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SEA-LEVEL CHANGES IN THE NETHERLANDS DURING THE EEMIAN[1]

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ABSTRACT

Zagwijn, W. H. 1983 Sea-level changes in The Netherlands during the Eemian. In: M. W. van den Berg & R. Felix (eds.): Special issue in the honour of J. D. de Jong – Geol. Mijnbouw 62: 437-450.

This paper deals with the determination of relative heights of the seal-level during the Eemian in The Netherlands and adjacent parts of the North Sea region. Dating was based on pollen analysis. Eight levels have been established, four of them determining the phase of rising levels, one indicating the peak height of the sea-level, which is estimated at 8 m below the present sea-level at high tide during the period of the *Carpinus* zone, and three indicating the phase of falling sea-level, which took place in the last part of the Interglacial.

After the beginning of the Weichselian, the sea-level dropped below minus 40 m and remained below that level until the early part of the Holocene. Comparison with the Channel area yielded a value of 1.42 cm/century for long-term subsidence of The Netherlands since the Eemian.

INTRODUCTION

Only a few papers have provided information on the problem of the reconstruction of Eemian sea-level in The Netherlands and the northwestern part of Germany (DECHEND, 1954; VON DER BRELIE, 1954; JELGERSMA, 1961), but analysis of data collected during the last twenty years has shed new light on the changes in relative sea-level during the Eemian interglacial in The Netherlands. Relevant information about such levels has proved much more difficult to obtain than in the case of the Holocene. For the latter, rather accurate data are available (e.g., BENNEMA, 1954b; JELGERSMA, 1961, 1966; LOUWE KOOIJMANS, 1974; VAN DE PLASSCHE, 1982), based on ^{14}C-dating of peat beds on a substratum free of compaction and detailed observations on the relationship between former water-tables and sea-levels and on sedimentary structures in exposures. Discussions on the validity of some values within the range of less than a metre or even some decimetres, are found in the literature. Compared with the refinement of these studies, the data presented in this paper may seem crude. However, geological conditions for observations in Holocene deposits are very different from those in Eemian beds.

The Eemian deposits are buried much deeper, the relief of the subsoil over which the sea transgressed was more irregular, there was no widespread peat development during the transgressional phase comparable to that of the basal peat of the Holocene, coastal barriers with their potentialities for conserving the traces of former sea-levels are not recognizable, observations in building pits are impossible as – for economic reasons – is the detailed mapping customary for Holocene deposits. Finally, it is impossible to obtain the kind of time resolution provided in the Holocene by radiocarbon dating.

Fortunately, pollen analysis makes it possible to subdivide the time-span of the Eemian into many zones and subzones which are so clearly marked that often even single spectra can be assigned to their proper place. Figure 1 shows the pollen zonation applied for The Netherlands (ZAGWIJN, 1961; ZAGWIJN, in prep.).

MÜLLER (1974) established a time-scale for the equivalents of pollen zones E 1 to E 4b, based on counts of annually layered lake sediments. The findings in the oldest zones (E 1 to E 2, this paper) indicate a very short duration amounting to only 100 to 200 years. However, in this case accurate counting of annual layering was difficult and the results may be biassed. The equivalents of pollen zones 3a and 3b had a layering that was easy to count and indicated a total duration of 900 years, whereas for zone E 4a, in which this was the case for only part of the sediment, a duration of 700 years was arrived at. The duration of zone E 4b was estimated at only 1000 to 1200

[1] Manuscript received: 1983-02-17.
Revised manuscript accepted: 1983-06-30.
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Eemian Pollen-zones			
E6	b	Pinus	h
	a	Pinus-Picea	
E5	b	Pinus-Carpinus	g
	a	Carpinus	
E4	b	Corylus-Taxus	f
	a	Corylus	
E3	b	Quercus-Ulmus-Corylus	
	a	Quercus-Ulmus	e
E2		Pinus	d
E1		Betula	c

Fig. 1
Pollen zonation of the Eemian in The Netherlands in relation to the zonation of JESSEN & MILTHERS (1928) (right side column).

years. From these data the duration of the entire interglacial was estimated at about 10 000 years, which conforms with SHACKLETON & OPDYKE's (1973) estimates based on the deep-sea record. This means that the best time resolutions now possible by means of pollen analysis may be of the order of magnitude of 500 to 1000 years.

It is clear from the foregoing that determinations of true rates of rise and fall in sea-level during the Eemian are not yet possible. Nevertheless, the data now available may be useful for the understanding of other phenomena, such as differences in regional subsidence. The results discussed in this paper were presented in abbreviated form in a lecture at the INQUA Congress held in Birmingham (ZAGWIJN, 1977).

DATA OBTAINED

Data from seafloor borings in the southern part of the North Sea (Fig. 2)

Pollen-analytical data deriving from a limited number of widely spaced borings from the southern part of the North Sea have permitted, in combination with lithological data, the construction of the section presented in figure 2. In this area the seafloor is between about 26 and 34 m below the present sea-level. Holocene marine sands only a few metres thick, lie just below the seafloor. Below these sands are non-marine beds varying in thickness and composed of typical eolian sands ('coversands'). In the basal part of this sequence a clay bed may be found (borings 2-4). This clay bed is known to extend over a considerable area and has been described as the Brown Bank Bed (OELE, 1971) or Brown Bank Formation (BROWN & HAGEMAN, 1983).

The Brown Bank Formation is of fresh-water origin except for its lowermost layers, which are marine in some places. It was deposited in a lagoon or a lake. Underlying these beds there are marine shelly sands which contain a fauna characteristic of the Eemian. These sands are rarely absent. Their thickness varies from around 10 m in the south to more than 20 m locally in the north. The base of these sands is flat in the south (at about 46 to 47.5 m below the present sea-level) and more incidented in the north. They overlie older beds of Saalian, Holsteinian, and 'Cromerian-complex' age, as can be seen in figure 2. A number of pollen spectra are available that permit more precise dating of these beds. Spectra from

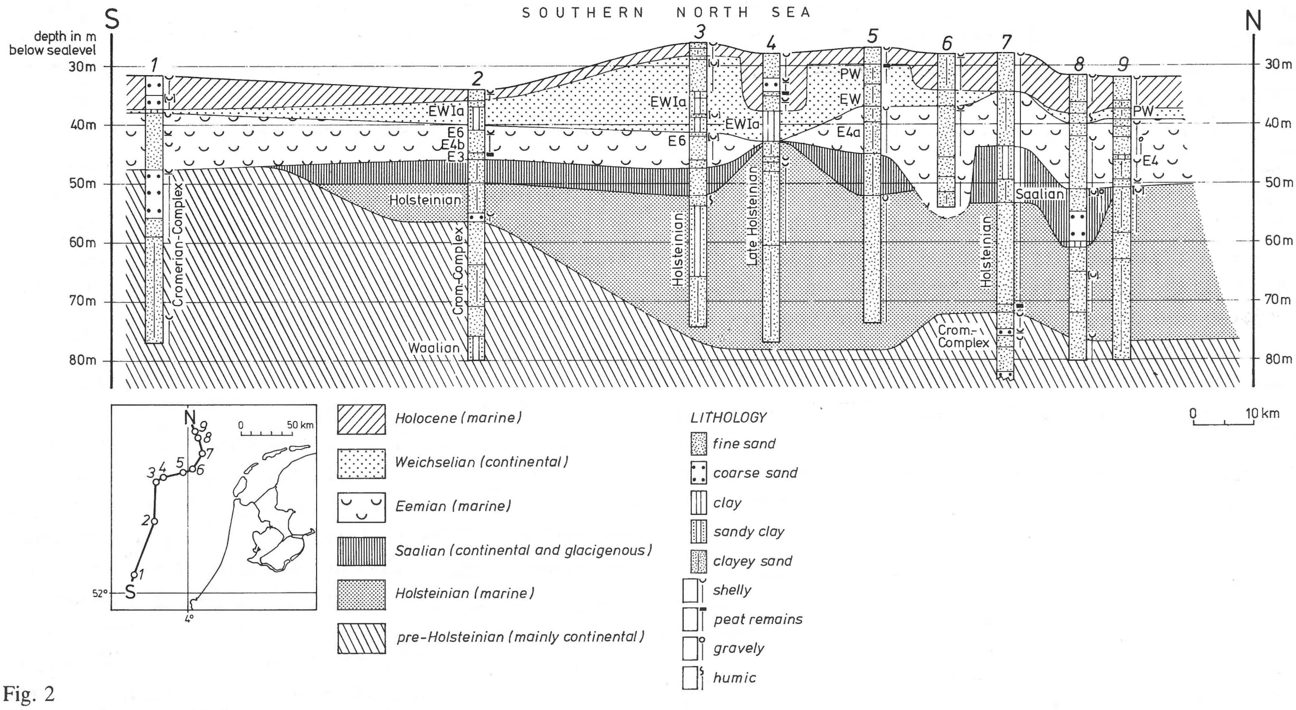


Fig. 2
South-north section in the southern North Sea.

Eemian and Weichselian beds in two borings have been selected to serve as examples (Table I).

The sands with an Eemian marine mollusc fauna yielded pollen spectra for borings 2, 3, 5, and 9. These spectra indicate that the majority of these beds date from the *Corylus* Zone (E 4). The spectra from the topmost beds can be assigned to pollen zone E 6 (dominance of *Pinus*).

Of some interest is the finding, at the very base of the marine deposits in boring 2, of a thin peat lense, whose pollen spectrum is characteristic of pollen zone E 3 (Table I) at a level of about 45 m below the present sea-level.

The pollen-analytic data for the Brown Bank Bed (borings 2-4) indicate that this bed dates from the late Eemian (pollen zone E 6) and the early Weichselian (pollen zone EW Ia). The transition from marine to fresh-water conditions is found at the transition from pollen zone E 6 to EW Ia at a level of about 40 m below the present sea-level (boring 2).

Two pollen spectra from thin peat beds intercalated in coversand (borings 5 and 9) clearly indicate that these beds were deposited during the Middle Weichselian (pollen zone PW).

Data from the sedimentary fill found in the glacial tongue-basin in the subsoil of Amsterdam (Fig. 3)

In the subsoil below the city of Amsterdam and its environs is a glacial tongue-basin surrounded by push-moraines. This tongue-basin has been mapped by JELGERSMA & BREEUWER (1975), and their data indicate that it has an elongated shape, the longest axis (about 25 km) having a northeast-southwest direction. The deepest part of the basin is in the Waterland area some ten kilometres northeast of Amsterdam and reaches down to over 125 m below the present sea-level. In the subsoil of Amsterdam proper, the floor of the basin is, generally speaking, between about 50 to 60 m below the present sea-level, with some local exceptions which will be discussed below.

The main data on the sedimentary filling of the basin will be reported in a separate publication (ZAGWIJN, in prep.). Here, a summary of the results will suffice. The section in figure 3 can serve as a basis for discussion. Surrounding the basin in the south are ice-pushed pre-Saalian deposits consisting of more or less coarsegrained sands and intercalated clay beds. These

Table I
Pollen-analytic data (in per cent) for Eemian and Weichselian beds below the floor of the southern part of the North Sea.

Boring 2

Depths in metres below the present seafloor	Pollen zone	*Abies*	*Alnus*	*Betula*	*Carpinus*	*Picea*	*Pinus*	Quercetum mixtum	*Corylus*	Non-arboreal pollen	Sample number
3.00- 3.10	EW Ia	1.0	2.0	5.0	–	2.5	18.5	–	1.5	69.5	798/1
3.90- 4.00	EW Ia	–	1.0	12.8	–	1.8	24.5	–	2.3	57.3	798/2
4.60- 4.70	EW Ia	–	2.0	6.0	–	0.5	13.5	–	2.0	76.0	798/3
5.10- 5.20	EW Ia	–	2.5	4.0	–	1.0	13.5	–	2.5	76.5	798/4
6.10- 6.20	E 6b	0.5	9.0	13.5	0.5	8.0	32.5	0.5	1.5	34.0	798/5
8.40- 8.50	E 6b	–	6.5	7.5	–	6.0	25.0	1.0	2.5	51.5	798/13
10.60-10.70	E 4b	0.5	23.5	12.5	2.5	4.5	15.0	5.5	13.0	22.5	798/6
11.70-11.80	E 3	–	11.0	4.0	–	1.0	19.0	41.0	–	23.0	798/16

Boring 5

Depths in metres below the present seafloor	Pollen zone	*Abies*	*Alnus*	*Betula*	*Carpinus*	*Picea*	*Pinus*	Quercetum mixtum	*Corylus*	Non-arboreal pollen	Sample number
4.60- 5.15	PW	–	–	16.6	–	–	1.0	1.0	–	79.0	1003/17
7.60- 8.02	EW	–	4.0	7.5	–	3.5	34.5	0.5	2.5	47.5	1003/19
9.35- 9.90	EW	–	2.9	6.7	–	6.7	37.6	1.0	–	40.9	1004/20
12.35-12.85	E 4a	–	7.5	2.0	–	2.5	28.0	17.0	31.5	7.5	1003/21
15.50-15.95	E 4a	–	35.7	0.5	–	1.0	10.9	9.6	33.3	7.1	1003/22

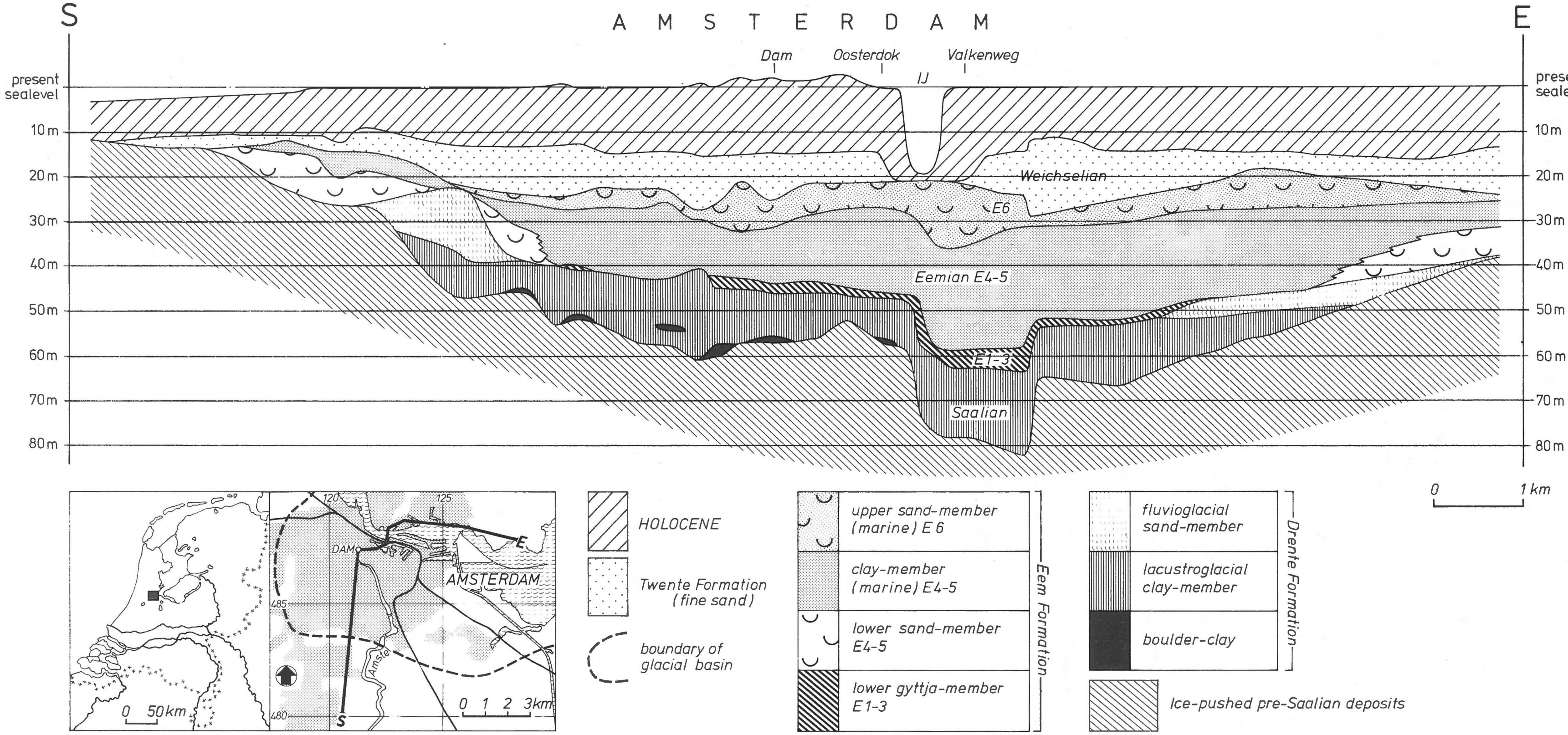


Fig. 3
Section through the glacial basin in the subsoil of the city of Amsterdam.

deposits belong to several stratigraphic units, in particular to the Urk and the Sterksel Formations (Middle Pleistocene). Overlying the floor of the basin in many places is till (boulder-clay) of the Drente Formation, varying in thickness from less than one metre to about two metres. The till is covered by lacustroglacial clays, which are found in almost all parts of the basin deeper than 35 m below the present sea-level. The lower part of the lacustroglacial clays is made up of typical warve clay (see JELGERSMA & BREEUWER, 1975, Fig. 3.4.3).

Along the edge of the basin there are some sediment bodies consisting of coarsegrained sands, which cover the just-mentioned lake clay. The present author interprets these sediment bodies as fluvioglacial delta fans deposited along the banks of a pro-glacial lake. The highest occurrence of these fluvioglacial delta-fan deposits is between 20 and 25 m below the present sea-level. Presumably, this was the height of the pro-glacial lake-level at that time.

According to JELGERSMA & BREEUWER's (1975) map, the basin is surrounded on the east, south, and west by ice pushed ridges lying higher than 25 m below the present sea-level. To the northeast, however, the basin is open at a level between minus 30 and minus 40 m. This means that the lacustroglacial clays and the fluvioglacial sand bodies must have been deposited in a lake dammed off by inland-ice present in the northeastern part of the glacial basin.

Overlying the lacustroglacial clays is a gyttja bed, rich in diatoms, which was first mentioned by HARTING (1852). The diatoms are partly fresh-water species, partly marine.

More detailed lithological and pollen-analytical studies (ZAGWIJN, in prep.) have revealed that in the greater part of the basin there must be a stratigraphic gap between the lacustroglacial clay and the gyttja bed. The top of the former is decalcified, and some decalcified sand may be present between the two beds, as for instance in the Oosterdok boring (25 E/254, depth 47.13-47.25 m below the present sea-level). On the other hand, in the deepest part of the basin (Valken boring 25 E/255) a continuous sedimentation was found, i.e., from lacustroglacial clay, through calcareous lake clay, lake marl, and fresh-water gyttja, to brackish-marine diatom gyttja.

As will be discussed below, the data obtained by pollen analysis have confirmed these observations and have defined the duration of the interval of non-sedimentation outside the deepest part of the basin.

The highest occurrence of the brackish-marine gyttja bed (Layer of HARTING) is at about 40 m below the present sea-level. However, the calcareous fresh-water beds underlying the brackish-marine gyttja in the deepest part of the basin are found in the Valken boring at a depth of 63.15-60.30 m below the present sea-level and are not known from a level higher than about 50 m. This probably means that at some time the original pro-glacial lake was drained and a much smaller lake was formed, its surface lying about 50 m below the present sea-level or slightly lower.

The rest of the former lake-floor fell dry temporarily and was leached. Later, the lake-level rose again, evidently in connection with increasing marine influence, passing from below minus 47 m (Oosterdok boring) to a level higher than 40 m below the present sea-level. If one corrects for compaction of the underlying lacustroglacial clay, an estimate of 35 m for the height of the original lake-level is acceptable.

Overlying the fresh-water and brackish-marine gyttja is a thick sequence of marine clay filling almost the entire basin, in some places even extending beyond the lacustroglacial clay, and attaining a thickness of about 30 m in the centre of the basin. Near the basin edges, coarsegrained sands rich in marine molluscs characteristic of the Eemian are found. These sands are covered by the marine clay member, and are therefore called the lower sand member. The sands are considered to represent beach and other near-shore deposits formed during the main phase of the Eemian transgression. They do not occur in the central parts of the basin, where they are replaced by clays (see Fig. 3). The highest known occurrence of these littoral sands is at about 14 to 15 m below the present sea-level.

Overlying the marine clay member is another marine sand member (upper sand member), which is also rich in shells typical of the Eemian. The thickness varies from a few metres at the edge to about 15 m in the centre of the basin. Their highest occurrence is at about 19 to 20 m below the present sea-level.

The available data indicate that after the brackish-marine lake stage the whole basin area was transformed into an open marine environment, forming part of the North Sea during that period of the Eemian. The highest sea-level must have been above 14 m. The centre of the basin was deep enough to permit continuous clay deposition in a full marine environment, well beneath the base of wave action. Later, however, sand could accumulate even in the basin centre. This might be explained by a drop of the sea-level (probably to about 19 m).

Finally, the whole area, including the margins of the basin, was covered by continental deposits showing the typical characteristics of a periglacial facies (Twente Formation). Besides fine grained coversands, some peaty-loam horizons with cryoturbations are common. At the end of this depositional phase, the original basin relief had been completely levelled, leaving a slightly inclined surface between 10 and 15 m below the present sea-level.

Finally, the area was covered by some 10 to 15 m of Holocene deposits (peat and marine clay), which are even thicker in the area of the former tidal inlet of the IJ.

Pollen analysis has made more precise dating of these beds and processes possible. A full documentation will be presented in a separate paper (ZAGWIJN, in prep.), which will also discuss the fact that between the beginning of deglaciation and the beginning of the Eemian only a gradual warming of the climate occurred. No climatic deterioration showing correlation with the Warthe stage of northern Germany has been found.

The main conclusions to be drawn from the foregoing data are:

1. The lacustroglacial clays are rich in reworked pollen and originate in a period distinctly predating the Saalian Lateglacial. This is consistent with the conclusion that they were laid down in an ice-dammed lake after retreat of the inland-ice from the outer moraine.
2. The calcareous lake deposits in the deepest part of the basin (Valkenweg boring) date from the later part of the Middle Saalian cold period (pollen zone PS), the Late Saalian (pollen zone LS), and the beginning of the Eemian (pollen zones E 1-3b). This means that the above-mentioned draining of the ice-dammed lake took place in the Middle Saalian.
3. The transition from fresh-water to brackish-marine conditions in the basin took place during Eemian pollen subzone E 3b.
4. The marine clay member of the Eem Formation was deposited during the interval between pollen zones E 4 and E 5.
5. The marine upper sand member of the Eem Formation dates, according to pollen-analytical data, from the Late Eemian (pollen zone E 6).
6. Pollen spectra of a pleniglacial type and deriving from peat and loam horizons found in the Twente Formation indicate a Middle Weichselian age (pollen zone PW).

Data on the sedimentary fill in the glacial tongue-basin in the subsoil of the Eem Valley at Amersfoort

Another tongue-basin at the outer limit of the Saalian inland-ice is formed by the Eem Valley. As early as 1852, in the subsoil of Amersfoort, HARTING described the marine beds now considered the stratotype of the Eemian Interglacial Stage. More details on the sediments filling the tongue-basin were given in the beginning of this century by LORIÉ (1906). Monographic studies on the Eemian type site were published by VAN VOORTHUYSEN (1957) and ZAGWIJN (1961). According to these studies, the base of the tongue-basin lies more than 50 m below the present sea-level in the area east of the town of Amersfoort. The valley floor is covered locally by some boulder clay representing the till of Saalian age. This till is also present along the flanks of the ice-pushed ridges at various depths, lying under a thick series of coarse sand and gravel, usually indicated as fluvioglacial. The surface of these beds has a south to north-dipping slope, and it has therefore been assumed that at least their upper part has a local rather than a fluvioglacial origin, perhaps as slope-wash from the nearby ice-pushed ridges.

In some places deep hollows filled with younger sediments have been found in the surface of this fluvioglacial sand member and have been interpreted as dead-ice depressions. One such depression occurs in the immediate surroundings of the Eemian stratotype (boring 1) near Amersfoort (Fig. 4). Its deepest part lies 53 m below sea-level, coinciding with the level of the former floor of the glacial tongue-basin. The height of the top of the fluvioglacial sands surrounding the hollow is between 17 and 19 m on the south, east, and north and between 13 and 15 m below the present sea-level on the west side.

The oldest sediments filling the depression are organic lake-sediments of fresh-water origin and, as far as their upper part is concerned, of brackish origin (lower peat member). These deposits, which are considered to be the basal member of the Eem Formation, are not found higher than about 22.5 m below the present sea-level and do not occur outside the dead-ice hollow. From these findings it can be deduced that the level of the lake in the dead-ice hollow lay between about 19 and 22 m. The deposits are covered by marine sands containing the characteristic marine 'Eem fauna' (sand member) found almost everywhere in the subsoil of the former glacial basin. These sands of littoral origin are covered by clay of tidal-flat and brackish-lagoonal origin. The top of these beds lies at about 10 m in the centre of the valley and at about 7.5 to 8 m in the west near the ice-pushed ridge.

Correction for compaction (estimated at 30%) for the combination of the highest elevation and minimum thickness of the clay bed yielded an original depth of 6.70 to 7.00 m below the present sea-level. In all probability the uppermost part of the clay member was deposited under salt-marsh conditions, which would mean well above the mean high-tide level in a brackish environment.

Overlying the clay member is a peat bed (upper peat member) consisting of *Phragmites* peat, wood peat, and *Sphagnum* peat, overlain by organic lake deposits. During the deposition of this member, which is the uppermost one of the Eem Formation, any marine influence had already disappeared from this area.

Overlying the Eem Formation are continental sands (of periglacial origin) with intercalated peat and loam horizons of the Twente Formation, which reach to the present surface.

According to the pollen diagrams (ZAGWIJN, 1961) the beds of the Eem Formation at Amersfoort can be dated as follows. The lower peat member dates from the early part of the Eemian (pollen zones E 2 to E 4a). The transition from fresh-water to brackish conditions occurs at the pollen-zone boundary E 3b/E 4a. The marine sand member dates from pollen zone E 4b and the clay member from pollen zone E 5. The upper fresh-water member dates from the Late Eemian and Early Weichselian (pollen zones E 6 and EW Ia).

The Scharnegoutum section (NW Friesland)

Marine deposits were laid down over a large area now found in the subsoil of the northwestern part of the province of Friesland. They fill a broad, rather shallow depression in the surface left after the Saalian glaciation; this depression was open to the north, permitting transgression of the sea.

A boring was made near Scharnegoutum (10F/37) by the staff of the North Mapping District of the Geological Survey to obtain a representative section for this area.

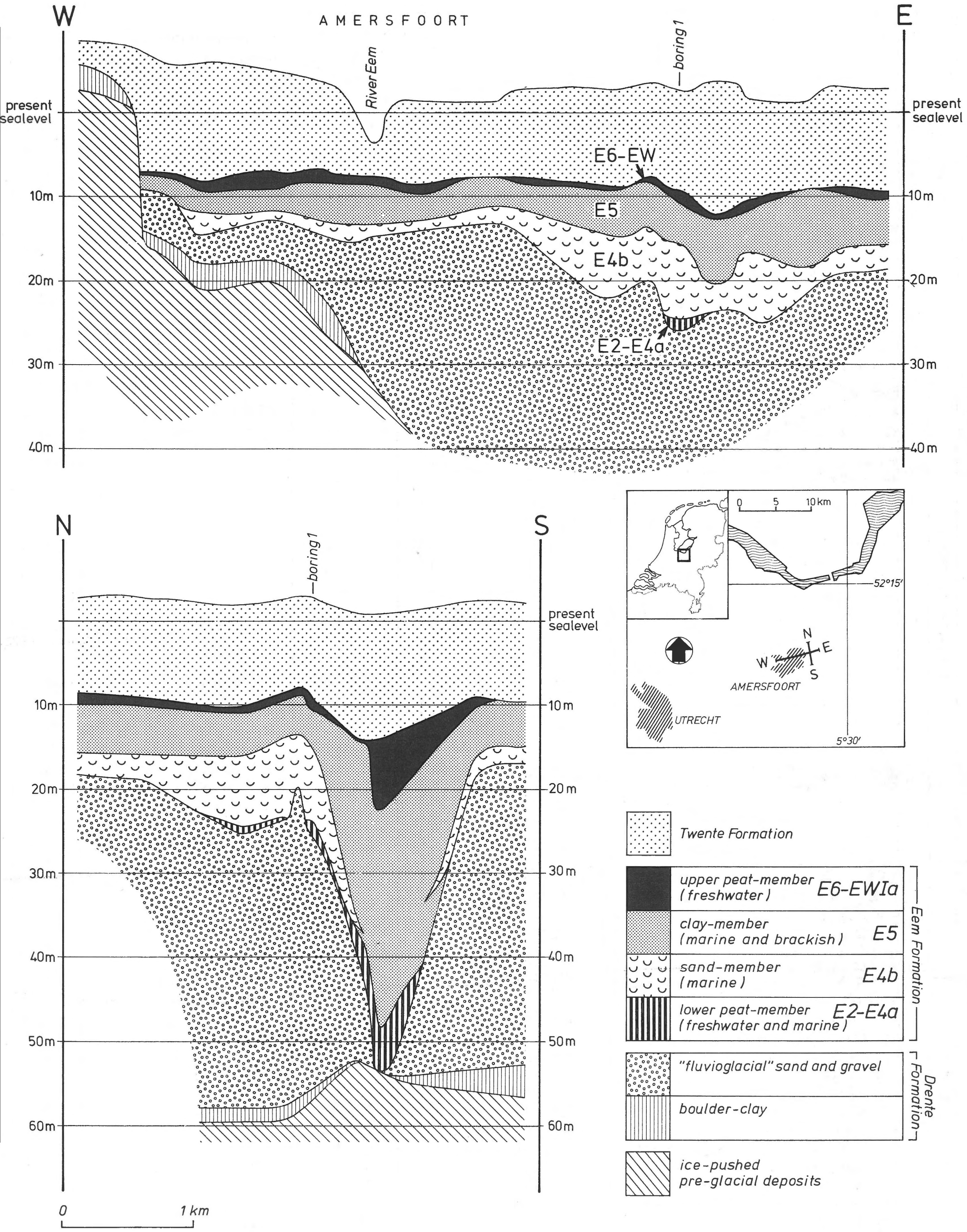
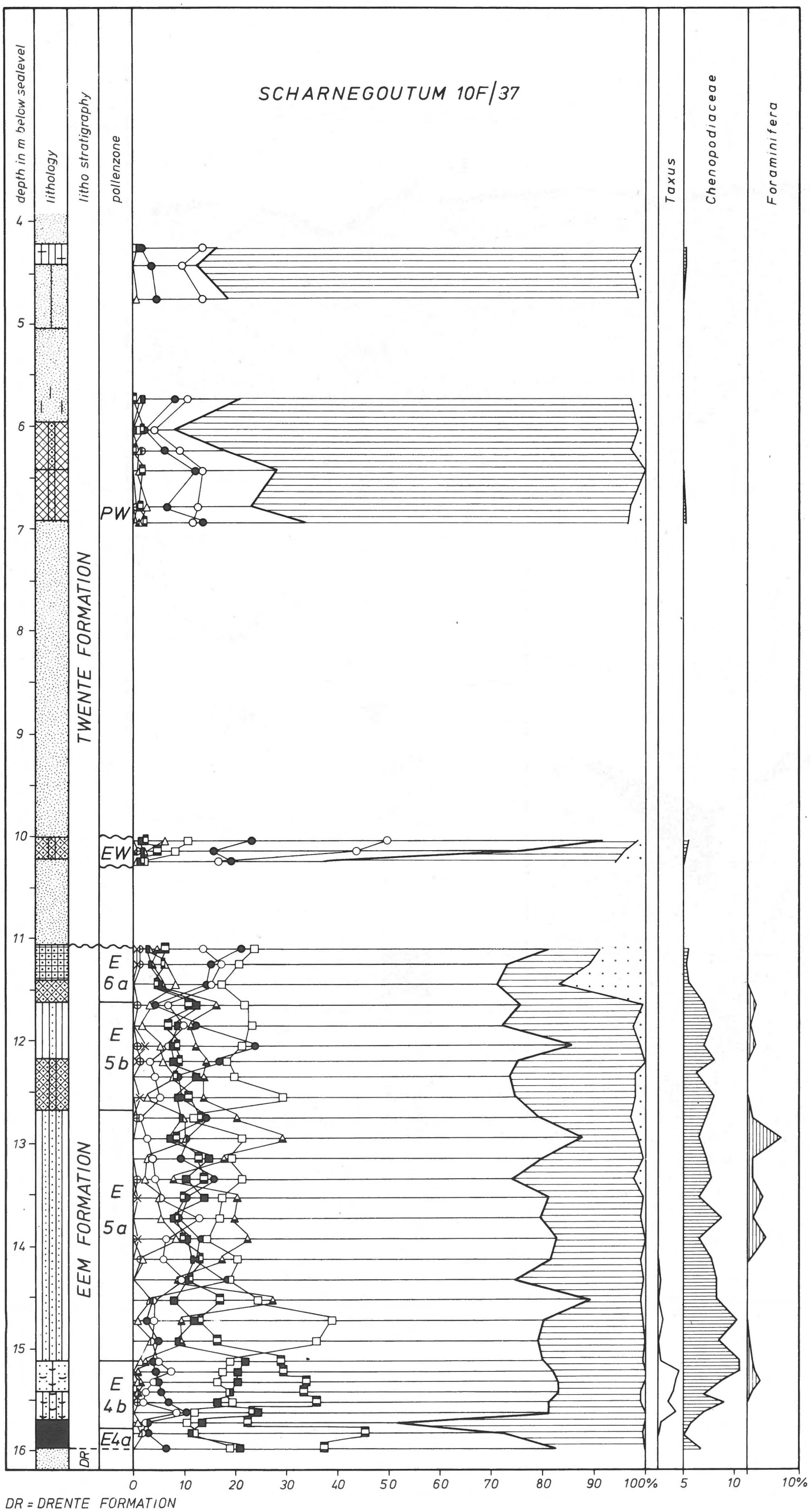


Fig. 4
Sections near the town of Amersfoort.



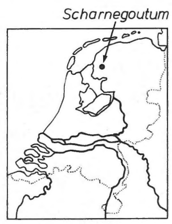


Fig. 5
Pollen diagram of the Scharnegoutum boring (province of Friesland).

Above sand belonging to the Drente Formation, a peat bed was found at a depth of 15.67-15.94 m below the present sea-level. This bed is covered by marine deposits, mainly clay, to a depth of 12.65 m, followed by gyttja and marine clay to a depth of 11.62 m, and then by non-marine gyttja. Overlying these beds of the Eem Formation are sands with some organic layers belonging to the Twente Formation.

The section is of particular interest, because it permits not only rather accurate determination of the height of the level of marine flooding of the thin peat bed at 15.67 m below the present sea-level but also allows dating of this level by pollen analysis. If it is assumed that the peat bed has been compressed to 25% of its original thickness, which is a reasonable assumption, the original level of flooding may have been at 14.86 m. Pollen analysis (Fig. 5) has shown that this level can be dated in the lower part of the *Corylus-Taxus* subzone of the Eemian (E 4b).

The upper part of the Eem Formation provides a level for the regression, which took place at the end of subzone E 5b, i.e., very similar to what happened in the Amersfoort area.

The original height of this level cannot be reconstructed with any certainty.

Data pertaining to the subsoil of the present North Sea coast in the province of Noord-Holland

Marine beds of Eemian age are commonly encountered in the subsoil of the coastal area of the western part of The Netherlands, at depths below 15 to 25 m. In the northwestern part of this region they consist mainly of rather coarse grained sands rich in molluscs. Their top is found between 15 and 30 m, and generally around 20 to 25 m below the present surface. In the particular section between Camperduin and Petten, which will be discussed here, these beds are more than 30 m thick, their base being more than 50 m below the present sea-level.

Locally, two sand members can be recognized, as indicated in figure 6. One (I) consists of coarse and fine shelly sands and has an overlying clay bed some metres thick, whose top lies at 16.3 m in boring 6 and at 18.4 m in boring 4. The other member (II) consist of coarse and fine shelly sand with intercalated clay beds. At its top, which is lower (around 23 m), it has no clay bed. Directly above member I is a peat bed which is not found above member II.

Overlying the two marine members of the Eem Formation are continental, mostly fine grained sands with some peat and

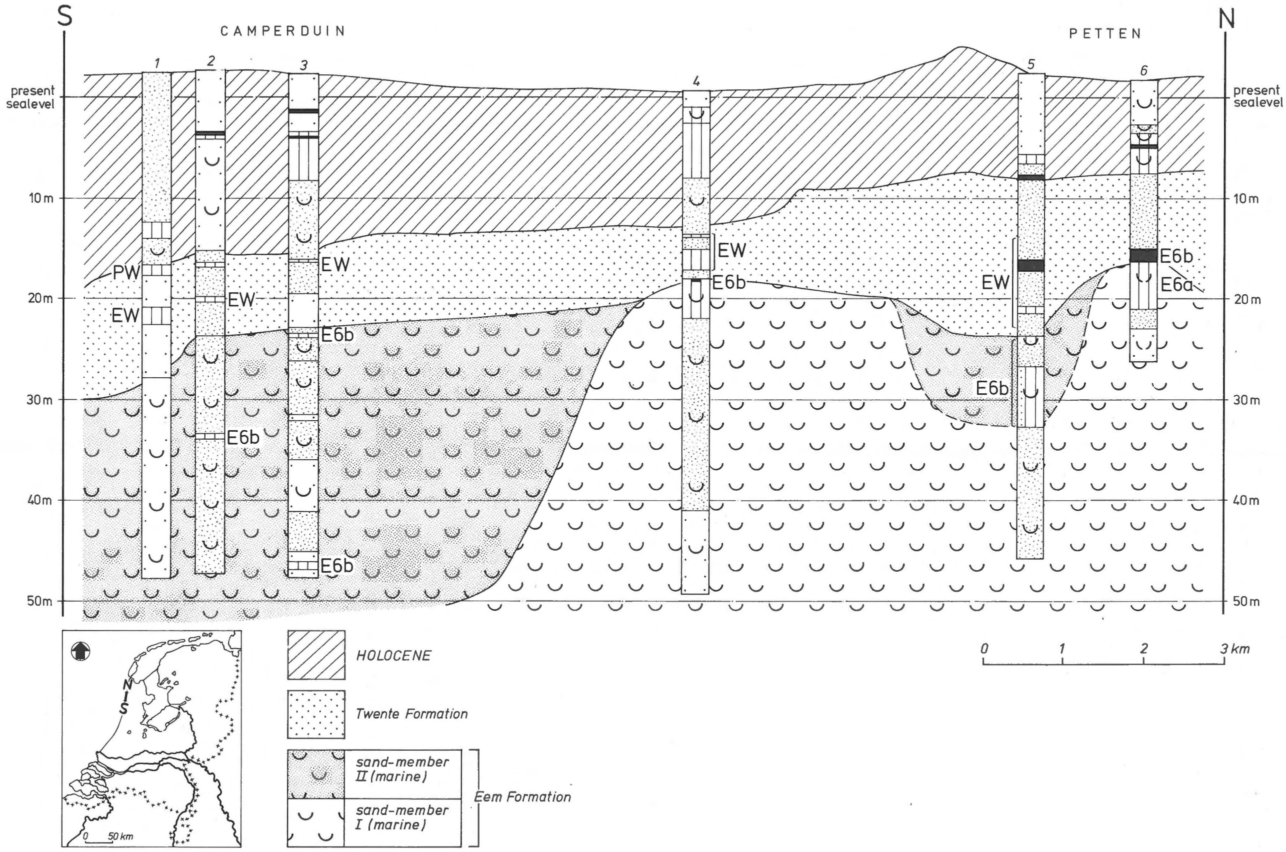


Fig. 6
Section through the subsoil of the coast between Camperduin and Petten (province of Noord-Holland). Lithology: for legend, see figure 5.

Table II
Pollen-analytic data (in per cent) for the Camperduin-Petten section.

Boring 1 (19A/231)

Depths in metres below the present seafloor		Pollen zone	*Abies*	*Alnus*	*Betula*	*Carpinus*	*Picea*	*Pinus*	Quercetum mixtum	*Corylus*	Non-arboreal pollen	Sample number
16.80-17.30	clay	PW	–	–	10.0	–	2.0	9.0	2.0	–	76.0	364/45
20.75-21.25	clay	EW	–	2.0	3.5	–	1.5	28.5	–	0.5	64.0	364/46

Boring 2 (19A/232)

Depths in metres below the present seafloor		Pollen zone	*Abies*	*Alnus*	*Betula*	*Carpinus*	*Picea*	*Pinus*	Quercetum mixtum	*Corylus*	Non-arboreal pollen	Sample number
19.90-20.40	clay	EW	–	2.7	4.5	1.8	0.9	36.6	–	0.9	52.6	364/34
33.40-33.90	clay	E 6b	0.5	4.3	6.3	1.3	9.3	64.3	1.6	3.0	9.3	364/35

Boring 3 (14C/9)

Depths in metres below the present seafloor		Pollen zone	*Abies*	*Alnus*	*Betula*	*Carpinus*	*Picea*	*Pinus*	Quercetum mixtum	*Corylus*	Non-arboreal pollen	Sample number
16.25-16.65	clay	EW	–	1.9	13.6	–	1.3	22.3	0.6	–	57.0	364/37
23.75-23.85	clay	E 6b	–	16.5	8.5	0.5	5.0	34.0	0.5	5.0	30.0	364/38
46.15-46.65	clay	E 6b	0.5	12.0	10.5	–	7.0	47.5	1.5	1.0	20.0	364/39
46.65-47.20	clay	E 6b	0.5	9.5	15.7	2.9	4.8	41.9	2.4	3.5	18.6	364/40

Boring 4 (14C/11)

Depths in metres below the present seafloor		Pollen zone	*Abies*	*Alnus*	*Betula*	*Carpinus*	*Picea*	*Pinus*	Quercetum mixtum	*Corylus*	Non-arboreal pollen	Sample number
13.65-13.80	clay	EW IV	–	16.0	17.6	1.6	15.2	19.2	–	–	25.6	364/41
15.20-15.30	clay	EW I	–	5.0	13.5	–	6.0	8.0	5.0	2.5	60.0	364/42
18.00-18.40	clay, hum.	E 6b	–	3.5	6.0	1.5	2.5	52.5	0.5	2.0	31.5	364/43

Boring 5 (14C/5)

Depths in metres below the present seafloor		Pollen zone		*Alnus*	*Betula*	*Carpinus*	*Picea*	*Pinus*	Quercetum mixtum	*Corylus*	Non-arboreal pollen	Sample number
12.64-13.00	gyttja	EW II/IV	–	4.2	23.3	1.4	2.8	23.3	1.4	7.6	35.6	364/2
15.90-16.20	peat	EW I	–	–	19.5	–	0.9	13.3	0.8	1.4	63.5	364/3
16.20-16.40	gyttja	EW I	–	9.0	3.5	1.0	1.0	6.0	1.0	–	77.5	364/4
20.70-20.85	clay	EW Ia	–	8.5	11.5	1.5	3.0	16.0	1.0	1.0	57.0	364/8
20.85-21.50	clay	EW Ia	–	0.5	9.5	2.0	4.0	32.0	1.0	2.5	42.5	364/9
23.60-24.60	clay	E 6b	0.6	10.2	10.2	2.8	5.7	49.0	4.0	1.2	20.2	364/10
26.60-27.60	clay	E 6b	–	7.5	14.5	0.5	6.5	51.5	0.5	3.5	15.0	364/11
27.60-32.60	clay	E 6b	–	15.5	12.0	3.5	7.0	40.5	1.0	5.5	15.0	364/12

Boring 6 (14C/13)

Depths in metres below the present seafloor		Pollen zone	*Abies*	*Alnus*	*Betula*	*Carpinus*	*Picea*	*Pinus*	Quercetum mixtum	*Corylus*	Non-arboreal pollen	Sample number
15.30-15.80	peat	E 6b	–	3.5	6.0	–	7.0	58.5	0.5	1.0	23.5	364/48
16.30-16.80	clay	E 6a	0.5	1.5	19.0	–	10.0	33.5	2.5	1.0	30.0	364/49
17.30-17.80	clay	E 6a	3.0	13.5	10.0	1.5	17.5	27.0	4.5	–	22.0	364/51
18.30-18.80	clay	E 6a	–	8.4	15.6	0.9	12.4	24.9	2.7	0.9	34.2	364/53
19.30-19.80	clay	E 6a	1.2	8.4	16.0	1.6	15.2	24.0	3.2	0.8	28.4	364/55
20.30-20.80	clay	E 6a	3.4	16.6	14.9	1.1	8.0	21.2	4.6	1.7	28.0	364/57
20.80-21.30	clay	E 6a	0.5	26.0	16.0	0.5	11.0	15.5	4.5	1.0	23.5	364/58

clay beds, which can be assigned to the Twente Formation. Finally, marine and near coastal beds of Holocene age are found on top of the sequence.

Of particular interest are the pollen-analytical data obtained from this section (Table II). These data show that the clay bed at the top of sand member I yielded pollen spectra indicative for pollen subzone E 6a (*Picea-Pinus*) of the Eemian (boring 6), whereas the spectra of the overlying thin peat bed are characteristic for pollen subzone E 6b.

The spectra of sand member II (borings 2, 3, and 5) belong to pollen subzone E 6b. Most of the spectra for the overlying Twente Formation can be considered characteristic of the Early Weichselian (pollen zone EW) and one of them – deriving from a clay lense in the uppermost part of this formation – of the Middle Weichselian or Pleniglacial (pollen zone PW). For more details on the zonation, the reader is referred to Table II.

These findings indicate that the upper part of sand member I was deposited before sand member II. If compaction is not considered, the transition seen in boring 6 (near Petten) from marine to non-marine sedimentation would have taken place at the end of pollen subzone E 6a and at a level of 16.3 m. A precise correction for compaction is difficult to make, but a value of 14 m for the original height of the top of the clay bed may be considered acceptable. On the basis of the lithological data, sedimentation in a salt-marsh environment is assumed.

The highest level of marine sedimentation during subzone E 6b lies at about 23 m below the present sea-level (Camperduin 3), a value which needs no correction for compaction. Member II is directly covered by beds belonging to the lower part of zone EW.

From the foregoing it is evident that the lower position of the top of the marine beds of Eemian age in the coastal area of Noord-Holland relative to that in the Amersfoort region, has to do with a difference in the age of the beds involved and is not the result of a difference in subsidence between the two areas. It can be concluded, furthermore, that the highest level of marine sedimentation was distinctly lower during the Late Eemian in the Noord-Holland area than it had been before, i.e. during the period of pollen zone E 5 in the region of Amersfoort.

DISCUSSION OF EEMIAN SEA-LEVELS

From the available data the following high-tide (mean high water) levels were calculated for The Netherlands (Fig. 7).

Pollen zone E 3 – In the North Sea area a level of 45 m below the present sea-level was surpassed by the rise which occurred some time during the period of pollen zone E 3. Another sea-level determination for this interval can be derived from the Amsterdam basin. Here, a lake with an estimated level at 35 m was invaded by sea-water – at least at high tide – during the period of pollen subzone E 3b.

Pollen zone E 4 – At Amersfoort the sea invaded, at least at high tide, a lake surrounded by a rim with a lowest elevation of minus 19 m at the very beginning of the interval of pollen subzone E 4a. At a later time, during subzone E 4b, a level of 14.86 m (corrected for compaction) was reached, at least at high tide (locality Scharnegoutum).

Pollen zone E 5 – During the period of this zone, sea-level reached its peak height. The best estimates have been based on the sections near Amersfoort. If the upper part of the clay bed dating from subzone E 5b was deposited under salt-marsh conditions, deposition at about 1 m above high-tide level may be assumed. In view of the computed height of deposition at 6.70 to 7 m, a mean high-tide level lying 8 m below the present sea-level is a probable value.

Pollen zone E 6 – From the data for the Noord-Holland coast it is apparent that during this interval the sea-level dropped appreciably after reaching its peak height. For the period of subzone E 6a, a level of 15 to 15.5 m can be derived from the data of boring 6 near Petten, if the same assumption is made about the height of salt-marsh accumulation above high-tide level as for the Amersfoort section. During subzone E 6b the high-tide level was even lower and did not reach higher than 23 m.

Pollen zone EW Ia – Finally, the data on the Brown Bank Formation in the southern North Sea area indicate that at the transition to the Early Weichselian (EW Ia) the sea-level dropped below minus 40 m. After that time it must have remained below this level until the Early Holocene, since no marine beds dating between the Eemian and the Holocene are known for the southern North Sea. Early and Middle Weichselian interstadial beds have been found occasionally, but only in fresh-water facies.

All of the sea-levels discussed so far are relative levels, because they have been affected by tectonic movements in the southern North Sea basin. Comparison with some data from the Channel region sometimes makes it possible to estimate the magnitude of such movements. At Selsey, a sea-level of 1.76 m below the present one was dated by WEST & SPARKS (1960) in Eemian zone f, which falls in the beginning of the period of the *Corylus* zone, subzone E 4a. The peak mean sea-level in that area as well as on the Normandy coast of the

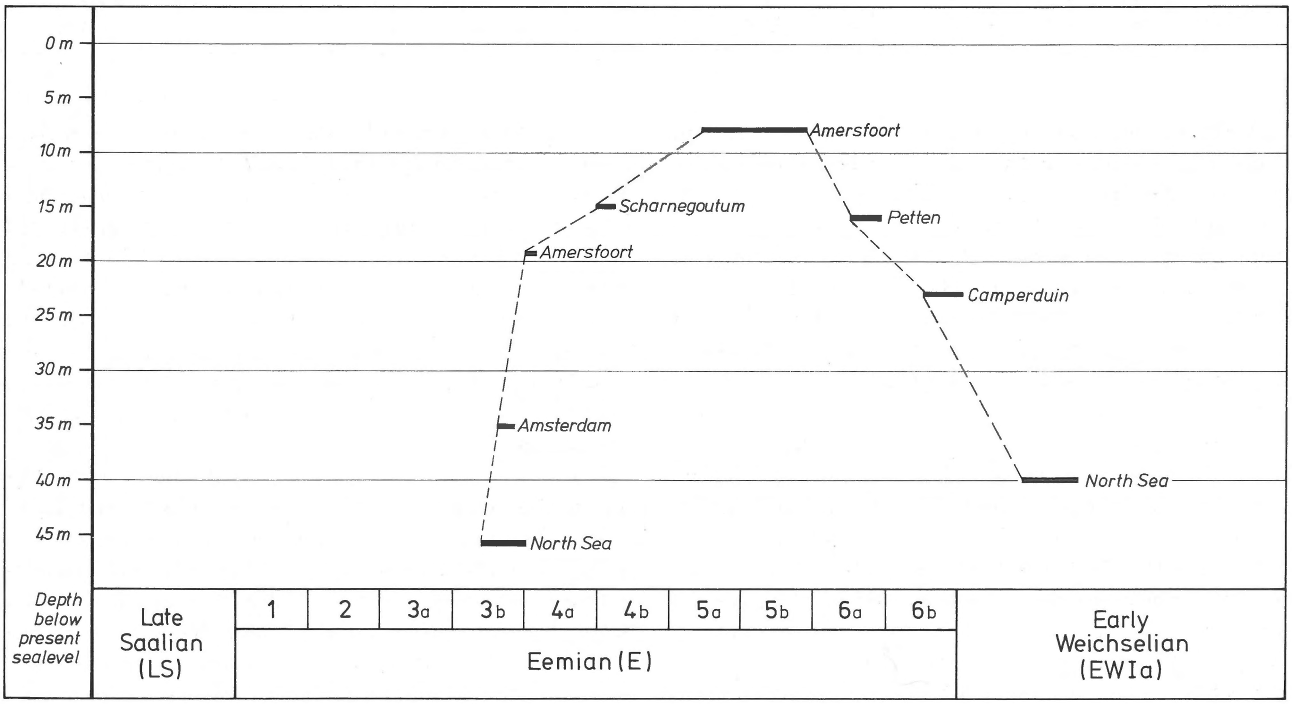


Fig. 7
High-tide levels of the Eemian Interglacial in The Netherlands.

Channel area lay about 8 m above the present mean sea-level. In Normandy, at Arromanches, a late Eemian estuarine deposit situated approximately at the present sea-level, may indicate according to these authors a former mean sea-level at 2 to 3 m below the present mean level, which can probably be placed in our zone E 6b. No pollen-analytic data for the age of the maximum height of sea-level could be obtained in the Channel area, but if we accept a date comparable to that of the maximum sea-level in The Netherlands, i.e., in pollen zone E 5, the following can be said.

In The Netherlands, the high-tide level rose in the period between E 4a to E 5 from minus 19 to minus 8 m, i.e., 11 m. In the Channel area the rise of the mean sea-level in the same interval was about 10 m. After the peak height of zone E 5, the sea-level dropped in subzone E 6 by about 15 m in The Netherlands and at least 10 to 11 m in Normandy. Despite all of the uncertainties involved, these data may be interpreted as indicating that the change of the sea-level was remarkably similar in the two regions.

This leads to two conclusions:

1. The differences in level observed in The Netherlands are a result of eustatic changes in sea-level. In particular, the drop of the sea-level during the Late Eemian is not the result of, for example, a temporary and local uplift of the crust during that time.
2. If we assume for the Netherlands region a tidal range of two metres, similar to that now prevailing in the coastal area under discussion, the difference in peak sea-level during E 5 between the presumably tectonically stable Channel area and the subsiding southern part of the North Sea basin would amount to 17 m.

Absolute dating of the Eemian is still a matter of dispute. The ^{14}C-dates indicate an age close to 75000 years ago for its final stage (GROOTES, 1977), but recently published Ionium-dates (albeit not yet from The Netherlands) resulted in a much higher estimate of 115000 years (VOGEL, 1982). Correlation of the Eemian with deep-sea oxygen-isotope stage 5e had been advocated many years ago (VAN DER HAMMEN ET AL., 1967), but was doubted in the light of the available ^{14}C-datings, because they contradicted an age of about 120000 years fixed for deep-sea stage 5e (SHACKLETON & OPDYKE, 1973). Since MANGERUD ET AL. (1979) clearly established the correlation of the pollen-analytically defined Eemian stage and the isotopic trends of deep-sea stage 5e, however, there is reason to doubt the validity of the ^{14}C-dates obtained for the final Eemian (as well as for the Early Weichselian). The recently published Ionium-dates support this view. Therefore, in accordance with deep-sea records, a round figure of 120000 years is accepted by the present author for the age of the peak sea-level during the Eemian.

This means that the rate of down-warping of The Netherlands in relation to the Channel area has been 1700 cm/1200 centuries = 1.42 cm/century. This figure compares well with some older estimates of long-term subsidence rates in The Netherlands (BENNEMA, 1954a; JELGERSMA, 1961).

ACKNOWLEDGEMENTS

The author wishes to express his gratitude to the following persons and institutions: the Director of the Geological Survey of The Netherlands, for permission to publish the results; his colleagues at the Geological Survey, for substantial help in providing materials for research and for fruitful discussions, in particular Saskia Jelgersma, who assisted in many ways, M. W. ter Wee, who provided the Scharnegoutum boring, and J. de Jong, who for so many years has been my closest collaborator in the investigations in the Paleobotanical Laboratory. The samples of the Amsterdam borings were put at my disposal by the Bureau Grondmechanica of the city of Amsterdam. The drawings were prepared by J. A. M. Bruinenberg, the manuscript was typed by Mrs. M. E. I. Jouini-Spruijt, and the English text was read by Mrs. I. Seeger.

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