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The reconstruction of Early and Middle Miocene climate and vegetation in Southern Germany as determined from the fossil wood flora

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Abstract

Early and Middle Miocene sediments of the North Alpine Foreland Basin (NAFB) in Southern Germany contain one of the world's richest regional records of silicified wood. Here we analyze over 1000 identifiable samples, belonging to 80 wood-anatomical taxa from 61 stratigraphically well-dated localities using principally the Coexistence Approach. The samples investigated originate from fluvial sediments representing periods of intensified surface runoff in the NAFB and therefore represent and provide information pertaining to the wet end-member of the fluctuating climate system. The dry end of the climate system is represented in the profiles either by hiatuses or palaeosoils.

The dataset is split into four xylofloras: (I) the Ortenburg xyloflora (Late Ottnangian; ~17.5 to 17.3 Ma) originating from a paratropical evergreen *Carapoxylon* (*Xylocarpus*) forest; (II) the Southern Franconian Alb xyloflora (Late Karpatian; 17.0 to ~16.3 Ma) originating from a subtropical semi-deciduous limestone forest; (III) the upper Older Series xyloflora (Early Badenian; ~16.3 to ~15.3 Ma) originating from a subtropical oak–laurel forest; and (IV) the upper Middle Series xyloflora (Middle Badenian; 14.3 to ~13.8 Ma) originating from a subtropical dry deciduous forest.

Our investigation documents the following important outcomes: (1) the Late Ottnangian seems to be the warmest period during the investigated time span, with a mean annual temperature (MAT) between 22.2 and 24.2 °C and a cold month temperature (CMT) around 16.7 °C. The Late Ottnangian is significantly warmer by at least 1.7 °C MAT and up to 3.4 °C CMT than the Mid-Miocene Climatic Optimum (i.e. MAT 17.4–20.5 °C and CMT 8.0–13.3 °C of the Late Karpatian to Middle Badenian, ~17 to ~13.8 My) and may correspond to the First Climatic Optimum (17.7–16.7 Ma) of the southern oceans [Pekar, S.F., Marchitto, T., Lynch-Steiglitz, J., 2002. Evidence for Water-Mass Changes on the Tasmanian Slope during the Early Miocene (19–16.5 Ma): Stable Isotope and Mg/Ca Records from ODP Leg 189 Site 1168. Eos, Transactions, American Geophysical Union 83(47), Fall Meet. Supplement, Abstract PP11C-06, F 926-927.]. (2) The cooling between both climate optima is documented by the Southern Franconian Alb xyloflora and probably reflects the Mi2 build-up phase of the Antarctic ice-sheets. (3) From Late Ottnangian to Middle Badenian the wet end-member of the climate system appears to be humid (Mean Annual Precipitation ~830–~1.350 mm) and with relatively even distribution of rainfall throughout the year. Only the Late Karpatian is characterized by the occurrence of a distinct dry season probably occurring during the early spring or late autumn. (4) We attributed the Early to Middle Badenian vegetation change to an increase in intra-basin relief, rather than to a different climate.

Keywords: Molasse basin; Miocene; Miocene Climatic Optimum; Wood; Vegetation; Palaeoclimate

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1. Introduction

The Neogene North Alpine Foreland Basin (NAFB) in Southern Germany is one of the richest and most intensively studied areas of the world with regard to silicified wood remains. Over 400 localities are known containing probably more than 10,000 wood samples, and many of them have been identified and published (e.g. Selmeier, 1985, 1988, 1998, 2000, 2001, 2003). Despite this excellent record the chronology of many of these samples remain obscure. In addition, no overview paper exists, and information about palaeoclimate and vegetation are tentative, widely published and not placed within a spatial and temporal context. Recent progress in litho-, cyclo-, bio- and chronostratigraphy (Fig. 1; Heissig, 1997; Doppler et al., 2000; Böhme et al., 2001; Doppler et al., 2002; Böhme, 2003; Rögl et al., 2003) has now enabled a reassessment of the material to determine the relative chronology over a significant part of the section.

Following the reassessment of the chronology, material originating from 61 localities with silicifed wood (Fig. 2, Table 1) spanning the time from Late Ottnangian to Middle Badenian is investigated. Samples are grouped according to their age into four composite xylofloras: Late Ottnangian (~17.5 to 17.3 Ma; Ortenburg xyloflora), Late Karpatian (17.0 to ~16.3 Ma; Southern Franconian Alb xyloflora), Early Badenian (~16.3 to ~15.3 Ma; upper Older Series xyloflora) and Middle Badenian (14.3 to ~13.8 Ma; upper Middle Series xyloflora). We present a vegetational reconstruction and palaeoclimatic analysis using the Coexistence Approach (Mosbrugger and Utescher, 1997) based on 1044 identified and well-dated wood samples belonging to 80 wood-anatomical taxa (Table 1, for more details see Appendix Tables 1–5). We demonstrate that significant palaeoclimate changes, accompanied by reorganisations in the regional vegetation, occurred during the late Early Miocene and Early to Middle Miocene transition, and that the warmest period in Central Europe predates the Miocene Climatic Optimum in the sense of Zachos et al. (2001).

2. Material and methods

Fossil wood material included in this study was only selected after due regard had been paid to any possible taphonomic process. Samples with clear indications of fluviatile transport after mineralization (rounding, sample size within the spectrum of maximum gravel size) are excluded (see Lang, 2001: his fig. 6). Samples from accumulation horizons at the base of Pleistocene periglacial or aeolian sediments were only included if (1) they showed no rounding after mineralization (2) they directly overlie the source strata, and (3) their size is significantly larger than the maximum gravel size of their source strata (see Lang, 2001: his fig. 2). Most of the samples studied are stored in the Bavarian Palaeontological State Collection. Additional material is deposited in the collections of the Naturmuseum Augsburg and the Historischer Verein Neuburg a. d. Donau (for more information concerning localities, sample preservation, size and weight of samples, collection numbers etc. see www.wahre-staerke.com/selm).

Climatic information of all known nearest living relatives (NLRs) of the fossil wood taxa was determined for the four xylofloras (see Appendix Tables 1–5). Each sample group was analysed using the Coexistence Approach (CA). Based on the assumption that the climatic requirements of Tertiary plant taxa are similar to those of their nearest living relatives (NLRs), the aim of the CA is to find the climatic ranges in which a maximum number of NLRs of a given fossil flora can coexist. These coexistence intervals–one for each climate parameter and independently achieved–are considered the best description to date of the palaeoclimate for that fossil flora. Typically, the resolution and the reliability of the resulting coexistence intervals increase with the number of taxa included in the analysis and are relatively high in floras with ten or more taxa for which climate parameters are known. A detailed description and discussion of the method can be found in Mosbrugger and Utescher (1997), Utescher et al. (2000), Bruch et al. (2002), and Uhl et al. (2003). In this study the climatic parameters estimated for each flora are: mean annual temperature (MAT), temperature of the coldest month (CMT), temperature of the warmest month (WMT), mean annual precipitation (MAP), precipitation of the wettest month (highest monthly precipitation, HMP), precipitation of the driest month (lowest monthly precipitation, LMP), and precipitation of the warmest month (WMP).

3. Geology and occurrence of fossil woods

3.1. Late Ottnangian: Ortenburg xyloflora

The Ortenburg gravel represents a delta gravel deposit of the Oncophora Lake in Lower Bavaria (Haas, 1987). At the end of the middle Ottnangian the shallow sea of the Upper Marine Molasse in the Western Paratethys became disconnected from the Central Paratethys Sea (Senes, 1973). Fluvial inflow from the alpine mountains freshened the restricted marine basin and formed the brachyhaline to oligohalin Oncophora

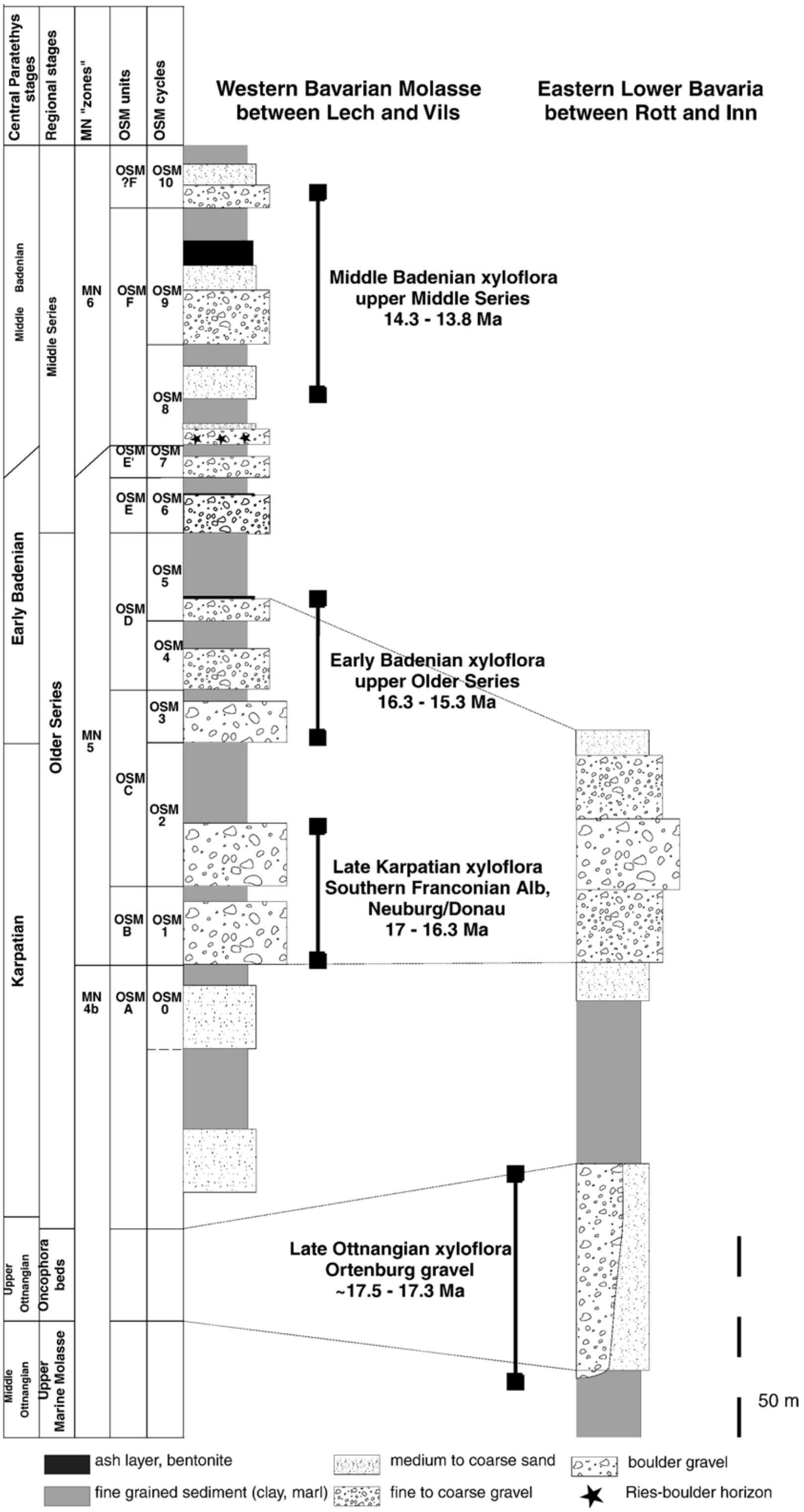

Fig. 1. Composite profiles, biostratigraphy (OSM units A to ?F after Heissig, 1997; Böhme et al., 2001), cyclostratigraphy (OSM cycles 0 to 10 after Heissig, 1997; Böhme et al., 2001), and the chronologic position of the investigated xylofloras from the upper Early Miocene and Middle Miocene Bavarian part of the North Alpine Foreland Basin (NAFB).

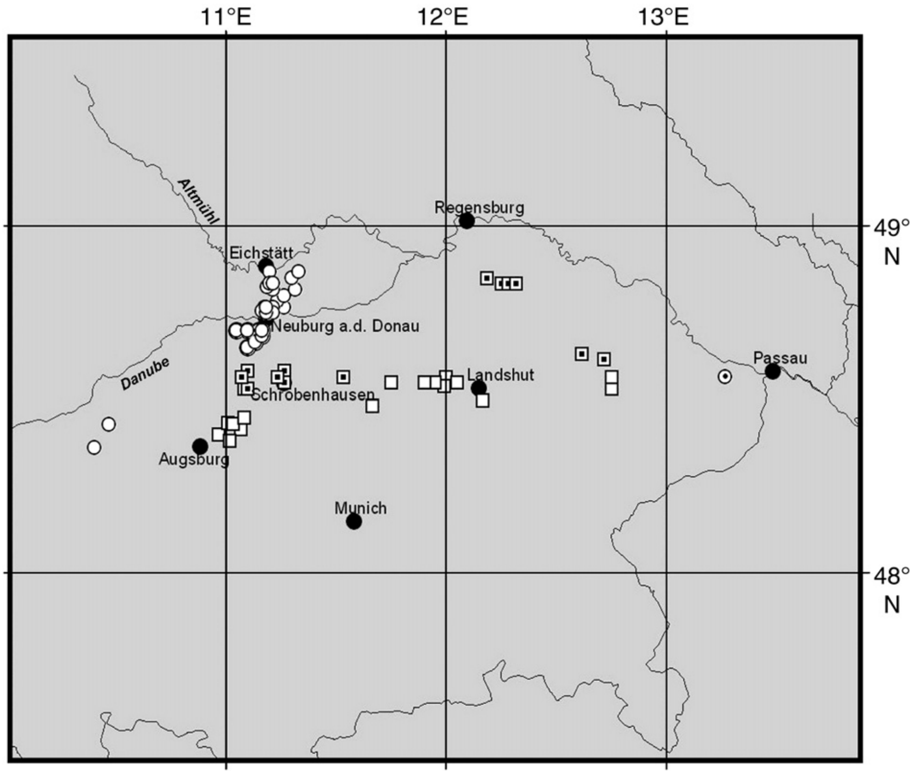

Fig. 2. Geographical position of 61 localities of silicified wood investigated. Symbols document the locality ages: dotted white circle—Late Ottnangian, white circle — Late Karpatian, dotted white square — Early Badenian, white square — Middle Badenian. Coordinates for all localities can be find in Appendix Tables 2–5.

Lake in the Late Ottnangian (Reichenbacher, 1993). The most important inflow came from the Ortenburg River, which, based on its heavy mineral spectrum appears to have originated in the alpine orogene (Unger, 1983). The Ortenburg River was deflected to the west following a blockage caused by crystalline moldanubic basement around Passau which led to the build-up of a delta into the Oncophora Lake (Haas, 1987). Silicified wood, including 7 m length trunks—the largest ever found in Southern Germany (Selmeier, 1985), was recorded in the Ortenburg gravel which represents the delta front (Haas, 1987). The lacustrine delta plain deposits (sands, marls, lignites, rooting soils) have yielded terrestrial and freshwater animals (molluscs, fishes, mammals), brackish molluscs (*Rzehakia gümbeli*, *Mohrensternia* sp.; Schlickum, 1964), drifted wood with *Teredo* vel *Bankia* (Schlickum, 1964), brackish fishes (*Dapalis formosus*; Reichenbacher, 1993) and sea cow remains (Sirenia indet.; Ziegler and Fahlbusch, 1986) indicating a connection to the brachyhaline lake and sporadic inflow of salt water (Schlickum and Strauch, 1968: 379). There was probably no tidal influence because of the dissociation from the oceans.

The age of the Ortenburg gravel can be restricted from the uppermost Middle Ottnangian (based on basal interfingering with the uppermost Upper Marine Molasse; Haas, 1987) to Late Ottnangian (based on molluscs and fishes from delta plain deposits; Schlickum and Strauch, 1968; Reichenbacher, 1993), which represents an absolute time span between ~17.5 and 17.3 Ma (Rögl et al., 2003). This agrees with macro-

Table 1
Numbers of specimens, localities and wood-anatomical taxa of the investigated xylofloras (for more details see Appendix Tables 1–5)

Xyloflora	No. of specimens	No. of localities	No. of taxa
Late Ottnangian (Ortenburg Gravel)	183	1	20
Late Karpatian (Southern Franconian Alb)	688	26	44
Early Badenian (upper part of Older Series)	147	20	10
Middle Badenian (upper part of Middle Series)	26	18	7

Fig. 3. Part of the holotype of *Carapoxylon ortenburgense* Selmeier, 1985 (BSP 1979 XV 2) from Rauscheröd showing preservation of bark. The length of the hammer is 30 cm. (Foto: G. Janβen, Munich).

and micromammals from the Ortenburg gravel and the delta plain deposits indicating the MN4b zone (locality Rauscheröd, Ziegler and Fahlbusch, 1986).

183 samples of silicified wood were found in the locality Rauscheröd (Fig. 2, Appendix Table 2) originating mostly from one gravel bed of 2 m thickness (Selmeier, 1985). The anatomical preservation of the primary large (1–2 m up to 7 m Selmeier, 1985) trunks is excellent and sometimes includes bark (Fig. 3) and branches. This indicates, together with the presence of wood from Bombacaceae with low resistance to fungal and insect decay (Selmeier, 1985), a spatially and temporally short transport and rapid burial and silicification. The woody elements are therefore most probably from trees growing in the vicinity of the delta plain.

3.2. Late Karpatian: Southern Franconian Alb xyloflora

The southern Franconian Alb represents the northernmost part of the Upper Freshwater Molasse (UFM) of the NAFB. Geophysical studies (Bader et al., 2000) reveal a distinct palaeo-relief characterized by several N–S orientated palaeo-valleys cutting into the ancient surface

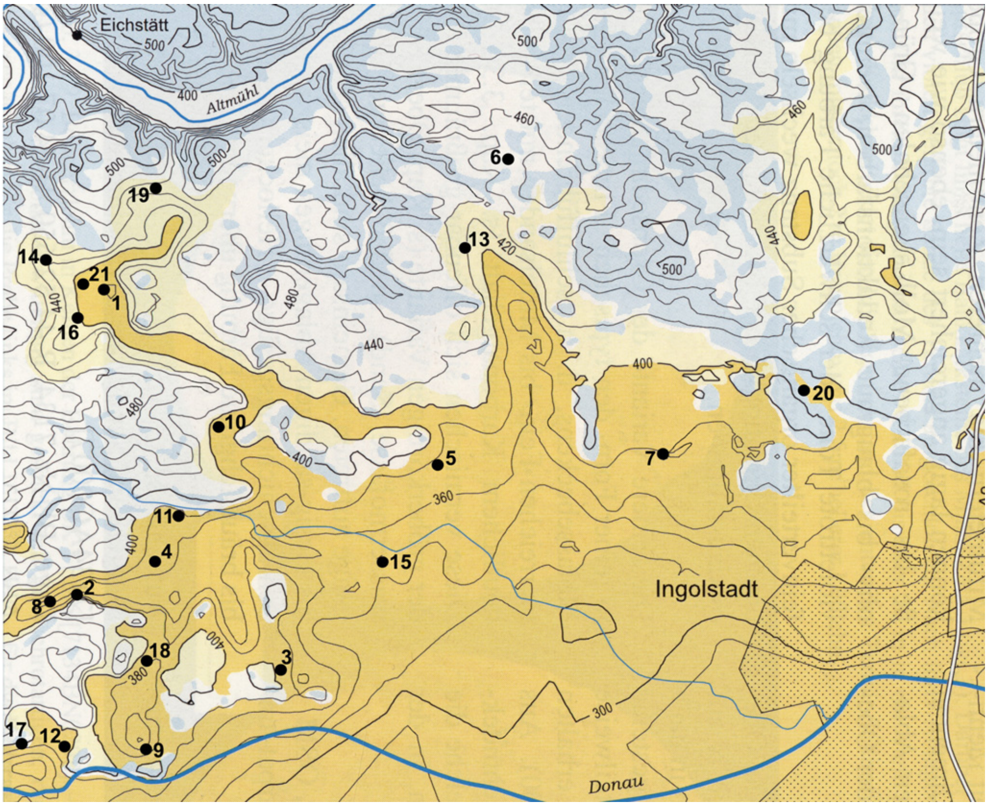

Fig. 4. Surface of Late Jurassic limestones, Neogene palaeo-valleys and localities of silicified wood on the northern border of the North Alpine Foreland Basin (NAFB) between the Altmuehl and Danube rivers (after Doppler et al., 2002). Blue — Late Jurassic, orange — base of Neogene sediments <400 m NN, yellow — base of Neogene sediments >400 m NN, white — valleys, residual clays and Pleistocene; 1 — Adelschlag, 2 — Attenfeld, 3—Bergheim, 4 — Egweil, 5 — Eitensheim, 6 — Hofstetten, 7 — Gaimersheim, 8 — Igstätterhof, 9 — Joshofen, 10 — Möckenlohe, 11 — Nassenfels, 12—Neuburg an der Donau, 13 — Oberzell, 14 — Ochsenfeld, 15 — Pettenhofen, 16 — Prielhof, 17 — Ried, 18 — Unterstall, 19 — Weiβenkirchen, 20 — Wettstetten, 21 — Wittenfeld. (Outside the map: locality Ziegelau 2.5 km NW of Neuburg an der Donau).

of Late Jurassic carbonates (Fig. 4). By correlation of the valleys distal base levels with the UFM discharge system, the incision could be dated to latest Ottnangian to Early Karpatian (Bader et al., 2000). These valleys are filled by fine grained sediments (micaceous sand, marl, calcareous palaeosoil) displaying alpine and moldanubic heavy mineral spectra indicating a mixing zone of southern sediment influx (alpine spectrum) and northern river discharge (moldanubic spectrum). Micromammals are known from several localities in these sediments (Doppler et al., 2002; Reichenbacher et al., 2004). According to the local biozonation (Heissig, 1997; Böhme et al., 2001), they indicate zone OSM B (*Megacricetodon bavaricus*) and early zone OSM C (*M.* aff. *bavaricus*), both belonging to the early MN5 which is correlated with the Late Karpatian (Rögl et al., 2003). In the cyclic UFM these biozones are found in the sedimentary cycles OSM 1 (fauna of Langenmoosen) and OSM 2 (fauna of Puttenhausen) — the initial cycles of the "Nördliche Vollschotter" (NVS) sedimentation display the largest gravel size (up to 22 cm) in the area of Landshut (Fig. 2). These ages are in accordance with the latest Ottnangian to Early Karpatian incision age of the valleys, which have been filled partly with alpine derived molasse sediments in the Late Karpatian, of between ~17.0 and ~16.3 Ma, through a rise in discharge levels marking the beginning of the NVS sedimentation to the east.

Localities with silicified wood (Adelschlag, Attenfeld, Bergheim, Egweil, Eitensheim, Gaimersheim, Hofstetten, Igstätterhof, Joshofen, Möckenlohe, Nassenfels, Neuburg a. d. Donau, Oberzell, Ochsenfeld, Pettenhofen, Prielhof, Ried, Unterstall, Weißenkirchen, Wettstetten, Wittenfeld, Ziegelau) are strongly associated with the courses of the valleys (Fig. 4) and are found either in micaceous sands or, more frequently, in accumulation horizons at the base of Pleistocene periglacial or aeolian sediments directly overlying micaceous sands. In the latter case, the wood shows characteristics of aeolian ablation such as deflation surfaces and aeolian polish. The size of the wood samples found today is medium to small (up to 6.7 kg; Selmeier, 2001), but their concentration over small areas (50–100 m; Holleis, 1992) and reference to them in historical works (cf. Selmeier, 1998) suggest that these were primarily larger trunks subsequently broken up by road works, agricultural practices and fossil hunters. The preservation of larger wood samples shows no signs of fluvial abrasion prior silicification which indicates low transport rates.

From the cyclic UFM only a few wood samples (3 of 688, see Appendix Table 3) are known of Late Karpatian age. They originate from the localities Roßhaupten and Jettingen, both having been dated by micromammals (OSM C, OSM 2) and Wagenhofen in the area south of Neuburg/Donau. Due to the existence of numerous bio- and cyclostratigraphical reference points in the cyclic UFM, the elevation of a locality is a good chronological indicator on the local scale. Thus Wagenhofen, at 380–385 m NN (meters above sea level), probably belongs to the cycle OSM 1 (zone OSM B), since nearby Langenmosen at 395–400 m NN has been biostratigraphically calibrated to the zone OSM B (sedimentary cycle OSM 1; Dehm, 1952; Heissig, 1997) and Unterhausen at 405–407 m NN dated to OSM C

Fig. 5. Recovery of one of the largest silicified trunk ever found in the cyclic Upper Freshwater Molasse from a sandpit at Goldbach near Jettingen (Upper Karpatian). Length of the trunk ca. 3 m, weight over 700 kg. (Foto: H. Hagn 1965).

(sedimentary cycle OSM 2). Notably, one of the largest trunks found in the cyclic UFM is documented from Goldbach near Jettingen (Fig. 5). It has a length of ca. 3 m and a weight of 750 kg.

3.3. Early Badenian: upper Older Series xyloflora

The biostratigraphic term Older Series of the UFM was defined initially by the absence of the proboscidian *Prodeinotherium bavaricum* (Dehm, 1955) and later by a succession of micromammalian communities (Heissig, 1997) belonging to the MN4b (zone OSM A) and to the older MN5 (zone OSM B to OSM D). These biozones could be incorporated to the cyclostratigraphy of the UFM (Fig. 1). By correlation with the Central Paratethys micromammalian record (Daxner-Höck, 2003) and due to first unpublished palaeomagnetic results, the zones OSM A (sedimentary cycle OSM 0) to early OSM C (sedimentary cycle OSM 2) were attributed to the Karpatian, whereas the late OSM C (sedimentary cycle OSM 3) to OSM D (sedimentary cycle OSM 5) belonged to the Early Badenian. Silicified wood remains from the Early Badenian (OSM 3 to OSM 5) was sampled from three areas: (1) south of Neuburg/Donau, (2) around Schrobenhausen, and (3) in the Lower Bavaria region (Fig. 2).

In the area South of Neuburg/Donau (localities: Ambach, Ergertshausen, Hollenbach, Straß, Sinning, Rohrenfels) fossil wood was found either in fluviatile sands (*Fluviatile Untere Serie* sensu Doppler, 1989) or reworked and accumulated at the base of Pleistocene gravels above these sands mostly between 395 and 430 m NN (Lang, 2001: 193, fig. 2). Around Schrobenhausen (localities: Affalterbach, Hagenauer Forst, Högenau, Oberbachern, Pöttmes, Schrobenhausen, Unterbachern) wood was sampled in the same lithostratigraphic unit (*Fluviatile Untere Serie*) between 420 and 450 m NN. Regional biostratigraphic calibration points for the age limits of these sands are the above mentioned localities of Langenmosen and Unterhausen, but also Dieshof, Schorn and Unterbernbach at 420–425 (430) m NN dated to OSM C (sedimentary cycle OSM 3), Walda 1 at 435–440 m NN dated to OSM D (top of sedimentary cycle OSM 4), and Walda 2, Affalterbach and Oberbernbach at 445–450 m NN, 448 m NN and 435–441 m NN respectively dated to OSM D (sedimentary cycle OSM 5; Heissig, 1997; Doppler et al., 2002). The base of the sedimentary cycle OSM 8 (Middle Badenian), characterized by the Ries boulder horizon (Böhme et al., 2001; Fig. 1), is situated in the area of Schrobenhausen between 480 and 485 m NN (Doppler et al., 2000, 2002). For the present investigation we chose only wood samples found between 410 and 450 m NN, which have a high probability of belonging to the sedimentary cycle OSM 3 to OSM 5 (note that the difference in sea level height between Walda 2 and Oberbernbach is due to the dip of the strata to the east).

In Lower Bavaria the cyclic UFM is represented by sedimentation of the coarse grained *Nördlicher Vollschotter* (NVS) (Doppler et al., 2000), which could be divided into a lower part (corresponding to the Older Series) and an upper part (corresponding to the Middle Series; Stiefel, 1957; Batsche, 1957). The sedimentary cycles OSM 3 to OSM 5 correspond to the upper part of the lower NVS. Silicified wood of this age is found from the area south of Regensburg (localities: Allkofen, Eggmühl, Inkofen, Obergraßlfing, Pullach) between 365 and 395 m NN (Quiel, 1971) and ENE of Landshut (localities: Dittenkofen, Mettenhausen) between 390 and 410 m NN (Buchner, 1963; Selmeier, 2003). For taphonomical observations see the end of the next chapter.

3.4. Middle Badenian: upper Middle Series xyloflora

Fossil wood from the upper part of the Middle Series is known mainly from three areas: (1) east of Augsburg, (2) the region around Malgersdorf, and (3) the region around Landshut. The fossil findings east of Augsburg (localities Derching, Obergriesbach, Oberschnaitbach, Pfaffenzell, Unterzell, Zahling) originating from the Gallenbach gravel (Fiest, 1989), represent the base of the OSM 9 cycle. The Gallenbach gravel has a maximum grain size of 4 cm and a thickness of ~10 m. It is deposited around 10 to 15 m above the Ries boulder horizon and ~5 m below the main bentonite layer. The fossil wood material in the area around Malgersdorf (Malgersdorf, Malgersdorf 1, Narnham) originates from the upper part of the upper NVS from a few meters to up to 20 m below the main bentonite layer. These sediments could be correlated to the sedimentary cycles OSM 8 and 9. The wood material from the area around Landshut (localities Engelsdorf, Attenhausen, Bruckberg, Gammelsdorf, Niederkam, Oberlenghart, Peterswahl) was sampled in bentonite pits and comes from the bentonite itself or from gravels just 2 or 3 m above the main bentonite layer. These fine to medium grained gravels are similar to the upper NVS below the bentonite and are referred to as *Jüngere Grobkiese* by Ulbig (1994). They probably correlate to the gravels and sands of the *Oberer Abschnitt Sand–Mergel–Abfolge* of Fiest (1989), which overlie the bentonites in the area east of Augsburg and represent the last cycle of the Middle Series (OSM 10).

The preservation of the fossil wood specimens found around Malgerdorf and Landshut is excellent. The size of the trunk fragments is usually around 1 m in length and around 0.5 m in diameter and show sometimes abraded wood texture typical of fluvial transported material prior to silicification. In some cases the trunks are only partly silicified at their base, whereas their upper part is preserved as a hollow space filled by limonitic duff, indicating that the silicification post-dated the deposition. Partly silicified trunks and fluvial abrasion prior to silification could also observed on wood from the upper part of the Older Series, which points to similar taphonomic processes in both formations. We include these woods in our analysis because, even if they are transported by basin-axial rivers over an unknown distance, they are not reworked and should give reliable palaeoclimatic results for the given time-slice.

4. Results

4.1. Edaphic conditions and vegetation cover

4.1.1. Late Ottnangian–Ortenburg gravel

The low-distance transport of the trunks and the overall geological situation suggest that the Ortenburg xyloflora probably grew on the Ortenburg fluvio-deltaic plain. A schematic facies distribution of the delta based on sedimentary features and molluscs is given by Schlickum and Strauch (1968: their fig. 7): Plio- to mesohaline lagoons fed by meandering and straight fluvial channel systems are accompanied by freshwater to mesohaline oxbows, and freshwater to oligohaline lakes and swamps. This reconstruction indicates a high groundwater level all through the year with partly saline groundwater and poorly-drained soils in the lower delta plain (lagoons and oxbows), and fluctuating groundwater levels with well-drained soils around the channels in the middle delta plain. In the interdistributary basins (lakes and swamps) periodically flooded, poorly-drained soils may have occurred.

The most dominant element of the Ortenburg xyloflora (75 of 180 samples, 42%) belongs to three species of *Carapoxylon* with the nearest living relative being *Xylocarpus* (Fig. 3, Gottwald, 1997). *Xylocarpus* is a hydrohalophyte which occurs in wet areas of the Old World tropics and tolerates full-strength sea water salinity (Aronson, 1989: 64). The majority of the extant species grow on the landward side of the mangrove forests (Gottwald, 1997), except for *Xylocarpus moluccensis* which is regarded as non-mangrove (Tomlinson, 1986). The abundance of *Carapoxylon* and the palaeogeographic and edaphic conditions described above, clearly imply the distribution of an evergreen *Carapoxylon* (*Xylocarpus)* forest on the lower delta plain. Because of the absence of a regular tidal influence true mangrove vegetation was probably unable to develop.

For the middle delta plains, a riparian forest with *Grewia*, Myricaceae, *Bombax* and Ebenaceae is thought to have dominated the well-drained levies and channel banks. Poorly-drained swampy areas and partially flooded interdistributary basins supported swamp forests with Taxodiaceae, Palmae, Lauraceae, Fagaceae and Ericaceae.

4.1.2. Late Karpatian

Nearly all samples (>99%, $n=686$) of the Late Karpatian xyloflora originate from palaeo-valleys on the Franconian Alb Jurassic limestone plateau on the northern border of the NAFB. The valleys are narrow (1 to 3 km), relatively steep (incision depth up to 100 m) and short (at maximum 10 km to the opening to the NAFB; Doppler et al., 2002). The location and preservation (no fluvial abraded wood texture, see chapter 3) of the fossil wood indicate a relatively short transport prior to the silicification. The parent vegetation probably grew on the floor and slopes of the palaeo-valleys. The palaeosoils of the Franconian Alb limestone plateau developed prior to the valley-incision and are chromic luvisols (Birzer, 1939; Andres, 1951). Due to the valley-incision during the Early Karpatian these soils are partially eroded and resedimented downstream or deposited on the valley floor. The significant lowering of the regional groundwater level is indicated by the intense karstification on the Franconian Alb at this time (several fissure fillings of MN4 age in the Petersbuch and Erkertshofen quarries 15 km to the north of the sampled area; Bolliger and Rummel, 1994). Fissure fillings of Late Karpatian age (early MN5) are unknown in this area, which lends support to a possible rise in the UFM discharge and regional groundwater level accompanied by a predominantly surface runoff. In the Late Karpatian we can distinguish three edaphic zones in the habitat of the parent trees in respect to the water availability and nutrient content: well drained, nutrient poor rendzic leptosols on the slopes of the valley and either well-drained alluvial soils (micaceous sand) or poorly drained, nutrient-rich chromic or calcic cambisols (calcic palaeosoils) on the valley floors.

The Late Karpatian xyloflora is characterized by a dominance of legumes and Lauraceae (together comprising 53%, $n=365$), a relatively high percentage of megathermal elements (26%, $n=179$) and of exceptionally high diversity (51 taxa from 23 families). Of the 23 families, Mimosaceae is the most diverse with 8 taxa, followed by Lauraceae with 5 taxa. In comparison with the Ortenburg xyloflora, several families are absent (Bombacaceae, Flacourtiaceae, Euphorbiaceae, Ericaceae, Myricaceae). The high familial diversity is reflected by the presence of mega- and mega-mesothermal elements such as Anacardiaceae (*Pistacia*), Capparaceae (*Capparis*), Dipterocarpaceae (*Shorea*), Ebenaceae (*Diospyrus*), Icacinaceae (*Cantleya*), Meliaceae (*Xylocarpus*, *Cedrela*/*Toona*), Sapotaceae (*Bumelia*) and Tilliaceae (*Grewia*). The gymnosperms are relatively poorly represented (7%, $n=48$) and include the genera *Podocarpus*, *Glyptostrobus*, *Cupressus* and *Juniperus*.

Azonal elements are rare in the xyloflora (9%, $n=62$; *Glyptostrobus*, *Liquidambar*, *Ulmus*, Palmae) and might be restricted to the riparian vegetation in the valleys whereas a subtropical semi-deciduous limestone forest dominated by legumes and Lauraceae grew on the oligotrophic soils (rendzic leptosols) of the valley sides.

4.1.3. Early Badenian

The majority of silicified wood (>90%, $n=137$) comes from the western part of the area sampled; i.e. south of Neuburg/Donau and especially around Schrobenhausen (Fig. 2). The wood-bearing sediments are carbonate-rich fluviatile sands of the *Fluviatile Untere Serie* (sensu Doppler, 1989), which show sedimentary characteristics of low sinuosity channels. Soils are therefore well-drained and nutrient-rich having formed under relatively high groundwater levels.

The Early Badenian xyloflora is characterized by a clear dominance (80%, $n=118$) of Lauraceae and Fagaceae (*Quercus*, *Castanopsis*) and a low percentage (3%, $n=4$) of megathermal elements (Mimosaceae, Meliaceae), which clearly indicates a subtropical oak–laurel forest similar in composition to that found today in Southern China.

4.1.4. Middle Badenian

The Gallenbach sand and gravel which contain the samples from the area east of Augsburg represent mature, carbonate-poor sediments of high sinuosity channels reflecting different transport energies (Fiest, 1989). An intra-basin relief up to 20 m is documented in this area and around Landshut (Ulbig, 1994; Fig. 2) and suggests an increase in available habitats. The increased maturity of these sediments indicates well-drained but nutrient-depleted soils formed under spatially altered groundwater levels, relative to the Early Badenian.

Despite the low number ($n=26$) of samples of Middle Badenian age, this xyloflora is dissimilar to the one from the Early Badenian in that there are low percentage (15%, $n=4$) of Lauraceae and Fagaceae (*Quercus*) and an unusual dominance of legumes and taxodiaceous conifers (both 65%, $n=17$). The comparatively high number of both Mimosaceae (15%, $n=4$, *Dichrostachys*/*Acacia*) and Caesalpiniaceae (27%, $n=7$, *Robinia*) indicates relatively xeric conditions characteristic of dry deciduous forest with few evergreen elements. Less humid conditions in a relatively open environment is supported by evidence of charcoalified wood on *Dichrostachyoxylon zirkelii* material from Narnham (Selmeier, 1988: 135, his fig. 9) and by the contemporary leaf flora from Wemding (Bolten et al., 1976).

4.2. Palaeoclimate

The results of the quantitative climatic analysis carried out with the CA are listed in Table 2. Details of the analysis are given for mean annual temperature analysis in Fig. 6.

4.2.1. Late Ottnangian–Ortenburg gravel

The Late Ottnangian xyloflora comprises 62% ($n=113$) of megathermal elements from five families (Meliaceae, Tiliaceae, Bombacaceae, Flacourtiaceae, Euphorbiaceae; see Appendix Table 2). The dominating element of the assemblage is *Carapoxylon* with 4 fossil wood species and 75 specimens out of 183. Using *Xylocarpus*/*Carapa* as the nearest living relative, the CA results for MAT and CMT are 22.2–24.2 °C and 16.7 °C respectively.

Notably, all other taxa of this xyloflora give very broad climate information. Without *Carapoxylon* the CA results for MAT and CMT would fall in the relatively wide range of 16.8–24.2 °C and 10.6–16.7 °C, respectively. But even then, the MAT and CMT values will be noticeably higher than those of the younger floras (see below). With the exclusion of *Xylocarpus*/*Carapa* also the WMT interval (24.7–28.1 °C) would broaden slightly, but precipitation parameters would not be affected due to the wide range of humidity requirements of this taxon.

4.2.2. Late Karpatian

The Late Karpatian xyloflora includes 26% ($n=179$) of megathermal elements from six families (Meliaceae, Mimosaceae, Dipterocarpaceae, Icacinaceae, Tiliaceae, Sapotaceae; see Appendix Table 3). Moreover, several taxa are present (*Crataegus*, *Cupressus*, *Robinia* and *Pistacia terebinthus*; 14%, $n=97$) that are not found in the Ottnangian sample which result in lower temperature values from CA analysis. The appearance of *Pistacia terebinthus* in particular and *Robinia* strongly influences the upper borders of coexistence intervals for MAT (15.7–20.5 °C) and CMT (5.6–13.3 °C), respectively (cf. Fig. 6 and Table 2). It might be that *Robinia* is not suitable for CA analysis because this new world genus may not totally reflect the climatic requirements of its European ancestors. Nevertheless, the other species point also to very similar CA values which are still significantly cooler than for the Ottnangian. If *Robinia* is excluded from the analysis results for CMT would fall to 5.6–13.9 °C.

In the Late Karpatian xyloflora *Carapoxylon* and *Shoreoxylon* still occur in low abundances (3 of 688

Table 2
Results of the quantitative climatic analysis with the CA for all climatic parameters investigated

	No. of climatic relevant taxa	Mean annual temperature [°C]			
		Min.	Max.	Min. border set by	Max. border set by
Late Ottnangian	20	22.2	24.2	Xylocarpus, Carapa	Castanea
Late Karpatian	42	15.7	20.5	Acacia catechu	Pistazia terebinthus
Early Badenian	10	15.7	20.8	Acacia catechu	Robinia
Middle Badenian	6	15.7	20.8	Acacia catechu	Robinia

	No. of climatic relevant taxa	Temperature of the coldest month [°C]			
		Min.	Max.	Min. border set by	Max. border set by
Late Ottnangian	20	16.7	16.7	Xylocarpus, Carapa	Castanea
Late Karpatian	42	5.6	13.3	Cupressus	Robinia
Early Badenian	10	4.8	13.3	Acacia catechu	Robinia
Middle Badenian	6	4.8	13.3	Acacia catechu	Robinia

	No. of climatic relevant taxa	Temperature of the warmest month [°C]			
		Min.	Max.	Min. border set by	Max. border set by
Late Ottnangian	20	25.5	28.1	Xylocarpus, Carapa	Lauraceae
Late Karpatian	43	25.5	27.3	Xylocarpus, Carapa	Pistazia terebinthus
Early Badenian	10	24.7	28.1	Toona sinensis	Robinia
Middle Badenian	6	20.2	28.1	Acacia catechu	Robinia

	No. of climatic relevant taxa	Mean annual precipitation [mm]			
		Min.	Max.	Min. border set by	Max. border set by
Late Ottnangian	20	867	1520	Bumelia	Taxodiaceae
Late Karpatian	44	1138	1355	Dipterocarpaceae	Crataegus
Early Badenian	10	828	1362	Cinnamomum	Robinia
Middle Badenian	6	828	1362	Cinnamomum	Robinia

	No. of climatic relevant taxa	Precipitation of the wettest month [mm]			
		Min.	Max.	Min. border set by	Max. border set by
Late Ottnangian	20	160	265	Cinnamomum	Taxodiaceae
Late Karpatian	43	160	185	Cinnamomum	Pistazia terebinthus
Early Badenian	10	160	195	Cinnamomum	Robinia
Middle Badenian	6	160	195	Cinnamomum	Robinia

	No. of climatic relevant taxa	Precipitation of the driest month [mm]			
		Min.	Max.	Min. border set by	Max. border set by
Late Ottnangian	20	32	67	*Bumelia*	Taxodiaceae
Late Karpatian	42	8	24	*Carya*	*Celtis*
Early Badenian	10	5	67	*Quercus*	Taxodiaceae
Middle Badenian	6	4	55	*Acacia*	*Morus nigra/rubrus*

	No. of climatic relevant taxa	Precipitation of the warmest month [mm]			
		Min.	Max.	Min. border set by	Max. border set by
Late Ottnangian	20	124	163	*Xylocarpus*, *Carapa*	*Bumelia*
Late Karpatian	43	124	163	*Xylocarpus*, *Carapa*	*Bumelia*
Early Badenian	10	108	180	*Toona sinensis*	*Quercus*
Middle Badenian	6	30	195	*Cinnamomum*	*Robinia*

specimens, <0.5% of the material described here; but there are additional records of *Carapoxylon* in the Late Karpatian locality Randecker Maar 120 km west of the studied area; Mädel, 1960). However, the high discrepancy of the climatic signals between these taxa and the cooler elements like *Pistacia terebinthus*, *Robinia* and

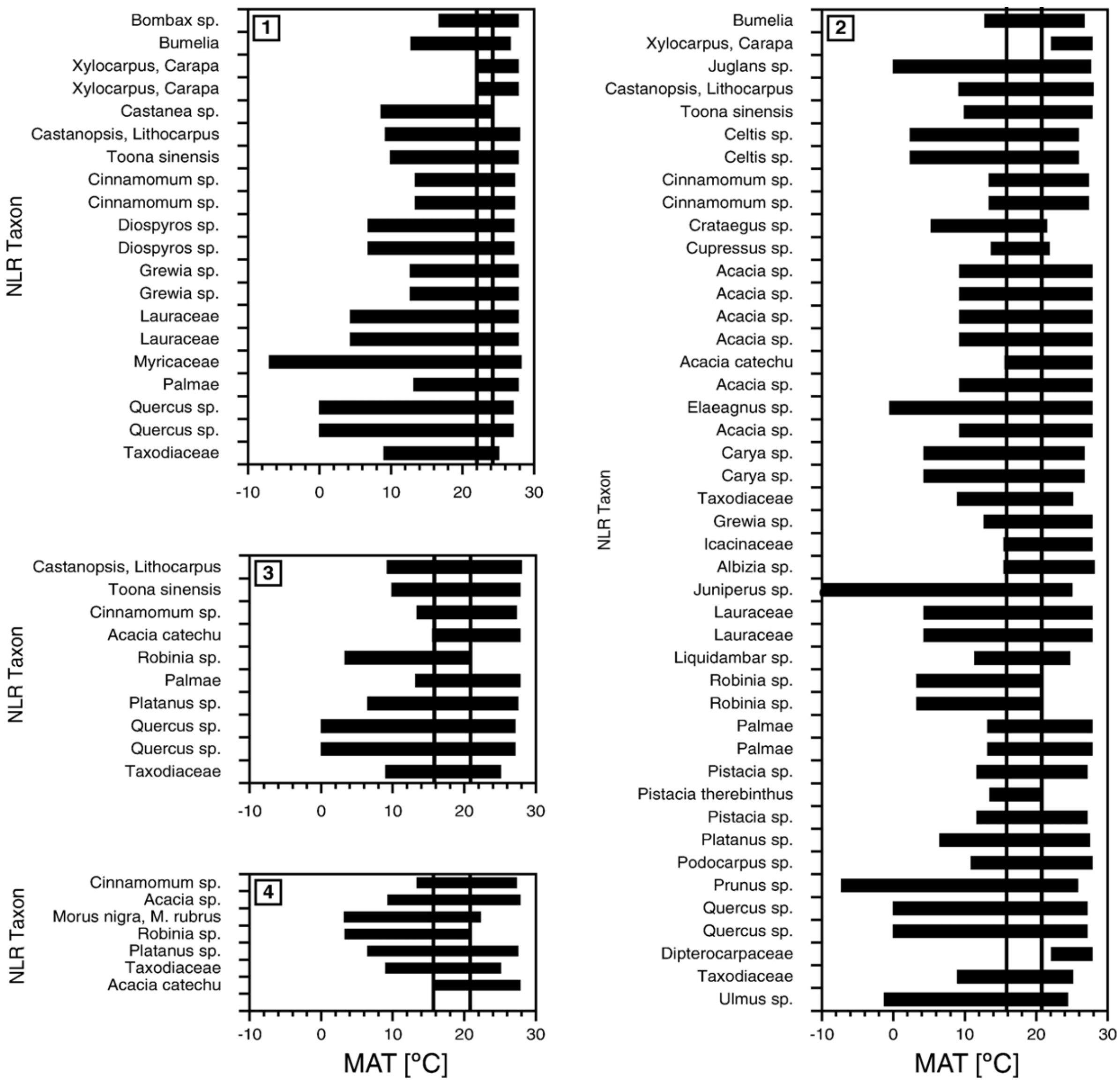

Fig. 6. Coexistence Approach analysis of mean annual temperature. 1: Late Ottnangian; 2: Late Karpatian; 3: Early Badenian; 4: Middle Badenian.

others leads to coexistence intervals (i.e. the interval with the highest number of coexisting taxa) that regularly leave out *Xylocarpus*/*Carapa* and Dipterocarpaceae (cf. Fig. 6). There are three possible ways of interpreting this discrepancy. First, the extant *Xylocarpus* did not fully reflect the climatic requirements of the extinct *Carapoxylon* (with implications for the interpretation of the Ottnangian flora). Second, because of the relatively high time averaging of more than half a million years (~17.0 to ~16.3 Ma) the samples represent different climate conditions. Third, *Carapoxylon* and the Dipterocarpaceae represent relict occurrences in the Karpatian flora.

4.2.3. Early Badenian

If truly representative, the Early Badenian xyloflora comprises only 3% ($n=4$) of megathermal elements from two families (Meliaceae, Mimosaceae; see Appendix Table 4). This suggests a distinct decrease in megathermal elements when compared to the Late Karpatian. This decrease in megathermal elements however is not reflected by the quantitative climatic values derived for temperature parameters (MAT 15.7–20.8 °C, CMT 4.8–13.3 °C). Although the low number of climatically relevant taxa does not give statistically significant results, the presence of *Robinia* ($n=6$) clearly indicates cooler conditions when compared with the Late Ottnangian.

4.2.4. Middle Badenian

The Middle Badenian xyloflora includes 19% ($n=5$) of megathermal elements from the families Mimosaceae and Meliaceae (see Appendix Table 5), indicating a higher abundance than in the Early Badenian. This flora also shows a reduction in family diversity (eight families instead of ten in the Early Badenian) and a dominance of legumes (42%, $n=11$ in comparison with 5%, $n=8$ in the Early Badenian).

Because the number of taxa is lower, results for the Middle Badenian sample are less significant (cf. Fig. 6). The resulting values for MAT and CMT are clearly lower than those for the Late Ottnangian sample due to the presence of *Robinia*. Reduced humidity as suggested by the vegetation (see above) is not supported by the CA results. This could be either due to the low number of taxa or the increase in basin relief providing more diverse habitats above the groundwater level which consequently led to a decrease in water availability (see Discussion).

5. Discussion

The climate dynamics of the Miocene are similar to those of the Pliocene/Pleistocene controlled by variations of the Earth's orbit (Zachos et al., 2001; Shevenell et al., 2004), which influenced, at different periodicities, regional scale climatic parameters such as precipitation. The samples investigated here come from fluvial sediments representing times of intensified surface runoff during the wet end of the climate system of the NAFB. Therefore the fossils can only provide climate information pertaining to the wet end of the climate system. The dry end is represented in the profiles either by hiatuses or by palaeosoils.

This intrinsic interrelation between wet and dry climate systems becomes obvious when interpreting the precipitation data (Table 2). The results for MAP, WMP and LMP remain relatively high and very similar over the studied time span. Only the values for LMP during the Late Karpatian are significantly lower (Table 2, Fig. 7). This indicates that from Late Ottnangian to Middle Badenian the wet end-member of the climate system appears to be humid (MAP ~830–~1.350 mm) and, with the exception of the Late Karpatian, rainfall was evenly distributed throughout the year. Similar precipitation values for the Early Badenian resulted from analysis using amphibian and reptiles as proxy-organisms (Böhme et al., 2006: Fig. 2). Only the Late Karpatian is characterized by the occurrence of a distinct dry season even during the wettest climate stages. Because of the high Late Karpatian WMP values, this dry season must have occurred during the cool season. This is in accordance with the distribution of snakehead fishes, indicating summer precipitation maxima in Central Europe from the Late Ottnangian to the Late Badenian (Böhme, 2004). The dry season probably did not occur during winter but probably during early spring or late autumn. This can be inferred because rubified palaeosoils occur in floodplain environments (Puttenhausen section; Schmid, 2002) and CMT (winter time) values for the Late Karpatian of 5.6–13.3 °C would be too cold for the dehydration of ferrihydrite (the mechanism of soil rubification).

The reduced humidity as indicated by the vegetation of the Middle Badenian is not supported by the CA results, which could be related to the small number of Middle Badenian taxa, or to an increase in topography. Based on geological evidence for an increased intra-basin relief (Ulbig, 1994, Heissig unpubl. results) we favour the latter possibility. This could explain the higher probability of forest fires as evidenced by charcoalified legume wood (Selmeier, 1988) and the dominance of legumes, generalists which today show higher diversity in areas of varied topography with seasonal climate (Polhill et al., 1981). Although there is a change in vegetation between the Early and Middle Badenian, we conclude, for the wet end-members of the climate system, similar conditions in terms of precipitation and temperature parameters.

The most striking feature of the temperature estimates are the warm, paratropical values for MAT (22.2–24.2 °C) and CMT (16.7–16.7 °C) for the Late Ottnangian associated with evergreen *Carapoxylon* (*Xylocarpus*) forest on the Ortenburg lower delta plain, and the cooler conditions of the Late Karpatian and into the Badenian (MAT 15.7–20.8 °C, CMT 4.8–13.3 °C) associated with subtropical semi-deciduous limestone forest (Late Karpatian), subtropical oak–laurel forests (Early Badenian) and dry deciduous forests (Middle Badenian). Since the diversity of taxa in the two xylofloras of Badenian age is low (Table 1) the resulting coexistence intervals cannot be taken as significant. Nevertheless, the cooler conditions of the Early Badenian are in good agreement with other data from the same time interval such as the macro- and microfloras from Central Europe (Bruch et al., 2004). In addition, estimates based on the Early and Middle Badenian micro-flora of Hungary show good correspondence not only in temperature (MAT 18–20 °C), but also in precipitation (MAP 1.200–1.400 mm, Jimenez-Moreno et al., 2005). From Ottnangian there are few well-dated leaf floras (e.g. Dolnice, Luzern, Oberdorf; Buzek et al., 1982; Mai, 1995; Meller et al., 1999) and estimation of temperature parameters are lower than the results from this study. Climate quantifications derived from the flora of Oberdorf resulted in data for MAT of 15.7–17.6°C, CMT of 9.6–11.7 °C, and WMT of 26.6–27.5 °C (Bruch and Kovar-Eder, 2003). In that study, the taxa in the Oberdorf

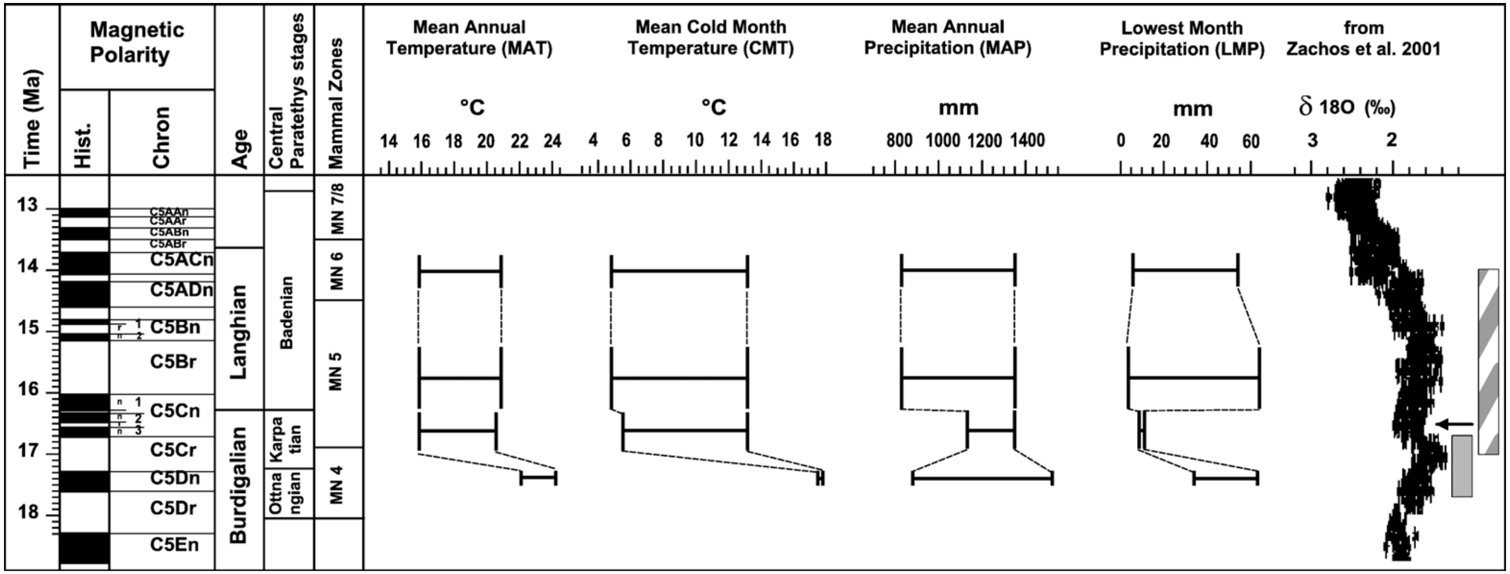

Fig. 7. Climate development from Early to Middle Miocene in the North Alpine Foreland Basin based on xylofloras compared to the global deep-sea oxygen isotope record. The arrow indicates the position of the Mi2 build-up phase of the Antarctic ice-sheets. The gray bar indicates the First Climatic Optimum after Pekar et al. (2002), the striped bar the Miocene Climatic Optimum after Shevenell et al. (2004).

flora that are tropically distributed today are regarded as exotic elements in the Neogene floral record and not taken into account for climate estimation by the authors. Nevertheless, including these taxa (*Reveesia* and *Gironniera*) led to results for mean annual temperature still lower than in our study (MAT 17.2–17.6 °C, Bruch and Kovar-Eder, 2003). This discrepancy in temperature values may be due to the differences of the habitats (this study: river delta close to the shore line at palaeo-sea level; Oberdorf: intramontane basin today at ~430 m altitude), due to a taphonomical bias of different plant organs (this study: wood, Oberdorf: pollen, leaves, fruits; cf. Utescher et al., 2000), or due to slightly different age (Oberdorf is based on the evolutionary stage of *Ligerimys florencei* older than the locality Rauscheröd from the Ortenburg delta plain, see Daxner-Höck et al., 1998; Oberdorf it is placed by biomagnetostratigraphic dating within the chron C5Dn between 17.23 and 17.53 Ma).

All palaeobotanical studies to date conclude that the Ottnangian localities belong to a thermal optimum — the so called "Younger Mastixioid" flora (floral complex Eichelskopf–Wiesa and Ipolytarnoc–Luzern of Mai, 1995; Meller et al., 1999). Palynological studies of Paratethyan sediments by Planderova (1990) also show, although with some uncertainties in correlation to the continental sequences of the NAFB, the highest abundance of thermophilic elements were growing during the Ottnangian. Additionally, based on ectothermic vertebrates, Böhme (2003) concluded that the peak of this warm and humid period occurred during the Ottnangian and Karpatian. Including ectothermic vertebrates to the results of this study by overlapping coexistence temperatures narrows the coexistence intervals. Böhme (2003) has shown, based on the occurrence of chameleons in Central Europe from the Eggenburgian to the Late Badenian, the MAT should have been above 17.4 °C and the long term minimal CMT above 8.0 °C. Combined (xyloflora, ectothermic vertebrates) temperature results for the Late Karpatian to Middle Badenian therefore result in a MAT ranging from 17.4 to 20.8 °C and a CMT from 8.0 to 13.3 °C. The combination of both approaches shifts the minimal interval borders 1.7 and 3.2 °C toward higher temperatures and gives narrower intervals.

Our data clearly indicate that the warmest Miocene period in Central Europe predates the Mid-Miocene Climatic Optimum usually placed either between 17 and 15 Ma (Flower and Kennett, 1994) or between 17 and 14 Ma (Shevenell et al., 2004). The paratropical climate conditions represented by the Late Ottnangian Ortenburg xyloflora (~17.5 to 17.3 Ma) are time equivalent and could probably correspond to the so called First Climatic Optimum (17.7–16.7 Ma) as determined from oxygen isotope and Mg/Ca ratios in the Tasmanian Sea (Pekar et al., 2002).

Based on the temperature values for the Late Karpatian it can be hypothesized that a significant cooling (>1.7 °C MAT, >3.4 °C CMT) occurred within the sampled time interval, e.g. between ~17.0 and ~16.3 Ma. This could correspond to the global cooling of the Mi2 build-up phase of the Antarctic ice sheet (Miller et al., 1991) between 16.5 and 16.0 Ma.

6. Conclusion

Our investigation documents the following important outcomes: (1) the Late Ottnangian (evergreen *Carapoxylon* (*Xylocarpus*) forest) seems to be the warmest period during the investigated time span, with a mean annual temperature (MAT) between 22.2 and 24.2 °C and a cold month temperature (CMT) around 16.7 °C. The Late Ottnangian is significantly warmer by at least 1.7 °C MAT and up to 3.4 °C CMT than the Mid-Miocene Climatic Optimum (i.e. MAT 17.4–20.5 °C and CMT 8.0–13.3 °C of the Late Karpatian to Middle Badenian, ~17 to ~13.8 My) and may correspond to the First Climatic Optimum (17.7–16.7 Ma) of the southern oceans (Pekar et al., 2002). (2) The cooling between both climate optima is documented by the Southern Franconian Alb xyloflora and probably reflects the Mi2 build-up phase of the Antarctic ice-sheets. (3) From Late Ottnangian to Middle Badenian the wet end-member of the climate system appears to be humid (mean annual precipitation ~830–~1.350 mm) and with relatively even distribution of rainfall throughout the year. Only the Late Karpatian (subtropical semi-deciduous limestone forest) is characterized by the occurrence of a distinct dry season probably occurring during the early spring or late autumn. (4) We attributed the Early to Middle Badenian vegetation change (subtropical oak–laurel forests to dry deciduous forests) to an increase in intra-basin relief, rather than to a different climate.

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Appendix A

Table 1
Late Ottnangian to Middle Badenian silicified wood from the NAFB: taxa, family assignment, botanical affinities, reference for taxonomical description, Nearest Living Relative (NLR) used for the Coexistence Approach (CA) analysis

Taxon	Family	Botanical Affinity	Reference	NLR used for CA analysis
Pistacioxylon holleisii	Anacardiaceae	*Pistacia*	Selmeier (2000a)	*Pistacia* sp.
Pistacioxylon praeterebinthus	Anacardiaceae	*Pistacia terebinthus*	Gottwald (2004)	*Pistacia terebinthus*
Pistacioxylon sp.	Anacardiaceae	*Pistacia*	Gottwald (2004)	*Pistacia* sp.
Palmoxylon lacunosum	Arecaceae	Palmae	Mägdefrau, 1956; Selmeier, 1998b	Palmae
Palmoxylon lacumnosum verum	Arecaceae	Palmae	Mägdefrau, 1956; Selmeier, 1998b	Palmae
Palmoxylon sp. — forma P.P.	Arecaceae	*Phoenix dactylifera*	Gottwald (2004)	*Phoenix* sp.
Palmoxylon sp. — forma R	Arecaceae	Rattan group	Gottwald (2004)	Rattan group
Palmoxylon sp.	Arecaceae	Palmae		Palmae
Bombacoxylon oweni	Bombacaceae	*Bombax*	Selmeier, 1985, 1999; Gottwald, 1997;	*Bombax* sp.
Palae–Robinioxylon zirkelii	Caesalpiniaceae	*Robinia*	Selmeier, 1979, 1984c	*Robinia* sp.
Palae–Robinioxylon sclerothylloides	Caesalpiniaceae	*Robinia*	Gottwald (2004)	*Robinia* sp.
Robinioxylon sp.	Caesalpiniaceae	*Robinia*		*Robinia* sp.
Capparisoxylon holleisii	Capparaceae	*Capparis*	Selmeier (2005)	*Capparis* sp.
Cupressinoxylon sp.	Cupressaceae	*Cupressus*	Gottwald (2002)	*Cupressus* sp.
Juniperoxylon sp.	Cupressaceae	*Juniperus*	Gottwald (2004)	*Juniperus* sp.
Shoreoxylon holleisii	Dipterocarpaceae	*Shorea*	Selmeier (1998a)	Dipterocarpaceae
Euebenoxylon polycristallum	Ebenaceae	*Diospyros* (*D. apiculata*, *D. ebenoides*)	Gottwald (1997)	*Diospyros* sp.
Eudiospyroxylon cf. *multiradiatum*	Ebenaceae	*Diospyros* (*D. lanceolata*, *D. hebecarpa*, *D. bourdilloni*, *D. burmanica*)	Gottwald (1997)	*Diospyros* sp.
Eleagnoxylon gregori	Eleagnaceae	*Eleagnus angustifolia*	Gottwald (2004)	Eleagnus sp.
Ericaceoxylon macroporosum	Ericaceae	Ericaceae	Gottwald (1997)	Ericaceae
Euphorbioxylon ortenburgense	Euphorbiaceae	Crotonoideae	Selmeier (1998c)	Euphorbiaceae
Castanoxylon zonatum	Fagaceae	*Castanopsis*	Selmeier, 1970a,b; Gottwald, 1997, 2002, 2004	*Castanopsis* sp., *Lithocarpus* sp.
Castanoxylon bavaricum	Fagaceae	*Castanea*	Selmeier, 1970a,b; Gottwald, 1997, 2002	*Castanea* sp.
Quercoxylon sp. 1	Fagaceae	Weißeichen (Sekt. *Lepidobalanus*, ? *Macrobalanus*), cf. *Quercus sessiliflora*, *Q. pedunculata*, *Q. alba*, *Q. crispula*	Selmeier, 1992	*Quercus* sp.
Quercoxylon sp. 2	Fagaceae	Roteichen (Sekt. *Erythrobalanus*, ?*Lepidobalanus*)	Selmeier, 1992a,b	*Quercus* sp.
Quercoxylon cerrisoides	Fagaceae	Roteichen (Sekt. *Erythrobalanus*), *Quercus cerris*	Gottwald (2004)	*Quercus* sp.
Homalioxylon europaeum	Flacourtiaceae	*Homalium*	Gottwald (1997)	*Homalium* sp.
Liquidambaroxylon sp.	Hamamelidaceae	*Liquidambar*	Selmeier (2002a)	*Liquidambar* sp.
Icacinoxylon cantleyoides	Icacinaceae	*Cantleya*	Gottwald (2002)	Icacinaceae
Icacinoxylon crassiradiatum	Icacinaceae	*Cantleya*	Gottwald (2002)	Icacinaceae
Eucaryoxylon rauscheroedense	Juglandaceae	*Carya* (*C. tokinense*)	Selmeier, 2001a,b	*Carya* sp.

(continued on next page)

Table 1 (*continued*)

Taxon	Family	Botanical Affinity	Reference	NLR used for CA analysis
Pistacioxylon holleisii	Anacardiaceae	*Pistacia*	Selmeier (2000a)	*Pistacia* sp.
Eucaryoxylon macroporosum	Juglandaceae	*Carya* (*C. tonkinense*)	Gottwald (2002)	*Carya* sp.
Eucaryoxylon cristalliferum	Juglandaceae	*Carya* (*C. tonkinense*)	Gottwald (2002)	*Carya* sp.
Eucaryoxylon guembelii	Juglandaceae	*Carya* (*C. tonkinense*)	Müller-Stoll and Mädel-Angeliewa (1983)	*Carya* sp.
Eucaryoxylon macrocristallum	Juglandaceae	*Carya* (*C. tonkinense*)	Gottwald (2004)	*Carya* sp.
Caryojuglandoxylon sp.	Juglandaceae	*Juglans*, *Carya*	Selmeier, 1986a; Gottwald, 2004	*Juglans* sp.
Caryojuglandoxylon schenkii	Juglandaceae	*Juglans*, *Carya*	Gottwald (2004)	*Juglans* sp.
Cinnamomoxylon areolosum	Lauraceae	*Cinnamomum parthenoxylon*	Gottwald (1997)	*Cinnamomum* sp.
Cinnamomoxylon limagnense	Lauraceae	*Cinnamomum* ssp. (part of *Lindera*, *Litsea*, *Persea*)	Gottwald, 1997; Selmeier, 1999	*Cinnamomum* sp.
Cinnamomoxylon seemannianum	Lauraceae	*Cinnamomum* ssp. (part of *Lindera*, *Litsea*, *Persea*)	Selmeier, 1967, 1969, 1999; Gottwald, 1997;	*Cinnamomum* sp.
Cinnamomoxylon franconicum	Lauraceae	*Cinnamomum* ssp. (part of *Lindera*, *Litsea*, *Persea*)	Gottwald (2004)	*Cinnamomum* sp.
Laurinoxylon cristallum	Lauraceae	*Cinnamomum*, *Actinodaphne*, *Litsea*, *Persea*	Gottwald (1997)	Lauraceae
Laurinoxylon annularis	Lauraceae	*Neolitsea*, *Actinodaphne*, *Persea*	Gottwald (1997)	Lauraceae
Laurinoxylon litseoides	Lauraceae	*Neolitsea*, *Actinodaphne*, *Persea*	Gottwald (2004)	Lauraceae
Laurinoxylon sp.	Lauraceae	Lauraceae	Gottwald (1997)	Lauraceae
Cedreloxylon cristalliferum	Meliaceae	*Toona sinensis*	Gottwald, 1997, 2002; Selmeier, 2003b, 2004; Gottwald, 2004	*Toona sinensis*
Cedreloxylon sp.	Meliaceae	*Toona sinensis*		*Toona sinensis*
			Selmeier (2003b)	
Carapoxylon xylocarpoides	Meliaceae	*Xylocarpus* (sensu *Carapa xylocarpoides*)	Gottwald, 1997; Selmeier, 1999	*Xylocarpus* sp.
Carapoxylon ortenburgense	Meliaceae	*Xylocarpus*, *Carapa*	Selmeier, 1985, 1989a,b,c	*Xylocarpus* sp.
Carapoxylon ornatum	Meliaceae	*Xylocarpus*, *Carapa*	Mädel, 1960; Selmeier, 1985, 1989a,b,c	*Xylocarpus* sp.
Carapoxylon sp.	Meliaceae	*Xylocarpus* (sensu *Carapa xylocarpoides*)	Gottwald (1997)	*Xylocarpus* sp.
Ingoxylon bavaricum	Mimosaceae	*Inga* (*Albizzia*)	Selmeier, 1973a, 1989c; Gottwald, 2002	*Albizzia* sp.
Ingoxylon sp.	Mimosaceae	*Inga* (*Albizzia*)		*Albizzia* sp.
Dichrostachyoxylon royaderum	Mimosaceae	*Dichrostachys*	Gottwald (2002)	*Acacia* sp.
Dichrostachyoxylon cf. *royaderum*	Mimosaceae	*Dichrostachys*	Gottwald (2004)	*Acacia* sp.
Dichrostachyoxylon zirkelii	Mimosaceae	*Dichrostachys*, *Acacia catechu*	Selmeier, 1986a,b, 1988; Privé-Gill et al., 1992; Gottwald, 2004	*Acacia catechu*
Dichrostachyoxylon acaciaeformae	Mimosaceae	*Dichrostachys*	Gottwald (2004)	*Acacia* sp.
Dichrostachyoxylon sp.	Mimosaceae	*Dichrostachys*		*Acacia* sp.
Dichrostachyoxylon thyllosum	Mimosaceae	aff. *Acacia dealbata*	Gottwald (2002)	*Acacia* sp.
Euacacioxylon taenialis	Mimosaceae	*Acacia gerrardi*, *A. raddiana*	Gottwald (2004)	*Acacia* sp.
Moroxylon sturmii	Moraceae	*Morus*	Selmeier (1993)	*Morus nigra*, *M. rubrus*
Myricoxylon zonatum	Myricaceae	*Myrica cerifera*	Gottwald (1997)	Myricaceae
Periplocoxylon	Periplocaceae	*Periplocoxylon graeca*	Gottwald (2004)	*Periplocoxylon*

Table 1 (*continued*)

Taxon	Family	Botanical Affinity	Reference	NLR used for CA analysis
Pistacioxylon holleisii praegraeca	Anacardiaceae	*Pistacia*	Selmeier (2000a)	*Pistacia* sp. *graeca*
Platanoxylon sp.	Platanaceae	*Platanus*	Selmeier, 1989c, 1996; Gottwald, 2004	*Platanus* sp.
Podocarpoxylon sp.	Podocarpaceae	*Podocarpus*	Gottwald (2004)	*Podocarpus* sp.
Prunioxylon sp.	Rosaceae	*Prunus*	Selmeier (1984a)	*Prunus* sp.
Crataegoxylon cristalliferum	Rosaceae	*Crateagus*	Selmeier, 1984a; Gottwald, 2004	*Crateagus* sp.
Bumelioxylon holleisii	Sapotaceae	*Bumelia*	Selmeier (1991)	*Bumelia* sp.
Bumelioxylon cf. *holleisii*	Sapotaceae	*Bumelia*	Gottwald (2004)	*Bumelia* sp.
Taxodioxylon gypsaceum	Taxodiaceae	Taxodiaceae	Selmeier, 1972, 1999	Taxodiaceae
Taxodioxylon sp.	Taxodiaceae	Taxodiaceae	Selmeier, 1972, 1999	Taxodiaceae
Glyptostroboxylon tenerum	Taxodiaceae	*Glyptostrobus*	Gottwald (2004)	Taxodiaceae
Grewioxylon microporosum	Tiliaceae	*Grewia* (*G. tiliaefolia*)	Gottwald, 2002, 2004	*Grewia* sp.
Grewioxylon auctumnalis	Tiliaceae	*Grewia* (*G. tiliaefolia*, *G. elastica*)	Gottwald, 1997, 2004	*Grewia* sp.
Grewioxylon neumaieri	Tiliaceae	*Grewia* ssp. (? *G. hirsuta*)	Selmeier, 1985; Gottwald, 1997; Selmeier, 1998b, 2000b	*Grewia* sp.
Grewioxylon ortenburgense	Tiliaceae	*Grewia* ssp. (? *G. hirsuta*)	Selmeier, 1985; Gottwald, 1997; Selmeier, 1998b, 2000b	*Grewia* sp.
Grewioxylon sp.	Tiliaceae	*Grewia* ssp.	Selmeier, 1985; Gottwald, 1997; Selmeier, 1998b, 2000b	*Grewia* sp.
Ulmoxylon sp.	Ulmaceae	*Ulmus*	Gottwald (2004)	*Ulmus* sp.
Celtixylon cristalliferum	Ulmaceae	*Celtis*	Selmeier (1989a)	*Celtis* sp.
Celtixylon sp.	Ulmaceae	*Celtis*	Gottwald (2004)	*Celtis* sp.

Table 2
Taxonomic composition and references of the Late Ottnangian Ortenburg xyloflora (locality Rauscheröd). Number of samples in brackets

Xyloflora Ortenburg Gravel, Rauscheröd ($n_{\text{sample}} = 183$)

Late Ottnangian (MN4b), ~17.5 to 17.3 My

Latitude 48.5667 N, Longitude 13.2667 E

Taxon	Family	Reference
Palmoxylon sp. (9)	Arecaceae	Selmeier (1999)
Bombacoxylon oweni (5)	Bombacaceae	Selmeier, 1985; Gottwald, 1997; Selmeier, 1999
Euebenoxylon polycristallum (1)	Ebenaceae	Gottwald, 1997; Selmeier, 1999
Eudiospyroxylon cf. *multiradiatum* (1)	Ebenaceae	Gottwald, 1997; Selmeier, 1999
Ericaceoxylon macroporosum (1)	Ericaceae	Gottwald, 1997; Selmeier, 1999
Euphorbioxylon ortenburgense (1)	Euphorbiaceae	Selmeier, 1998c, 1999
Castanoxylon zonatum (2)	Fagaceae	Gottwald (1997)
Castanoxylon bavaricum (4)	Fagaceae	Gottwald (1997)
Quercoxylon sp. (2)	Fagaceae	Selmeier (1999)
Homalioxylon europaeum, *H.* sp. (3)	Flacourtiaceae	Gottwald, 1997; Selmeier, 1999
Eucaryoxylon rauscheroedense (1)	Juglandaceae	Selmeier (2001a)
Cinnamomoxylon areolosum (1)	Lauraceae	Gottwald (1997)
Cinnamomoxylon limagnense (1)	Lauraceae	Gottwald (1997)
Cinnamomoxylon cf. *limagnense* (1)	Lauraceae	Selmeier (1999)
Cinnamomoxylon seemannianum (2)	Lauraceae	Gottwald (1997)
Cinnamomoxylon sp. div. (8)	Lauraceae	Selmeier, 1998b, 1999

(*continued on next page*)

Table 2 (*continued*)

Xyloflora Ortenburg Gravel, Rauscheröd ($n_{\text{sample}}=183$)		
Late Ottnangian (MN4b), ~17.5 to 17.3 My		
Latitude 48.5667 N, Longitude 13.2667 E		
Laurinoxylon cristallum (1)	Lauraceae	Gottwald (1997)
Laurinoxylon annularis (2)	Lauraceae	Gottwald (1997)
Laurinoxylon sp. (2)	Lauraceae	Gottwald (1997)
Cedreloxylon cristalliferum (1)	Meliaceae	Gottwald, 1997; Selmeier, 1999
Carapoxylon xylocarpoides (2)	Meliaceae	Gottwald, 1997; Selmeier, 1999
Carapoxylon ortenburgense (17)	Meliaceae	Selmeier, 1983, 1985; Gottwald, 1997; Selmeier, 1999
Carapoxylon cf. *ornatum* (2)	Meliaceae	Selmeier, 1989a,b,c
Carapoxylon sp. (56)	Meliaceae	Selmeier (1999)
Myricoxylon zonatum (4), *Myricoxylon* sp. (15)	Myricaceae	Gottwald, 1997; Selmeier, 1999
Taxodioxylon sp. (14)	Taxodiaceae	Selmeier, 1998a,b, 1999
Grewioxylon auctumnalis (5)	Tiliaceae	Gottwald, 1997; Selmeier, 1999
Grewioxylon neumaieri (3)	Tiliaceae	Selmeier, 1985; Gottwald, 1997; Selmeier, 1999
Grewioxylon ortenburgense (6)	Tiliaceae	Selmeier, 1985, 1999, 2000a,b
Grewioxylon sp. (11)	Tiliaceae	Selmeier, 1985, 1999, 2000b

Table 3
Localities, taxonomic composition and references of the Late Karpatian Franconian Alb xyloflora. Number of samples in brackets

Localities Late Karpatian				
$n_{\text{samples}}=688$, $n_{\text{localities}}=26$				
Lower MN5, OSM B/C, ~16.4–16.7 My				
Locality	Taxa	Latitude	Longitude	Reference
Adelschlag	*Cedreloxylon* sp. (3), *Laurinoxylon* (*?Cinnamomoxylon*) sp. (7), *Dichrostachyoxylon* sp. (4), *Robinioxylon* sp. (5), *Palmoxylon* sp. (3)	48.8333	11.2167	Selmeier, 2003a,b
Attenfeld	*Bumelioxylon holleisii* (1), *Bumelioxylon* cf. *holleisii* (1), *Capparisoxylon holleisii* (1), *Caryojuglandoxylon* sp. (1), *Caryojuglandoxylon schenkii* (2), *Castanoxylon zonatum* (15), *Cedreloxylon cristalliferum* (14), *Cedreloxylon* sp. (2), *Celtixioxylon cristalliferum* (3), *Celtixylon* sp. (1), *Cinnamomoxylon franconicum* (1), *Crataegoxylon cristalliferum* (3), *Cupressinoxylon* sp. (1), *Dichrostachyoxylon royaderum* (4), *Dichrostachyoxylon* cf. *royaderum* (1), *Dichrostachyoxylon acaciaeformae* (1), *Dichrostachyoxylon zirkelii* (2), *Dichrostachyoxylon* sp. (6), *Euacacioxylon taenialis* (1), *Eucaryoxylon crystallophorum* (4), *Eucaryoxylon macrocristallum* (1), *Grewioxylon auctumnalis* (2), *Grewioxylon microporosum* (2), *Glyptostroboxylon tenerum* (4), *Icacinoxylon cantleyoides* (1), *Icacinoxylon crassiradiatum* (3), *Juniperus sp.* (2), *Laurinoxylon litseoides* (1), *Laurinoxylon* sp. (34), *Palae–Robinioxylon sclerothylloides* (3), *Pistacioxylon holleisii* (2), *Pistacioxylon praeterebinthus* (1), *Pistacioxylon* sp. (1), *Prunoxylon* sp. (4), *Palmoxylon* sp. (1), *Platanoxylon* sp. (6), *Podocarpoxylon* sp. (4), *Robinioxylon* sp. (6), *Shoreoxylon holleisii* (1), *Taxodioxylon* sp. (17), *Ulmoxylon* sp. (4)	48.7667	11.1833	Selmeier, 1970a,b, 1984a, 1986a, 1989a, 1991, 1998a,b, 2000a, 2001b; Gottwald, 2002; Selmeier, 2003a,b, 2004; Gottwald, 2004, Selmeier, 2005
Bergheim	*Caryojuglandoxylon schenkii* (1), *Caryojuglandoxylon* sp. (2), *Castanoxylon zonatum* (5), *Cedreloxylon cristalliferum* (2), *Celtixioxylon* sp. (1), *Cinnamomoxylon franconicum* (2), *Cinnamomoxylon seemannianum* (1), *Crataegoxylon cristalliferum* (1), *Dichrostachyoxylon royaderum* (1), *Euacacioxylon taenialis* (1), *Eucaryoxylon* sp. (2), *Grewioxylon microporosum* (2), *Glyptostroboxylon tenerum*	48.7667	11.2667	Mägdefrau, 1956; Selmeier, 1986a; Gottwald, 2002; Selmeier, 2003a; Gottwald, 2004

Table 3 (*continued*)

Localities Late Karpatian

$n_{\mathrm{samples}}=688$, $n_{\mathrm{localities}}=26$

Lower MN5, OSM B/C, ~16.4–16.7 My

Locality	Taxa	Latitude	Longitude	Reference
Bergheim	(2), *Icacinoxylon cantleyoides* (2), *Icacinoxylon* sp. (1), *Laurinoxylon litseoides* (1), *Laurinoxylon* sp. (13), *Robinioxylon* sp. (2), *Palae–Robinioxylon sclerothylloides* (2), *Palmoxylon lacunosum* (1), *Palmoxylon* sp. — forma P.P. (2), *Palmoxylon* sp. — forma R. (1), *Palmoxylon* sp. (2), *Periplocoxylon praegraeca* (1), *Platanoxylon* sp. (3), *Quercoxylon cerrisoides* (1), *Ulmoxylon* sp. (2)			
Eichstätt	*Carapoxylon* sp. (1), *Laurinoxylon* (*?Cinnamomoxylon*) sp. (2)	48.8833	11.1833	Selmeier (2003a)
Egweil	*Caryojuglandoxylon schenkii* (6), *Caryojuglandoxylon* sp. (3), *Castanoxylon zonatum* (4), *Cedreloxylon cristalliferum* (15), *Celtixylon* sp. (6), *Cinnamomoxylon seemannianum* (1), *Cinnamomoxylon franconicum* (2), *Crataegoxylon cristalliferum* (1) *Dichrostachyoxylon thyllosum* (2), *Dichrostachyoxylon zirkelii* (1), *Dichrostachyoxylon acaciaeformae* (1), *Dichrostachyoxylon* cf. *royaderum* (1), *Euacacioxylon taenialis* (2), *Eleagnoxylon gregori*(1), *Eucaryoxylon macroporosum* (1), *Eucaryoxylon macrocristallum* (1), *Grewioxylon auctumnalis* (1), *Grewioxylon microporosum* (4), *Icacinoxylon cantleyoides* (3), *Icacinoxylon crassiradiatum* (4), *Laurinoxylon litseoides* (2), *Laurinoxylon* sp. (9), *Palae–Robinioxylon sclerothylloides* (1), *Podocarpoxylon* sp. (2), *Quercoxylon cerrisoides* (1), *Ulmoxylon* sp. (3)	48.7667	11.1750	Selmeier, 1984a,b; Gottwald, 2002; Selmeier, 2003a; Gottwald, 2004
Eitensheim	*Liquidambaroxylon* sp. (1)	48.8167	11.3167	Selmeier (2003a)
Hofstetten	*Carapoxylon* sp. (1)	48.8667	11.3333	Selmeier (2003a)
Gaimersheim	*Robinioxylon* sp. (1)	48.8167	11.3667	Selmeier (2003a)
Igstätterhof	*Castanoxylon zonatum* (1), *Laurinoxylon litseoides* (1), *Laurinoxylon* (*?Cinnamomoxylon*) sp. (4), *Grewioxylon* ` *microporosum* (1), *Pistacioxylon* sp. (1), *Taxodioxylon* sp. (1)	48.7667	11.1750	Gottwald, 2002; Selmeier, 2003a; Gottwald, 2004
Jettingen	*Platanoxylon* sp. (1)	48.3621	10.4055	Selmeier (1989c)
Joshofen	*Cinnamomoxylon seemannianum* (1), *Laurinoxylon* (*?Cinnamomoxylon*) sp. (5), *Platanoxylon* sp. (5)	48.7500	11.2167	Selmeier, 1967, 2003a
Möckenlohe	*Dichrostachyoxylon* sp. (3), *Ingoxylon bavaricum* (1), *Laurinoxylon* (*?Cinnamomoxylon*) sp. (10), *Liqudamberoxylon* sp. (4), *Robinioxylon* sp. (4)	48.8167	11.2167	Selmeier, 1973a,b, 1989c, 2003a
Nassenfels	*Castanoxylon zonatum* (1), *Laurinoxylon* (*?Cinnamomoxylon*) sp. (2), *Robinioxylon* sp. (11), *Palmoxylon lacunosum verum* (1), *Platanoxylon* sp. (1)	48.8000	11.2667	Selmeier, 1998b, 2003a
Neuburg an der Donau	*Dichrostachyoxylon* sp. (1), *Laurinoxylon* (*?Cinnamomoxylon*) sp. (4), *Liquidambaroxylon* sp. (1), *Robinioxylon* sp. (1)	48.7333	11.1833	Selmeier (2003a)
Oberzell	*Grewioxylon auctumnalis* (1)	48.8500	11.3000	Gottwald (2004)
Ochsenfeld	*Cedreloxylon* sp. (1)	48.8500	11.1667	Selmeier, 2003a,b
Pettenhofen	*Caryojuglandoxylon* sp. (1)	48.7833	11.3000	Gottwald (2004)
Prielhof	*Castanoxylon zonatum* (17), *Cedreloxylon* sp. (3), *Dichrostachyoxylon* sp. (36), *Euebenoxylon* vel *Eudiospyroxylon* sp. (1) *Eucaryoxylon* sp. (2), Gymnospermae indet. (19), *Ingoxylon bavaricum* (6), *Ingoxylon* sp. *(17)*, *Laurinoxylon* (*?Cinnamomoxylon*) sp. (77), *Liquidambaroxylon* sp. (17), *Robinioxylon* sp. (36), *Palmoxylon* sp. (6), *Platanoxylon* sp. (15)	48.8250	11.1900	Selmeier, 1973a, 1986a, 1989a,b,c, 2003a,b
Ried	*Robinioxylon* sp. (1)	48.7500	11.1833	Selmeier (2003a)
Roßhaupten	*Robinioxylon* sp. (1)	48.4309	10.4697	Selmeier (2003a)
Unterstall	*Palmoxylon* sp. (1)	48.7667	11.2167	Selmeier (2003a)

(*continued on next page*)

Table 3 (*continued*)

Localities Late Karpatian

$n_{\text{samples}}=688$, $n_{\text{localities}}=26$

Lower MN5, OSM B/C, ~16.4–16.7 My

Locality	Taxa	Latitude	Longitude	Reference
Wagenhofen	*Eucaryoxylon guembelii* (1)	48.7000	11.1667	Müller-Stoll and Mädel-Angeliewa, 1983; Selmeier, 2003a
Weißenkirchen	*Dichrostachyoxylon* sp. (6), *Liquidambaroxylon* sp. (1), *Robinioxylon* sp. (5)	48.8667	11.2000	Selmeier, 2002a, 2003a
Wettstetten	*Robinioxylon sp.* (1)	48.8333	11.4167	Selmeier (2003a)
Wittenfeld	*Caryojuglandoxylon schenkii* (1), *Castanoxylon zonatum* (2), *Cedreloxylon cristalliferum* (5), *Cinnamomoxylon franconicum* (1), *Dichrostachyoxylon royaderum* (1), *Grewioxylon auctumnalis* (1), *Grewioxylon microporosum* (1), *Ulmoxylon* sp. (2)	48.8333	11.2000	Gottwald, 2002; Selmeier, 2003a
Ziegelau	*Dichrostachyoxylon royaderum* (1), *Dichrostachyoxylon* sp. (1), *Laurinoxylon* (?*Cinnamomoxylon*) sp. (1), *Liqudamberoxylon* sp. (1), *Robinioxylon* sp. (1)	48.7550	11.1667	Selmeier, 2001a,b; Gottwald, 2002; Selmeier, 2003a

Table 4

Localities, taxonomic composition and references of the Early Badenian xyloflora. Number of samples in brackets

Localities Early Badenian–upper part Older Series xyloflora

$n_{\text{samples}}=147$, $n_{\text{localities}}=20$

MN5, OSM 3–5, OSM C/D, 16.3–~15.5 My

Locality	Taxa	Altitude m NN	Latitude	Longitude	Reference
Affalterbach	*Quercoyxylon* sp. 1 (1)	448	48.5667	11.5333	Selmeier (2002b)
Allkofen	*Quercoyxylon* sp. 1 (3)	365–395	48.8333	12.2667	Quiel, 1971; Selmeier, 1992a
Ambach	*Liquidambaroxylon* sp. (2), *Palae–Robinioxylon zirkelii* (1), *Platanoxylon* sp. (2), *Quercoyxylon* sp. 1 (1)	415–430	48.6500	11.1000	Selmeier, 2002b, 2003a
Dittenkofen	*Cedreloxylon* sp. (1)	410	48.6333	12.6167	Selmeier (2003b)
Eggmühl	*Taxodioxylon gypsaceum* (1)	365–395	48.8500	12.1833	Quiel, 1971; Selmeier, 1972
Ergertshausen	*Castanoxylon zonatum* (1), *Laurinoxylon* sp. (2)	410–420	48.7000	11.1500	Selmeier, 1989c, 1992b, 2002b, 2003a
Hagenauer Forst	*Palmoxylon lacunosum* (1)	430–450	48.5667	11.2350	Mägdefrau (1956)
Högenau	*Laurinoxylon* sp. (7)	420–430	48.5833	11.2667	Selmeier (1989c)
Hollenbach	*Liquidamberoxylon* sp. (1)	410–420	48.6667	11.1333	Selmeier, 2002b, 2003a
Inkofen	*Laurinoxylon* sp. (1), *Quercoyxylon* sp. 2 (1)	365–395	48.8333	12.2500	Quiel, 1971; Selmeier, 1992a
Mettenhausen	*Taxodioxylon gypsaceum* (1)	390–398	48.6167	12.7167	Buchner, 1963; Selmeier, 1972
Oberbachern	*Quercoyxylon* sp. 1 (9), *Quercoyxylon* sp. 2 (5)	440–450	48.5333	11.0833	Selmeier (1992a)
Obergraßlfing	*Quercoyxylon* sp. 1 (2)	365–395	48.8333	12.2833	Quiel, 1971; Selmeier, 1992a
Pöttmes	*Dichrostachyoxylon* ?cf. *zirkelii* (1)	?	48.5833	11.1000	Selmeier (1989c)
Pullach	*Cedreloxylon* sp. (1)	365–395	48.8333	12.3167	Quiel, 1971; Selmeier, 2003b
Rohrenfels	*Platanoxylon* sp. (2)	410	48.6833	11.1667	Selmeier, 2002b, 2003a
Schrobenhausen	*Castanoxylon zonatum* (2), *Dichrostachyoxylon* ?cf. *zirkelii* (1), *Laurinoxylon* sp. (80), *Platanoxylon* sp. (1)	?420–440	48.5500	11.2667	Selmeier, 1970a, 1989c, 1992b
Sinning	*Ulmoxylon* sp. (2), *Liquidambaroxylon* sp. (1), *Quercoylon* sp. 1 (1)	410–420	48.7000	11.1000	Selmeier, 2002b, 2003a
Straß	*Castanoxylon zonatum* (1), *Liquidamberoxylon* sp. (2), *Palae–Robinioxylon zirkelii* (5), *Platanoxylon* sp. (2), *Quercoyxylon* sp. 1 (1)	410–425	48.7000	11.0500	Selmeier, 1992b, 2002a, 2003a
Unterbachern	*Platanoxylon* sp. (1)	435–440	48.5333	11.1000	Selmeier, 1992a, 1996

Table 5
Localities, taxonomic composition and references of the Middle Badenian xyloflora. Number of samples in brackets

Localities Middle Badenian–upper Middle Series xyloflora

$n_{\text{samples}}=26$, $n_{\text{localities}}=18$

MN6, OSM 8–10, OSM F, ~14.3–~13.9 My

Locality	Taxon	Altitude	Latitude	Longitude	Reference
Attenhausen, (around bentonite)	*Taxodioxylon gypsaceum* (3)	?	48.5667	12.0000	Selmeier (1973b)
Au in der Hallertau (?above bentonite)	*Moroxylon sturmii* (1)	?	48.5500	11.7500	Selmeier (1993)
Bruckberg (above bentonite)	*Palaeo–Robinioxylon zirkelii* (1)	?	48.5400	11.9900	Selmeier, 1979, 1986a,b, 1989a,b,c
Derching	*Cedreloxylon cristalliferum* (1), *Palaeo–Robinioxylon zirkelii* (1), *Taxodioxylon* sp. (1)	?	48.4000	10.9667	Selmeier, 1972, 1989a,b,c; Gottwald, 2004
Engelsdorf (2 m above bentonite)	*Taxodioxylon* sp. (1)	483	48.5500	11.9833	This paper
Gammelsdorf (around and within bentonite)	*Cinnamomoxylon* cf. *seemannianum* (1), *Platanoxylon* sp. (2)	?	48.5500	11.9500	Selmeier, 1989a,b,c, this paper
Geierlambach	*Palaeo–Robinioxylon zirkelii* (1)	?	48.4833	11.6667	Selmeier, 1989a,b,c
Malgersdorf 1 (20 m below bentonite)	*Palaeo–Robinioxylon sp.* (1)	410	48.5500	12.7500	This paper
Malgersdorf (around bentonit)	*Dichrostachyoxylon* ?cf. *zirkelii* (1)	?	48.5333	12.7500	Selmeier, 1989a,b,c
Narnham (few meter below bentonite)	*Dichrostachyoxylon zirkelii* (1)	?	48.5667	12.7500	Selmeier, 1986a,b, 1988
Niederkam (around bentonite)	*Dichrostachyoxylon* ?cf. *zirkelii* (1)	?	48.5000	12.1667	Selmeier, 1989a,b,c
Obergriesbach	*Palaeo–Robinioxylon zirkelii* (1)	?	48.4167	11.0667	Selmeier, 1989a,b,c
Oberlenghart (2 m above bentonite)	*Dichrostachyoxylon* sp. (1)	485	48.5500	12.0500	This paper
Oberschneitbach, (few meter below bentonite)	*Cinnamomoxylon* cf. *seemannianum* (1)	495–500	48.4500	11.0833	Selmeier (1969)
Peterswahl (3 m above bentonite)	*Taxodioxylon* sp. (1)	487	48.5500	11.9000	This paper
Pfaffenzell (few meter below bentonite)	*Laurinoxylon* sp. (1), *Palaeo–Robinioxylon* sp. (1)	?	48.4356	11.0100	Selmeier (2002b)
Unterzell (around bentonite)	*Palaeo–Robinioxylon* sp. (1), *Quercoxylon* sp. 1 (1)	?	48.3833	11.0167	Selmeier (2002b)
Zahling (around bentonite)	*Platanoxylon* sp. (1)	?	48.4333	11.0333	Selmeier (2002b)

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Further-reading

All climate data provided here are accessible by the world data base PANGAEA under the reference Böhme, M., Bruch, A.A, Selmeier, A., 2007. Miocene palaeoclimate reconstructions from the North Alpine Foreland Basin in Germany. PANGAEA., doi:10.1594/PANGAEA.587447.