4 Early Pleistocene Tiglian sites in The Netherlands: a revised view on the significance for Quaternary stratigraphy

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Abstract
Paloynological research at the Tiglian sites of the Dutch-German border area near Venlo forms the backbone of the Early Pleistocene stratigraphy in The Netherlands. The onset of the Quaternary in this part of Europe is well expressed by the extinction of the so-called 'tertiary elements' in the pollen diagrams. The Tiglian stratigraphy is based on palynological investigations of clay deposits in a number of excavations situated along the Dutch-German border. Three locally defined pollen zones, respectively T-A, T-B, and T-C have already formed for a long time the basis for the main chronostratigraphical subdivision of the Tiglian Stage.

Sedimentological interpretation of the Early Pleistocene fluvial sequence in the Tegelen-Maalbeek area shows that the deposits were deposited in a fine-grained meandering river system. The floodplain facies show facies associations that typify, for instance, the infilling of oxbow lakes, deposition of massive clays in floodbasins or back-swamps, and the formation of crevasse-splay and overbank deposits. These facies associations occur at nearly all levels within the up to 10 m thick fine-grained upper part of the fluvial sequence.

Pollen assemblages derived from the fine-grained floodplain sediments show that they are partly influenced by the fluvial development but they also reveal indications of climate change.

The correlation of the pollen zones from the Tegelen-Maalbeek fluvial sequence with the much thicker and stacked Early Pleistocene fluvial sequences in the Roer Valley Graben (RVG) reveals a number of problems. The former in the RVG interpreted Tiglian A part appears to be an equivalent of the Oehel Beds and is of Late Pliocene age. The position of pollen zone T-B is still uncertain. Finally the detailed subdivision of the Tiglian C at its stratotype in the Russel-Tigha-Egypte pit cannot be correlated correctly to borehole sequences in the RVG. The sediments of the so-called cool or cold phase of pollen zone T-C are interpreted as having formed during the onset of crevasse and therefore its significance as a regional climate indicator is discussed.

As a consequence the extrapolation of the Tiglian pollen zones into chronostratigraphical substages is questioned and it is concluded that the chronostratigraphical subdivision of the Early Pleistocene, based on palynological characteristics and palaeontological analyses, requires reconsideration.

4.1 Introduction
Geological research on the Early Pleistocene Tiglian Stage sites of the Dutch-German border area, near Venlo and Tegelen, has formed the framework of the Early Pleistocene stratigraphy in The Netherlands (Kend & Reid, 1915; Van der Vlerk & Ploetschitz, 1969; Zagwijn, 1969, 1970). Basically it is developed by compilation of evidence derived from palaeontological (i.e. pollen and plant macro remains), sediment petrological (heavy-minerals), lithostratigraphical and palaeontological (small and large mammal) investigations. However, palynology played the central role in the development of Early Pleistocene stratigraphy in these sequences (Fig. 4.1).

Sediment palynological investigations as carried out by Zonneveld (1947b, 1950, 1958) and his successors in the Geological Survey of The Netherlands, formed a firm basis for the stratigraphical interpretation of the biological evidence in the Plio-Pleistocene fluvial sequences at several sites in the south-eastern part of the Netherlands. Basically it provided a lithostratigraphical separation of the Upper Pliocene and Lower Pleistocene fluvial deposits that comprised the Ploecoe Kieseloolite Formation (typified by stable heavy-mineral associations), the Lower Pleistocene Tegelen Formation (typified by unstable heavy-mineral associations), and the overlying Kedichem Formation (typified by a stable heavy-mineral content). This three-fold subdivision (Zagwijn, 1960; Zonneveld, 1958; chapter 2) strongly controlled the interpretation of pollen assemblages derived from these deposits. Since the 1970s it has become clear that the marked change in heavy-mineral content of the Plio-Pleistocene fluvial sequences does not coincide with the Plio-Pleistocene transition but had already taken place during the Pliocene (Boenigk, 1970, 1978, 2002; Hagedorn, 2004; Kemna 2005; Westerhoff et al. 2008; chapter 2). Furthermore it appeared that at least the lower part of the former Kedichem Formation (part of which is now assigned to the Stramproy Formation, Westerhoff et al. 2003, chapter 2) was deposited simultaneously with the former Tegelen Formation (now part of the Waalre Formation, Kasse, 1990; chapter 2; Westerhoff et al., 2008).

The Early Pleistocene pollen record of The Netherlands is mainly derived from fluvial deposits and generally interpreted by a straightforward equation of vegetation development and climate change. All of the sites investigated form part of the Plio-Pleistocene Rhine-Meuse river system and have provided a huge amount of data. Some of the sites are situated on the tectonic 'high' of the Peel Block, where Lower Pleistocene deposits are situated at or near the surface. Complementary data were derived from boreholes situated in the adjacent subsiding Roer Valley Graben RVG.

Figure 4.1: Chronostratigraphical subdivision of the Early Pleistocene with pollen-defined stages and substages, and a pollen-based temperature curve (Zagwijn, 1968), compared with the Marine Isotope Stages (composite of cores ODP946, G057, YO-25-26) and the palaeomagnetic record.
During the Pliocene the vegetation in the area was dominated by the so-called ‘ternary elements’ (e.g. Zagwijn, 1960). Their extinction at the end of that epoch took place more or less simultaneously with changes in the mammal and mollusc fauna, and forms one of the striking features that characterise the onset of the Quaternary in this area.

The Tiglian stratigraphy is primarily based on pollen analytical investigations of fluvial clay deposits at the Russel-Tiglia-Egypte pit, near Tegelen, and borehole data in the vicinity of Eindhoven (Zagwijn, 1963a). Three pollen zones, respectively T-A, T-B, and T-C form the main subdivision of the Tiglian Stage. Pollen zone T-A is defined by the presence of Fagus, a genus that lacks in younger pollen zones for a very long time and only re-enters The Netherlands in the Holocene (Van der Hammen et al., 1971). It was first described from a clay deposit in the Jansen-Dings excavation near Belfeld (Van der Vlerk & Florschütz, 1953; Zagwijn, 1963). The T-B pollen zone is dominated by high values of Ericaceae accompanied by some Artemisia pollen and a general low content of tree pollen. This pollen zone was first described from borehole 51G0218, near Eindhoven in the RVG (Zagwijn, 1963). However, it was realised that this zone showed an incomplete picture (Zagwijn, 1975). Pterocarya is a characteristic and often dominant taxon in the T-C pollen zone. This zone was first defined with detailed subdivisions from the Russel-Tiglia-Egypte pit, near Tegelen (Zagwijn, 1963).

Absolute ages are not known but detailed correlation with the palaeomagnetic timescale has provided some indications (Van Montfrans, 1971; Kasse, 1996). Based on their scale the whole of the Tiglian Stage probably lasted from c. 2.2 until c. 1.7 Ma (Zagwijn, 1998). However, in many papers these boundaries vary between 2.4 and 1.8 or 1.6 Ma.

Two main questions arise from a closer examination of the Tiglian pollen zones. The first problem concerns the up-scaling of the relatively thin (10-20 m) fluvial sequences in the Tegelen exposures to the thick (100 m) Early Pleistocene sequences in the RVG. It is unlikely that the sequences of both areas reflect a similar amount of time. Extrapolation of the Tiglian pollen zones to a regional scale and their chronostratigraphical significance needs to be reconsidered. The second question deals with the general problem of interpreting the pollen record from discontinuous fluvial sequences. The main issue is how to distinguish autochthonous and allochthonous signals. Sedimentological interpretations of the type site sequences demonstrate a correlation of facies change and pollen content.

However, time control is poor and the fluvial record might be expected to contain many hiatuses. Therefore, reconstruction of a pollen and climate-based stratigraphy can only be achieved when it is based on a firm lithostratigraphical and sediment-architectural framework.
Figure 4.4. Cross-section along the Dutch-German border in the Tegelen-Maalbeek area (location indicated in Fig. 4.3). The position of the lithostratigraphical units is based on field observations, borehole data and cone penetration tests. The heavy-mineral data from three boreholes clearly show the differences between the pre-Rhine (stable) and Alpine-influenced (unstable) Rhine-Meuse deposits. The northward dipping of the main lithostratigraphical units results from the generally NE orientated tilting of the main tectonic blocks in the area.
4.2 Geological background

From a tectonic point of view, the south-eastern Netherlands form part of the Lower Rhine Embayment (LRE) a tectonically subsiding area on the south-eastern margin of the North Sea Basin. To the southeast it is bounded by the Paleozoic rocks of the Rheinischer Massiv (Fig. 4.2). The main tectonic elements are the subsiding RVG and the adjacent Peel Block (Kleistemann, 1983; Geluk et al., 1994; Ziegler, 1994; Michon et al., 2003; Van Balen et al., 2005). The whole area forms part of the Roe Valley Rift System. The RVG itself is bounded by two major faults. The Midhuns Fault Zone and Gîte Rijen fault form the southern and western border respectively, while the Peel Boundary fault is the main bounding fault along the eastern side of the RVG (Fig. 4.2). The Peel Block area especially is strongly dissected by a number of SE-NW running faults.

Fluvial sedimentation in the LRE began at the end of the Miocene and extended gradually westwards through the Pliocene. These Pliocene fluvial deposits are assigned to the Kieseloolite Formation. The full sedimentary sequence of this formation reaches a thickness exceeding over 200 m in the RVG. It consists of thick sand bodies repeatedly interrupted by up to ten or more metres thick clay deposits with characteristic intercalations of peat or browncoal strata. The uppermost part of this deposit has been described as the Reuver Clay (now formally assigned as Reuver Bed) and was initially studied in several pits on the Peel Block, south-east of Tegelen, near Reuver (Reid & Reid, 1915). The Kieseloolite Formation is typified by a stable heavy-mineral content (Boenigk, 1970; Kemna, 2005, chapter 2). The overlying fluvial deposits are assigned to the Waalre Formation (W eierts et al., 2000; Westerhoff et al., 2003, chapter 2). They consist of mixed Rhine-Meuse deposits, with an unstable heavy-mineral content, and they may reach a maximum thickness of c. 100 m in the RVG. Remnants of the Waalre Formation on the Peel Block show an average thickness of 15 to 25 m. The Waalre Formation was deposited during the Late Pliocene and Early Pleistocene. Formerly the larger part of the Waalre Formation was assigned to the Tegelen Formation (cf. Doppert et al., 1975).

4.3 Lower Pliocene fluvial deposits in the Tegelen-Maalbeek area.

4.3.1 Lithostratigraphy

The Dutch-German border area, east of Tegelen, has a long history of geological research and includes a number of Late Pliocene and Early Pleistocene ‘type-sites’ (Fig. 4.3; for extended references see: Zagwijn, 1998; Meijer, 1998). As a result of its position on the Peel Block, Late Pliocene and Early Pleistocene deposits are situated at or near the surface. The area is marked by a pronounced terrace escarpment formed by the Meuse which, reinforced by tectonic movements, has undergone a major shift eastwards across the Peel Block since the Miocene and extended gradually westwards through the Pliocene. This is strongly dissected by a number of SE-NW running faults.

A diagrammatic record of Lower Pleistocene deposits has been preserved in the Netherlands-German border area east of the terrace escarpment. An overview of the general lithostratigraphy in this area is shown in the nomenclature section. (Fig. 4.4). The section is based on borehole data, core penetration tests (CPT), field observation in excavations and the results of regional mapping. All units show a NW-oriented tilting on the tectonic blocks. The sequence comprises five lithostratigraphical units which are listed below:

1. The base is formed by the Reida Formation, consisting of fine-grained and glauconite-bearing marine deposits of Miocene age.

2. The Kieseloolite Formation unconformably overlies the Reida Formation. The unit consists of up to 30 m thick medium to coarse-grained fluvial deposits which grade into a several metre thick clay deposit towards the top. The latter is assigned to the Reuver Bed. (Zagwijn, 1960; Boenigk, 1970; Westerhoff, 2004; Kemna, 2005, 2008) that normally contains two characteristic peat or browncoal strata in its uppermost part. The sand is typified by a dominant stable heavy-mineral content (Fig. 4.4). The unit is of Miocene (Pannonian) age.

3. The Waalre Formation consists of a sequence of fluvial deposits up to 25 m of the Early Pliocene Rhine-Meuse System. The basal part consists of coarse-grained gravel and sand that grades upwards into fine-grained and clayey deposits. An erosional boundary marks the transition into the underlying Kieseloolite formation. The heavy-mineral content is typified by a dominance of unstable minerals, with a clear presence of quartz, that often culminates in and around the clayey deposits. Two subunits can be recognised within the Waalre Formation. Firstly, deposits near Higher Stall form the southern part of the Waalre Formation. (Fig. 4.4.4) are assigned as subunit WA-1. They are characterised by an unstable heavy-mineral association and form part of the so-called Oebel Beds (Boenigk, 1970; Kemna, 2005, 2008; Boenigk & Prensch, 2006; Heumann & Uut, 2002; Westerhoff, 2004). The uppermost part of subunit WA-1 consists of a clay deposit that lithologically resembles the Reuver Bed and yields typical Late Pliocene pollen assemblages (e.g. presence of ‘Bemmel element’ Zagwijn, 1974)-. However, the lithology (micaceous sand and clay) and the predominance of an unstable heavy-mineral association of this subunit bear all the characteristics of an ‘Alpine-influenced’ Rhine deposit and therefore it forms part of the Waalre Formation. North of the fault that separates the Hoher Stall area from the Maalbeek-Tegelen area (Fig. 4.5) gravel, sand and clay deposits of the Waalre Formation overly the Reuver Bed and are assigned to the Tegelen Member. This member of the Waalre Formation comprises all the deposits of the formation that occur on the Peel Block (Tegelen, 1960). The second site of interest is at Prestetje-Sigla Egypt where Zagwijn (1963) defined his subdivision of the pollen zone T-C. Both pits have been abandoned since the 1960’s. More recent work has been carried out in the neighbouring pits of Maalbeek, Laums and Boveste Molen (Fig. 4.4). The Maalbeek pit is of particular interest because the exposed clay was first assigned to the Eburonian Stage (Zagwijn, 1963c). However, recent investigations have demonstrated that part of the clay deposits at Maalbeek can be interpreted as belonging to Zagwijn’s pollen zone T-A (Westerhoff et al., 1998). This particular part of the clay at Maalbeek is situated between other clay deposits that show pollen assemblages which can be assigned to the pollen zones T-A and T-C respectively.

For the purpose of this paper more detailed descriptions of the clay deposits of the Maalbeek and Laumanns pits will be given.

4.3.2.1 Maalbeek Pit

The site of Maalbeek is known from several earlier publications (Nota, 1956; Kortenbout van der Sluis, 1960; Zagwijn, 1963b; Boenigk, 1970; Urban, 1978, Westerhoff et al., 1998). The general stratigraphical sequence is presented in the cross-sections (Figs. 4.4.4, 4.5). Remnants of the Stramproy Formation intercalated between the Tegelen and Waalre Formations are preserved very locally. It seems that these erosional remnants are preserved in the lower parts of the undulating top of the Waalre Formation. From the base to top four facies units are recognised within the clay deposits of the Waalre Formation at Maalbeek (Fig. 4.5).

Formation. The lower boundary forms an erosional contact with the underlying deposits. The formation is about 20 m thick and forms part of the so-called upper terrace series (UTS) in Germany. Its heavy-mineral content is characterized by unstable (Rhine) associations in which epideite dominates.

4.3.2 Facies associations within the Waalre Formation

The deposits of the Waalre Formation are of central importance to the Early Pliocene stratigraphy. This is well illustrated by the data from five pits in the border area. At first this concerns the Janssen Dings pit where a pollen zone T-A (Yugus) typified clay deposit was exposed (Van der Vark & Pootshuck, 1953; Zagwijn, 1963). The second site of interest is at Prestetje-Sigla Egypt where Zagwijn (1963) defined his subdivision of the pollen zone T-C. Both pits have been abandoned since the 1960’s. More recent work has been carried out in the neighbouring pits of Maalbeek, Laums and Boveste Molen (Fig. 4.4). The Maalbeek pit is of particular interest because the exposed clay was first assigned to the Eburonian Stage (Zagwijn, 1963c). However, recent investigations have demonstrated that part of the
Figure 4.6. Lithology and pollen diagrams from pit Maalbeek (for location see Figs. 4.3. and 4.5). The lower two pollen diagrams are derived from borehole 58E0269. The upper diagram is sampled from the excavation in 1993 (Westerhoff et al., 1998). The overlap of the borehole and excavation face is indicated met red arrows. Note the relative high values of 'Tertiary elements' in the middle diagram results from the relative high values of Parotia persicana. This species can continue in the Early Pleistocene (see text for explanation). Main pollen zones have a grey background. Facies and lithostratigraphy are at the right-hand side of the diagram (legend lithology borehole, see also Fig. 4.4).
### Lithology

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>Clay</td>
</tr>
<tr>
<td>10-20</td>
<td>Sand</td>
</tr>
<tr>
<td>20-30</td>
<td>Gravel</td>
</tr>
<tr>
<td>30-40</td>
<td>Reworked</td>
</tr>
</tbody>
</table>

### Pollen Diagram

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Pollen Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>Conifers</td>
</tr>
<tr>
<td>10-20</td>
<td>Gramineae</td>
</tr>
<tr>
<td>20-30</td>
<td>Cyperaceae</td>
</tr>
</tbody>
</table>

### Tertiary Elements

- Conifers
- Gramineae, Cyperaceae
- Pioneers
- Herbs
- Plants of relatively acid soils
- Aquatic

### Pollen Sum

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Pollen Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>Tertiary elements</td>
</tr>
<tr>
<td>10-20</td>
<td>Deciduous trees</td>
</tr>
<tr>
<td>20-30</td>
<td>Trees of relatively wet soils</td>
</tr>
</tbody>
</table>

### Figure 4.7

Lithology and pollen diagram of borehole Maalbeker Hohe (SBR79M) (for location see Figs. 4.3 and 4.5). Main pollen zones have a grey background. Facies and lithostratigraphy are at the right-hand side of the diagram.
The channel-fill deposits in borehole 5880284 are underlain by the same coarse-grained sand and gravel deposit as in the Maalbeek pit.

The deposits of the Tegelen Member are underlain by the Keur Bed (figs. 4.4, 4.5, 4.6, 4.7). It also seems that the deposits of subunit WA-1 (Dobbel Beds) are absent from the subsurface of the Maalbeek site. However, the single unstable heavy-mineral spectrum in the Keur Bed, observed in borehole 5880286, probably indicates the nearby presence of the Alpine-influenced Rhine. The Keur Bed itself is interpreted as a flood-basin deposit with extensive swamps where peat accumulated.

4.3.2.2 Laumans pit

The Laumans pit is situated 1.5 km north of Maalbeek (fig. 4.3). Because of the lack of good pollen data and only a few rare fossils of fossil remains the Laumans pit is mentioned in a limited number of papers (Zagwijn, 1967; Zagwijn 1971; Westerhoff & Crevieringa, 1996; Kasse & Bohmke, 2001; Vanderbeughe, 2001). Noteworthy is the paper by Van Straaten (1996) who described cryoturbation phenomena and frost wedges in the nearby situated and already since a long time abandoned pit Wambach. These indicators for cold climatic conditions were observed in deposits that are nowadays assigned to the Strandnyp Formations.

The general stratigraphy resembles that of the Maalbeek pit (fig. 4.8). A main difference is the greater thickness of the basal coarse-grained part of the Waalte Formation. As can be seen in the main cross-section (fig. 4.8), this is related to the northeastwards tilt of the tectonic blocks in this part of the Venlo Block.

The clay deposits of the Waalte Formation at the Laumans pit are interpreted as floodplain fine sediments. Only the upper c. 4 m of the clay are regularly exposed (photo 4). Here, in general it is a massive clay deposit lacking clear sedimentary structures. The uppermost part (ca. 0.5–1.0 m) generally has a smooth structureless appearance but locally fine cm-thick laminations occur in the uppermost part (section 2, fig. 4.9). The latter might indicate regular influx of clastic material in a back-swamp environment. The larger part of the exposed clay shows crumbly and prismatic structures that may be the result of initial soil formation (Kasse & Bohmke, 2001) in a floodplain with fluctuating groundwater tables. The top few metres of the deposits may be heavily affected by (postdepositional) enrichment of siderite and formation of siderite nodules (photo 5, 6). This often has resulted in well-developed Liesegang ring formations but this unfortunately masks the original structure of the deposits. Another marked feature in the occurrence of a large-scale polygonal network of wedges in the upper part of the clay deposits which indicate cold climate conditions after deposition of the clay. The deeper part of the clay deposits, with a maximum thickness of 9 m, is only known from cored boreholes and CPTs (cone penetration tests, fig. 4.8). From these data it becomes clear that the crumbly structured floodplain deposit has a thickness of about 5 m. Below some 2 to 3 m of massive clay occurs lacking any sedimentary structures. Further downwards the clay grades...
The Stramproy Formation shows a lower level of cryoturbations and an upper level of large frost-wedges separated by a humic soil horizon. Table 4.1. Overview of the presented pollen analytical data from sections and boreholes.

Figure 4.8. Detailed cross-section from Laumans pit. Note the frost-wedges at the top of the floodbasin clay of the Waalre Formation which form a polygonal pattern.

From the base to top three main facies types can be recognised within the clayey deposits of the Waalre Formation (Fig. 4.10).

- **RTS 1.** An approximately 6 m thick sequence of laminated clay that is interpreted as the infilling of an abandoned meander. This facies resembles the channel infill at Maalbeek (MLBK 2) and is much more widespread in the area than previously thought (Kortenbout van der Sluijs and Zagwijn, 1962). Like similar deposits in the other pits the clay is rich in silt.

- **RTS 2.** Channel deposit in a complex of crevasse splay and overbank deposits. The unit starts with a thin layer of fine sand that contains many plant macro remains (seeds, fruits, and leaves) and grades into sandy clay. This crevasse splay is interpreted as the result of reactivation of the uncompletely filled oxbow of facies-type RTE-1.

- **RTS 3.** A floodbasin facies consisting of fine-grained clay deposits with two intercalated peat horizons indicating swamp conditions. This facies-type forms the final part of the sequence at the site.

4.4 Polen analytical sequences from the Tegelen-Maalbeek area.

4.4.1 Introduction

Several sections in the pits and material retrieved from cored boreholes in the pits or from nearby sites have been analysed for their pollen content. A selection of them is presented in this paper (Table 4.1). Pollen samples are treated using the standard procedure of the Geological Survey of the Netherlands which basically follows that of Faegri and Iversen (1975). Counting is based on a total pollen sum of at least 200 pollen grains. The pollen sum is subdivided into 5 main groups of trees and 3 groups of non-arboreal pollen (see legend in Fig. 4.6). From the Russel-Tiglia-Egypte pit only the main pollen diagram is shown and redrawn from the original publication (Zagwijn, 1963). This main diagram therefore retains the original subdivision by Zagwijn (1963) (Fig. 4.10).

4.4.2 Pollen assemblages from the Maalbeek pit

Firstly the pollen analytical results of the Revuer Bed of the two boreholes (58E0269 and 58E0284) will be given. Three pollen zones are distinguished in the pollen diagram from the Revuer Bed of borehole 58E0269 (Fig. 4.6): 

- **Pollen zone 0A (14.60-15.20 m) shows decreasing values of Sciadopitys and Tilia-type pollen while most “tertiary elements”, like other trees, are absent. Only Pinus shows increasing values.**

### Table 4.1: Overview of the presented pollen analytical data from sections and boreholes.

<table>
<thead>
<tr>
<th>Sections</th>
<th>Interval (m)</th>
<th>Facies</th>
<th>Thin paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maalbeek</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excavation face C</td>
<td>0.00-7.60 m</td>
<td>Facies MLBK 2&quot;, MLBK 2,</td>
<td>Fig. 4.6 (Weershoff et al., 1999)</td>
</tr>
<tr>
<td>Borehole SME0269</td>
<td>7.03-11.74 m</td>
<td>Facies MLBK 2</td>
<td>Fig. 4.6</td>
</tr>
<tr>
<td>Borehole SME0284</td>
<td>14.65-17.75 m</td>
<td>Revuer Bed</td>
<td>Fig. 4.6</td>
</tr>
<tr>
<td>Borehole SME0284</td>
<td>15.26-17.45 m</td>
<td>Facies MLBK 2</td>
<td>Fig. 4.7</td>
</tr>
<tr>
<td>Borehole SME0284</td>
<td>22.00-28.40 m</td>
<td>Revuer Bed</td>
<td>Fig. 4.7</td>
</tr>
<tr>
<td>Laumans</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section I</td>
<td>0.00-2.50 m</td>
<td>Floodbasin facies</td>
<td>Fig. 4.6, 4.9</td>
</tr>
<tr>
<td>Section II</td>
<td>0.00-6.60 m</td>
<td>Fine bedded top of floodbasin facies</td>
<td>Fig. 4.8, 4.9</td>
</tr>
<tr>
<td>Borehole SME0446</td>
<td>2.50-7.00 m</td>
<td>Floodbasin facies</td>
<td>Fig. 4.8, 4.9</td>
</tr>
<tr>
<td>Borehole SME0446</td>
<td>7.00-9.00 m</td>
<td>Interbedded clay of transitional channel fill facies</td>
<td>Fig. 4.8, 4.9</td>
</tr>
<tr>
<td>Russel-Tiglia-Egypte</td>
<td>0.00-1.80 m</td>
<td>RTE 1</td>
<td>Fig. 4.10 (Zagwijn, 1963)</td>
</tr>
<tr>
<td>Russel-Tiglia-Egypte</td>
<td>1.80-3.03 m</td>
<td>RTE 2</td>
<td>Fig. 4.10</td>
</tr>
<tr>
<td>Russel-Tiglia-Egypte</td>
<td>3.50-10.00 m</td>
<td>RTE 3</td>
<td>Fig. 4.10</td>
</tr>
</tbody>
</table>

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Figure 4.8: Detailed cross-section from Laumans pit. Note the frost-wedges at the top of the floodbasin clay of the Waalre Formation which forms a polygonal pattern.

The Chroming Formation shows a lower level of cryoturbations and an upper level of large frost-wedges separated by a humic soil horizon.
Figure 4.9. Lithology and pollen diagrams from the Laumans pit. The two upper pollen diagrams are sampled from the section at the top of the exposed clay deposits (Fig. 4.8). The lower pollen diagram is derived from borehole S889466 that was executed in the pit (see Fig. 4.8). Main pollen zones have a grey background. Facies and lithostratigraphy are at the right-hand side of the diagram.

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Pollen diagram, groups of the pollen sum</th>
</tr>
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<tbody>
<tr>
<td>Crumbly to prismatic soil horizon</td>
<td>Tertiary elements</td>
</tr>
<tr>
<td>Enrichment of organic matter</td>
<td>Deciduous trees</td>
</tr>
<tr>
<td>Siderite nodules</td>
<td>Conifers</td>
</tr>
<tr>
<td>Rootlets</td>
<td>Pioneers</td>
</tr>
<tr>
<td>Lenses of sand</td>
<td>Plants of relatively acid soils</td>
</tr>
<tr>
<td></td>
<td>Gramineae, Cyperaceae</td>
</tr>
</tbody>
</table>

**Main pollen diagram**
- **Total counts pollen sum**
  - **Carpinus**
  - **Cupressaceae**
  - **Sample point**
  - **Corylus**
  - **Eucommia**
  - **Fagus**
  - **Fraxinus**
  - **Ilex**
  - **Quercus**
  - **Tilia**
  - **Ulmus**
  - **Alnus**
  - **Pterocarya**
  - **Dryoptheris-t.**
  - **Osmunda**
  - **Picea**
  - **Pinus**
  - **Tsuga**
  - **Betula**
  - **Juniperus**
  - **Salix**
  - **Cyperaceae**
  - **Gramineae**
  - **Artemisia**
  - **Chenopodiaceae**
  - **Comp. Lugiliflorae**
  - **Comp. Tubiliflorae**
  - **Calluna**
  - **Ericales var.**
  - **Sphagnum**
  - **Typhaceae**
  - **Pediastrum**
  - **Hystrichospheridae**

**Section II**
- **Borehole 58E0466**
  - **Facies type**
    - Flood basin
    - Transition to channel
  - **Facies**
    - Massive clay
    - Crumbly soil horizon
    - Fine bedded upper part
    - Massive clay oxidised siderite enrichments
  - **Lithology**
    - Enrichment of organic matter
    - Siderite nodules
    - Rootlets
    - Lenses of sand

**No pollen**

<table>
<thead>
<tr>
<th>Pollen zone</th>
<th>Facies type</th>
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<tr>
<td>Plm 4</td>
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<tr>
<td>Plm 3</td>
<td>Transition to channel</td>
</tr>
<tr>
<td>Plm 2</td>
<td>Flood basin clay</td>
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<tr>
<td>Plm 1</td>
<td>Massive clay</td>
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<table>
<thead>
<tr>
<th>Poor in pollen</th>
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</thead>
<tbody>
<tr>
<td>Deciduous trees</td>
<td>Tertiary elements</td>
</tr>
<tr>
<td>Trees of relatively wet soils</td>
<td>Conifers</td>
</tr>
<tr>
<td>Plants of relatively acid soils</td>
<td>Gramineae, Cyperaceae</td>
</tr>
</tbody>
</table>
Two pollen zones can be recognised in the pollen diagram from the Revuer Bed in borehole 58E0244 (Fig. 4.7).

- **Pollen zone MLBKH 1A** (22.90-24.70 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 1B** (24.70-26.60 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 2A** (26.60-30.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 2B** (30.00-32.50 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 2C** (32.50-33.30 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 3A** (33.30-36.20 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 3B** (36.20-38.10 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 3C** (38.10-40.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 4A** (40.00-42.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 4B** (42.00-44.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 4C** (44.00-46.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 5A** (46.00-48.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 5B** (48.00-50.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 5C** (50.00-52.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 6A** (52.00-54.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 6B** (54.00-56.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 6C** (56.00-58.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 7A** (58.00-60.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 7B** (60.00-62.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 7C** (62.00-64.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 8A** (64.00-66.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 8B** (66.00-68.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 8C** (68.00-70.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 9A** (70.00-72.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 9B** (72.00-74.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 9C** (74.00-76.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 10A** (76.00-78.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 10B** (78.00-80.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 10C** (80.00-82.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 11A** (82.00-84.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 11B** (84.00-86.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 11C** (86.00-88.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 12A** (88.00-90.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 12B** (90.00-92.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 12C** (92.00-94.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 13A** (94.00-96.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 13B** (96.00-98.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
- **Pollen zone MLBKH 13C** (98.00-100.00 m) shows low but continuous curves for Taxodiaceae, Fagus, Cupressaceae and Ulmus. A low but continuous curve for Juniperus is present.
Furthermore, the highly variable values for *Sequoia*-type in the deposit (borehole S800015; Zagwijn, 1960) and the borehole data presented here (S802269 and S802284) show that the pollen content of this type of fluvial swamp deposits may reveal a high degree of regional variability, while similar vegetation assemblages may occur over long periods of time. The present re-evaluation demonstrates that the clay deposit at the top of the Kieselolite Formation in the study area forms the lateral continuation of the Reveur Bed in the Brachterwald (Boenigk, 1970; Kemna 2005) and therefore lithostratigraphically forms part of that unit.

4.5.3 Palynological interpretation of the clay deposits of the Waalre Formation

4.5.3.1 The Waalre site

Based on the clear presence of *Ficus* the pollen diagram of the lowest floodbasin fine sediment unit (facies unit MLBK 1*, pollen zone 1, Fig. 4.6) in the Maalbeek pit might be interpreted as representing part of pollen zone T-A (cf. Zagwijn, 1967). The overlying floodbasin clay (facies MLBK 1*, pollen zone 2, Fig. 4.6) shows low values of tree pollen and a dominance of Ericaceae among the non-arboreal pollen. Concurrently *Artemisia* is present in the middle part of pollen zone 2 (Fig. 4.6). Based on these observations the clay can be interpreted as part of pollen zone T-B (cf. Zagwijn, 1963, Westerhoff et al., 1998). According to Zagwijn (1975) this particular pollen zone was not known in detail although it was interpreted from a borehole near Lindenhoven in the KVG (Zagwijn, 1963). More recently it was demonstrated that the clay deposit at Maalbeek, formerly interpreted as part of the Eburon-S Zieg (Zagwijn, 1963) in fact forms part of facies unit MLBK 1* (Westerhoff et al., 1998). This pollen assemblage shows generally low values of tree pollen and a dominance of Ericaceae and *Sphagnum*. The latter two taxa culminate in pollen zone 2* (Fig. 4.6). At the lower and upper side of this culmination increased influxes of reworked (old) pollen occur (pollen zone 2, and 30C in Fig. 4.6). At the same levels the lithology shows some thin lenses of fine sand, above the peat layer at about 4.75 m as well as above the uppermost soil at about 1.60 m. These sand lenses may indicate the onset of renewed clastic sedimentation in the floodbasin. These observations may explain that, apart from the local vegetation with sedges, grasses and some elder, the larger part of the pollen and spore assemblage in zone 2A was derived from other sources. The peat layer at the top of facies unit MLBK 1* separates the lowest floodbasin fines from the upper part (facies unit MLBK 1, Fig. 4.6). The transition marks a change in the pollen and spore assemblages that for a part can be explained by the increase of allochthonous pollen and spores (i.e. the culmination of *Ericaceae* and *Sphagnum*). However, the hiatus at the top of the peat layer is thought to represent only a relative short period of time, since the facies types above and below do not change drastically and mapping in the area has demonstrated that the entire fluvial sequence near Maalbeek can be regarded as one coarse to fine fluvial cycle (Fig. 4.4). Thus, it seems that the change in pollen assemblages between the two facies units may be influenced by an increase of sedimentary pollen in the floodbasin. It is known that infuxes of allochthonous pollen and spores occur frequently in clay deposits of the Holocene fluvial and coastal plain (Cretz, 1978, Van der Woude, 1983). However, the almost total absence of tree pollen from pollen zone 2 of the Maalbeek section (Fig. 4.6), and the overall picture of the changing pollen assemblages of the two facies units, may also indicate that the sequence has registered a change in climate.

Pollen zone 3 of the section at Maalbeek pit (Fig. 4.6) shows that the decrease of the Ericaceae is followed by a reappearance of local elements. This is expressed by a small peak of *Julina*, a culmination of *Cyperaceae* and pollen of aquatic like *Nymphaea* and *Myriophyllum*. Subsequently *Butera* appears just like *Pterocarya*, *Quercus* and *Corylus*. The occurrence of *Pterocarya* characteristically refers to pollen zone T-C (cf. Zagwijn 1963, Westerhoff et al. 1998). This part of the section belongs to facies unit MLBK 2 that corresponds to the infill of an abandoned channel which was cut into the floodplain deposits of facies unit MLBK 1* (Fig. 4.5). The pollen content of this channel-deposit up to 12 m thick is displayed in the diagram of borehole S802284 (Fig. 4.7). The diagram is subdivided into two local pollen zones. The lower part of the diagram (pollen zone MLBK 2B, Fig. 4.7) shows a close fit with the uppermost part of the pollen diagram of pit Maalbeek (pollen zone 3, Fig. 4.6). Only the pioneer *Juniperus* has a better expression. The general picture of the entire pollen zone MLBK 2 in borehole S802284 clearly points to a *Fagus* C pollen assemblage and shows striking similarities with the pollen zones T-C2 to T-C4 of the diagram for Resselt-Tiglia-Egypt (Zagwijn, 1963)’. The upper part (pollen zone MLBK 2A, Fig. 4.7) shows distinct curves for Gramineae and *Cyperaceae* which may indicate elements of the local vegetation at or near the abandoned channel. The continuation of nearly all species in straight-lined curves is remarkable and may result from high sedimentation rates. The same conclusion is drawn from the sedimentary structures that typify the infill of the abandoned channel.

Summarising it can be stated that the floodplain fine unit at the Maalbeek site reveals the three typical pollen zones of the Tigilian (T-A, T-B and T-C, cf. Zagwijn, 1963). However, it remains questionable whether these three zones can be fully linked to the long-lasting chronostratigraphical subdivisions Tigilian A, Tigilian B and Tigilian C (Fig. 4.3). Such a linkage would imply an unlikely long deposition phase of the floodplain fine sedimentation or the presence of large depositional gaps. The latter seems unlikely because the sedimentation observed between the fine-grained facies units does not show any relation to coarse-grained material that resulted from reactivation or newly formed fluvial channels (Figs. 4.4, 4.5).

4.5.3.2 Laumans pit

The lower part of the floodplain fine unit at Laumans pit (pollen zone MLBK 3, between boreholes 58e0284, 4.6, 4.8, 4.9) is dominated by *Picea* and *Pinus* pollen. The curves of these two species are accompanied by a continuous but low curve of *Pterocarya*. *Quercus* shows even lower values. Other species (arboral as well as non-arboral) are

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**Figure 4.3** Facies units, lithology, stratigraphy and summary pollen diagram of the Russel-Tiglia-Egypte pit. The stratigraphical and climatic interpretations of the pollen zones are derived from the original publication (Zagwijn, 1967).
nearly absent or show an irregularly scattered picture. Such pollen assemblages are generally seen as belonging to the uppermost parts of pollen zone T-C (i.e. pollen zone T-C5, and T-C6, cf. Zagwijn, 1963). However, such correlations are doubtful because Early Pleistocene deposits hardly show any pollen-based diagnostic criteria that can be related to a specific Late Eburonian (Kasse & Bohncke, 2001; Urban 1978). Furthermore, Pisum-Pinus-dominated deposits do not typify the wet and clayey environment of the floodbasin. Apart from the low values of Pterocarya, signs of the local vegetation are lacking that could be explained by a near absence of local vegetation during deposition, high sedimentation rates, or selective preservation of pollen by post-depositional corrosion. Similar observations are known from the Eburonian site Eindhoven (Van der Woude, 1983). Except for the uppermost pollen spectrum at 5 m (Fig. 4.9), pollen zones seem unlikely because of the absent vegetation and reworked pollen.

The interval between 2.5-5.5 m (Fig. 4.9) lacks any pollen, while between 2.0-2.5 m the clay is poor in pollen. This absence of pollen is probably mainly caused by post-depositional geochemical processes. This part of the analysed section is strongly affected by the formation of iron hydroxides which result from oxidation of siderite. Only reworked pollen, a few resistant pollen types, and spores from ferns have survived the corrosion process.

Pollen zone Plm 2 shows the development of the local vegetation in the area and surrounding area; while ferns may form an undergrowth of the brook vegetation. The absence of Picea is striking and differs from the diagram of the same clay deposits published by Kasse & Bohncke (2001). The small scale fluctuations in the dominance of Picea in pollen zones Plm 3 and Plm 4 (Fig. 4.7) from the correlation with the transition of pollen zone T-C6 to pollen zone EB-1 (Zagwijn, 1967; Kasse & Bohncke, 2001). Due to the fact that the larger part of the Pinus pollen is broken and partly corroded, it is likely that the upper part of the clay deposits at Laumans has suffered from post-depositional geochemical processes (isodrate enrichments and oxidation).

As a result of the incomplete infilling of the oxbow lake at RTE, reactivation took place and overbank deposition (facies unit RTE-2, fig. 4.10). The base of this second facies unit consists of a thin layer of fine sand lacking pollen and spore. This layer has been assigned to pollen zone T-C2 (cf. Zagwijn, 1963), enclosure 6. Based on the poor pollen content, the dominance of Pinus, the decline of thermophilous trees, and correlations to other sites Zagwijn (1967) concluded that the mean summer temperature during this pollen zone T-C2 declined considerably. From the fact that this cold phase is not well recorded in the sequence of RTE it was attributed to a large hiatus between facies units RTE-1 and RTE-2. This interpretation was supported by the red-brown coloured sand at the top of the facies unit RTE-3 that was interpreted as a soil. However, soil formation in clayey and poorly drained deposits of floodbasins is typically gleyed and weakly developed. Under temperate climate conditions, it is assumed that the duration of the Tiglian C Substage is notably important. The small variations in the diagram were interpreted in terms of climate change (Zagwijn, 1963). Part of this pollen fill is formed during a relatively warm temperate phase. However, the small-scale variance 200 to 400x is probably due to the high resolution of the Tiglian C Substage, as indicated in numerous tables of the Early Pleistocene. In terms of climate change, the pollen diagram of RTE clearly shows a decline of thermophilous taxa. A similar signal of climate change is also observed in the sequence of Maalbeek pit. However, to correlate the small-scale fluctuations to specific phases like Tiglian C4 seems to go beyond the resolution of the pollen analytical method.

4.5.4 Correlation between Tegelen-Maalbeek and the Roer Valley Graben

It is of interest to correlate the thin and discontinuous sequence of Lower Pleistocene deposits in the Tegelen-Maalbeek area with the much thicker but also fragmentary sequence of Lower Pleistocene fluvial deposits in the Roer Valley Graben. A borehole near Eindhoven was analysed for its pollen and spore, and heavy-mineral content. The borehole evidence shows up to 10 stacked fluvial-fining-upwards cycles between the Kieselsolone and Sterkzolone formations. The stratigraphy of this recently recovered borehole (S1004x, 4.11) shows that the uppermost part of the borehole sequence at the Roer Valley Graben, published by Zagwijn (1963)-enclosure 4, Eindhoven 1, S1G2Q8 and enclosure 5, Eindhoven 2, S1G2D03. For correlation purposes between these two boreholes significant zones adjacent to the data of the new borehole are included (Fig. 4.5). The mixed Rhine-Meuse deposits of the Waalte Formation intergrade with deposits supplied by rivers which originated in Belgium and that belong to the Stramproy Formation (chapter 2). The Waalte Formation is subdivided into three subunits from bottom to top respectively indicated as WA-1, WA-2 and WA-3 (Fig. 4.11).

Subunit WA-1 is typified by a strong increase of unstable heavy-minerals and the presence of ‘tertiary elements’ in the pollen diagram. This marks the transition from the southwards extension of the Rhine catchment into southern Germany and the Alpine area, and occurred during the Late Pliocene (Borgschulte, 1970, 2002; Borgschulte & Frechen, 2006; Hagedorn & Borgschulte, 2006; chapter 2). Therefore, subunit WA-1 can be correlated with the Oelbe beds in Germany (Borgschulte & Frechen, 2006). The clear presence of ‘tertiary elements’ in the pollen assemblages confirms a Late Pliocene age. The same conclusion can be drawn from Zagwijn’s (1963) data in Eindhoven borehole. The pollen diagram of Eindhoven 2 borehole shows a considerable amount of ‘tertiary elements’ in the same interval where heavy-mineral data also demonstrate an increase of unstable heavy-minerals (the heavy-mineral data are available in the files of NIOO Geological Survey of the Netherlands). These observations show that the lowermost fluvial-fining-upwards sequence of the Waalte Formation in the RVC, near Eindhoven, lithostratigraphically forms part of the Late Pliocene Oelbe Beds. However, this interval was previously assigned to pollen zone T-A of Early Pleistocene age (Zagwijn, 1963). The main reason for this interpretation was the assumption that the remarkable change in heavy-mineral composition at about 210 m in (Fig. 4.11) marked the Plio-Pleistocene boundary (Zagwijn, 1964). As a consequence of this re-evaluation the Fagus-dominated pollen zone T-A (cf. Zagwijn, 1963) is absent in the boreholes near Eindhoven. The taxon is lacking, or only present in very low quantities. From subunit WA-2 to WA-3, a single site on the same section in the borehole (fig. 4.11). This is also known from other sites with Early Pleistocene deposits and therefore Fagus seems to be unsuitable for Early Pleistocene correlations (Meijer et al., 2006).

Another point of discussion concerns the interval between 144-158 m. Here, the Waalte Formation is intercalated by quartz-rich sand and it is debated whether these deposits that typify deposits of the Stramproy Formation. This intercalation is bounded by subunits WA-2 and WA-3 of the Waalte Formation (fig. 4.11). Such intercalations of the Stramproy Formation indicate that during its deposition, the Rhine-Meuse system had abandoned the RVC (chapter 2 and 6; Westerhoff et al., 2008). The same intercalation occurs in Eindhoven 2 borehole and was previously assigned to pollen zone T-B (cf. Zagwijn, 1967). Zagwijn (1963) - p. 60 and p. 68) stated that ‘perhaps the minimum in thermophilous trees at 154 m represents zone T-B’, and ‘pollen zone T-B must have witnessed low summer temperatures but data are scanty’. In borehole S1D043 (Fig. 4.11) an increase in pollen percentage of predominantly Ericaceae, can be noticed. Traditionally such pollen assemblages are regarded as indicative of climate deterioration. It is remarkable that the heavy-mineral diagram shows changes at the same level. Apart from climate change this may also indicate that the change in vegetation cover could have been affected by changing depositional conditions. The deposits of the Waalte
Formation were formed in the Rhine-Meuse alluvial plain which is typified by nutrient-rich wet environments with extended deposition of flood-basin fines. In contrast, the deposits of the Stramproy Formation consist of quartz-rich sediments with probably a lower availability of nutrients and less extensive fine-grained floodbasin deposits. It is difficult to make a positive correlation with pollen zone 2 (Fig. 4.6) or pollen zone T-B (cf. Zagwijn, 1963; Westerhoff et al., 1998) from the Maalbeek site to this particular intervalization of the Stramproy Formation in the boreholes near Eindhoven. The absence of pollen zone T-A (cf. Zagwijn, 1963) make such correlations rather insecure.

The interval between 126-144 m shows all characteristics of the T-C pollen zones (cf. Zagwijn, 1963) but detailed subdivisions and correlations to the sequence of Russel-Tigla-Egypte are impossible. This is not surprising because in the Tegelen-Maalbeek region part of the pollen zones are related to specific lithofacies. Similar facies occur repeatedly in the stacked fining-up sequences near Eindhoven and subsequently a repetition of comparable pollen assemblages in such sequences is to be expected.

4.5.5 Chronostratigraphical implications

The Early Pleistocene pollen zones originally defined by Zagwijn have gradually transferred into chronostratigraphical substages and thus the resulting chronostratigraphical subdivision of the Early Pleistocene is used as a standard throughout NW Europe (Zagwijn, 1992). Considering the discussion of the key sites stated above, it is questionable whether the extrapolation of local-defined pollen zones has such a wide regional chronostratigraphical significance.

The term Tigian was introduced in the early 1950’s as a result of thorough investigations that provided a palaeontological framework for the subdivision of the Quaternary (van der Vlerk & Florschütz, 1950, 1953). Large and small mammal remains, molluscs, plant macrofossils and pollen formed the main elements for defining the substages. Further elaboration of the concept was mainly based on extensive pollen analytical research (Zagwijn, 1957, 1960, 1963, 1967; Kasse, 1988; Kasse & Bohncke, 2001). The application of palaeomagnetic methods and long-distance correlations to the Mediterranean finally provided (although still insecure) indications of absolute ages (van Montfrans, 1971, 1972; Zagwijn, 1974; Zagwijn & Suc, 1973, Zagwijn & Suc, 1983; Kasse, 1996).

The fluvial sequence of Russel-Tigla-Egypte pit serves as stratotype (type section) of the Tigian C Substage. It is a nominal and exemplary stratotype and not a boundary-defining stratotype (Walsh, 2005). The Tigian B Substage has no properly defined stratotype. It was first described in the Eindhoven and 2 boreholes (Zagwijn, 1963) but in fact, the Tigian B is strongly the result of conceptual thinking as is illustrated by the following quote: ‘Then follows a zone (T) which is not yet known in much detail with a vegetation of cool character’ (Zagwijn, 1975, p. 142). The Tigian A Substage is defined by the presence of Fagus in a clay deposit exposed in the former Janssen-Dings pit near Belfeld (situated just south of the Maalbeek site, Fig. 4.3). This pit may serve as an exemplary stratotype. However, there is no proper published description of this already long abandoned excavation.

Based on the observations from the Maalbeek pit given above it can be concluded that three main pollen zones (T-A, T-B and T-C; cf. Zagwijn, 1963) are present in the fluvial sequence of Maalbeek. It also shows that pollen assemblages characteristic of a specific pollen zone may be influenced by the depositional conditions of the facies in the sequence. As a result several questions about the correlation and chronostratigraphical position may arise. For example:

- The pollen assemblages of pollen zone 2 (facies unit MLKR 1”, Maalbeek, Fig. 4.6) were formerly interpreted as belonging to the Eburonian (Zagwijn, 1963; Westerhoff et al., 1998) and indeed show resemblance to the pollen assemblages of similar floodbasin facies (BTE-3) as developed in the sequence of Russel-Tigla-Egypte.
- Warm-temperate pollen assemblages indicated as characteristic of pollen zones T-C2 and T-C3 occur repeatedly in Early Pleistocene estuarine sequences (Kasse & Bohncke, 2001). Therefore, lat diagnosis criteria for chronostratigraphical correlation.
- The forced extrapolation of the thin fluvial sequence of Tegelen-Maalbeek area to the thicker sequences in the RVG is difficult. The RVG the Tigian T-B pollen zone (cf. Zagwijn, 1963) parallels influxes of material from the Stramproy Formation, as is demonstrated by a change in sediment provenance. The latter must result from major shifts in the hydrogeographical pattern and the disappearance of the Rhine-Meuse system from the RVG (chapter 2, Westerhoff et al., 2008).
- The lowermost part of the Waalbe Formation in the boreholes near Eindhoven characterized by Fagus, is now interpreted as part of the Late Pleistocene instead of the Early Pleistocene Tigian A Substage.

From the previous lithostratigraphical description, the sedimentary facies interpretations, and the palaeobotanical interpretations it appears that the three-fold subdivision of the Tigian Stage, as defined in the Tegelen-Maalbeek area, cannot be maintained. A major argument is that the fluvial sequence of Tegelen-Maalbeek cannot span the entire Tigian time period. Most authors estimate the age of the Tigian between about 2.5-1.78 Ma (e.g. Zagwijn, 1985, 1998; Gibbard et al. 1998; Ruhlman, 2004) and it is clear from this study that the fluvial sequences of Tegelen-Maalbeek cannot reflect a period of about 700 Ka. Probably large gaps within the fluvial sequence of this area, especially in the fine-grained part, are excluded on the basis of the sedimentary characteristics.

It can be expected that large gaps in the Tegelen-Maalbeek sequences are present at the base of the coarse-grained deposits situated underneath the floodplain fines (Fig. 4.4). Summarizing, it may be concluded that the use of the three-fold subdivision Tigian A, Tigian B, and Tigian C as chronostratigraphical Substages of the Tigian Stage should be discontinued.

Similar remarks could be made on the definition of the Tigian Stage itself. The area of Tegelen-Maalbeek area could serve as a nominal stratotype but there is no type section where its boundaries can be defined. The same holds true for some
other pollen-defined stages of the Early Pleistocene. Initially they have been formulated as part of a climate-stratigraphic concept, and discussion of warm and cooler phases (Zagwijn, 1979, 1960, 1963a, 1963b). However, the results of deep sea research have shown that climate alternated in a much greater detail than was believed to be possible over fifty (Pee-Ma) years. This difference is clearly demonstrated by comparing the pollen-defined temperature curve for the Pleistocene with the Marine Isotope Stages (Fig. 4.1). The evidence presented above clearly shows that the pollen record of the fluvial sequence of the Tegelen-Maalbeek area reveals indications for climate change. However, it does not show diagnostic criteria for assignment to a specific glacial-interglacial cycle. As long as absolute age determination cannot be used for subdivision of the Early Pleistocene, it must be realised that even the thick accumulation of fluvial deposits in the KVG may include several hiatuses. Major fluvio-deltaic accumulations of Neogene deposits occur in the central part of the North Sea Basin. Several recent studies have demonstrated that the sequence preserved in that region is suitable for high resolution stratigraphical analyses (Husse et al., 2001; Oehren et al., 2001; Oehren, 2002; Kuhlmann, 2004; Kuhlmann et al., 2006). The concept of a three-fold subdivision of the Tiglian Stage into pollen-defined sub-stages is no longer tenable on the basis of the Tegelen-Maalbeek type-sections. When up-scaling of pollen zones into chronostratigraphical sub-units of regional significance is applied, pollen associations of only local environmental significance should be avoided.

The chronostratigraphic subdivision of the Early Pleistocene that is based on pollen records from partially preserved fluvial successions, as at Tegelen-Maalbeek, should be revised. Such a revision will benefit from improved age determinations.

Part of formerly Tiglian A-aged deposits in the KVG, near Eindhoven is of Late Pliocene age and is equivalent to the Orbis Beds in the B韧cherwald area in Germany.

References


