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STRATIGRAPHICAL POSITION OF PERIGLACIAL PHENOMENA IN THE CAMPINE CLAY OF BELGIUM, BASED ON PALAEOBOTANICAL ANALYSIS AND PALAEOMAGNETIC DATING

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SUMMARY: Thanks to a combined study of plant-remains and periglacial phenomena in the Campine Clay, it became possible to make a subdivision into an upper clay member, Formation of Turnhout, and a lower one, Formation of Rijkevorsel. They are believed to correspond to warm periods of the old Pleistocene and are separated by a complex formation of sand and peat, with several periglacial levels, representing the Formation of Beerse. Palaeomagnetic results do not contradict the by palaeobotanical data established age of the different members, namely Waalian for the Turnhout clay, Eburonian for the Formation of Beerse, and Tiglian for the Rijkevorsel clay.

RÉSUMÉ: Grâce à l'étude combinée des phénomènes periglaciaires et des végétaux fossiles, il a été possible de subdiviser les Argiles de la Campine en une formation supérieure, appelée Argile de Turnhout, et un membre inférieur appelé Argile de Rijkevorsel. Correspondant à des périodes chaudes, elles sont séparées par la formation de Beerse, représentant un complexe de sables et de tourbes, cryoturbé à plusieurs niveaux. Les âges présumés par les résultats paléobotaniques, notamment le Waalien pour l'Argile de Turnhout, l'Eburonien pour la formation de Beerse et le Tiglien pour l'Argile de Rijkevorsel, ne sont pas infirmés par les résultats paléomagnétiques.

1. INTRODUCTION

Periglacial phenomena, such as frost wedges and cryoturbations, are important stratigraphical marker horizons indicating cold periods in the Pleistocene so that climatological subdivisions can be established. They have proved to be useful in comparing stratigraphical sequences of the Late Pleistocene of Belgium and the Netherlands (R. PAEPE and R. VANHOORNE, 1967; T. VAN DER HAMMEN et al., 1967; W. H. ZAGWIJN and R. PAEPE, 1968). These features, characteristic of lithostratigraphical sequences, become even more valuable if studied in combination with biostratigraphical evidence such as palaeobotanical data, which is the case here. It is then possible to arrange these phenomena within a climatochronological scheme. This is the purpose of this, albeit preliminary, study.

In the complex of sands and clays, referred to as the Campine clay, several disturbances pointing to periglacial conditions have been noticed for years. Many interpretations were given until C. H. EDELMAN and R. TAVERNIER (1940) and later R. TAVERNIER (1942) alone, spoke of periglacial, cryoturbatical phenomena. Apparently, the authors only mentioned disturbances affecting the very upper part of the Campine Clay so that they were believed to be younger than the clay sedimentation itself.

R. TAVERNIER upholds this point of view in his later publications (1954) and therefore considers the whole of these formations as belonging to one and the same interglacial viz. the Günz-Mindel. Moreover, on basis of mineralogical and petrographical similarities this author correlated the Campine Clay with the Tegelen Clay of the Netherlands. Shortly after, in 1956, one of us, (R. VANHOORNE, 1957) drew for the first time the attention to the presence of a disturbed formation within the Campine Clay. A palynological study of peat layers occurring in this disturbed formation pointed to cool climate circumstances. The disturbed nature of these layers, which could be due to cryoturbatic phenomena, and the cool flora of this formation, lying between two clay deposits with a warmer character, suggested the possibility to subdivide the Campine Clay. Later on the same author (R. VANHOORNE, 1965) confirmed the existence of a cold stage in the Lower Pleistocene sediments of the Belgian Campine. He considered its correlation with the Eburonian of the Netherlands as the most plausible solution.

In actual fact, the presence of cryoturbatical disturbances within a sand body sandwiched between two independent, thick clay layers can be clearly demonstrated. E. M. DRICOT (1962) had already made an attempt to date the intercalated layer, but he found it impossible to make decision between an Eburonian or a Menapian age.

From this it follows that with regard to the age, only part of the Campine Clay belongs to the Tiglian. It thus became necessary to determine more closely the nature, position and number of periglacial marker horizons in the complex of the Campine Clay and more especially in the sandy interlayer of Eburonian age. A comparison of various sections in these formations and the establishment of a complete stratigraphical sequence was of utmost importance.

2. LITHOSTRATIGRAPHICAL HORIZONS AND PALAEOBOTANICAL DATA

Most of the numerous clay pits have exposed the Campine Clay down to the bottom of the second, most important clay member, at a depth of roughly 10 m below the surface. Here, very often, a fine micaceous sand layer (so-called silver sand) is reached. A short review of the clay pits studied up to the present times is given in the following paragraphs.

2.1. Claypit „Sint Franciscus'' (Beerse)

In this clay pit (Fig. 1) a rather complete sequence was obtained so that a detailed description of the lithological sequences is given:

1: White-yellowish sands with diffuse grey bands; podzol in the topzone; sharp truncating lower limit with frost wedges.
2: Yellowish finely layered sand with sharp lower limit with frost wedges.
3: Loam and coarse sand disturbed by the penetration of overlying frost wedges.
4: Grey-blue, heavy clay; topzone highly affected by red coloration and with large irregular sand filled frost wedges; in between disturbed peat (V5) lumps; oxidation horizon (oblique dashes) at the base, which truncates underlying sands or clays.
5: Brown, oxidized sands.
6: Strongly disturbed peat (V3b).
7: Grey-white sands.
8: Brown-grey sands with oxidation zone at the base, double layered.
9: Moderately disturbed peat layer (V3a); often overlying and partly mixed with blue grey fine sands; Fe/Mn concretions.
10: Brown-yellowish finely layered sands.
11: Silty sands with oxidized basal part with frost wedges.
12: Weakly disturbed peat (V2) layer.
13: Bluish heavy clay.
14: Bleu-grey fine micaceous sands.

The first important erosional contact occurs, working down from the surface, at the boundary between beds 3 and 4, and is characterized by the subhorizontality of the erosion limit and by the sudden occurrence of extremely large frost wedges along its line, which facilitates its recognition in the field. Because of

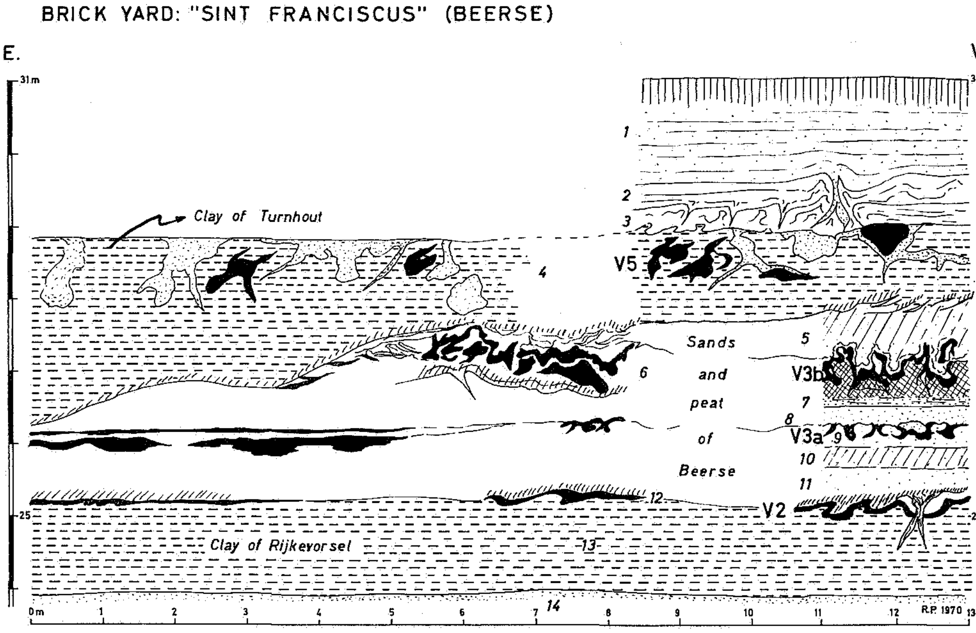

Fig. 1

their steady presence, as a covering mantle in the present landscape, the uppermost series of sands (1, 2, 3) are considered as mainly belonging to the Late Pleistocene.

An enormous lithostratigraphical and time hiatus thus separates it from the layers below.

Clay sedimentation took place seemingly under shallow water conditions as one can infer from the presence of many rootlets, pointing to an abundant vegetation. As the clay sedimentation slowed down it was overtaken by peat growth. Thus the peat and clay formation apparently date from the same period and are called "Turnhout (clay) formation".

The sand layers would suggest deposition by more rapidly flowing water. The presence of a number of flow structures is evidence for this. However, at least two interruptions are observed here, viz. peat layer V3a and V3b. Both were formed under cold conditions which latter are also characterized by the presence of strong cryoturbation features ("sands and peat of Beerse").

Finally, the presence of important frost wedges at the bottom of these sands strongly supports the belief that one is dealing here with sedimentation occurring under strictly cold circumstances, with only a few milder fluctuations.

In much the same way as the upper clay member, the deposition of the lower clay occurred under shallow water in the presence of an abundant vegetation. It is possible that the micaceous "silver sands" are to be considered as waterlaid to a greater extent and probably under partly marine circumstances. They are referred to as "Rijkevorsel (clay) formation".

In 1956 in the then existing clay pit, situated about 200 m N.W. of the present excavation, "the sands and peat of Beerse" were not visible. The profile showed only one continuous clay deposit extending in depth from 2.50 m to 6.30 m. At the base of this clay a 20 cm thick peat layer, containing pieces of wood was present. This peat probably corresponds with V1, mentioned in the description of clay pit Cobricam (St. Lenaarts) (p. 204). It yielded a lot of megasporangia of *Azolla tegeliensis* FL. and *Salvinia natans* ALL. Besides we found seeds and fruits of *Potamogeton* sp., *Alisma plantago* L., *Scirpus* cf. *carinatus* SM., *Scirpus lacustris* L., *Scirpus mucronatus* L., *Scirpus tabernaemontani* GMEL., *Scirpus* sp., *Heleocharis palustris* R. BR., *Juncus effusus* L., *Juncus* sp., *Ceratophyllum submersum* L., *Ranunculus flammula* L., *Ranunculus lingua* L., *Ranunculus sceleratus* L., *Batrachium* sp., *Hypericum* sp., *Menyanthes trifoliata* L., *Lycopus europaeus* L. and *Mentha* sp.

The palynological investigation led to the following spectrum, in which the percentages are calculated in function of the tree pollensum: *Pinus:* 88.1 %, *Betula:* 11.9 %, *Gramineae:* 2.3 %, *Caryophyllaceae:* 2.3 %, *Ericales:* 7.1 %, *Artemisia:* 7.1 %.

The great quantity of megasporangia of *Azolla regeliensis* FL., more than 9000 specimens of which have been counted, indicates a Tiglian age of the peat layer.

In 1970 a new pit was opened on the other side of the road from Beerse to Rijkevorsel at a distance of about 150 m West of the excavation, described on page 202. We could observe two clay units separated by a sand deposit, containing a contorted peat layer, which yielded the following macroflora. The identification and the number of seeds extracted from a volume of 21,25 litre are mentioned in the following table.

Caryophyllaceae	1
Ranunculus flammula L.	108
Batrachium div. sp.	20
Hypericum humifusum L.	1
Comarum palustre L.	3
Hippuris vulgaris L.	76
Menyanthes trifoliata L.	60
Mentha sp.	6
Alisma plantago L.	2
Potamogeton div. sp.	9
Juncus sp.	6
Sparganium sp.	1
Scirpus lacustris L.	1
Heleocharis sp.	3
Carex div. sp.	57

It is hard to draw conclusions from this macroflora other than to note its aquatic character. However, its stratigraphical position corresponds with the peat layer V3a in the neighbouring clay pit described on page 204.

2.2. Clay pit "Cobricam" (St. Lenaarts)

The description of the different profiles visible in 1956 is given by one of us (P. GREGUSS et R. VANHOORNE, 1961). The main difference between this section and the previous one is the absence of the upper clay, which is only occurring as isolated clay lenses, and the presence of another peat member (V1) at a still lower level, viz. at the contact between the silver sand and the overlying clay of Rijkevorsel. A palynological study of thin peaty layers interbedded in the sands of the Formation of Beerse enables us to represent the fluctuation of the flora in the form of a pollen diagram (Fig. 2).

The dominant trees are *Pinus* and *Betula,* whereas the anemophilous herbs show a great development in the lower part of the diagram. The pollen of *Ericales,* which occur in enormous quantitites at the top, are not included in the pollensum but mentioned in the last column. The dominance of *Pinus* and *Betula,* the high percentages of anemophilous herbs in the lower part of the diagram and the presence of *Selaginella* point to cold climatological conditions. The landscape was probably covered by a heath vegetation with scattered trees, among which pines and birches were the most frequent.

The humid places were probably occupied by *Alnus.* Here and there *Picea* and *Salix* were also present. The vegetational cover indicates that the climate was not extremely cold in the Eburonian stage as was the case in the last glaciation when a tundra covered the landscape in Western Europe.

The peaty top of the clay, corresponding with V2 of the clay pit "St. Franciscus" at Beerse, yielded the following pollen spectrum: *Picea:* 3.1 %, *Pinus:* 89.2 %, *Salix:* 1.2 %, *Betula:* 3.7 %, *Alnus:* 1.2 %, *Quercus:* 0.6 %, *Ulmus:* 0.6 %, *Sphagnum:* 19.6 %, *Gramineae:* 95.5 %, *Cyperaceae:* 3.7 %, *Chenopodiaceae:* 0,6 %, *Caryophyllaceae:* 3.7 %, *Umbelliferae:* 1.2 %, *Ericales:* 31.0 % and *Compositae:* 3.7 %.

In establishing this spectrum, only tree pollen were contained in the pollensum. It is obvious that the climate became already

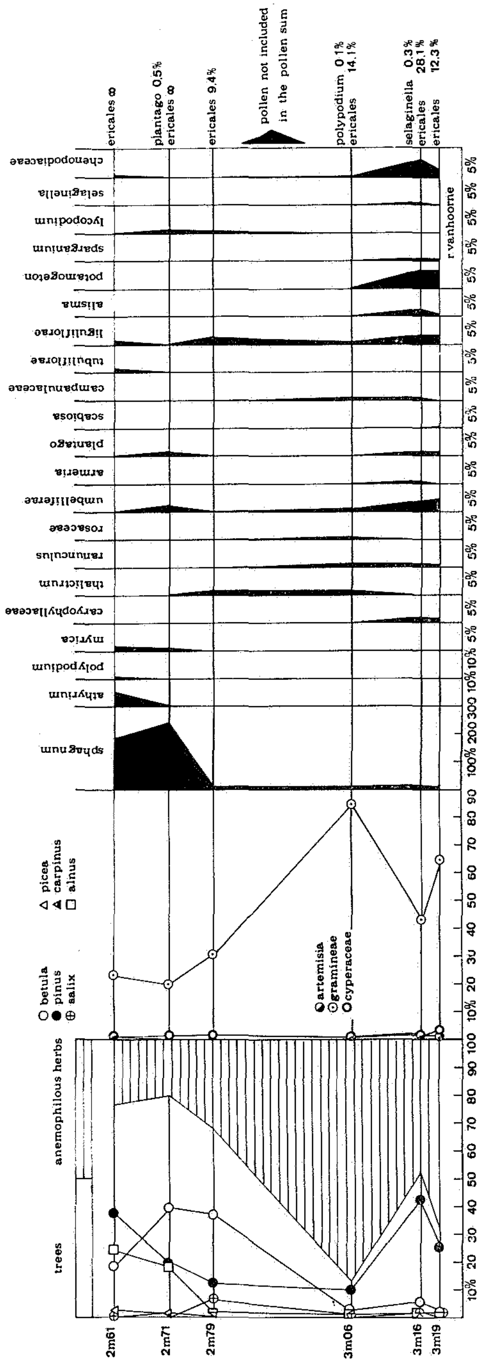

Fig. 2 Pollen diagram of peaty layers in sands belonging to the Formation of Beerse

cold but less so than in the higher described Eburonian stage so that thermophilous elements as *Ulmus* and *Quercus* had not yet completely disappeared. This peat, which probably corresponds with the top of the Tiglian, yielded two oospores of *Chara* sp. and one seed each of *Hypericum* sp. and *Myriophyllum spicatum* L.

The peat layer at the base of the clay (V1) contains many pieces of wood, belonging to different species. This wood was determined by P. GREGUSS, while R. VANHOORNE determined the other remnants of this important macroflora (P. GREGUSS and R. VANHOORNE, 1961).

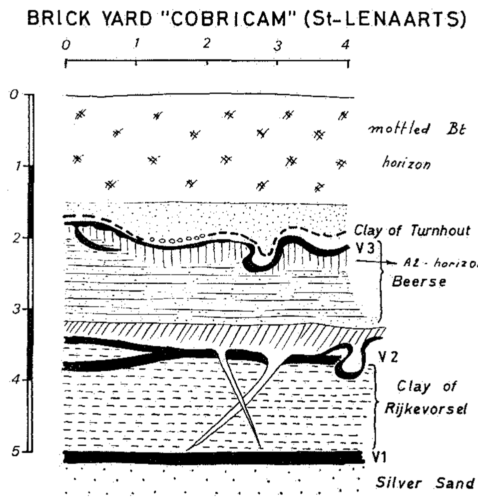

Fig. 3

The flora is characterized by the coexistence of a North-American element and an East-Asiatic one. To the first group belong *Chamaecyparis thyoides* and *Thuja occidentalis,* while the second comprises *Pinus tabulaeformis* var. *funebris, Pinus pumila, Chamaecyparis taiwanensis* and *Sciadopitys.* Besides three fossil species were found to occur i.e.: *Azolla tegeliensis, Thuja vanhoornei* and *Brasenia tuberculata.*

The pollen diagram (P. GREGUSS and R. VANHOORNE, 1961) reveals a forest vegetation, dominated by *Alnus* except at the bottom, where *Pinus* is the most important tree. Thermophilous trees such as *Carpinus, Quercus* and *Ulmus* occur in small quantities only, while *Tsuga* was found at one level.

All these palaeobotanical data point to a

Tiglian age for the clay of Rijkevorsel, beginning with the peat layer (V1), in which the vegetation evolved from cold to warm and ended with another peat (V2) announcing by its cold flora the approach of the Eburonian glacial stage.

2.3. Clay pit "De Toekomst" (Beerse)

The lithological sequence is the following (Fig. 4):

1: Mottled sandloam with clayloam
2: Blue heavy clay with cryoturbated upper part and peat V5
3: Yellowish stratified sand and peat V4
4: Blue heavy clay
5: Grey sand with peat V3 at base and frost wedges
6: Greyish sand with peat V2 at base and large frost wedges
7: Greyish sand
8: Blue heavy clay
9: Blue gray micaceous sand
10: Blue heavy clay.

This clay pit is of great importance for the subdivision and position of the clay members. It appeared obvious that the bulk of the lower clay member (8) extends below the silver

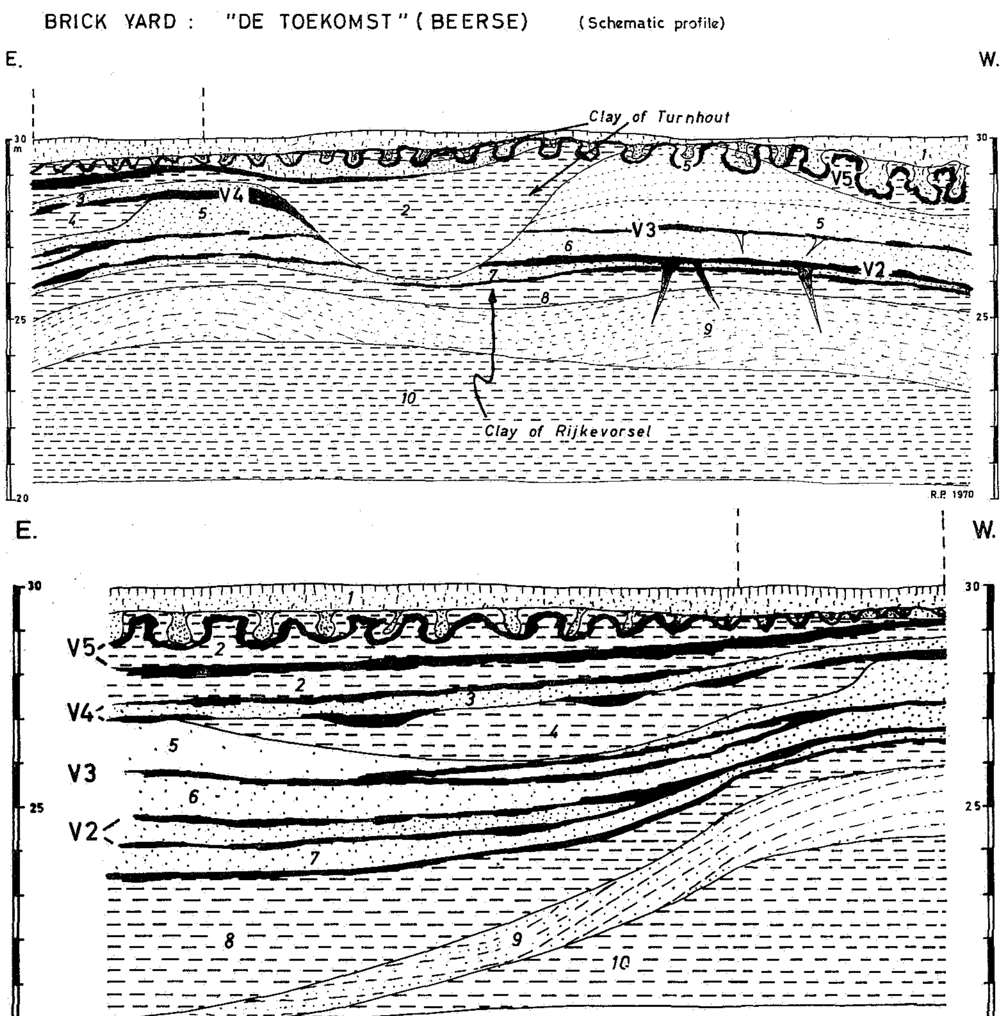

Fig. 4 Sections between dotted vertical lines in both drawings represent common part.

sands (9) in a thick clay formation (10). Thus the sandy phase only represents a textural variation within the climatical phase responsible for the deposition of the whole of the lower clay member, which corresponds to the whole of the "Rijkevorsel (clay) formation".

The top of this clay formation contains a discontinuous peat horizon which should correspond to the V2 peat of other places. Above, it becomes more complicated though. It rather seems that the overlying peat layer which is locally disturbed by frost wedges, belongs to the same cycle of peat formation and resembles the morphology of the V2 peat at Sint-Franciscus. As of then, peat layer V3 is without doubt the same as the one of the two encountered at this level in Sint Franciscus.

Both layers are cut by the Turnhout clay which is filling up a gully and then, more to the east of the section, they all are doubled.

At this place of the section, a new peat horizon V4 occurs and is also doubled. The lower member of it is discontinuous where it rests on clay lens (4), but it forms a real peat layer elsewhere. One may see it bend along the Turnhout clay filled gully so that it is believed to be contemporaneous of the clay sedimentation cycle. In fact a similar situation occurs with the lower peat member of V5, occupying a median position in the Turnhout clay but bending also along the lower limit of a lensshaped sand filled fully surimposed on the Turnhout clay gully. The disturbed peat horizon at the top (upper member of V5) covers, as everywhere else, the whole of the Turnhout clay.

2.4. Clay pit Kievitsheide (Rijkevorsel)

Here the lithological sequence is as follows (Fig. 5).

1: Yellowish fine sand
2: Whitish sand, A_2-horizon
3: Red and humic Bir/H-horizon
4: Mottled loam with medium sized frost wedges
5: Yellowish-brown sand and loam with fine frost wedges
6: Blue heavy clay with large frost wedges and cryoturbations filled with loams and sands different from bed 5.
7: Mixture of white, grey and rusty sand, regularly cross bedded with numerous annelide tubules
8: Blue-grey clay
9: Brown sand
10: Grey brown sand which is also filling up frost wedges of peat layer V3; locally, the latter peat is doubled
11: Grey-white sands with subhorizontal stratification
12: Bleu heavy clay

Late Pleistocene coversands are present and separated into two main parts by a row of frost wedges.

The upper clay member appears sporadically in the southern part of the section, and increases rapidly to the north with the lowering of the basal boundary; it finally excavates the lower clay layer in the form of a wide gully with flat bottom.

The texture in this gully changes rapidly into quick alternating sand and clay layers, with a remarkable stratification. The direction changes frequently from one to another layer and in considering their thickness one may assume that slow-moving water periodically changing in direction was responsible for these deposits. In other words, a tidal regime seems the most plausible explanation, so that these deposits are to be looked on as belonging to a wadden system. This has already been stated by F. GULLENTOPS and E. M. DRICOT (1962).

Regardless of the clays thickness, large frost wedges constantly develop along the upper limit of the clay; they are still present where the clay is lacking. As a consequence, it is believed that strong subhorizontal erosion took place between the clay formation and the development of frost wedges.

Below this clay member beach deposits occur. They slope gently from south to north in the exposure. The whole is impregnated with fingerlike disturbances resulting from

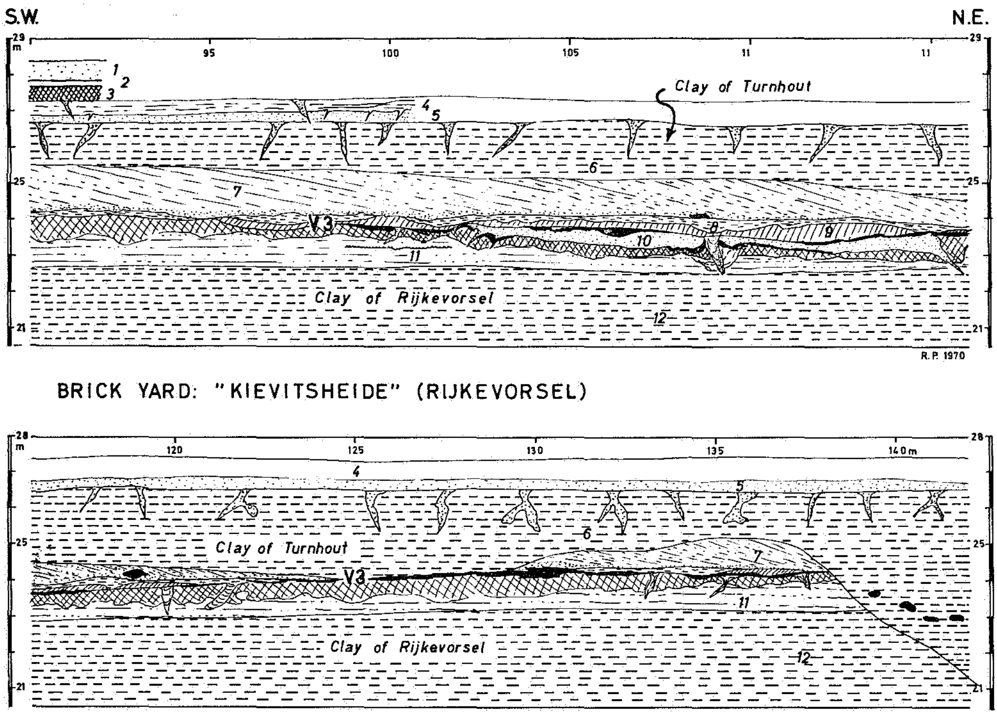

Fig. 5

intense biological activity. Since it would seem as if these beach sands gradually grade into the overlying clay, together they could indicate the complete marine transgression of this period. Indeed, the former deposits lay on pure continental sediments consisting of fluviatile and eolian material. This sequence was at least twice interrupted by peat formation with subsequent frost wedge formation.

The peat, sampled at a place where it was developed as a single layer, yielded many seeds, the number of which found in a volume of 9.25 litre is mentioned in the following table:

Ranunculus flammula L.	30
Ranunculus lingua L.	2
Batrachium div. sp.	7
Myriophyllum alterniflorum P. DC.	1
Menyanthes trifoliata L.	501
Stratiotes intermedius (HARTZ)CHANDLER	3
Potamogeton div. sp.	15
Scirpus lacustris L.	22

The different identified species or genera belong to an aquatic flora without any climatological character. *Stratiotes intermedius* (HARTZ)CHANDLER is a fossil species first described by N. HARTZ (1909) as *Stratiotes aloides* L. var. *intermedius* from the Pliocene of Denmark. It was raised by CHANDLER to the level of a species. It has also been found by J. BAAS (1932) in German deposits of Lower Pleistocene age, belonging to the Mainz basin, in the Needian clay at the Dutch locality of Neede by F. FLORSCHÜTZ and F. P. JONKER (1942), in the Tiglian of the Netherlands by T. VAN DER HAMMEN (1951), and in the Belgian Rijkevorsel clay at Kalmthout by R. VANHOORNE (1957). It can be distinguished from the actual living species, *Stratiotes aloides* L., by the occurence of many warts and the more robust form. The seeds discovered here are not so robust as the one found in the Rijkevorsel clay at Kalmthout and have a characteristic bent apex. It is the first time that they are mentioned from a cold period in the Lower Pleistocene.

Below these sediments the second clay

formation occurs and the same wadden sedimentary structures may be observed here as in the upper clay deposits. The upper limit of the clay is regular and subhorizontal.

3. PALAEOMAGNETIC DATING

H. M. VAN MONTFRANS has undertaken the first palaeomagnetic dating from the following pits: De Toekomst and St. Franciscus. We will hive here a short review of those datings which have been kindly reported to the authors before their publication[1].

3.1. Sint Franciscus (Beerse)

From top to bottom there was found:
— Reversed polarity in the lower part of the upper clay (sample 4 through 5).
— Measurements in the sands were rejected (samples 29 through 34).
— Reversed polarity for the lower part of the lower clay (sample 7 through 10).

3.2. De Toekomst (Beerse)

From top to bottom there was found:
— Normal polarity for the upper part of the upper clay.
— Normal polarity for the upper parts, reversed polarity for the lower part of the sand formation.
— Reversed polarity for the lower clay.

3.3.

These results lead to the conclusion that upper clay formation must partly be placed in the Jamarillo event (0.87-0.92 M.y.ago) and older. Datings of the lower part of the sands contain the upper level of the Gilsa event (1.6 M.y.ago). As a result the lower clay formation is believed to be older than this level.

4. CONCLUSIONS

The Campine Clay can be subdivided into two tidal flat clay deposits separated by sands mainly of continental origin. It is proposed to call the upper clay, the Turnhout clay formation and the lower one, the Rijkevorsel clay formation. They are separated by the Beerse sand formation.

In the Turnhout clay formation, at least three phases of clay deposition were found to exist. They are separated by phases of gullying and peat formation. The middle clay member is preceeded by a strand formation; it further shows the best developed gully system as well as the greatest thicknesses. It may represent the main part of the corresponding transgression.

The Rijkevorsel clay formation can be subdivided into two clay members also, separated by the silver sand.

Both clay formations correspond to a rise of sea level and hence with a warm period. The "wadden" character of these deposits is proved by the sedimentation pattern and the presence of peat or vegetation remnants in the clay. The palaeobotanical results prove that the upper clay formation, characterized by pollen of *Tsuga, Pterocarya* and *Eucomnia* but without *Azolla tegeliensis,* should be placed in the Waalian interglacial and the lower one, with *Azolla tegeliensis* in the Tiglian. The sand deposits should then correspond to the Eburonian glacial phase in which several phases of relatively colder or milder conditions are found. Indeed, the fluviatile and eolian sands which are found at this level together with peat horizons carrying the only frost wedge zones of the lithological sequence, point to severe continental conditions. With regard to their absolute ages, the Turnhout clay occurs in the time span of 0.87 to 0.92 M.y.ago, while the Rijkevorsel clay is believed to be older than 1.6 M.y.ago. A synoptic table is given hereafter.

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(1) Note of the authors:
In the span of time that this paper was in press, the results have been published in "Palaeomagnetic Dating in the North Sea Basin" by H.M. VAN MONTFRANS (1971).

TABLE

WAALIAN	— Peat (upper V5) with frost wedges and cryoturbations — Turnhout clay 3 as small lenses in shallow gullies (end phase) — Peat with sand (lower V5) — Turnhout clay 2 as thick masses, also filling deep gullies — Peat (V4) enclosing sand layers; sometimes strand deposits with oblique cross bedded layers containing (vertical) tubulations — Turnhout clay 3 as medium thick lenses	*Turnhout Formation*
EBURONIAN	— Brown humic sands — Cryoturbated peat (V3b) with frost wedges — Gray white sands overlying ocrous stratified sands — Cryoturbated peat (V3a), with frost wedges, in places doubled — Fine sands and silts	*Beerse Formation*
TIGLIAN	— Rijkevorsel clay 2 with doubled V2 peat layer (with frost wedges at the top) — Peat V1 with *Azolla tegeliensis* — Micaceous sands (silver sands) — Rijkevorsel clay 1	*Rijkevorsel Formation*

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