LATE PLEISTOCENE AND HOLOCENE IN THE NEIGHBOURHOOD OF BRUGGE

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J. VANDENBERGHE, N. VANDENBERGHE
and
F. GULLENTOPS

with

APPENDIX

THE DIATOM FLORA OF THE STEENBRUGGE CLAY (EEMIAN)

by

R. CLARYSSE

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SUMMARY

LATE PLEISTOCENE AND HOLOCENE IN THE NEIGHBOURHOOD OF BRUGGE

by

J. VANDENBERGHE, N. VANDENBERGHE *
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SAMENVATTING

Een drietal ontsluitingen in de omgeving van Brugge (Belgische kustvlakte) leverden belangrijk materiaal voor de kennis van de laat-kwartaire stratigrafie en de paleogeografie van het gebied. De ontsluitingen zelf zijn gelegen in de Zwin-Waardamme-depressie en aan de rand van de Vlaamse vallei.

De bovenste sedimenten bestaan steeds uit een eolische dekmantel, met typische schuine gelaagdheden (Beerse member). In lage gebieden zijn deze duinzanden bedekt door het Holland-veen dat hier gevormd werd vanaf het begin van het Boreaal. In al de secties werd het duindek aan de onderzijde begrensd door een veenhorizont daterende uit de Bølling en het einde van het pleniglaciaal. In de profielen te Brugge werd bovendien de diepe insnijding teruggevonden van de Waardamme-beek uit het Allerød. De duinmantel zelf werd dus gevormd tijdens het Jongste-Dryas en het Preboreaal.

Het bovenste gedeelte van het Weichselien-pleniglaciaal (Brabantien) was gekenmerkt door een eerder droog, zeer koud klimaat wat door de belangrijke vorstverschijnselen en pollenanalyses aangetoond werd. Licht siltige dekzanden werden afgezet (Wildert-formatie). Middenin werd een keienvloertje (PB1) aangetroffen dat te korreleren valt met de Beuningengravel en juist daarboven werd in een venig siltlaagje een warmere oscillatie waargenomen (Katelijne-oscillatie). Een belangrijker veenlaag kwam voor dicht tegen de top van de onderliggende gelamineerde zanden en silten. De pollensamenstelling wees op een uitgesproken warm klimaat, overeenkomende met het Kesselt-interstadiaal.

Tijdens het oudste gedeelte van het Weichselien-pleniglaciaal (Hesbayen) werden fijn gelaagde zanden en venige silten van niveo-fluviatiele en niveo-eolische oorsprong afgezet. Er grepen geen grote vorstverschijnselen plaats en ook de pollenanalyses wezen op een niet al te koud eerder vochtig klimaat.

Een zeer belangrijke lithologische eenheid is een kleilaag die zich onder de vorige sedimenten bevindt (Steenbrugge-member). Lithologie,

* Aspirant bij het Nationaal Fonds voor Wetenschappelijk Onderzoek.

strukturen, fauna (mollusken, diatomeeën) en flora wezen ontegensprekelijk op een brak getijde- of lagunair milieu. Door pollenanalyse werd deze schorreklei gedateerd in de periode 4b van het Eemien. Door vergelijk met andere Eem-afzettingen kon afgeleid worden dat N-Vlaanderen sinds het Eemien zeker tot het dalende Noordzeebekken behoort.

Tenslotte komen onderaan nog pleistocene groene glauconietrijke zanden voor, afgezet in een estuarien of littoraal milieu. Aan de top is een bodem ontwikkeld en daaronder bevindt zich een groene verweringsklei die lokaal sterk opgeperst is. Naargelang de interpretatie van deze vervormingen moet de afzetting van deze glauconietzanden in het begin van het Eem ofwel in een vroeger interglaciaal gesitueerd worden.

Van al de sedimenten werd een grondige granulometrische en mineralogische studie doorgevoerd, alle veenhorizonten werden palynologisch onderzocht en in een appendix wordt de diatomeeën-flora beschreven van de Steenbrugge-klei.

INTRODUCTION

Excavations made to the South of Brugge, to improve the Ostend-Brugge Canal, have revealed interesting profiles in Quaternary deposits. In conjunction with the study of these sections we have also examined profiles in two sandworkings to the NE of Brugge, one in Vijve-Kapelle and the other in Oedelem.

The results of these studies are presented here together because of the related and complementary character of the sediments and the similitude of the paleogeographical environment (Fig. 1). The profiles to the South of Brugge are situated in the Zwin-Waardamme depression (De Moor, 1960), those of Vijve-Kapelle on the margin of the Flemish Valley (Tavernier, 1946; De Moor, 1963) whilst the section in Oedelem is situated on the southern edge of this valley.

I. FIELD-OBSERVATIONS

1. The profiles at Brugge

In 1969 we followed the excavations made in the canalworks at Brugge (51° 12' NB, 3° 15' EL). The location of the various pits is shown on fig. 2 together with the different generalized profiles. We will describe the successive sediment units, indicated by letters, beginning from the top. More detailed profiles are shown in fig. 3-9.

A. The sands at the top of the profiles

All the profiles begin with a thick layer of uniform pale yellow, medium grained, loose sands. In fresh exposures, they show practically no structures, but on windblown walls, delicate laminae appear individualised by a succession of slightly coarser and finer sands. These laminae are fre-

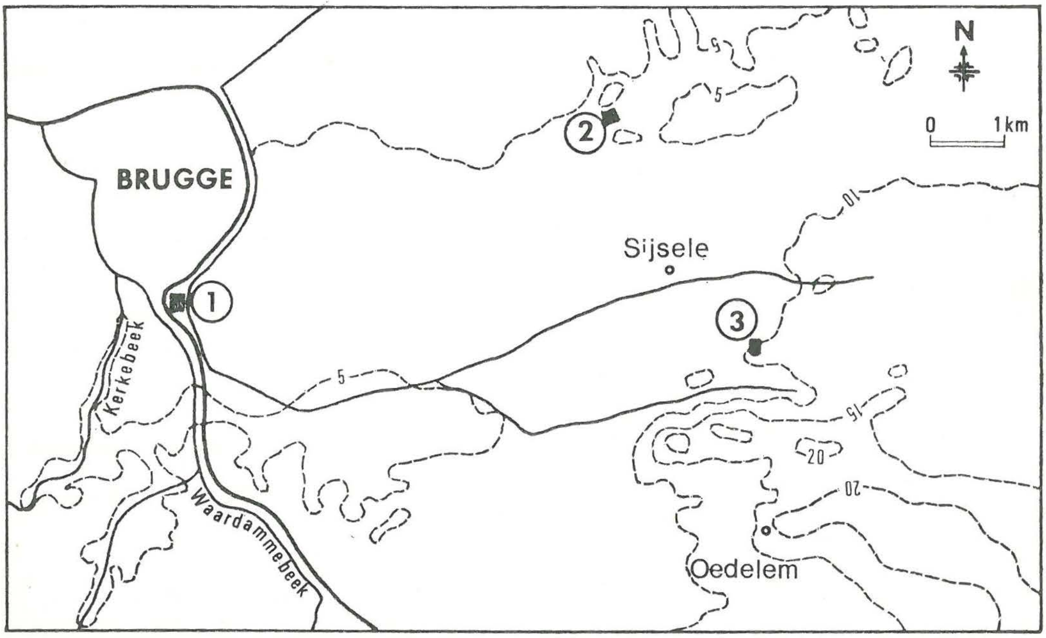


Fig. 1 : Situation of the studied profiles
Situatieschets van de bestudeerde profielen

quently horizontal, mostly inclined in different directions with low angles with a maximum of 20°. The lower parts of the cross strata are frequently asymptotic with respect to the top of the underlying unit. The individual sets have thicknesses of 10 to 20 cm.

Towards the base of this layer some other structures appear : in pit 1, small gullies up to 30 cm deep are present and are filled with laminated, more heterogeneous sands and reworked peatfragments. The general appearance is more cross-bedded; additionally in pit 4 the base of the sands contains a thin horizon of very thinly bedded, horizontal laminae of somewhat finer, clayey sands.

The homogeneity of this continental deposit excludes a fluviatile origin. All the characteristics point to an eolian origin. The deposit does not form a morphological dune landscape and lacks also the typical straight avalanche stratification. The structures however are very closed to the accretion-laminae (Allen, 1971) formed by sedimentation of eolian saltation and traction load. We suspect however that the fine lamination and low angle indicate the eolian sedimentation in a rather humid climate with simultaneous influence of rain-wash.

This reworking by water becomes very evident at the base where the eolian characteristics are suppressed by running water structures.

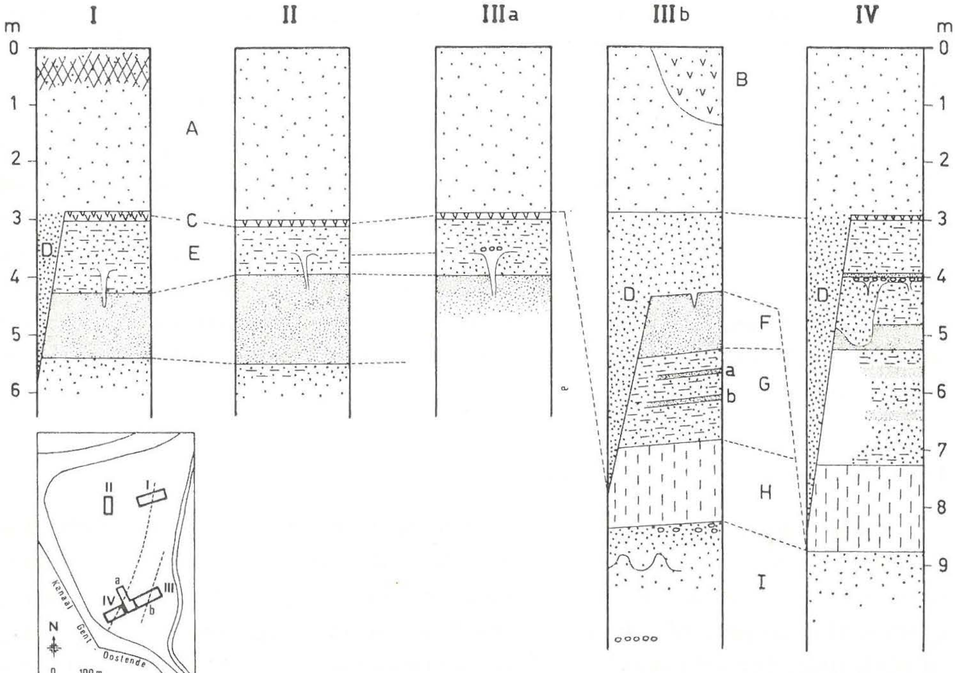


Fig. 2 : Generalized profiles and location of the different pits at Brugge
Schematische profielen en localisatie van de verschillende putten te Brugge

At the top of these sands a typical podzol profile appears in pit I. Generally the A horizon is completely reworked and homogenized by cultivations, but occasionally remnants of the whitish grey A, are preserved. The B horizon is formed by a blackish-brown humic B underlain by a hard iron B.

This succession is interpreted as the complete Holocene pedogenesis with first development of grey-brown podzolic degenerated later to a humic podzol (Scheys et al. 1954).

B. The surface peat

In the extreme eastern corner of pit IIIb, a peat member (B) has filled a depression in the sands A. The peat is up to 1,5 m thick, at the place where it was continuously sampled for palynological analysis. It is quite pure without any sand or clay mixture and contains numerous twigs.

Beneath the peat, we found no trace of the above discussed soil formation, nor any signs of erosion. We can thus assume that the peat grew in a natural depression of the sand landscape.

C. The peat layer below the yellow sands

A very continuous peat layer underlies the yellow sands everywhere, except in pit IIIb and part of pit I, and pit IV. The black peatlayer is normally about 10 cm thick, but may thin out to a few cms.

A profile was taken for palynological analysis at a place where the deposit had a maximum thickness of 42 cm. From 21 to 30 cm the peat was homogeneous and pure black. It is covered by a laminated deposit of alternate dark brown humic peat layers and irregular sand layers or lenses. It is underlain by 12 cm of bluish-grey sands with fine peaty layers.

The peat contains Lymnaea palustris (Müller) indicating quiet, fresh water conditions. The layered nature of the deposit, its extension, the presence of Lymnaea prove the deposit was formed in an extensive swamp landscape.

D. Riverchannel sediments

Where peat layer C was lacking a typical ravinating sandbody was found. The fluvial character of this deposit was proved by the erosive, clear cut channel walls, by the composition of several interpenetrating gullies, the deepest of which reaches 4 m, by the large scale crossbedding in each unit, the sets reaching all thicknesses up to 3 feet, by the presence of heterogeneous grainsize in the form of coarse sand laminae, gravel layers, peat boulders at the base of the gullies and drifted wood fragments.

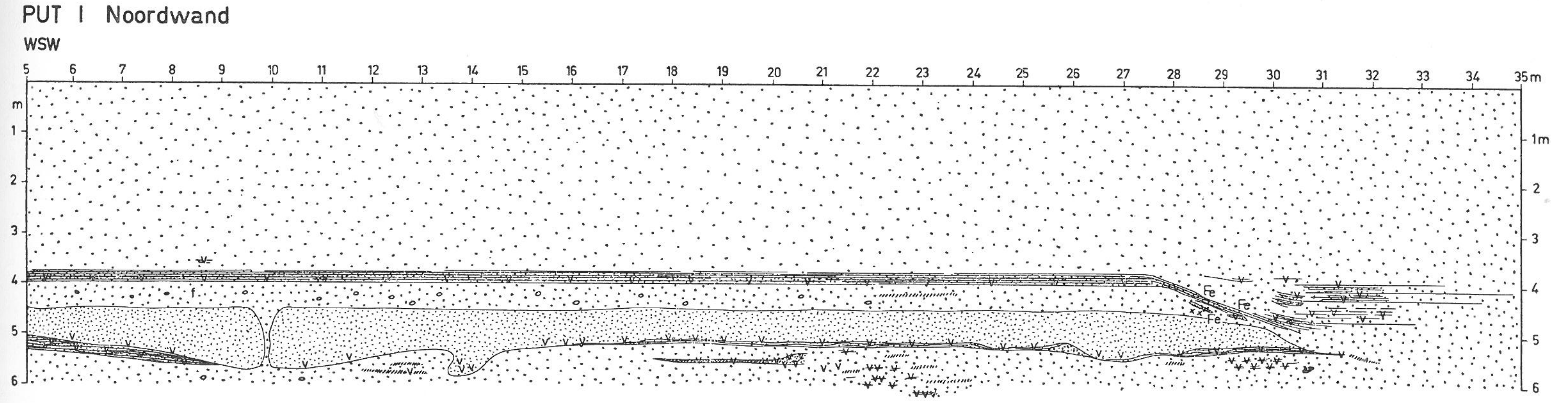


Fig. 3 : The profile of the northern wall in pit I at Brugge
Profiel op de noordwand in put I te Brugge

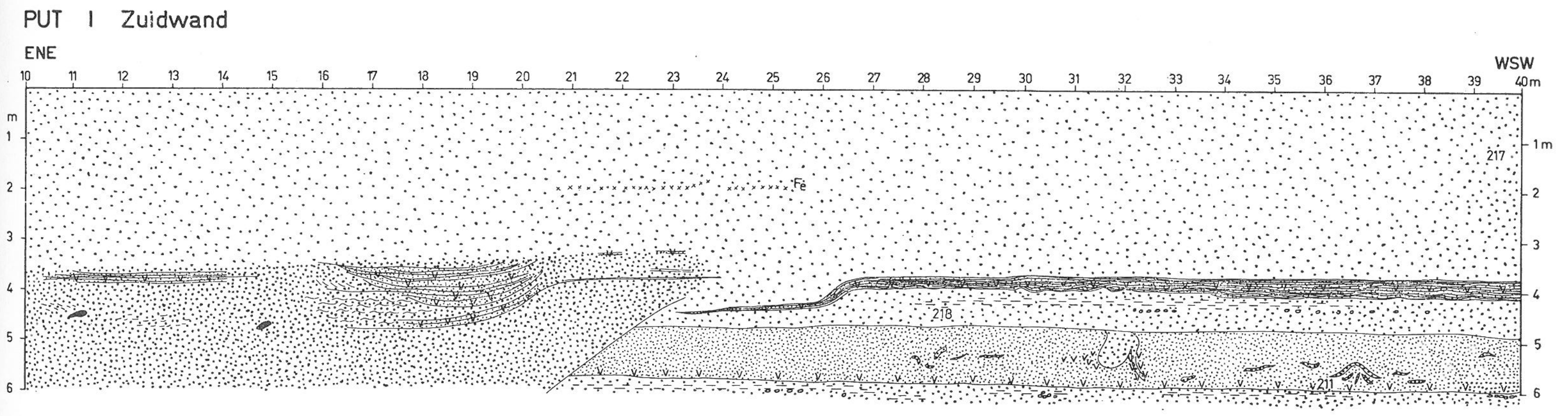


Fig. 4 : Profile and sample location on the southern wall in pit I at Brugge
Profiel en bemonsteringsplaatsen op de zuidelijke wand in put I te Brugge

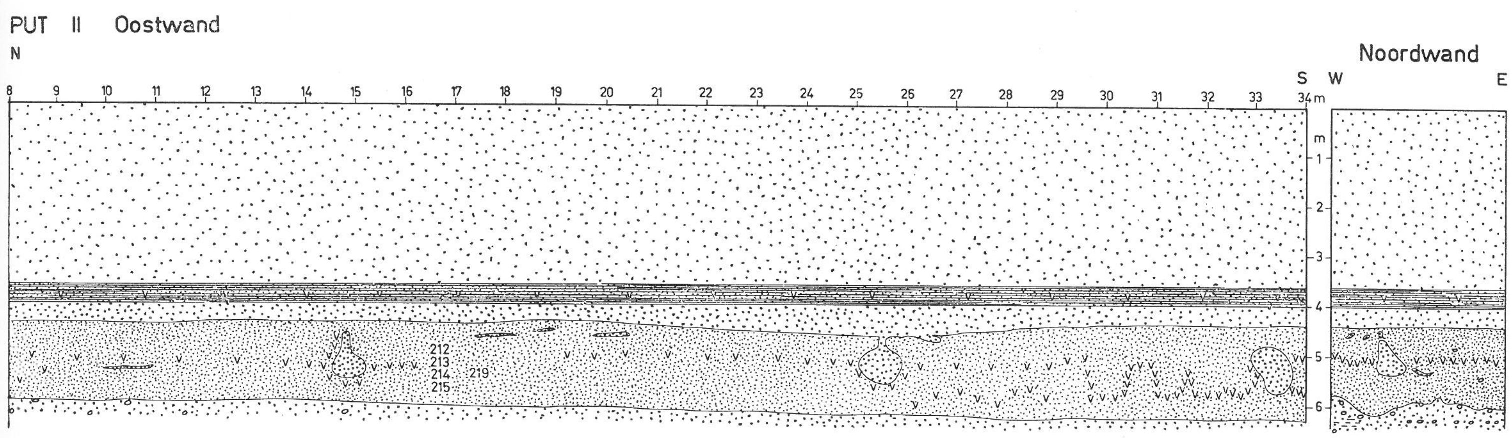


Fig. 5 : Profile and sample location on the eastern wall of pit II
Profiel en bemonsteringsplaatsen op de oostelijke wand in put II

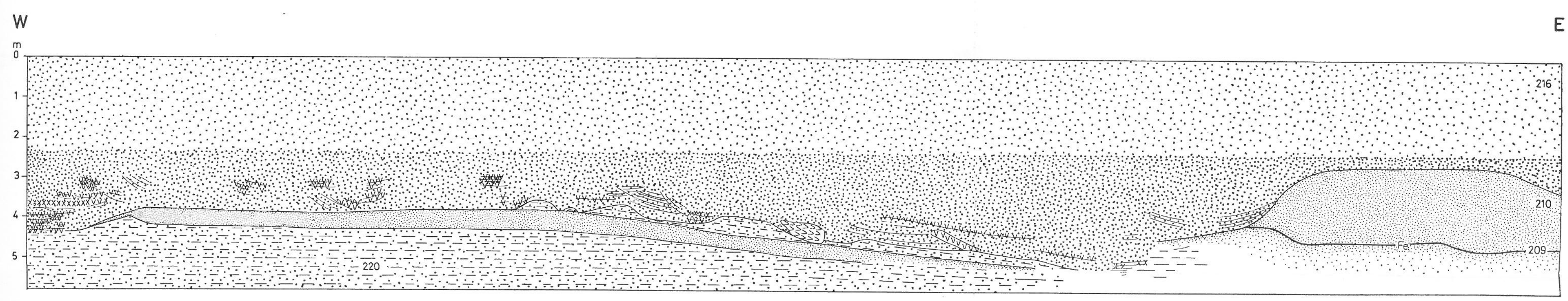


Fig. 7 : Profile and sample location on the northern wall in pit III_b (more to the north of the profile in fig. 6)
Profiel en bemonsteringsplaatsen op de noordwand van put III_b

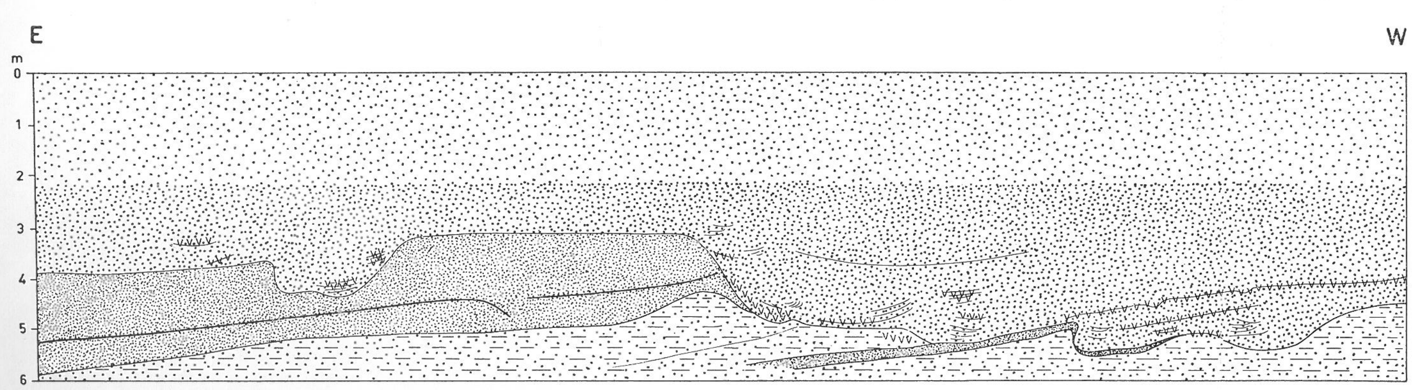


Fig. 8 : Profile on the southern wall of pit III_b
Profiel op de zuidwand van put III_b

On figure 2 the location of these channel sands in the profiles has been indicated and this allowed us to determine the course of the riverchannel (between the dashed lines). The course is NNE and the width of the channel 80 m. We may assume that the channel is a fossil course of the actual Waardamme, a small brook draining the area from the South. A peculiar phenomenon was observed on the channel wall in pit I. The peat layer C was not only cut off, but abruptly bent down over a depth of 60 cm (Photo 1). The base of the overlying sands followed this curvature (fig. 4). The underlying sand has clearly been sucked away from beneath the more coherent and elastic peat layer which consequently was bent down and deformed. This could happen when the channel was being eroded and the channel wall exposed. The sand units have been completely saturated with water so as to form quicksand which could flow away under the consistent peat layer. Deformations of this kind could be confused with cryoturbation phenomena, they need however a clearly unfrozen soil. The phenomenon is closely related to slumping, though of a special origin.

Finally we took a series of samples in the gullies consisting of peat fragments and peaty sand layers for palynological analysis.

E. The sands beneath the peat layer

Between the peat layer C and a very continuous loamy horizon F there exists in all the exposures a body of fine laminated grey sands E with a maximum thickness of 2 m. Characteristics were rather different in the various pits. Their study however allowed to trace the lateral variations and to establish a succession of subhorizons which was most complete in pit IV. (fig. 9).

E1 : at the base exists over maximum 80 cm a sequence of alternating coarser and finer somewhat loamy sands each layer being 2-3 cm thick. The coarser layers are micro-cross-laminated and show micro-gullies a few cms large. At the top of this subunit the sand contains a molluscan fauna which has been sampled (F_0). In pit IIIa these gullies become more important and are associated with small flint pebbles mostly fractured by frost action. This deposit is originated by areal sheetwash with alternating very continuous small layers of undeep rill-deposits and layers of homogeneous loamy coversand. This complex is interpreted as niveo-fluvial deposits formed by diffuse snow meltwater action.

E2 : The previous unit is cut off locally by erosion channels, with a maximum depth of 1,20 m penetrating in the underlying silt layer F. The channel is filled up with sands of the same grain size arranged in three cross laminated sets, each set being about 50 cm high and large.

This subunit proves that at the end of period E, the areal sheetwash was replaced by deeper gullies which indicate a more concentrated drainage.

E3 : Frost wedge horizon

At this level a frostwedge horizon develops in all the pits, the wedges penetrating in E2 or E1. Their spacing is rather regular, their distance was about 1 m in pit IV. The wedges have a varied size, depending partly on the physical nature of the soil and on the period of formation, as will be shown later. Thus, after the concentrated erosion E2 a deep permafrost developed with formation of toundra polygons. Simultaneously with the permafrost, homogeneous sands were carried in, probably by wind action. They are however only preserved as icewedge fillings.

E4 : Pebble layer

Indeed, on top of the icewedge horizon exists a very thin gravel layer, only one pebble thick, without structures and even discontinuous. The pebbles are not found in the icewedge fillings, but the horizon may bent slightly down above the biggest wedges. It must be interpreted as a pavement, erosion remnant probably caused by wind action at the end of period E3.

E5 : Loamy layer

Only in pit IV the pebble layer was covered by 10 cm of grey reduced loam, rapidly turning brown when exposed to the air. Thin coarse sand layers are interstratified. They even contain some pebbles and peaty lenses of which a sample was analysed palynologically. After the dry and cold periods E3-4 humid conditions prevailed without frostphenomena, leading to the formation of local swamps.

E6 : Towards the top horizon E ends on a somewhat loamy sand, of maximum 1 m, similar to E1 and also originated by areal sheetwash.

F. Silt horizon

The sands E are underlain everywhere by a continuous greyish silt horizon varying in thickness from 40 cm in pit IV to 200 cm in pit III_b. The silt is interbedded with small sandy lenses less than 1 cm thick and only a few cms broad; sometimes these lenses are undulated by frost action. Everywhere organic material is present in the form of very thin laminae.

In the middle of the layer this organic content increases suddenly, forming even a small peaty horizon (F_a) in pit I, II and IV, sometimes very strongly disturbed by cryoturbation (Photo 2). Laterally in pit IV this horizon is represented by a brown coloured ferrugineous clayey silt still containing organic material and also abundant molluscshells (Fig. 6-7).

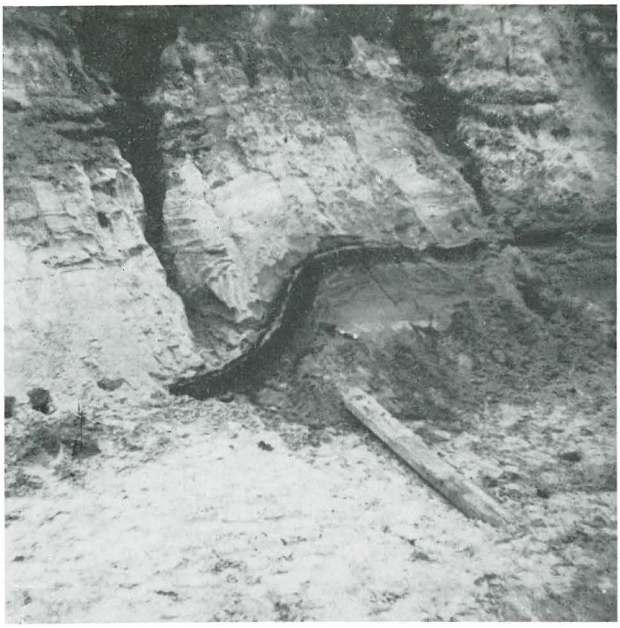


Photo 1 : The peatlayer C is cut off by river sands and is bent down.
Veenlaag C wordt door rivierzanden afgesneden en is bovendien naar onderen geplooid

Photo 2 : Cryoturbation of peat F_a in siltlayer F at Brugge
Kryoturbatie van veen F_a in siltlaag F te Brugge

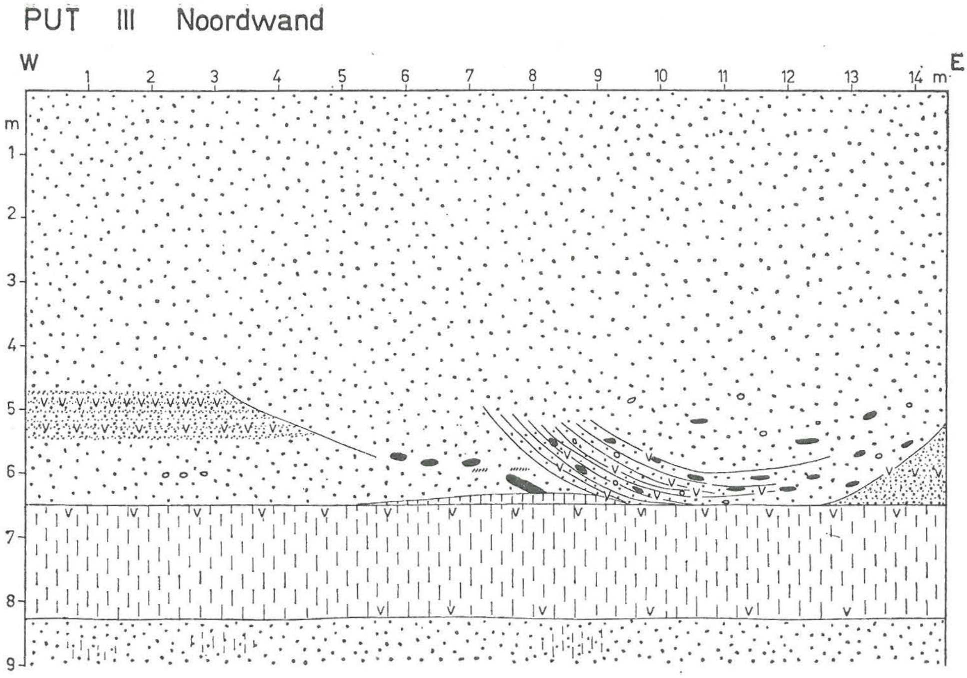


Fig. 6 : Profile in the east-west direction in pit III_b
Oost-west profiel in put III_b

At the base of the layer in pit I and II the deposit is much more layered with alternation of sandy and peaty laminae also sampled (F_b) for palynological analysis (Fig. 3).

The loess-like silt has been deposited in a wet environment as demonstrated by the numerous organic laminae. The presence of running water in that environment is shown by the sandy lenses as well, and this happened in a toundra climate as proved by the cryoturbation in the active layer.

G. The lower laminated sands and silts

— In pit III_b and IV the underlying 2 m were essentially characterised by laminated loamy sands.

— In pit III_b the sands eroded the underlying clay H and in the erosion gullies concentrations of large broken pebbles exist. Above, these whitish grey sand alternate regularly every few cms with finer grained silty green laminae. The laminations are clearly cut and often disturbed by small frost wedges. In the upper middle two silt layers are conspicuously thicker and peatier. They have been sampled as layers G_a and G_b for pollen analysis.

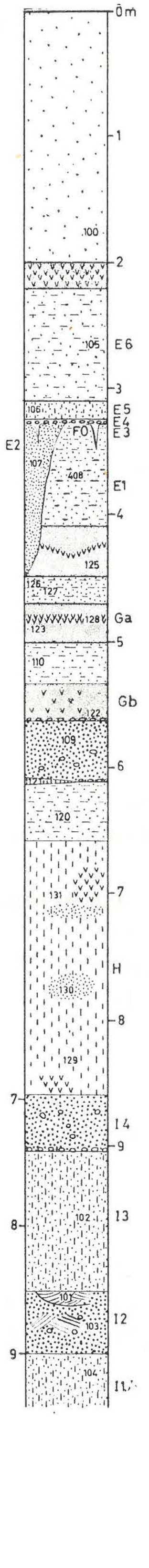


Fig. 9 : Profile and sample location in the northern part of pit IV
Profiel en bemonsteringsplaatsen in het noordelijk gedeelte van put IV

— In pit IV an erosion gully filled with coarse sands and broken pebbles occured even 45 cm above the base (Fig. 9). The middle of horizon G was more silty and the contacts between sand and silt layers much more gradual. However, the concentration of peaty silts in two horizons is also recognizable. They are also very reduced; the fresh grey colour turns very quickly brownish grey when exposed to the air. Only once we observed a sharp contact between G and F, while normally this contact is a gradual transition to silt unit F.

— In pit I and II only the top of this unit was visible; there however the laminated sands contained pebble horizons (Fig. 3, 4).

We interprete the deposition of horizon G as due to niveofluviatile sedimentation with a predominance of sheet deposits; concentrated gullies occur at different levels. In the middle part of the horizon G, swamp conditions resulting in the deposition of peaty silts appeared. The whole took place in a cold climate.

H. Clay member

A continuous clay layer of nearly 2 m thick underlies unit G. In the clay pure white sand layers, sharply limited and laterally very persistant occur (photo 3). The organic content of the clay is highest near the base where the colour can be dark grey, but the whole layer has been sampled for pollen analysis.

In pit III_b the clay contained Macoma baltica and Scrobicularia plana (da Costa)*, while in pit IV irregularly shaped calcareous concretions occured. This deposit must be interpreted as a salt marsh sediment laid down under tidal influence with the washed sand brought in by flood water.

I. The glauconitic sands

Under the clay exists a complex of sands with a general green colour due to the presence of glauconite (Fig. 10).

I_1. At the base a maximum thickness of 1 m green clayey glauconitic sand without visible layering was present. A boring found under 1,10 m of the same sands a gravel layer, consisting of rounded dark silex pebbles, flattened or oblong, most of them broken, together with pieces of glauconitic sandstone and small flat very rounded, white quartz pebbles. The dark silex and the glauconitic sandstone are reworked from the local marine eocene. The ratios : thickness /length and breadth /length of the flat quartz pebbles match the shape diagrams (Hemschoote, 1966) of the

* determination by A. Ringelé.

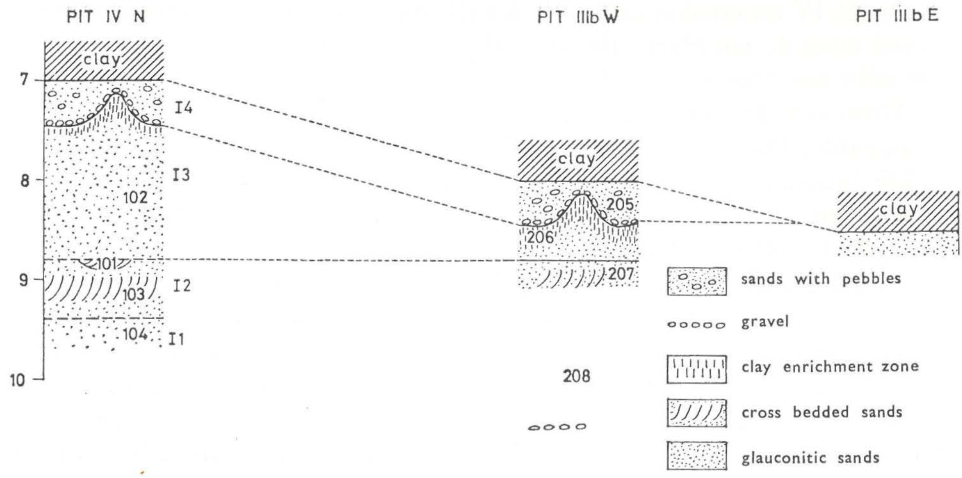


Fig. 10 : Sample location and detailed profiles of the top of the glauconitic sands I
Bemonsteringsplaatsen en gedetailleerde profielen van de top van de glauconiethoudende zanden I

gravels occuring on the top of the hills of Oedelem at a height of +30 m. This proves that the gravel layer of the boring contains reworked tertiary marine gravels and that the overlying sands are of quaternary age.

I_2. Above this member exists a layer of 50 cm of coarser, pale, glauconitic cross laminated sands. The cross laminated units are generally 10 cm thick and inclined in different direction. The laminae are well defined due to the succession of pale quartz layers and dark green glauconite layers. Typical worm burrows appear as pale patches surrounded by a ring of glauconite.

This unit is typically a marine sand, laid down in turbulent water.

I_3. A variable thickness, maximum 1,10 m, of green glauconitic clayey sand, similar to I_1 overlies I_2. Towards the top the clay content increases and forms a dark green sandy clay. Horizontal twig remnants and some vertical root traces occur.

I_4. The upper horizon is very different by its general white-grey colour and the absence of a clay fraction in the sands. The top, immediately below the peaty base of clay H has a diffuse dark grey colour due to humic content over some 10 cm. It is followed downward by a strikingly white grey clayless, structureless sand over some 20 cm, while in the lower part the loose grey sand takes a light green hue. Dispersed in the whole horizon but markedly concentrated at the base, numerous broken flint pebbles occur. The contact between I_4 and the clayey upper part of the underlying horizon I_3 is irregular. The clay I_3 is squeezed up into the upper white sands in points at regular intervals (Photo 4). The upward points are sym-

Photo 3 : Pure, white sand laminae in the Steenbrugge-clay
Dunne zuivere zandlaagjes in de Steenbrugge-klei

Photo 4 : The clay I_3 is squeezed into the I_4 whitish sands
De klei I_3 is opgeperst in de witte zanden I_4

metrical and up to 40 cm high. The distance between the points is around 1 m. The gravel base of I_4 follows the same movement. Of this disturbance nothing appears at the base of the peaty clay H.

Horizon I_4 does not contain any sedimentological structures which could give a clue to the depositional environment. However, the presence of numerous dispersed gravels in the sand, point to a waterlaid sediment. It was afterwards submitted to a pedogenesis in humid leaching conditions.

The A_1 en A_2 are preserved together with a texture-B formed by decomposition of glauconite in the top of the underlying horizon I_3 and by the leaching effect of the pedogenesis.

In order to explain the origin of the disturbances at the clayey top I_3 and the base of I_4, we have to consider several hypotheses.

Cryoturbations can have been responsible for the squeezing. In that case, a cold period can be assumed after the soil formation, but before the deposition of clay H. Then the disturbances are considered as a soil of the type Brödelboden.

On the other hand we cannot exclude the possibility that the Brödelling occured as a deep seated phenomenon at the time of the toundra surface G; the disturbance would then have formed, at a depth of 2,5-3 m, a squeezed mud layer between a deep permafrost and a refreezing upper soil.

However, the phenomenon is not necessarily related to frost action. It could have been caused simply by loadcasting after the soil formation; but in the case of loadcasting one should expect more irregular forms than those observed in the field.

It is clear that the presence or absence of a cold period between the soil formation and clay H deposition, will considerably change stratigraphic interpretation.

However it is important as well, to remember that at the moment of the disturbance, the soil must have been formed already. Indeed the pedogenesis has formed two layers with a mechanical different behaviour. This difference was necessary for the deformations to take place.

2. The sand-pit of Vijve-Kapelle

A sand-pit in Vijve-Kapelle (coord. 51° 14' NB, 3° 19' EL) allows the study of some of the same units as in Brugge. From top to bottom the following units can be distinguished (Fig. 11).

I. Eolian sands

In the upper part of the profile there are about 3,5 m of yellowish stratified sands. The laminae, each a few cms thick, are alternately finer

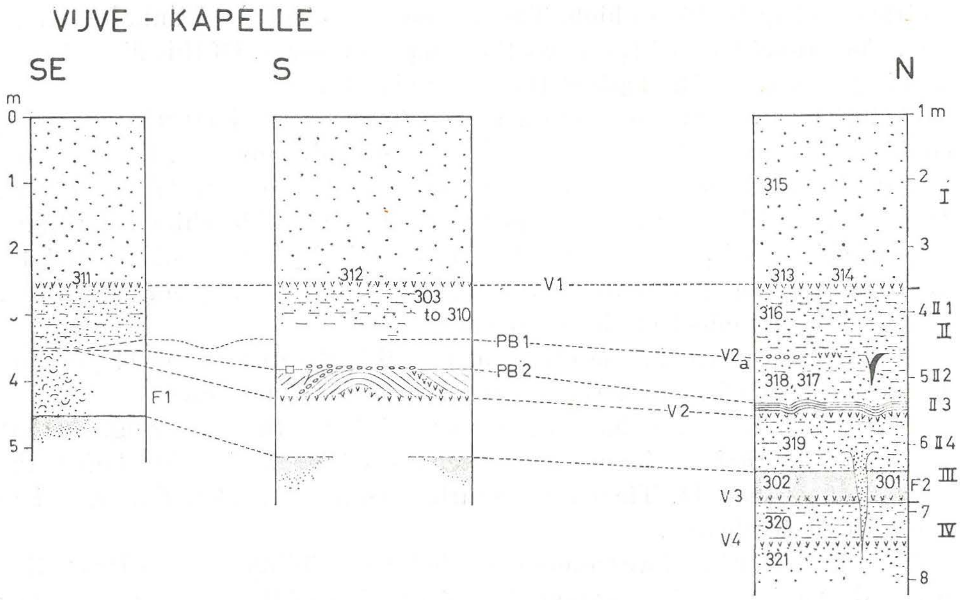


Fig. 11 : Profiles and sample location at Vijve-Kapelle
Profielen en bemonsteringsplaatsen te Vijve-Kapelle

and coarser grained. They show cross-bedding with foresets asymptotically curved towards the base (photo 5). In the weathering on top of the sands a succession of grey-brown podzolic soil followed by a podzol can be seen. Deeper in the sands iron concretions and laminae of a gley on the normal watertable occur.

The base of the sands is somewhat more clayey and contains small pebbles.

These sands which were sampled for pollenanalysis rest on a continuous peat layer V_1, generally about 10 cm thick.

These sands are the same as the uppermost formation in Brugge and, have the same characteristics of an eolian deposit with waterreworking at the base, and the same Holocene soil development at the top.

II. The laminated silty sands

Under these sands a complex of laminated sands up to 3 m thick follows. From top to bottom can be distinguished :

II_1 : 1 m of grey laminated silty sands containing a few small gullies filled with slightly coarser sand. At the base a discontinuous pebble layer (PB_1) occurs, (the pebbles mostly less than 1 cm and generally broken), and occasionally a very thin peat seam (V_{2a}).

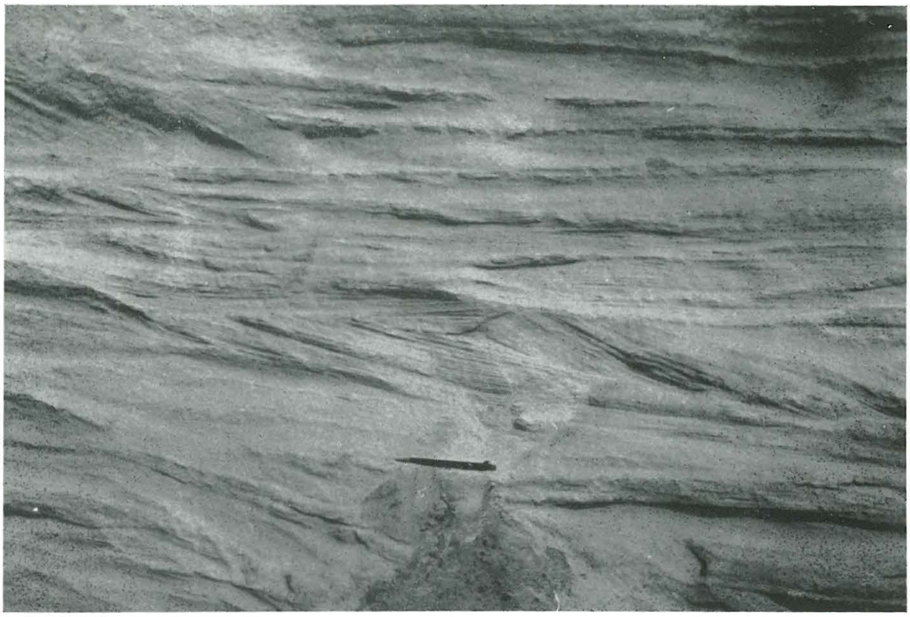


Photo 5 : Sedimentary structures in the upper eolian sands at Vijve-Kapelle
Sedimentatie strukturen in de bovenste eolische zanden te Vijve-Kapelle

Photo 6 : The cryoturbation of peatlayer V_2 at Vijve-Kapelle
De kryoturbatie van veenlaag V_2 *te Vijve-Kapelle*

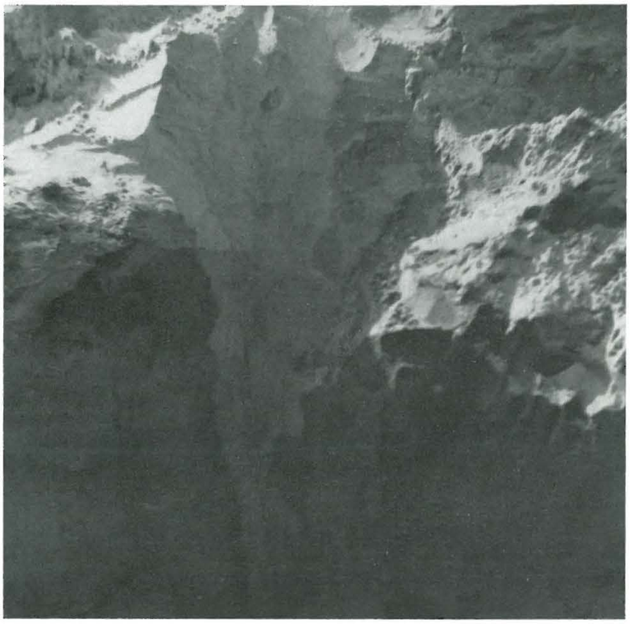


Photo 7 : Large ice wedges piercing through the siltlayer at Vijve-Kapelle
Grote ijswiggen dringen door de siltlaag te Vijve-Kapelle

II_2 : 1 m of brownish more compact silty sands but still horizontally stratified. In the top of these sands frost wedges mostly around 0,5 m deep and irregularly spaced are developed.

II_3 : 30 cm of stratified sandy silts which become charged with organic material towards the base, which is a real peat (V_1). The whole layer is disturbed intensily by frost-action (Photo 6). In the southern part of the pit these disturbances were eroded and a gravel layer forms the basis of II_2 (PB_2).

II_4 : 1 m of grey laminated silty sands, very similar to II_2. In the middle of this layer begins a row of large ice-wedges, reaching 1,5 m of depth, filled with the same sands, but most clearly developed when piercing through the underlying silt layer. (Photo 7). Towards the SE the sands are coarser and contain many shells which were sampled for identification (F_1). Here also II_1 rests immediately on II_4.
The whole succession is typical for a niveo-fluviatile deposit of more or less silty sands in a cold climate which shows three maxima of frost activity and two erosion periods.

III. Silt layer

The underlying grey silt layer, up to 80 cm thick, is very continuous; it contains small sandy lenses and thin peaty seams developing at the base into a more pure peat layer V_3. Here also, a molluscan fauna, sampled for identification was found (F_2).

It is a loess like silt of eolian origin but deposited in wet conditions with snow meltwater activity.

IV. The lower silty sands

Underneath, visible to a maximum thickness of 80 cm, silty laminated sand occurs again; the greenish loamy bands are about 1 cm thick and alternate with thicker sandy laminae.

Small pieces of cacholonized white flint occur together with broken reworked cardium shells. At a depth of 70 cm a peaty horizon V_4, locally disturbed by frost action occurs, together with Limnaea palustris and Gyraulus laevis (Alder)*.

To this deposit a niveo-fluviatile origin in a cold climate can be attributed with running water and marshy conditions.

* Determinations by A. Ringelé

3. Oedelem

A local small sandpit at Oedelem (coord. 51° 12' NB, 3° 20' EL) was incorporated into the study because under the same yellow topsands a peat layer which was sampled for pollenanalysis occured again. It covered under the groundwaterlevel, greenish layered silty sands which were only observed in a handboring.

II. LABORATORY-ANALYSES

A. POLLEN-ANALYSIS

BRUGGE

1. THE SURFACE PEAT B (PIT III_b) (Table I)

Description

From 92 cm downwards, the content of arboreal pollen varies between 45 % and 70 %. The fluctuations are considerable. Between 67 cm and 92 cm the content is more constant at about 65 %. Above 61 cm the content of herbaceous pollen increases suddenly (70 % to 80 %), but thereafter decreases gradually upwards to about 55 %.

A.P. — Below 120 cm there is a great variety and all the trees represented higher in the sequence are already present. From 110 cm to 120 cm Pinus is predominant (10 % to 15 %). There is very little Fraxinus, Betula and Quercus. Above 108 cm the composition changes sharply. The percentage of Pinus and Corylus decreases, but we find 25 % Alnus and 5 % to 10 % Tilia. Betula, Salix and Quercus are present, but in small quantities. Between 36 cm and 57 cm there is again an important change. The Pinus content decreases again and at a certain point reaches zero as does Tilia. The percentage of Alnus also decreases to 16 %. Quercus and Betula are present as well (1 % to 3%), and Salix and Fraxinus occur in small quantities. Above 36 cm we have another change. The Pinus percentage increases gradually to 10 % at the top, as do Tilia (0.5 to 3 %) and Quercus (3 to 7 %). The Salix percentage also increases (max. 13 %). On the other hand Alnus decreases further to about 10 %. Betula is always present (2.5 %). Fagus appears only from 33 cm.

N.A.P. — Between 61 cm and 127 cm the most important herb components are Dryopteris (20 to 40 %) and Cyperaceae (3 to 13 %). The proportion of Gramineae remains constant (max. 4 %). Between 80.5 cm and 99.5 cm we also find Chenopodiaceae and Compositae. Rosales, Pteris, Sphagnum and Osmunda are sometimes present. Between 42.5 cm and 57.5 cm the percentage of Dryopteris reaches about 55 %. The Ericaceae appear at 57.5 cm and increase to max. 9 % at 33 cm. Above 36 cm the amount of Dryopteris falls again (5-15 %) and the Cerealia (max. 5 %) and Crepis (max. 11 %) appear. We also regularly find Chenopodium, Rosaceae, type Aster, Sphagnum and some others.

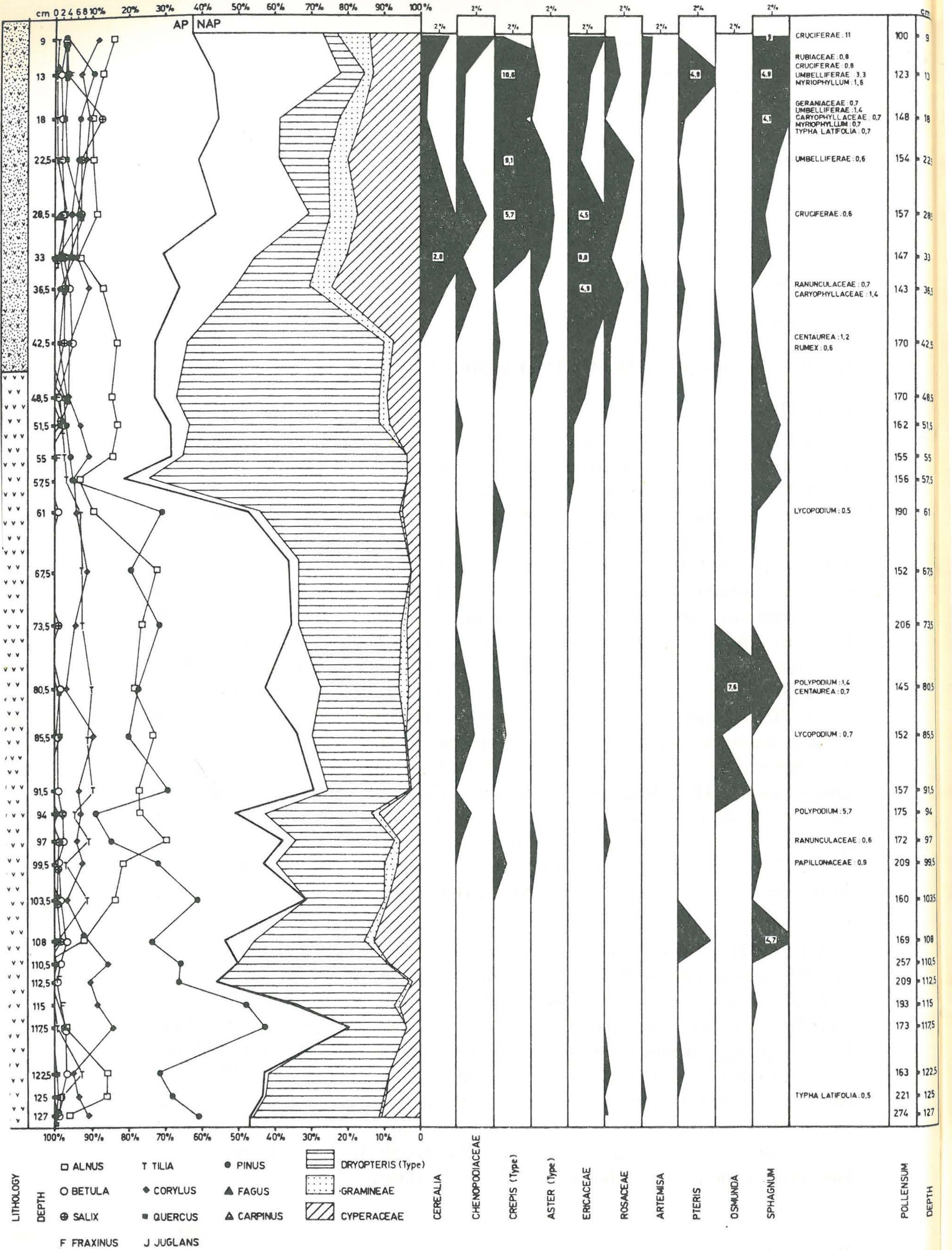


TABLE I

Pollen diagram of the surface peat B (pit III_b)

Pollen-diagramma van het oppervlakteveen B (put III_b) te Brugge

Interpretation

From 127 cm to 108 cm : Boreal :

Extension of Corylus and dominance of Pinus. The zone beneath 120 cm represents the start of the Boreal characterized by the appearance of thermofilous elements (Van der Hammen en Wijmstra, 1972, New Dinkel diagram 1).

From 108 cm to 61 cm : Atlantic :

Great extension of Alnus and Tilia, presence of Chenopodiaceae. For the zone 96.5 cm - 101.5 cm a date of 6.070 B.C. $\pm$ 200 was obtained with the aid of the radiocarbon method (sample LV 569).

From 61 cm upwards : Subboreal :

Extension of Dryopteris, appearance of Ericaceae and decrease of Alnus, Tilia, and Pinus percentages. The peat between 46.5 and 50.5 cm is absolutely dated at 1730 B.C. $\pm$ 120 (sample LV 571).

We could say that the Subatlantic started from 36.5 cm (appearance of Cerealia; extension of Ericaceae, Crepis, Chenopodium and other herbs at the expense of Dryopteris), but there is the problem that Fagus and Carpinus hardly ever occur whilst in all the published diagrams consulted they appear sporadically from the end of the Subboreal and continue during the Subatlantic (Jelgersma, De Jong, Zagwijn en Van Regteren Altena, 1970; Van Hoorne, Stockmans en Van den Berghen, 1954).

2. The peat layer C beneath the yellow sands A (Table II)

Description

Ratio N.A.P.-A.P. (without water plants) — At the bottom of the layer there is a 27 % tree content, but from 37.5 cm upwards this diminishes to only 12 % and is down to 6 % at 23.5 cm. From this point the proportion of trees rises again to about 30 %.

A.P. — In the lowest part, Pinus is dominant, Betula being next in importance. Salix and Picea are present only in small quantities. Between 37.5 cm and 23.5 cm the amount of Pinus decreases slowly and at the end Pinus disappears. On the other hand the percentage of Salix increases. From 33.5 cm Juniperus is present (max. 8 % on 29.5 cm). From 21 cm, the content of Salix (10 to 15 %) and Betula (17 %) increases, but Pinus is represented by less than 1 %, Juniperus is usually present (max. 3 %).

N.A.P. — Below (up to 21 cm) Cyperaceae are more numerous than Gramineae (a ratio 4:1). These two are the main herbaceous constituents. Up to 27.5 cm Equisetum is present, and occasionally other waterloving

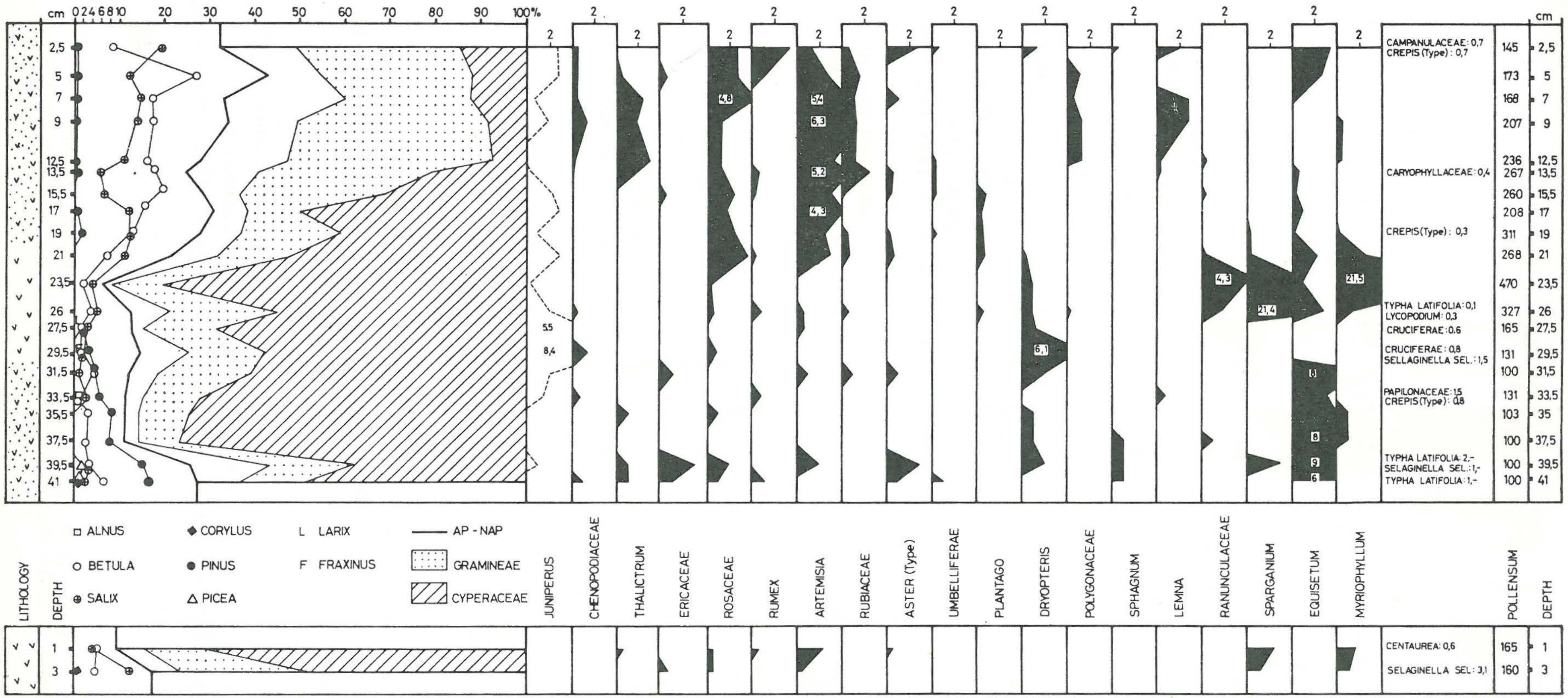


TABLE II

Pollen diagram of the peatlayer C beneath the yellow sands A at Brugge

Pollen-diagramma van veenlaag C onder de bovenste gelige zanden A te Brugge plants such as Lemna, Typha latifolia, Sparganium, Chenopodium and Myriophyllum also occur. Sphagnum, Dryopteris and Compositae are frequently present. Sometimes Selaginella selaginoïdes is present and once we found Artemisia.

Between 27.5 cm and 21 cm there is a great extension of water plants at the expense of the Cyperaceae. Sparganium (21 %) and Typha latifolia (10 %) are the first to appear, and higher up there is a marked development of Myriophyllum and Ranunculaceae (4 %). Equisetum is present in small quantities, but there is practically no Chenopodium. Between 19 cm and 12 cm there are scarcely any water plants, but from 9 cm there are again small percentages of Lemna, Equisetum, Chenopodium. Myriophyllum is also present but in even smaller quantities.

From 21 cm the amount of Gramineae increases considerably at the expense of the Cyperaceae to such an extent that they replace the Cyperaceae. Other herbs also become more numerous : Rosales, Compositae and occasionally also the Rubiaceae, Polygonaceae and Umbelliferae. Between 21 cm and 15 cm Plantago is present in small quantities and between 14 and 5 cm Thalictrum is found. In this zone Artemisia is always present (max. 6 %).

Conclusion

The phase between 38 cm and 23 cm represents a very cold period, because there are only 10 % trees. The sporadic presence of Selaginella selaginoïdes also points to lower temperature conditions. Beneath this zone there is evidence of a slightly warmer period : 25 % trees and small quantities of Picea together with Typha latifolia and Sparganium. The cold period was followed by a warmer period. The percentage of herbs decreases to 70 % and the amounts of Betula, Salix and Artemisia increase.

It would seem that the cold phase ended with a very wet period as the water plant content is about 35 % (between 26 cm and 21 cm). Right at the top there was possibly another colder phase because Betula and Artemisia decrease and Salix becomes more numerous. It is noteworthy that during warmer periods Betula is more numerous than Salix, but as a colder period begins (2.5 cm and 21 cm) the reverse is true. This phenomenon has already been described by Van der Hammen (1951) who explained it in terms of the tree limit, where Salix is most numerous. However, the Salix peak is not as clear at the beginning of a warm phase as it is at the end. This is also indicated on Van der Hammen's diagrams. Van der Hammen believed that at the beginning of the warm period the tree limit was not so pronounced. Together with the Salix peak there is also a Juniperus peak but this is not so evident.

For the dating we propose two hypotheses. Firstly it is possible that the warmer period corresponds to a Bølling oscillation, followed by a cold

Early-Dryas, followed in its turn by the Allerød oscillation. Secondly, the cold period beneath could represent the end of the pleni-Würm. In this case the tardiglacial phase would begin at 27.5 cm with the appearance of Artemisia and the pronounced improvement in the climate from 21 cm, would correspond to the Bølling. We prefer the latter, because in many published diagrams as in our own Betula dominated during the Bølling, and Pinus is practically absent. On the other hand Pinus dominates during Allerød (see De Ploey, 1961 and Paulissen and Munaut, 1969). At this point it is clear we need C_{14} dating. The top of the cold period (24-27 cm) was dated at 10.920 B.C. $\pm$ 230 (LV-572), that means at the end of the Early Dryas (Ia). So the warm period (2.5-21 cm) corresponds to the Bølling oscillation.

Note : In pit IV the finer peat layer that corresponds stratigraphically to the thicker one of pits I and III_b, contains 9 to 17 % arboreal pollen with a preponderance of Salix and Betula. The Cyperaceae and the Gramineae are the commonest herbs. We also found 5 % waterplants. This spectrum of plant life corresponds very well to the zone between 19 and 21 cm as shown on the diagram (transition from Early Dryas to Bølling).

3. The peat in the river sands D

The peat has been analysed from a depth of 3.6 m to 5.9 m in pit I.

The whole profile is very irregular and contains a mixture of trees and herbs, that are normally found in both warm and cold climates. It was impossible to date the river on the basis of pollenanalysis because the river has eroded older peats and, thus produced a mixed assemblage. However, we can estimate a minimum age, because no Tilia is present. As Tilia appears only from the Atlantic onwards (see B), the erosion must be pre-Atlantic. This is not surprising because the stratigraphic position of the river sands indicates that they were deposited before the beginning of the growth of the surface peat (Boreal) and before the deposition of the eolian sands which everywhere cover the riversands. On the other hand the stratigraphic position of the channel indicates that it is younger than the continuous peat layer found everywhere at a depth of about 3-4 m.

From pit III we have analysed a peat sample from the bottom of the river channel at a depth of 7.85 m. The same mixing was found.

The conclusion is that the river was formed between Early-Dryas and Boreal.

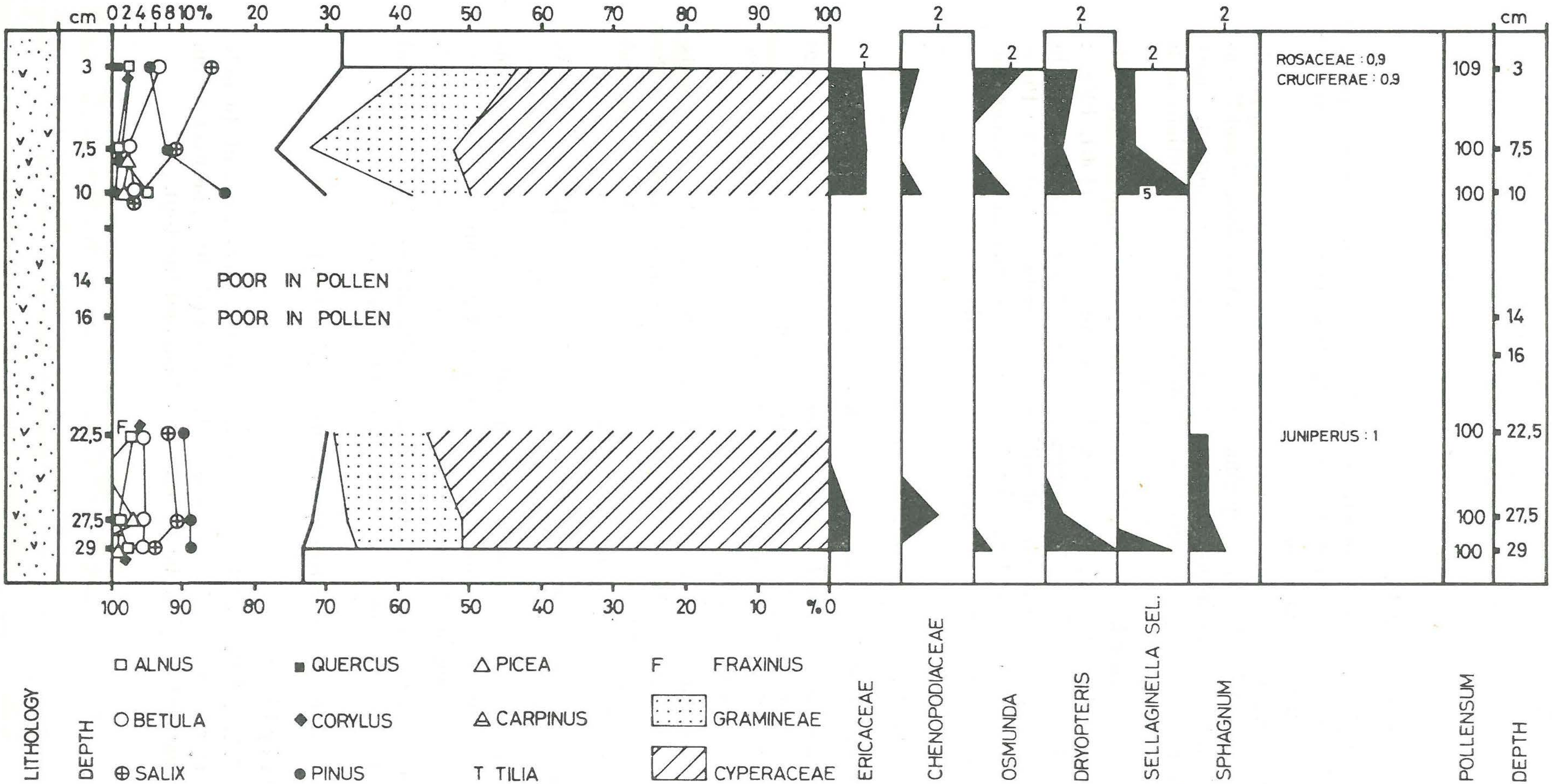


TABLE III

Pollen diagram of the cryoturbated peatlayer F_a at Brugge

Pollen-diagramma van de gekryoturbeerde veenlaag F_a te Brugge

4. The loamy layer E_5

From pit IV we have described the thin brown silt layer with peaty lenses, just overlying the pebble layer E_4. We have examined the peat and have been able to analyse one level.

There are as many trees as herbs. Among the herbs there are approximately equal quantities of Sphagnum, Cyperaceae, Graminaeae and Ericaceae. Pinus is the dominant tree, but Betula is also very important. Apart from these there are some genera which demand warmer conditions such as Corylus (7 %), Picea (3 %) and Alnus (2 %).

Though a correlation is fairly dangerous, we can compare here with the Laugerie-Lascaux oscillation found by Leroi-Gourhan (1964, 1968) : up to 33 % treepollen (Pinus dominant) and also reported by Bastin (1970) from a loam environment with more treepollen (±70 %) : Pinus dominant (± 60 %) and further Alnus, Corylus, Betula, Quercus and Salix. The appearance with our spectrum is striking.

5. The peaty layers in the silt horizon F

a) *The cryoturbated peaty layer F_a* (Table III)

The samples analysed were taken from pit II between depths of 5.20 m and 5.50 m; they proved to be impoverished.

Ratio N.A.P.-A.P. — The ratio AP-NAP is relatively constant; the tree content varies between 23 and 32 %.

A.P. — Except at the top, Pinus dominates (16 %), followed by Salix (±12 %). Betula (4 %) and Alnus (1 to 5 %) are always present. At the top, the amount of Pinus decreases whereas Salix (14 %) increases and Quercus (1 %) appears. At the base of the peat we also found a Tilia-pollen.

N.A.P. — Cyperaceae are represented in great quantity (43 to 56 %). As the Gramineae are also important (8 to 20 %) there is little room for other herbs, of these Dryopteris, Sphagnum and Ericaceae are the most important. Osmunda and Chenopodium are sometimes present. Also noteworthy is the continuous presence of Selaginella selaginoïdes (max. 5 %).

Interpretation : The small quantity of trees indicates a cold phase. The presence of Selaginella sel. points to the same conclusion.

b) *The peat F_b at the bottom of the siltlayer* (Table IV)

Description

Ratio N.A.P.-A.P. — Right at the bottom the trees amount to only 16 %. This percentage increases towards the top (± 40 % between 65 cm and 38 cm and 50 % to 65 % between 38 cm and the top).

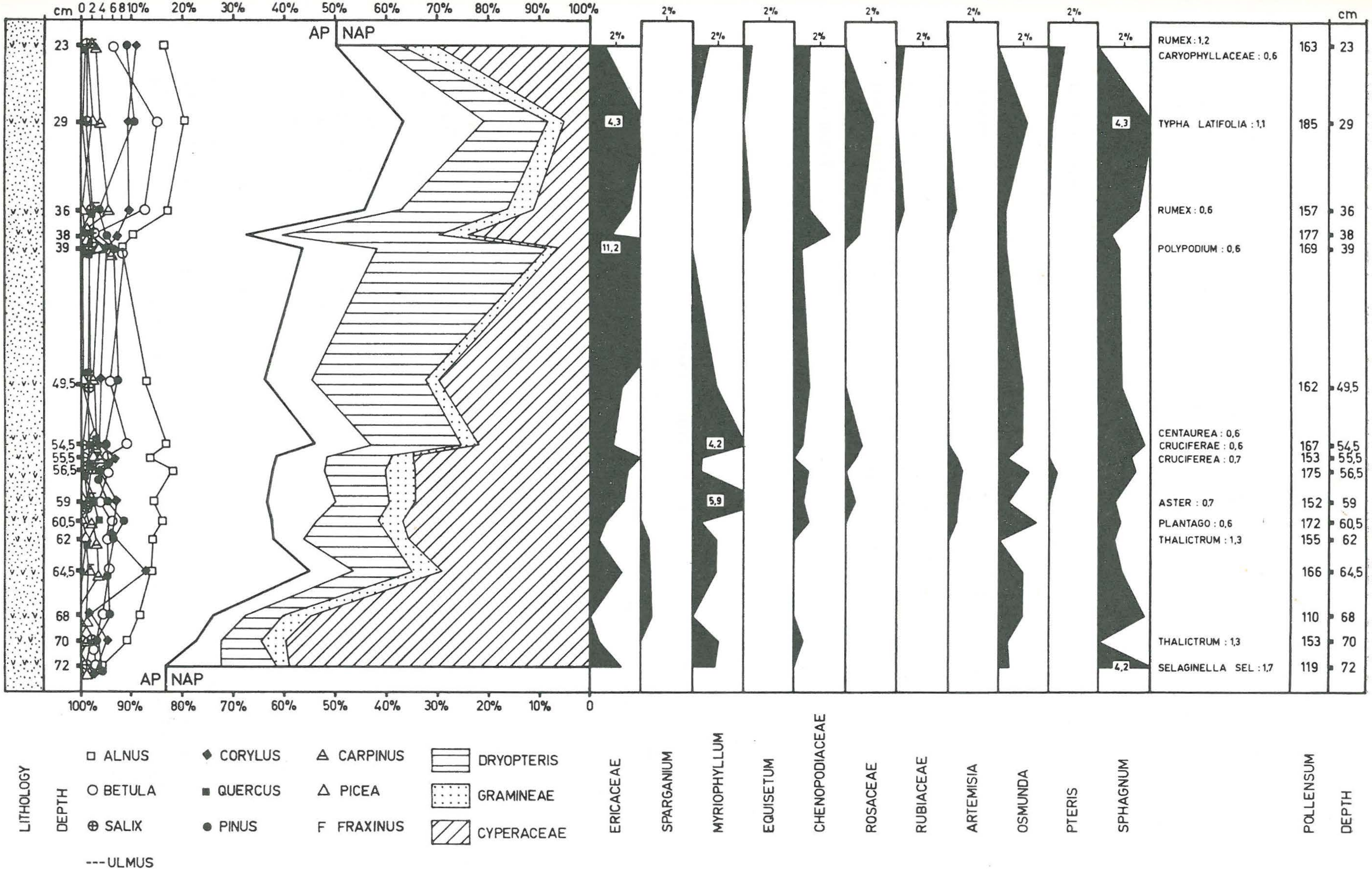


TABLE IV

Pollen diagram of the peat F_b at the bottom of the siltlayer at Brugge

Pollen-diagramma van het veen F_b aan de basis van de siltlaag te Brugge

A.P. — Alnus is dominant but there is a great variety of trees. In the lowest layer Corylus, Pinus, Betula and Salix each represent less than 5 %. Carpinus and Picea are present in even smaller quantities. From 64 cm, Alnus varies around 15 %, Pinus and Betula between 4 and 7 %. This latter is also the percentage for Corylus, but the distribution is somewhat irregular. Picea and Carpinus are always present. Quercus appears. Fraxinus is regularly present in small quantities and Ulmus is found sporadically. The increase in the number of trees from 36 cm is due to the extension of Pinus, Betula, Corylus and Alnus.

N.A.P. — At the bottom, the Cyperaceae represent about 3/4 of the herbs. Dryopteris and Gramineae are represented in smaller amount. Osmunda, Sphagnum, Chenopodium and Ericaceae are regularly present. In the lowest sample we found 1,7 % Selaginella selaginoïdes. Above 68 cm the amount of Cyperaceae decreases strongly while Dryopteris and the other herbs increase slowly up to 39 cm. The Ericaceae attain their maximum at 39 cm (11.2 %). Myriophyllum attains a maximum of 4.2 %. Chenopodium, Sphagnum, Osmunda, as well as Artemisia and Rosaceae are practically always present. Above 36 cm the amount of Dryopteris decreases again.

Interpretation

It is clear that we pass from a cold phase into a really warm phase. The trees attain a level of abundance approaching that characteristic of the Atlantic which is a distinctly higher level than that of a warm period in the tardiglacial, and is also higher than that of the warm oscillation found in E_5. Moreover, practically all trees that enjoy warm conditions are present. The percentages of Alnus and Corylus are notably high. At the top the increase of the Cyperaceae seems to announce a new cold period.

The very warm period must have been an interstadial. Indications of such a favourable climate have never been found in the pleni-Würm deposits and therefore we exclude the Hengelo, Moershoofd or Odderade interstadial as the corresponding periods. From stratigraphical point of view it seems us unlikely that the peat was formed during the Brørup or Amersfoort interstadials. Indeed, below this peat indications of a strong cold were found (see section G). The peat was dated at > 28.300 B.C. (Lv-573), and we consider it to represent the Kesselt interstadial. Only in the last few years there were some palynological investigations of the Arcy-Stillfried B-Kesselt interstadial. In the Dinkel-Valley (the Netherlands) Vander Hammen and Wijmstra stipulate the vegetation in the Denekamp-interstadial as a shrub-tundra with only 10 à 22 % treepollen (dominance of Betula). In the loamy regions Bastin (1971) analysed the cryoturbated Kesselt-soil in the type-locality. The trees attain 50 à 70 %

with dominance of Pinus (47 %) and representation of Betula, Alnus, Corylus, Quercus, Larix, Picea and Carpinus. The Gramineae are dominant among the herbs. The climatic conditions in the Dinkel-valley are still severe near the Würm-icecap. Local circomstances — such as a loamy cover — can cause changes in the relative importance of some plants in the vegetation-pattern. As in Kesselt we can determine this vegetation pattern in Brugge as a temperature wood (Assebroek peat).

6. The peaty layers G_a and G_b in the lower laminated sands and silts (Table V)

D e s c r i p t i o n

The uppermost peatlayer (a) contains 35 % to 45 % treepollen. No single species is dominant; the trees are represented by Alnus, Pinus, Corylus, Salix and to a lesser degree by Betula. Among the herbs the Cyperaceae are dominant. The percentage of the Gramineae and Dryopteris ranges from 9 % to 14 %. Sphagnum (max. 6 %), Selaginella selaginoïdes (max. 6 %), and some Ericaceae and Rosaceae are also relatively important.

The lowest peatlayer (b) normally contains fewer trees, but Carpinus and Picea are occasionally present; and Quercus and Tilia occur sporadically.

The tree spectrum is the same as in (a) except that Salix is relatively unimportant. The spectrum of the herbs is also very similar to (a). However we also find in (b) Chenopodium, Myriophyllum, Artemisia, but there are fewer Selaginella selaginoïdes and Sphagnum. These samples were taken in pit III_b. Another sample was taken in pit IV. It was almost identical to that already described. The only difference was the sporadic presence of Juglans.

I n t e r p r e t a t i o n

As we found elements suggesting both cold and warm conditions it is possible that there has been some reworking. Lower down the section, the peats contain only warm elements (see later) so that if there has been reworking, only the warmer elements could be derived. Most important is the evidence of a relatively cold period. The presence of warm trees could be attributed to a warm period that had just finished or to the reworking of an older peat.

We can cite Bastin (1971) who found that during the Mesowürm the löess regions of Belgium are characterized by 20 to 40 % AP among which were Corylus, Betula, Pinus, Ulmus, Salix, Quercus and Alnus. De Ploey (1961) described a park landscape at the beginning of the Würm by a pollen zone A. If warm trees are autochthonous we interprete the peat as

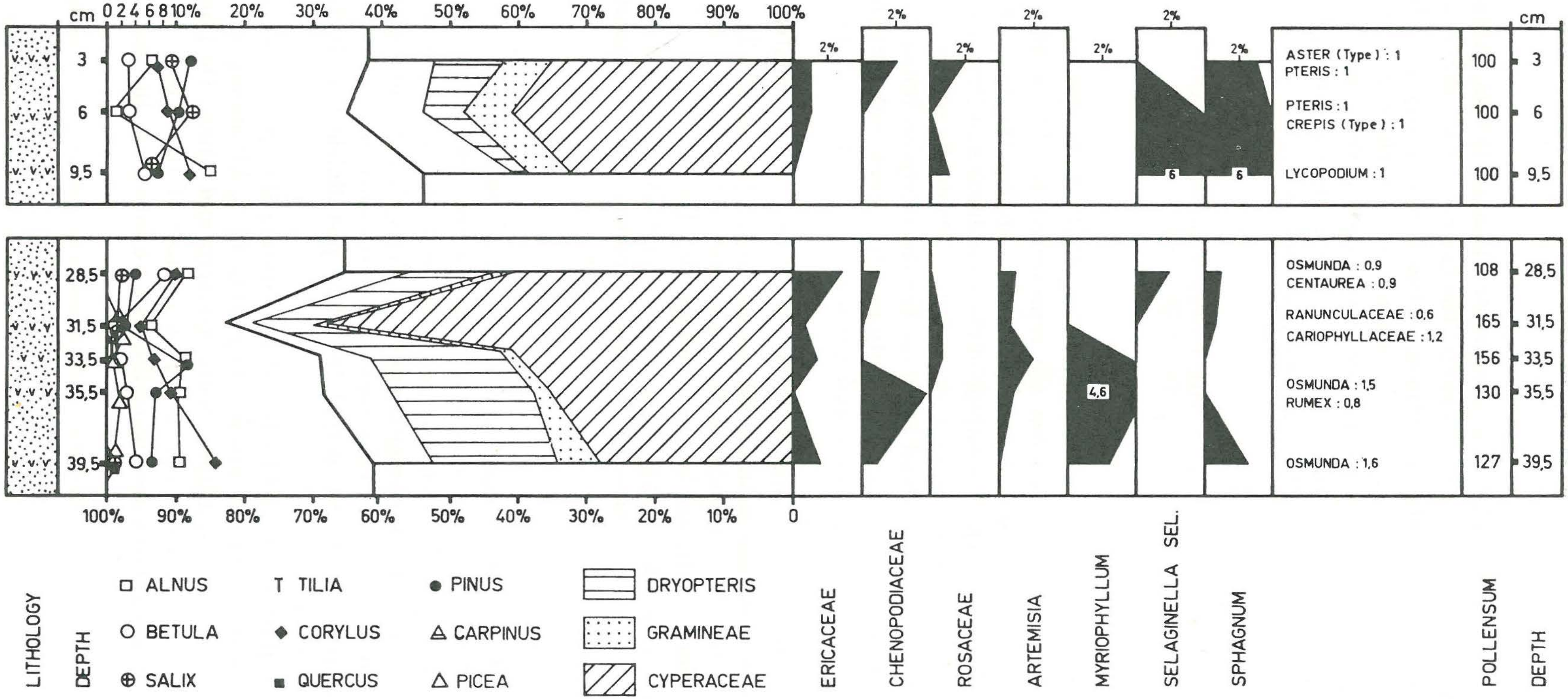


TABLE V

Pollen diagram of the peaty layers G_a and G_b in the lower laminated sands and silts at Brugge

Pollen-diagramma van de venige horizonten G_a en G_b in de onderste gelamineerde zanden en silten te Brugge

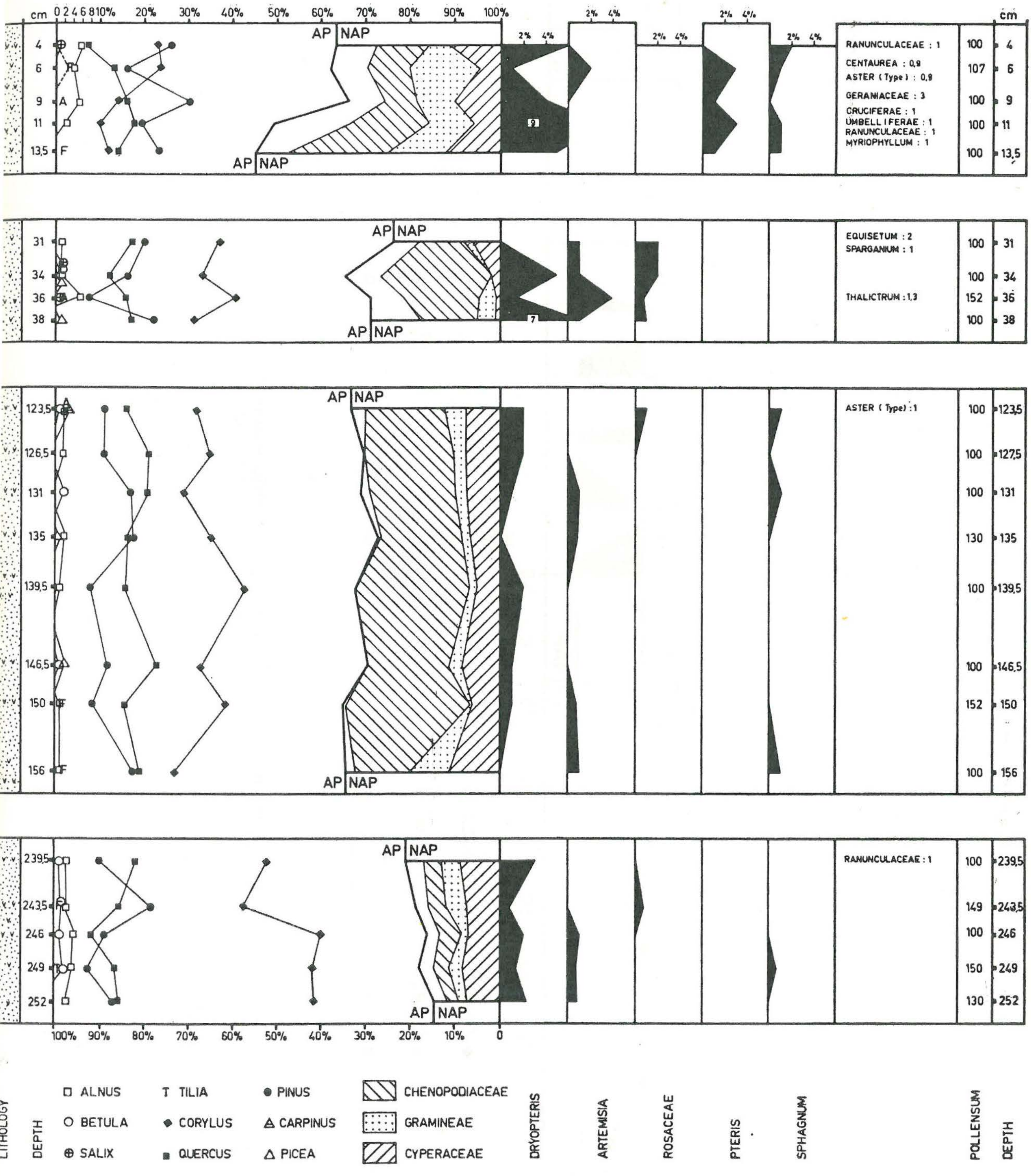
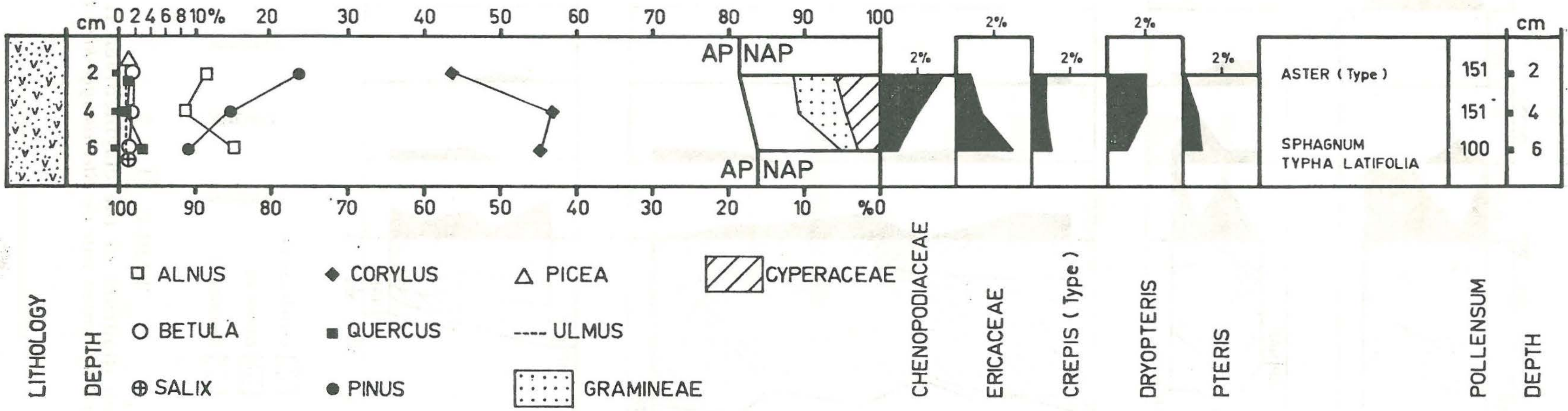


TABLE VI

Pollen diagram of the claymember H

Pollen-diagramma van de Steenbrugge-klei H



TABEL VII

Pollen diagram of the top of the glauconitic sands I

Pollen-diagramma van de top van de glauconiet zanden I having originated during the first period of the Würm, when warm trees still persisted but when the climate had already become cold. We refer here to our datation of the ,,Assebroek peat'', which was shown to be younger than Brørup. The Weichselian climate before Brørup was not so severe that 6 % Selaginella could occur as in these underlying peaty layers (G_a en G_b).

7. The clay member H (Table VI)

Description

Ratio A.P.-N.A.P. — The trees are present in very large numbers (65 to 85 %) except right at the top.

A.P. — Throughout the profile Corylus dominates; Quercus and Pinus are also important. This is most striking at the bottom of the profile whilst at the top the tree species are equally represented. Alnus and Betula are present in smaller quantities (less than 5 %) whilst Picea, Salix, Fraxinus, Acer, Ulmus and Tilia occur sporadically.

N.A.P. — Gramineae, Cyperaceae and Dryopteris are always present, but in relatively small quantities (less than 5 %). The greatest proportion is made up of the Chenopodiaceae which increase from 3 % at the bottom to 31 % in the middle, and then decrease again to ± 12 % at the top. Rosaceae, Artemisia and Sphagnum are frequently present but in small amounts.

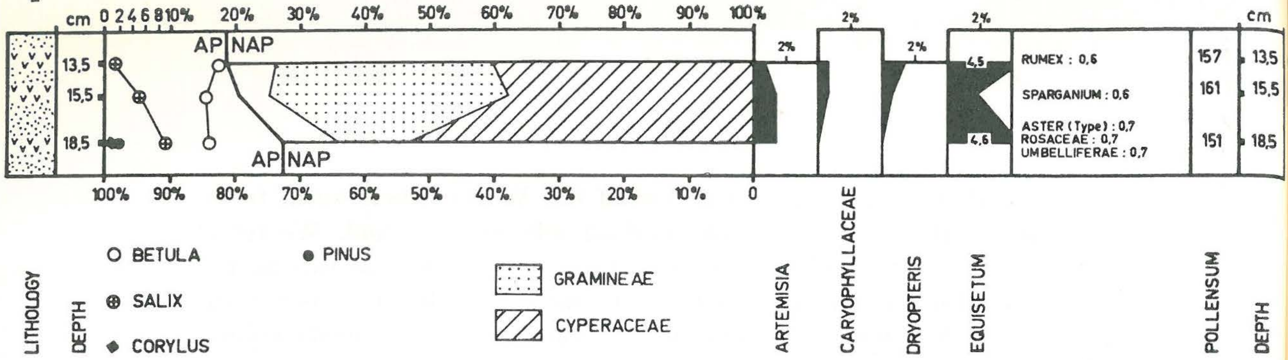
Interpretation

The great abundance of trees and the presence of so many warm types leaves no doubt that this peat originated during a climatic phase that must have been at least as favourable as our present climate. As these peats are overlain by the Würm deposits they must represent the Eemian interglacial. The abundance of Chenopodiaceae indicates a high sea level and, more specifically a schorre environment. We can be even more specific about the dating, when we compare our diagram with Zagwijn's of Amersfoort (Zagwijn, 1961). Our diagram fits very well with the zone 4b, which is characterized by the dominance of Corylus over Quercus. Indeed, zone 4 is named the Corylus zone (Steenbrugge-clay).

8. The top of the glauconitic sands I (Table VII)

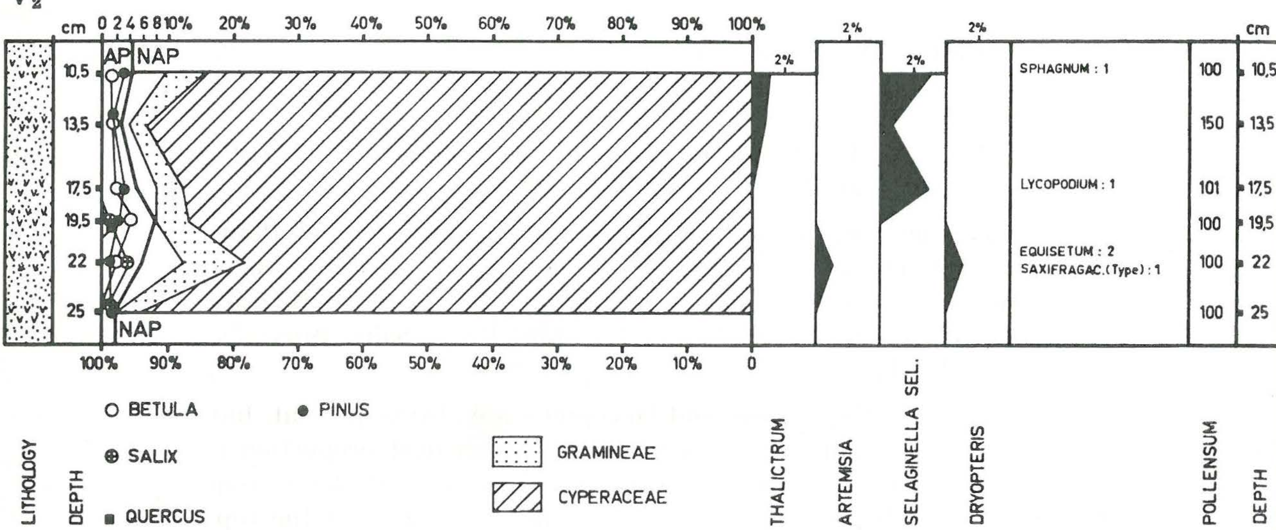
Only the upper few cm were rich in pollen. The pollen content decreases rapidly downwards. 80 to 85 % is arboreal pollen, half of which is Corylus, 10 to 25 % is Pinus, 10 to 15 % Alnus, 1 to 3 % Quercus, and 0,7 % Ulmus. Betula, Salix and Picea occur sporadically. Among the herbs Cyperaceae,

V1



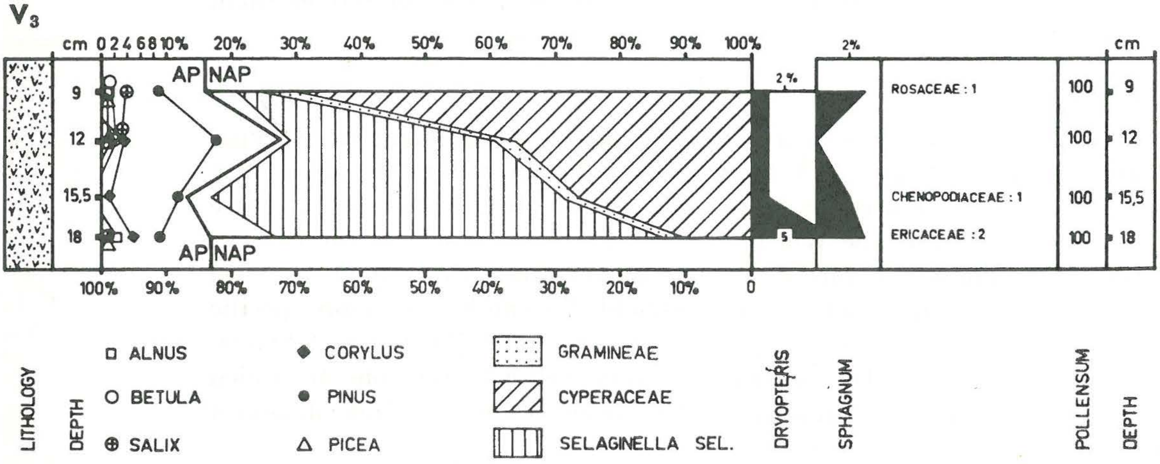
cm
0 2 4 6 8 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
AP NAP
13,5
15,5
18,5
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0
2%
4,5
4,6
RUMEX : 0,6
SPARGANIUM : 0,6
ASTER (Type) : 0,7
ROSACEAE : 0,7
UMBELLIFERAE : 0,7
157
161
151
LITHOLOGY
DEPTH
BETULA
SALIX
CORYLUS
PINUS
GRAMINEAE
CYPERACEAE
ARTEMISIA
CARYOPHYLLACEAE
DRYOPTERIS
EQUISETUM
POLLENSUM

V2



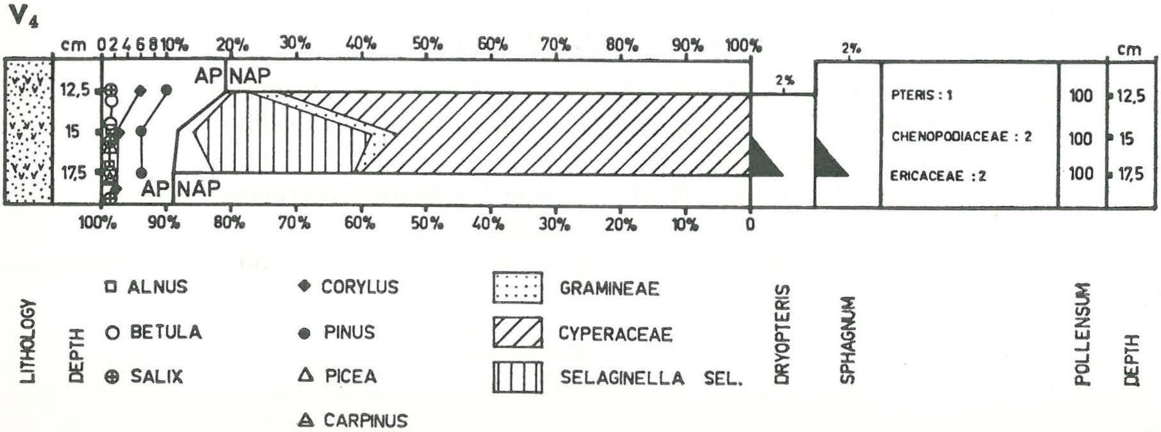
cm
0 2 4 6 8 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
AP NAP
10,5
13,5
17,5
19,5
22
25
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0
2%
SPHAGNUM : 1
LYCOPODIUM : 1
EQUISETUM : 2
SAXIFRAGAC.(Type) : 1
100
150
101
100
100
100
LITHOLOGY
DEPTH
BETULA
SALIX
QUERCUS
PINUS
GRAMINEAE
CYPERACEAE
THALICTRUM
ARTEMISIA
SELAGINELLA SEL.
DRYOPTERIS
POLLENSUM

V3



cm
0 2 4 6 8 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
AP NAP
9
12
15,5
18
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0
2%
5
ROSACEAE : 1
CHENOPODIACEAE : 1
ERICACEAE : 2
100
LITHOLOGY
DEPTH
ALNUS
BETULA
SALIX
CORYLUS
PINUS
PICEA
GRAMINEAE
CYPERACEAE
SELAGINELLA SEL.
DRYOPTERIS
SPHAGNUM
POLLENSUM

V4



cm
0 2 4 6 8 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
AP NAP
12,5
15
17,5
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0
2%
PTERIS : 1
CHENOPODIACEAE : 2
ERICACEAE : 2
100
LITHOLOGY
DEPTH
ALNUS
BETULA
SALIX
CORYLUS
PINUS
PICEA
CARPINUS
GRAMINEAE
CYPERACEAE
SELAGINELLA SEL.
DRYOPTERIS
SPHAGNUM
POLLENSUM

Gramineae, Chenopodiaceae and Dryopteris are present. Compositae are also present but less important. Except for the small quantity of Quercus, the diagram is identical to that for the overlying clay H.

There is a striking resemblance of this pollen association to that of phase 4a of the Eemian interglacial (Zagwijn, 1961). Thus the pollen of the last vegetation before the deposition of the overlying clay H had infiltrated in the top layer of the soil on the top of the green sands.

VIJVE-KAPELLE (Table VIII)

1. The peatlayer V_1

The trees are present in relatively small amounts (18 to 24 %) and are dominated by Betula and to a lesser extent, by Salix. Among the herbs, the Cyperaceae dominate, followed by the Gramineae. Equisetum and Artemisia are always present but in small quantities.

The lithostratigraphic position of this peat-layer invites comparison with that underlying the yellow sands in the profile at Brugge (C). The pollen diagram removes all doubt as to their equivalence : it corresponds to the warm Bølling oscillation during the Tardiglacial.

2. The peaty seam V_{2a}

At the level of the pebble layer PBI we found some peat lenses. The peat was impoverished but it contained a great diversity of trees and herbs. The trees attain somewhat less than 50 % : they are represented by Pinus, Betula, Corylus, Alnus and Picea. Among the herbs, Sphagnum, Cyperaceae, Gramineae and Ericaceae dominate.

Again there is a strong lithostratigraphic resemblance to the small peaty silt layer (E_5). In both profiles the peat lies between two units of niveo-fluviatile sands and immediately above a pebble layer beneath which there is a frost wedge row. The pollen diagrams also correspond perfectly. This peat represents the same warm oscillation.

3. The peat V_2

The very small content of arboreal pollen is noteworthy. Pinus, Betula and Salix are present. The largest proportion of herbs is in the Cyperaceae. The Gramineae attain 5 to 10 % and the Selaginella sel. content ranges up to 3 %. This peat represents a very cold period.

TABLE VIII

◄ **Pollen diagrams of the peatlayers V_1, V_2, V_3 and V_4 at Vijve-Kapelle**

Pollen-diagramma's van de veenlagen V_1, V_2, V_3 en V_4 t_4 Vijve-Kapelle

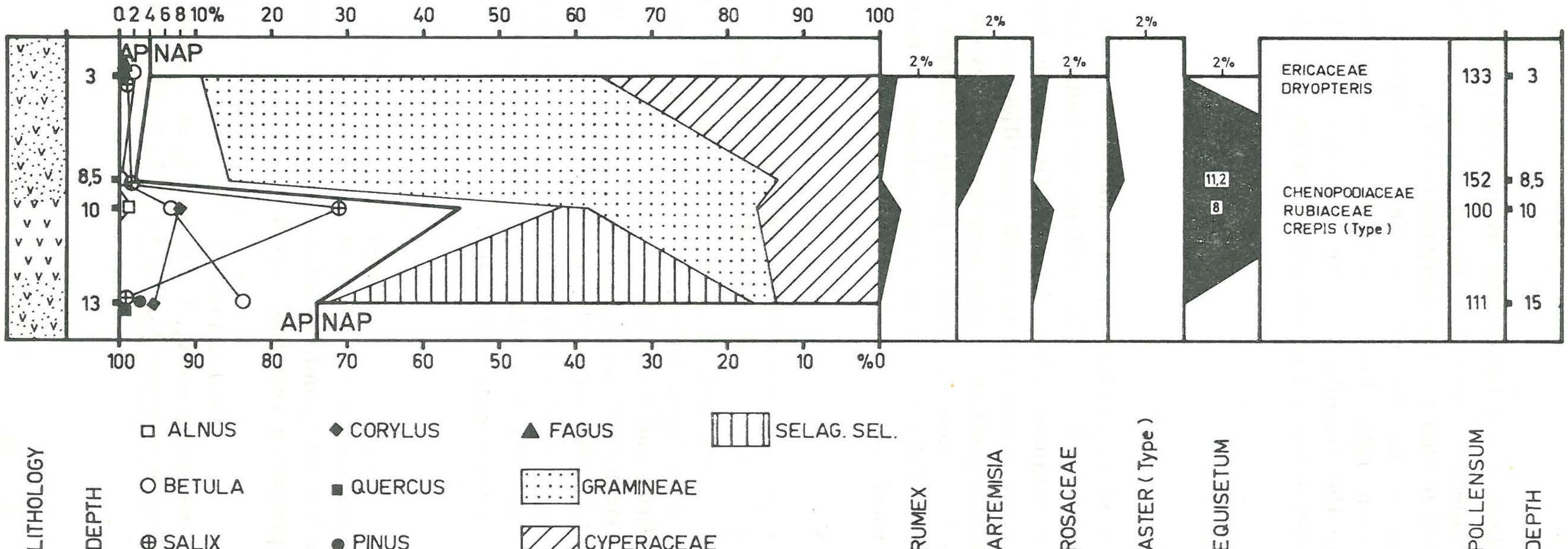


TABLE IX

Pollen diagram of the peat at Oedelem

Pollen-diagramma van de veenlaag te Oedelem

4. THE PEAT LAYER V_3

The arboreal pollen reach ± 20 %, but the most remarkable feature is the high proportion of Selaginella sel. (61 %). Hence, although this peat contains more arboreal pollen than does the peat V_2, it was formed during a cold period. Among the herbs Cyperaceae, Gramineae and Sphagnum occur, whilst Pinus is the dominant tree; Salix, Corylus, Betula, Alnus and Picea are always present in very small quantities.

5. THE PEATY HORIZON V_4

This pollen diagram is identical to that of peat V_3.

OEDELEM (Table IX)

The upper part of the pollen diagram corresponds to the uppermost peat in Vijve-Kapelle and to the middle part of the peat beneath the yellow sands in the profile at Brugge. This resemblace is shown by the dominance of the Gramineae over the Cyperaceae among the herbs, the presence of Artemisia, and the small percentage (4 %) of trees. The middle part of the peat corresponds to the peat layer (V_2) in Vijve-Kapelle with only 2% trees and, among the herbs, the dominance of Cyperaceae over Gramineae. The lower part of the peat corresponds to a vegetation similar to that of the third and fourth peat (V_3 and V_4) in Vijve-Kapelle : 26% trees (Betula, Corylus, Pinus, Salix and Quercus) and Selaginella sel. (57 %) dominant among the herbs.

So, in Oedelem, there was continuous peat growth from the Pleniglacial into the Tardiglacial. This is in sharp contrast to the situation at Brugge and particularly at Vijve-Kapelle where several different phases of detrital sedimentation took place during the period of peat growth at Oedelem.

B. MOLLUSC ASSEMBLAGES

The inventory of the three studied faunas, as identified by Mrs E. Wagemans, is given in table X*. The species have been classified in the 10 ecological groups proposed by Lozek (1964). Very apparent is the complete absence of species, characteristic of wooded or warm areas.

Group 5 is only present in open landscapes, while group 7 assembles very adaptable species. In group 8 are placed molluscs of humid conditions, and really marshy ones in group 9, while group 10 contains freshwater molluscs.

* We thank very cordially Mr. J. Puisségur for discussing these results.

Apart from P. loessica and V. parcedentata only known as a fossil from loess deposits, T. hispida and the freshwater molluscs, all the others are designated by Likharec and Rammelmeier (1962) as widely distributed. The fact that only these are found is typical for very severe conditions realised only in a tundra environment. Typical species of the taiga are event absent.

So it can be concluded that :

F_0 is a fauna typical for a wet tundra environment

F_1 is a thanatocoenosis of a tundra marsh with running water and washed in land snails

F_2 is a tundra environment occasionaly influenced by river flooding.

TABLE X

Percentual composition of mollusc assemblages F_0, F_1, F_2
Percentuele samenstelling van mollusken fauna F_0, F_1, F_2

		F_0	F_1	F_2
5	Pupilla muscorum (Linné)	13	4	35
	Columella columella (Martens)	6	6	20
	Pupilla loessica (Lozek)			8
	Vertigo parcedentata (Braun)		2	14
7	Limacidae	4		
	Trichia hispida (Linné)	15		
8	Succinea oblonga (Draparnaud)	62	56	17
10	Pisidium sp.		18	1
	Lymnaea palustris		2	
	Lymnaea peregra (Müller)		9	
	Anisus leucostomus (Millet)			2
	Gyraulus laevis (Alder)			3
	Planorbis planorbis (Linné)		2	
	Armiger crista (Linné)		1	

C. GRANULOMETRIC ANALYSES

The intention of this chapter on granulometric analysis is firstly to be descriptive; therefore all parameters used, are brought together in a table XI, and cumulative curves are shown in fig. 12-18.

In addition to this descriptive aim, we have used these parameters together with an inspection of the whole granulometric curve to find

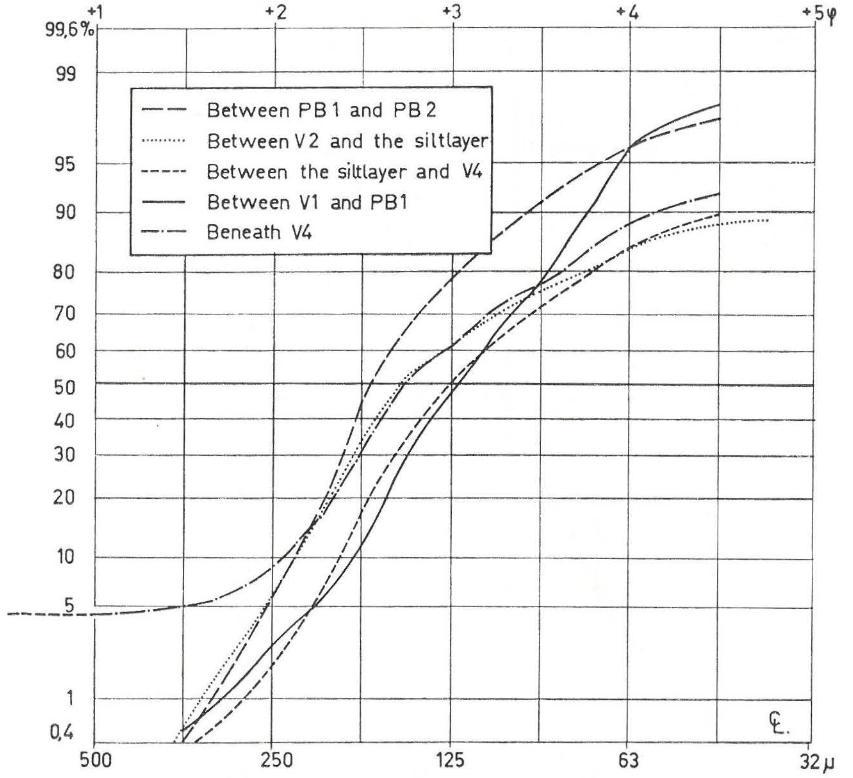


Fig. 12 : Cumulative grain size curves of the coversands at Vijve-Kapelle
Kumulatieve korrelgrootte-verdelingen van de dekzanden te Vijve-Kapelle

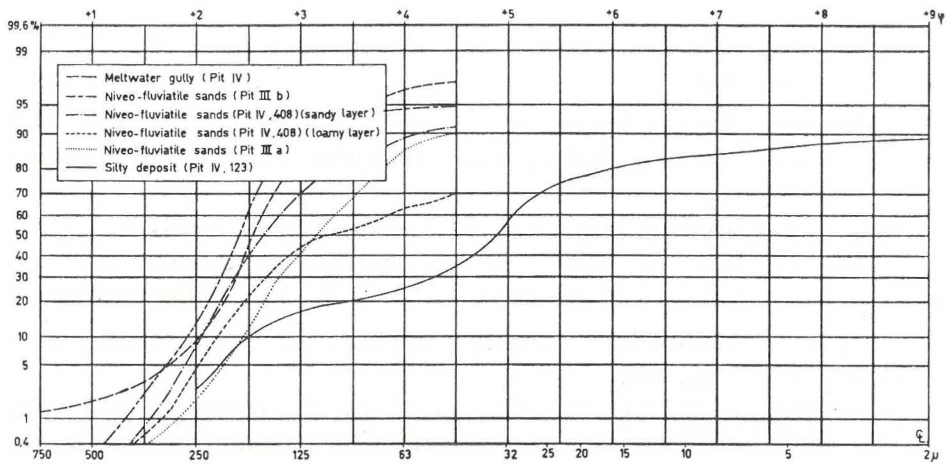


Fig. 13 : Cumulative grain size curves of the coversands at Brugge
Kumulatieve korrelgrootte-verdelingen van de dekzanden te Brugge

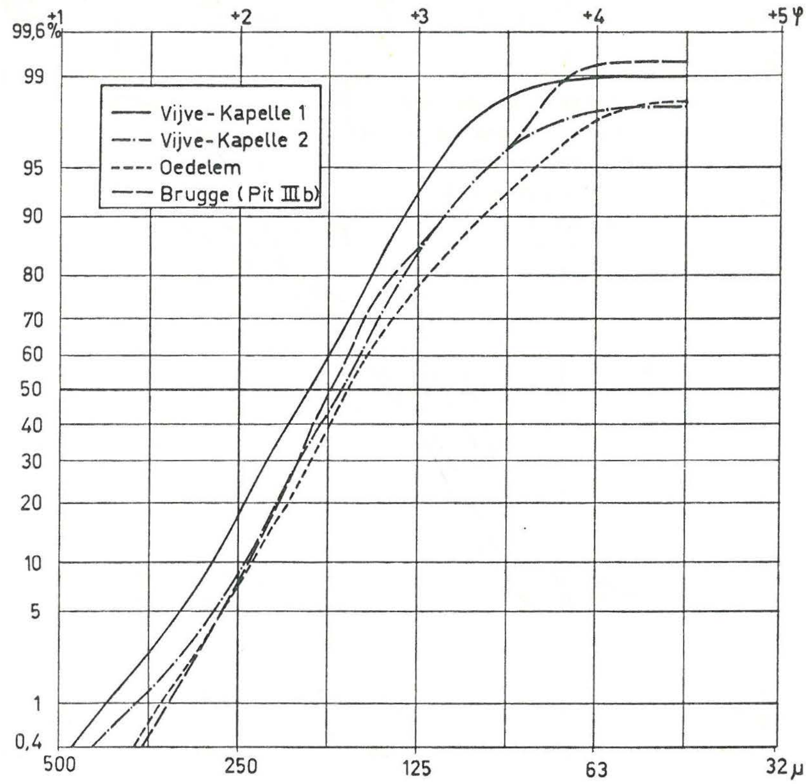


Fig. 14 : Cumulative grain size curves of the eolian top sands
Kumulatieve korrelgrootte-verdelingen van de bovenste eolische zanden

additional information about the nature of the depositional environment of the different units.

I. Eolian top sands

a.1. The sands have a modal size of about 2,6 φ. They are very well sorted and always have a slight positive skewness. They are all unimodal curves (fig. 14).

Dune sands are very often composed of this type of sands (e.a. Allen, 1971; Selley, 1971; Kukal, 1971). Thus our field hypothesis about the eolian origin of the sands is not contradicted by the type of granulometric curve.

a.2. We have combined the different graphic Folk-Ward parameters in all possible ways (fig. 19).

The patterns observed are determined by the narrow range of M_Z and Sk_I values, and the relatively wider range of K_G and σ_I values. So the patterns are horizontal or vertical lines or a cloud of scattered or concentrated points.

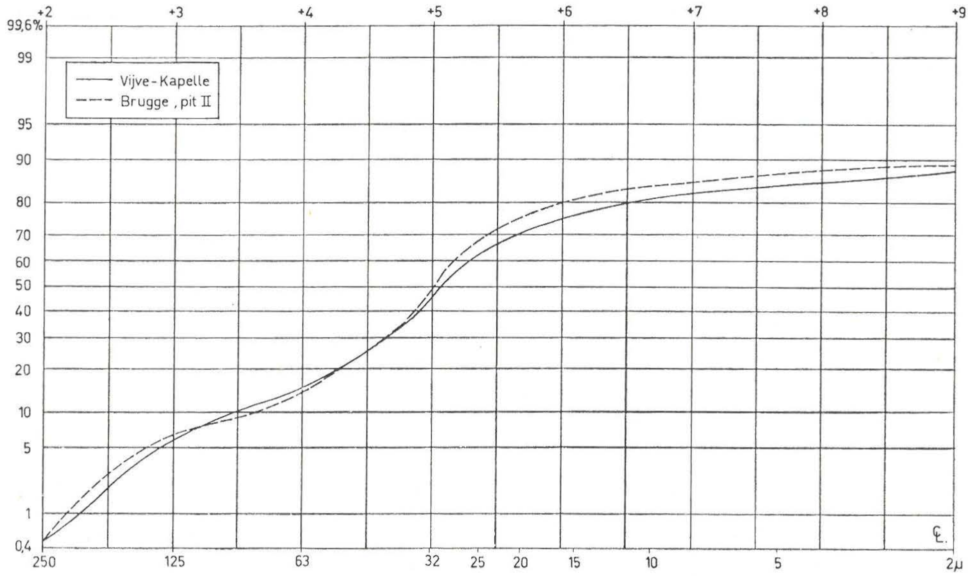


Fig. 15 : Cumulative grain size curves of the siltlayers at Brugge and Vijve-Kapelle
Kumulatieve korrelgrootte-verdelingen van de siltlagen te Brugge en Vijve-Kapelle

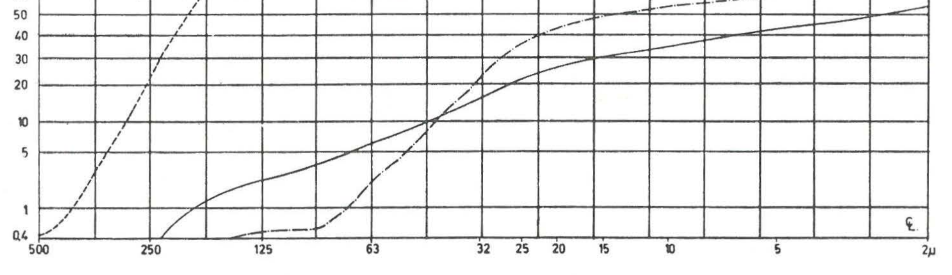


Fig. 16 : Cumulative grain size curves of the Steenbrugge-clay
Kumulatieve korrelgrootte-verdelingen van de Steenbrugge-klei

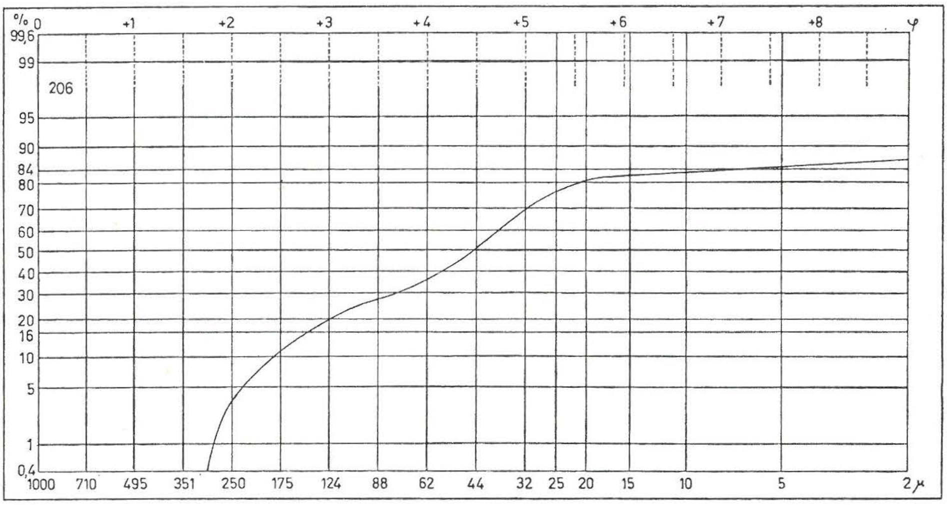


Fig. 17 : Cumulative grain size curve of the clay enrichment zone 206
Kumulatieve korrelgrootte-verdeling van de kleinaanrijkszone 206

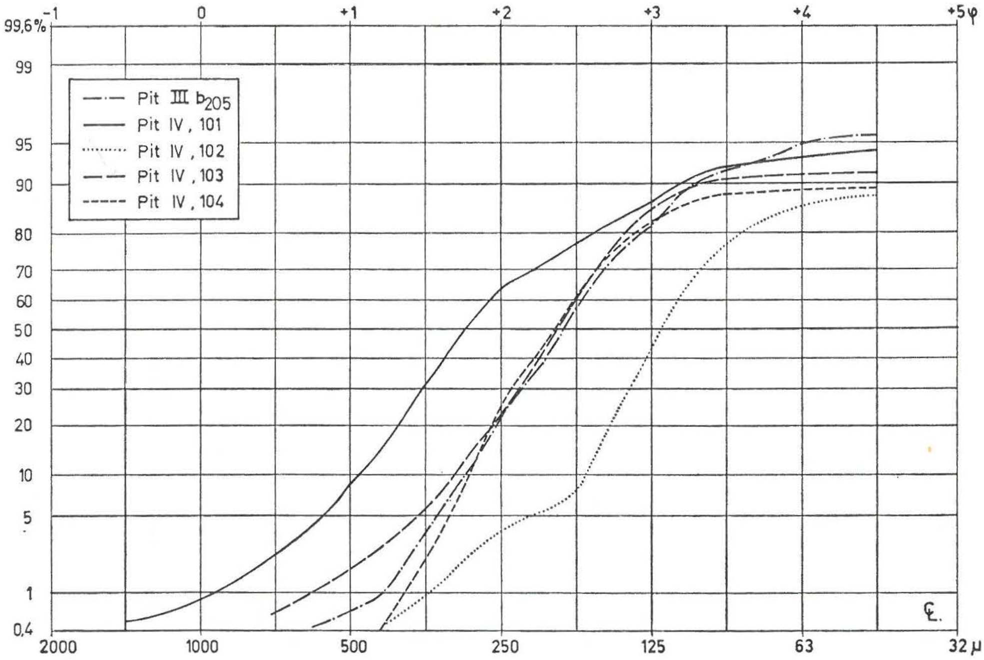


Fig. 18 : Cumulative grain size curves of the glauconitic sands
Kumulatieve korrelgrootte-verdelingen van de glauconiet zanden

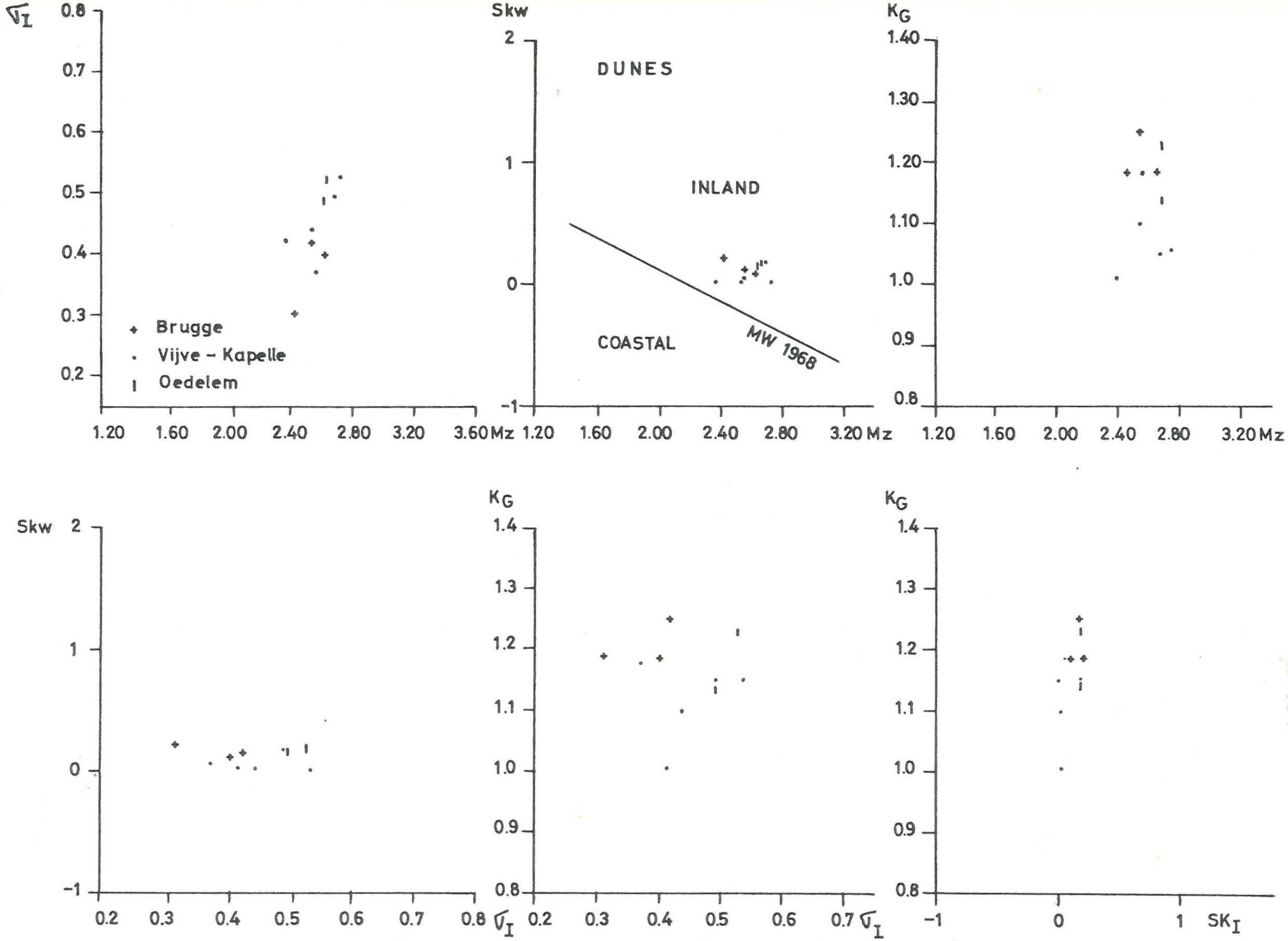


Fig. 19 : Combination of the different Folk-Ward parameters for the eolian top sands
Folk-Ward parameters tegenover elkaar uitgezet van de bovenste eolische zanden

a.3. We payed special attention to the combination Sk and M_Z (fig. 19). Indeed Moiola-Weiser (1968) were able to make a distinction between inland and coastal dunes, based on this diagram. We have plotted their limit in our scatter diagram and may conclude that in this case there is an agreement between our establishment that the dunes are belonging to a row of inland dunes and their granulometric composition as compared to the generally encountered granulometric features of such type of dunes.

a.4. We also compared the granulometry of the light mineral fraction and the heavy mineral fraction. We separated heavy and light minerals from a large quantity of sand from Oedelem and Brugge, and sieved both fractions with a 1 /4 φ interval. From both populations m-statistic mean and standard deviation were calculated.

The ratios of both parameters were plotted on a diagram (fig. 20) (Friedman, 1961, based on Von Engelhard). The separation of eolian and water transport fields in the diagram is explained by the different apparent density of a mineral in water and in air.

Once again granulometric analyses agree with our field hypothesis that the sands have an eolian origin.

Sample	Mean heavy	Mean light	St. dev. heavy	St. dev. light
Oedelem	3,4147	2,8672	0,5277	0,4858
Brugge	3,3466	2,885	0,4785	0,4312

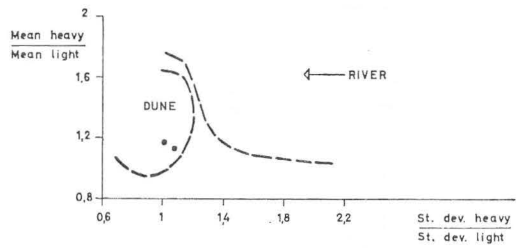


Fig. 20 : Relation between mean and standard deviation of grain size distribution from heavy and light minerals of the eolian top sands
Diagramma van de mean en de standaard-deviatie van de korrelgrootte-verdeling van zware en lichte mineralen van de bovenste eolische zanden

a.5. Buller and McManus (1972) published diagrams based on simple metric arithmetric parameters already proposed by Krumbein (1936). They were able to separate different sedimentary environments, by the slope of the straight lines they fitted through their sample points, plotted in the diagram. The small differences in Md did not permit to construct their Q_{Da}-Md diagram. However the Ska-Q_{Da} diagram (fig. 21) is in accordance with what is expected for eolian sands. The slope is even lower

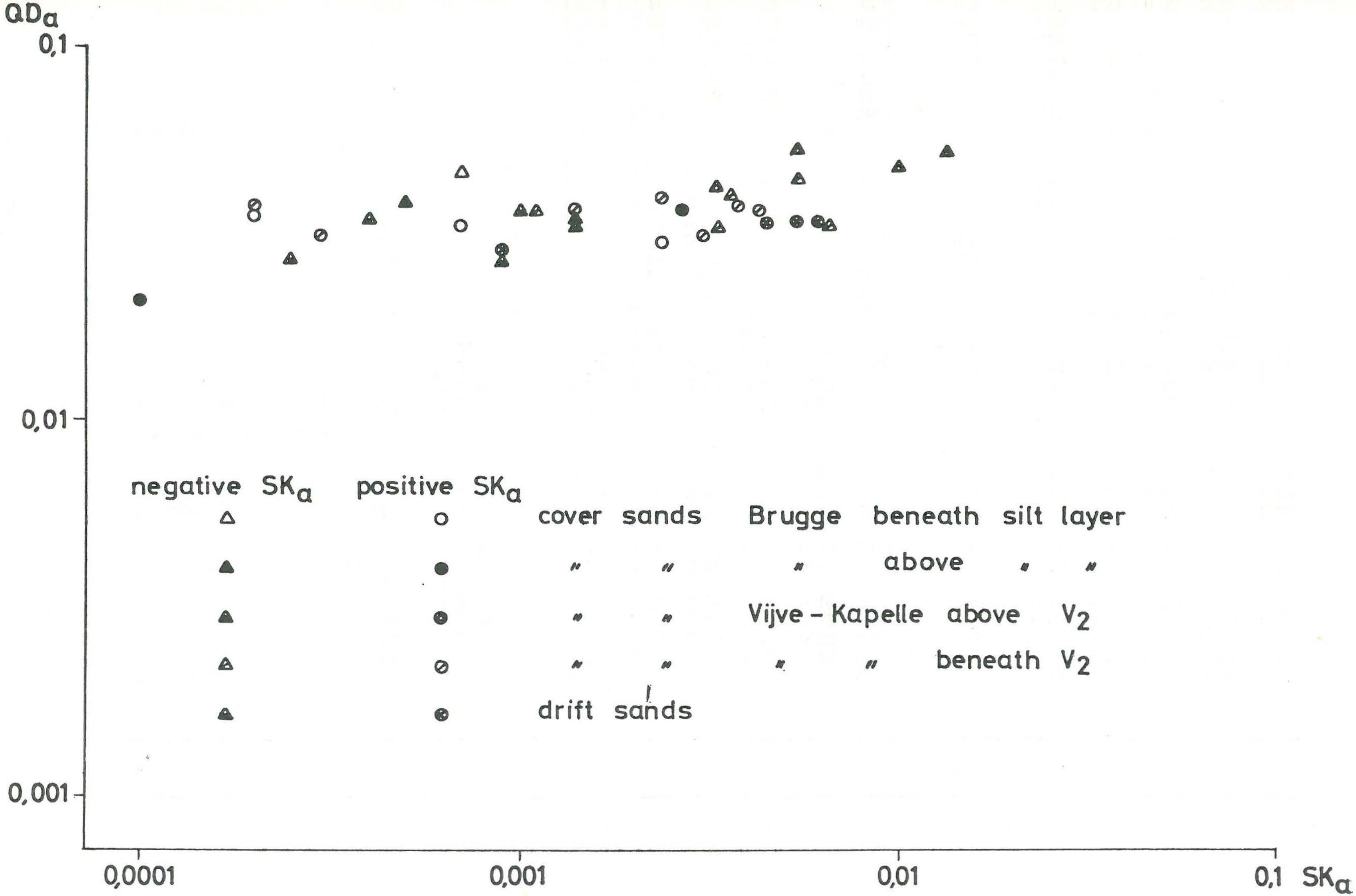


Fig. 21 : Ska-Q_{Da} diagram of the eolian top sands and coversands at Brugge and Vijve-Kapelle
Ska-Q_{Da} diagramma van de bovenste eolische zanden te Brugge en Vijve-Kapelle

TABLE XI

Grain size parameters of the different lithological units

Korrelgrootte-verdelingsparameters van de verschillende lithologische eenheden

Locality	Sample	1	2	3	4	5	6	7	8	9	10	11	12	13
AEOLIAN SANDS														
Vijve-Kapelle	315	2.6	169.6	2.60	2.59	0.35	0.38	26.7	— 0.25	0.11	0.07	0.08	0.90	1.11
	311	2.63	167.8	2.57	2.57	0.42	0.45	33.6	+ 5,5	0	0.13	0.04	0.81	1.16
	312	2.69	146.1	2.75	2.75	0.15	0.53	33.9	+ 6.25	0.05	0.10	0.02	0.85	1.1
	313	2.38	189.5	2.39	2.39	0.41	0.42	38.35	+ 5.45	0.03	0.03	0.02	0.73	1.02
	314	2.62	159.3	2.73	2.70	0.46	0.49	32.9	— 1.40	0.18	0.36	0.19	0.84	1.15
Oedelem	top	2.54	162.7	2.68	2.66	0.47	0.50	33.8	— 0.4	0.13	0.36	0.16	0.85	1.14
	bottom	2.57	162.7	2.70	2.67	0.50	0.53	24.4	— 1.0	0.16	0.40	0.19	0.88	1.23
Brugge	216	2.55	173.7	2.59	2.57	0.41	0.43	28.5	+ 0.9	0.15	0.27	0.15	0.76	1.25
	217	2.60	163.8	2.66	2.65	0.38	0.40	26,6	— 0.9	0.14	0.20	0.13	0.78	1.19
	100	2.40	188.9	2.46	2.45	0.28	0.31	24.8	0	0.16	0.65	0.25	0.95	1.18
NIVEO-FLUVIATILE SANDS														
Vijve-Kapelle	303	2.65	148.7	2.57	2.75	0.54	0.48	31.2	+ 3.1	0	0.08	0.02	0.86	1.14
	304	2.48	164.9	2.62	2.62	0.50	0.52	37.1	+ 3.8	0.05	0.28	0.10	0.80	1.15
	305	2.71	146.1	2.77	2.77	0.51	0.54	35.8	+ 4.3	0.01	0.14	0.03	0.85	1.11
	306	2.45	162.1	2.74	2.7	0.54	0.57	39.7	— 3.6	0.21	0.47	0.23	0.86	1.11
	307	2.68	156.6	2.69	2.69	0.50	0.54	39.1	+ 2.4	0.04	0.27	0.09	0.87	1.06
	308	2.47 (bi)	164.9	2.71	2.67	0.59	0.61	32.6	— 5.4	0.19	0.39	0.20	0.79	1.06
	309	2.71 (bi)	118.7	3.17	3.14	0.62	0.66	35.9	+ 1.4	0.16	0.55	0.23	0.85	1.07
	310	2.69 (tri)	125.0	3.12	3.08	0.60	0.61	26.8	+ 0.2	0.20	0.44	0.23	0.67	0.94
	316	2.72 (tri)	122.4	3.10	3.07	0.52	0.52	31.2	+ 0.3	0.13	0.11	0.10	0.61	0.92
	317	2.46 (bi)	170.8	2.71	2.66	0.46	0.52	32.6	— 6.6	0.34	0.76	0.36	1.01	1.32
	318	2.57	157.2	2.67	2.64	0.45	0.52	32.2	— 3.3	0.21	0.67	0.26	1.15	1.38
	319	2.50 (bi)	153.9	3.13	2.99	0.87	—	50.8	—13.2	0.49	—	—	—	—
	320	(tri)	125.0	3.23	3.15	0.75	—	40.4	— 3.3	0.31	—	—	—	—
	321	(tri)	149.7	3.02	2.93	0.75	—	46.6	—10.0	0.38	—	—	—	—
Brugge	218	—	170.8	2.63	2.60	0.47	0.50	33.0	— 1.4	0.17	0.44	0.20	0.85	1.15
	pit IIIa	—	113.0	3.24	3.21	0.66	—	36.0	+ 2.7	0.15	—	—	—	—
	106	—	89.9	3.66	3.60	0.59	—	21.8	+ 0.1	0.32	—	—	—	—
	105	—	133.0	3,06	3.01	0.66	—	37.7	— 0.5	0.23	—	—	—	—
	219	—	178.0	2.50	2.50	0.45	0.51	27.7	+ 2.4	0.02	0.45	0.12	1.07	1.59
	127	—	153.9	2.84	2.79	0.56	—	35.4	+ 0.2	0.24	—	—	—	—
	110	—	176.8	2.62	2.58	0.62	—	45.4	— 0.7	0.20	—	—	—	—
	220	—	192.1	2.40	2.40	0.34	0.67	32.4	+ 0.7	0.07	2.81	0.33	3.78	2.76

SILT

		1	2	3	4	5	6	7	8	9	10	11	12	13
Vijve-Kapelle	301	—	—	4.86	4.85	2.05	—	—	—	0.01	—	—	—	—
	302	—	—	5.72	5.51	1.62	—	—	—	0.40	—	—	—	—
Brugge	128	—	—	5.37	5.25	1.87	—	—	—	0.20	—	—	—	—
	123	—	—	4.85	4.86	1.90	—	—	—	—0.03	—	—	—	—
	108	—	—	4.47	4.44	1.02	—	—	—	0.10	—	—	—	—
	125	—	—	4.43	4.46	0.80	—	—	—	—0.12	—	—	—	—
	209	—	—	5.36	5.28	2.01	—	—	—	0.11	—	—	—	—
	pit IIIa	—	—	4.05	4.05	1.27	—	—	—	0	—	—	—	—
	210	—	—	5.91	5.68	1.53	—	—	—	0.46	—	—	—	—
	211	—	—	4.62	4.65	1.90	—	—	—	—0.05	—	—	—	—
	212	—	—	5.31	5.20	1.19	—	—	—	0.26	—	—	—	—
	213	—	—	6.33	5.93	1.92	—	—	—	0.63	—	—	—	—
	214	—	—	5.87	5.63	1.52	1.60	—	—	0.49	0.68	0.43	0.81	1.62
	215	—	—	5.28	5.18	2.01	—	—	—	0.15	—	—	—	—
GLAUCONITIC SANDS														
Brugge	104	—	—	2.47	2.43	0.59	—	—	—	0.21	—	—	—	—
	103	—	—	2.40	2.39	0.55	—	—	—	0.05	—	—	—	—
	101	—	—	2.05	1.95	0.80	—	—	—	0.37	—	—	—	—
	102	—	—	3.26	3.20	0.59	—	—	—	0.32	—	—	—	—
	208	—	—	3.19	2.94	1.36	—	—	—	0.54	—	—	—	—
	207	—	—	2.62	2.60	0.38	0.60	—	—	0.12	2.16	0.36	2.57	2.02
	206	—	—	5.54	5.20	2.85	—	—	—	0.36	—	—	—	—
	205	—	—	2.47	2.46	0.57	0.67	—	—	0.09	0.73	0.21	1.20	1.42

Legende

1. Mode (phi)

2. Median (micron) (Md)

3. Mean $\frac{\varphi 84 + \varphi 16}{2}$ (phi)

4. Mean $\frac{\varphi 16 + \varphi 50 + \varphi 84}{3}$ (phi) (Mz)

5. Standard deviation $\frac{\varphi 84 - \varphi 16}{2}$ (phi)

6. Standard deviation $\frac{\varphi 84 - \varphi 16}{4} + \frac{\varphi 95 - \varphi 5}{6.6}$ (phi) (σ_I)

7. Arithmetic quartile deviation $\frac{Q3 - Q1}{2}$ (micron) (Qda)

8. Quartile skewness $\frac{Q_3 - Q_1 - 2Md}{2}$ (micron) (Ska)

9. 'Central' skewness $\frac{\varphi 84 + \varphi 16 - 2\,\varphi 50}{\varphi 84 + \varphi 16}$ (phi)

10. 'Extreme' skewness $\frac{\varphi 95 + \varphi 5 - 2\,\varphi 50}{\varphi 84 - \varphi 16}$ (phi)

11. Skewness $\frac{\varphi 16 + \varphi 84 - 2\,\varphi 50}{2(\varphi 84 - \varphi 16)} + \frac{\varphi 5 + \varphi 95 - 2\,\varphi 50}{2(\varphi 95 - \varphi 5)}$ (phi) (Sk_I)

12. Kurtosis $\frac{\frac{\varphi 16 - \varphi 5}{2} + \frac{\varphi 95 - \varphi 84}{2}}{\text{stand. dev. (5)}}$

13. Kurtosis $\frac{\varphi 95 - \varphi 5}{2.44\,(\varphi 75 - \varphi 25)}$ (K_G)

than that found in the sample of Buller and McManus. We also plotted in the same diagram the lines for the cover sands in Brugge and Vijve-Kapelle. They also show the low slope said to be typical for eolian sands.

II. Coversands (fig. 12 and 13)

a. As was shown on the diagram of Buller and McManus these coversands show a slope typical of eolian transported sands. In addition, the scatter diagrams of the combination of the different Folk and Ward graphic parameters show a grouping of points very similar to those of the uppermost eolian sands (fig. 22).

b. Considering these graphic parameter diagrams more accurately, we can establish several 'trend' differences between the uppermost sands and the underlying sands. In order of decreasing importance :
— the sorting of the drift sands becomes better
— the mean of the drift sands becomes shifted to slightly coarser values (micron)
— the skewness becomes more negative in the drift sands.
Undoubtedly these phenomena are related to a decrease of 'finer than 62 μ' material in the drift sands.

c. Indeed a plot of silt + clay content versus modal size produces a net separation between the pleistocene eolian sands and their drift sand relatives (fig. 23). The decrease in silt + clay content in the drift sands is not a sudden phenomenon. Indeed table XII shows that the decrease is rather

TABLE XII

Average values of percentage < 50 μ and presence of pebbles in coversands at Vijve-Kapelle

Gemiddelde waarden van de percenten < 50 μ en de aanwezigheid van keitjes in de dekzanden te Vijve-Kapelle

Lithological units at Vijve-Kapelle	Number of samples	Number of samples containing pebbles	Average values % < 50 μ
Uppermost yellow sands	4	—	1.8
(peat V_1)			
Niveo-fluviatile sands	11	6	2.9
(pebble layer PB_1)			
Niveo-fluviatile sands	3	1	3.5
(pebble layer PB_2)			
Silty zone	2	0	25
(peat V_2)			
Niveo-fluviatile sands	2	2	12
Silt layer	2	—	70.5
Niveo-fluviatile sands (320)	1	1	12
(peat V_4)			
Niveo-fluviatile sands (321)	1	1	9

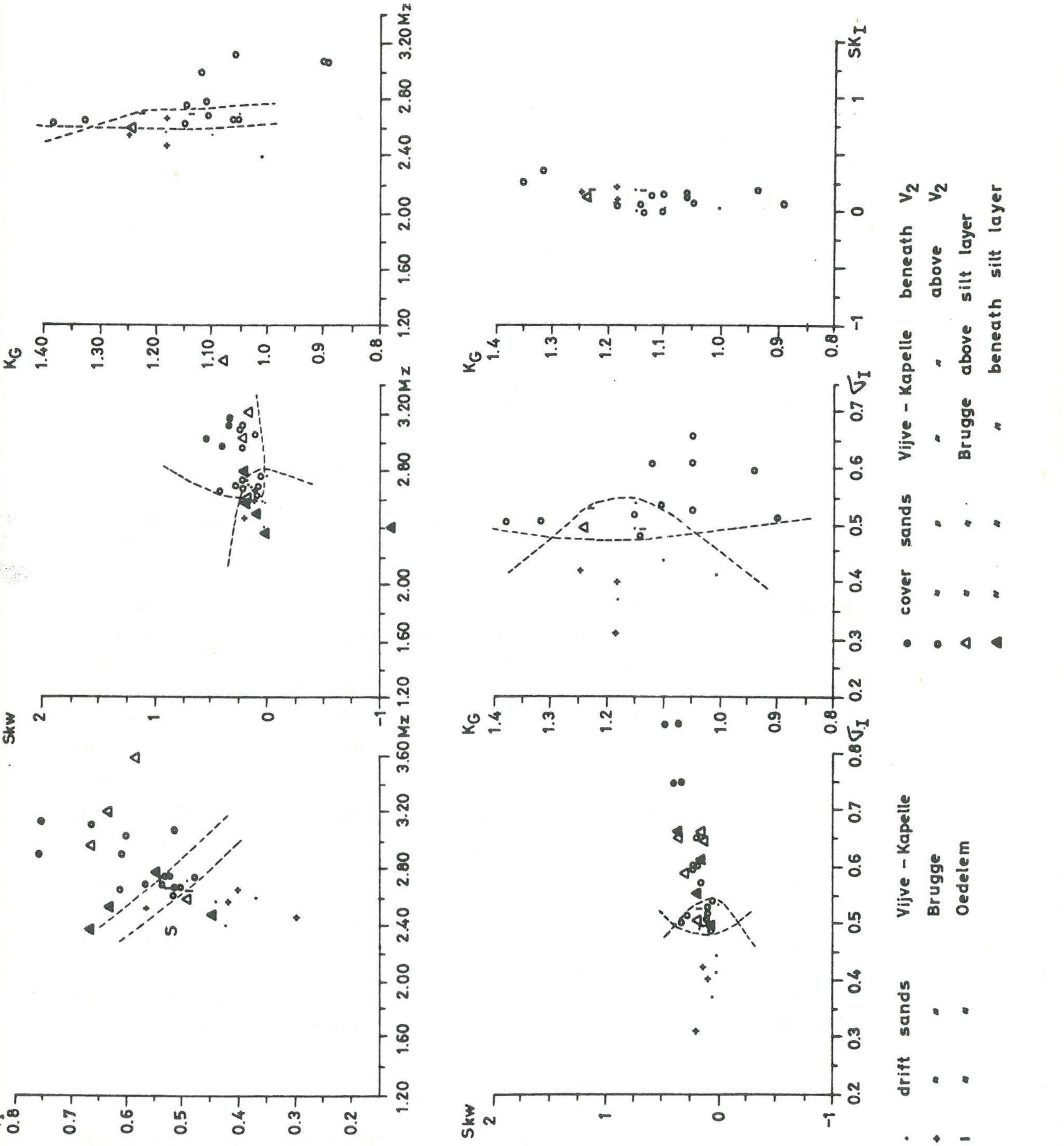


Fig. 22 : Combination of the different Folk-Ward parameters of the coversands
Folk-Ward parameters van de dekzanden tegenover elkaar uitgezet

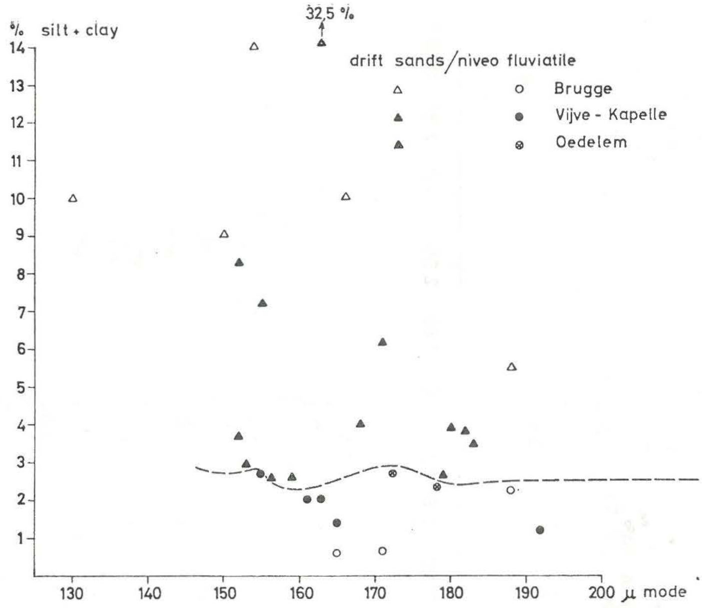


Fig. 23 : Silt and clay content versus modal size of drift- and coversands
Silt- en kleigehalte tegenover modale korrelgrootte van duinzanden en dekzanden

gradual, except for the essentially silty layers. This means that the drift phenomenon is a phenomenon that already started before the formation of peat C and peat V_1. This gradual change in granulometry from beneath the profile up to the top in Vijve-Kapelle is especially clear from scatter diagrams Sk_I/Mz and σ_I/Mz (fig. 22). The mean modal and mean size tend to be smaller in the pleistocene eolian sands than in the drift sands. This is shown on table XIII.

d. In table XII the number of samples containing pebbles is indicated. The common presence of pebbles justifies the term niveo-fluviatile.

e. When considering the first percentile C as an indicator of maximal transport capacity (Passega, 1957) we find that in Vijve-Kapelle and Oedelem the drift sands (table XIV) show distinctly higher capacity than the pleistocene eolian sands.

The sands in Brugge show the inverse phenomenon, when on the contrary the increase of modal size in the drift sands was evident.

III. The silt layer (Vijve-Kapelle, Brugge) (fig. 15)

Compared with a typical eolian löss granulometric composition (Fink, Nestroi, 1967) several of our samples contain too much sand. This high sand content was to be expected as our field observations already showed

TABLE XIII

Average sand content and modal size of driftsands and coversands
Gemiddeld zandgehalte en modale korrelgrootte van de stuif- en dekzanden

	Number of samples	Average % <62 μ %	Extreme values %	Average modal size μ	Extreme values μ
DRIFT SANDS					
Vijve-Kapelle	5	1.9	(1.2 — 2.7)	167	(155 — 192)
Oedelem	2	2.5	(2.3 — 2.7)	170	(168 — 172)
Brugge	3	1.2	(0.6 — 2.3)	174	(165 — 188)
COVERSANDS					
Vijve-Kapelle	12	4.2	(2.6 — 8.3)	167	(152 — 182)
Oedelem	1	32.5	—	163	—
Brugge	5	9.7	(5.5 — 14.0)	157	(130 — 188)

TABLE XIV

The mean and extreme first percentile values of the drift- and coversands
De gemiddelde en extreme waarden van de eerste percentiel van de stuifzanden en de dekzanden

Locality	Number of samples	Coversands	Number of samples	Drift sands
Brugge	3	351 μ (308-400)	2	304 μ (281-328)
Vijve-Kapelle	13	335 μ (297-412)	5	358 μ (312-417)
Oedelem	2	287 μ	2	345 μ (337-354)

small lenses of sandy material, pointing to a reworking of the material by water. This reworking is proved also by the presence of small pebbles found in the coarsest sieves of samples 123 and 122. However, although water action is thus proved, the clay content still remains low and always below the limit of 25 % proposed by Nestroi and Fink (*op. cit.*).

The modal size of the silt fraction corresponds also with that found in typical Belgian löss material (Gullentops, 1954; Pissart, Paepe, Bourguignon, 1969). Pissart e.a. (1969) stated also that the Krumbein Q_D φ sorting measure for pure eolian material varied between 0.38 and 1.68 φ.

Our results are given in table XV.

We can conclude that the granulometry of these silts shows their eolian origin and their mixing with local material by water action. In all the samples this local material is sand, except in sample 122, when on the contrary the normal clay content has doubled. Sample 122 has a Q_d φ that points to a non-pure eolian origin as well.

TABLE XV

Grain size characteristics of the siltlayer
Korrelgrootte eigenschappen van de siltlaag

Locality	Sample	Number of samples	% >62 μ	% silt	% <2 μ
Brugge					
Pit IV	128	1	22.3	65	12.7
	123	1	24.9	64	11.1
	122	1	9.7	66	24,3
Silt layer in					
Pit I		1	35.1	54.2	10.7
II		4	14.6	75.2	10.2
IIIa		1	49.3	44.4	6.3
IIIb		2	9.6	80.2	10.2
IV		2	32.3	60	7.7
Vijve-Kapelle					
Silt layer	302	1	14.7	72.3	13
	301	1	33.5	55.5	11

Locality	Sample	Modal size of the silt μ	Qd phi (Krumbein)
Vijve-Kapelle	302	30	0.75
Brugge Pit I	211	32	1.17
Pit II	212	31.9	0.57
Pit II	213	32.8	1.
Pit II	214	29.2	0.7
Pit II	215	32	0.8
Pit IV	122	29.2	2.
Pit IV	123	33.3	0.77
Pit IV	125	34.7	0.5
Pit IV	128	30	0.77

IV. The Eemian clay layers

The remnants of life in the sediments and the sedimentary structures are much more powerfull indicators of the paleo-environment of the clay layer than granulometry can be. However, we give a figure (fig. 16) and a table with the most important granulometric features of the sediment (table XVI).

TABLE XVI

Grain size characteristics of the Steenbrugge-clay
Korrelgrootte eigenschappen van de Steenbrugge-klei

Clay layer					
Pit	Samples	% >62 μ	% silt	% <2 μ	Modal size μ
IIIb	top	21	54.8	24.2	53
	bottom	74.4	nb	nb	220
IV	(131)	2.1	64.2	33.7	29.6
	(130)	6.3	47,1	464.6	26.3
	(129)	2.2	59.2	38,6	29.6

We note that variations in sand content are dependent on the sampling method, as sandy laminations are present. This is certainly true for sample 130.

However, the sandier clay in pit III_b must be seen as a coarser lateral equivalent of the clay in pit IV.

V. Glauconite sands

a. The presence of burrows has indicated the paleo-environment more clearly than granulometry. For descriptive aims we calculated the graphic parameters and have plotted these parameters in several scatter diagrams. No further conclusions could be drawn from these data.

b. The question remained whether the uppermost whitish sands with concentrated pebbles at the base, belong to the same group as the underlying glauconitic units or whether they represent a different sedimentation phase.

An inspection of the cumulative diagrams (fig. 18) clearly shows that the white sands (205) have a very close relationship with samples 103 and 104. However the clay enrichment zone (206) has a cumulative curve (fig. 17) quite different from the other samples. A new, essentially coarse silt population is mixed with the original sands. This points to an at least partly new source area or a new depositional environment.

c. The clay content in the zone 206 amounts to about 15 %; this means an absolute enrichment of about 10 % with regard to the other samples. As the clay is green it is clearly derived from glauconite decomposition.
It can have been leached out from the clayless white overlying sands or it can represent an in situ decomposition of glauconite. The latter hypothesis is supported by the absence of glauconite grains in sample 206 (see light mineral analysis, table XVII).

D. MINERALOGICAL ANALYSES

a. *Method*

The fraction between 250 and 44 micron has been investigated. The heavy fraction was separated by bromoform. About 200 transparent heavy minerals were counted in each sample; for about half of the samples the grain size of the heavy minerals was measured.

The light minerals were immersed in an oil with refractive index 1,544 and 200 grains were counted in each slide.

b. *Results*

The results are given in table XVII.

The reader is referred to table XI and fig. 12-18 which contain information about the granulometric characteristics of the samples.

c. *Discussion of the results*

c.1. Heavy minerals

— The heavy mineral content of the reworked glauconitic sands is low with regard to all the overlying deposits. The opaque and altered heavy minerals differ between the same groups as well. In the unaltered glauconitic sands the altered minerals have not the saussurite character whilst this saussurite is common in sample 206 and the overlying deposits. Remarkable are samples 205 and 206 which contain amounts of altered, transparent and opaque minerals ranging between the amounts of the underlying glauconitic sands and the overlying sediments. Sample 110 and 123 show the same intermediate amount but only for the opaque minerals.
— Tourmaline is present in distinctly higher amounts in the glauconitic sands than in the overlying sediments. Sample 206 has a tourmaline

TABLE XVII

Mineralogical analyses
Mineralogische analyses

	Sample	% quartz	% feldspar	% glauconite	% heavy min.	% opaque	% transparent	% altered	chloritoide	garnet	tourmaline	zircon	rutile	sphène	anatase	staurolite	kyanite	andalousite	epidote group	hornblende	augite
Eolian yellow sands																					
Oedelem					0.6	15.5	64.5	20	—	36	7.5	1.5	2	—	—	4.5	0.5	—	39	8.5	—
Brugge			n.d.		0.5	20.5	59.5	20	—	27	7	7	2.5	—	—	3.2	0.7	—	44	6.5	—
Vijve-Kapelle					0.2	16.5	48	36	—	43.5	11.5	3	0.3	—	—	6	—	—	29	6.5	—
Niveo-fluviatile sands	316				1.25	16.5	76.5	7	1.4	39.8	4.3	18	2.4	—	0.9	3.8	0.5	—	21.3	6.6	—
and silts (Würm)	317				0.7	17.5	70	12.5	—	28.8	5.5	2.7	1.8	—	—	4.1	—	0.9	42.5	13.2	—
Vijve-Kapelle	302		n. d.		0.68	31.1	58.2	10.7	—	19.5	6.3	5.2	1.1	—	—	1.1	0.6	—	51.7	13.8	—
	320				0.8	19	75	6	—	22.9	5.3	13.2	3.1	—	0.9	2.6	0.9	0.5	38.3	12.3	—
	321				1	19	71.5	9.5	—	33	6.1	13.7	4.2	—	—	2.8	—	—	30.7	8.5	—
Niveo-fluviatile sands	105	86	13	1	0.6	22.4	63	14.6	1.7	33.9	9	9.6	1	0.5	2.8	2.3	0.6	—	22.6	14.1	0.5
and silts (Würm)	408	86	14	—	0.3	19.3	58.5	22.2	—	14.7	7.35	4	3	0.5	1	2	—	0.5	40.7	24.5	1
Brugge	125	87	13	—	1.2	19.3	70.8	9.9	—	19.2	4.8	4.8	2.4	1.5	3.4	2.9	—	—	34.1	25.5	1.5
	213	78	17	5	1.3	16.3	76.6	7.1	—	14.1	5.6	11.3	3.8	0.5	5.2	0.5	1.4		35.7	21.6	0.5
	110	97	3	—	0.3	35.2	55.5	9.3	—	28.7	16.7	7.2	3.3	0.5	3.3	7.6	4.8	2	18.7	6.7	0.5
	123	92	8	—	0.4	34.2	50.2	15.6	—	25.2	14.1	13.7	4.9	—	2.2	4	1.3	2.2	19	12.8	0.5
	109	80	14	6	0.1	16	68.5	15.5	—	26.1	10.8	8.9	3.9	—	1.5	8.4	2	3.5	25.6	9.(	—
	120	84	15	1	0.4	22.5	71.1	6.4	—	18.7	11	3.8	2.4	—	1.9	3.8	—	—	34.1	24	—
	220		n. d.		0.4	19	67	14	—	35.9	22.3	2.3	—	—	0.5	8.2	0.9	0.5	25	3.2	—
Eemian	131	84	15	1	0.9	27.5	63.5	9	—	11.8	9	7.1	7	0.5	6.6	1.9	—	—	33	22.7	0.5
	130	80	18	2	0.9	28.1	59.3	12.6	—	17.3	8.7	11.9	1	0.5	8.2	0.9	—	—	33.8	17.8	—
	129	78	20	2	0.4	25.9	65.2	8.9	—	12.7	9.8	7.8	5.9	0.5	4.4	2	1.5	—	31.4	23	1
	IIIb		n. d.		0.16	29.7	61.6	8.7	—	32.7	22.3	11.8	1.4	—	—	5	1.4	—	22.7	1.4	—
top	205		n. d.		0.1	45.6	48.8	5.6	—	33.1	16.6	9.8	2.4	—	3.7	5.6	3.1	1.8	19	4.9	—
	206	90	10	—	0.25	36.1	55.7	8.2	—	21.7	5.6	16.2	9.2	1.4	3.7	3.2	1.8	—	27.3	9.7	—
Glauconitic sands																					
changed	102		n. d.		0.12	69.5	26.7	3.8	—	17.8	14.6	29.3	9.9	—	5.8	4.2	7.8	0.5	9.9	—	—
	207	92	3	5	0.1	44.6	52.5	2.9	—	12.1	36.9	9.8	7.9	0.5	1.8	4.7	3.7	7.9	9.3	4.2	1
	104		n. d.		0.03	62.5	35	2.5	—	4	40	12	11	—	2	5	7	9	10	—	—
	208	79	6	15	0.2	59.7	44.4	5.9	—	15.7	22.2	23.3	4.6	0.5	5.5	7.4	3.7	2.8	13	2.3	—

content much too low with respect to the underlying glauconitic sands. The Weichselian sands and silts, as well as the Eemian clay and Holocene drift sands contain tourmaline, derived from the glauconitic sands. Indeed this tourmaline is a typical large, rather rounded orange-brown tourmaline. The other tourmalines are rather dark greenish brown, more prismatic and smaller as well. Consequently tourmaline fluctuations will depend at least partly, on differences in granulometric composition (compare the sandy Eemian clay with the clayey samples 129, 130, 131). However the general decrease in tourmaline content from the glauconitic sands towards the top of the profile shows the diminishing importance of the tertiary source, while this diminishing importance of tertiary source material is shown by the rutile variation as well.

— The garnets are present in smaller amounts in the glauconitic sands than in the overlying sediments. Samples 206 and 205 are much closer related to the overlying sediment than to the unchanged glauconitic sands. The garnets are associated with coarser grain sizes. This granulometric dependence explains the variation in the Eemian samples.

— The amount of metamorphic minerals (staurolite - kyanite - andalousite) is larger in the glauconitic sands than in the overlying deposits. Samples 206 and 205 occupy an intermediate position, whilst samples 109, 123-110 show amounts somewhat lower but very close to the amount in the glauconitic sands. These minerals are all concentrated in the coarse grain size. This explains some low values, especially those of the Eemian clay samples 129-130-131.

— In the epidote group, grains of coloured epidote, colourless epidote and zoïsite are grouped together. There is a very clear separation between the unaltered glauconitic sands and the overlying sediments. The top of the glauconitic sands (205, 106) and the samples 110 and 123 occupy intermediate positions.

— The hornblende content is distinctly higher in the top of the glauconitic sands and the overlying deposits as in the unchanged glauconitic sands.

c.2. The light minerals

All Eemian and Weichselian deposits are characterized by higher feldspar content than the unchanged glauconitic sands. The top of the glauconitic sands occupies an intermediate position. The difference between these top sands and the underlying sands is also stressed by the absence of glauconite in sample 206. Samples 110 and 123 show feldspar values as low as those in the unchanged glauconitic sands.

c.3. Conclusions

c.3.1. The unchanged glauconitic sands are clearly related to a tertiary source rock with a typical B-province composition (see also Tavernier, 1946). The low feldspar content is normal in this type of tertiary material. These glauconitic sands represent a reworking of the local tertiary substratum.

c.3.2. From the Eemian clay on, a new source of material existed, characterized by higher amounts of heavy minerals. Consequently a decrease of minerals herited from the local tertiary substratum is seen. They are replaced by a garnet — epidote — hornblende and saussurite association. This shows that both, the marine Eemian and the mainly eolian Weichselian sediments got a new source of A-province material. This association is characterized by a relatively high feldspar content.

c.3.3. The top of the glauconitic sands clearly represents a mixed horizon as is shown by both the light and the heavy mineral associations. This means that in this horizon the new A-province material appears for the first time, carried on by an eolian or (more probably) a pure marine process.

c.3.4. It is striking that in the Weichselian deposits some horizons (110 and 123) occur which have a light and heavy mineral composition resembling very closely that of the glauconitic sands. Such a horizon represents a period or a micro-environment where the influence of the tertiary substratum dominated that of the new A-province source. This means that the balance between local erosion and eolian supply was in favour of the former.

III. LITHO- AND CHRONOSTRATIGRAPHY

A. LITHOSTRATIGRAPHY

In order to establish a stratigraphy of the observed sections a lithostratigraphic subdivision has to be constructed first.

1. The Holland-peat member

The surface peat B, which covers the dune sands, comprises at the rim of the coastal plain, the junction of a lower peat, known as ,,veen op grote diepte'' and an upper peat, known as ,,oppervlakteveen''. It is lithologically sufficiently characterized to correlate it with the same unit in the Netherlands where it has been named *Holland Peat Member* (see J. D. de Jong, 1971).

It could only be argued that this unit is sufficiently important to rank as a Formation with essentially two mappable subunits which would than be members. As our profiles however are not in a suitable situation to establish these formal units we adapt the unchanged terminology of the Netherlands.

2. The Beerse Formation

The sands A at the top of the profiles are part of a mappable unit of inland dune sands in which J. De Ploey (1961) distinguished three formations. In our profiles the yellowish sands start in the Tardiglacial and end with a complete podzol profile which allows us to correlate them with certainty, with the lowest unit : the Formation of Beerse.

All these inland dune sands could be united in one Formation name, the units being of a lower rank, namely members.

The peat C, of Bølling age, is found elsewhere (Paulissen and Munaut, 1969) immediately after the beginning of the Tardiglacial dune-formation. The corresponding soil has there been called the Opgrimbie Soil, which has bed rank; a corresponding peat has been named Stabroek Soil by R. Paepe (1967) on the basis of a publication by F. Gregus et al. (1966). At Stabroek however this was a peat layer and not a real soil.

These uppermost, yellow sands are belonging to an E-W trending dune belt, expressed as a morphological entity in the landscape between Brugge and Stekene.

3. The Waardamme River-bed

The riverchannel D of our description is a fluviatile infilling of a deep erosion-channel, the direction of which could be established. We concluded that these fluviatile sands were a deposit of a prior Waardamme river.

The erosion takes place after the formation of the Bølling-peat, and the sedimentation of a first dunal sand layer, which can be placed in the older Dryas. This makes it extremely probable that the erosion took place during the Alleröd.

A tendency for vertical erosion of the rivers during the short, but important, climatic amelioration of the Alleröd can be explained by several causes :

a. Soil fixation by a first forest vegetation which brought to an end the strong eolian activity and diminished the run off, thus drastically reducing the load of the rivers.

b. The disappearing of permafrost, increasing percolation and changing areal run-off into concentrated gullies.

Concentrated flow and reduced load initiated vertical erosion.

c. This was at the same time favoured, but not caused, by a still lower sea level position.

After a vertical erosion of more than 4 m the channel was filled with coarse crossbedded fluviatile sands and reworked plant remains. We assume that this filling up must have taken place at the end of the Alleröd or in the beginning of the Late Dryas.

As fluviatile deposits of this age are rather common and may be mappable, we propose to give them a lithological unit-name : the Waardamme River-bed.

The datation of the Waardamme River-bed allows to situate more precisely the important overlying dune sands in the Late Dryas and the Preboreal.

4. The Wildert Formation

Under the Beerse-Formation exists in the profiles a complex in the description named : „sands beneath the peat layer''.

From the base to the top the following succession can be distinguished correlating all our profiles :

1. laminated sands with some silt intercalation containing mollusc-fauna of toundra conditions
2. at their top large frostwedges superposed by a cryoturbated V_2 peat horizon, with very cold toundra vegetation
3. Fluviatile channeling, covered with a pebble layer PB2

4. laminated coversands, ending with formation of deep but fine frost-wedges and cut off by a new pebble layer PB_1
5. just above this gravel a characteristic peat seam V_{2a} with indication of a warmer oscillation.
6. Finally a very general, homogeneous coversand horizon ends the complex.

This lithological complex is dominated by the presence of coversands, with typical grainsize, mineralogical and structural characteristics, mixed with subsidiary waterlaid deposits.

A similar complex, consisting of even finer coversands, was named Formation of Wildert by De Ploey (1961). Although the facies characteristics are slightly different and point towards somewhat wetter environment in the low lying plain of Brugge, we see no valid reason not to use here the formal name proposed by De Ploey.

They are known as Older Coversands in the Netherlands, recently named Lutterzand Member (Vander Hammen et al., 1971) and grouped as „coversands" by Paepe and Van Hoorne, 1967).

This Formation has been divided (Vander Hammen, 1967) into the coversands 1 and 2 by the Beuningen gravel. The more general occurrence of our gravel accompanied by the characteristic frost wedges (Paepe, 1972) makes it most probable that this gravel (PB_1) corresponds to the Beuningen gravel.

The lower coversands here contain more information than described until now. We find however that more profiles have to be analysed to give formal names to these horizons. We propose one exception for the peaty layer V_{2a} overlying the gravel at the base of the uppermost coversands. This warm oscillation is sufficiently important as a markerbed : Kathelijne-bed and Kathelijne-oscillation.

5. The laminated sands and silts

Beneath the „coversands" we described silt horizon F and the lower laminated sands ans silts G. These layers can be grouped, because the more silty character distinguishes them strikingly from the upper coversands. Furthermore they contain a peat layer, and several of the silt horizons are very peaty. Small frostwedges occur throughout the formation.

This corresponds with the lithological characteristics of the „peaty loam formations" of Paepe(1967) and the Loamy Beds and Peat of Vander-Hammen (1967). The only regularly nominated formation is the one introduced by De Ploey (1961) as Formation of St-Lenaarts. However, the lithological characteristics of this type-unit are much more sandy. Peat layers do exist with numerous cryoturbations and De Ploey signalises exceptionally one silt horizon. Our profile can be a lateral more silty facies of the St-Lenaarts-Formation. As it is not clear yet how much lithological variation is allowed in a Formation, we keep this unit in our profiles under a descriptive heading.

6. The Steenbrugge Member

A very important lithologic unit is the underlying Clay Layer H. Its lithology, structures, faunal and floral content shows that the sedimentation of this clay took place in a brackish tidal marsh or lagoonal environment. The palynological analysis showed the Eemian age, zone 4b. The clay is then part of the marine Oostende-Formation. Its importance and its specific lithological character merits the introduction of a new lithological unit name of member status : the Steenbrugge Member, locality near the excavation-site.

During the mineralogical investigation of this clay it was found to be rich in diatom skeletons. Samples of the clay layer were submitted to Dr. R. Clarysse for study of its diatom-contents. The results are reproduced in extenso in an appendix.

It was proved that from the top to 135 cm, and at the base, the deposition environment had a marine character. The fresh water influence was most important at 160 cm and the sediments between 175 en 135 cm were deposited in a brackish environment.

7. The glauconitic sands

In the sandy unit occuring under the Steenbrugge clay can be distinguished from base to top :

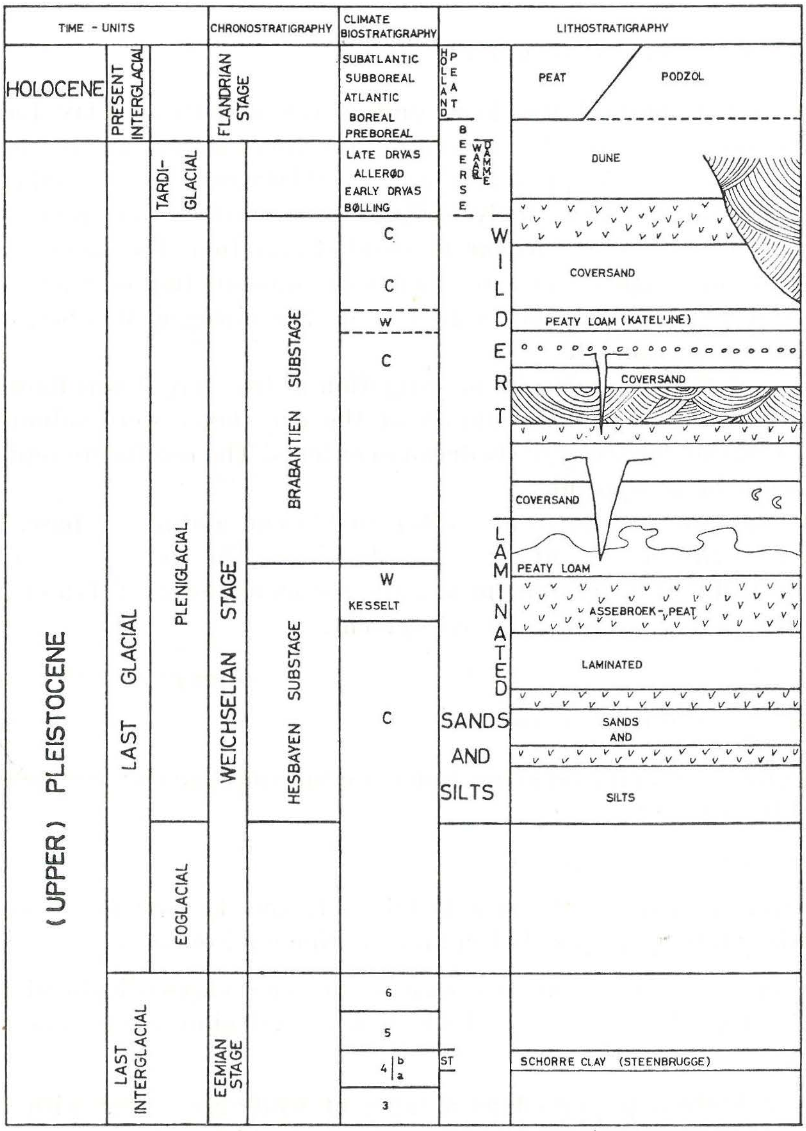
1. a pleistocene base gravel
2. glauconitic sands, with crossbedding, I_1 and I_2, essentially reworked tertiary minerals deposited in an estuarine environment
3. clayey glauconitic sand (I_3) with a deformed clay-enrichment horizon at the top, the mineralogy of which show arrival of a new mineralogical suite
4. a soil horizon preserved as a layer of white-grey sand with pebbles essentially at the base, the mineralogy of which is the same as at the top of I_3.

The succession can best be interpreted as a fluvial or estuarine environment followed by a progression of a marine beach which emerged for a short period, during which a soil formation took place and finally

TABLE XVIII

Correlation between the lithostratigraphic units and the chronostratigraphic sequence in Western Europe

Korrelatie tussen de lithostratigrafische eenheden en de chronostratigrafische opeenvolging in West-Europa



followed by the deposition of the Brugge salt marsh clay. In this case the glauconitic sands are part of the Oostende Formation.

However the interpretation of the deformed glauconitic clay is not clear and in one hypothesis it could be due to cryoturbation prior to the Brugge-clay.

This uncertainty and the fact that a probably similar soil has been signalized by Paepe and Van Hoorne (1972) at another locality induced us not to give any formal new names to these sands, however important.

B. CHRONOSTRATIGRAPHY

Here we comment the table XVIII which brings the general correlation of the lithostratigraphic units with actual chronostratigraphic sequence in W-Europe on the basis of all elements with paleo-climatological significance as floral and faunal variations, sedimentological, pedological and geomorphological indications aided by C_{14} determinations.

During the Holocene the Flandrian stage is represented by the very end of the dune building (Beerse Member) followed by practically continuous peat growth in the topographical depressions and by soil formation in the higher parts.

The last Glacial has been very generally divided in W-Europe in Eoglacial (Frühglacial, Early Glacial, Eowürm), Pleniglacial and Tardiglacial.

Concerning the Tardiglacial substage of the Weichselian we follow the sound proposal of Vander Hammen (1951) to put its beginning at the former I_6, Bølling oscillation which is situated in our peat C.

In the Netherlands and Belgium the Pleniglacial has recently been divided into three parts.

We prefer to follow here the two-fold division from F. Gullentops (1954) in the substages Brabantien and Hesbayen, the last one ending with the Kesselt soil.

The Brabantien is represented by the Wildert Formation consisting essentially of coversands deposited in rather dry toundra conditions, with periods of frostwedges, deflation, and very cold flora and fauna.

The Katelijne peat represents an important warmer oscillation but without C^{14}-datation we have no definite arguments to correlate it with one of the oscillations described as Laugerie or Lascaux (Leroi-Gourhan, 1968; Bastin, 1971).

The Hesbayen comprises all the sediments grouped as laminated sands and silts deposited in rather humid subarctic conditions as indicated by the laminated sediments, the cryoturbations and the peatlayers which we do not consider as the result of climatological oscillations but of favourable edaphological conditions.

Near the top however occurs the warm Assebroek peat which we correlate, without definite C^{14} proof, with the Kesselt soil and Denekamp peat, being the major warm sub-division of the Pleniglacial at the end of the Hesbayian.

The next layer, the clay of Steenbrugge, a typical schorre-clay, can be correlated on palynological grounds with zone 4b of the Eemian stage.

This is remarkable because any other deposits of the later phases of the Eemian and of the Eoglacial are lacking. This timespan must be represented by the erosion-hyathus at the top of the clay.

We have no definite arguments for a chronostratigraphical attribution of the underlying glauconitic sands with their final soil formation. The most reasonable correlation is to attribute them to the earlier Eemian.

Interpretation of North Atlantic deep-sea cores by McIntyre and Ruddiman (1972) and by Sancetta et alt (1972) shows the existence in the Eemian of three warm phases separated by two rather cold intervals. When interpreted in this sense the profile described here would indicate that the Eemian is much more complicated than hitherto accepted. The Steenbrugge Member would then be representative of the last warm phase of the Eemian, the glauconitic sands of an earlier warm phase. The soil-formation on top of these sands could then be explained as an emersion due to a cold interval leading to an inter-Eemian cryoturbation. Much new observations will be needed before these hypotheses become real interpretations and before is understood what happened during this approximately 50.000 year long interglacial.

IV. PALEOGEOGRAPHICAL CONCLUSIONS

The three excavation sites are situated just to the north of the hills of „Binnen-Vlaanderen".

The sediments at Brugge are deposited at the mouth of the Waardamme-river and near the limit of the „polders", while the profiles of Vijve-Kapelle and Oedelem are situated at the southern boundary of the Flemish Valley.

The oldest quaternary sediments (—4.5 à —2.3 m) are deposited in an estuarine environment and are characterized by cross bedding structures, the presence of bore-holes, and the occurrence of reworked glauconite and tertiary heavy minerals. In the uppermost part of these green glauconitic sands a new mineral suite appears. On the top of this sediment unit disturbances occur and a soil formation took place.

These estuarine sands were dated as pre-Eem 4b : early Eem or an older interval according to the interpretation of the origin of the disturbances.

We mention a Cardium-layer with underlying peat in the neighbourhood of Lo (42 km to the southwest of Brugge) dated as Needien by Tavernier and de Heinzelin (1962) and Van Hoorne (1962). They are situated at + 1.45 à +12.20 m.

The Steenbrugge-clay (top at —0.5 à —1 m or —2.9 à —3.4 m NAP, base at —2.3 à —3 m or —4.7 à 5.4 m NAP) was determined as a schorre-clay by the sedimentological structures, the granulometric characteristics, the fauna and flora. By pollen analysis as well as by the study of the diatoms, oscillations from marine to brackish conditions were indicated. The clay layer was deposited in the period 4b (Zagwijn, 1963) of the Eem interglacial.

A similar layer was found at the northern side of Brugge by Paepe, Deraymaeker and Van Hoorne (1972). This is an indication for the greater extension of this schorre-clay.

On the basis of the position of the Eemian clay in our sections we can get some idea of the relationship between land and sea level in the Brugge area and the surrounding regions. The top of the clay was 4.5 m lower than the present-day sea level. The same tidal environment as that of the Eemian clay now occurs on our coast at an altitude of about 4.5 m. If we take into account a possible lowering of the clay top by compaction of 1 m, then the maximum Eemian sea level was 3.5 m lower than the present-day sea level near Brugge. The fossile beach of Sangatte has been determined by de Heinzelin (1964) as formed by a 4.80 m higher sea level. No definite proof is yet available that it is older than Eemian. On the contrary in Holland it is is well known that the Eemian maximum sea level is much lower, about at —8 m in the Gelderse Vallei. This indicates that the downwarping of the North Sea basin continued considerably since the Eemian and that it also affected Northern Belgium.

The overlying Weichselian deposits show two different kinds of paleo-environment. The lower part is from niveo-fluviatile and niveo-eolian origin. It consists of a variation of fine laminated peaty silts and sands with rare small gullies. Granulometry and mineralogy of the silt indicate a „loess''-origin. The sediments were dated as Hesbayian. The corresponding strata elsewhere are the loamy beds and peat (Vander Hammen et al., 1967), the peaty loam formations (Paepe and Van Hoorne, 1967) and loamy beds and (cover) sands (Vander Hammen and Wijmstra, 1971). At the top the warmer Kesselt-oscillation was represented in a peat layer. The uppermost silt-layer was affected by the same cryoturbations by which the Kesselt-soil is often folded and is dated in the humid early-Brabantien.

The younger part of the Weichselian is represented by eolian less silty coversands characterized by series of frost wedges. The climate was very cold and relatively dry : only in short periods a fluviatile activity occured. These deposits were determined as older coversands by Vander Hammen et al. (1967) and named Wildert-formation by De Ploey (1961). In the middle of the formation the Beuningen gravel appears, overlain by a peaty siltlayer deposited during the slightly warmer Katelijne oscillation, possibly corresponding to the Lascaux-interstadial.

The Tardiglacial sequence is characterized by strongly varying conditions. Eolian activity (dune sands) during Late Dryas and Preboreal alternated with vertical erosion (Allerød) and peat growth (Bølling). The dune sands are part of the great dune complex in the neighbourhood of Brugge and Eeklo. During the Holocene, peat growth took place in the lower parts of this complex at the rim of the coastal plain and on the higher parts of the dunes a soil was formed.

Laboratorium voor
Geomorfologie en
Sedimentologie
Katholieke Universiteit te
Leuven

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