a maximum thickness of 6 metres and is assigned to the Griendtsveen Formation. Pollen diagram 8 (figure 4.13) is derived from the basal part of the gyttja in the depression and is dated to the Late Glacial. The depression has a diameter of 100 metres and is surrounded by a deposit of unsorted sand with gravel which is interpreted as a slope deposit. As this deposit has its maximum elevation near the depression it is here interpreted as a rampart. This rampart overlies the peaty top layer of the Middle Aa Deposits, which has a radiocarbon date for the insoluble fraction of 37,37,250±950 BP (GrN8942) while the extract gives 29,140±250 BP (GrN10328).

Because of the age of the depression, the rampart, the depth and its semi-circular plan, this feature is interpreted as a pingo remnant.

Aeolian sand covers most of the area but is present only to a small extent within the pingo remnant. This may be explained either as a result of the trapping of the sand in the vegetation growing on the rampart, or by the assumption that the pingo had not completely melted out during the deposition of this sand in the Late Glacial.

3 Balloöerveld

The Balloöerveld (common field of the hamlet of Balloo) is a remnant of the former far more extensive heath areas on the Drenthe plateau. The Balloöerveld is located between the Andersche Diep and Amer Diep valleys just south of their confluence near Oudemolen (figure 4.1). During a 2-hour walk on the field the following geological and archaeological phenomena will be demonstrated.

a Pingo remnant versus aeolian depression

At the first stop an aeolian depression and a pingo remnant will be examined which are located close to each other. Figure 4.4 gives a cross-section across both depressions.

The pingo remnant is located in a former valley (compare figure 4.3) and is surrounded by a rampart composed of non-aeolian material. This rampart is covered by Late Glacial aeolian sand with a maximum thickness of 4 metres. However the sand is hardly found anywhere within the pingo remnant. The aeolian depression is of about the same size and appearance as the pingo remnant except that the organic infilling material has been removed by peat digging. The cross-section shows that the aeolian depression is far less deep and located above the continuous groundwater level. Thus the water level in the aeolian depression is an apparent groundwater level, perched on a B2-ir horizon.

Shallow aeolian depressions may be surrounded by a rampart composed of aeolian sand. They have a flat bottom and may also be related to former valley systems. As an hypothesis, they are thought to have been formed by aeolian sedimentation trapped in willow-rings which were located in lower, more humid, localities than surrounding topography. Willow-rings are described by Meyboom (1966) from hummocky moraine in Canada.

It should be noted that although the geomorphological appearance of pingo remnants and aeolian depressions may be quite identical, the pingo remnants are older (Pleniglacial) than the aeolian depressions (Late Glacial, possibly early Holocene).

b Celtic Fields

About one kilometre south of both depressions a complex of celtic fields is located, described by Brongers (1976) and dated to the Iron Age. This celtic field complex is located on the water divide between the Andersche- and Amer Diep valleys. The position of the field complex is possibly influenced by the presence of erosion remnants of loamy Saalian till (Drenthe Formation; table 1) near the surface on this locality.

c Bronze-age burial hills

Close to the celtic field system concentrations of Late Bronze age burial hills are located.

d Cart-track relief

A remarkable relief is located in the eastern part of the Balloöerveld. This relief is composed of a great number of north-south directed ridges and valleys which run more or less continuously all over the Balloöerveld. The relief between ridges and valleys varies between 0.3-1.5 metres, the width of the valleys varies between 1: 5-2 metres, and the ridges are generally between 2-3 metres wide. The total width of the system is about 400 metres, in which up to 50 parallel valleys can be distinguished. The system runs along some bronze age burial hills which are located in the northern part of this complex.

The relief of small ridges and valleys can be explained by the erosion caused by the passage of carts across the field, which occurred until ca. 1850. This geomorphological phenomenon will be demonstrated in a small exposure (figure 4.5).

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CHRONO-STRATIGRAPHY			POLLEN DIAGRAM TYPES AND DESERT PAVEMENTS		LITHOSTRATIGRAPHY		LITHOLOGY						
HOLOCENE					GRIENDTSVEEN AND SINGRAVEN FORMATIONS		PEAT AND GYTJA						
WEICHSELIAN (TUBANTIAN)	LATE GLACIAL (WEICHSELIAN)	PEBBLE BAND		PB 3	TWENTE	BEUNINGEN GRAVEL-BED	Fm	WELL SORTED AEOLIAN SAND; UNSORTED SAND AND GRAVEL (SLOPE DEPOSIT); DESERT PAVEMENTS	AND PEAT LAYERS				
		LT 5		ALLERØD									
	PLENIGLACIAL	UPPER	PEBBLE BAND							PB 2	Aa DEPOSITS	UPPER Aa D	COARSE SAND
		MIDDLE	LT 4									MIDDLE Aa DEPOSITS	
			LT 3										
			LT 2										
			LT 1										
			PEBBLE BAND		PB1								
			LOWER	ET 3						"PAPENVOORT"			
		EARLY GLACIAL (WEICHSELIAN)	ET 2		ODDERADE								
	ET 1		BRØRUP										
	EM		EEMIAN										
	EEMIAN												
SAALIAN					DRENTE FORMATION		TILL						
HOLSTEINIAN													
ELSTERIAN					PEELO FORMATION		SAND AND CLAY (POTKLEI)						

Table 4.1 Lithology and stratigraphy of the Drentsche Aa valley sediments.

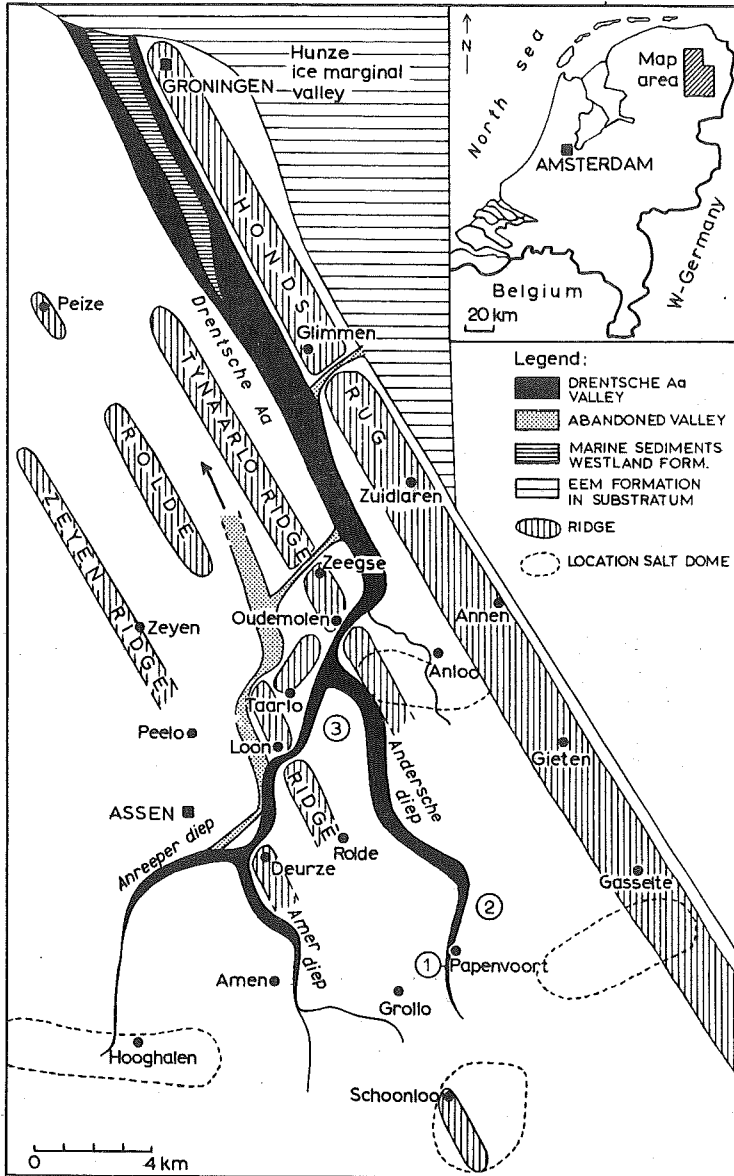


Fig. 4.1 The Drentsche Aa valley area and the location of the points to be visited.

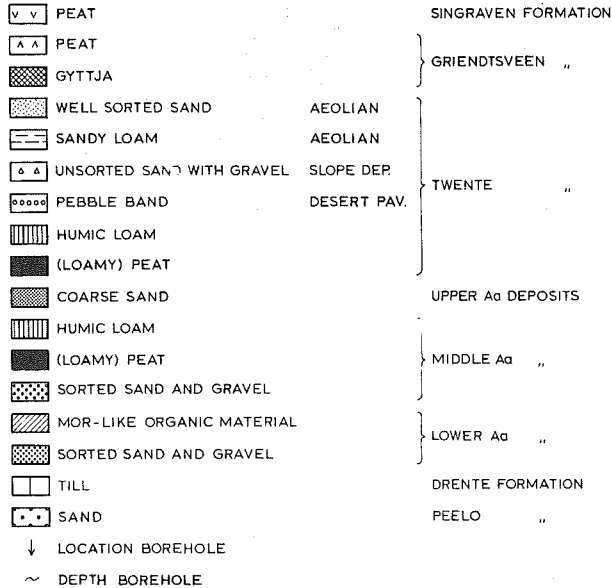
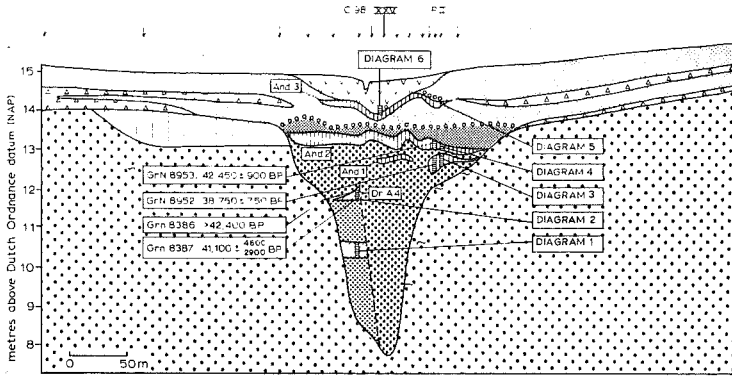


Fig. 4.2 Cross section Papenvoort (Excursion Point 1). For location, see Fig. 4.1.

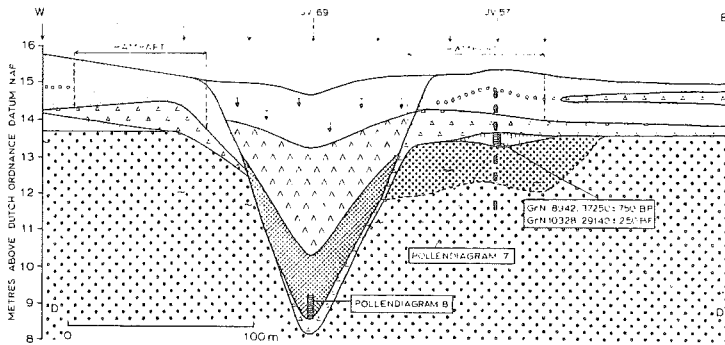


Fig. 4.3 Cross section through the pingo remnant at Gasselterveld: Legend, Fig. 4.2. (Excursion Point 2).

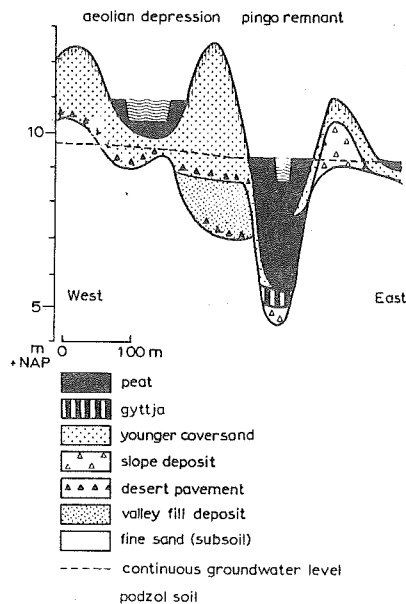


Fig. 4.4 Section across an aeolian depression and a pingo remnant on the Balloërveld (Excursion Point 3).

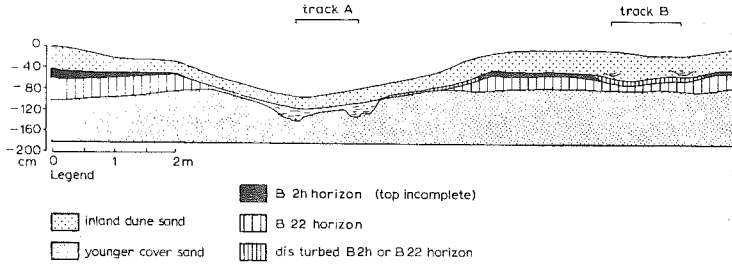


Fig. 4.5 Small exposure in cart-track-relief on the Balloöerveld.

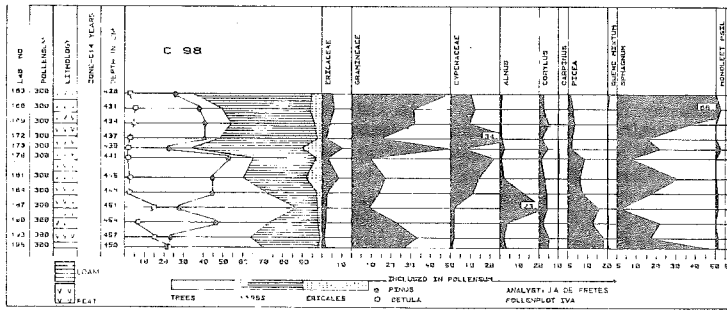


Fig. 4.6 Pollen diagram 1. Odderade Interstadial (boring C98; section Papenvoort).

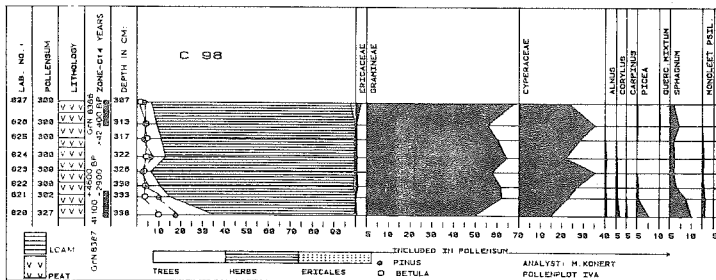


Fig. 4.7 Pollen diagram 2. Papenvoort pollen zone (boring C98; section Papenvoort).

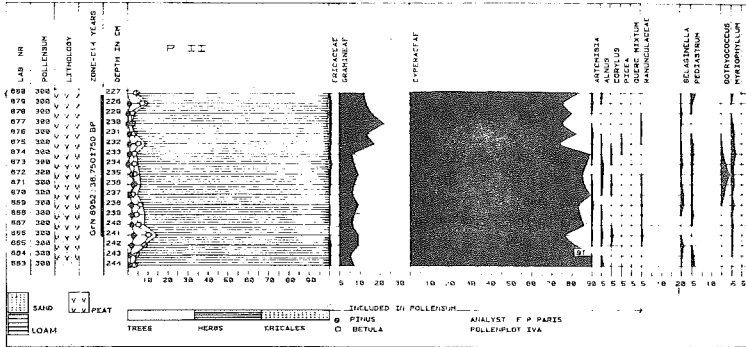


Fig. 4.8 Pollen diagram 3. Type LT1 (boring PII; section Papenvoort).

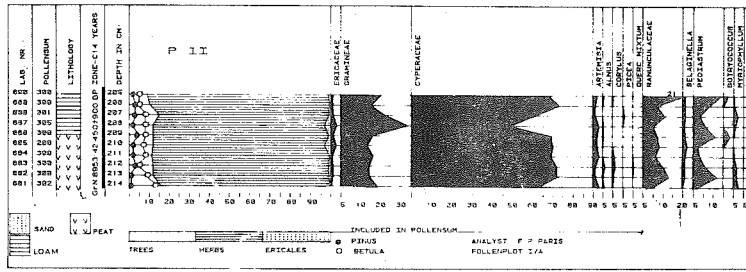


Fig. 4.9 Pollen diagram 4. Type LT2 (boring PII; section Papenvoort).

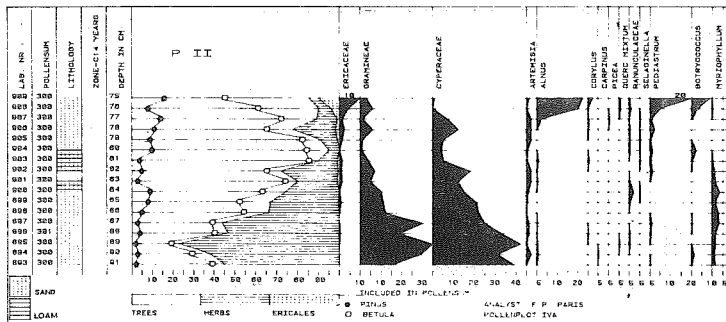


Fig. 4.10 Pollen diagram 5. Type LT5/Allerod (boring PII; section Papenvoort).

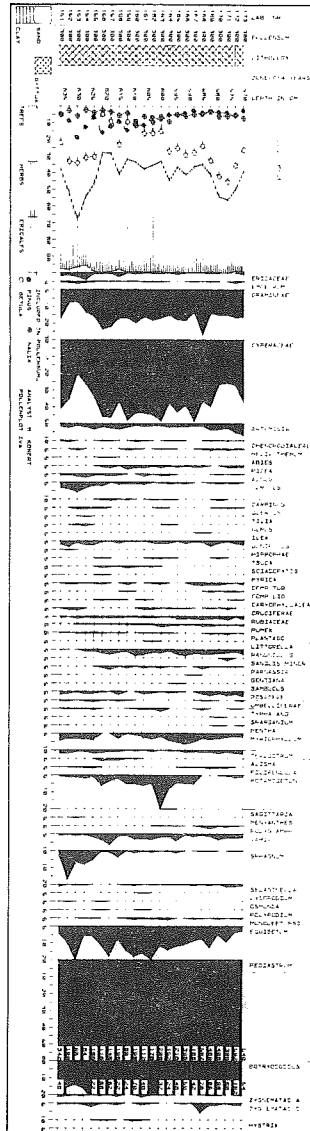


Fig. 4.13 Pollen diagram 8. Late Glacial (boring JV67; section, pingo remnant Gasselternveld).

THE HOLOCENE IN THE LAKE IJssel REGION

Figure 5.1 shows the contours of the Pleistocene surface in relation to the Late Pleistocene braided river systems of the IJssel, Vecht and Eem, all accompanied by river bank dunes, as well as with regard to the adjacent contemporaneous (aeolian) coversand area. The general contours for the lower part of the Netherlands are given by Pons, Jelgersma, Wiggers and De Jong (1963). They stressed the great influence of the Pleistocene relief upon the development of the Holocene coastal history.

Related to the Pleistocene topography and the rise in sea level, the marine influence extended eastward in the course of time. Towards the end of the Atlantic time a retardation of the rise in sea level took place, while the coastline attained (at about 7000-5000 Before Present) approximately the position it has today (Jelgersma et al, 1970; see also figure 5.7b).

Beach barriers or rather barrier islands came into existence. Van Straaten (1965) suggested that before about 5300 BP barriers had already been formed. The area between the barrier coast and the peat hinterland was called the intracoastal area. Behind the barrier islands a lagoon originated by the drowning and partial abrasion of the fen peat. Through the inlets between the barrier islands sand and clay were carried into the lagoon and deposited as inner tidal deltas or tidal flats or other strictly lagoonal bottom deposits. Locally rivers from the east brought in fresh water - and sometimes sediments - which may have led to more lacustrine conditions. Van Straaten stressed already that because of the Pleistocene topography, the Lake IJssel region never received enough sediment for the development of extensive tidal flats. Instead lagoonal, lacustrine and peat swamp environments prevailed.

While the coastal barrier system gradually reached a stable condition the continued rise in sea level caused the intracoastal environment to extend over the fen peat. This process was occasionally interrupted, as is shown by the presence of peat layers in, for instance, clayey deposits. It is assumed that a climatic factor was responsible in one way or another.

The existence of earlier beach barriers, that is to say those formed before 4800 BP, is hypothetical, insofar as it is suggested by the remnants of associated tidal flats (Van Straaten, 1965; Riezebos and Du Saar, 1969). After 4800 BP beach barriers were formed that have been completely preserved. A backward retreat of the barrier coast turned into a forward build-up. Two major phases of barrier formation are distinguished between 4800 and 3500 BP.

The Calais Deposits

The intracoastal deposits of marine origin older than about 3750 BP are

called Deposits of Calais (Hageman, 1963) - as opposed to the younger Deposits of Duinkerke. These deposits are divided into a number of phases on a lithostratigraphical basis. In several places the phases are separated by peat layers. Radiocarbon dating of the peat layers proved that these are generally of more than local character. This gives the division at the same time a chronostratigraphic basis (figure 5.2).

Subdivision of the Calais deposits

Calais IV 4550-3750 BP (2600-1800 BC)

Calais III 5250-4750 BP (3300-2800 BC)

Calais II 6250-5250 BP (4300-3300 BC)

Calais I 7950-6450 BP (6000-4500 BC)

The presence of the Calais I phase is doubtful in Eastern Flevoland (Ente, 1971). The bulk of the Calais deposits certainly consists of the sediments of the Calais II phase.

The Calais II Deposits

The palaeogeography of the Calais II deposits was given by Pons et al. (1963). Some details have been added since (Ente, 1971; Ente, 1976; Ente et al. 1975; see figures 5.3 and figures 5.4a and 5.4b).

The Calais II deposits in Southern Flevoland can be described as follows. In accordance with the Pleistocene topography the Calais II deposits penetrate far into the area. They might reach the present mouth of the river Bem. The highest parts reach up to 1.80 m below ground level (5.30 m below NAP: NAP is ordnance datum and corresponds to mean sea level). On the seaward side the central gullies have cut into the Pleistocene deposits (see 5.5).^{*} Here sand has been deposited. In the backswamps clays prevail. In the central area a peat intercalation is often found (dated 5980 BP). Before this standstill in sedimentation the stream had developed ripened (compact) clayey levees. Renewed sedimentation, mainly in a soft clayey reed marsh facies, followed until 5410 BP. At this time the formation of peat started again.

The Calais II deposits in Eastern Flevoland can be described as follows.

A well developed system of creeks with levees and backswamps existed in the northwestern area (figure 5.4b and figure 5.6). The levee deposits are compact to a great depth, in contrast to the backswamp deposits which are very soft. The compactness of the levee deposits can be explained by the higher position and consequently the better drainage during sedimentation, together with the evapotranspiration due to climate and vegetation at that time. The soft backswamp deposits are relatively rich in organic matter (up to 20%) partly consisting of clearly distinguishable debris of reeds and, near Swifterbant, also of wood.

Originally the backswamp deposits must have reached a higher level (Ente, 1964). Compression of the clays and the underlying peat has led to the present position (in contrast to the levee deposits which can be regarded as being almost insusceptible to compression). Both levee and backswamp deposits consist of clay, generally containing about 40% of

^{*} (Apology! owing to the present stage of road building the way to an interesting profile of figure 5 has been blocked).

particles smaller than 2 μm . This clay was derived mainly from the west. Minor amounts of clay may have been supplied by the rivers, which certainly supplied large quantities of fresh water, for diatoms have indicated a fresh-brackish environment (Gulinck and Van Voorthuysen, 1961).

The compactness viz. the physical "ripeness" (Pons and Zonneveld, 1965) of the levee deposits down to 2-3 m below the top points to a very gradual slitting up, keeping pace with the rising sea level during the latter part of this phase. For the former part of this phase a more rapid sedimentation can be assumed, resulting in subaquatic deposits without remains of vegetation near the later creeks.

Only locally is the Calais II deposit divided into two subphases. Here the younger subphase consists usually of soft homogeneous reed containing clays without prominent levees.

Near Swifterbant the sediments of the younger subphase end in an area in which the clay layer is relatively thin and not overgrown. The clay is embedded in a kind of coarse peat-detritus gyttja. A hinterland lake or mere must have existed here. Much of the reed-sedge peat surrounding this area has been eroded at a later stage. The same has occurred with the peat bed formed on top of the Calais II sediments elsewhere. The end of this sedimentation was recently determined by means of a radiocarbon dating of the base of the remnants of the overlying peat bed. The outcome is 5250 BP.

In Eastern Flevoland the Calais II deposits - as well as the outcropping Late Pleistocene river bank dunes (figure 5.7a) - have been inhabited (so-called Swifterbant culture). Five radio carbon datings of organic fragments in the levees of the Calais II creeks vary between 5375 and 5230 BP. (figure 5.7b). During archaeological investigations 9 skeletons have been found in the levees. Sedimentation of the Calais III deposits brought the inhabitation to an end.

The Calais III Deposits

In Eastern Flevoland the presence of a thin bed (10-20 cm) of Calais III deposits in a subaquatic clayey facies can be demonstrated only locally. It had been radiocarbon dated (4955 BP for the base of a peat layer at the top of the clay bed).

The Holland Peat

After the ending of the Calais III sedimentation, Holland Peat began to be formed again on a large scale.

Turning Point in the Development of the Region

About 4000 BP a very large sea-inlet was formed in the Westfrisian area (Hoorn, Enkhuizen, Medemblik). It penetrated far into the hinterland, destroyed much of the Holland Peat and left Cardium-shells and Cardium-clays behind in subaquatic positions (see stratigraphy figures 5.2 and 5.8). Although this invasion was originally attributed to the Duinkerke 0 sedimentation phase, two recent datings of large Cardium-shell samples of 3995 and 3920 BP point towards the end of the Calais deposition phase -

although theoretically these datings could be up to 200 years too old. In the Cardium-clay, foraminifera, ostracods and diatoms indicate the depositional environment as being alpha-mesohaline (total salt content 8-16‰; Gulinck and Van Voorthuysen, 1961).

In the Westfrisian area the inlet silted up and was closed at 3200 BP = 1250 BC and inhabited. It left a complex of lakes in the hinterland: this is the origin of the Roman Lake Flevo (Flevomeer).

The Duinkerke Deposits

In this complex of lakes the Flevomeer-deposits (young peat detritus-gyttja) were formed under oligohaline environmental conditions. They are composed partly of the remains of the flora and fauna living in the water and partly of peat detritus derived from the adjacent peat areas.

After the beginning of the present phase of sedimentation, the northern connection with the North Sea via the Wadden Sea was enlarged to such an extent that material from the Wadden Sea became deposited in the IJsselmeer region. The salinity was not markedly increased, however, because of the continued influx of fresh water from the rivers. In this oligohaline to mesohaline (total salt content 0.5 - 8‰) environment the Almere-deposits were laid down (figure 5.9). In a complete sequence the proportion of organic material decreases and the mineral components increase upwards. The influx of sand and silt from the north must in general have taken place between 1000 and 1400 AD. Next to the aforementioned subaquatic facies, the Almere phase also shows a supra-littoral facies on the adjacent peat lands. An example is found on the former island Schokland (excursion item).

Between 1550 and 1932 the Zuiderzee-deposits were formed. The present IJsselmeer area was called Zuiderzee (Zuyder Zee) in that period. The increase of the salinity of the water in the Zuiderzee towards the end of the sixteenth and the beginning of the seventeenth century was mainly caused by the decreasing supply of fresh water by the rivers, especially by the river IJssel. The deposits are characterised faunally by large numbers of relatively small specimens of *Mya arenaria*. From various data it is known that this species reached Western Europe only during the second half of the sixteenth or early in the seventeenth century. The environment can be determined as alpha-mesohaline (total salt content 8-16‰), since a free connection to the open sea was present (figures 5.10, 5.11 and 5.12).

During the time of deposition of the Almere- and Zuiderzee-deposits no peat formation took place. On the contrary, great devastation of the peat lands occurred: in the Northeast polder this continued even in the 13th and 14th centuries, although the Dutch had already begun to defend themselves more and more with dikes. However the island of Schokland had to be abandoned for inhabitation in 1859.

After the construction of the Enclosing Dam in 1932, separating the Zuiderzee from the Wadden Sea, a rapid freshening of the water occurred. The name Zuiderzee was then changed into IJsselmeer (IJssel Lake). As a consequence of drastic hydrographical changes (falling off of tidal currents) erosion occurred locally, the material being re-deposited elsewhere as IJsselmeer deposits. The environment can now be regarded as oligohaline

(total salt content 0.5 - 2‰).

EXPOSURES

1 Slingerweg/Nijkerkerweg (Nz 40) circa 2 m below NAP

Ditchwall exposure: Remainder of man-made sand depôt, overlying a thin bed of Duinkerke deposits (circa 0.40 m; particularly IJsselmeer-deposits, Zuiderzee-deposits, Almere-deposits?), overlying a thin layer of Holland peat (relict), underlain by Pleistocene sand within circa 1.30 m.

2 Vogelweg/Wulpeg/Gruttoweg (Gz 48) circa 3.80 m below NAP

At this location the bed of the Duinkerke deposits is relatively thick, in contrast to that of the Calais deposits. The two beds are in a way complementary.

Pit exposure: Duinkerke deposits, particularly IJsselmeer-deposits, Zuiderzee-deposits and Almere-deposits in clayey facies, in a partly ripened condition.

Exposed boring: Duinkerke deposits, particularly Almere-deposits (continued), Flevomeer-deposits overlying relic of Holland peat, underlain by Calais II deposits of a reed marsh facies.

<u>Depth(cms)</u>	<u>Deposits</u>	<u>Facies</u>	<u>% Organic mat.</u>	<u>Clay</u>	<u>CaCO₃</u>
0-10?	IJsselmeer	clayey	4	33	11
10-50	Zuiderzee	clayey	3	38	10
50-130	Almere	clayey	6	31	9
130-280	Almere	humic clayey	13	31	5
280-340	Flevomeer	very humic clayey	25	23	2
340-375	Holl. peat	organic	64	15	$\frac{1}{2}$
375-600 _o	Calais	clayey	10	44	1

3 Rijksweg 6 (G97) circa 4.30 m below NAP

Ditchwall exposure: The accent lies on Almere-deposits in a sandy/silty facies, showing clear depositional structures.

Several authors have proved (see Ente, 1971) from the general topography and the grain size data that the main influx of sand came from the north (progressive decrease of grain size from the north to the margins). It is assumed that in the northern part of the Almere current velocities were responsible for sediment transport and that in the southern basin wind wave effects have been the main mechanism of transport. Boersma (1970) in a thorough study of sedimentological structures has put the sedimentological arguments in favour of wind wave action in a list:

- 1 the very gradual lagoon-ward slope of the layers (1-2: 10,000).
- 2 the great lateral extent of sub-units (many km's),
- 3 the levelling effect of Almere-deposits on the irregular substratum relief,
- 4 the intercalation of horizontally-laminated (fine-sand) layers of a few to five centimetres thick resting on a horizontally

- truncated underlying layer caused by storms(?),
- 5 the orientation of ripple crests being almost exclusively NW-SE (right angles to the direction of the prevailing strong SW-winds),
- 6 the occurrence of many compound (interference) ripple patterns in the Almere Unit.

With regard to (5), it is regretted that the orientation of the section is only north-south.

4 Visvijverweg (G15) circa 4.50 m below NAP

See figure 5.6 for profiles (a), (b) and (c).

- a Most common, normal profile: well-developed Duinkerke deposits overlying poorly developed Calais deposits in backswamp facies.

Ditchwall exposure: IJsselmeer-deposits in clayey facies, underlain by Zuiderzee-deposits in sandy facies, underlain by Almere-deposits in sandy facies.

Exposed boring: Almere-deposits in sandy facies (continued) overlying Almere-deposits in humic facies, underlain by Holland peat (relict), underlain by Calais deposits in clayey reed marsh/backswamp facies.

- b Less common, transitional profile: moderately developed Duinkerke deposits overlying a creek fill of respectively, Cardium deposits, old detritus gyttja and Calais II deposits.

Ditchwall exposure: IJsselmeer-deposits in clayey facies, underlain by Zuiderzee-deposits in sandy facies, underlain by Almere-deposits in sandy facies and possibly exposed humic facies.

Exposed boring: Almere-deposits in humic facies (continued), underlain by Cardium clay (subaquatic facies), underlain by old detritus gyttja (subaquatic facies), underlain by Calais II deposits in a creek bottom facies.

- c Less common, special profile: poorly developed Duinkerke deposits overlying well developed high lying Calais deposits, lastly in a levee facies.

Ditchwall exposure: IJsselmeer-deposits in clayey facies, underlain by Zuiderzee-deposits in sandy facies, underlain by Almere-deposits in respectively sandy and humic facies underlain by Calais deposits in clayey, ripened, levee facies.

Exposed boring: Calais deposits in clayey, ripened, levee facies of a few metres thickness, changing into less ripened, clayey reed marsh/creek bottom facies.

5 Schokland circa 1.25 m below NAP, incl. 1.30 m subsidence

Exposed boring: Zuiderzee- and Almere-deposits (circa 1.50 m clay) in supralittoral facies with a gradual transition changing into reed/sedge peat.

See figure 14.

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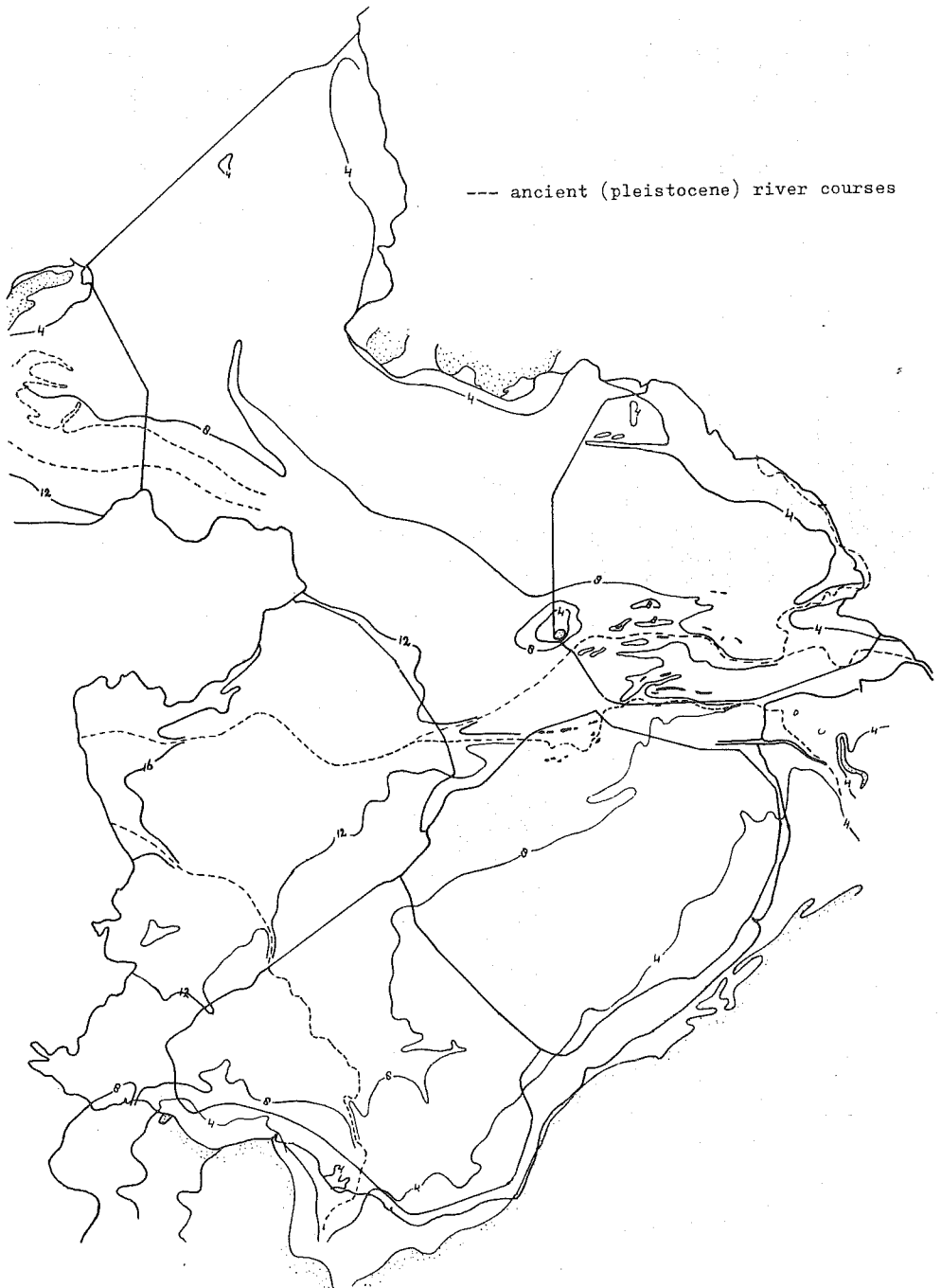


Fig. 5.1 Topography c.10,000 B.P., showing contour-lines of the top of the Pleistocene sands in metres below NAP.

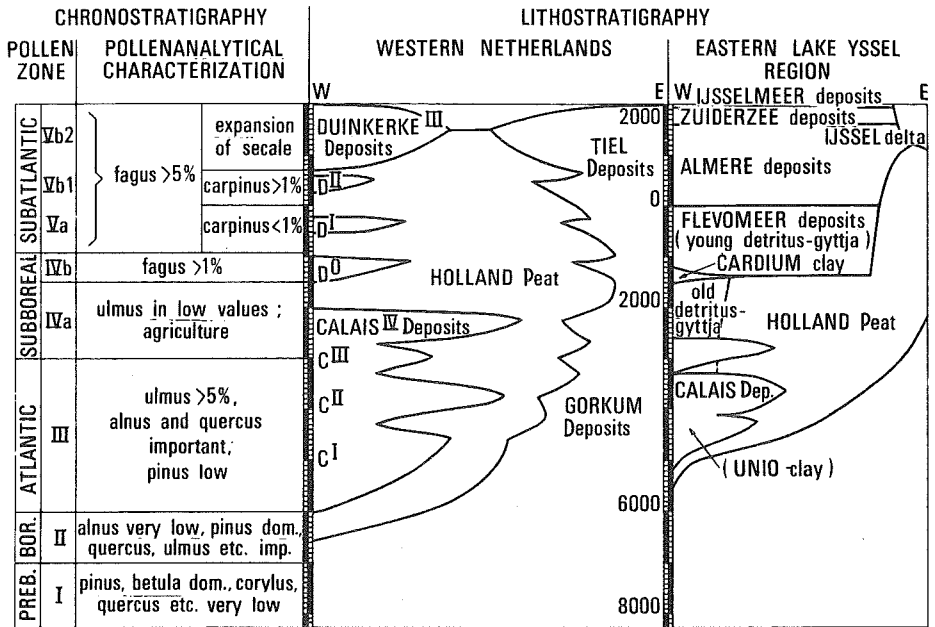


Fig. 5.2 Holocene stratigraphy (after Jelgersma 1961; Hageman, 1969; Verbraeck, 1970).
N.B. Recent C14 dates suggest the Cardium clay should belong to the Calais deposits.

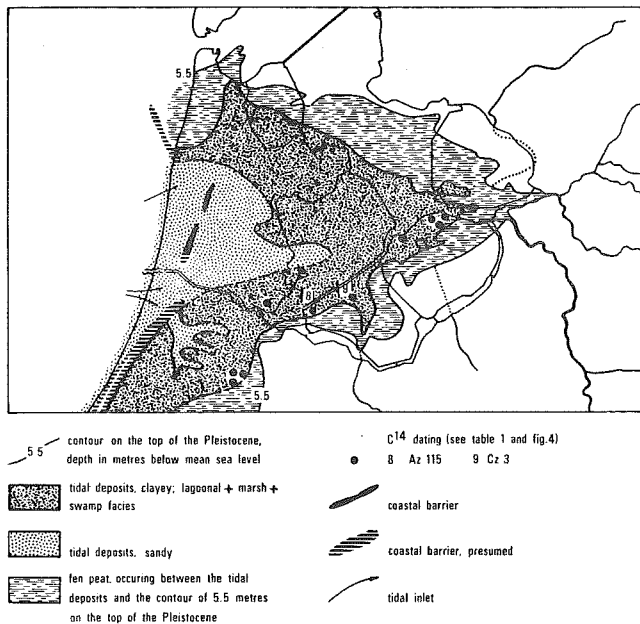


Fig. 5.3 Environment of deposition in the period 6250-5600 B.P. (Calais II phase). After Pons et al (1963), amended.

MARKERMEER



Fig. 5.4a The top of the Calais deposits in Southern Flevoland (m below ground level).
 --- section at Trekweg (Fig. 5.5).
 + exposure at Vogelweg.

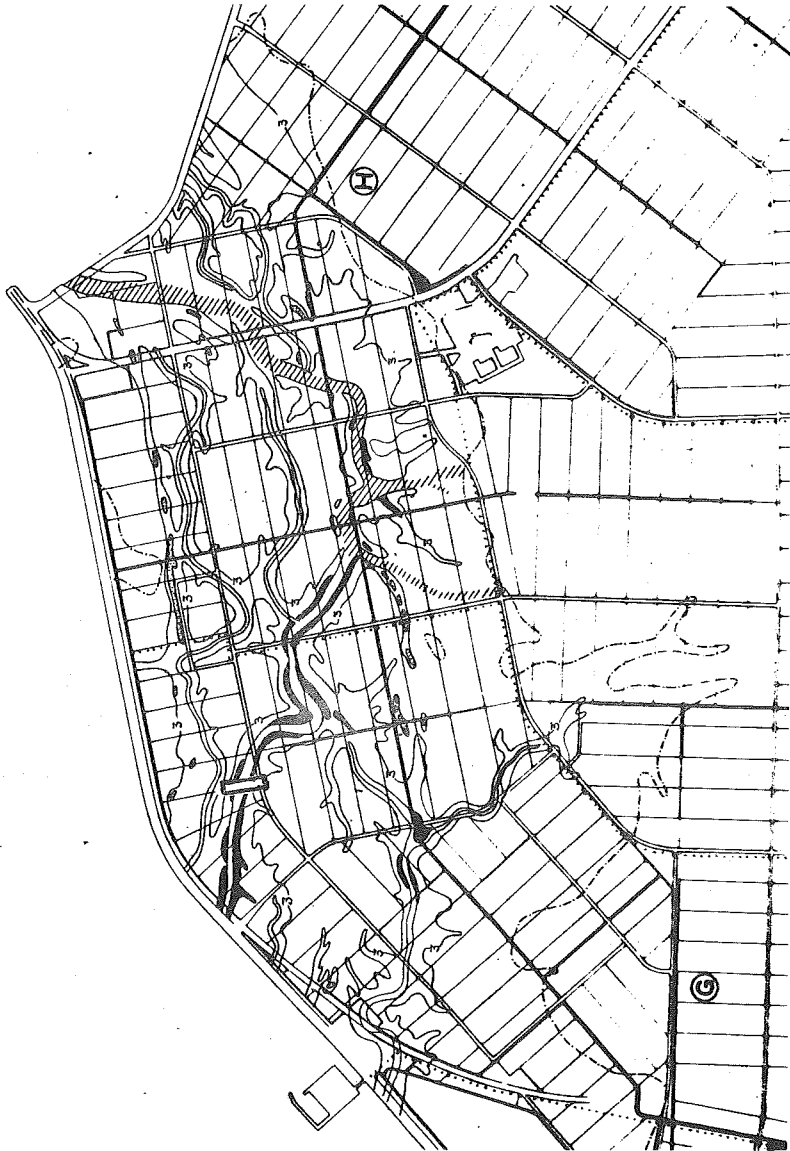


Fig. 5.4b The top of the Calais II deposits in Eastern Flevoland (m below ground level).

- exposure at Visvijverweg.
- river bank dunes.

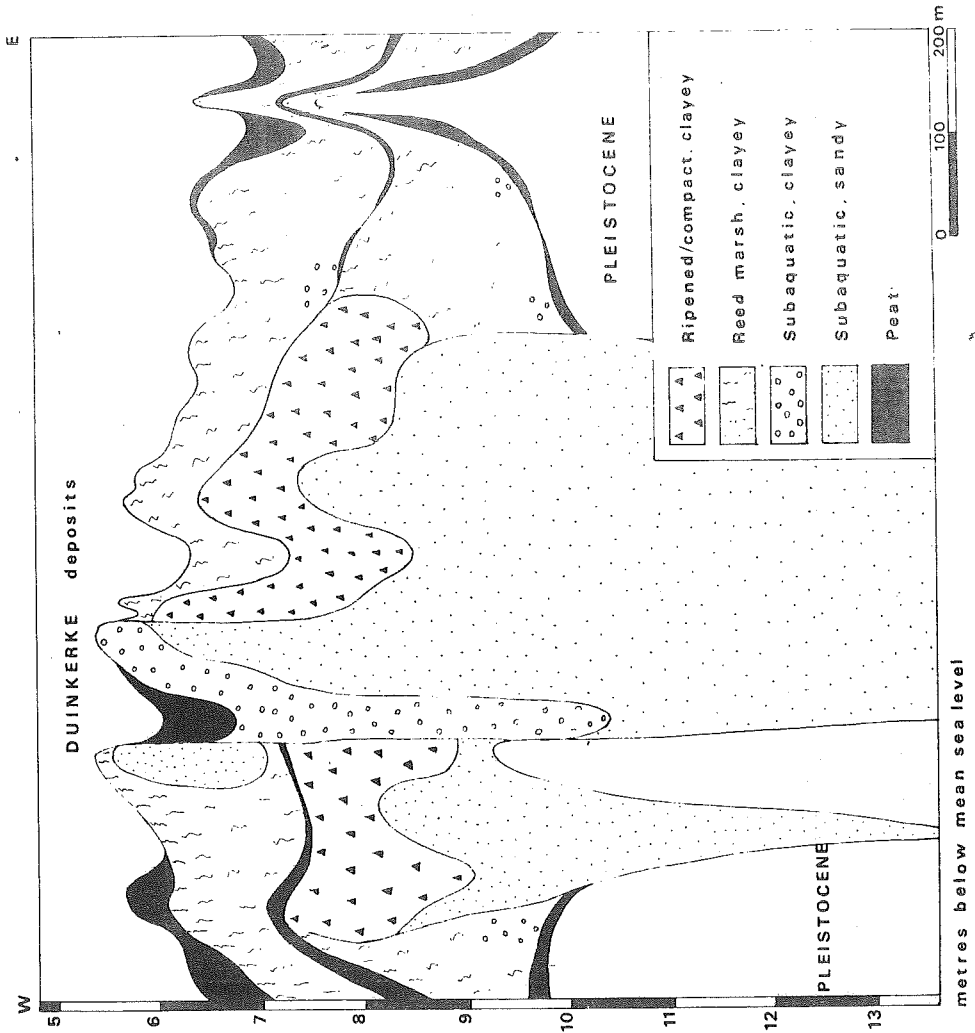


Fig. 5.5 Tregweg (for location see Fig. 5.4a). A cross-section through the main creek with details of sub-phases of Calais II deposits.

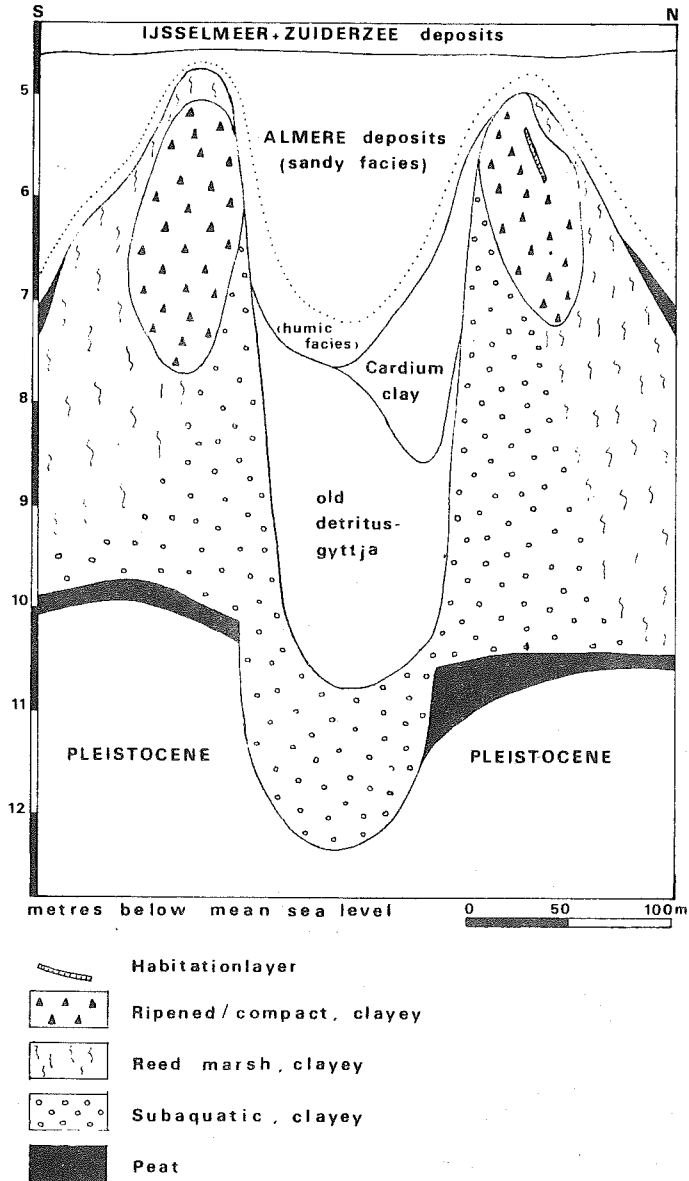


Fig. 5.6 Visvijverweg (for location see Fig. 5.4b). A cross-section with details of sub-phases of Calais II deposits.

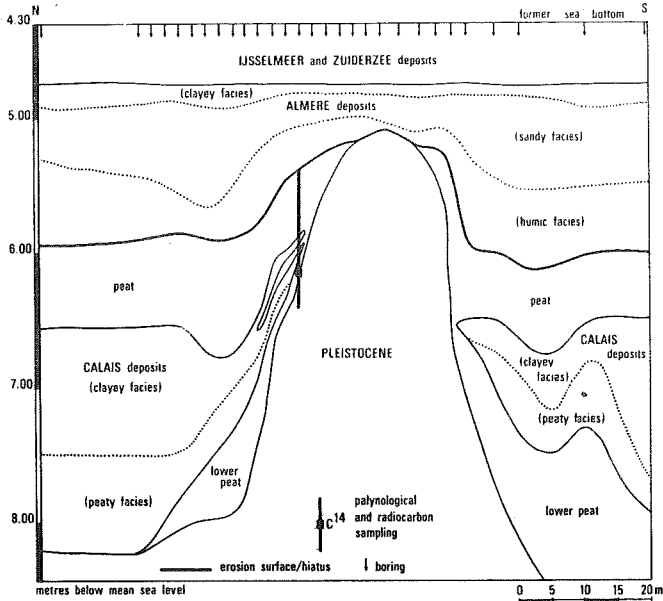


Fig. 5.7a (top) Section in river bank dune surrounded by Calais deposits and peat at parcel H46.

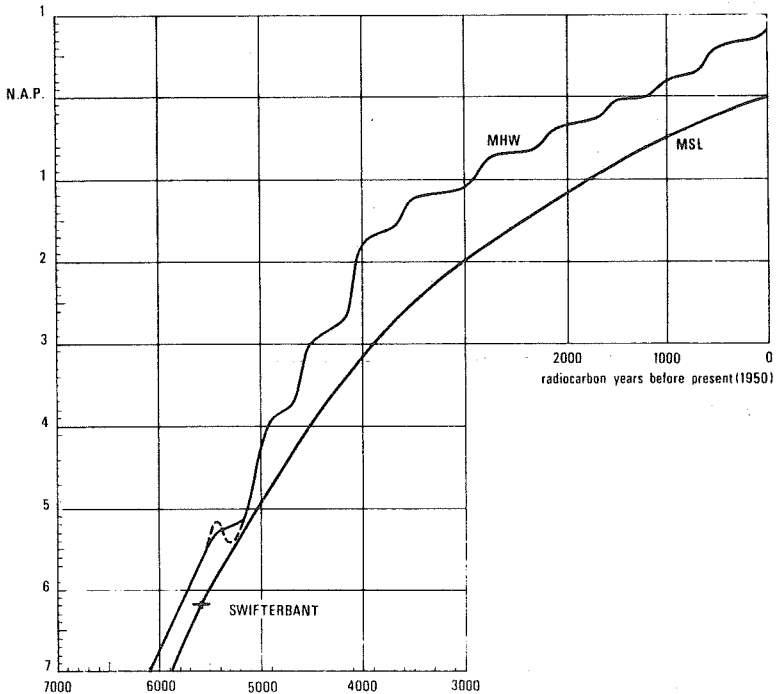
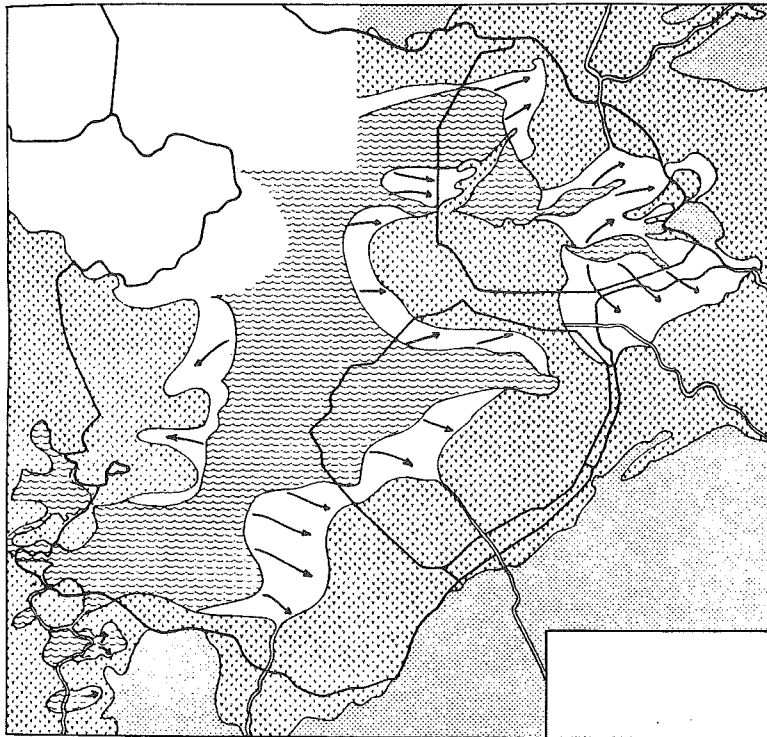


Fig. 5.7b (bottom) Time/depth diagram with curves for mean sea level (MSC) and high water (MHW). The C^{14} dating of Fig. 5.7a fits exactly within the MSC curve.







- | | |
|--|---|
| <p>  Lakes formed by inroads of the sea into a peat area between 2000 and 1250 B.C. </p> <p>  Enlargement of the lakes between 1250 B.C. and 250 A.D. </p> | <p>  Peat </p> <p>  High-lying sand deposits </p> |
|--|---|

Fig. 5.8 The origin of Lake Flevo.

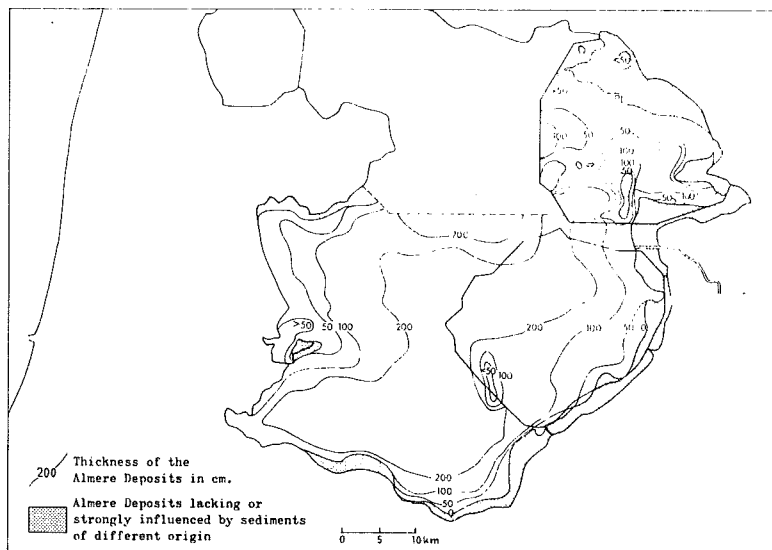


Fig. 5.9 Thickness of the Almere deposits.

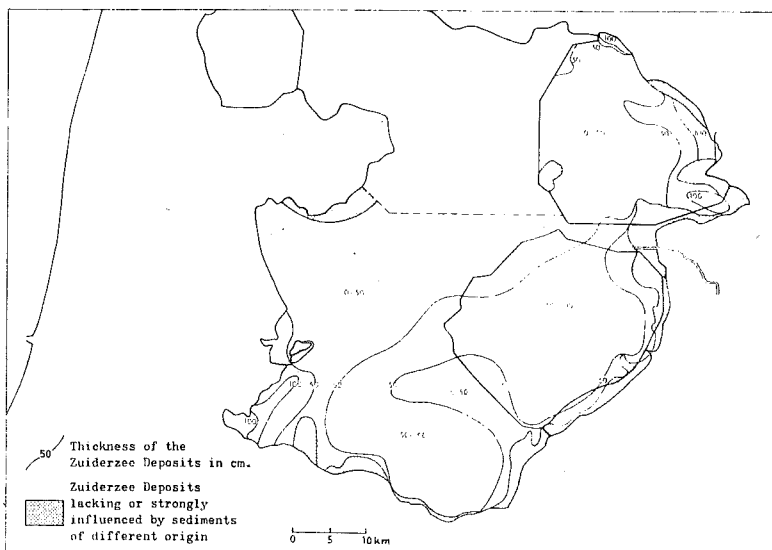


Fig. 5.10 Thickness of the Zuiderzee deposits.

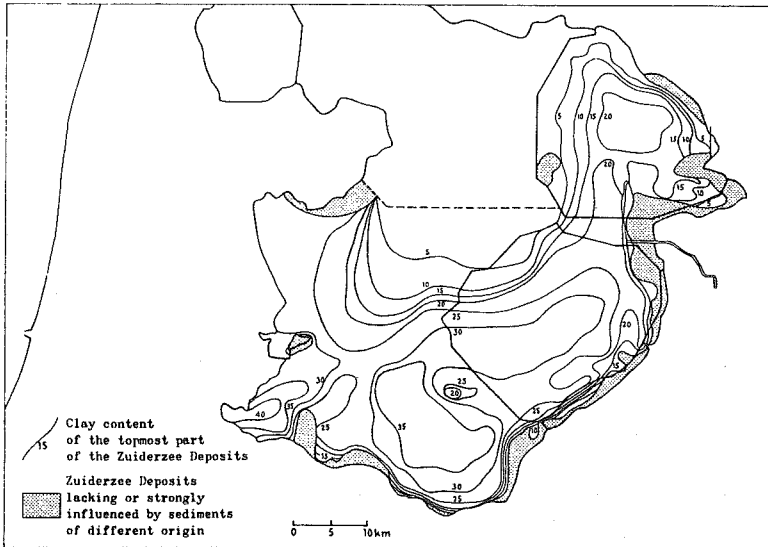


Fig. 5.11 Clay content of the Zuiderzee deposits.

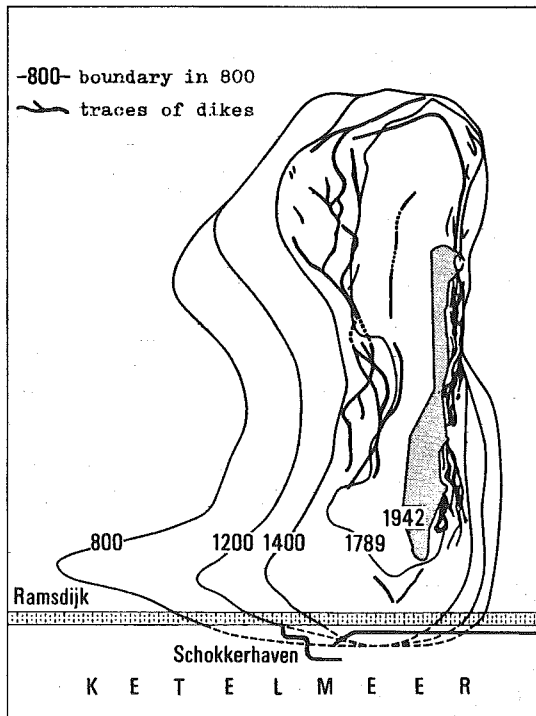


Fig. 5.12 Reduction of the Island Schokland since 800 AD.

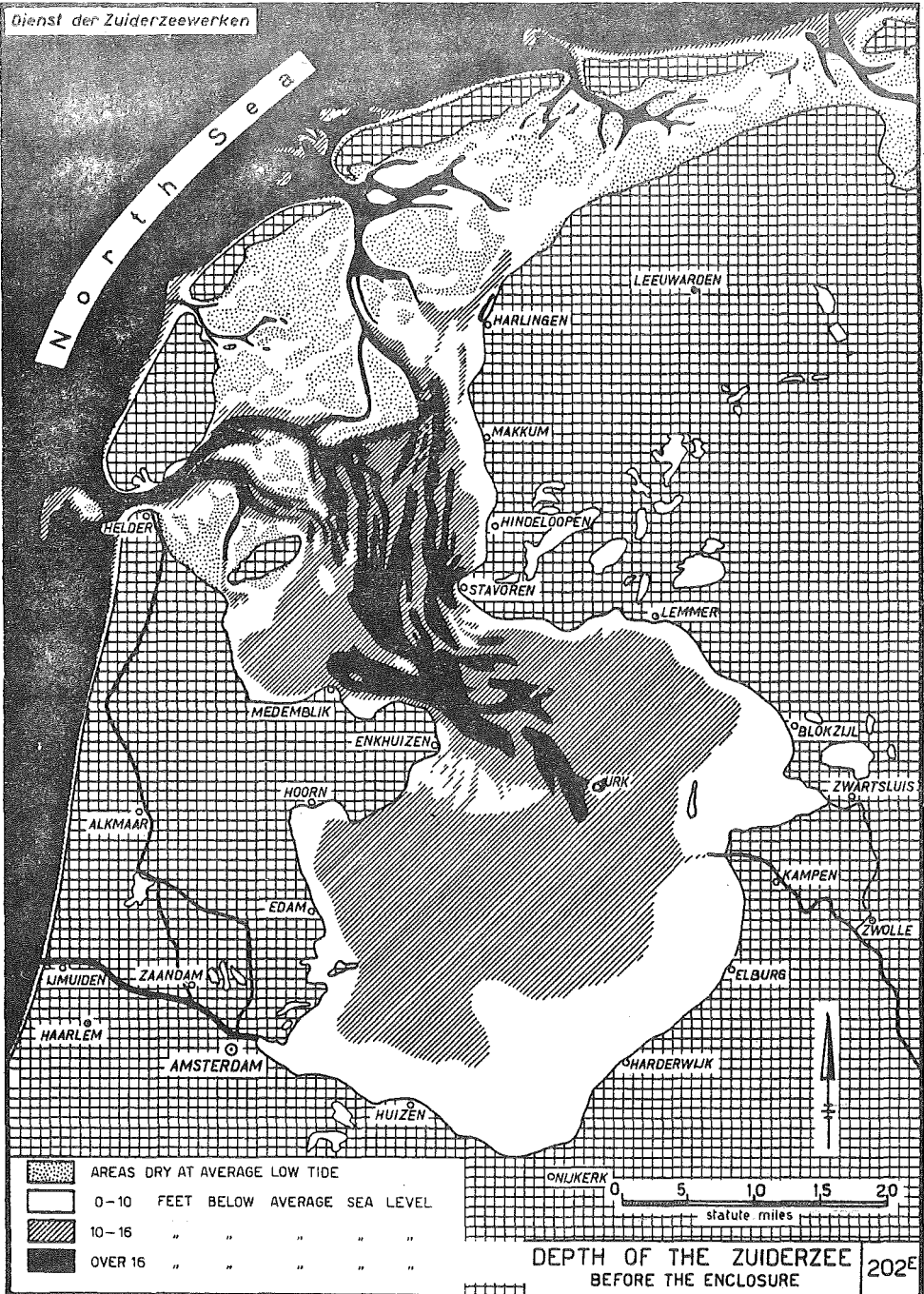


Fig. 5.13 Depth of the former Zuiderzee.

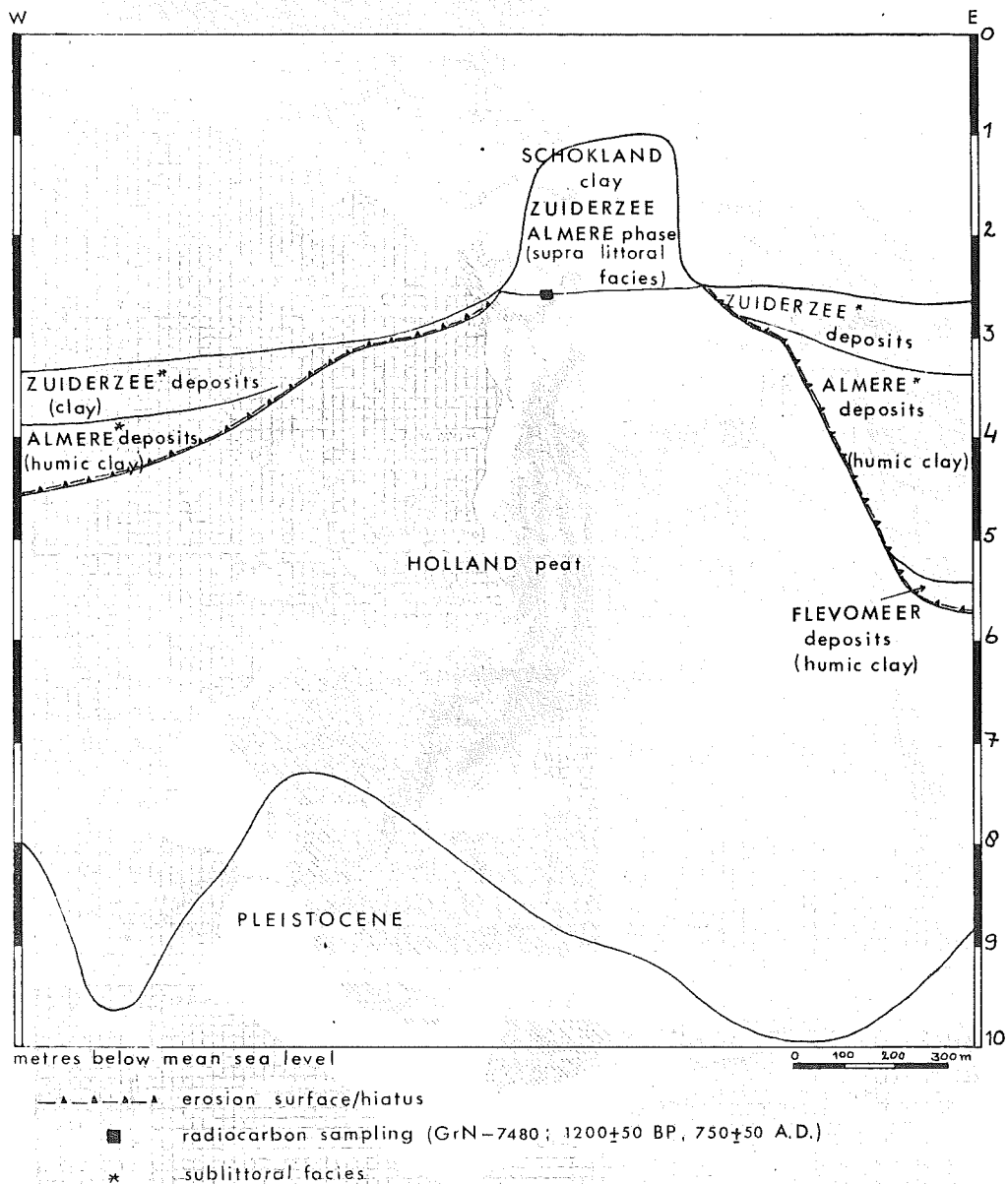


Fig. 5.14 Section at Schokland.