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A new fossil sinoalid species from the Middle Jurassic Daohugou beds (Insecta: Hemiptera: Cercopoidea)

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A new fossil species, *Luanpingia daohugouensis* sp. nov., belonging to the family Sinoalidae is described from the Middle to Upper Jurassic Daohugou beds of Inner Mongolia, China, on the basis of two well-preserved complete specimens. The described species of Sinoalidae are reviewed and *Jiania gracila* is considered a junior synonym of *Jiania crebra*. The new discovery increases the palaeodiversity of sinoalids from the Daohugou beds. It also indicates stratigraphic correlation between the Daohugou beds, the Haifanggou Formation at Haifeng, Beipiao City, West Liaoning Province, and the Jiulongshan Formation at Zhouyingzi, Luanping County, Hebei Province. All of these units host the 'early assemblage' of the Yanliao biota.

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Key words: Sinoalidae, *Luanpingia*, Daohugou, Middle–Late Jurassic, Yanliao biota.

THE SUPERFAMILY Cercopoidea Leach, 1815, is the second largest group of modern Cicadomorpha, comprising approximately 3000 described species (Hamilton 2001, Dietrich 2002). Adult cercopoids are commonly called froghoppers, because they hop around on plants and shrubs like tiny frogs (Burrows 2003). Their nymphs, known as spittlebugs, surround themselves with foamy spittle, composed of tiny air bubbles, providing protection from predation, parasitism and desiccation (Hamilton 1982, Li *et al.* 2013). Cercopoidea was suggested to be derived from the Triassic family Hylicelloidea (Shcherbakov 1992, 1996). The oldest family of Cercopoidea, namely Procercopidae, was established based on several tegmina and hind wings from the Lower Jurassic of Germany (Handlirsch 1906–1908). Fossil cercopoids are of relatively low diversity with only 13 genera attributed to three families in the Jurassic, Procercopidae, Sinoalidae and Clastopcaridae (Chen *et al*. 2015). They are very abundant groups with representative species in the Yanliao biota, e.g., *Anthoscytina longa* (Hong 1983). Sinoalids, however, are relatively rare in the Yanliao biota, being represented by five genera and six described species. They include *Luanpingia longa*, *Huabeicercopis yangi* and *Hebeicercopis triangulata*, which were originally described from the Middle Jurassic Jiulongshan Formation at Zhouyingzi Village, Luanping County, Hebei Province (Hong 1983), and *Sinoala parallelivena*, *Jiania crebra* and *J. gracila*, which were described from Daohugou Village, Ningcheng County, Inner Mongolia (Wang *et al.* 2012).

Material and methods

Only two females were examined out of 60 000 specimens in our collection from the Daohugou beds, Ningcheng County, Inner Mongolia, China (Fig. 1). The holotype was collected from a hill behind the Beigou locality, which is slightly higher stratigraphically than the conchostracan layers; the paratype was collected from strata at the Xiayingzi locality, which occur below the 'conchostracan' layers (Fig. 1; for geological background, see Huang 2015, Huang *et al*. 2015). The holotype was compressed dorso-laterally and preserved in greyish tuffaceous shale as a dark brown film. The paratype was preserved in dorso-ventral view in greyish tuffaceous shale and is darkly coloured.

Specimens were prepared carefully using a sharp knife, and studied with a Leica MZ16A dissecting microscope. Maps and line drawings were drafted with CorelDRAW X7 graphic software. Photographs were taken with a digital camera attached to a Zeiss Discovery V20 microscope, and some were moistened with

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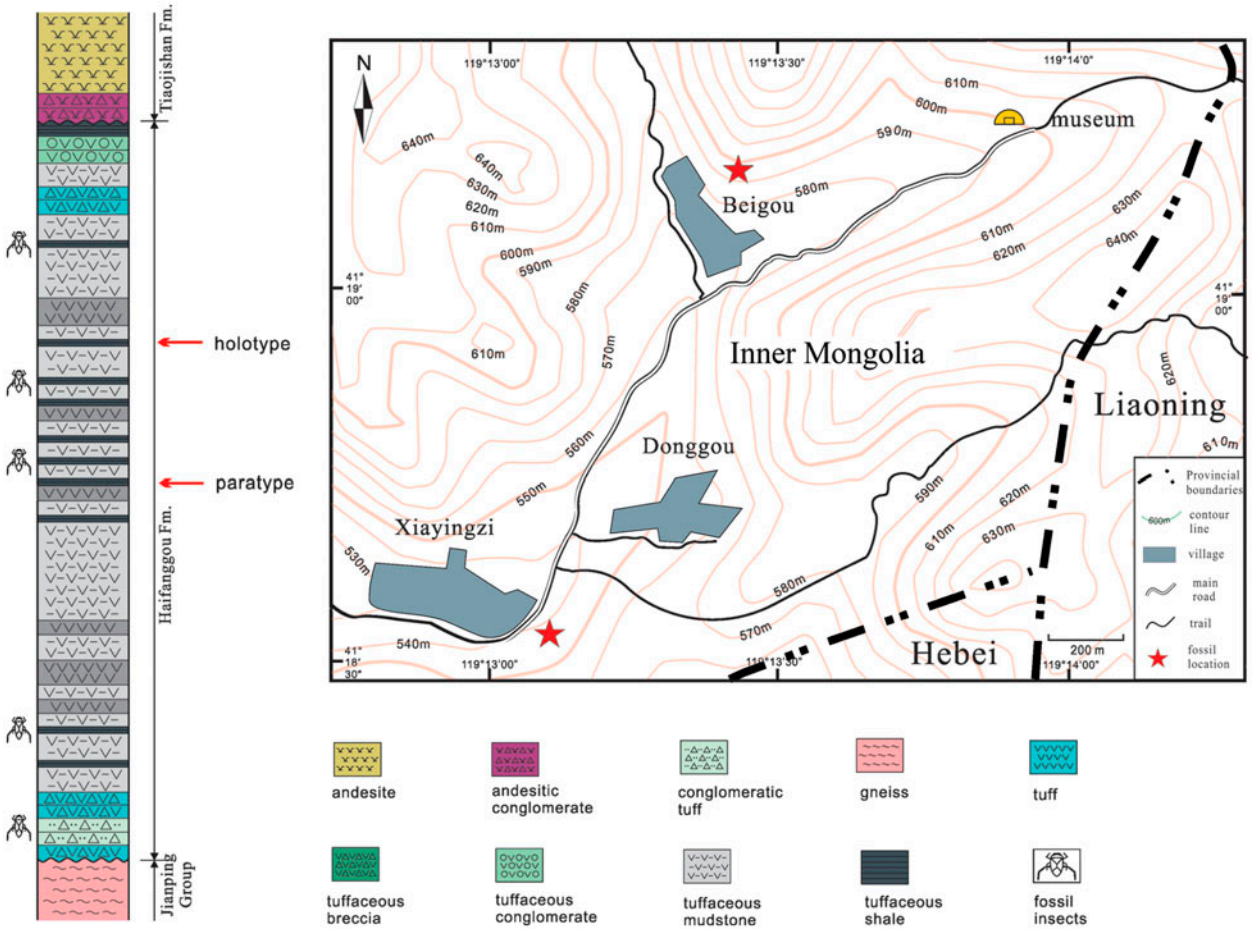

Fig. 1. Map of fossil localities, with stars indicating the Beigou and Xiayingzi localities, at which the holotype and paratype were discovered respectively.

70% ethanol to show fine details. Photomicrographs of general habitus were taken using a Canon EOS 5D Mark II camera with a Canon 100 mm macro lens. All type material is deposited at the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing, China.

Systematic palaeontology

Order HEMIPTERA Linnaeus, 1758
Suborder CICADOMORPHA Evans, 1946
Superfamily CERCOPIDEA Leach, 1815
Family SINOALIDAE Wang *et al.*, 2012

Luanpingia Hong, 1983

Diagnosis (revised based on Wang *et al.* 2012). Tegmen with length/width ratio about 3.0, basal cell long, about one-quarter of tegmen length; stems ScR, vein M and CuA leaving basal cell at common point; branch ScRA no more than twice as long as stem Sc + R; terminal $ScRA_1$ short; ScRA branching into vein $ScRA_1$ and RA_2 slightly after vein M branching; cross-vein ir nearly at the same level as im; stem CuA convex at base; vein A_1 distinctly curved.

Type species. *Luanpingia longa* Hong, 1983, from the Daohugou beds, Ningcheng County, Inner Mongolia of China, Middle to Upper Jurassic.

Luanpingia daohugouensis sp. nov. (Figs 2–4)

Etymology. From 'Daohugou' indicating the source of the fossils.

Material. Holotype, NIGP166023, a complete female with the right forewing expanded. Paratype, NIGP166024, a complete female.

Occurrence. Middle to Upper Jurassic Haifanggou Formation; Daohugou, Ningcheng County, Inner Mongolia, northeastern China.

Diagnosis. The species is distinguished from the type species by following characters: branch ScRA nearly twice as long as stem Sc + R, which are relatively shorter than in the type species; radial cell wide; cell C3 almost as long as adjoining apical cell instead of cell C3 being about three times longer in the type species; cross-vein r-m nearly at the same level as m-cu compared with m-cu invisible in the type species; branch CuA_1 almost twice as long as CuA_2.

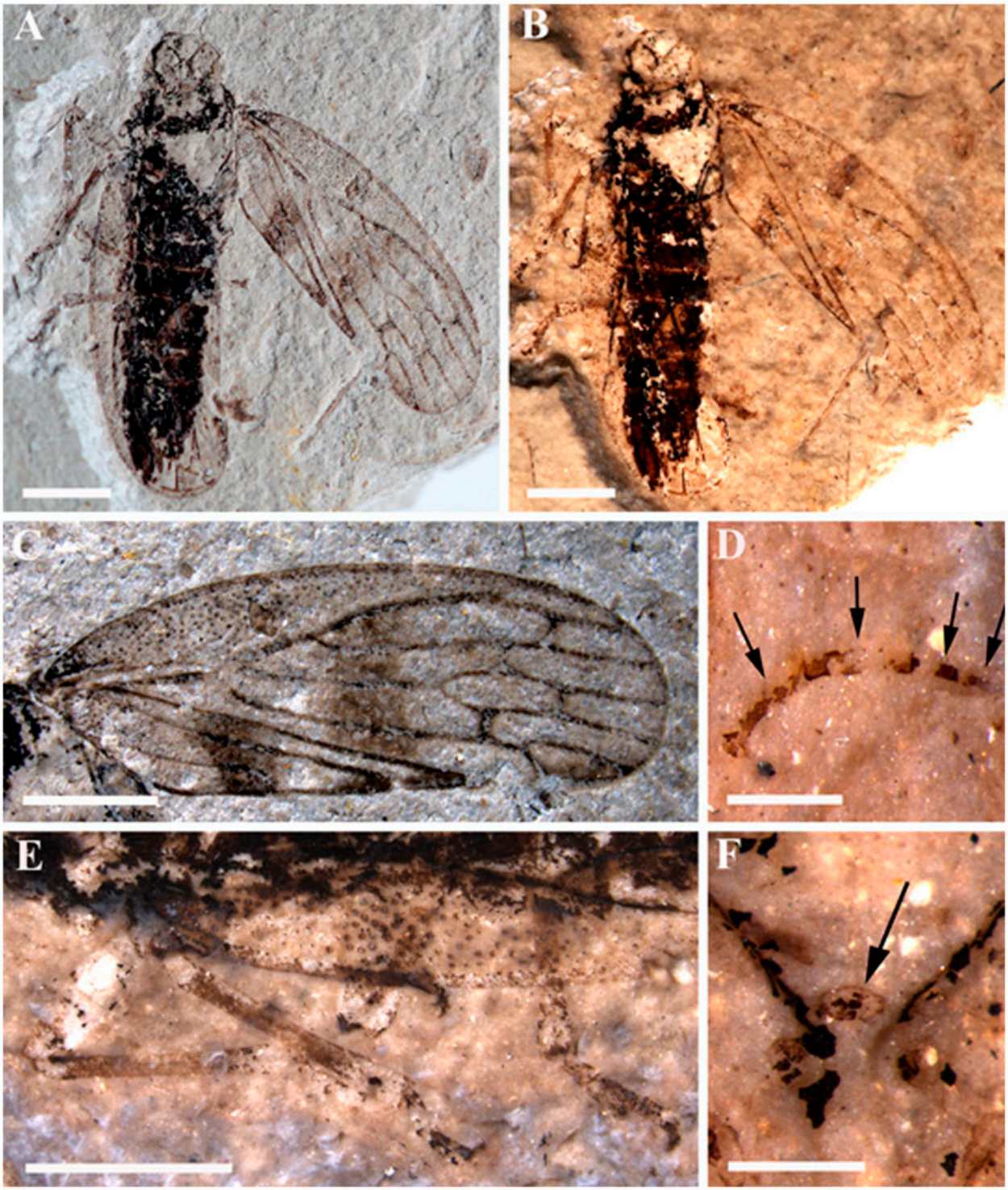

Fig. 2. Luanpingia daohugouensis sp. nov., holotype, NIGP166023 from Daohugou. **A**, General habitus. **B**, General habitus moistened with 70% ethanol. **C**, Enlargements of A, showing the right tegmen. **D**, Enlargements of B, showing the details of antenna. **E**, Enlargements of B, showing the details of legs. **F**, Enlargements of B, showing the details of three ocelli. Scale bar = 2 mm in **A**–**C**, **E**, 500 μm in **F**, 200 μm in **D**.

Description. Total length about 10.7 mm (Figs 2A, B, 3A, B, 4A, B) with tegmen in holotype and about 10.5 mm in the paratype; tegmen about 9.5 mm long and 3.3 mm wide.

Head not flattened, rounded apically (Fig. 3B), nearly three-quarters of pronotum width; compound eyes located laterally, oval; three ocelli present, ocellar triangle distinct, separated by the sutures, median ocellus oval and lateral ocelli globular (Fig. 2F); postclypeus swollen, with transverse muscular impressions, about 0.86 mm long and 0.37 mm wide, in facial portion with median concavity exceeding somewhat to crown; anteclypeus about half the length of postclypeus, and clypellus is elongate triangular; lora are relatively

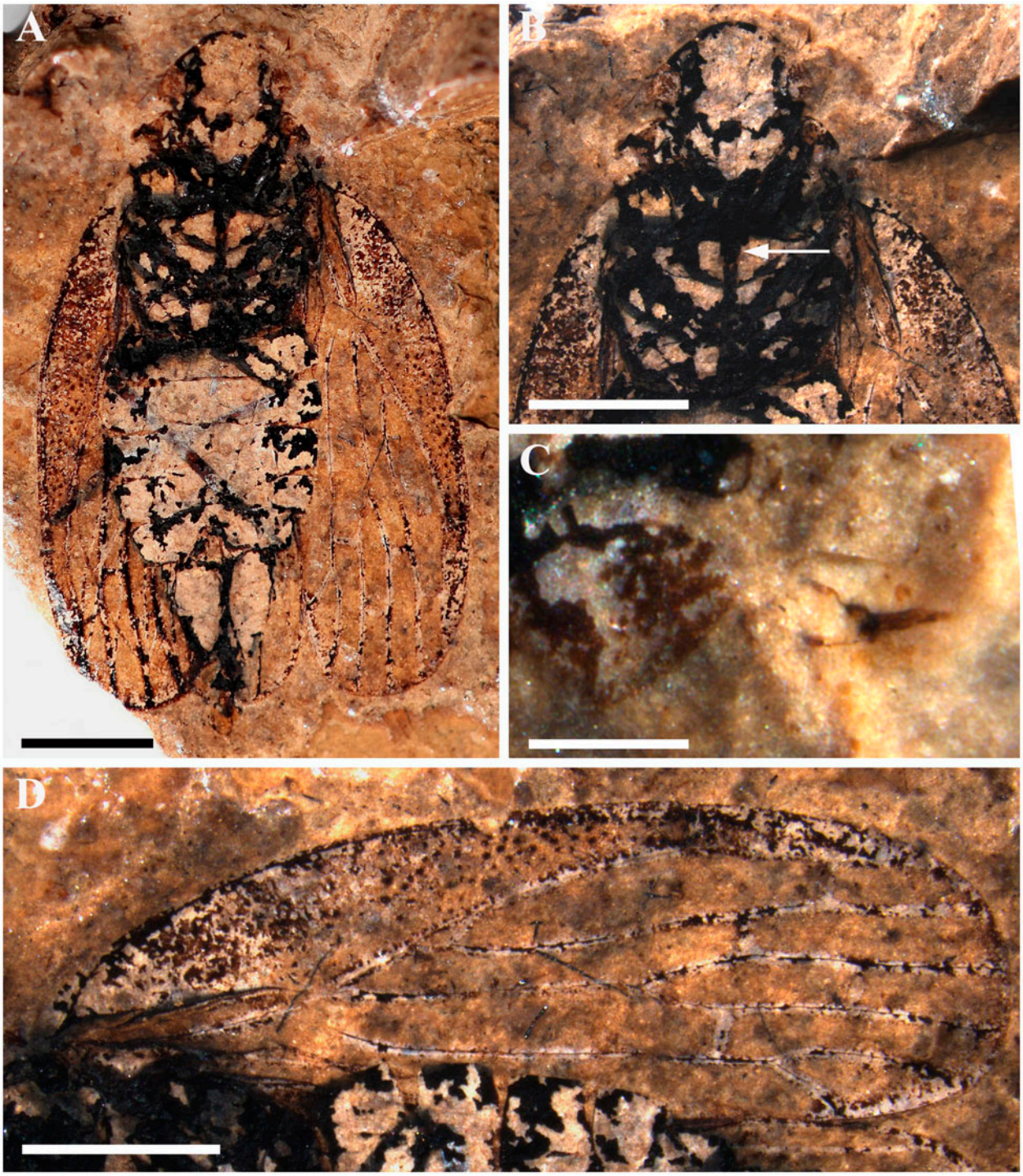

Fig. 3. Luanpingia daohugouensis sp. nov., paratypes, NIGP166024 from Daohugou. **A**, General habitus moistened with 70% ethanol. **B**, Enlargements of B, showing the head and rostrum. **C**, Enlargements of B, showing the basal antenna. **D**, Enlargements of A, showing the right tegmen. Scale bars = 2 mm in **A**, **B**, **D**, 200 μm in **C**.

large, emarginated; genal portion of the head capsule is very narrow; coronal suture distinct; antennae aristate, with four flagellomeres visible, scape large but short, pedicel distinct, thinner and shorter than scape, flagellomeres 1–4 becoming progressively shorter (Figs 2D, 3C); rostrum long, extending to hind coxae (Fig. 3B).

Pronotum (Fig. 3B) anterior edge slightly concave; posterior angles rounded; posterior edge almost straight; mesonotum in midline longer than pronotum, longer than wide at base, scutellum triangular distinct, with wavy wrinkles, delimited by a shallow furrow, about 2.0 mm long and 2.1 mm wide.

Tegmen with length/width ratio about 2.9 (Figs 2C, 3D, 4D); two dark bands on the lower median section of tegmen (Fig. 2C); costal margin thickened and arched at base, posterior margin straight, apical margin rounded; costal cell and claval portion of tegmen punctate; basal cell about 0.26 times as long as tegmen

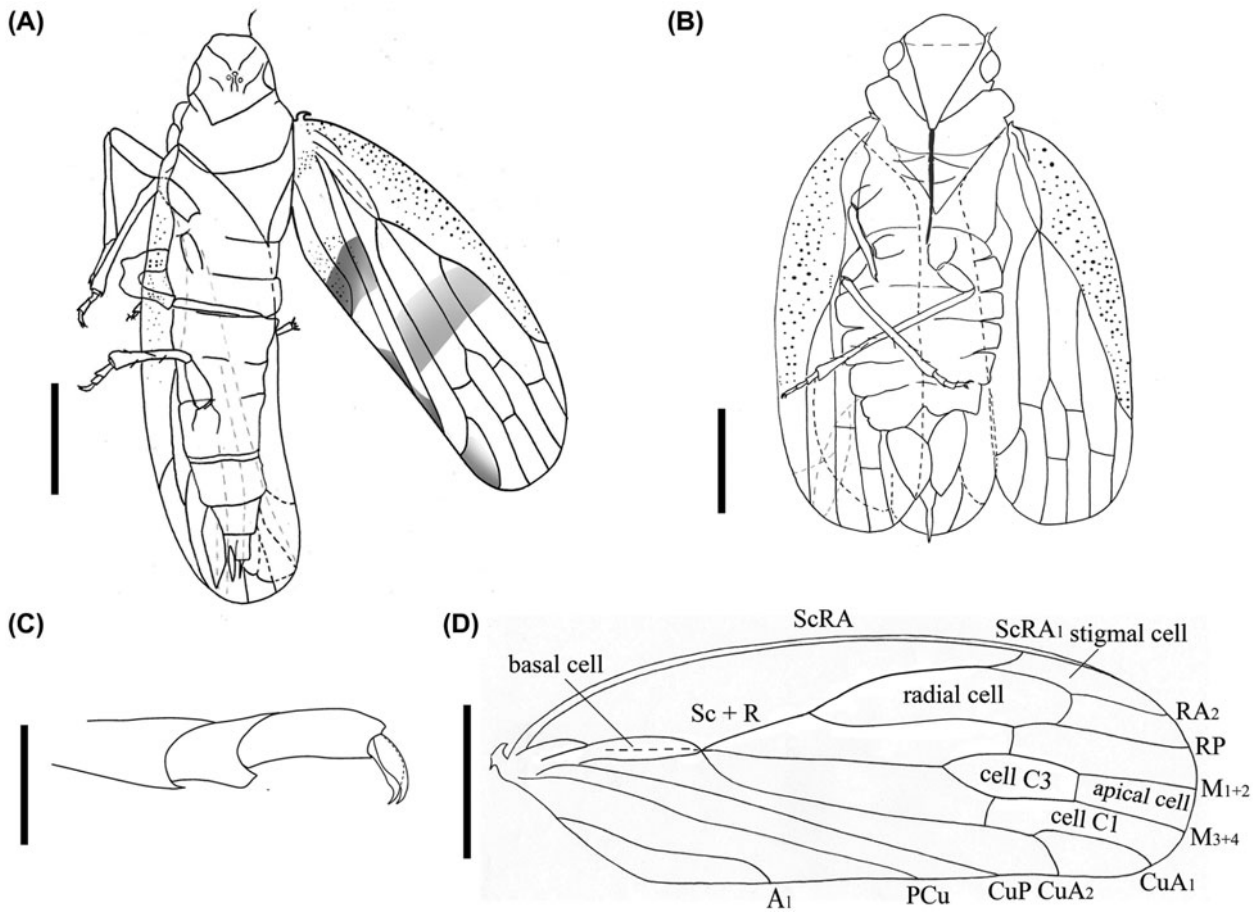

Fig. 4. Line drawings of *Luanpingia daohugouensis* sp. nov., **A**, NIGP001; **B**, NIGP002. **C**, Hind tarsus of the holotype. **D**, Tegmen of the holotype. Scale bar = 2 mm in **A**, **B**, **D**, 500 μm in **C**.

length; branch ScRA about 1.6–1.8 times as long as stem Sc + R and branching into vein $ScRA_1$ and RA_2 at basal 0.69 tegmen length, slightly after vein M branching; radical cell nearly twice as wide as stigmal cell; vein RA_2 straight, connected with vein RP by cross-vein ir at basal 0.83 tegmen length; vein RP single, connected with vein M_{1+2} by cross-vein r-m at basal 0.73 tegmen length; vein M branching basal of CuA branching at basal 0.64 tegmen length; stem CuA at base convex, then nearly straight and bifurcating into branches CuA_1 and CuA_2 at basal 0.78 tegmen length; branch CuA_1 mildly convex at base and almost twice as long as CuA_2; cross-vein m-cu basal of stem CuA forking; cell C1 nearly 1.5 times as long as adjoining apical cell; cell C3 slightly longer than adjoining apical cell in the holotype but nearly 1.4 times longer than apical cell in the paratype; cross-vein r-m almost at the same level as m-cu; cross-vein ir slightly basal of cross-vein im in the holotype but distinctly basal of cross-vein im in the paratype; vein CuP straight, ending at basal three-quarters of wing length, and nearly parallel to vein PCu, terminating just basal of vein CuA_2 ending; vein A_1 distinctly curved.

Fore femur strong; fore tibia 2.9 mm long, approximately twice as long as fore femur; middle tibia 3.2 mm long; middle tarsus 0.9 mm long; hind coxa widened outwards; hind tibia 3.5 mm long, tibiae gradually widened apically, armed with two rows of 6–7 lateral spines; hind tarsus 1.5 mm long with three tarsomeres (Figs 2E, 4C), first tarsomere as long as third tarsomere, about 0.6 mm long, and nearly twice as long as second tarsomere, second tarsomere about 0.26 mm wide, nearly as wide as first tarsomere and 1.4 times as wide as third tarsomere; tarsal claw robust, slightly curved, with a strong basal tooth, about 0.3 mm long.

Abdomen with six segments visible, segments III–VIII of similar length. Hind wings only partly preserved, barely visible. Ovipositor short, not extending beyond tips of tegmina.

Remarks. Luanpingia longa was established on the basis of three tegmina (Hong 1983). However, the original description, line drawing, and figures do not correspond exactly. The original description indicated that the vein CuP is slightly wave-shaped, but it is in fact straight in the drawing and figures. The vein CuP and PCu are clearly parallel in Plate 12-4 (Hong 1983), unlike their depiction in the line drawing. The cross-vein m-cu is present in all sinoalids, except *L. longa*. Thus, we can not exclude its possible

presence. In addition, the holotype is more elongate than one of the paratypes in plate 14-4 of Hong (1983) (the tegmen with length/width ratio about 2.8 in the holotype, versus length/width ratio of about 3.7 times in the paratype). Therefore, we can not conclude that all the specimens are attributable to the same species (*Luanpingia longa*).

Discussion

To date, five genera from the Mesozoic of China have been attributed to Sinoalidae (Wang *et al.* 2012). *Jiania crebra* and *J. gracila* were both collected from the same bed and locality, having nearly identical venation and similar length and width of the tegmen. Both species have variable lengths (total length with ovipositor) ranging from 17.9 to 23.4 mm. Thus, we consider *J. gracila* a junior synonym of *J. crebra.* In addition, *Hebeicercopis triangulata* has been established based on two hind wings (Hong 1983), but it can not be compared with other known species owing to the absence of diagnostic characters. Considering the existence of intra-specific or even intra-individual variation in the venation, a classification based on isolated hind wings is difficult to establish with satisfaction. Therefore, the precise systematic position of *Hebeicercopis triangulata* requires further examination of more complete specimens.

The stratigraphic correlation between the Haifanggou Formation at Beipiao and the Jiulongshan Formation at Luanping is well accepted by most authors (Hong 1983, Ren *et al*. 2002, Huang *et al.* 2006). However, this hypothesis has been challenged by some recent studies that suggested the fossil insects from the Jiulongshan Formation at Zhouyingzi, Luanping, belong to an older entomofauna (Zhang 2015, Zhang *et al*. 2015). The assumption was based on an incorrect stratigraphic interpretation, which suggested that the Jiulongshan Formation lies below the Daohugou beds (Liu *et al*. 2006). The argument was strongly countered by recent biostratigraphic and lithological studies (Huang 2015, 2016, Huang *et al*. 2015). The present material provides new evidence indicating stratigraphic correlation between the fauna of the Haifanggou Formation and the Jiulongshan Formation at Zhouyingzi. This correlation was also supported by recent studies of branchiopods revealing that these formations host very similar, but not identical, faunal assemblages (Liao *et al*. 2017).

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Disclosure statement

No potential conflict of interest was reported by the authors.

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