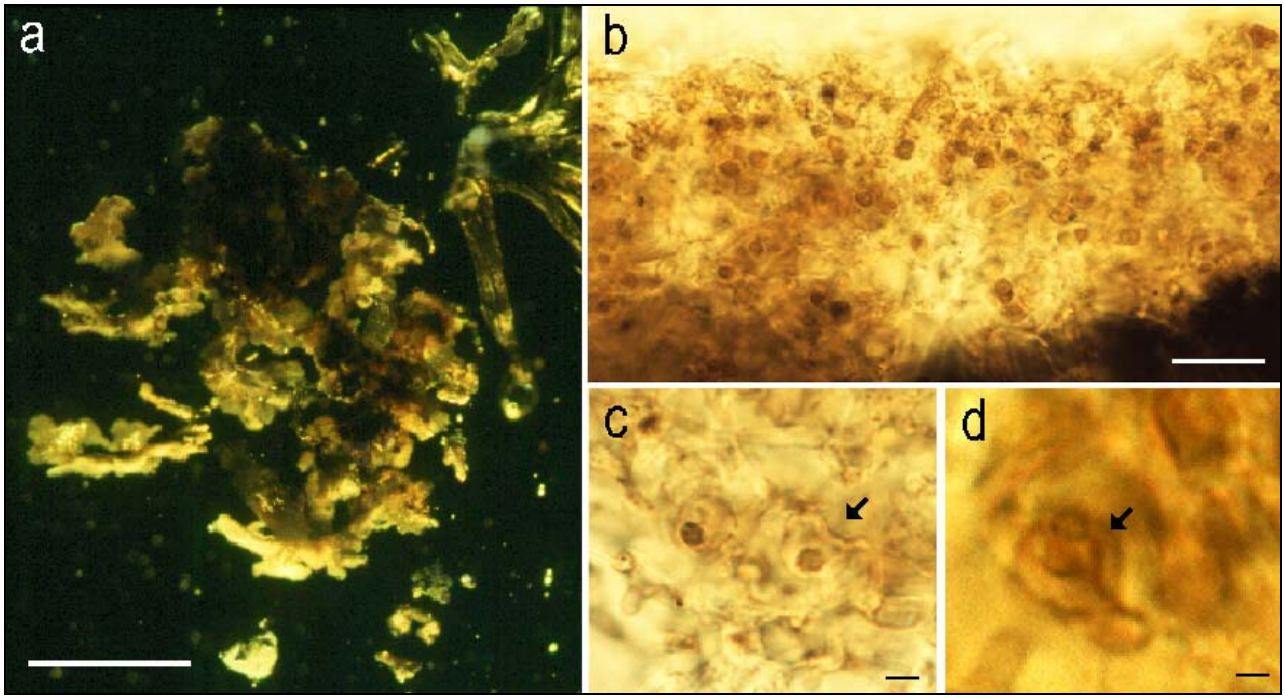
PALEOBIOLOGY OF CRYPTOGAMS PRESERVED IN AMBER

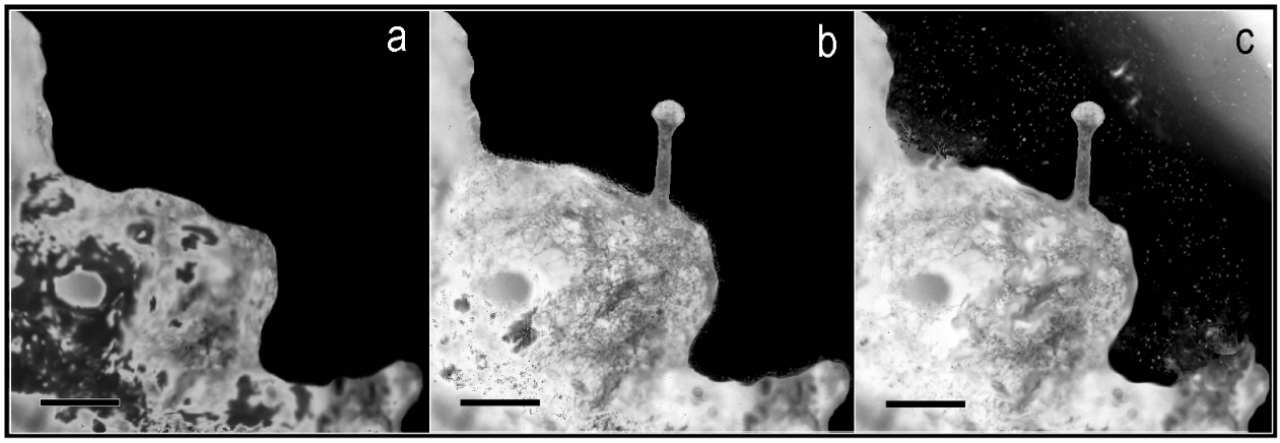
This project concentrates on the study of fossilized cryptogams (fungi, algae, lichens and bryophytes) preserved in amber. Amber is fossilized plant exudate made of nonvolatile terpenoid materials which have been oxidized and polymerized to a point where they can withstand chemical and microbiological attack. Evidence of true terpenoid resins appears with arborescent plants in the Carboniferous. Cretaceous ambers have yielded a number of fungal fossils but the most abundant fungal remains in amber occur in Tertiary deposits. Amber fossils, mainly from private collections, allow us to reconstruct ancient cryptogam biota of Late Cretaceous-Early Eocene forests of Europe (Schliersee, Baltic, and Bitterfeld amber), Mid Cretaceous forests of Asia (Burmese amber), and Late Oligocene-Early Miocene forests of the Caribbean region (Dominican and Mexican amber).

The discovery of even a single fossil may give minimum age estimates for the origins of multiple evolutionary lineages. However, for this, one must not only be able to accurately place the fossil into an extant lineage, but also requires phylogenetic resolution for the fossil-bearing lineage. The combination of molecular techniques with phylogenetic methods is providing a wealth of new information on extant fungi. As more detailed phylogenetic hypotheses are rapidly emerging for different lineages, the few available fossils become crucial for timing branching events and calibrating molecular clocks.



Fossil lichen in Dominican amber. Dominican amber is fossilised exudate of the now-extinct leguminous tree *Hymenaea protera*. Its exact age is unknown, with estimates ranging from 15–20 million years to 30–45 million years. **a,** Foliose lichen (cf. *Phyllopsora*) preserved together with bryophyte (cf. *Syrrhopodon*), scale bar 1 mm. **b,** Photobiont layer of cross-sectioned thallus, scale bar 50 µm. **c,** Two green algal photobionts, scale bar 10 µm. Note dark, shrivelled protoplasts inside the algal cells and flat intercalary appressorium pressed against one algal cell (arrow). **d,** Fungal-algal interface, scale bar 5 µm. Note tip of hyphal branch (arrow) pressing against algal cell wall. (Rikkinen unpubl.).

Fungi are unlikely candidates for fossilization and thus almost everything what is presently known about their evolution is based on comparative studies of extant taxa. However, amber is not only a superb medium for the preservation of microorganisms, but due to its very nature, it represents a perfect selective trap for resinicolous fungi.



Diagrammatic reconstruction of stages in the preservation of a resinicolous calicioid (*Chaenothecopsis bitterfeldensis*). **Stage a**: Resin settles on an irregular bark surface. **Stage b**: Resinicolous fungi colonise the semi-hardened resin and form an extensive, partly aerial mycelium. Fungal ascomata grow to project over the hardened resin surface. **Stage c**: The old resin surface and resinicolous fungi are embedded by fresh resin. The fresh exudate detaches and encapsulates ascospores and also lifts loose hyphae and spores from the old resin surface. Limited mixing of trapped material occurs between the two successive resin flows. Scale bars 0.5 mm. (Rikkinen & Poinar 2000).

We have found several specimens of epiphytic lichens and sooty moulds from Baltic and Bitterfeld ambers dating back to approx. 40 million years ago. The excellent preservation of these fossils has permited detailed comparisons with modern analogues. It seems that the early divergence of many cryptogam lineages may have been intimately linked to the initial development of sucking herbivorous insect guilds producing liquid excretes rich in carbohydrates. Piercing-and-sucking mouthparts evolved in several insect groups in the Late Carboniferous and also honeydew production may have originated as early as in the Permian. Aphids and scale insects were already diverse in the Cretaceous and it has been suggested that sucking herbivorous insects may have been the dominant primary consumers in many Mesozoic land ecosystems. If so, the sucking herbivores must have produced large amounts of honeydew which provided an attractive food source for fluid-feeding insects and other organisms, including many yeasts and filamentous fungi.

Publications

Rikkinen, J. 2003: Calicioid lichens from European Tertiary amber. – Mycologia 95: 1032–1036.

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Rikkinen, J. & Poinar, G. 2002: Fossilised *Anzia* (Lecanorales, lichen-forming Ascomycota) from European Tertiary amber. – Mycological Research 106: 984–990.

Rikkinen, J. & Poinar, G. 2002: Yeast-like fungi in Dominican amber. – Karstenia 42: 29–32.

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Rikkinen, & J. Poinar, G. 2000: A new species of resinicolous *Chaenothecopsis* (Mycocaliciaceae, Ascomycota) from 20 million year old Bitterfeld amber, with remarks on the biology of resinicolous fungi. – Mycological Research 104: 7–15.