First record of Bystrowianid Chroniosuchians
(Amphibia: Anthracosauromorpha) from the Middle Permian of China

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Abstract: Chroniosuchians are basal tetrapods owing to Anthracosauromorpha and the oldest species of chroniosuchians have been recorded in the Late Permian of Russia so far. In this study, we present evidence for their existence in the Middle Permian of China, based on well preserved diagnostic vertebrae with associated osteoderms from the Dashankou fanua in northwestern China. The finds clearly show interosseous articulation pattern between the adjacent scutes in bystrowianids. The features observed in *Yumenerpeton yangi* may warrant the close proximity or phyletic succession of the chroniosuchid and bystrowianid types of the osteoderm design.

Key words: Bystrowianidae, Chroniosuchia, osteoderms, Middle Permian, China

1 Introduction

Chroniosuchians form typical components of Upper Permian tetrapod faunas in European Russia (Golubev, 1998a, b; Golubev, 1999). They are aquatic, piscivorous non-amniotic tetrapods that superficially resemble extant varanids in body proportions (Novikov et al., 2000; Witzmann et al., 2008). They are relict group of reptilomorph amphibians (anthracosaurus) from the Middle Permian to Middle –Late Triassic, mostly known from Russia and China (Shishkin et al., 2014). Chroniosuchia have a number of apomorphies: the presence of sculptured dermal scutes, typical intercentra that possessing a unique ball-shaped or biconvex morphology (Novikov and Shishkin, 2000; Witzmann et al., 2008).

Chroniosuchia can be classified in two families: Chroniosuchidae and Bystrowianidae (Golubev, 1998a, b; Witzmann et al., 2008; Shishkin et al., 2014; Jiang Shan, 2014). As to the structure of dermal scutes, the Bystrowianidae differ from the Chroniosuchidae by their dermal scutes sutured to the neural spine, and only corresponding to the median part of chroniosuchid scute (Novikov and Shishkin, 2000; Shishkin et al., 2014). Chroniosuchids flourished in Late Permian (Golubev, 1998a, b; Golubev, 1999; Golubev, 2000; Novikov et al., 2000; Shishkin et al., 2014), while bystrowianids are only known by incomplete scutes and vertebræ from China (Young, 1979; Liu Jun et al., 2014) and Russia (Novikov and Shishkin, 2000). However, to date, the majority of bystrowianid taxa include 4 genera with 5 species in the Triassic deposits from Russia (Novikov and Shishkin, 2000) and Germany (Witzmann et al., 2008). *Madygernerpeton pustulatus* is the only known chroniosuchid from the Triassic of Kyrgyzstan (Schoch et al., 2010).

Chroniosuchian material was first reported from China by Young Zhongjian (1979). The fragmentary material from the Upper Permian Shangshizi Formation of Henan Province consists of a small armor scute and a dorsal vertebra, *Bystrowiania sinica* (Young zhongjian, 1979; Liu Jun et al., 2014). Liu Jun (2014) described two poorly preserved armor scutes from the same locality, named as *Jiyuanictectum flatum* and *Dromotectum largum*. Li Jinling and Cheng Zhengwu (1999) reported the earliest record of this group from the Middle Permian Dashankou fanua of China, including *Pharatochronis gilianensis* and *Ingentidens corridoricus*, known from an incomplete right maxilla and a large lower jaw respectively. The latter possibly belongs to Bystrowianidae (Shishkin et al., 2014). Here we describe the surprising finds of a new bystrowianid chroniosuchian, *Yumenerpeton yangi* (gen. et sp. nov.), from the same locality of Li Jinling and Cheng Zhengwu (Figs. 1 and 2). The specimens of *Yumenerpeton yangi* (gen. et sp. nov.) are well preserved and reveals many features formerly unknown for bystrowianids, prompting anatomical comparison within the group. The new taxon *Yumenerpeton yangi* resembles most closely to

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the bystrowianid *Synesches* and documents the first definitive record of bystrowianid in Middle Permian of China. Moreover, it represents one of the geologically oldest examples of a member of bystrowianid.

2 Systematic Paleontology

**Chroniosuchia** Tatarinov, 1972

**Bystrowianidae** Vjuschkov, 1957

**Bystrowianinae** Novikov and Shishkin, 2000

*Yumenepetron* gen. nov.

*Yumenepetron yangi* gen. et sp. nov.

**Etymology:** ‘Yumen’, the city where the holotype specimen was collected; yangi, honoring the late eminent Chinese vertebrate palaeontologist Yang Zhong-jian.

**Holotype:** GS–DSK–016, a nearly complete sacral vertebra with dermal scute (Fig. 3).

**Referred specimen:** GS–DSK–017, two articulated dorsal vertebrae with dermal scutes (Fig. 4).

**Type locality:** Dashankou, Yumen City, western Gansu Province, northwestern China; Upper Member of Xidagu Formation, Middle Permian.

**Diagnosis:** Large bystrowianid with combined autapomorphies: (1) large bystrowianids with osteoderms up to 80 mm wide; (2) transversally elongated osteoderms (sculptured region with the ratio of width to length ranging from 1.6 to 2); (3) prominent ventral process posteriorly behind the corresponding scute edge; (4) dermal ornament of the scutes pectinate, distinguished from all the other bystrowianids; (5) osteoderms moderately convex in cross section; and (6) the maximum width of the anterior wings over half of total width of scute.

3 Description

3.1 Vertebrae

Apart from the presence of dermal scutes, the most distinctive feature of bystrowianids is in the structure of their vertebral centrum. As in most early tetrapods, the vertebrae of bystrowianids consists of three parts: neural arch, intercentrum, and pleurocentrum. The intercentrum and pleurocentrum form the vertebral body, with the latter as the dominant element in connection with the spine of the neural arch. The pleurocentrum is typically amphicoelous, whereas the intercentrum is biconvex or spherical.

GS–DSK–016 is a nearly complete sacral vertebra articulated with its corresponding scute. The sacral vertebra is large and over the scute in length and width while the neural spine is relatively slender. Up to now, this specimen is the only available sacral vertebra known for bystrowianids. The diagnostic features of the sacral vertebra are the narrow postzygapophysis and the wide and thin costal sacral.

The pleurocentrum of GS–DSK–016 is deeply amphicoelous, round anteriorly and nearly straight ventrally caused by extrusion. There is a cylinder, fusing with the pleurocentrum. It is hard to distinguish the original shape of the cylinder. We can induce that it is the intercentrum based on its size and location. The pleurocentrum is sutured with the neural arch. On the neural arch, the articular surface of the zygapophysis slopes medially at an angle of 22° to the horizontal plane in anterior view. The zygapophyses of the neural arch are widely spaced and the prezygapophyses are obviously longer than the postzygapophyses (Fig. 3b). The neural canal is obvious between the prezygapophyses and postzygapophyses. Compared to the massive pleurocentrum, the neural spine is slender. The height of the neural spine is equal to the height of the pleurocentrum and neural arch. The neural spine is bilaterally compressed, with nearly smooth surfaces except one or two crests.

GS–DSK–017 consists of two dorsal vertebrae in tight articulation, with an intercentrum wedged between the two pleurocentra (Fig. 4). The pleurocentra are typically amphicoelous, rounded posteriorly, and weakly narrowed ventrally in lateral view. The wedged intercentrum is a much smaller element compared to the size of the pleurocentra. The prezygapophyses are oriented dorsomedially and slightly anteriorly, whereas the postzygapophyses are oriented ventrolaterally and posteriorly. There are paired deep paraneural canals on
anterior and posterior surfaces of the neural arch. The neural spine of the GS–DSK–017 is relatively short and thick. The scute is prominent for its size. The transverse processes of the vertebrae are relatively long, oriented dorsolaterally. The length of the processes is almost equal to the width of the corresponding pleurocentrum. Anatomically, the two vertebrae in GS–DSK–017 are probably from the middle portion of trunk region, as indicated by the long tranverse processes of the neural arch. Further support for this assumption is that the spine of the anterior vertebra is slightly higher than that of the posterior one.

### 3.2 Osteoderm plates

Here we adopt the terminology from Novikov and Shishkin (2000). The osteoderms known for the new taxon include one nearly complete sacral dermal scute in association with the vertebra in GS–DSK–016, and two well-preserved scutes in tight articulation with their corresponding vertebrae in GS–DSK–017.

These large scutes are transversely expanded, moderately convex in cross section. The maximum width is up to 80 mm as seen in GS–DSK–017. The maximum width is behind of anterior wings. The lateral edges of these scute displays a rounded outline in dorsal view, except the paired incisures between the anterior wings and the sculptured scutes. The sculpture type of the scutes can be assigned to the pectinate type, which is distinguished
from other all bystrowianids. The sculptured surface is composed of isolated tubercles, transverse pectens and longitudinal swollen crests only in the middle portion. There is a prominent longitudinal crest along the whole ornamented surface, separating the sculptured surface into two symmetrical portions (Fig. 5a).

In bystrowianids, the dorsal facets of the anterior portion of each wing underplate the ventral facets of the proceeding osteoderm (Novikov and Shishkin, 2000; Witzmann et al., 2008). The anterior wings are well developed and have a greater width than incisures between them, ending anteriorly in two tapering processes. The maximum width of the wings can be half of the width of the scute. They are distinguishable from the central body.
in dorsal view by their nearly smooth dorsal facets. Each wing bears one or two weakly developed longitudinal ridges for the attachment of the ligaments (Novikov and Shishkin, 2000). They locate below the sculpture surface of the scute. The accessory process is absent by original observation of the GS–DSK–016 (Fig. 5). The anterior middle portion of the GS–DSK–017 is incomplete, but the absence of accessory processes can be deduced (Fig. 6).

The posterior median articular plate is incomplete for its posterior end of GS–DSK–017 (Fig. 6a). It locates below the sculpture surface of the scute. The articular plate is narrow and protrudes beyond the caudal margin of the
ornamented central body, fusing with the ventral process anteriorly and form a shelf. The dorsal surface of the articular plate is almost smooth and convex (Figs. 5 and 6).

On the ventral side of the scute, there is a wide depression between the medial edges of the anterior wings. The depression is overlapped by the posterior articular plate of the adjacent scute. The surface of the depression prominently below the ventral surface of the scute (Fig. 6b, d). The ventral depression is semicircle in outline and is rounded posteriorly to join the ventral process. The ventral process occupies the posteromedial part of the ventral surface of the body of the scute. It is well developed, extending strongly in longitudinally and fuses with the tip of the neutral spine. The length of the ventral process is more than half of the width of the scute. The base of the process backwards is beyond the level of the ornamented osteoderm field. The anterior and posterior edges of the processes are rounded, and the ventral processes of the two scutes of GS–DSK–017 do not meet each other (Fig. 6b, d). However, the anterior edge of the ventral process reaches the posterior edge of the posterior plate of the next scute (Fig. 6b, d). Cristae obliquae is distinct and runs along almost straight line from the anterior margin of base of ventral process to a triangular elevation at the anterior margin of each wing. It is partly overlapped by the posterolateral margin of the posterior plate of the next scute. The ventral facet is a shallow and nearly semicircular facet, located laterally to the ventral process on each side. It is wide and its width is almost half of the whole scute. It is the articular facet for the anterior wing of the next scute and its ligament.

4 Comparison and Discussion

According to the shape and structural features of the scutes, three types: Bystrowiana (I), Dromotectum (II) and Axitectum (III), were recognized by Novikov and Shishkin (2000) in the evolution of axial scutes of Triassic bystrowianids. Shishkin et al. (2014) reported new materials of Triassic bystrowianids and classified all known bystrowianids in three subfamilies: Bystrowianinae, Dromotectinae and Axitectinae. The subfamily Bystrowianinae is composed of 4 genera: Bystrowiana, Synesuchus, Bystroviella and Vyushkoviana. The subfamily Bystrowianinae is characterized by transverse expansion of the scute, deep ventral depression, and well-developed anterior wings. Liu Jun et al. (2014) erected the genus Jiyuanitectum, which is closely related to Synesuchus and Bystroviella for the absence of accessory processes, and the presence of oblique crests. Liu Jun et al. (2014) estimated the scutes of Jiyuanitectum were wider than long, based on a nearly complete right side scute.

The new materials described in this paper are GS–DSK–016 and GS–DSK–017. They share a lot of features, such as transversally elongated osteoderms, prominent ventral processes posteriorly behind the corresponding scutes edge, pectinate ornament of the scutes, osteoderms moderately convex in cross section, the maximum width of the anterior wings over half of total width of scutes and so on. According to these, we can assign them to the same genus and species. Based on the oval ventral process fusing with the neural spine, paired deep paraneural canals on anterior and posterior surfaces of the neural arch, they can be assigned to Bystrowianidae. Yumenerpeton belongs to subfamily Bystrowianinae and shares synapomorphies with Synesuchus and Bystroviella for the absence of the accessory process and the transverse expansion of the scutes, deep ventral depression, well-developed anterior wings, and smooth oblique crests on the ventral surface that terminate anteriorly in the triangular elevation.

However, Yumenerpeton can be distinguished from Synesuchus and Bystroviella by the prominently convex cross-section and the sculpture of the osteoderm, the position of the ventral process. The angle between the left and right side of the scute is nearly 100°. The sculpture type of the scutes in Yumenerpeton can be assigned to the pectinate type. The base of the ventral process of Yumenerpeton backwards beyond the level of the ornamented osteoderm field. There are just two lateral crests of the posterior median articular plate can be recognized in Yumenerpeton while there are three in Synesuchus and Bystroviella.

Having scutes with convex cross section is the character of Dromotectinae and Axitectinae, and in Bytrowianinae all scutes are flat in cross-section expect for that of Bystrowiana sinica, which is slightly convex (Shishkin et al., 2014). The presence of vaulted type of scutes in Yumenerpeton and other undescribed scutes of bystrowianids in Dashankou of the same locality (original observation by Jiang Shan) suggests that this character may be shared by Bytrowianinae, Dromotectinae and Axitectinae. And the former lose this feature while the Dromotectinae-Axitectinae keep it in evolution, probably.

The sculpture type of the Middle Permian bystrowianid Yumenerpeton is pectinate while the the sculpture type of Triassic bystrowianids is pitted (Shishkin et al., 2014). Golubev (1998b) revised the Late Permian chroniosuchids from Eastern Europe and concluded that the morphological row of dermal ornament scute types in the chroniosuchids (pustular-pectinate-cristate-pitted) reflected an evolutionary trend. This inference is a good explanation for the difference between the sculpture type
of *Yumenerpeton* and that of all the other bystrowianids. On the other hand, the primitive sculpture type of *Yumenerpeton* in Middle Permian in China affirms this suggestion. The shape of scutes of *Yumenerpeton yangi* is more or less similar to that of chroniosuchids in some degree. The features observed in *Yumenerpeton yangi* may warrant the close proximity or phyletic succession of the chroniosuchid and bystrowianid types of the osteoderm design.

In conclusion, *Yumenerpeton* can be classified in the subfamily Bystrowianinae. The vaulted type of scutes presenting in *Yumenerpeton* in this study and other undescribed scutes of bystrowianids in Dashankou of the same locality (original observation by Jiang Shan) suggests that this character may share by Bytrowianinae, Dromotectinae and Axitectinae in Middle Permian or even earlier. And the former lose this feature while the Dromotectinae-Axitectinae keep it in evolution, probably. The shape of scutes of *Yumenerpeton yangi* is more or less similar to that of chroniosuchids in some degree. The features observed in *Yumenerpeton yangi* may warrant the close proximity or phyletic succession of the chroniosuchid and bystrowianid types of the osteoderm design.

**5 Conclusion**

(1) In this study, we present evidence for their existence in the Middle Permian of China, based on well preserved diagnostic vertebrae with associated osteoderms from the Dashankou fanua in northwestern China.

(2) The finds clearly show interosteoderm articulation pattern between the adjacent scutes in bystrowianids.

(3) The features observed in *Yumenerpeton yangi* may warrant the close proximity or phyletic succession of the chroniosuchid and bystrowianid types of the osteoderm design.

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