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First discovery of large-bodied dromaeosaurid fossil materials (Dinosauria: Theropoda) from the Upper Cretaceous Quantou Formation, Songliao Basin, Northeast China

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A B S T R A C T

This paper reports the first discovery of large-bodied dromaeosaurid fossil materials (Dinosauria: Theropoda) from the lower Upper Cretaceous Quantou Formation, in Changchun area, Jilin Province. The specimens include a manual ungual and a pedal penultimate phalanx. The manual ungual is the larger of the two and laterally flattened, curved and sickle-shaped from the middle to the distal end; the pedal penultimate phalanx is strongly constricted centrally with the subcircular fossae on both sides of the trochlea located in the upper part of the geometric center of the articular arc. The available evidence indicates that these specimens likely belong to an eudromaeosaur. This new discovery provides important reference materials for studies of dromaeosaurid evolution and distribution, as well as a deeper understanding of the paleocommunity and diversity of northeast Asia during the Cretaceous Period.

1. Introduction

The Changchun area of Jilin Province, China, is one of the most important Cretaceous dinosaur fossil localities in northeast Asia. Since the early 21st century, ornithopods (including basal ornithopods and *Iguanodon*) (Chen et al., 2008; Jin et al., 2010; Chen et al., 2018), ceratopsians (Jin et al., 2009), theropods (Zan et al., 2003; Wang, 2005), sauropods (Wu et al., 2006), dinosaur egg fossils (Wang et al., 2006), crocodiles fossils (Zan et al., 2003), and eutherian fossils (Zan et al., 2006) have been unearthed from the Cretaceous Quantou Formation of this area. This vertebrate fossil assemblage was named the *Changchunsaurus* Fauna (Wang et al., 2022a), after the ornithopod *Changchunsaurus parvus*, which is the most commonly occurring taxon in the assemblage and is represented by several complete and near complete skeletons. In this paper, we report the discovery of a dromaeosaurid on the basis of very fragmentary materials, including a manual ungual and a pedal penultimate phalanx. The fossils were unearthed from the sandstone bed of the Upper Cretaceous Quantou Formation in Shanqian Village, Liufangzi Town, Gongzhuling City, Changchun Area, Jilin Province, China.

Dromaeosaurids are small to medium-sized carnivorous dinosaurs, and they occur from the Early Cretaceous to the Late Cretaceous (Turner et al., 2012). Since the middle of last century, a series of discoveries have been made in North America (Senter et al., 2012; Evans et al., 2013; Currie and Evans, 2020; Jasinski et al., 2020), South America (Novas and Puertat, 1997; Makovicky and Sues, 1998; Case et al., 2007; Brum et al., 2021), Europe (Le Loeuff and Buffetaut, 1998; Allain and Taquet, 2000; Bolotskii et al., 2019), Africa (Rauhut and Werner, 1995; Forster et al., 1998), Antarctica (Ely and Case, 2019) and Asia (Lü and Brusatte, 2015; Xing et al., 2016; Maisch and Matzke, 2020; Turner et al., 2021; Tsukiji et al., 2021). In particular, the most interesting of these discoveries are the specimens from the Lower Cretaceous Yixian Formation in Liaoning, China, many of which preserved epidermal structures, including feathers (Pei et al., 2014). These have played a key role in understanding the origins of birds (Weishampel et al., 1990), with dromaeosaurids being a

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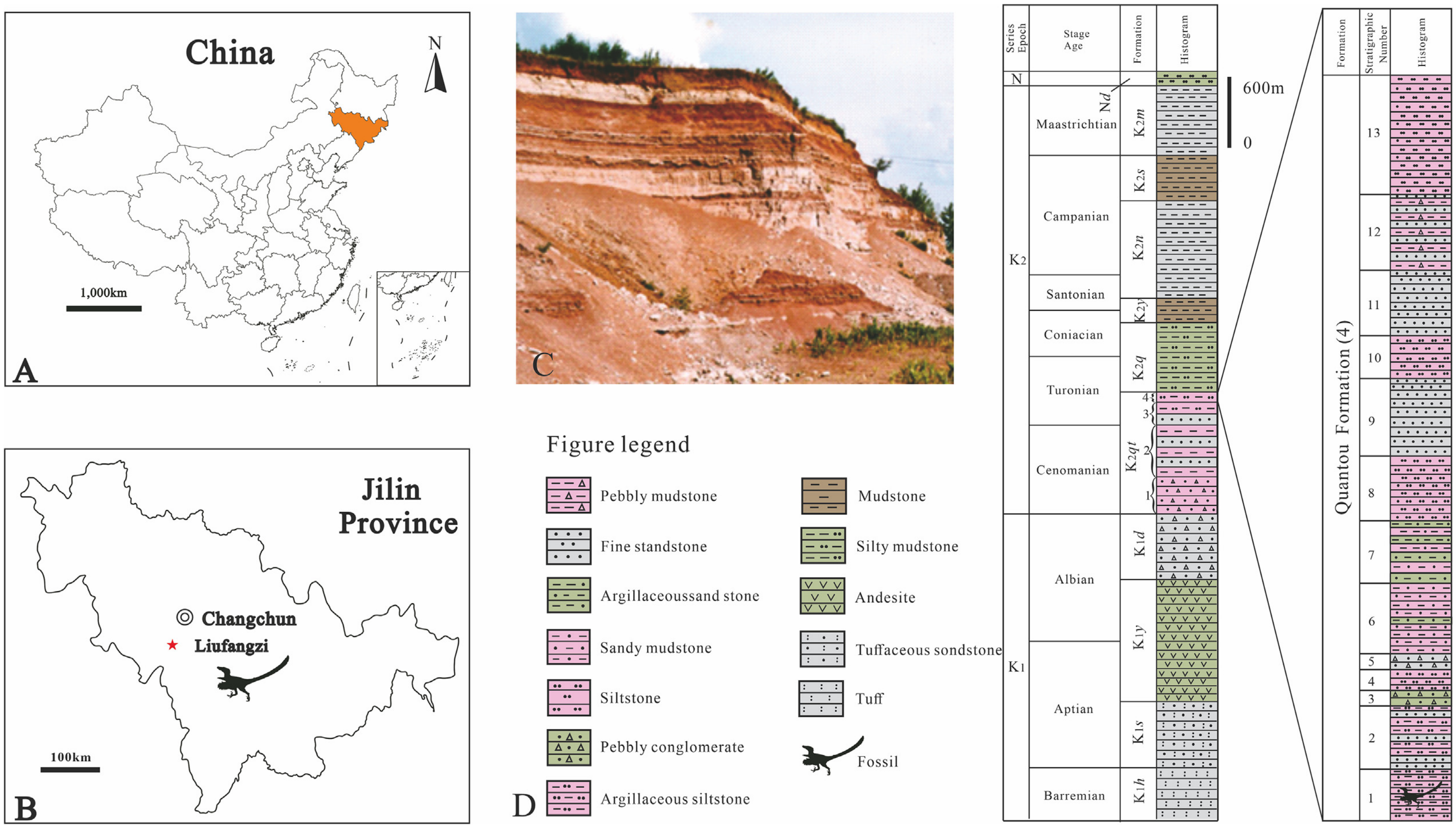

Fig. 1. The fossil site location maps and stratigraphic columns. A, B, location of the fossil materials yielding; C, stratigraphic section of fossil materials yielding; D, The stratigraphic columns of the fourth member of Quantou Formation and Cretaceous Strata in Songliao Basin, Jilin Province. K_1h, Huoshiling Formation. K_1s, Shahezi Formation. K_1y, Yingcheng Formation. K_1d, Denglouku Formation. K_2qt, Quantou Formation. K_2q, Qingshankou Formation. K_2y, Yaojia Formation. K_2n, Nenjiang Formation. K_2s, Sifangtai Formation. K_2m, Mingshui Formation. Nd, Da'an Formation.

Table 1
Measurements of the fossil materials (in millimeters).

Ungual (JLUM-D1-1)	L	WA	HA
	76	13	38
Penultimate phalanx (JLUM-D1-2)	L	DH	DW
	32	15	19

Notes: DH, Distal height; DW, Distal width; HA, The height of the articular surface; L, Maximum length between distal to proximal articular surface ventral margin in lateral view; WA, The width of the articular surface.

focus of many studies because of their close relationship to Avialae (Holtz, 2000; Norell et al., 2001).

Here we describe the detailed characteristics of two phalanx fossils from the *Changchunsaurus* Fauna in the Quantou Formation in Jilin Province. The features of these fossils suggest that the materials likely belong to a dromaeosaurid of large size. Furthermore, it is the first discovery of large-bodied dromaeosaurid fossil materials from the Cretaceous Strata of Songliao Basin, northeast China.

1.1. Institutional abbreviations

JLUM – Jilin University Museum, Changchun, Jilin Province, People's Republic of China.

2. Geological setting

The Changchun to Gongzhuling area in central Jilin Province is located at the southern margin of the Songliao Basin, which represents a Cretaceous sedimentary location in northeast China (Li, 2001). The basin is mainly filled with Mesozoic and Cenozoic strata, from bottom up as the Huoshiling Formation, Shahezi Formation, Yingcheng Formation, and Denglouku Formation of the Lower Cretaceous Period, corresponding to Barremian - Albian; the Quantou Formation, Qingshankou Formation, Yaojia Formation, Nenjiang Formation, Sifangtai Formation, Mingshui Formation, of the Upper Cretaceous, corresponding to Cenomanian - Maastrichtian; and the Paleogene, the Neogene and the Quaternary (Zhu et al., 2001; Xi et al., 2019) (Fig. 1).

The Cretaceous strata in the Songliao Basin are well-developed, widely distributed, and contain abundant vertebrate fossils (Zan et al., 2005). In particular, the vertebrate fossils are richly yielded in the Quantou Formation. The sedimentary environment of the Quantou Formation represents a freshwater system of rivers and lakes (Zhang et al., 2006). The stratum of the Quantou Formation could be subdivided into four Members from bottom to top: the first member is interbedded by purple-red siltstone, gray-white thin sandstone and purple-red gravel-bearing mudstone, formed by alluvial fans and braided river surface deposits dominated by coarse-grained debris; the second member is gray-white fine sandstone, purple-red argillaceous sandstone and gray-green mudstone, with widely developed fluvial-phase fine clastic deposits; the third member is composed of gray-white gravel-bearing sandstone, purple-red siltstone and gray-green sand conglomerate, where, like the second member, fluvial-phase clastic deposits are extensively developed; lastly, the fourth member is composed of purple-red argillaceous siltstone, mixed with gray-white siltstone, characterized by meandering river development (Li et al., 2022), and contains a large number of dinosaur and mammal fossils (Zan et al., 2003; Chen et al., 2008, 2018; Wang et al., 2022a).

The fossils we describe in this paper were collected from the fourth member of Quantou Formation. In this project, we organized a detailed field survey of the fossil site and constructed a stratigraphic column of the outcrop (Fig. 1). The exposed strata of the section can be divided into 13 layers from bottom to top according to lithology, with a total thickness of 24.92 m. It is mainly composed of siltstone, argillaceous siltstone, and sandstone, which is generally brick red and purple red in color, reflecting the hot and dry sedimentary environment. The fossils were mainly found at the bottom, especially the first layer, which is about 1.57 m thick and is purple-red argillaceous siltstone.

3. Systematic palaeontology

Theropoda Marsh, 1881
Dromaeosauridae Matthew and Brown, 1922
Eudromaeosauria Longrich and Currie, 2009

Eudromaeosauria indet.

Material. A manual ungual (JLUM-D1-1) and a pedal penultimate phalanx (JLUM-D1-2).
Locality and horizon. Shanqian Village, Liufangzi Town, Gongzhuling City, Changchun Area, Jilin Province, northeast China; Quantou Formation (lower Upper Cretaceous, Cenomanian).
Description. Ungual (JLUM-D1-1): The ungual (terminal phalanx), has a maximum length measured from the anterior and posterior edges of the retained portion of 76 mm; it is strongly curved from the middle to the distal end, with a sickle-shape (Table 1). The specimen is highly compressed laterally and teardrop-shaped in cross-section, with the middle contracted more than the upper and lower edges. The ratio of the length of the front and rear edges to the maximum width of the left and right edges is about 5.4, and the ratio of the height of the ungual to the width is about 3 (Table 1). The distal tip is missing; the keratinous sheath is not preserved; the ventral process is developed, but the flexor tubercle is weakly developed, indicating the absence of a strong flexor. There are apparent wrinkles on the flexor tubercle extending beyond the lower edge of the articular surface. The proximodorsal lip of the ungual is missing, while the proximal superior articular surface is shallow, elliptically curved in lateral view with asymmetry on both the left and right sides, and a narrow rectangular area with parallel sides in proximal view; this articulating surface is divided in half by a strong and vertical ridge; a very small portion of the lower articular surface is missing and in proportion to the upper articular surface is about twice as large (Table 1). The surface of the ungual is compressed, and the surface closer to the ventral margin collapses, causing it to be slightly deformed in dorsal view; a distinct “Y”-shaped groove is apparent on the side, and the collateral groove is located near the dorsal margin of the paw at the distal end. Although the distal end is missing, the collateral groove may have extended to the dorsal edge of the distalmost portion of the ungual. On the proximal end, the groove is close to the ventral edge of the ungual, while the opposite surface of the ungual appears almost flat, and the collateral groove is faintly present in the lower middle part of the ungual (Fig. 2A-E, A′-E′).
Penultimate phalanx (JLUM-D1-2). The isolated phalanx is relatively short. Relative to the distal and proximal ends, it is retracted in the dorsal abdomen in the middle of the phalangeal shaft, forming a deep neck. The maximum length of the anterior and posterior edges is 32 mm, and the width-to-height ratio at the distal end is 1.3 (Table 1). The proximal articular surface is attached to the matrix, while the dorsal side extends backward in a tongue shape, and the ventral extension is similar in length to the dorsal side; the distal articular surface is well-preserved. In cross-section, the phalanx appears wedge-shaped, separated by a vertical groove, and almost symmetrical on the medial and lateral sides. In lateral view, the trochlea has a downward semicircle shape. Each side of

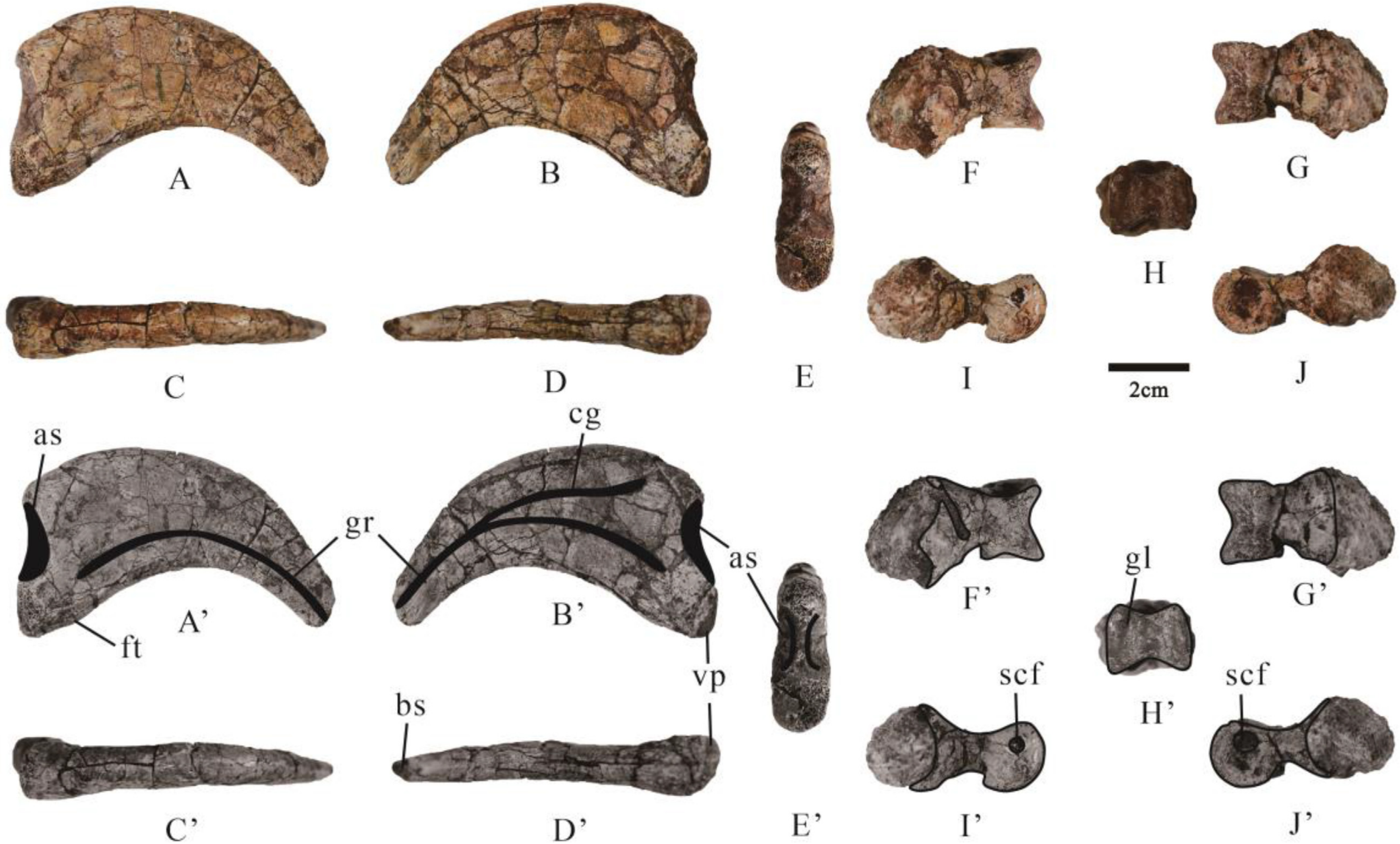

Fig. 2. Photographs of ungual (JLUM-D1-1) and penultimate phalanx (JLUM-D1-2). Ungual in medial (A), lateral (B), dorsal (C), ventral (D), posterior (E) views; penultimate phalanx in dorsal (F), ventral (G), anterior (H), lateral (I), medial (J) views. (A′) to (J′) are corresponding images in black and white with labels. Abbreviations: as-articular surface, bs-broken surface, cg-collateral groove, ft-flexor tubercle, gl-ginglymoid articular, gr-groove for ungual sheath, scf-subcircular, vp-ventral process.

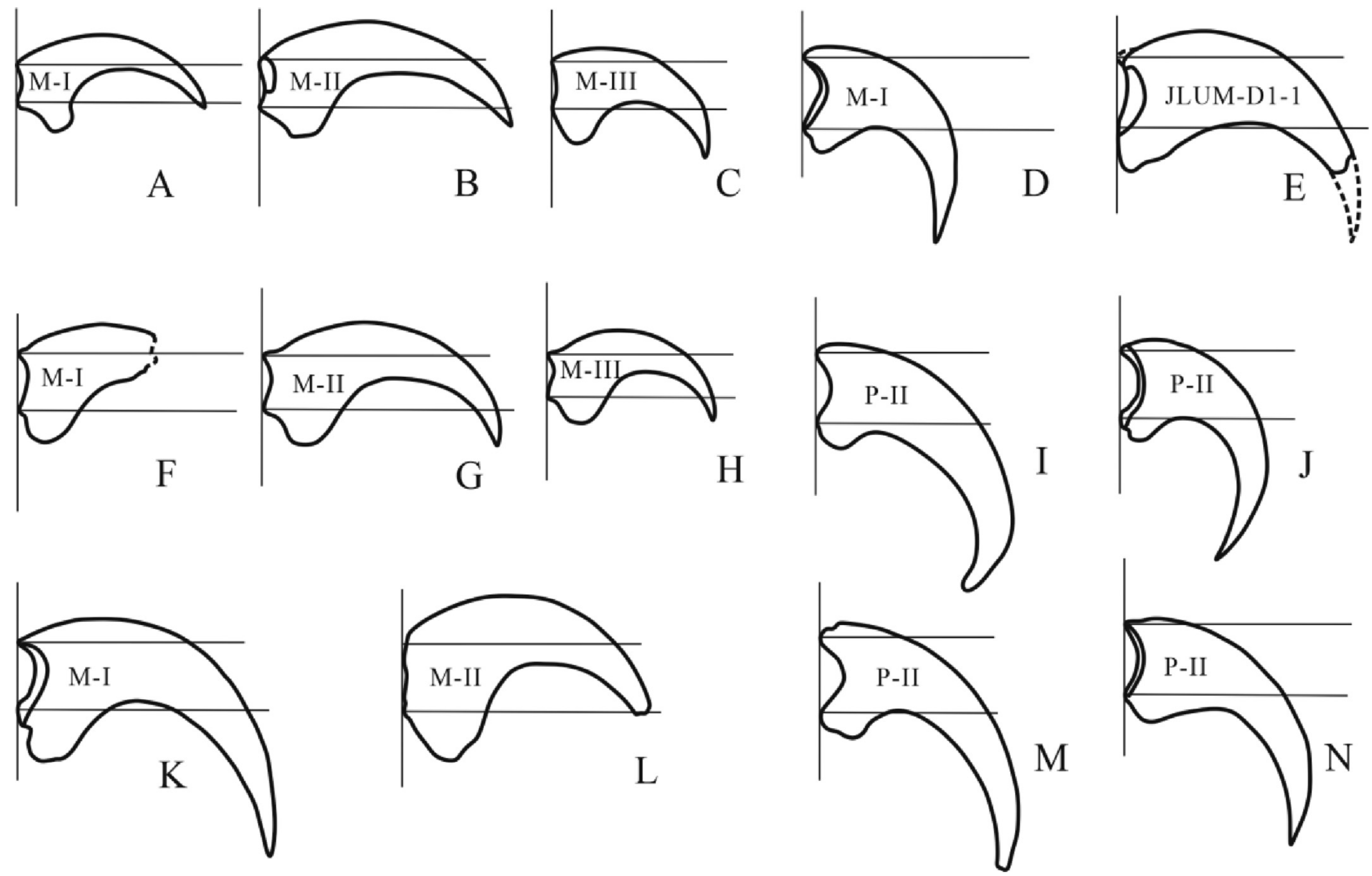

Fig. 3. Schematic diagram of ungual outlines of dromaeosaurids (reference from Phil, 2007) (not to scale). A–C. Ungual of manual digit I (A), II (B) and III (C) of *Sinornithosaurus millenii* (Xu et al., 1999). D. Ungual of manual digit I of *Utahraptor* (Kirkland et al., 1993). E. The specimens studied in this paper (JLUM-D1-1). F–H. Ungual of manual digit I (A), II (B) and III (C) of *Saurornitholestes lungstoni* (Sues, 1978). I. Ungual of pedal digit II of *Pyroraptor olympius* (Phil, 2007). J. Ungual of pedal digit II of *Deinonychus* (Ostrom, 1969). K. Ungual of manual digit I of *Deinonychus* (Ostrom, 1969). L. Ungual of manual digit II of *Unenlagia paynemili* (Phil, 2007). M. Ungual of pedal digit II of *Rahonavis ostromi* (Phil, 2007). N. Ungual of pedal digit II of *Utahraptor* (Kirkland et al., 1993).

the distal articular surface has an extremely deep subcircular pit, which are the attachment sites of the lateral collateral ligaments, whose primary function is to prevent detachment of the phalangeal articular surface. The subcircular fossae on both sides of the trochlea are located in the upper position of the geometric center of the articular arc (Fig. 2F-J, F′-J′).

4. Discussion

Theropod dinosaurs had curved, sickle-shaped unguals, with differently shaped manual and pedal elements. In most theropod dinosaurs, the manual claws are more clearly laterally compressed than the pedal claws and are more curved and bilaterally symmetrical (Weishampel et al., 1990; Holtz et al., 2004). The ungual (JLUM-D1-1) is larger than the penultimate phalanx, strongly flattened laterally, and almost dumbbell-shaped in cross-section in the center. It is sickle-shaped, strongly curved from the middle to the distal end, and almost symmetrical on the left and right sides. These characters are similar to the manual unguals of dromaeosaurids summarized by Jasinski et al. (2020).

Furthermore, Phil (2007) proposed a better methodology based on a series of consistent differences between manual and pedal unguals of theropods. The three main aspects are as follows: the first, in manual unguals, the dorsal margin arches high above the articular surface when the articular surface is oriented vertically, while the dorsal margin of the pedal unguals exhibits no such arch; the second is that flexor tubercles of manual unguals extend far palmarly to the articular surface, whereas flexor tubercles of the pedal unguals do not; and the third difference is that manual unguals usually exhibit a proximodorsal lip, while pedal unguals do not (Fig. 3). According to the above method, it can be seen from Fig. 3 that the dorsal margin arches of JLUM-D-1 are high above the artificial surface. Although the development of the flexor tuberosity is weak, it still extends far palmarly to the articular surface. Even if the proximodorsal lip of JLUM-D1-1 is missing, some upwardly developed folds can be clearly seen at the position of proximodorsal lip. Following the above criteria, JLUM-D1-1 can be confidently identified as a manual ungual.

It is generally accepted that the outer side of the manual ungual has a deeper collateral groove, and the flatter side is the inner side (Longrich and Currie, 2009). JLUM-D1-1 has a distinct collateral groove and a vascular groove on the outside, forming a Y-shaped structure common in eudromaeosauria (Longrich and Currie, 2009). However, Turner et al. (2012) suggested that Y-shaped grooves are also present on the unguals of some coelurosaurs, such as tyrannosaurids, oviraptorosaurs and

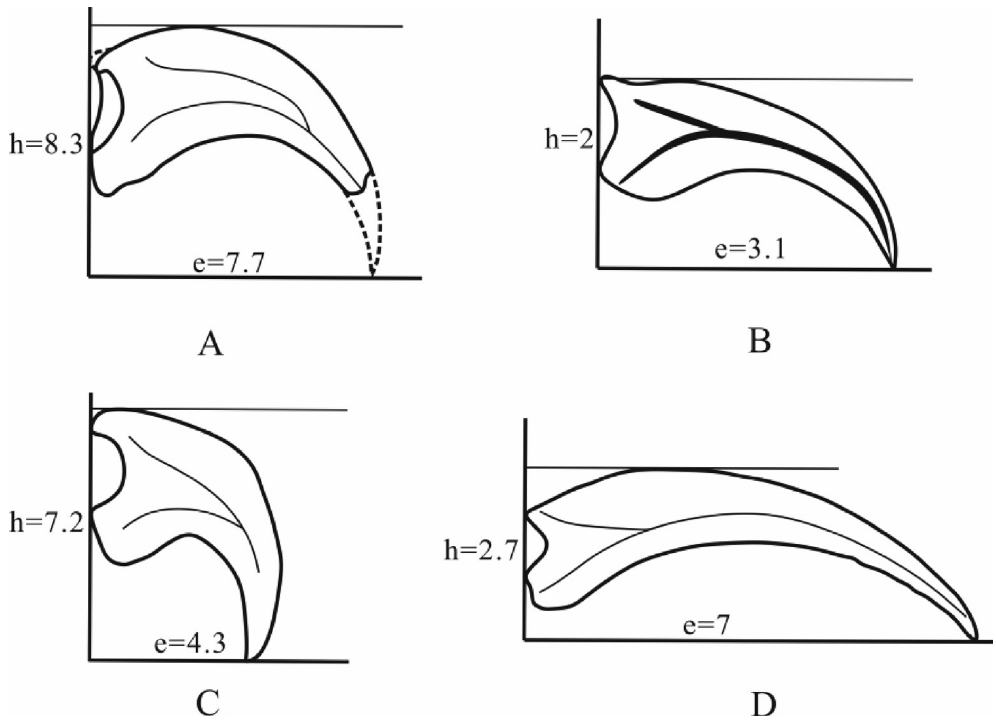

Fig. 4. Comparison of JLUM-D1-1 with other taxa of manual unguals in the class coelurosauria. When the proximal articular surface is vertical, h is the height in the vertical direction from the dorsal side of the ungual to the distal extension of the ungual; e is the length of the distal extension of the ungual. All linear dimensions are in centimeters. A. The specimens studied in this paper (JLUM-D1-1). B. Ungual II of *Guanlong wucaii* (Xu et al., 2006). C Ungual II of *Khaan mckennai* (Balanoff and Norell, 2012). D. Ungual II of *Therizinosaurus cheloniformis* (Zanno, 2010).

therizinosaurids. Tyrannosaurids (Fig. 4B) have short, thick unguals with a very high degree of flexion (Xu et al., 2006); oviraptorosaurs (Fig. 4C) have a deep and wide lateral groove located in the middle of the lateral surface, separating the proximal articular surface from the flexor tubercle (Balanoff and Norell, 2012); the unguals of therizinosaurids (Fig. 4D) are generally thin and slender, and are readily recognizable (Zanno, 2010). Although similarly shaped lateral grooves are present on their unguals, it is very different in profile from JLUM-D1-1. Moreover, JLUM-D1-1 has a shallower groove on the medial side, but the distal end does not converge toward the dorsal surface. Thus, the grooves on the medial and lateral sides are offset, which is similar to the ungual character of some eudromaeosaurs (Kirkland et al., 1993; Ostrom and Gauthier, 2019) in that the lateral groove is shifted toward the dorsal edge of the ungual, and the medial groove is shifted ventrally. Therefore, JLUM-D1-1 is probably the left manual ungual of an eudromaeosaur.

The articular surface of JLUM-D1-1 is the hinge joint, which provides considerable flexion and extension, but in a restricted plane with characteristics similar to those of digits I and II of eudromaeosaurs. However, the two sides of the ridged surface of the digit II manual ungual are asymmetric and slightly inclined; accordingly, the ungual must be rotated inward (in supination) when flexing (Ostrom and Gauthier, 2019). JLUM-D1-1 differs from digit II in that the two sides of its proximal ridge surface are almost symmetrical, and JLUM-D1-1 probably represents the manual ungual of digit I of left manus (i.e., the left manual phalanx I-2).

The lack of material makes it difficult to assign JLUM-D1-1 to a more specific taxonomic unit. We have tried to use mathematical methods to compare the characteristics of the sickle-shaped manual ungual I of some of the main representative species of dromaeosaurids and theropods more widely, like *Allosaurus*. Here, we refer to the Ostrom and Gauthier (2019) method to distinguish fossil materials and between closely related taxa. When similar unguals are in the same position, their abrupt curvature relative to the chord of the articular surface (the line connecting the upper and lower ends of the articular surface when viewed laterally) is most apparent. For example, as shown in Fig. 5A-E, we compared unguals on several theropods' manual digit I, where the articular surface chord is oriented vertically. When the fulcrum is fixed, the direction indicated by the arrow refers to the direction indicated by the end of the ungual, and its angle with the horizontal axis is the bending degree of the ungual. As shown in Fig. 5A, the radial of JLUM-D1-1 bending arc has a radius of 90°, which is similar to that of *Achillobator* and *Deinonychus* (Fig. 5B, C), and much smaller than that of *Utahraptor* (Fig. 5D) and *Allosaurus* (Fig. 5E). Furthermore, their differences can also be expressed as the ratio of height (h) to extension (e). The ungual height to the extension ratio of JLUM-D1-1 is 1.08, which is larger than the ratios of *Achillobator* (0.72) and *Deinonychus* (0.92), but much smaller than that of *Utahraptor* (1.49) and *Allosaurus* (1.42). At the same time, this relationship is also evident in the much steeper orientation of the ungual bending radius (r) from the center of rotation to the tip (Fig. 5A-E). Such an allometric relationship appears to be correlated with the orientation of the end of the ungual relative to both the articular surface and the lever arm (r) of the ungual (Ostrom and Gauthier, 2019).

To provide a quantitative perspective, we compared data on the ungual heights and extensions in some coelurosaurs by means of a table (Table 2), and constructed a scatter plot showing the ratio between ungual height and extension as seen in Fig. 6. By comparing the measurements with those of other coelurosaurs, we found that JLUM-D1-1 is more comparable to *Deinoychus* and *Achillobator*, and even exceeds most dromaeosaurids in terms of size. Therefore, we can determine that JLUM-D1-1 belongs to a large-bodied dromaeosaurid, possibly a type of eudromaeosaur.

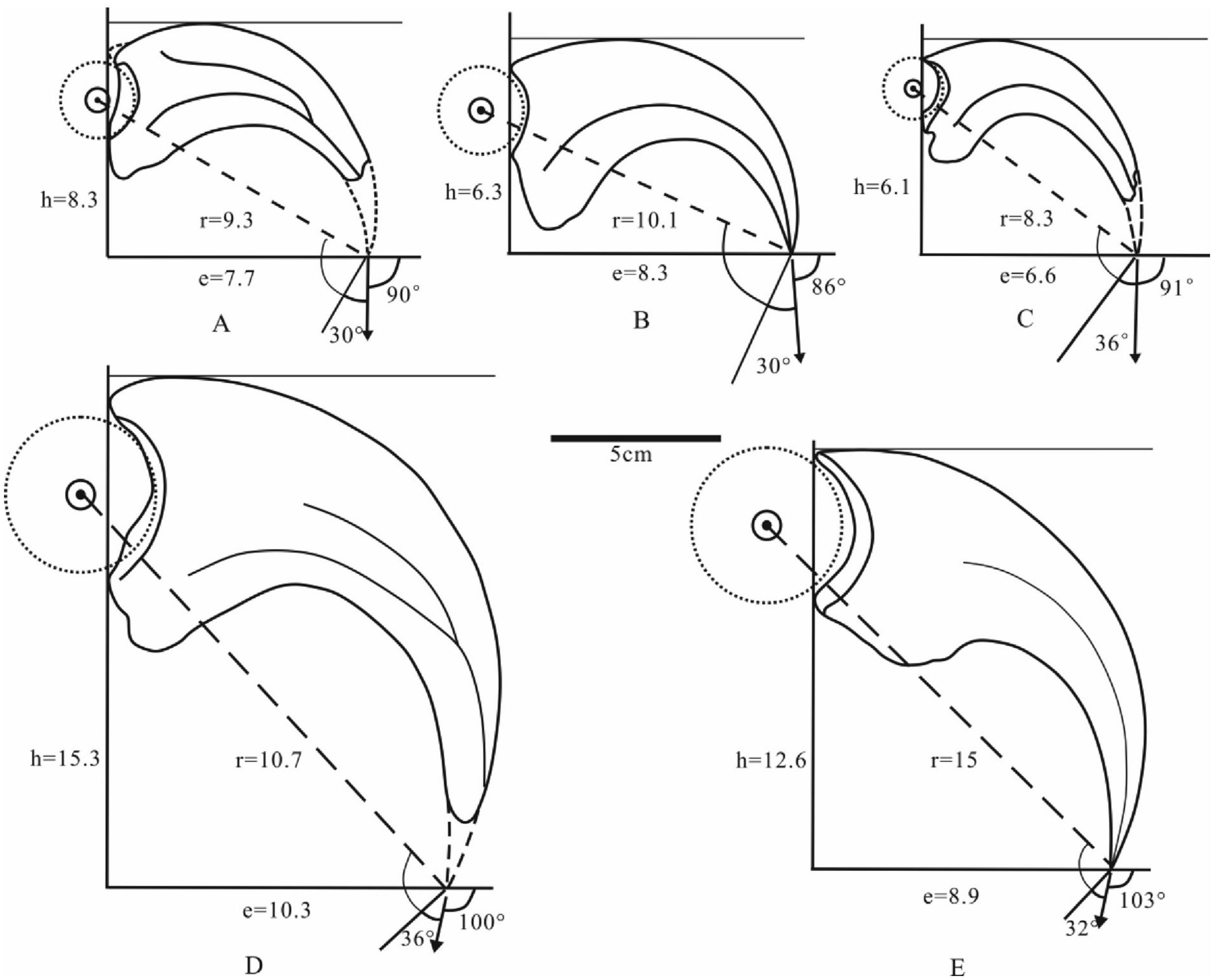

Fig. 5. Comparison of JLUM-D1-1 (a) with manual unguals of other dromaeosaurids and *Allosaurus* (e). *Allosaurus* is here to provide comparison with the laterally extended ungual form (reference from Ostrom and Gauthier, 2019). All drawn in simple profile. To facilitate comparison, all have the chord of the articular surface arc oriented vertically. This chord has been extended (h) to meet a perpendicular (e) from the ungual extremity. The radius (r) of ungual rotation (flexion) has been drawn (dashed line) from the center of rotation to the extremity of each ungual. These radii may also be considered as ungual lever arms. All linear dimensions are in centimeters. A = JLUM-D1-1; B = *Achillobator giganticus*, manual digit I (Phil, 2007); C = *Deinonychus antirrhopus*, manual digit I (Ostrom, 1969); D = *Utahraptor*, manual digit I (Kirkland et al., 1993); E = *Allosaurus jragilis*, manual digit I (Ostrom and Gauthier, 2019).

Table 2
Measurements of unguals of manual digit I for some coelurosaurs and *Allosaurus* (in millimeters).

	h	e	Data source
JLUM-D1-1	83	77	
Yianxianosaurus longimanus	26	13	Xu and Wang. (2003)
Sinornithosaurus millenii	15	26	Xu et al. (1999)
Deinonychus antirrhopus	61	66	Ostrom (1969)
Allosaurus jragills	12.6	8.9	Ostrom and Gauthier (2019)
Achillobator giganticus	63	83	Phil (2007)
Utahraptor	153	103	Kirkland et al. (1993)
Graciliraptor lujiatunensis	18	15	Xu and Wang. (2004)
Tianyuraptor ostromi	24	24	Zheng et al. (2010)
Balaur Bondoc	38	14	Csiki et al. (2010)
Paralitherizinosaurus japonicus	85	135	Kobayashi et al. (2022)
MPC-D 100/133	24	40	Chinzorig et al. (2018)
Trierarchuncus	28	17	Fowler et al. (2020)
Sinornithoides youngi	17	15	Currie and Zhiming (2001)
Khaan mckennai	20	38	Balanoff and Norell (2012)

Notes: h, the height in the vertical direction from the dorsal side of the ungual to the distal extension of the ungual; e, the length of the distal extension of the ungual.

Moreover, albeit based on the limited data, we also tried to analyze the function of the manual ungual JLUM-D1-1. In Fig. 5, the phalangeal rotation radius indicates its lever arm according to the method used by Ostrom and Gauthier (2019). The dashed lines show the lever arms of the various unguals, connecting the fulcrum of each ungual to its terminus. Considering the ungual alone, the maximum force that can be applied by the ungual, as it pivots about its fulcrum, acts perpendicular to that lever arm (tangential to the ungual flexion arc). In Fig. 5A-E, it is clear that the end of JLUM-D1-1 deviates from the vertical line at a smaller angle than that of the other unguals. In other words, the shape of JLUM-D1-1 is almost coincident with the maximum force axis and can be interpreted as being designed for maximum penetration. Nevertheless, to understand more about manual function, this element should to be interpreted in combination with the other phalanges.

JLUM-D1-2 is relatively short, and the dorsal abdomen in the middle of the phalangeal shaft is clearly constricted, forming a deep neck, indicating that it is the pedal phalanx of a theropod dinosaur. JLUM-D1-2 has a collateral ligament fossa on each side of the distal

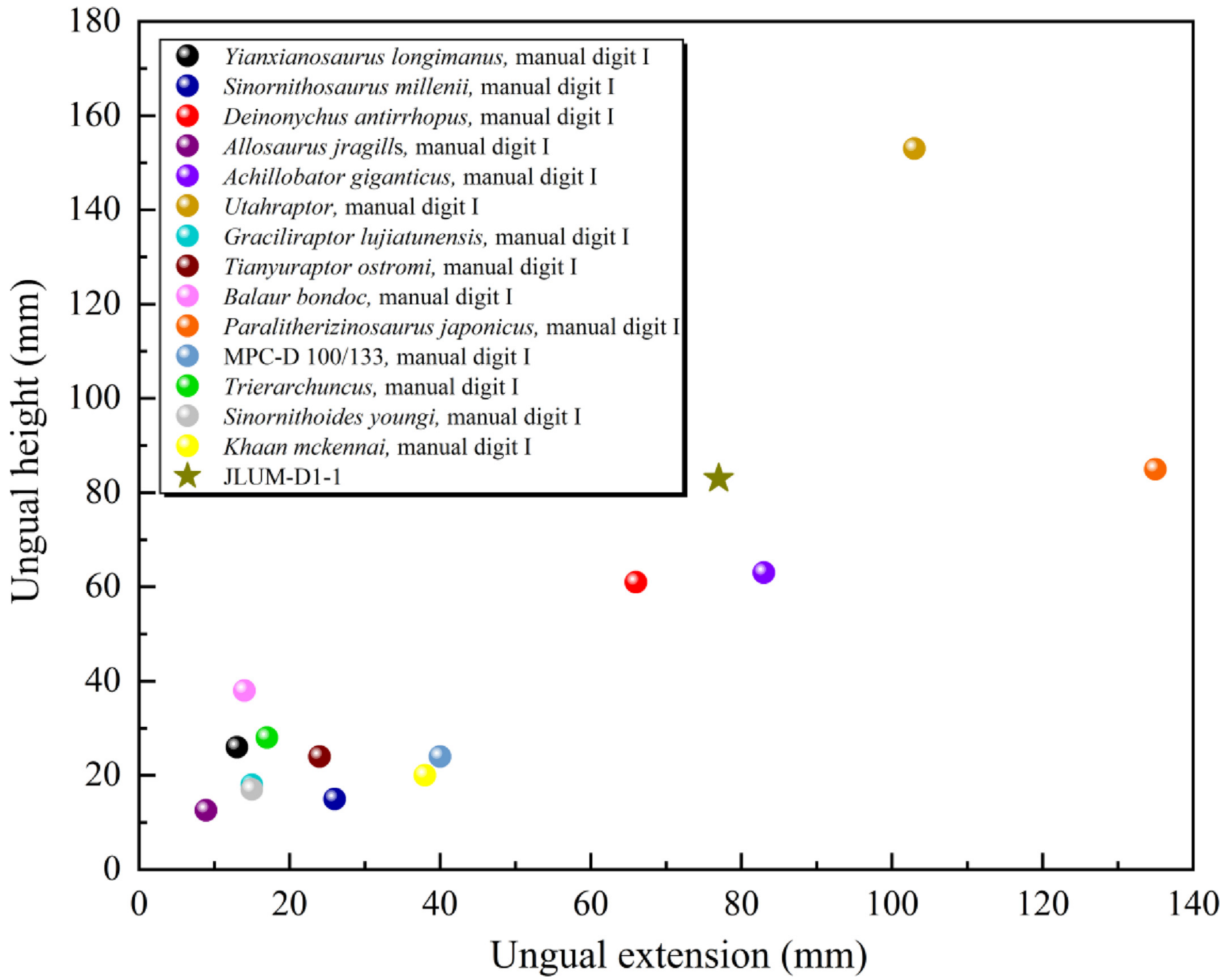

Fig. 6. Scatter plot of h/e ratio of unguals of manual digit I including some coelurosaur species and *Allosaurus* (all data are measurements without the keratinous sheath).

trochlea. It is generally accepted that the side with the smaller subcircular fossa is considered to be the medial side in theropods (Turner et al., 2012). Further, the proximal dorsal margin of JLUM-D1-2 has a wide tongue-shaped outline, wide on the left and narrow on the right, indicating it is the left pedal digit. Moreover, the fossa for the lateral collateral ligament in JLUM-D1-2 is located above the geometric center of the articular arc, a characteristic feature of penultimate phalanges of dromaeosaurids (Ostrom and Gauthier, 2019). Therefore, based on these characteristics, JLUM-D1-2 is here considered to be the penultimate phalanx of a left pedal element.

The pedal digits I and V are eliminated in theropods, and the middle three functional digits are used for weight-bearing, especially in dromaeosaurids and troodontids, which use only digit III and digit IV to support their bodies due to their highly specialized digit II (Holtz et al., 2004). The vertical constriction of JLUM-D1-2 also indicates that it belongs to one of the middle three digits. In lateral view, the diameter of the trochlea occupies approximately 1/2 of the length of JLUM-D1-2, suggesting that this phalanx is relatively short and unlikely to be digit II or III. The trochlea has no distinct dorsal lip and its dorsal margin intersects the neck of the phalanx at a near vertical angle. At the proximal end, the ventral heel is not strongly developed, with the upper and lower sides of the proximal articular surface extending essentially equally. This feature suggests that JLUM-D1-2 is probably the pedal penultimate phalanx of digit IV of a left pes, (i.e., the left pedal phalanx IV-4). Further comparison of JLUM-D1-2 with similarly sized pedal phalanges of other theropods indicates that the specimen is similar in appearance to pedal phalanx IV-4 of dromaeosaurids (Ostrom and Gauthier, 2019) and therizinosaurids (Sues and Averianov, 2016). In particular, the two features of the dorsal margin of the trochlea without dorsal lip and the rudimentary proximal ventral branch are what is expected in a large-bodied dromaeosaurid. However, the paucity and lack of additional material makes it difficult to identify at a less inclusive taxonomic level.

In summary, the two bones are the left manual phalanx I-2 and the left pedal phalanx IV-4. Although they were found from the same stratum and location, there appears to be no evidence that they belonged to the same individual. Ostrom and Gauthier (2019) suggested that where the claw is highly curved and very sharp, there is usually a lengthened penultimate phalanx. This phalangeal lengthening may be related to the flexion of the claw, and the lengthened penultimate phalanx may provide increased leverage. Interestingly, JLUM-D1-2 is very short and strongly constricted both distally and proximally, and it is proportionally much smaller than JLUM-D1-1, which should have a larger penultimate phalanx.

The geological age of the Quantou Formation is of great significance for the establishment of the Cretaceous chronostratigraphic system in the Songliao Basin, especially for the boundary between the Lower and Upper Cretaceous. In previous studies, the geologic age of the Quantou Formation was proposed to be either Albian (Gao, 1982; Gao et al., 1994; Gao et al., 1999) or Cenomanian to Turonian (Li and Liu, 1994; Li, 2001). Based on the magnetic chronology, SIMS zircon U–Pb chronology and lithological data, the stratigraphic correlation of six upper Cretaceous strata has been carried out Deng et al. (2013) and determined that the Quantou Formation belongs to the Cenomanian to Turonian. The latest research of the Well SK-1 in the Songliao Basin demonstrated that the age of Quantou Formation is limited to 91.923 + 0.475/−0.086 Ma and 96.442 + 0.475/−0.086 Ma, which spanned from the late Cenomanian to early Turonian (Wang et al., 2022b).

Eudromaeosaurs appear to have flourished during the Cretaceous Period. According to the fossil record, the earliest eudromaeosaurs were *Utahraptor ostrommaysi*, found in Barremian deposits, Lower Cretaceous (Kirkland et al., 1993). In contrast, *Deinonychus* was found in the early Aptian − middle Albian, Lower Cretaceous (Ostrom and Gauthier, 2019). Most other eudromaeosaurs were found in the Campanian to Maastrichtian, Upper Cretaceous (Turner et al., 2012). The eudromaeosaur *Achillobator*, mostly considered as sister to *Utahraptor* but variously placed either within dromaeosaurines, or close to velociraptonines (Currie and Evans, 2020), likely lived in the Cenomanian to Santonian and was found in Inner Mongolia which is not far from the Songliao Basin. Combined with the above discussion on the age of Quantou Formation as being late Cenomanian to early Turonian, we suggest that the fossil materials in this paper may be related to *Achillobator*. However, given the paucity of the fossil record and the lack of connectivity between specimens, we can only argue that it represents an eudromaeosaurian taxon.

5. Conclusions

- This paper presents new information on the stratigraphy of the fossil locality from the Upper Cretaceous Quantou Formation in Shanqian Village, Liufangzi Town, Gongzhuling City, Changchun Area, Jilin Province, northeast China, providing opportunities for further research in the future.
- The ungual of the digit I of left manus and the penultimate phalanx of the digit IV of left pes, which were recovered from the Quantou Formation, represent the first evidence of large-bodied dromaeosaurids in the Cretaceous strata of the Songliao Basin, northeast China.
- Compared with the ungual parameters of other theropods, these specimens likely belong to an eudromaeosaur, and is likely closely related to *Achillobator.* This new discovery provides important reference materials for studies of dromaeosaurid evolution and distribution, as well as a deeper understanding of the paleocommunity and diversity of northeast Asia during the Cretaceous Period.

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