A New Species of *Cathayornis* from the Lower Cretaceous of Inner Mongolia, China and Its Stratigraphic Significance

LI Jianjun[1, 2, *], LI Zhiheng[3], ZHANG Yuguang[2], ZHOU Zhonghe[3], BAI Zhiqiang[1], ZHANG Lifu[4] and BA Tuya[5]

1 *School of Earth and Space Sciences, Peking University, Beijing 100871, China*
2 *Beijing Natural History Museum, Beijing 100050, China*
3 *Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, China*
4 *Otog Field Museum of Geological Vestige, Otog Banner, Inner Mongolia 016100, China*
5 *Qab Dinosaur Museum, Otog Banner, Inner Mongolia 016108, China*

Abstract: An incomplete postcranial avian skeleton is described from the Lower Cretaceous Jingchuan Formation of Otog Banner of western Inner Mongolia and referred to a new species of *Cathayornis, C. chabuensis* sp. nov. This is the first report of a *Cathayornis* from outside Liaoning Province. The new discovery indicates that *Cathayornis* coexisted with *Otogornis genghisi*, and a more detailed comparison between these two enantiornithine genera shows that *Otogornis* represents a more primitive genus than *Cathayornis*. Our analyses further indicate that *Cathayornis* is an arboreal bird. The discovery of a *Cathayornis* from this region also confirms that the avian fossil-bearing Jingchuan Formation is comparable to the Jiufotang Formation of the upper Jehol Group in western Liaoning, and should be referred to the middle-late Early Cretaceous.

Key words: *Cathayornis*, stratigraphy, Lower Cretaceous, Otog Banner, Inner Mongolia

1 Introduction

Otogornis genghisi was the first Mesozoic bird reported from Inner Mongolia (Hou, 1994). With the abundant discoveries of Lower Cretaceous avians from Liaoning Province and neighboring regions, however, little progress has been made from the type locality of *Otogornis* in Chabu Sumu, Otog Banner, western Inner Mongolia (Fig. 1). In 2002, a new fossil bird was discovered in the Lower Cretaceous lacustrine deposits of the Jingchuan Formation of Chabu Sumu.

Although this new specimen is represented only by an incompletely preserved skeleton without skull, based on the proportions of limb bones, the longitudinal groove on the dorsal surface of the radius, intermetacarpal space nearly absent between major and minor metacarpals, and the sole and reduced phalanx of minor manual digit tightly attached to the first phalanx of the major manual digit, it can be referred to *Cathayornis* (Zhou et al., 1992; Zhou, 1995; Zhou and Hou, 2002), one of the most common avian genera from the Jehol Biota. Morphological comparisons between this new find and the holotype of *Cathayornis yandica* show that the new specimen represents a new species of the genera. The new discovery not only adds new data for the vertebrate assemblages of the Jingchuan Formation but also provides new evidence for the biostratigraphic comparison between this formation and the Jiufotang Formation of the upper Jehol Group in western Liaoning. A further comparison between *Cathayornis* and *Otogornis* also shows that the later is more primitive than the former in characters.

2 Geologic Setting

Otog Banner is located in the northwestern part of the Ordos Basin that is a large successive sedimentological basin developed since the Jurassic (Guo, 1999). According to the Inner Mongolia Geological Survey Team, there is a big fault trending north-south in the Ordos Basin, which stretches from Abudatai in the north, via Nalinshili, to Uxin Banner. The fault divides the Ordos Basin into two smaller sedimentary basins in the west and east, respectively. The east sedimentary basin mainly comprises deposits of the Yijinhuoluo Formation and Dongsheng Formation. The

* Corresponding author. E-mail: ljj5681@126.com

west sedimentary basin mainly comprises deposits of the Zhidan Group that is composed of the Luohandong, Jingchuan, and Lamawan formations of the Lower Cretaceous (Chen, 2003; Chen et al., 2006; No. 1 Territorial Survey Team of Inner Mongolia Geological Bureau, 1980; Wu et al., 2005). The bird fossil was collected from the Jingchuan Formation, which is composed of sediments of fluvio-lacustrine facies with some tuffaceous materials (Lockley et al., 2002).

Chabu Sumu is situated in southwest of Otog Banner. The Jingchuan Formation is mainly composed of grey green, blue grey, brown grey, dark brown and red colored mudstones, sandwiched by grey green calcareous fine sandstones and argillaceous limestone (Guo, 1999). Besides the bird fossil bones, a huge amount of dinosaur and bird tracks have been found around the bird fossil site (Lockley et al., 2002; Li et al., 2006). Other fossils found in the Jingchuan Formation in Chabu area include reptiles: *Psittacosaurus*, Hadrosauridae (Guo, 1999), *Ikechaosaurus* (*Eotomistoma multidentata*, Young, 1964) and Chelonia (Guo, 1999); the bird: *Otogornis genghisi* (Hou, 1994); the fish: *Lycoptera woodwardi, Lycoptera kansuensis* and *Sinomia zdanskyi*; ostracodes: *Cypridea koskulensis, Lycopterocypris circultata, Darwinula* sp. and *Mongolianella* aff. *Palmosa*; conchostracans: *Yanjiestheria* cf. *Y. sinensis* and *Y.* cf. *yumenensis*; bivalves: *Nakamuranaia chingshanensis* and *Sphaerium* spp.; the insect: *Mesolygeus totandocephalus*; and the plant: *Cladophlebis* sp. (Guo, 1999; Chen et al., 2006).

We measured a stratigraphic section near the bird fossil site (Fig. 2) to show the horizontal relationship among the sites of the bird fossil described in this paper and that described by Hou (1994), and several dinosaur and bird track sites .

The horizon of *Otogornis genghisi* (Hou, 1994) is 70 cm lower than that of the fossil bird described here in the section. Some insect fossils and the fossil fish *Lycoptera kansuensis* were discovered very close to the fossil bird in the same horizon. Also, in the upper part of the section, a lot of dinosaur and bird tracks were preserved in different horizontal positions.

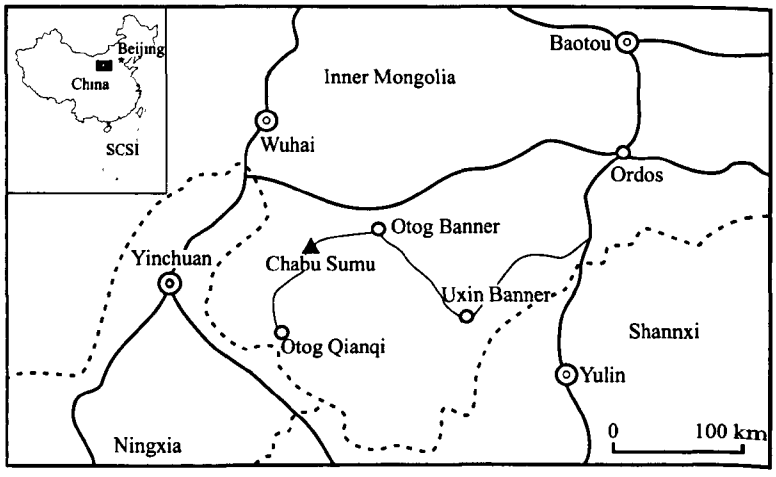

Fig. 1. Map of the fossil locality (Chabu Sumu).

3 Systematic Description

Aves Linnaeus, 1758
Enantiornithes Walker, 1981
Cathayornithiformes Zhou, Jin et Zhang, 1992
Cathayornithidae Zhou, Jin et Zhang, 1992
Cathayornis Zhou, Jin et Zhang, 1992

Cathayornis chabuensis sp. nov.

Holotype: BMNHC-Ph000110 a, b (Beijing Natural History Museum Collection), an incomplete postcranial skeleton (part and counterpart) mainly preserved as bone fragments or impressions (Fig. 3a, b; Fig. 4a, b; Table 1).

Locality and horizon: Chabu Sumu, western Inner Mongolia; Jingchuan Formation (Early Cretaceous) (Chen et al., 2006).

Etymology: The species name is derived from the locality "Chabu".

Diagnosis: The new species is distinguishable from *Cathayornis yandica* in possessing a sternum with a pair of more laterally projected lateral trabeculae and a more caudally extended carina.

Description: The preserved skeletal elements include the cervical vertebrae, dorsal vertebrae, scapulae, coracoids, humeri, ulnae, radii, carpometacarpi, manual digits, sternum, femurs, tibiotarsi, fibulae, tarsometatarsi and pedal digits. The skeleton is dorso-ventrally preserved. Since the most bones are fragmentary, in order to facilitate detailed anatomical study, all bones are mechanically removed to expose the impressions on both the part and counterpart. As a result, description of the specimen is mainly based on the casts of both sides (Fig. 5a, b). Right behind the pectoral girdle, there exists a row of tightly arranged feathers (Fig. 3b), which are slender, with little morphological information that can be easily recognized. A few more isolated feathers are also preserved in the specimen. None of the feathers is attached with any bone.

Vertebral column—At least 10 more or less articulated cervical vertebrae are preserved. The length and width of each cervical vertebra are equal. Posterior cervical vertebrae are also preserved with a pair of cervical ribs, which are short, curved and slender. Six dorsal vertebrae are preserved in articulation. The dorsal vertebrae have amphicoelous central articulation. Two dorsals are

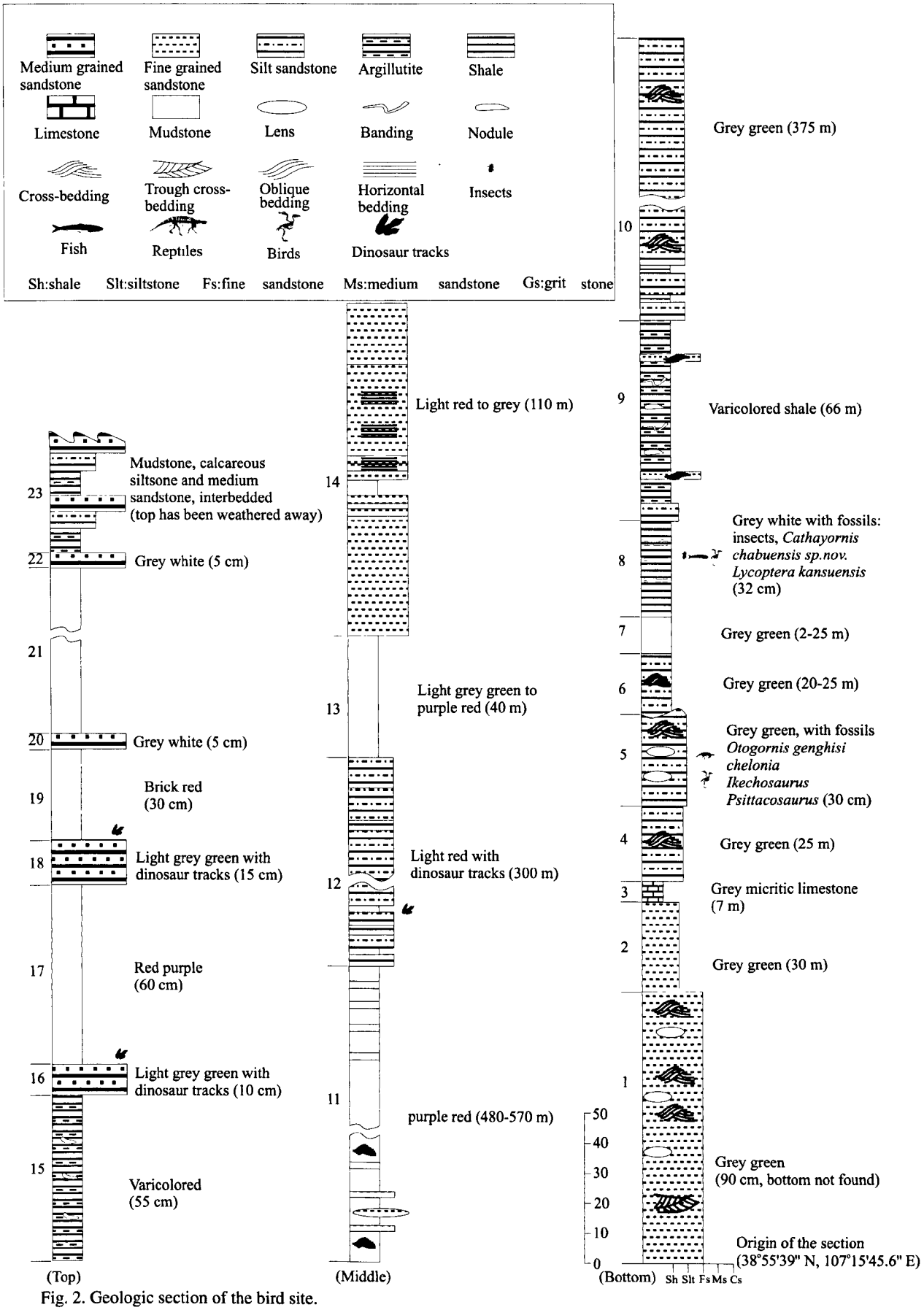

Fig. 2. Geologic section of the bird site.

Fig. 3. Holotype of *Cathayornis chabuensis* sp. nov. from western Inner Mongolia (BMNHC-Ph000110 a, b).
(a) A part and (b) a counterpart.

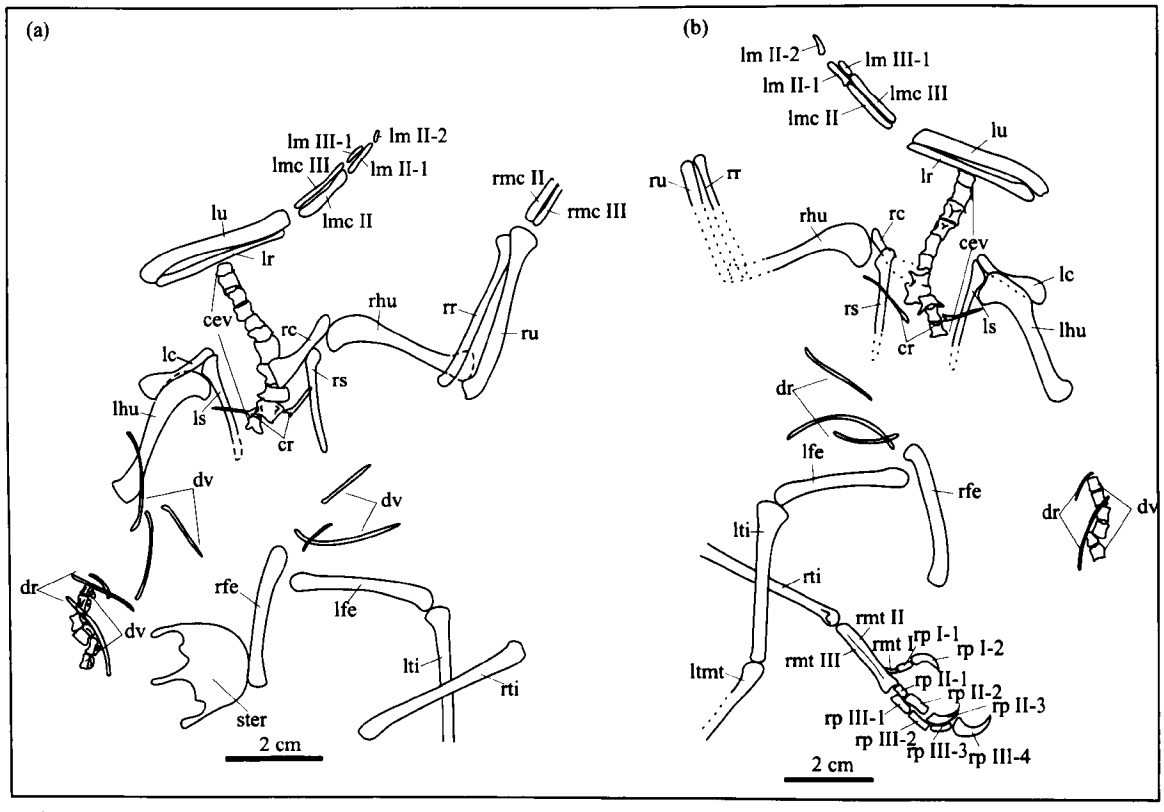

Fig. 4. Line drawing of the part and the counterpart of holotype of *Cathayornis chabuensis* sp. nov. (BMNHC-Ph000110 a, b).
(a) A part and (b) a counterpart. Abbreviations: cev – cervical vertebrae; dv – dorsal vertebrae; dr – dorsal rib; ster – sternum; ru – right ulna; rr – right radius; rs – right scapula; rc – right coracoid; rmc II, III – right metacarpals II, III; rm II, III – right manual digits II, III; rfe – right femur; rti – right tibiotarsus; rmt I, II, III – right metatarsals I, II, III; rp I, II, III – right pedal digits I, II, III; lu – left ulna; lr – left radius; ls – left scapula; lc – left coracoid; lmc II, III – left metacarpals II, III; lm II, III – left manual digits II, III; lfe – left femur; lti – left tibiotarsus; ltmt I – left tarsometatarsus.

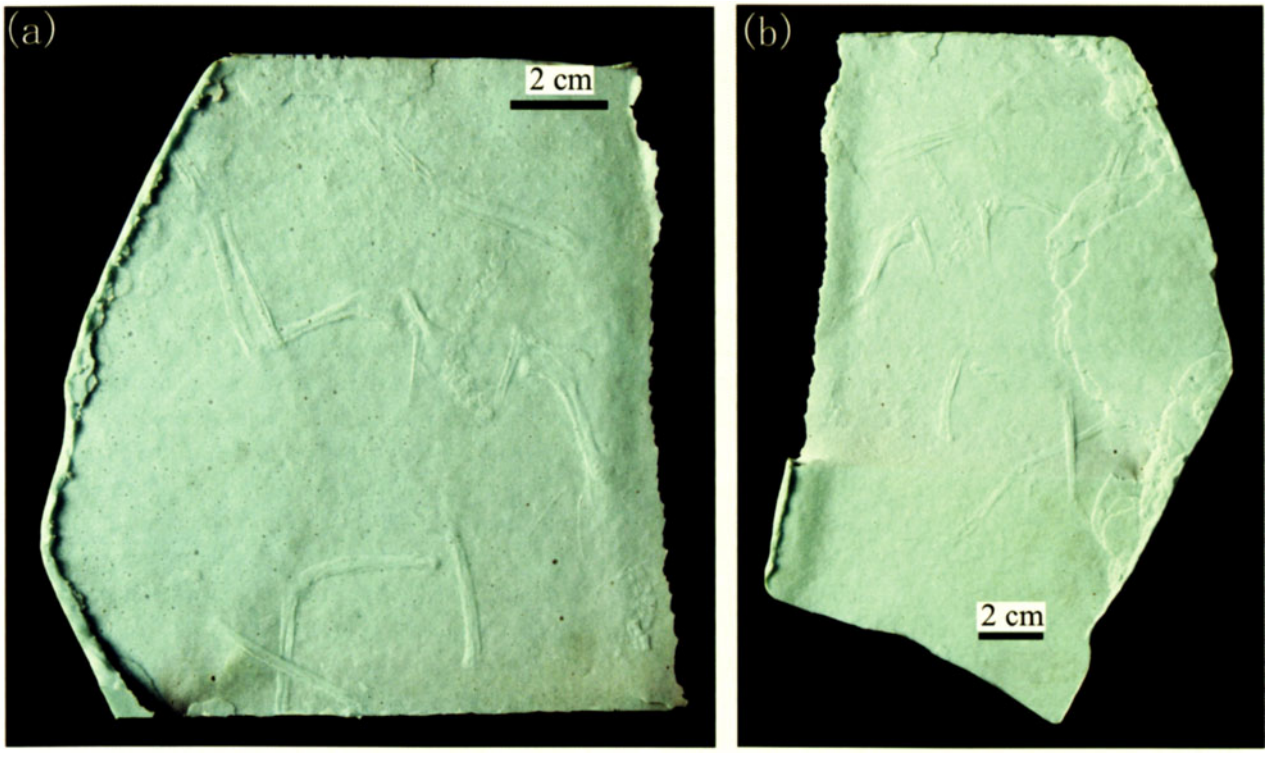

Fig. 5. Casts of the holotype of *Cathayornis chabuensis* sp. nov. (BMNHC-Ph000110 a, b).
(a) A part and (b) a counterpart.

equipped with lateral excavations. The dorsal ribs are long and slender.

Pectoral girdle—Both the scapula and coracoid are preserved on left and right sides. The scapula is unfused with the coracoid. The left scapula is in articulation with the coracoid, and both form an angle less than 90 degree. The scapula is markedly shorter than the humerus as in many primitive birds. The scapular shaft is straight with a long ventral groove, and its distal width is approximately the same as its proximal portion. The acromion process is straight and well developed. The glenoid facet faces laterally. The coracoid is strut-like, narrow proximally with a straight acrocoracoidal process. The procoracoid is not well developed. Distally, the coracoid is expanded with a concave dorsal surface and convex lateral margin as typical of enantiornithines, but lacks a distinctive articulation with the sternum. The lateral process is not developed. The distal width of the coracoid is less than half its length.

The furcula is not preserved. The sternum is well preserved. It is short and its main body is nearly round. Unlike in *Cathayornis yandica*, a pair of lateral trabeculae are not parallel to each other, but are slightly projected laterally, with an expanded distal extremities. The carina is low and ridge-shaped and extends more caudally than in *Cathayornis yandica*.

Forelimbs—Both humeri are nearly completely preserved. The proximal humerus is significantly twisted, and the humeral shaft is "S"-shaped. Elongated longitudinal grooves are seen on both ventral and dorsal sides of the humerus. The deltopectoral crest is narrow and moderately protruding, and its width is less than that of the humeral mid-shaft. The humeral head is low and strap-shaped, lacking a distinctive prominence in the middle. At the proximal humerus, there are a narrow coracobrachial impression and transverse ligmental sulcus, and both the ventral tubercle and capital incision are well-developed. The bicipital crest is prominent and ball-shaped. However the dorsal tubercle is not well developed. The distal humerus is only slightly twisted and expanded dorso-ventrally. Both the dorsal and ventral condyles are cranially located, but are not well defined.

The ulna is about as long as the humerus. The ulna is significantly wider than the radius. The distal one third length of ulna is slightly curved. Little anatomical information, however, can be revealed from its proximal and distal ends. The radius is straight and slender, with a long longitudinal groove on its dorsal surface.

The carpometacarpus is preserved. Proximally the carpals are not well preserved. Both the major and minor metacarpals are straight and tightly attached, lacking a distinctive intermetacarpal space. The minor metacarpal extends past the major metacarpal distally as typical of

enantiornithines.

The major manual digit preserves only the first two phalanges. The first is long and rod-like, lacking a distinctive lateral expansion. The second phalanx is shorter than the first and tapers distally. The minor manual digit preserves only the first phalanx, which is short and tightly attached to the first phalanx of the major digit. The alular digit is not preserved.

Hindlimbs—The femur is curved, and slightly shorter than the humerus. The femoral head is ball-shaped, but lacks a distinct neck. The great trochanter is low and flat. No fourth trochanter or posterior trochanter can be recognized. At the distal end of the femur the medial condyle is semicircular in shape.

The tibiotarsus is slender and much longer than the femur, and lacks a prominent fibular crest. The tibiotarsus is well fused distally, with well-developed trochlea. The fibula is preserved only proximally, and it appears to be quite reduced, and remains unfused with the tibiotarsus.

The left tarsometatarsus is incomplete, and appears to be fused at the proximal end. Metatarsal V is missing. The right hindlimb preserved only metatarsals I-III, lacking metatarsal IV. Metatarsal I has a low articulation with metatarsal II. The lengths of metatarsals II and III are approximately half that of the tibiotarsus. The trochlea of metatarsal II is higher than that of metatarsal III. Pedal digit I is reversed as compared to other digits. The second phalanx (ungual) of digit I is curved and longer than the first. Digit II is more robust than digits I and III. The second phalanx of digit II is longer than the first, but shorter than the third (ungual). The first three phalanges of digit III are approximately of the same length while the fourth phalanx (ungual) is the longest. All unguals of all the pedal digits are sharp and strongly curved.

4 Discussion and Comparison

The newly discovered avian specimen was from the Lower Cretaceous Jingchuan Formation of Otog Banner of western Inner Mongolia. The only other known Mesozoic bird from the same horizon of this region is *Otogornis* (Hou, 1994). Therefore the new specimen represents the second example of Mesozoic birds from western Inner Mongolia.

Although most of the bones of the new bird are well ossified, there is evidence indicating that it probably represents a subadult individual. For example, the distal end of the tibiotarsus, proximal end of the tarsometatarsus (metatarsal IV is missing), distal end of the humeurs, proximal end of the carpometacarpus, and the distal end of the scapula are either less well ossified or less defined.

Despite the subadult status of the new specimen, it has preserved several diagnostic features suggesting that it is undoubtedly an enantiornithine (Walker, 1981; Chiappe and Walker, 2002). Such features include the minor metacarpal obviously extending more distally than the major metacarpal, the convex lateral margin of the coracoid and the strape-like humeral head etc. (Zhou, 1995).

The new fossil is about the same size as the holotype of *Cathayornis yandica*, from which it is also morphologically hardly distinguishable based on the preserved elements shared by both, such as the proportions of limb bones, the longitudinal groove on the dorsal surface of the radius, intermetacarpal space nearly absent between major and minor metacarpals, and the sole and reduced phalanx of minor manual digit tightly attached to the first phalanx of the major manual digit. However, the new specimen does show some difference from the holotype of *Cathayornis yandica* in the morphology of the sternum. For instance, the sternum of the new specimen has a pair of lateral trabeculae that are more laterally projected (parallel to each other in *C. yandica*) and a more caudally extended carina.

Compared with *Otogornis*, both the new specimen and the holotype of *Cathayornis* are slightly smaller. *Cathayornis* is also distinguishable from *Otogornis* in lacking a process dividing the capital groove and a pneumatic fossa at the proximal humerus (Hou, 1994), but distally possessing a smaller sulcus hum. tricep. (Fig. 6). Therefore, *Otogornis* appears to be at least slightly more primitive than *Cathayornis*. On the other hand, compared to more advanced enantiornithines, both *Cathayornis* and *Otogornis* have a flat and less prominent humeral head.

Like other *Cathayornis* specimens, the new fossil also shows typical arboreal features in the hindlimb bone proportions and the morphology of the unguals. For instance, the new fossil shows a low-positioned articulation between metatarsals I and II. Pedal digit I is long and possesses a large and curved claw like other digits. The tarsometatarsus is about half the length of the tibiotarsus, and the tarsometatarsus is only about 20% the total length of hindlimb (femur+tibiotarsus+tarsometatarsus), which is smaller than many other enantiornithines. Based on studies of extant birds (data mainly come from Columbiformes), those with such ratio lower than 24% are usually arboreal types (Hopson, 2001). These analyses strongly suggest that *Cathayornis* is an arboreal bird, as typical of early enantiornithines (Feduccia, 1999; Zhou, 2004; Zhou and Zhang, 2006).

It is worth noting that many fossil bird tracks have been found from the Jingchuan Formation in this area, but bird track-bearing horizon is slightly higher than that of *Cathayornis chabuensis* sp. nov. These bird tracks, which are now under study, are mostly around 5 cm long and 6 cm wide.

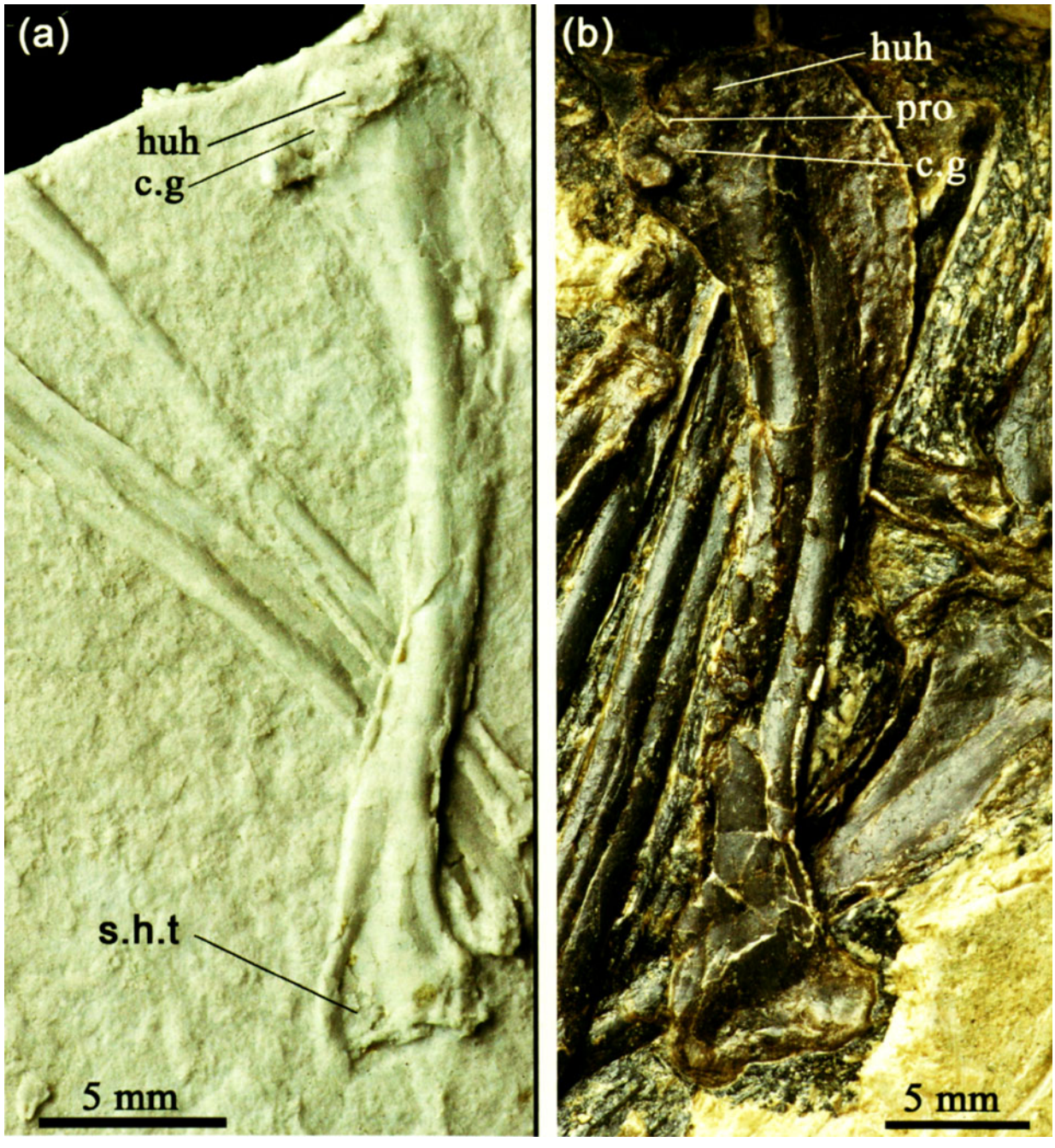

Fig. 6. Comparison of the humerus of the holotype of *Cathayornis yandica.* (a) and *Otogornis genghisi* (b) (right side in caudal view).

The discovery of *Cathayornis* from Otog Banner in western Inner Mongolia also bears some biostratigraphic significance. Although Hou (1994) reported that the *Otogornis*-bearing deposits belong to the Yijinhuoluo Formation, the same sediments in this sedimentary basin actually generally refer to the Jingchuan Formation of the Zhidan Group, which generally refers to the Early Cretaceous (Cheng et al., 2003; Wu et al., 2005). Wu et al. (2005) further argued that the Jingchuan Formation belongs to the late Early Cretaceous. The discovery of a *Cathayornis* from the Jingchuan Formation appears to have provided further evidence in support of this hypothesis and provided important vertebrate evidence for the correlation between the bird-bearing Jingchuan Formation in Inner Mongolia and those in western Liaoning in northeastern China. Also, the discovery supports the hypothesis that the *Cathayornis* experienced a rapid and extensive radiation during the Early Cretaceous (Zheng et al. 2007).

Mesozoic birds in western Liaoning have been mainly discovered in two avifauna: One is dominated by *Confucisornis* (Hou, 1997) from the lower part of the Yixian Formation, the other is dominated by an antiornithid

Cathyornis from the upper part of the Jiufotang Formation (Li et al., 2006). Recent Ar-Ar dating of the *Cathayornis*-bearing beds that belongs to the second member of Jiufotang Formation in Liaoning Province according to Zhang et al. (2007) has been dated as 120 Ma, which corresponds to the middle and late Early Cretaceous (He et al., 2004). Although many early birds have been found from the Yixian Formation, none of the enantiornithines from this formation can be referred to *Cathayornis*. In fact the age of the Yixian Formation (125 Ma) also suggests that it belongs to the middle Early Cretaceous (Swisher et al., 1999, 2002). The enantiornithines known from the Yixian Formation or corresponding deposits include *Eoenantiornis* (Hou et al., 1999; Zhou et al., 2005), *Eocathayornis* (Zhou, 2002) *Liaoxiornis* (Hou and Chen, 1999), *Longirostravis* (Hou et al., 2004; Zhou et al., 2006) and *Vescornis* (Zhang et al., 2005), all of which appear to be more primitive than *Cathayornis*. The most primitive enantiornithine *Protopteryx* (Zhang and Zhou, 2000) is clearly more primitive than *Cathayornis* and all other known enantiornithines, and it comes from the Dabeigou Formation, which is now known to be older than the Yixian Formation (131Ma) (He et al., 2006; Zhou, 2006). As a result, we propose that the Jingchuan Formation most likely corresponds to the Jiufotang Formation in western Liaoning, and should be referred to the middle-late Early Cretaceous.

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