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EEMIAN DEPOSITS IN THE NEIGHBOURHOOD OF BRUGGE : A PALEOGEOGRAPHICAL AND SEA LEVEL RECONSTRUCTION

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INTRODUCTION.

In the neighbourhood of Brugge, Eemian deposits form an important part of the Quaternary sediments. Continental and marine Eemian deposits have been found underneath fluvioperiglacial Weichselian sediments or immediately underneath Holocene tidal gully infillings (fig. 1), locally burdening continental quaternary pre-Eemian deposits.

Some excavations have been studied in the area in great detail (see ref. 4, 5, 7, 10, 11, 15). Much less, however, is known about the threedimensional distribution pattern of the Eemian strata and about their detailed local lithostratigraphy. In the last few years a large number of borings were made and new excavations were studied which provide a more distinct picture of the successive Eemian layers.

This paper deals with the geographical and chronological changes in depositional sedimentary environments during the Eemian interglacial and with the major factors and processes commanding these depositional variations. Following major aspects have been studied : the recognition and definition of the Eemian deposits, the identification of the sedimentary environments and the analysis of the lateral and vertical distribution pattern of the sedimentary units.

Hence it becomes feasible to elaborate the paleogeography and its evolution, taking into account sea level changes and its effects on deposition and on coastal barrier migration, and the impact of tidal action on a small valley system.

METHODOLOGY.

The identification of the sedimentary depositional environments is based on comparison with present day active sedimentation areas and with comparable Holocene deposits.

The most important criteria used for recognition are : granulometric characteristics, mollusc shell assemblages, sedimentary structures, the geographical position and extension, and some palynological indications. Full diagnosis however depends on a combination of these characteristics. A synthesis of the main characteristics for identification of the subenvironments as well as one of the stratigraphical position of the strata is given in table 1.

Any such stratigraphical unit is known by a symbol comprising a lithological indication (Z for sand, K for clay, P for peat) and by a number being the stratigraphical indication Z 0 the older, Z 5 the younger unit). Deposits of marine offshore and litoral environments have been found : coastal barrier deposits, intracoastal marine sediments (tidal flats), beach deposits.

For the interpretation of mollusc shell assemblages, the various species have been grouped according to VAN STRAATEN L. M. J. U. (1965). Two supplementary groups had to be defined in order to take into account local and specific Eemian biocoenosis (group 7-8, table 2). Analysis of the group percentages results in a number of typical associations whose importance as well as the occurence of specific groups reflect paleoenvironmental conditions.

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TABLE 1 : Identification subenvironments : synthesis characteristics

Layer	(base/top levels) m.o.P.	Biocoenosis	Granulometric characteristics	Sedimentary structures	Paleo - environment
Z 5	(-7.0/>-2.0)	5 6 3	fine , medium sands	unknown	sand flats/tidal gullies
K 5	(-7.0/-4.0)	(6) 5 4	clay and loam	tabular fine laminations	mudflats
Z 4 s	(-2.0/>+1.0)	5 2 3 6 7	medium sands shell layers	cross-bedding complex	beach/shore
Z 4 c	(-14.0/-1.0)	5 2 3	shell poor fine silty sand - clay lamination	unknown (except tabular clay lamination)	offshore
Z 4 m	(-17.5/-3.0)	(2) 5 4 (1)	shell bearing fine sands clay intercal ations	unknown tabular clay lamination	offshore
K 3 '	(-1.0/+2.0)		clay with humic inter- ca lations	tabular homogeneous	marshes/swamps
K 3	(-4.0/+1.0)	(6) 5	clay	tabular	mudflats
P	(-3.5/-3.0)		peat	- - - - -	swamp
Z 2 s	(-8.0/-5.0)	(7) 2 5	medium sands, muddy fine sands, shell accumulation	unknown	sublitoral/near shore upper offshore / shoreface
Z 2 N	(-16.0/-8.0)	upperpart : 5 2 7 lower part :(8)5 7	shell accumulations coarse sands	unknown	lower offshore
K 1 s	(-8.0/-4.0)	(6) 5	clay - loam	homogeneous tabular	mud flats marshes
K 1 n	(12.5/-4.0)	(6) 5	clay layers (heavy)	tabular	mud lats/marshes
Z 0	(-18.0/-12.0)	(5) 8 3	fine and medium sands coarse elements : marine shells	unknown	tidal gully / sand flat

OPEN SEA DEPOSITS			INTRACOASTAL DEPOSITS	
NEAR SHORE ON SHORE	SUBLITORAL NEAR SHORE	ALONG THE COAST OFF SHORE	TIDAL FLATS/ESTUARIES/LAGOONS	HIGHEST PART OF TIDAL FLATS
1. Spisula subtruncata Spisula solida Spisula sp.	7. Amygdala aurea Amygdala decussata Nassarius reticulata Bittium reticulatum	2. Mactra corallina Donax vittatus Abra alba	4. Mytilus edule	6. Scrobicularia plana Cardium glaucum Hydrobi a ulvae Hydrobia sp.
3. Macoma balthica Barnea candida			3. Macoma balthica Barnea candida	
5. Cardium edule		5. Cardium edule		
OLD TERTIARY DEPOSITS (reworked) 8. Cardita planicosta Turitella solanderi				

Based on VAN STRAATEN L.M.J. U (1965).

TABLE 2

Table 1 provides a classification of the three most important groups, the specific groups are put between brackets. Interpretation is based on the assumption that Eemian and Holocene mollusc shell assemblages have comparable ecological meaning. However important similarities and differences have already been noticed (NOLF, D., 1973; SPAINK, G., 1958). Very striking for the Eemian deposits are the little importance of Spisula sp. and the occurence of characteristic species e. g. Amygdala aurea var. eemiensis and Cardium exiguum in some separate layers.

An indirect method is used to reconstruct sea level changes based on the relationship of the facies of the sediments to the sea level at the time of their formation.

Mudflat and saltmarsh deposits are used as paleogeographic indicators (K1, K3, K5). These sediments occur above mean sea level. Due to different factors such as compaction, tidal range, etc... that level can be underestimated by a value up to several meter. Underestimation due to compaction depends on the thickness and the lithology of the sediments.

Peat layers are important sea level indicators in coastal Holocene sequences. Although the relation ground water level - sea level is debatable, especially in the immediate neighbourhood of an uprising hinterland (JELGERSMA, S., 1979) it may be assumed that in coastal marsh regions ground water levels correspond to mean sea level. Near Brugge only very locally Eemian peat (P) has been noticed immediately overlying older deposits (PAEPE, R., *et al.*, 1972). This layer corresponds to a mean sea level of about -3m Z.0.*

Beach deposits (Z4s) indicate intertidal circomstances. It is very difficult to identify the subtidal - intertidal boundary, as well as the exact position of the beach sediment in relation to the mean low water level even in excavations (BEETS, D. J., ROEP, T., DE JONG, J., 1981). High water levels were not recognisable by such deposits because of later erosion; dune belts were not found either. As tidal amplitudes during the Eemian are assumed to vary between 2,5 m and 5 m, the error made by deriving mean sea levels from beach deposit levels varies between 1 and 3 m.

Different sublitoral deposits have been found (Z2s, Z4c, Z4n) on ground of typical mollusc shell assemblages (NOLF, D., 1973, DE MOOR, G. en DE BREUCK, W., 1973). The highest position of sublitoral deposits is considered as the minimum low water level implicating minimum sea levels between -1,5 m and 0,0 m Z.0. for sedimentary unit Z2s.

Morphological characteristics of river channels and river patterns allow to situate the upstream limit of tidal influence. Upstream that point the thalweg quickly rises above high tide level. Tidal gullies and perimarine rivers are characterised by important vertical erosion during their formation. These thalwegs do not distinctly indicate any sea level position although gully infillings may provide an idea of the tidal range. A synthesis of sea level reconstruction is indicated in figure 2. For mudflats and salt marshes sediment accretion is shown by a full line and the lithostratigraphic top is used as mean high water level indicator. The sediment base in this environment is considered as a maximum for the mean sea level. The peat level corresponds to mean sea level. The highest values for the top level of sublitoral deposits are used as mean low water indicator. The variations of the mean sea level as indicated on figure 2 rest upon these sea level values. However, as the argument is not the mean sea level but a value too high (mud flats) or too low (nearshore deposits) its value has been estimated by substracting half a tidal amplitude for mudflat top deposits and adding half a tidal amplitude for the top levels of the nearshore deposits. Figure 2 provides two sea level curves : one for a tidal range of 2,5 m, one for a tidal range of 5 m. No quantitative reduction of the sea level has been computed for possible postsedimentary displacements of the original sedimentary reference level due to compaction (mudflats), erosion, etc...

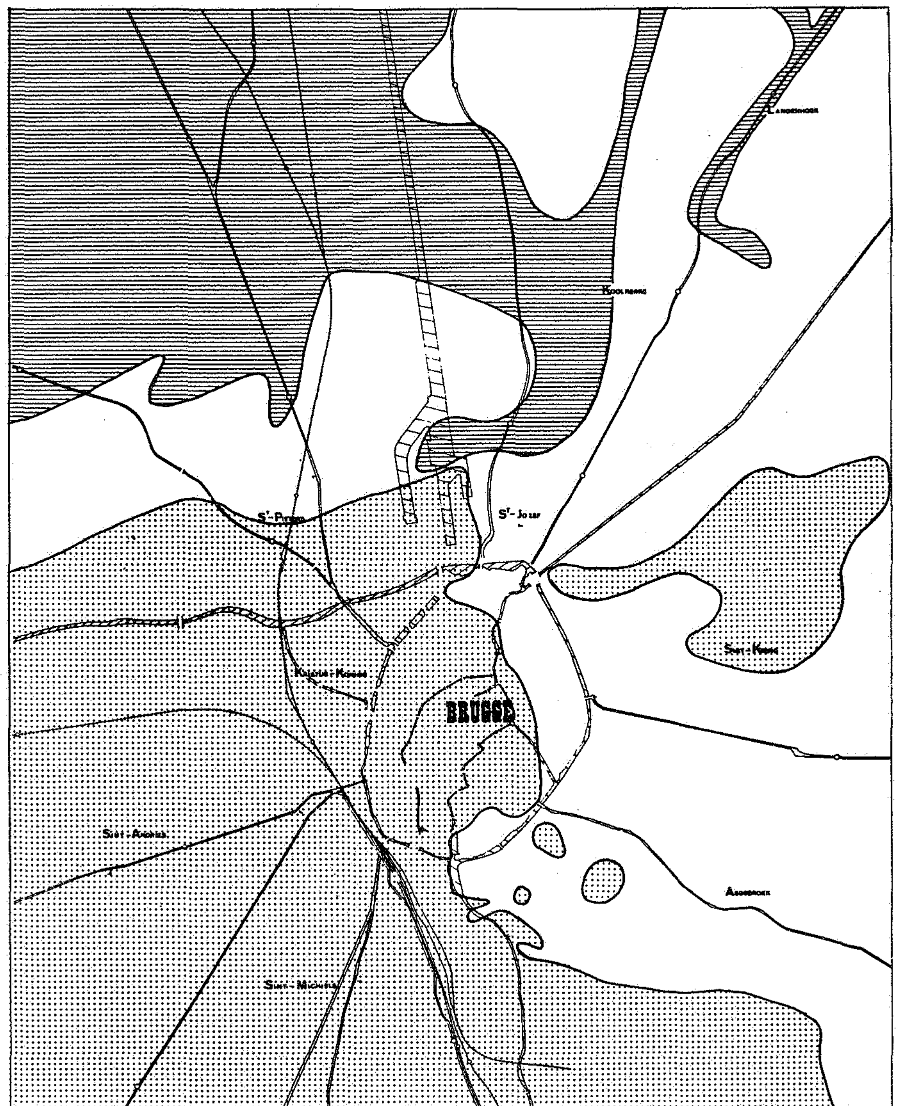
RECONSTRUCTION OF THE PALEOGEOGRAPHIC EVOLUTION.

The topography of the base of the Quaternary deposits reflects a polygenetic surface (figure 3). Before the Eemian transgression reached the area a valley and interfluvia topography was deeply cut in the Tertiary substratum mainly by fluviatile processes, partly conditioned by differential erosion with less erodible sandstone, clay and shell layers forming the interfluves. The deepest pre-Eemian scourings here occur at -12 m Z.0. These deep valleys were filled in with fluvioperiglaciaal sands and fan deposits, and eolian sediments (PAEPE, R., *et al.*, 1972). Especially in the northern part of the area the Eemian transgression developed a new topography as marine erosion preceding the landward migration of coastal barriers scoured the existing topography. Locally the tertiary substratum was deeply eroded up to levels of about -25 m Z.0. Later, the Tertiary substratum was scoured again, especially at the beginning of the Weichselian and even during the Holocene.

In the area tidal gully deposits (Z 0), mudflats and saltmarsh sediments (K1) could develop as soon as sea level reached approximately -13 m. The central valley, already existing, got under tidal influence, accompanied by a vertical and lateral enlargement of the thalweg.

Remnants of the tidal flats (K1) have been found between -13 m and -4 m proving a sea level rise between these heights, implicating the existance of a protecting barrier system more seaward. Figure 4 shows the accretion and gradual extension in that valley as expressed in the topography of the base of the tidal flats (K1). As soon as sea level reached

* Z.0. : Level of Oostende = Zéro du dépôt de la Guerre.



EXTENSION: Eemian Deposits

Continental Weichselian immediately overlying marine Eemian deposits

Marine Holocene immediately overlying marine Eemian deposits

FIGURE I

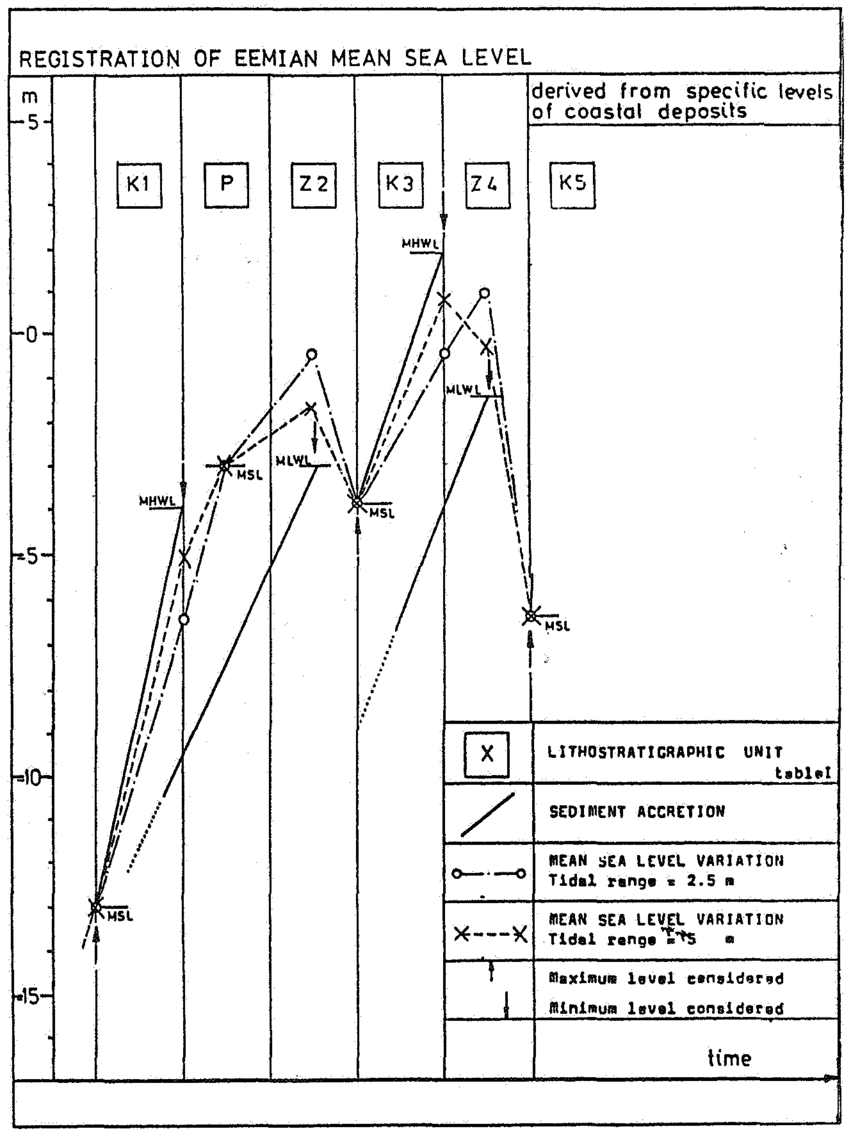


FIGURE 2

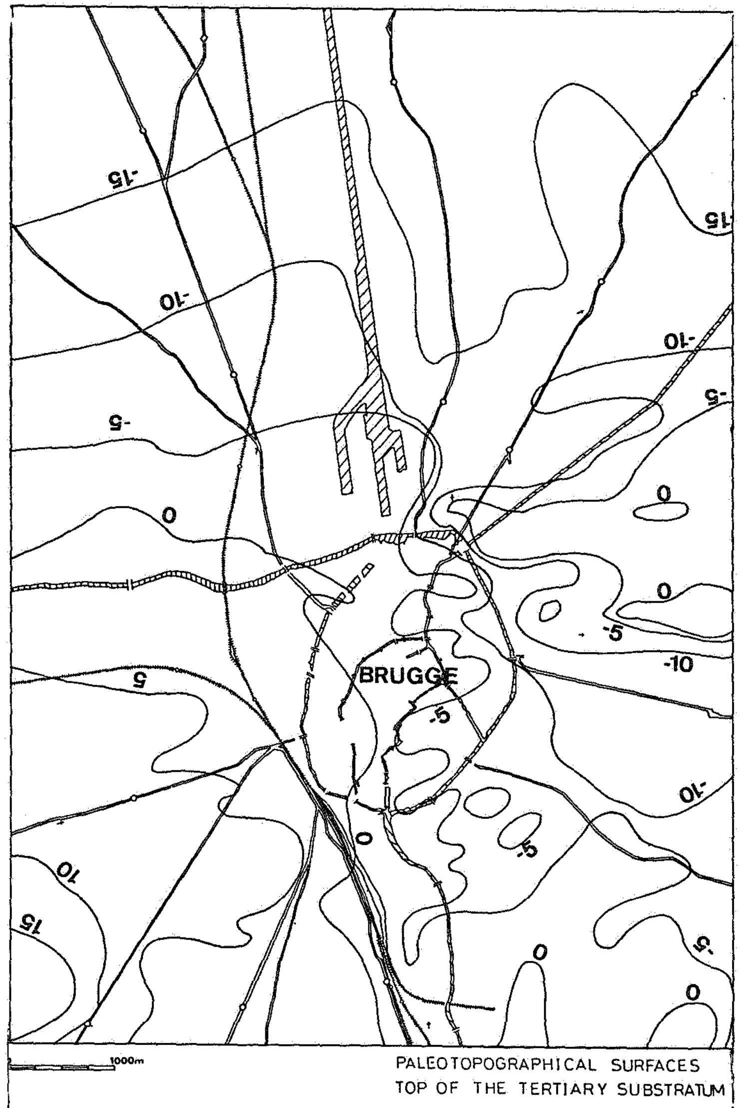


FIGURE 3

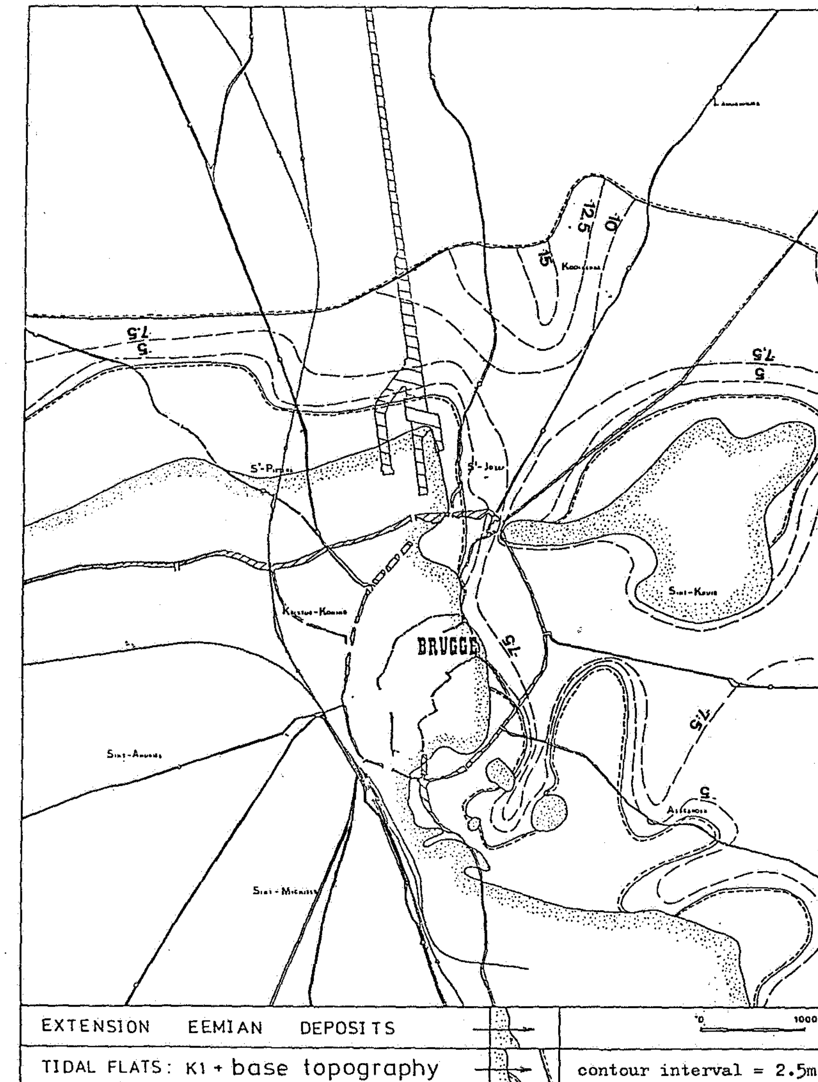


FIGURE 4

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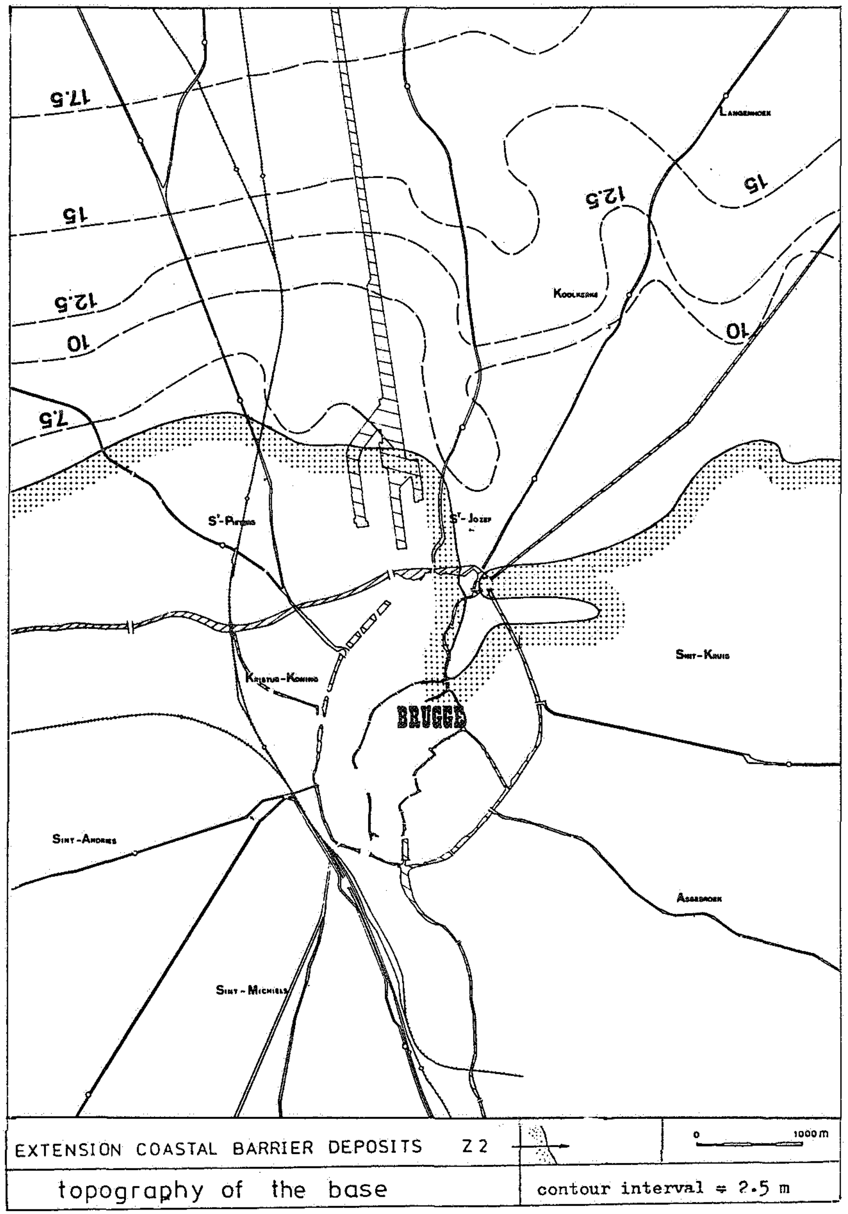


FIGURE 5

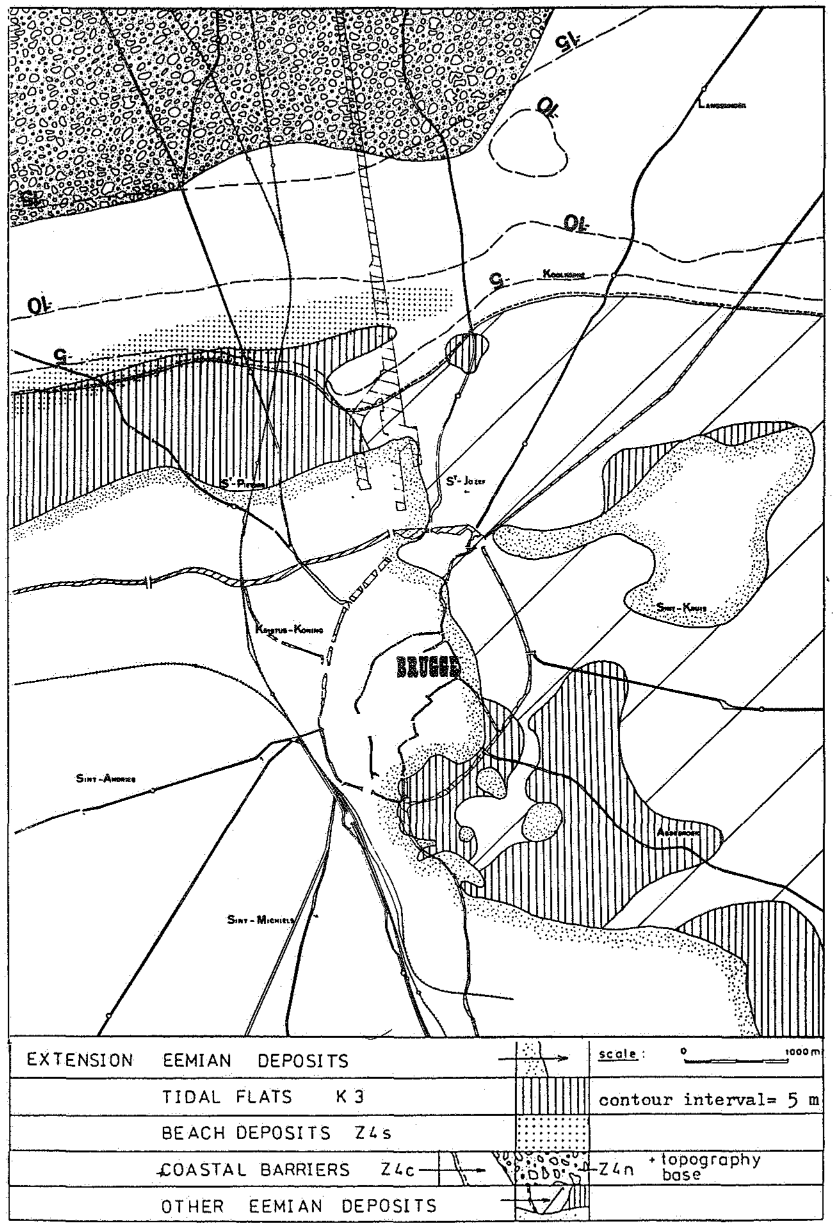


FIGURE 6

about -8 m tidal flats developed in the valley system east and south-east of Brugge causing burdening of Tertiary and older Quaternary deposits whose surface shows no evidence of previous erosion. The highest parts of the tidal flats, consisting of clay, were particularly resistant to the erosive phases by later beach migration or fluviatile scouring.

More landward soil formation took place (remnants are found between -3 and -4 m) and very locally peat could develop (P).

The coastal barrier deposits (Z2) overlying the tidal flats K1, indicate that the coastal barrier, protecting the tidal flats has migrated southward reaching this area. Its migration deeply eroded the tidal flats and older deposits. The maximum extension, corresponding to the assumed most southward coastline and the topography of the base of the coastal barrier and subtidal deposits have been drawn on figure 5. A Northward dipping coastal slope (shoreface) developed.

Nearshore and intracoastal subtidal deposits reached maximum levels of -3,5 m at Meetkerke (Z2s). The corresponding minimum mean sea level varied approximately between -1 m and 0 m. Z.0. Coastal barrier deposits and offshore sediments developed but no contemporaneous beach deposits have already been found back. The nearshore deposits (Z2s) are characterised by the appearance of Amygdala aurea. The offshore deposits (Z2n) are polygenetic sediments consisting of shell layers and coarse sands. They also contain reworked Tertiary shells and Quaternary terrace materials proving reworking of older deposits. In the southern area tidal flats still existed. To the west of Brugge the coast was very much like a mainland coast and to the east it was barrier island coast with important tidal inlets.

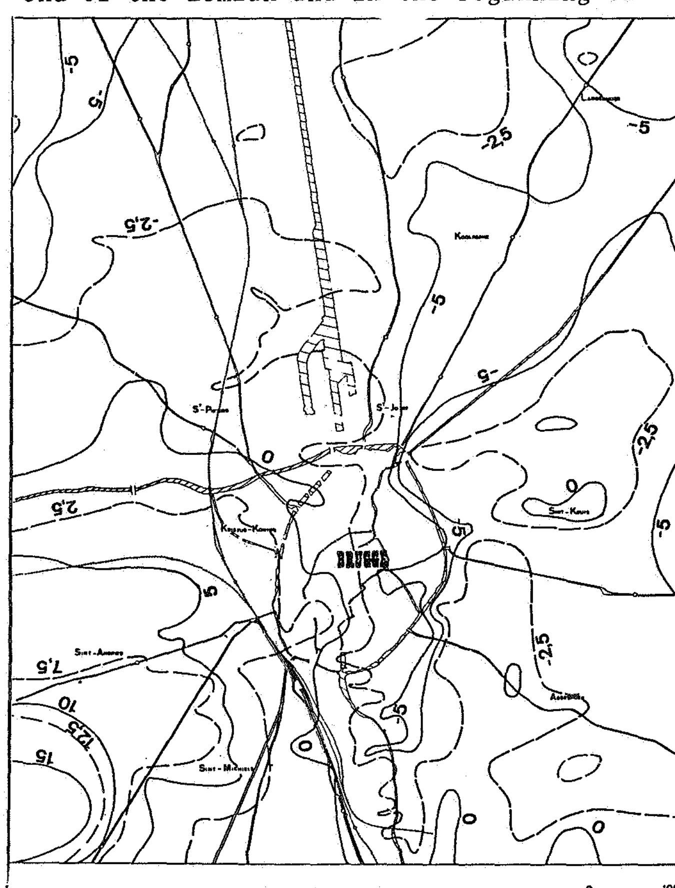
The intertidal flats (K3) at a level -4 m. Z.0. immediately overly sublitoral deposits (Z2) which elsewhere attain levels of -3 m corresponding with sea levels of 0 m. This indicates a lowering of the sea level to -4 m implicating the formation of a new coastal barrier more seaward. This lowering corresponds to a brutal change in the shell assemblage with almost a complete disappearing of group 7 which according to NOLF, D. (1973) indicated slightly warmer conditions. The poor Cerastoderma assemblage reflects much more present day or even colder circumstances. The formation of bars developping to barrier islands with superposition of sublitoral and tidal flat deposits due to new transgression after a sea level lowering has already been described in models for other regions (COLQUHOUN, D. J., 1969). The thickness of the mudflat clay layers (K3) proves sea level rise from -4 m to at least 1 m Z.0. This rise was accompanied by a new landward migration of the coastal barrier.

The sediments (Z4) consisting of three facies prove a continued seaward migration of the coastal barrier accompanied by important deposition due to regression (figure 6) :

- Remnants of beach deposits (Z4s) correspond to the most landward coastline. This shore level partly covered the tidal flats (K3) and locally eroded them (figure 6).
- The nearshore and offshore deposits (Z4c) consist of fine sands with clay lamination between -6 m and -10 m and with a poor Cerastoderma mollusc assemblage.
- Further to the north identical sands (Z4n) occur with typical coastal and open sea mollusc assemblages.

During this part of the evolution very little changed in the southern area where a large tidal flat still existed. That is shown by a continuous clay layer K3 that meanwhile developed. Distinction between K1 and K3 however is very hard. Hardly the top level K3' could be recognised. These clayey deposits contain humic intercalation with fresh water to brackish mollusc assemblage. This stresses the lowering of the sea level and the resulting change of the width of the tidal flats as well as the growing importance of river supply. These deposits have been recognised at different levels but always on top of the Eemian marine deposits showing a seaward migration in relation to the sea level fall.

In the north-eastern part tidal gully deposits and sand flats (Z5) occur with very locally some remnants of mudflats and salt marshes (K5) corresponding to sea levels between -5 m and -7 m. These facts prove that behind a coastal barrier or possibly in a river estuarium tidal flats existed. The sea level lowering at the end of the Eemian and in the beginning of



TOPOGRAPHY: - TOP OF THE EEMIAN DEPOSITS.
- BASE OF THE WEICHSELIAN   contour interval =1 m

FIGURE 7

the Weichselian stage caused quite an important erosion. The erosion basis in the neighbourhood of Brugge reached about -7 m. This is illustrated on the map of the paleotopography of the base of the Weichselian deposits (figure 7). The northwestern part however reflects later Holocene tidal gully erosion.

CONCLUSION.

This paper stresses the importance of the study of top levels of successive coastal deposits as a mean of reconstruction of the Eemian mean sea level variations. The study proves as well the great use of mollusc shell assemblages and that of sedimentologic criteria for a detailed paleoenvironmental interpretation and recognition of specific levels of coastal deposits. A model of Eemian sea level variation is presented for a relatively small area. It proves the occurrence of at least one sea level lowering during the period of Eemian highest sea level. As there is no detailed datation of these sediments, no attempt has been made for a further chronologic interpretation of these variations. The model however takes into account that the present day level as an indicator of a former mean sea level depends on the former tidal range and on postgenetic elevation changes due to sediment compaction and other reasons of soil movements.

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