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A new Late Triassic tetrapod locality from North China

SHI Yu-Tai[1,2] CHEN Jian-Ye[1] LIU Jun[1,2*]

(1 *Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences*, *Institute of Vertebrate Paleontology and Paleoanthropology*, *Chinese Academy of Sciences* Beijing 100044)
(2 *College of Earth and Planetary Sciences*, *University of Chinese Academy of Sciences* Beijing 100049)
* Corresponding author: liujun@ivpp.ac.cn

Abstract No definite tetrapod body fossil is known from the Late Triassic of North China. Here we report new tetrapod remains from the Upper Triassic Tanzhuang Formation of Jiyuan, Henan Province. Most of the specimens can be referred to the temnospondyls, and show affinity with *Mastodonsaurus*. Previously, *Mastodonsaurus* is only know from Europe. So that, this finding indicates that a clade including *Mastodonsaurus* and its close relatives had a wide distribution from Europe to East Asia during the Late Triassic. A possible pelvis indicates the presence of another tetrapod group. This discovery fills a tetrapod body record gap in Chinese Late Triassic.

Key words Jiyuan, Henan; Late Triassic; Tanzhuang Formation; tetrapod; temnospondyls; *Mastodonsaurus*

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1 Introduction

In the Late Triassic of China, terrestrial tetrapod records are rare (Li et al., 2008; Liu, 2018). Some tetrapod bones were reported from the Late Triassic but none of them can be certain. Some fossils from the lower part of the Xiaoquangou Group of Junggar Basin were named as *Bogdania fragmenta* (Metoposauridae) and *Fukangolepis barbaros* (Aetosauridae), and were supposed to be Late Triassic in age (Young, 1978). Later, this horizon was recognized as the lower part of the Huangshanjie Formation (Zhao, 1980) or upper part of the Karamay Formation (Cheng, 1986). Then *Bogdania fragmenta* was assigned to the capitosauroids (Lucas and Hunt, 1993a), and *F. barbaros* was shown to represent dicynodont fragments (Lucas and Hunt, 1993b). Because of these assignments, no evidence supports this horizon to be Late Triassic so far (Lucas, 2001), although this possibility cannot be excluded. *Yonghesuchus sangbiensis* from the Tongchuan Formation was initially viewed as Carnian (Liu et al., 2001; Wu et al., 2001), but its age was revised to the Ladinian based on the U-Pb geochronologic results (Liu et al., 2018). Fossil footprints show that tetrapods should have thrived in the Late Triassic of Sichuan. These footprints were probably from the Rhaetian, and trackmakers could be dinosaurs and therapsids (Xing et al., 2013, 2014).

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In this paper, we report a new tetrapod locality from Jiyuan, Henan Province, North China. Together with fossil plants, this site bears scattered bones and teeth, most of which belong to the Stereospondyli. Stereospondyli became the major group of temnospondyls during the Triassic, this group was diverse in the Early and Middle Triassic, declined in the Late Triassic, and went extinct after the Triassic except for three (super)families: Brachyopidae, Chigutisauridae and Trematosauroidea (Schoch and Milner, 2000; Shishkin, 2000; Maisch et al., 2004). In the Triassic of China, only capitosauroid (mastodonsauroid) temnospondyls are confidently known (Liu and Wang, 2005; Li et al., 2008; Liu, 2016), and the latest occurrence of Triassic stereospondyls prior to this study was from the Tongchuan Formation (Wu et al., 2022).

Institutional abbreviations IVPP, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing, China; SGU, University of Saratov, now housed at Borissiak Paleontological Institute, Russian Academy of Sciences, Russia; ZPAL, Institute of Paleobiology, Polish Academy of Sciences, Warsaw, Poland.

2 Geological setting

The traditional Yanchang Group is divided into the Youfangzhuang, Chunshuyao, and Tanzhuang formations from bottom to top in western Henan. Tanzhuang Formation is roughly correlated to the Wayaopu Formation or Hujiachun Formation of Ordos Basin, and its base is regarded as Norian or Carnian in age based on comprehensive stratigraphic correlation (Yang et al., 2000; Tong et al., 2021). Fossils were collected from a small village, Shigou of Jiyuan, Henan Province. In this locality, Tanzhuang Formation is dominated by yellow thick-layered calcareous siltstone, and the lowest horizon is well exposed.

Fossil plants and bones are scattered on the same layer. The bones include ribs of small tetrapods, teeth (temnospondyl?), vertebrae, interclavicle and some unidentifiable elements. These fossils might be deposited within one flood.

3 Systematic paleontology

Temnospondyli Zittel, 1887-1890

Stereospondyli Zittel, 1887-1890

Capitosauroidea Säve-Söderbergh, 1935 sensu Schoch, 2013

Material IVPP V31168, interclavicle; V31169, ?rib; V31170, V31171, V31172, three intercentra.

Horizon Base of the Tanzhuang Formation; Late Triassic.

Description An interclavicle (IVPP V31168) is the most informative bone from the site (Fig. 1D, E). Its anterior process is lost but the other portions are almost complete. The preserved length is ~19 cm, and the width is ~18 cm. The articular facets for the clavicles are only partially preserved on the right. It is a concave area with a convex medial margin. The

posterolateral edges are concave. The posterior process distinctly narrows in width posteriorly.

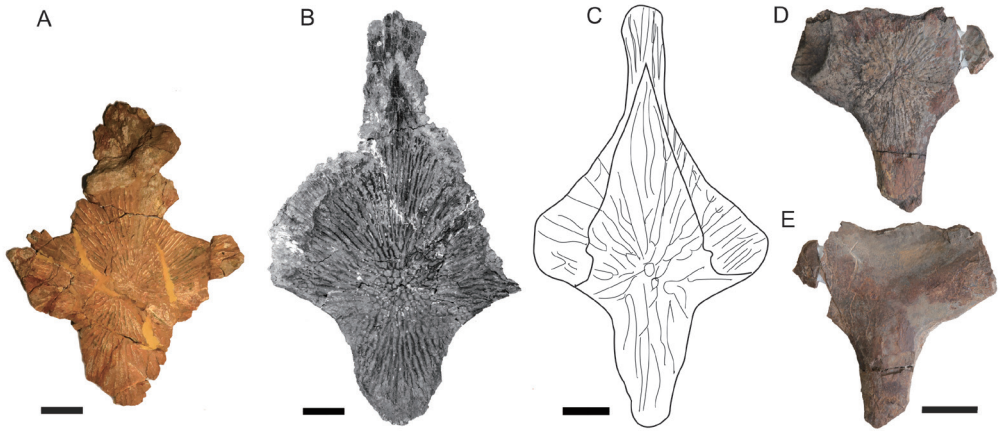

Fig. 1 IVPP V31168 and similar capitosauroid interclavicles
A. *Eryosuchus* (SGU 104/3090-4); B. *Cyclotosaurus intermedius* (ZPAL Ab III 887/1); C. *Mastodonsaurus giganteus* (redrawing from Schoch, 1999); D, E. IVPP V31168
A–D. ventral view; E. dorsal view. Scale bars equal 5 cm

The ornament is well developed on the ventral surface. The sculpture includes radially ridges and grooves from the ossification center (which lies on the midline intersecting with a line slightly anterior to the level of the posterior margin of the articular facets for clavicles). Some roughened ridges are distributed on the articular facet.

The dorsal surface is smooth. The lateral wings are strengthened by mediolaterally directed, paired trabeculae clavicularis (sensu Bystrow and Efremov, 1940), which form a concave area anteriorly and unite in the middle with a single anteroposteriorly directed trabecula sternalis at eminentia centralis, forming a Y-shaped structure. The eminentia centralis is a flat area.

An incomplete rod-like bone (IVPP V31169) is ~12 cm in length. It is here identified as part of a rib (Fig. 2). It is slender and long, unlike any limb bones of large temnospondyls such as *Mastodonsaurus* and *Metoposaurus* (Schoch, 1999; Sulej, 2007). One side is oval in cross-section, and the other side is nearly triangular in cross-section. On the triangular side, a square broken surface indicates the bone should be much thicker here. Close to this side, dorsal margin is distinctly convex. Based on the rib morphology of *Mastodonsaurus* and *Metoposaurus* (Schoch, 1999; Sulej, 2007), the dorsal margin of the tuberculum cannot be convex, so the oval side is identified as the proximal side. The convex margin should be part of the uncinate process. A shallow fossa lies between the shaft and uncinate process. On the posterior surface, furrow and ridges are distributed along the shaft-direction.

The intercentra (IVPP V31170–V31172) are separated from the neural arches. They have nearly complete disks that are dorsally slightly narrow. The top is roughened and slightly worn. On the anterior right side of V31172, partial neural arch is preserved on the facies pleurocentralis (Fig. 3C). The centra are weakly amphicoelous. The anterior surface

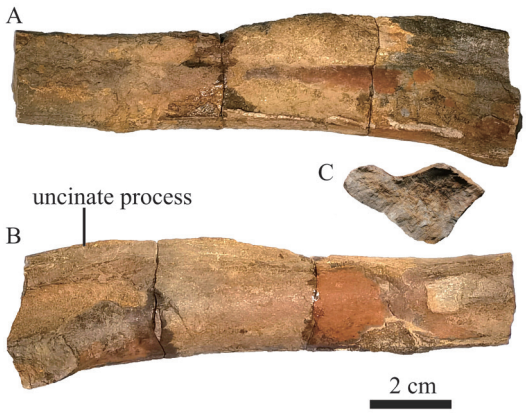

Fig. 2 An incomplete stereospondyls ?rib from Jiyuan (IVPP V31169) in posterior (A), anterior (B) and distal (C) views

is smaller than the posterior surface. Some pits are observed on the central area of the disks surfaces (Fig. 3). The chorda incisure, foramen for the chorda rudiment, lies near the top on both the anterior and posterior surfaces (Fig. 3A).

The latera is smooth and distinctly concave, ending well above the parapophysis. The parapophyses rise from the upper half of the intercentrum, and lie close to the posterior rim of the latera. It indicates that the three intercentra should be anterior thoracic based on the morphology of *Mastodonsaurus giganteus* (Schoch, 1999).

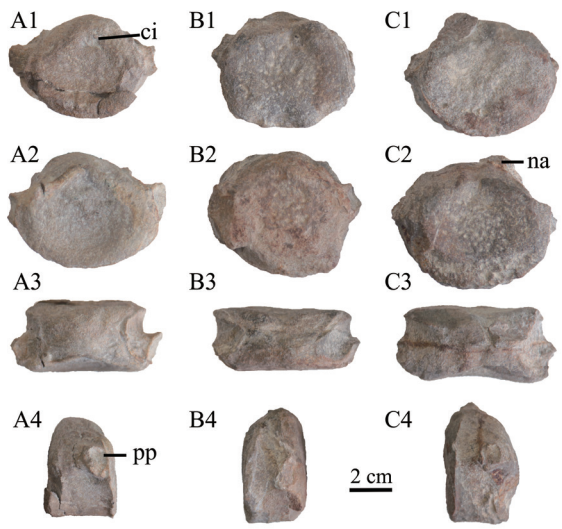

Fig. 3 Photos of three stereospondyl intercentra from Jiyuan in anterior (A1, B1, C1), posterior (A2, B2, C2), dorsal (A3, B3, C3) and left lateral (A4, B4, C4) views
A. IVPP V31170; B. V31171; C. V31172
Abbreviations: ci. chorda incisure; na. neural arch; pp. parapophysis

Tetrapoda indet.

Material IVPP V31173, a ?pelvis.

Description This is a large, flat element, and is tentatively identified as a pelvis based on the rounded hole in the middle (Fig. 4). One side is nearly complete and fan-shaped; another side is a posteriorly inclined slab with incomplete margins. No clear suture can be traced. In stereospondyls, the dorsal component of the ilium is a posterodorsally inclined rod (Schoch and Milner, 2000). If the incomplete bone is ilium, the puboischia seems fused too. This is quite different from Triassic temnospondyls, in which the ilium, ischium and

pubis are separate elements (Warren and Snell, 1991). Under this condition, the posterodorsal margin of the ischium is directed ventrally, rather than nearly horizontal as most tetrapods (Romer, 1956). If the expanded portion is the ilium, the pubic portion is almost absent, and the ischium is partially preserved. In some Triassic stereospondyls such as *Benthosuchus* and *Parotosaurus*, the iliac dorsal blade expands dorsally, but the lower portion around the acetabulum is wide (Bystrow and Efremov, 1940; Howie, 1970). In this specimen, the acetabulum approaches the posterior margin, which may be due to the incomplete preservation.

The bone is rather thin, maybe related to the aquatic habitat of the animal. The expanded bone like here in the pelvis is present in some aquatic reptiles such as the ischium of *Nothosaurus* (Shang, 2006). However, its acetabulum is quite different. It is much different from temnospondyl bones, and should represent another tetrapod group.

Fig. 4 Photo of a possible pelvis in lateral view (IVPP V31173) from Jiyuan
The black line shows the outline of bone

4 Discussion and conclusion

The interclavicle is a common postcranial element in temnospondyl fossil record. It became a rhomboidal-shaped bone that is longer than wide in the Stereospondylomorpha (Witzmann and Voigt, 2015). Although the anterior portion is missing, IVPP V31168 can be diagnosed as a stereospondylomorph. In basal sterospondyls, some genera have similar shaped interclavile as V31168 such as *Lapillopsis* (Yates, 1999) and *Lydekkerina* in some degree (Watson and Hill, 1920; Pawley and Warren, 2005). However, they differ greatly in size and geological age, and V31168 cannot be referred to these clades. From Middle Triassic, large-sized stereospondylomorph temnospondyls (body size > 1m) appeared in the following clade Trematosauroidea, Brachyopoidea, Plagiosauridae, and Capitosauroidea (Maisch et al., 2004; Schoch, 2013). In Trematosauroidea, the interclavicle has a posterior process with relatively straight or slightly concave lateral margins, e.g., *Wantzosaurus* (Steyer, 2002), *Metoposaurus* (Sulej, 2007) and *Trematosaurus* (Schoch, 2019). In Brachyopoidea, the interclavicle is kite-shaped with a squared-off posterior process (Warren and Marsicano, 2000). In Plagiosauridae, the interclavicle is unique in with two posterolateral processes (Warren and Snell, 1991; Jenkins et al., 2008). IVPP V31168 is quite different from them in having a narrowing posterior

process with distinct concave lateral margins. In Capitosauroidea, the interclavicle also has a nearly triangular posterior process in most species (Watson, 1958; Steyer, 2003; Liu, 2016; Schoch, 2018), but it is similar to V31168 in some species, e.g., *Eryosuchus*, *Cyclotosaurus*, and *Mastodonsaurus* (Ochev, 1972; Schoch, 1999; Sulej and Majer, 2005).

Within *Eryosuchus*, *Cyclotosaurus* and *Mastodonsaurus*, *Eryosuchus* ranged only in the Middle Triassic, while the other two genera lived in the Late Triassic (Schoch and Milner, 2000). *Cyclotosaurus* should have lived in North China based on its distribution from Germany to Thailand (Nonsrirach et al., 2021). However, the interclavicle of *Cyclotosaurus* is different with IVPP V31168, the posterior process is distinctly narrow in V31168 as in *Mastodonsaurus*, slenderer than in *Eryosuchus* or *Cyclotosaurus* (Fig. 1).

The center of ossification of the interclavicle (as shown by the center of radiation of the ornamentation) lies slightly behind the widest part in the Capitosauridae and markedly behind the widest part in the Metoposauridae (Warren and Snell, 1991); although it is not true for *Metoposaurus* (Sulej, 2007). In fact, the center of ossification lies close to the level of the posterior margin of the facets for clavicles in the Capitosauroidea (sensus Schoch and Milner, 2000) plus *Metoposaurus*.

The morphology of the interclavicle (IVPP V31168) suggests it can be referred to *Mastodonsaurus* or its closely related taxon, so *Mastodonsaurus* or its closely related taxon existed in Henan, China during the Late Triassic. *Mastodonsaurus* were only known from Europe (Schoch and Milner, 2000), the new specimen expands their distribution to the Late Triassic of East Asia, showing that they had a wider distribution than previously known, suggesting the high adaption of this clade.

In some recent phylogenetic trees, *Eryosuchus* and *Mastodonsaurus* form a monophyletic clade, *Cyclotosaurus* may or may not closely relate to this clade (Schoch, 2013; Sidor et al., 2014; Liu, 2016); but the close relationship between *Eryosuchus* and *Mastodonsaurus* was not recovered in other trees (Schoch, 2018). The shape of the interclavicle supports a monophyletic clade including *Eryosuchus*, *Mastodonsaurus*, plus *Cyclotosaurus*, as the phylogenetic hypothesis of Liu (2016) and Sidor et al. (2014).

From this locality, IVPP V31168, V31170–V31172 represent a valid temnospondyl record, V31173 a possible strange pelvic, may not be a temnospondyl but may rather represent a different tetrapod clade. The exact taxonomic affiliation of this specimen is unclear at the moment, but may be solved with future discovery from this locality. These fossils represent first definitive Late Triassic tetrapod body records in China.

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中国北方一晚三叠世四足动物化石新地点

石雨泰[1,2] 陈建业[1] 刘 俊[1,2]

(1 中国科学院古脊椎动物与古人类研究所，中国科学院脊椎动物演化与人类起源重点实验室 北京 100044)

(2 中国科学院大学地球与行星科学学院 北京 100049)

摘要：中国北方还没有发现过确凿无疑的晚三叠世的四足动物化石。报道了河南省济源市的一个四足动物化石新地点(柿沟)。化石产自晚三叠世谭庄组。目前采集到的标本大部分可以归入离片椎类，并显示出与乳齿鲕(*Mastodonsaurus*)的高度相似性。之前，乳齿鲕只在欧洲有记录。因此这一发现表明乳齿鲕这一支系在晚三叠世曾广泛分布于欧洲与东亚地区。一块疑似腰带化石指示还有另一类四足动物共存。这一发现填补了我国晚三叠世四足动物实体化石记录的一个空白。

关键词：河南济源，晚三叠世，谭庄组，四足动物，离片椎类，乳齿鲕

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