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Pygmy moths (Lepidoptera, Nepticulidae) from Baltic Amber (Eocene)

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Abstract

Pygmy moths (Nepticulidae, Lepidoptera) from Eocene Baltic amber are described with five new specimens, representing the only specimens beyond one described before. Some of the findings differ from *Stigmellites baltica* Kozlov in species and sex. They are formally described as new species *Bohemannia butzmanni* and *B. aschaueri*. Phylogenetic and paleoecological aspects of Nepticulidae from Baltic amber are discussed.

Key words: Baltic amber, *Bohemannia*, Eocene, leaf mining, Nepticulidae, pygmy moths

Zusammenfassung

Fünf neue Arten von Zwergminiermotten (Nepticulidae, Lepidoptera) werden aus Baltischem Bernstein (Eozän) beschrieben; zusammen mit einer bereits früher beschriebenen Form (*Stigmellites baltica* Kozlov) stellen sie die einzig bekannten Fossilien dieser Tiergruppe dar. Da einige der hier beschriebenen Fossilien sich von *S. baltica* deutlich unterscheiden, werden sie als neue Arten, *Bohemannia butzmanni* und *B. aschaueri*, beschrieben. Phylogenetische und paläoökologische Aspekte der Nepticulidae im Baltischen Bernstein werden diskutiert.

Schlüsselwörter: Baltischer Bernstein, *Bohemannia*, Eozän, Blatt-minierer, Nepticulidae, Zwergminiermotten

1. Introduction

Nepticulidae are a monophyletic (natural) family of glossatan, monotrysian and heteroneurous Lepidoptera (Scoble 2002). Together with the closely related extant family Opostegidae they form the superfamily Nepticuloidea. The family Nepticulidae comprises the smallest imagos of all Lepidoptera; the larvae mine leaves or other living plant surface tissues (petioles, bark, samaras) (Scoble 2002; Grimaldi and Engel 2005). With its leaf mining habit, the family is of great ecological importance and also has economic impact on a number of crop plants.

As a basal group of Lepidoptera phylogeny of Nepticulidae is of concern, but members of the family are extremely rare as fossils (Sohn et al. 2012). Furthermore, most reports refer only to the typical traces of mining activity found in fossil leaves (mostly described as *Stigmellites*; see Sohn et al. 2012), the oldest of which come from the Mid-Cretaceous Dakota formation and are suggested to have been produced by *Stigmella* and *Ectoedemia* (Nepticulidae) (Labandeira et al. 1994). Lepidopterous mines in leaves of the seed fern *Pachypteris* from the Australian Upper Jurassic/Lower Cretaceous might be an even older evidence for Nepticulidae (Rozefelds 1988). Undescribed putative nepticulid imagos are known from Cretaceous Siberian amber (mentioned in Grimaldi and Engel 2005) and from Canadian Late Cretaceous amber (mentioned in Kristensen and Skalski 1999). The evolution of Nepticulidae and other lepidopterous leaf miners is supposed to be closely linked to angiosperm radiation and hence host plant evolution (Labandeira et al. 1994; Grimaldi and Engel 2005). A first fossil nepticulid imago was mentioned by Skalski (1976, 1990) from Eocene Baltic amber and affiliated to *Ectoedemia* sp. without description or even information on its deposition. Kozlov (1988) described a female imago as *Stigmellites baltica*. Some of the nepticulid imagos studied

here clearly differ from *Stigmellites baltica*, and also represent the first male specimens discovered from Baltic amber.

2. Material and Methods

The amber pieces were purchased from trusted amber dealers. The inclusions were photographed with a binocular microscope (Zeiss Stemi 2000-C) to which is attached a digital camera system (Leica DFC 320, software LAS 4.1) (specimens 5058, 5166); other images were obtained with the inclusions (specimens 5198, 5199, 5217). The specimens were preserved by treatment with an acryl varnish and are kept in the author's collection at constant temperature in plastic clip bags within metal boxes excluding oxygen and light. However, transfer to a public collection (Bayerische Staatsammlung für Paläontologie und Geologie, München, Deutschland) is envisaged.

3. Systematic paleontology

A total of five new nepticulid imagos have been discovered in the Eocene Baltic amber pieces.

Lepidoptera Linnaeus, 1758
Superfamily Nepticulidea Stainton, 1854
Family Nepticulidae Stainton, 1854

Genus *Bohemannia* Stainton, 1859

Bohemannia butzmanni nov. spec.
Fig. 1

Holotypus: Specimen ex coll. Fischer no. 5058, Fig. 1

Locus typicus: Amber mine of Yantarni, GUS

Stratum typicum: "Blaue Erde" (Upper Eocene – Lower Oligocene)

Etymology: The name is given to acknowledge the numerous paleontological activities of Mr. Rainer Butzmann (Munich, Germany)

Repository: Bayerische Staatssammlung für Paläontologie und Geologie, Munich, Germany; accession number SNSB-BSPG 2013 I 93

Diagnosis: Very small moth with broad head, vertex smooth but with frontal tuft, epicranial notch visible, piliform scales at collar, bases of antennas form eye caps, filiform antenna, length about ¾ of forewing length with 30–35 segments (partly invisible), two-segmented upwards-pointed labial palps, last segment with a thick middle part and a fine tip, three-segmented downwards-pointing maxillary palps, very short and blunt proboscis, abdomen slightly flat with tips of valves visible, no epiphysis, coxa and femur with transversal rows of scales, spur formula 0-2-4, middle hind spurs at half the length of hind tibia, five tarsomers, thorax with triangular tegulas, cilia at forewings and hindwings, twice as long at the hindwings, wing tips acute, venation consisting of sc, r1, r2-3, r4, r5, m1, m2, cu, and a; m1, m2 and cu distally diverging from r5.

Differential diagnosis: In comparison to *Stigmellites baltica* Kozlov 1988 this specimen differs in the following characters: wing venation, (sex,) length of antennas, tibial spurs, hindwings broader, coxa and femur with transversal rows of scales. Affiliation to the extant genus *Bohemannia* is mainly supported by the structure of the venation and the presence of a collar of scales.

Description: Total length 2,2 mm, head 400 µm broad, vertex smooth, frontal tuft, epicranial notch visible, collar with piliform scales, eyes 130 µm in diameter, bases of antennas forming eye caps, filiform antennas with a length of about ¾ of forewing length with 30–35 segments (partly invisible), labial palps 150 µm with two segments, last segment with a thick middle part and a fine tip, pointed upwards, maxillary palps 250 µm with three visible segments, folded downwards, proboscis very short (100 µm) and blunt, mesonotum 400 µm broad, abdomen 870 µm long, slightly flat and with irregularly preserved scales, male genitalia (tips of valves) visible, no epiphysis at front legs, coxae and femurs with transversal rows of scales, spur formula 0-2-4, middle hind spurs positioned at half the length of the hind tibia, five tarsomers, thorax with triangular tegulas, forewings 1,8 mm long, cilia at forewings and hindwings, twice as long at the hindwings (up to 500 µm), scale covering only preserved at the proximal parts of the wings, wing tips acute, venation consisting of sc, r1, r2+3, r4+5, m1, m2, cu, and a; m1, m2 and cu diverging from r4+5 in the very distal part of the latter. There are no syninclusions preserved in this piece of amber.

Specimen 5217
Imago of pygmy moth (Nepticulidae)
Fig. 2

Description: Total length 2,2 mm, head 400 µm broad, frons and vertex smooth, collar without scales, diameter of eyes ca. 150 µm, eye caps at bases of antennas, filiform antennas with ca. 20 segments and a length half of that of forewings, maxillary (or labial?) palps bent and with 2 visible segments, other palps not visible, proboscis very small, abdomen length ca. 800 µm, mesonotum ca. 450 µm broad, spur formular 0-2-4, forewing length 1,9 mm, cilia at wings.

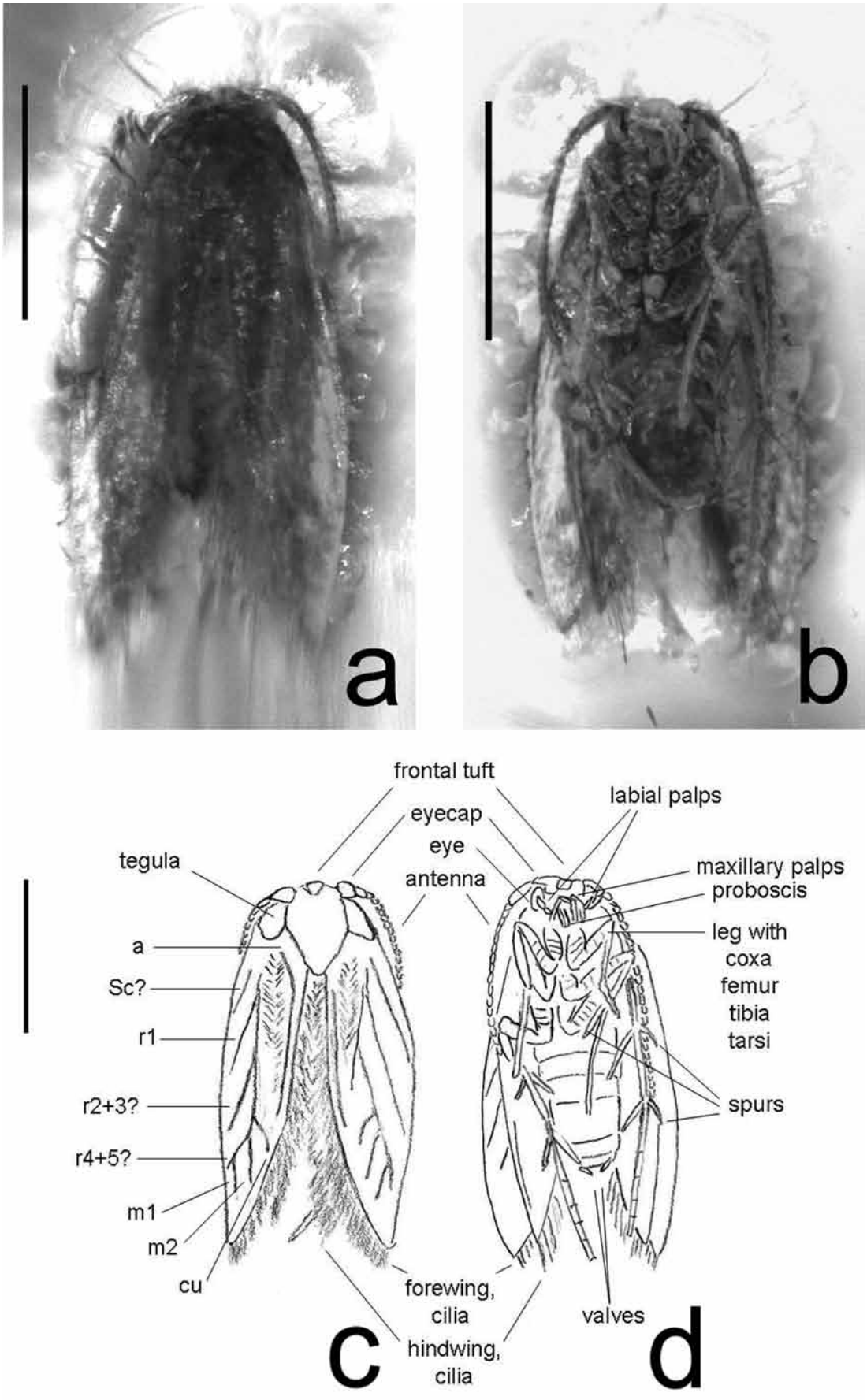

Figure 1: Male pygmy moth (Nepticulidae), *Bohemannia butzmanni* nov. spec., from Eocene Baltic amber (SNSB-BSPG 2013 I 93); **(a)** Dorsal view; **(b)** Ventral view; total length of imago: 2,2 mm; **(c)** Corresponding line drawings with organ identification. Scale bars = 1 mm.

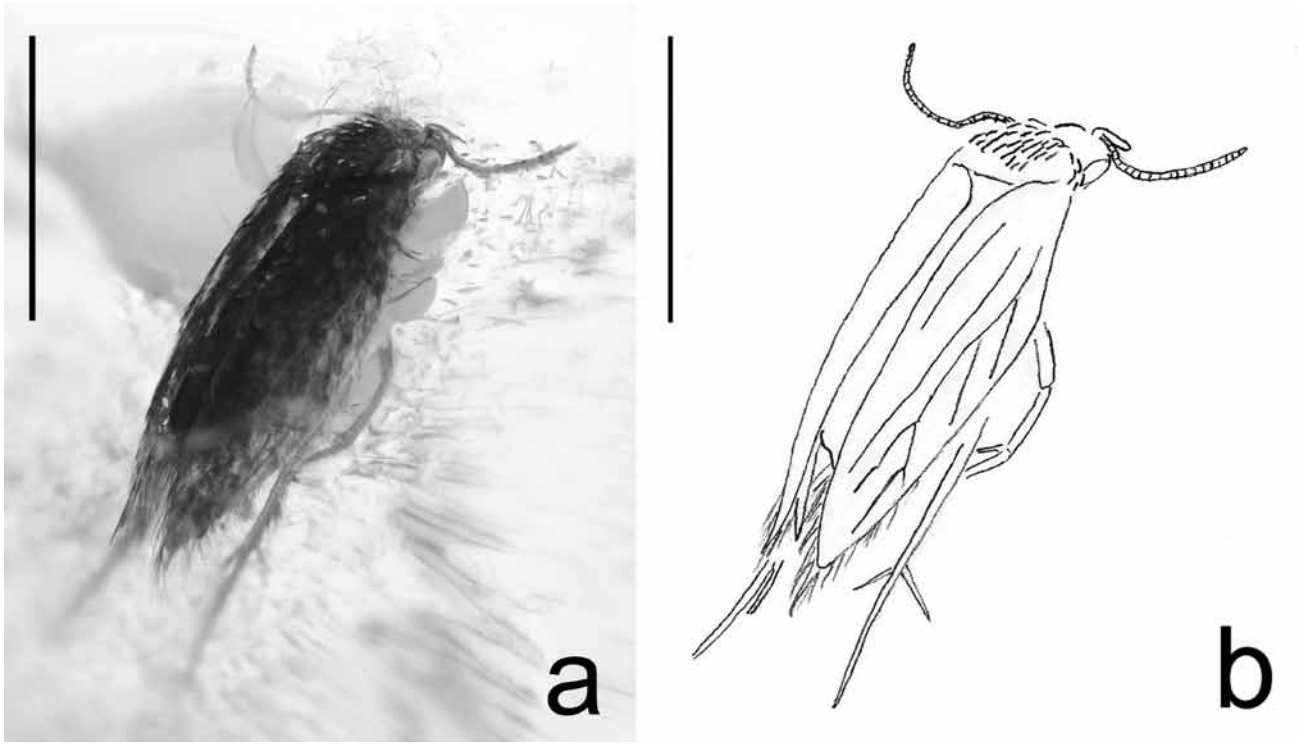

Figure 2: Pygmy moth (Nepticulidae) from Eocene Baltic amber (coll. T Fischer no. 5217); **(a)** Dorsal view; total length of imago: 2,2 mm; **(b)** Corresponding line drawing. Scale bars = 1 mm.

This specimen may be conspecific with specimen 5058, showing the same fore wing venation and also a smooth vertex.

Syninclusions: Cecidomyiidae (no. 5218), *Germaraphis* sp. (no. 5219).

Genus *Bohemannia* Stainton, 1859

Bohemannia aschaueri nov. spec.

Holotypus: Specimen ex coll. Fischer no. 5199, Fig. 3

Locus typicus: Amber mine of Yantarni, GUS

Stratum typicum "Blaue Erde" (Upper Eocene – Lower Oligocene)

Etymology: The name is given to acknowledge the numerous paleontological activities of Birgitt and Karl Aschauer (Waidhofen an der Ybbs, Austria).

Repository: Bayerische Staatssammlung für Paläontologie und Geologie, Munich, Germany; accession number SNSB-BSPG 2013 I 94

Syninclusions: Trichomes, Arthropleones.

Diagnosis: Eye caps with scales, trochanter with rows of scales, proboscis very small, galeae separated, spur formula 0-2-4, frons with erect scales, vertex smooth (with scales?), tegulas triangular, forewing length 1,95 mm, heteroneurous, wing tips pointed, hindwings not broad, cilia at front and hind wings, antennas with at least 26 segments (but antennas broken), labial palps three-segmented, maxillary palps with two- (or three-) visible segments, valves.

Differential diagnosis: Venation same as 5058 (hence different to *Stigmellites baltica*), but frons with erect scales and galeae of proboscis slightly separated. Preparation of genitals as performed in studies with extant Nepticulidae is not possible. Affiliation to the extant genus *Bohemannia* is due to the similarity of the venation.

Specimen 5198
Imago of pygmy moth (Nepticulidae)
Fig. 4

Total length with legs 2,8 mm, head 400 µm broad, vertex with erect scales, collar with bundles of piliform scales behind antennas, eyes 180 µm in diameter, eye caps, filiform antennas short (2/5 of front wing length) with 19 segments and pointed at the tip, labial palps two-segmented and downwards-pointing, maxillary palps not visible, proboscis very short and with slightly separated galeae, mesonotum 400 µm broad, abdomen 1100 µm long, no epiphysis, spur formula 0-2-4, tibias with scales, middle hind spurs positioned at 2/5 of length from basis of femur, five tarsomers, forewing length 1,8 mm, wings with scales preserved, cilia and longitudinal scales up to 200 µm long at wing edges, wing tips acute.

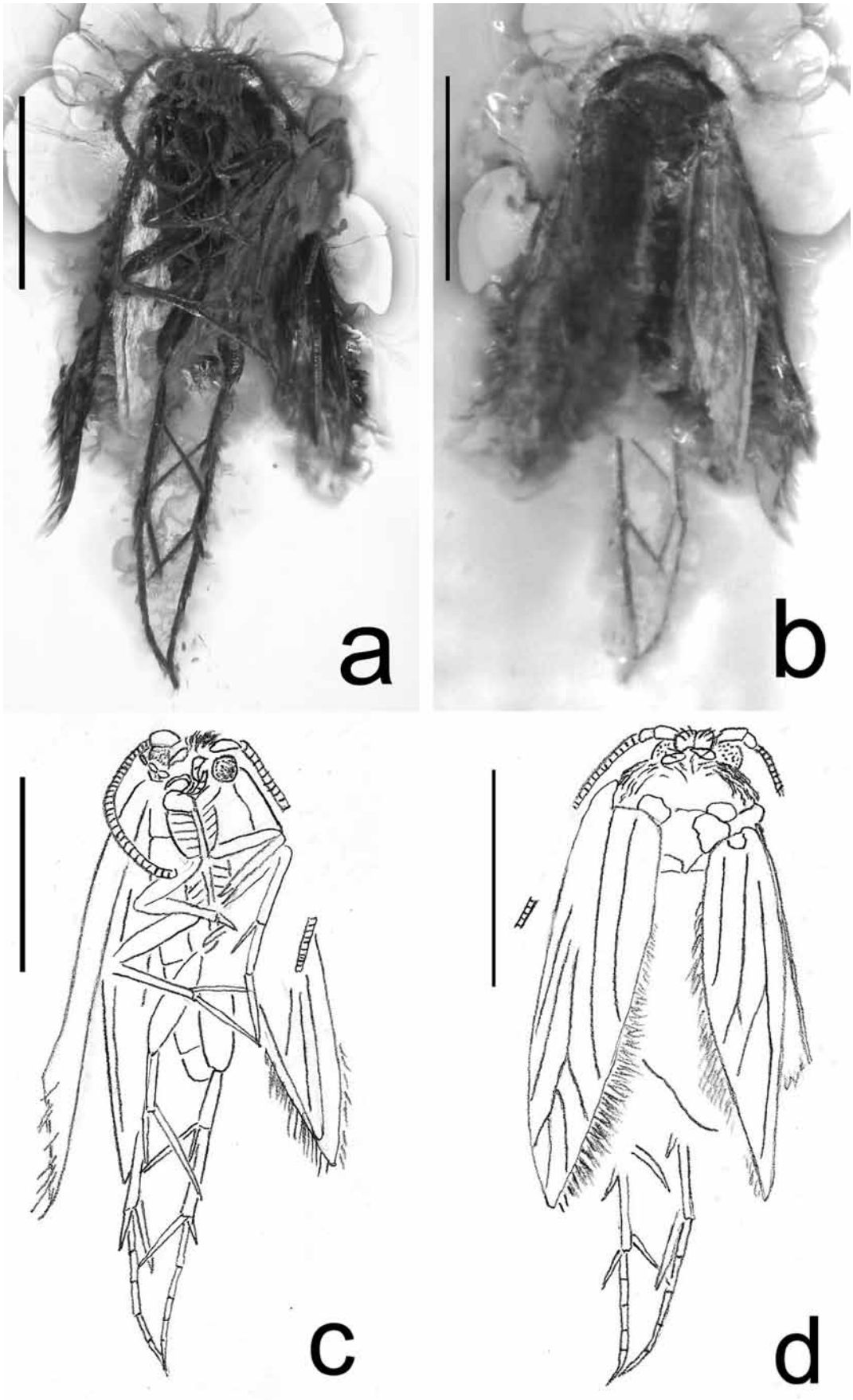

Figure 3: Male pygmy moth (Nepticulidae), *Bohemannia aschaueri* nov. spec., from Eocene Baltic amber (SNSB-BSPG 2013 I 94); **(a)** Ventral view; total length of imago: 3 mm, body 2 mm; **(b)** Dorsal view; **(c & d)** Corresponding line drawings. Note that in dorsal view the right visible wing is the hindwing with a different venation than the forewing. Scale bars = 1 mm

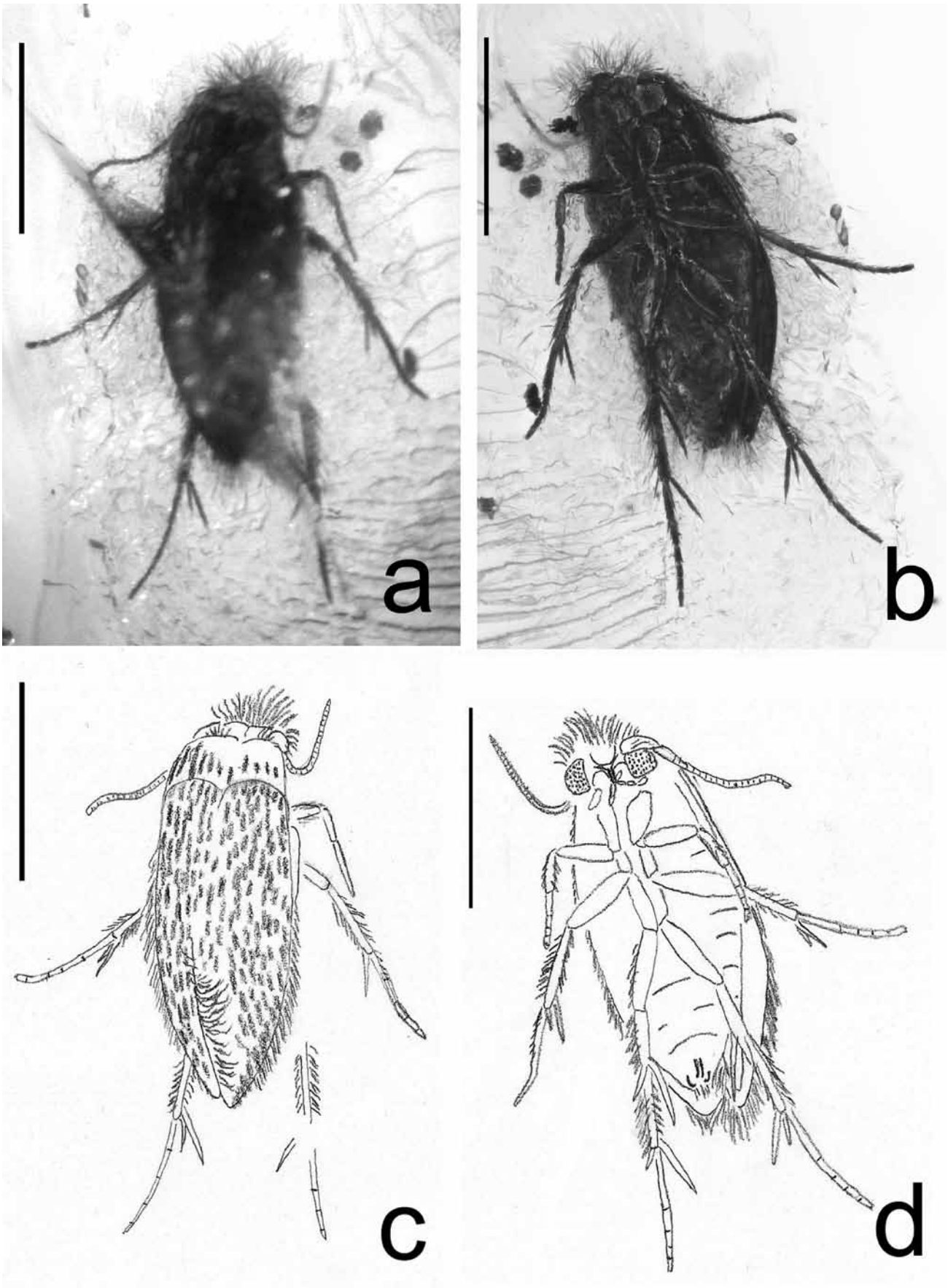

Figure 4: Female (?) pygmy moth (Nepticulidae) from Eocene Baltic amber (coll. T Fischer no. 5098); **(a)** Dorsal view; **(b)** Ventral view; total length of imago: 3 mm, body 2 mm; **(c & d)** Corresponding line drawings. Scale bars = 1 mm.

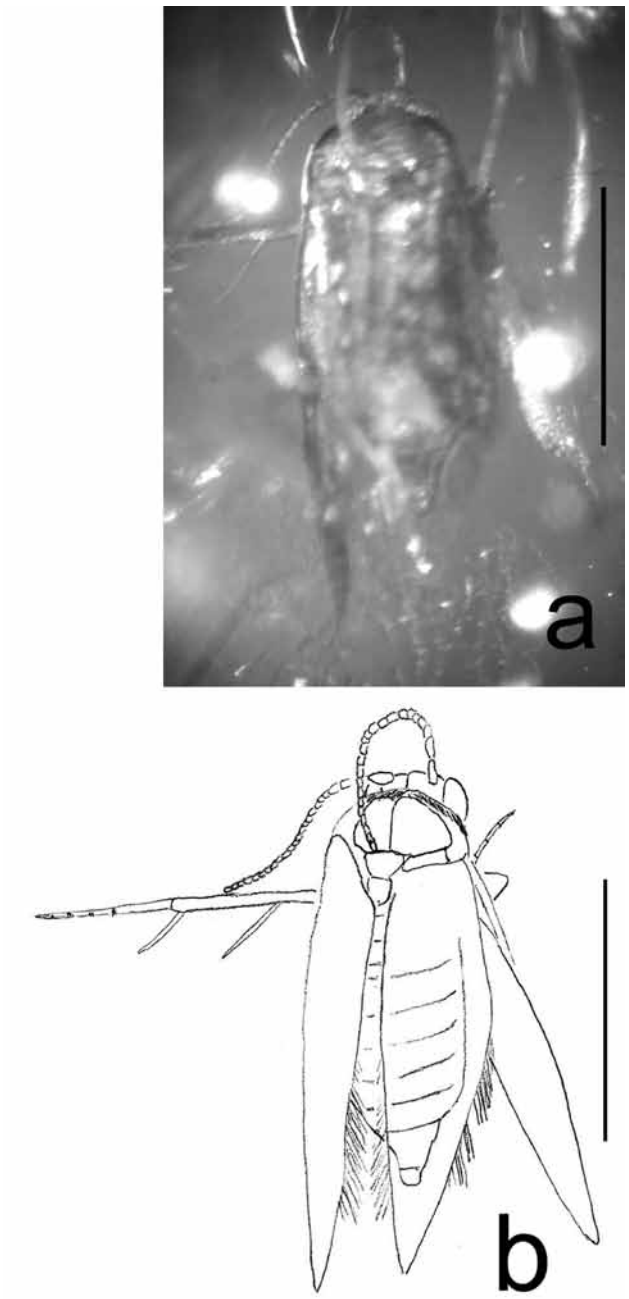

Figure 5: Pygmy moth (Nepticulidae) from Eocene Baltic amber (coll. T Fischer no. 5166); **(a)** Dorsal view; **(b)** Corresponding line drawing. Scale bars = 1 mm.

Due to the lack of observable wing venation identification is only possible at the family level (Nepticulidae).

Specimen 5166
Imago of pygmy moth (Nepticulidae)
Fig. 5

The specimen can positively be identified as belonging to the Nepticulidae because of the small body length of 2 mm and the presence of eye caps. However, identification is only possible at the family level (Nepticulidae) due to the lack of observable wing venation Also sex is not determinable. The inclusion is positioned deep within the amber piece, the ventral side is hidden behind a large air bubble.

Description: Total length 2,2 mm, head 400 µm broad, epicranial notch visible, collar with piliform scales, eyes 150 µm in diameter, antennas filiform, length about half of the forewing, bases of antennas form eye caps, antenna length about 2/3 of forewing length with ca. 22 segments, mesonotum 300 µm broad, abdomen 1 mm long, end of the abdomen pointed as ovipositor, spur formula ?-?-4, five tarsomers, thorax with triangular tegulas, forewings 1,9 mm long, cilia at forewings and hindwings, wing tips acute, venation not visible.

Syninklusions: Ensifera (no. 5162), Dolichoderinae (no. 5163), Chironomidae (no. 5164) with two *Leptus* sp. (Acari) (no. 5165), Trichoptera, trichomes.

4. Discussion

Morphology and size clearly indicate that the fossils described in the paper belong to the superfamily Nepticuloidea. Eye caps are also characteristic, even if similar caps are also found in other families. Among the Nepticuloidea, the family Opostegidae can be excluded since members in this family are characterized by a reduced wing venation, with all the veins separate and relatively straight (Hoare 2000; Davis 1999). Conversely, Nepticulidae possess branched and stalked veins (Davis 1999). Moreover, Opostegidae are somewhat larger than extant Nepticulidae (Parenti 2000) and the fossils considered here. Based on fore wing venation (Van Nieukerken 1986) the specimens with visible venation are affiliated to the extant genus *Bohemannia* Stainton, 1859. Extant species of *Bohemannia* occur in central, western and northern Europe, as well as in eastern Russia and Japan (Van Nieukerken 1986).

Skalski (1976, 1990) mentions the occurrence of the closely related genus *Ectoedemia* in Baltic amber. Since this record does not contain a detailed description of the fossil and no repository information, the new fossils described in this paper could not be compared with this specimen.

The syninclusions of the Nepticulidae imagos represent systematic groups that are quite common as inclusions in Baltic amber, including Nematocera (Cecidomyiidae, Chironomidae), Collembola (Arthropleones), Acari (*Leptus* sp.), Trichoptera, Formicidae (Dolichoderinae), Aphidae (*Germaraphis* sp.), and oak trichomes (*Quercus* sp.). Only Ensifera are not abundant fossils among these inclusions. As a result, taphonomy of Nepticulidae imagos in Baltic amber does not seem to have involved special life communities or specific processes in fossilization. It seems quite likely that the rarity of Nepticulidae inclusions in Baltic amber reflects their rarity in the amber forest habitat. Most extant Nepticulidae live on an-

giosperms, whereas the amber forest is assumed to have been dominated by an amber-producing gymnosperm and also oak trees. It is therefore reasonable to assume that the Nepticulidae lived on oak or some of the rare, diverse angiosperm taxa which are known from the fossil record of Baltic amber (Conwentz 1886; Czeczott 1961). Woody plants of the orders Hamamelidae, Rosidae, and Dilleniidae are important host plants of extant Nepticulidae (Labandeira et al. 1994). For some extant species of *Bohemannia* biology is known; these animals live on deciduous trees, including *Malus* sp. (Rosaceae), *Alnus glutinosa* (Betulaceae) and *Quercus* spp. (Fagaceae) (Van Nieukerken 1986).

5. Conclusions

The fossil Nepticulidae from Baltic amber are remarkably similar in morphology and size to extant taxa. Two new fossil species are described and affiliated to the extant genus *Bohemannia*. Along with another three fossil imagos they provide a more complete insight into the evolution of Nepticulidae, allowing also the definition of a minimal age of the genus and calibration of phylogenetic trees.

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