

A second enantiornithean (Aves: Ornithothoraces) wing from the Early Cretaceous Xiagou Formation near Changma, Gansu Province, People's Republic of China

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Abstract: A new specimen of an enantiornithean bird from the Lower Cretaceous Xiagou Formation of Gansu Province, northwestern China, consists of an articulated distal left humerus, ulna, radius, carpus, and manus. The specimen may represent a primitive enantiornithean because it lacks a longitudinal sulcus on the radius, has incompletely fused alular and major metacarpals, and possibly retains a remnant of a second phalanx on the minor digit. It differs from all other known enantiornitheans, and exhibits possible autapomorphies, including peculiar, flat humeral epicondyles, a pair of eminences on the distal minor metacarpal, and an enormous flexor tuberculum on the alular ungual. The specimen probably pertains to the same taxon as a previously described enantiornithean arm from Changma; the incompleteness of the taxon precludes erecting a new name, but it provides new information concerning enantiornithean diversity in the Early Cretaceous of central Asia.

Résumé : Un nouveau spécimen d'un oiseau enantiornithien de la Formation de Xiagou du Crétacé inférieur de la province de Gansu, du nord-ouest de la Chine, consiste en un humérus distal gauche articulé, un cubitus, un radius, un carpe et une paume. L'absence d'un sillon longitudinal sur le radius, la fusion incomplète de l'alulaire et des métacarpiens majeurs, ainsi que la présence possible d'une deuxième phalange vestigiale sur le doigt mineur pourraient indiquer qu'il s'agit d'un enantiornithien primitif. Le spécimen se distingue de tous les autres enantiornithiens connus et présente possiblement des autapomorphies dont de singuliers épicondyles aplatis de l'humérus, une paire d'éminences sur le métacarpien mineur distal et un énorme tubercule fléchisseur sur l'unguéal alulaire. Ce spécimen est probablement associé au même taxon qu'un bras enantiornithien provenant de Changma décrit précédemment. Étant donné la nature incomplète du taxon, il est impossible de proposer un nouveau nom, mais le spécimen fournit toutefois des nouvelles données sur la diversité des oiseaux enantiornithiens durant le Crétacé précoce en Asie centrale.

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Introduction

Taxa pertaining to the avian clade Enantiornithes are widely recognized as the most common and diverse birds of the Cretaceous Period. Though the first discovered fossils now attributed to the clade are from Upper Cretaceous sediments (Brodkorb 1976; Elzanowski 1976, 1977; Walker 1981), most of the best known enantiornitheans have been recovered from Lower Cretaceous sediments, particularly in Spain (Sanz et al. 2002) and Jehol Biota-bearing deposits in northeastern China (Gong et al. 2004; Hou et al. 2004; Zhang et al. 2004; Zhou and Hou 2002). Historically, however, Early Cretaceous birds in China were initially represented by the fragmentary

non-enantiornithean ornithothoracean *Gansus yumenensis* from the Xiagou Formation in western Gansu Province, northwestern China (Hou and Liu 1984). Following its description, a nearly two-decade long hiatus followed, in which no new birds were discovered in Gansu.

In 2004, a collaborative expedition led by researchers from the Chinese Academy of Geological Sciences and Carnegie Museum of Natural History revisited these Xiagou Formation outcrops (Fig. 1) and recovered numerous partial to nearly complete avian skeletons, several preserving feather and soft-tissue impressions. Of these, two enantiornithean specimens have already been briefly described (O'Connor et al. 2004; Lamanna et al. 2005; You et al. 2005). Here a third speci-

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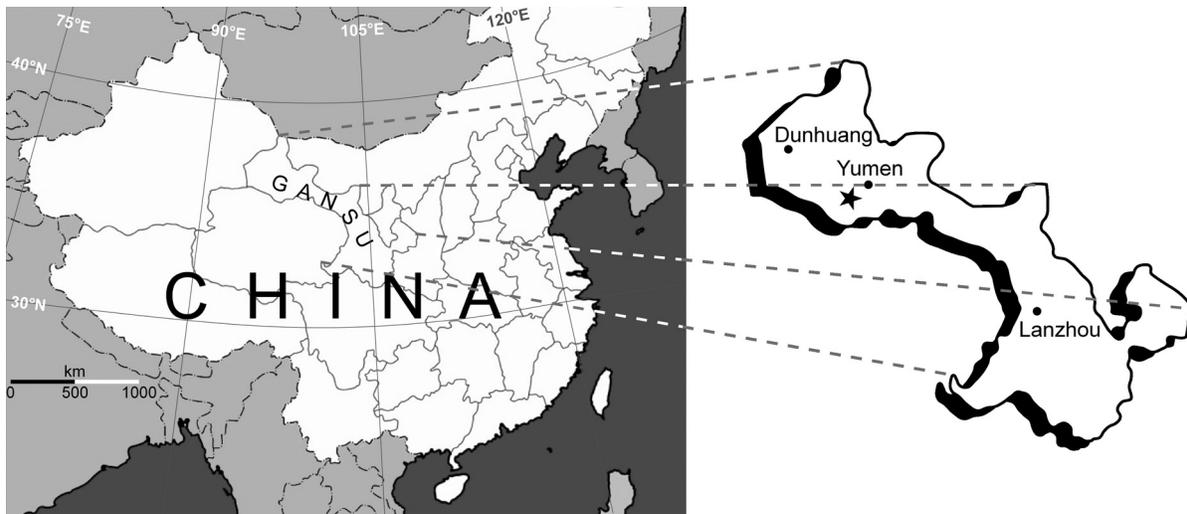
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Fig. 1. Locality (star) from which CAGS-IG-04-CM-023 was recovered near Changma, Gansu Province, People's Republic of China.



men, an incomplete, articulated forelimb of a finch-sized enantiornithean, is described.

The specimen is clearly avian because it possesses a carpometacarpus in which the semilunate carpal is fused to at least the major and minor metacarpals (Chiappe 2002). It demonstrably pertains to the Ornithothoraces because its alular digit does not surpass the major metacarpal in length (Chiappe 2002). The specimen can be assigned to the Enantiornithes because its minor metacarpal extends further distally than the major metacarpal. The radius appears to lack the sulcus on its interosseous surface that may be autapomorphic of the Euenantiornithes (Chiappe and Walker 2002). The specimen also lacks diagnostic ornithuromorph characters, such as a wide interosseous space and a carpometacarpus with distally fused major and minor metacarpals. Three-dimensional preservation allows for especially detailed morphological observations.

Terminology

Because the specimen described herein pertains to a bird, osteological terminology used herein follows Baumel and Witmer (1993). The term “enantiornithean,” rather than “enantiornithine,” is used herein as an informal shorthand for a member of the clade Enantiornithes because the latter implies the existence of, and membership in, a clade “Enantiornithinae” despite the fact that no such clade has ever been recognized. Similarly, “ornithothoracean” is used instead of “ornithothoracine” because there is no clade “Ornithothoracinae,” only Ornithothoraces. The same logic applies to “ornithuran” versus “ornithurine” for Ornithurae, as well as “neornithean” versus “neornithine” for Neornithes and “galloanseran” versus “galloanserine” for Galloanserae, although the latter clade is not discussed herein. This pattern conforms to prevalent usage for other avian and nonavian theropod clade names with similar suffixes (e.g., “avian” rather than “avine” for Aves, “avialan” rather than “avialine” for Avialae, and “tetanuran” rather than “tetanurine” for Tetanurae) and brings paleornithological terminology into congruence with the nomenclature of other organisms (e.g., “gnetalean” for Gnetales, “aranean” for Araneae, “schizacean” for Schizaceae, etc.).

Abbreviations

CAGS-IG, Chinese Academy of Geological Sciences, Institute of Geology, Beijing, China.

Systematic Paleontology

Aves Linneus, 1758 (Avialae sensu Gauthier 1986)
 Pygostylia Chatterjee, 1997 (sensu Chiappe 2002)
 Ornithothoraces Chiappe, 1995
 Enantiornithes Walker, 1981
 Taxon indet.
 (Figs. 2–4)

SPECIMEN: CAGS-IG-04-CM-023 (hereinafter CM-023 for the sake of brevity), an incomplete, articulated left thoracic limb, consists of a distal humerus and complete ulna, radius, carpus, carpometacarpus, and manual digits.

LOCALITY: Near the town of Changma in the Changma Basin of northwestern Gansu Province, China (Fig. 1).

HORIZON: Lower Cretaceous (?Aptian–Albian) Xiagou Formation, middle unit of the Xinminpu Group.

DESCRIPTION:

Humerus: The preserved portion of the humerus (Figs. 2, 3) is exposed in cranioventral view and measures 21.8 mm. The shaft is roughly circular in cross section and expands mediolaterally to a width of about 5.9 mm across the epicondyles a short distance proximal to the distal end. Proximal to the condyles, a shallow, triangular fossa embays the cranial surface (Fig. 3) that tapers proximally. This fossa may be homologous with the brachial fossa, although it is shallow and smooth rather than a distinct scar like the brachial fossa of neornithean birds. The ellipsoidal dorsal and ventral condyles are subequal in size. The condyles lie immediately adjacent to one another, with only a shallow intercondylar sulcus between them. Both condyles are offset from the humeral long axis toward the ventral side of the humerus. Relative to the longitudinal axis of the humerus, the ventral condyle parallels the entire humeral distal margin with its long axis

Fig. 2. CAGS-IG-04-CM-023, articulated distal humerus, ulna, radius, carpus, and manus of *Enantiornithes* indet. in ventral view.

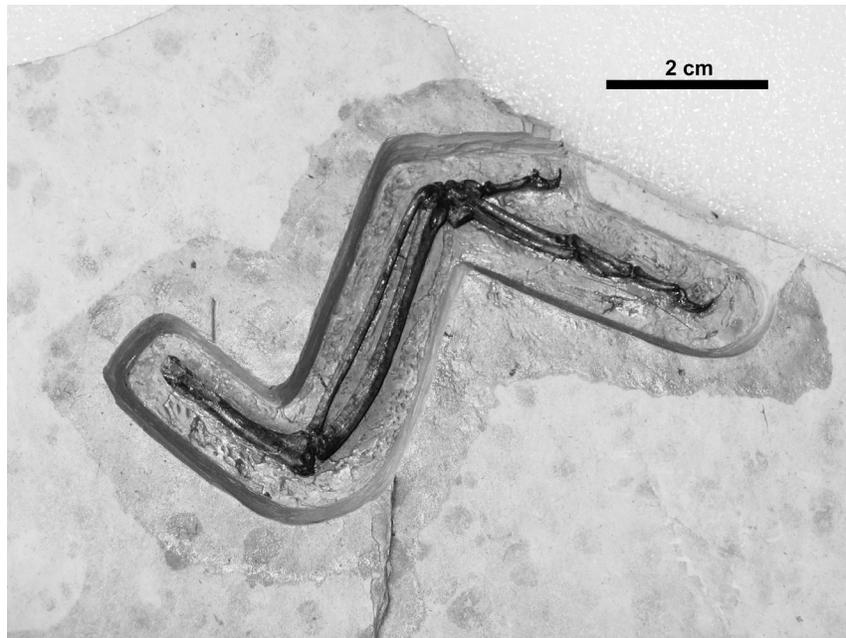
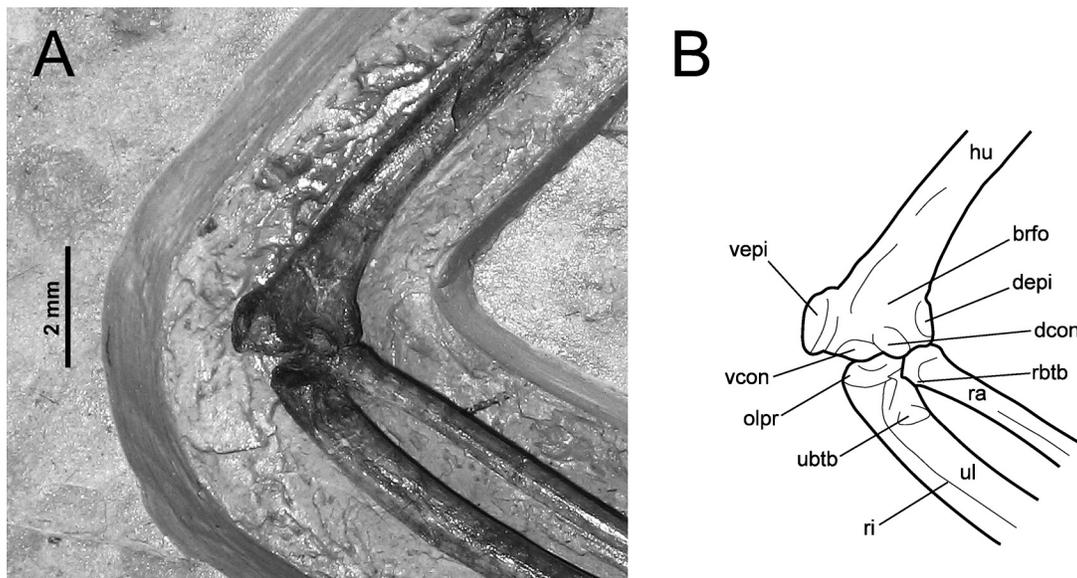


Fig. 3. (A) Photograph and (B) schematic of distal humerus and proximal ulna and radius. brfo, brachial fossa; dcon, dorsal condyle; depi, dorsal epicondyle?; hu, humerus; olpr, olecranon process; ra, radius; rbtb, biceps tubercle of the radius; ri, ridge; ubtb, biceps tubercle of the ulna; vcon, ventral condyle; vepi, ventral epicondyle?

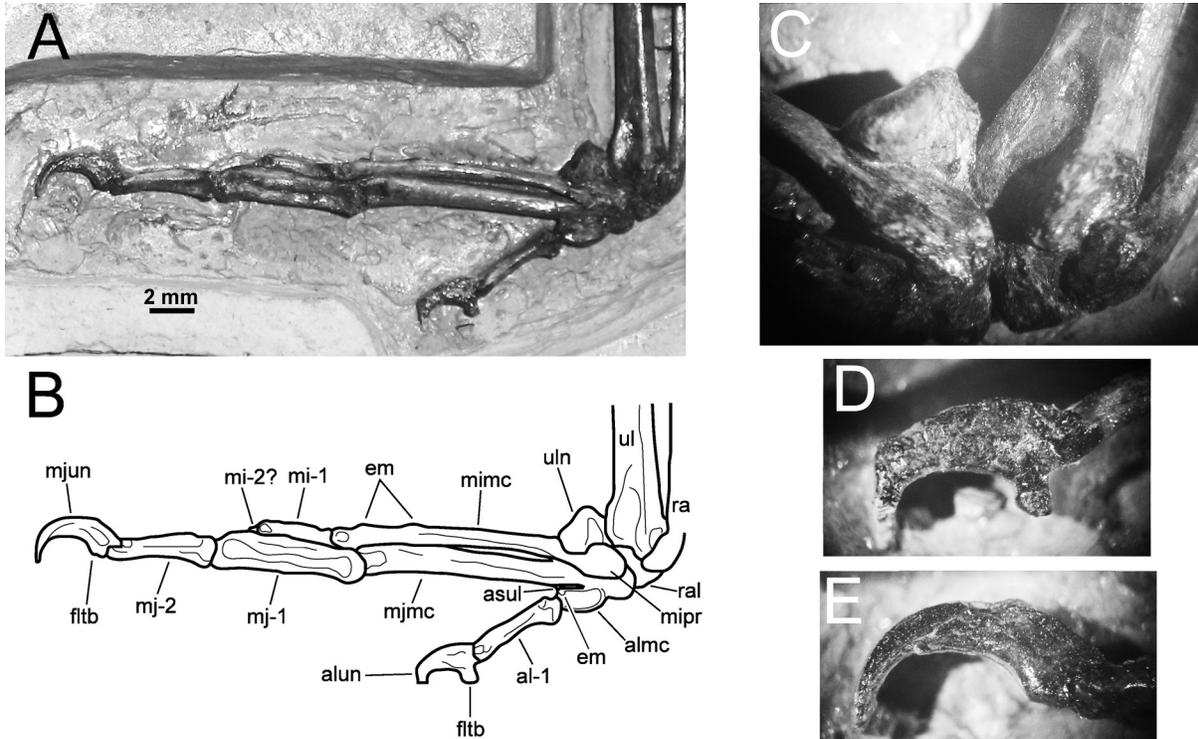


oriented distoventrally–proximodorsally. In contrast, the dorsal condyle is oriented more horizontally, closer to perpendicular to the long axis of the humeral body. The dorsal condyle also sits in a slightly more proximal position than the ventral; its proximal margin thus invades the brachial fossa. The ventral condyle instead faces almost entirely distally. The ventral side of the distal end bears a large, circular, flat-topped but modestly rugose eminence in place of a typical, protuberance-style ventral epicondyle. Dorsal to the dorsal condyle, the distal humerus is attenuated into a relatively long process. At the dorsalmost visible margin, there is a short, cranioventrally projecting ridge that demarcates the

edge of a flat, craniodorsally facing, slightly elevated platform that may represent a dorsal epicondyle.

Ulna: The 33.6 mm long ulna (Figs. 2, 3, 4A–4C) appears to have rotated slightly dorsally from its articulation with the humerus and radius and is thus exposed in ventromedial view. Its shaft is bowed caudally for its proximal one-third, but straightens distal to that. The articular cotyle is triangular and canted proximocaudally–distocranially. The slightly concave articular surface is not obviously divided into distinct cotyles, though the accessory processes associated with such cotyles still exist. The olecranon process consists of a very

Fig. 4. (A) Photograph and (B) schematic of distal ulna and radius, carpus, and manus. (C) Close-up of ulnare (overlaps proximal minor metacarpal and overlapped by distal ulna). (D) Close-up of alular digit ungual. (E) Close-up of major digit ungual. al-1, alular digit, phalanx 1; almc, alular metacarpal; alun, alular digit ungual; asul, sulcus separating alular and major metacarpals; em, eminence; fltb, flexor tuberculum; mi-1, minor digit, phalanx 1; mi-2?, minor digit, phalanx 2?; mimc, minor metacarpal; mipr, process of proximal minor metacarpal that overlaps proximal major metacarpal; mj-1, major digit, phalanx 1; mj-2, major digit, phalanx 2; mjmc, major metacarpal; mjun, major digit ungual; ra, radius; ral, radiale, ul, ulna; uln, ulnare.



short, blunt, rounded protuberance. The dorsal cotyle is hidden by the humerus and radius; the ventral cotyle extends onto a flat, roughly circular protrusion. There is no fossa distal to the ventral cotyle for the *M. brachialis*. The radial incisure is demarcated at its proximal end, immediately distal to the articular cotyles, by a shallow, oblong fossa that is bounded distally by a low, transversely oblong ulnar bicapital tubercle (Fig. 3). A low ridge, more pronounced proximally than distally, runs the length of the ulnar ventral surface from the ventral cotyle to the ventral condyle at the distal end. The ulnar body is 2.2 mm wide at midshaft and featureless, lacking papillae or other features except the aforementioned ridge. The caudoventral surface of the distal end bears a shallow, proximally tapering, triangular fossa that separates the ventral and dorsal condyles and is contiguous with the carpal trochlea (Figs. 4A–4C). A small, shallow fovea occupies the ventral surface of the ventral condyle. The precise morphology of the condyles is uncertain because they are covered by the radius, ulnare, and minor metacarpal.

Radius: The ventrally exposed radius (Figs. 2, 3, 4A–4C) is straight and measures 32.2 mm; although absolutely shorter than the ulna, it protrudes a bit further distally than the latter. The proximal end of the radius is only slightly more expanded dorsoventrally than the main body; its articular cotyle cannot be seen. A radial bicapital tubercle is present as a low, axially elongate intumescence on the caudoventral side of the proximal

end (Fig. 3). At midshaft, the element is 1.3 mm wide and is wider craniocaudally than dorsoventrally. The distal end also expands dorsoventrally and hooks caudally and wraps around the end of the ulna (Figs. 4A–4C). Although not visible in articulation, a portion of the radius was temporarily removed so its opposing surface could be clearly viewed; it lacks a longitudinal sulcus on its interosseous margin.

Carpals: A small, thin, flat bone, disarticulated and lying between the caudal surfaces of the distal ulna and the minor metacarpal (Figs. 4A–4C) is similar in morphology to the ulnare of *Sinornis santensis* as identified by Sereno et al. (2002, fig. 8.3); because of this similarity and because of its position in the specimen, it is herein identified as that element. It appears to be broadly crescentic (boomerang-shaped), but whether or not the crescent is symmetrical cannot be ascertained because one end is hidden under the distal ulna. Its proximal surface bears a shallow sulcus that bisects the crescentic shape. The visible arm of the element twists along its axis from being flattened proximodistally near the center of the bone to being craniocaudally compressed at its distal end. A second, probably smaller carpal, almost certainly the radiale, is visible in articulation primarily with the distal radius, though it also contacts the distal ulna as well (Figs. 4A–4C). Its morphology cannot be discerned.

Carpometacarpus: The carpometacarpus (Figs. 4A, 4B) has a maximum length of 17.1 mm from its carpal trochlea

(which is hidden by the distal ulna and radius and proximal minor metacarpal) to the distal end of the minor metacarpal; it is 15.7 mm along the major metacarpal. All metacarpals, as well as their associated digits, are exposed in ventral view, except the unguals, which are exposed in lateral view, having been compressionally rotated into the same plane as the remainder of the fossil. Details of the proximal articular surface cannot be seen due to the articulation of the element with the ulnare and distal ulna and radius.

Alular digit: The 2.8 mm long and 1.3 mm wide alular metacarpal (Figs. 4A, 4B) is a subrectangular, blocky element that appears to be fused to the major metacarpal at its proximalmost end but is separated for the remainder of its length by a deep sulcus, possibly indicating that it was not fused distally. Whether this constitutes a plesiomorphy or is a function of the ontogenetic stage of the individual cannot be determined. The lateral surface of this element is straight, paralleling the major metacarpal, but its medial surface is convex, especially at its proximal end, where it tapers to a blunt point, rendering the bone wider at its distal, accondylar end. The entire ventral surface of the bone is occupied by a shallow, longitudinal sulcus, and there is no extensor process. The distal end also appears dorsoventrally thicker because of a small eminence that forms its distolateroventral corner.

The alular digit (Figs. 4A, 4B) is 9.0 mm long and consists of a 5.6 mm long first phalanx and a strongly recurved, 4.1 mm long ungual (the additive lengths of the phalanges is greater than the provided length of the digit because the ungual was measured using the method of Sereno et al. (2002, p. 189)). The phalanx is very slender and gently curved. Its proximal articular surface is ginglymoid (more planar than cotylar) and broader than the rest of the element; its distal end is trochlear and has a small collateral ligament pit. The sharply recurved ungual (Figs. 4A, 4B, 4D) bears a remarkably pronounced, rectangular flexor process. The bone is somewhat crushed, but appears to have borne a lateral sulcus at least at its proximal end. Its distal end is missing, but appears to have protruded further cranially than the flexor process.

Major digit: The major metacarpal (Figs. 4A, 4B), the most robust bone of the carpometacarpus, is straight and has a subcircular shaft cross-sectional shape, except at its proximalmost end. Adjacent to the alular metacarpal, the cranial surface of the major metacarpal slopes ventrally, flattening the element and contributing to the marked width of the deep sulcus between it and the alular metacarpal. Its distal end is only slightly expanded. Its length (not including the carpal trochlea) is 14.1 mm and, at midshaft, its width is 1.2 mm. The ventral surface of the distal end is embayed by a shallow sulcus; both the proximal and distal ends of the groove deepen into small pits.

The major digit is 18.4 mm long, longer than the alular digit by 204% and the minor digit by 368%. Its first phalanx is 7.9 mm; the second phalanx is 6.1 mm, and the ungual is 5.2 mm (measured as the alular ungual, earlier in the text). The first phalanx (Figs. 4A, 4B) resembles its metacarpal by being a broad, robust, rectangular element whose proximal and distal ends are approximately the same width as the inter-

vening shaft. A shallow, longitudinal sulcus is the predominant feature on the ventral surface. The second phalanx has a more typical phalangeal morphology, but tapers because its distal end is much narrower than its proximal end. Like the first phalanx, the ventral surface is marked by a shallow sulcus, but it occupies only the proximal end of the bone (Figs. 4A, 4B). As with the first alular phalanx, the element is arched (ventrally concave) and has a small collateral ligament pit at its shallowly trochlear distal end. The ungual (Figs. 4A, 4B, 4E) has a much smaller flexor tuberculum than its alular counterpart. On the proximal half of the bone, a shallow vascular sulcus is visible on the lateral surface. The claw tapers gradually to a sharp point and is so recurved that its ventral surface is nearly “U”-shaped.

Minor digit: The body of the minor metacarpal (Figs. 4A, 4B) is straight and parallels that of the major metacarpal; it is separated from that element for most of its length by a narrow, gradually distally tapering intermetacarpal space. About three-fourths along the length of the carpometacarpus, the gap closes and the major and minor metacarpals are in direct contact from this point distally. The proximal end of the minor metacarpal is strongly flattened craniocaudally and includes a relatively long, rounded process that wraps ventrally around the proximal end of the major metacarpal (Figs. 4A, 4B). The flattening persists for about two-fifths the length of the element; distal to that, the bone appears to revert to a more typical, gently tapering, subcylindrical morphology. Distal to the flattened portion, the width of the bone is roughly 0.8 mm, about two-thirds that of the major metacarpal. The entire bone is arched (ventrally concave). At a point even with the distal terminus of the intermetacarpal space, the caudal surface of the minor metacarpal bears a very low, rounded eminence. A second, more pronounced eminence lies on the caudal surface slightly proximal to the distal end, even with the distal end of the major metacarpal. This tubercle gives the distalmost end of the metacarpal the impression of being kinked medially. Neither tubercle appears to represent a healed fracture. There is no collateral ligament pit.

Only a single phalanx of the minor digit is clearly visible; it is 5.0 mm long. The distal end of the phalanx is somewhat damaged, but appears inflated and bears a large and deep collateral ligament pit. If this interpretation is correct, then there is a tiny, tapering, blunt nubbin of bone attached to, but demarcated by a visible line from, the end of the element that may represent the remnant of a second phalanx (Figs. 4A, 4B).

Anatomical Comparisons

Brachial fossae on the distal humeri were reported absent in *Enantiornis leali* (Walker 1981), *Concornis lacustris* (Sanz et al. 1995), *Neuquenornis volans* (Chiappe and Calvo 1994), *Kizylkumavis cretacea* (Kurochkin 2000; Nessov 1984), and *Gobipteryx minuta* (Kurochkin 1996) (including “*Nanantius valifanovi*” sensu Chiappe et al. 2001), unlike in CM-023. The distal articular condyles in CM-023 are closely appressed and roughly centered on the humeral long axis; in *Eocathayornis walkeri* (Zhou 2002), the condyles are both closer to the

ventral margin of the humerus, whereas in *Enantiornis* and several other, unassigned humeri from the Upper Cretaceous Lecho Formation of Argentina, either the dorsal condyle or both condyles are very close to the dorsal margin (Chiappe and Walker 2002). The acute angle subtended by the long axes of the humeral distal condyles in CM-023 renders it more similar to *Cathayornis yandica* (Zhou and Hou 2002), *Eocathayornis* (Zhou 2002), and *Vescornis hebeiensis* (Zhang et al. 2004) than to many other enantiornitheans, such as those from the Lecho Formation, in which the condylar long axes are close to parallel (Chiappe and Walker 2002).

The ulna:radius width ratio of CM-023 (1.7) is similar to that of *Longipteryx chaoyangensis* (Zhang et al. 2001), smaller than the typical, approximately 2.0 ratio reported for most other enantiornitheans, including *Eoenantiornis buhleri* and the possibly basal (sensu Chiappe and Walker 2002 and Zhang and Zhou 2000, respectively) *Iberomesornis romerali* and *Protopteryx fengningensis* (Chiappe and Walker 2002; Elzanowski 1981; Gong et al. 2004; Hou et al. 2004; Sanz et al. 1995, 1996, 2002; Sereno 2000; Sereno et al. 2002; Zhang and Zhou 2000; Zhou and Hou 2002; Zhou et al. 2005), but is greater than the subequal dimensions reported for *Noguerornis gonzalezi* (Chiappe and Lacasa-Ruiz 2002), the ratio of roughly 1.3 reported for *Eocathayornis* (Zhou 2002), and the ratio of about 1.5 in *Cathayornis* (Zhou and Hou 2002). There is no pit on the olecranon process of CM-023 like the one reported in *Alexornis antecedens* (Brodkorb 1976). The articular cotyles of the proximal ulna are not separated in CM-023 by a sulcus like they are in *Concornis*, *Eoenantiornis*, and *Enantiornis* (Chiappe and Walker 2002; Zhou et al. 2005). *Concornis* and *Neuquenornis* are the only other enantiornitheans for which an ulnar bicipital tubercle has been reported (Chiappe and Calvo 1994; Sanz et al. 1995); rather than representing a true, phylogenetically informative character, the “absence” of this structure in other taxa could be due to preservational issues or to the fact that several enantiornitheans have, as yet, received only preliminary descriptions.

The 0.51 ratio of carpometacarpus:ulna length in CM-023 is slightly larger than those reported for *Cathayornis* and *Eoenantiornis* but apparently smaller than in *Confuciusornis* and more derived birds (Hou et al. 1999; Zhou et al. 2005). A more rectangular than circular shape of the alular metacarpal is shared among CM-023, *Eoenantiornis*, and *Longipteryx chaoyangensis* (Chiappe and Walker 2002). The ratio of its length to that of the major metacarpal in CM-023 (0.2) is similar to that reported for *Vescornis* (Zhang et al. 2004) but smaller in CM-023 than in either *Longipteryx* or *Protopteryx* (roughly 0.25) (Zhang and Zhou 2000; Zhang et al. 2001). Apparent lack of fusion between the alular and major metacarpal, as in CM-023, was also reported in *Vescornis* (Zhang et al. 2004) and may be inferred from its disarticulation in *Sinornis* (Sereno et al. 2002). Metacarpals of approximately equal length were also reported as unfused in *Otogornis genghisi* (Hou 1994), both conditions dissimilar to CM-023.

A sulcus on the first phalanx of the major metacarpal, with a pit at its proximal end, was also reported in *Sinornis santensis* and *Eoalulavis hoyasi* (Sereno et al. 2002). The manual claws of CM-023 are much more recurved than those of other enantiornitheans for which the morphology has been described, including *Sinornis* (Sereno et al. 2002). Alular

ungual morphology in *Eoenantiornis* has been described only as “curved” and “sharp” (Zhou et al. 2005); it is depicted as having a relatively large flexor tuberculum and being relatively recurved, possibly rivalling the condition in CM-023 (Hou et al. 1999; Fig. 1B). The existence of a possible rudimentary second phalanx on the minor digit was reported in *Longipteryx* (Zhang et al. 2001) and posited for the euenantiornithean *Sinornis* (Chiappe and Walker 2002; Sereno et al. 2002); the minor digit was reported to possess a greatly reduced ungual as a second phalanx in *Eocathayornis* (Zhou 2002) which, if correct, would imply that two intervening phalanges were lost in this taxon. An ungual on the minor digit was reported to follow two phalanges in *Jibeinia luanhera* (Hou 2000, pp. 54, 56).

The marked curvature of the manual unguis warrants comment. Peters and G6rgner (1992) demonstrated that strongly recurved claws (albeit pedal claws) typically characterize (but are not limited to) trunk-climbing, cliff-climbing, and predatory birds; sharply pointed unguis are also characteristic of trunk- and cliff-climbers. It may thus be postulated that the Xiagou Formation taxon represented by CM-023 utilized its manus as an aid in grasping tree trunks and (or) branches during arboreal ambulation. This is not to say that this was the sole function of the unguis — they may also have been utilized in such behaviors as grasping or grooming (Rietschel 1985). Given that some non-avian theropods (particularly some small deinonychosaurs) also exhibit features interpreted as arboreal adaptations (Xu et al. 2000; Zhang et al. 2002), both this morphology and postulated behavior in the taxon represented by CM-023 could be plesiomorphic retentions. However, Peters and Ji (1999) and Chiappe et al. (1999) note that marked manual ungual recurvature is also plesiomorphic, retained from dinosaurian ancestors (and retained in other deinonychosaurs) that were not arboreal, weakening the correlation between claw curvature and behavior. Nevertheless, ungual curvature in CM-023 appears to be greater than in more basal avians, such as *Confuciusornis* (Chiappe et al. 1999), which suggests that retention, and possibly increase, of marked curvature was selected for in this taxon and indicates that manual claw function, whatever it may have been, was important in its behavior.

Discussion

Although both consist of enantiornithean forelimbs and possess numerous overlapping elements, comparison of CAGS-IG-04-CM-023 with the somewhat larger CAGS-IG-02-0901 (O'Connor et al. 2004; You et al. 2005) is rendered difficult by the poorer preservation and the absence of the possibly autapomorphic alular ungual in the latter. There are no features in CM-023 that differentiate it from CAGS-IG-02-0901; indeed, both lack an interosseous sulcus on the radius. While this feature (if indeed a symplesiomorphy) cannot be used to unite these specimens in a single taxon, the rarity of this feature among enantiornitheans — reported elsewhere only in the basal taxon *Noguerornis gonzalezi* from the Barremian of Spain (Chiappe and Lacasa-Ruiz 2002) — makes such conspecificity tempting. However, the two specimens differ somewhat in their proportions: the ulna and radius of CM-023 are each about 68% the lengths of their counterparts in CAGS-IG-02-0901, but most of the manual elements

consistently measure between 70% and 80% the lengths of those in CAGS-IG-02-0901. The exceptions are the first phalanges of the alular and minor digits, which are 170% and 109% the lengths of the corresponding phalanges in CAGS-IG-02-0901, respectively. Whether these differences are taxonomic or ontogenetic in nature remains unknown. Until demonstrated otherwise, CM-023 is tentatively referred to the same taxon as CAGS-IG-02-0901 (*Enantiornithes* indet.). CAGS-IG-02-0901 exhibits no autapomorphies that could be used to place it in a specific taxon (existing or new) (O'Connor et al. 2004; You et al. 2005); the only potential autapomorphies identifiable in CM-023 are the peculiar, disc-like dorsal and ventral epicondyles of the humerus, the two low eminences on the lateral surface of the minor metacarpal, and the proportionately enormous flexor tuberculum on its alular ungual. Because these regions tend to be underreported in existing publications of most enantiornitheans, the status of these characters as autapomorphies in a formal phylogenetic analysis cannot be fairly assessed. Therefore, we await better material and follow You et al. (2005) in resisting the temptation to erect a new taxon based on these features. The lack of overlapping, and thus obfuscating, elements, coupled with the more three-dimensional preservation of CM-023 than CAGS-IG-02-0901, greatly improves the understanding of the morphology of this taxon.

Although it appears to represent an adult individual of markedly smaller size, it is possible that the partial euenantiornithean appendicular skeleton CAGS-IG-04-CM-007, also recovered from the Xiagou Formation (Lamanna et al. 2005) a short distance from the locality that produced CM-023, also pertains to the same taxon. Regrettably, however, no elements overlap between CM-023 and CAGS-IG-04-CM-007, precluding their direct comparison.

Conclusion

CAGS-IG-04-CM-023 provides additional information on the enantiornithean component of the Xiagou Formation avifauna. This avifauna is best known for the non-enantiornithean ornithothoracean *Gansus yumenensis*, of which more complete, articulated, as-yet undescribed specimens have been recovered from the same quarries that produced the enantiornitheans discussed herein. The fact that these quarries have produced more complete bird skeletons implies that the potential is high for recovering further material of the enantiornithean taxon represented by CM-023. Enantiornitheans remain rare in the Xiagou Formation compared with *Gansus yumenensis*; whether this is reflective of actual population statistics or some sort of taphonomic bias remains to be seen.

CM-023 exhibits characters that have previously been interpreted as primitive, including the lack of a longitudinal sulcus on the radius, possibly incompletely fused alular and major metacarpals, and a possible remnant of a second phalanx on the minor digit. However, the phylogenetic distribution of the radial sulcus is not clear, the lack of fusion at the proximal metacarpus could be ontogenetic, and a few other enantiornitheans reportedly possess a second phalanx on the minor digit, including the euenantiornithean *Sinornis*. Furthermore, the relatively short alular digit in CM-023 suggests a more derived condition for the taxon represented by the specimen. Although CM-023 possesses possibly autapomorphic features,

including the unusual morphology of the humeral epicondyles, the eminences on the minor metacarpal, and the proportionately enormous flexor tuberculum on the alular ungual, they are few and do not warrant the erection of a new taxon. In tandem with other features, they do, however, demonstrate that this taxon is not conspecific with any known enantiornithean. It thus augments the known diversity of enantiornitheans in the Early Cretaceous of central Asia. Because most other Lower Cretaceous enantiornithean specimens have been heavily compressed or split between slab and counterslab, the three-dimensional preservation of CM-023 further enhances the understanding of the thoracic limb morphology of Early Cretaceous enantiornithean birds.

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