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A new scorpion from a Permian peat swamp in Inner Mongolia, China

Xiaojie Lei[a,b,*], Weiming Zhou[a], Mingli Wan[a], Haibo Wei[c], Bo Wang[a]

[a] State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology and Center for Excellence in Life and Paleoenvironment, Chinese Academy of Sciences, 39 East Beijing Road, Nanjing, 210008, China
[b] University of Science and Technology of China, No.96, JinZhai Road Baohe District, Hefei, Anhui, 230026, China
[c] Institute of Deep Time Terrestrial Ecology Yunnan University, Kunming, 650500, China

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ABSTRACT

Palaeozoic scorpions are diverse in Europe and North America but are rarely found in Asia. Here we describe a fossil scorpion from the Lower Permian of Wuda, Inner Mongolia, China. It is very similar to *Eoscorpius sparthensis* from the Late Carboniferous, but differs from the latter in having posterior location of the ocellar node. The preabdomen of the new specimen is complete and its preanal is not elongated. Our discovery is not only the second Palaeozoic scorpion from China, but also the third scorpion from the Permian in the world.

1. Introduction

Scorpions now live in the low and middle latitude areas and may be one of the most diverse arthropod groups in the Late Carboniferous (Pennsylvanian) Coal Measures of Europe and North America (Dunlop et al., 2008). There are dozens of fossil species from the Carboniferous, but Permian scorpions are extremely rare (Dunlop et al., 2018), with only two valid species, *?Opsieobuthus tungeri* Dunlop et al. (2016) from Germany and *Permomatveevia perneri* Dammann (2017) from Russia, and some fragmentary (Fet et al., 2011) and trace fossils (Lucas et al., 2013). Moreover, most Palaeozoic scorpions are known from Europe and North America.

Very few fossil scorpions have been reported from China. Until now, only two valid species have been described including *Sinoscorpius shandongensis* Hong (1983) from the Miocene of Shandong Province and *Hubeiscorpio gracilitarsis* Walossek et al. (1990) from the Devonian of Hubei Province. Here we report a new specimen from the Lower Permian of Wuda, Inner Mongolia, China. This new specimen is the third Permian scorpion in the world and the third fossil scorpion in China.

Our present species of *Eoscopius* was living in the coal swamp, particularly in an area of *Coradites* dominated forest in the southern part of the basin. The reconstruction of the vegetation has been conducted by Opluštil et al., n.d.. The forest here is a two-storeys forest with *Cordaites* as the tallest trees that covered over 50 % of the quatitatively documented area. Two species of marattialean tree ferns with a single plant Cycadophyte *Pterophyllum* formed the lower canopy, covering over 20 % of the area. Herbaceous groundcover consisted of sphenopsid *Sphenophyllum oblongifolium*, and small ferns mostly with sphenopteroid type of foliage, covering 7 % of the area, representing the most diverse story of the peat-forming forest.

2. Material and methods

The new specimen reported here was collected from the volcanic tuff bed between Coal No. 6 and No. 7 in Wuda Coalfield, Inner Mongolia, China and is presently held in the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences as specimen no.LS01. The tuff bed belongs to the uppermost part of Taiyuan Formation. Unpublished isotopic dating indicates the tuff bed to be Asselian in age (Wang et al., 2014). Details of the geological setting refer to Pfefferkorn and Wang (2007). The specimen was photographed and scanned using a Nikon D300S camera, a LEO 1530VP scanning electron microscope and a Zeiss Stereo Discovery V16 microscope. The line drawings were finalized using photographs and image-editing softwares (CorelDRAW X7 and Adobe Photoshop CS6). The terminology follows Kjellesvig-Waering (1986) and Dunlop et al. (2008).

Abbreviations used in the drawings are: me, median eyes; on, ocellar node; ca, cephalic area; ta, thoracic area (Fig. 1).

* Corresponding author at: State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology and Center for Excellence in Life and Paleoenvironment, Chinese Academy of Sciences, 39 East Beijing Road, Nanjing, 210008, China.
E-mail address: xjlei@nigpas.ac.cn (X. Lei).

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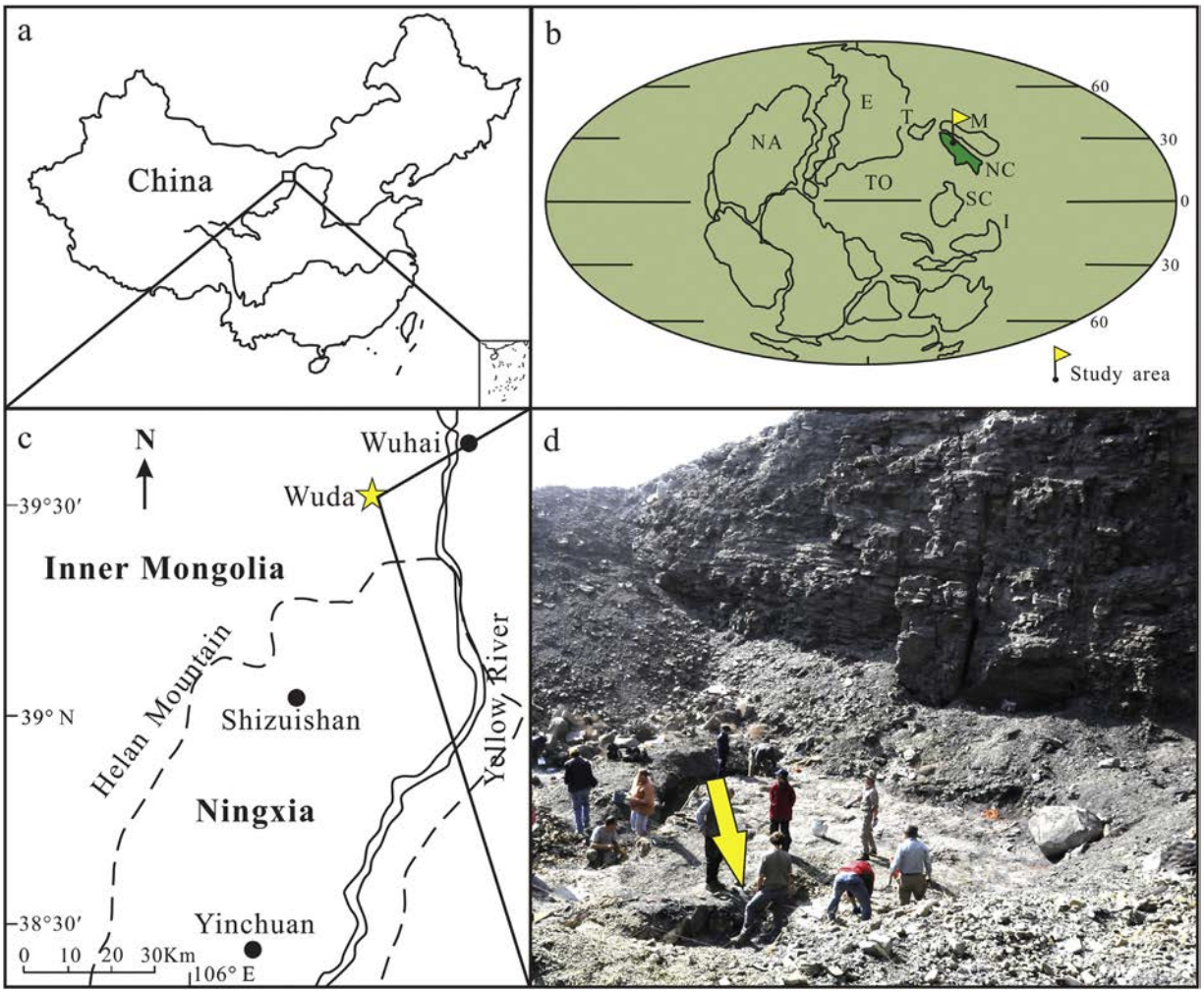

Fig. 1. *Eoscorpius* sp., NIGP172215-b, a, photograph of part of the postbdomen; b, interpretation of part of the postabdomen. Scale bars =5 mm.

3. Systematic palaeontology

Order Scorpiones Koch (1851)
Family Eoscorpiidae Scudder (1884)
Genus *Eoscorpius* Meek and Worthen (1868)
Eoscorpius sp.

3.1. Morphological description

The specimen, consisting of part and counterpart, shows most of the postabdominal tergites with some parts covered with well-preserved cuticle. When collected, it was cracked into several parts: (i) part of the preabdomen (from carapace to 4th tergite, Fig. 2), (ii) part of the postabdomen (from 4th to 9th tergites, Fig. 3), (iii) the counterpart of the body (from 3rd tergite to telson, Fig. 4), (iv) the preanal segment and the telson (Fig. 5), (v) a segment of one walking leg (Fig. 6) and (vi) a segment of the 4th walking leg (Fig. 7).

The anterior margin of the carapace is rounded with a small triangular prominence, but other body parts overlap the lateral margin so it is hard to see the whole shape of the carapace there is a prominent marginal rim along at least the anterior side. The elevated and lacrimiform, large ocellar node is located nearly behind the anterior margin. An inverted V-shaped ridge between the two median eyes separates them. The left median eye is large and elliptical. A Y-shaped sulcus surrounds the ocellar node dividing the carapace into two elevated cephalic areas in the centre and two less-pronounced thoracic areas laterally. The thoracic cheeks are smaller than the cephalic areas and not as inflated as the cephalic cheeks. Small and round concave pits are irregularly distributed. The lateral eyes are unobservable but may be present.

There are some cuticle scraps in front of the carapace and their boundaries cannot be distinguished. They may belong to the body parts of the chelicerae and pedipalp.

The chelicerae are large and protrude beyond the margin of the carapace. The specimen shows three podomeres of the right chela. The chela is curved. The fingers are large and slender (each should have two large teeth although no teeth have been observed). The rim of the hand is ornamented with pustules.

The pedipalp is long and relatively stout. With the rims preserved, the trochanter and the femur are stout and coarse on the surface, and the femur is ornamented with several distinct carinae. The hand is wide and short. The fingers are long, partly covered by the trochanter of the pedipalp, and so are difficult to distinguish. The free finger shows the small denticles with blunt tops (Fig. 8a). Several large setae are present on the middle part of the free finger (Fig. 8b) and small setae occur on the rim (Fig. 8c).

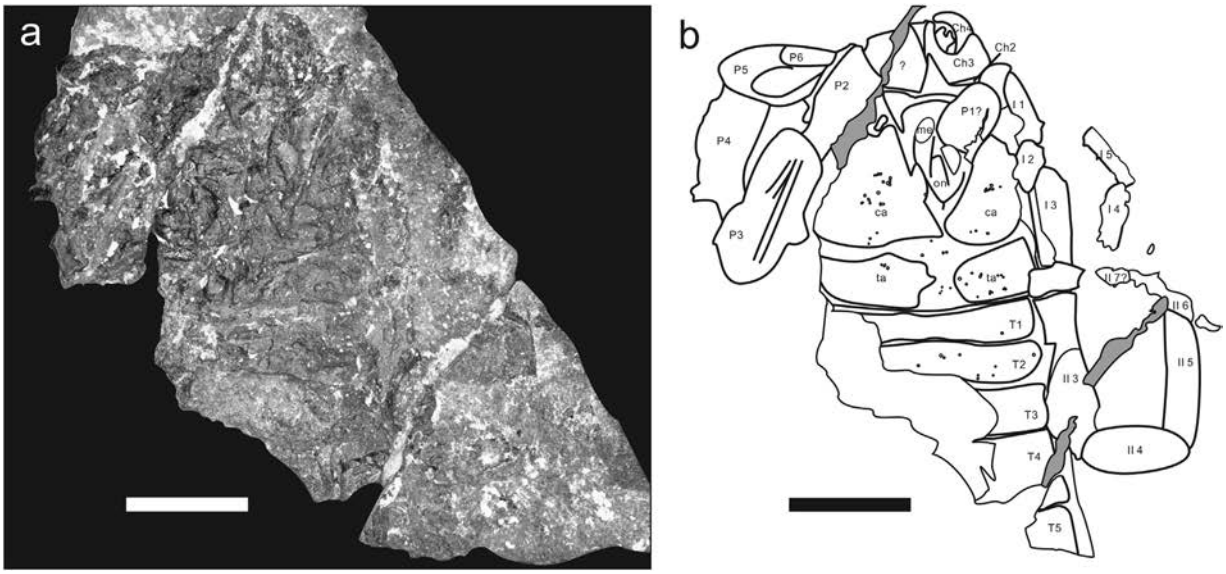

Fig. 2. *Eoscorpius* sp., NIGP172215-c, a, photograph of the counterpart of the body; b, interpretation of the postabdomen. Scale bars =10 mm.

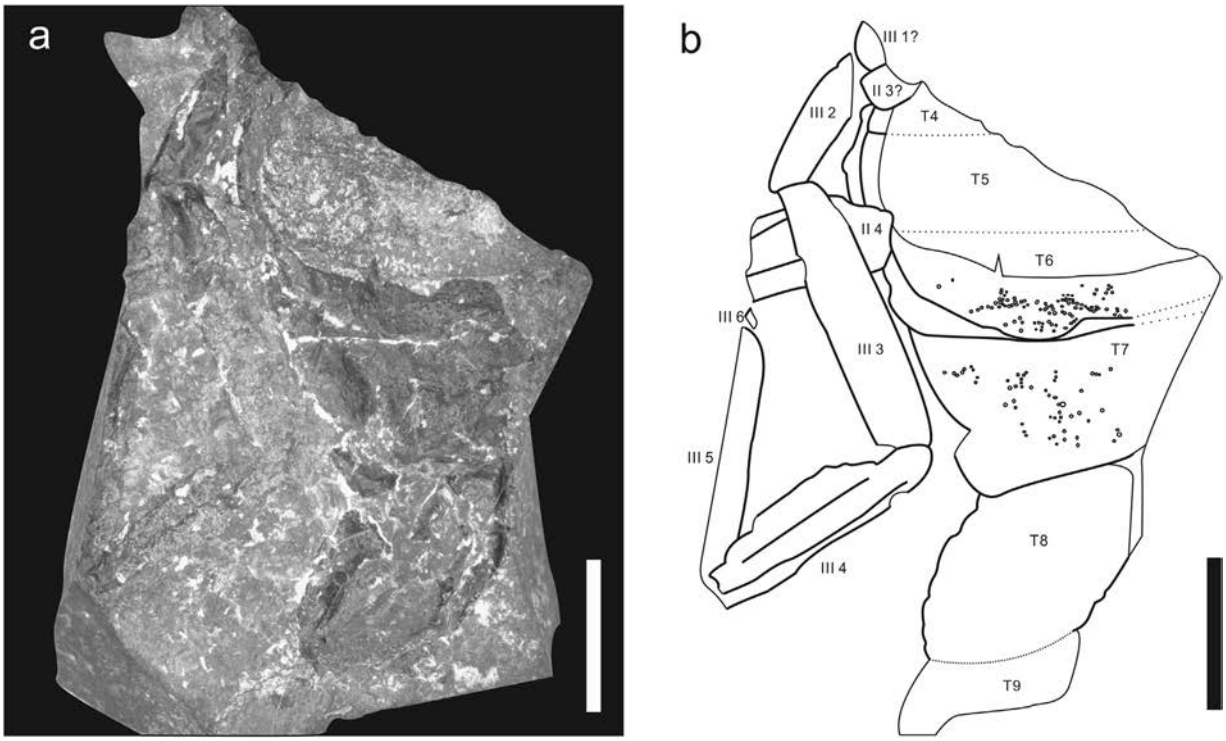

Fig. 3. *Eoscorpius* sp., NIGP172215-d, a, photograph of the preanal segment and the telson; b, interpretation of the preanal segment and the telson. Scale bars =1 mm.

The walking legs are preserved in part.

The first right walking leg shows five joints (coxa, trochanter, femur, patella and tibia). The coxa is rectangular with a round margin. The trochanter is short and much smaller than the other joints. The femur is long and stout. The patella is preserved distally, but is longer than the trochanter. The tibia is slim and long.

The second right walking leg shows at least four joints (femur, patella, tibia and basitarsus), while the left one displays six (coxa, trochanter, femur, patella, tibia and anterior part of the basitarsus). The coxa is long and stout. The trochanter is slim and short. The femur is rectangular and stouter than other joints and it should be the longest segment judging from the left leg. The patella is inflated, and much slimmer and a little shorter than the femur. The tibia is rectangular, narrower and shorter than the patella. The tarsus may be present but is hard to distinguish.

The third left walking leg shows six joints (coxa, trochanter, femur, patella, tibia and anterior part of the basitarsus). The

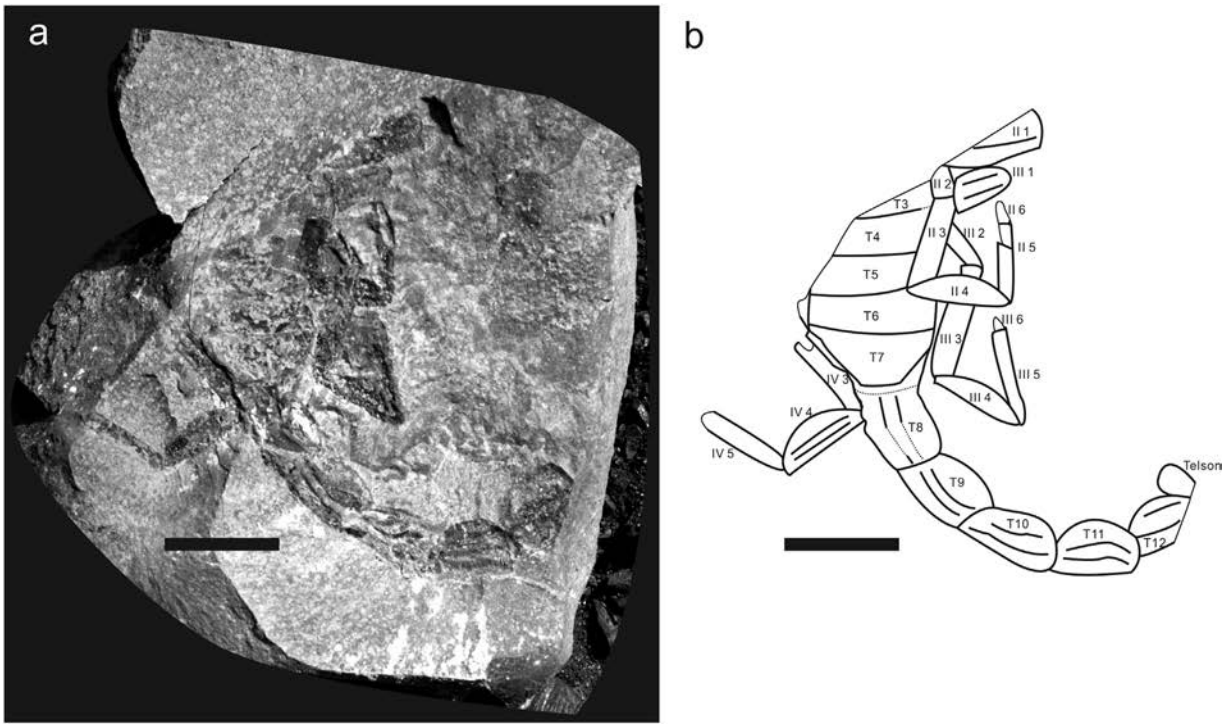

Fig. 4. *Eoscorpius* sp., NIGP172215-e, a, photograph of the segment of one of the walking legs. Scale bars =1 mm.

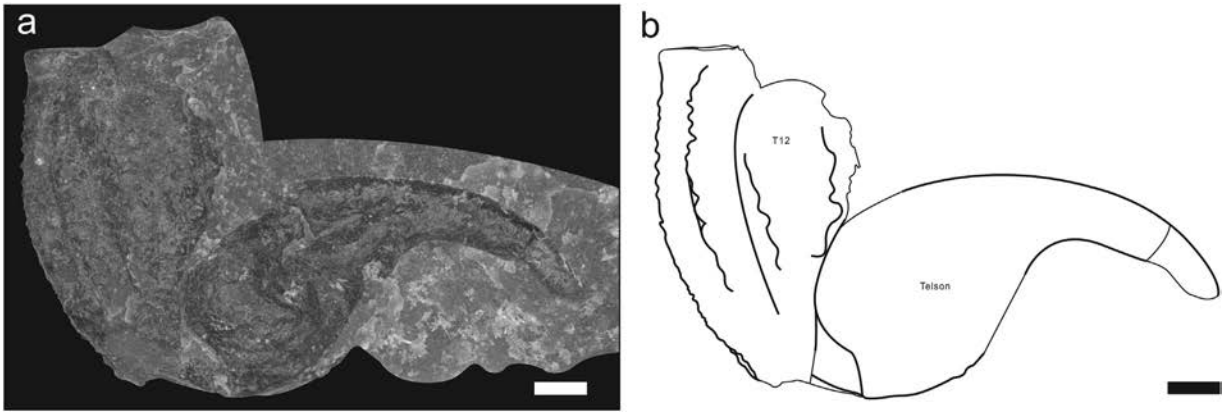

Fig. 5. *Eoscorpius* sp., NIGP172215-f, a, photograph of the single segment of the 4th walking leg. Scale bars =2 mm.

coxa is long, stout and rectangular with a round margin. The trochanter is rectangular also with a round margin, narrower than the coxa and femur, but wider than the other segments, and it is the shortest of all the segments preserved. The femur is rectangular and the longest segment. The patella is inflated, slimmer and a little shorter than the femur. The tibia is rod-like, and much narrower than the patella but may be not shorter than the patella. The basitarsus is much slimmer than the tibia.

The fourth right walking leg shows three joints (femur, patella and tibia) while the left one displays six (coxa, trochanter, femur, patella, tibia and a little anterior part of the basitarsus). The fourth resembles the third walking leg in shape and size.

Long ridges can be observed on the coxa of the second and third left walking legs and the patella of the fourth right walking leg. The base of the spurs can be seen at the distal end of the second left walking leg's tibia (Fig. 8d). Many setae are present on the leg segments (podomeres). Many round trichopores are present on part of the 4th walking leg (Fig. 9a,b).

All tergites are preserved but the first to fifth ones are damaged or covered laterally. The short, transverse marginal rim is visible in the first to third segments. The length of the preabdominal tergites

Fig. 6. Details of *Eoscorpius* sp. under Zeiss Stereo Discovery V16 microscope. a, the denticles on the free finger of the pedipalp; b, large setae on the middle part of the free finger of the pedipalp, arrowheads show the positions of the setae; c, small setae on the rim of the free finger of the pedipalp; d, the bottom of the spurs on the distal end of the tibia of the 2nd walking leg, arrowheads show the positions of the areas of observation of each photo. Scale bars a, b, d, e =0.5 mm; c =0.1 mm.

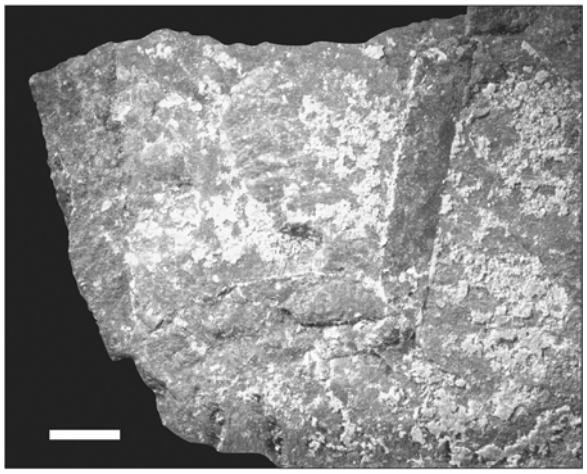

Fig. 7. SEM images of *Eoscorpius* sp. a, trichopores on the femur of the 4th walking leg, arrowheads show the positions of the trichopores; b, detail of one trichopore; c, small setae on chela; d, pustules on the 6th tergite; e, details of one pustule; f, detail of the cuticle of 6th tergite. Scale bars a, c, d =100 μm; b =10 μm; e =20 μm; f =20 μm.

increases posteriorly. The width increases progressively from the first segment to the fourth, and decreases from the fifth to the seventh. Both the length and width of the postabdominal tergites decreases progressively. Each postabdominal tergite is ornamented with pustules and two ridges. The telson shows a long, stout and curved aculeus and a bulbous vesicle.

The cuticle of the specimen is preserved very well with fine detail under a LEO scanning electron microscope (Fig. 9c–f). The pustules decorating the scorpion are round in shape with ridges resembling dumplings. The surface of the cuticle is made up of dense polygonal cells with a protruding boundary.

3.2. Remarks

The specimen, only exhibiting the dorsal side, has a carapace with a lacrimiform ocellar node behind the anterior margin and a Y-shaped sulcus dividing the carapace. These characteristics are shared by the families Eoscorpiidae Scudder (1884) and Scoloposcorpionidae Kjellesvig-Waering (1986). Eoscorpiidae is distinguished mainly from Scoloposcorpionidae by the existence of the lateral eyes (Kjellesvig-Waering, 1986). Unfortunately, this character is invisible in our new specimen because the lateral part of the specimen is not preserved.

The family Scoloposcorpionidae comprises two genera, *Benniescorpio* Wills (1960) and *Scoloposcorpio* Kjellesvig-Waering (1986), each with only one species, *Benniescorpio tuberculatus* Peach (1883) and *Scoloposcorpio cramondensis* Kjellesvig-Waering (1986). Comparing the new specimen with *Benniescorpio tuberculatus* and *Scoloposcorpio cramondensis*, neither of the scoloposcorpionids have the inverted V-shaped ridge between the two median eyes. Thus the new specimen doesn't belong to the family Scoloposcorpionidae, but belongs to the family Eoscorpiidae, some of which have the same feature.The family Eoscorpiidae comprises three genera: *Eoscorpius* Meek and Worthen (1868), *Eskiscorpio* Kjellesvig-Waering (1986), and *Trachyscorpio* Kjellesvig-Waering (1986). The specimen is different from *Eskiscorpio* by the much wider cephalic areas (Kjellesvig-Waering, 1986), and from *Trachyscorpio* mainly due to the larger middle eyes and no observable lateral eyes in front of the middle eyes (Kjellesvig-Waering, 1986). The new specimen agrees with the features seen in *Eoscorpius* so may belong to this genus.

The genus *Eoscorpius* has seven species: *Eoscorpius bornaensis* Sterzel (1918), *Eoscorpius carbonarius* Meek and Worthen (1868), *Eoscorpius casei* Kjellesvig-Waering (1986), *Eoscorpius distinctus* Petrunkevitch (1949), *Eoscorpius mucronatus* Kjellesvig-Waering (1986), *Eoscorpius pulcher* Petrunkevitch (1949) and *Eoscorpius sparthensis* Baldwin and Sutcliffe (1904).

The new specimen has relatively stout pedipalps, differentiating it from *Eoscorpius carbonarius* which has long and slim pedipalps. Also, *Eoscorpius carbonarius* doesn't have the inverted V-shaped ridge between the two median eyes which the new specimen has. *Eoscorpius bornaensis* and *Eoscorpius casei* are not preserved in dorsal view, so it is not possible to compare it with the new specimen. The new specimen differs from *Eoscorpius distinctus* mainly in having the inverted V-shaped ridge between the two median eyes. Also, the pustules of *Eoscorpius distinctus* surmount the ridges and follow the contours of the Y-shaped sulcus, while the pustules of the new specimen are distributed irregularly. *Eoscorpius mucronatus* has both cephalic and thoracic cheeks prominently displayed, but the new specimens has the thoracic cheeks not so inflated as the cephalic cheeks. Also, *Eoscorpius mucronatus* doesn't have the inverted V-shaped ridge between the two median eyes. The new specimen differs from *Eoscorpius pulcher* mainly in having the inverted V-shaped ridge between the two median eyes. *Eoscorpius pulcher* also has a longer telson than the new specimen. The new specimen differs from *Eoscorpius sparthensis* in the position of the new specimen's ocellar node located a little more posteriorly than in *Eoscorpius sparthensis* and the 7th tergite of the new one is slightly longer.

For all these reasons, the new specimen belongs to the genus *Eoscorpius*, but it is different from other species of this genus and some characteristics are currently not observable so we assign the new specimen to *Eoscorpius* sp.

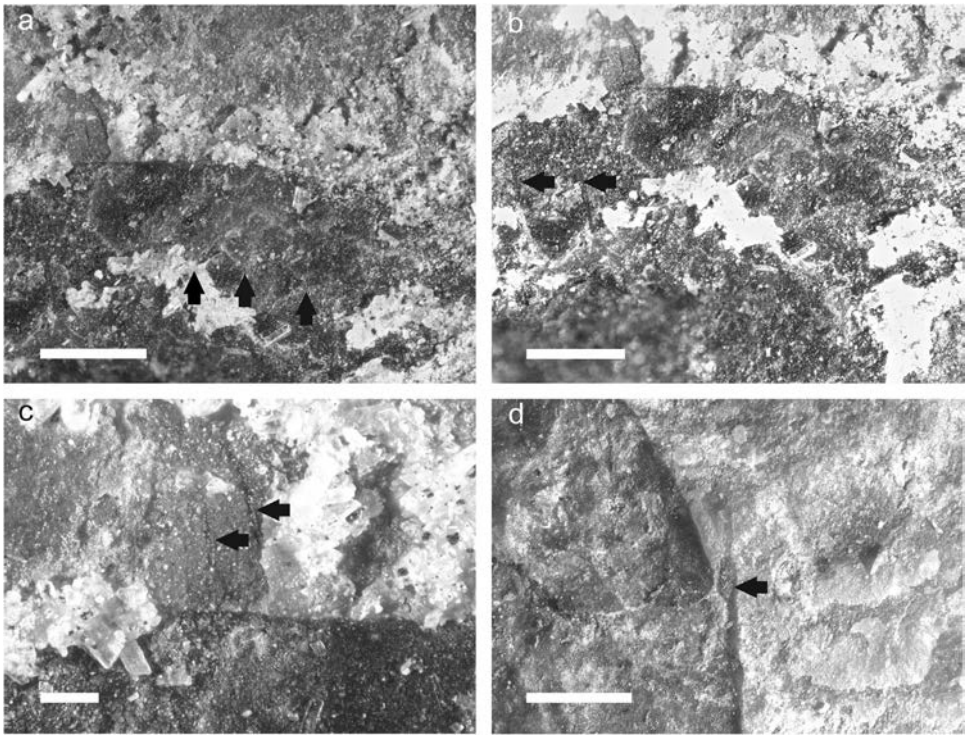

Fig. 8. The location of the study area. a, the position of the study area in China; b, the palaeogeographic position of the study area in the Permian Period; c, the position of Wuda; d, the outcrop of the scorpion-bearing beds in the section.

4. Discussion

Jeram (1994a, b) suggested that a long preanal segment (the 12th tergites) is an important distinctive feature between Mesoscorpionina and Neoscorpionina. Although there are many specimens of *Eoscorpius*, the absence of the 12th tergite is generally the case. The only specimen that has a complete preabdomen is the one described by Kjellesvig-Waering in 1986 (Kjellesvig-Waering, 1986, text-fig. 77) of which the preanal is not elongated. Dunlop et al. (2008) treated it with uncertainty. Our new specimen has the complete telson and its preanal segment is not elongated, like the specimen of *Eoscorpius pulcher* reported by Kjellesvig-Waering (1986).

McCoy and Brandt (2009) put forward a protocol for the distinction between carcasses and moults of fossil scorpions. According to their criteria, when a fossil scorpion is a dead body, it will show a high likelihood of retracted chelicerae, straight body line (in dorsal view) with the metasoma extended straight back, pedipalps pulled in towards the prosoma, and walking legs folded against the body. On the contrary, if the fossil scorpion is a moult, it often has extended chelicerae, curved body line and curved metasoma, pedipalps pulled well back from the prosoma in an extended position, and splayed walking legs. The new specimen meets three characteristics of the moults except the condition of the pedipalps. The new specimen is likely a moult.

In the Wuda tuff bed, the fossil plants in the lower tuff layers contain the ground cover, fragments dropped from the canopy and understory. They preserved mingling and badly overlapped that they were difficult to be identified. However, the middle tuff layers show more complete fossil plants from the canopy and understory. Individual fossils were much more distinct and discrete (Zhou et al., n.d.). The preservation of the fossil scorpion was found in the middle tuff layers, and it may be a moult. So it suggests that this animal could live on a high part of the tree and ecdysis could also happen there.

In contrast to the plant fossils collected ubiquitously, animal fossils are rarely found in the tuff bed, which may due to the difficult identifications of the litter layer. The present scorpion represents the first known animal fossil living in "vegetational Pompeii" forest. However, as we know that scorpions were probably predators in ancient times (Dunlop et al., 2016), it can be easily deduced that smaller herbivores as the prey of scorpions were certainly existed in this swampy forests. This could also be supported by the diverse insect-mediated damages found on the plant fossils (Feng et al., n.d.).

The genus *Eoscorpius* was widely distributed in. England, France, Germany, Canada and the USA in the Carboniferous (Meek and Worthen, 1868; Baldwin and Sutcliffe, 1904; Petrunkevitch, 1913; Sterzel, 1918; Petrunkevitch, 1949; Kjellesvig-Waering, 1986; Dunlop et al., 2008; Poschmann et al., 2016). Kjellesvig-Waering thought that all Palaeozoic scorpions were aquatic (Kjellesvig-Waering, 1986). However, there is cumulative evidence implying that the late Palaeozoic scorpions were terrestrial (Poschmann et al., 2016). This new specimen implies the continuation of *Eoscorpius* in Asia just after the Carboniferous. Scorpions in North China may have a similar ecological feature as their relatives in Europe and North America at the time of the Early Permian.

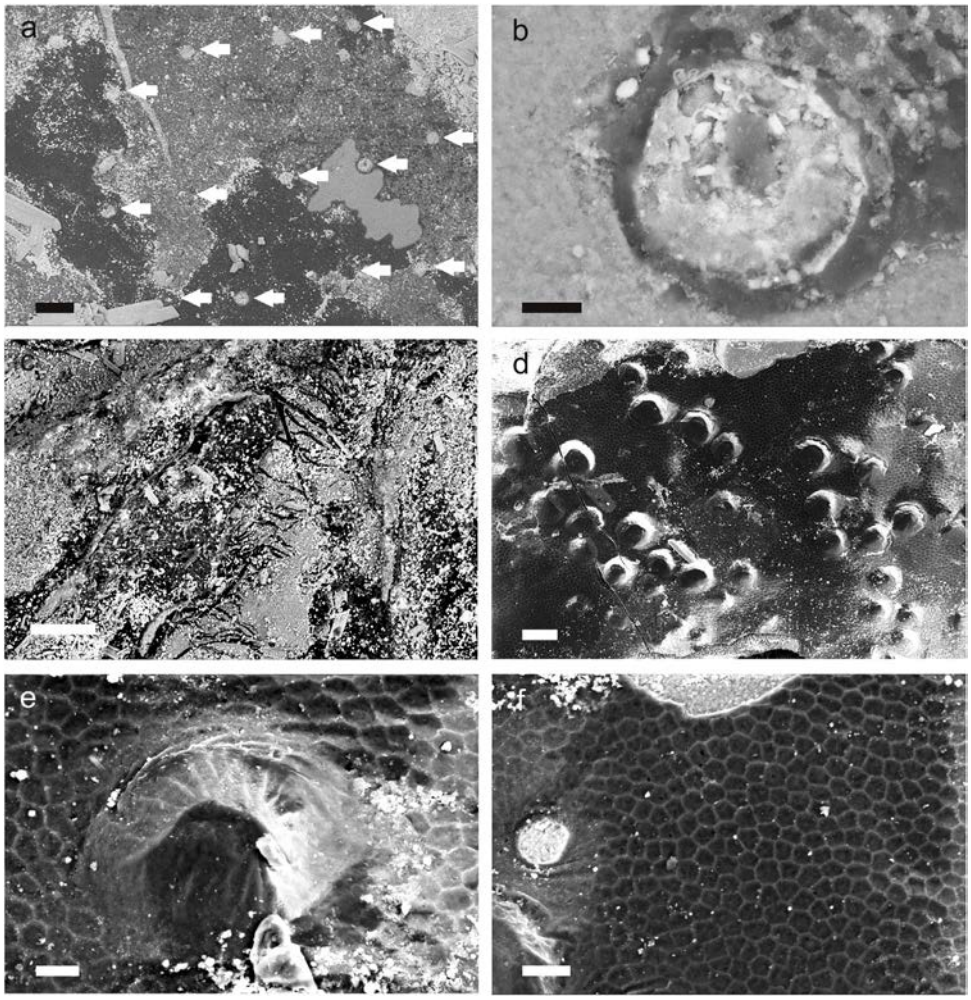

Fig. 9. *Eoscorpius* sp., NIGP172215-a, a, photograph of part of the preabdomen; b, interpretation of part of the preabdomen. Scale bars =5 mm.

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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