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The floral change in the Tertiary of the Rhön mountains (Germany)

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ABSTRACT. A total of 438 species from 8 stratigraphically well-dated macro- and microfloras from the Rhön mountains (Central Germany) are biostratigraphically and palaeoecologically analysed. The formations are stratigraphically discontinuous but span the age range mid/late Eocene to late Pliocene (ca. 39 Ma to 2.15 Ma). The primary compositional elements and ecological character of each formation's flora is as follows:

– Kaolinitic Formation: Eocene with *Beckettia, Steinhauera, Sterculia, Wardensheppeya*; Pollenflora of SPP-zone 16/17 (Bartonian).

– Sieblos Formation: early Oligocene. Palynological spectrum including *Boehlensipollis hohlii*; invasion of Arctotertiary elements. Many *Nymphaea* remains.

– Kühnstein Formation: "Marxheim"– pollen-spectrum of early late Oligocene. No macroflora.

– Oberleichtersbach Formation: dated to the late Oligocene by small mammals and gastropods. 100 plant species of fruits and seeds. Mixed mesophytic forest of the Carpino-Ostryon-type; many semihumid elements and herbs.

– *Escheri* Formation: beds south of Theobaltshof; small flora with *Alnus julianiformis, Fagus deucalionis, Quercus drymeja* and *Q. kubinyi.* Palynological ratio between *Triatriopollenites coryphaeus* and *T. rurensis* indicates early Miocene.

– Kaltennordheim Formation: fossil floras of Kaltennordheim, Hochrain, Bauersberg and Lettengraben with more than 65 plant species, characterized by typical elements of the so called Younger Mastixioid floras (*Eomastixia hildegardis*); optimal warm, humid climatic phase. Latest early Miocene to early middle Miocene.

– Wollbach Formation: dominated by *Quercus pseudocastanea*, together with *Acer pseudomiyabei, Alnus ducalis, Buxus pliocenica,* and *Eucommia europaea.* Warm temperate, deciduous broad-leaved forest of late Miocene affinity.

– *Borsoni* Formation: 130 plant species from six localities belonging to 59 families. Deciduous broad-leaved warm-temperate forests and different aquatic- and swamp-plant taphocoenoses with many exotic species. Marked east-European influence. Two different floral complexes document a late Pliocene warming (Gerstungen, Oberzella) and an intra-Pliocene cooling (Kaltensundheim).

KEY WORDS: macrofloras, microfloras, floral change, Tertiary, Rhön mountains, Germany

INTRODUCTION

The Rhön mountains, a volcanic low mountain range in the centre of Germany (Fig. 1), lies between Bavaria, Hesse and Thuringia (Schmeer 1964) and yield numerous Tertiary floras of different ages. Knowledge of these plant fossils goes back to the 19th century (Zenker 1833, Hassencamp 1858, 1860, Heer 1859) and increased after investigations in recent years (Geyer 2002, Gümbel & Mai 2002, 2004, 2006, Mai in press). Fossil fruits and seeds, leaves, pollen and spores, woods and charophytes have been investigated. More than 450 fossil plant species have been discovered and described. These plant fossils are well placed stratigraphically by association with fossil gastropods and mammalian remains, together with several radiometric dates of the volcanites (Lippoldt 1978). The sequence of floras (Fig. 2) started with many gaps in the Eocene and terminated in the Upper Pliocene (Martini et al. 1994). The floral change over this long time (39 Ma – 2.47 Ma) was very significant.

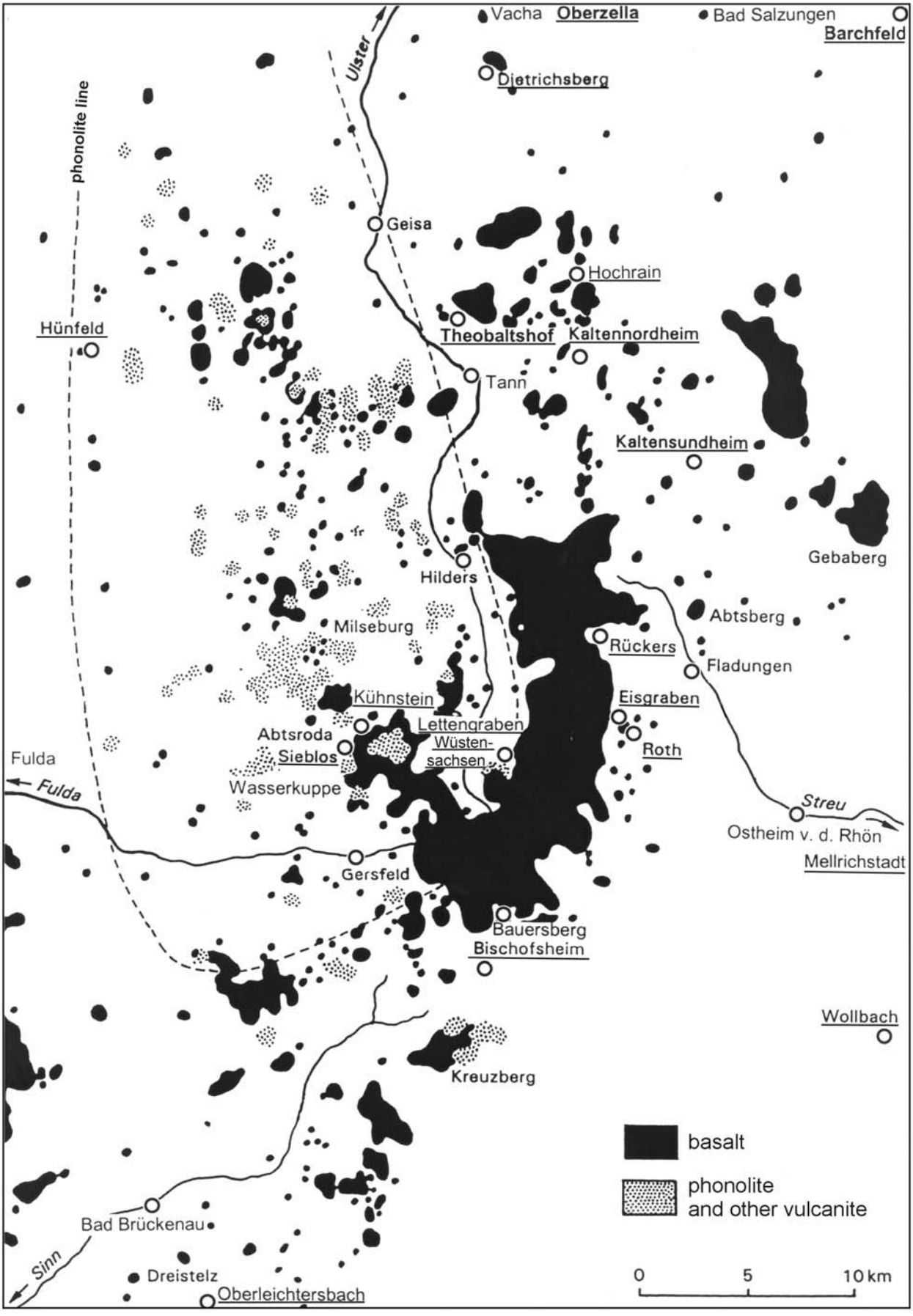

Fig. 1. The distribution of volcanic rocks with the main fossiliferous places in the Rhön mountains. After Gümbel & Mai (2006) – localities, and Schmeer (1964) – volcanic rocks

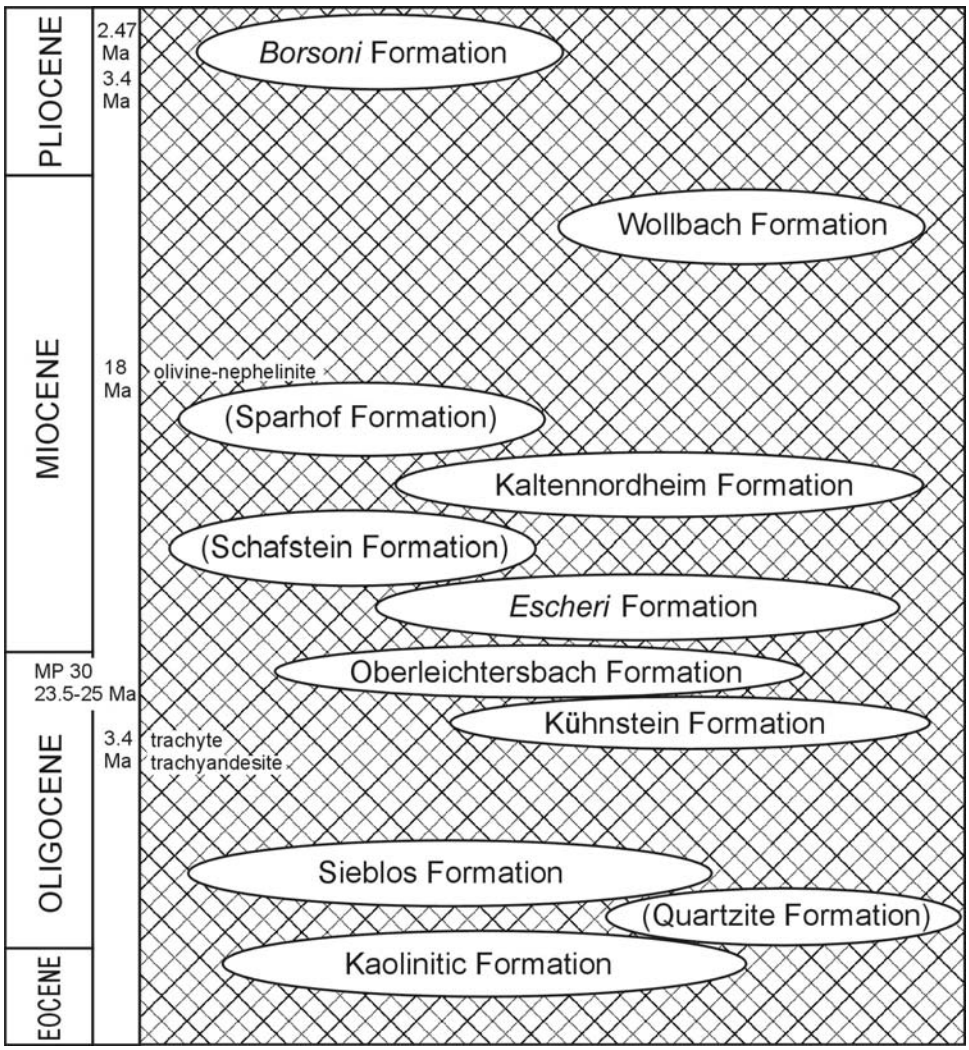

Fig. 2. The stratigraphical assignment of the sedimentary and fossiliferous beds of the Rhön mountains (no true to time scale and to massivness of the sediments). After Martini et al. (1994), changed

EOCENE

KAOLINITIC FORMATION

Palaeocarpological remains were described only from the research drilling Sieblos 1994/1 near the Wasserkuppe in a depth of 36.65 to 38.10 m. The macroflora of 16 species from clayey coal seam sediment (Kaolinitic Formation) lying immediately above Lower Muschelkalk indicates middle to late Eocene age.

Flora. *Beckettia mastixioides* Reid & Chandler, *Steinhauera subglobosa* Presl, *Sterculia subovoidea* (Reid & Chandl.) Mai, and *Wardensheppeya marginata* (Chandl.) Eyde are most important species. The palynological investigation of the borehole Sieblos 1994/1 yielded microfloras only from the underlying substratum. Significant pollen are *Compositoipollenites rhizophorus* (R. Pot.) R. Potonié, *Intratriporopollenites ceciliensis* Krutzsch, *I. minimus* Mai, *Labrapollis labraferus* (R. Pot.) Krutzsch, and *Plicatopollis plicatus* (Kr.) Krutzsch.

Age. The pollen assemblage places the Paleogene basal layers into the Eocene. This might be correlated with the SPP – zone 16/17 after Krutzsch et al. (1992); Bartonian, ca. 39 Ma.

References. Krutzsch et al. (1992), Hottenrott (1998), Mai (1998).

OLIGOCENE

SIEBLOS FORMATION

The abandoned coal mine of Sieblos at the Wasserkuppe was famous for its fossil contents already during the 19th century and has been

accepted as a classical locality of the German palaeobotany. Since most of the fossils so far collected were from mining dumps, they could not be positioned into a relative stratigraphical succession. The Tertiary period was re-examind by scientific drillings in the years 1994, 1998, and 1999. The results of the investigations of the whole Sieblos Formation were published in monographical studies. Many details about the sedimentology, palaeoecology, volcanology, and geochemistry of this remarkable freshwater deposit in the Oligocene of Central Europe are well known. The structure Sieblos is suggested as a suberosional depression.

Flora. A dysodile bed of Sieblos has included many plants of intrazonal vegetation, predominantly *Nymphaea nymphaeoides* (Ett.) Weyland (= *N. rhoenensis* Kurtz 1894), and *Spirematospermum wetzleri* (Heer) Chandl. The association of *Glyptostrobus europaeus* (Brongn.) Heer – *Nyssa disseminata* (Ludw.) Kirchh. verified the swampy forest, possibly together with *Myrica banksiaefolia* Unger, and the fern *Lygodium* cf. *kaulfussii* Heer. The zonal vegetation was characterized by the members of a mixed mesophytic forest. Important elements of this forest were *Tetraclinis salicornioides* (Ung.) Kvaček, *Carya rostrata* (Schloth.) Schimper, *Engelhardia orsbergensis* (Wessel & Web.) Jähnichen et al., *Quercus lonchitis* Ung., *Tilia irtyshensis* (Shaparenko) Grubov, *Zanthoxylum europaeum* Ung., and many Lauraceae. This is very similar to the conditions known from the volcanodetritic series in the Bohemian mountain range. The macroflora of only 32 species contrasts with a richer microflora of 48 species with typical elements as *Cicatricosisporites paradorogensis* Krutzsch, *Momipites quietus* (R. Pot.) Nichols., and *Boehlensipollis hohlii* Krutzsch, verifying unambiguously older Oligocene. Worth mentioning is the strong invasion of Arctotertiary elements as in the "floral complex Valeč" at the same time.

Age. The palynological picture, mainly *Boehlensipollis*, demonstrates typical Oligocene. Based on recently found teeth of smaller mammals, especially by the presence of *Melissiodon* (family Melissiodontideae) the age of the Sieblos Formation can be determined more precisely as early Oligocene.

References. Hassencamp (1858, 1860), Heer (1859), Schenk (1891), Kurtz (1894), Müller-Stoll (1936), Jähnichen & Rüffle (1988), Hottenrott (1988, 1998), Martini & Rothe (1998, 2005).

KÜHNSTEIN FORMATION

At the bend of the street no. 284 south-east of the Wasserkuppe near Gersfeld in a landslide a small deposit of brown-coal clay and dysodile was investigated in 1975. This was named after the neighbouring hill as Kühnstein beds.

Flora. A microflora (only 56 species) from these beds shows very characteristical amounts of *Sparganiaceaepollenites, Cyperaceaepollis, Alnus* and *Platanus* pollen grains. Very typical elements are also *Polypodiaceoisporites marxheimensis* (Mürr. & Pflug) Krutzsch, *Diplopollis kockelii* Pflanzl (= *Calamus*), *Momipites punctatus* (R. Pot.) Nagy (= *Engelhardia),* and *Tricolporopollenites cingulum (*R. Pot.) R. Pot. & Pflug. One uncertain specimen of *Boehlensipollenites hohlii* Krutzsch possibly indicates early late Oligocene.

Age. The differences between this "Marxheim pollen spectrum" of the Kühnstein Formation and the younger microfloras of Hesse and the Rhön mountains are evident. No macroflora has been discovered.

The lithological composition, thickness, and regional extent of the Kühnstein Formation is unknown. Therefore nothing can be said about the overlapping with volcanites (tuffs) and their radiometric age. The eruptions in the region of the Wasserkuppe started approximately before 25.0 Ma., that is in accordance with the new time scale late Oligocene (Chattian).

References. Hottenrott (1992), Krutzsch (1993), Hottenrott et al. (1998).

OBERLEICHTERSBACH FORMATION

The fossil remains at the locality Oberleichtersbach near Bad Brückenau (Bavarian Rhön) derive from a blue-black clayey sediment of the filling of a doline in the Muschelkalk. This sediment is very rich in fossil fruits and seeds, ostracods, snails, shells, and mammal bones in excellent preservation.

Age. Based on gastropods, e.g. the stratigraphically important *Ferussina (Strophonema) tricarinata* M. Braun, and a great diversity especially of small mammals the sediments can be placed in the latest late Oligocene (Neochattian, Paleogene mammal zone – MP 30, Coderet). The assignment of

a very rich macroflora to a generally new floral assemblage "Oberleichtersbach" (24.5 Ma to 23.0 Ma) is quite within bounds of probability.

Flora. On the basis of fossil fruits and seeds, 100 plant species belonging to 63 families have been described from the locality till now. Many other species await a description. This well-preserved flora is one of the richest and most interesting Tertiary floras of Central Europe. The composition reflects a mixed mesophytic forest of the Carpino – Ostryon -type with many semihumid – humid alternating elements. Dominant species are *Carpinus cordataeformis* Mai and *Ostrya scholzii* Gregor together with *Carya rostrata* (Schloth.) Schimper, *Celtis lacunosa* (Reuss) Kirchh., *Cynoxylon carolii* Mai, *Ehretia europaea* E. M. Reid, *Gironniera carinata* Mai, *Schisandra moravica* (Mai) Gregor, *Toddalia latisiliquata* (Ludw.) Gregor, *Wikstroemia thomasii* Gregor & Geissert, and *Zizyphus striatus* (Ludw.) Mai & Gregor. Palaeobiological significance had also some annual plants of open environments, e.g. *Amethystea heckiana* Mai, *Chenopodium wetzleri* Gregor, *Polanisia sibirica* Dorof., *Silene microsperma* Mai etc. A new aquatic plant of paratethyan affinity is *Ceratostratiotes antiquus* Mai. So far, this fossil flora is unique.

References. Martini (2000), Mai (in press).

MIOCENE

ESCHERI FORMATION

The stratigraphically important series of Miocene sediments in the Rhön mountains is developed south of Theobaltshof near Tann. Tuff and tuffites verify an intensive volcanism at the time of sedimentation. Above a basal tuff-limestone horizon follows the original *escheri* – horizon, gray-green, coarse-grained tuffites with the snail *Brotia escheri aquitanica*, in the upper part mixed with clay, sand or tuffites. Country-loving snails and mammals, and also the plant remains were introduced from the surrounding woodlands.

Flora. The aquatic vegetation was obviously dominated by charophytes. Important macrofossils are *Fagus attenuata* Goepp. resp. *F. saxonica* Kvaček & Walth., Betulaceae aff. *Alnus, Carya* sp. aff. *ventricosa* (Stbg.) Ung., *Celtis lacunosa* (Reuss) Kirchh., and *Pinus* sp.

Next to the deposit of Theobaltshof *escheri* beds are known from Kaltennordheim, Eisgraben near Hausen, Erdpfahl near Roth, and Bauersberg near Bischofsheim, mostly without fossil plants. Plant macrofossils are well-known only from the "underlying brown clays" (tuffites or ash-tuffites) and lacustric marls in Kaltennordheim. The poor flora (16 species) yields *Alnus julianiformis* (Stbg.) Kvaček & Holý, *Engelhardia macroptera* (Brongn.) Ung., *Fagus deucalionis* Ung., *Quercus drymeja* Ung., *Q. kubinyi* (Ett.) Czeczott, *Trigonobalanopsis rhamnoides* (Rossm.) Kvaček & Walth., and *Zelkova zelkovifolia* (Ung.) Bůžek & Kotl., which are of stratigraphical interest.

The dysodiles of the Dietrichsberg Member near Vacha with a fish fauna of *Palaeoleuciscus dietrichsbergensis* M. Böhme and an undescribed macroflora with many winged fruits and seeds *Buzekia tertiaria* (Weyland) Manchester may be contemporaneous with the *Escheri* Formation.

Age. Important to the biostratigraphy however are the palynological investigations. The diagram of the relations between *coryphaeus/ rurensis (= Triatriopollenites coryphaeus punctatus* (R. Pot.) Th. & Pf. */Triatriopollenites rurensis* Th. & Pf.) shows the assignment of the *Escheri* Formation to the Lower Miocene (M 1) in Hesse.

The molar of *Amphitragalus* cf. *boulangeri* Pomel, a precursor of the deer family, is also a sure reference of early Miocene (Neogene mammal zone MN3).

References. Knobloch (1971), Moayedpour (1977), Gregor (1982), Hottenrott (1988), Böhme (1996), Geyer (2002), Gümbel & Mai (2002).

KALTENNORDHEIM FORMATION

The Kaltennordheim Formation covers a changing succession of clayey and calcareous marly sediments together with plentiful brown-coal seams, which were the objects of many mines in the former time. Plant fossils were found at different localities. A *Gyraulus* horizon, named after the lacustric gastropod *Gyraulus trochiformis dealbatus* Thomae, a leading horizon of tuffitic and lacustric sediments meshed with basalt, may be present in all the local basins of the Kaltennordheim Formation (Fig. 2).

Flora. The main localities of fossil floras are Kaltennordheim, Hochrain near Gersten-

grund, Bauersberg north of Bischofsheim, and the mine "Barbara" at the Lettengraben (Herrenwasser) near Wüstensachsen – Ehrenberg. All these localities contain fossils of evergreen, broad-leaved and mixed mesophytic forests with many characteristic geofloral elements.

A very rich macroflora comes from the mine "Barbara" where 63 plant species belonging to 38 families were described. Important are the newly discovered evergreen trees and shrubs of the families Taxaceae (*Amentotaxus),* Lauraceae, Magnoliaceae, Rutaceae (*Toddalia, Zanthoxylum),* Sabiaceae (*Meliosma),* Symplocaceae, Ericaceae (*Vaccinioides),* Fagaceae (*Trigonobalanopsis),* Hamamelidaceae (*Distylium*), Menispermaceae (*Parabaena),* Moraceae, Myricaceae, Staphyleaceae (*Turpinia)*, and Styracaceae. This flora represents a typical warm-temperate rain forest that is assigned to the floral assemblage "Eichelskopf – Wiesa" by 74.6 % of all species.

From the brown-coal bed and the clayish intermediate sediments at the mine "Einigkeit" of the Bauersberg comes also a macroflora of 65 species partly known since the 19th century. Remarkable is the enriching of aquatic plants as *Potamogeton schenkii* Kirchh., *Salvinia cerebrata* Nikitin, or *Stratiotes kaltennordheimensis* (Zenker) Keilhack in the brown-coal. Palynological investigations of the Bauersberg lignite-seam reveal a microflora of more than 45 species and allow the correlation of this seam with lignite-bearing sediments from the area of Frankfurt am Main (*Prososthenia* – Beds).

From the brown-coal layers of Kaltenordheim and the neighbouring Hochrain in the same basin 36 plant species belonging to 27 families have been described on the base of fossil fruits and seeds. The most important plant fossils are *Eomastixia hildegardis* (Ung.) Holý, and *Actinidia germanica* Mai, two species of middle Miocene range.

Fauna. Small mammals were found in the marly limestone beds of the Kaltenordheim Formation (see Geyer 2002): *Glirundinus* sp., *Heteromyoxus wetzleri* Schlosser*, Melissiodon schlosseri* Schaub, *Miopetaurista* sp., *Peridyromys* sp., *Pseudotheridomys parvulus* Schlosser. Remains of the big mammal *Aceratherium* sp. derive from the coal clay of Kaltennordheim. Common at most localities was the fish *Leuciscus* (*Palaeoleuciscus*) *dietrichsbergensis* M. Böhme. No index mammalian species were discovered, but the composition of the fauna is of a Lower to Middle Miocene character.

Age: The fossil flora is characterized by typical elements of the so-called Mastixioid floras, which generally attest to an optimal warm humid climatic phase of the Miocene. The age of this phase is Lower to Middle Miocene based on the very likely assignment of the Lettengraben flora to the floral assemblage "Eichelskopf – Wiesa" (zone VI – VIII) or the Kaltennordheim flora to the floral assemblage "Kleinleipisch – Františkove Lázně"(zone X – XII). The age 16.8 Ma to 17.5 Ma is conform to the radiometric dates of the neighbouring basalts (18 Ma). The palynostratigraphic correlation of the Bauersberg lignite-seam with the sediments of the *Prososthenia* – beds near Frankfurt am Main support the latest Early Miocene age.

References. Zenker (1833), Heer (1859), Hassencamp (1860), Müller-Stoll (1936), Kelber & Gregor (1987), Gregor (1990), Hottenrott (1992), Geyer (2002), Gümbel & Mai (2002, 2006).

WOLLBACH FORMATION

Cross-bedded gravels in small areas are preserved in the south-eastern foothills of the Rhön mountains. The conservation of such relics of a Tertiary fluvial system are related to the subrosion of Triassic salt layers in the underground. In the gravel pit Wollbach near Bad Neustadt a lense of plastic clay contains a very poor leaf flora of not more than 34 species from 16 families.

Flora. The floral assemblage, mainly dominated by *Quercus pseudocastanea* Goepp., and also with the presence of *Acer pseudomiyabei* Baikovskaja, *Aesculus* sp., *Alnus ducalis* Gaudin emend. Knobloch *(*younger synonym *A. hoernesii* Stur), *Buxus pliocenica* Saporta & Marion, shows unmistakeably a floristical relationship to floral assemblages of the Pannonian or Pontian in the Paratethyan region of Europe. The flora reflects a warm-temperate, deciduous broad-leaved forest.

Age. The flora is of Upper Miocene affinity. In contradiction, mammals from a similar fluviatile series of Ostheim vor der Rhön indicate late Pliocene age. New fossil material and the future investigation of the whole flora may contribute to solve the problem of age correlation.

References. Kelber (1980, 1988), Knobloch (1986).

PLIOCENE

BORSONI FORMATION

The *borsoni* beds are of fluvial origin and represent the youngest Neogene sediments of the Rhön. At some places the sediments are sunken into subrosion depressions and are clearly limited. At other places they are only relics of thick gravel bodies marking former river courses. On account of the time of their genesis and the remains of mammalian teeth at many localities the term "*arvernensis*-time" is applied. In the northern foreland of the mountains near the river Werra the fillings of local dolines were found at Gerstungen, Oberzella near Vacha, Barchfeld near Bad Salzungen, and Kaltensundheim at the Felda river, and near the river Haune the dolines of Buchenau and Hünfeld with minimal brown-coal seams. They represent fossiliferous clay lenses with floral remains, mostly fruits, seeds, and pollen grains .

Flora. In summary from the six localities 127 plant species belonging to 59 families were described and evaluated palaeoecologically and biostratigraphically. Deciduous warm-temperate forests and different aquatic- and swamp-plant taphocoenoses are recognized. Important exotic trees and shrubs are *Acanthopanax uralensis* Dorof., *Alnus lusatica* Mai, *Carpinus miocenica* Negru, *Cunninghamia minisperma* Mai & Walth., *Glyptostrobus brevisiliquatus* (Ludw.) Mai, *Ilex thuringiaca* Mai, *Magnolia cor* Ludw., *Meliosma miessleri* Mai, *Nyssa disseminata* (Ludw.) Kirchh., *Phellodendron elegans* C. & E.M. Reid, *Picea omoricoides* C.A. Web., *P. rotunde-squamosa* (Ludw.) Mai & Walth., *Pseudolarix schmidtgenii* Kr., *Pterocarya limburgensis* C. & E.M. Reid, *Sequoia abietina* (Brongn.) Knobl., *Stachyurus merkaensis* Mai, *Stewartia beckerana* (Ludw.) Kirchh., *Symplocos casparyi* Ludw., *Taxodium rossicum* Dorof., *Trema lusatica* Mai, *Trichosanthes fragilis* C. & E.M. Reid, *Tsuga moenana* Kirchh., etc. Remarkable species of the aquatic vegetation are *Lobelia pliocenica* (Dorof.) Mai, *Microdiptera menzelii* (E.M. Reid) Mai, *Nuphar canaliculata* C. & E.M. Reid, *Ranunculus gailensis* E.M. Reid, *Salvinia miocenica* Dorof., and *Trapa heerii* Fritsch. Biostratigraphically important and phytogeographically very interesting are species such as *Acorus palaeocalamus* Dorof., *Acorellus distachyoformis* Łań.-Środon., *Alnus tanaitica* Dorof., *Betula cholmechensis* Dorof., *Eleocharis praemaximowiczii* Dorof., *Ficus tambovica* Dorof., *Myrica goretzkyi* Dorof., *Potamogeton aculeatus* Dorof., *P. borysthenicus* Dorof., *P. felixii* Dorof., *Ranunculus tanaiticus* Dorof., *Teucrium pripiatense* (Dorof.) Wieliczk. & Zastawniak, and *Typha pseudovata* Dorof. as pieces of evidence of east-European influence in the west-European uppermost Neogene. Pollenanalytical investigations from Oberzella, Kaltensundheim and Mellrichstadt shows typical spectra of the Upper Pliocene.

Fauna. Significant in some localities of the *Borsoni* Formation of the Rhön are fossil teeth of mastodons (Fulda, Sülzfeld, Jüchsen, Ostheim vor der Rhön) or skeletons (Kaltensundheim): *Mammuthus (Zygolophodon) borsoni* Hays, *Anancus arvernensis* Croiz. & Job., and *Tapirus arvernensis* Croiz & Job., and some deer-like mammals as *Hypolagus* and *Metacervoceros*. All these mammalian fossils facilitate to date these deposits into the Late Pliocene.

Age. The middle to late Pliocene age of the *Borsoni* Formation in the Rhön mountains is based on mammals as well as on palaeomagnetic dates of the sediments (Wiegank 1981, 1982). The time interval lies between 2.8 Ma to 2.1 Ma. The palaeofloristically well investigated floral assemblages "Ceyssac – Kaltensundheim" (2.8 Ma to 2.56 Ma) and "Berga – Reuver" (2.65 Ma to 2.47 Ma) most probably correspond to the late Pliocene. The first assemblage documents a cooling, the second a warming, . The assemblage of Hünfeld, which may be "Perrier – Rippersroda" (2.3 Ma to 2.15 Ma) is uppermost Pliocene representing a new forest phase (Krutzsch 1988).

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