13 Eemian and Holocene sedimentary sequences on the Belgian coast and their meaning for sea level reconstruction

F. MOSTAERT and G. DE MOOR

Laboratory of Physical Geography, Geological Institute,
State University of Gent, Krijgslaan 281/S8, B-9000 Gent,
Belgium.

INTRODUCTION

The Quaternary deposits of the eastern part of the present-day Belgian coastal plain comprise two major marine sequences : Holocene and Eemian sedimentary layers. These sequences are composed of coastal, nearshore, perimarine and tidal flat deposits.

In this paper emphasis is put on the comparison of these marine sequences.The lateral and vertical distribution pattern of Eemian and Holocene lithofacies together with the sedimentary characteristics of the units allowed to compare local palaeogeographical conditions during both interglacial periods. Furthermore this paper deals with the interpretation of important palaeomorphological surfaces, which might explain the pattern of the different palaeoenvironments of sedimentation conditions. The substantial amount of data makes it possible to draw conclusions with regard to the deduction from the sedimentary record of coastline migration and relative sea level changes.

Conclusions are based on numerous test borings, on the study of temporary excavations and on the reinterpretation of other available geological data. The techniques applied during the field and laboratory investigation included a detailed analysis of the sedimentary characteristics in the various deposits. Mollusc shell assemblages, micropalaeontological aspects, sedimentary structures, granulometrical and petrological characteristics made it possible to get a fair impression of large- and small-scale facies variations and of environmental changes both in time and regionally.

EEMIAN AND HOLOCENE DEPOSITS OF THE EASTERN PART OF THE BELGIAN COASTAL PLAIN

The present-day Belgian coastal plain is bordered to the south by the uprising Pleistocene and Tertiary substratum. The outcropping deposits consist of Holocene intracoastal tidal deposits and of present-day beach and dune sediments (figure 1). In this text attention is focused on the southern margin of the coastal plain near to Brugge.

Apart from the Holocene sequences, important Eemian marine deposits were identified most of the time underneath fluvioperiglacial and aeolian sediments of Weichselian age. Often Eemian deposits are immediately covered by Holocene marine layers. No older Quaternary marine deposits were found in the eastern coastal plain.

Both the Eemian and Holocene sequences reflect very much the same depositional conditions. The area was characterized by the existence of a barrier coast with intracoastal tidal sedimentation under rising sea level conditions. The impact of sea level lowering during the Weichselian with the associated fluvioperiglacial erosion, did not succeed in scouring completely the Eemian transgressive sequence. It is obvious that the Holocene sequence corresponds to a transgressive prism as well. Till now, regressive interruptions, if any at all, were rather unimportant.

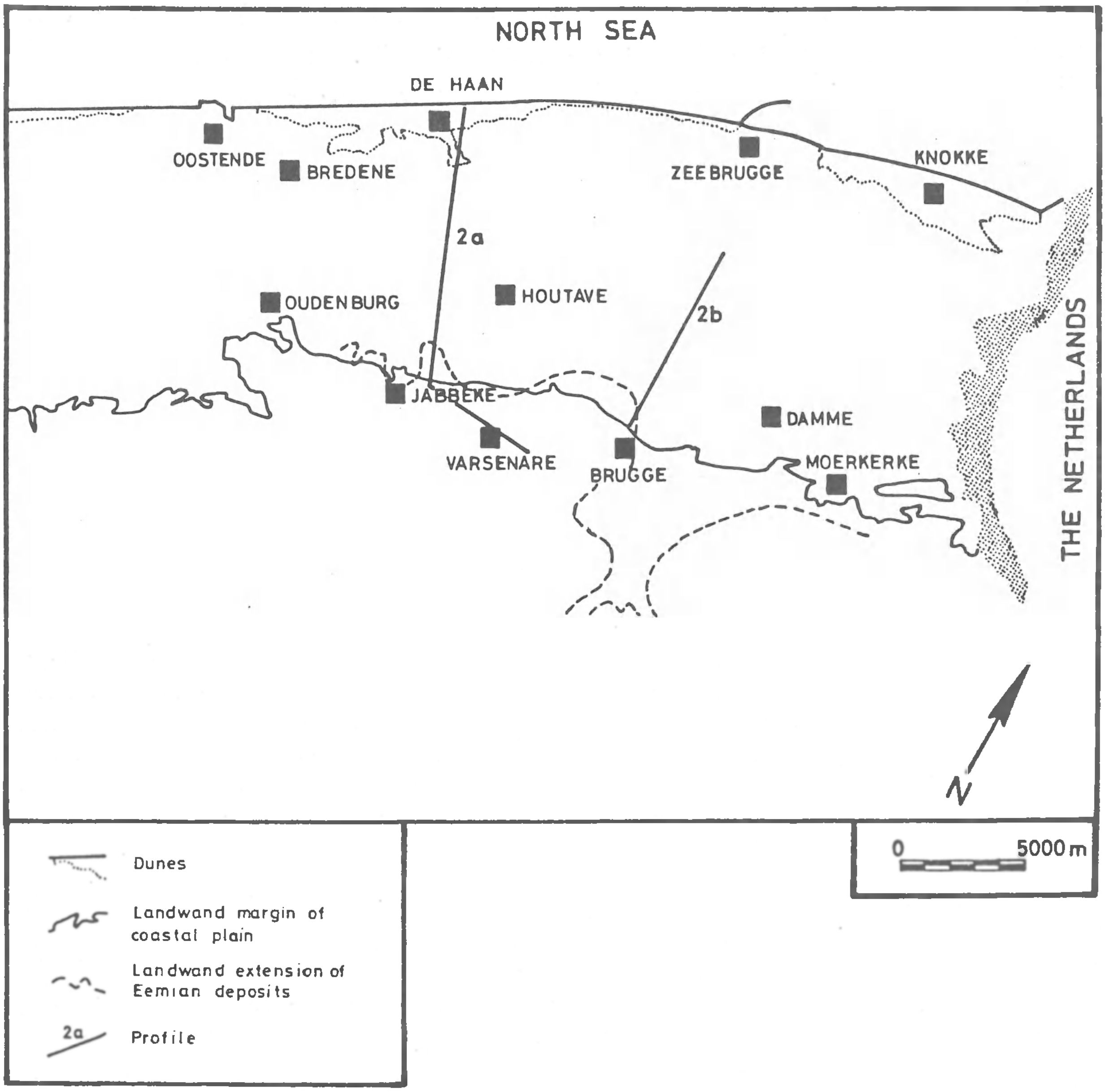


Figure 1 Situation of the study area.

The major difference between Eemian and Holocene sequences concerns the areal and vertical distribution pattern of the sedimentary units and the corresponding depositional environments. This can be proved by means of the synthetical geological profiles (figures 2a and 2b) and by means of maps with specific facies distribution (figures 3a, 3b and 3c). An attempt is made to visualize the palaeogeographical changes during Eemian phases periods with specific sea level stands.

The maximum landward extension of intertidal sediments, reflecting the highest interglacial sea level stands, was very much the same for both the Eemian and Holocene (figure 1). However, Eemian tidal flats locally penetrated further to the south than during the Holocene period in a valley system in the neighbourhood of Brugge. A Late Weichselian aeolian sand ridge dammed this valley system, preventing southward penetration of Holocene tidal impact. Although highest sea level stands reached comparable heights during both interglacials, the most southern margin of open marine Eemian conditions was once situated about 7 km south of the most landward Holocene coastal barrier system (figure 3c). This explains the rather restricted area with preserved Eemian intracoastal marine deposits contrary to the Holocene intracoastal extension corresponding to 95 % of the present-day coastal plain.

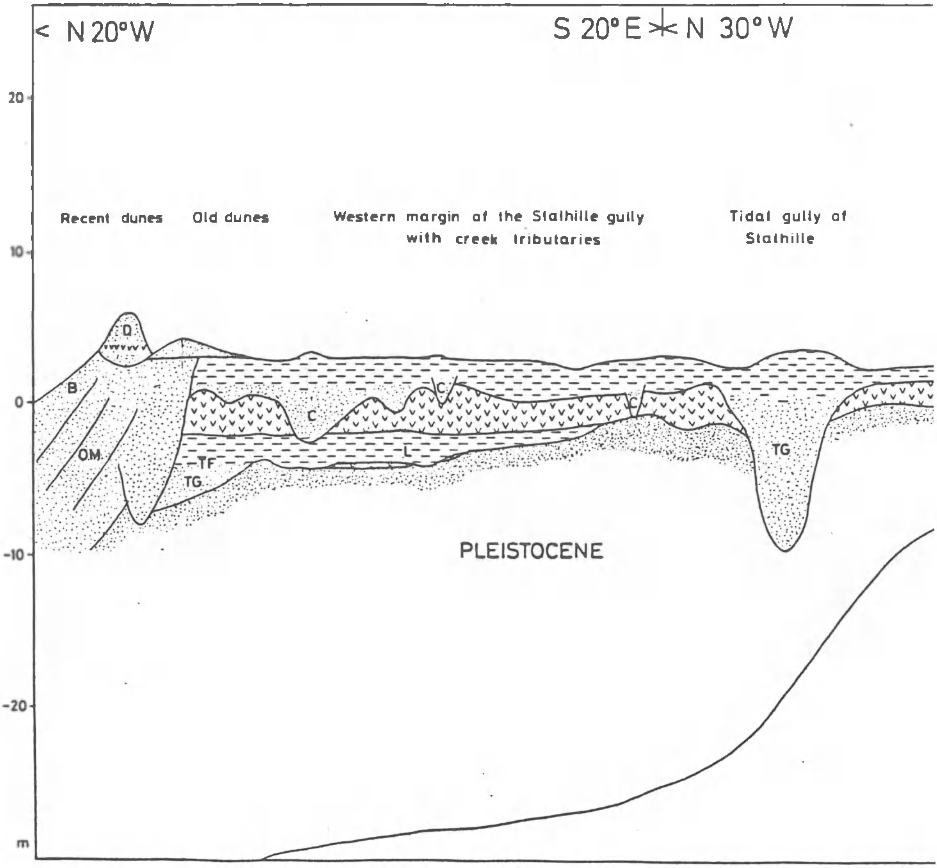
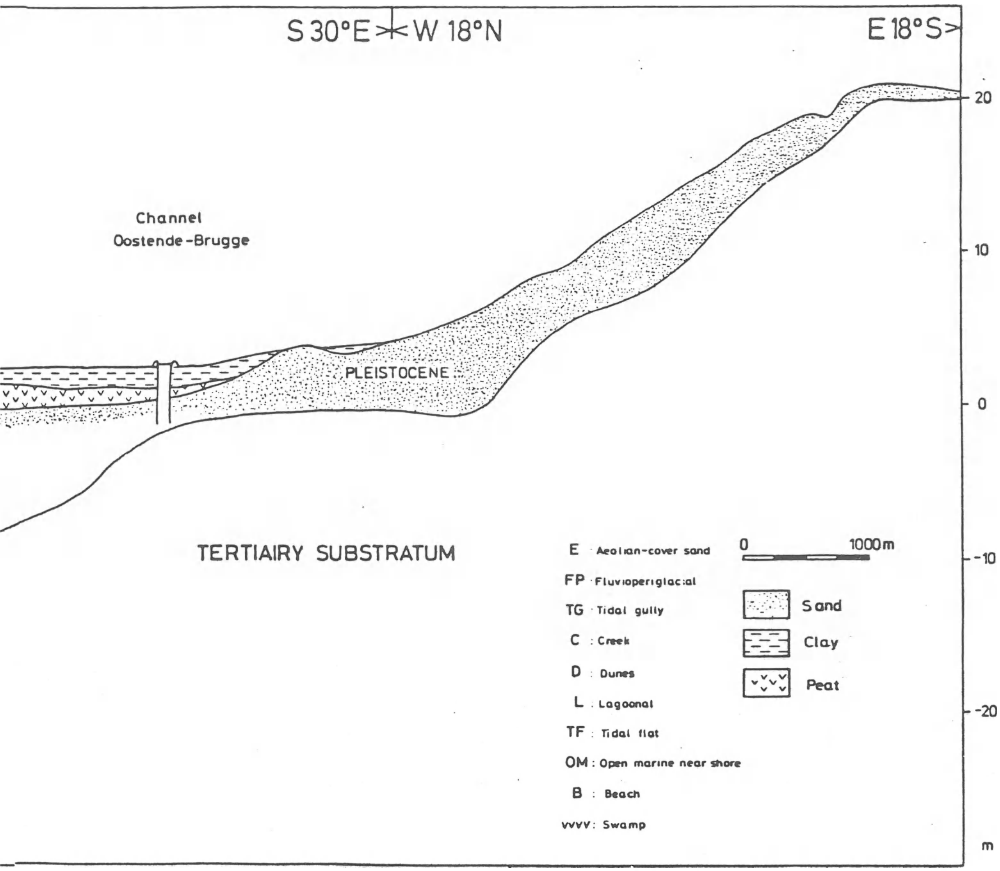


Figure 2a Holocene sequences.



S 30°E
W 18°N
E 18°S
Channel
Oostende-Brugge
PLEISTOCENE
TERTIAIRY SUBSTRATUM
20
10
0
-10
-20
m
E : Aeolian-cover sand
FP : Fluvioperiglacial
TG : Tidal gully
C : Creek
D : Dunes
L : Lagoonal
TF : Tidal flat
OM : Open marine near shore
B : Beach
vvvv : Swamp
0
1000m
Sand
Clay
Peat

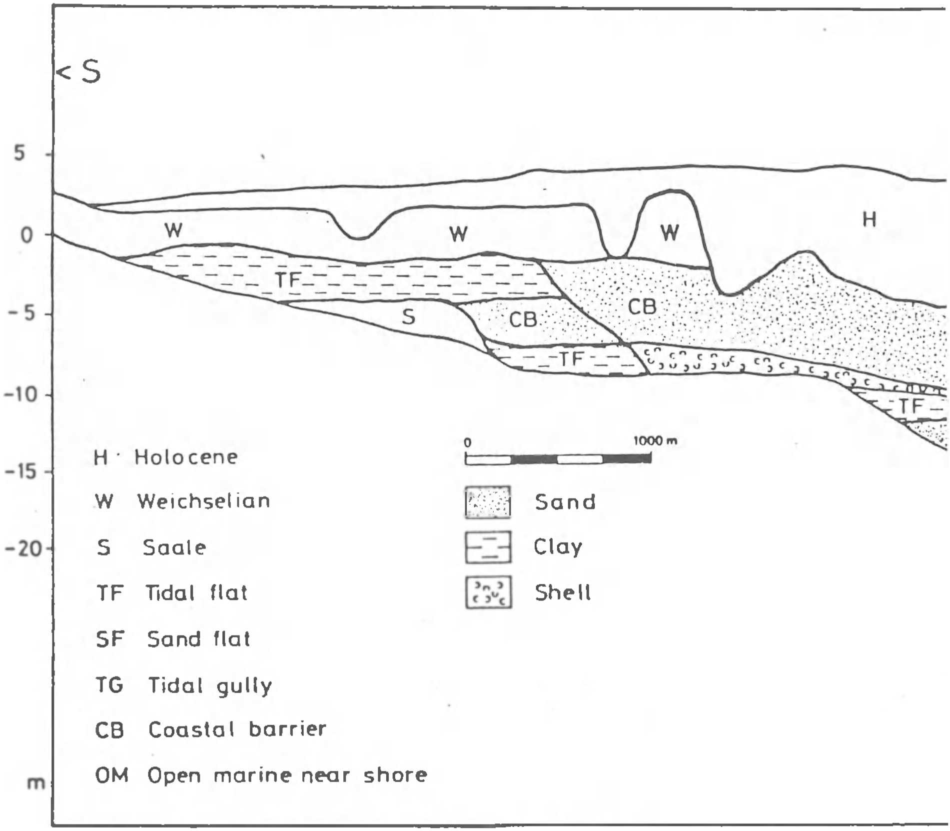
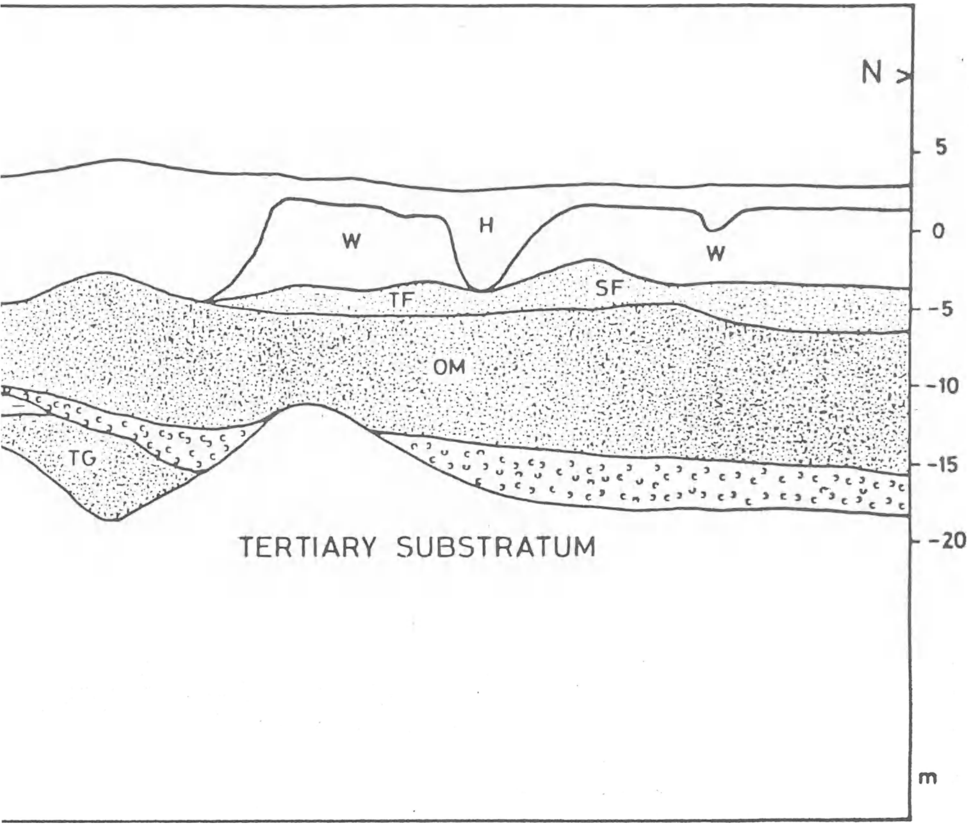


Figure 2b Eemian sequences.



N >
5
0
-5
-10
-15
-20
m
W
H
W
TF
SF
OM
TG
TERTIARY SUBSTRATUM

The synthetical sections (figures 2a and 2b) illustrate the stratigraphical position of the lithological sequences with the interpretation of the corresponding environmental conditions. In this part of the Belgian coastal plain, the thickness of the Eemian remnants is far more important than that of the Holocene strata. The Eemian layers form a wedgelike sedimentary body which thickens to the north. The northward thickening Holocene layers show important irregularities corresponding to tidal gully infillings and to the Upper Holocene beach and nearshore deposits.

Contrary to the Holocene sequences little or no important tidal gully deposits could be traced in the Eemian intracoastal area. The most important Eemian tidal gully corresponds to the Eemian estuary of the Reie-Waardamme river (figures 1 and 3a). Most of those sandy gully infillings were more susceptible to erosion during the Weichselian period than the surrounding clayey mudflat deposits. Therefore the deepest Weichselian river incision corresponds more or less to the course of an Eemian tidal channel in so far that nowadays little marine gully sediment is left in situ. The Weichselian fluvioperiglacial sandy sediments contain reworked marine mollusc shells which originate from the Eemian tidal channel and tidal flats.

The intracoastal Holocene sequence is characterized by an alternation of peat and tidal flat deposits, while extended Eemian peat layers are almost lacking. Rather thick Eemian mudflat sequences are found, showing continuous tidal flat conditions during sea level rise. Remnants of Eemian coastal barriers, important enough to prevent the area from tidal action have not been detected, while Holocene coastal barriers protected the hinterland temporarily to such an extent that swamps could develop. The absence of dune remnants in the presumed coastal area of the Eemian period might give an extra indication of the poorly developed coastal protection in comparison with the existing Holocene one, even during active transgression phases.

During the Eemian, the region of Brugge was characterized by an exposed tidal flat merely protected by low beach ridges comparable with the present-day German Bight conditions (REINECK *et al.*, 1968), while the conditions during the Late Holocene transgressive phases resembled present-day Wadden Sea conditions with larger tidal range however. During peat development and during the so-called Subatlantic (Late Holocene) regressions the coastal barrier system was nearly closed.

RECONSTRUCTION OF THE LANDSCAPE EXISTING BEFORE THE LATE QUATERNARY MARINE INGRESSIONS

The palaeorelief which got influenced by the Eemian transgression was totally different from the Early Holocene landscape. This explains the major differences of the areal and vertical distribution pattern of the Holocene and Eemian sedimentary environments. The Eemian marine ingression attacked regressively on old, partly infilled valley system. As soon as sea level reached -13 m OL (OL = Ostend Level), tidal flats already developed in the immediate surroundings of Brugge (figure 3a).

Holocene tidal deposits came into existence on a palaeosurface of Weichselian fluvioperiglacial deposits covered with a thin coversand sheet and with east-west orientated coversand ridges. This seaward dipping topography was lying high enough to prevent the largest part of the eastern coastal plain from marine influence until the Dunkerquian I flooding (2500 BP).

The pre-Eemian landscape

A geomorphological map of the basal surface of the Quaternary deposits is presented (figure 4) indicating the morphography, the genesis and the age of the dominant erosion phases. The pre-Eemian morphology is partly reflected in the palaeosurface of the base of the Quaternary. Before the Eemian transgression reached the area of Brugge, a valley and interfluvium morphology existed. This morphology is more or less preserved in the southern part of the studied area. In this region only minor modifications of the erosion surface at the top of the Eocene sediments have taken place due to Eemian and Holocene tidal gully erosion or due to Weichselian fluvioperiglacial phenomena and mass movements.

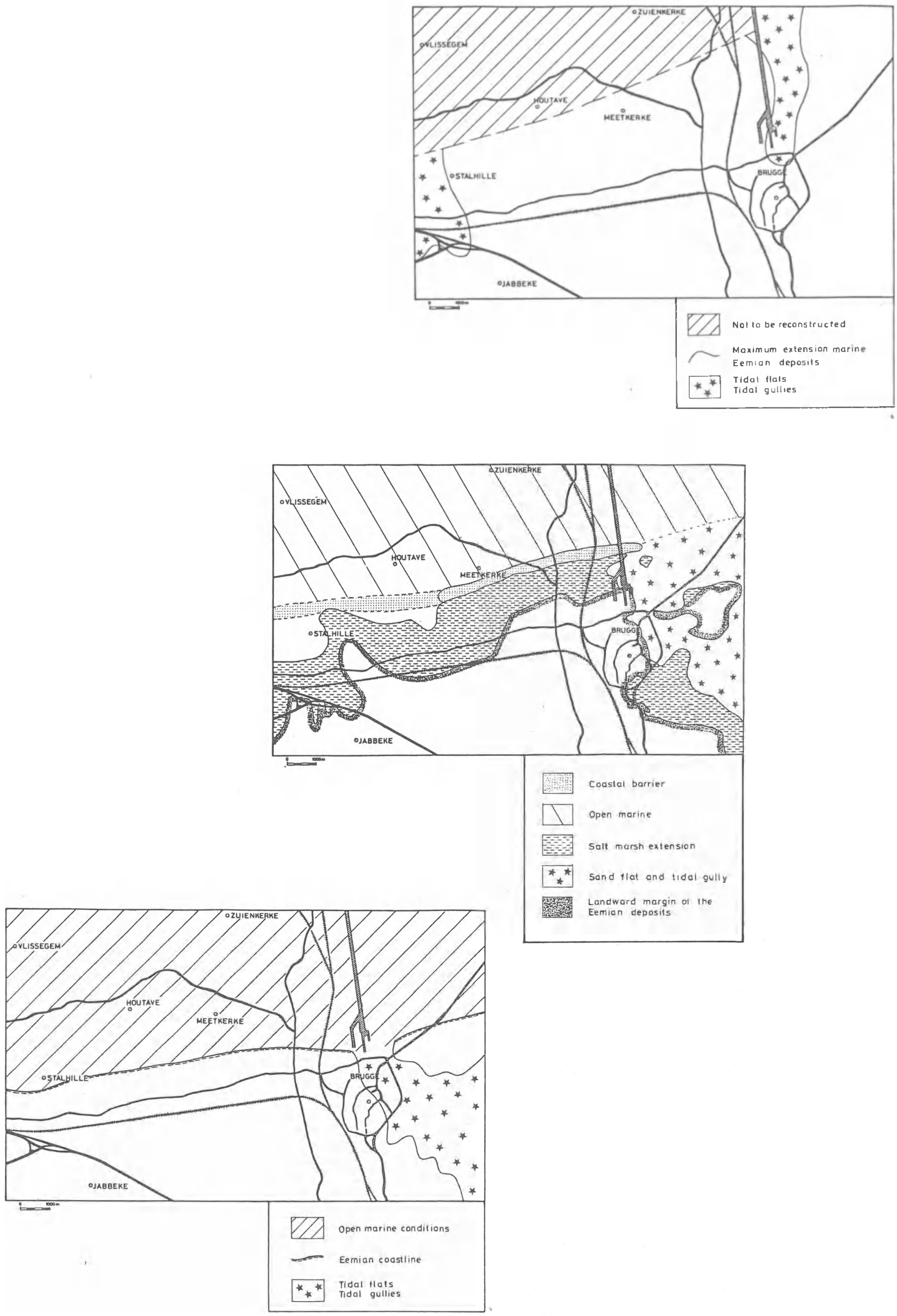


Figure 3 **a.** Sea level -10 OL.
b. Sea level -5 OL.
c. Eemian highest sea level stands.

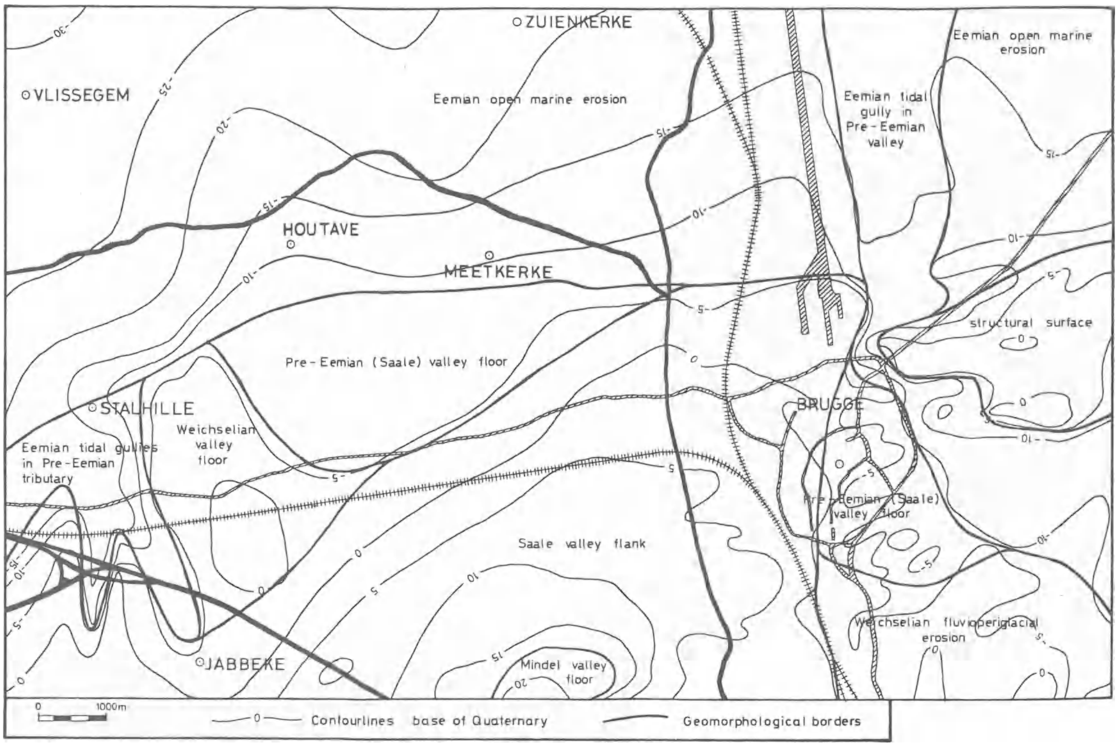


Figure 4 Geomorphology of the surface at the base of the Quaternary.

The Quaternary erosion phases have been conditioned by the lithological characteristics of the Tertiary substratum (figure 5). This substratum consists of slightly northeasterly dipping (1 %) alternating clay and sand units of some 5 to 20 m thickness each. The hills to the southwest of Brugge (St.- Andries), reaching an elevation up to 20 m OL were protected from fluviatile erosion by a semi-continuous sandstone layer which covers rather erosion-sensitive sands. Southeastward of Brugge (Oedelem), resisting Bartonian clay layers occur giving rise to a scarp-like landscape. To the northeast of Brugge (St. Kruis) Upper Paniselian shell layers with intercalated sandstone levels could not be removed by fluviatile nor by marine erosion.

Apart from the Waardamme Valley, a smaller pre-Eemian river system existed to the west of Jabbeke and Stalhille. This valley incision lays in front of a now buried cuestalike ridge formed by a 8 m thick clay layer (Merelbeke clay). This river system came into existence before Eemian marine ingressions reached the area after the general northward dipping slope of the Tertiary substratum already existed.

Both the Waardamme and the Jabbeke Valleys are tributaries of a larger valley system running parallel to and underneath the present-day coastline (the Ostend Valley). This palaeovalley runs about perpendicular to the strike of the slightly northeast dipping Tertiary layers. To the west, the valley joins an analogue valley underneath the western coastal plain. This buried valley system found its way to the North Sea area northwesterly of Ostend (MOSTAERT *et al.*, this volume). The relationship of this pre-Eemian valley system with the Flemish Valley, situated further to the east is not clear yet.

The map (figure 5) combining the Tertiary lithology and stratigraphy with the topography of the base of the Quaternary shows that the Waardamme river found its way to the north eroding sands (Vlierzele sand), sand-clay layers (Oedelem-Beernem-Aalter sands) and clays (Bartonian, Asse clay). This river axis followed a pre-Holsteinian consequent river direction. Further south of Oedelem, the Waardamme river system has a subsequent orientation. The localization of a consequent river system in the surroundings of Brugge breaking through the Bartonian cuesta is made possible by lithological facies changes and geometrical changes within the Bartonian layers.

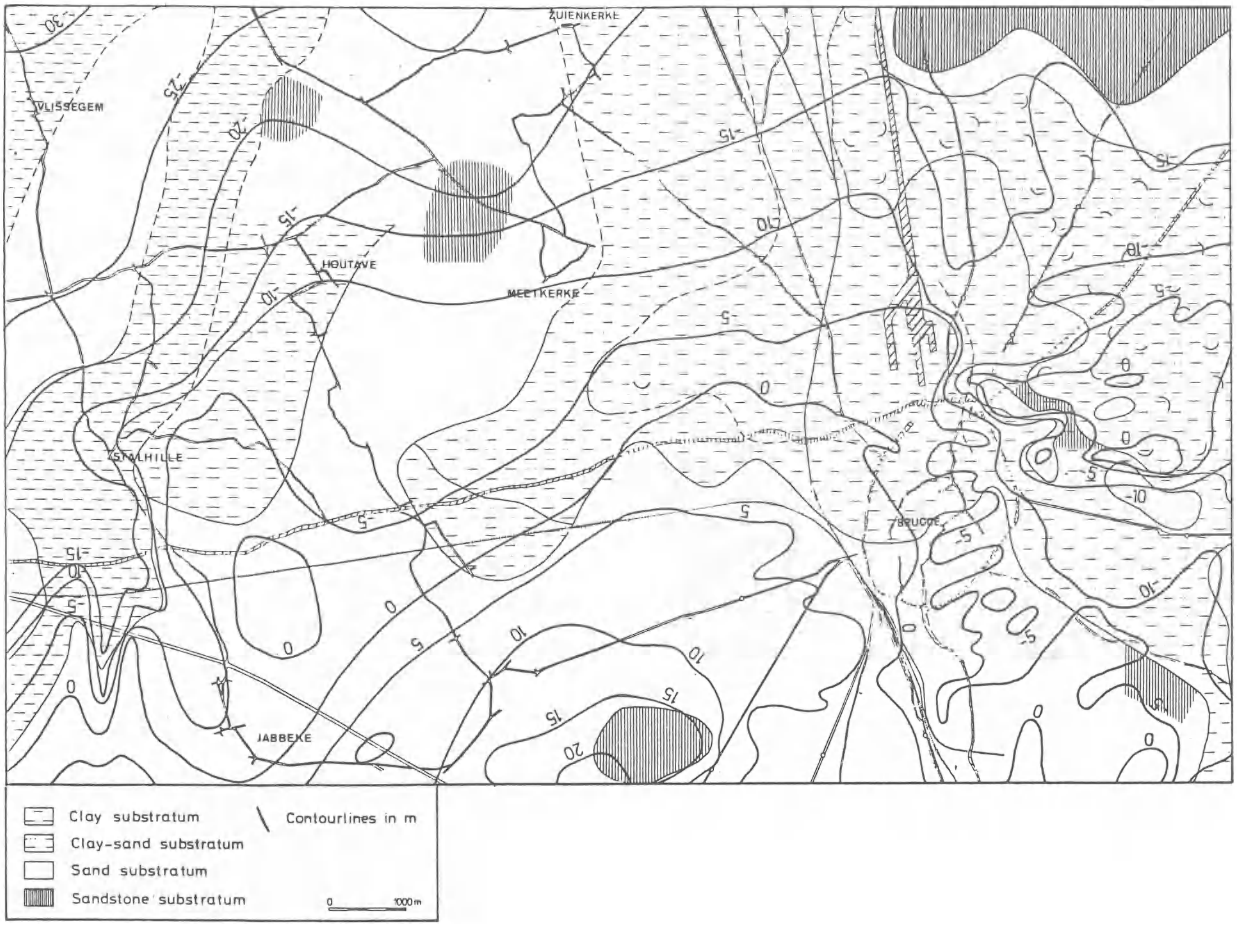


Figure 5 Lithology of the Tertiary substratum and base topography of the Quaternary.

The part situated higher than -7 m OL existed before the Eemian sea reached the area. Originally it corresponded with what was the southern flank of a Saalian river system. During the Eemian and especially during the Weichselian period only slight modifications of this slope occurred due to mass movements and cryoturbations. Below -7 m OL Eemian erosion deepened and steepened the original Ostend Valley. As no Saalian sediments have been found below -7 m OL in the Waardamme tributary and in this part of the Ostend Valley we suspect marine Eemian erosion to have deepened this area from -7 m to more than -20 m OL. The area where Eemian salt marsh deposits immediately covered the pre-Eemian sediments without previous marine erosion prove that minimum incision depth of the pre-marine fluviatile landscape was at least -7 m OL.

The pre-Eemian landscape of the southern part corresponds approximately to the erosion surface of the base of the Quaternary. The existing older Quaternary deposits consisted of thin fluviatile valley infillings. In the area considered, the net effect of the Saalian period was lowering by erosion. Early Eemian fluviatile action might as well be responsible for the modelling of the erosion relief on which marine sediments came into existence.

Eemian tidal impact first occurred in the Waardamme Valley by regressive tidal gully erosion. Tidal gully erosion caused overdeeping of the original valley which allowed later tidal flat deposition at levels beneath the pre-marine valley floor level.

The palaeomorphology at the beginning of the Holocene

A detailed geomorphological map of the base of the Holocene deposits has not yet been achieved : a conceptual framework is presented on figure 6. This map illustrates the basal surface of the main Holocene peat layer which corresponds to the base of the Holocene except for the dotted area (figure 6) where older marine Holocene tidal flat and lagoonal deposits exist. Three main zones can be distinguished :

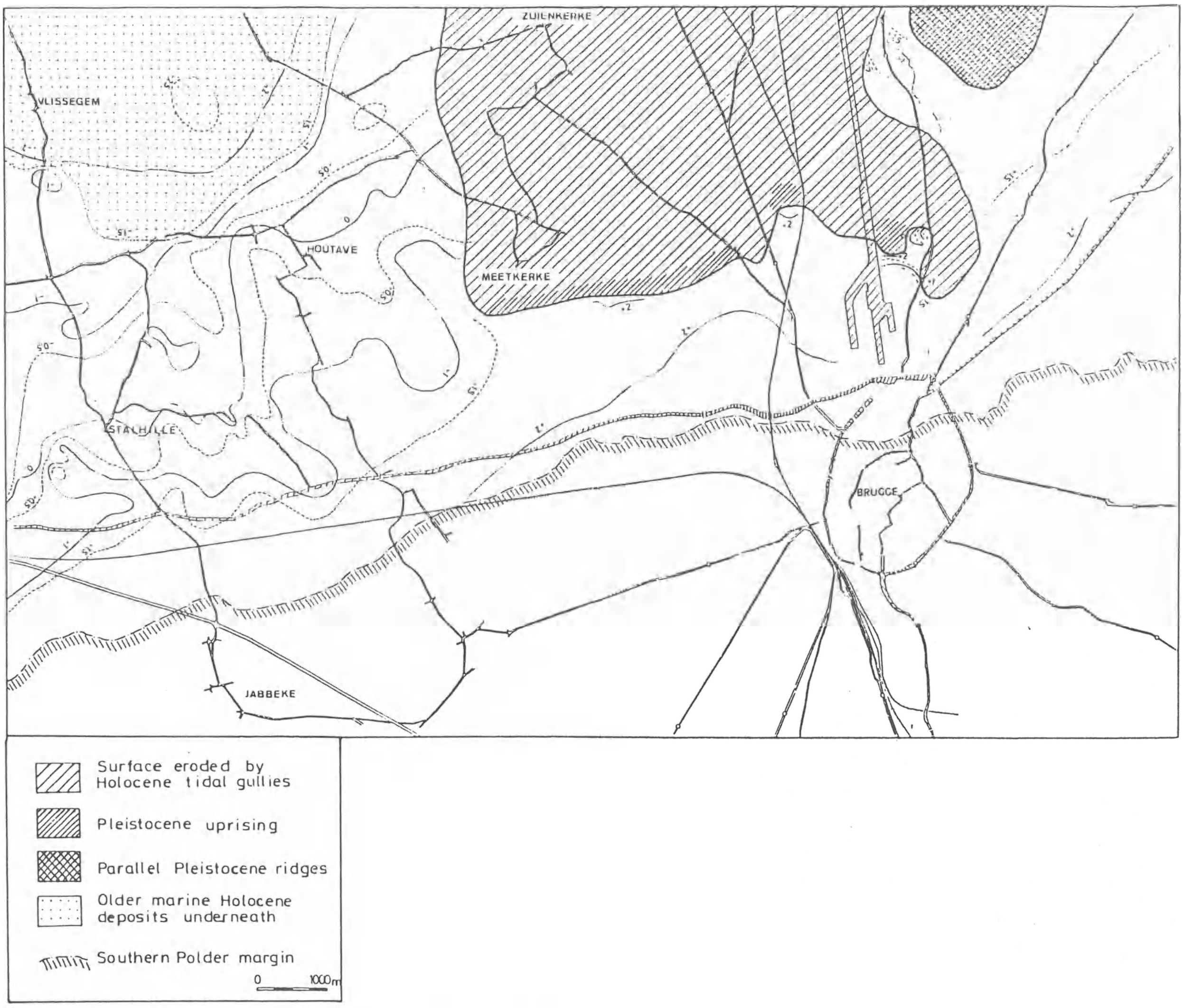


Figure 6 Base of the main peat layer. Reconstruction of the Pleistocene substratum.

- The area where Holocene phenomena were restricted to soil formations.

  This zone is bordered to the north by the coastal plain. It consists of an outcropping coversand ridge running east-west and it is merely interrupted by the small river system of Brugge, the relict of the large Weichselian Waardamme river.

- The region where the Late Weichselian landscape is preserved underneath a Holocene cover.

  Most of the times this Pleistocene substratum is covered by peat and/or salt marsh deposits. Often the pre-existing Early Holocene soil profile is preserved underneath the cover. Where older profile Holocene marine deposits occur underneath the main peat layer (dotted area on figure 6) the original Late Weichselian landscape is still intact as well.

- The area where former Holocene, laterally migrating tidal gullies or coastal processes shaped the Late Pleistocene palaeosurface.

The first two zones allow to reconstruct the Early Holocene landscape which did not change until marine influences reached the area or until peat growth started. It was a rather flat, slightly seaward dipping fluvioperiglacial surface. Southward, flat and low aeolian ridges with east-west orientation existed (e.g. north of the Moeren of Meetkerke), culminating in the most important ridge Gistel-Brugge-Stekene. This large ridge is a combination of several subridges with interjacent depressions. Microridges and depressions with wavelengths of 100-200 m and height differences of less than 2 m are found north of Dudzele and in Zeebrugge. In this landscape the unimportant Waardamme River system found its way to the north. The incision depth since 5600 BP was never below +3 m in Brugge and -2 m in Zeebrugge.

The rather flat and rather high lying surface of the Pleistocene substratum was extremely favourite for peat development due to rising water table conditions associated with sea level rise. Before 5600 BP, tidal impact only reached the extreme western part of the eastern coastal plain. There, tidal flat and lagoonal conditions existed. Extensive peat growth started from 5600 BP, which is obviously earlier than in the western part of the coastal plain. While sea level rose, peat development penetrated further to the south reaching about the present-day coastal plain border. Generally speaking, the eastern coastal plain is not flooded before 2500 BP, when mean sea level reached at least 0.5 to 1 m OL. This Subatlantic transgression occurred on a very flat peat landscape reaching top levels of +2 m, exceptionally up to 3 m OL. It can be proved that tidal action did not disappear from the coastal plain since 2500 BP until medieval reclamation. The Roman regression corresponds with local enlargement of the salt marsh area. Salt water influence still reached the southern border of the coastal plain. A post-Roman enlargement of some gullies could be derived from the sedimentary record, while other tidal gully systems did not change at all.

SEA LEVEL CHANGES

Both the Holocene and the Eemian sedimentary layers came into existence under varying sea level conditions. The relative elevation and stratigraphical position of mudflat and salt marsh deposits, of coastal plain peat layers, of subtidal and intertidal open marine and intracoastal facies, were the major criteria for Eemian and Holocene sea level reconstruction. Far more detailed sea-level studies can be produced for the Holocene sequences while absolute ^{14}C-datings of sea level indicators are potentially available because of the appearance of peat and shell layers corresponding to critical levels. Here, abstraction is made of the absolute datings and the same interpretation method was applied for both the Holocene and Eemian sequences of the study area. Figure 7 confronts Holocene and Eemian sea level interpretation of the area. The interpretation of the Eemian sea level indicators is based on assumptions of tidal range possibly varying between 2.5 and 5 m. The assumed Holocene tidal range is an extrapolation of the present-day range (± 4 m). Eemian sequences indicate at least one sea level lowering during the period of Eemian highest sea level stands. This lowering is deduced from the immediate superposition of subtidal open marine sediments by supratidal salt marsh deposits indicating important sea level lowering and seaward migration of the coastal barrier system (MOSTAERT and DE MOOR, 1985). Only minor sedimentary indications are left of the definitive sea level retreat at the end of the Eemian interglacial period.

Sedimentological, stratigraphical arguments and absolute datings cannot prove the existence of general sea level lowering during the Holocene. Palaeogeographical changes as the general appearance or disappearance of swamp conditions giving rise to peat layers, so-called regression and transgression phases can all be explained without the necessity of accepting real sea level changes. Local fluctuations of the tidal levels within the tidal flats itself might have occurred due to a combination and interaction of factors which are all related with the changing flood basin morphology. The flood basin effect certainly makes sea level interpretation of intracoastal zones very difficult as it can be very important (up to 2 m in the estuary of the river Scheldt, cf. KIDEN, this volume). The flood basin effect changes in time and is influenced by a number of factors, e.g. by tidal gully infilling or enlargement, differential sedimentation and erosion. The flood basin effect influences these sedimentation levels which are important high water indicators (e.g. the top of salt marsh deposits). The cyclicity of the so-called Dunkerque transgressive phases and their appearance over larger areas seem to indicate the control of a general process like sea level changes. However, the sedimentary sequences of the eastern coastal plain cannot entirely prove a general flooding at once in distinct transgression phases and even if so, other long-run mechanisms than sea level changes could have controlled the mechanism : open marine sediment dynamics, coastal dynamics, tidal range changes. Earlier investigations might have confused local gully development or successive gully shiftings with transgressions.

No such small-scale palaeogeographical changes due to minor high water level changes and corresponding with varying flood basin effects could be traced in the Eemian sequences. This is probably due to the exposed character of the area.

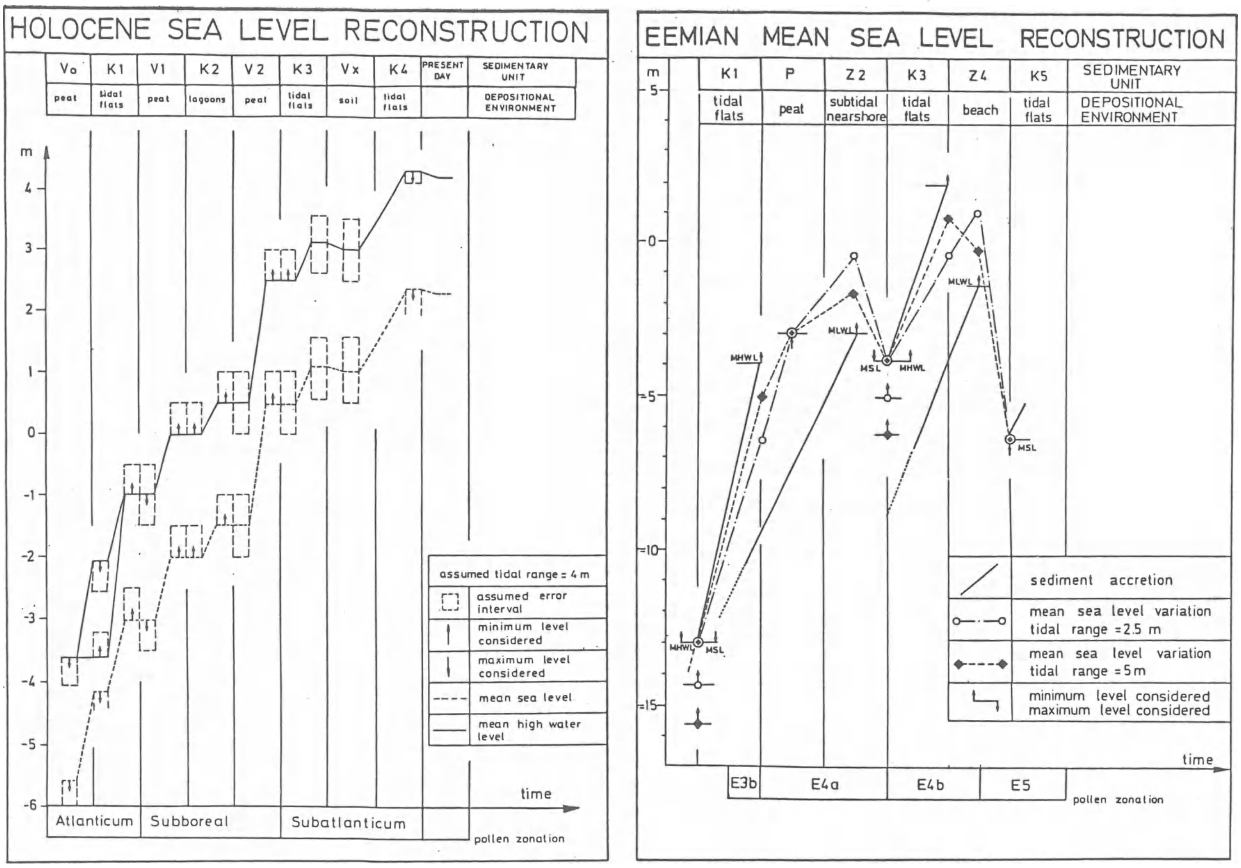


Figure 7 Sea level reconstruction.

CONCLUSIONS

The Eemian and Holocene sequences show important differences indicating different palaeogeographical conditions. These differences are highly conditioned by the existing landscape before the marine ingressions.

Another important factor with consequences for the variable palaeogeographical conditions is the appearance of the coastal barrier. During the Holocene a protecting coastal barrier system existed allowing peat development in the hinterland while the poorly developed Eemian barriers implied continuous tidal action.

The palaeogeographical consequences of a net sea level lowering during the Eemian could be detected and compared with Holocene transgressive and regressive effects which did not necessarily correspond with real sea level fluctuations.

The stratigraphical and sedimentological approach, the inventory of the facies, allowed to reconstruct sea evel and coastal migration for regions and for sequences of which no absolute datings are available.

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