An evaluation of the Early Pleistocene chronology of The Netherlands

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15 figures, 4 tables, 2 appendices

Abstract

The Early Pleistocene subdivision of The Netherlands is evaluated, based on published research since 1950. The subdivision is a biostratigraphy, almost exclusively based on palynological research. Palaeomagnetic research provided a correlation with the palaeomagnetic timescale.

The classical subdivision of the Early Pleistocene is based on a mosaic of short pollen sequences, mostly of unknown duration, position and age. The Pretiglian is reconsidered as a cool oscillation within the Pliocene. Re–evaluation leads to the conclusion that the age of the Pliocene–Pleistocene boundary, set at approximately 2.5 Ma is highly questionable. The position, duration and subdivision of the Tiglian stage is subject to serious doubts. The evidence related to the Eburonian, Waalian, Menapian and Bavelian is considered to be too limited to allow confirmation of the existence of any of these stages.

Faunal data are too limited to add to our understanding of the Early Pleistocene.

The Early Pleistocene of The Netherlands, its subdivision, climatic development and duration is considered poorly known.

Contents

1. Introduction

The biostratigraphy of the Early Pleistocene of The Netherlands has been outlined by Van der Vlerk & Florschütz (1950, 1953) and elaborated through the palynological research of Zagwijn (1957, 1960, 1963, 1975, 1985, 1996, 1998), and Zagwijn & De Jong (1985). Palaeomagnetic research (Van Montfrans, 1971) linked the biostratigraphy to the palaeomagnetic timescale, thus providing absolute ages for the various biochronological stages of the Pleistocene. The faunal record of the Early Pleistocene of The Netherlands is in sharp contrast with the palynological record. Whilst rich faunal assemblages are recognised from the Tiglian and Bavelian/Cromerian, the Eburonian, Waalian and Menapian have yielded virtually no fossils. This marked difference between the floral and faunal records of the Early Pleistocene triggered the present research, an evaluation of palynological, palaeomagnetic and palaeontological literature, published since the 1950's in The Netherlands.

This paper evaluates the Early Pleistocene biochronology by means of literature research and a re–evaluation of the original data. First of all the classical subdivision of the Early Pleistocene of The Netherlands will be outlined, together with a short description of the lithology of that period. The next section is a detailed discussion of the published palynological evidence of each stage of the Early Pleistocene followed by comparable sections on the palaeomagnetic and palaeontological evidence.

The Pliocene–Pleistocene boundary (PPB) as postulated by Zagwijn (1974) instead of the official PPB is used within the context of this paper. This choice does not reflect a preference by the author.

2. Classical subdivision of the Pleistocene

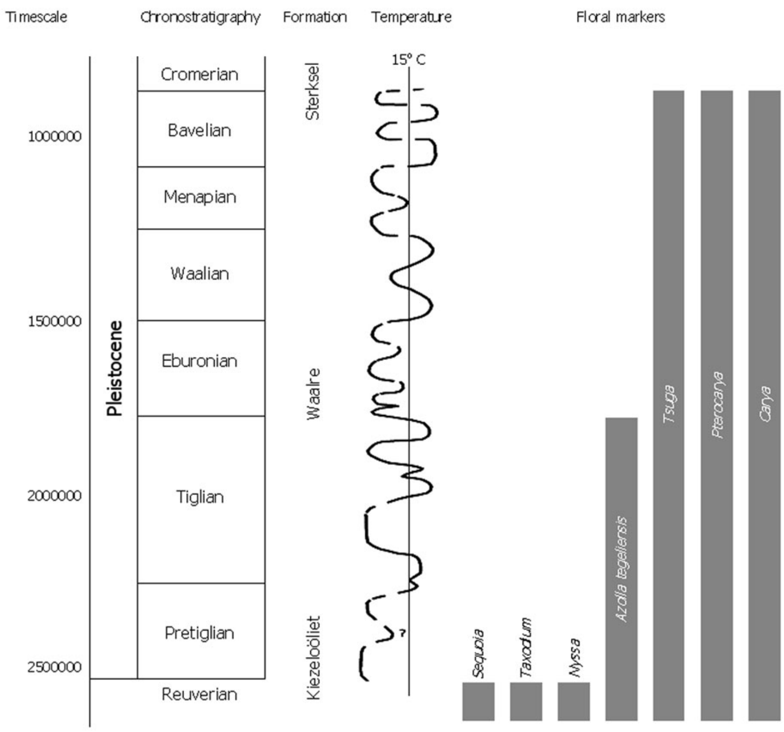

Figure 1. The chronostratigraphy of the Early Pleistocene of The Netherlands, after Zagwijn (1998) and lithological formations (after Weerts et. al*, 2000), climatic reconstruction (after Zagwijn, 1998) and floral markers (after Zagwijn, 1957, 1960, 1963, 1975, 1985, 1996, 1998 and Zagwijn & De Jong, 1985).*

Zagwijn (1957, 1960) outlined the structure for subdivision of the Early Pleistocene through the recognition of glacials and interglacials, using palynological data as a proxy for palaeoclimatic development. The alternation of these stages is considered a unique feature of the Pleistocene and is therefore used as the foundation for its subdivision.

The subdivision of the Early and early Middle Pleistocene of The Netherlands is almost exclusively based on palynological research, started by Van der Vlerk & Florschütz (1950, 1953) and continued by Zagwijn (1957, 1960, 1963, 1975, 1985, 1996, and 1998) and Zagwijn & De Jong (1985). Their research resulted in a detailed chronostratigraphy together with a climatic reconstruction of this period, as shown in figure 1. This subdivision is based on the following observations:

- The transition of the Pliocene Reuverian to the Pleistocene Pretiglian is recognised by the disappearance of a number of 'Tertiary' elements (*Sequoia, Taxodium, Nyssa, Liquidambar, Sciadopitys*, etc.). The Pretiglian cold stage is considered to be responsible for the disappearance of these elements from The Netherlands.
- Tiglian substage TA is recognised by the (high) presence of *Fagus,* which is no longer present in following stages of the Early Pleistocene.
- The transition from the Tiglian to later stages is recognised by the disappearance of *Azolla tegeliensis*, being replaced by *Azolla filliculoides*.
- The first interglacial in the Bavelian stage, the Bavel interglacial, is distinguished from the second interglacial and the Waalian stage by a higher percentage of *Tsuga*.
- The transition of the Early to the Middle Pleistocene is recognised by the disappearance of *Tsuga*, *Pterocarya* and *Carya*.

Although glacials are considered responsible for the permanent disappearance of floral elements, the picture of a stepwise, linear disappearance of floral elements is complicated by the cyclic disappearance and reappearance of floral elements during glacial/interglacial cycles. Long and continuous sequences of pollen bearing sediments are therefore considered mandatory to ensure a proper correlation of a pollen sequence with the overall biostratigraphy of the Early Pleistocene.

According to Zagwijn (1957, 1960) all glacials during the Early Pleistocene (Pretiglian, Eburonian, and Menapian) lack floral markers to allow recognition of a specific glacial phase through palynological research alone. The same holds true for the glacial substages of the Bavelian. The recognition of a glacial during the Early Pleistocene thus hinges on the recognition of the preceding and following interglacials, and requires well–documented contacts with these interglacials.

Although Zagwijn (1960: 15) uses the term "palynological dating" it is strictly impossible to use a palynological sample as a possible date marker.

3. Lithostratigraphy

A brief overview of the continental lithostratigraphy of the Pliocene and Pleistocene of The Netherlands is given in this section. Fluviatile sediments from the middle and southern parts of The Netherlands have yielded data leading to the detailed subdivision of the Early Pleistocene (Zagwijn, 1957, 1960). Recently, the lithostratigraphic subdivision has been reviewed (Weerts *et al.,* 2000), resulting in a limited number of formations which are considered relevant within the context of the present paper (figure 1).

The Kiezeloöliet Formation consists of fine to very coarse, locally gravel containing, sands intercalated with clay layers, frequently containing brown coal (Brunssum, Venlo, and Reuver). This formation is predominantly found in the southeastern and eastern part of The Netherlands.

The overlying Waalre Formation consists of moderately fine to coarse sands very regularly intercalated with clay layers, some of which contain brown coal. This formation is present in the southern part of The Netherlands. The Waalre Formation is a combination of the Tegelen Formation and that part of the Kedichem Formation whose sediments originate from the Rhine group.

The Sterksel Formation consists of moderately coarse to coarse, gravel containing sands. This formation is present in the southern and western part of The Netherlands and contains local clay layers, especially in the west of The Netherlands.

Palynological research depends on the availability of clay or peat sediments. Based on the lithostratigraphy it is clear that the continental palynological record of the Early Pleistocene of The Netherlands is largely fragmentary. This is to be expected, since the sediments were formed in a delta, and deposition depends on change in the course of rivers and changes in the sea level. Therefore it is not an environment in which to expect long, continuous sections suitable for palynological studies. Also, the sediments from which the Early Pleistocene of The Netherlands has been reconstructed come from a tectonically complex area, the Roer Valley Rift System. This clearly increases the difficulty of reliable correlations across faults, especially in combination with the fragmentary palynological record.

Weerts *et al.* (2000) warn against the use of non–lithologic information in the creation of a lithostratigraphic classification. They reject the possibility of positioning a lithostratigraphic unit into a biostratigraphy unit based on its pollen content. The literature depicts multiple instances of this practice. According to Zagwijn (1963: 53): "[…] the Belfeld Clay, which is characterized by the presence of *Fagus* […]". Zonneveld (1947) found the Formation of Sterksel to lie directly on top of the Kiezeloöliet Formation; Zagwijn (1960) assumes the presence of the Kedichem Formation in Meinweg based on palynological research. Van der

Meulen & Zagwijn (1974) assume a depositional hiatus in the Icenian based on the absence of Tiglian substage A en B pollen spectra.

4. Pretiglian

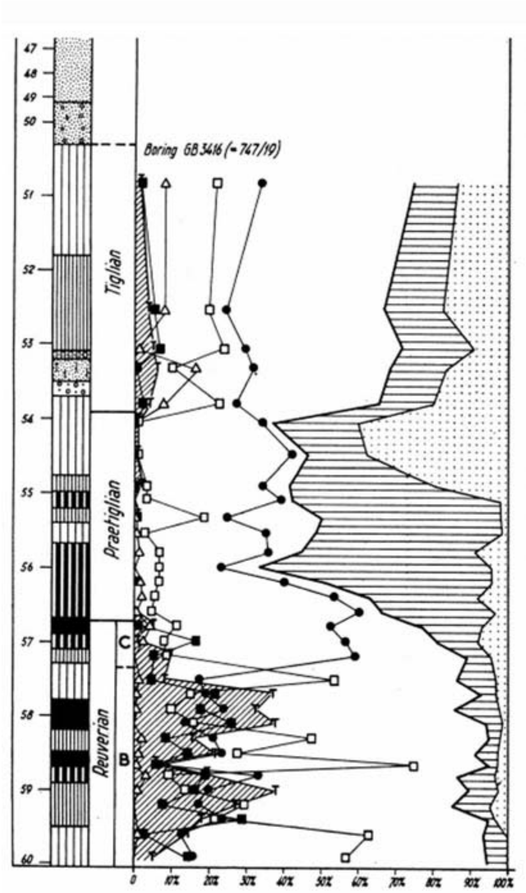

Figure 2. Meinweg pollen diagram from boring 3416 showing the Reuverian and Pretiglian sequence (after Zagwijn, 1960).

The Pretiglian is defined by Van der Vlerk & Florschütz (1953) as all Pleistocene time between the end of the Pliocene and the beginning of the Tiglian. Zagwijn (1957, 1960) defined a marked cooling, demonstrated in a section of a pollen diagram of Meinweg (figure 2), as the Pretiglian. Zagwijn attributed the lower section to the Pliocene Reuverian (high percentage of Tertiary pollen), the middle section to the Pretiglian and the upper section to the Tiglian (low percentage of Tertiary pollen). The marked reduction of Tertiary pollen in the Tiglian is considered to be the result of the cold Pretiglian (Zagwijn, 1957, 1960). Zagwijn concludes that the Pretiglian resulted in the permanent disappearance of *Sequoia, Taxodium, Nyssa, Liquidambar, Sciadopitys*, and other floral elements. While Zagwijn used boring 3416, multiple borings are available from the Meinweg locality (3414, 3438, 3431, 3416, and 3484; courtesy Nederlands Instituut voor Toegepaste Geowetenschappen–TNO [NITG–TNO]). Boring 3438 yielded four pollenspectra ranging from 47.65 m to 49.70 m; just above the upper limit of section 3416 (50.80–60.00) used by Zagwijn (1957, 1960; see figure 2). When the results of 3416 and 3484 are combined, a different picture emerges (figure 3). Tertiary pollen, including *Sequoia, Taxodium, Sciadopitys,* and *Nyssa*, become abundant again in the upper part of the combined section.

Since Zagwijn considers the cold Pretiglian to be responsible for the permanent disappearance of a number of Tertiary pollen that reappear in section of core 3848, it seems possible that the recognised cold section in core 3416 may not be attributed to the Pretiglian. Instead, it could be looked upon as a cold oscillation during the Pliocene. This seems to be reinforced by the fact that the section attributed to the Tiglian by Zagwijn lacks a relatively high percentage of *Fagus*, considered to be a marker for the first stage of the Tiglian, Tiglian A (Zagwijn, 1963). As a consequence, the Pleistocene is left without a well–defined lower boundary, since the Meinweg sequence is the only sequence to date where the Pretiglian is recognised in–between two interglacials (appendix I).

All other pollen sequences where the Pretiglian is identified lack an upper boundary and are thus considered questionable. This is based on the fact that all glacials during the Early Pleistocene (Pretiglian, Eburonian, and Menapian) lack floral markers to allow recognition of a specific glacial phase through palynological research alone (Zagwijn, 1957, 1960). In view of the absence of an upper boundary in a well–defined interglacial it is impossible to positively link a cold period to a specific stage of the chronostratigraphy. In addition to this fundamental shortcoming, most sequences consist of only a few pollen spectra and/or a coarse sampling interval, further questioning the validity of the original assessments (see appendix I for a detailed account of published pollen sections).

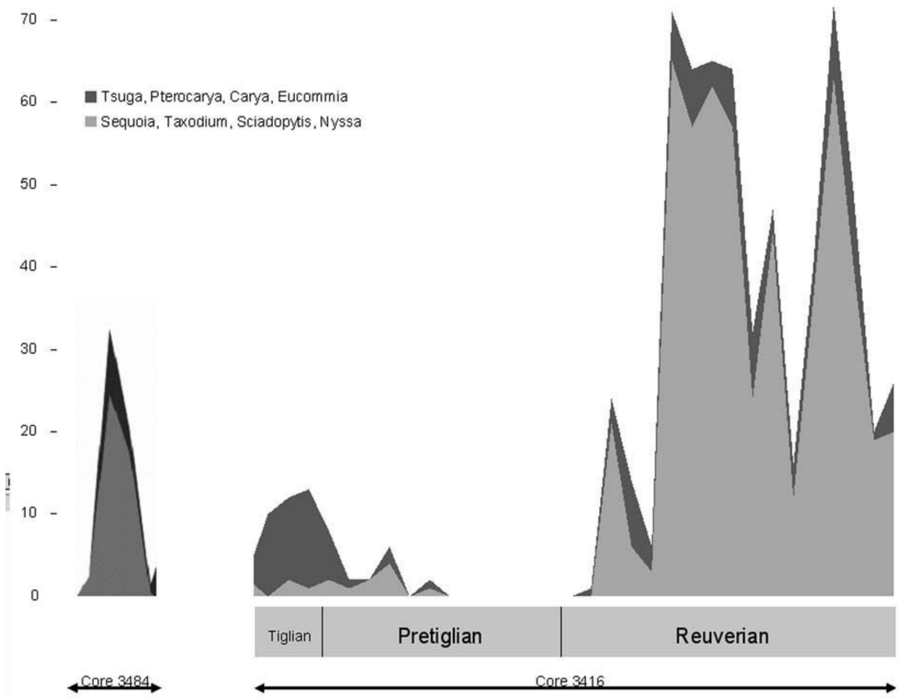

Figure 3. Selected counts of Tertiary pollen from Meinweg 3416 and 3484, after Zagwijn (1957, 1960) and original data (source data of NITG–TNO).

5. Tiglian

The Tiglian stage was originally described by Reid & Reid (1915) and attributed to an interglacial by Van der Vlerk & Florschütz (1950, 1953). A detailed palynological study, performed by Zagwijn (1963) resulted in a subdivision of this interglacial into three substages: Tiglian A (TA), with interglacial character; Tiglian B (TB), a cool oscillation; and Tiglian C (TC), again of interglacial character. Tiglian C was further subdivided into TC1–TC6 with a more detailed subdivision of TC2–TC4. The different substages will be discussed prior to an overall assessment of the Tiglian.

5.1. Tiglian A

Van der Vlerk & Florschütz (1953) published a pollen diagram of the pit Janssen–Dings near Belfeld, originating from a clay bed with an assemblage that in general resembles that of the Tegelen Clay, with the exception of a high percentage of *Fagus* (figure 4). Zagwijn (1963) considered a high presence of *Fagus* the most important marker of TA.

Allthough Zagwijn considered a relatively high presence of *Fagus* to be a marker for TA, a number of localities lack this characteristic. Eindhoven I, De Meern and Meinweg all show less than 2% *Fagus*. No data is available from De Banken. Furthermore, the presence of Tiglian TA in Meinweg is questioned since Tertiary relics reoccur just above the level attributed to the Tiglian (see also the previous section dealing with the Pretiglian). This leaves Janssen–Dings, Maalbeek C1 and Eindhoven II as localities with a high percentage of *Fagus*; Maalbeek C1 is the only locality with a detailed sampling frequency. However, the short length of the sequence of Maalbeek C1 as well as the absence of a conformable lower boundary makes it impossible to positively attribute this section to the Tiglian TA.

Eindhoven II also shows a consistent but limited presence of 'Tertiary' relics all through the TA section (ranging from 1.5% at the lower margin to 4% at the transition to TB; for *Sequoia, Taxodium, Nyssa* and *Sciadopitys*). The considerable difference in *Fagus* percentages between localities attributed to Tiglian TA, the limited number of pollen spectra and the lack of conformable boundaries with other stages all contribute to the uncertainty with respect to the definition and recognition of the TA substage of the Tiglian.

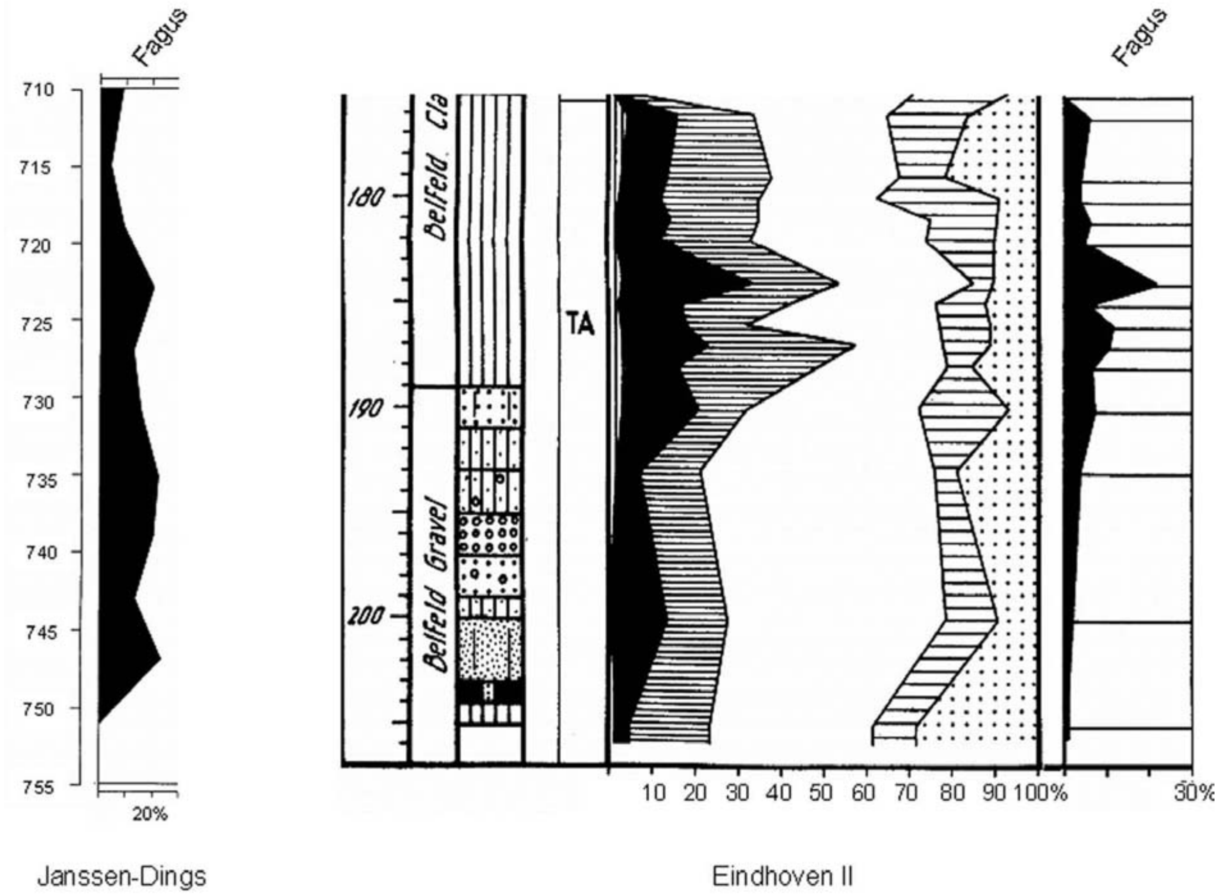

Figure 4. Pollen diagram of Fagus *from Janssen–Dings (left, after Westerhoff* et al.*, 1998) and of Eindhoven II (right, after from Zagwijn, 1963).*

5.2. Tiglian B

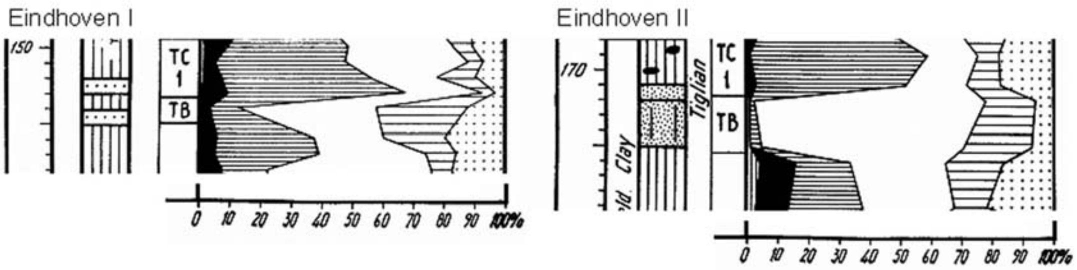

Figure 5. Tiglian B in cores Eindhoven I and II (after Zagwijn, 1963).

The TB substage of the Tiglian was originally demonstrated by Zagwijn (1963) in two cores: Eindhoven I and Eindhoven II (figure 5). While Zagwijn (1963) described TB as a cool oscillation since the percentage of herbaceous pollen does not increase, Westerhoff *et al.* (1998) change TB to a full glacial through a pollen diagram of Maalbeek C1 and by repositioning the Maalbeek sequence (Pit van Cleef) which was originally attributed to the Eburonian (Zagwijn, 1963; see also figure 6). The pollen diagrams of Maalbeek C1 and Pit van Cleef both indicate cold climatic conditions, with a dominance of *Ericales* and herbs. This clearly contradicts the initial recognition of TB (in Eindhoven I and II) as a cool oscillation. As a consequence, this also creates uncertainty as to the assignment of the Tiglian substages in Eindhoven I and II by Zagwijn (1963).

The number of TB sequences is very limited (appendix I). Due to the recent recognition of TB as a glacial period in Maalbeek C1 the original position of TB in Eindhoven I and Eindhoven II is considered questionable. Since the Maalbeek, Pit van Cleef sequence lacks conformable boundaries in clearly identified interglacial stages, an attribution to a specific glacial period is considered tentative. Maalbeek C1 is thus the only sequence which has both detailed sampling as well as conformable boundaries.

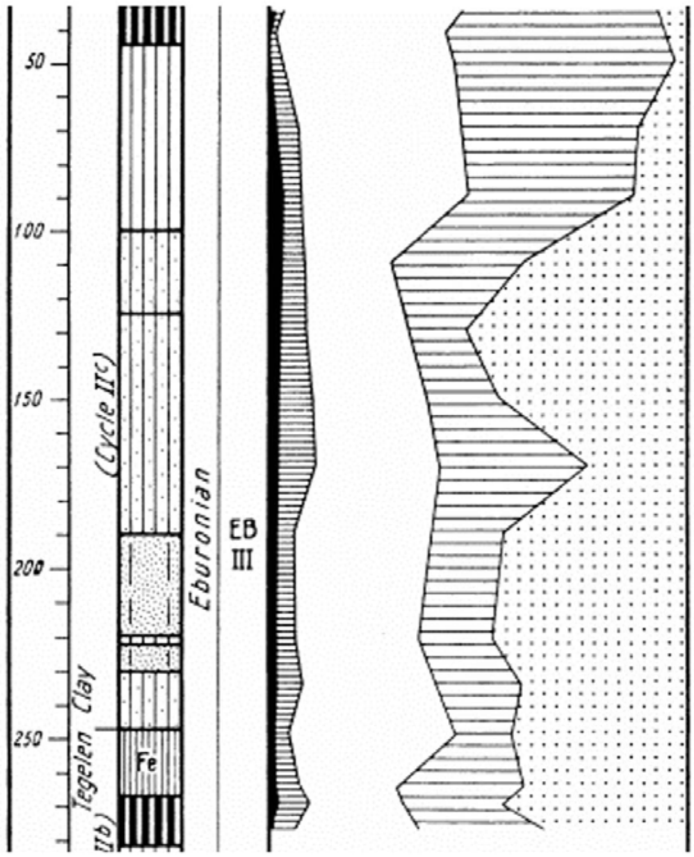

Figure 6. Pollen diagram of Maalbeek, originally attributed to Eburonian by Zagwijn (1963) and later attributed to Tiglian substage B by Westerhoff et al. *(1998), after Zagwijn (1963).*

5.3. Tiglian C

The Tiglian C substage has been subdivided by Zagwijn (1963) into six sections, TC1–TC6, with a more detailed subdivision of sections TC2–TC4. The type locality for TC2–TC6 is de pit Russel–Tiglia–Egypte (figure 7); TC1 is first recognised in Eindhoven I and II (figure 5).

The detailed subdivision of this substage, with the exception of TC1, completely hinges on a single sequence, the pit Russel–Tiglia–Egypte. The pollen sequence of this locality consists of three separate sections, taken at close proximity but under differing sedimentary conditions.

The lower section was taken from sediments deposited in an abandoned meander (figure 7, between 3.60 m and 10.00 m). Zagwijn (1963) identified TC2–TC4 from this section, with a further subdivision of each of these substages (TC2a, TC2b; TC3a–TC3c; TC4a–TC4c).

The middle section (figure 7, between 1.90 m and 3.50 m) was taken from sediments including a gully filling. The bottom part of this section came from the lake–clay from which the lower section was also taken. A small stream cuts through the lake clay deposits. The middle part of the section was taken from sediments that were deposited by this small stream. The differing sedimentary conditions closely reflect the observed changes in the pollen diagram, where an increase in warmth–loving plants of wet environments can be directly correlated with the clay–gyttja sediments of the small stream. Zagwijn (1963) considered the changed floral assemblage of this section to reflect different climatic conditions and created TC5. The change in pollen assemblage is almost exclusively based on a very significant increase in *Pterocarya* pollen (figure 8). This points to a plausible alternative: the pollen assemblage from the infill shows a strong local signal and not necessarily a climatic variation.

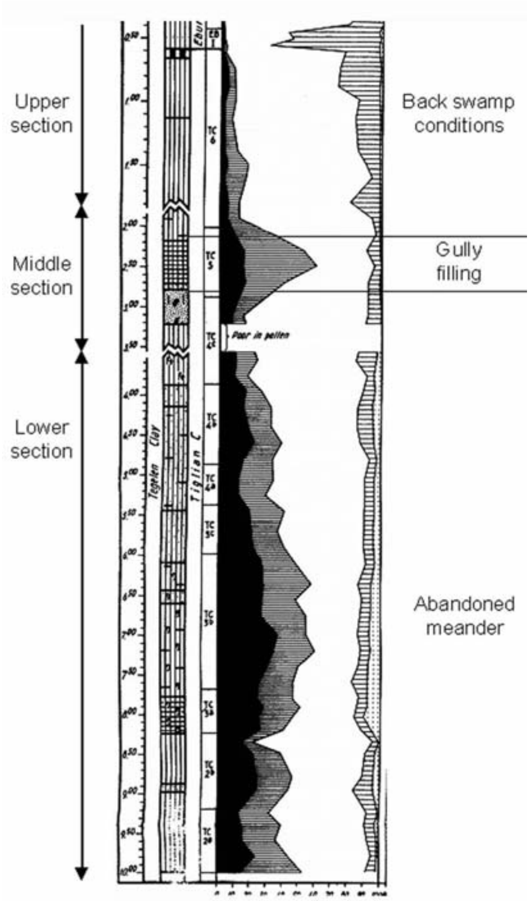

Figure 7. Tiglian TC2–TC6 in pit Russel–Tiglia–Egypte (after Zagwijn, 1963).

The upper section was taken from sediments, deposited in back swamp conditions (figure 7, between 0.00 m and 1.80 m). Zagwijn (1963) identified TC6 as well as three different substages of the Eburonian in this section.

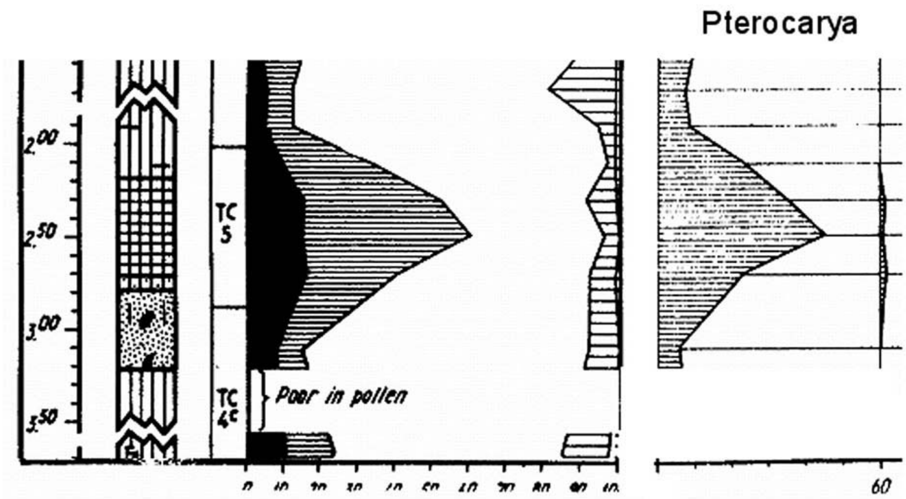

Figure 8. The middle section of Pit Russel–Tiglia–Egypte (left) combined with Pterocarya *pollen percentages (right).*

Because of the possibility of a misinterpretation of a local pollen signal for climatic variation, leading to the introduction of TC5, the identification of TC6 as a separate zone in Russel–Tiglia–Egypte can also be considered questionable. Although no absolute age indicators are available for this locality, the conditions for sedimentation (abandoned meander, small stream and back swamp) indicate potentially rapid sedimentation, suggesting a relatively short deposition period. This is reinforced by the alternative explanation for the gully infilling: the recognition of a local signal presupposes sedimentation for a short time interval. If we assume a more or less comparable speed of sedimentation through the complete Russel–Tiglia–Egypte section, this would then point to a short sedimentation period. This is in sharp contrast with the current view of Tiglian C, this substage being presented as a period of approximately 250.000 years (see also Zagwijn, 1998).

Whilst the original identification of TC5 in Russel–Tiglia–Egypte is already considered highly questionable, subsequent identifications of TC5 are also subject to multiple uncertainties since all instances are based on very limited numbers of pollen, with a coarse to extremely coarse sampling distance. In addition, in most cases the upper and/or lower boundaries are considered ill–defined since they are either not conformable or only based on small numbers of pollen themselves (see also appendix I).

TC1 was first recognised in two short sections in Eindhoven (figure 5 and appendix I), but now its seems uncertain since the preceding Tiglian substage TB is considered poorly established, having originally been identified as a cool oscillation whereas Westerhoff *et al.* (1998) consider TB to be a fully developed glacial. In addition, TB was recognised in the Eindhoven sequences on the basis of an extremely limited number of pollen (appendix I). Other sequences attributed to Tiglian substage TC1 are too limited to contribute to our understanding of the validity of this substage.

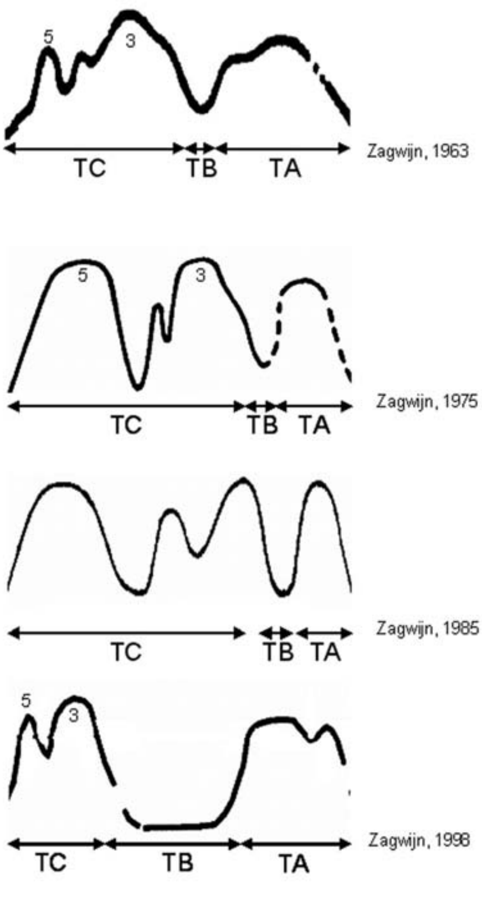

Figure 9. The subdivision of the Tiglian stage over time (after Zagwijn, 1963, 1975, 1985, 1998).

5.4. Discussion of the Tiglian stage

The Tiglian stage is highly detailed in terms of the number of substages, zones and subzones, suggesting a detailed knowledge of this period. This suggestion does not appear to be substantiated by the underlying data on close inspection.

Although many pollen samples, of different localities, have been attributed to the Tiglian, this has often been done on few and/or coarsely sampled pollen spectra (appendix I). Upper and lower substages in a conformable sedimentation sequence are either absent or uncertain, creating a high level of uncertainty with respect to the correctness of correlations. The literature shows numerous examples of determinations down to a subzone level based on a single pollen spectrum (*i.e.* TC4c: Eindhoven I, Eemnes, Uitdam Rotterdam) or of coarsely sampled pollen spectra (*i.e*. Öbel, Eemnes, Rotterdam, Uitdam).

In addition, the detailed subdivision of the Tiglian substage C (TC2–TC6) is based on a single, composite sequence found at Russel–Tiglia–Egypte. The apparent possibility that these localities were subject to different sedimentary conditions was not taken into account. Lacking absolute age points, the duration of the Russel–Tiglia–Egypte sequence is also completely unknown.

The uncertainty with respect to the climatic changes and their duration over the course of the Tiglian stage is perhaps best illustrated by the changes made to the climatic curve over time (figure 8). It is evident that duration and amplitude of each substage differs considerably over time. However, these changes were never explicitly supported by published discussion (Zagwijn, 1963, 1975, 1985, 1998).

One can only conclude that current data on the Tiglian and its substages is too limited to determine duration and amplitude of climatic changes. Furthermore, as we are lacking clear upper and lower boundaries as well as objective, absolute date points, the overall duration and position in time of the Tiglian stage is also questionable.

6. Eburonian–Bavelian

Zagwijn (1957) proposed a subdivision of the Taxandrian as recognised by Van der Vlerk & Florschütz (1950), introducing the Eburonian, Waalian and Menapian stages. The subdivision was based on palynological evidence found in the Kedichem Formation and upper part of the Tegelen Formation (Zagwijn, 1957). The subdivision of the Taxandrian is primarily based on a pollen diagram from Veghel (figure 10), considered to be one of the most complete pollen diagrams of the Kedichem Formation (Zagwijn, 1957). The Kedichem and Tegelen Formations were recently combined by Weerts *et al.* (2000) to constitute the Formation of Waalre.

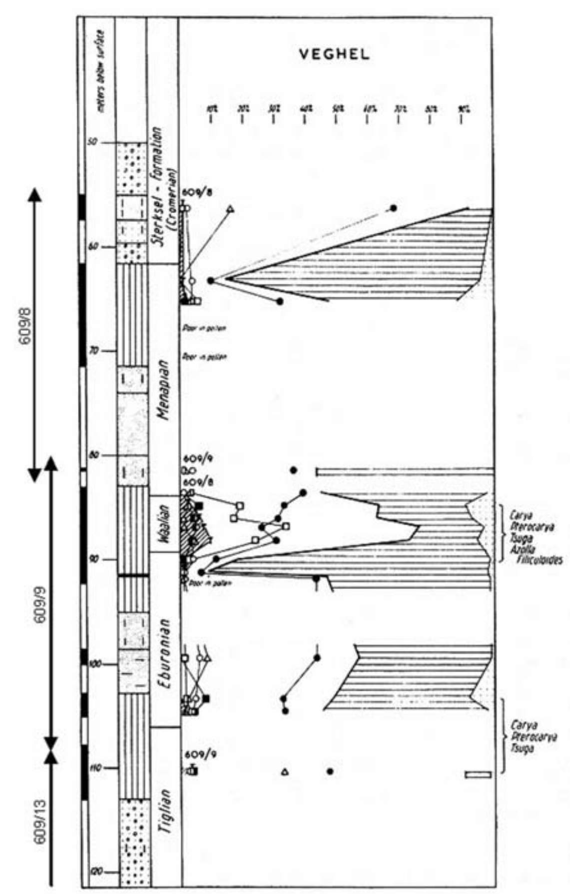

Figure 10. Pollen diagram of Veghel (after Zagwijn, 1957) showing the separate sections 609/8, 609/9 and 609/13 on the left hand side of the diagram.

The Veghel sequence is a composite diagram, consisting of three separate sections (see left hand side of figure 9). The Cromerian and Menapian are recognised from section 609/8, while the Waalian and Eburonian are recognised from 609/9. The Tiglian is recognised from a third section 609/13.

As becomes clear from figure 9, the Veghel sequence is in fact a highly fragmented diagram, with a coarse and irregular sampling of pollen spectra due to the scarcity of pollen bearing sediments. In addition, the Eburonian, Waalian and Menapian stages are recognised on the basis of a very small number of pollen spectra (table 1).

Veghel (Zagwijn, 1957)	# spectra	Leffe (Lona, 1950)	
Cromerian	1	Günz – Mindel	Temparate
Menapian	4	Günz III	Cold
		Günz II/III	Temparate
Waalian	7	Günz II	Cool oscillation
		Günz I/II	Temparate
Eburonian	4	Günz I	Cold
		Donau – Günz	Temparate
Tiglian	1	Donau III	Cool oscillation
		Donau II/III	Temparate
Pretiglian		Donau II	Cold

Table 1. Correlation of the Veghel and Leffe sequences (after Zagwijn, 1957). The second column shows the number of pollen spectra of Veghel for each identified stage.

Zagwijn (1957) proposed a close correlation between the Veghel sequence and the pollen diagram of Leffe (Lona, 1950) at that time considered the most complete record of the Early Pleistocene (Zagwijn, 1957; see also table 1). Unlike the Veghel sequence, the sequence from Leffe shows regular sampling in a continuous pollen bearing sequence.

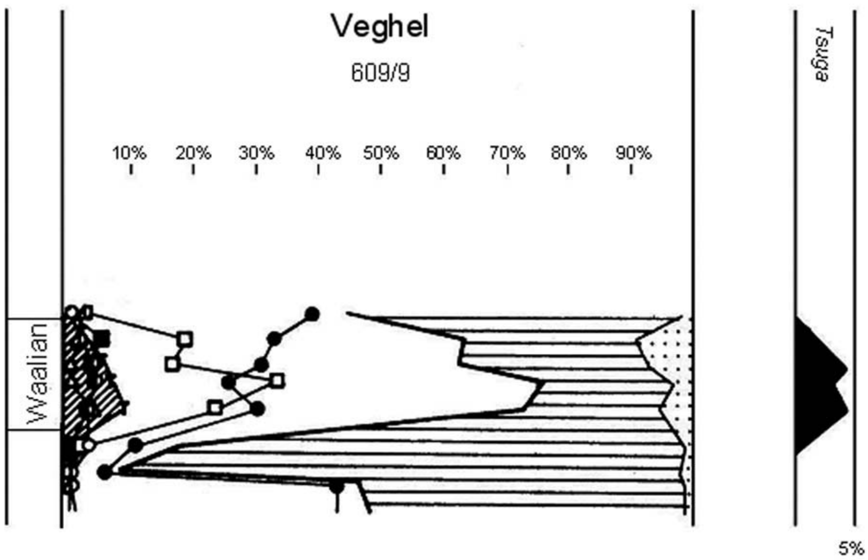

Figure 11. Waalian stage of Veghel, Tsuga presence (after Zagwijn, 1960).

New research in the Leffe area (Ravazzi & Rossignol Strick, 1995) revealed that the sequence of Lona (1950) covers a much shorter time span than was originally proposed. Ravazzi & Rossignol Strick demonstrated that the Leffe sequence can be related to the Matuyama reversed epoch between two normal events, Olduvai at the base and Jaramillo at the top. This leaves the Veghel sequence without any reliable correlations since the Cromerian, Menapian and Tiglian are all positioned outside of this period.

Zagwijn & De Jong (1985) consider a relatively high percentage of *Tsuga* in a pollen assemblage in the Kedichem or Sterksel Formations to be a marker for the Bavelian. Although the Waalian was originally recognised by Zagwijn (1957, 1960) in the Veghel sequence (section 609/9) this section also contains a relatively high percentage of *Tsuga* (figure 11), allowing a possible alternative interpretation as Bavelian for part of the sequence.

The composite diagram, the limited number of pollen spectra per recognised stage, the incorrect correlation with Leffe and a possible alternative interpretation of the section originally identified as Waalian clearly indicate that the Veghel sequence is too inconclusive to serve as the reference locality on which the subdivision of the Taxandrian was based. As a consequence this seriously questions the validity of the original subdivision of the Taxandrian into Eburonian, Waalian and Menapian as well as all subsequent attributions to any of these stages.

6.1. Eburonian

The Eburonian was first identified in a pollen diagram from Veghel (Zagwijn, 1957; see also figure 9). A stratotype has never been published. The only detailed pollen sequence known from this stage is from Eindhoven I (figure 12).

The pollen diagram of Eindhoven I shows a number of uncertainties, with the coarse sampling of pollen as the most important one. A second issue is the uncertainty of the recognition of the Waalian in Eindhoven I. In Eindhoven I, the Waalian C substage shows a high value of *Tsuga*, considered by Zagwijn & De Jong (1985) to be a marker for the Bavel interglacial of the Bavelian stage. Since glacial stages of the Early Pleistocene lack any markers in their floral assemblage, their recognition strongly relies on the unequivocal recognition of preceding and following interglacials that do show distinctive markers. Because the Waalian in Eindhoven I could also be interpreted as Bavelian, the recognition of the Eburonian becomes questionable.

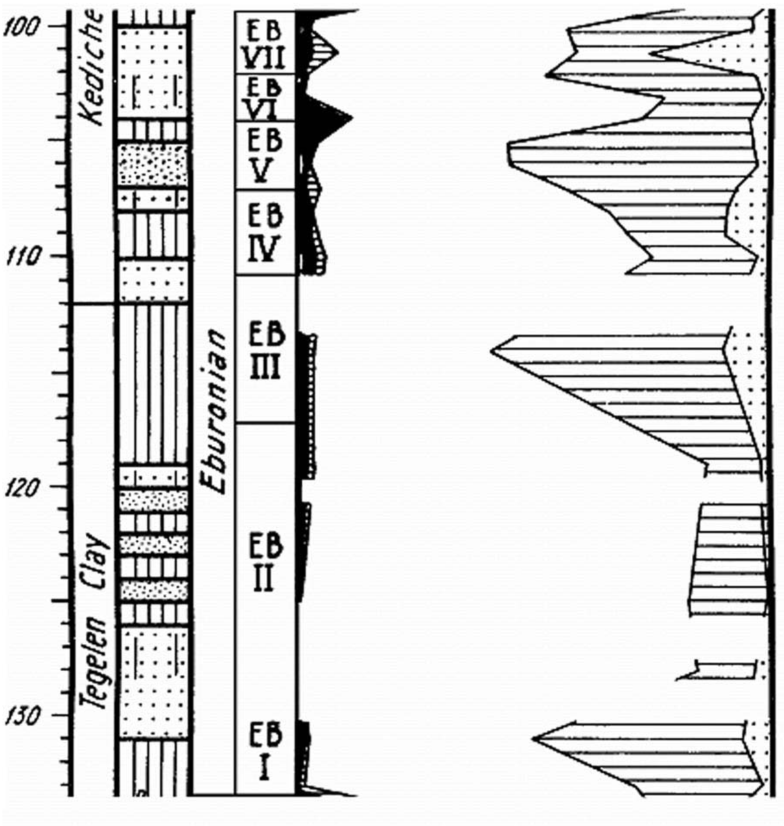

Figure 12. Eburonian from Eindhoven I (after Zagwijn, 1963).

Other sequences attributed to the Eburonian are also subject to one or more uncertainties (coarse sampling, few pollen spectra, poorly established interglacials, no conformable upper or lower boundaries). For additional information on these sequences please refer to appendix I.

It is therefore concluded that the Eburonian glacial stage, as proposed by Zagwijn (1957) is not clearly established in the biostratigraphy of the Early Pleistocene of The Netherlands. Any reference to the Eburonian beyond the observation of a cold period in the Waalre Formation should be considered tentative.

6.2. Waalian

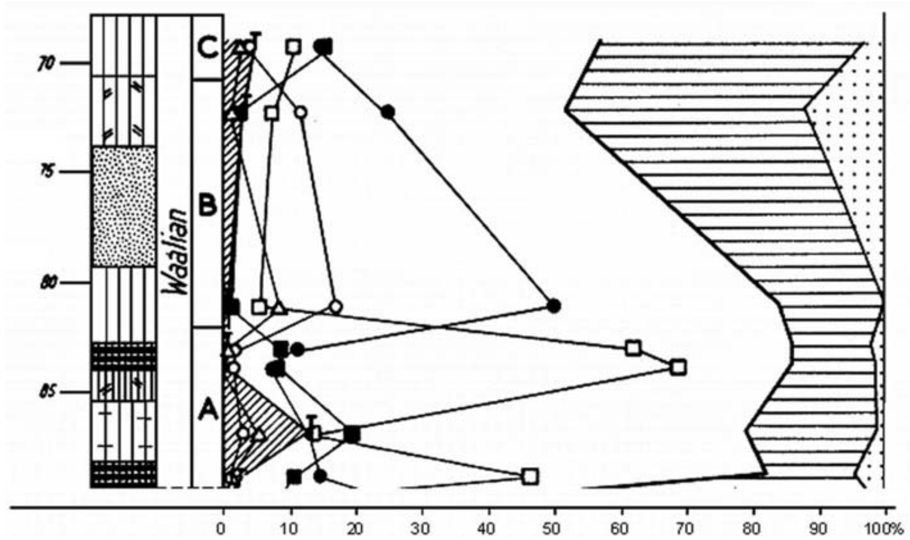

Figure 13. Stratotype of Waalian, Zaltbommel (after Zagwijn, 1960).

The Waalian was first recognised in a pollen diagram from Veghel (Zagwijn, 1957, 1960; see also figure 10). The stratotype of the Waalian is Zaltbommel (figure 13) although a formal description of the stratotype was never published.

An overview and detailed discussion of sequences, attributed to the Waalian, is given in appendix 1. As mentioned before, the original recognition of the Waalian is now considered questionable due to a relatively high percentage of *Tsuga* pollen, indicating a possible Bavelian position.

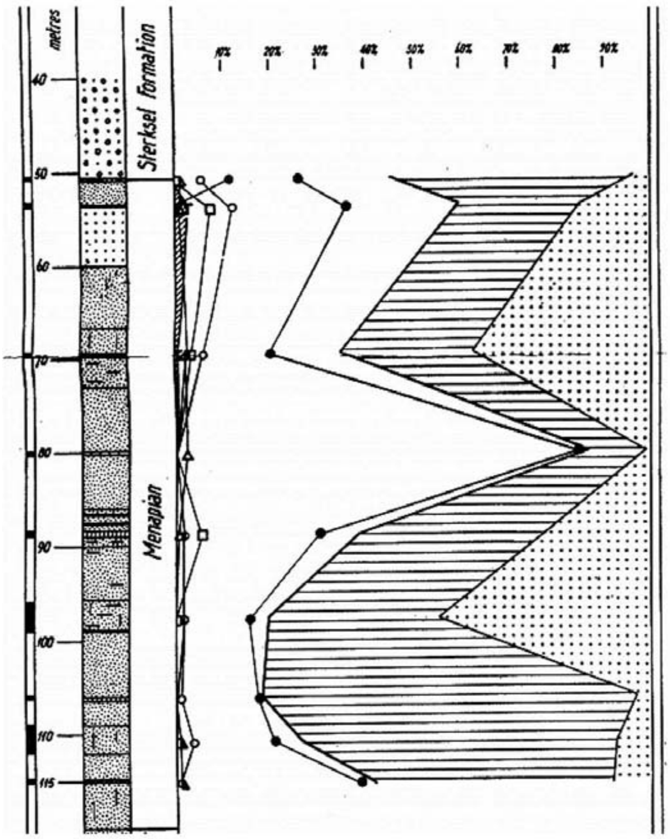

Figure 14. Menapian as recognised from Herten (after Zagwijn, 1960).

Other pollen diagrams from The Netherlands that have been attributed to the Waalian question the validity of the identification (few pollen samples, coarse samples and/or lack of conformable boundaries). The distinction between Waalian and Bavelian seems to be a matter of interpretation, rather than a clear–cut difference in floral assemblages. In the absence of clear boundaries for most sequences, this makes it impossible to determine the correct position, especially in the absence of other dating or correlating means. As a result of these observations the Waalian stage is considered to be very poorly established.

6.3. Menapian

The stratotype of the Menapian is Veghel (Zagwijn, 1957, 1960; see also figure 10). A definition of the stratotype has not been published. Since the Waalian stage in Veghel is later repositioned as a substage of the Bavelian (Zagwijn & De Jong, 1985), the Menapian stage of Veghel is no longer valid as the stratotype since it now postdates the original position of the Menapian. Thus, no stratotype of the Menapian is known. Figure 14 shows a sequence from Herten that was attributed to the Menapian stage by Zagwijn (1960).

Since the Menapian is a cold stage, lacking a distinctive floral assemblage, it can only be determined through preceding and subsequent interglacials with floral markers. However, all sequences attributed to the Menapian are subject to several uncertainties (coarse sampling, few pollen spectra, poorly established interglacials, no conformable upper or lower boundaries, see also appendix I). The Menapian stage is therefore considered to be poorly established.

6.4. Bavelian

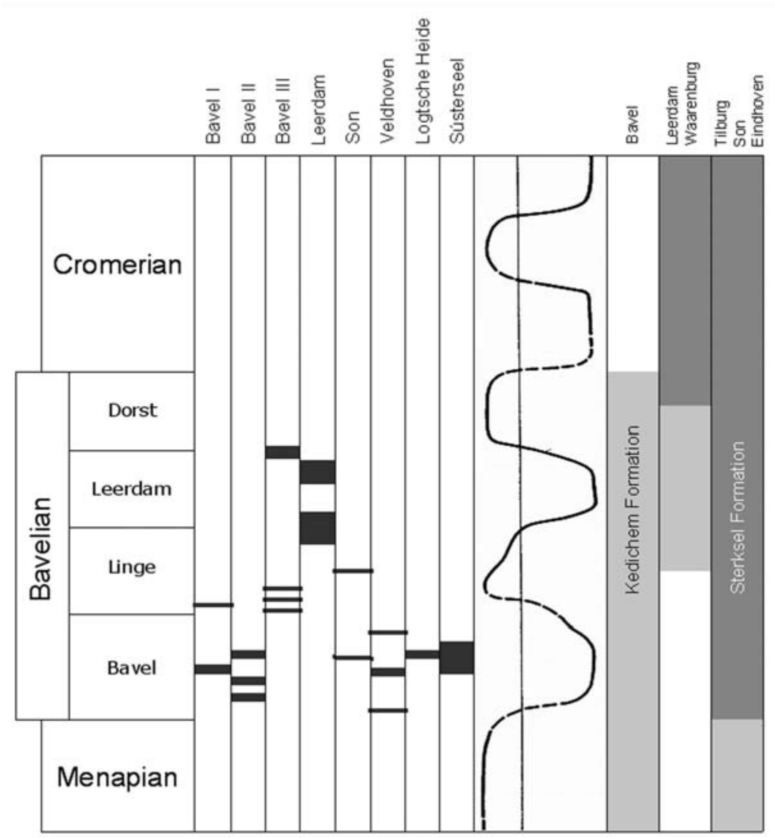

Figure 15. Pollen spectra and their position in the Bavelian (after Zagwijn & De Jong, 1985).

The Bavelian was introduced by Zagwijn & De Jong (1985). It consists of two full glacial–interglacial cycles and is positioned by the authors at the end of the Early Pleistocene, after the Menapian stage and before the Cromerian stage. This position is based on:

- The lithostratigraphic position, top of the Kedichem Formation and bottom of the Sterksel Formation
- The presence of *Tsuga, Pterocarya* and *Carya* during both interglacial periods. These are absent in the Middle Pleistocene according to Zagwijn & De Jong (1985).
- A high percentage of *Tsuga* in the Bavel interglacial, not encountered in the Waalian.

- Palaeomagnetic evidence. The lower part of the Bavelian is normally magnetised while most of the upper part shows reverse magnetisation. As a result it is placed during and after the Jaramillo event.

The Bavelian and its subdivision is based on nine extremely short sequences (figure 15), originating from different localities over a distance of four kilomoeters (Bavel I, Ia, II and III). No continuous pollen diagram of the Bavelian is known, including clear–cut upper and lower boundaries with the preceding Menapian and subsequent Cromerian stage.

Since the Bavelian is reconstructed on the basis of multiple short sequences from four different localities there is no stratotype. The lack of clear–cut upper and lower boundaries with other stages increases doubts with respect to the nature of the Bavelian. Also, the rather wide range of *Tsuga* values within the Bavel interglacial itself seems to contradict what has been proposed as the single most differentiation factor of the Bavelian, a high *Tsuga* percentage.

7. Palaeomagnetic research

Palaeomagnetic results can be used to date sediments if remanent magnetism is still present. By a correlation of the results with the palaeomagnetic timescale possible age limits can be obtained for a sediment. The most precise possible correlations are those that incorporate a polarity reversal, allowing positioning on the palaeomagnetic timescale. However, to determine the correct polarity reversal, other data are required. As a consequence, palaeomagnetic results always need interpretation and cannot be looked upon as absolute and objective date markers. Only through correlation with lithostratigraphic or biostratigraphic data is it possible to determine a position on the palaeomagnetic timescale.

The duration of periods of normal and reversed polarity can be used to search for an optimal fit with the standard magnetic time scale. However, in order to use this method, long sections with more or less continuous sedimentation are needed. Clearly, the Early Pleistocene of The Netherlands lacks these conditions.

The only palaeomagnetic study spanning the Pleistocene and part of the Pliocene of The Netherlands was performed by van Montfrans (1971). His study correlated the already existing biostratigraphy of the Pleistocene with the palaeomagnetic timescale. A discussion of his research is added in appendix II. As with palynological research, palaeomagnetic research lacked a continuous record of the Early Pleistocene, forcing Van Montfrans (1971) to use a large number of short sequences from different localities (see appendix II). Van Montfrans used the biostratigraphy of Zagwijn as a reference to correlate his samples. Van Montfrans (1971), Zagwijn *et al.* (1971), and Zagwijn (1974) reached the following conclusions, based on the palaeomagnetic results:

- A polarity reversal during the Cromerian period was correlated with the Matuyama–Brunhes border (Van Montfrans, 1971; Zagwijn *et al.,* 1971).
- A polarity reversal observed between Waalian and Menapian was correlated with the Jaramillo event (Van Montfrans, 1971).
- A polarity reversal between Eburonian and Tiglian was correlated with the Olduvai event (Van Montfrans, 1971).
- The Pliocene–Pleistocene boundary was set at approximately 2.3 Ma (Van Montfrans, 1971).
- The Pliocene–Pleistocene boundary is set at approximately 2.5 Ma (Zagwijn, 1974).
- A polarity reversal between Reuverian and Pretiglian was correlated with the Gauss–Matuyama border (Zagwijn, 1974).

These conclusions were based on the following assumptions:

- The sediments processed for palaeomagnetic research were all of known stratigraphic age.
- An almost complete sequence of Pleistocene sediments was present in The Netherlands (Van Montfrans & Hospers, 1969).
- The relative speed of sedimentation (personal comment by Zagwijn to Van Montfrans) of Pleistocene fluviatile sediments was known.
- The biostratigraphy of the Early Pleistocene was established.

The validity of these assumptions is questioned, based on the following observations:

- The sequences used by Van Montfrans (1971) were not always of known stratigraphic age, as has been shown in the previous section. In addition, sections originally attributed to Eburonian (Maalbeek) and to Menapian or Waalian (Waardenburg, Leerdam, Dorst, Bavel) were later repositioned to Tiglian TB and Bavelian, respectively.
- The limited availability of sediments that can be used for palynological and palaeomagnetic research is contradictory to the assumption that an almost complete sequence of Pleistocene sediments is available.
- The relative speed of sedimentation up until 1.6 Ma was known according to Van Montfrans (1971), basing himself on a personal comment of Zagwijn. However, since Van Montfrans was the first to fix absolute age to the stratigraphy, this hypothesis cannot be objectively tested.

- As shown in the previous section, the biostratigraphy of the Early Pleistocene of The Netherlands is considered far from established.

None of these assumptions are considered valid. The resulting conclusions of Van Montfrans (1971), Zagwijn *et al.* (1971), and Zagwijn (1974) are therefore questionable, with the exception of the correlation of the first observed polarity reversal with the Matuyama–Brunhes boundary.

The extrapolation of the relative speed of sedimentation provided Van Montfrans (1971) the means to determine the age of the Pliocene–Pleistocene boundary. He reached an estimate of 2.3 Ma for this boundary. In turn, Zagwijn (1974) proposed an age of 2.5 Ma as a working hypothesis for the Pliocene–Pleistocene boundary, just below the Matuyama–Gauss reversal (of that time). His proposal was also based on the fact that (Zagwijn, 1974: 87): “The very few Pretiglian measurements have shown a normal, followed by a reversed polarity”. While nothing more than a working hypothesis, the proposed age of the Pliocene–Pleistocene boundary has never been questioned since.

Zagwijn (1998) changed this picture by correlating the reversal observed in the Pretiglian with the short–lived normal polarity event Réunion I, thus positioning the Gauss–Matuyama reversal, now placed at 2.8 Ma, somewhere during the Reuverian substage C. The reason for this change is not explained. It seems that this change is to fit the Reuverian–Pretiglian boundary to the original working hypothesis of 2.5 Ma. Clearly, the original estimate for the Plio–Pleistocene boundary of Van Montfrans (1971) is not valid since it is based on many questionable assumptions, also adversely affecting the conclusions made by Zagwijn (1974). The information on the polarity reversal observed during the Pretiglian also requires closer inspection.

The only palaeomagnetic measurements in which the presence of the Reuverian–Pretiglian boundary is cited are Core Meinweg (58G/71) and Pit Mols. The palaeomagnetic data at Core Meinweg was of low quality, leaving a very limited number of measurements. Van Montfrans (1971) only accepted the reversed polarity measurements, which were younger than the Eburonian. As was shown in the discussion of the palynological results of Meinweg, the recognition of the Pretiglian in this core is uncertain and the cool oscillation could also be looked upon as a cold period during the Pliocene.

Pit Mols is a very short sequence (3.5 m) where Van Montfrans (1971) rejected three of the nine measurements. Here Van Montfrans found reversed polarity in the upper part of the section and normal polarity in the lower part. This short sequence is ‘dated’ by Zagwijn (personal communications to Van Montfrans) who determines it to “probably at about the boundary Pretiglian–Reuverian”. A palynological study of pit Mols has never been published. It is therefore impossible to confirm the validity of the original determination of Zagwijn. As a consequence, the results from the Pit Mols cannot be taken as establishing the age of the Pliocene–Pleistocene boundary as previously recognised by Zagwijn.

The polarity reversal between Eburonian and Tiglian is based on the localities pit Maalbeek, pit de Toekomst and pit Sint Fransiscus. All three have sediments with a reversed polarity while three localities that were attributed to the boundary Eburonian–Tiglian (pit Kurstjens, pit Wambach, and pit Laumans) all show normal polarity. Westerhoff *et al.* (1998) reposition pit Maalbeek to Tiglian substage TB. The results from pit Sint Franciscus and pit de Toekomst were only published in a guidebook to an excursion in Belgium (Paepe, 1970). The information in this publication is too limited to allow an objective validation. Isolated pollen spectra were used to correlate clay beds to Waalian and Tiglian respectively in pit Sint Franciscus. Pit de Toekomst showed no characteristic pollen spectrum, but the clay bed from which the spectrum originated was nevertheless attributed to the Waalian. Although Van Montfrans (1971) mentioned a second section attributed to the Eburonian, the original publication makes no such reference (Paepe, 1970).

The identification of the Eburonian–Tiglian boundary in pit Kurstjens is questioned here, since no pollen samples have yielded any indication of either period. The sequence of 2.5 m only yielded pollen over a section of 40 cm and these spectra were assigned to the Waalian stage (Van Montrfrans, 1971). Only through a correlation of the lower boundary of the Kurstjens sequence with the upper boundary of the Russel–Tiglia–Egypte sequence it was inferred that the Eburonian–Tiglian boundary was present in the Kurstjens sequence. However, no evidence was presented by Kortenbout van der Sluis & Zagwijn (1962) to support this correlation. Palynological evidence from pit Wambach, and pit Laumans were never published.

It is concluded that the existence of a polarity reversal between Tiglian and Eburonian has not been clearly established. The polarity reversal related to the Jaramillo event is based on samples that were later related to the Bavelian (pit Bavel, pit Dorst, core Leerdam, core Waardenburg, pit Süsterseel, core Rijswijk) by Zagwijn & De Jong (1985). The presence of a reversal between Waalian and Menapian was originally correlated with the Jaramillo event (Van Montfrans, 1971), pushing earlier observed reversals to older polarity events. The readjustment of this situation due to the introduction of the Bavelian requires a complete reinterpretation of Van Montfrans’ original conclusions. Given the many uncertainties with the palynological record, an attempt at such a reinterpretation is not considered within the context of this paper.

8. Palaeontological research

Fossil material of terrestrial mammals from the Early and early Middle Pleistocene, has been found in a number of localities (table 2). In 50% of all localities material was not found *in situ* (*e.g.* North Sea, Oosterschelde, and Maasvlakte). Each locality will be discussed in more detail, with reference to its relevance for the biostratigraphy.

Location	Age	*In situ*	Micro	Macro
Tegelen – Maalbeek	Tiglian TB	Yes/No	No	Yes
Tegelen	Tiglian TC5 – TC6	Yes	Yes	Yes
Zuurland	Various	Yes	Yes	No
North Sea I	Tiglian – Eburonian	No	No	Yes
Oosterschelde	Tiglian TC3	No	No	Yes
Zuurland, 42 – 56 m	Tiglian – Eburonian	Yes	Yes	No
Maasvlakte, fauna 0	Eburonian – Waalian	No	Yes	Yes
Bavel	Bavelian	Yes	Yes	No
Dorst-Surae	Bavelian	Yes	No	Yes
Zuurland 27 – 37 m	Bavelian – Cromerian	Yes	Yes	No
Maasvlakte, fauna I	Bavelian – Cromerian	No	Yes	Yes
North Sea II	Bavelian – Cromerian	No	No	Yes

Table 2. Overview of localities (after Van Kolfschoten, 2001) with some characteristics (after different authors).

8.1. Tegelen–Maalbeek

This locality yielded remains of *Tapirus arvernensis* and *Anancus arvernensis*. A molar of *Anancus* was found *in situ*. The exact provenance of the *Tapirus* fossils is unknown (Kortenbout van der Sluijs, 1960). Based on palynological research of Zagwijn (1963) on the Maalbeek clay and on sediment adhering to the *Anancus* molar the fossils were thought to originate from the Eburonian glacial period.

Recently Westerhoff *et al.* (1998) have attributed the Maalbeek sequence to the TB substage of the Tiglian. They also position *Anancus* in TB and assume that *Tapirus* is slightly older; as a result it is placed in Tiglian TA. Both conclusions are considered questionable. Westerhoff *et al*. (1998) found TB to be a glacial stage, yet *Anancus arvernensis* is not known from any glacial period. Positioning *Tapirus* in TA is speculative since its provenance is unknown.

Westerhoff *et al*. (1998) correlate the Maalbeek material with the Triversa faunal unit of the Early Villafranchian. While *Anancus arvernensis* and *Tapirus* are present at Triversa (see also Sardella *et al*., 1998), this locality is dated at approximately 3.2 Ma. This is inconsistent with a TB and TA age for the Maalbeek fossils. Since *Tapirus* is not found beyond the Triversa faunal unit it is considered possible here that this material comes from Pliocene sediments.

8.2. Tegelen

The rich fossil material from Tegelen is considered to be of late Tiglian age, TC5 – TC6.

8.3. Zuurland

Fauna	Section			Age
Fauna 6	42.2 m	–	42.6 m	No age given
Fauna 7	43.8 m	–	46.0 m	Eburonian, early Waalian
Fauna 8	50.0 m	–	56.0 m	Close to Fauna 7
Fauna 9	63.1 m	–	64.0 m	Late Villanyian, Eburonian
Fauna 10	62.3 m	–	66.6 m	Latest Tiglian (TC6) or earliest Eburonian
Fauna 11	91.0 m	–	96.0 m	Earlier phase of Tiglian (TC4?)

Table 3. Early Pleistocene and Pliocene faunas from Zuurland (after Van Kolfschoten, 1988).

The Zuurland bailer core sampling has yielded considerable amounts of microfossils that were found *in situ*. Pollen analysis of this locality is inconclusive (De Jong, 1988). The pollen samples were assumed to represent a pre–Bavelian flora; possibly Waalian or Tiglian. Van Kolfschoten (1988) recognised 11 faunas in total, six of which could have dated from the Early Pleistocene and Pliocene (table 3).

Reumer & Hordijk (1999), investigating the Insectivora of Zuurland, concluded that probably one fauna is present between the 36.25 m and 66.6 m and that this fauna can be correlated with a warm phase of the Tiglian C substage, tentatively correlating it with TC5. However, they did not exclude a position in the Waalian.

Van Kolfschoten (2001) recognised four Zuurland faunas, reducing the number of faunas with respect to his earlier subdivision of eleven faunas. Three faunas could have dated from the Early Pleistocene and Pliocene (table 4).

Fauna	Section			Age
	42 m	–	56 m	Late Tiglian – Early Eburonian
	62 m	–	66 m	Tiglian TC5 – TC6
	50.0 m	–	56.0 m	Tiglian TB – TC3

Table 4. Early Pleistocene and Pliocene faunas from Zuurland (after Van Kolfschoten, 2001).

The reasoning underlying these date ranges, as well as the marked reduction in the number of faunas in comparison to the previous account (Van Kolfschoten, 1988) is not given by the author. Reumer & Hordijk (1999) concluded that four of the five faunas that were identified by Van Kolfschoten (1988), could be combined into one fauna of Tiglian or perhaps Waalian age. While the findings of Reumer & Hordijk (1999) and Van Kolfschoten (2001) differ, it seems that both point to a Tiglian (and earlier) age for assemblage(s) recognised below 36.25 m. In addition a fauna of Bavelian–Cromerian age was recognised by Van Kolfschoten (1988) and Reumer & Hordijk (1999).

8.4. North Sea

North Sea I (Van Kolfschoten, 2001) is characterised by *Anancus arvernensis* and *Mammuthus meridionalis*. Since the co–existence of these two species is not established by material from a single locality it is considered unwarranted to attribute these species to a single fauna and to attribute this to a specific stage. Geological evidence allows a middle Tiglian–early Eburonian age to be suggested for the material.

Post *et al.* (2001) recognised a mammal fauna from the North Sea which they attributed to the Bavelian, based on similarity of species with the localities Untermassfeld and Saint–Prest. Species found include: *Mammuthus* sp. (*meridionalis* or *trogontherii*), *Hippopotamus antiquus*, *Alces latifrons*, *Megaloceros dawkinsi*, *Eucladoceros ctenoides*, *Bison menneri*, *Equus major*, *Stephanorinus etruscus*, *Homotherium* cf. *latidens*, *Ursus* cf. *etruscus*.

Van Kolfschoten (2001) recognised a fauna (North Sea II) consisting of *Mammuthus (A.) meridionalis, Mammuthus trogontherii, Equus bressanus, Dicerorhinus etruscus, Hippopotamus major, Alces latifrons, Bison menneri* cf., *Praeovibos priscus* cf., which he attributed to the Bavelian to early Cromerian stages. *Trogontherium cuvieri* is also recognised from the North Sea (Mol *et al.,* 1998), attributed to the Early or Middle Pleistocene.

Mol *et al.* (2003) recognised a Bavelian fauna from the locality Het Gat from the so–called Deep Water Channel. The attribution to the Bavelian is based on a single pollen spectrum taken at a neighbouring locality outside the area from which the fossil bones originate. A comparison of the faunal list with other localities leads to a correlation with Untermassfeld and Saint–Prest. Species found include: *Mammuthus* sp. (*meridionalis* and/or *trogontherii*), *Hippopotamus antiquus*, *Alces latifrons*, *Megaloceros dawkinsi*, *Megaloceros savini*, *Eucladoceros ctenoides*, *Bison menneri*, *Equus major*, *Stephanorinus etruscus*, *Homotherium* cf. *latidens*, *Ursus* cf. *etruscus*. Since all this material is dredged from the sea–floor it is impossible to recognise it as a single fauna. The fossil yielding sediments of the Yarmouth Roads Formation from which they are derived span the late Waalian–early Cromerian, leaving the fossil material potentially heterogeneous.

A comparison with mammal faunas of localities such as Untermassfeld and Saint–Prest is thus impossible. Moreover, the comparison by Post *et al.* (2001) and Mol *et al.* (2003) is biased, since large mammals found in these two localities were not included, creating an artificial similarity.

8.5. Oosterschelde

The Oosterschelde material has been described in detail (Mol & De Vos, 1995; Reumer *et al.,* 1998). The fossils are dredged up from the sea–floor from exposed fossilbearing layers. Mol & De Vos (1995) consider the fossils to belong to one fauna and correlate the fauna with Chilhac (approximately 1.9 Ma), also placing the material in TC3 of the Tiglian stage.

Since the material was not found *in situ* the contemporaneity of the fossils is impossible to establish. Placing this material into one fauna suggests simultaneous appearance or existence of the species identified. This fact was not established since all the material was dredged from the sea–floor. Lithostratigrahic evidence allows a Tiglian age to be attributed to the material.

8.6. Maasvlakte

The Maasvlakte is an artificially created area, using sediments from different suction–dredging localities. A detailed lithostratigraphic account of the original sources of sediments has never been published. This locality yielded a large number of fossils, most of them fragmented. Two different faunas were recognised in the Maasvlakte material for the Early Pleistocene; Maasvlakte faunas 0 and I.

Maasvlakte fauna 0 is described by Van Kolfschoten & Vervoort–Kerkhoff (1999) and Van Kolfschoten (2001) and consists of *Mimomys reidi, Mimomys tigliensis, Galemys kormosi (?), Desmana thermalis (?), Petenyia hungarica (?), Sorex Drepanosorex praearaneus, Eucladoceros sp., Alces* cf. *gallicus* and *Cervus sp.* The authors attribute an Eburonian–Waalian age to this assemblage.

Maasvlakte fauna I is described by Van Kolfschoten & Van der Meulen (1986), Vervoort–Kerkhoff & Van Kolfschoten (1988), Van Kolfschoten & Vervoort–Kerkhoff (1999), Van Kolfschoten (2001) and consists of *Galemys kormosi (sp.), Desmana thermalis, Sorex Drepanosorex praearaneus (sp.), Petenyia hungarica, Mimomys savini, Mimomys sp.* (small species), *Ursus* aff. *deningeri, Trogontherium cuvieri ssp, Aonyx antiqua, Lynx lynx, Mammuthus (A.) meridionalis, Equus sp., Dicerorhinus etruscus, Sus scrofa, Hippopotamus major,* cf. *Megaloceros verticornis, Megaloceros sp., Dama dama, Cervus elaphus, Alces latifrons, Soergelia minor,* cf. *Praeovibos priscus.* A Bavelian–Cromerian age was attributed to this group.

Lacking a detailed lithostratigraphy of the localities from which the Maasvlakte sediments originate, Van Kolfschoten & Vervoort–Kerkhoff (1999) turn to the Zuurland boring as a reference. According to them (1999: 374) the Maasvlakte Fauna 0 is derived from a "stratigraphical hiatus between the late Tiglian/early Eburonian Allophaiomys level and the Bavelian/early Cromerian" of the Zuurland boring. It is considered unnecessary to elaborate on the improbability of this statement.

The Maasvlakte Fauna I is correlated with Zuurland level –28 to –36 m. In both the Zuurland as well as the Maasvlakte Fauna I a small *Mimomys* species and the advanced *Mimomys savini* are present and *Allophaiomys* is absent. This is correlated with a Bavelian to early Cromerian age.

As mentioned in discussing the material from the North Sea, it is impossible to recreate a fauna from material found *out of situ*. The same holds true for the Maasvlakte material, even more so because the material originates from different sources of unknown lithostratigraphy.

8.7. Bavel

Van Kolfschoten & Van der Meulen (1986) mentioned the following species, *Desmana thermalis* (determination *cf.* or *aff.*), *Talpa fossilis* (determination *cf.* or *aff.*), *Spermophilus undulatus* (determination *cf.* or *aff.*), *Mimomys savini*, *Microtus arvalis*, and *Microtus* sp. The authors positioned this fauna in the Bavel interglacial of the Bavelian. Van Kolfschoten (1990) mentioned that the fossils were found in two different localities at the Bavel Ia locality of Zagwijn & De Jong (1985).

8.8. Dorst–Surae

Van Kolfschoten (1990) describes *Elephas antiquus*, *Archidiskodon meridionalis* and *cf. Eucladoceros sedgwicki* from Dorst–Surea. He attributes the material to the Leerdam interglacial of the Bavelian stage.

8.9. Discussion of palaeontological results

Lacking clear stratigraphic position, the material from the North Sea, Maasvlakte, and Oosterschelde is considered of limited value beyond the recognition of individual species and fixing a broad time range to the material, based on lithostratigraphic evidence. The Zuurland boring seems to be a source of considerable confusion with respect to the correlation of sediments, and thus fossils, to a specific biostratigraphic (sub)stage. Until this issue is clarified, the fossils of Zuurland do not add to our understanding of the Early and early Middle Pleistocene.

The material found at Tegelen–Maalbeek, Bavel and Dorst–Surae is too limited to serve as comparative material in an attempt to assess the biochronology. As a result the only conclusion that can be drawn is that the fossil material of terrestrial vertebrates has no bearing on an attempt to validate the Pleistocene biostratigraphy of The Netherlands.

9. Discussion

The classic biostratigraphy of the Early Pleistocene of The Netherlands is almost exclusively based on palynological research. Whilst of value, this research was impeded by the lack of long and continuous pollen–bearing sequences, leading to a mosaic of (on average) short sequences, each consisting of a few pollen samples, often coarsely sampled along the core length. This resulted in problematic correlation of sequences. Also, most Early Pleistocene pollen sequences originate from a tectonically complex area, further complicating any attempt to correlate the individual sequences.

An additional complicating factor is the complete absence of objective and absolute time markers, making it impossible to ascertain the duration of sedimentation of any individual pollen bearing sequence. Results from palaeomagnetism and vertebrate palaeontology are too limited and fragmentary to be of any use.

Ravazzi & Rossignol Strick (1995) performed a very detailed sampling on a continuous, pollen-bearing sediments in the Early Pleistocene sequence of Leffe, Italy. On the basis of this succession Leroy & Ravazzi (1997) were able to show climatic cycles, reflected in a cyclic vegetation succession, of approximately 30 ka. However, the chronostratigraphy of the Early Pleistocene of The Netherlands shows cycles of approximately 100 ka, all along its length.

The lack of recognition of a higher number of vegetation successions in The Netherlands is probably due to the type of sediment (Leroy & Ravazzi, 1997). High sedimentation marine sites and deep lacustrine basins are more favourable to provide a detailed signal than are fluviatile or fluvio–lacustrine sequences. The fluviatile sequences of the middle and southern parts of The Netherlands predominantly consist of sands with intercalated clay bands. As a result only a fragmentary record of past vegetation successions is available, which may have resulted in missing intermittent climatic signals. These two factors are considered the main cause of the oversimplified chronostratigraphy of the Early Pleistocene of The Netherlands. The 40 ka climatic cyclicity, as demonstrated in the deep sea record, is simply impossible to detect under such conditions.

10. Conclusions

Detailed inspection of the published evidence, as well as unpublished research data (courtesy of NITG–TNO), results in the following conclusions:

- The position of the Pretiglian as the first glacial of the Pleistocene is considered uncertain. The section from Meinweg could also represent a cool oscillation during the Reuverian, in view of the reappearance of ‘Tertiary relics’ above the deposits attributed to the ‘Pretiglian’ and ‘Tiglian’. As a consequence, the recognition of the Pretiglian, with Meinweg as type locality, as the base of the Pleistocene is considered inconclusive.
- The subdivision of the Tiglian is considered questionable:
    - The Tiglian substage A is poorly established since its marker, a high percentage of *Fagus*, is missing from a number of sequences attributed to TA.
    - The Tiglian substage B, originally identified as a cool oscillation in two cores at Eindhoven (Zagwijn, 1963), has recently been repositioned as a glacial (Westerhoff *et al*., 1998). This questions the two Tiglian sequences at Eindhoven now that TB is considered to be incorrect as this locality.
    - The Tiglian substage C (with the exclusion of TC1) is identified from a single sequence from the pit Russel–Tiglia–Egypte. It is a composite sequence of unknown duration, with possibly a local vegetation signal. This substage is therefore considered questionable.
- The limited knowledge of the climatic development during the Tiglian is clearly demonstrated through its different interpretations over time, as depicted by Zagwijn (1963, 1975, 1985, 1998; see also figure 8).
- The original subdivision of the Taxandrian based on the Veghel sequence (figure 9) creating the Eburonian, Waalian and Menapian stages, is considered erroneous since it is based on an incorrect correlation with the Leffe sequence of Lona (1950). In addition, the recognition of the Waalian in the Veghel sequence seems uncertain since it could also be attributed to the Bavelian, based on a relatively high percentage of *Tsuga* pollen. This in turn questions all subsequent attributions of pollen assemblages to any of these three stages.
- The Bavelian is constructed from a high number of extremely short sequences, originating from different, yet neighbouring, localities. Most sequences lack upper and/or lower boundaries. These uncertainties seriously place in question the validity of correlation of these sequences.
- The results of palaeomagnetic research on Early Pleistocene sequences are considered useless since the samples were ‘dated’ using palynological data. Because the palynological results of the Early

Pleistocene are subject to many uncertainties the palaeomagnetic results are inconclusive. Since the palaeomagnetic research was used to tie the different pollen sequences to the palaeomagnetic timescale this also leaves the whole of the Early Pleistocene without dating points. The start of the Pleistocene as well as the duration of the different stages of the Early Pleistocene are thus left undefined.

- The material of vertebrate fossils of the Early Pleistocene of The Netherlands is too limited to clarify any uncertainties of the palynological and palaeomagnetic records.

It is therefore concluded that the Early Pleistocene of The Netherlands, its subdivision, climatic development and duration in time is poorly known. This is contrary to popular belief that The Netherlands has yielded one of the most complete and well–known records of the Early Pleistocene of northwest Europe. Published correlations with the Early Pleistocene chronology of The Netherlands should therefore be subject to a critical evaluation since they are not based on a sound scientific foundation.

Given the unfavourable conditions for sediments with continental facies in The Netherlands during the Early Pleistocene, any attempt to recreate the biochronology of this period using currently published data seems to be unwarranted.

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Appendix I. Localities of palynological research

This appendix contains an overview of all pollen spectra that have been to one of the Early Pleistocene stages. Each stage is considered separately, with a table of localities and a brief discussion of each locality, mentioning any issues and uncertainties.

The table of localities consists of 7 columns containing the following data:

1. Locality. The locality of the pollen spectrum. If a locality yielded pollen spectra of more than one stage (or substage in the case of the Tiglian) the locality is discussed at the appropriate section in each stage recognised.
2. Section. The approximate length of the section.
3. #. The number of pollen samples assigned to the stage.
4. Avg. dist. The average sampling distance, based on the section length and the number of samples.
5. Upper. The upper conformable boundary with a younger stage, if present.
6. Lower. The lower conformable boundary with an older stage, if present.
7. Literature. The author and date of publication of the pollen sample and/or detailed discussion of the sample.

Pretiglian

Locality	Section	#	Avg. dist.	Upper	Lower	Literature
Meinweg	3.00 m	11	0.3 m	(Tiglian)	Reuverian	Zagwijn (1957, 1960)
Bouwberg	?	1	–	–	Reuverian	Zagwijn (1960)
Zeeuws–Vlaanderen	3.00 m	3	1.3 m		Reuverian	Zagwijn (1960)
Lilbosch	17.00 m	2	–	–	Reuverian	Zagwijn (1960)
Susteren	8.00 m	3	2.7 m	–	Reuverian	Zagwijn (1960)
Herkenbosch	2.00 m	4	0.5 m	–	Reuverian	Zagwijn (1960)
Koningsbosch	8.00 m	4	2.0 m	–	Reuverian	Zagwijn (1960)
Brielle 37D – 134	12.00 m	4	3.0 m	–	–	Van der Meulen & Zagwijn (1974)
De Meern	90.00 m	24	3.8 m	–	–	Zagwijn (1975)
Eemnes	23.00 m	7	3.3 m	–	–	Zagwijn (1975)
Diemerbrug	60.00 m	5	12.0 m	–	–	Zagwijn (1975)

Meinweg is considered the clearest example of the Pretiglian since it shows a climatic deterioration from the Pliocene Reuverian towards the Pleistocene Pretiglian and the subsequent climatic improvement during the onset of the Tiglian. The attribution of the upper limit to the Tiglian stage is now questioned, due to the probable reappearance of 'Tertiary' relics (see section on Pretiglian in the main text).

A single pollen spectrum at Bouwberg assigned to the Pretiglian stage lacks a conformable upper boundary. The lower conformable boundary was attributed to the Reuverian on the basis of two pollen spectra. The section of Reuverian and Pretiglian is coarsely sampled.

Three pollen spectra in Zeeuws–Vlaanderen are assigned to the Pretiglian. No conformable upper boundary is present. The Reuverian and part of the Pretiglian are recognised from littoral, not continental, sediments.

Lilbosch consists of two pollen spectra over a distance of 17 m each showing an assemblage reflecting cold conditions. The distance between pollen samples is too large to allow a reliable attribution to a single stage. At Susteren three pollen spectra lacking a conformable upper boundary are assigned to the Pretiglian.

At Herkenbosch four pollen spectra are assigned to the Pretiglian. Subsequent pollen spectra were attributed to the Eburonian although the pollen assemblages of Pretiglian and Eburonian are both considered remnants of cold climatic conditions and are thus not discernable from one another.

Four pollen spectra at Koningsbosch are assigned to the Pretiglian. The lower boundary is assigned to the Reuverian, exhibiting a high percentage of 'Tertiary' pollen. No conformable upper boundary is present. The pollen diagram of Koningsbosch (Zagwijn, 1960: Plate IX) combines chronostratigraphic stages (Reuverian, Pretiglian) with lithostratigraphic formations (Sterksel Formation).

The section of Brielle, assigned to the Pretiglian, consists of four pollen spectra. The section has no conformable upper and lower boundary. The sediments are of marine origin.

The material of De Meern, Eemnes and Diemerbrug was not published in sufficient detail to allow independent validation. Because the Pretiglian is identified as a cold stage or glacial its floral assemblage lacks marker species (Zagwijn, 1957, 1960). The Pretiglian can only be recognised through the presence of conformable upper and lower boundaries with the following respectively preceding interglacials, provided these interglacials have marker species to allow objective and positive identification.

Since all sections lack a conformable upper boundary it is considered impossible to positively identify the Pretiglian in any of these sections. This leaves the Early Pleistocene of The Netherlands without a reliable pollen sequence of this stage. As a consequence, the definition of the Pliocene–Pleistocene boundary is also considered problematic.

Tiglian A

An overview of published sections, attributed to Tiglian substage A, is given in the table below:

Locality	Section	#	Avg. dist.	Upper	Lower	Literature
Janssen–Dings, TA	0.45 m	12	< 0.05 m	–	–	Van der Vlerk & Florschütz (1953) Zagwijn (1957, 1960, 1963) Westerhoff *et al.* (1998)
Meinweg, Tiglian	2.80 m	11	0.3 m	–	Pretiglian	Zagwijn (1957, 1960, 1963)
Eindhoven I, TA	25.00 m	10	2.5 m	(TB)	–	Zagwijn (1963)
Eindhoven II, TA	35.00 m	14	2.5 m	TB	–	Zagwijn (1963)
De Banken, TA	–	?	–	–	–	Zagwijn (1975)
De Meern, TA	–	1(?)	–	–	–	Zagwijn (1975)
Maalbeek C1, TA	1.20 m	12	0.1 m	TB	–	Westerhoff *et al.* (1998)

A section of the pit Janssen–Dings was originally published by Van der Vlerk & Florschütz (1953) and subsequently discussed by Zagwijn (1957, 1960, 1963) and Westerhoff *et al.* (1998). The section was attributed to TA by Zagwijn (1963). It is a short section sampled at very short intervals, showing a high percentage of *Fagus* pollen. It lacks upper and lower conformable boundaries.

A section at Meinweg was attributed to the Tiglian, based on the conformable lower boundary identified as Pretiglian. Due to the reappearance of Tertiary relics just above Tiglian in another section at the same locality, the validity of the identification of the Tiglian in Meinweg is considered questionable. This is reinforced through the absence of a relatively high percentage of *Fagus*.

A section at Eindhoven I was attributed to TA but lacks a conformable lower boundary. The upper boundary is considered questionable since it is based on only two pollen spectra that were attributed to TA after a section of 10 m that is poor in pollen. Below this section TA is also recognised. The actual data of the pollen spectra of Eindhoven I that were attributed to TA reveal that of a total of 11 pollen spectra only five contain *Fagus* pollen, in percentages varying from 0.5–2% (data courtesy NITG–TNO):

No	Niveau	Pollensom	Fagus	Fagus%
449/76	156	200	0	0.0
449/77	157	200	2	1.0
449/78	158	200	4	2.0
449/87	168	200	1	0.5
449/88	169	200	0	0.0
449/89	170	100	1	1.0
449/90	171			
449/91	172			
449/92	173	200	1	0.5
449/93	174	200	0	0.0
449/94	175			
449/95	176			
449/96	177	200	0	0.0
449/105	178	100	0	0.0
449/106	179	210	0	0.0
449/97	180	200	0	0.0

The pollen diagram of Eindhoven II (Zagwijn, 1963) showed TA over a length of 35 m. The irregular and very coarse sampling distance of this core makes it difficult to positively attribute this section to a single substage. A conformable lower boundary is lacking. *Fagus* is present in considerable, yet strongly varying percentages. Tertiary pollen are also present in all pollen spectra that were attributed to TA (data courtesy of NITG–TNO):

No	Niveau	Pollensom	Fagus	Fagus %	Sciadopitys %	Sequoia %	Taxodium %	Nyssa %	Tertiary %
210/14	175.5	200	11	5.5	1.5	0.5	2.0		4.0
210/13	178.5	200	7	3.5		1.5	1.0		2.5
210/12	179.5	200	7	3.5		1.0	1.0		2.0
210/11	180.5	200	11	5.5			1.0		1.0
210/10	181.5	125	5	4.0			1.6		1.6
210/9	183.5	200	42	21.0	1.0	0.5	1.3	0.5	3.3
210/8	184.5	200	10	5.0		0.5	1.0		1.5
210/7	185.5	200	22	11.0		1.5	1.0		2.5
210/6	186.5	200	20	10.0	0.5	1.0	1.0	0.3	2.8
210/5	187.5	150	9	6.0		0.7	3.0		3.7
210/4	189.5	300	21	7.0	0.6	0.6	1.3	0.3	2.8
210/3	192.5	125	4	3.2	0.8		0.8		1.6
210/2	199.5	200	3	1.5	0.4				0.4
210/1	204.5	200	1	0.5		0.5	0.5	0.5	1.5

The material from De Banken has never been published in sufficient detail to allow independent validation. Zagwijn (1975) does not mention the presence or absence of *Fagus*. The material from De Meern seems limited to a single pollen spectrum (No. 953/33, from a depth between 217–218 m below the surface) and is probably attributed to TA based on the presence of *Fagus* (1.5%, data courtesy of NITG–TNO). Another spectrum from a depth between 213–214 m below the surface yielded no *Fagus*.

A short section at Maalbeek C1 was attributed to TA The section is well sampled at short intervals. TA is recognised on the basis of a high *Fagus* percentage. A lower conformable boundary is missing.

Tiglian B

Locality	Section	#	Avg. dist.	Upper	Lower	Literature
Eindhoven I	–	1	–	TC1	TA	Zagwijn (1963)
Eindhoven II	–	2	–	TC1	TA	Zagwijn (1963)
Eemnes	–	1 / 2	–	TC 2/3	–	Zagwijn (1975)
Maalbeek C1	2.00 m	10	0.2 m	TC	TA	Westerhoff *et al.* (1998)
Maalbeek, Pit van Cleef	2.40 m	16	0.2 m	–	–	Zagwijn (1963) Westerhoff *et al.* (1998)

At Eindhoven I a single pollen spectrum is assigned to TB. From a short section at Eindhoven II two pollen spectra are assigned to TB. The material from Eemnes has never been published in sufficient detail to allow independent validation.

A section at Maalbeek C1 revealed a pollen assemblage reflecting glacial conditions attributed to TB. This resulted in the changing of TB into a glacial by Westerhoff *et al.* (1998), see also the climatic curve of Zagwijn (1998: 31).

The Maalbeek, Pit van Cleef pollen diagram was originally attributed to the Eburonian (Zagwijn, 1963), later repositioned to TB (Westerhoff *et al.,* 1998). The section lacks conformable boundaries.

Tiglian TC1 (+TC)

Locality	Section	#	Avg. dist.	Upper	Lower	Literature
Eindhoven I, TC1	4.00 m	3	1.4 m	TC 2/3	TB	Zagwijn (1963)
Eindhoven II, TC1	3.00 m	2	–	TC2/3	TB	Zagwijn (1963)
De Meern, TC1	?	?	–	TC 2/3	–	Zagwijn (1975)
Dongen, TC1	?	?	–	TC 2/3	–	Zagwijn (1975)
De Banken, TC1	?	?	–	TC 3	–	Zagwijn (1975)
Maalbeek C1, TC	2.00 m	11	0.2 m	–	TB	Westerhoff *et al*. (1998)
Maalbeek C2, TC	5.00 m	28	0.2 m	–	–	Westerhoff *et al*. (1998)

At Eindhoven I three pollen spectra are assigned to TC1. At Eindhoven II two pollen spectra are assigned to TC1. The material from De Banken, Dongen and De Meern has never been published in sufficient detail to allow independent validation.

Maalbeek C1 and Maalbeek C2 both show a detailed sampled section attributed to TC. No substage or more detailed subdivision is presented.

Tiglian TC2/3

Locality	Section	#	Avg. dist.	Upper	Lower	Literature
Russel–Tiglia–Egypte, TC2a	0.8 m	5	0.1 m	TC2b	–	Zagwijn (1963)
Russel–Tiglia–Egypte, TC2b	1.0 m	4	0.2 m	TC3a	TC2a	Zagwijn (1963)
Russel–Tiglia–Egypte, TC3a	0.5 m	4	0.1 m	TC3b	TC2b	Zagwijn (1963)
Russel–Tiglia–Egypte, TC3b	1.7 m	8	0.2 m	TC3c	TC3a	Zagwijn (1963)
Russel–Tiglia–Egypte, TC3c	0.6 m	3	0.2 m	TC4a	Tc3b	Zagwijn (1963)
Eindhoven I, TC 2/3	8.0 m	4	2.0 m	TC4c	TC1	Zagwijn (1963)
Eindhoven II, TC2/3	6.0 m	3	2.0 m	(TC4)	(TC1)	Zagwijn (1963)
Rotterdam, TC3	24.0 m	3	8.0 m	TC4a+b?	–	Zagwijn (1963)
Rosmalen, TC3	4.0 m	2	–	TC4a	–	Zagwijn (1963)
Eemnes, TC3	< 10.0 m	2	–	TC4a+b	–	Zagwijn (1963)
Eemnes, TC2–3	?	?		TC4b	TB	
Öbel (Pit Laumans), TC3b	0.5 m	5	0.1 m	TC3c	–	Zagwijn (1963)
Öbel (Pit Laumans), TC3c	0.5 m	2	–	TC4a	TC4b	Zagwijn (1963)
Brielle 37D – 134, TC3	?	?	–	–	–	Van der Meulen & Zagwijn (1974)
Diemerbrug, TC3/TC4b	?	?	–	–	–	Zagwijn (1975)
De Meern, TC2/TC3	?	?	–	–	–	Zagwijn (1975)
Dongen, TC2/TC3	?	?	–	–	–	Zagwijn (1975)
Den Osse, TC3	?	?	–	–	–	Zagwijn (1975)
De Banken, TC3	?	?	–	–	–	Zagwijn (1975)

The locality Russel–Tiglia–Egypte yielded a very detailed subdivision of the Tiglian substage C. This locality is considered the type locality for TC2–TC6. TC2 and TC3 are further subdivided based on a limited number of pollen spectra per subsection. A conformable lower boundary is missing. The section shows regular and detailed sampling.

At Eindhoven I four pollen spectra are assigned to TC2/TC3. At Eindhoven II three pollen spectra are assigned to TC2/TC3. Conformable upper and lower boundaries are considered questionable. The lower boundary with TC1 is separated by a section without pollen samples of four meters in length and the upper boundary with TC4 is separated by a gap of nearly 30 m lacking pollen.

At Rotterdam (37M–201) a section of approximately 24 m was attributed to TC3, based on no more than three pollen spectra. No conformable lower boundary is present. The upper boundary is TC4 recognised on the basis of no more than two pollen spectra in a core length of more than 10 m. The sediments are of marine origin.

The Rosmalen core is a composite core, consisting of two separate borings. Boring 45B–6, from which TC5 is recognised, and boring 45B–7 (published by Doppert & Zonneveld, 1955), where TC3, TC4a–TC4c is recognised. The sediments have a marine facies, although the published pollen diagram mentions the presence of Tegelen Clay and Tegelen Gravel, which have a continental, fluviatile facies. TC3 is recognised on the basis of two pollen spectra. No lower conformable boundary is present.

At Eemnes (26D–5) the bottom section of a pollen diagram, originating from marine facies, was attributed to TC3 on the basis of two pollen spectra. No conformable lower boundary is present. Later, the same author (Zagwijn, 1975) published an identical diagram from Eemnes, now spanning the Pretiglian to TC5. TC3 is changed to TC2–3, and TC4a+b is adapted to TC4b. These changes are not explained by the author.

At Öbel (Pit Laumans) a short sequence was attributed to TC3b, TC3c and TC4a. The section lacks conformable boundaries. *Azolla tegeliensis* is present in the lower part of the section. Sequences are correlated to the different TC substages on the basis of a very limited number of pollen spectra.

At Brielle a coarsely sampled section of 90 m, with no more than 14 pollen spectra along the sections length was attributed to TC3–TC6, without a clear separation between the substages. Upper and lower conformable boundaries are missing. The section is a mix of sediments of marine (lower part) and continental origin (upper part). Van der Meulen & Zagwijn (1974: 3) assume an hiatus between the Pretiglian and TC3 since “typical pollen assemblages referable to pollen–zones TA and TB of the Tiglian (Zagwijn, 1963) were not found” (reference in original). The authors use the absence of pollen of a particular composition (namely of TA and TB composition) as proof for the existence of a depositional hiatus. This is incorrect. The material from Diemerbrug, De Banken, Dongen and De Meern has never been published in sufficient detail to allow independent validation.

Tiglian TC4

Locality	Section	#	Avg. dist.	Upper	Lower	Literature
Russel–Tiglia–Egypte, TC4a	0.5 m	2	–	TC3c	TC4b	Zagwijn (1963)
Russel–Tiglia–Egypte, TC4b	1.0 m	5	0.2 m	TC4a	TC4c	Zagwijn (1963)
Russel–Tiglia–Egypte, TC4b	1.0 m	3	0.4 m	TC4b	TC5	Zagwijn (1963)
Eindhoven I, TC4c	3 m	1	–	TC5	TC 2/3	Zagwijn (1963)
Eindhoven II	?	1	–	–	–	Zagwijn (1963)
Rotterdam, TC4a+b?, TC4c	30 m	2	–		–	Zagwijn (1963)
Rosmalen, TC4a	5.0 m	3	1.7 m	TC4b	TC3	Zagwijn (1963)
Rosmalen, TC4b	10.0 m	1	–	TC4c	TC4a	Zagwijn (1963)
Rosmalen, TC4c	–	1	–	–	TC4b	Zagwijn (1963)
Uitdam	30 m	3	10.0 m	TC5	–	Zagwijn (1963)
Eemnes, TC4a+b, TC4c	30 m	5	6.0 m	TC5	TC3	Zagwijn (1963)
Eemnes, TC4b, TC4c	?	?	–	–	–	Zagwijn (1975)
Öbel (Pit Laumans), TC4a	0.5 m	1	–	–	TC3c	Zagwijn (1963)
Brielle 37D – 134	?	?	–	–	–	Van der Meulen & Zagwijn (1974)
Leerdam, TC4b, TC4c	?	?	–	TC5	–	Zagwijn (1975)
Scharwoude, TC4b, TC4c	85 m	10	8.5 m	–	–	Zagwijn (1975)
Diemerbrug, TC3–TC4b, TC4c	45 m	5	9.0 m	–	–	Zagwijn (1975)
De Meern, TC4c	?	1	–	–	–	Zagwijn (1975)
Dongen, TC4b, TC4c	?	?	–	–	–	Zagwijn (1975)
De Banken, TC4b, TC4c	?	?	–	–	–	Zagwijn (1975)
Den Osse, TC4c	?	?	–	–	–	Zagwijn (1975)

The locality Russel–Tiglia–Egypte yielded a very detailed subdivision of the Tiglian substage C. It is considered the type locality for TC2–TC6. TC4 is further subdivided based on a limited number of pollen spectra per subsection. The section shows relatively detailed sampling. The section attributed to TC4 consists of two different cores.

At Eindhoven I a single pollen spectrum is recognised to belong to TC4c. At Eindhoven II a single pollen spectrum is recognised to belong to TC4. As with the section attributed to TC2/TC3, no reliable boundaries are present.

The Rosmalen core is a composite core, consisting of two separate borings. Boring 45B–6, from which TC5 is recognised, and boring 45B–7 (published by Doppert & Zonneveld, 1955), where TC3, TC4a–TC4c is recognised. The sediments have a marine facies, although the published pollen diagram mentions the presence of Tegelen Clay and Tegelen Gravel, which have a continental, fluviatile facies. A gap of approximately 30 m separates TC4c from TC5. TC4b and TC4c are both recognised based on a single pollen spectrum, TC4a is recognised on the basis of three pollen spectra.

At Uitdam a section of nearly 30 m was attributed to TC4, with a further subdivision to TC4a+b (one pollen spectrum) and TC4c (two pollen spectra). No conformable lower boundary is present, the upper boundary is TC5 (based on two pollen spectra). The section shows very coarse sampling. The sediments are of marine origin.

A section at Rotterdam was attributed to TC4 (TC4a+b? and TC4c) based on only two pollen spectra. The published pollen diagram of Rotterdam is highly suggestive implying certainty with respect to the floral development over the observed period even though only eight pollen spectra were collected over a core length of 70 m.

At Eemnes a very coarsely sampled section of approximately 30 m was attributed to TC4, with two pollen spectra attributed to TC4a+b and another two to TC4c. The upper conformable boundary is formed by TC5 (recognised on a single pollen spectrum). The lower boundary is positioned in TC3, based on two pollen spectra. The core shows extremely coarse sampling. The same author (Zagwijn, 1975) published an identical diagram from Eemnes, now spanning the Pretiglian to TC5. TC3 is changed to TC2–3, and TC4a+b is adapted to TC4b. These changes are not explained.

At Öbel (Pit Laumans) a short sequence was attributed to TC3b, TC3c and TC4a. The section lacks conformable boundaries. Azolla tegeliensis is present in the lower part of the section. Sequences are correlated to the different TC sections on the basis of a very limited number of pollen spectra.

At Brielle a coarsely sampled section of 90 m, with 14 pollen spectra was attributed to TC3–TC6, without a clear separation between them. Upper and lower conformable boundaries are missing. The section covers a change of sediments from marine (lower part) to continental origin (upper part). The material from Leerdam, Scharwoude, Diemerbrug, De Banken, Dongen, De Meern and Den Osse has never been published in sufficient detail to allow independent validation.

Tiglian TC5

Locality	Section	#	Avg. dist.	Upper	Lower	Literature
Russel–Tiglia–Egypte	0.9 m	4	0.3 m	TC6	TC4c	Zagwijn (1963)
Eindhoven I	3.0 m	4	0.8 m	Eburonian	TC4c	Zagwijn (1963)
Eindhoven II	12.0 m	3	4.0 m	Eburonian	(TC4)	Zagwijn (1963)
Rotterdam	15.0 m	3	5.0 m	TC4c	TC4c	Zagwijn (1963)
Rosmalen	15.0 m	4	3.8 m	–	–	Zagwijn (1963)
Leerdam	?	?	–	Eburonian	TC4c	Zagwijn (1975)
Uitdam	35.0 m	3	11.7 m	–	TC4c	Zagwijn (1963)
Eemnes Eemnes	10.0 m	2	–	–	(TC4c)	Zagwijn (1963) Zagwijn (1975)
Brielle 37D – 134	?	?	–	–	–	Van der Meulen & Zagwijn (1974)
Scharwoude	?	?	–	–	–	Zagwijn (1975)
Diemerbrug	?	?	–	–	–	Zagwijn (1975)
De Meern	?	?	–	–	–	Zagwijn (1975)
Dongen	?	?	–	–	–	Zagwijn (1975)
De Banken	?	?	–	–	–	Zagwijn (1975)
Den Osse	?	?	–	–	–	Zagwijn (1975)

At Russel–Tiglia–Egypte a short section with relatively detailed sampling was attributed to TC5. See the main text for a detailed discussion of this section.

At Eindhoven I four pollen spectra were attributed to TC5. At Eindhoven II three pollen spectra were attributed to TC5. The upper boundary is formed by the Eburonian stage, recognised on the basis of a single pollen spectrum. The lower boundary is not conformable and was attributed to TC4 based on a single pollen spectrum.

At Rotterdam a section of 15 m, yielding three pollen spectra, was attributed to TC5. No conformable upper boundary is present, the lower boundary was attributed to TC4c. The section shows very coarse sampling.

The Rosmalen core is a composite core, consisting of two separate borings. Boring 45B–6, from which TC5 is recognised, and boring 45B–7 (published by Doppert & Zonneveld, 1955), where TC3, TC4a–TC4c is recognised. The sediments have a marine facies, although the published pollen diagram mentions the presence of Tegelen Clay and Tegelen Gravel, which have a continental, fluviatile facies. A gap of approximately 30 m separates TC4c from TC5.

TC5 is recognised in a section of 15 m on the basis of four pollen spectra. It is considered to belong to TC since *Fagus* is absent and attributed to TC5 as its pollen assemblage is of warm temperate character. The section lacks upper and lower boundaries.

At Uitdam a section of 35 m was attributed to TC5 based on only three pollen spectra. Within the whole core a section of 25 m yielded no pollen but was correlated to TC5. No conformable upper boundary is present, the lower boundary is TC4c (based on two pollen spectra). The sediments are of marine origin.

At Brielle a coarsely sampled section of 90 m with 14 pollen spectra was attributed to TC3–TC6, without a clear separation between them. Upper and lower conformable boundaries are missing. The section covers a change of sediments from marine (lower part) to continental origin (upper part).

At Eemnes TC5 is recognised on the basis of two pollen spectra. The lower boundary is formed by TC4c, a distance of nearly two meters separates the last pollen spectrum of TC4c and the first pollen spectrum of TC5. No conformable upper boundary is present.

The material from Leerdam, Scharwoude, Diemerbrug, De Banken, Dongen, De Meern and Den Osse has never been published in sufficient detail to allow independent validation.

Tiglian TC6

Locality	Section	#	Avg. dist.	Upper	Lower	Literature
Russel–Tiglia–Egypte	1.4 m	10	0.1 m	Eburonian	TC5	Zagwijn (1963)
Brielle 37D – 134, TC3 – TC6	90.0 m	14	6.4 m	–	–	Van der Meulen & Zagwijn (1974)
Scharwoude	?	1	–	–	TC5	Zagwijn (1975)
De Meern	5.0 m?	2	–	–	–	Zagwijn (1975)
Dongen	18.0 m?	Appr. 10	–	Eburonian	–	Zagwijn (1975)
De Banken	?	?	–	Eburonian	–	Zagwijn (1975)

TC6 is recognised from the upper section of the composite pollen diagram of Russel–Tiglia–Egypte with an upper boundary in the Eburonian and a lower boundary in TC5. This is the type locality for TC6, and to date also the only locality where TC6 has been recognised in enough detail to allow independent validation.

At Brielle a coarsely sampled section of 90 m, with 14 pollen spectra was attributed to TC3–TC6, without a clear separation between them. Upper and lower conformable boundaries are missing. The section covers a change of sediments from marine (lower part) to continental origin (upper part). The suggested upper boundary with the Eburonian is considered problematic, since no pollen assemblage of cold climate was found. The material from Scharwoude, De Banken, Dongen and De Meern has never been published in sufficient detail to allow independent validation.

Eburonian

Locality	Section	#	Avg. dist.	Upper	Lower	Reference
Veghel	6 m	3	2.0 m	–	–	Zagwijn (1957, 1960)
Veghel	2 m	3	0.7 m	Waalian	–	Zagwijn (1957, 1960)
Meinweg GB3431	–	1	–	–	–	Zagwijn (1960)
Meinweg GB3416	–	1	–	–	–	Zagwijn (1960)
Zaltbommel 550/35	10 m	5	2.0 m	Waalian	–	Zagwijn (1960)
Venlo 713/29	6 m	1	–	Sterksel F.	(Tiglian)	Zagwijn (1960)
Russel–Tiglia–Egypte	0.6 m	10	0.1 m	–	Tiglian TC6	Zagwijn (1963)
De Banken	?	–	–	–	Tiglian TC5/6	Zagwijn (1975)
Leerdam	?	2	–	–	Tiglian TC5	Zagwijn (1975)
Dongen	?	2	–	–	Tiglian TC6	Zagwijn (1975)
Leerdam 38H – 95 bis	–	2	–	–	–	Zagwijn & De Jong (1985)
Leerdam 38H – 95 bis	–	2	–	–	–	Zagwijn & De Jong (1985)
Veldhoven 51D – 141	9.5 m	13	0.7 m	–	–	Zagwijn (1960)
Son 51B – 58	14 m	3	4.7 m	–	–	Zagwijn & De Jong (1985)
Eindhoven I, EBI		2		EBII	Tiglian TC5	Zagwijn (1963)
Eindhoven I, EBII		3		EBIII	EBI	Zagwijn (1963)
Eindhoven I, EBIII		1		EBIV	EBII	Zagwijn (1963)
Eindhoven I, EBIV	32.0 m	3	1.8 m	EBV	EBIII	Zagwijn (1963)
Eindhoven I, EBV		3		EBVI	EBIV	Zagwijn (1963)
Eindhoven I, EBVI		3		EBVII	EBV	Zagwijn (1963)
Eindhoven I, EBVII		3		Waalian	EBVI	Zagwijn (1963)
Eindhoven II	12 m	4	3.0 m	Waalian	Tiglian TC5	Zagwijn (1963)
Herkenbosch 747/25	26 m	6	4.3 m	–	–	Zagwijn (1960)
Herten 746/75	20 m	8	2.5 m	Waalian	Tiglian	Zagwijn (1960)

The Eburonian is identified as a glacial and its floral assemblage lacks characteristic marker species (Zagwijn, 1957, 1960). It is therefore impossible to recognise the Eburonian without the presence of conformable upper and lower boundaries with the following and preceding interglacials, provided these interglacials have floral markers to allow objective and positive identification.

Three spectra from Veghel, with an average sampling interval of approximately two meters were attributed to the Eburonian by Zagwijn (1957, 1960). Since the position of the Waalian stage is now considered erroneous (since it could also be attributed to the Bavelian) it is uncertain if the three spectra of Veghel are indeed of Eburonian age.

Two isolated pollen spectra, from different cores at Meinweg, are pictured in one pollen diagram (Zagwijn, 1960) and are both attributed to the Eburonian. The lack of upper or lower boundaries of different stages with a distinctive pollen assemblage makes it impossible to attribute these two spectra to a specific glacial period.

Five spectra, with an average sampling interval of approximately two meters were found at Zaltbommel (550/35) and attributed to the Eburonian by Zagwijn (1960). The overlying Waalian is capped by the Sterksel Formation, now suggesting an alternative position in the Bavelian (Leerdam interglacial). This could position the Eburonian pollen spectra as a cold or dry period in the Bavelian. The pollen diagram of Zaltbommel 550/33 combines chronostratigraphic data and lithological data (Zagwijn, 1960: Plate XV).

From Venlo one spectrum is known, in a layer that was identified as the Tegelen Clay (Zagwijn, 1960). No upper boundary is known. A spectrum five meters lower was identified as Tiglian. The section is capped by the Sterksel Formation. No clear conformable boundaries with identified interglacial stages have thus been established.

The pit Russel–Tiglia–Egypte was sampled in detail. The resulting pollen diagram is a composite diagram in which the upper section yielded spectra attributed to Tiglian TC6 and Eburonian (Zagwijn, 1963). An upper boundary was not established. Because of the origin of the sediment it seems questionable that this sequence spans almost all of Tiglian substage C and the first half of the Eburonian.

While pollen spectra from the Banken, Leerdam and Dongen were attributed to the Eburonian (Zagwijn, 1975), no detailed information is available on these pollen diagrams, making them impossible to evaluate. In Leerdam 38H–95 bis four spectra were attributed to the Eburonian (Zagwijn & De Jong, 1985). No upper or lower boundaries were established.

In Veldhoven 51D–141 a total of 13 spectra over a core length of 9.5 m were attributed to the Eburonian (Zagwijn & De Jong, 1985). Upper and lower conformable boundaries are missing, a gap of more than 10 m separates the spectra from pollen spectra that were attributed to the Waalian.

In Son 51B–58 three spectra over a core length of approximately 14 m were attributed to the Eburonian (Zagwijn & De Jong, 1985). No upper or lower conformable boundaries were established.

Eindhoven I could be considered the stratotype of the Eburonian, since this locality appeared to show the full sequence of the Eburonian, as well as most of the Tiglian and the Waalian. A total of 18 spectra over a length of approximately 32 m were attributed to the Eburonian by Zagwijn (1963). This author subdivides the Eburonian into seven different sections (EBI–EBVII). Three of these sections were defined (Zagwijn, 1963) in some detail. EBI through EBIII were recognised from the Tegelen Clay.

Each Eburonian substage was recognised through an extremely limited number of pollen spectra, never more than three. These spectra were or coarsely and irregularly sampled along the length of the core section attributed to the Eburonian. According to recent interpretations high *Tsuga* values in the section attributed to Waalian substage C could indicate a Bavelian age, also questioning the correctness of the attribution of this pollen section to the Eburonian.

At Eindhoven II the Eburonian was recognised from a section of 12 m on the basis of four pollen spectra. Within this section no pollen spectra were available over a length of seven meters. The upper section of the Eburonian showed a very suggestive change in pollen assemblage although this upper section only consisted of a single pollen spectrum. The same holds true for the lower section of the Eburonian. Borderline changes pictured in the published pollen diagrams were apparently not based on pollen counts.

In Herkenbosch 747/25 6 spectra over a distance of 26 m were attributed to the Eburonian (Zagwijn, 1960). A possible upper boundary was established through one pollen spectrum, attributed to the Waalian, subsequent spectra were attributed to the Menapian glacial. Thus the upper boundary is now considered uncertain. The lower boundary was formed by spectra attributed to the Pretiglian. This in turn was probably determined based on the presence of a high percentage of 'Tertiary' pollen below it.

In a boring in Herten 746/75 a total of eight pollen spectra, over a length of 20 m, were attributed to the Eburonian (Zagwijn, 1960). A single spectrum attributed to the Tiglian constitutes the lower boundary while a single spectrum attributed to the Waalian is considered the upper boundary. Both upper as well as the lower boundary are considered here very poorly established, leaving ample room for doubt whether Tiglian and Waalian were indeed identified.

Sampling was again coarse and the upper and lower boundaries poorly established, casting doubt with respect to the nature of the period in between. The extreme variations in the pollen assemblage over short distances raise questions with respect to possibility of changes having been missed due to coarse sampling.

Waalian

Locality	Section	#	Avg. dist.	Upper	Lower	Reference
Veghel	5 m	4	1.3 m	Menapian	Eburonian	Zagwijn (1957, 1960)
Meinweg GB3438	1 m	2	–	–	–	Zagwijn (1960)
Brielle 37D – 134	10 m	5	2.0 m	–	–	Van der Meulen & Zagwijn (1974)
Zaltbommel 550/35	20 m	7	2.9 m	Sterksel F.	Eburonian	Zagwijn (1960)
Veldhoven 51D – 141	3 m	7	0.4 m	–	–	Zagwijn (1960)
Leerdam 38H – 95 bis	12 m	?	–	–	–	Zagwijn & De Jong (1985)
Son 51B – 58	–	1	–	–	–	Zagwijn & De Jong (1985)
Veldhuizen	23 m	10	2.3 m	Sterksel F.	–	Zagwijn & De Jong (1985)
Eindhoven I	16.0 m	12	1.3 m	–	Eburonian	Zagwijn (1963)
Eindhoven II	10.0 m	3	3.3 m	Menapian	Eburonian	Zagwijn (1963)
Dordrecht 38C/384 bis	–	–	–	–	–	Zagwijn *et al.* (1971)
Herkenbosch 747/25	–	1	–	Menapian	–	Zagwijn (1960)
Herten 746/75	–	1	–	–	–	Zagwijn (1960)
Kurstjens	0.4 m	8	0.05 m	–	–	Kortenbout van der Sluis & Zagwijn (1962)

In Veghel four spectra were attributed to the Waalian with conformable upper and lower boundaries with Menapian and Eburonian. The spectra attributed to the Waalian show a relatively high percentage of *Tsuga*, later considered to be a marker of the Bavel interglacial of the Bavelian stage (Zagwijn & De Jong, 1985). However, the Veghel sequence was never re–evaluated. Because upper and lower boundaries are glacial stages (without distinctive floral markers) this is without value. The position of this segment of the Veghel sequence is thus unclear. The pollen diagram of Veghel combines chronostratigraphic stages with lithostratigraphic Formations.

At Meinweg GB3438 two spectra were attributed to the Waalian. In Brielle 37D–134 a total of five spectra over a segment length of 10 m was attributed to the Waalian substage A (Van der Meulen & Zagwijn, 1974). Upper and lower conformable boundaries are missing. A lower boundary with the Eburonian is considered problematic since no pollen assemblage indicating a cold climate was found. The section without pollen spectra, tentatively attributed to the Eburonian by Van der Meulen & Zagwijn (1974) is located in the Kedichem formation. Weerts *et al.* (2000) have proposed the Formation of Waalre, combining the Tegelen and Kedichem Formations. This adds uncertainty to the attribution to the Waalian of the upper part of the section lacking pollen. An alternative explanation is to attribute this section to the Tiglian.

In Zaltbommel 550/35 seven pollen spectra over a length of more than 20 m were attributed to the Waalian (Zagwijn, 1960) and considered to be the stratotype for this stage. The Eburonian was recognised at the lower level while the Sterksel Formation starts just above the last pollen spectrum attributed to the Waalian.

In Veldhoven 51D–141 seven pollen spectra over a distance of three meters were attributed to the Waalian by Zagwijn & De Jong (1985). Conformable upper and lower boundaries are missing since both show a gap of approximately 15 m without pollen spectra.

In Leerdam 38H–95 bis pollen spectra over a length of 12 m were attributed to the Waalian by Zagwijn & De Jong (1985). The authors considered the Leerdam sequence to be in perfect correlation with the stratotype at Zaltbommel. Considering the large difference in the number of pollen spectra and the difference in sampling interval, this seems to be a rather unsupported conclusion.

In Son 51B–58 one pollen spectrum was attributed to the Waalian (Zagwijn & De Jong, 1985). No upper or lower boundaries are recognised. A gap of more than six meters without pollen spectra exists on either side.

In Veldhuizen 10 pollen spectra over a core length of approximately 23 m were attributed to the Waalian (Zagwijn, 1957, 1960). The original pollen diagram of Veldhuizen was published by Doppert & Zonneveld (1955). Zagwijn (1957) attributed it to the Waalian and recognised a cool oscillation (Waalian B), resulting in a division of the Waalian into three substages, Waalian A through Waalian C. The Veldhuizen sequence was sampled in some detail in the substages attributed to Waalian A and B and very coarsely in the section attributed to Waalian C. The Veldhuizen sequence further lacks upper and lower boundaries. The substage attributed to Waalian A shows a high percentage (over 15% at its peak value) of *Carya, Pterocarya* and *Tsuga* (the individual percentage of *Tsuga* is not given). According to current interpretations an allocation to the Bavelian cannot be excluded on the basis of this information.

At Eindhoven I a section of 16 m was attributed to the Waalian. The section was thought to depict the three substages, Waalian A–Waalian C, with Waalian B recognised on the basis of three pollen samples. The section was coarsely sampled and lacked a conformable upper boundary. A relatively high percentage of *Tsuga* pollen in part of the section attributed to Waalian C could also indicate Bavelian.

At Eindhoven II the Waalian was recognised from a section of 10 m on the basis of three pollen spectra. As with the Eburonian, the published pollen diagram suggests changes in pollen assemblage that are apparently not substantiated by the published pollen counts.

In Dordrecht 38C/384 bis the Waalian was recognised below layers attributed to the Cromerian Interglacial I. In between these sections a disconformity is present (Zagwijn *et al*., 1971). The part recognised as Waalian lacks upper and lower boundaries, making it impossible to attribute with certainty to this stage.

In Herkenbosch 747/25 a single pollen spectrum was attributed to the Waalian (Zagwijn, 1960), marking a transition to the Menapian above it. No lower boundary is present, the Eburonian is recognised approximately seven meters below. The Herkenbosch core has very coarse sampling along its length. The Herkenbosch pollen diagram (Zagwijn, 1960: Plate VI) depicts the Pretiglian, Eburonian and Menapian glacial stages, the latter two are separated by a single pollen spectrum attributed to the Waalian.

In Herten 746/75 a single pollen spectrum was attributed to the Waalian (Zagwijn, 1960), marking the transition from the Eburonian (two pollen spectra) immediately below it. As already discussed with the Eburonian evaluation, the coarse sampling at Herten makes it impossible to check the validity of the determination. The Waalian section has no conformable upper boundary. The Menapian is recognised five meters higher in the sequence.

In the pit Kurstjens a sequence of 40 cm is assigned to the Waalian (Kortenbout van der Sluis & Zagwijn, 1962). Since conformable boundaries with Eburonian and Menapian are lacking it is impossible to confirm this statement. The authors combine the sequence of Russel–Tiglia–Egypte and pit Kurstjens into one pollen diagram, suggesting a continuity from Tiglian TC until the Menapian which is non–existent in the field.

Menapian

Locality	Section	#	Avg. dist.	Upper	Lower	Literature
Veghel	± 4 m	2	–	Cromerian	–	Zagwijn (1957, 1960)
Veghel	2 m	2	–	–	Waalian	Zagwijn (1957, 1960)
Eindhoven II	7.0 m	9	0.8 m	–	Waalian	Zagwijn (1963)
Son 51B–58	–	1	–	–	–	Zagwijn & De Jong (1985)
Waardenburg 39C/106	7 m	± 10	± 0.7 m	–	–	Zagwijn *et al*. (1971)
Herkenbosch 747/25	60 m	7	8.6 m	Cromerian	Waalian	Zagwijn (1960)
Herten 746/75	65 m	9	7.2 m	Sterksel F.	–	Zagwijn (1960)
Bavel I	0.3 m	3	0.1 m	–	–	Zagwijn & De Jong (1985)

The Menapian is identified as a glacial and its floral assemblage lacks characteristic marker species (Zagwijn, 1957, 1960). It is therefore impossible to recognise the Menapian without the presence of conformable upper and lower boundaries with the following and preceding interglacials, provided these interglacials have floral markers to allow objective and positive identification.

At Veghel four pollen spectra were attributed to the Menapian. These spectra are widely separated from one another and originated from different borings (figure 9).

At Eindhoven II the Menapian was recognised from a section that was relatively finely sampled and yielded one of the most detailed accounts. While the Menapian seems to be capped by another stage, based on the published pollen diagram, no name was attributed to this stage. Zagwijn & De Jong (1985) published a figure (figure 8) with a lithostratigraphy of cores in which the Bavelian was recognised, showing the Bavelian in the Eindhoven II core just above the Menapian. This attribution to the Bavelian was only shown in the figure, and not discussed in the text.

At Son 51B–58 a single and isolated pollen spectrum was attributed to the Menapian, most probably in view of the recognition of the Bavelian above and the Waalian below this spectrum. Both the Bavelian as well as the Waalian stage are recognised at a vertical distance from the proposed Menapian spectrum of between eight to 10 m, making it difficult to ascertain the validity of the determination.

The Menapian stage recognised in the Waardenburg 39C/106 core was later attributed to the Dorst glacial substage of the Bavelian (Zagwijn & De Jong, 1985) and will be dealt with in the Bavelian section. At Herkenbosch a very coarsely sampled sequence was interpreted as having a lower boundary attributed to the Waalian (one pollen sample) and ending in the Sterksel Formation (Zagwijn, 1960). The sampling frequency was considered here to be too coarse to allow samples to be attributed to a single stage.

At Herten (figure 6) a very coarsely sampled sequence was described with an upper boundary in the Sterksel Formation (Zagwijn, 1960). A conformable lower boundary was not identified. The three spectra of Bavel I come from a different locality to that which yielded the pollen spectrum that has been attributed to the Bavelian. While the results were presented in a single pollen diagram, the sections were sampled at different times, at different positions and by different teams. In view of these differences it is proposed here to disregard this section.

Bavelian

Locality	Section	#	Avg. dist.	Upper	Lower	Literature
Bavel I	1.0 m	10	0.1 m	–	–	Zagwijn & De Jong (1985)
Bavel Ia	–	1	–	–	–	Zagwijn & De Jong (1985)
Bavel Ia	10 m	4	2.5 m	–	–	Zagwijn & De Jong (1985)
Bavel II Serie P2	0.9 m	6	0.2 m	–	–	Zagwijn & De Jong (1985)
Bavel II Serie B	0.5 m	6	0.1 m	–	–	Zagwijn & De Jong (1985)
Bavel II Serie A	0.5 m	5	0.1 m	–	–	Zagwijn & De Jong (1985)
Bavel III	0.1 m	2	–	–	–	Zagwijn & De Jong (1985)
Bavel III	0.1 m	3	< 0.1 m	–	–	Zagwijn & De Jong (1985)
Bavel III	0.1 m	2	–	–	–	Zagwijn & De Jong (1985)
Bavel III	0.5 m	11	< 0.1 m	–	–	Zagwijn & De Jong (1985)
Son 51B–58	9 m	2	–	–	–	Zagwijn & De Jong (1985)
Son 51B–58	11 m	3	3.7 m	–	–	Zagwijn & De Jong (1985)
Veldhoven 51D–141	7 m	16	0.4 m	–	–	Zagwijn & De Jong (1985)
Leerdam 38H–93 bis	13 m	22	0.6 m	–	–	Zagwijn & De Jong (1985)
Logtsche Heide 51A–54	1.2 m	5	0.2 m	–	–	Zagwijn & De Jong (1985)
Susterseel–Zelfkant	0.8 m	9	0.1 m	–	–	Zagwijn & De Jong (1985)
Dorst Grube Surea	3.2 m	12	0.3 m	–	–	Zagwijn & De Jong (1985)
Waardenburg 39C/106	7 m	± 10	0.7 m	–	–	Zagwijn *et al.* (1971)

In Bavel I 10 pollen spectra over a length of one meter were attributed to the Bv3b section of the Bavel interglacial. An upper boundary is missing. The lower boundary in the data presented is artificial since the information originates from samples from another locality, collected by another team at a different time. *Tsuga* values vary between approximately 2–9%.

In Bavel Ia a few pollen spectra were taken from two localities. A single pollen spectrum from the north side was attributed to the Linge glacial. Four pollen spectra from the west side, over a length of 10 m were attributed to Bv3b of the Bavel interglacial. *Tsuga* values of the Bv3b section range from approximately 3–15%. Both sequences lack conformable upper and lower boundaries.

The Bavel II locality yielded three separate sections (Serie P2, Serie B, Serie A) that were combined into one pollen diagram. All sections were attributed to the Bavel interglacial:

- P2 yielded six spectra over a length of 90 cm attributed to the Bv4, *Tsuga* values ranged from approximately 4–10%.
- Serie B yielded six spectra over 50 cm that were attributed to Bv3a with *Tsuga* values between 0–1%.
- Serie A yielded five spectra over a length of 50 cm that were attributed to Bv2, with *Tsuga* values between 0–1%.

The combined series lack upper and lower conformable boundaries.

In Bavel III a composite pollen diagram based on four very short sections from different positions was attributed to the Leerdam interglacial (Ld3) and the Linge glacial:

- A section of 11 spectra over a length of 50 cm was attributed to Ld3.
- A section of two spectra over 10 cm was attributed to the Linge glacial.
- A section of three spectra over 10 cm was attributed to the Linge glacial.
- A section of two spectra over 10 cm was attributed to the Linge glacial.

The combined series lack upper and lower conformable boundaries.

In Son 51B–58 five spectra over a distance of more than 30 m were attributed to the Linge glacial and Bavel interglacial periods of the Bavelian by Zagwijn & De Jong (1985). The two pollen spectra of the Bavel interglacial yielded appoximately 17% and 30% of *Tsuga* pollen. Upper and lower conformable boundaries are lacking, six meters below the Bavelian spectra is a single spectrum that was attributed to the Menapian (Zagwijn & De Jong, 1985).

In Veldhoven 51D–141 a total of 16 pollen spectra over a length of seven meters were attributed to the Bavel interglacial of the Bavelian (Zagwijn & De Jong, 1985), more specifically the Bv1, Bv3b and Bv5 sections of this interglacial. The sequence lacks upper and lower boundaries.

In Leerdam 38H–93 bis 22 spectra over a length of 13 m were attributed to the Bavelian (Zagwijn & De Jong, 1985). The sequence lacks upper and lower boundaries. The Waalian was recognised three meters below the first spectrum attributed to the Bavelian. The Sterksel Formation was recognised on top of the section attributed to the Bavelian, with one isolated spectrum attributed to an interglacial.

In Logtsche Heide 51A–54 five pollen samples over a length of just over one meter were attributed to the B4 section of the Bavel interglacial. It shows values of *Tsuga* between 5-15%. The sequence lacks upper and lower boundaries.

In Süsterseel–Zelfkant nine pollen spectra over a distance of 80 cm were attributed to the Bv3–Bv5 sections of the Bavel Interglacial (Zagwijn & De Jong, 1985). The sequence lacks upper and lower boundaries. *Tsuga* values range from 0–10%.

In the Dorst Grube Surea 12 pollen spectra over a core length of 3.2 m were attributed to the Leerdam interglacial (section Ld3) and the Dorst glacial. *Tsuga* values ranged from 0–1%. The sequence lacks upper and lower boundaries.

At Waardenburg 39C/106 a section that was originally attributed to the Menapian stage (Zagwijn *et al.*, 1971) has been re–assigned to the Bavelian (Zagwijn & De Jong, 1985). The sequence lacks an upper and lower boundary. Eight meters above the Bavelian section Interglacial I of the Cromerian stage was recognised (Zagwijn *et al.*, 1971).

Appendix II. Palaeomagnetic results

	Date		Depth (m)			
Site	**Upper**	**Lower**	**Upper**	**Lower**	**Ref.**	**Magn.**
Core Waardenburg 39C/106	Glacial B	Menapian	20.70	60.00	2	
Core Dordrecht 38C/184	Glacial A	Waalian A	29.00	54.20	2	Reversed
Core Leerdam 38H/95	Menapian	Iceanian (marine)	55.00	138.75	1	Reversed
Core Rijswijk 30G/320	Eemian	Iceanian (marine)	36.87	98.62	1	Reversed
Core Meinweg 58G/71	Eburonian	Reuverian B	49.00	54.80	1	Reversed
Pit Süsterseel	Probably Menapian		4.00	11.30	1	Reversed
Pit Dorst	Upper Waalian, part of Waalian C		0.10	1.60	1	Normal
Pit Bavel	Upper Waalian, part of Waalian C		1.60	7.50	1	Normal
Pit de Toekomst	Waalian	Eburonian	0.90	4.70	5	Normal
Pit Sint Fransiscus	Waalian	Eburonian	0.10	4.00	5	Reversed
Pit Maalbeek	Lower Eburonian		4.50	6.30	6	Reversed
Pit Kurstjens	Boundary Eburonian – Tiglian		0.10	2.60	7	Normal
Pit Wambach	Boundary Eburonian – Tiglian		0.20	2.00	7	Normal
Pit Laumans	Boundary Eburonian – Tiglian		0.20	2.00	7	Normal
Pit Chaamse Bossen	Lower Pleistocene, probably Tiglian		2.00	2.30	1	Normal
Pit Öbel	Tiglian C		0.40	1.40	1	Normal
Pit de Toekomst	Tiglian		3.60	7.50	5	Reversed
Pit Sint Fransiscus	Tiglian		4.00	5.00	5	Reversed
Pit Egypte	Tiglian TC4a, b	Tiglian TC3	3.00	7.70	6	Normal
Pit van Cleef	Tiglian A		1.50	3.30	1	Normal
Pit Mols	Probably boundary Reuverian–Pretiglian		1.50	5.00	1	Reversed
Pit Coumans & Schepers	Upper part of Reuverian		3.50	3.70	8	Normal
Pit Reuver	Reuverian		4.50	6.50	1	Normal
Pit van Eyck	Upper part of Reuverian B		0.30	1.80	1	Normal
Pit Janssen–Dings	Reuverian B		1.2		8	Normal
Pit Öbel	Reuverian B		10.00	14.50	9	Normal

Reference:
1 = Zagwijn (personal communication)
2 = Zagwijn *et al.* (1971)
3 = De Ridder & Zagwijn (1962)
4 = Zagwijn & Zonneveld (1956)
5 = Paepe (1970)
6 = Zagwijn (1963)
7 = Kortenbout van der Sluis & Zagwijn (1962)
8 = Zagwijn (1963)
9 = Boenigk (1970)

Core Waardenburg 39C/106. The core between 53.8–60.0 m was attributed to the Menapian (Zagwijn *et al.,* 1971). The clayish part of the core was sampled at intervals not exceeding 50 cm. The section between 59 and 60 m below surface shows reversed polarization (four accepted measurements). Zagwijn & de Jong (1985) attributed this section to the Bavelian.

Core Dordrecht 38C/184. The core between 47.17–48.10 was attributed to Waalian C, between 48.10–48.50 to Waalian B (probably), between 50.40–50.85 to Waalian B and between 50.85–54.20 to Waalian A (Zagwijn *et al.*, 1971). The clay parts of the core were sampled at intervals not exceeding 50 cm.

Just above the Waalian C segment a stratigraphic hiatus exists, possibly influencing the palaeomagnetic orientation of the samples. Just below the hiatus multiple measurements (three samples) showing normal magnetization, further down the samples show reversed magnetization (three samples). The section attributed to (probably) Waalian B shows predominantly normal magnetization while the section attributed to Waalian A shows predominantly reversed magnetization. Due to their close proximity to the stratigraphic hiatus it seems prudent to ignore the measurements attributed to the Waalian C.

Core Leerdam 38H/95. The core between 55–67.8 m was attributed to the Menapian, between 71.75–74.15 m to Waalian C, between 74.15–78.4 m to Waalian B and between 78.4–83.2 m to Waalian A by Zagwijn in a personal communication to Van Montfrans. Zagwijn & De Jong (1985) changed the Menapian to the Bavelian. All palaeomagnetic measurements show reversed magnetization with the exception of two of normal polarization at 72 m.

Core Rijswijk 30G/320. The core between 36.87–71.30 m was attributed to Waalian (A?) by Zagwijn in a personal communication to Van Montfrans. Reversed polarity dominates, although normal polarity was found at

53 m. It is unclear if this core is still considered Waalian or should be attributed to the Bavelian. Since a pollen spectrum was never published it is impossible to validate the original attribution.

Core Meinweg 58G/71. This was taken close to the Meinweg borehole GB 3438 (Zagwijn, 1960, 1963). The section above 49.0 m was attributed to the Eburonian by Zagwijn in a personal communication to Van Montfrans. Reversed polarity was accepted between 29 m and 31 m below the surface (three measurements).

Core Rijswijk (Zagwijn, personal communication to Van Montfrans) yielded four reversed samples and one normal sample from Tiglian, younger than TC4 covering 12 m in length. Pit Süsterseel. Loess bed of 7.3 m. Attributed to the Menapian by Zagwijn in a personal communication to Van Montfrans. Of the 18 measurements 10 were rejected. The other eight show reversed polarity (six) and normal polarity. The middle section seems to be of reversed polarity.

Pit Dorst. A clay bed of which the upper 1.5 m was exposed. A total of five measurements showed normal polarity. Originally attributed to the upper part of the Waalian (uppermost part of Waalian C), this locality was later attributed to the Bavelian (Zagwijn & De Jong, 1985). The short sequence and the lack of a published pollen diagram or lithological data make it impossible to compare the results of this palaeomagnetic study. A total of six palaeomagnetic measurements were taken, all of normal polarity.

Pit Bavel. A clay bed from 1.6–7.5 m below surface. Originally attributed to the upper part of the Waalian (uppermost part of Waalian C), this locality was later attributed to the Bavelian (Zagwijn & De Jong, 1985). Of a total of 22 approved measurements, all but one showed normal polarity. The lack of a published pollen diagram or lithological data makes it impossible to compare the results of these determinations.

Pit de Toekomst (Paepe, 1970). At this pit both the Turnhout Clay and Rijkevorsel Clay are recognised. Palynological results of the Turnhout clay are not characteristic, but the author assumes a Waalian age because it lies above a sand layer with cryoturbatic features. No palynological results are published from the Rijkevorsel Clay.

A total of six palaeomagnetic measurements were taken from the Turnhout Clay, only the upper three were accepted, all showing normal polarity. This section was also showing cryoturbatic features, clearly introducing a risk with respect to the reliability of these measurements.

A second clay bed with peaty intercalations of 2.9 m was exposed. According to Van Montfrans this clay bed was attributed to the Eburonian by Paepe (1970). However, Paepe (1970) attributed the second clay bed to the Rijkevorsel Clay, without any reference as to the chronostratigraphy. A total of eight measurements were accepted, showing normal magnetization in its upper part and reversed magnetization in its lower part.

Pit Sint Franciscus showed two exposed clay layers:

- The upper layer (Turnhout Clay) was attributed to the Waalian based on a single pollen spectrum containing *Carya, Pterocarya* and *Tsuga* and the absence of *Azolla tegeliensis* (Paepe, 1970). There was cryoturbation in upper part. Seven palaeomagnetic measurements from the lower part were accepted, all showing reversed polarity.
- The lower layer (Rijkevorsel Clay) was attributed to the Tiglian on the basis of a single pollen spectrum containing Azolla tegeliensis (Paepe, 1970). The clay bed was one m in thickness, yielding three valid measurements, all of reversed polarity.

Pit Chaamse Bossen showed of a clay bed of 30 cm (three valid palaeomagnetic measurements), which was attributed an Early Pleistocene age, probably Tiglian, based on a personal comment of Zagwijn to Van Montfrans. Lack of pollen sequence and a clear stratigraphic position makes it impossible to confirm this.

Pit Kurstjens (Kortenbout van der Sluis & Zagwijn, 1962) is a clay bed of 2.5 m placed by the authors on the boundary of Tiglian and Eburonian and shows normal polarity (11 accepted measurements). The assigned stages are considered questionable. The sequence of Pit Kurstjens only yielded pollen samples over a distance of 40 cm, these were assigned to the Waalian. No pollen samples were assigned to the Eburonian. However, by combining the sequences of pit Kurstjens and Pit Russel–Tiglia–Egypte, Kortenbout van der Sluis & Zagwijn (1962) implied that the lower boundary of the Kurstjens sequence could be correlated with the upper boundary of the Russel–Tiglia–Egypte sequence. This enabled the authors to assign a Tiglian–Eburonian boundary to the lower part of the Kurstjens sequence.

Pit Wambach (Kortenbout van der Sluis & Zagwijn, 1962) consisting of a clay bed of 1.8 m placed by the authors on the boundary of Tiglian and Eburonian and shows normal polarity (four accepted measurements). Pit Laumans (Kortenbout van der Sluis & Zagwijn, 1962) is a clay bed of approximately two meters yielding 16 valid measurements placed by the authors on the boundary of Tiglian and Eburonian. Fourteen out of 16 measurements show normal and two show reversed polarity.

Pit Öbel (Zagwijn, 1963) is dated Tiglian C. A clay, locally humid, bed of one meter yielding six valid measurements, all with normal polarity. Pit Egypte (Zagwijn, 1963), Tiglian C3–TC4 a, b. Clay bed of 4.7 m yielded 12 valid samples of normal polarity.

Pit van Cleef (van der Vlerk & Florschütz, 1953): Tiglian A (Zagwijn, personal comment to Van Montfrans). Clay bed of 1.8 m yielding three valid measurements of normal polarity.

Pit Mols, a clay bed of 3.5 m dated to the boundary Reuverian–Pretiglian (Zagwijn, personal comment to Van Montfrans) yielding six valid measurements (three reversed (upper part), three normal (lower part)).

Pit Maalbeek. A clay bed of which 1.8 m is exposed, originally attributed to the Lower Eburonian (EB III) by Zagwijn (1963), but later attributed to Tiglian substage TB by Westerhoff *et al.* (1998). A total of nine measurements all show reversed polarity.

Pit Kurstjens. Clay bed of 2.5 m, attributed to the top of the Tegelen clay (top of the Formation of Tegelen). It was attributed to the Tiglian–Eburonian boundary by Kortenbout van der Sluis & Zagwijn (1962). A total of 11 accepted measurements all show normal polarity.

Pit Wambach. A clay bed of 1.8 m was attributed to the Tiglian–Eburonian boundary by Kortenbout van der Sluis & Zagwijn (1962). Four accepted measurements all yielded normal polarity.

Pit Laumans. A clay bed of 1.4–2.1 m was attributed to the Tiglian–Eburonian boundary by Kortenbout van der Sluis & Zagwijn (1962). Two sections were identified. A central part was considered of slightly older age than the eastern side, but the reasoning behind this was not discussed by Van Montfrans (1971). The lowermost part of the central part is reversed (two measurements), the remainder (14 measurements) show normal polarity.

The palaeomagnetic data from two pits in Belgium (Sint Franciscus and de Toekomst) are considered problematic due to the very limited and inconclusive evidence from the two localities. Apart from a guidebook for an excursion no other publication has presented more specific and detailed information from these localities making it impossible to confirm the interpretations of Paepe (1970).

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