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Cretaceous Research 26 (2005) 299–306

CRETACEOUS RESEARCH

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The first non-avian maniraptoran skeletal remains from the Lower Cretaceous of Korea

Haang Mook Kim[a], Alan D. Gishlick[b], Takanobu Tsuihiji[c,*]

[a] Department of Geology, College of Natural Science, Pusan National University, Pusan 609-735, South Korea
[b] National Center for Science Education, Oakland, CA 94609, USA
[c] Department of Geology and Geophysics, Yale University, New Haven, CT 06511, USA

Received 18 March 2004; accepted in revised form 10 January 2005
Available online 10 March 2005

Abstract

Most dinosaurian material discovered on the Korean Peninsula remains undescribed and poorly documented. The specimen DGBU-78 is a well-preserved, non-avian theropod femur found in the Hayang Group of the Gyeongsang Supergroup in Korea. A phylogenetic analysis based on femoral characters suggests that it belongs to non-avian Maniraptora more derived than Oviraptorosauria. This specimen possesses a crest-like fourth trochanter, which is similar to those in dromaeosaurids such as *Adasaurus mongoliensis* and *Velociraptor mongoliensis*, suggesting a possible close phylogenetic relationship to these taxa. Non-avian maniraptorans including dromaeosaurids have been found in roughly contemporaneous deposits in China and Japan. Therefore, the discovery of the present material in the Korean Peninsula provides further supporting evidence for possible faunal exchange within East Asia during the Early Cretaceous.

Keywords: Korea; Hayang Group; Gyeongsang Supergroup; Theropoda; Maniraptora; Femur

1. Introduction

Since the first discovery of dinosaurian material in the "Dinosaur Valley" of Geumseong-myeon in 1973, the Hayang Group of the Gyeongsang Supergroup has provided most of the identifiable dinosaurian material found in the Korean Peninsula (Kim, 1983, 1993; Zhen et al., 1993; Lee et al., 1997). Unfortunately, with respect to dinosaurian paleontology, the Korean Peninsula remains largely unexplored, and the few specimens that have been discovered remain mostly undescribed (Lee et al., 2001). Herein we hope to begin to correct this deficiency with the first detailed description of any non-avian theropod material from the peninsula. The material was collected from the Hayang Group, and was originally described as a hadrosaur femur by one of us (Kim, 1983). More recently, it has been referred to as "*Koreanosaurus*" or "*Deinonychus koreanensis*" in literature published in Korea (e.g., Zhen et al., 1993) without a proper description, and thus both names are here regarded as nomina nuda. The material is proposed here to belong to a non-avian maniraptoran theropod of possible dromaeosaurid affinities based on a systematic character analysis. This identification and description of the specimen suggests that paleontological data from the Korean Peninsula will contribute to a better understanding of regional faunas in East Asia during the Early Cretaceous.

Institutional Abbreviations. DGBU, Department of Geology, Pusan (Busan) National University, Pusan, Korea; GI, Geological Institute, Mongolian Academy

* Corresponding author. Division of Amphibians and Reptiles, Department of Zoology, Field Museum of Natural History, 1400 South Lake Shore Drive, Chicago, IL 60605-2496, USA.
E-mail address: ttsuihiji@fieldmuseum.org (T. Tsuihiji).

0195-6671/$ - see front matter
doi:10.1016/j.cretres.2005.01.001

of Sciences, Ulaan Baatar, Mongolia; YPM, Peabody Museum of Natural History, Yale University, New Haven, Connecticut, USA.

2. Geological setting

The specimen, DGBU-78, was found in the "Dinosaur Valley" of Geumseong-myeon, Euiseong-gun, North Gyeongsang Province, Korea (Fig. 1). The Iljig, Gumidong, and Gugyedong formations belonging to the Hayang Group crop out across this region (Chang, 1975). The specimen was found, along with an angular bone fragment, by J. Kim in 1978 in the lower part of the Gugyedong Formation at a cliff along Bongam Pass, 1.6 km southwest of Tabri Station. From 1973 to 1994 the same locality also yielded the proximal part of a sauropod humerus, part of a centrum, a few more bone fragments, and mud-turtle carapaces (Kim, 1983, 1993; Zhen et al., 1993; Lee et al., 1997). The Gugyedong Formation at this locality consists predominantly of grayish red beds. The specimen was found in a lens of matrix-supported conglomerate up to 1 m thick (Fig. 2), which lies 47 m above the base of the formation. The Early Cretaceous conifer *Pseudofrenelopsis parceramosa* (Fontaine) was found from the light, grayish green siltstone layer right above the lens, which confirms that these layers belong to the Hayang Group (Choi, 1985). This siltstone is overlain by light gray argillite containing very coarse, pebble-sized, calcareous concretions. An age of 113.6 ± 10 Ma was obtained by U–Pb dating of a felsic tuff bed (Kusandong Tuff) at about the middle of this group, confirming an Aptian–early Albian age for the group (Chang et al., 2003).

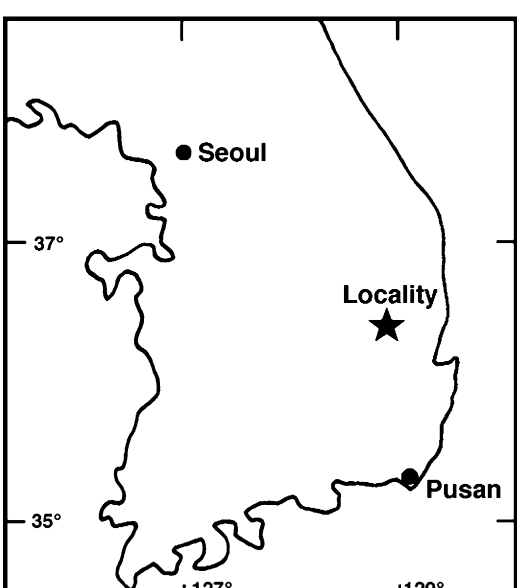

Fig. 1. Map showing the locality from which DGBU-78 was collected.

3. Systematic paleontology

Dinosauria Owen, 1841
Theropoda Marsh, 1881
Maniraptora Gauthier, 1986
?Dromaeosauridae Matthew and Brown, 1922

Gen. et sp. indet.
Figs. 3, 4A

Material. DGBU-78, a virtually complete left femur. A cast of the specimen is also housed at the Division of Vertebrate Paleontology, Peabody Museum of Natural History, Yale University (YPM 56692).

Locality and stratigraphic horizon. Bongam Pass, near Tabri Station, Geumseong-myeon, Euiseong-gun, north Gyeongsang Province, Korea; Gugyedong Formation, Hayang Group, Aptian–lower Albian.

Description. The specimen is well preserved with the only post-mortem distortion being anteroposterior compression and some crushing on the anterior face of the shaft distal to the lesser trochanter. There was also some artificial alteration to the bone during preparation, including some filling, lengthening and straightening, which affects its overall appearance, but does not affect its anatomical details (Fig. 3). The total length is approximately 400 mm, and the transverse widths of the proximal (including the femoral head) and distal ends are approximately 80 and 75 mm, respectively. The breakage reveals the hollow nature of the shaft, which is a characteristic of Theropoda (Gauthier, 1986), although similarly thin-walled femora are also seen in pterosaurs and poposaurid pseudosuchians (Hutchinson, 2001). The shaft is anteriorly and medially bowed, as in dromaeosaurids (Ostrom, 1990; Norell and Makovicky, 1999), although the post-mortem distortion and preparation has somewhat obscured the anterior bowing.

The femoral head is sharply offset from the shaft, roughly making a right angle. A shallow but broad sulcus separates the head from the greater trochanter, which is partially weathered (Figs. 3, 4A). On the posterior surface of the head, a shallow groove runs diagonally as in *Velociraptor mongoliensis* (Norell and Makovicky, 1999; Fig. 4A). The greater trochanter is laterally almost confluent with the lesser trochanter, with only a small notch separating them proximally, as in *Deinonychus antirrhopus* (Ostrom, 1976) and *V. mongoliensis* (Norell and Makovicky, 1999).

The proximal end of the lesser trochanter is broken off, and accordingly its proximal extent cannot be determined precisely. However, it appears not to extend beyond the level of the middle of the femoral head. The lesser trochanter extends as a rugose ridge along the

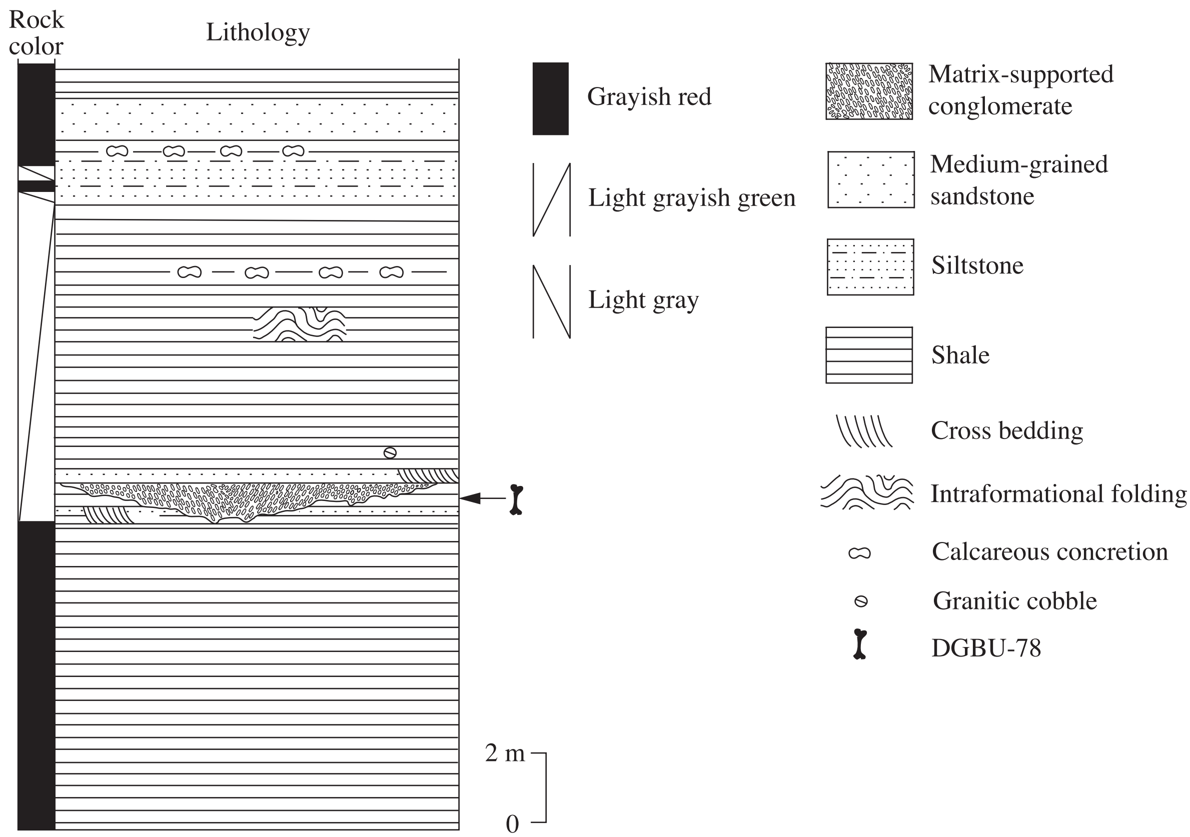

Fig. 2. Stratigraphic column at the locality that yielded DGBU-78, modified from Kim (1983).

anterolateral surface of the shaft for approximately one-fifth of the length of the bone (Fig. 3C, D). The posterior trochanter is a rugose ridge extending longitudinally along the posterolateral edge of the shaft distal to the greater trochanter. Anterior to the posterior trochanter lies a longitudinally long fossa, which is bounded distally by a mound-like trochanteric shelf (Fig. 4A). The linea intermuscularis lateralis (Hutchinson, 2001), or lateral ridge (Norell and Makovicky, 1999), extends distally from the trochanteric shelf for at least two-thirds of the shaft until it is obscured by the attached matrix.

The fourth trochanter is present as a distinct rugosity along the medial side of the shaft (Figs. 3C, 4A). This is similar to those in *Velociraptor mongoliensis* (Norell and Makovicky, 1999) and other more basal theropods, but unlike that in *Deinonychus antirrhopus*, which was described as lacking a recognizable fourth trochanter (Ostrom, 1976).

The distal end is divided into two condyles that appear to be directed posteromedially due to the oblique crushing (Fig. 3). On the posterior surface, the deep flexor groove bearing a low prominence on its floor separates the two condyles. The anterior surface is convex and apparently lacks an extensor groove. The lateral condyle appears to extend further distally than the medial condyle. The ectocondylar tuber (crista tibiofibularis) is proximodistally tall and deflected laterally at its posterior end as in *Velociraptor mongoliensis* (Norell and Makovicky, 1999). This tuber and the distal projection of the lateral condyle are distinctly separated from each other by a notch (Fig. 3D). A prominent mediodistal crest (medial epicondyle) and the associated, distinct muscle scar are absent from the anterodistal part of the femoral shaft unlike in non-maniraptoran theropods such as ornithomimids and allosauroids (e.g., Osmólska et al., 1972; Currie and Zhao, 1993).

4. Discussion

4.1. Phylogenetic affinity of the specimen

In the following discussion, names of theropod clades follow Padian et al. (1999). Hutchinson (2001) analyzed the evolution of femoral morphology in Archosauromorpha in detail with a particular focus on Theropoda, and his work provides a framework for discussing the possible phylogenetic affinity of DGBU-78. The specimen shows several unambiguous tetanurine and maniraptoran synapomorphies identified by Hutchinson (2001). The head of the femur is oriented medially with respect to the transverse axis through the femoral condyles. This condition is a synapomorphy of Avetheropoda plus

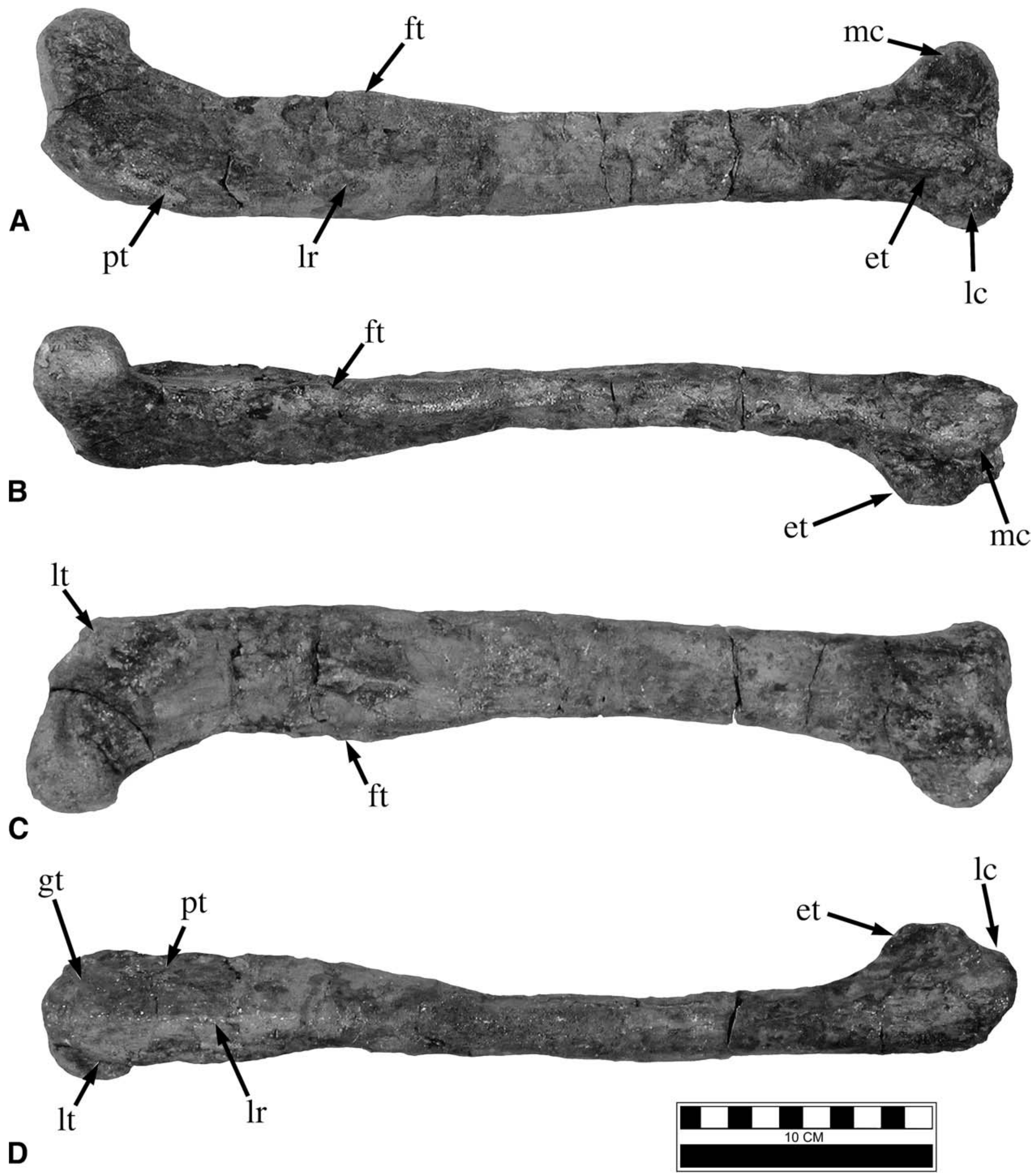

Fig. 3. DGBU-78 in A, posterior, B, medial, C, anterior, and D, lateral views, with relevant anatomical features identified. Abbreviations: et, ectocondylar tuber; ft, fourth trochanter; gt, greater trochanter; lc, lateral condyle; lr, lateral ridge; lt, lesser trochanter; mc, medial condyle; pt, posterior trochanter.

"basal Tetanurae 2" (Hutchinson's character 1, state 2). The lesser trochanter is appressed to the greater trochanter, which is a feature shared by several basal members of Maniraptora (character 7, state 4). Unambiguous eumaniraptoran synapomorphies identified by Hutchinson (2001) that can be recognized in this specimen include the presence of the lateral ridge (characters 6, state 3), the prominent shelf-like posterior trochanter (character 8, state 1), and the absence of the accessory trochanter (character 10, state 0). Thus, DGBU-78 most likely belongs to the Maniraptora. In order to confirm this inference and to determine a more specific phylogenetic affinity for this specimen, we conducted a phylogenetic analysis based on Hutchinson's (2001) data matrix (21 characters) with the addition of DGBU-78 (see Appendix for the coding of this specimen)

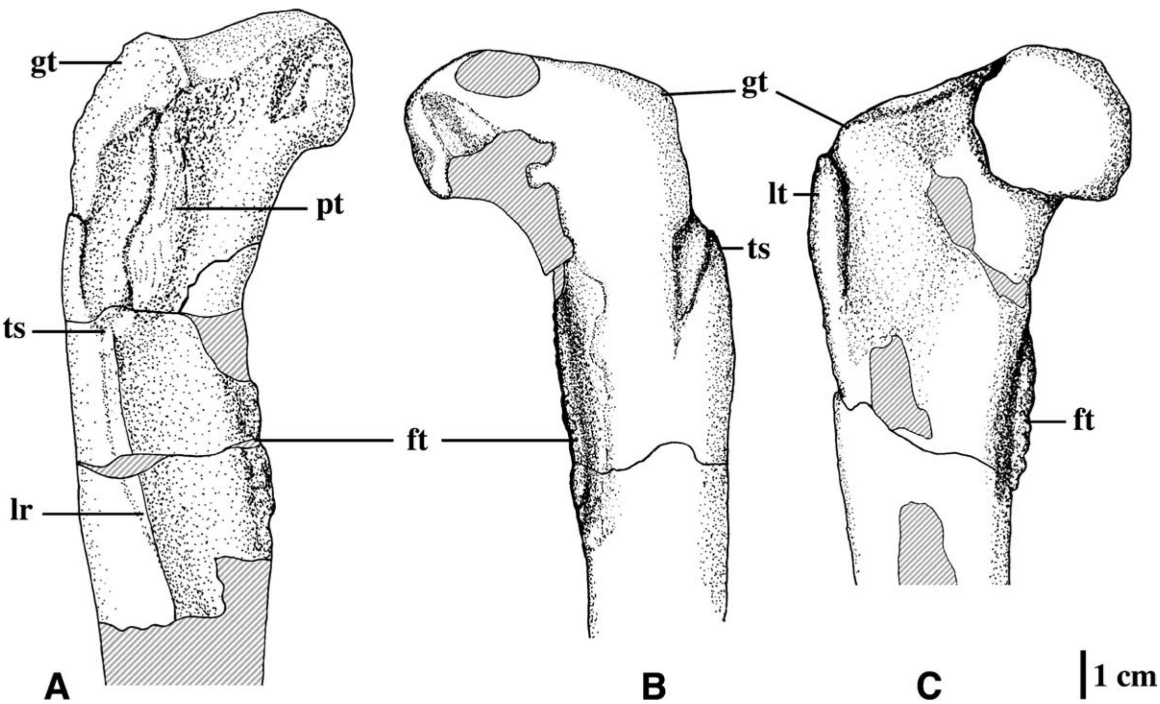

Fig. 4. Proximal ends of DGBU-78 (left femur) and right femur of *Adasaurus mongoliensis* (GI 100/20). A, posterior view of DGBU-78; B, C, posterior and anteromedial views of *A. mongoliensis*, respectively. Abbreviation: ts, trochanteric shelf; see explanation of Fig. 3 for other abbreviations.

using PAUP 4.0b10 (Swofford, 2000). Ingroup taxa were reduced to 16 including the current specimen by culling several taxa from Hutchinson's (2001) original analysis. Fig. 5 shows the strict consensus tree of 234 most parsimonious trees found in the analysis. DGBU-78 falls within the Maniraptora as expected, and is further found to be closer to Aves than to Oviraptorosauria. Because this analysis is based solely on femoral characters, the lack of resolution and an unconventional branching pattern (especially within Paraves) are evident. However, unambiguous eumaniraptoran synapomorphies in Hutchinson (2001) mentioned above do characterize Maniraptora excluding Oviraptorosauria (=clade Paraves) in this tree. In addition, the absence of the accessory trochanter, as well as the absence of the mediodistal crest and associated scar, also characterizes Paraves including DGBU-78.

The shape of the fourth trochanter is a potentially informative character for further clarifying the phylogenetic affinity of the specimen. As described above, this

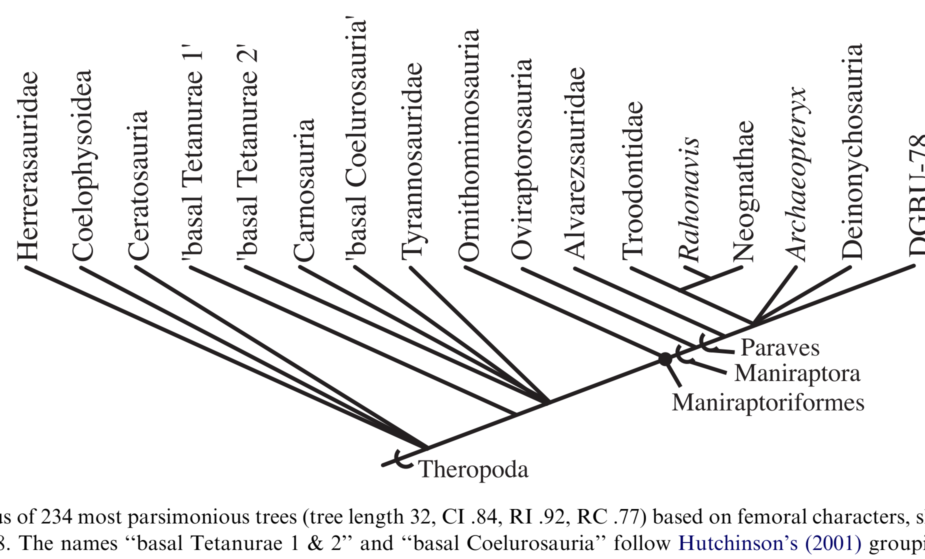

Fig. 5. Strict consensus of 234 most parsimonious trees (tree length 32, CI .84, RI .92, RC .77) based on femoral characters, showing the phylogenetic position of DGBU-78. The names "basal Tetanurae 1 & 2" and "basal Coelurosauria" follow Hutchinson's (2001) groupings.

trochanter is prominent and crest-like in DGBU-78 (Fig. 4A). According to the analysis by Hutchinson (2001), the crest-like fourth trochanter is plesiomorphic for Archosauria and its reduction to just a scarring is optimized to characterize Eumaniraptora or possibly a more inclusive clade. In our analysis, the reduction of the fourth trochanter is found to be a synapomorphy of Maniraptoriformes (the clade consisting of Ornithomimosauria plus Maniraptora). In extensive analyses of phylogenetic relationships among coelurosaurians, Norell et al. (2001) and Xu et al. (2002b) used the character "the presence/absence of the fourth trochanter" (character 185 in Norell et al., 2001; character 151 in Xu et al., 2002b), which is basically identical to the character 5 in Hutchinson (2001), "the fourth trochanter crest-like or scarring only". We optimized this character on the tree presented by Xu et al. (2002b) using the "hard polytomy" option in MacClade 4.0 (Maddison and Maddison, 2000). The character state "the absence of the fourth trochanter" was optimized to be plesiomorphic at least for the clade of Paraves + (Oviraptorosauria + Therizinosauroidea), although this optimization was equivocal below this node owing to missing data and/or polytomies (i.e., this character state may have evolved earlier than the node). Therefore, the presence of the crest-like fourth trochanter in DGBU-78 is a reversal to the ancestral archosaruian condition within this clade. A similar, crest-like fourth trochanter is described in *Velociraptor mongoliensis* (Norell and Makovicky, 1999). Furthermore, the fourth trochanter is developed as a prominent, rugose ridge in *Adasaurus mongoliensis* (GI 100/20; Fig. 4B, C). Although Ostrom (1990) questioned its dromaeosaurid affinity, the analysis by Xu et al. (2002b) placed *A. mongoliensis* in this clade as Barsbold (1983) originally suggested. Within Paraves, no other taxa examined by Norell et al. (2001) and Xu et al. (2002b) have this reversal. Thus, this condition might diagnose a subclade within Dromaeosauridae including *V. mongoliensis* and *A. mongoliensis*, and may possibly suggest a close affinity of DGBU-78 with these dromaeosaurids. However, with no definite characters diagnosing Dromaeosauridae yet recognized in the femur, it is most reasonable to consider DGBU-78 as Maniraptora incertae sedis pending discoveries of additional material.

4.2. Geographic and stratigraphic significance of the specimen

Lee et al. (2001) reviewed the vertebrate faunas from the Gyeongsang Supergroup and concluded that, while Korea had much to offer in terms of vertebrate fossil data, most material remained not fully described. The current work marks the first time that any of the theropod material from these strata is identified to any degree of taxonomic detail with specific synapomorphies. This, then, adds to our knowledge of the biogeographic distribution of dinosaurs on the Korean Peninsula during the Early Cretaceous and gives us a more complete picture of overall theropod diversity in East Asia. A diverse assemblage of maniraptoran theropods has been reported from the Yixian Formation in Liaoning Province, China. The Yixian non-avian maniraptorans include dromaeosaurids (Xu et al., 1999b, 2000; Norell et al., 2002), and a troodontid (Xu et al., 2002b). Oviraptorosaurians and therizinosauroids, which are placed within Maniraptora in Norell et al. (2001) and Xu et al. (2002a), have also been found in Liaoning localities (Ji et al., 1998; Xu et al., 1999a, 2002a; Zhou and Wang, 2000). According to Swisher et al. (1999), Barrett (2000), and Smith et al. (2001), the age of the Yixian Formation is considered to be middle Early Cretaceous, and specifically the radiometric dating by Swisher et al. (1999) indicates that it is middle Barremian in age. According to Lee et al. (2001) and Chang et al. (2003), the age of the Hayang Group of the Gyeongsang Supergroup in which DGBU-78 was found is Aptian–early Albian, and thus is only slightly younger than that of the Yixian Formation. A faunal similarity between these two regions during the Early Cretaceous is not unexpected because the Korean terrane collided with the North China Block, on which the Liaoning localities are located, during the Late Jurassic (Enkin et al., 1992).

Terrestrial faunas roughly contemporaneous to those of the Hayang Group are also represented in the lower to middle parts of the Tetori Group in the central part of Honshu, Japan (e.g., Azuma and Tomida, 1995; Manabe and Hasegawa, 1995; Evans et al., 1998; Manabe et al., 2000; Barrett et al., 2002). Manabe et al. (2000) reported a manual ungual that is referable to the clade of Oviraptorosauria + Therizinosauroidea from the Kuwajima Formation. Evans et al. (1998) reported a diverse vertebrate fauna from the Okurodani Formation, whose faunal list includes remains of a velociraptorine theropod. Both the Kuwajima and Okurodani formations are considered to be Early Cretaceous in age, possibly Berriasian (Evans et al., 1998; Manabe et al., 2000), and thus are older than the Hayang Group. Evans et al. (1998) compared the Okurodani vertebrate fauna with Chinese Early Cretaceous counterparts and found broad similarities between them. This is not unexpected (Barrett et al., 2002), considering that the several terranes comprising southwestern Japan lay at the eastern margin of the Sino-Korean continent during the Early Cretaceous (e.g., Kojima, 1989; Isozaki, 1996) and that a land connection between these two areas may have been present (Azuma and Tomida, 1995). However, Evans et al. (1998) also pointed out that the Okurodani lizard assemblage is quite distinct from those of any other localities including Chinese ones. Therefore, it has not yet been conclusively determined whether a cosmopolitan terrestrial vertebrate fauna was present throughout East Asia, or a distinct faunal assemblage existed in each region during the Early Cretaceous. The discovery of a non-avian maniraptoran femur in the Korean Peninsula confirms the potential of this region as another rich source of information on the Early Cretaceous dinosaurian fauna in East Asia. With further paleontological work in Korea, more detailed, taxon-by-taxon comparison of East Asian regional faunas suggested by Evans et al. (1998) will become possible.

Acknowledgements

We thank R. Barsbold (Mongolian Paleontological Center, Ulaan Baatar) for allowing us to illustrate the *Adasaurus* specimen in his care, and M. Fox (YPM) for finishing the preparation of DGBU-78 and molding and casting it. L.J. Hickey (Yale University) read an early draft of the stratigraphic part of the paper and his comments greatly improved the clarity of the final draft. TT is grateful to M. Watabe (Hayashibara Museum of Natural Sciences, Okayama, Japan) for hospitality during his stay in Ulaan Baatar. HMK thanks L.K. Murray (YPM; now University of Texas, Austin) for hospitality during his work at YPM. The original manuscript for this paper benefited greatly from thoughtful reviews of T.R. Holtz, Jr. (University of Maryland) and an anonymous referee.

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Appendix

Character state values of DGBU-78 for the 21 characters in Hutchinson's (2001) data matrix used in the present analysis

Characters	10	20	
DGBU-78	21121341? 0	?011100002	?