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A New Enantiornitine Bird with Four Long Rectrices from the Early Cretaceous of Northern Hebei, China

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Abstract: *Paraprotopteryx gracilis*, a new enantiornithine bird from the Early Cretaceous Yixian Formation in Fengning, northern Hebei Province is erected, based on the following characters: Y-shaped furcula with a long hypocleidum and a much narrow interclavicular angle, and the morphology of the sternum are different from other enantiornithines. Additionally, alular digit bearing the biggest manual claw extends distally to the distal end of the major metacarpal; the minor metacarpal is slender than the major metacarpal. Carpometacarpus only fused proximally; astragalus and calcaneum partially fused to one another but unfused to the tibia. This is the first record of Mesozoic birds in having four long rectrices, which may represent morphologically a secondary sexual character, an intermediate stage from elongated scale to branched feather, and possess functional advantage in supplementing the lifting surface to compensate the unskilled flight.

Key words: Early Cretaceous, *Paraprotopteryx gracilis*, enantiornithine, rectrices, Fengning, Hebei Province

1 Introduction

Enantiornithines are known as the most dominant birds and found nearly worldwide throughout the entire span of the Cretaceous (Chiappe, 1995; Feduccia, 1996). The Jehol Group that comprises the Yixian and Jiufotang Formations and is famous for fossil diversity and abundance in the world has yielded nearly 20 enantiornithine birds till now. Most of them- *Longipteryx, Eocathayornis, Aberratiodontus, Dapingfangornis, Sinornis, Boluochia, Cathayornis, Cuspirostrisornis, Largirostrornis, Longchengornis* are from the Jiufotang Formation of Chaoyang, western Liaoning Province (Zhang et al., 2001; Zhou, 2002; Gong et al., 2004; Li et al., 2006; Sereno and Rao, 1992; Zhou, 1995; Zhou et al., 1992; Hou, 1997); the others, *Eoenantiornis, Longirostravis, Liaoxiornis, Dalingheornis* from the Yixian Formation of Beipiao, Yixian and Linyuan (Zhou et al., 2005; Hou et al., 2004; Hou and Chen, 1999; Zhang et al., 2006); *Vescornis, Protopteryx* and *Jibeinia* from the Yixian Formation of Fengning in northern Hebei Province (Zhang et al., 2004; Zhang and Zhou, 2000; Hou, 1997); *Otogornis* from southeastern Inner Mongolia (Hou, 1994). Moreover, three unnamed, incomplete enantiornithine specimens from the Early Cretaceous Xiagou Formation of Gansu Province have been described after a collaborative expedition in 2004 (Harris et al.,2006; Lamanna et al., 2005, 2006; O'Connor et al., 2004; You et al., 2005).

The diversification of opposite birds from Jehol in the disparity of rostral morphology (Zhou, 1995; Zhang et al., 2001; Hou et al., 2004), the ratio of forelimb to hindlimb (Zhang et al., 2001), and the foot type(Zhang et al., 2006) indicate that the opposite birds had experienced a rapid and extensive radiation by the Early Cretaceous. *Protopteryx* is thought to be the most primitive enantiornithine bird in having the long hand and alular digit, unfused carpometacarpus and tibiotarsus; the two, long and scale-like tail feathers make it unique among all known opposite birds. A new species from the same locality represents another novel type of tail feathers.

2 Systematic Paleontology

Aves Linnaeus, 1758
Enantiornithes Walker, 1981
Paraprotopteryx gracilis gen. et sp. nov.

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Etymology: Genus name is composed of the Latin prefix "*para*" and *protopteryx* indicates the new bird much similar to another enantiornithine bird *protopteryx*. Species name, *gracilis* in Latin means pretty.

Holotype: Skull, a pair of forlimbs and hindlimbs, coracoids, scapula, furcula, parts of cervical and dorsal vertebrae, sternum and rib fragments. The holotype is split into two slabs (PlateI-1,2). The specimen is housed at Tianyu Natural Museum of Shandong Province, collection number STM V001.

Locality and Horizon: The city of Fengning, northern Hebei, China. Yixian Formation, Early Cretaceous (~125 mya)(Swisher, 2002; Zhou et al., 2003).

Diagnosis: scapular long; length of the coracoid 2.5 times of the width; interclavicular angle less than 40°, hypocleideum three-fourths the length of the clavicular ramus; medial process of the sternum longer and robust than the lateral process; alular digit with the biggest manual claw extends distally to the distal end of the major metacarpal; minor metacarpal more slender than major metacarpal; the first phalanx of major digit longer than the second phalanx; carpometacarpus only fused proximally; tibiotarsus unfused; pedal claws strong and curved; pygostyle long and bears four long tail feathers which are ribbonlike for most of the length whereas present symmetrical or asymmetrical vane at the expanded distal end.

3 Description

Paraprotopteryx is small-sized. The measurements of the specimen are listed in Table 1. The skull is badly crushed and seems not to be the same individual as the postcranial bones after careful examination. Preservative status of the vertebral column is not good enough to count the exact number of vertebrae, but it seems having a relatively long neck. Information from the preserved fragments shows that the dorsal vertebrae are broader and shorter than the cervicals; the prezygapophyses and postzygapophyses, as well as the costal processes are well-developed.

The scapula is relatively long, nearly four-fifths the length of the humerus. The shaft is straight and strap-like, almost the same width throughout the length; the acromion is developed and slightly rounded. The coracoids are distinguishable in the counter slab; it is about a third shorter than the scapula as in *Eoenantiornis*, and expands distally to form a broad sternal end, the ratio of the length to the width is 5:2; the sternal half is triangular-shaped, it has a concave medial margin and a less convex lateral margin as is typical of enantiornithine birds; there is no indication of the presence of a precoracoid process. The furcula is Y-shaped, with a long hypocleideum that is 3/4 the length of the clavicular ramus as in *Eoalulavis* (Sanz et al, 1996), the hypocleideum is preserved as an impression in the main slab; the interclavicular angle is less than 40°, the angle is approximately 60° in *Concornis* and *Dalingheornis*, 50° in *Longipteryx*, *protopteryx*, *Vescornis*, 45° in *Eoalulavis* and *Eoenantiornis*, and 48° in *Sinornis* (Chiappe and walker, 2002) (PlateII-1, 2).

Table 1 Measurements of *Paraprotopteryx gracilis* (in mm)

	Length	Width
Humerus	22.6	-
Ulna	23.5	-
Coracoid	12.8	-
Sternal end of coracoid	-	5.4
Clavical ramus	8.3	-
Hypocleideum	6.1	-
Carpometacarpus	11.5	-
The first phalanx of alular digit	2.9	-
The first phalanx of major digit	5.5	-
The second phalanx of major digit	3.5	-
The first phalanx of minor digit	2.9	-
Femur	22.2	-
Tibia	26.3	-
Tarsometatarsus	15.7	-
Pygostyle	12.9	-
Tail	101.2	-
Distal end of the central tail feather	-	4.9
Proximal end of the central tail feather	-	1.9
Distal end of the lateral tail feather	-	3.1
Proximal end of the lateral tail feather	-	1.6

The anterior margin of the sternum is parabolic; the caudal part is notched with a long narrow xiphoid process, a pair of lateral and medial sternal processes; medial sternal processes are longer and somewhat curved medially (PlateII-1, 2), contrary to *Concornis*(Sanz et al, 1995), *Eocathayornis* and most enantiornitines; the xiphoid process is visible in the counter slab. Fragments of the sternal ribs and gastralia are preserved.

Both forelimbs are in articulating. The humerus is slightly shorter than the ulna, and the deltoid crest is well developed, whereas the bicipital crest is less prominent at the proximal end; the humeral head is compressed and lies more ventrally than extant birds. The distal end with a deep olecranon fossa deflects anteroventrally, thus making the humerus a gently S-shaped. The ulna is about twice as wide as the radius and curves slightly at the proximal half, a less prominent olecranon is visible; the distal end is a little enlarged. The radius is straight; there is a narrow spindle spatium interosseum at the proximal half of the forearm. Two proximal carpals are preserved, the ulnare is nearly rectangle and larger than the radiale. The carpometacarpus is half the length of the ulna, and only fused proximally. Alular metacarpal is short and semicircular. Both the major and the minor metacarpals (metacarpal II and III) are straight for almost the total length except the distal extremities which are oblique anteriorly, the major metacarpal is robust and less than 2 times the width of the minor metacarpal. The intermetacarpal space is very narrow. All manual phalanges are preserved; the phalangeal formula is 2-3-2. The alular digit extends distally to the distal end of the major metacarpal and bears the largest manual claw. The proximal phalanx of the major digit is longer than the intermediate phalanx as in most of the known enantiornithines except *Protopteryx* and *Dalingheornis*, the ungual phalanx is smaller than that of the alular digit. The first phalanx of the minor digit is the smallest of all manual phalanges and ends in a vestigial claw (Plate II-1, 2).

The right femur is preserved and exposed laterally; it's nearly the same length as the humerus. The tibia is 118% longer than the femur; the needlelike, pointed fibula is short, only a little longer than one-thirds of the tibia. Two proximal tarsi - astragalus and calcaneum are partially fused to one another but unfused to the tibia, as in *Archaeopteryx* (Ostrom, 1976), *Rahonavis* (Forster et al, 1998), *Jeholornis* (Zhou and Zhang, 2002) and *Protopteryx*; this may represent a primitive or an ontogenetic feature. The tarsometatarsus is more than half the length of tibia and fused at the proximal end; metatarsal III is the longest and with the broadest trochlea, Metatarsi II and IV are nearly the same length and slightly narrower than metatarsal III; metatarsal I attaches to the distal end of metatarsal II and reaches the base of trochlea II, trochlea I is more expansive than trochleae II and III, but less prominent than trochlea III. The toes are relatively long; pedal claws are long and curved.

The most striking features of the new birds are the number and structure of rectrices. Four long tail feathers attach to the pygostyle; the central pair is the same length as, and a little broader than the lateral pair. They are similar in gross morphology, the proximal four-fifths is ribbonlike without branching, whereas the oval-shaped enlarged distal extremity shows clearly the occurrence of shaft, barbs, and pennaceous vane as in modern birds. The central pair is a little asymmetrical, presenting a narrow outer vane; the lateral pair is symmetrical. The width of the tail feathers is almost the same throughout its length before the expansive distal end, the measurement of the central rectrices is 1.9 mm, slightly wider than that of the lateral ones; the distal ends are 4.9 mm and 3.1mm respectively (Plate II-3).

4 Comparison and Discussion

Paraprotopteryx can be referred to Enantiornithines by the presence of a Y-shaped furcula with long hypocleideum, the coracoid with a convex lateral margin and a concave medial surface, a sternum with a parabolic anterior margin, and the minor metacarpal obviously extending past the major metacarpal distally. Compared with other Enantiornithines, the new bird is most similar to *Protopteryx* that was found from the same locality.

Paraprotopteryx shares with *Protopteryx* in having long ribbonlike rectrices, unfused tibiotarsus, unfused carpometacarpus and complete manual claws. But they are apparently different in the three main aspects: (1) pectoral girdle. There is a procoracoid process and a prominent lateral process in *Protopteryx*, the interclavicular angle is 50°, and the hypocleideum about half the length of the clavicular ramus. Whereas, the distal end of the coracoid is triangular and there is no indication of the presence of a precoracoid process in *Paraprotopteryx*, the hypocleideum is relatively longer, the interclavicular angle is smaller than that of *Protopteryx*. (2) manus. In *Protopteryx*, the alular digit is long with the distal end exceeding the carpometacarpus, the proximal phalanx of major digit shorter than the intermediate phalanx, and the major claw larger than the alular claw. Quite the contrary, the alular digit is distally on the same level with the carpometacarpus, the proximal phalanx of major digit longer than the intermediate palanx, and the alular claw is the biggest of all wing claws in *Paraprotopteryx*. (3) tail. Two long scalelike rectrices in *Protopteryx* versus four in *Paraprotopteryx*; since the distal ends of *Protopteryx* are missing, the morphology and structure of them are not clear unless new complete specimen is found.

The origin and early evolution of feather and flight is one of the most interesting issues in the study of fossil birds. Feathers may evolve from reptilian scales and have complicated function other than aerodynamic purpose (Feduccia, 1996). Four long ribbonlike rectrices with expanded barbing extremity found in *Paraprotopteryx* may suggest: (i) from evolutionary aspect, an intermediate stage from elongated scale to feather; (ii) an indicator of sexual dimorphism and the purpose of display, as in male shaft-tailed whydah (*Vidua regia*) who has four elongated black tail shaft feathers with expanded tips during the breeding season. (iii) the functional advantage in supplementing the lifting surface to compensate the unskilled flight as in some extant birds. Immature raptors that are learning to fly tend to have longer tails and a more buoyant flight than do adults, which apparently reduces the chance of injury and also facilitates their mastery of flight (Gill, 1994).

External structural characters, such as the bill, feet, remiges, and rectrices are of great value in classifying birds (Pettingill, 1985). More and more fossil birds, such as *Confuciusornis* (Hou et al, 1999), *Changchengornis*(Ji et al, 1999)*Dapingfangornis* (Li et al, 2006) and *Protopteryx* preserving with feathers, especially long tail feathers have been found, and probably will be found in the future. It's necessary for us to pay more attention to the external structural characters on the functional and taxonomic study of fossil birds.

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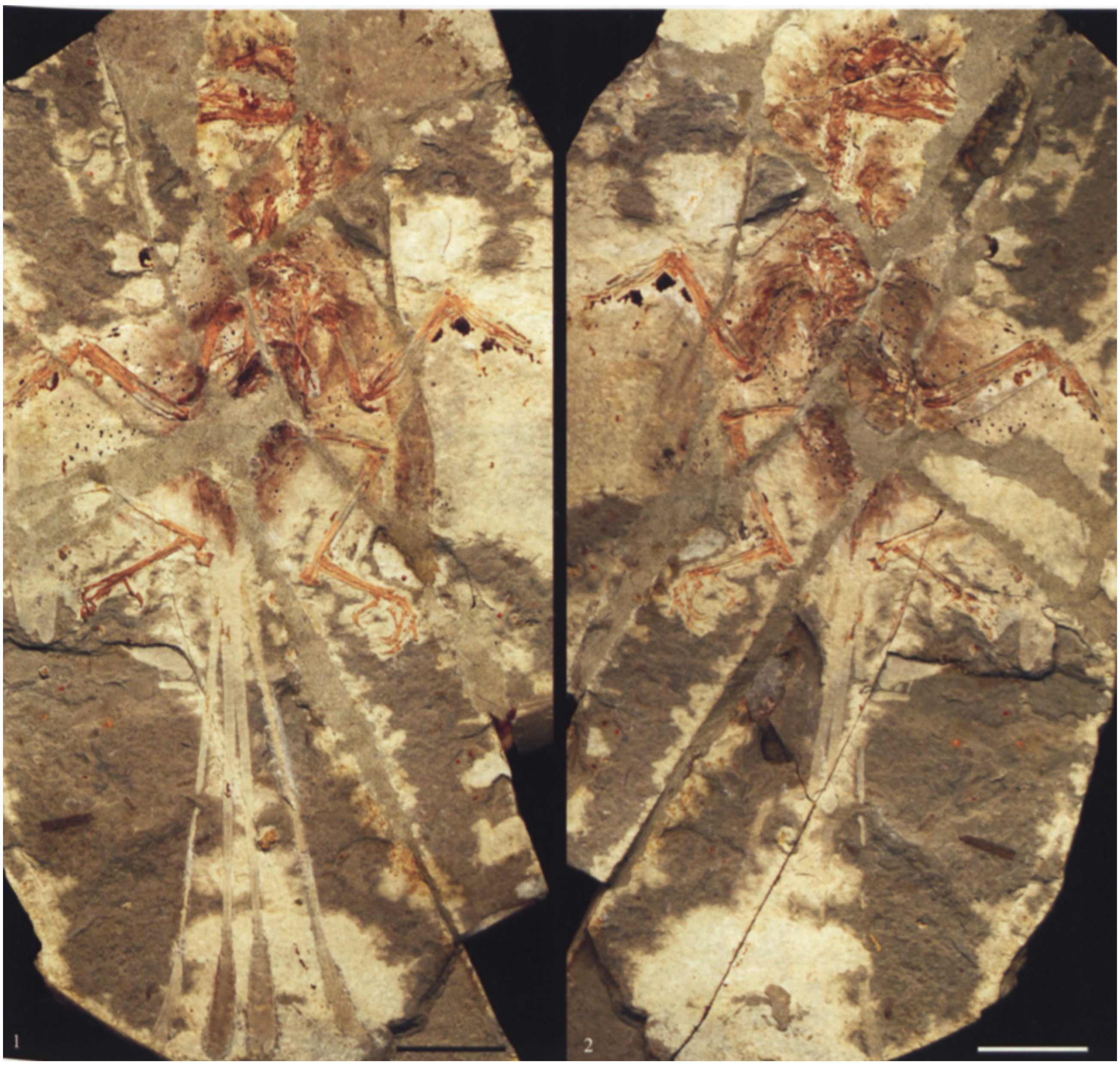
Explanation of plates

Plate I

1. Main slab of *Paraprotopteryx gracilis* gen. et sp. nov (STM V001). Scale bar, 2cm
2. Counter slab of *Paraprotopteryx gracilis* gen. et sp. nov (STM V001). Scale bar, 2cm



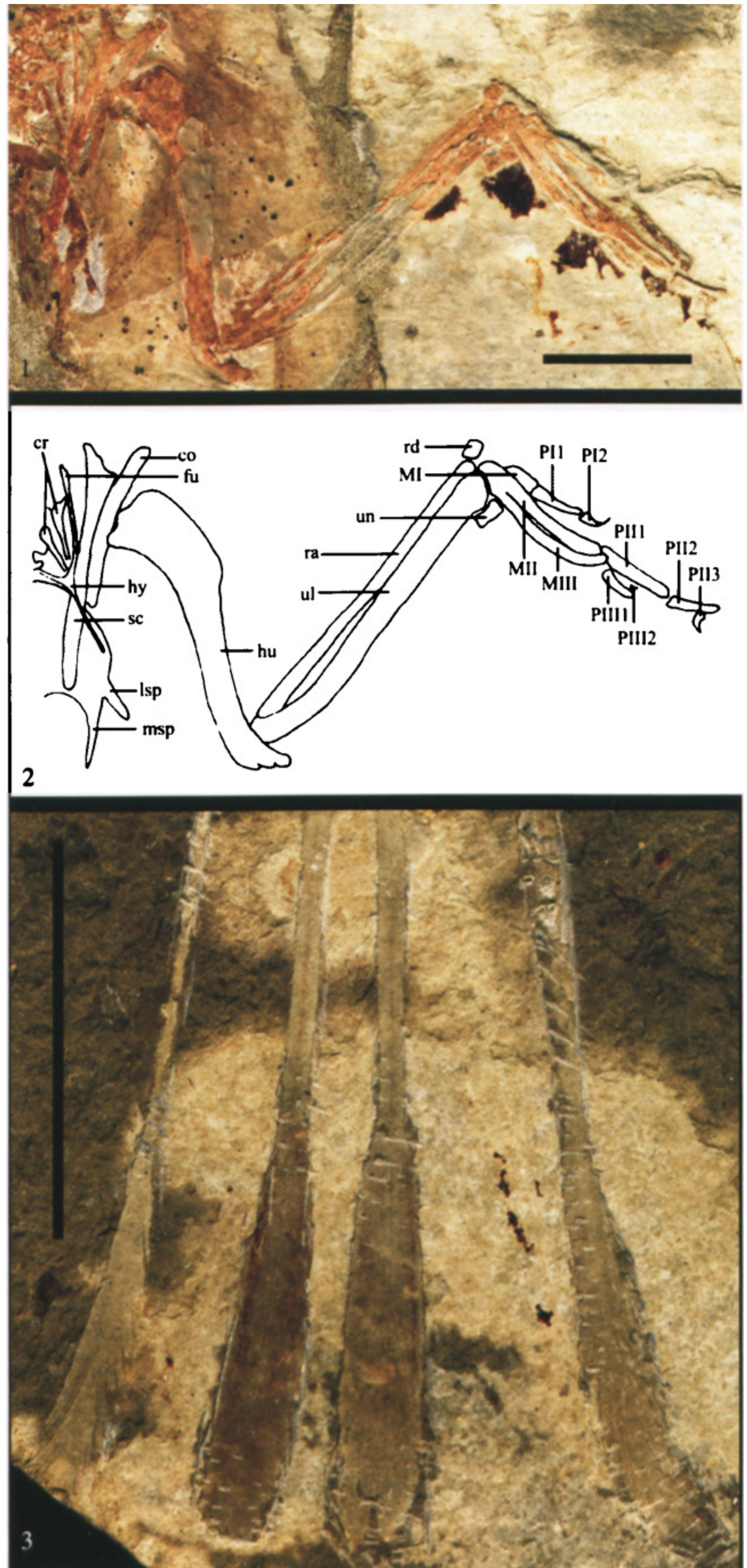


Plate II

1. Sternum, pectoral girdle and forelim of *Paraprotopteryx gracilis*. Scale bar, 1cm
2. Line drawing of sternum, pectoral girdle and forelim of *Paraprotopteryx gracilis*

   Abbreviation: co, coracoid; cr, cervical ribs; fu, furcula; hu, humerus; hy, hypocleideum; lsp, lateral sternal process; msp, medial sternal process; MI, alular metacarpal; MII, major metacarpal; MIII, minor metacarpal; PI1, first phalanx of digit I; PI2, second phalanx of digit I; PII1, first phalanx of digit II; PII2, second phalanx of digit II; PII3, third phalanx of digit II; PIII1, first phalanx of digit III; PIII2, second phalanx of digit III; ra, radius; rd, radiale; sc, scapula; ul, ulna; un, ulnare.
3. Diatal end of the rectrices of Paraprotopteryx gracilis. Scale bar, 2cm