Cretaceous Research 74 (2017) 192–197

Contents lists available at ScienceDirect

Cretaceous Research

journal homepage: www.elsevier.com/locate/CretRes

Short communication

New Early Cretaceous dragonfly *Sinojagoria magna* Li et al., 2012 (Odonata, Gomphaeschnidae) emending the Chinese tribe Sinojagorini

Daran Zheng [a, b, *], Su-Chin Chang [b], Bo Wang [a, c], Haichun Zhang [a, **]

[a] State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, 39 East Beijing Road, Nanjing 210008, China
[b] Department of Earth Sciences, The University of Hong Kong, Hong Kong Special Administrative Region, China
[c] Key Laboratory of Zoological Systematics and Evolution, Institute of Zoology, Chinese Academy of Sciences, 1, Beichen West Road, Beijing 100101, China

ARTICLE INFO

Article history:
Received 3 January 2017
Received in revised form
27 February 2017
Accepted in revised form 8 March 2017
Available online 9 March 2017

Keywords:
Sinojagorini
Aeshnoptera
Anisoptera
Yixian Formation
Earliest Aptian
China

ABSTRACT

The monotypic dragonfly tribe Sinojagorini was only recorded from the Lower Cretaceous Yixian Formation of the Huangbanjigou outcrop of western Liaoning, NE China. Its diagnostic characters are incomplete because its subordinates were established based on forewings and fragmentary hindwings or only forewings. A well-preserved dragonfly attributed to *Sinojagoria magna* Li et al., 2012 is described herein from the same horizon and locality of the type specimen, not only improving the description of this species but also providing additional diagnostic characters for Sinojagorini. The new specimen further supports the sister-group relationship between Sinojagorini and the remaining Gomphaeschnaoidinae.

1. Introduction

The clade Aeshnoptera Bechly 1996 is one of the most diverse fossil odonatan groups widely distributed around the world (Bechly et al., 2001). In China, many aeshnopteran dragonflies were recorded from the Lower Cretaceous Yixian Formation of Inner Mongolia (Nel and Huang, 2010) and western Liaoning, northeastern China (Bechly et al., 2001; Li et al., 2012). The Gomphaeschnaoidinae Bechly et al., 2001 is a subfamily of Aeshnoptera, and currently comprises the genus *Anomalaeschna* Bechly et al., 2001, and the tribes Sinojagorini Bechly et al., 2001 and Gomphaeschnaoidini Bechly et al., 2001. The monotypic Sinojagorini (containing the genus *Sinojagoria* Bechly et al., 2001) was only recorded in the Lower Cretaceous Yixian Formation of the Huangbanjigou outcrop, western Liaoning, NE China, with *Sinojagoria* including the type species *Sinojagoria imperfecta* Bechly et al., 2001, and the other remaining two species *S. cancellosa* Li et al., 2012 and *S. magna* Li et al., 2012. *S. imperfecta* was preserved with complete forewings and fragmentary hindwings, while the other species were solely based on forewings, which constraint a comprehensive consideration and discussion for Sinojagorini. In the present paper, a new specimen with a nearly complete forewing and a hindwing attributed to *S. magna* is described. The new specimen can help to emend the diagnostic characters of *S. magna* and Sinojagorini, and to discuss the relationship between Sinojagorini and the other sister groups.

2. Material and methods

The new dragonfly was collected from the Jianshangou Bed (about 125 Ma, earliest Aptian; Chang et al., 2009) of the Yixian Formation of the Huangbanjigou outcrop in Beipiao (see Zheng et al., 2016: fig. 1), western Liaoning, northeastern China.

The specimen was examined dry using a Nikon SMZ1000 stereomicroscope. Photographs were prepared using a Canon 5D

* Corresponding author. State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, 39 East Beijing Road, Nanjing 210008, China.
** Corresponding author.
E-mail addresses: dranzheng@gmail.com (D. Zheng), hczhang@nigpas.ac.cn (H. Zhang).

http://dx.doi.org/10.1016/j.cretres.2017.03.008
0195-6671/

digital camera, and the line drawings were prepared from photographs using image-editing software (CorelDraw X7 and Adobe Photoshop CS6). The specimen is housed at the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPAS). The electronic publication LSID: urn:lsid:zoobank.org:pub:59407392-8032-49B2-947C-F50186E95032.

The nomenclature of the dragonfly wing venation used in this paper is based on the interpretations of Riek (1976) and Riek and Kukalová-Peck (1984), as modified by Nel et al. (1993) and Bechly (1996). The higher classification of fossil and extant Odonatoptera, as well as family and generic characters followed in the present work, is based on the phylogenetic system proposed by Bechly (1996) and Bechly et al. (2001). Wing abbreviations are as follows: AA, anterior anal; AL, anal loop; Arc, arculus; Ax0, Ax1, Ax2, primary antenodal crossveins; CuAa, distal branch of anterior cubitus; CuAb, proximal branch of anterior cubitus; CuP, posterior cubitus; DT, discoidal triangle; HT, hypertriangle; IR1, IR2, intercalary radial veins; MA, anterior median; MP, posterior median; Mspl, median supplement; N, nodus; 'O', oblique vein; PC, paranal cell; PsA, pseudo-anal vein; Pt, pterostigma; RA, anterior radius; RP, posterior radius; Rspl, radial supplement; ScP, posterior subcosta; SdT, subdiscoidal triangle; Sn, subnodal crossvein.

3. Systematic palaeontology

Order Odonata Fabricius, 1793
Suborder Anisoptera Selys-Longchamps, 1854
Clade Aeshnoptera Bechly, 1996
Family Gomphaeschnidae Tillyard and Fraser, 1940
Subfamily Gomphaeschnaoidinae Bechly et al., 2001
Tribe Sinojagorini Bechly et al., 2001

Genus Sinojagoria Bechly et al., 2001
Type species: *Sinojagoria imperfecta* Bechly et al., 2001
Other species: *Sinojagoria cancellosa* Li et al., 2012, and *Sinojagoria magna* Li et al., 2012.

Emended diagnosis. Based on forewing and hindwing characters: forewing discoidal triangle elongated, 2–4-celled; hindwing discoidal triangle three- or four-celled, rather stout; anal loop large, 5–7-celled, nearly as wide as long; forewing Ax2 lying on level of basal side of discoidal triangle; one or two secondary antenodal crossveins present between Ax1 and Ax2; RP2 undulated; pterostigma covering two or three cells; only four antesubnodal crossveins present between RA and RP basal of subnodus in forewing; Rspl and Mspl more or less straight with single row of cells between Rspl and IR2, and between Mspl and MA; IR2 slightly undulated; RP3/4 and MA more or less parallel and gently undulated; MA distally more undulated than RP3/4, resulting in short widened area with two rows of cells inbetween; MP diverging strongly from MA in hindwing; CuAa with 4–6 well-defined posterior branches.

Sinojagoria magna Li et al., 2012
Figs. 1–4

New material. NIGP165093, imprint of well-preserved dragonfly with two pairs of wings attached to fragmentary thorax: right forewing and hindwing nearly complete, while left forewing and hindwing only with basal half preserved; deposited in Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing, China.
Locality and horizon. Huangbanjigou Village, Beipiao City, Liaoning Province, China; Jianshangou Bed of the Yixian Formation, Lower Cretaceous (lowermost Aptian).
Emended diagnosis. Based on forewing and hindwing characters: large size with forewing reaching ca. 45 mm long; two antenodal crossveins present in first row between Ax1 and Ax2; discoidal triangle three-celled; subdiscoidal triangle empty in forewing but two-celled in hindwing; anal loop five- or six-celled; longitudinally elongated paranal cell well defined basal of anal loop in hindwing; pseudo-IR1 originated from distal side of pterostigma; pterostigma covering three cells; RP2 strongly undulated below Pt; CuAa with 4–6 posterior branches.
Description. Right forewing (Figs. 1A, 2A, 3A). Wing hyaline, length, 44.47 mm; width at level of N, 9.37 mm; distance from wing base to Arc, 5.78 mm, from Arc to N, 16.09 mm, from N to Pt, 14.47 mm, from Pt to wing apex, 8.17 mm. Pt length 2.91 mm and maximum width 1.03 mm, narrow elongate, covering three cells. Pt-brace in same oblique with Pt base, and aligned with Pt base. Primary antenodal crossveins Ax1 and Ax2 present; Ax2 2.73 mm distal of Ax1 and 0.89 mm distal of Arc, and almost at level of basal side of T. No secondary antenodal crossveins basal of Ax1, two secondary antenodal crossveins of second row between Ax1 and Ax2. Seven postnodal crossveins and seven postsubnodal crossveins present before Pt; nine postnodal crossveins and ten postsubnodal crossveins present distal of Pt. One oblique crossvein 'O' between RP2 and IR2, lying one cell distal of Sn. Median and submedian spaces free of crossveins. Hypertriangle (Fig. 4A) free, 5.6 mm long and maximum 0.66 mm wide. Discoidal triangle 1.17 mm distal of Arc, wide and free, with anterior side 4.62 mm, basal side 1.82 mm, and distal side (MAb) 4.65 mm long. Subdiscoidal triangle free, limited by strong oblique PsA, with anterior side (PsA) 1.71 mm, basal side 2.73 mm and distal side 1.82 mm long. Postdiscoidal area with two row of cells basally, three cells below base of IR2 and more than ten cells along wing margin. Mspl well defined, originated below midfork, with one row of cells between it and MA. Basal area between RA and RP with two crossveins present basal of RP3/4, and two crossveins present distal of base of RP3/4 and basal of Sn. Eight antefurcal crossveins between RP and MA basal of midfork. Area between RP2 and IR2 distally with one row of cells for long distance, expanded distally, with four or five cells along wing margin. RP2 obviously undulated below Pt (Fig. 4B). IR1 short, zigzagged, originated two cells basal of Pt-brace, but vanished distally. Pseudo-IR1 well defined, branching just below distal part of Pt. RP1 and RP2 basally parallel with Pt; area between RP1 and RP2 narrow with one row of cells basally, becoming divergent with two rows just below Pt-brace, and at least eight cells along wing margin. Rspl well defined, with one row of cells between it and IR2. RP3/4 and MA running almost parallel basally, divergent distally, with one row of cells inbetween. Area between CuA and MP with one row of cells basally, and expanded distally. Anal area with one or two rows of cells.

Right hindwing (Figs. 1D, 2B, 3B). Wing hyaline, length, 41.34 mm; width at level of N, 13 mm; distance from wing base to Arc, 6.32 mm, from Arc to N, 11.29 mm, from N to Pt, 16.69 mm, from Pt to wing apex, 8 mm. Pt length 2.81 mm and maximum width 0.89 mm, covering three cells. Pt-brace well defined and aligned with basal side of Pt. Primary antenodal crossveins present; Ax0 2.08 mm distal of wing base, Ax1 2.75 mm distal of Ax0, Ax2 5.09 mm distal of Ax1 and 3.54 mm distal of Arc. No secondary antenodal crossveins present basal of Ax1, two secondary antenodal crossveins of first row and one of second row between Ax1 and Ax2; five secondary antenodal crossveins of first row distal of Ax2. Postnodal crossveins not well preserved before Pt; five postnodal and nine postsubnodal crossveins preserved distal of Pt. Hypertriangle free (Fig. 4C), 4.93 mm long and maximum 0.69 mm wide. Discoidal triangle 1.08 mm distal of Arc, wide and three-celled, with anterior side 4.07 mm, basal side 2.36 mm, and distal side 4.07 mm long. Subdiscoidal triangle crossed by one vein, limited by strong oblique PsA, with anterior side 1.69 mm, basal

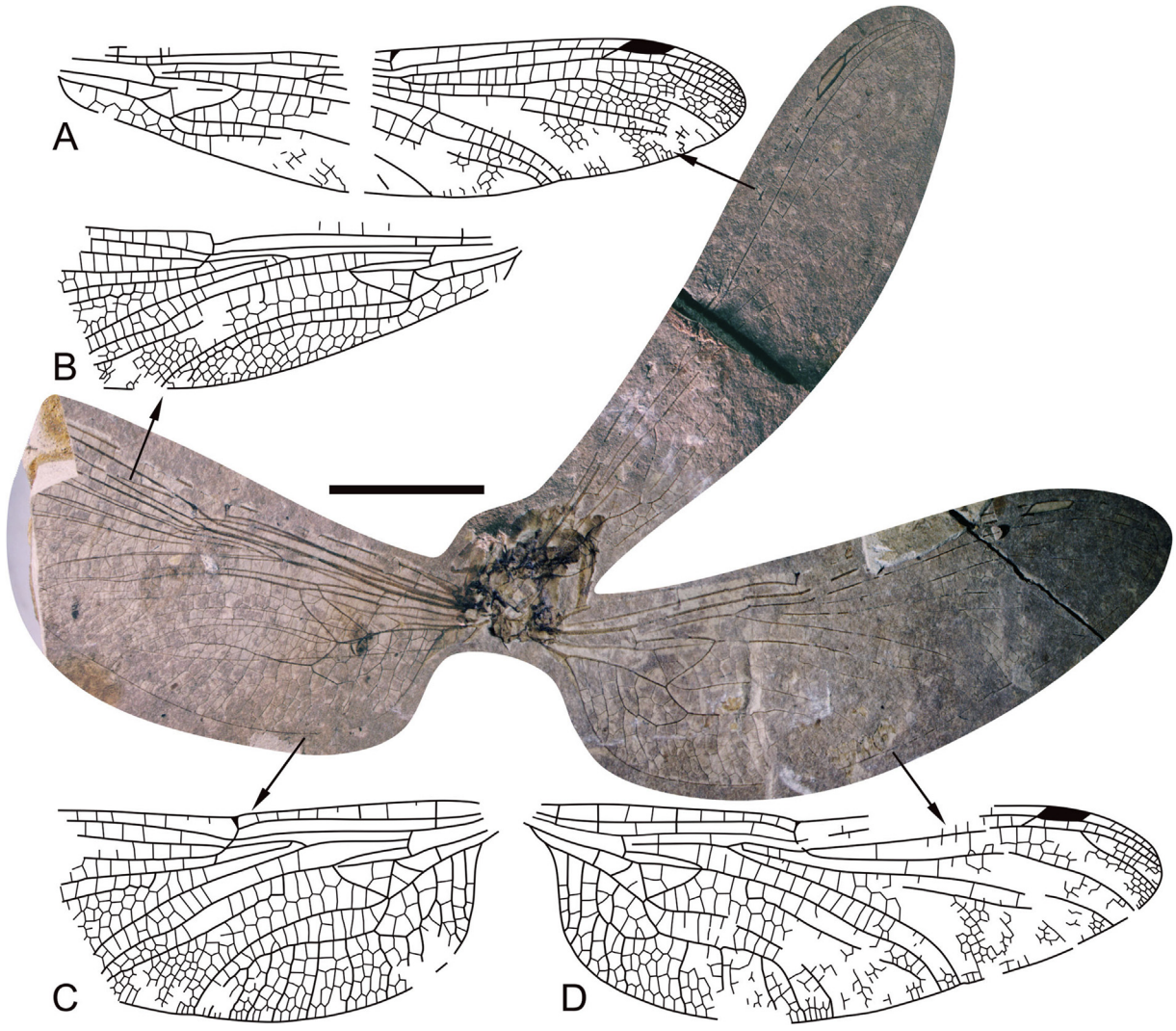

Fig. 1. *Sinojagoria magna* Li et al., 2012 (NIGP165093), photograph and line drawings of right forewing (A), left forewing (B), left hindwing (C) and right hindwing (D). Scale bar = 10 mm.

side 2.73 mm, and distal side 2.36 mm long. Postdiscoidal area with one row of cells basally, two cells below distal end of discoidal triangle, three cells below base of IR2 and over ten cells along wing margin. Msp1 well defined, originated just below base of IR2, with one or two row of cells between it and MA. Basal area between RA and RP with two crossveins present basal of RP3/4, and no crossveins present distal of base of RP3/4 and basal of Sn. Three antefurcal crossveins present between RP and MA basal of midfork. Base of RP2 aligned with Sn. Area between RP2 and IR2 with one row of cells basally, expanded distally. IR1 short, zigzagged, originated four cells basal of Pt-brace, but vanished distally. Pseudo-IR1 well defined, branching just below distal part of Pt. RP1 and RP2 basally parallel with Pt; area between RP1 and RP2 narrow with one row of cells basally and becoming divergent, with two rows near Pt-brace, and 11 cells along wing margin. Rspl well defined, with one row of cells between it and IR2. RP3/4 and MA running almost parallel basally, divergent distally, with one row of cells for long distance and three rows inbetween along wing margin. Area between CuA and MP with one row of cells basally, and five cells along wing margin. Anal area broad, with maximum six cells, and three posterior branches of AA directed towards posterior wing margin. Anal loop closed, 3.02 mm long and 3.52 mm wide, and divided into six cells. CuAb strongly curved towards secondary anal vein AA1b. Cubital anal area broad, with maximum five rows of cells between CuA and posterior wing margin; CuAa with four well-defined posterior branches.

Remarks. The original diagnosis for *Sinojagoria* was only based on forewings and poor-preserved hindwings (Bechly et al., 2001), then slightly emended after two single forewings attributed to *S. cancellosa* and *S. magna* (Li et al., 2012). The diagnosis for *Sinojagoria* and *S. magna* is emended here after adding complete hindwing characters.

4. Discussion

The new specimen can be attributed to the tribe Sinojagorini Bechly et al., 2001 after the diagnostic characters of Bechly et al. (2001) revised by Li et al. (2012): (1) forewing discoidal triangle longitudinally elongated and two-celled (but three-celled in *Sinojagoria magna* Li et al., 2012 and four-celled in *S. cancellosa* Li et al., 2012); (2) hindwing discoidal triangle four-celled and rather stout; (3) anal loop large, six- or seven-celled, nearly as wide as long; (4)

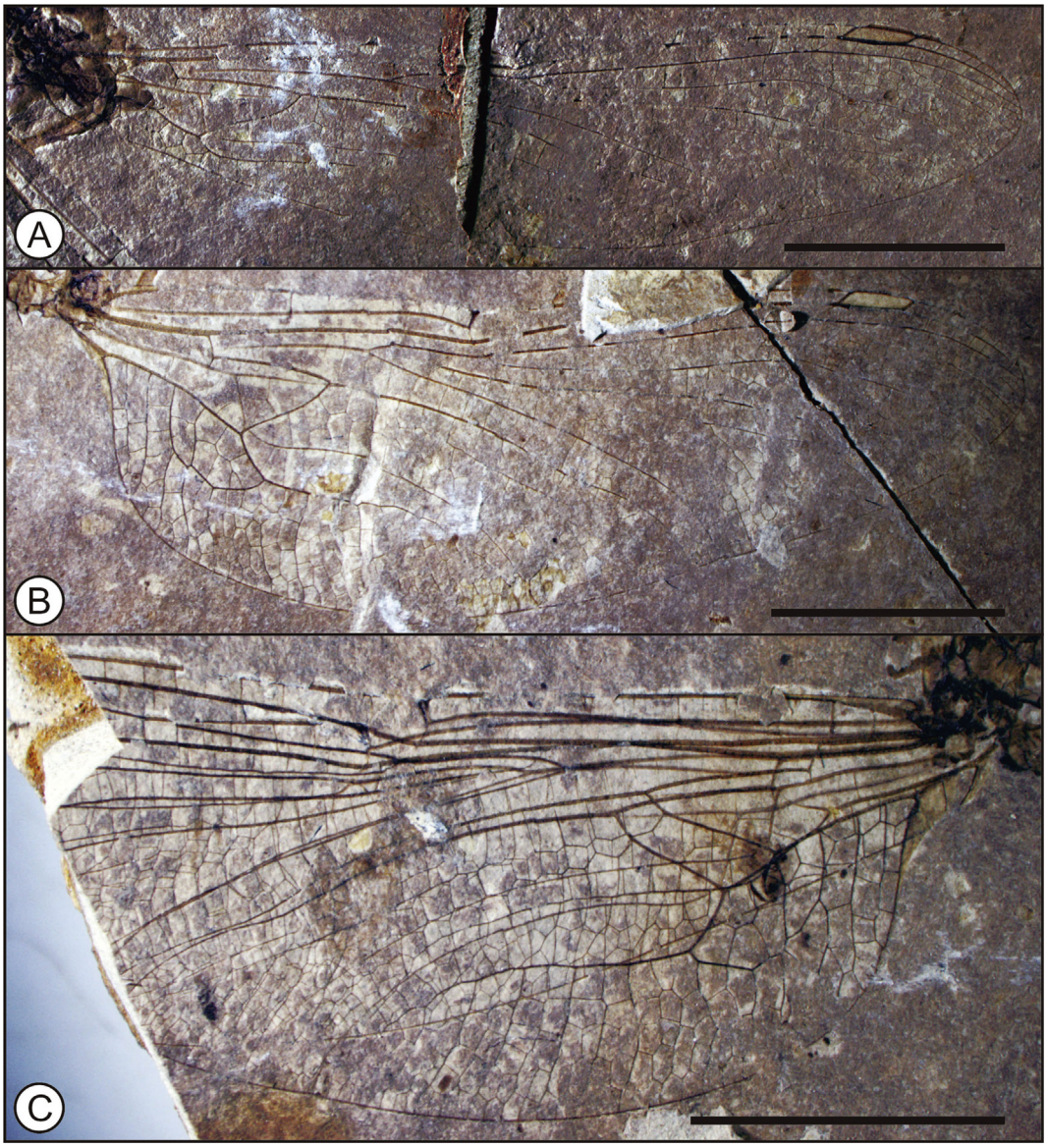

Fig. 2. *Sinojagoria magna* Li et al., 2012 (NIGP165093), photographs of right forewing (A), right hindwing (B), and left pair of wings (C). Scale bars = 10 mm.

Ax2 on level of basal side of discoidal triangle in forewing; (5) one secondary antenodal crossvein between Ax1 and Ax2 in forewing (but two crossveins in *S. magna*), and two in hindwing; (6) RP2 weakly undulated; (7) pterostigma covering two cells (but covering three cells in *S. cancellosa* and *S. magna*); (8) only four antesubnodal crossveins between RA and RP basal of subnodus in forewing; (9) Rspl and Mspl more or less straight with single row of cells between Rspl and IR2, and between Mspl and MA; (10) IR2 straight; (11) RP3/4 and MA more or less parallel and gently undulated; (12) MA distally more undulated than RP3/4, resulting in short widened area with two rows of cells inbetween; (13) MP diverging strongly from MA in hindwing.

The new specimen shares all these characters except for (2), (3), and (6). In the new specimen, the hindwing discoidal triangle is three-celled instead of four-celled in *S. imperfecta* Bechly et al., 2001. The anal loop is similar to that in *S. imperfecta* in shape, but five- or six-celled instead of six- or seven-celled in the latter. Vein RP2 is not weakly but quite undulated especially in the forewing. Although presence of the above weak differences, the new specimen should be undoubtedly attributed to *S. magna* after Li et al. (2012): distinctly larger size; discoidal triangle three-celled; pseudo-IR1 originated at level of distal third of pterostigma; pterostigma covering three cells.

The well-preserved specimen contributes to emending the diagnostic characters of both Sinojagorini and *S. magna*. The diagnosis of Sinojagorini is renewed after the above characters (2), (3), and (6) emended and a new character added: CuAa with 4–6 well-defined posterior branches. The original diagnosis of *S. magna* was only based on the forewing, and is emended here by adding the following characters for both forewing and hindwing: two antenodal crossveins present between Ax1 and Ax2; discoidal triangle three-celled; subdiscoidal triangle empty in forewing but two-celled in hindwing; anal loop five- or six-celled in hindwing; longitudinally elongated paranal cell well defined basal of anal loop in hindwing; RP2 strongly undulated below pterostigma; CuAa with 4–6 well-defined posterior branches.

According to Bechly et al. (2001), Sinojagorini is well distinguished from the other groups within Gomphaeschnaoidinae

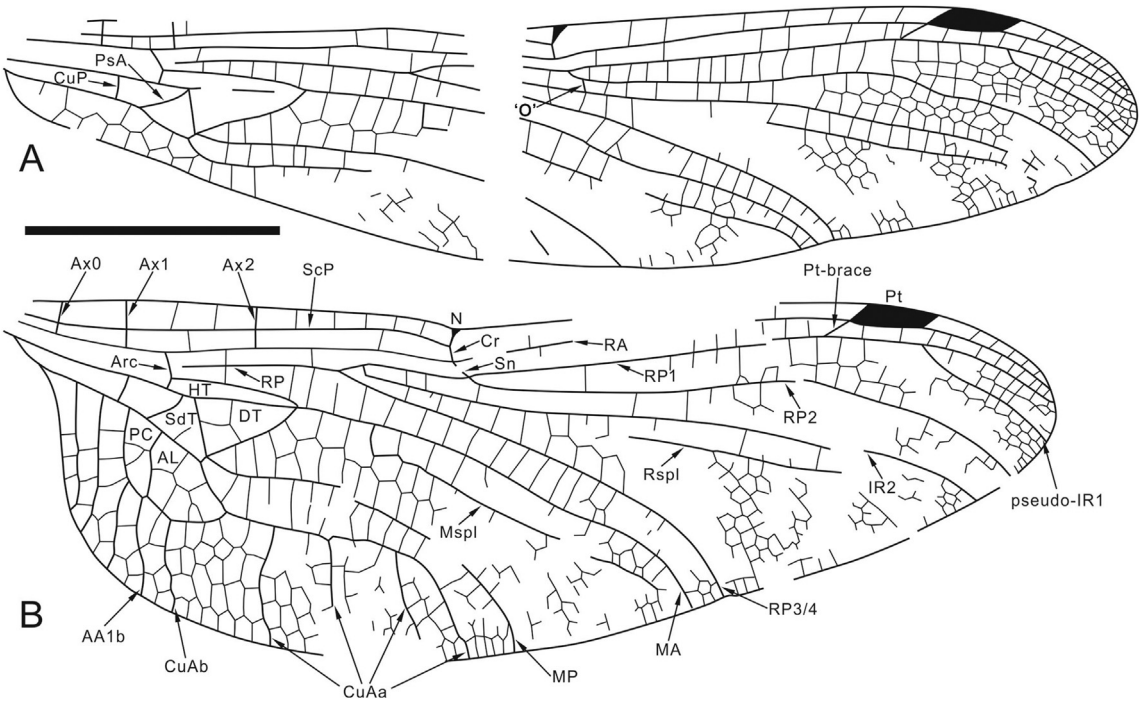

Fig. 3. *Sinojagoria magna* Li et al., 2012 (NIGP165093), line drawings showing venation of right forewing (A) and right hindwing (B). Scale bar = 10 mm.

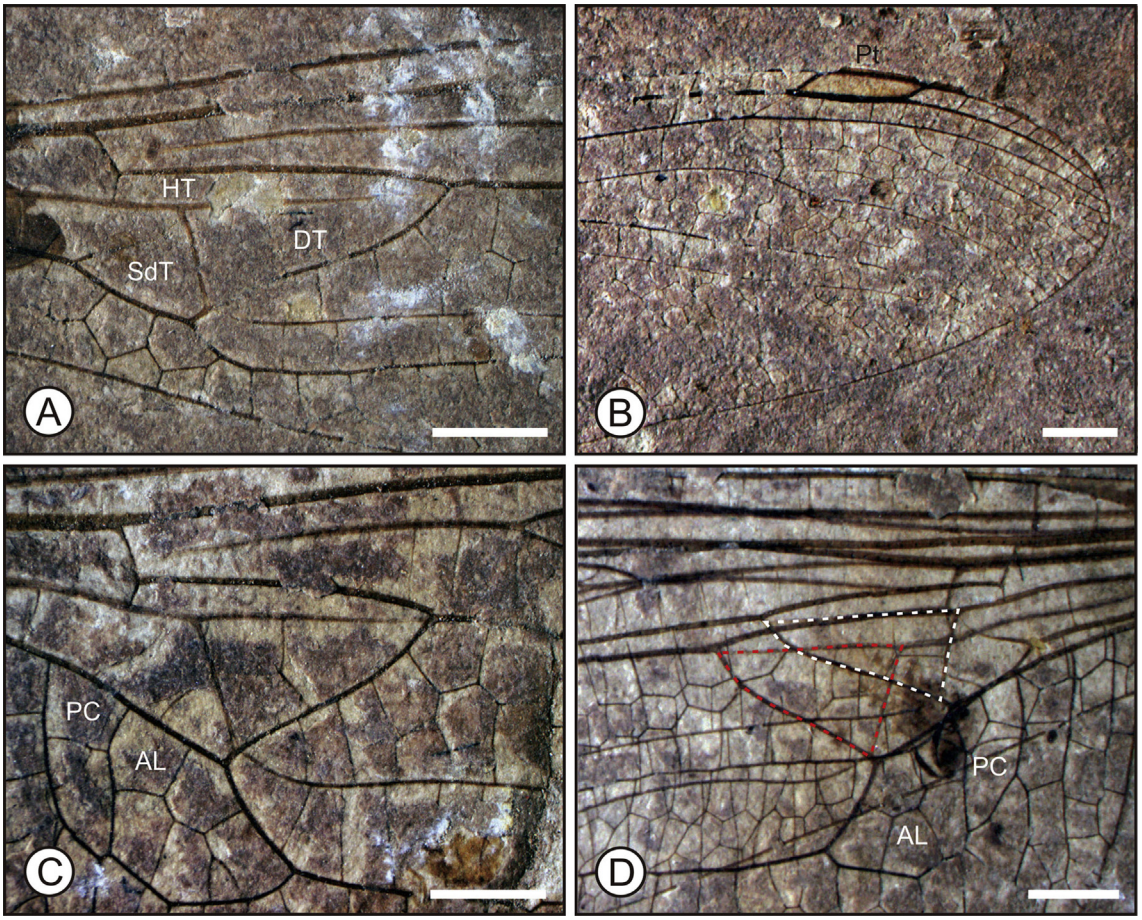

Fig. 4. *Sinojagoria magna* Li et al., 2012 (NIGP165093), photographs showing detail of right forewing discoidal area (A) and distal half (B), right hindwing discoidal area (C), and left forewing (white dashed) and hindwing (red dashed) discoidal areas (D). Scale bars = 2 mm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Bechly et al., 2001 in the two plesiomophies: absence of characteristic elongated distal paranal cell in hindwing just basal of anal loop; pterostigmal brace not undulated. However, the new specimen has a well-defined, unique paranal cell which is longitudinally elongated not horizontally elongated. Bechly et al. (2001) has also indicated two known autapomorphies of the Gomphaeschnaoidini which are not preserved or unknown in *S. imperfecta*: basally widened cell below pterostigma (absent) and weakly defined posterior branches of hindwing CuAa (unknown). The new specimen lacks a widened cell below the pterostigma and has well-defined posterior branches of CuAa in the hindwing, supporting a sister-group relationship between Sinojagorini and the other remaining Gomphaeschnaoidinae.

5. Conclusions

A well-preserved dragonfly attributed to *Sinojagoria magna* Li et al., 2012 is described from the Lower Cretaceous Yixian Formation of the Huangbanjigou outcrop, western Liaoning, NE China. The new specimen helps to emend the diagnosis of the Early Cretaceous tribe Sinojagorini and provides hindwing characters for *S. magna*. The presence of a well-defined paranal cell and posterior branches of CuAa in the hindwing indicates the close relationship between Sinojagorini and the remaining Gomphaeschnaoidinae.

Acknowledgements

This research was supported (grant nos in parentheses) by National Natural Science Foundation of China (41272013, 41572010, 41622201, 41688103), and the HKU Seed Funding Program for Basic Research (201210159058). We offer our sincere gratitude to Dr. Eduardo Koutsoukos for editing, and two anonymous reviewers for the very useful comments on the earlier version of the manuscript.

References

Bechly, G., 1996. Morphologische Untersuchungen am Flügelgeäder der rezenten Libellen und deren Stammgruppenvertreter (Insecta; Pterygota; Odonata), unter besonderer Berücksichtigung der Phylogenetischen Systematik und des Grundplanes der Odonata. Petalura 2, 1–402.

Bechly, G., Nel, A., Martínez-Delclòs, X., Jarzembowski, E.A., Coram, R., Martill, D., Fleck, G., Escuillié, F., Wisshak, M.M., Maisch, M., 2001. A revision and phylogenetic study of Mesozoic Aeshnoptera, with description of several new families, genera and species (Insecta: Odonata: Anisoptera). Neue Paläontologische Abhandlungen 4, 1–219.

Chang, S.C., Zhang, H., Renne, P.R., Fang, Y., 2009. A high-precision $^{40}Ar/^{39}Ar$ age for the Jehol Biota. Palaeogeography, Palaeoclimatology, Palaeoecology 280, 94–104.

Fabricius, J.C., 1793. Entomologia systematica emendata et aucta, secundum classes, ordines, genera, species, adjectis synonymis, locis, observationibus, descriptionibus. C.G. Proft, Hafniae (= Copenhagen) 3, 1–487.

Li, Y., Nel, A., Ren, D., Pang, H., 2012. New gomphaeschnids and progobiaeshnids from the Yixian Formation in Liaoning Province (China) illustrate the tremendous Upper Mesozoic diversity of the aeshnopteran dragonflies. Geobios 45, 339–350.

Nel, A., Huang, D., 2010. A new Mesozoic Chinese genus of aeshnopteran dragonflies (Odonata: Anisoptera: Progobiaeshnidae). Comptes Rendus Palevol 9, 141–145.

Nel, A., Martínez-Delclòs, X., Paicheler, J.C., Henrotay, M., 1993. Les 'Anisozygoptera' fossiles. Phylogénie et classification (Odonata). Martinia, Numéro Hors Série 3, 1–311 (in French).

Riek, E.F., 1976. A new collection of insects from the Upper Triassic of South Africa. Annals of the Natal Museum 22, 791–820.

Riek, E.F., Kukalová-Peck, J., 1984. A new interpretation of dragonfly wing venation based upon Early Carboniferous fossils from Argentina (Insecta: Odonatoidea) and basic characters states in pterygote wings. Canadian Journal of Zoology 62, 1150–1166.

Selys-Longchamps, E.de, 1854. Monographie des Calopterygines. Mémoires de la Société royale des Sciences de Liége 9, xi + 291 pp (in French).

Tillyard, R.J., Fraser, F.C., 1940. A reclassification of the order Odonata based on some new interpretation of the venation of the dragonfly wing. Part III. Continuation and conclusion. The Australian Zoologist 9 (4), 359–396.

Zheng, D., Nel, A., Wang, B., Jarzembowski, E.A., Chang, S.-C., Zhang, H., 2016. The first Early Cretaceous damsel-dragonfly (Odonata: Stenophlebiidae: *Stenophlebia*) from western Liaoning, China. Cretaceous Research 61, 124–128.