A pinophiline rove beetle (Coleoptera: Staphylinidae: Paederinae) from the early Eocene Fur Formation, Denmark

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Sammendrag

Rovbiller (Coleoptera: Staphylinidae) omfatter omkring 67.000 beskrevne arter og er en af de mest diverse dyregrupper på Jorden. Selvom gruppen er velkendt fra kænozoiske aflejringer, bl.a. fra Green River Formation (USA) og i rav fra Sen Eocæn i Europa, er den kun kendt i fåtal fra Danmarks tidligste Eocæn. Gruppen er generelt dårligt repræsenteret i Paleocæn og tidlig Eocæn. Her rapporteres en rovbille fra det tidligste Eocæn (Ypresian), fra Fur Formationen, Danmark. Fossilet kan henføres til undertribus Pinophilina (Coleoptera: Paederinae: Pinophilini), men er ikke formelt beskrevet, da fossilet ikke er tilstrækkeligt bevaret. Fur Formationens palæomiljø diskuteres.

Abstract

Comprising close to 67,000 described species, rove beetles (Coleoptera: Staphylinidae) are one of the most diverse groups of animals on Earth. Whilst they are well represented in Cenozoic deposits, such as the Green River Formation (USA) and late Eocene ambers of Europe, they are in general poorly represented in the Paleocene and early Eocene fossil record, and only very few are known from the earliest Eocene of Denmark. Here a rove beetle from the earliest Eocene (Ypresian) Fur Formation of Denmark is reported. The fossil can be assigned to the subtribe Pinophilina (Coleoptera: Paederinae: Pinophilini) but is not formally described due to its incomplete preservation. The palaeoenvironmental conditions of the Fur formation are discussed.

Introduction

The earliest Eocene Ølst (Heilmann-Clausen et al., 1985) and Fur (Pedersen & Surlyk, 1983) formations from the Limfjord area in Denmark, together with Paleocene Menat (France), are the oldest known insectiferous Lagerstätten from the Paleogene of Europe. Fossils of over 200 species from 15 insect orders (Willmann, 1990) have been described from the Fur Formation (Larsson, 1975; Rust, 1998; Willumsen, 2004; Bechly & Rasmussen, 2019). Despite an abundance of insect fossils from the Ølst and Fur Formations, just one representative of Staphylinidae has been reported in the literature (Rust, 1999).

The fossil record of the megadiverse beetle family Staphylinidae dates to the Jurassic (Tikhomirova, 1968; Fikáček et al., 2020) and currently comprises about 642 described species, versus almost 67,000 extant species (Newton, 2022). The Paleocene and early Eocene represent a significant gap in knowledge, with few rove beetles known from these epochs. Several fossil rove beetles are reported from the Paleocene (Selandian) of Menat, France (Piton, 1940; Jenkins Shaw et al., 2023a) and four are known from the Fur Formation – one mentioned by Rust (1999), and three additional unpublished specimens (personal observation). This contrasts with the younger late Eocene European ambers, which preserve an impressive diversity of rove beetles, including at least 77 described species in Baltic amber

at the time of the last checklist (Alekseev, 2013), with many more described since.

Here we report a fossil rove beetle collected from the earliest Eocene (Ypresian) Fur Formation, that is assigned to the subtribe Pinophilina (Coleoptera: Staphylinidae: Paederinae). We discuss palaeoenvironmental conditions of the Fur Formation.

Materials and methods

The specimen was collected by the second author (C.N.) from washed out stones in a large landslide, just before a cliff near Gammelgård Strand, Fur (56.841262 N, 8.992038 E) in January 2020. The rove beetle seems to be an impression of the ventral side, with some characters from the dorsal side of the beetle also preserved. It was studied using a Leica M165 C stereomicroscope. Photographs were taken using a Canon EOS 6D with Canon MP-E 65 mm macro lens and Leica M205 C stereoscope with Canon EOS 5D. Images were stacked using Zerene Stacker. Images were taken of the specimen dry (Fig. 1A) or under 70% alcohol (Fig. 1B). The specimen is housed in the collections of the Natural History Museum of Denmark (NHMD). Measurements were taken using ImageJ (Rasband, 2018).

Figure 1. Pinophilina (Paederinae: Pinophilini) NHMD 1651631 (DK 1238). Scale bar = 1 mm. – A: dry. – B: under 70% alcohol.

Systematic palaeontology

Order Coleoptera Linnaeus, 1758
Family Staphylinindae Latreille, 1802
Subfamily Paederinae Fleming, 1821
Tribe Pinophilini Nordmann, 1837
Subtribe Pinophilina Nordmann, 1837

PINOPHILINA GEN. SP. (FIGS 1, 2)

Material examined

Male, collected by Christian Nielsen in January 2020. NHMD 1651631; Danekræ No. DK 1238 (NHMD).

Locality and horizon

Fur Formation (56.841262, 8.992038, Gammelgård Strand, Fur, Denmark). Collected from a carbonate concretions horizon between ash layers -24 to -29. Ypresian (early Eocene), ca. 55.8 Ma–ca. 55.6 Ma (Stokke et al., 2020).

Description

Total body length (incl. abdomen): 26 mm; head and pronotum length (from anterior margin of left mandible to posterior margin of prothorax): 6.5 mm; head width (including eyes): 2.57 mm; head length (midline including left mandible): 3.2 mm; pronotum width (widest point): 3.1 mm; pronotum length (midline): 3 mm; abdomen length (from anterior edge of sternite III to apex of genital segment): 15.1 mm.

Head rather long (about 1.2x as long as wide), frons appears elongated. Eyes seem to be situated in posterior ¼ of head (Fig. 2A, eye?). Edge of mandible evenly curved (Fig. 2A, Mb?)

Pronotum widest just behind anterior angles; both anterior margin of pronotum (Fig. 2A, A-Pr) and anterior margin of basisternum visible (Fig. 2A, A-Bs). Pronotum possibly rather tuberculate or punctate, but poor preservation makes it difficult to be sure.

Elytra evenly curved along length of outer edge, humeri indistinct; elytra widest at apical third. Prepectus of mesosternum rounded, visible anteriad of mesosternal process (Fig. 2B, Prp). Mesosternal process acutely pointed (Fig. 2B, Ms), projecting between mesocoxal cavities (Fig. 2B, MsC); metacoxae elongate (Fig. 2C, MtC)

Abdomen widest at sternite VII; sternite VIII with deep apical incision which almost has a 90 degrees angle. Sternite III with keel between metacoxae (Fig. 2C, Ke). Intersegmental membranes of abdomen with distinct brick-wall pattern (Fig. 2D).

Comments.

Reliable identification of Pinophilina at the species and sometimes even generic level relies on examination of the male sexual characters (Assing, 2022). Such sexual characters and external characters that are useful for identifying genera (e.g. mandibular structure) are unfortunately not preserved in the studied fossil and we therefore opt to leave it unnamed. The specimen can be identified as a male due to the presence of a deep apical incision of sternite VIII.

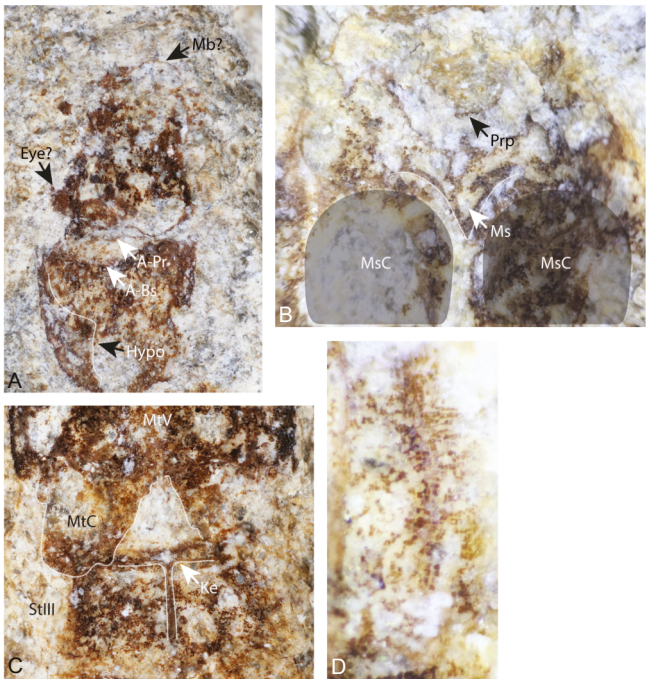

Figure 2. Morphological details of Pinophilina (Paederinae: Pinophilini) NHMD 1651631 (DK 1238). – A: Head and prothorax. – B: Meso- and metaventrite. – C: Metaventrite and sternite III. – D: Intersegmental membrane of abdominal segments. Abbreviations: A-Bs = anterior margin of the basisternum; A-Pr = anterior margin of pronotum; Hypo = hypomeron; Ke = keel; Mb? = mandible?; Ms = mesosternum; MsC = mesocoxal cavities; MtC = metacoxae; MtV = metaventrite; Prp = prepectus of mesosternum; StIII = sternite III.

Discussion

NHMD 1651631 (DK 1238) is a rove beetle due to the short, truncate elytra exposing several abdominal segments. Unambiguous characters that allow its placement in Paederinae are not visible (e.g. visibility of antennal insertions) however the following ambiguous (with respect to other subfamilies) characters are indicative of the subfamily Paederinae when combined: very large size; pronotum widest just behind anterior angles; large pronotal hypomeron present; intersegmental membranes of abdomen with distinct brick-wall pattern. The following combination of characters are indicative of the subtribe Pinophilina (inside Paederinae): very large size; pronotum widest just behind anterior angles; large pronotal hypomeron present; tergites III to VIII each with two pairs of paratergites; intersegmental membranes of abdomen with distinct brick-wall pattern (best visible on membrane connected to anterior margin of sternite III); sternite III with keel between metacoxae. Placement beyond subtribal level is not possible due to the lack of preserved morphological characters. Specimen NHMD 1651631 is different from three other rove beetle fossils known from the Fur Formation. It differs from the only published Fur Formation rove beetle "MM 1833" mentioned by Rust (1999) in its larger size and pronotum widest in front – according to Rust (1999) specimen MM 1833 is 6.9 mm long and the pronotum is overall narrow, but much narrower at the front than at the back. Specimen MM 1833 was not studied during preparation of this manuscript.

The subfamily Paederinae is represented by 41 described fossils (Żyła et al., 2019; Tokareva et al., 2023) with many undescribed from various deposits. The tribe Pinophilini is divided into the subtribes Pinophilina and Procirrina. Jenkins Shaw et al. (2020) described the oldest Pinophilini from mid-Cretaceous Burmese amber, *Cretoprocirrus trichotos* Jenkins Shaw and Żyła 2020, placed in the subtribe Procirrina. Recently, a new genus and species placed in Pinophilina was described from the Upper Cretaceous Orapa Diamond Mine in Botswana

(Mnguni et al., 2022), but is problematic since the introduced genus and species names are published as an online preprint and the name(s) are not registered in ZooBank. In addition, it is apparent from the photographs in Mnguni et al. (2022) that whilst the Orapa specimen does belong to the subfamily Paederinae, it most likely belongs to the tribe Lathrobiini. Chatzimanolis (2018, Fig. 3.2) reported two undescribed fossil representatives of the tribe Pinophilini from the mid Ypresian–earliest Lutetian Green River Formation (53.5 to 48.5 Ma) – one specimen (USNM 53181) can be assigned to the subtribe Pinophilina and the other specimen (USNM53181) is possibly closely related to the genus *Palaminus* Erichson, 1839 (Pinophilini: Procirrina). One rove beetle fossil from the Ypresian Messel shales (Germany) likely belongs to Pinophilina (personal observation by the first author). Kirejtshuk et al. (2019) reported a single specimen assigned to the subtribe Pinophilina from the late Eocene of Bembridge Marls, Isle of Wight, England. Seevers (1971) and Herman (2010) reported a species of *Palaminus* from Miocene Mexican amber. At least nine specimens of *Palaminus* are known from the Miocene Dominican amber (Dagmara Żyła, personal observation in Jenkins Shaw et al., 2020).

In the extant fauna, the subtribe Pinophilina contains 30 genera (Newton, 2022) after the recent monumental work by Assing (2022), which contained the description of 12 new genera. The majority of Pinophilina are (sub)tropical in distribution (Abarbanell & Ashe, 1989), however some taxa appear to be cold tolerant, occurring as far north as 44° (New England, USA) based on citizen science data (iNaturalist, 2023). Such northern records have a Mean Temperature of Coldest Quarter of -6°C (Fick & Hijmans, 2017), whilst the highest Mean Temperature of Coldest Quarter, 26°C, comes from the Philippines. The potential of reconstructing palaeoenvironments based on linking fossil occurrences with citizen science data of extant taxa seems great, however, accurate taxonomic assignment of fossils (ideally to species-group of genus level) is critical.

Assing (2022) stated that little is known about the natural history of Pinophilina. Most of the species occur at low to intermediate altitudes, and a few at high elevations (up to more than 3000 m). Most specimens are collected at light, often near lakes, rivers, or streams. Some species were exclusively extracted from forest litter or soil, and dead wood (bark or logs). The available data suggest that the reproduction habitats are of a cryptic, partly probably subterranean nature.

Fossils from three deposits show that Pinophilina rove beetles were present in Europe throughout the Eocene: specimen NHMD 1651631 from the Ypresian Fur Formation (Denmark) reported here, one specimen from Ypresian Messel shales (Germany), and specimen I. 17423 (Kirejtshuk et al., 2019) from the latest Eocene (Priabonian) Bembridge Marls (Isle of Wight, UK; Ross & Self, 2014). Despite this, they are absent in all European amber deposits, possibly due to taphonomic bias or climatic factors. Some Pinophilina are clearly not cryophobic sensu Archibald et al. (2023), they are tolerant to below freezing temperatures (see above) whilst many are also tropical in distribution. Until recently, the plant and animal community of the Fur Formation was considered strongly thermophilic, subtropical, or even tropical. We have the same problem that was discussed for more than a hundred years concerning European amber biota (as well as biota of Bembridge Marls). The well-known simultaneous presence of both temperate and cryophobic elements (Archibald & Farrell, 2003; Matalin et al., 2021; Radchenko & Perkovsky, 2021; Yamamoto et al., 2022; Anisyutkin & Perkovsky, 2023, Kirichenko-Babko & Perkovsky, 2023; Jenkins Shaw et al.,

2023b; Legalov et al., 2023a,b; Nabozhenko & Perkovsky, 2023; Telnov et al., 2023; Turbanov et al., 2023) is impossible in the extant icehouse climate, but was normal in the greenhouse climate of early Eocene Okanagan (British Columbia and Washington, high microthermal equable climate; see Archibald et al., 2014, and references therein; Archibald et al., in press).

On the one hand, we have glendonites as indicators of the cold bottom temperatures (Vickers et al., 2020, 2023) together with the reconstructed sea surface temperatures from biomarkers for northern Denmark suggested that short-term cooling events of magnitude c. 5 - 7 °C may have punctuated the late Paleogene to early Eocene (Vickers et al., 2023, and references therein). On the other hand we have, e. g., presence of juvenile sea turtle *Tasbacka danica* Karl & Madsen, 2012 (Lindgren et al., 2017), indicating the *Tasbacka* hatching in the area (Lindow, pers. com.). More thorough examination of fossil plants from the Fur Formation (Herold et al., 2014), as well as an evident similarity of microthermal far-western American Okanagan fauna with that of the Fur Formation (Archibald & Makarkin, 2006; Archibald et al., 2006, Archibald & Cannings, 2019; Simonsen et al., 2022), and the presence of genera that are shared with the high microthermal Florissant Formation (Colorado, latest Eocene e. g. Makarkin & Perkovsky, subm.) also contradict subtropical conditions for the Fur Formation. Our specimen was found in the lower part of the Fur Formation. Many insect fossils are present in both the lower and upper parts of the Fur Formation and remain to be studied and described. Entomological indicators of the cooling are, e. g., disappearance of giant ants in the Fur Formation (Rust & Andersen, 1999; Rust, 1999) and the presence of numerous aphids in the higher levels of the Fur Formation, where the glendonites are also present (Rust 1999). Systematic inventory of Fur Formation biota, especially the study of aphids from the different levels of the Fur Formation could help us to understand the dynamic of cooling events. In particular, insect fossils could help us understand whether there was one episode of regional cooling or whether it included some local warming phases, when cryophobic elements were better represented in Fur Formation biota and maybe even some thermophilic elements occurred.

European amber contains diverse members of the subfamily Staphylininae (Brunke et al., 2019), which is closely related to Paederinae, albeit they are much scarcer than Paederinae. Pinophilini are not known from late Eocene European amber (Dlussky & Rasnitsyn, 2009; Lyubarsky et al., 2023) which is otherwise rich in Paederinae, especially the tribe Lathrobiini (Bogri et al., 2018, 2020; Kypke & Solodovnikov, 2020). Given the Eocene age and palaeogeographical proximity of the Fur Formation and European amber forests, it is unsurprising that they are reciprocally important in terms of systematics, palaeoecology, and inferring the age of redeposited fossil resins such as Baltic amber (e.g. Meier et al., 2022).

It seems possible that Pinophilina in Eocene Europe suffered extinctions and/or range contractions in response to the Eocene-Oligocene cooling (e.g. Prothero, 1994; Eldrett et al., 2009). Baltic amber Staphylininae are comparable in body size to Pinophilina. However, understanding what prevented the preservation of the latter in Baltic amber is a difficult task. It is notable that Staphylininae are not reported from the Bembridge Marls (see Radchenko & Perkovsky, 2021, and references therein for details of Bembridge Marls paleoenvironment).

We hope that the present contribution will stimulate further studies on the insect fossils of the Fur Formation.

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