# The Mesozoic amber of Schliersee (southern Germany) is Cretaceous in age

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The Mesozoic amber of Schliersee (southern Germany) is about 130 myr younger than previously proposed. Using biostratigraphic and petrographic data as well as field evidence we demonstrate that the amber-bearing sandstone is of Late Cretaceous age (Cenomanian, 99–93 Ma) and that the previously proposed Late Triassic age (Carnian, 230–220 Ma) must be rejected. This has several consequences for the interpretation of the fossil micro-organisms included in the amber.

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## 1. Introduction

The Mesozoic amber of Schliersee (southern Germany) has become known for the wealth of fossil micro-organisms it contains combined with its supposed very great age. Fossil bacteria, fungi, algae and protozoa from this amber have already been described (e.g., Poinar *et al.*, 1993a; Vávra, 1996; Dörfelt & Schäfer, 1998; Schönborn *et al.*, 1999) and the micro-inclusions have been investigated for over three years at the Institute of Ecology at Jena University.

The discoverer of the amber, U.-Ch. Bauer, Schliersee, saved it by careful collection work in the 1980s and made it available to science as 'Schlierseerit'. This term for the fossil resin is, however, nomenclaturally invalid and is only a working label.

Both the complicated tectonic situation and the small number of exposures in the locality resulted in Bauer assigning the amber-bearing sediments to the Carnian Raibler sandstones (Late Triassic), and consequently the amber is refered to in the literature as Late Triassic (Poinar *et al.*, 1993a). Vávra (1996) also cited Bauer's remarks. Subsequent publications on the amber cite these two references and so the micro-inclusions have also been regarded as Triassic.

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We have applied a variety of biostratigraphic and petrographic methods to the amber-bearing sandstones in order to define correctly the age of the fossilized micro-organisms included in the amber.

## 2. Geological situation

The amber is found at outcrop on the western slope of Leitnernase, a hill near the village of Schliersee, Bavaria, southern Germany. The exposure is located in the embankment of a path at Leitnerbichl, 940 m above sea level (location R.$^{44}$9089, H.$^{52}$8709 on the geological map of Pflaumann & Stephan, 1968). The locality is mapped as Cretaceous, Cenomanian, by Pflaumann & Stephan (1968). The Carnian Raibler Formation on the Leitnernase is represented exclusively by limestones and dolomites. Raibler sandstones are generally rare in the Schliersee area and are absent on the Leitnernase. Pflaumann (pers. comm., 2000) has excluded the occurrence of other Mesozoic and Cenozoic sandstones at this locality.

## 3. Biostratigraphic investigations

### 3.1. Macrofossils

The section exposed does not yield any marine macrofossils. There are numerous fragments of coalified plant debris on the bedding planes of the sandstones
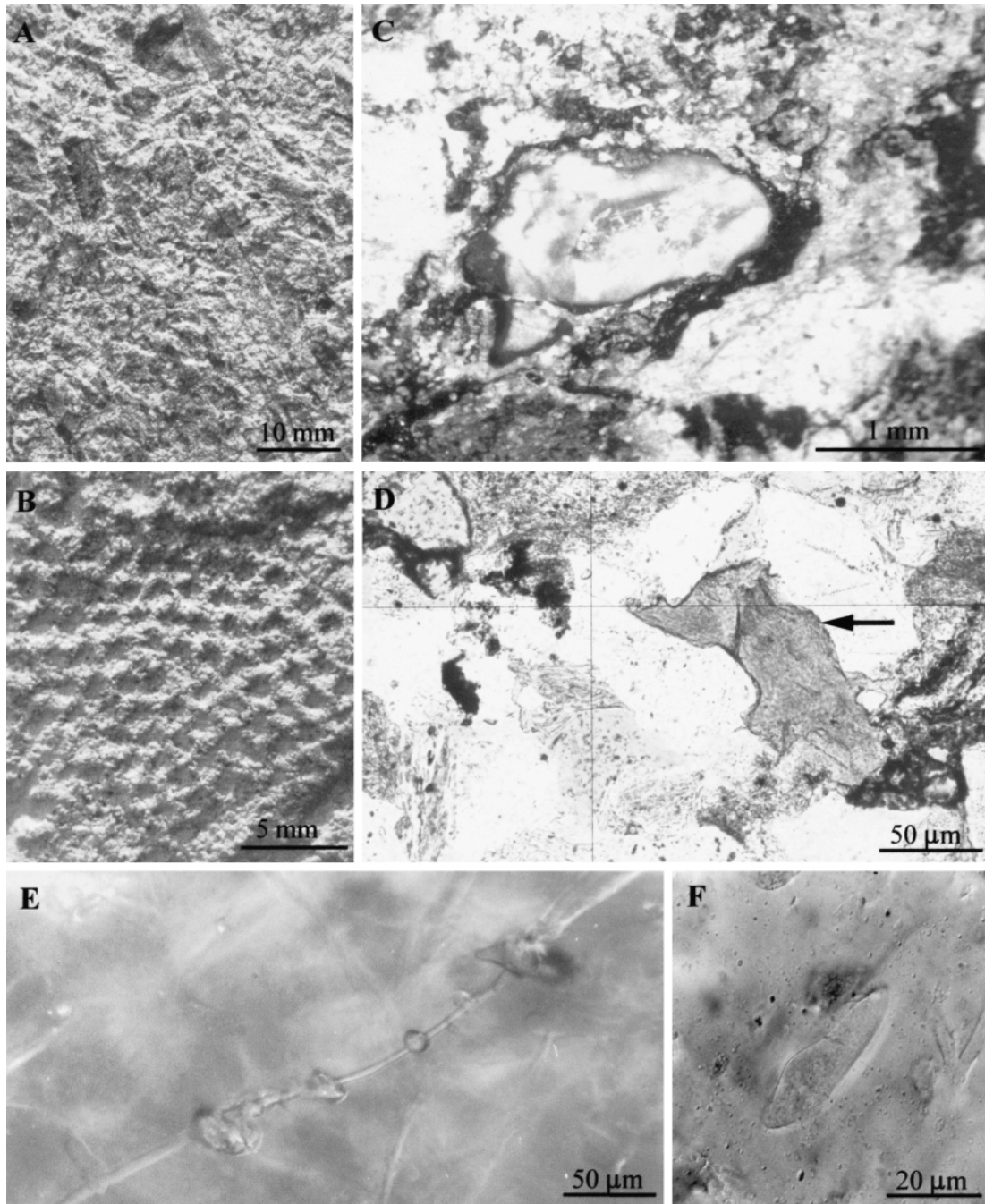
**Figure 1.** Photomicrographs documenting major results of this study. A, bedding plane of the amber-bearing sandstone with coalified plant debris. B, *Paleodictyon minimum* on bedding plane. C, a piece of amber associated with coalified plant debris embedded in the sandstone. D, thin-section of the amber-bearing sandstone with serpentinite (arrow). E, a hypha of the archaic fungus *Palaeodikaryomyces baueri* with clamps and loops. F, rare inclusion of *Paramecium triassicum* in amber. Photographs by U. Schäfer, A. R. Schmidt and H. von Eynatten.

(Figure 1A). The several genera identified by Poinar & Poinar (1994), namely *Annularia, Baiera, Sphenophyllum* and *Walchia*, do not stand up to critical examination because whole leaves or parts thereof are not recorded. *Annularia* and *Sphenophyllum* have to be incorrectly identified because they are only known from the Carboniferous and Permian (Hirmer, 1927; Gothan & Weyland, 1964; Mägdefrau, 1968) and there are no Palaeozoic sediments in the area (Pflaumann & Stephan, 1968). Also *Pterophyllum*

*jaegeri* Brongniart, mentioned by Bauer (1993) and Poinar *et al.* (1993a), is not identifiable here.

### 3.2. Microfossils

The amber-bearing sandstone contains few microfossils. In the marls of neighbouring exposures Pflaumann & Stephan (1968) found the foraminifera *Rotalipora appenninica appenninica* (Renz), *R. brotzeni* (Sigal), *Hedbergella delrioensis* (Carsey) and *Praeglobotruncana stephani* (Gandolfi), verifying a Cenomanian age, probably Early to Mid Cenomanian according to the zonation of Caron (1985). Searching for spores and pollen we found *Cicatricosisporites*, which is largely a Cretaceous taxon, *Classopollis* and *Trilites*, both of which are common in Jurassic and Cretaceous deposits (Döring *et al.*, 1966). No Triassic palynomorphs were found in either the sandstones or the marls.

### 3.3. Ichnofossils

Some sandstone bedding planes show traces of *Paleodictyon minimum* Sacco (Figure 1B). In general, *Paleodictyon* is restricted to marine environments and is typical of ichnocenoses of turbidite deposits (Bromley, 1996). This is in contrast to the shallow marine to fluvial depositional environment of the Late Triassic Raibler sandstone (Jerz, 1966; Pflaumann & Stephan, 1968). In addition, *P. minimum* has so far only been reported from Cretaceous–Neogene (Miocene) strata and is most common in the Late Cretaceous and early Tertiary (Crimes & McCall, 1995). It is reported in the Northern Alps from Albian–Turonian strata (Gaupp, 1980). Seilacher (1977) emphasized that it has not been recorded from Triassic or Jurassic ichnocenoses.

## 4. Petrographic investigations

The amber-bearing sediments are greenish grey to yellowish, poorly to moderately sorted fine- to medium-grained sandstones (maximum grain size 3 mm) which are intercalated with marls. Macroscopically visible components of the sandstones are quartz, a variety of rock fragments (lithoclasts), and occasionally a large amount of coalified plant debris concentrated on the bedding planes. Rare micas were also observed on the bedding planes. Thus, these sandstones have to be classified as litharenites (e.g., McBride, 1963). The amber is macroscopically visible (maximum 1 cm) and is generally associated with plant debris (Figure 1C).

We present below the results of thin-section petrography and heavy mineral analysis and compare these observations with those obtained from sandstones of the Late Triassic Raibler beds (Jerz, 1966) and from Cretaceous sandstones (Faupl & Wagreich, 1992a; von Eynatten, 1996; von Eynatten & Gaupp, 1999) at the northern margin of the Northern Calcareous Alps (NCA).

### 4.1. Thin-section petrography

Individual grains are angular to subrounded and grain contacts indicate considerable compaction. Major components are quartz grains and lithoclasts in roughly equal proportions of 40–50%. The latter are in part modified owing to mechanical compaction and diagenetic reactions. Quartz grains include both monocrystalline and polycrystalline varieties but the former are more frequent. The following lithoclasts can be specified (in descending order of frequency): carbonates (both limestones and dolomites), quartz-chlorite-mica aggregates, cherts, serpentinites, and volcanics. Feldspar (5–10%) and mica/chlorite (<5%) are minor constituents. Rarely observed heavy minerals include zircon, tourmaline, rutile and chrome spinel (for heavy mineral analysis see below). This petrographic composition is similar to Cretaceous synorogenic sandstones of the northern NCA. Serpentinite (Figure 1D) in particular is a typical constituent of these rocks (Wagreich, 1993; von Eynatten & Gaupp, 1999) but has not been reported from Raibler sandstones. These sandstones usually have a lower lithoclast content (<30%, matrix included) with fewer than 5% carbonate clasts, and a higher feldspar content (mostly >20%) (Jerz, 1966) compared to the amber-bearing sandstone.

### 4.2. Heavy mineral analysis

A heavy mineral analysis of the sandstones was performed following the method described in von Eynatten & Gaupp (1999). The heavy mineral separate is dominated by opaque Fe-oxide phases and chlorite. The more diagnostic group of translucent non-micaceous heavy minerals was analysed quantitatively by counting 100 grains. The analysis of four samples reveals the following range of heavy mineral composition: apatite 29–42%, tourmaline 12–22%, zircon 17–24%, rutile 4–13% and chrome spinel 13–19%. Traces ($\leq$3%) of garnet, brookite/anatase, epidote, and chloritoid were also observed. Whereas the stable heavy minerals zircon, tourmaline and rutile are common in most sandstones, significant amounts of

chrome spinel are indicative of sandstones deposited during orogenic phases (Zimmerle, 1984). In the European Alps this is especially true for Cretaceous synorogenic sandstones (e.g., Woletz, 1963; Gaupp, 1982; von Eynatten & Gaupp, 1999). In contrast, heavy mineral spectra of the Raibler sandstones do not contain significant amounts of chrome spinel but generally higher amounts of garnet and zircon (Jerz, 1966). Chloritoid has never been reported.

In summary, the petrographic investigations reveal several differences in mineralogical composition between the amber-bearing sandstones and the Late Triassic Raibler beds, and close similarities between amber-bearing sandstones and the Cretaceous synorogenic sandstones of the northern NCA. It is most likely that they belong to the Lower Branderfleck Formation (Gaupp, 1982).

## 5. Discussion

The Cretaceous synorogenic sandstones were deposited in relatively small sedimentary basins located on the prograding nappes of the NCA. Sediment input was transverse to the emerged fronts of these nappes, and transported by small rivers into the shallow marine environment followed by mostly longitudinal redeposition into deeper water by gravity-driven mass flows (mostly turbidites) (Gaupp, 1982; Faupl & Wagreich, 1992b; von Eynatten, 1996). This scenario is in agreement with the low maturity of the amber-bearing sandstone, as indicated by the high proportion of lithoclasts and the low degree of sorting and rounding. Redeposition of Triassic amber into Cretaceous sandstones can be excluded because the coalified plant debris associated with the amber would not have survived the high-energy processes of erosion, transport and deposition.

Based on both biostratigraphic and petrographic results, the amber-bearing sandstones are Cretaceous in age (Cenomanian, 99–93 Ma; Gradstein *et al.*, 1995). The Late Triassic age suggested by Poinar *et al.* (1993a) has to be rejected.

Accepting a Cretaceous age for Schliersee amber necessitates a re-evaluation of the previous interpretations based on an assumed age of 230 Ma. The microfossils in the amber are in fact about 130 myr younger than previously proposed; their status must, therefore, be reconsidered.

The following new genera and species were described as Triassic: *Hyalosphenia baueri* Schönborn *et al.* (Rhizopoda), *Palaeodikaryomyces* Dörfelt, *P. baueri* Dörfelt (Eumycota) (Figure 1E), *Palaeozygnema* Dörfelt, *P. spiralis* Dörfelt (Zygnematophyceae), *Paramecium triassicum* Foissner & Schönborn

(Ciliophora) (Figure 1F), *Triassamoeba* Poinar *et al.* and *T. alpha* Poinar *et al.* (Rhizopoda) (Poinar *et al.*, 1993b; Dörfelt & Schäfer, 1998, 2000; Schönborn *et al.*, 1999).

Furthermore Schönborn *et al.* (1999) found microfossils that on the basis of their morphological characters cannot be differentiated confidently from extant species. These are conidia of the fungus *Pithomyces*, the algae *Chlamydomonas*, *Chlorella*, *Chloromonas* and *Euglena*, the Testacea *Centropyxis aculeata* var. *oblonga* Deflandre and *Cyclopyxis eurystoma* Deflandre, as well as the Ciliophora *Bryometopus triquetrus* Foissner, *Cyrtolophosis mucicola* Stokes, *Mycophagophrys terricola* Foissner, *Paracondylostoma*, *Pseudoplatyophrya nana* (Kahl) Foissner and *Tetrahymena rostrata* (Kahl) Corliss. Poinar & Waggoner (1992), Poinar *et al.* (1993a) and Poinar & Poinar (1994) had also previously found sheathed bacteria, Cyanobacteria, Ciliophora, Testacea, green algae and fungal spores that are morphologically similar to extant species.

The evolutionary consequences of these observations particulary affect the interpretation of *Palaeodikaryomyces baueri*. This archaic fungus, common in Schliersee amber but absent from recent biocenoses, has a basal position between the Asco- and Basidiomycetes on the one hand and the Zygomycetes on the other (Dörfelt & Schäfer, 1998). It represents a fungus that has preserved the essential characters of the primary Dikaryomycetidae, undifferentiated into Asco- and Basidiomycetes, that was probably most abundant during the Palaeozoic. Believing *Palaeodikaryomyces baueri* to be Triassic, Dörfelt & Schäfer (1998) remarked on its early date as a terrestrial saprophytic fungus in contrast with the mostly parasitic and symbiotic fossil fungi of the Palaeozoic and early Mesozoic. No other fungus of this rather primitive degree of organization is known from the Mesozoic or Cenozoic, however, and following Dörfelt & Schäfer's hypothesis it may be concluded that *Palaeodikaryomyces* was an archaic fungus that persisted into the late Mesozoic.

The alga *Palaeozygnema spiralis* now also belongs to the Cretaceous flora although it remains the earliest evidence of the Zygnematophyceae. This fossil differs from extant species in the shape of the zygote and in the manner of the gametogenesis (Dörfelt & Schäfer, 2000).

All the other micro-organisms from this amber show many similarities with extant species but the deduction drawn by Poinar *et al.* (1993a) and Schönborn *et al.* (1999) that these organisms have shown little or no evolution since the early Mesozoic is now only supported for the late Mesozoic onwards. The micro-organisms nevertheless still

belong to the oldest non-marine algae, ciliates and amoebae known.

The following publications have incorrectly assigned the Schliersee amber or its inclusions to the Triassic: Poinar (1992), Poinar & Waggoner (1992), Bauer (1993), Poinar et al. (1993a, b), Poinar & Poinar (1994), Nickel (1995), Krumbiegel & Krumbiegel (1996), Vávra (1996), Dörfelt & Schäfer (1998), Foissner et al. (1999), Krüger (1999), Schönborn et al. (1999) and Dörfelt & Schäfer (2000). The re-dating to Cretaceous means that unfortunately the names *Paramecium triassicum* and *Triassamoeba alpha* are inappropriate for organisms that lived during the Late Cretaceous.

## Acknowledgements

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