



Original article

A new genus and species of eurypterid (Chelicerata, Eurypterida) from the Lower Devonian Xiaxisancun Formation of Yunnan, southwestern China [☆]



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ABSTRACT

Eurypterids constituted an important component of Paleozoic marine ecosystems, but their fossil record has been mainly reported from North America and Europe, and the evolution of this group in other regions such as East Asia remains poorly understood. A new eurypterid, *Malongia mirabilis* nov. gen., nov. sp., is described from the Lower Devonian (Lochkovian) Xiaxisancun Formation of Qujing, Yunnan, southwestern China. The holotype shows a ventral prosoma with appendages II–VI and part of the opisthosoma. The characters indicating a dolichopterid affinity of the new taxon include: metasoma anterior cordate and basally truncated; appendage III bearing multiple enlarged spines; appendage V nonspiniferous; long appendage VI with expanded distal podomere and narrow triangular VI-7a; sub-rhomboidal coxa of appendage VI with a rounded principal tooth. *Malongia* nov. gen. is the fourth genus described within the Dolichopteridae Kjellesvig-Waering and Størmer, 1952, other members of which are *Dolichopterus* Hall, 1859, *Clarkeipterus* Kjellesvig-Waering, 1966, and *Ruedemannipecterus* Kjellesvig-Waering, 1966; it represents the only record of this family in South China.

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1. Introduction

Eurypterids are an extinct group of arthropods that have received much attention for achieving large sizes among a number of their constituent clades (Braddy et al., 2008; Chlupáč, 1994; Lamsdell and Braddy, 2010). Originating in the Middle Ordovician, eurypterids flourished in the Silurian, began to decline in the Devonian, and finally became extinct in the Permian (Lamsdell et al., 2015; Lamsdell and Selden, 2017). The Silurian saw the great diversification of eurypterids, during which they occupied different ecological niches, acting as predators (Braddy et al., 2008; Chlupáč, 1994; McCoy et al., 2015; Poschmann et al., 2016), scavengers (Waterston, 1979; McCoy et al., 2015; Poschmann et al., 2016; Bicknell et al., 2018), or sweepfeeders (Waterston et al., 1985; Hughes and Lamsdell, 2021). However, the diversity of eurypterids

shows a marked decline after the Silurian-Devonian boundary (Lamsdell and Selden, 2017).

Eurypterids have been mainly reported from North America and Europe (Tetlie, 2007). By contrast, the fossil record of this group in China or, more broadly, in eastern Asia, is sparse (Table 1). *Adelophthalmus chinensis* Grabau, 1920, *Hughmilleria wangi* Tetlie, Selden and Ren, 2007, and *Terropterus xiushanensis* Wang et al., 2021 were reported from China (Grabau, 1920; Tetlie et al., 2007; Zong et al., 2017; Wang et al., 2021), along with some isolated records from the late Silurian of Vietnam (Braddy et al., 2002). The evolution of eurypterids outside of North America and Europe remains poorly understood.

Here, we describe a new member of the Dolichopteridae, *Malongia mirabilis* nov. gen., nov. sp., from the lowest Devonian (Lochkovian) Xiaxisancun Fm. of Qujing, Yunnan Province, southwestern China. Three Laurussian genera were previously included in this family, namely *Dolichopterus* Hall, 1859, *Clarkeipterus* Kjellesvig-Waering, 1966 and *Ruedemannipecterus* Kjellesvig-Waering, 1966, and their records are all from the Silurian, except for the poorly preserved material of *?Dolichopterus asperatus* Kjellesvig-

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Table 1
Fossil record of eurypterids from the Paleozoic of China and northern Vietnam.

Taxon	Age	Distribution	Reference
<i>Adelophthalmus chinensis</i>	Asselian?	Zhaogezhuang Formation (Luan County, Hebei, China)	Grabau (1920)
Pterygotidae gen. et sp. indet.	Lochkovian	Xitun Formation (Qujing, Yunnan, China)	Wang and Gai (2014)
Eurypterida gen. et sp. indet.	Lochkovian	Khao Loc Formation (Tong Vai, Ha Giang, Vietnam)	Racheboeuf et al. (2005)
<i>Rhinocarcinosoma dosonensis</i>	upper Silurian	Dô Son Formation (Dô Son, Vietnam)	Braddy et al. (2002)
<i>Hughmilleria</i> sp.	upper Silurian	Ibid.	Braddy et al. (2002)
<i>Hughmilleria wangi</i>	Llandovery	Xiaoxiyu Formation (Longshan, Hunan, China)	Tetlie et al. (2007)
? <i>Eurypterus yangi</i>	Llandovery	Xintan Formation (Zigui, Hubei, China)	Chang (1957)
? <i>Eurypterus styliformis</i>	Llandovery	Ibid.	Chang (1957)
? <i>Eurypterus loi</i>	Llandovery	Ibid.	Chang (1957)
? <i>Mixopterus</i> sp.	Llandovery	Ibid.	Chang (1957)
<i>Hughmilleria wangi</i>	Llandovery	Fentou Formation (Wuhan, Hubei, China)	Zong et al. (2017)
<i>Terropterus xiushanensis</i>	Llandovery	Xiushan Formation (Xiushan, Chongqing, China)	Wang et al. (2021)

Waering, 1961 from the Lower Devonian of Ohio, USA (Kjellesvig-Waering, 1961a, 1966; Tetlie, 2007; Dunlop et al., 2020). Our finding presents a new record of eurypterids outside North America and Europe, and sheds new lights on the geographic distribution and dispersal of dolichopterids around the world.

2. Geological background

The Xiaxisancun Fm. is mainly composed of light gray quartz sandstone intercalated with yellowish-green siltstone and black shale (Fang et al., 1985; Ma et al., 2009). The lower part of the Xiaxisancun Fm. comprises of yellowish green silty mudstone intercalated with fine quartz sandstone (Hou et al., 2000). Below the Xiaxisancun Fm. is the Yulongsi (Yulungssu) Fm., which contains rich marine fossils indicative of a Pridoli age. The previously described fossils from the Xiaxisancun Fm. include: abundant fishes including galeaspids, placoderms and sarcopterygians (Zhao and Zhu, 2010; Meng and Gai, 2022); the early vascular plant *Zosterophyllum xishanense* Hao et al., 2007 (Hao et al., 2007); mollusks (Fang et al., 1994); crustaceans, including leperditiids and ostracodes (beyrichiids and cryptophyllus) (Wang et al., 1992; Wang, 1994); another euchelicerate arthropod (*Houia yueya* (Lamsdell et al., 2013; Selden et al., 2015)); etc. On the basis of the lithology and fossil content, it is considered that the Xiaxisancun Fm. was deposited in a foreshore-offshore environment (Zhao and Zhu, 2010).

There is still some controversy about the age of the Xiaxisancun Fm. (see Zhao et al., 2021 for a recent review). Some studies suggested that the Silurian-Devonian boundary (SDB) is at the base of the Xiaxisancun Fm. (Cai et al., 1994; Fang et al., 1994; Zhao and Zhu, 2010; Zhao et al., 2021), but other studies placed the SDB within the Xiaxisancun Fm., or even within its overlying unit, the Xitun Fm. (Rong et al., 1990; Tian et al., 2011; Rong et al., 2019). Here, we follow the first scheme, and interpret the present fossil from the lowermost part of the Xiaxisancun Fm. as earliest Lochkovian in age.

3. Material and methods

The only specimen described in this paper, including part (2011xxs01a) and counterpart (2011xxs01b), was collected from the yellowish-green siltstone of the lowermost part of the Xiaxisancun Fm., at a locality near Liaojiatian Village, Malong District, Qujing, Yunnan Province, southwestern China (Fig. 1). All photographs were taken with a stereoscopic zoom microscope (Nikon SMZ 1500, captured by Nikon digital sight DS-U1) and a LSR camera (Nikon D90). The specimen is housed at the Geological Museum, the School of Earth and Space Sciences, Peking University.

Eurypterid terminology follows Tollerton (1989) for the shape of the carapace, prosomal appendages, metastoma, genital appendage and opisthosomal differentiation. Terminology for labeling of the appendages follows Selden (1981) and the ventral plate follows Tetlie et al. (2008). Terminology for cuticle layer of the gnathobasic tooth follows Richards (1951) and Dalingwater (1975).

4. Systematic palaeontology

Phylum Arthropoda von Siebold, 1848
Subphylum Chelicerata Heymons, 1901.
Order Eurypterida Burmeister, 1843.
Suborder Eurypterina Burmeister, 1843.
Family Dolichopteridae Kjellesvig-Waering and Størmer, 1952.
Genus *Malongia* nov. gen.

Derivation of the name: Named after Malong District where the fossil was collected. Feminine.

Type species: *Malongia mirabilis* nov. gen., nov. sp., by monotypy.

Diagnosis: Dolichopteridae with subquadrate prosoma; third to fourth paired appendages spinous; one enlarged long spine per spinous podomere of appendage IV; two or three enlarged long spines per spinous podomere of appendage III; fifth paired appendages slim and non-spinous; distal podomeres of sixth paired appendages enlarged; lateral margin of paddle smooth; VI-1 with a principal tooth and posterior smaller teeth; angle between VI-3 and VI-4 near 180°; VI-4, VI-5 and VI-8 long; metastoma cordate anteriorly and truncated posteriorly; anterior notch of metastoma with small denticles.

Malongia mirabilis nov. gen., nov. sp.

Figs. 2–4.

Derivation of the name: The species name is from the Latin *mirabilis*, meaning ‘wonderful’, referring to the nature of the taxon.

Holotype: One specimen with part and counterpart (2011xxs01a and 2011xxs01b).

Type locality and level: A locality near Liaojiatian Village, Malong District, Qujing, Yunnan Province, southwestern China; lowest part of the Xiaxisancun Fm.

Diagnosis: As for genus, by monotypy.

Description: The holotype displays the ventral surface. The postabdomen is partially preserved, and the part after the XVI somite is missing. The visual structures (such as lateral eyes and ocelli which are on the carapace), ornament of the tergites, and telson are not preserved. The terms right and left in the description below refer to the living organism, not to the fossil as observed by us.

Only the ventral anterior part of the carapace is exposed and the frontal margin is slightly convex. Narrow marginal rim is ca. 1 mm wide. Based on the edge of the front of the preabdomen and the position of the axis of body symmetry, we have a reasonable estimate of the size of the carapace. The carapace is characterized by a length:width ratio of 0.65 to 0.8 and a lateral angle of 95° to 115°.

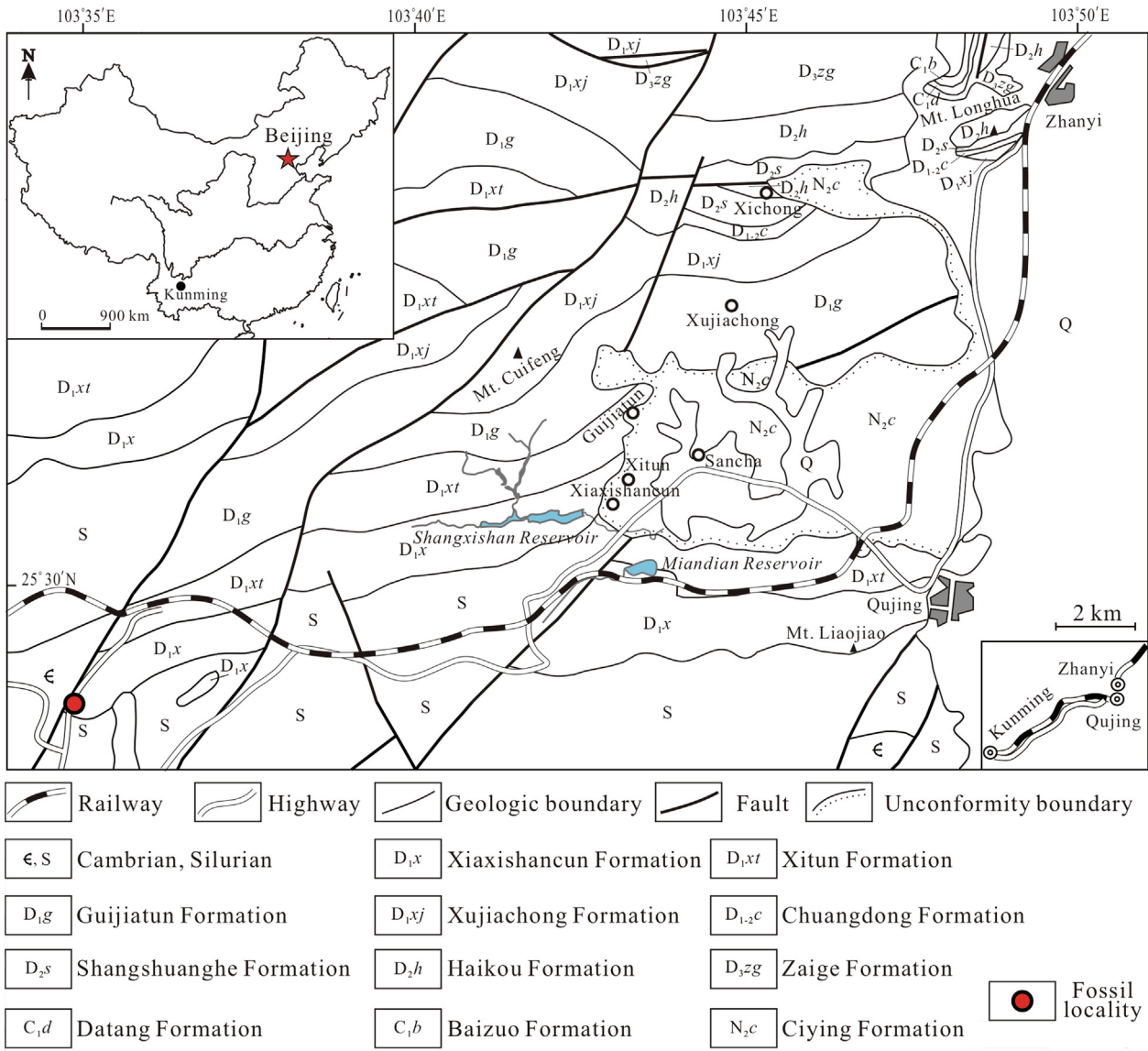


Fig. 1. Maps showing the fossil locality and the geology near Qujing, Yunnan, China.

subquadrate in shape. The ventral plates have opened and the opening consists of two symmetrical unconnected parts. The gap between these two parts is narrow anteriorly and widens posteriorly. The narrowest part of this gap is only ca. 3 mm. The opening and the offset of the coxae both indicate that the specimen is a molt (ecdysis). The ventral plates are similar to the *Megalograptus*-type (Tollerton, 1989; Tetlie et al., 2008).

Prosomal appendages. The coxae of all appendages are slightly out of their original place and twisted backward, but the relative position of the appendages still remains, so that each appendage can be recognized. The first appendage (chelicera) is missing. The walking legs increase in length posteriorly and decrease very little in width distally. Prosomal appendage II is fragmentarily preserved, with scattered intermittent fragments showing no useful anatomical information. The spiny sides of Appendages III and IV are directed backward, but we consider that this orientation resulted from ecdysis and/or preservation process. Appendage V is dislocated and is the thinnest of all known appendages, only 3–5 mm; it shows indistinct segmentation and is not spinous.

Appendage III (Fig. 2(C, E)) preserves seven recognized podomeres, five of them showing spines with longitudinal striations

(Fig. 2(E)). The second podomere (III-2) bears two rows of small nodules (Fig. 3(I)) and almost equal with the coxa (III-1) in length and width. They are 3.5 times as long as wide. The boundary between the third (III-3) and the fourth podomeres (III-4) is not clear; nor is the boundary between the fifth (III-5) and the sixth podomeres (III-6). The third to the seventh podomeres are a little longer than wide. The third podomere (III-3) and the fourth (III-4) podomere are 15 mm long and 6 mm wide in total, bearing five spines; from proximal to distal part of the podomere, the spines increase in width, but the last three spines are nearly the same width. Except for the first spine, all other spines are partially covered by appendage IV, so that the length of these spines is difficult to measure. However, considering the width and length of similar spines are positively correlated in eurypterids, it is reasonable that this length:width relationship is also valid in our taxon. The fifth podomere (III-5) is distinctly slender and more curved; the first spine of III-5 is short and stout (Fig. 3(D)), while the other spines are longer and nearly same in width. The seventh podomere (III-7) bears two moderately long spines, whose orientation extends gradually towards the end of the podomere.

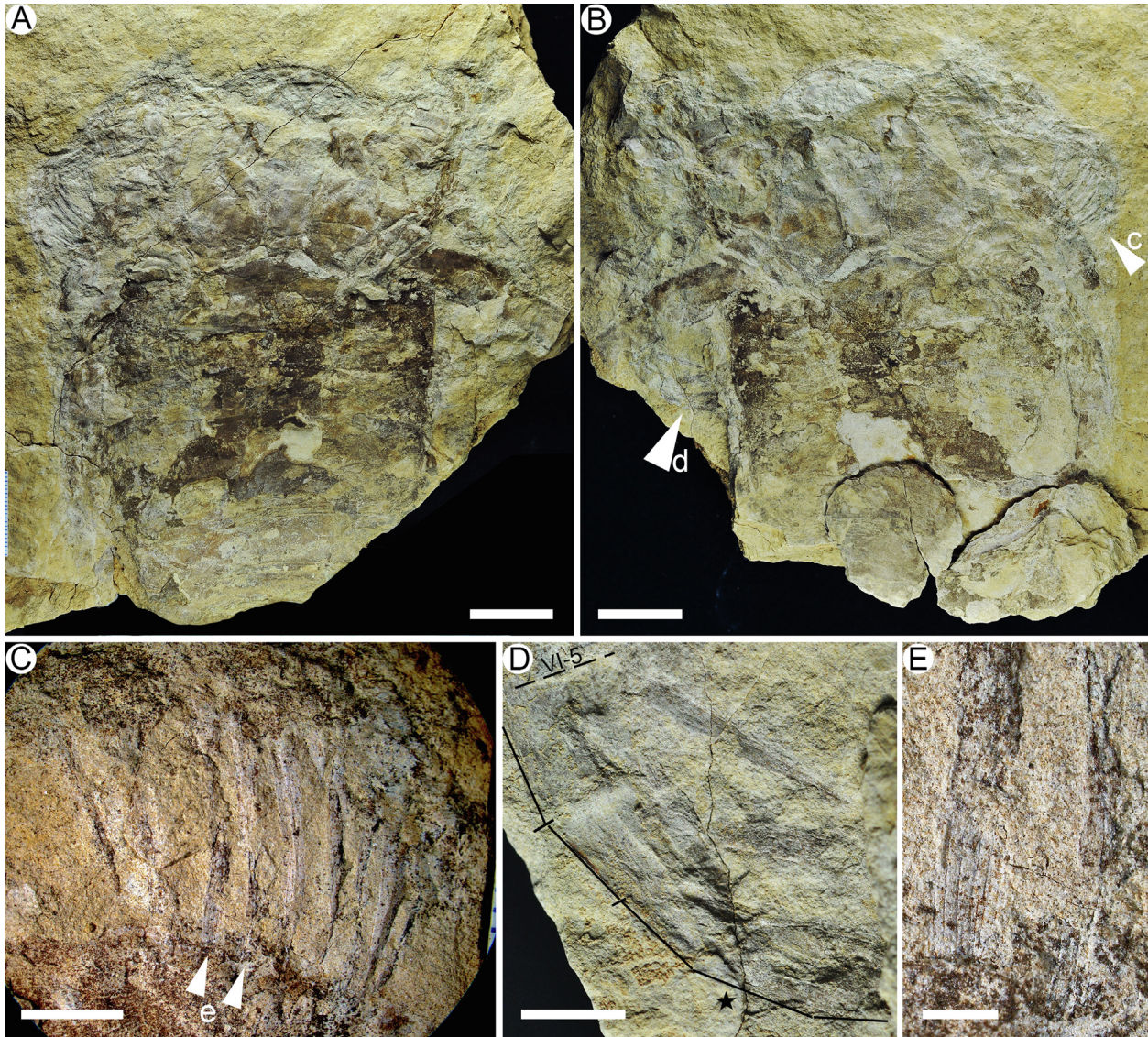


Fig. 2. *Malongia mirabilis* nov. gen., nov. sp. from Qujing, Yunnan, China. **A, B.** Holotype, part and counterpart, 2011xxs01a, 2011xxs01b; arrows c and d indicate the part enlarged in pictures C and D, respectively. **C.** Close-up of the podomere 5 and 6 of appendage III; arrows e indicates the spine enlarged in picture E. **D.** Close-up of the podomeres of appendage IV; star indicates the last podomere of appendage IV. **E.** Spines showing longitudinal striations. Scale bars: 20 mm (A, B), 5 mm (C, D), 1 mm (E).

Appendages IV shows at least six podomeres, with spines on each of the last, penultimate and third from last podomeres. The second podomere (IV-2) is rectangular in shape and 20 mm in length. From the proximal end to the distal end, the width decreases from 10 mm to 8 mm. The left third podomere (IV-3) is covered by the appendage VI and the right third podomere overlying the spines of the appendage III. The visible portions of prosomal appendage VI consist of at least eight podomeres. The second (VI-2) and third (VI-3) podomeres are very short. The second podomere is 5–7 mm in length and 15 mm in width. The third podomere is 2–3 mm in length and 11–13 mm in width. The fourth (VI-4) and fifth podomeres (VI-5) are relatively longer. The fourth podomere is 23–24 mm in length and 8–10 mm in width. The fifth podomere is 14 mm in length and 7–10 mm in width. The sixth podomere (VI-6) is 7–10 mm in length and 8–10 mm in width. It has an anterior semicircular depression of 1 mm radius. The posterior part is covered by the seventh podomere (VI-7). The seventh and eighth podomeres (VI-7 and VI-8) are broken. VI-7a is elongated triangular in shape and not wider than half of the seventh podomere; it is 6 mm long and 2 mm wide (Fig. 3(A)). The eighth

podomere expands into a large paddle, and the broadest part is more than 14 mm wide. The anterior edge of the eighth podomere consists of intermittent line segments.

Coxa. There are eight coxae preserved in total (Fig. 4), which belong to two types. The first type of coxae belongs to swimming leg coxa (VI-1) which is subrhomboidal in shape. The width of this type expands from proximal to distal. It develops a large plate at the distal end, and has an anterior projection termed “ear” by [Tetlie and Cuggy \(2007\)](#) (Fig. 3(F, G)). The coxal ear is elongate rectangular in shape. Lunule-like ornaments cover the entire coxa. The surface of the coxa near the gnathobase is covered with setae (Fig. 3(F)). The gnathobase is at the inner end and has an anterior principal tooth which is rounded (Fig. 3(G)). In addition, there is a row of smaller triangular teeth on a posterior higher plane. In the second type, the width of the coxa is gradually increased from proximal to distal or almost constant. This type bears 5 to 6 robust triangular teeth which are striated near the edge (Fig. 3(E, H)).

Metastoma. The metastoma is rectangular in shape (Fig. 3(B)), with the following parameters: length:width ratio

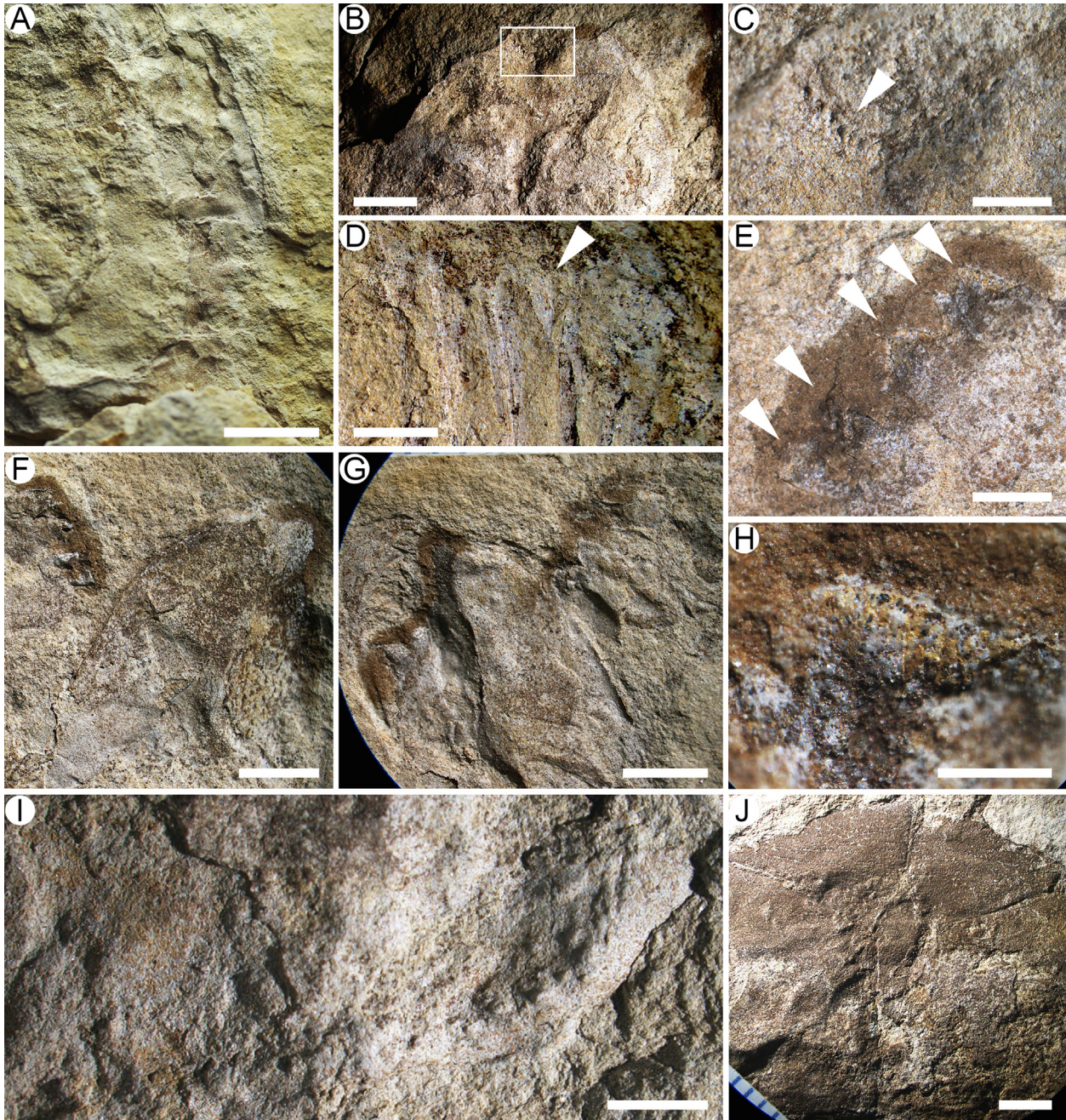


Fig. 3. *Malongia mirabilis* nov. gen., nov. sp. from Qujing, Yunnan, China; enlarged view of the characters in the Holotype. **A.** Fifth to eighth podomeres of appendage VI, 2011xxs01a. **B.** Top half of the metastoma, 2011xxs01a; the rectangular indicates the part enlarged in picture C. **C.** V-shaped depression of the metastoma; arrow indicates the position of a row of denticles. **D.** Podomere 5 and 6 of appendage III, 2011xxs01b; arrow points to a stout spine. **E.** Teeth of the coxa of the appendage (left) IV, 2011xxs01a; each arrow points to a tooth. **F.** Coxa of the appendage (right) IV and VI with teeth and small setae, 2011xxs01a. **G.** Coxa of the appendage (right) IV and VI with teeth, 2011xxs01b. **H.** Exocuticle layer and endocuticle layer with striation on teeth of the coxa of the appendage IV, 2011xxs01a. **I.** Podomere (distal from III-2) of the appendage (right) III, with two rows of nodules, 2011xxs01a. **J.** Genital appendage, 2011xxs01a. Scale bars: 10 mm (A), 3 mm (B, D, F, G, J), 1 mm (C, E), 0.5 mm (H), 2 mm (I).

25 mm/16 mm; lateral angle 85–90°; angle of cordation 115°; position of greatest width anterior third; anterior cordate; posterior truncated; sides slightly convex; shoulder semi-angular. There is a circular bulge on the posterior part of the metastoma. The anterior metastomal margin presents a row of more than 15 short triangular denticles (Fig. 3(C)). These spines are nearly equal in length, each ca. 0.3–0.4 mm long.

Opisthosoma and genital appendage. The cuticle of the ventral sternite is very thin. Because of compression during preservation, the fossil shows overprinting of the dorsal tergites. Somites VIII–XVI are preserved and the lengths of these somites expand from

anteriority to posteriority. The preabdominal somites are 7–9 mm in length and the postabdominal somites are 10–12 mm in length. The width of the abdominal somites is incomplete. The articulation facets show a smooth belt which consists of two slim ridges on both sides between the preabdominal somites, but between the postabdominal somites, it consists of more than two ridges.

The genital operculum and genital appendage are partially preserved (Fig. 3(J), 4). The genital operculum consists of three fused plates. The anterior opercular plate is narrow and poorly preserved. It is ca. 2 mm long and accounts for a tenth of the length of the

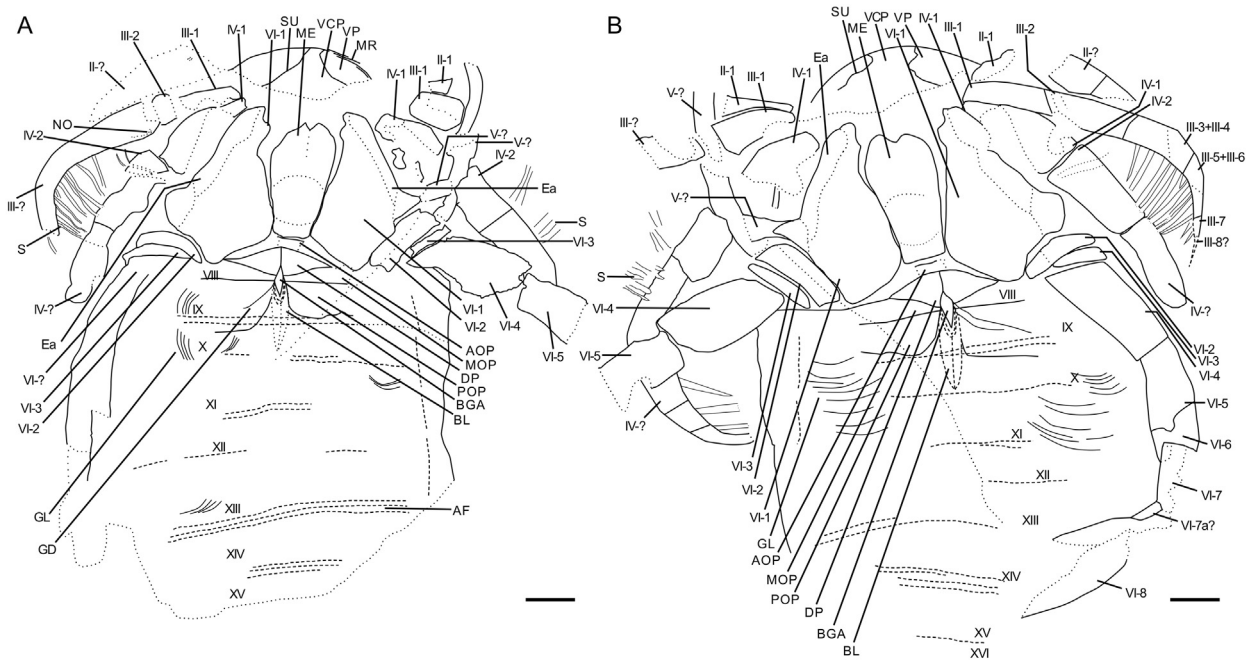


Fig. 4. Interpretative drawings of the part (A: 2011xxs01a) and counterpart (B: 2011xxs01b) of the Holotype. Abbreviations: II–VI, prosomal appendages II–VI; II-1, first podomere of appendage II; VIII–XVI, somites VIII–XVI; AF, articulation facet; AOP, anterior opercular plates; BGA, basal segment of the genital appendage; BL, blades of the genital appendage; DP, deltoid plate; Ea, ear on coxa VI; GL, gill; ME, metastoma; MOP, median opercular plates; POP, posterior opercular plates; S, spine; SU, suture; VCP, ventral carapace; VP, ventral plate. Scale bars: 10 mm.

whole genital operculum. The posterior opercular plates make up half length of the whole genital operculum and are united with median opercular plates by a straight transverse suture. The deltoid plates are quadrilateral in shape. The deltoid plates and the median opercular plates are united by oblique sutures and they are in transverse series. The central anterior part of this series is convex. The oblique sutures extend anterolaterally from the basal segment of the genital appendage. The deltoid plates and the anterolateral margin of basal segment of the genital appendage are united by sutures. There are lunule-like ornaments on the deltoid plates (Fig. 3(J)). Basal segment of the genital appendage is 3 mm wide and 7 mm long. It is elongated rhombic in shape and surrounded by a 2 mm thick concentric decoration on the lower half part. Two long, symmetrical blades are adjacent to the posterolateral margin of basal segment of the genital appendage; they are appressed on the median groove. The median groove extends from somite IX to somite X. In the posterolateral edge of the basal segment of the genital appendage, there are imprints of a tubular conduit (Fig. 4). The book gills occur on the genital operculum and the Blattfüsse are between somites IX and XIII (Fig. 2(A, B), 4).

5. Discussion

5.1. Justification as a new genus of the Dolichopteridae

Prosomal appendage differentiation is one of the major morphological changes that occur throughout post-embryonic development of eurypterids (Lamsdell et al., 2015; Lamsdell and Selden, 2013). Because the prosomal appendages of the holotype of *Malongia mirabilis* nov. gen., nov. sp. appear highly differentiated (Fig. 4(B)), it is believed that this specimen represents an adult or an approaching adult. The present taxon is close in many aspects to the members of the family Dolichopteridae. In the following, this taxon is compared in detail with the known records of dolichopterids in order to justify the establishment of a new genus and species and as well as, its assignment to the Dolichopteridae.

Following Dunlop et al. (2020), the Dolichopteridae includes three genera: *Clarkeipterus*, *Dolichopterus*, and *Ruedemanniapterus*. The records of *Dolichopterus* are numerous, including four well-defined species (*D. gotlandicus* Kjellesvig-Waering, 1979; *D. jewetti* Caster and Kjellesvig-Waering, 1956; *D. macrocheirus* Hall, 1859; and *D. siluriceps* Clarke and Ruedemann, 1912) and some questionable ones (?*D. asperatus*; ?*D. bulbosus* Kjellesvig-Waering, 1961b; and ?*D. herkimerensis* Caster and Kjellesvig-Waering, 1956). Two species were assigned to *Clarkeipterus* (*C. otisius* (Clarke, 1907) and *C. testudineus* (Clarke and Ruedemann, 1912)), and only one species to *Ruedemanniapterus* (*R. stylonuroides* Clarke and Ruedemann, 1912).

There are numerous similarities between *Malongia* nov. gen. and *Dolichopterus*, indicating closer relationship than to other genera, as follows:

- **Carapace.** Carapace is subquadrate-shaped in both taxa; the anterior of the carapace is slightly convex in *Malongia* gen. nov. and ?*Dolichopterus asperatus* (Kjellesvig-Waering, 1961a);
- **Metastoma.** In both taxa, metastoma is cordate anteriorly and truncated at the base; lateral margin of metastoma is nearly straight or slightly concave; the length of metastoma is more than half of the length of carapace, and the maximum width of metastoma is in the anterior quarter part and about half of its length, and then the width decreases posteriorly. In addition, there is a bulge on the metastoma in both *Malongia* nov. gen. and *D. macrocheirus* (Clarke and Ruedemann, 1912: pl. 44). A row of short triangular denticles occurs on the anterior notch of the metastoma of *Malongia* nov. gen., and such structures also occur in *D. gotlandicus*, showing as a row of seven denticles along each side of the of the median notch (Kjellesvig-Waering, 1979: fig. 34A). Similar structures are common in horseshoe crabs today and also found in other eurypterids such as the mixopterid *Lanarkopterus dolichoschelus* (Størmer, 1936) (Ritchie, 1968: Fig. 2);

- Coxa and gnathobase.** In both taxa, coxa VI-1 is subrhomboidal in shape; there is subquadratic coxal ear and anterior distal plate on coxa VI-1; coxae of appendages II-IV are subrectangular or subtriangular in shape, and each coxa of appendages II-IV bears five to six robust triangular teeth. There is a rounded principal tooth on coxa VI-1 in *Malongia* nov. gen., similar to *D. macrocheirus* (Clarke and Ruedemann, 1912: pl. 45) and *Dolichopterus* sp. (Specimen YPM IP 209058 deposited in the Invertebrate Paleontology Division, Yale Peabody Museum). Teeth are striated near the edge in *Malongia* nov. gen. and *D. gotlandicus* (Kjellesvig-Waering, 1979: fig. 34C). Such striations on the teeth of coxa VI of *Malongia* nov. gen. (10 μm in width) and *D. gotlandicus* may represent the interspace within the fibrous exocuticle layer (darkened layer in Fig. 3(H)) and endocuticle layer (beneath the darkened layer). Similar phenomenon has been observed in the horseshoe crab *Limulus polyphemus* (Linnaeus, 1758) (Dalingwater, 1975: pl. 3, Fig. 5; Bicknell et al., 2018: fig. 10). Dalingwater (1975) indicates that “pore canals traverse the cuticle perpendicularly”. As shown in Bicknell et al. (2018: Fig. 3(B, C)), sediments filled the interspace within the fibrous layers during preservation, and the original fibers were decomposed. These type of teeth enables animals to consume shelled organisms, implying that *Malongia* nov. gen. might be a shell crusher, as also supported by its multiple enlarged spines on appendages III-IV (Schmidt et al., 2022);
- Appendage III.** In *Malongia* nov. gen., there are multiple enlarged and markedly striated spines concentrated in the distal part of the appendage III (Fig. 2(E)), and each podomere has two or three spines that are ca. 1 mm wide. Same spines are common in *D. macrocheirus* (Clarke and Ruedemann, 1912) and *D. jewetti* (Specimen YPM IP 215069 deposited in the Invertebrate Paleontology Division, Yale Peabody Museum);
- Appendage V.** In both taxa, appendage V is slender and non-spinous;
- Appendage VI.** Both taxa show short VI-2 and VI-3, very long VI-4, expanded distal podomeres, narrow triangular VI-7a, and their VI-8 is longer than VI-7;

- Genital operculum and genital appendage.** The similarities and differences are listed in a later separate paragraph.

However, the differences between *Malongia* nov. gen. and *Dolichopterus* are evident, indicating their distinctness at generic level. The anterior of the carapace in *Dolichopterus macrocheirus* and *Dolichopterus jewetti* is broadly emarginate (Hall, 1859; Clarke and Ruedemann, 1912) or straight (Clarke and Ruedemann, 1912; J. C. L. pers. obs. on specimens YPM IP 542608 and YPM IP 428218 deposited in the Invertebrate Paleontology Division, Yale Peabody Museum), while it is slightly convex in *Malongia* nov. gen. There is a circular bulge on the posterior part of metastoma in *Malongia* nov. gen. Such a bulge is also present in *D. macrocheirus* (Clarke and Ruedemann, 1912: pl. 44), but in the latter it occupies almost the entire area of the metastoma. The principal tooth of *Malongia* nov. gen. is rounded, different from the truncated principal tooth of *D. gotlandicus* (Kjellesvig-Waering, 1979: fig. 34C). The striations on the teeth of *Malongia* nov. gen. are radial, while they are parallel in *D. gotlandicus* (Kjellesvig-Waering, 1979: fig. 34C). Each podomere of appendage IV has only one enlarged spine in *Malongia* nov. gen. (similar to specimens of *Eurypterus tetragonophthalmus* Fischer de Waldheim (1839) in Selden, 1981), but there are multiple enlarged spines per podomere in *Dolichopterus*. The posterior angle between VI-3 and VI-4 is near 180° in *Malongia* nov. gen., while this angle is larger than 180° in *Dolichopterus*. VI-5 of *D. macrocheirus* (Clarke and Ruedemann, 1912) and *D. jewetti* (Tetlie and Cuggy, 2007) are nearly-one-fifth to one-fourth times longer than wide, while that of *M. mirabilis* nov. gen. is one and a half times longer than wide. VI-7 and VI-8 of *Malongia* nov. gen. are longer than those of *Dolichopterus*. The lateral serrate margin of expanded podomere of *Dolichopterus* is not seen in *Malongia* nov. gen.

The genital operculum of *Malongia* nov. gen. is similar to that of *D. jewetti* (Caster and Kjellesvig-Waering, 1956: Fig. 1), which in both taxa consists of three fused plates. A genital operculum composed of three fused plates is common among basal Eurypterina (Lamsdell, 2011). However, the anterior opercular plate of *Malongia* nov. gen. is shown as a narrow strip, different from two trian-



Fig. 5. Paleogeographic base map (late Silurian-Early Devonian; ca. 420 Ma) modified from Huang et al. (2018), showing the known Dolichopteridae-bearing localities. 1. Ohio, USA: *Dolichopterus asperatus*, based on Kjellesvig-Waering (1961a). 2. New York, USA: *Clarkeipterus?otisius*, *Clarkeipterus testudineus*, *D. jewetti*, *D. macrocheirus*, *D. siluriceps*, *D. herkimensis*, and *Ruedemannipterus stylonuroides*, based on Clarke (1907), Clarke and Ruedemann (1912), Caster and Kjellesvig-Waering (1956), and Hall (1859). 3. Pennsylvania, USA: *Clarkeipterus?otisius* and *Dolichopterus*, based on Plotnick (1983: table 51, localities 204 and 210) and Vrazo et al. (2014). 4. Ontario, Canada: *D. macrocheirus*, *D. siluriceps*, and *D. herkimensis*, based on Ciarca and Rochester (1982: Fig. 5C, D), Batt (1999), Tetlie (2007), and Dunlop et al. (2020). 5. Herefordshire, UK: *D. bulbosus*, based on Kjellesvig-Waering (1961b). 6. Gotland, Sweden: *D. gotlandicus*, based on Kjellesvig-Waering (1979). 7. Qujing, China: *Malongia mirabilis* nov. gen., nov. sp., this study. The taxonomy of Dolichopteridae is based on Dunlop et al. (2020). Abbreviations (tectonic blocks): MOB, Mongolia; NCB, North China; SCB, South China.

gular plates of *D. jewetti*. The latter has posterior wings or horns on posterior opercular plates near genital appendage, while none wings or horns are shown in *Malongia* nov. gen. The genital appendage of *Malongia* nov. gen. consists of a rhombic basal segment and two elongated blades; by contrast, the genital appendage of *D. jewetti* consists of a longer basal segment, which is proximally hastate, and two shorter blades. It is noted that tubular conduits are preserved as imprints in specimens of *Malongia* nov. gen. and *D. jewetti*, and Caster and Kjellesvig-Waering (1956) suggested that tubular conduits of the latter might be seminal vesicles or oviducts.

The previously described specimens of *Clarkeipterus* and *Ruedemanniapterus* are poorly preserved, only showing features of carapace and appendage VI. *Malongia* nov. gen., *Clarkeipterus* and *Ruedemanniapterus* share a short VI-2 and VI-3, long VI-4, narrow VI-7a and smooth margin of expanded podomere. Unlike subquadrate carapace of *Malongia* nov. gen., the carapace of *Clarkeipterus* is spatulate or subquadrate whereas that of *Ruedemanniapterus* is campanulate (Clarke and Ruedemann, 1912). There are acute angular projections on the anterior of carapace in *Clarkeipterus* and *Ruedemanniapterus*, while the anterior of carapace in *Malongia* nov. gen. is rounded. The posterior angle between VI-3 and VI-4 is near 180° in *Malongia* nov. gen., while this angle is larger than 180° in *Clarkeipterus* and *Ruedemanniapterus* (as in *Dolichopterus*). VI-7a of *Ruedemanniapterus* is oval (Tetlie and Cuggy, 2007: Fig. 5H), but that of *Clarkeipterus* and *Malongia* nov. gen. is triangular. VI-7 and VI-8 of *Malongia* nov. gen. are broken and partly preserved, but their lengths seem to be comparable with those of *Ruedemanniapterus*.

5.2. Paleobiogeographic considerations

Eurypterids in East Asia have been reported only from China and Vietnam (Table 1). Grabau (1920) described *Adelophthalmus chinensis* from the Zhaogezhuang Fm. (Asselian?, early Permian) of Luan County, Hebei Province, China, representing the first report of this group in China. Grabau (1926) also described an unnamed, poorly preserved eurypterid telson collected by Dr. Wenjiang Ding from the upper Silurian of eastern Yunnan Province, China. Chang (1957) described three species of *Eurypterus* and an uncertain species of *Mixopterus* Ruedemann, 1921 from the Xintan Fm. (Llandovery, Silurian) of Zigui, Hubei, China, although the taxonomic assignment of these species has been questioned (Braddy et al., 2002; Tetlie, 2007). Chang's (1957) specimens may represent eurypterids, but the available material includes only some isolated coxae and a rough outline of the prosoma and opisthosoma, with no complete prosomal appendages and no connected telson.

Braddy et al. (2002) described *Rhinocarcinosoma dosonensis* Braddy, Selden and Doan, 2002, and *Hughmilleria* sp. from the upper Silurian of the Dô Son Fm., Dô Son, northern Vietnam. Racheboeuf et al. (2005) described an indeterminate type of eurypterids from the Khao Loc Fm. (Lochkovian) in Tong Vai, Ha Giang Province, northern Vietnam.

Tetlie et al. (2007) reported *Hughmilleria wangi* from the Xiaoxiyu Fm. (Llandovery) of Longshan County, Hunan Province. Another specimen of *H. wangi* was recently described from the Fentou Fm. (Llandovery) of Wuhan, Hubei Province (Zong et al., 2017). Wang and Gai (2014) described a pterygotid chelicera from the Lower Devonian of Qujing, Yunnan, and the horizon belongs to the Xiaishancun Fm. (Dr. Zhikun Gai, pers. comm., 2022), the same formation as *M. mirabilis* nov. gen., nov. sp. Wang et al. (2021) described *Terropterus xiushanensis* from the Xiushan Fm. (Llandovery) of Xiushan, Chongqing, China, and *Terropterus* sp. from the Fentou Fm. of Wuhan. Except for the specimen of *Adelophthalmus chinensis* described by Grabau (1926) and the pterygotid described by Wang and Gai (2014), the rest of the eurypterid fossils in China are all from the Llandovery (Table 1).

The discovery of *Malongia mirabilis* nov. gen., nov. sp. extends the geographic distribution of dolichopterids to South China (Fig. 5). Previous records of this family are all from the Silurian of North America and Europe, except for *Dolichopterus asperatus* that was reported from the Lower Devonian (Lochkovian-Pragian), Ohio, USA (Kjellesvig-Waering, 1961a). However, it is noted that *Dolichopterus asperatus* is represented by poorly preserved specimens (Kjellesvig-Waering, 1961a), and its taxonomic assignment as a dolichopterid has been questioned (Dunlop et al., 2020). Thus, *Malongia mirabilis* nov. gen., nov. sp., as an unequivocal record of dolichopterid, confirms the survival of this group after the Silurian-Devonian boundary, if we accept the scheme suggesting an earliest Devonian age (Lochkovian) for the Xiaishancun Fm. (see Zhao et al., 2021).

6. Conclusions

A new eurypterid, *Malongia mirabilis* nov. gen., nov. sp., is described from the lowest part of the Xiaishancun Formation of Malong District, Qujing, Yunnan, southwestern China, a rich source of many sorts of marine animals such as fishes but where arthropod fossils have been only rarely documented so far. The recognized characteristics of the new taxon include: prosoma subquadrate; metastoma cordate anteriorly and truncated posteriorly; third to fourth paired appendages spinous; fifth paired appendages slim and non-spinous; distal expanded podomeres of sixth paired appendages with smooth lateral margin; VI-1 with principal tooth; VI-4, VI-7 and VI-8 long. *Malongia mirabilis* nov. gen., nov. sp. is closely similar to *Dolichopterus* and can be assigned to the Dolichopteridae, representing the only report of this family outside Laurussia.

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.

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