

New Material of *Zhenyuanopterus* (Pterosauria) from the Early Cretaceous Yixian Formation of Western Liaoning

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Abstract: A new partial specimen of *Zhenyuanopterus* from the Lower Cretaceous Yixian Formation of Beipiao city, Liaoning Province is described. This specimen is slightly larger than half the size of the holotype. Although it is not complete, it provides new information on *Zhenyuanopterus* both in taxonomy and ontogeny: the total number of the caudal vertebrae is 15; the forelimb is more robust than the hindlimb; the growth rate of the humerus and femur is constant, and their ratio is about 1. Compared with the holotype, the scapula and coracoid grow faster than the humerus and the femur. The scapula and coracoid may slow their growth rate after a certain ontogenetic stage. The pectoral girdle, robust forelimb and weak hindlimb of the new material (XHPM1088) together with data from the holotype of *Zhenyuanopterus* indicate that this taxon spent less time on land than in the sky or other ecological niches such as forests and cliffs.

Key words: Boreopteridae, *Zhenyuanopterus*, ontogeny

1 Introduction

Six genera belonging to Ctenochasmatoidea and four genera belonging to Boreopteridae were discovered in the Early Cretaceous Yixian Formation from western Liaoning and its surrounding areas. They are the ctenochasmatooids *Eosipterus* (Ji and Ji, 1997), *Beipiaopterus* (Lü, 2003), *Elanodactylus* (Andres and Ji, 2008), *Gegepterus* (Wang et al., 2007), *Cathayopterus* (Wang and Zhou, 2006) and *Gladocephaloideus* (Lü et al., 2012a), and the boreopterids *Boreopterus* (Lü and Ji, 2005), *Feilongus* (Wang et al., 2005), *Zhenyuanopterus* (Lü, 2010) and *Moganopterus* (Lü et al., 2012b). All of them are tooth-bearing and the ctenochasmatooids are relatively smaller than the members of Boreopteridae. *Zhenyuanopterus* Lü is a large sized and almost complete pterosaur belonging to the family Boreopteridae (Lü et al. 2006). It is mainly characterized by a low and much elongated skull with more than 160 teeth in total, the third wing phalanx, humerus and femur are equal in length, and the feet are especially small (Lü, 2010). *Zhenyuanopterus*

has a powerful front limb and a weak hindlimb. The only defect of the holotype is its incomplete tail. Herein we report a partial skeleton of *Zhenyuanopterus* collected from the Lower Cretaceous Yixian Formation in Huangbanjigou of Chaomidianzi, Shangyuan Town, Beipiao County, Liaoning Province which is the same site as the holotype (Fig. 1). Although the newly discovered material is not complete, and only a partial skeleton is preserved, it provides new information about the taxon such as the details of the complete tail, ontogenetic information such as the growth relationship of the humerus and femur, and the allometry of the pectoral girdle and limb elements.

2 Systematic Paleontology

Pterosauria Kaup, 1834

Pterodactyloidea Plieninger, 1901

Ornithocheiroidea Seeley, 1891

Boreopteridae Lü, Ji, Ji and Yuan, 2006

Boreopterinae Lü, Pu, Xu, Wu and Wei, 2012

Zhenyuanopterus Lü, 2010

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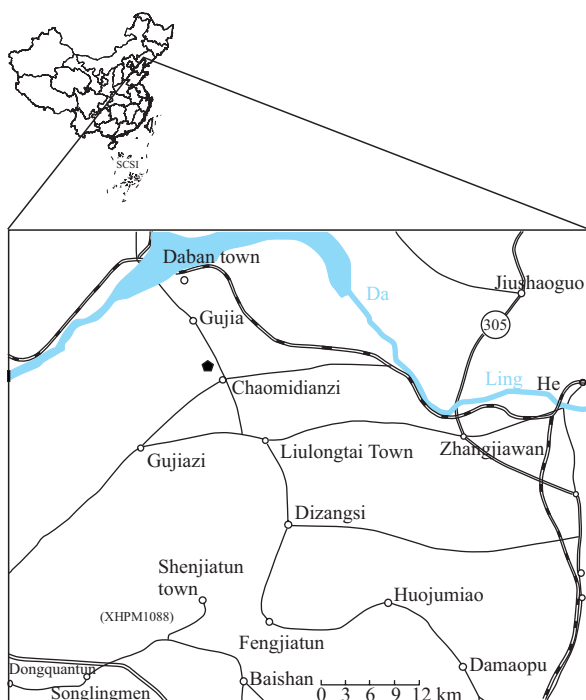


Fig. 1. Map of the fossil locality.
The solid pentagon represents the fossil site.

Zhenyuanopterus longirostris Lü, 2010

Referred specimen: A partial skeleton (XHPM1088) (Fig. 2). The specimen is housed at the Dalian Xinghai Paleontological Museum, Liaoning Province, China.

Locality and horizon: Huangbanjigou of Chaomidianzi, Shangyuan Town, Beipiao County, Liaoning Province, China; Yixian Formation.

Description

Bones of the specimen are displaced. The skull, most of the vertebral column and the wing fingers are all missing, but other parts are preserved such as the humerus, pectoral girdle, femur, tibia, ilium, tail and some dorsal ribs (Table 1). The tail is essentially complete as only a small portion of the last caudal vertebra is missing (Fig. 2). Two isolated dorsal vertebrae are distributed near the anterior dorsal rib and right coracoid. The dorsal vertebrae are not well-preserved. Two sacral vertebrae are preserved near the left tibia. Their neural spines are fused into a plate-like structure. The foramen between the sacral ribs is suboval. There are 15 caudal vertebrae. The last one is very small, with its distal portion missing. The size variation of the caudals along the tail suggests that the last one should correspond to the tip of the tail. Thus the total number of the caudal vertebrae is 15. The caudal vertebrae are exposed along their ventral surfaces. The first caudal vertebra is anteroposteriorly short but from the second caudal vertebra towards the mid-tail, the caudals become progressively elongated. The seventh caudal vertebra is the longest. Posterior to the eighth caudal vertebra, the caudals become anteroposteriorly shorter and shorter. The distal caudal vertebrae are anteroposteriorly short and rod-

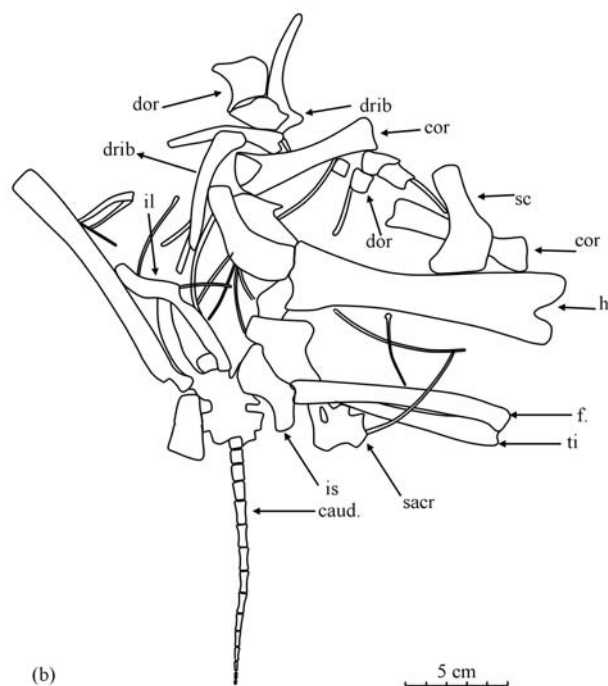


Fig. 2. Photograph of *Zhenyuanopterus* (XHPM1088) (a) and line drawings (b).

Abbreviations: caud., caudal vertebrae; cor., coracoid; dor., dorsal vertebrae; drib., dorsal ribs; f., femur; h., humerus; il., ilium; is., ischium; sacr., sacral vertebrae; sc., scapula; ti., tibia.

Table 1 Measurements of *Zhenyuanopterus* (XHPM1088) in mm

	Length	Width
Anterior dorsal rib	54.4	5.8
Total length of the tail	120	-
Caudal vertebrae (from first to seventh)	5.1;6.5;8.4;9.3;10.8;11.1;11.3	5.2;5.9;5.2;5.2;5.2;3.6;3.1
From eighth to 15th	10.6;9.3;8.2;7.7;6.7;5.0;4.0;1.9	2.7;2.7;2.1;0.9;0.81.8;1.6;1.2
Scapula	51.4	11.3 (narrowest part of the shaft); 13.5 (distal end); 26.5 (proximal end)
Coracoid	69.3	9.3 (narrowest part of the shaft); 21.4 (proximal end); 14.5 (distal end)
Humerus	127.5	19.3 (narrowest part of the shaft); 34.0 (proximal end); 34.9 (distal end)
Ilium	73.1	-
Preacetabular process	22.3	8.2
Postacetabular process	42.9	-
Ischium	30.1	17.7 (distal end)
Femur	128.0	10.5

like. In ventral view, the first to fifth caudal vertebrae are rectangular in shape, and the middle portions of the centra are not constricted. From the sixth caudal vertebra onwards, the middle of the centra are constricted. The anterior articular ends are larger than their posterior articular ends.

Both the right and left scapulae and coracoids are preserved. The scapula and coracoid are not fused. The scapula is stout and short compared with coracoid. The distal end of the scapula is slightly expanded, and its proximal end is strongly expanded. The articular portion with the coracoid is straight. In lateral view, the dorsal margin of the scapula is concave ventrally due to the strongly extended margin near the scapulocoracoid suture. Distinct rugose areas occur on lateral surface above the glenoid concavity, similar to the holotype of *Zhuangyuanopterus* (Lü, 2010). The lateral surface of the scapular shaft is smooth.

Coracoid: The coracoid is much more slender and longer than the scapula. However, the proximal ends of both coracoids are not well preserved, and their detailed structure is not clear. The coracoid is straight. The length ratio of coracoid to scapula is 135%. In lateral view, the margin of the distal end is concave, which means that the coracoid bears a distinct articular surface for the sternum. The anteroventral corner of the distal end of the coracoid bears a pronounced process.

Humerus: The right humerus is preserved. Its proximal end is damaged, and the detailed structure is not clear, but its length can be measured. The humerus is much more robust than the femur, although their lengths are almost equal. The ratio of widths at the narrowest part of the humerus compared to femur is 1.84.

Pelvic girdle: The pelvis is strongly displaced. The ilium is detached from the ischium. The ilium is shallow and elongate with a long postacetabular process. The preacetabular process is shorter than the postacetabular process. In lateral view, the dorsal margin of the ilium is concave ventrally above the acetabulum. The distal end of the preacetabular process is round. The dorsal portion of

the ilium above the acetabulum is shallow. The pubis is not preserved. The left ischium is almost complete with only a small distal portion missing. The upper portion of the ischium forms part of the acetabulum. The anterior margin of the ischium is slightly concave and its posterior margin is curved too.

Both the right and left femora are preserved. In lateral view, the shaft of the femur is convex anteriorly. The femoral head is semi-ball shaped, with a distinct neck. The rugose area on the posteromedial margin near the proximal portion of the femur may present the location of fourth trochanter. The angle between the axis of the neck and the femoral shaft is 170 degrees.

Tibia: The left tibia is well preserved, but its distal end is covered by the proximal end of the femur. Thus its length cannot be measured. The tibia is slightly more slender than the femur.

3 Discussion and Comparison

Based on the shape of the scapula and the length ratio of humerus to femur, the new material is assigned to *Zhenyuanopterus* (Lü, 2010). Except for its relatively small size, this new material is slightly larger than half the size of the holotype based on the lengths of the humerus and femur. However, the length ratios of humerus to femur in both the holotype and the new specimen are almost identical, which may indicate that the growth rate of the humerus and femur is isometric. The new specimen therefore provides important additional information on *Zhenyuanopterus*.

At present, four genera of Boreopteridae have been discovered from western Liaoning and its surrounding areas. The new specimen (XHPM1088) is different from other pterosaurs from western Liaoning and its surrounding areas. Comparisons of the new specimen are best made with boreopterid pterosaurs. However, only the skull and cervical vertebrae were found for *Moganopterus* (Lü et al., 2012b) and only the skull is represented in *Feilongus* (Wang et al., 2005; Lü et al., 2012b). There are

no other limb elements found in the two aforementioned genera so it is difficult to make comparisons with them. Most of the postcranial skeleton is preserved in both *Boreopteris* (Lü and Ji, 2005) and *Zhenyuanopterus* (Lü, 2010). The short, stout scapula and coracoid of the new specimen (XHPM1088) are almost identical in shape to those of the holotype *Zhenyuanopterus*. Comparisons of the lengths of the limb and pectoral girdle elements (scapula and coracoid) of the specimen (XHPM1088) with those of holotype *Zhenyuanopterus* show that the length ratio of the humerus to femur in both specimens is isometric, even though the new specimen (XHPM1088) is only slightly larger than half the size of the holotype. The coracoid is longer in the new specimen (XHPM1088) than in the holotype, which means that the coracoid may slow dramatically in relative growth compared to the other bones or that the size of the coracoid of the type specimen is not reliable. The wing span of the adult size of the specimen (XHPM1088) is estimated to be larger than 4 meters. The length ratio of coracoid to scapula of the new specimen (XHPM1088) is 135%, but the scapula is longer than the coracoid in the holotype, which is regarded to be a reversal of the usual ornithocheiroid condition (Unwin, 2003; Lü, 2010). As the coracoid of the holotype is not well-preserved, we use the length ratio of coracoid to scapula in the new specimen (XHPM1088) to predict the length of the coracoid in the holotype as 10.8 cm.

Therefore, the original estimated length of the coracoid (6 cm) may be wrong.

The stout pectoral girdle elements (scapula and coracoid) and the strong humerus may have functional significance. The strong pectoral girdle and humerus would offer a stout place for the attachment of musculature related to the forelimb. One of the unique characters of *Zhenyuanopterus* is that it bears small feet (Lü, 2010). The holotype and the new specimen (XHPM1088) indicate that *Zhenyuanopterus* has a robust forelimb and a weak hindlimb and so it may have spent more time in the sky than on land or in other ecological niches such as forests and cliffs (Fig. 3).

4 Conclusions

This new specimen provides new information on *Zhenyuanopterus*. For example, it is inferred from the new specimen that the forelimb is more robust than the hindlimb, and that the total number of the caudal vertebrae is 15. Another fact worth mentioning is the skeleton's ontogenetic change during growth: the scapula and coracoid begin relatively larger than the humerus and femur. The humerus and femur grow at the same rate, which means that the length ratio of the humerus to femur is constant. Both the holotype and the specimen (XHPM1088) have a robust forelimb and weak feet,



Fig. 3. The living scene of *Zhenyuanopterus* (Drawn by Zhao Chuang)

indicating that *Zhenyuanopterus* may have spent less time on land than in the sky or other ecological niches such as forests and cliffs.

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