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Early and Middle Pleistocene pollen assemblages of deep core drillings in the northern Upper Rhine Graben, Germany

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Abstract

Recent core drillings, carried out during water-economic exploration in the area of Mannheim/Ludwigshafen/Schifferstadt (Rhine-Neckar region, Germany), have produced a more differentiated stratigraphic division of the Pleistocene sediments of the northern Upper Rhine Graben. Pollen analytical investigations as well as malacological, heavy mineral, palaeomagnetic and lithological research have led to a stratigraphic reinterpretation of the gravel layers and intermediate horizons. Based on the results of the pollen analyses, the Mannheim interglacial period in the upper intermediate horizon (Oberer Zwischenhorizont, OZH) cannot be assigned to the Eemian as stated earlier. The occurrence of *Fagus*, *Celtis* and *Azolla*, along with the results of malacological analyses, indicate a Cromerian age for the Mannheim Interglacial. In addition, a pollen sequence from a different interglacial in the core sediments from Schifferstadt could also be assigned to the Cromerian. The Schifferstadt Interglacial is divided into a lower optimum phase with high values of *Ulmus*, *Quercus* and *Corylus* while *Carpinus* is completely absent, and an upper optimum phase with low values of *Carpinus*. *Fagus* is absent in the whole sequence. The OZH comprises not only the two interglacial pollen sequences described above but also parts of at least four Middle Pleistocene Interglacials. In the lower part of the drillings in Schifferstadt and Ludwigshafen, which are assigned to the Early Pleistocene, pollen assemblages with *Fagus* are likely to correlate with parts of the Tiglian A substage. There is a clear change to a Tertiary type of pollen flora at 91 m at Schifferstadt and at 186 m in Ludwigshafen.

Keywords: Pollen analysis, Early Pleistocene, Middle Pleistocene, Upper Rhine Graben, Germany

Introduction

The Upper Rhine Graben is a zone of tectonic subsidence. Thick layers of sediment have been deposited since the Eocene particularly in the western part of the investigated area, where increased subsidence took place during the Tertiary period. In the Heidelberg/Mannheim area the Pliocene and Pleistocene layers were formed during a younger phase of subsidence of the basal deposits.

The lithogenic-petrographic sequence of Pliocene and Quaternary layers in the study area (Fig. 1) has been intensively investigated, and a stratigraphic division has already been established (Bartz, 1959, 1982; Kärcher, 1987). The Tertiary layers are characterised by silt and clay, whereas the Quaternary deposits comprise gravel, sand and finer grained sediments (silt, clay, organic horizons). The division into lower, middle and upper aquifers (gravel layers, Kieslager) and intermediate layers (Zwischenhorizonte) is based on lithological data. Interdisciplinary studies in the northern part of the Upper Rhine Graben have been described in a special publication (Von Koenigswald, 1988), dealing with the lithological-stratigraphic sequences, as well as the remains of Upper Pleistocene mammals, snails, wood and pollen. Pollen analytical investigations of sediments deposited prior to the Holocene were only possible within the scope of water-economic and raw material explorations. Previous studies were often carried out on isolated, single samples which produced limited evidence (Von der Brelie in: Bartz, 1976, 1982; Hottenrott, 1995). More recently undertaken pollen analytical studies (Schedler, 1981; Küttel et al., 1986; Beug, 1988; Bludau, 1993, 1995; Knipping, 2002, 2004a, 2004b) have led to an increase of knowledge and a differentiated point of view. For example, the study of Steinbach (Schedler, 1981) led to a revision of the former Holsteinian age to a position within the Cromerian

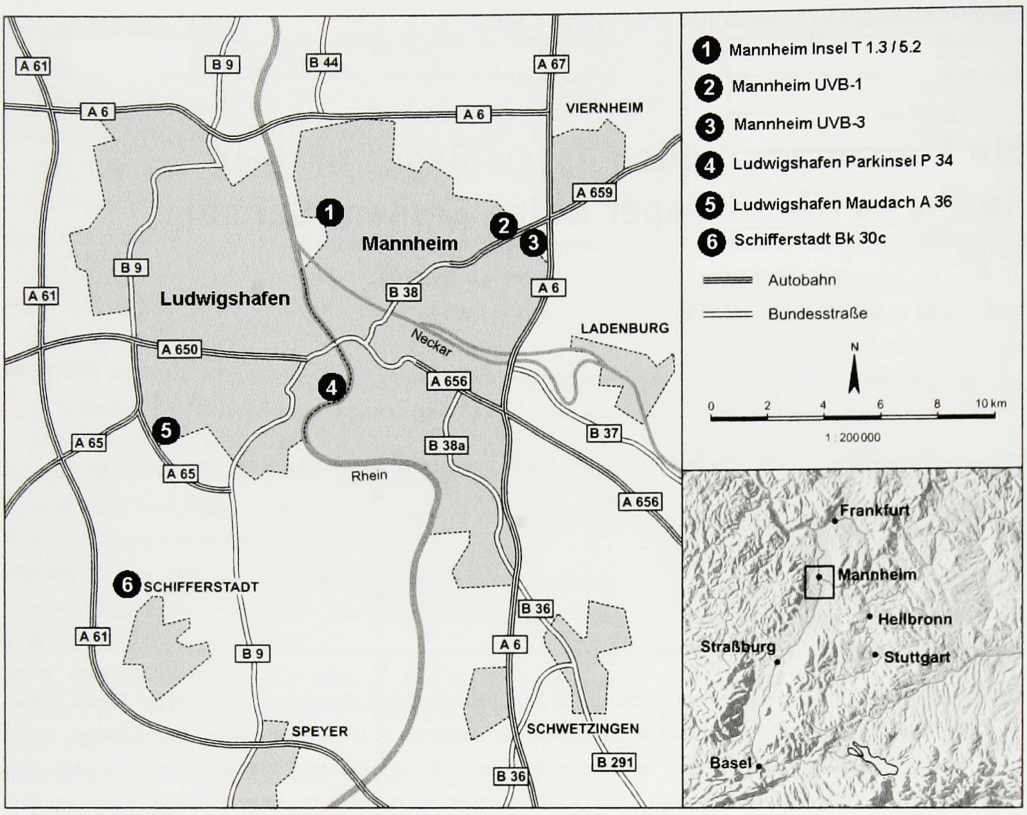

Fig. 1. Location of investigated sites (for geological setting see: Weidenfeller & Kärcher, 2008).

Complex. Bludau (1993, 1995) analysed predominantly Early Pleistocene sediments in the central part of the Upper Rhine Graben, and described three interglacial sequences from Tiglian A to Bavelian. But so far, most of this pollen data has not been published. Isolated pollen assemblages representing boreal forest or phases of open vegetation have been analysed by several authors (Beug, 1988; Bludau, 1993; Knipping, 2002, 2004, unpublished data), but until now a correlation with well-defined sequences has not been possible. From the upper aquifer (OKL) only the pollen sequence of Rösbach with a boreal forest could be dated by ^{14}C to the Würmian (Küttel et al., 1986). Several single samples, indicating mainly boreal conditions, were dated by the U/Th method to between 118Ka and 279Ka (Beug, 1988; Schweiss, 1988). However, the exact stratigraphic position of these samples is uncertain since they were recovered during dredging activities below the groundwater table. Validated pollen sequences representing the Eemian in the Upper Rhine Graben have never been described, although several profiles thought to date to this period have been analysed (Bludau, 1993; Knipping, 2002, 2004a, unpublished data).

Pollen analytical investigations on the fluvial deposits of the Rhine raise many problems. The sequences are frequently incomplete due to discontinuous sedimentation, erosion and reworking of sediments, and the fact that only organic or fine-grained sediments are conducive to the preservation of pollen. In addition, there are uncertainties when comparing the results of pollen analyses from the Upper Rhine Graben with those from northwestern Germany and the Netherlands because of the warmer climate of the Upper Rhine Graben and the near migration way through the Rhone-Rhine system.

In Central Europe long terrestrial pollen sequences comprising several successive warm and cold phases are rare (Menke, 1975; Welten, 1982, 1988; Müller, 1986, 1992; Grüger et al., 1994; Reille & de Beaulieu ,1995; Urban, 1995, 2006). Therefore the deep drillings in the Upper Rhine Graben are of special interest for stratigraphic subdivisions. The current interdisciplinary studies (Hagedorn & Boenigk, 2004, 2008; Weidenfeller & Kärcher, 2004, 2008; Rähle, 2005; Rolf, 2004, 2008) will contribute to a better understanding of the Early and Middle Pleistocene stratigraphy in this area.

Methods

The larger part of the investigated samples is derived from cored drillings. The preparation of the Mannheim samples has been carried out at the University of Hohenheim and the samples from Schifferstadt and Ludwigshafen at the laboratory of LGB Rheinland-Pfalz. Important results are presented in this paper in form of pollen diagrams, which are all depicted in the same manner and show only reduced pollen spectra. The reference sum for calculation includes all terrestrial plants except local elements (such as Cyperaceae, aquatic taxa) and spores. Pollen preservation is widely differentiated and indicates the conditions under which sedimentation took place. Pre-Quaternary taxa and indeterminable types can be used as indicators of redeposited sediment.

Results

Borehole Schifferstadt

Schifferstadt BK 30c GM, core drilling 0 - 200 m, (OZH 5.3 - 49.0 m) (Fig. 1)

The Schifferstadt sequence comprises mainly finely-grained sediments (silt, clay, sand); gravel is rare. The heavy mineral spectra of the upper 6.5 m are of Alpine type, and represent an embankment of the river Rhine. Local, non-calcareous sediments from the Pfälzer Wald are present to a depth of 77 m. Rhine deposits are predominant calcareous and occur between 77 - 91 m. Below 91 m non-calcareous Pliocene Sediments appear (Hagedorn, 2004; Hagedorn & Boenigk, 2008).

S-I-A + B, Schifferstadt Interglacial, 21.82 - 24.14 m (Fig. 2, 8)

The pollen diagram can be divided into 10 local pollen assemblage zones (PZ).

The sequence starts with a typical late-glacial pollen flora (*Juniperus*, *Betula*, *Artemisia*), but the immigration phase of thermophilous taxa is not represented (PZ 1). The interglacial sequence is divided into a lower optimum phase with high values of *Ulmus*, *Quercus* and *Corylus* while *Carpinus* is completely absent (PZ 2, 3), and an upper optimum phase with low values of *Carpinus* (PZ 9, 10). *Fagus* is absent in the whole sequence, and *Celtis* is rare. In pollen assemblage zone 5 reworking of sediment has probably led to the poor preservation of thermophilous taxa, resulting in increases in the amounts of indeterminable pollen and low pollen concentrations. It is uncertain if reworking took place under interglacial or stadial conditions. In the latter case, this sequence may represent two separate interglacials.

S-I-C, Schifferstadt, 36.21 – 36.58 m (Fig 3, 8)

The short sequence within the OZH layers of sandy silt can be divided into two pollen zones. In the lower zone *Betula*, *Pinus*, *Alnus* and *Picea* dominate the arboreal spectrum with low values of thermophilous trees and *Tsuga*. Higher values of *Pinus* and increasing *Tsuga* pollen characterises the upper zone. NAP (non arboreal pollen), mainly of Poaceae and Ericales is frequent in both zones.

S-I-D, Schifferstadt, 51.71 – 52.34 m (Fig. 4, 8)

In contrast to the oceanic phase with *Tsuga* mentioned above, several sections can be detected which indicate continental climate (*Larix*, *Ephedra*, *Artemisia*, Chenopodiaceae). During these phases Ericales and *Tsuga* are rare or absent.

S-I-E Schifferstadt, 80.21 – 84.53 m (Fig. 5, 8)

The sediment in this section consists of mainly clayey, sandy silt alternated with darker layers containing a high organic component derived from redeposited Tertiary material.

The pollen diagram in Figure 5 can be divided into four major zones. The first zone (PZ 1) includes a pollen assemblage of *Pinus*, *Pinus cembra* type, Pliocene taxa, reworked pre-Quaternary taxa and a high amount of indeterminate types. The second zone (PZ 2) comprises high values of *Ulmus* and lower amounts of *Pinus*. The third zone (PZ 3) is characterised by high values of *Picea*, *Picea omorica* type, *Pinus* and *Pinus cembra* type and a regular occurrence of *Fagus*. The upper zone (PZ 4) shows lower values of *Pinus cembra* type, while counts of *Fagus* attain more than 10% in two samples. In the upper two zones, samples apparently containing reworked Tertiary pollen are visible (see arrows in the diagram, Fig. 5). Higher amounts of indeterminate taxa, pre-Quaternary taxa, and few spores of the Pliocene relict *Verrucatosporites* (Menke, 1975) support this assumption. In samples without reworked taxa pollen concentration is low, but preservation is good. Reworked Tertiary pollen is present throughout both of the lower sections. The reworking of older material means that it is difficult to assign the pollen types to autochthonous or allochthonous taxa. In PZ 2 *Ulmus* seems to be autochthonous, as well as *Picea*, *Picea omorica* type, *Pinus*, *Pinus cembra* type, *Fagus*, *Tsuga* and *Eucommia* in PZ 3 and 4.

A Pliocene pollen flora with high values of Tertiary elements is present below 91 m. This stratigraphic position is confirmed by heavy mineral analysis (Hagedorn, 2004).

Boreholes Mannheim

Several sites have been investigated in the Mannheim area (Fig. 1; Knipping, 2004a) and some of the results of these investigations are presented in this paper (Fig. 6, 7).

M-I-A, Mannheim UVB-3, 34.1 m (OKL 0 - 42.5 m) (Fig. 8)

An interglacial pollen assemblage with *Pinus*, *Betula*, *Picea*, *Quercus*, *Carpinus*, *Abies*, *Fagus* and *Buxus* could be determined in a single sample of fine-sandy sediment within the upper gravel layer (OKL). *Pterocarya* pollen is not present in this sample.

M-I-B + C, Mannheim UVB-3, 42.52 - 43.6 m, core drilling (OZH 42.5 m ≥ 43.60 m) (Fig. 6)

The pollen diagram can be subdivided into two zones. In the lower zone (M-I-C, PZ 1) the deposits comprise calcareous, slightly humic silts and in the upper zone (M-I-B, PZ 2) silty humic non-calcareous clays. At 42.98 m intercalated sand and gravel in between the two layers probably indicates a

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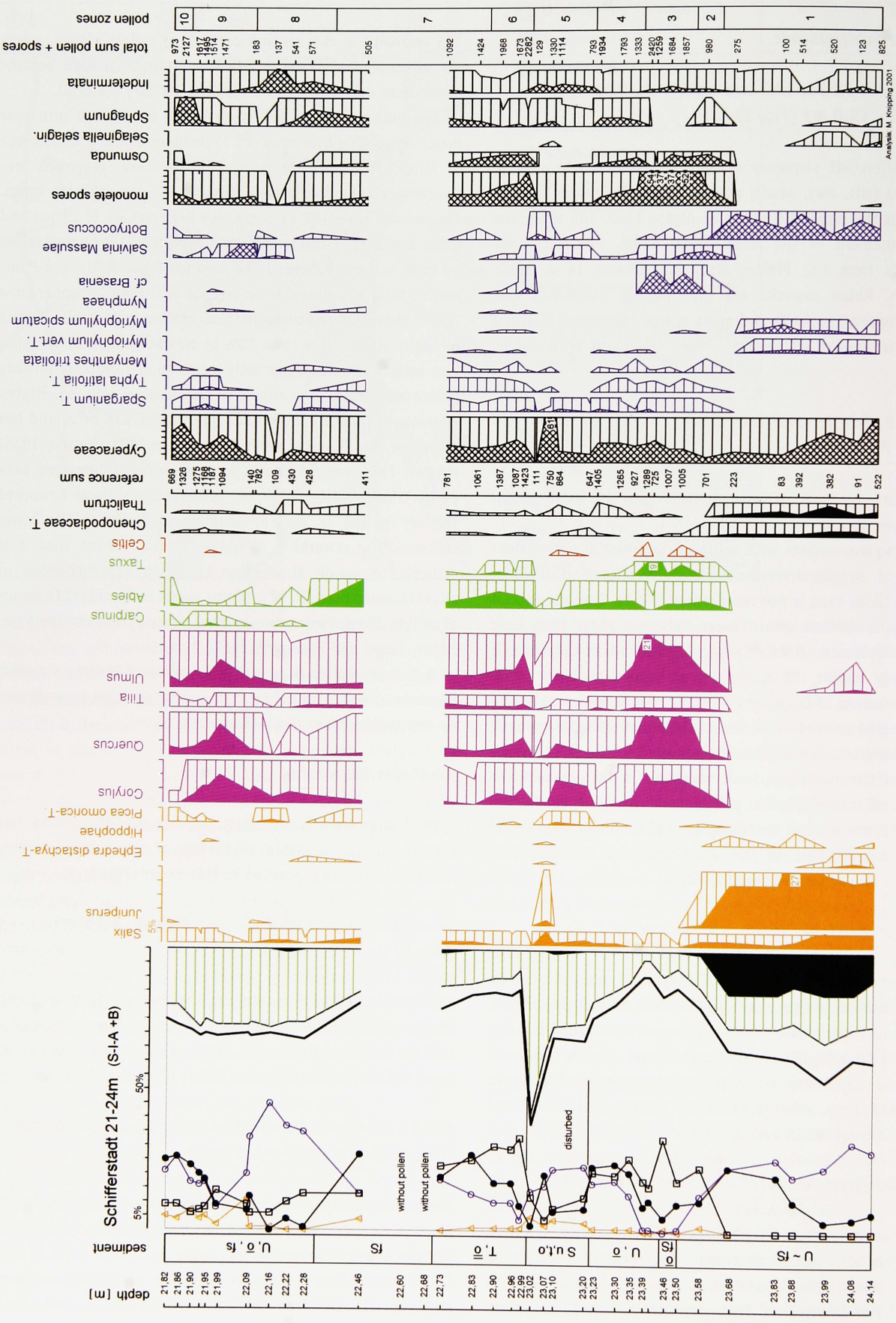

Fig. 2. Simplified pollen diagram of the Schifferstadt Interglacial S-I-A + B; 21.82 - 24.14 m (for legend see Fig. 3).

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discordance in the deposits. The pollen assemblage in PZ 1 is characterised by *Alnus*, *Carpinus*, *Ulmus*, *Corylus*, *Quercus* and *Taxus*. Remarkable are the occurrence of *Vitis* and single grains of *Celtis* and *Tsuga*. Pollen preservation is variable but there is hardly any indication of reworked taxa. The presence of still or sluggish water is indicated throughout the sequence by the occurrence of *Nymphaea*, *Nuphar*, *Potamogeton*, *Brasenia*, *Myriophyllum* and *Azolla*. With the change of sediment the character of the pollen assemblage also changes, as is indicated by the high values of (local) *Alnus*, *Abies* and *Fagus* in PZ 2. *Celtis* is present, single massulae of *Azolla* and Salvinia indicate still eutrophic water and warm summer conditions.

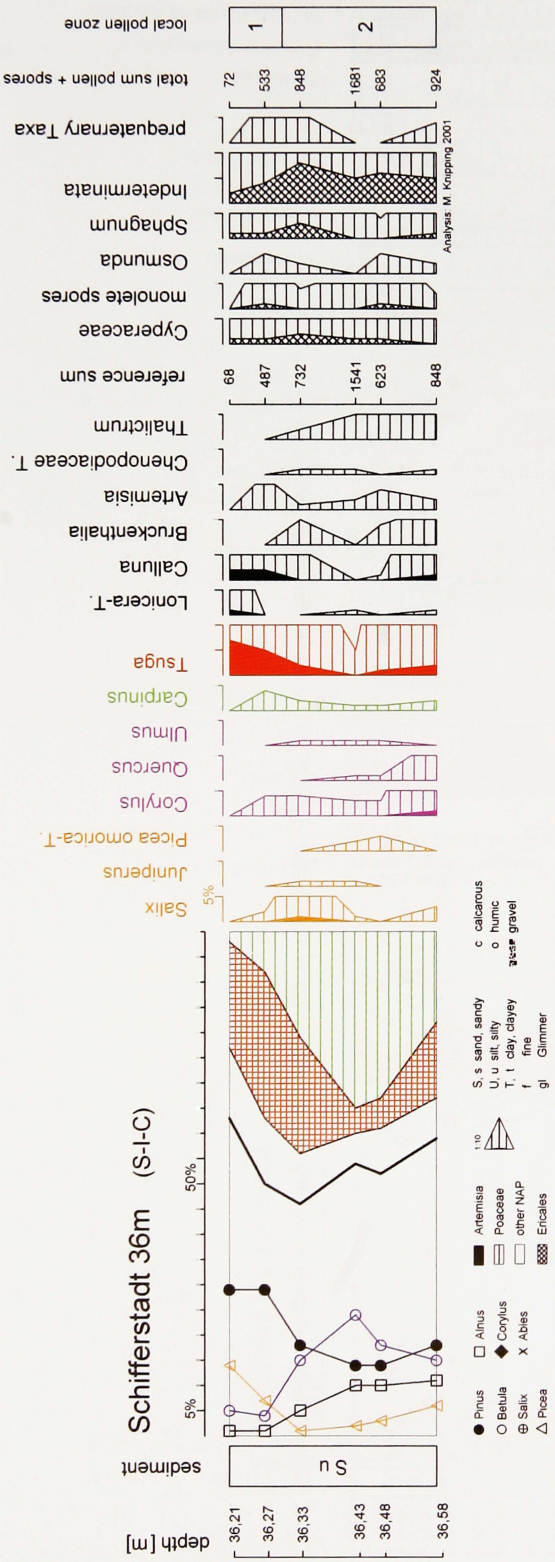

Fig. 3. Pollen sequence of Schifferstadt S-I-C with an oceanic character; 36.21 - 36.58 m.

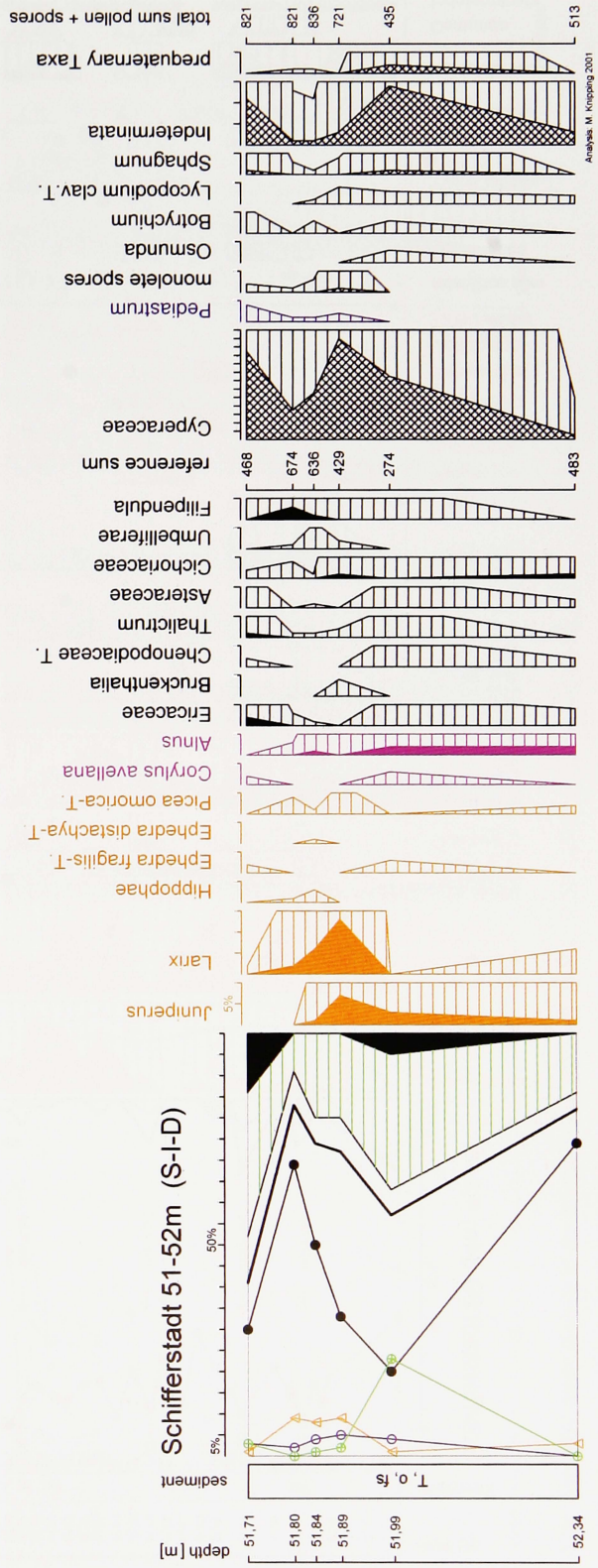

Fig. 4. Pollen sequence from Schifferstadt S-I-D with a continental character; 51.71 - 52.34 m (for legend see Fig. 3).

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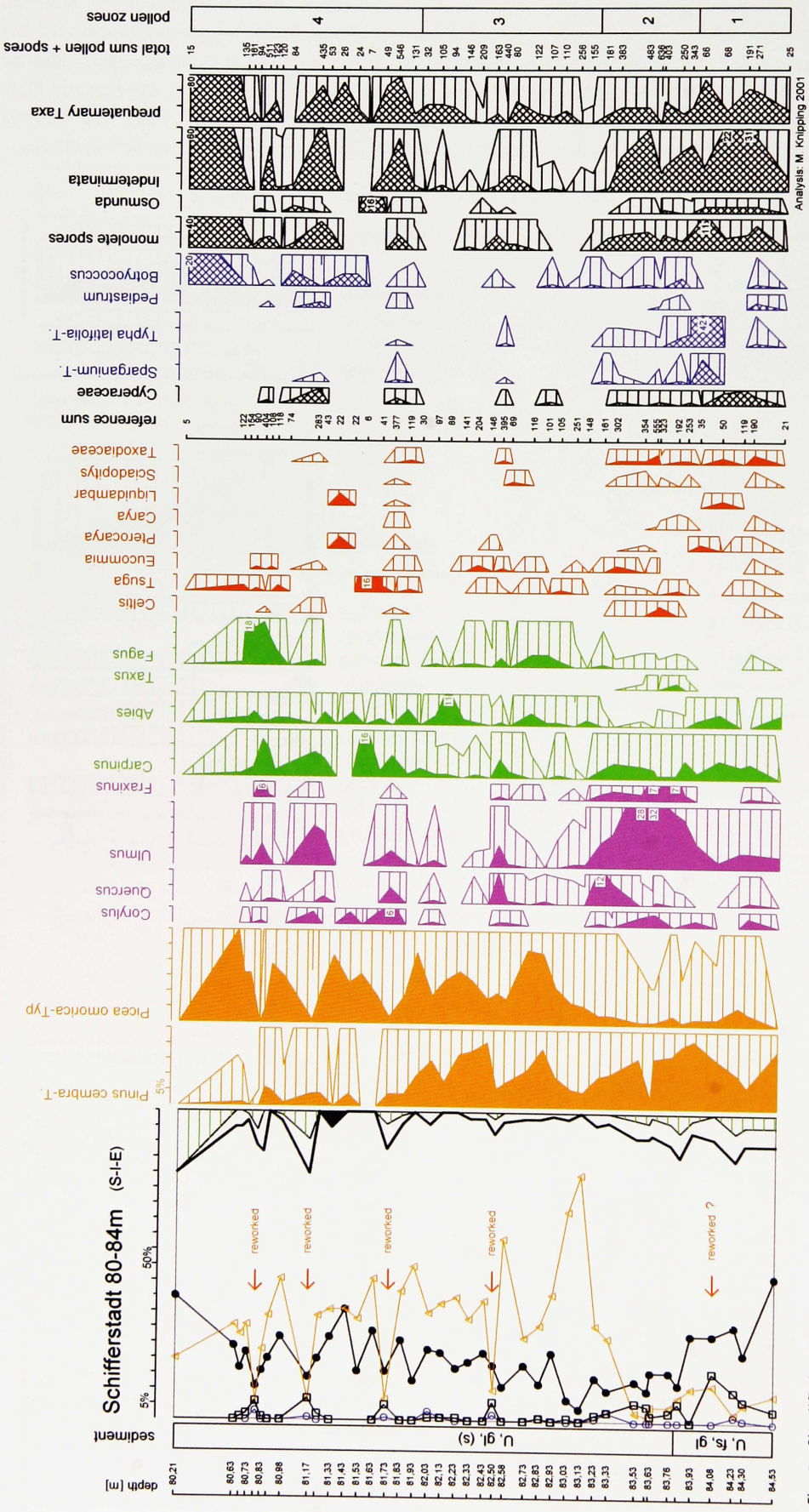

Fig. 5. Simplified pollen diagram of an Early Pleistocene sequence in Schifferstadt, S-I-E; 80.21 - 84.53 m (for legend see Fig. 3).

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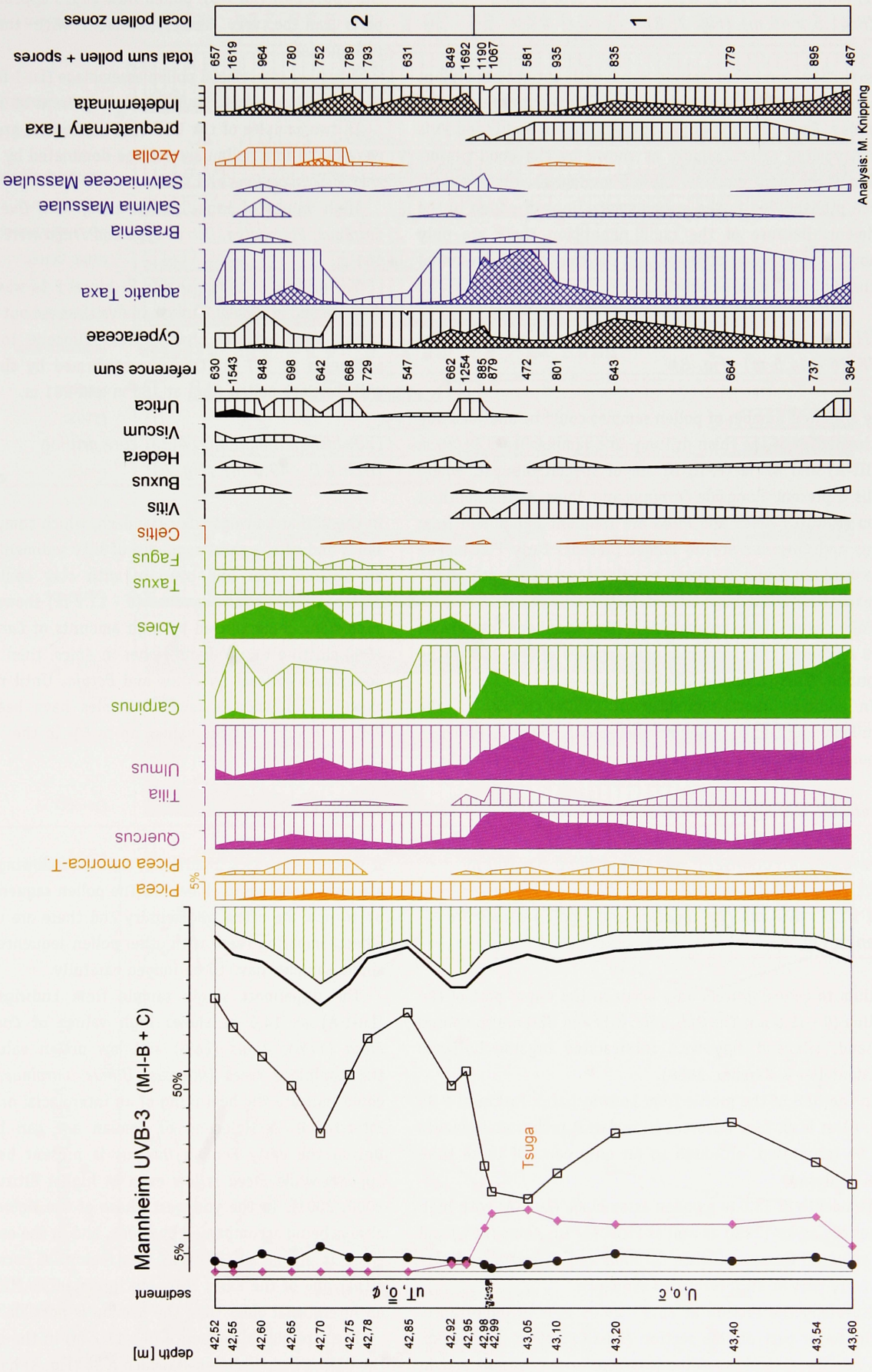

Fig. 6. Simplified pollen diagram of the Mannheim Interglacial M-I-B + C; 42.52 - 43.60 m (for legend see Fig. 3).

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M-II, Mannheim UVB-1, 41.7 - 45 m, core drilling (OZH 41.5 ≥ 45 m) (Fig. 7, 8)

This section comprises mainly sand with intercalated plant remains. The pollen assemblage with *Alnus*, *Abies*, *Corylus*, *Carpinus*, *Taxus* and low values of *Celtis*, *Fagus*, *Buxus* and *Vitis* was deposited rather rapidly as shown by the good preservation of the plant remains. These were deposited in the sand, which probably led to the low concentrations of pollen in the sediment. Because of the rapid deposition there are only minor changes in the sequence, and the time-span represented in the sediment may be short.

M-III, Mannheim Insel T 1.3/5.2, flush drilling 0 - 124 m (OZH 26 - 44.5 m) (Fig. 8)

Only a limited number of pollen samples could be analysed due to the nature of the flush drilling. The samples from 29/30 m (M-III-A) and 42 m (M-III-B) are of special interest, where *Fagus* is present alongside *Carpinus* and *Abies*. At the depth of 44 m (M-III-C) *Abies* and *Picea* are frequent but pollen from *Fagus* and *Carpinus* are no longer present. Early Pleistocene taxa were not found in several samples down to a depth of 124 m, except for some fragments of *Tsuga* at 99 m.

Pollen assemblages comparable to the Mannheim Interglacial were recovered from several single samples of the OZH in the Mannheim area (Knipping, 2004a).

In addition short sequences or single samples in the Mannheim and Ludwigshafen boreholes with pollen assemblages of boreal forests or stadial vegetation are common (Fig. 8).

Boreholes Ludwigshafen

Ludwigshafen Parkinsel P 34, core drilling 0 - 300 m (OZH 12.8 - 39.35 m, ZH2 + ZH3 39.35 - 91.6 m, UZH 91.6 - 177 m) (for location see Fig. 1; results are given in Fig. 8)

Medium to coarse gravels only occur in the upper part of the drilling (0 - 12.8 m). The OZH, ZH2, ZH3 and UZH are composed of sand, silt and clay with intercalated organic horizons (Weidenfeller & Kärcher, 2008).

In the OZH of the profile from Ludwigshafen Parkinsel P 34 (Fig. 8) at least four different interglacial pollen assemblages can be recognised, although so far only parts of these have been analysed.

At a depth of 13.6 m a pollen assemblage (Lu-I-A) with high values of *Corylus* (22%) as well as Picea (17%), *Alnus* (26%) and low values of *Quercus*, *Ulmus*, *Carpinus* and *Abies* may indicate the early part of an interglacial sequence.

Especially the section at 26.5 - 29.05 m is of importance. In the lower part of this section (Lu-I-C) pollen from *Abies*, *Carpinus*, *Taxus* and massulae from *Azolla* are present and in the upper part (Lu-I-B), pollen from *Fagus* appears. These two parts can be very likely correlated with the Mannheim Interglacial.

A further interglacial pollen assemblage (Lu-I-D) with *Picea*, *Quercus*, *Alnus*, *Ulmus* and *Corylus* is present at 37 - 38 m.

In two samples of the UZH (103 m) several grains of *Tsuga* were found in a pollen assemblage dominated by *Pinus* alongside *Picea*, *Carpinus* and *Ulmus*.

High values of Fagus pollen along with *Quercus*, *Ulmus*, *Carpinus*, *Pterocarya*, *Ostrya* type and *Tsuga* were recovered at 161 m.

The drilling of Ludwigshafen Parkinsel P 34 was constructed down to 300 m. Heavy mineral analysis carried out by Hagedorn (2004) detected the change from Pliocene to Pleistocene sediments at 177 m. This was confirmed by single samples with Tertiary pollen flora at 186 m and 201 m.

Ludwigshafen-Maudach A 36, core drilling (OZH 6.0 - 49.6 m) (Fig. 8):

In the OZH at Ludwigshafen-Maudach, which comprises mainly sands and silts, a short sequence of silty sediments covered by an organic layer and overlain with clay could be partly analysed. The pollen sequence (9 - 11.2 m) shows interglacial conditions characterised by high amounts of *Carpinus* (up to 40%) shifting to woodland richer in *Abies*, then in *Picea* and dominated at least by *Pinus* and *Betula*. Until now *Fagus* is absent, even though several samples have been analysed. Pollen of *Buxus* attains values up to 5% in the lower part of the interglacial.

Discussion

It should be stressed in advance, that the following correlations are only tentative in character. The pollen sequences recorded up to now are often fragmentary and there are uncertainties when comparing these with other pollen sequences. Especially single samples have to be judged carefully.

The uppermost single sample from Ludwigshafen P 34 (Lu-I-A) at 14.6 m shows high values of *Corylus* (22%), *Picea* (17%), *Alnus* (26%) and low pollen values of other thermophilous trees (*Quercus*, *Ulmus*, *Carpinus*, *Abies*) and could indicate the beginning of an interglacial or a temperate interstadial. A Holocene or Eemian age can be excluded. During the early Eemian *Quercus* is present before *Corylus* appears while *Picea* is low even in higher altitudes (Müller, 2000, 2001). In the youngest phase of the Holocene *Picea* is always being accompanied by *Fagus*, and in the early Holocene there is almost no *Picea* in this region. A correlation with either one of the Early Würmian interstadials MIS 5a or 5c or an interglacial older than the Eemian is possible.

The interglacial sequence (9 - 11.2 m) in the upper part of the OZH at Ludwigshafen-Maudach A 36 (Fig. 8) has been partly

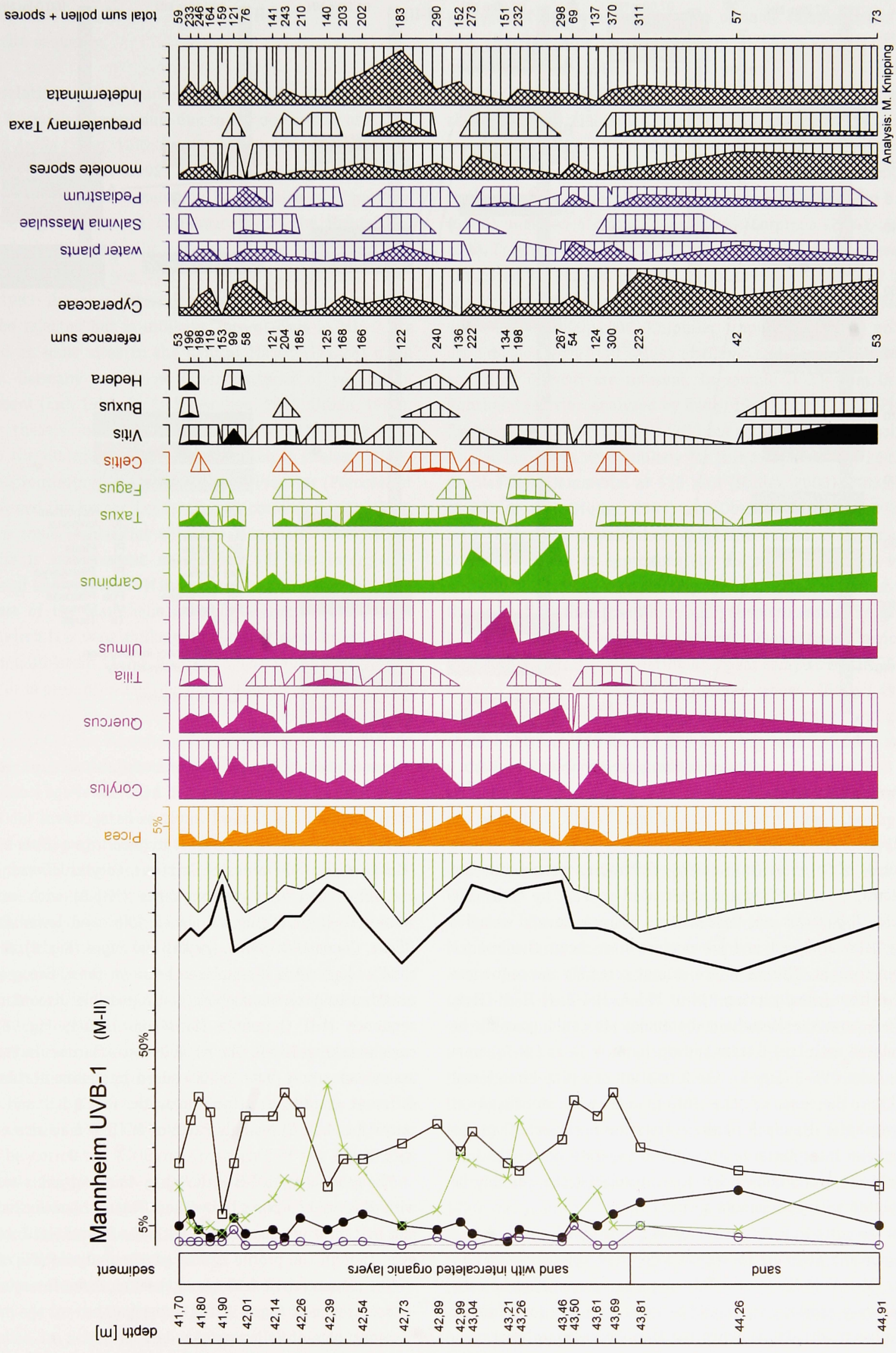

Fig. 7. Simplified pollen diagram from Mannheim UVB-1, M-II; 41.70 - 44.91 m (for legend see Fig. 3).

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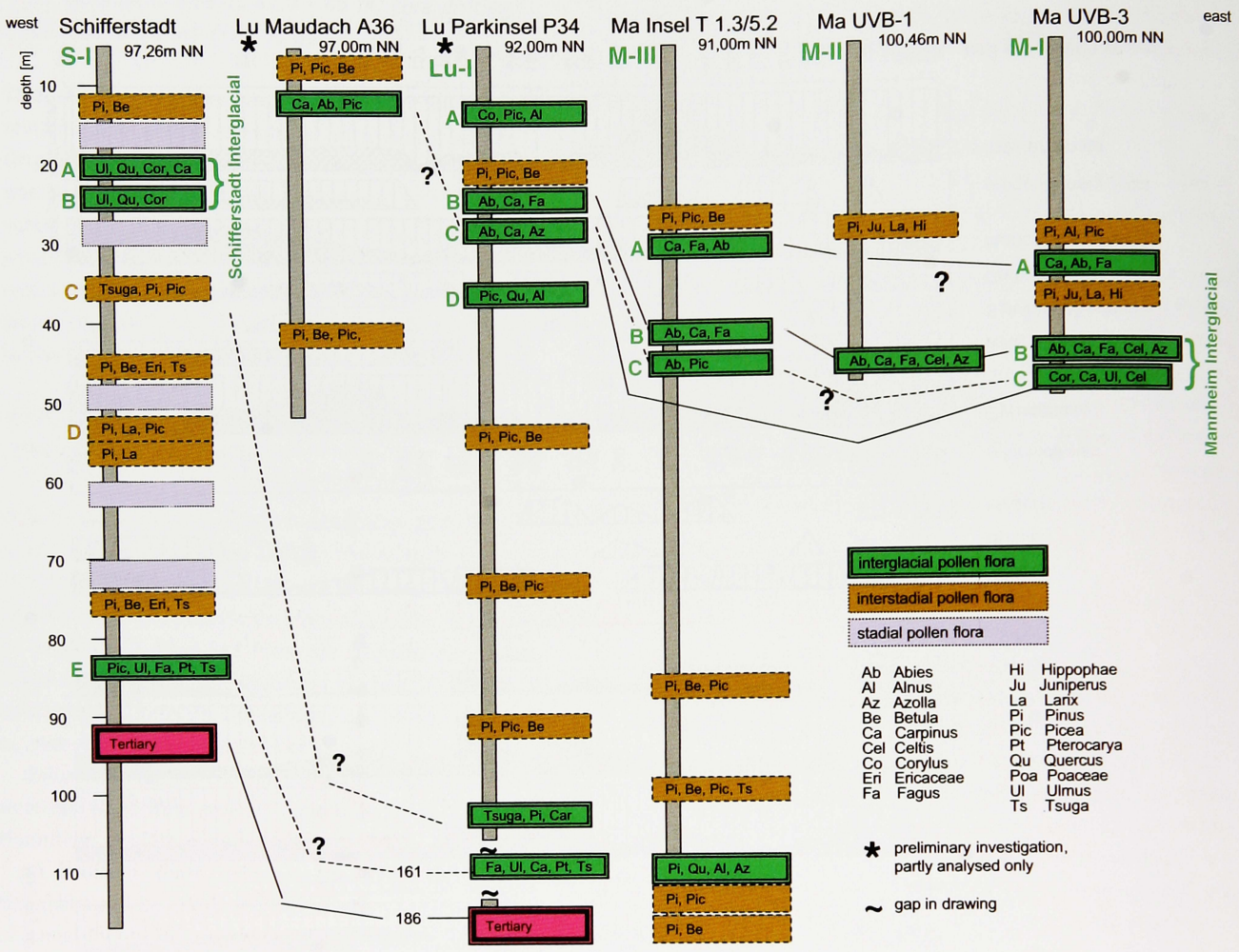

Fig. 8. Overview of investigated profiles in the Mannheim area with a preliminary correlation (A, B, C and D refer to discussed sections, see text for further explanation).

analysed. It shows interglacial conditions characterised by high amounts of *Carpinus* (up to 40%), shifting to woodland richer in *Abies*, then in *Picea* and dominated at least by *Pinus* and *Betula*. *Fagus* was not found, even though several samples have been analysed and all samples have been checked for pollen content. This sequence cannot resemble the sequences Lu-I-B from Ludwigshafen P34 or M-I-A, M-I-B, M-II, M-III-A, M-III-B from the Mannheim boreholes. It could possibly be correlated with Lu-I-C from Ludwigshafen P 34 and M-I-C from Mannheim UVB-3 (Fig. 8). The formation of a pine-birch forest marking the end of the interglacial was identified at Ludwigshafen-Maudach. If the correlation is correct, then the Mannheim Interglacial resembles two separate units. The lack of *Celtis* or *Azolla* allows that the interglacial can possibly be correlated with the Eemian so far.

In the cores from Mannheim three single samples with *Fagus*, *Carpinus* and *Abies* are present at a depth of approximately 29 - 34 m (M-I-A, M-III-A). Though single samples should be estimated very carefully this could be taken as a hint for a further Interglacial with Fagus above the Mannheim Interglacial.

The Mannheim Interglacial is divided into a lower sequence (M-I-C) with high values of *Carpinus*, *Corylus*, *Ulmus*, *Quercus* and *Alnus* and an upper sequence (M-I-B) with very high values of *Alnus*, rising values of *Abies* and lower values of *Ulmus*, *Quercus*, *Carpinus*, *Corylus* and *Fagus* (Fig. 6). A layer of sand and gravel is intercalated between these two sequences, pointing to an erosion phase and a possible discordance. The sequence M-II (borehole Mannheim UVB-1, Fig. 7) likely correlates with M-I-B. The notable dissimilarities in the pollen assemblages may have been caused by sedimentation under different conditions: standing water for M-I-B and flowing water for M-II. The single samples M-III-B may also correlate with M-I-B.

The sequences Lu-I-B with *Fagus*, *Abies*, *Carpinus* and Lu-I-C with *Abies* and *Carpinus* but without *Fagus* of Ludwigshafen P 34 can be tentatively correlated with the Mannheim Interglacial even though the profile is only partly analysed (Fig. 8).

The characteristic features of the Mannheim Interglacial are:

- occurrence of Fagus in the upper part;
- occurrence of Celtis and Azolla;

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- lack of Early Pleistocene elements;
- lack of Pterocarya;
- bipartite sequence.

A correlation of the Mannheim Interglacial with the Eemian or Early Würmian is impossible due to the occurrence of *Fagus*, *Celtis* and *Azolla* (Beug, 1979; Drescher-Schneider, 2000a; Müller, 2000, 2001; Wegmüller, 1992; Beaulieu & Reille, 1992). Since there are no Pliocene elements an Early Pleistocene position has to be rejected too. A correlation with the Holsteinian position is highly unlikely because of the high values of deciduous trees and the lack of *Pterocarya* (Müller, 1974; Grüger, 1983; Drescher-Schneider, 2000b). A position in MIS 7 cannot be rejected but is unlikely. Interglacials in MIS 7 are described at some sites in the Central Massif (France) or in northern Germany and show other patterns of vegetation development (Erd, 1973; Reille & Beaulieu, 1995; Urban, 1995). However, these sites are located far away from the study area. Recently the interglacial profile of Meikirch II (Welten, 1982, 1988) was reinterpreted by Drescher and Preusser (Preusser et al., 2004) and the former 'Eemian' is now correlated with MIS 7. There are some similarities with the Mannheim Interglacial, but *Celtis* is not present at Meikirch. If the interglacial sequence of Ludwigshafen-Maudach can be correlated with the lower part of the Mannheim Interglacial than a correlation with Meikirch II is very unlikely. In the two lower Interglacials of Meikirch 'Holstein 1' and 'Holstein 2' *Carpinus* pollen is very rare, but it is present in Ludwigshafen-Maudach with values of up to nearly 40%.

The spectra of the Mannheim Interglacial seem to correlate best with those known from the Cromerian Complex. However, a Cromerian I age is excluded because *Eucommia* has not been found in our investigated sections. Even so a correlation with Cromerian II (Zagwijn,1996) or Hunteburg (Hahne et al., 1994) seems highly unlikely because the very low counts of *Carpinus*. A tentative correlation of the Mannheim Interglacial with the Rhume (Salzderhelden BK20) Interglacial (Müller, 1986, 1992) or the Kärlich Interglacial (Urban, 1983; Bittmann, 1991) might be possible due to the occurrence of *Celtis* (even *Celtis* charcoal, Schoch in Urban, 1983), *Fagus* and *Azolla* as well as thermophilous deciduous trees.

Faunal remains of the OZH in the drilling Mannheim-Lindenhof P 18 were assigned by Rähle (2005) to the Cromerian Complex. First pollen results from the same samples reveal a pollen flora with *Abies*, *Carpinus*, *Fagus* and *Azolla* which can possibly be correlated with the upper part of the Mannheim Interglacial. Furthermore malacological investigations from Engesser & Münzing (1991) in the area of Phillipsburg-Mannheim also lead to the assignment of the OZH to the Cromerian Complex, at least in parts.

In a former interdisciplinary study (Von Koenigswald, 1988) an Eemian age for the upper clay (OZH) was assumed. With the new studies in Schifferstadt, Mannheim and Ludwigshafen this theory can be rejected. Interesting in this context are the analyses of pollen and the dating of some samples from the OKL and OZH from the northern Upper Rhine Graben (Beug, 1988; Schweiss, 1988). From 16 pollen samples only two samples from Groß-Rohrheim (ca. 25 km north of Mannheim) show an interglacial pollen assemblage. Assuming that the two interglacial samples from the upper clay (OZH) belong to the Younger Pleistocene, Beug (1988) assigned these two samples to the Eemian. In sample I 17 (Groß-Rohrheim) of the by Beug (1988) analysed section *Ulmus* (34%), *Carpinus* (27%), *Abies* (8%), *Corylus* (7%), *Quercus* (2%) and *Pinus* (13%) are present. Compared to Eemian profiles in southwestern Germany and the Vosges mountains (Frenzel, 1991; de Beaulieu & Reille 1992; Müller 2000, 2001; Knipping, unpublished data) pollen assemblages with high values of *Ulmus* and *Carpinus* and low values of *Quercus* are unusual. In sample II 23 from Groß-Rohrheim (section analysed by Beug, 1988) *Picea* (40%), Pinus (30%), *Abies* (14%), *Quercus* (7%) but no Carpinus were noted. An Eemian age is very unlikely for this sample. In the Eemian profiles from Jammertal at 578 a.s.l (Müller, 2000), Füramoos at 662 m a.s.l (Müller, 2001) and Oberschwarzach at 696 m a.s.l (Knipping, unpublished data) the values of *Abies* and *Carpinus* decline at approximately the same time. It is very unlikely that in the considerably lower situated region of the Upper Rhine Graben (ca. 100 m a.s.l) *Carpinus* would not grow, but in stead would be able to survive in mountainous regions. Of further interest is the dating of 6 peat samples by the U/Th method during the study mentioned above (Beug, 1988; Schweiss, 1988). All samples show boreal conditions and gave ages of between 118 Ka and 279 Ka. They were collected with a dredger below the groundwater table and therefore the stratigraphic position is not secure. However, it is highly probable that these samples are derived from the upper aquifer (OKL). This means that the OKL sediments include deposits that cover the time span from MIS 7 to MIS 5, and the Würmian.

Below the sequences in Ludwigshafen assigned to the Mannheim Interglacial a further sequence Lu-I-D with *Picea*, *Pinus*, *Quercus*, *Ulmus*, *Alnus*, few *Tilia* and high values of fern spores has been observed. Until now no pollen of *Fagus*, *Carpinus* or *Abies* were found. Maybe this sequence represents a temperate interstadial. It resembles in part with the thermomere previous to the Rhume (synonym: Bilshausen) Interglacial in the drilling of GoHy 1270 as described by Müller (1992). He mentioned a cool forested sequence with mainly *Pinus* and lower values of *Quercus* and *Alnus*. A tentative correlation of the Mauer Interglacial with the sequence GoHy 1270 was made by Urban (1997). The sequence of Lu-I-D is analysed in parts only, therefore a reliable correlation with the sequences previous to the Ruhme or the Mauer Interglacial is not possible at the moment.

In the profile of Schifferstadt an almost complete interglacial sequence is recorded (S-I-A+B, Fig. 2). Due to the

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occurrence of *Celtis* in this Interglacial a correlation with the Eemian or Early Würmian is impossible (Beug, 1979; Drescher-Schneider, 2000a; Müller, 2000, 2001; Wegmüller, 1992; Beaulieu & Reille, 1992). A position in MIS 7 is unlikely. If we follow the arguments of Preusser et al. (2004) and correlate the former 'Eemian' in Meikirch II (Welten, 1982, 1988) with MIS 7 then the Schifferstadt Interglacial cannot be an equivalent because of the total lack of *Fagus* in the Schifferstadt samples. If both lower interglacial sequences 'Holstein 1' and 'Holstein 2' correlate with Schifferstadt we should assume higher values of *Carpinus* in the younger 'Holstein 2'. A further argument is the lack of *Celtis* at Meikirch. A Holsteinian position is very unlikely because of the high values of deciduous trees and the absence of *Fagus* and *Pterocarya* (Grüger, 1983; Drescher-Schneider, 2000b). Since there are no Pliocene floral elements an Early Pleistocene position can also be rejected, too.

Characteristic for the Schifferstadt Interglacial (S-I-A, S-I-B) is the lack of *Carpinus* in the first optimum phase und a weak occurrence in the second phase. Pollen profiles without *Carpinus* were described by several authors (Harreskov and Ølgod: Andersen, 1965; Ferdynandów: Janczyk-Kopikowa, 1975; Ottostraße: Grüger, 1996; Hunteburg: Hahne, 1996; Surheide: Behre, 2004). The Schifferstadt Interglacial resembles the Ferdynandowian Interglacial in Poland (Janczyk-Kopikowa, 1975) and its equivalents (Rzechowski, 1996) rather well, although the sites are at a distance of several hundred kilometres. In the Ferdynandowian Interglacial high values of *Corylus*, *Ulmus*, *Quercus* and the absence of *Carpinus* are characteristic for the lower optimum. The same can be said for the Schifferstadt Interglacial. In the second optimum phase *Carpinus* is well represented in Ferdynandów while *Abies* is almost absent. In Schifferstadt *Carpinus* is weak and *Abies* is present with low values.

Due to high values of *Corylus*, *Ulmus* and *Quercus* the profile from Hunteburg (Hahne, 1996) is comparable with the first optimum phase in Schifferstadt except for a weak occurrence of *Carpinus* and a late spread of *Abies* at the end of the interglacial sequence at Hunteburg. Discussion about the accurate stratigraphic position of the Ferdynandowian Interglacial in relation to the marine isotope stages as well as to other interglacials lacking *Carpinus* discussion is continuing (Turner, 1996; Zagwijn, 1996; Behre, 2004).

The short sequence with *Tsuga* and low thermophilous elements at Schifferstadt S-I-C (Fig. 3) may be part of an interstadial or represents the end of an interglacial and is assigned to the OZH. In Schifferstadt *Tsuga* is present during those phases of interstadials when oceanic climatic conditions prevailed, usually in association with abundant Ericales. *Tsuga* does not occur in the pollen sequences from the continental and possibly cold climatic phases, characterised by *Larix*, *Juniperus* and *Artemisia*.

Tsuga is usually described as a characteristic Early Pleistocene floral element (Urban, 1978a; Müller, 1986; Lang, 1994). If this is true, then in Schifferstadt the OZH was formed, at least partly, during this time span. Currently it is not possible to assign the sequence with *Tsuga* at Schifferstadt (S-I-C) to a part of the Middle Pleistocene or to the Early Pleistocene e.g. the Bavelian (Zagwijn & De Jong, 1984). The second possibility is more likely due to the high values of Ericales.

In the sequence from Mannheim M-I-C (Fig. 6) a single grain of *Tsuga* could be determined. Bludau (2001) also determined several pollen grains of *Tsuga* in the drilling from 'Mannheim Ergo BK 3' and he discussed a Cromerian age. For these interglacial sequences a correlation with the Early Pleistocene seems impossible. If the presence of *Tsuga* pollen can be confirmed in further studies of the Ludwigshafen cores, then we can reject *Tsuga* as an index fossil for the Early Pleistocene. Because of the warmer climate it cannot be precluded that this tree species did survive in the Upper Rhine Graben up to the Cromerian Complex even though it had become extinct in the northern part of Central Europe.

In contrast to the oceanic phase with *Tsuga* and Ericales mentioned above, several sections could be detected pointing to a continental climate indicated by *Larix*, *Ephedra*, *Artemisia*, *Chenopodiaceae* (S-I-D).

In several parts of the profiles from Schifferstadt, Mannheim and Ludwigshafen (Fig. 8, Knipping 2002, 2004a) pollen assemblages indicating boreal forests with *Pinus*, *Picea* and *Betula* are very common. These single, short sequences cannot be assigned with any certainty to known stratigraphic positions at the moment, but a combination of these characteristic patterns of vegetation change of oceanic or continental climates may enable a correlation with well dated time slices.

The pollen assemblages in PZ 2-4 from the Early Pleistocene sequence at Schifferstadt (S-I-E, Fig. 5) can probably be assigned to a part of the Tegelen A due to the occurrence of *Fagus* as well as Tertiary relicts (*Eucommia*, *Tsuga*, *Pterocarya*) (Zagwijn, 1963; Urban, 1978a). PZ 1 is possibly part of the Pretiglian, though this interpretation is uncertain due to the reworked pollen taxa. A warm climate can be assumed for PZ 2 with high values of *Ulmus* and a cooler climate for PZ 3 and PZ 4. Very unusual is the occurrence of *Pinus cembra* type at Schifferstadt, as this pollen type is lacking in most of the pollen diagrams described by other authors and assigned to the Tegelen Complex. Only Urban (1978b) had determined *Pinus cembra* type in the 'van Eyck-Interstadial' and correlated it with Tegelen C 5-6 (cf. Zagwijn, 1963). In the Frechen Interglacial (Urban, 1978a), correlated with Tiglian A, *Pinus cembra* type is absent. The single sample from the drilling Ludwigshafen (161 m) with pollen from *Fagus*, *Tsuga*, *Pterocarya*, and *Carpinus* may also be correlated with the Tiglian Complex (Tiglian A) (Urban, 1978a; Zagwijn, 1963).

Conclusions

In the following a tentative correlation of the investigated sites is attempted.

Assuming that the sequence of Ludwigshafen-Maudach is an equivalent to the lower part of the Mannheim Interglacial (M-I-C, Lu-I-C) all investigated interglacial pollen assemblages are necessarily older than MIS 7. At the investigated sites there are no hints of Holsteinian, correlated now with MIS 9 (Geyh & Müller, 2005). A possible assignment of the Mannheim Interglacial is to the Rhume (synonym: Bilshausen) Interglacial (Müller, 1992) and to its equivalent the Kärlich Interglacial (Urban, 1983; Bittmann, 1991). These sequences show just like the Mannheim Interglacial *Fagus*, *Celtis* and *Azolla* beside high pollen values of *Abies*, *Carpinus*, *Quercus* and *Corylus*. Bittmann & Müller (1996) correlated the Kärlich with the Rhume Interglacial and assigned them to MIS 11 to the younger Cromerian Complex. A consequence of this correlation with the Mannheim Interglacial is that the pollen assemblages of M-I-A and M-III-A may date to a younger Interglacial. An assignment to a certain marine isotope stage is not possible yet. The sequence in Ludwigshafen (Lu-I-D) below the Mannheim Interglacial shows no traces of *Abies*, *Carpinus* or *Fagus*. A definite assignment is not possible yet, but resembling assemblages can be found in the sequence of Gorleben GoHy 1270 that precede the Rhume Thermomere (Müller, 1992). All above named sequences are derived from the OZH (Oberer Zwischenhorizont), the last one from the OZH is the Schifferstadt Interglacial for which also a position within the Cromerian Complex is assumed. The most likely correlation is with the Ferdinandów Interglacial (Janczyk-Kopikowa, 1975) and in parts with the Hunteburg Interglacial (Hahne, 1996).

Tsuga is proven in the OZH of the Schifferstadt drilling. Further investigations may help to decide whether *Tsuga* is really a characteristic indicator of the Early Pleistocene or whether this species became extinct during the Middle Pleistocene. The last assumption seems to be more likely.

The intermediate layers ZH 2 and ZH 3 in the drilling of Ludwigshafen show to the current state of analysis only interstadial or stadial sequences. Early Pleistocene relicts are not present, a Middle Pleistocene age is therefore assumed.

Early Pleistocene sequences are present in the lower intermediate horizon (UZH). Pollen assemblages with *Fagus*, *Tsuga* and *Eucommia* are correlated within the Tiglian Complex (Tiglian A).

From the current state of knowledge a time span from younger Middle Pleistocene to the Würmian is not represented with longer sequences. This might be due to an intensive fluvial erosion phase and/or a decreased tectonic subsidence rate in the investigated area.

The preliminary correlation of the investigated sites (Fig. 8) leads to the conclusion that the OZH in the area Mannheim/Ludwigshafen has definitely not been formed during a single specified time span. It is certainly not of Eemian age. In view of its thickness and position in the Upper Rhine Graben and due to the fact that it contains different Interglacials it might rather be of Cromerian age as already supposed in former investigations (Bludau, 1993; Engesser & Münzing, 1991). Within the upper aquifer (OKL) Würmian, Eemian and at least parts of MIS 7 are present.

The deep drillings of Ludwigshafen Parkinsel with the current interdisciplinary studies (Hagedorn, 2004; Rolf, 2004; Weidenfeller & Kärcher, 2008) may be a key for the reinterpretation of unconsolidated rocks in the Mannheim/Ludwigshafen area.

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