

Short communication

Two new species of Ghilarellinae (Hymenoptera, Cephioidea, Sepulcidae) from the Lower Cretaceous

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ABSTRACT

One new species, *Ghilarella elegantula* sp. nov., in the family Sepulcidae is described and illustrated based on a well-preserved compression fossil specimen from the Lower Cretaceous Yixian Formation of northeastern China. The new species is characterized by having a large body size; forewing with costal area obviously narrowed basally, Sc and 2r-m absent, 1-Rs short, cell 1mcu large; and ovipositor elongated. In addition, *Ghilarella* cf. *mercurialis* is given its own name *Ghilarella kopylovi* as the new species in *Ghilarella*. An updated key for the known species of *Ghilarella* is provided. Moreover, a well-preserved ovipositor is reported for the first time in the subfamily Ghilarellinae. The two new species not only improve our understanding of *Ghilarella* by adding more morphological features, but also expand the distribution ranges of Ghilarellinae fossil records.

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1. Introduction

Cephioidea now comprises an extant family Cephidae, and an extinct family Sepulcidae. Morphology and some molecular analyses strongly suggest Cephioidea is the sister group of Siricoidea + [Xiphydrioidea + (Orussoidea + Apocrita)] (Sharkey et al., 2012; Malm and Nyman, 2015). Sepulcidae is a diverse though not the most abundant group of siricomorph wasps (Rasnitsyn and Martínez-Delclòs, 2000). Sepulcids were first described from the Jurassic deposits of Karatau, Kazakhstan, and then transferred to Cephioidea based on a flat and saw-like ovipositor, being as a stem group to the family Cephidae (Rasnitsyn, 1968, 1988). The compression fossils of Sepulcidae have been documented from the Early Jurassic to the Late Cretaceous (Kopylov and Rasnitsyn, 2014), reaching its maximum

species diversity from the Late Jurassic to the Early Cretaceous (Kopylov and Rasnitsyn, 2017a). There are five subfamilies in the Sepulcidae: Parapamphilinae Rasnitsyn, 1968; Sepulcinae Rasnitsyn, 1968; Trematothoracinae Rasnitsyn, 1988; Ghilarellinae Rasnitsyn, 1988; Xyelulinae Rasnitsyn, 1993a, b. To date, 56 species within 15 genera belonging to five subfamilies of Sepulcidae have been reported in the Mesozoic (Darling and Sharkey, 1990; Rasnitsyn, 1993a, b; Rasnitsyn and Ansoerge, 2000; Jattiot et al., 2011; Kopylov and Rasnitsyn, 2014, 2017a, b; Li et al., 2023).

So far, a total of five species in two genera are assigned to the subfamily Ghilarellinae: *Ghilarella mercurialis* Rasnitsyn, 1988 (Dzun-Bain Formation, the Lower Cretaceous of Mongolia); *G. nivalis* Rasnitsyn, 1993 (Amka Formation, the Upper Cretaceous of Russian); *G. alexialis* Kopylov and Rasnitsyn, 2017 (Dzun-Bain Formation, the Lower Cretaceous of Mongolia); *G. masculina* Kopylov and Rasnitsyn, 2017 (Zaza Formation, the Lower Cretaceous of Russian); and *Meiaghilarella cretacica* Rasnitsyn and Martínez-Delclòs, 2000 (la Pedrera de Rubies Formation, the Lower Cretaceous of Spain). Recently, we collected a well-preserved fossil sepulcid (including part and counterpart) from the Early Cretaceous, Yixian Formation of northeastern China, which belongs

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to the famous Jehol Biota (Ren et al., 1995; Hong, 1998). The Yixian Formation is widely distributed in the eastern part of western Liaoning Province of China, which are intermediate-basic-acid volcanic rocks with sedimentary rocks, the upper part is dominated by andesite, rhyolite and dacite, and the lower part is mainly basalt and volcanic hornblendite (Su and Zhu, 2022). One of the great things about controversy is regarding the age debate (Zhou et al., 2003; Chen et al., 2004). Recent studies, using the zircon U-Pb dating and $^{40}\text{Ar}/^{39}\text{Ar}$ isotope age period, indicated that this volcanic rock was formed at 130–120 Ma (Xu et al., 2012; Zhang et al., 2016; Su and Zhu, 2022). The western part of Liaoning Province is the core area for the distributions of the Jehol Biota. The fossils were mainly hosted in the Yixian Formation and Jiufotang Formation, which represent the early and middle development stages of the Jehol Biota. It is generally recognized by the academic community that the age of the main fossil-bearing layer is about 125 Ma (Swisher III et al., 1999, 2002; He et al., 2006; Zhong et al., 2021; Li et al., 2022; Yu et al., 2023).

In this paper, we report a new fossil species and give *Ghilarella* cf. *mercurialis* its own name (Kopylov and Rasnitsyn, 2017b). The structures of ovipositor of Sepulcidae are examined and compared. These new characters can enhance our understanding of the Mesozoic taxa in Sepulcidae and provide more comprehensive evidence to compare and study the early evolution of Cephioidea.

2. Material and methods

The holotype specimen of *Ghilarella elegantula* sp. nov. (part and counterpart, P/C) was collected from the Yixian Formation, Liutiaogou, Dashuangmiao Town, Ningcheng County, Inner Mongolia, China (Fig. 1). The new specimen described in the paper is housed at the fossil collection of the Key Lab of Insect Evolution and Environmental Changes, at the College of Life Sciences, Capital Normal University (CNU; Dong Ren, Curator), in Beijing, China. The holotype and paratype specimens of *Ghilarella kopylovi* sp. nov. were collected from lower part of the Gusinoe Ozero Group (no formation specified), Khasurty 10 km south Tsakir vill., Zakamensk Region, Buryatia Rep., Russia (Kopylov et al., 2020).

The specimen was examined and photographed under Nikon SMZ 25 dissecting microscopes with an attached Nikon DS-Ri2 digital camera system. The line drawings were prepared using Affinity Designer V1. The wing venation nomenclature used in this study is modified from Huber and Sharkey (1993), with the

following abbreviations: A, anal vein; C, costal vein; Cu, cubital vein; M, median vein; R, radial vein; 1cu-a, crossvein between 1-Cu and 1A; 2r-m and 3r-m, crossveins between Rs and M; 1m-cu and 2m-cu, crossveins between M and 1-Cu; a, crossvein between 1A and 2A+3A; succeeding sections of respective veins counted from base to apex of wing.

This published work and the nomenclatural acts it contains have been registered in ZooBank, the online registration system for the ICZN. The LSID for this publication: urn:lsid:zoobank.org:pub:C6E61BA1-DAD0-4EE0-B92F-1D2669288806.

3. Systematic palaeontology

Order Hymenoptera Linnaeus, 1758.

Suborder Symphyta Gerstaecker, 1867.

Superfamily Cephioidea Newman, 1834.

Family Sepulcidae Rasnitsyn, 1968.

Subfamily Ghilarellinae Rasnitsyn, 1988.

Genus *Ghilarella* Rasnitsyn, 1988.

Type species: *Ghilarella mercurialis* Rasnitsyn, 1988.

Species included. *Ghilarella mercurialis* Rasnitsyn, 1988; *Ghilarella nivalis* Rasnitsyn, 1993; *Ghilarella alexialis* Kopylov and Rasnitsyn, 2017; *Ghilarella masculina* Kopylov and Rasnitsyn, 2017; *Ghilarella elegantula* Li, Wang, Rasnitsyn and Shih, sp. nov.; *Ghilarella kopylovi* Li, Wang, Rasnitsyn and Shih, sp. nov.

***Ghilarella elegantula* Li, Wang, Rasnitsyn and Shih, sp. nov.**

(Figs 2, 3, 4)

Material. Only the holotype, CNU-HYM-NN2023001(P/C).

Etymology. The specific epithet (Latin) means “elegans”, and refers to the general appearance of the type specimen.

Locality and horizon. Lower Cretaceous (125 Ma), Yixian Formation, Liutiaogou, Dashuangmiao Town, Ningcheng County, Inner Mongolia, China (41°52.583 N, 118°92.472 E).

Diagnosis. Large body size (nearly 29 mm in length). Forewing only with transverse dark band under pterostigmal base; 2r-rs extending from the pterostigma near its mid-length; vein a extending from 1A proximally than 1cu-a; ovipositor sheaths longer than cells 1r and 2r combined.

Description. Female. Body slim and long, including head, thorax and abdomen. Head entirely or predominantly dark, slightly darker than thorax and abdomen, with ovipositor slightly darker; legs lightly colored; wing veins dark; pterostigma dark, sclerotized completely (Figs 2A, 3A).

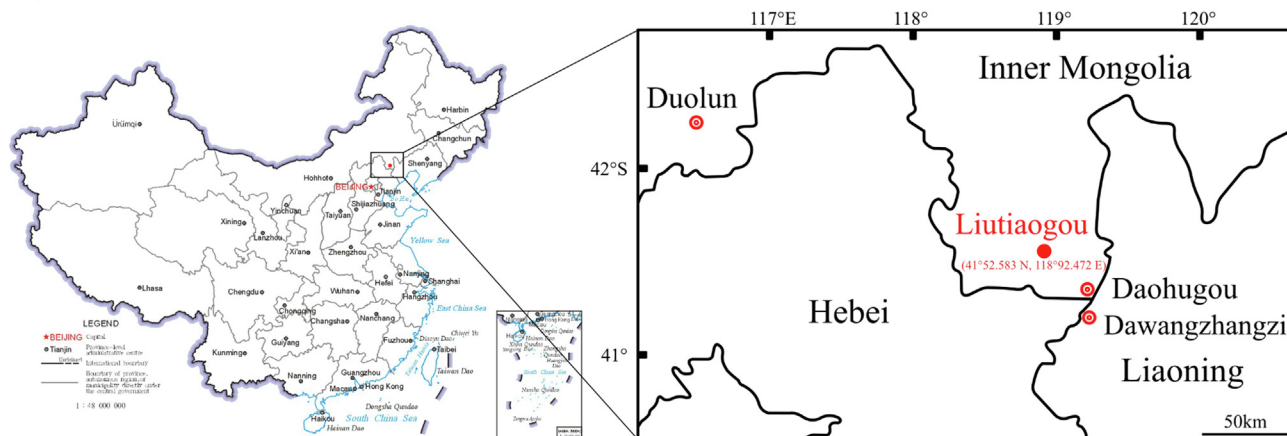


Fig. 1. Geographical sketch map showing the insect fossil locality Yixian Formation, Liutiaogou, Dashuangmiao Town, Ningcheng county, Inner Mongolia, China (41°52.583 N, 118°92.472 E). The map is based on the standard map of GS (2019) 1673 downloaded from the standard map service website of the National Bureau of Surveying, Mapping and Geoinformation, and the base map is not modified.

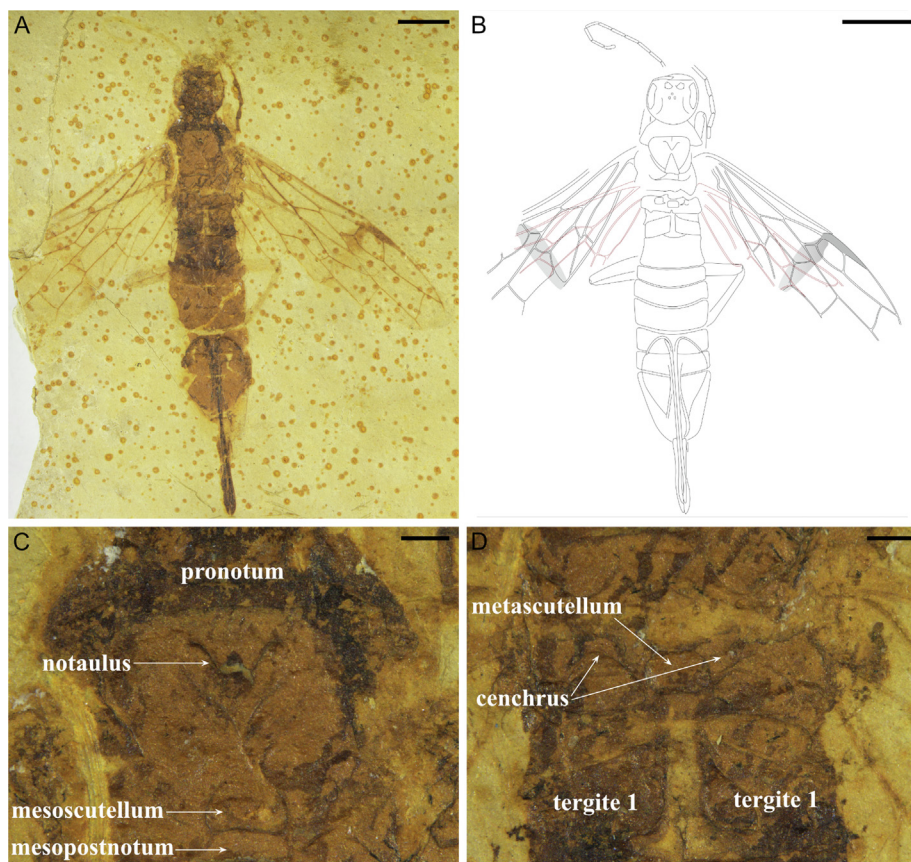


Fig. 2. Photographs of *Ghilarella elegantula* sp. nov., holotype (specimen CNU-HYM-NN-2023001 P/C) female. (A), dorsal view as preserved. (B), line drawing of dorsal view. (C–D), photos of thorax and part of abdomen. Scale bars: 2 mm in (A, C, D); 5 mm in (B).

Head: Surface sculpture coarsely punctated, moderately large, narrower than thorax, nearly round shaped; length nearly equal to width. Eye narrow and half of head length, extending to the mandibular base; ocelli small, in high triangle. Mandible strong and long, sickle-shaped and bent inward. Antenna thin, filiform, apparently short, with ten flagellomeres visible, maximum 1.05 mm in length and 0.33 mm in width (Figs 2A, B).

Thorax: Pronotum short and trapezoid, with no medial line or furrow, at least four times as wide as long; pronotum posterior border slightly curved in dorsal view; mesoscutum large, with anterior margin nearly straight, notauli strongly impressed, converging to meet prior to mesoscutellum; mesoscutellum triangular, ratio of lengths of prescutum, longitudinal sulcus between notauli and mesoscutum-mesoscutellar sulcus, and mesoscutellum 4 : 1 : 7 (Fig. 2C); mesopostnotum trapezoid, slightly narrower than metascutellum; metascutum with metascutellum small, rounded quadrangular, transverse; cenchrus large and oval (Fig. 2D).

Legs: Legs poorly preserved, fore and hind coxa sub-equal, relatively large and trapezoid; femora and tibiae thin, rather short, tarsi not preserved (Fig. 3B).

Wing: Forewing long and narrow, three times as long as wide, with pterostigma completely sclerotized; veins dark; vein C straight and slightly thickened; Sc lost; R greatly thickened; costal area obviously narrowed basally. 1-Rs short; 1r-rs straight and short; distance between 1r-rs and 2r-rs 2.7 times as long as 1r-rs; 2r-rs extending from the pterostigma near its mid-length; cell 2r long and narrow; 4+5-Rs 2.75 times as long as 6-Rs; M+Cu straight; cell 1mcu large; cross-vein a subvertical, located proximally of 1cu-a; 2r-m absent; 3r-m strongly inclined; 2cu-a vertical; cross-veins 1cu-a and 2cu-a present; 1A straight; 2A+3A with pronounced

arch midway before 1cu-a (Fig. 3C). In hind wing, cells r and mcu long and wide; base of 1-M sharply bent; 2-Rs 1.3 times as long as 1-Rs, 1-M 2.2 times as long as 2-M; m-cu and r-m present; M+Cu bifurcated before cu-a; 2-M longer than m-cu; 2-Cu long; cu-a joining 1A slightly distal to vein a; both 1A and 2A with free endings (Fig. 3D).

Abdomen: Abdomen slightly wider than the mesothorax, parallel-sided, with nine segments visible, widest at sixth segment, with first tergum split medially (Fig. 2B).

Ovipositor: First valvifer small, subhemicircular as visible, first valvula (ventral stylet) with the remus basally, with four transverse ridges apically; second valvifer large, with thickening medially and distally, narrowing up to single thickening before meeting with valvula 3 (saw sheath), 0.9 times as long as valvula 3, valvula 2 (dorsal stylet) visible only basally at its thickened base (Figs 4A, 4B); ovipositor straight, roundish in cross-section, sword-shaped; ovipositor full length equal to $0.72 \times$ forewing length (Figs 4A, 4B); ovipositor sheaths almost straight, elongated and narrowly rounded apically, prominent significantly behind abdomen, valvula 3 0.29 times as long as forewing length (Figs 4C, 4D).

Measurements (in mm): Body excluding ovipositor about 28.60 in length; head about 4.10 in length, 3.85 in width; thorax about 7.41 in length; abdomen about 18.10 in length; forewing (incompletely preserved) about 20.08 in length, maximum width 6.40; ovipositor about 14.56 in length.

Remarks. *Ghilarella elegantula* sp. nov. can be assigned to the subfamily Ghilarellinae based on the forewing with costal area obviously narrowed basally; 2r-m and Sc absent; 1-Rs short; M+Cu straight; 1mcu large; and to the genus *Ghilarella* based on

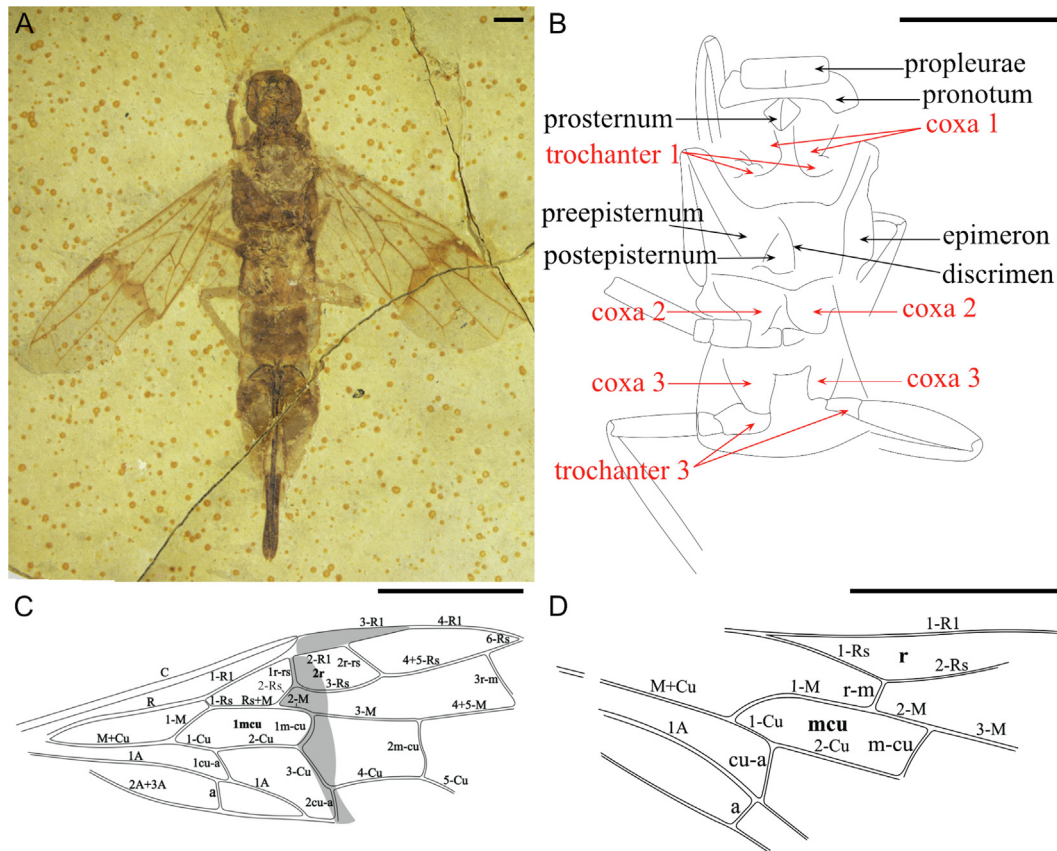


Fig. 3. Photographs of *Ghilarella elegantula* sp. nov., holotype (specimen CNU-HYM-NN-2023001 P/C) female. (A), ventral view as preserved. (B), line drawing of ventral view with part legs and thorax. (C), line drawing of ventral view with forewing (D), line drawing of ventral view with hind wing. Scale bars: 2 mm in (A, B); 5 mm in (C, D).

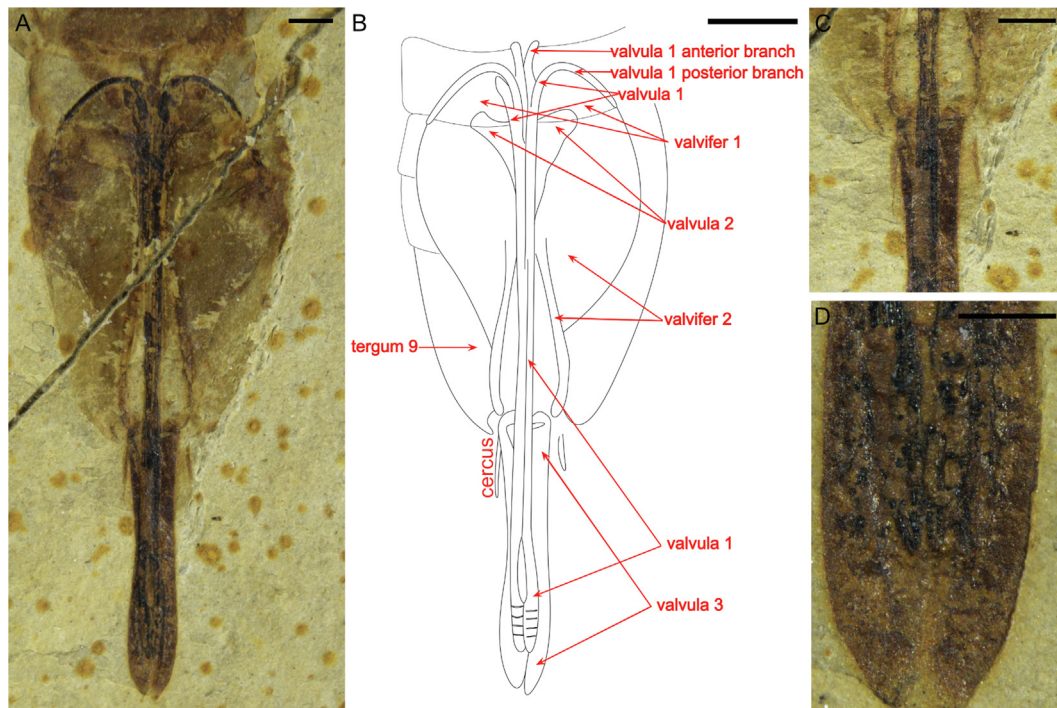


Fig. 4. Photographs of *Ghilarella elegantula* sp. nov., holotype (specimen CNU-HYM-NN-2023001 P/C) female. (A), photo of ovipositor. (B), line drawing of ovipositor. (C–D), photo of part ovipositor. Scale bars: 2 mm in (A, C–D); 5 mm in (B).

pterostigma long and narrow; cell 2r large, 2r-rs after pterostigmal mid-length, 3r-m closer to apex rather than to base of cell 3r. In order to better distinguish the six species of *Ghilarella*, we selected the key characters and established the relevant key to their identification (see below).

***Ghilarella kopylovi* Li, Wang, Rasnitsyn and Shih, sp. nov.**

Ghilarella cf. *mercurialis*: Kopylov and Rasnitsyn (2017b), p. 294–295, figs. 5–6.

Material. Holotype, PIN, no. 5340/55.

Etymology. The species is named in honor of Dmitry S. Kopylov who identified the species as distinct from *G. mercurialis*.

Locality and horizon. Lowermost Cretaceous, lower part of the Gusinoe Ozero Group (no formation specified), Khasurty 10 km south Tsakir vill., Zakamensk Region, Buryatia Rep., Russia (50°21' N, 103°38' E; cf. Kopylov et al., 2020).

Diagnosis. Body size small (some 15 mm, forewing 10.7 mm). Wing membrane with no color pattern. Pterostigma sclerotized. 2r-rs at distal third of pterostigma. 2-M aligned with Rs+M. Vein a extending from 1A proximally than 1cu-a. Ovipositor sheaths shorter than cell 1r.

Description. Female. Description is provided by Kopylov and Rasnitsyn (2017b), essentially to stress similarity of the material to *G. mercurialis* except the completely colorless wing membrane. The present addition is 2-M aligned with Rs+M, the only currently available non-coloristic difference from *G. mercurialis*.

Remarks. Kopylov and Rasnitsyn (2017b) realized the species level distinction of the present species and yet they left it unnamed because of absence of non-coloristic diagnostic characters because the color pattern may not preserve in fossils. Now we know at least one venational difference between *G. mercurialis* and the present species and have sufficient reasons to give the latter its own name.

Identification Key for Species of the Genus *Ghilarella*

1. Forewing lacking color pattern. 2-M aligned with Rs+M. Ovipositor sheaths shorter than cell 1r *G. kopylovi* sp. nov.
- Forewing with dark spots or bands. 2-M aligned or angled with Rs+M.....2
2. Forewing with dark spot extending along 1r-rs and 2-M only. 2-M aligned with Rs+M. Vein a extending from 1A distally than 1cu-a..... *G. alexialis* Kopylov and Rasnitsyn, 2017
- Forewing with dark with complete transverse dark band extending from pterostigmal base to apex of 1A+2A vein. Vein a extending from 1A not distally than 1cu-a.....3
3. Forewing additionally with two dark spot at base of 1rm cell and along 1-Rs and 1-M. 2-M aligned with Rs+M. 3r-m near cell 3r mid-length. Vein a extending from 1A opposite 1cu-a.....*G. nivalis* Rasnitsyn, 1993
- Forewing only with transverse dark band under pterostigmal base. 3r-m distinctly behind cell 3r mid-length. Vein a extending from 1A proximally than 1cu-a, even if minimally.....4
4. 2r-rs extending from pterostigma near its mid-length. 2-M aligned with Rs+M. Ovipositor sheaths longer than cells 1r and 2r combined..... *G. elegantula* sp. nov.
- 2r-rs extending from the apical third of pterostigma. Ovipositor sheaths when known much shorter.....5
5. Pterostigma sclerotized. 2-M angled with Rs+M. Hind wing with cu-a joining 1A distally than vein a..... *G. mercurialis* Rasnitsyn, 1988
- Pterostigma edge sclerotized. 2-M aligned with Rs+M. Hind wing with cu-a joining 1A proximally than vein a.....*G. masculina* Kopylov and Rasnitsyn, 2017

4. Discussion

Before this study, only two fossil species, *Trematothorax liaoningensis* H. Zhang, F. Zhang and Wei, 2001 and *Xaxaxis longhuaensis* (Hong, 1984) (as “*Euryxyela*”), have been reported from China in Sepulcidae (Darling and Sharkey, 1990; Zhang et al., 2001). *G. elegantula* is assigned to the Ghilarellinae based on the combination of following characters: costal area obviously narrowed basally; 2r-m and Sc absent; 1-Rs short; M+Cu straight; 1mcu large. *G. elegantula* sp. nov. cannot be assigned to Cephidae since it presents cenchri (vs. cenchri lost in Cephidae) (Kopylov and Rasnitsyn, 2016). It is the first fossil record of Ghilarellinae in China hitherto, providing important characters which can enhance our knowledge on diverse morphological characters of Sepulcidae. The Cretaceous period in eastern Inner Mongolia is mainly dominated by volcanic rocks and tuff. Affected by the Yanshanian structure, volcanic activity was extremely frequent; the paleoclimate was mainly subtropical warm and humid environment, which was inland lake facies or lake marsh facies (Ma et al., 2022). The evolution of sedimentary paleogeography, paleoclimate and paleoecological environment in the Cretaceous period of Inner Mongolia has significant constraints and synergy with the radiation evolution of the Jehol Biota (Ma et al., 2022). It is significant that extensive geographical distributions of the Cretaceous Jehol Biota in Inner Mongolia and the diversity fossil categories provide important fossil evidence for better understanding the composition and radiation evolution on the biodiversity of global terrestrial ecosystem in Early Cretaceous.

Kopylov and Rasnitsyn (2017b) found an interesting pattern based on a relatively large series during the measurements of the forewings of *G. mercurialis*: the females of *G. mercurialis* belong to the small size class, the length of the females forewing is 9.2–10.5 mm (vs. the length of the males 12.0–15.1 mm), and the differences in male and female sizes could have been explained by sexual dimorphism. It seems to be different from our perception that females of sawflies are usually larger than males, also the similar phenomenon appears in many cimbicids. All four previously described species of *Ghilarella* (two females, one male and an unknown gender), and our new species (female) are summarized in Table 1. The body sizes range from 13.0 to 28.6 mm, and their forewings length range from 8.50 to 20.08 mm. The ratios of wing length/body length range from 0.61 to 0.76. These data show that *G. elegantula* is considered to be the largest fossil specimen in the subfamily Ghilarellinae. Up to now, *G. elegantula* is much larger than all males of previously described *Ghilarella*, and the size of the male individuals of *G. elegantula* and *G. kopylovi* are unknown, pending future collection of more insect fossils to verify whether this is the sexual dimorphism in family Sepulcidae.

Before this study, Trematothoracinae was the subfamily of Sepulcidae with the largest body size (Kopylov and Rasnitsyn, 2014). *Trematothorax kasparyani* Kopylov and Rasnitsyn, 2014 and *T. demeter* Kopylov and Rasnitsyn, 2014 were remarkable in their forewing lengths over 13.0 mm. *Thoracotrema*, compared other Trematothoracinae, had a longer ovipositor. The longest ovipositor within Trematothoracinae is in *Thoracotrema caudatum* Rasnitsyn, 1988. In our research, *G. elegantula* possesses the well-preserved ovipositor similar to Trematothoracinae. Its straight and elongate ovipositor is needle-like and as long as abdomen or forewing, or even longer. Other species of Ghilarellinae have their ovipositor shorter. However, Xyelulinae have their ovipositor also long but usually wide (compressed, that is saw-like rather than needle-like, except *Onokhoius* Rasnitsyn, 1988 with the ovipositor long and needle-like (Rasnitsyn, 1969,

Table 1
Known fossil species of Ghilarellinae.

Taxa	Locality and horizon	Sex	Wing length (mm)	Body length (mm)	vein a extending from 1A more distally or proximally than 1cu-a on forewing	Ratio between 2-R1 and 3-R1 on of forewing	Ratio between 4+5-Rs and 6-Rs on of forewing
<i>Ghilarella alexialis</i>	Mongolia, K1	?	8.50	NA	more distally	1.20	1.24
<i>G. masculina</i>	Russian, K1	Male	11.40	18.70	more proximally	1.50	1.27
<i>G. mercurialis</i>	Mongolia, K1	Female	9.20	13.00	more proximally	1.50	1.71
<i>G. nivalis</i>	Russian, K2	?	16.00 (–3r)	NA	from 1A opposite	2.25	0.71
<i>G. elegantula</i> sp. nov.	China, K1	Female	20.08	28.60	more proximally	1.14	2.86
<i>G. kopylovi</i> sp. nov.	Russian, K1	Female	10.70	15.00	more proximally	1.64	1.85
<i>Meiaghilarella cretacea</i>	Spain, K1	?	5.70	10.50	more proximally	0.40	0.69

Notes. Measurement data are based on the holotype. NA = not available.

1993a; Rasnitsyn et al., 2003; Kopylov and Rasnitsyn, 2017a). Parapamphiliinae and Sepulcinae have their ovipositor usually saw-like and short, slightly protruding the apex of the abdomen (Rasnitsyn, 1968, 1993a; Kopylov and Rasnitsyn, 2017a). *G. elegantula* has its ovipositor apex with strong ridges and grooves apparently used to help drilling hard substrate, probably wood. Similar armament is characteristic of the living xylophylous wasps and particularly of Siricidae (e.g., Schiff et al., 2012: fig. A3:17). Unfortunately, these structures are not very often preserved in fossils.

CRediT authorship contribution statement

Yi Li: Writing – original draft, Conceptualization. **Mei Wang:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization. **Alexandr P. Rasnitsyn:** Writing – review & editing. **Chungkun Shih:** Writing – review & editing. **Jialiang Zhuang:** Writing – original draft. **Dong Ren:** Writing – review & editing, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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