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## New orthophlebiid mecopteran from the Middle Jurassic Yan'an Formation, China

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### Abstract

A new species of Orthophlebiidae, *Orthophlebia lini* Lian & Huang, **sp. nov.**, is described and illustrated from the Middle Jurassic Yan'an Formation of Yan'an City, north China. The species is erected based on a specimen preserving both a forewing and a hindwing, and a paratype preserving only a hindwing. These specimens demonstrate variability in the relative lengths of  $Rs_{1+2}$  and  $Rs_{3+4}$  even within the same individual, confirming that previous taxonomic systems relying heavily on these features may be flawed. This new species represents the first mecopteran fossil species from the Yan'an Formation and increases our understanding of the species richness of Orthophlebiidae during the Jurassic.

**Key words:** Mesozoic, scorpionflies, Panorpoidea, Ordos Basin

### Introduction

Mecoptera, now a small relic order, comprise over 700 extant species in nine families, with Panorpidae and Bittacidae being the most diverse (Bicha 2018; Wang & Hua 2022). In contrast, the fossil record of Mecoptera demonstrates considerable diversity. This is evidenced by the discovery of more than 600 fossil species across 40 families and by the remarkable morphological disparity exhibited by extinct taxa (Zhang *et al.* 2023). Among these, the Orthophlebiidae and Protorthophlebiidae were polyphyletic and megadiverse groups thriving during the Mesozoic (Handlirsch 1906; Martynova 1948; Willmann 1989; Soszyńska-Maj *et al.* 2020).

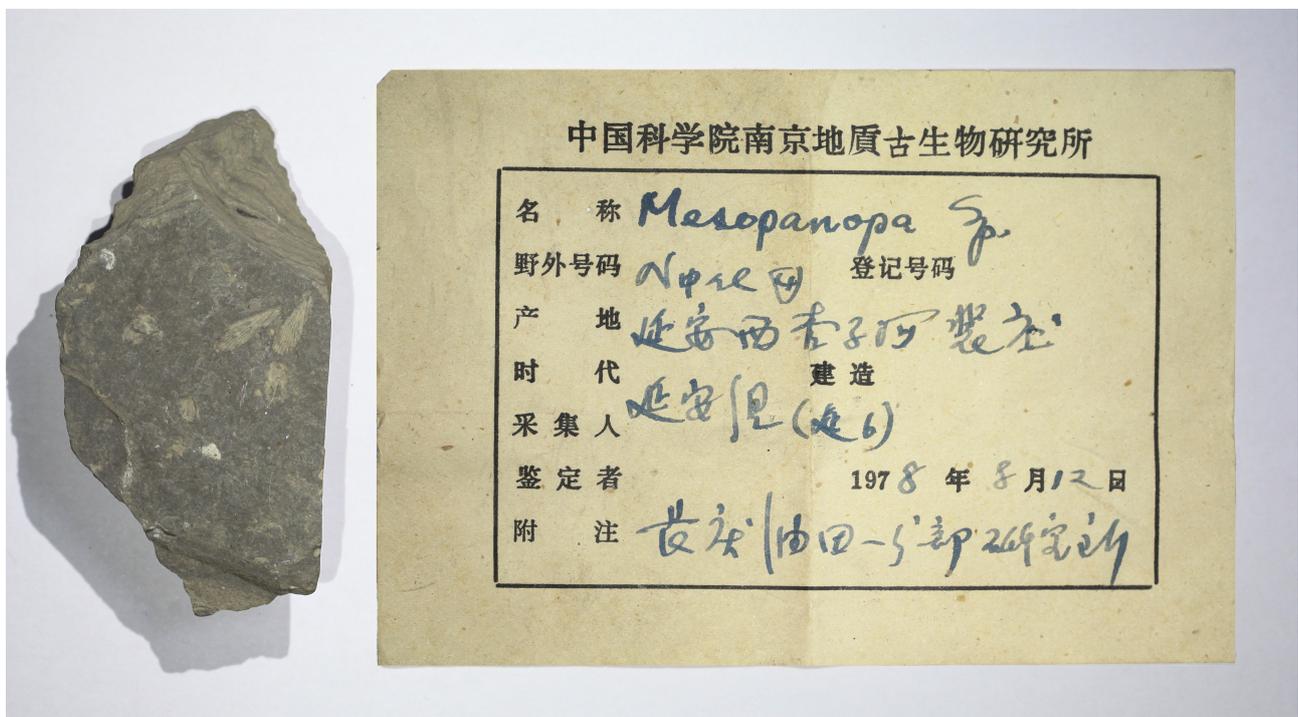
'Orthophlebiidae' (including Orthophlebiidae and Protorthophlebiidae) are characterized by several morphological features, including upturned, scorpion tail-like genitalia, elongated clypeus forming the rostrum, and wings with pectinate branches of the  $Rs_{1+2}$ . The historical progress of their study has been summarized by Zhang (1996) and Hong and Zhang (2007). Most species within these families are assigned to *Orthophlebia* Westwood, 1845, *Protorthophlebia* Tillyard, 1933, and *Mesopanorpa* Handlirsch, 1906 (Lin 1986; Carpenter 1992; Zhang 1996; Hong & Zhang 2007; Jarzembowski & Soszyńska-Maj 2017). Notably, *Mesopanorpa* has been synonymized with *Orthophlebia* due to the length of  $Rs_{1+2}$  and  $Rs_{3+4}$  stems showing continuous variation, rendering these characters unreliable as diagnostic characters at generic level (Willmann 1989).

Recent studies propose that species with  $Rs$  exhibiting five branches should be placed within Protorthophlebiidae, while those with six or more branches are assigned to Orthophlebiidae (Soszyńska-Maj *et al.* 2020). Furthermore, exquisitely preserved specimens from the Daohugou Biota and Kachin amber have provided a wealth of information about their body structures. These include details of the mouthparts, coercive mating apparatus of the abdomen and genitalia, and leg morphology, offering insights into potential behaviors such as sexual display (Soszyńska-Maj *et al.* 2022; Zhang *et al.* 2021, 2023).

To date, no mecopteran fossils have been reported from the Yan'an Formation. Here, we present the first mecopteran fossil species discovered from the Middle Jurassic Yan'an Formation in Yan'an City, Shaanxi Province, China.

## Material and methods

The holotype, NIGP206315, was provided by the late Professor Qibing Lin. The specimen and its accompanying label are preserved together (Fig. 1). The label contains information handwritten by Professor Qibing Lin, indicating that it was donated by the First Research Division Institute of Changqing Oilfield. It was collected from the Sixth Member of the Middle Jurassic Yan'an Formation near Xixingzi River, Western Peizhuang Village, Yan'an City, Shaanxi Province, but the exact collection section remains unspecified. The specimen was originally identified as *Mesopanorpa* sp. by Professor Qibing Lin, but as discussed earlier, the genus *Mesopanorpa* has since been rejected, and the specimen is now re-identified as belonging to the genus *Orthophlebia*. Recently, we have collected abundant insect fossils from the Yan'an Formation at the Peizhuang area (Huang 2023; Xu *et al.* 2023, with fossil locality map), including the paratype. The paratype was collected from the Zaoyuan Member, upper part of Yan'an Formation, which is primarily composed of interbedded gray-green sandstones, gray-black to dark gray shales, mudstones, and oil shales (Shaanxi Provincial Bureau of Geology and Mineral Resources 1998). Palynological evidence indicates that the depositional environment corresponded to a warm and humid subtropical to temperate climate (Sun *et al.* 2017).



**Figure 1.** Holotype of *Orthophlebia lini* Lian & Huang **sp. nov.**, along with the label written by Prof. Qibin Lin.

All specimens were carefully prepared using a sharp knife. Photographs were taken using a digital camera attached to a Zeiss AxioZoom V16 stereomicroscope, and a Canon EOS 5D Mark II camera with a Canon 100 mm macro lens attached. Scanning electron microscopic (SEM) image was captured with a Hitachi SU 3500 scanning electron microscope, operating at an accelerating voltage of 20 kV and a chamber pressure of 150 Pa. Line drawings were made using Adobe Illustrator 2019. The specimens are stored at the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (China).

The nomenclatures follow Minet *et al.* (2010) and Bashkuev and Sukatsheva (2021). Venational abbreviations are as follows: C, costa; Sc, subcosta; h, humeral vein; R<sub>1</sub>, first branch of the radius; R<sub>s</sub>, radial sector; M, media; CuA, anterior cubitus; CuP, posterior cubitus; A, anal vein; m-cua, the crossvein between the media and anterior cubitus.

## Systematic palaeontology

### Order Mecoptera Packard, 1886

### Superfamily Panorpoidea Latreille, 1805

### Family Orthophlebiidae Handlirsch, 1906

### Genus *Orthophlebia* Westwood, 1845

#### *Orthophlebia lini* Lian & Huang, sp. nov.

(Figs 1–4)

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**Material.** Holotype, NIGP206315, preserved a forewing and a hindwing (Fig. 2). Paratype NIGP206316a, b, part and counterpart, a complete hindwing (Fig. 4).

**Etymology.** The specific name is in memory of Prof. Qibin Lin and for providing the holotype, and is to be treated as a noun in genitive case.

**Diagnosis.** Sc unbranched, costal space narrow; Rs with six branches, fork of  $Rs_{1a+b}$  small.

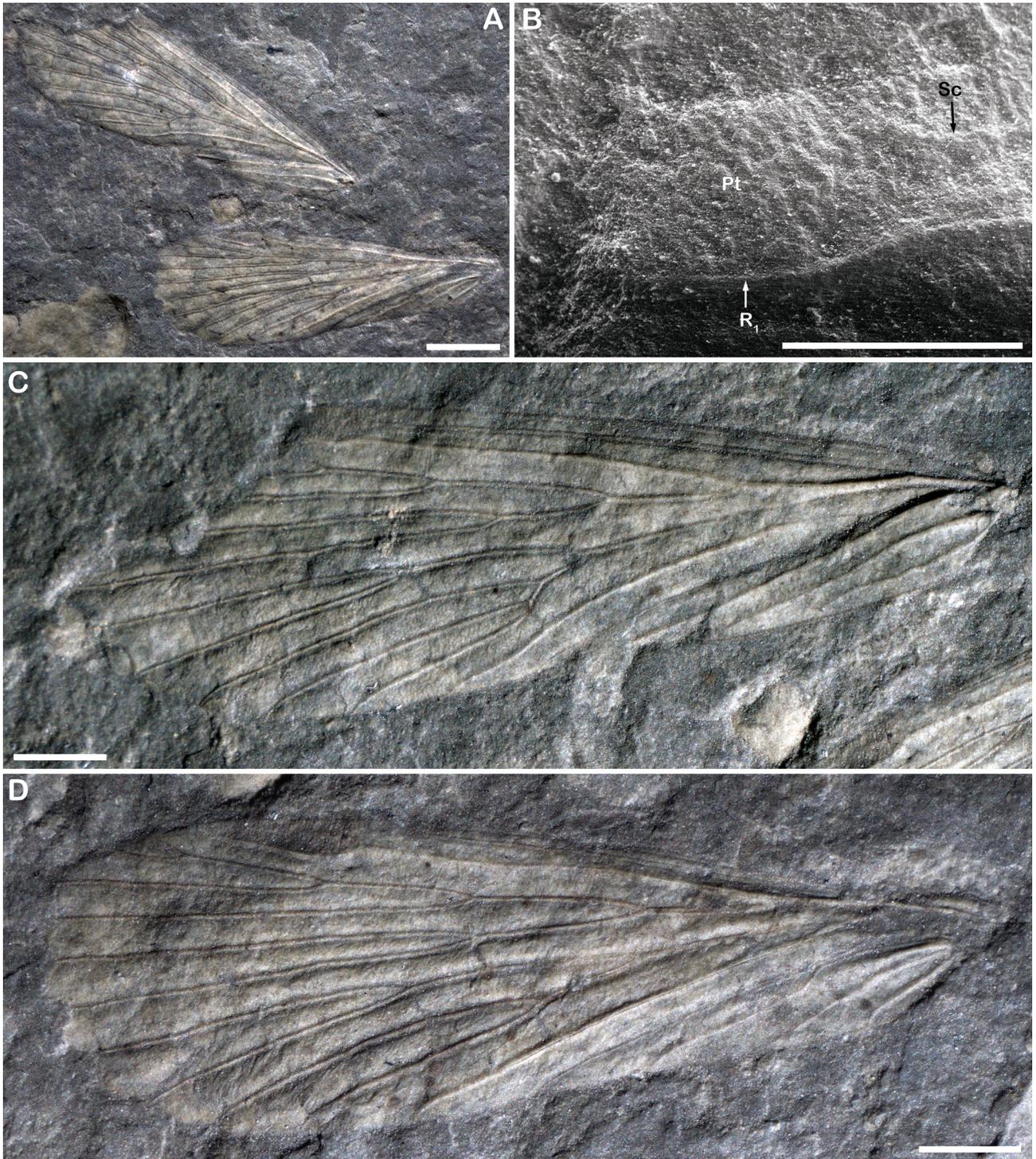
**Type locality and horizon.** A locality near the Peizhuang Village, Yan'an City, Shaanxi Province, China; Yan'an Formation, Middle Jurassic.

**Description.** Holotype: forewing elongate, without apical part, 10.5 mm long (as preserved), and 3.4 mm wide; wing narrows gently towards base; Sc long, parallel to C, tip ending into pterostigma; costal space half as wide as subcostal area (at the maximal width of subcostal area); humeral vein present;  $R_1$  curved after entering pterostigma; pterostigma consisting of dense nodules; Rs fork located distinctly before M fork; Rs preserved with five branches, stem  $Rs_{1+2}$  1.6 times as long as stem  $Rs_{3+4}$ , stem  $Rs_1$  as long as stem  $Rs_{3+4}$ ; M with five branches, M fork desclerotized, thyridium present; stem  $M_{1+2}$  ca. 3.5 times as long as stem  $M_{3+4}$ , stem  $M_{3+4}$  more than twice as long as stem  $M_4$ ; crossvein m-cua connecting  $M_4$  distad its fork into  $M_{4a}$  and  $M_{4b}$ ; Cu fork located at level of crossvein  $a_1-a_2$ , CuA and CuP slightly curved;  $A_1$  and  $A_2$  sub-straight,  $A_3$  with a small apical fork; crossveins sc- $r_1$  present at the level of Rs fork; one crossvein present between CuA and CuP, and between  $A_1$  and  $A_2$ , respectively; numerous crossveins present between Rs and M branches.

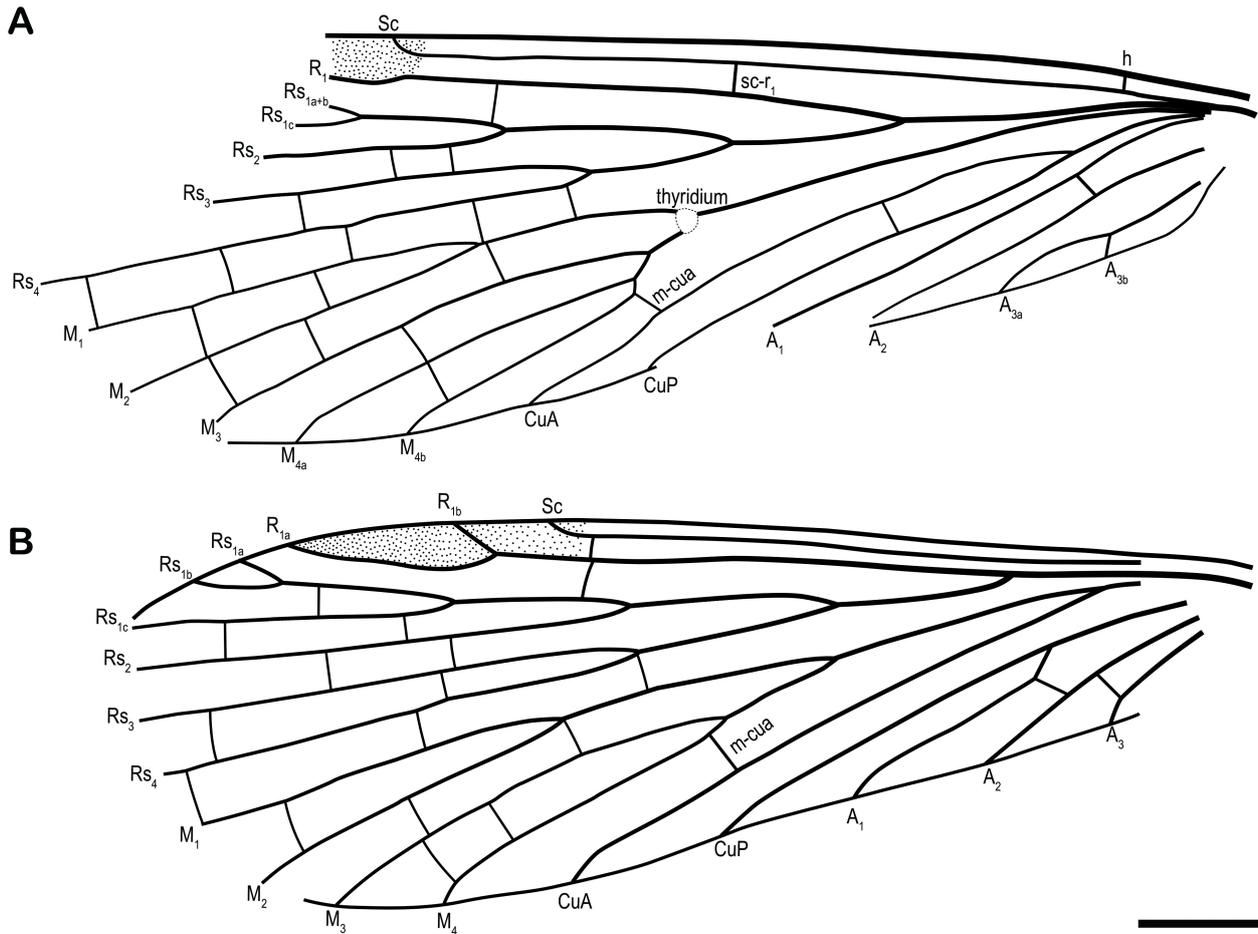
Hindwing similar to forewing in shape, 9.1 mm long (as preserved) and 3.2 mm wide, except base narrower; Sc long, terminating inside pterostigma; costal space more than half as wide as subcostal space; pterostigma elongate, consisting of dense nodules;  $R_1$  forked into two branches near apex; one crossvein connects end of Sc and  $R_1$ , and  $R_1$  and stem  $Rs_1$  each; Rs with six branches,  $Rs_{1a}$  and  $Rs_{1b}$  very short; stem  $Rs_{1+2}$  as long as stem  $Rs_{3+4}$ , stem Rs as long as stem  $Rs_{1a+b}$  and shorter than stem  $Rs_{1+2}$ ; M with four branches, stem  $M_{1+2}$  twice as long as stem  $M_{3+4}$ ; crossvein m-cua connects  $M_4$  (near origin) and CuA; CuA and CuP straight and unbranched; CuP fused with  $A_1$  basally;  $A_1$  and  $A_2$  connected by a crossvein,  $A_2$  and  $A_3$  connected to each other by a crossvein; numerous furry crossveins connecting Rs and M branches.

Paratype (Fig. 4): hindwing 11.7 mm long, 3.7 mm wide, with Sc long, terminating beyond  $Rs_{1+2}$  fork, one crossvein connecting apex of Sc and  $R_1$ ; costal area narrowed towards apex;  $R_1$  forked into two branches near apex, pterostigma large, with a vein-like lower boundary; Rs with six branches, stem  $Rs_{1+2}$  slightly longer than  $Rs_{3+4}$ , stem  $Rs_1$  slightly longer than stem  $Rs_{1a+b}$ ;  $Rs_{1a+b}$  forking apically,  $Rs_{1a}$  and  $Rs_{1b}$  branches short; M with four branches, stem  $M_{1+2}$  twice as long as stem  $M_{3+4}$ ; crossvein m-cua connecting basal part of stem  $M_{3+4}$  and CuA; CuA and CuP straight, a crossvein present between each other; CuP fused with  $A_1$  basally; three anal veins present;  $A_1$  and  $A_2$ ,  $A_2$  and  $A_3$  connected by a crossvein each; numerous crossveins present between Rs and M branches.

**Remarks.** The new species, *Orthophlebia lini* Lian & Huang, sp. nov., is confidently placed within Orthophlebiidae based on the presence of a  $Rs_{1+2}$  with four pectinate branches, forewing has a five-branched M, and hindwing has a four-branched M. The new species is similar to some species, but it can be distinguished from the others by the following characters: it differs from *Mesopanorpa brooksorum* Jarzembowski & Soszyńska-Maj, 2017 by its forewing having a distal  $Rs_{1a+b}$  fork, a much larger  $M_{1+2}/M_{3+4}$  ratio (4 vs. 1.8), a long and forked  $A_3$ , and its hindwing with  $R_1$  two branched instead of unbranched, a distal  $Rs_{1a+b}$  fork, and stem  $Rs_{1+2}$  and  $Rs_{3+4}$  being nearly the same length. It differs from *Mesopanorpa luanpingensis* Hong, 1983 by its smaller wing size (forewing length slightly over 10.5 mm vs. > 23 mm), and  $R_1$  without an apical fork. It differs from *Orthophlebia quadrimacula* Lin, 1982 by its forewing with a Sc running parallel to C,  $Sc_2$  absent, colour bands absent, and present of a distal  $Rs_{1a+b}$  fork.



**Figure 2.** *Orthophlebia lini* Lian & Huang **sp. nov.**, holotype, NIGP206315, the Middle Jurassic Yan'an Formation. **A**, Photograph showing the forewing and hindwing of one individual preserved together. **B**, High-resolution SEM image focusing on pterostigmal area of forewing, highlighting structural nodules of pterostigma. **C**, Enlargement of forewing. **D**, Enlargement of hindwing. Scale bars = 2 mm in **A**, 0.5 mm in **B**, 1 mm in **C** and **D**.



**Figure 3.** Line drawings of the holotype of *Orthophlebia lini* Lian & Huang **sp. nov.** **A**, Forewing. **B**, hindwing. Scale bars = 2 mm.

## Discussion

The new species, *Orthophlebia lini* Lian & Huang, **sp. nov.**, can be confidently placed within the group ‘Orthophlebiidae’ (encompassing Orthophlebiidae and Protorthophlebiidae) based on: forewing with  $Rs_{1+2}$  pectinate,  $Rs_{3+4}$  with only two branches, vein M with five branches, and the hindwing with vein M having four branches (Willmann 1989; Hong & Zhang 2007). According to the recently proposed diagnoses for Orthophlebiidae and Protorthophlebiidae, the number of Rs branches is a critical distinguishing feature: Orthophlebiidae possess Rs with six or more branches, whereas Protorthophlebiidae exhibits Rs with five branches (Soszyńska-Maj *et al.* 2020).

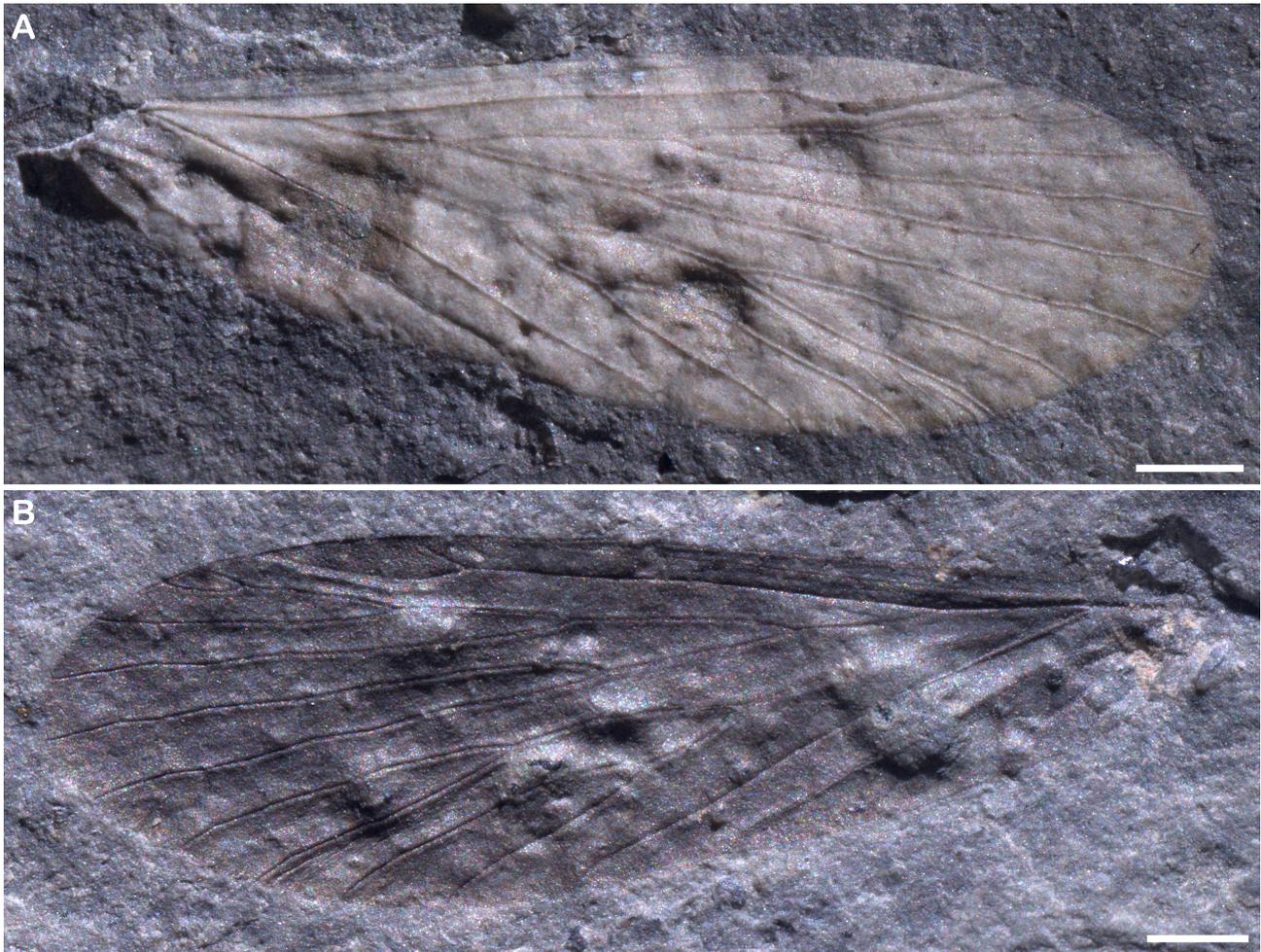
The new species has a small  $Rs_{1a+b}$  fork, with  $Rs_{1a}$  and  $Rs_{1b}$  being notably short, which may reflect individual variation. If this hypothesis holds, a ‘normal’ specimen would possess an Rs with five branches, thereby placing it to Protorthophlebiidae. However, our examination of the paratype reveals a consistency in the configuration of Rs, indicating that it is not the result of individual variation. Consequently, *Orthophlebia lini* Lian & Huang, **sp. nov.**, with its six-branched Rs, can be confidently assigned to Orthophlebiidae.

The relative lengths of stem  $Rs_{1+2}$  and  $Rs_{3+4}$  were historically significant diagnostic character for distinguishing ‘Orthophlebiidae’ at the genus level (Handlirsch 1906; Hong & Zhang 2007; Jarzembowski & Soszyńska-Maj 2017). In taxa where  $Rs_1$  has two or three branches, the ratio of  $Rs_{1+2}$  to  $Rs_{3+4}$  being approximately 2:1 was considered a defining character of *Mesopanorpa* (Zhang 1996; Hong & Zhang 2007). In contrast, *Protorthophlebia* and *Orthophlebia* exhibit a more balanced ratio between  $Rs_{1+2}$  and  $Rs_{3+4}$  (Jarzembowski and Soszyńska-Maj 2017). However, Willmann (1989) proposed that this ratio varies within different genera and, therefore, cannot be regarded as a generic character.

In the holotype of *Orthophlebia lini* Lian & Huang, **sp. nov.**, the relative lengths of stem  $Rs_{1+2}$  and  $Rs_{3+4}$  differ between the forewing and hindwing. In the forewing, stem  $Rs_{1+2}$  is 1.6 times longer than  $Rs_{3+4}$ , while in the hindwing, the ratio is 1:1. In the paratype,  $Rs_{1+2}$  is slightly longer than  $Rs_{3+4}$ . These findings confirming that this character is

variable, even within a single individual, supporting the rejection of *Mesopanorpa* as a valid genus. Moreover, it is important to note that many ‘Orthophlebiidae’ species were erected based solely on hindwings. Our study confirms potential inconsistencies between forewings and hindwings in characters such as the relative lengths of  $R_{s_{1+2}}$  and  $R_{s_{3+4}}$ . Additionally, the following features of the hindwings distinguish them from the forewings: the Sc vein is shorter, the  $R_1$  vein bifurcates at the tip, the M vein has four branches, and the CuP vein basally connects to  $A_1$ . These discrepancies make it difficult to reliably match hindwings with corresponding forewings. Consequently, species established solely on hindwings may represent synonyms of those based on forewings. As emphasized in our earlier works, hindwings alone are insufficient for describing new species within Mecoptera (Lian *et al.* 2023, 2024).

*Orthophlebia lini* Lian & Huang, **sp. nov.**, represents the first mecopteran species reported from the Middle Jurassic Yan’an Formation in the Ordos Basin. This discovery increases our understanding of the species richness of Orthophlebiidae during the Jurassic.



**Figure 4.** *Orthophlebia lini* Lian & Huang **sp. nov.**, paratype, NIGP206316, hindwing. **A**, NIGP206316a. **B**, NIGP206316b. Scale bars = 1 mm.

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