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POLLEN ASSEMBLAGES, PLANT COMMUNITIES AND BIOSTRATIGRAPHY OF THE LOWER PLEISTOCENE CAMPINE CLAY IN BELGIUM.

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(17 figures & 5 tables)

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SUMMARY. This paper deals with the palaeobotany and the stratigraphy of the Formation of Weelde, a lithostratigraphical unit grouping the uppermost clays and sands of the Early-Pleistocene Campine Clay, situated in the North of Belgium. This Formation is divided into the Rijkevorsel Clay Member underneath, the Turnhout Clay Member above and the intervening Beerse Sand Member. The pollen analysis of the peaty sediments included in the Rijkevorsel Clay reveals a boreal *Pinus*-biozone at the bottom, followed by a temperate biozone, dominated by *Alnus*, and finally ending with another boreal *Pinus*-zone at the top of the sequence. This vegetational cycle is believed to correspond with an interglacial. The Turnhout clay shows a similar, botanical succession, but incomplete because the lower, boreal *Pinus*-biozone could not be demonstrated. Nevertheless an interglacial character is attributed to this vegetational cycle. Both Members are separated from each other by the Beerse Member, composed of fluviatile and eolian sands with peat inclusions and displaying cryoturbatic features. Palynologically it shows a threefold alternation of arctic and subarctic episodes. The Beerse Glacial is proposed for this Member. The plant macrofossils, recovered from the peat and peaty sediments, belong to aquatic and marshy plant communities. Noteworthy are the megasporangia of *Azolla tegeliensis* and *Salvinia natans*, which occur in all three Members. A comparative study with the Early-Pleistocene deposits in the South of the Netherlands could not remove all the doubts of a correct correlation with the European chronostratigraphy.

KEYWORDS. Belgium, Campine Clay, Lower Pleistocene, palaeobotany, stratigraphy.

SAMENVATTING. Een paleobotanische en stratigrafische studie werd uitgevoerd van de Weelde Formatie, een lithostratigrafische eenheid, die de bovenste klei- en zandafzettingen van de Onder-Pleistocene Kempen Klei in België samenbundelt. Deze Formatie wordt ingedeeld in drie leden, die respectievelijk de Rijkevorsel Klei onderaan, de Beerse Zanden in het midden en de Turnhout Klei bovenaan bevatten. Uit de palynologische analysen van de venige sedimenten in de Rijkevorsel Klei is gebleken dat daarin een onderste *Pinus*-biozone, een middenste *Alnus*-biozone en een bovenste *Pinus*-biozone kunnen onderscheiden worden. Deze vegetatiecyclus stemt overeen met de botanische opeenvolging in een tussenijstijd, die het Rijkevorsel interglaciaal wordt genoemd. De Turnhout Klei vertoont een gelijkaardige vegetatieontwikkeling, die echter onvolledig is daar de onderste *Pinus*-biozone niet kon aangetoond worden. Nochtans zijn er aanwijzingen uit de literatuur dat er zich hier ook een volledige, tussenijstijdse ontwikkeling heeft afgespeeld, die is doorgegaan in het Turnhout interglaciaal. Beide voorgaande leden zijn van elkander gescheiden door het Beerse Lid, waarin cryoturbate, fluviatiele en eolische zanden met ingesloten venige sedimenten aangetroffen worden. Palynologish kunnen er drie arctische fasen in aangetroffen worden, die van elkander gescheiden zijn door subarctische intervallen. Dit geheel werd ondergebracht in een ijstijd, het Beerse glaciaal genoemd. De macroscopische plantenoverblijfselen, teruggevonden in de venige sedimenten, behoren hoofdzakelijk tot zoet water- en moerasassociaties. Vermeldenswaard zijn de macrosporangiën van *Azolla tegeliensis* en *Salvinia natans*, die aangetroffen werden in de drie Leden. Een vergelijkende studie met de Onder-Pleistocene afzettingen in Zuid-Nederland heeft de laatstste twijfels betreffende een sluitende correlatie met de Europese chronografie niet kunnen wegnemen.

SLEUTELWOORDEN. België, Kempen Klei, Onder-Pleistoceen, paleobotanie, stratigrafie.

RESUME. Cet article est le fruit d'une étude paléobotanique et stratigraphique de la Formation de Weelde, une unité lithostratigraphique groupant les argiles et sables supérieurs des Argiles de la Campine d'âge Pléistocène Inférieur en Belgique. Cette Formation se divise en trois sous-unités lithostratigraphiques qui sont de bas en haut: le Membre de l'Argile de Rijkevorsel, le Membre des Sables de Beerse et le Membre de l'Argile de Turnhout. L'analyse palynologique des sédiments tourbeux de l'Argile de Rijkevorsel a dévoilé une bio-zone boréale à *Pinus* à la base, suivie d'une bio-zone tempérée, dominée par *Alnus*, et une bio-zone terminale à *Pinus*, également boréale. Cette succession botanique correspond à un cycle végétal interglaciaire. L'Argile de Turnhout a subi une évolution botanique similaire mais incomplète car la bio-zone boréale, inférieure à *Pinus* n'a pas été décelée. Toutefois ce cycle végétal incomplet est considéré comme appartenant à un interglaciaire. Les deux Membres précités sont séparés par le Membre de Beerse, composé de sables fluviatiles et éoliens comprenant des inclusions tourbeuses.L'analyse palynologique des ces dernières a révélé trois épisodes arctiques alternant avec autant d'épisodes subarctiques. La période glaciaire de Beerse est proposée pour cet ensemble. Les restes végétaux macroscopiques provenant des sédiments tourbeux inclus dans les trois Membres appartiennent à des associations végétales aquatiques et marécageuses d'eau douce. Signalons la présence de mégasporanges d'*Azolla tegeliensis* et de *Salvinia natans* dans les sédiments tourbeux des trois Membres. Une étude comparative avec les dépôts du Pléistocène Inférieur du Sud des Pays-Bas n'a pas pu lever tous les doutes concernant une corrélation adéquate avec la chronostratigrphie du Pléistocène Inférieur en Europe.

MOTS-CLES. Belgique, Argile de la Campine, Pléistocène Inférieur, Paléobotanique, Stratigraphie.

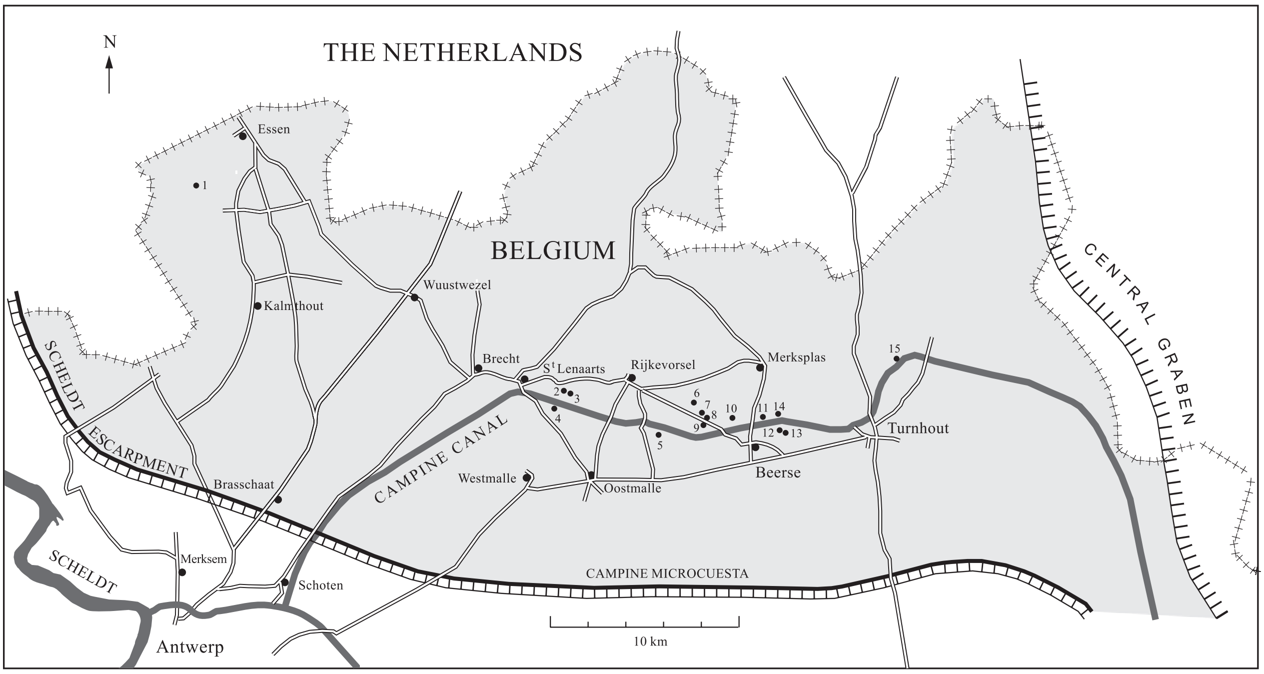

Figure 1. Range of the Campine clay in Belgium (hatched area) and location of the studied clay pits 1-15.

1. Introduction

The Campine clay is a complex of clay and sand deposits situated close to the surface in the North of Belgium. lt can reach a thickness of more than forty metres. Capped by sandy and loamy sediments of Holocene, Late glacial and Weichselian age, it overlies the marine Sands of Merksplas, considered to correspond stratigraphically with the continental Mol Sands of Upper Pliocene and Praetiglian age. To the West the Campine clay is bounded by an escarpment of the river Scheldt and to the South by the Campine microcuesta. The eastern limit is formed by the western faults of the Central Graben (Fig. 1). To the North it extends into the Netherlands, where it is mapped lithostratigraphically as the Tegelen and Kedichem Formation. ln a upward succession the Tegelen Formation is then chronostratigraphically composed of a lower Tiglian Stage overlain by the lower part of the Eburonian Stage, and the Kedichem Formation by the upper part of the Eburorian Stage, the Waalian Stage and the Menapian Stage. In the Belgian lithostratigraphical classification the Campine Clay, earlier labeled as Campine Clay and Sand Formation (Paepe & Vanhoorne, 1976, p.17), was raised by Bogemans (1997) to the rank of Group, consisting of the Weelde Formation and the underlying Malle Formation. The former is subdivided into the Turnhout Member (the uppermost clay of the Waalian Stage), the intermediate Beerse Member (periglacially disturbed sand and peat layers of the Eburorian Stage) and the underlying Rijkevorsel Member (the lowermost clay of the Tiglian Stage) (see below Table 5). The latter Formation comprises the Vosselaar Member and the underlying Brasschaat Member.

ln the present paper only the upper part of the Campine clay, visible in the exposures of the clay pits, is dealt with. The fieldwork was carried out between 1952 and 1982, when there were many clay pits in the region, where the clay was extracted for the brickmaking industry, so that the outcrops were easily accessible. The sampling for micro- and macrobotanical analysis was limited to peat and peaty anorganic sediments. Even in this case the pollen grains were scarce or absent and their preservation was often so bad that the result of the analysis of a series of samples in one bed was reduced to one pollenspectrum. The basis for calculation of all pollen assemblages is as follows: the percentage base is the sum of all land plant pollen (AP + NAP), while the percentages of aquatics, pteridophytes and mosses are based on the total of AP + NAP. Pollen assemblages with another percentage base, which are already published, are recalculated. The diaspores extracted from the samples were counted and, if necessary, presented in tables.

2. Stratigraphy of the outcrops and micro- and macrobotanical analysis.

2.1. Pit 1.

A pit was dug in the vegetable garden of the Redeemer college (former Rauw Moershof) at Essen (Fig. 1) in order to examine stratigraphically the plant remains discovered fortuitously by one of the staff members. Below 1.10 m of sand a grey clay deposit with a black cryoturbated peat at the top and a brown, peaty, interbedded horizon between 2.30 and 2.50 m depth, passed gradually into micaceous sand.

2.1.1. Palynology.

The recalculated pollen diagram of the clay bed (Fig. 2) is dominated by arboreal pollen, *Pinus* being the most

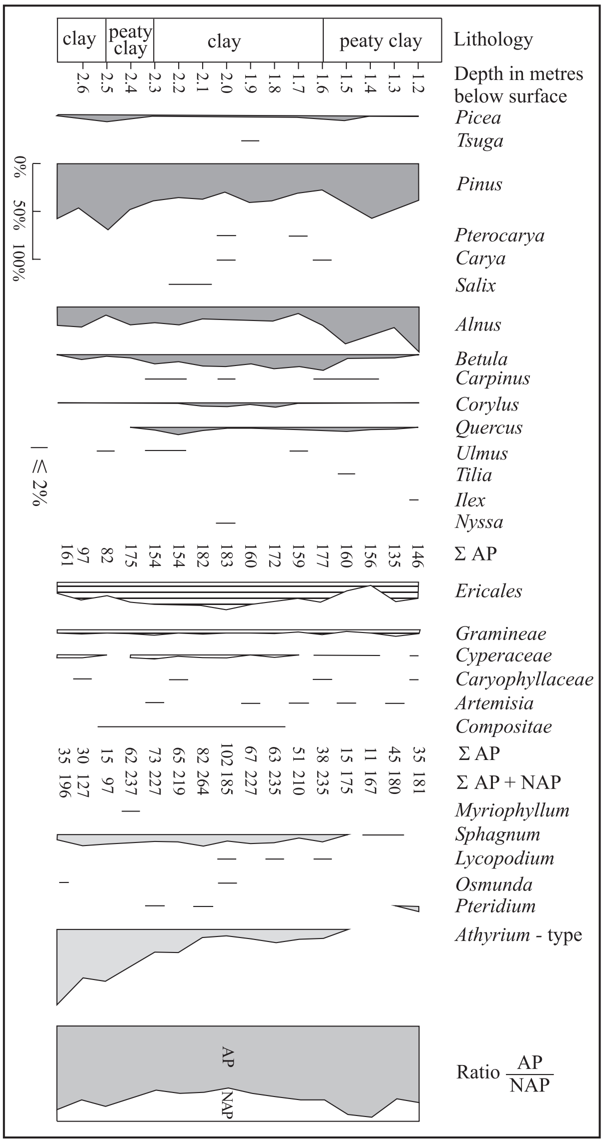

Figure 2. Pollen diagram of the peaty clay and clay in pit 1.

frequent tree, followed by *Alnus* except at the top level, where *Alnus* slightly exceeds *Pinus*. Beside these two genera, *Betula* and *Picea* occur in a continuous curve. This tree pollen assemblage is completed by some thermophilous trees, only represented in small quantities. Amongst the NAP, reaching up to 36 % at 2 m depth, *Ericales* constitute the most important part. The pollen records reveal a landscape covered by *Pinus*, associated with *Alnus*, *Betula* and *Picea*. Some accompanying, thermophilous trees, occurring in traces, are stratigraphically important as *Tsuga*, *Carya* and *Pterocarya*, because the first one has disappeared after the start of the Mid-Pleistocene and the two others at the beginning of the Upper Pleistocene. The field layer of this boreal *Pinus* forest is largely dominated by heath.

2.1.2. Macrobotanical remains.

The macrobotanical remains are listed in Table 1. Aquatics are numerous, amongst which *Azolla tegeliensis* is stratigraphically the most striking feature, because it indicates according to Zagwijn (1963, p.63) the Tiglian Interglacial. The black, peaty top of the clay bed yielded one seed of *Vitis vinifera*, the northern limit of which lies in the vicinity of the 49-parallel in Western Europe. *Selaginella selaginoides* and *Selaginella helvetica*, occurring only in the lower half of the deposit, point to boreal, climatic conditions. Apart from the plant remains recorded in Table 1, one seed of *Stratiotes intermedius* (HARTZ) CHANDLER , 1923 was found without a precise depth in the peaty, interbedded horizon between 2.3 m and 2.5 m. It is oblong, slightly hooked at the base, with a length of 8 mm and a breadth of 2.5 mm. The woody testa is ornamented with some, elongated tubercules, arranged in longitudinal rows.

From a phytosociological point of view all the macroscopic plant remains belong to a freshwater and marsh vegetation, although some of them also tolerate brackish water. They can be referred to the following plant sociological assemblages:

Lemnion minoris
Azolla tegeliensis, Salvinia natans
Charetea
Nitella
Nymphaeion
Nymphaea alba, Myriophyllum verticillatum
Parvopotamion
Myriophyllum verticillatum
Hydrocharito-Stratiotetum
Stratiotes intermedius
Parvopatamion
Ranunculus subg. *Batrachium*
Potamion graminei
Sparganium natans, Myriophyllum alterniflorum
Littorellion uniflorae
Ranunculus flammula, Isoetes lacustris
Nanocyperion flavescentis
Eleocharis palustris, Juncus bufonius
Elatine hydropiper ssp. orthosperma
Bidentetea
Ranunculus sceleratus
Agropyro-Rumicion crispi
Juncus effusus
Phragmitetea
Alisma plantago-aquatica
Glycerio-Sparganion
Hippuris vulgaris
Phragmition
Scirpus lacustris, Ranunculus lingua
Oenanthion aquaticae
Sparganium emersum, Eleocharis palustris
Montion
Montia fontana ssp. *rivularis*
Parvocaricetea
Comarum palustre, Myriophyllum verticillatum
Menyanthes trifoliata
Caricion curto-nigrae
Ranunculus flammula, Juncus filiformis
Nardion strictae/Caricion davallianae
Selaginella selaginoides, *Selaginella helvetica*
Alnion glutinosae
Alnus glutinosa

Lithology		peat				clay				peaty clay				
Depth in metres below surface		1.10-1.25	1.25-1.40	1.40-1.50	1.50-1.60	1,60-1,70	1,70-1,80	1,80-1,90	1,90-2,00	2,00-2,10	2,10-2,20	2,20-2,30	2,30-2,40	2,40-2,50
Oospore	*Nitella sp.*											1		
Megaspores	*Selaginella selaginoides LINK*											2	1	1
	Selaginella helvetica (L.) SPRING						1	2	1		1	1		
	Isoetes lacustris L.		2	1	1	6	33	14				5	24	3
Megaspo-rangia	*Azolla tegeliensis FLORSCH.*	81	501	437	91	2	2	3			3		3	
	Salvinia cf. natans ALL.	258	755	81	12	1	1	1			2		4	1
Fruits or seeds	*Sparganium natans L.*									1	6	1		
	Sparganium emersum REHM.									8	5	42	11	
	Potamogeton sp. 1					3	33	60		17	27	86	36	
	Potamogeton sp. 2						2	2					2	
	Alisma plantago-aquatica L.		10	114						6	2	8		
	Carex sp. 1						1		8	38	37	127	94	
	Carex sp. 2										1		5	
	Carex sp. 3												7	
	Carex sp. 4												5	
	Eleocharis cf. palustris R. & SCH.							1		169	57	249	31	
	Juncus bufonius L.									6	4			
	Juncus effusus L.										8			
	Juncus filiformis L.									2	2			
	Juncus sp. 1									22	7			
	Juncus sp. 2										1			
	Juncus sp. 3										3			
	Juncus spec. div.										9			
	Betula sp.							1	2		1			
	Alnus glutinosa GAERTN.													1
	Montia fontana L.												13	25
	Caryophyllaceae											1		
	Nymphaea alba L.													1
	Ranunculus flammula L.													4
	Ranunculus lingua L.											1		2
	Ranunculus sceleratus L.										3	1	16	24
	Ranunculus subg. Batrachium					1	183	68	12		273	204	609	942
	Rubus sp.													4
	Comarum palustre L.													44
	Vitis cf. sylvestris GMEL.			1										
	Hypericum sp.											1	3	6
	Elatine orthosperma DÜREN											1		
	Viola sp.											2	12	
	Myriophyllum alterniflorum DC.										1			
	Myriophyllum verticillatum L.						61	1	4		35		8	3
	Hippuris vulgaris L.						2				18	20	30	52
	Menyanthes trifoliata L.											4	68	455
	Mentha sp.										1		2	12
Catkin	*Betula sp.*													1
Leaves	*Ericaceae*						1							3

Table 1. Numbers of macroscopic plant remains from the peat, peaty clay and clay in pit 1

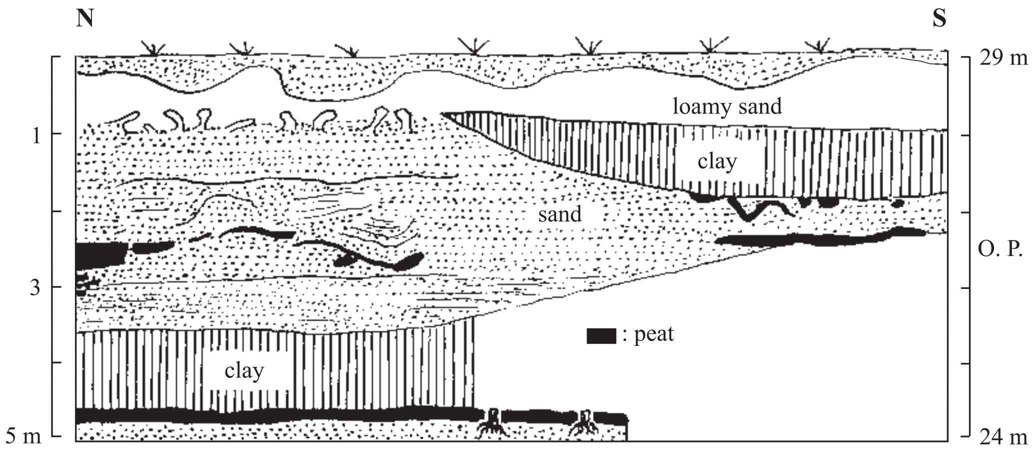

Figure 3. Section of pit 3 (Cobricam) at the south corner of the excavation.

2.1.3 Stratigraphical conclusion.

No marked disconformity could be observed in the fining-up succession of the underlying, micaceous sands to fine, clastic material. The inclusion in the latter of a freshwater macroflora, containing megaspores of *Selaginella selaginoides* and *Selaginella helvetica* in the lower part of the clay, combined with a *Pinus-Alnus-Betula-Picea* pollen assemblage with an AP-preponderance, pleads for a boreal woodland. A correlation with the Vosselaar Member is plausible, although its geographical distribution lies more to the South (Bogemans, 1997). Biostratigraphically one may assign this clastic deposit to the TB-zone in the Netherlands (Zagwijn, 1963, p. 59). The ultimate dominance of *Alnus* at the top of the pollen diagram might foreshadow the climate warming in the TC biozone.

2.2. Pits 2 and 3.

The two clay pits Janssen (pit 2) and Cobricam (pit 3) situated at St-Lenaarts, are dealt with simultaneously as they are located close to each other, showing a comparable, stratigraphical succession. The exposures have been fully described by Vanhoorne (Greguss & Vanhoorne, 1961, p. 2 & 3-4) and De Ploey (1961, p. 25-26, pl. 9 and p. 28, pl. 11). Furthermore a schematic profile of the Cobricam clay pit (pit 3) is published (Paepe & Vanhoorne, 1970, Fig. 3). In summary, the basal, white sands, undoubtedly of eolian origin according to De Ploey (1961, p.23), including at the top vertical standing stumps of *Cupressaceae* trees, are capped by a laminated peat bed with abundant, flattened wood fragments and fallen tree trunks. The peat bed is overlain by a clay deposit. Then follow white sands, including peat beds and displaying cryoturbatic features. Finally these sands are covered by loamy sands grading into pure sands with development of a podzol soil at the top. In all these descriptions, an upper clay bed is never recorded. The progression of the excavation fronts finally exposed in the west corner of clay pit Janssen (pit 2) and at the southern end of the exposed section of the Cobricam clay pit (pit 3) a continuous upper clay bed,

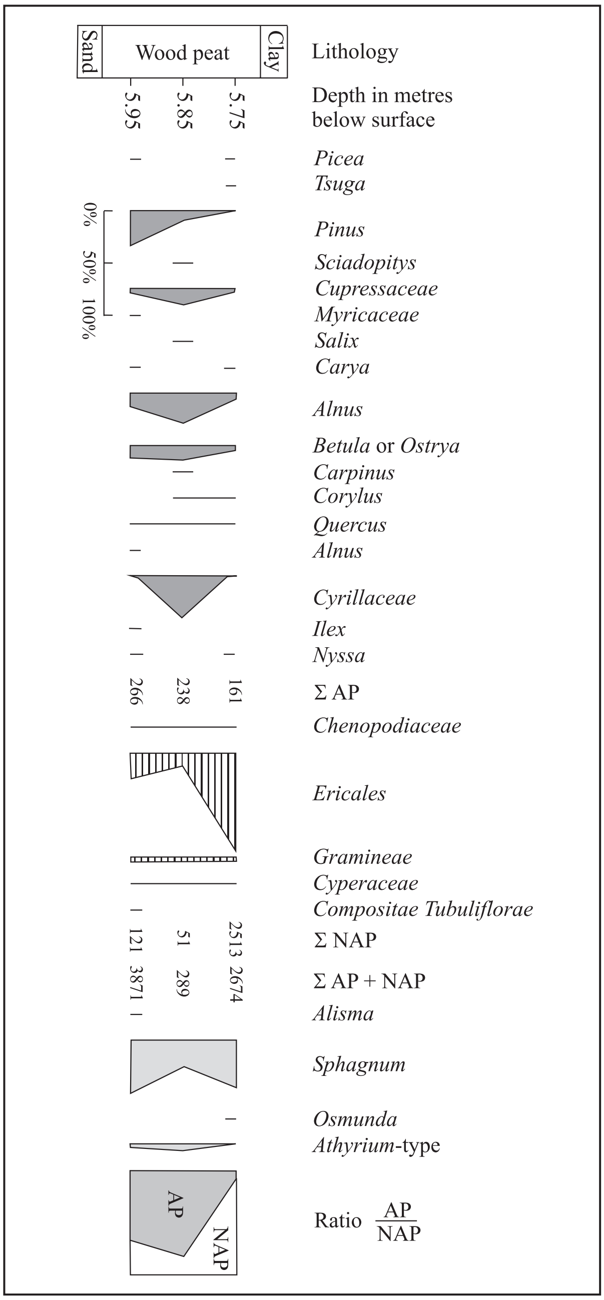

Figure 4. Pollen diagram of the wood peat at the base of the Rijkevorsel Clay at clay pit 2 (Janssen).

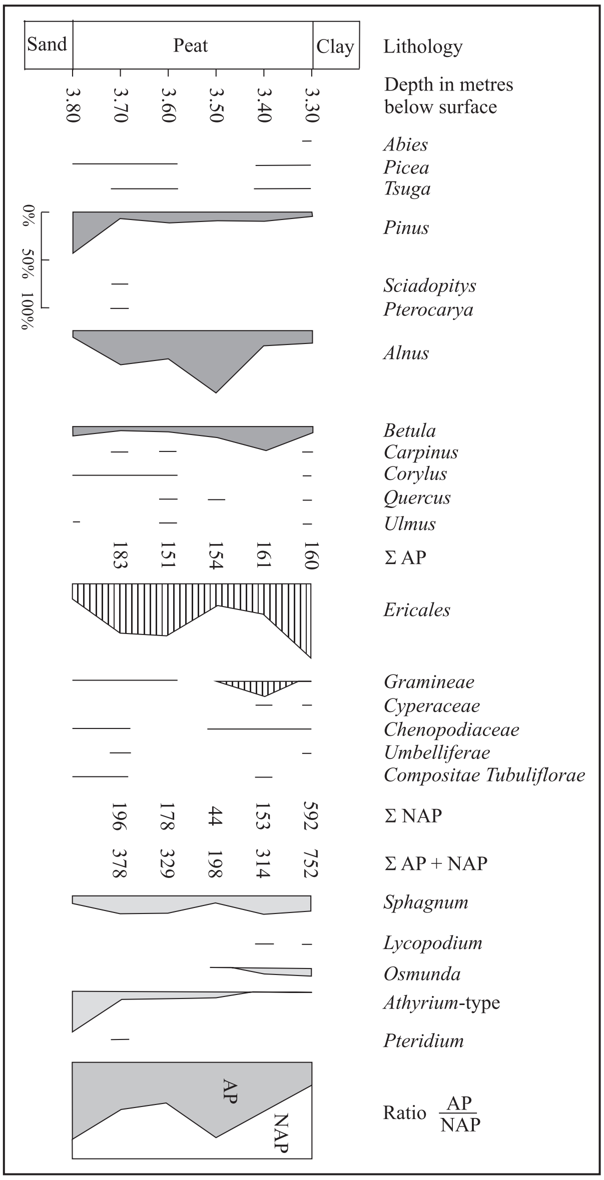

Figure 5. Pollen diagram of the peat bed at the base of the Rijkevorsel Clay at clay pit 3 (Cobricam).

appearing between the underlying, white, cryoturbated sands and the overlying, loamy sands (Fig. 3). This superposition also proves that at St-Lenaarts two clay beds, separated by periglacial sands, occur. It confirms the former interpretation of Vanhoorne (Paepe & Vanhoorne, 1970, p. 204) that the lower part of the sands, resting on the clay bed, belongs to the Beerse Member.

2.2.1 Palynology.

a) Peat at the base of the lower clay bed
The recalculated pollen diagram of the basal peat in clay pit Janssen (pit 2) (Fig. 4) shows a dominance of AP save for the top, where NAP exceeds largely AP. Owing to the lion's share of the *Ericales* in the total number of NAP, it is likely that the fen carr locally graded into an acid flat or raised bog with heather as a result of the changing waterbalance between inundation water and rain water. Therefore these high frequencies of NAP at the top of the peat bog are not interpreted as a sign of deforestation of the area but are believed to indicate the appearance of clearings, covered by heath and scattered in the surrounding forest. Looking at the arboreal pollen flora, one may distinguish two biozones : a lower one dominated by *Pinus* and an upper one, in which *Alnus* was the most frequent tree. In the middle of the pollen diagram of clay pit 2 (Fig. 4) *Cupressaceae* occur with percentages of about 15%, while *Tsuga* and *Sciadopitys* appear only in small quantities. *Carya, Cyrillaceae* and *Nyssa* are only recorded in clay pit Janssen (pit 2) and *Pterocarya* in the Cobricam clay pit (pit 3) (Fig. 5).

b) Humic upper part of the lower clay bed.
- Pit 2
Recalculated pollen spectrum : *Picea* : 2.5%, *Pinus* : 51.8, *Salix* : 0.6, *Betula* : 2.1, *Carpinus* : 0.6, *Quercus* : 0.3, *Ulmus* : 0.3, (∑ AP : 58.2 %), *Ericales*: 33.5, *Gramineae* : 6.1, *Caryophyllaceae* : 1.0, *Compositae Tubuliflorae* : 1.1 (∑ NAP : 41.7 %), *Sphagnum* : 10.4. Number of pollen grains counted : 161 AP + 117 NAP = 278 (see below Fig. 17).
- Pit 3
Recalculated pollen assemblage : *Picea* : 1.3 %, *Pinus* : 37.2, *Salix* : 0.5. *Alnus* : 0.5, *Betula* : 1.6, *Quercus* : 0.3, *Ulmus* : 0.3 (∑ AP : 41.7 %), *Ericales* : 12.9, *Gramineae*: 39.8, *Cyperaceae* : 1.6, *Chenopodiaceae* : 0.3, *Caryophyllaceae* : 1.6, *Umbelliferae* : 0.5 ∑(∑ NAP : 56.7 %), *Athyrium*-type : 1.6, *Sphagnum*, 8.2 (Fig. 17). Number of pollen grains counted : 158 AP + 221 NAP = 379 (Fig. 17).
Both pollen assemblages reveal a landscape covered by a more or less dense, mixed coniferous deciduous forest, in which *Pinus* was the most frequent tree.

c) Peat bed included in the periglacial, white sands above the lower clay
- Pit 3
The assemblages in the pollen diagram (Fig. 6) are characterized by an important dominance of NAP, attaining 92.5 % at the top. Solely at 2.79 m depth AP exceed NAP. The latter are mainly composed of *Ericales* and *Gramineae*. Noteworthy is the appearance of *Selaginella selaginoides* at 3.16 m depth. The pollen assemblages suggest an open landscape, covered with a herbaceous vegetation mainly composed of grasses and heath with perhaps some scattered trees, the best represented of which belong to *Pinus*. At 2. 79 m milder climatic conditions allowed an afforestation with *Pinus*, *Picea*, *Betula* and *Alnus*. Finally this boreal forest retreated, making place for a heath, in which very few trees of the earlier woodland could survive.

2.2.2. Macrobotanical remains

The botanical, macroscopic study has been treated at length by Vanhoorne (Greguss & Vanhoorne, 1961). The peat embedded in the cryoturbated Beerse Sands are poor in macroscopic plant remains, while the humic upper part of the lower clay bed is very rich, as well as the wood peat at the base of this clay. On reexamination *Selaginella* sp. proved to be *Isoetes lacustris*.

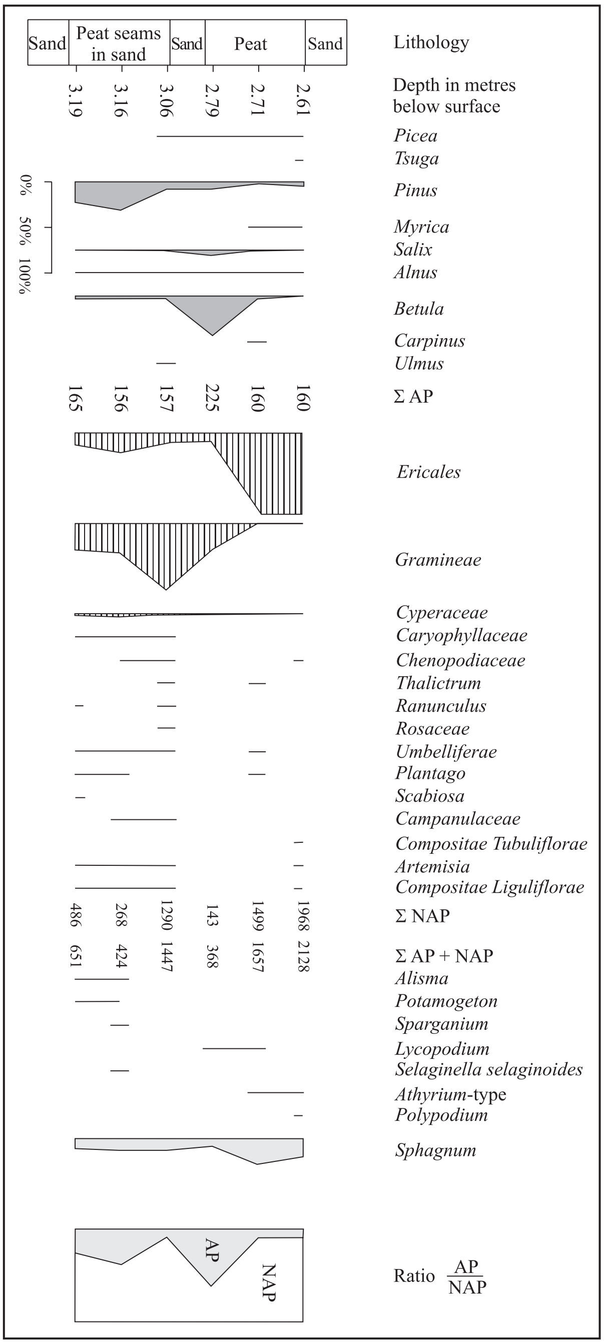

Figure 6. Pollen diagram of the peat inclusions in the Beerse Sands at clay pit 3 (Cobricam).

a) Humic upper part of the lower clay bed.
- Pit 2
Plantsociologically the following plant communities may be distinguished:

Magnopotamion
*Potamogeton praelongus*_
Nymphaeion
Myriophyllum spicatum, Potamogeton natans
Callitricho-Batrachion
Ranunculus subg. *Batrachium*
Potamion graminei
Myriophyllum alterniflorum, *Sparganium natans*
Littorellion uniflorae
Isoetes lacustris, Ranunculus flammula
Agropyro-Rumicion crispi
Juncus effusus, *Ranunculus flammula*_
Cicution virosae
Carex paniculata, *Comarum palustre*, *Menyanthes trifoliata*
Phragmitetea
Alisma plantago-aquatica
Phragmition
*Scirpus lacustris, Scirpus tabernaemontani, Carex paniculata, Comarum palustre, Ranunculus lingua*_
Oenanthion aquaticae
Sparganium emersum (= *Sparganium simplex*)_
Magnocaricion
Carex paniculata
Parvocaricetea
Comarum palustre, Menyanthes trifoliata, Ranunculus flammula

- Pit 3.
The humic clay does not show such a great botanical diversity as in pit 2. All the diaspores also occur in pit 2 except *Chara*, belonging to the Charetea. In summary, all the recorded plant remains belong to a freshwater aquatic and marshy vegetation.

b) Wood peat bed at the base of the lower clay.
- Pit 2.
The diaspores recorded by Vanhoorne (Greguss & Vanhoorne, 1961, p. 10) presently belong to the following plant communities:

Nymphaeion
Nuphar, Euryale europaea
Parvopotamion
Ranunculus subg. *Batrachium*_
Littorellion uniflorae
*Isoetes lacustris, Ranunculus flammula, Elatine*_
Nanocyperion flavescentis
Elatine
Phragmitetea
Sparganium erectum, Alisma plantago-aquatica
Glycerio-Sparganion
Hippuris vulgaris
Phragmition
Sparganium emersum, Scirpus lacustris, Comarum palustre
Parvocaricetea
Comarum palustre, Menyanthes trifoliate

All the diaspores came from freshwater plants, native to western Europe except for *Euryale europaea*, Weber, 1907, which is an extinct species probably very close to *Euryale ferox*, occurring in southern and middle Asia today. The leaves of *Calluna vulgaris* and *Vaccinium oxycoccus* belong to Oxycocco-Sphagnetea. The wood derives from the *Cupressaceae Chamaecyparis thyoides* and *Thuja occidentalis*. The former is a swamp tree, native in Atlantic North America, occurring now from North Florida in the USA to Canada ; the latter occupies swampy grounds in East North Armerica from New Brunswick and Nova Scotia in Canada to N. E. Tennessee in USA. A wood sample taken from a stool implanted in the underlying sand, could belong to *Thuja occidentalis* or *Chamaecyparis obtusa* var. *formosana* (= *Chamaecyparis taiwanensis*) (Greguss & Vanhoorne, 1982, p. 3). Beside, a new extinct species, *Thuja vanhoornei*, established by Greguss (Greguss & Vanhoorne, 1961, p. 20-24) resembles very closely the above cited species of *Chamaecyparis*.

- Pit 3.

The macroscopic plant remains, poor in comparison with pit 2, are recorded by Vanhoorne (Greguss & Vanhoorne, 1961, p. 11). It is noteworthy to recall the occurrence of *Azolla tegeliensis*, accompanied by *Salvinia natans* and *Brasenia tuberculata* Reid C. & E., 1915, very close to the extant species *Brasenia purpurea*, occurring in all the continents except Europe. The abundant wood fragments and fallen trunks derive from *Thuja occidentalis*, *Pinus pumila* and *Pinus tabulaeformis* (= *Pinus tabuliformis* var. *funebris*) (Greguss & Vanhoorne, 1982, p. 6). The former *Pinus* species is native to E. Asia, occurring in Kamchatka, Siberia, Amurland, Sachalin, Kurile Islands and Japan. The latter *Pinus* sp. is common on the mountains of Central and W. China and at lower levels in N. China and in Korea (Dallimore & Bruce Jackson, 1948).

The macrobotanical data combined with the palynological results in pit 2 and 3 reveal a landscape covered with an open swamp forest, mainly composed of *Pinus, Chamaecyparis, Thuja* and *Alnus*, in which aquatic and subaquatic habitats alternate with marshes and fens, developing locally into acid bogs.

2.2.3. Stratigraphic conclusion.

The tripartition of the exposed sediments of the Campine clay at St-Lenaarts allows a correlation of the lowermost clay bed with the Rijkevorsel Clay, the uppermost one with the Turnhout clay and the intervening sandy deposits with the Beerse Sands. Where the uppermost clay is lacking, the Beerse Sands covering the solely preserved clay bed, are overlain by loamy sands, containing locally pebbles at the base. De Ploey (1961, pp. 57-59, 63-64 & 105-107) grouped the here labeled Beerse Sands in the Formation of St-Lenaarts, limited underneath by the Lower Pleistocene substratum and overlain by the Wildert Formation. He attributed a Weichselian age to these sands. However the superposition of a clay bed, correlated with the Lower Pleistocene, point to an older age of the Formation of St-Lenaarts. In order to uniform the stratigraphic division in the area, the Beerse Member of the Weelde Formation is recommended for the Beerse Sands at St-Lenaarts.

2.3. Pit 4.

The exposed section of the clay pit, exploited by the brickyard Veraart & Floren at St-Lenaarts, situated at about 1.5 km south of the clay pits 2 and 3, showed in 1959 a good resemblance with those. Under a sand mantle with cryoturbatic phenomena such as drop structures at 1.15 m depth, occurs a clay bed, the upper 20 cm of which are humic and the base at 5.4 m more sandy. The lower part of the capping sands may be correlated with the Beerse Sands.

2.3.1. Palynology.

From the three samples taken in the humic, upper part of the clay, only one at 2.3 m depth contained pollen. The following pollen assemblage was obtained : *Picea* : 0.4 %, *Pinus* : 7.3, *Cupressaceae* : 0.4. *Salix* : 0.4, *Alnus* : 20.6, *Betula* : 1.9, *Corylus* : 2.1 (∑ AP : 33.1 %) *Ericales*: 66.8, *Armeria* B-line : 0.2 (∑ NAP : 67 %). Number of pollen grains counted : 156 AP + 319 NAP = 475 (see belw Fig. 17). This pollen assemblage betrays a heathland with some trees of *Alnus*, *Pinus*, *Picea* and *Cupressaceae*. Compared with similar pollen assemblages from the upper humic part of the clay bed in pits 2 and 3, it represents a more advanced grade of the forest opening. The presence of *Armeria* deserves mention as it might indicate an inshore, marine environment. Overlain by a thin surface cover, the periglacial Beerse Sands appear at a shallow depth. They cap the clay deposit, corresponding with the Rijkevorsel Clay. A similar sequence was observed in pit 3.

2.4. Pit 5.

The section of the claypit situated in the "Kievit Heide" (Fig. 1) in the southwestern part of Rijkevorsel, was described in detail by Paepe (Paepe & Vanhoorne, 1970, p. 207-208). In summary, below a cover of Late Pleistocene sand, two clay beds occur separated by cryoturbated sands, including a peat layer.

2.4.1. Macrobotanical remains.

The diaspores retrieved from the peat bed, included in the cryoturbated sands, are listed by Vanhoorne (Paepe & Vanhoorne, 1970, p. 208). Phytosociologically they belong to the following plant communities:

Potametea
    Potamogeton
Hydrocharito-Stratiotetum
    Stratiotes intermedius
    (HARTZ) CHANDLER, 1923
Parvopotamion
    Ranunculus subg. *Batrachium*
Potamion graminei
    Myriophyllum alterniflorum
Littorellion uniflorae
    Ranunculus flammula
Phragmition
    Ranunculus lingua, *Scirpus lacustris*
Parvocaricetea
    Menyanthes trifoliata

Noteworthy is *Stratiotes intermedius*, an extinct species occurring from the Pliocene to the Holsteinian and probably very close to the extant *Stratiotes aloides*.

2.4.2. Stratigraphic conclusion.

The tripartition of the observed sediments leaves no doubt about the assignation of the lower and upper clay bed respectively to the Rijkevorsel and Turnhout Member, whereas the intermediate sands belong to the Beerse Member.

2.5. Pit 6.

ln the clay pit of the brickyard "Algemeen Bouwbedrijf" at Beerse only one clay bed could be observed in 1956 and 1959. The exposed section was described in detail by De Ploey (1961, p. 33, pl. 13) and Vanhoorne (1963, p. 449-450). Summarizing, the clay bed with peaty top is resting on micaceous, tidal marsh sand, exhibiting bioturbatic traces. The clay is overlain by grey sand including at the base a thin gravel bed. From the latter frostwedges, filled with the overlying sand and gravel, penetrate into the upper part of the clay. Locally pockets with wood fragments and other organic remains embedded in sand, intrude down into the clay. Above the grey sand lies a loam bed, peaty at the top (3.50 - 5.50 m) capped by thin sandy seams passing at the top into peaty loam (2.9 - 3.0 m depth). This loam bed is overlain by grey, fine sand. Then follows an alternation of thin loamy and sandy laminae, displaying frostwedges and likely deposited in the Weichselian ice stage. Finally occur the Weichselian cover sands including locally a cryoturbated peat layer of Late glacial age.

2.5.1. Palynology.

The loam covering the laminated, sandy loam and extending from 2.9 until 3.0 m, yielded the following, recalculated pollen spectrum: *Picea* : 7.5%, *Pinus* : 52.5, *Pinus haploxylon* : 2.5, *Betula* : 10.0, *Alnus* : 10.0 (∑ AP : 82.5 %), *Gramineae* : 12.5, *Cyperaceae* : l2.5, *Ericales*: 2.5 (∑ NAP : 27.5 %), *Athyrium*-type : 2.5, *Sphagnum* : 5.5 (Fig. 14). Number of pollen grains counted : 33 AP + 7 NAP = 40. One pollen grain of *Tsuga* occurred in the slide outside the counted zone. Another, recalculated pollen spectrum was obtained from the top of the loam at 3.5 - 3.55 m depth : *Picea* : 3.9 %, *Abies* : 1.3 , *Pinus*: 76.6, *Corylus* : 1.3, *Betula* : 1.3, *Alnus* : 7.8, *Tilia* : 1.3 (∑ AP : 93.5 %), *Cyperaceae* : 2.6, *Ericales* : 3.8 (∑ NAP : 6.4 %), *Athyrium*-type : 1.3, *Sphagnum* : 1.3 (see below Fig. 14). Number of pollen grains counted : 72 AP + 5 NAP = 77. Both pollen assemblages reveal a mixed coniferous deciduous forest, in which *Pinus* was the dominant tree.

From the different samples, collected in the organic material occurring in the pockets sunk into the upper part of the clay, two pollen assemblages were obtained. First pollen spectrum : *Cupressaceae* : 0.7 %, *Taxus* : 1.7, *Picea* : 0.3, *Pinus* : 4.6, *Myrica* : 7.6, *Alnus* : 72.7, *Betula* : 2.7, *Carpinus* : 0.7, *Corylus* : 2.0, *Quercus* : 2.6, *Ulmus* : 0.3, *Ilex* : 1.0 (∑ AP : 96.9 %), *Chenopodiaceae* : 0.3, *Ericales* : 1.7, *Gramineae* : 0.7, *Compositae Tubuliflorae* : 0.3 (∑ NAP : 3 %), *Athyrium*-type : 1.3, *Sphagnum* : 0.3. Number of pollen grains counted : 292 AP + 9 NAP = 301 (Fig. 14). Second pollen spectrum : *Tsuga* : 0.5%, *Taxus* : 0.5, *Pinus* : 6.8, *Alnus* : 69.1, *Betula* : 2.4, *Carpinus* : 0.5, *Corylus* : 14.5, *Quercus* : 2.3, *Ulmus* : 0.5, *Ilex* : 0.5 (∑ AP 97.6 %), *Gramineae* : 1, *Ericales* : 2.4 (∑ NAP : 3.4 %), *Athyrium*-type : 3.4. Number of pollen grains counted : 200 AP + 7 NAP = 207 (Fig. 14). Both pollen assemblages are comparable and indicate a temperate forest, in which *Alnus* was the most frequent tree.

A sample of the peaty top of the clay yielded the following, recalculated pollen spectrum : *Pinus* : 52.2 %, *Picea* : 0.8, *Alnus* : 5.1 (∑ AP : 58.1 %), *Epilobium*-type : 0.8, *Ericales* : 2.7, *Gramineae* : 18.4, *Cyperaceae*: 20.0 (∑ NAP : 41.9 %). Number of pollen grains counted: 148 AP + 107 NAP = 255 (see below Fig. 17). This pollen assemblage suggests a moderately forested area, in which *Pinus* was the most frequent tree, followed by *Alnus* and *Picea*.

2.5.2. Macrobotanical remains.

The plant remains of the loamy bed are recorded in Table 2. Stratigraphically important is the presence of megasporangia of *Azolla tegeliensis* at 2.9 - 3.0 m and 3.5 - 3.55 m in the loam deposits. This aquatic fern is also represented in the peaty upper part of the clay. Wood of *Taxus baccata* has been found in the pockets, filled with organic material and sunk into the upper part of the clay (Fig. 7).

2.5.3. Stratigraphical conclusion.

Because no intensive erosion could be observed between the clay and the underlying, micaceous sands, De Ploey (1961, p. 31) inferred that a gradual transition took place from tidal marsh sand to mud flat clay without any hiatus. The possible correspondence of the tidal marsh sand with the Brasschaat Sands and the occurrence of cryoturbation at the top of the clay suggest that the clay deposit is the counterpart of the Rijkevorsel Clay. In this case, the cryoturbated sand capping the clay represents the Beerse Sands. The superposition of the loam immediately above the Beerse Sands, the occurrence of *Azolla tegeliensis*, the pollen assemblages with *Tsuga* and the mineral A-association (De Ploey, 1961, p. 34) imply that the loam may be considered as a textural variation of the Turnhout Clay. The pockets, filled with organic material embedded in the sand might originate from the overlying loam. ln this case they may also belong to the Turnhout Clay.

LITHOLOGY		PEATY LOAM	PEATY LOAM	PEATY CLAY TOP
DEPTH IN METRES BELOW SURFACE		2.90 - 3.00	3.50 - 3.55	4.20 - 4.30
MEGASPORANGIA	*AZOLLA TEGELIENSIS FLORSCH.*	1	7	2
ENDOCARPS	*POTAMOGETON SP.*	3		
NUTS	*CAREX SP. 1*	1	6	
	CAREX SP. 2	14		
ACHENE	*RANUNCULUS SUBG. BATRACHIUM*	1		

Table 2. Numbers of macroscopic plant remains from the peaty loam and the peaty clay top in pit 6

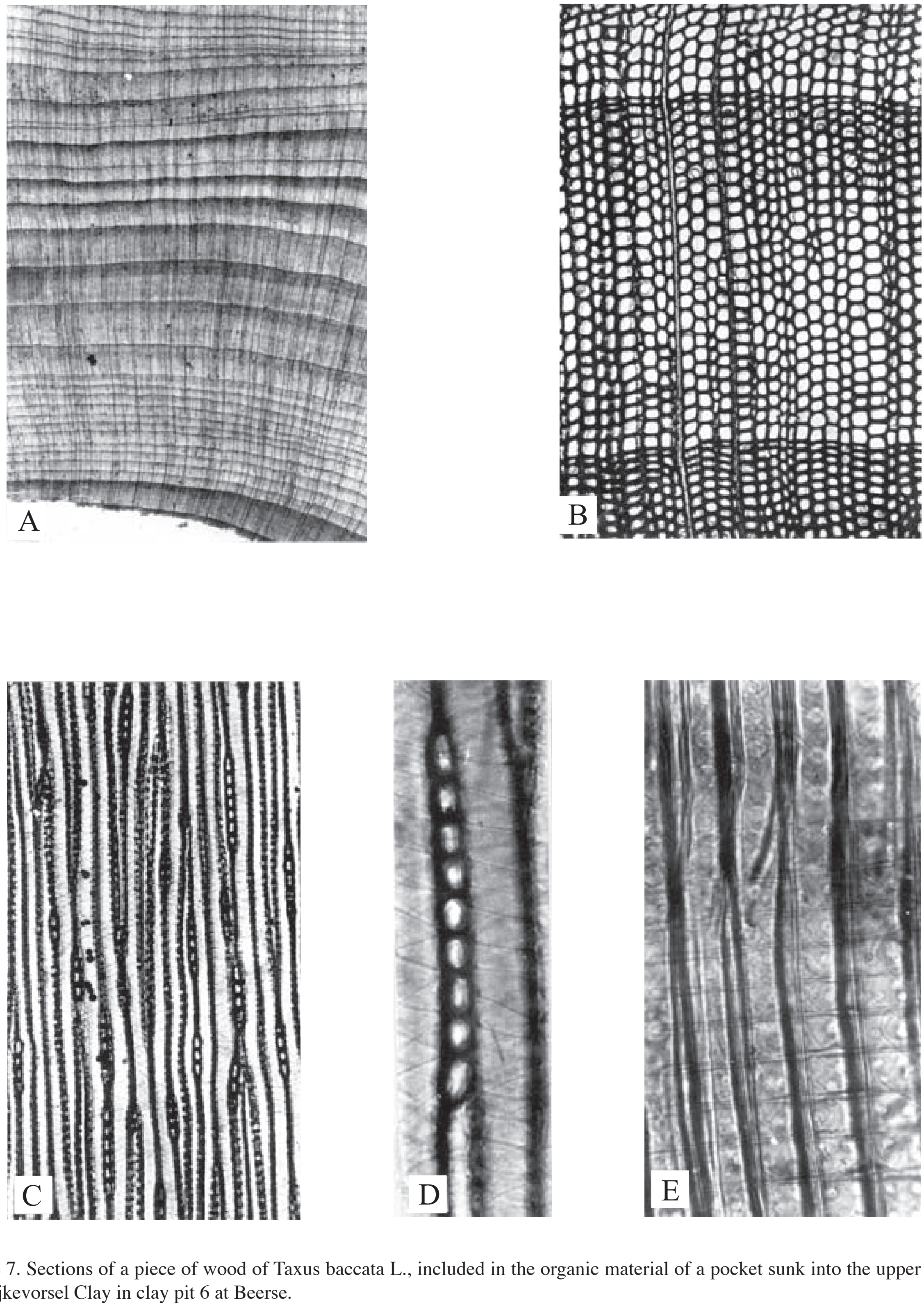

Figure 7. Sections of a piece of wood of Taxus baccata L., included in the organic material of a pocket sunk into the upper part of the Rijkevorsel Clay in clay pit 6 at Beerse.

A. Transversal section. Distinct limits between the annual rings.
No resin canals nor parenchym (x 10).

B. Transversal section. Note the crescent lines in some tracheids suggesting
the occurrence of spiral thickenings (x 100).

C. Tangential section. The ray height = 1 to 8 cells. No wood parenchym (x 100).

D. Tangential section. A ray of 9 cells high.
Distinct spiral thickenings of the tracheids (x 400).

E. Radial section. One row of bordered pits in the radial walls of the tracheids.
Uneven thickening of the horizontal ray-cell wall.
In the crossfield 1 to 2 or 4 simple circular pits.

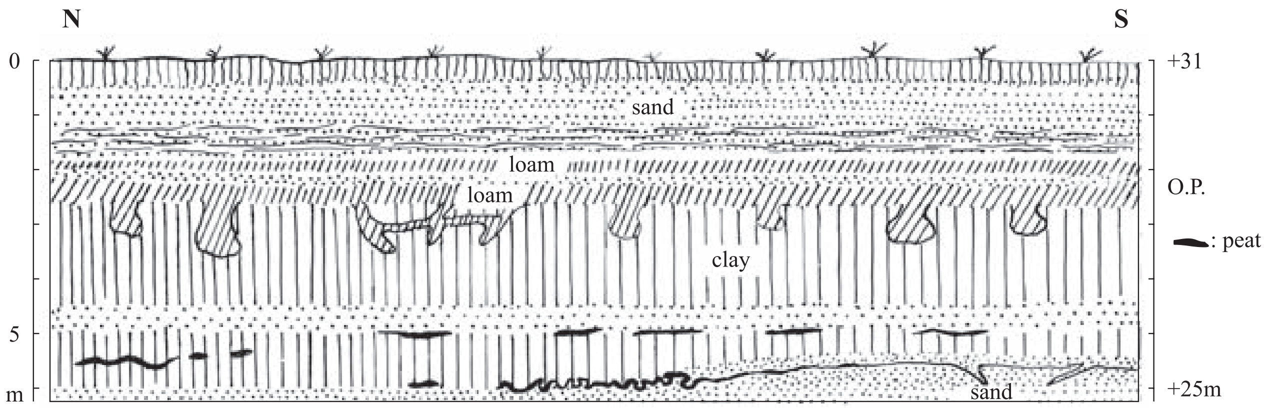

Figure 8. Section of the clay pit 7, visible in 1959, at Beerse.

2.6. Pits 7, 8 and 9.

Three clay pits, exploited by the brickyard St-Franciscus, are dealt with together as they are situated about 400 m laterally, showing in their exposures a transition of one clay bed overlying cryoturbated sands in pit 7 to two clay units separated from each other by a sandy deposit. The latter includes up to three, superposed, cryoturbated peat beds in pits 8 and 9.

2.6.1. Pit 7.

In 1956 clay pit 7 exhibited one clay bed overlain by sand, becoming more loamy downwards. It capped a contorted peat layer, including pieces of wood, and rested on sand. On the occasion of a later visit I could observe that the cryoturbated peat bed was embedded in sand, brown coloured above and white underneath. It had only developed in low-lying places and above it, it graded into a horizon, where frost wedges penetrate the underlying white sand (Fig. 8).

a) Palynology.
Peaty clay occurring between 3.5 and 3.8 m in the middle of the sole clay bed, exposed in the north corner in 1956, yielded the following pollen spectrum : *Abies* : 0.5 %, *Pinus* : 12.4, *Alnus* : 73.0, *Betula* : 1.1 (∑ AP : 87.0 %), *Ericales* : 2.7, *Gramineae* : 1.6, *Cyperaceae* : 5.4, *Caryophyllaceae* : 1.6, *Compositae Tubuliflorae* : 2.5 (∑ NAP : 13.8 %). Number of pollen grains counted : 161 AP + 25 NAP = 186 (Fig. 14). This pollen assemblage reveals a forested area, in which *Alnus* was the most frequent tree folowed by *Pinus* and *Betula*. Another peaty inclusion in the clay, collected at about 5.1 m depth (Fig. 8) in 1959, revealed the following pollen assemblage: *Abies* : 11.1 %, *Tsuga* : 13.9, *Pinus* : 27.8, *Alnus* : 44.4 (∑ AP : 97.2 %), *Gramineae* : 2.7 (∑ NAP : 2.7 %), *Athyrium*-type : 2.7. Number of pollen grains counted : 35 AP + 1 NAP = 36 (see below Fig. 14). The supremacy of AP betrays a forested landscape, in which *Alnus*, *Pinus* and *Tsuga* are the major constituent trees. *Tsuga* is a significant, stratigraphic marker because it is considered to have disappeared from Western Europe at the end of the Bavelian. A third sample of a peaty inclusion in the clay, taken in 1959 at about 5.6 m depth (Fig. 8) is dominated by NAP, in which *Chenopodiaceae* pollen totals about 72 %. Although the slide was very poor in pollen (only 11 units), it may be concluded that the high amount of *Chenopodiaceae* indicates a tidal litter zone vegetation (Fig. 14). A sample of the basal, cryoturbated peat, taken in 1956 at 6.3 - 6.5 m depth, exhibited the following, recalculated pollen assemblage: *Pinus* : 74.0 %, *Betula* : 10.0, (∑ AP : 84%), *Ericales* : 6.0, *Gramineae* : 2.0, *Caryophyllaceae* : 2.0, *Artemisia* : 6.0 (∑ NAP : 16 %). The number of pollen grains counted attained 42 AP + 8 NAP = 50. The dominance of arboreal pollen, uniquely belonging to *Pinus* and *Betula* suggests the existence of a boreal forest during an interstadial of the Beerse Sands (see below Fig. 16).

b) Macrobotanical remains.
From the peaty clay at 3.5 - 3.0 m depth only five achenes of *Ranunculus* subg. *Batrachium* and one nut of *Myriophyllum alterniflorum* were recovered. On the other hand the basal, contorted peat bed belonging to the Beerse Sands at 6.3 - 6.5 m depth was rich in diaspores. The list recorded by Vanhoorne (Paepe & Vanhoorne, 1970, p. 303-204) revealed a freshwater, aquatic and marshy vegetation, characterized by abundant megasporangia of *Azolla tegeliensis* and *Salvinia natans*. The diaspores belong to the following plantsociological associations:

Lemnion minoris
Azolla tegeliensis, *Salvinia natans*
Potametea
Potamogeton
Parvopotamion
Ceratophyllum submersum,
Ranunculus subg. *Batrachium*
Littorellion uniflorae
Ranunculus flammula
Nanocyperion flavescentis
Eleocharis palustris
Bidentetea
Ranunculus sceleratus
Agropyro-Rumicion crispi
Juncus effusus
Phragmitetea
Alisma plantago-aquatica, *Lycopus europaeus*
Phragmition
Ranunculus lingua, *Scirpus lacustris*,
Scirpus mucronatus
Parvocaricetea
Menyanthes trifoliata

Noteworthy is *Scirpus mucronat*us as it is not indigenous to the actual western European flora. The occurrence of *Azolla tegeliensis* and *Salvinia natans* is remarkable because it is the first time that these waterferns are recorded in the Beerse Sands.

2.6.2. Pit 8.

The exposed section, visible in 1959 in clay pit 8, situated at a distance of 200 m SE of clay pit 7, provided an opportunity to see the lower clay bed, that could not be observed in pit 7. A detailed description was given by Paepe (Paepe & Vanhoorne, 1970, p. 202, Fig. 1). Summarizing, below a mantle of sand and loam, two clay units were separated by sands including three superposed, disturbed peat beds, the lowest of which was situated at the limit of these sands and the underlying clay.

a) Palynology.

The cryoturbated peat, lying at the limit of the intermediate sand and the lower clay bed, yielded the following pollen assemblage : *Abies* : 0.7 %, *Picea* : 0.5, *Pinus* : 15.2, *Salix* : 0.4, *Alnus* : 0.7, *Betula* : 1.6 ($\sum$ AP : 19.1 %), *Ericales* : 31.8, *Cyperaceae* : 8.1, *Gramineae* : 18.4, *Caryophyllaceae* : 4.1, *Polygonum* : 1.3, *Chenopodiaceae* : 0.2, *Ranunculus* : 1.3, *Artemisia* : 1.7 ($\sum$ NAP : 66.9 %), *Sphagnum* : 3.2, *Selaginella selaginoides* : 0.4, *Athyrium*-type : 0.9. Number of pollen grains counted : 106 AP + 448 NAP = 554 (Fig. 16). This pollen assemblage reflects an open landscape, the vegetation cover of which was characterized by heath with some scattered trees, the most abundant being *Pinus* followed by *Betula*, *Alnus* and *Salix*. The occurrence of *Selaginella selaginoides* confirms the cold character of the deposit.

2.6.3 Pit 9.

The clay pit was opened at the other side of the road from Beerse to Rijkevorsel at a distance of about 150 m SW of pit 8. The exposure showed the same stratigraphic sequence as pit 8 except that only one contorted peat layer was included in the intermediate sands, lying between the two clay beds.

a) Macrobotanical remains.

The diaspores, retrieved from the contorted peat bed, lying in the intermediate sands, are listed by Vanhoorne (Paepe & Vanhoorne, 1970, p. 204). They belong to the following plantsociological assemblages:

Potametea
    Potamogeton
Parvopotamion
    Ranunculus subg. *Batrachium*
Nanocyperion flavescentis
    Hypericum humifusum
Phragmitetea
    Alisma plantago-aquatica
Glycerio-Sparganion
    Hippuris vulgaris
Phragmition
    Scirpus lacustris
Parvocaricetea
    Menyanthes trifoliata, Comarum palustre

2.6.4. Stratigraphic conclusion.

The brown sands, occurring in the only clay bed of pit 7 at 4.5 - 5.0 m (Fig. 7) represent a textural variation of the clay. They do not correspond with the Beerse Sands as they show no disturbance caused by cryoturbation. Therefore it is judicious to correlate the underlying, cryoturbated sands, including a contorted peat bed, with the Beerse Sands. In that view the clay bed should be ascribed to the Turnhout Clay. In the other two clay pits the upper and lower clay beds are referred respectively to the Turnhout and Rijkevorsel Member and the intermediate sands to the Beerse Member. The high frequency of *Chenopodiaceae* in the basal part of the Turnhout Clay in pit 7 may point to the proximity of the sea.

2.7. Pit 10.

Only one continuous clay bed was visible in the exposed section of the clay pit "De Toekomst" at Beerse in 1956. This clay, peaty at the top, lies below cryoturbated sand. In 1959 two clay beds could be observed, separated from each other by sand. A disturbed peat bed occurred at the lower limit of the overlying sand and the top of the underlying clay (Fig. 9). Below the lower clay bed, micaceous, tidal flat sand occurred, including clayey seams. In 1970 the section, described by Paepe (Paepe & Vanhoorne, 1970, p. 204, Fig. 4) underlined the tripartition of the Weelde Formation and demonstated

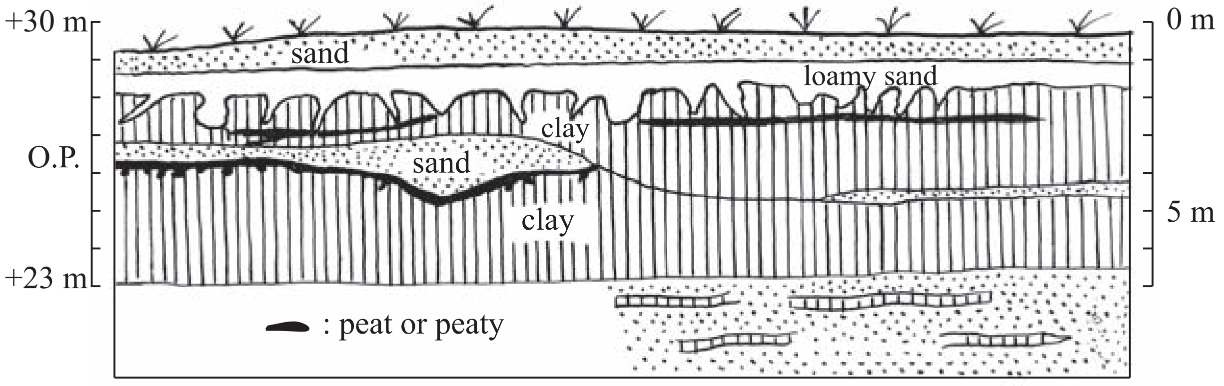

Figure 9. Section of the clay pit 10 at Beerse.

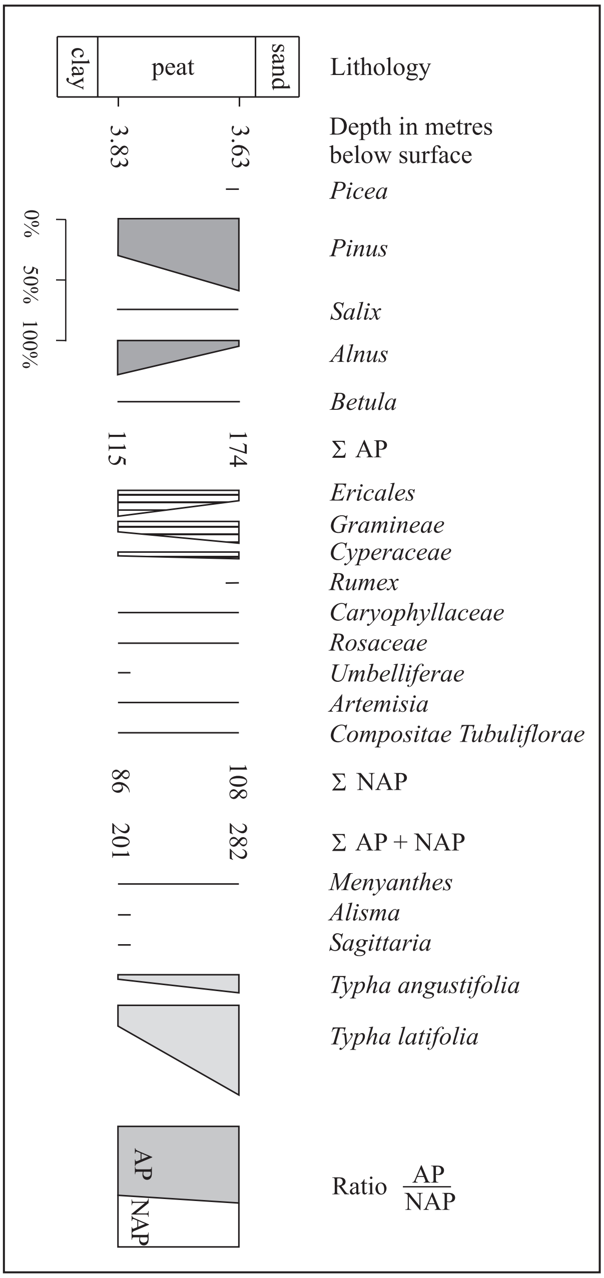

Figure 10. Pollen diagram of the cryoturbated peat bed, occurring at the limit of the overlying Beerse sands and the underlying Rijkevorsel Clay in pit 10 at Beerse.

the erosive character of the upper clay, which was deposited in two gullies, cut into the underlying, cryoturbated sand.

2.7.1. Palynology.

One sample, taken in 1956 from the peaty upper part of the sole clay bed, yielded the following, recalculated pollen assemblage : *Tsuga* : 0.4 %, *Picea* : 0.2, *Pinus* : 9.7, *Alnus* : 70.1, *Betula* : 0.8, *Ulmus* : 0.2 (∑ AP : 81.4 %), *Viscum* : 0.2, *Polygonum persicaria*-type : 0.2, *Caryophyllaceae* : 0.2, *Chenopodiaceae* : 0.4, *Umbelliferae* : 0.2, *Ericales* : 7.6, *Compositae Tubuliflorae* : 0.6, *Gramineae* : 5.0, *Cyperaceae* : 4.1 (∑ NAP : 18.5), *Myriophyllum* : 0.4, *Alisma* : 0.2, *Typha latifolia* : 1.2, *Osmunda* : 0.2, *Athyrium*-type : 53.4. Number of pollen grains counted : 395 AP + 90 NAP = 485 (see below Fig. 17). This pollen assemblage suggests a forested area, in which *Alnus* was the dominant tree, preceding *Tsuga*, *Picea*, *Pinus*, *Betula* and *Ulmus*. Four superposed samples were collected in 1959 from the cryoturbated peat layer, situated at the base of the intermediate sands. Unfortunately only two of them contained enough pollen for reliable results. The deepest sample at 3.83 m depth betrays a forested environment with *Pinus*, prevailing scarcely over *Alnus*. The accompanying trees are *Betula* and *Salix*, only represented in small amounts. The uppermost sample at 3.63 m depth showed a substantial dominance of *Pinus*, leaving *Alnus*, *Corylus*, *Salix* and *Betula* far behind (Fig. 10). The landscape was still forested with *Pinus* as dominant tree. The regression of *Alnus* in favour of *Pinus* reflects the transition of a cold temperate to a boreal climate, announcing the onset of the glacial period, represented by the capping sands.

2.7.2. Macrobotanical remains.

Only two seeds of *Hypericum* sp. were retrieved from the peaty upper part of the lower clay bed.

2.7.3. Stratigraphic conclusion.

The sole clay layer observed in 1956 and lying below cryoturbated sand may be assigned to the Rijkevorsel Member. The cryoturbated sand, sandwiched between two clay beds, observed in 1959, confirms this view. There is no doubt that the upper clay bed belongs to the Turnhout Member.

2.8. Pit 11.

The clay pit, exploited by the brickyard "St-Franciscus" in 1956, was situated at Beerse at about 2.6 km east of the three clay pits exploited by the same brickyard and dealt with under the heading 2.6 (Pits 7, 8, and 9).
The exposed section showed two clay beds separated by cryoturbated sand. The upper clay bed, displaying frost wedges at the top, was capped by sand and sandloam. The lower clay bed rested on sand.

2.8.1 Palynology.

A sample collected in 1956 in a disturbed peat bed, situated at the base of the intermediate sand between 5.5 and 6.1m depth, yielded the following pollen assemblage: *Picea* : 3.0 %, *Pinus* : 76.6, *Alnus* : 1.0, *Betula* : 1.0 (∑ AP : 81.6 %), *Ericales* : 8.1, *Artemisia* : 0.5, *Gramineae*: 7.1, *Cyperaceae* : 2.5 (∑ NAP : 18.2 %), *Typha* : 1.0, *Athyrium*-type : 2.0. Number of pollen grains counted : 161 AP + 36 NAP = 197 (see below Fig. 16). This pollen assemblage suggests a boreal, forested environment, in which *Pinus* was the dominant tree, accompanied by *Picea*, *Alnus* and *Betula*.

2.8.2. Macrobotanical remains.

The disturbed peat at the base of the intermediate sands yielded 4 endocarps of *Potamogeton*, two nuts of

Myriophyllum spicatum and 1 achene of *Ranunculus* subg. *Batrachium*. Plantsociologically the two first recorded genera may belong to a Nymphaeion and the last one to a Callitricho-Batrachion. The examined sample of the peaty clay, lying in the upper clay bed between 1.8 and 3.8 m contained 5 megasporangia of *Azolla tegeliensis*, considered by Zagwijn (1963, p. 63) as a guide-fossil of the Tiglian in the Netherlands.

2.8.3. Stratigraphic conclusion.

The uppermost clay bed may be assigned to the Turnhout Member of the Weelde Formation. The disturbed peat bed situated at the base of the intermediate Beerse Sands may be have deposited in the beginning or in a later interstade of the Beerse glacial stage.

2.9. Pit 12 and pit 13.

The sections of the two clay pits exposed in 1956 and 1959 were similar. Below a cover of sandy loam, two clay beds were separated by cryoturbated sand, including a contorted, basal peat bed that graded upwards into a peaty clay. The exposure of pit 12 is represented in figure 11.

2.9.1. Pit 12.

a) Palynology.
Only two samples of those collected in 1956 at 5.0 - 5.1 m depth from the cryoturbated peat bed, included in the sand deposit, sandwiched between the two clay beds, could be used for pollen analysis. Unfortunately they are not superposed. Here follow the two pollen spectra :
First sample : *Picea* : 0.2 %, *Pinus* : 30.7, *Salix* : 0.2, *Betula* : 3.9 (∑AP : 35.0 %), *Ericales* : 2.9, *Gramineae* : 21.2, *Cyperaceae* : 36.6, *Caryophyllaceae* : 3.6, *Compositae Tubuliflorae* : 0.5 (∑ NAP : 64.8 %), *Menyanthes* : 1.2, *Lycopodium* : 0.2. The total of the pollen grains counted is 144 AP + 266 NAP = 410 (see below Fig. 16). Second sample : *Picea* : 3.1, *Pinus* : 57.9, *Betula* : 0.4 (∑AP : 61.4 %), *Ericales* : 13.0, *Gramineae* : 14.3, *Cyperaceae* : 8.3, *Caryophyllaceae* : 11.4, *Artemisia* : 1.2, *Compositae Tubuliflorae* : 0.4 (∑ NAP : 48.6 %), *Menyanthes* : 1.2. The total of the pollen grains counted : 156 AP + 98 NAP = 254 (see below Fig. 17). The first pollen spectrum recalls an open landscape with few scattered trees, whereas the second indicates a boreal forest, dominated by *Pinus*.

A series of samples collected in 1959 in the peaty clay, occurring in the intermediate sands, allowed the construction of a pollen diagram (Fig. 12). It showed a dominance of NAP, increasing in the basal, peaty part at 4.6m depth. The clayey, upper part (4.1 - 4.5 m) betrays an open woodland dominated by *Pinus*. The basal, peaty part (4.6 m depth) indicates a more open landscape with fewer trees. *Pinus* remains the most frequent tree.

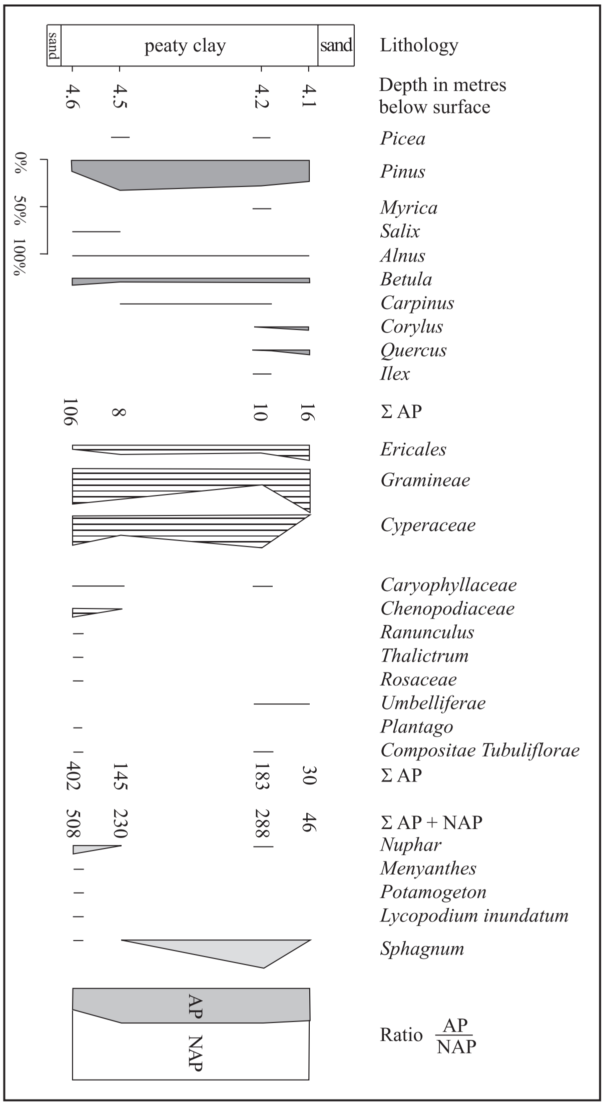

Figure 12. Pollen diagram of the peaty clay included in the Beerse Sands of pit 12 at Beerse.

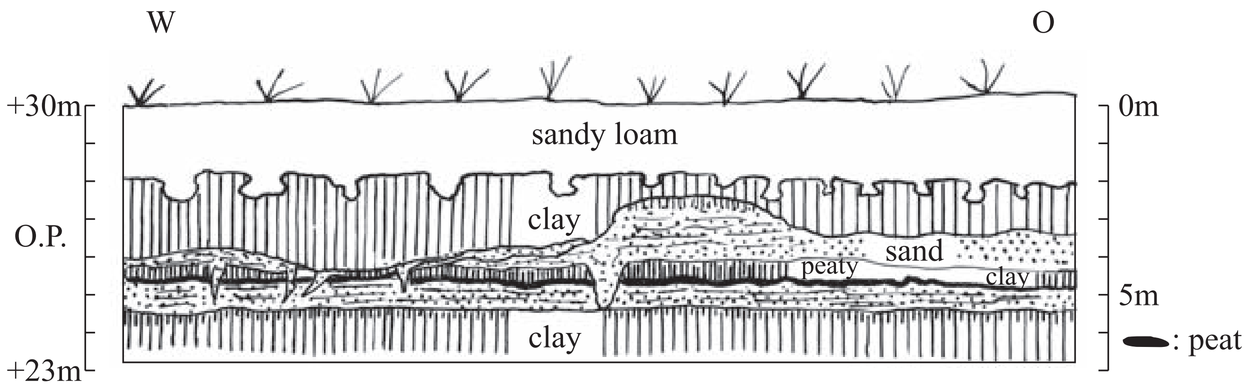

Figure 11. Section of the clay pit 12, exposed at Beerse in 1959.

Number and type of diaspores	Name of diaspores	Plant community
10 macrospores	*Isoetes lacustris*	*Littorellion uniflorae*
1 fruit	*Alisma plantago-aquatica*	Phragmitetea
12 seeds	*Montia fontana ssp. rivularis*	Montion
80 achenes	*Ranunculus sceleratus*	Bidention
9 achenes	*Hippuris vulgaris*	*Glycerio-Sparganion*

Table 3.

The peaty, upper part of the lower clay bed, sampled in 1956, yielded the following, palynological results : *Picea* : 12.6, *Pinus* : 86.0 (∑ AP : 98.6 %), *Ericales* : 2.2, *Gramineae*: 1.5, *Cyperaceae* : 1.5, *Caryophyllaceae* : 2.4, *Artemisia* : 0.8 (∑ NAP : 8.4 %), *Lycopodium* : 0.8, *Athyrium*-type : 0.8. Total of the pollen grains counted : 124 AP + 11 NAP = 135 (see below Fig. 17). This pollen spectrum indicates a boreal forest dominated by *Pinus*, followed by *Picea*.

b) Macrobotanical remains.
Only the peaty base of the clay embedded in the intermediate sands contained diaspores deriving from *Isoetes lacustris*, *Alisma plantago-aquatica*, *Montia fontana* ssp. *rivularis*, *Ranunculus sceleratus* and *Hippuris vulgaris*. The number of the diaspores and the plant communities they belong to are recorded in Table 3.

2.9.2. Pit 13.

The clay pit 13 was opened in 1964 at about 200m SE of the flooded, preceding pit 12.

a) Palynology.
From the three samples collected in 1964 from the peaty top of the lower clay bed, only the lowermost at 5.23 m depth contained enough pollen. The result of the pollen analysis was the following : *Abies* : 1.6 %, *Picea* : 1.6, *Pinus* : 11.9, *Alnus* : 6.2, *Betula* : 2.3 (∑ AP : 23.6 %), *Ericales* : 16.4, *Gramineae* : 25.0, *Cyperaceae* : 28.9, *Caryophyllaceae* : 0.8, *Epilobium*-type : 0.8, *Umbelliferae* : 3.1, *Compositae Tubuliflorae* : 0.8, *Artemisia* : 1.6 (∑ NAP : 77.4 %). *Potamogeton* : 0.8,

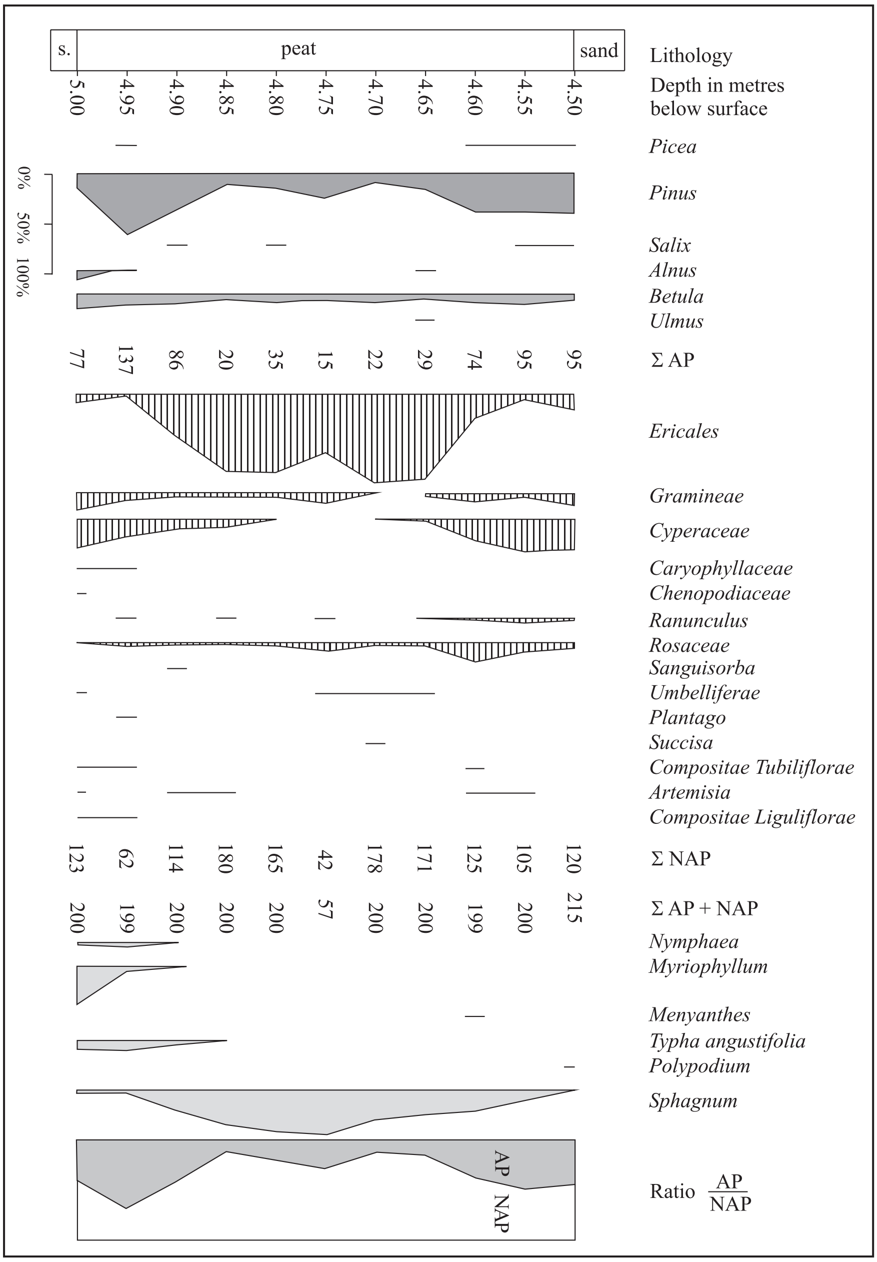

Figure 13. Pollen diagram of the peat bed included in the Beerse Sands of pit 14 at Beerse.

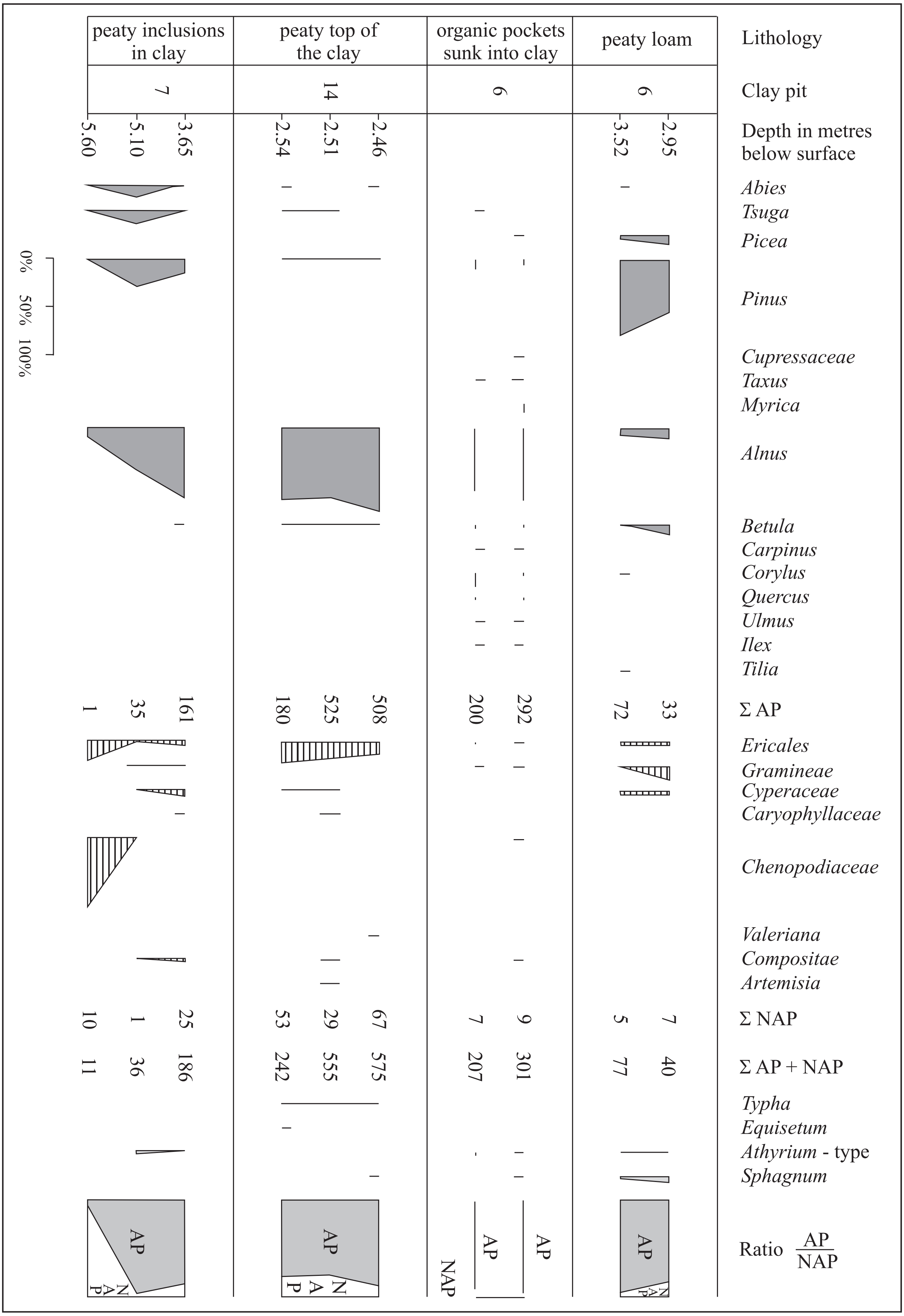

Figure 14. Synoptic review of the pollen assemblages from peaty inclusions in the Turnhout Clay from different clay pits.

Myriophyllum spicatum : 0.8. Number of pollen grains counted : 29 AP + 99 NAP = 128 (Fig. 17). This pollen assemblage reflects an open landscape with scattered trees, the best represented of which was *Pinus* followed by *Alnus*, *Betula*, *Abies* and *Picea*.

b) Stratigraphic conclusion.
In the light of the regional stratigraphy, it is clear that the lower clay bed corresponds with the Rijkevorsel Clay and the upper clay bed with the Turnhout Clay. The intermediate, periglacial sands with peaty inclusions represent the Beerse Sands.

2.10. Pit 14.

The clay pit of the brickyard "Nova" offered in 1978 and 1982 sections exhibiting two clay beds separated by cryoturbated sands. The latter include a peat deposit, which is sometimes divided into three cryoturbated layers, separated from each other by sand. The upper clay deposit was covered by laminated sand, from where big icewedges start and penetrate the underlying upper clay bed. Above loamy and sandy deposits complete the section.

2.10.1 Palynology.

In 1978 a series of eleven, superposed samples was collected in a peat deposit of 0.55 m thickness included in the intermediate Beerse Sands. The pollen diagram (Fig. 13) shows a succession of three cold episodes alternating with three warmer intervals. The cold episodes in the middle of the diagram are characterized by high frequencies of Ericales and low values of trees, belonging to the genera Pinus, Betula, Salix and occasionally Alnus. The diminution of Ericales and the increase of trees are indicative for the warmer intervals. It may be concluded that, during the deposition of the peat, a glacial climate alternated with subarctic weather conditions. The trifold repetition of cold and warmer climatic conditions corresponds with the superposition of three, cryoturbated peat layers separated by sand, observed in 1982.
The peaty cap of the uppermost clay bed yielded a pollen diagram (Fig. 14) dominated by trees, amongst which Alnus reaches high frequencies. It reveals the occurrence of a closed Alnus forest, in which Tsuga, Pinus and Betula played a minor role. The ground vegetation was mainly composed of Ericales.

2.10.2 Stratigraphic conclusion.

The threefold repetition of stadials and interstadials in the peat deposit, included in the Beerse Sands, is similar to the succession in the Eburonian, described by Zagwijn in the boring Eindhoven I in the Netherlands (1963, p. 53, encl. 4).
The peaty top of the uppermost clay may correspond with one of the zones W-A and W-C of the Waalian in the Netherlands (Zagwijn, 1963, p. 60, encl. 4), although there is not such a great diversity of thermophilous trees in the Turnhout Clay.

2.11. Pit 15.

ln the clay pit of the brickyard "Congoster" at Turnhout only one clay bed could be observed in 1956. This clay was overlain by cryoturbated sand with peat inclusions, belonging to the Beerse Sands. The latter was covered by sand of Upper Pleistocene and Holocene age. A peat bed, extending from 2.5 to 2.65 m depth, was included in the clay, which itself was peaty from 3.65 to 3.75 m and slightly peaty from 6.55 to 8.10 m depth.

2.11.1 Palynology.

The peat and the peaty clay yielded a pollen diagram (Fig. 15), which is dominated underneath by *Alnus* and above by *Pinus*. *Picea* is present at the four, examined levels, while *Tsuga* scanty appears at 2.47 m depth, *Sciadopitys* at 2.5 m depth and *Ostrya* at 7.4 m depth. The AP/NAP ratio suggests a forest becoming less dense upwards. The replacement of *Alnus* by *Pinus* as dominant tree and the decrease of the ratio AP/NAP indicate a climatic recession of a forested area, dominated by *Alnus*, to a more open woodland, in which *Pinus* was preponderant.

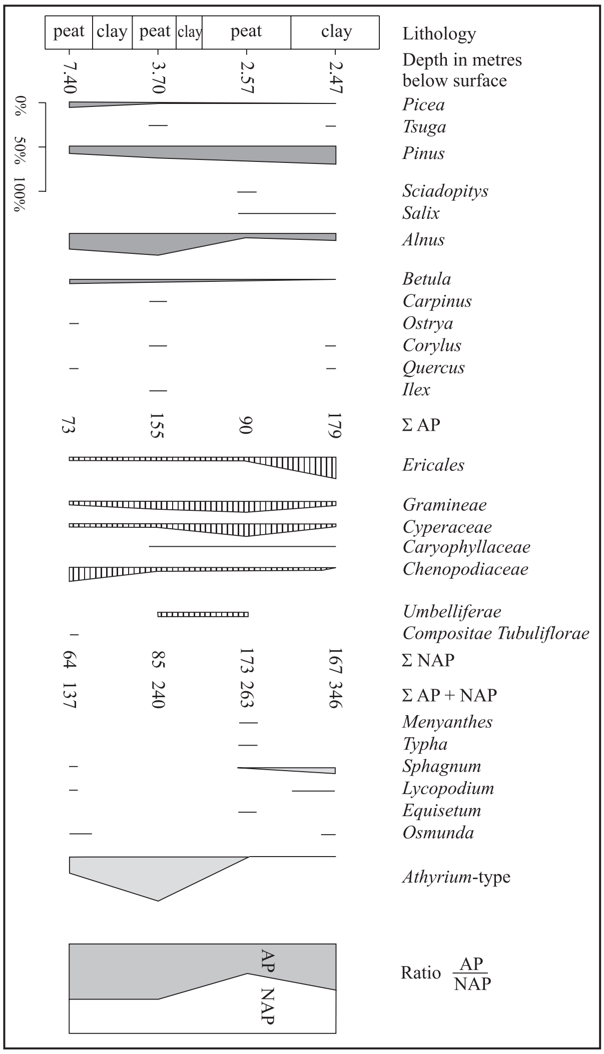

Figure 15. Pollen diagram of peat and clay samples collected in the Rijkevorsel Clay of clay pit 15 at Turnhout.

2.11.2 Macrobotanical remains.

The diaspores, compiled in Table 4, reveal an aquatic and marshy environment as well a heath in the real peat bed. The following plant communities could be identified:

Lemnion minoris
Azolla tegeliensis, Salvinia natans
Potamion graminei
Myriophyllum alterniflorum, Sparganium natans
Littorellion uniflorae
Ranunculus flammula
Nanocyperion flavescentis
Eleocharis palustris
Glycerio-Sparganion
Hippuris vulgaris
Caricion curto-nigrae
Ranunculus flammula
Oenanthion aquaticae
Sparganium emersum
Parvocaricetea
Comarum palustre, Menyanthes trifoliata
Nardion strictae/Caricion davallianae
Selaginella selaginoides
Rynchosporion albae
Andromeda polifolia

Noteworthy is *Selaginella selaginoides*, occurring in the clay immediately above the uppermost peat bed and pointing to colder climatic conditions. Also *Azolla tegeliensis* is important as stratigraphic marker.

Most of the recorded diaspores belong to a freshwater vegetation, except *Andromeda polifolia*, which points to a heath.

2.11.3 Stratigraphic conclusion.

The position of the clay below the Beerse Sands hints at a Rijkevorsel age. This is supported by the occurrence of megasporangia of *Azolla tegeliensis* and pollen of *Tsuga*.

3. General conclusions

The threefold, lithostratigraphical division of the Weelde Formation into a lower Clay Member of Rijkevorsel, an intermediate Sand and Peat Member of Beerse and an overlying Clay Member of Turnhout could be confirmed for a large area. Indeed the superposition of these three Members, originally only visible in the clay pits around Beerse, could be extended westwards towards the area around St-Lenaarts. This implies abandoning of the Formation of St-Lenaarts, introduced by De Ploey (1961) for the lower part of the sediments covering the Rijkevorsel Clay and composed of sand with peat inclusions, the latter being assigned to the Beerse Sand and Peat Member. The Rijkevorsel Clay could be observed in all the examined sections as a continuous layer, deposited partly in marine and partly under fluviatile conditions. It has a wider range than the Turnhout Clay, which occurred mainly in erosion gullies. The largest east-west distance between the clay pits, where the Turnhout Clay was observed, reach about

	Lithology	**Clay**	**Peat**	**Clay**	**Peaty clay**	**Peaty clay**
	Depth in meters below surface	2.45-2.50	2.50-2.65	2.65-2.70	3.65-3.75	6.55-8.10
Megaspore	*Selaginella selaginoides LINK*	1	–	–	–	–
Megaspo-rangia	*Azolla tegeliensis FLORSCH.*	_	_	_	1	_
	Salvinia cf. natans ALL.	_	_	_	17	_
Fruits or seeds	*Sparganium natans L.*	_	1	_	_	_
	Sparganium emersum REHN.	_	5	_	_	_
	Potamogeton sp.	_	1	_	_	_
	Carex spec. div.	_	19	2	_	_
	Carex sp. 1	11	6	_	_	_
	Eleocharis cf. palustris R. BR.	3	_	_	_	_
	Ranunculus flammula L.	_	209	_	_	_
	Comarum palustre L.	_	36	1	_	_
	Myriophyllum alterniflorum P.DC.	1	–		–	–
	Hippuris vulgaris L.	17	_	3	_	_
	Andromeda polifolia L.	_	50	_	_	_
	Menyanthes trifoliata L.	_	385	_	_	_

Table 4. Numbers of macroscopic plant remains from the peat, peaty clay and clay in pit 15.

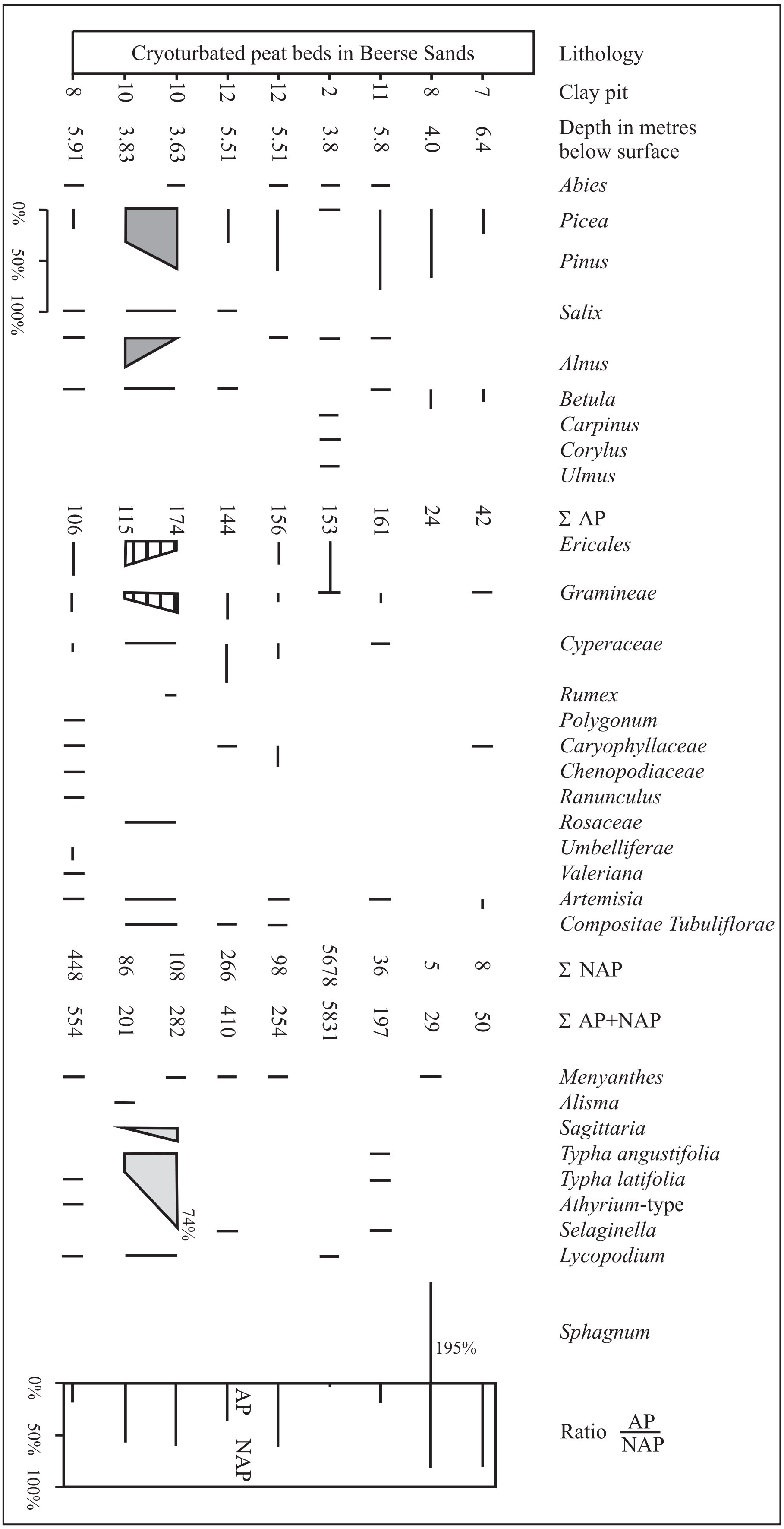

Figure 16. Synoptic review of the pollen spectra from peat samples included in the Beerse Sands at different clay pits.

twelve km. This figure may reflect the tentative breadth of the estuary. The intercalated Beerse Sands are fluviatile and eolian in origin and may include cryoturbated peat beds. These sands may be partly or completely eroded by Turnhout Clay. The following, ideal profile may be established for the studied area:

- Holocene sands with podzol formation at the top and sometimes lower down in the sand
- Late glacial, sandy and loamy sediments, including locally a peat bed of Allerød age
- Loamy sands and loams of Weichselian origin
- Turnhout Clay with locally a peaty, upper part
- Beerse Sands with peat inclusions, displaying periglacial structures
- Rijkevorsel Clay with occasionally a peaty, upper part and a peat bed at the base
- Estuarine and exceptionally eolian sands, the former displaying sometimes bioturbation.

The palynological results of the Rijkevorsel Clay reveal a forested area in which *Pinus*, preponderant at the base and the top, was replaced by *Alnus* in the middle. The lower *Pinus*-biozone, recorded in the clay and peat deposit in pit 1, is characterized by a *Pinus-Alnus-Picea-Betula* pollen assemblage, which combined with the occurrence of *Selaginella selaginoides* and *S. helvetica*, suggests a forest of boreal type, comparable with the Middle Boreal region of Finland (S. Hickx, 1977). Rapidly more temperate trees such as *Corylus*, *Quercus*, *Ulmus*, *Carpinus*, *Tilia*, and *Ilex* as well as the stratigraphically significant trees *Tsuga*, *Pterocarya*, *Carya* and *Nyssa* invade that boreal forest. The gradual increase of *Alnus* leads to its supremacy at the top of the diagram (Fig. 2), introducing the onset of the *Alnus*-biozone.

The latter is more developed in the peat beds of pits 2, 3 and 15, where *Cupressaceae*, *Cyrillaceae*, *Ostrya* and *Sciadopitys* form part of the woodland. The rise of the sea level leads to the deposition of clay of fluviatile and later of estuarine origin. Little palaeobotanical information is available from these deposits. After the regression of the sea, a fluviatile, peaty clay was deposited, containing an aquatic and marshy macroflora. Palynologically it represents the upper *Pinus*-biozone. Then the landscape was covered by a mixed coniferous deciduous forest, in which *Pinus* was the most frequent tree and accompanied by *Picea*, *Alnus* and *Betula* (Fig. 17). The dominance of *Pinus* and the relatively high NAP-content attribute a boreal character to this woodland. The successional change from a boreal to a temperate and again to a boreal woodland tallies with an interglacial vegetation cycle.

The limit between the Rijkevorsel Clay and the overlying Beerse Sands roughly corresponds with the transition of an interglacial to a glacial stage. The Beerse Sands, including up to three cryoturbated peat beds, exhibits an alternation of full-glacial and interstadial substages. The former display the prevalence of a treeless vegetation, very rich in heath, open herbaceous and aquatic communities, while the latter are characterized by a restricted woodland with trees of boreal type or a park tundra with scattered trees of *Pinus*, *Betula*, *Salix* and *Alnus*. In pit 7 (Fig. 8) a freshwater, aquatic and marshy macroflora was included in a contorted peat bed at the top of the Beerse Sands. The abundant occurrence of megaspores of *Azolla tegeliensis* and *Salvinia natans* reveals that these waterferns still occurred at least in one of the interstadials of the Beerse Sands.

The periglacial Beerse Sands are overlain by the Turnhout Clay which was not as widespread as the Rijkevorsel Clay. The palynological study of a peaty inclusion in the Turnhout Clay at 5.6 m depth in pit 7 (Fig. 8) reveals the prevalence of NAP, principally *Chenopodiaceae*, which may

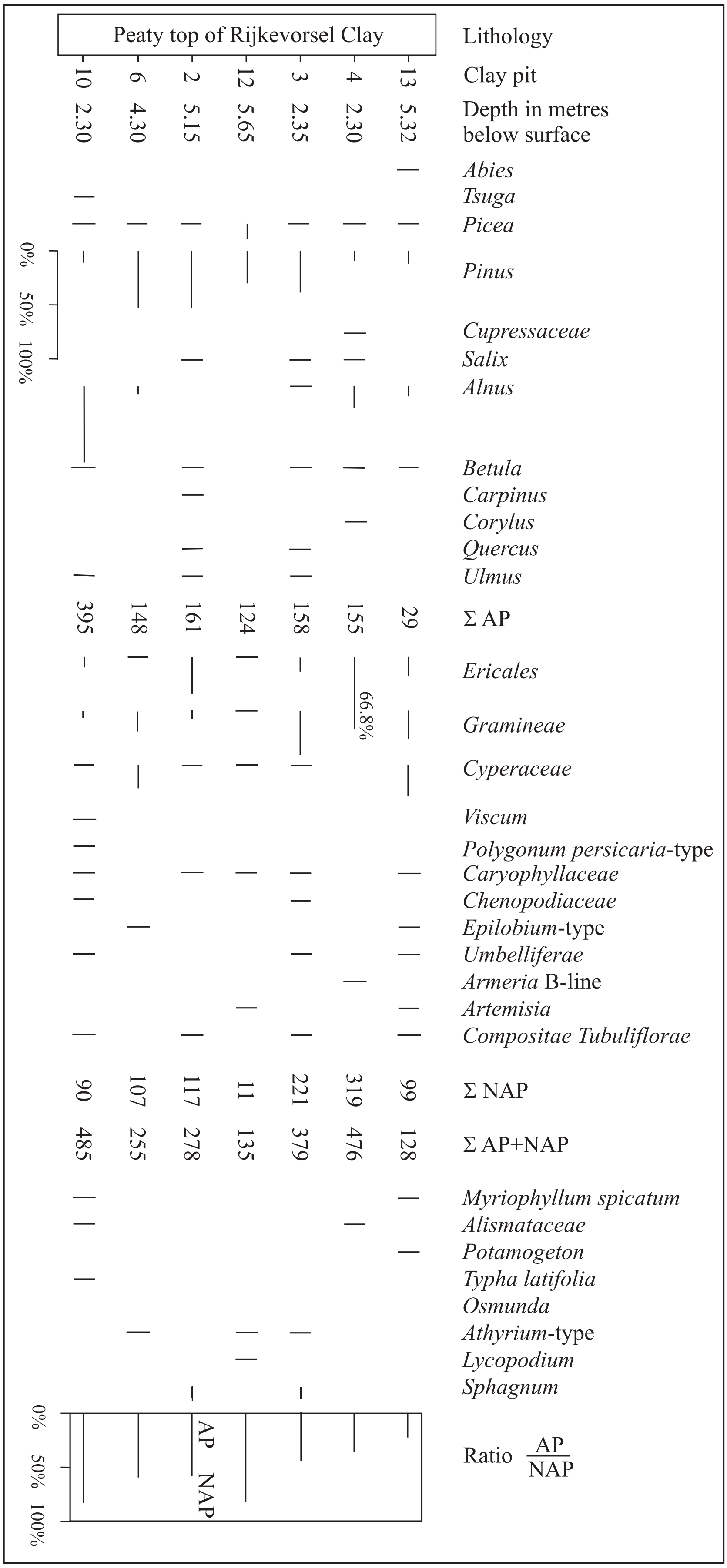

Figure 17. Synoptic review of the pollen assemblages from the humic top of the Rijkevorsel Clay in different clay pits.

<table>
<tr><th colspan="3" rowspan="2">Lithostratigraphy</th><th rowspan="2">Chrono-strati-graphy</th><th colspan="2"></th><th colspan="3">Previous correlations</th></tr>
<tr><th>Biozone</th><th>Vegetational succession based on palynological data</th><th>Paepe & Vanhoorne, 1970</th><th>Kasse, 1988</th><th>Bogemans, 1999</th></tr>
<tr><td rowspan="14">Campine Group</td><td rowspan="12">Weelde Formation</td><td rowspan="3">Turnhout Clay Member</td><td rowspan="3">Turnhout inter-glacial stage</td><td>3</td><td>Boreal forest dominated by Pinus</td><td rowspan="3">Waalian</td><td rowspan="3">Tiglian C5</td><td rowspan="12">Tiglian C</td></tr>
<tr><td>2</td><td>Temperate forest dominated by Alnus</td></tr>
<tr><td>1</td><td>?</td></tr>
<tr><td rowspan="6">Beerse Sand Member</td><td rowspan="6">Beerse glacial stage</td><td>6</td><td>Park tundra</td><td rowspan="6">Eburonian</td><td rowspan="6">Tiglian C4</td></tr>
<tr><td>5</td><td>Open vegetation principally heath</td></tr>
<tr><td>4</td><td>Park tundra</td></tr>
<tr><td>3</td><td>Open vegetation principally heath</td></tr>
<tr><td>2</td><td>Boreal forest dominated by Pinus</td></tr>
<tr><td>1</td><td>Park tundra</td></tr>
<tr><td rowspan="4">Rijke-vorsel Clay Member</td><td rowspan="4">Rijkevorsel interglacial stage</td><td>4</td><td>Park tundra</td><td rowspan="4">Tiglian</td><td rowspan="4">Tiglian C3</td></tr>
<tr><td>3</td><td>Boreal forest dominated by Pinus</td></tr>
<tr><td>2</td><td>Temperate forest dominated by Alnus</td></tr>
<tr><td rowspan="3">Malle Formation</td><td>1</td><td>Boreal forest dominated by Pinus</td><td>Tiglian B</td></tr>
<tr><td>Vosselaar Clay Member</td><td colspan="5" rowspan="2"></td><td rowspan="2">Tiglian A</td></tr>
<tr><td></td><td>Brasschaat Sand Member</td></tr>
</table>

Table 5. Synoptic review of the lithostratigraphic, chronostratigraphic and biostratigraphic units of the Campine Group and a comparison with the Dutch Tiglian.

indicate the proximity of the transgressive sea (Fig. 14). Peaty inclusions higher up point to a forested area (Fig. 4), in which *Alnus* was by far the most important tree. It was accompanied by small quantities of *Abies*, *Picea*, *Tsuga*, *Pinus*, *Cupressaceae*, *Taxus*, *Betula*, *Carpinus*, *Corylus*, *Quercus* and *Ulmus*. The upper part of the Turnhout Clay, represented by loam deposit in pit 6, yielded a *Pinus-Alnus-Betula-Picea* pollen assemblage. The high frequency of AP suggests a boreal forest, in which *Pinus* was a substantial component (Fig. 14). Although the initial, boreal zone is lacking, it may be conjectured that an interglacial succession occurred in the Turnhout Clay similar to that of the Rijkevorsel Clay, as cold, climatic conditions are reflected in diagram Merksplas 1 (Kasse, 1988, p. 116) at the base of the Turnhout Clay.

On geomorphological, sedimentological and palaeobotanical grounds the Rijkevorsel and the Turnhout Clay were deposited during an interglacial partly under marine, partly in fluviatile conditions; the intermediate Beerse Sands were deposited during a glacial stage in a fluviatile and eolian environment. Comparing with the chronostratigraphy of the Netherlands, Paepe and Vanhoorne (1970, p. 209-210) correlated the Turnhout Clay with the Waalian interglacial, the Rijkevorsel Clay with the Tiglian and the intermediate Beerse Sands with the Eburonian glacial. In 1988 Kasse placed the whole sequence in the Tiglian interglacial. He correlated the Rijkevorsel Clay with the TC3-zone in the Netherlands, the Beerse Sands with the TC4 and the Turnhout Clay with TC5. However, the correlation of the Beerse Sands with the TC4-biozone in the Netherlands cannot be confirmed by the palynological data. Indeed TC4, as introduced by Zagwijn (1963, p. 53) for a cooler oscillation in the Tiglian, still shows the occurrence of a forest, in which *Pinus* and *Picea* dominated *Betula*, *Salix*, *Abies* and *Tsuga*. These trees were still accompanied by thermophilous genera such as *Quercus*, *Corylus*, *Tilia*, *Carpinus*, *Ostrya*, *Magnolia*, *Phellodendron*, *Parthenocissus*, *Ilex, Eucommia*, *Ulmus*, *Fraxinus*, *Vitis* and *Carya*. Therefore it is hard to compare this palynological assemblage with that of the Beerse Sands, characterized by an alternation of a tundra and a taiga vegetation. Moreover *Azolla tegeliensis*, used by Kasse (1988, p. 118) as a master argument for the correlation of the Beerse Sands with the TC4-biozone, seems to have a wider stratigraphic range than the Tiglian since three megasporangia of this extinct waterfern were discovered in a peat deposit of Cromerian age (early Middle Pleistocene) at Lo in NW-Belgium (Vanhoorne, 2003, p. 79 & 81). On the other hand it is of particular interest that the alternation of stadials and interstadials in the Beerse Sands agrees well with a similar succession in the Dutch Eburonian (Zagwijn, 1963, p. 53 & encl. 4). Although the palynological data of the Turnhout Clay are sparse, they exhibit a, vegetational picture similar to the Waalian in the Netherlands, where *Alnus* is also the dominant tree in the two warmer episodes WA and WB, however accompanied by a greater diversity of thermophilous trees. Although the correlation put forward by Paepe & Vanhoorne (1970, p. 209 & 210) seems on palynological grounds to be the most plausible, biostratigraphic interpretation, it is perhaps more prudent to use a local, stratigraphic nomenclature. Therefore, the present author proposes the Rijkevorsel interglacial, the Beerse glacial and the Turnhout interglacial respectively for the Rijkevorsel Clay, the Beerse Sands and the Turnhout Clay (Table 5).

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