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A New Species of *Huaxiapterus* (Pterosauria: Tapejaridae) from the Early Cretaceous of Western Liaoning, China

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Abstract: A new species of *Huaxiapterus*: *H. benxiensis* sp. nov. is erected based on the new specimen. The diagnostic characters of *Huaxiapterus benxiensis* are well-developed premaxillary crest and parietal spine, the crest and spine parallel and extending posterodorsally, and a shallow groove present on the dorsal surface of the anterior portion of the mandibular symphysis. The different skull morphologies of Chinese tapejarid pterosaurs indicate that they are much more diverse than the previous thought.

Keywords: *Huaxiapterus benxiensis*, Chinese tapejarid pterosaurs, Early Cretaceous, Western Liaoning

1 Introduction

Tapejarid pterosaurs of a clade of toothless forms were found mainly from Brazil (Kellner, 1989; 2004; Wellnhofer and Kellner, 1991; Frey et al., 2003) and China (Wang and Zhou, 2002; Li et al., 2003; Lü and Yuan, 2005; Lü et al., 2006a, b, c). At present, four species of two genera of tapejarid pterosaurs have been reported from the Jiufotang Formation of western Liaoning; these include *Sinopterus dongi* (Wang and Zhou, 2002; Lü et al., 2006b), *S. gui* (Li et al., 2003), *Huaxiapterus jii* (Lü and Yuan, 2005) and *Huaxiapterus corollatus* (Lü et al., 2006a). Herein described is a new species of *Huaxiapterus* with a soft tissue preserved near the long head crest. The specimen is briefly introduced by Lü et al. (2006c). It is different from *Huaxiapterus jii*, *Huaxiapterus corollatus* and *Sinopterus dongi* in bearing a long, slender parietal spine (crest), and a shallow groove on the dorsal surface of the mandibular symphysis; however, the skull morphology of the new specimen is more close to that of *Huaxiapterus* than to *Sinopterus*, thus a new species of *Huaxiapterus*, *H. benxiensis* sp. nov. is proposed.

2 Systematic Paleontology

Order Pterosauria Kaup, 1834
Suborder Pterodactyloidea Plieninger, 1901
Superfamily Azhdarchoidea Unwin, 1995
Family Tapejaridae Kellner, 1989
Genus *Huaxiapterus* Lü et Yuan, 2005
Species *Huaxiapterus benxiensis* sp. nov.
(Figs. 1–3)

Diagnosis: A new *Huaxiapterus* with an elongate

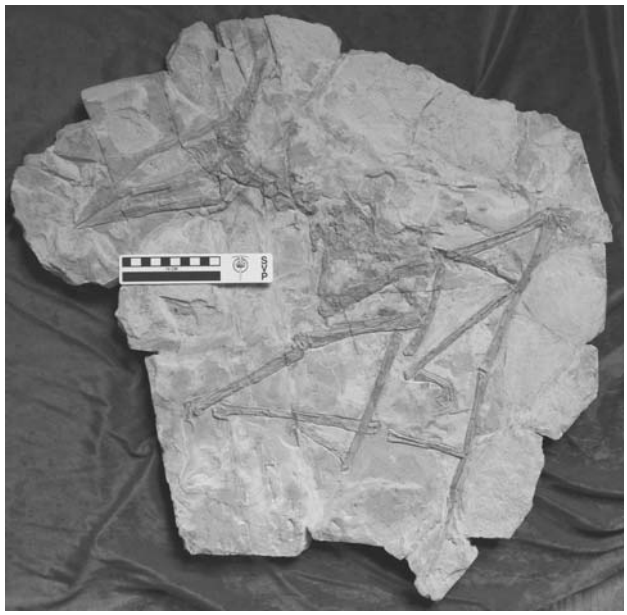

Fig.1. Photograph of *Huaxiapterus benxiensis* sp. nov. (BXGM V0011).

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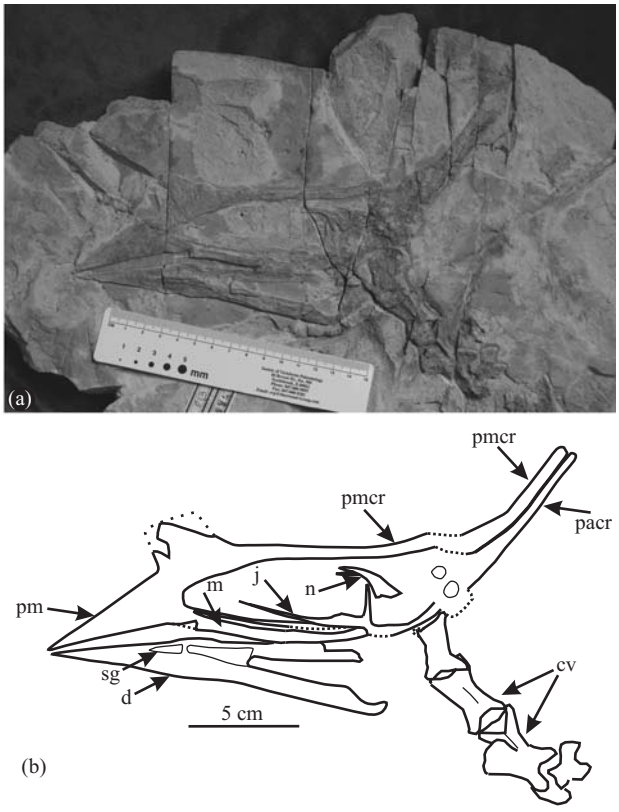

Fig. 2. Close-up the skull of *Huaxiapterus benxiensis* sp. nov. (BXGM V0011), photograph (a) and line drawings (b).
Abbreviations: cv, cervical vertebrae; d, dentary; j, jugal; m, maxilla; n, nasal; pacr, parietal crest; pm, premaxilla; pmcr, premaxillary crest; sg, shallow groove.

Fig. 3. The manus of *Huaxiapterus benxiensis* sp. nov. (BXGM V0011), showing the pneumatic opening (po) on the proximal end of the first wing phalange.

parietal spine and well-developed premaxillary crest, whose posterior portions extend posterodorsally and nearly parallel to each other. A shallow groove appears on the dorsal surface of the anterior portion of the mandibular symphysis.

Type locality and horizon: Lianhe Town, Chaoyang City of Liaoning Province; Jiufotang Formation.

Table 1 Measurements of *Huaxiapterus benxiensis* (in cm)

	Length	Width
Upper jaw	16.5	-
Rostrum (anterior to the anterior margin of the nasoantorbital opening)	6.4	-
From tip to the distal end of the parietal spine	26.0	-
Parietal crest (spine)	8.1	-
Nasoantorbital opening	9.0	-
Lower jaw	14.9	-
Mandibular symphysis	8.0	-
The third cervical vertebra	2.3	1.1
The fourth cervical vertebra	2.4	1.2
The fifth cervical vertebra	2.6	0.9
The sixth cervical vertebra	2.5	0.8
Humerus	6.2	0.9
Deltopectoral crest	2.0	1.0
Ulna	11.9	0.7
Radius	11.9	0.6
Pteroid	6.0	0.2
Metacarpal IV	13.3	1.0
Wing phalanges 1–4	17.6,13,9.8,3.3 (pres.)	0.76,0.6,0.3,0.1
Manual claw	1.7	-
Femur	11.2	0.76
Tibia	15.4	0.8
Metatarsal III	3.5	-
Pedal claw	0.8	-

Notes: pres., preserved length

Etymology: The specific name refers to the Benxi Geological Museum, at which the holotype specimen is housed.

Holotype: A nearly complete skeleton with a skull and a lower jaw (BXGM V0011). Specimen housed in the Benxi Geological Museum, Liaoning Province, China.

3 Description

The skeleton is almost complete with a skull and a lower jaw preserved (Fig.1; Table 1). The soft tissue is also preserved near the elongate parietal spine.

Skull: The skull is exposed its left side. The portion near the braincase is exposed dorsally and displaced; however, the detailed structure is not clear.

Premaxilla: The suture between the premaxilla and maxilla is clear. It starts at the vertical level of the anterior margin of nasoantorbital opening near the ventral margin of the upper jaw, extends posterodorsally, and disappears at the ventral margin of the nasoantorbital opening. The front end of the upper jaw is completely preserved except for missing its surface. The tip of the upper jaw is strongly pointed. There is a hatch-shaped crest, whose long axis is perpendicular to the anterodorsal margin of the nasoantorbital opening, although the hatch-shaped crest is not well-preserved. The broken surface of the crest shows that the crest is formed by a very thin outer layer of bone and a trabecular internal structure, which is similar to that of *Tapejara wellnhoferi* (Wellnhofer and Kellner, 1991). The hatch-shaped crest is similar to that of *Huaxiapterus corollatus* (Lü et al., 2006b). But the portion anterior to

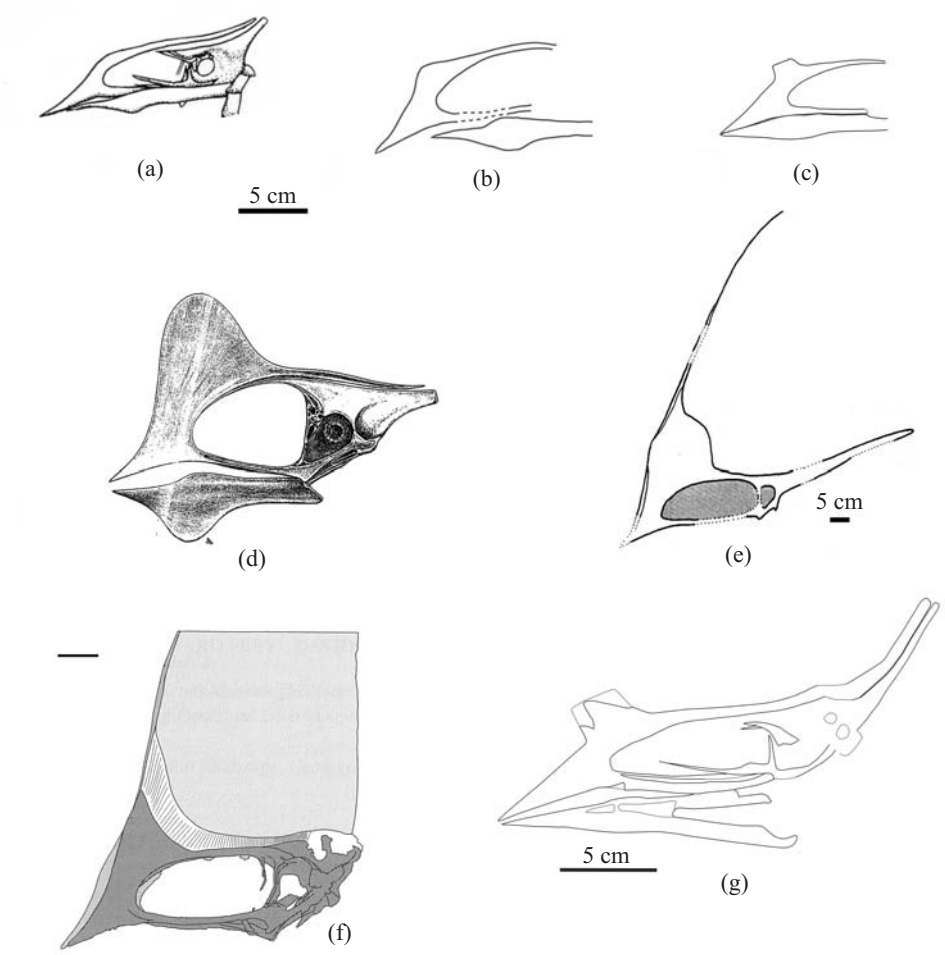

Fig. 4. Comparison of the skulls of tapejarids.
(a) *Sinopterus dongi* (reversed, modified from Wang and Zhou, 2002); (b) Anterior portion of the skull of *Huaxiapterus jii* (Lü and Yuan, 2005); (c) Anterior portion of *Huaxiapterus corollatus* (reversed, from Lü et al., 2006a). (d) *Tapejara wellnhoferi* (reversed, from Wellnhofer and Kellner, 1991); (e) *Tapejara imperator* (modified from Campos and Kellner, 1997); (f) *Tapejara navigans* (reversed and modified from Frey et al., 2003); (g) *Huaxiapterus benxiensis* sp. nov. Scale bar=5cm. A-C, same scale.

the anterior margin of the nasoantorbital opening is much narrower and elongated than that of *Huaxiapterus corollatus*. The pointed tip is inclined downwards by an angle of about 40°relative to the ventral margin of the nasoantorbital opening. The premaxilla forms the anterodorsal margin of the nasoantorbital opening. The slender process of the premaxilla separates from the skull roof formed by the frontals and overlies the upper margin of the base of the parietal spine. It extends posterodorally and ends much posterior to the posterior margin of the orbit, similar to the case in *Tapejara wellnhoferi* (Wellnhofer and Kellner, 1991), *Tapejara imperator* (Campos and Kellner, 1997) and *Sinopterus dongi* (Wang and Zhou, 2002) (Fig.4).

Maxilla: The maxilla forms the ventral margin of the nasoantorbital opening. Its posterior portion is missing. The maxilla is narrow and plate-like. The anterior portion of the maxilla is curved ventrally.

Nasals: Both the left and the right nasals are slightly overlapped. The left nasal is preserved in its natural position as a triangularly curved element situated in the upper posterior corner of the nasoantorbital opening. The dorsal process of the nasal is pointed, curved and extends forwards. The nasal is separated from the frontal by its smooth suture and is ventrally overlapping the lacrimal as the case in *Tapejara wellnhoferi* (Wellnhofer and Kellner, 1991).

Frontal/parietal: The skull roof is essentially built up by the fused frontals and parietals. The frontals are not well-preserved. The bones are missing and exposed the large, bulging hemispheres of the forebrain of the braincase. The parietal is well-developed. It bears an elongated process which extends posterodorsally by an angle of about 60° relative to the ventral margin of the skull (Fig.2), although this may be exaggerated due to the preservation. The base of the parietal is wider than its distal portion. The parietal process (spine) is about 8.1 cm long, and it is longer than the rostral portion of the skull (It is 6.4 cm from the tip of the upper jaw to the anterior margin of the nasoantorbital opening). The ventral portion of the process is much more ossified than its upper portion along the long axis of the process. The upper portion is preserved as a mould with mineralized replacements of unknown minerals. It is possible that these soft tissues extend anteriorly to connect with the hatch-shaped crest, forming a large sail-like structure, whose function may be similar to that of *Tapejara navigans* (Frey et al., 2003).

Jugal: Both jugals are preserved. The right jugal is displaced from its original place. The posterior portion of the jugal is not well-preserved. The anterior process of the jugal is long and slender. Originally, it must have

overlapped the lateral surface of the maxilla forming most of the lower margin of nasoantorbital opening. The nearly vertical slender bone, which is near the posteroventral corner of the nasoantorbital opening, may be the ascending process of the jugal.

Quadrate: There is an obliquely elongate bone lying under the braincase, whose one end is near the posterior end of the mandibular; this bone should be the quadrate. The position of the quadrate relative to the ventral margin of the skull is inclined about 140° backwards.

Lower jaw: As in other tapejarid pterosaurs, the lower jaw of *Huaxiapterus benxiensis* is toothless. The ventral symphyseal bony crest is weak, shallow, similar to those of Chinese tapejarid pterosaurs (Wang and Zhou, 2002; Lü and Yuan, 2005; Lü et al., 2006a), unlike those of Brazilian tapejarid pterosaurs, which have a highly developed, deep dentary crest (Kellner, 1989; Wellnhofer and Kellner, 1991). The distal end of the right mandibular ramus is missing. The left mandibular ramus is well-preserved. There is a shallow depression on the dorsal surface of the mandibular symphysis, which is similar to that of *Tapejara wellnhoferi*, but differs from that of *Huaxiapterus jii,* whose dorsal surface of the mandibular symphysis is flat (Lü and Yuan, 2005). A transverse ridge is present on the dorsal surface of the mandibular symphysis. This ridge is almost located at the level of the anterior margin of the nasoantorbital opening. No sutures can be observed in the lower jaw.

Postcranial skeleton:

Cervical vertebrae: There are four connected cervical vertebrae preserved. The anterior one is located near the posterior portion of the skull. Therefore, these four cervical vertebrae are inferred to be from the third to the sixth cervical vertebrae. The anterior three are preserved as dorsoventrally, and exposed their dorsal surfaces. These vertebrae are short with short neural spines. There is a pleuroceol on the lateral surface of the fourth cervical vertebra. The ventral surface of the sixth cervical vertebra is exposed, and it is smooth without any keel or groove. The ratio of the length to width is greater than 2.0.

The dorsal vertebrae and sacral vertebrae are not well-preserved, and their structures are not clear.

Coracoid and scapula: both the coracoid and the scapula are not well-exposed, thus their structures are not clear.

Humerus: Both humeri are not well-preserved, and the detailed structures of both ends are not clear. It is not clear whether there is a pneumatic opening or not at the proximal end of the humerus. The deltopectoral crest of the humerus is enlarged, proximally placed with almost straight proximal margin.

Ulna and radius: The ulna and radius are parallel. The ulna is slightly curved, and the radius is straight. The ulna is slightly thicker than the radius, and the ratio of the diameter of the ulna to radius is about 1.2.

Carpals: The proximal carpals are smaller than distal carpals. The distal carpals are fused into a rectangular unit. The dorsal surface of the fused carpal is slightly concave. In front of the fused carpal, there is a small bone whose articular surface is smooth. This bone is supposed to articulate with the pteroid.

Metacarpals: All the metacarpals are preserved. Metacarpals I-III are slender and they are not articulating with carpi. Metacarpal IV is straight and it is slightly longer than the ulna. The manual claw is curved and sharp and they are slightly larger than the pedal claws.

Wing phalanges: Wing phalanx 1 is straight. The olecranon-like extensor tendon process is fused to the proximal end of the first wing phalanx, indicating that this specimen is an adult individual (Kellner and Tomida, 2000; Bennett, 2001). A pneumatic opening is present on the proximal end of the first wing phalanx, which is similar to that of *Huaxiapterus* (Lü and Yuan, 2005). Wing phalanx 2 is almost straight, although it is slightly curved near its distal end due to the preservation. Wing phalanx 3 is much thinner than wing phalanx 2. The ratio of the diameter of wing phalanx 3 to wing phalanx 2 is 0.5. Wing phalanx 3 is curved posteriorly and wing phalanx 4 is much shorter and thinner than wing phalanx 3.

Hindlimb: The shaft of the femur is curved. The tibia is straight and the proximal end of the tibia is oblique. The ratio of the length of the tibia to the femur is about 1.4. The ratio of the length of the metatarsal III to that of the tibia is about 0.22. The fifth pedal digit is extremely reduced and the last phalanx of pedal digit V is absent.

4 Discussion

The new specimen is assigned to *Huaxiapterus*, based on the following characters: the premaxillary sagittal crest and the sagittal crest on the lower jaw are deeper than those in *Sinopterus*, but shallower than those in *Tapejara*. The posterior extension of the premaxillary crest arced in lateral view, and the ventral margin of the upper jaw smoothly curved ventrally (Lü and Yuan, 2005; Lü et al., 2006a).

Huaxiapterus benxiensis differs from all other Chinese tapejarid pterosaurs with skull preserved in bearing a highly developed parietal spine, which extends posterodorsally and the posterior portion of the premaxillary crest is parallel with the parietal spine (Fig.4). *Huaxiapterus benxiensis* is different from *Sinopterus dongi* (Wang and Zhou, 2002) in that the premaxillary crest and parietal crest are very short in

Sinopterus, whilst these crests are well-developed in *Huaxiapterus benxiensis*. Although the posterior portion of the skulls are not well-preserved in *Huaxiapterus jii* (Lü and Yuan, 2005) and *Huaxiapterus corollatus* (Lü et al., 2006a), the tendency of the premaxillary crest indicates that the premaxillary crest is short, and extends not as long as that of *Huaxiapterus benxiensis* (Fig. 4b, 4c). The elongate parietal crest (spine) of *Huaxiapterus benxiensis* is similar to that of *Tapejara imperator* (Campos and Kellner, 1997); however, the position of the premaxillary crest in the skull of *Huaxiapterus benxiensis* is different from the above-mentioned tapejarid. The premaxillary crest ends either near the vertical level of the posterior margin of the nasoantorbital opening (*Tapejara imperator*), or ends much anterior to the posterior margin of the nasoantorbital opening (*Tapejara navigans*).

5 Conclusion

The new species is distinguished by at least two autapomorphies (an elongate parietal spine and a well developed premaxillary crest, whose posterior portions extend nearly parallel to each other) from other tapejarid pterosaurs. The discovery of *Huaxiapterus benxiensis* indicates that Chinese tapejarid pterosaurs are much more diverse than the previous thought.

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