

## The first tyrannosauroid tooth from Korea

Yuong-Nam Lee\* *Geology and Geoinformation Division, Korea Institute of Geoscience and Mineral Resources, Daejeon 305-350, Korea*

**ABSTRACT:** A tyrannosauroid premaxillary tooth has been discovered for the first time in the Hasandong Formation (Lower Cretaceous) in South Korea. Carinae on the tooth form both the mesial and distal edges of the lingual face, producing a “D-shaped” cross section typical of tyrannosauroids. The Korean premaxillary tooth is different from those of other known Early Cretaceous tyrannosauroids (*Dilong*, *Eotyrannus*, and a Japanese tooth) in having a distinct lingual ridge on the lingual surface. This discovery probably indicates a subsequent Asian diversification of this group (Korea, China and Japan) after the origination of tyrannosauroids in the early Late Jurassic (e.g., *Guanlong*) in China.

**Key words:** tyrannosauroid premaxillary tooth, Hasandong Formation, Lower Cretaceous, Sacheon City, Korea

### 1. INTRODUCTION

Tyrannosaurids are among of the most distinctive theropods by reason of their large skulls and greatly reduced forelimbs. In addition to these features, a specialized heterodont dentition due mainly to D-shaped premaxillary teeth, makes them most easy to distinguish from non-tyrannosaurid taxa (Holtz, 2004). Tyrannosauroida proper originated in Asia from the Late Jurassic (e.g., *Guanlong*, Xu et al., 2006) and became more geographically widespread, but their giant descendants, Tyrannosauridae, appeared first at the Albian-Cenomanian boundary in Utah (represented by typical incassate maxillary and dentary teeth from the Cedar Mountain Formation, Kirkland et al., 1997) and were distributed afterward only in North America (e.g., *Tyrannosaurus*, *Daspletosaurus*, *Albertosaurus*) and Asia (e.g., *Tarbosaurus*) until the end of Cretaceous.

Especially in Asia, the record of tyrannosauroids is good and continuous from the early Late Jurassic to late Late Cretaceous. Consequently, Asia is believed as one of the most important areas to study the tyrannosauroid evolution. The discovery of tyrannosauroids had been mainly made in China and Mongolia until an incomplete tyrannosaurid tooth was found in Japan (Manabe, 1999). The latter implied a high probability that tyrannosauroids lived in Korea as well because Japan was a part of eastern Asia, juxtaposed to the Korean Peninsula from the Late Jurassic to the Middle Miocene (Otofujii et al., 1985; Lee et al., 1996). Such probability becomes truth with the discovery of the first fossil of a tyrannosauroid in Korea in 2005 (Fig. 1). Although the

specimen is an isolated premaxillary tooth, it adds an important datum to the paleogeographic distribution of this group. The purpose of this paper therefore is to describe the first tyrannosauroid premaxillary tooth from Korea, to compare it morphologically to other basal tyrannosauroid premaxillary teeth, and to discuss the paleobiological implications.

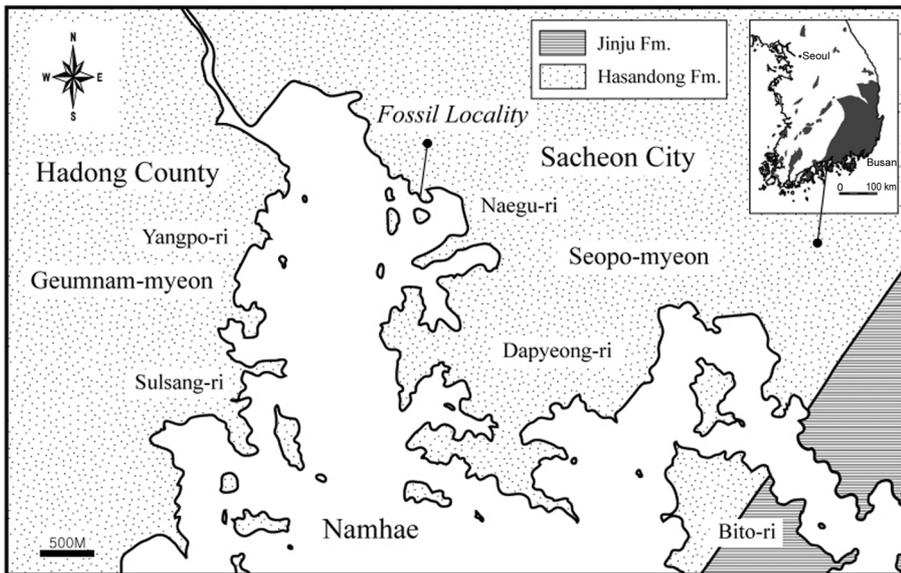
### 2. GEOLOGICAL SETTING

The tyrannosauroid tooth described here originated from the Hasandong Formation, which forms the middle unit of the Sindong Group, the lowermost group of the Gyeongsang Supergroup. The Hasandong Formation has yielded the most abundant vertebrate body fossils in the Gyeongsang Supergroup (Lee, 2003). Most bones occur as scattered, broken, and isolated pieces which had probably undergone long aerial exposure, transportation, and scattering on the floodplain before burial (Paik et al., 2001). To date, among vertebrate faunas from the Hasandong Formation, dinosaurs include allosauroid (Park et al., 2000), megalosaurid (Lim et al., 2002), and carcharodontosaurid theropod teeth (Lee, 2007), which clearly indicate that at least three different theropod dinosaurs existed during the time of Hasandong deposition. Other dinosaur remains are the sauropods *Pukyongosaurus millenniumi* (Dong et al., 2001), currently considered a *nomen dubium* (Upchurch et al., 2004), and three isolated teeth of sauropods (Lee et al., 1997), and ovalolith-type dinosaur eggs (Yun and Yang, 1997).

The Hasandong Formation is characterized by red beds, including reddish and grey sandstone and reddish to greenish grey sandy mudstone, and dark grey shale. The formation shows alternating channel and interchannel sediments with floodplain deposits (Choi, 1986). Non-marine trace fossils from the Hasandong Formation, such as *Skolithos* and *Palaeophycus* ichnotaxa, also indicate high-energy channel levee environments and low-energy floodplain settings (Kim et al., 2002). The formation is about 1,200 m thick on average and its strike and dip are N30°~70°E and 8°~20°SE, respectively.

The fossil site (Fig. 1) is a small outcrop exposed along the coastal area at Naegu-ri, Seopo-myeon, Sacheon City, South Gyeongsang Province (35°0'17.63", 127°56'9.62"). The well exposed vertical section (approximately 4.5 m above sea level) represents the middle part of the Hasandong Formation (Fig. 2). The section is divided into a lower

\*Corresponding author: ylee@kigam.re.kr



**Fig. 1.** Location map for the Lower Cretaceous tyrannosauroid premaxillary tooth locality in the Hasandong Formation.

fine sandstone and siltstone unit and an upper massive mudstone layer. The lower unit is characterized by a lower fine sandstone layer with a very high density *Brotiopsis waki-noensis* horizon at the top, and an upper laminated siltstone layer with lenses of calcareous, very fine sandstone. The upper division consists of greenish massive mudstone that contains randomly distributed, pebble-size calcareous nodules. This layer also produces randomly distributed molluscan fossils (*Plicatounio naktongensis*) and small broken bone pieces including the tyrannosauroid premaxillary tooth. These sediments are thought to have been deposited in small swamps associated with floodplains between channels (Choi, 1986).

The age of the Hasandong Formation has been regarded as Aptian to Albian by molluscan faunas (Yang, 1982), and as Hauterivian to Barremian by palynomorphs (Choi, 1985, 1989; Yi et al., 1994). The age of the Hasandong was also reported to be Hauterivian on the basis of paleontological and radiometric data (Chang, 1988). Recently, ion microprobe dating of a dinosaur tooth from the Hasandong Formation indicated a  $^{238}\text{U}$ - $^{206}\text{Pb}$  isochron age of  $117 \pm 18$  Ma (i.e., Aptian; Sano et al., 2002).

### 3. SYSTEMATIC PALEONTOLOGY

Theropoda Marsh, 1881  
 Coelurosauria von Huene, 1914  
 Tyrannosauroidea Osborn, 1905  
 Genus and species indeterminate

#### 3.1. Material

KIGAM VP 200504 (Korea Institute of Geoscience and Mineral Resources, Vertebrate Paleontology), an isolated, incomplete right premaxillary tooth (Fig. 3).

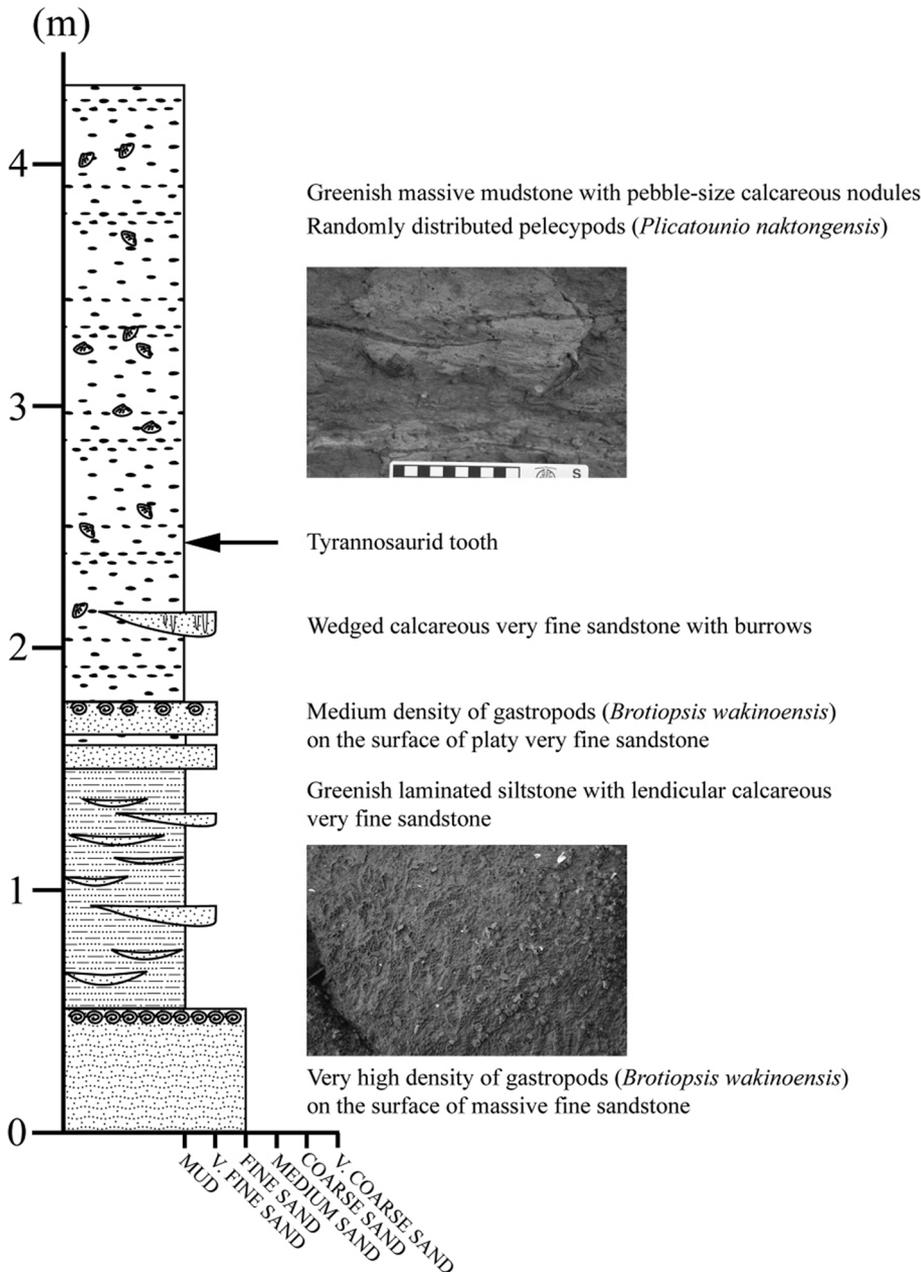
#### 3.2. Locality and Horizon

The premaxillary tooth was collected in 1995 by the author in western coastal outcrops at Naegu-ri, Seopo-myeon, Sacheon City, South Gyeongsang Province, Korea ( $35^{\circ}0'17.63''$ ,  $127^{\circ}56'9.62''$ ). It is from the middle part of the Hasandong Formation of the Sindong Group, Gyeongsang Supergroup.

#### 3.3. Description

When found this premaxillary tooth was missing a part of the apex and the root. As preserved the tooth is 13.6 mm in crown height. Crown basal length and width are 8.8 mm and 5.9 mm, respectively and crown/base ratio (0.67) is somewhat high, making a narrow oval profile in cross section. The long axis of the tooth is oriented labiolingually. The labial face is ovate and very convex toward the rostral end, but the lingual face is very weakly convex, resulting in a shallow, wide ridge. The lingual face flattens out proximal to the carinae, which are located at the mesiolingual and distolingual corners of the crown (Fig. 3D). The mesial carina is 3.5 mm shorter than the distal carina, and it terminates before reaching the base. The shorter mesial carina indicates that this premaxillary tooth is from the right side (Smith, 2005). A shallow groove runs immediately next to the mesial carina. The carinae form the mesial and distal edges of the lingual face in lingual view. The crown therefore demonstrates a typical “incisiform”, “U-shaped”, or “D-shaped” cross section.

There is no enamel “cap” (operculum) on the serrations, nor are there “blood grooves” and flask-shaped ampulla between serrations at the bottom as in tyrannosaurids (Currie et al., 1990; Alber, 1992, 1997; Fiorillo and Currie, 1994). Narrow slots (diaphyses) form the junction between



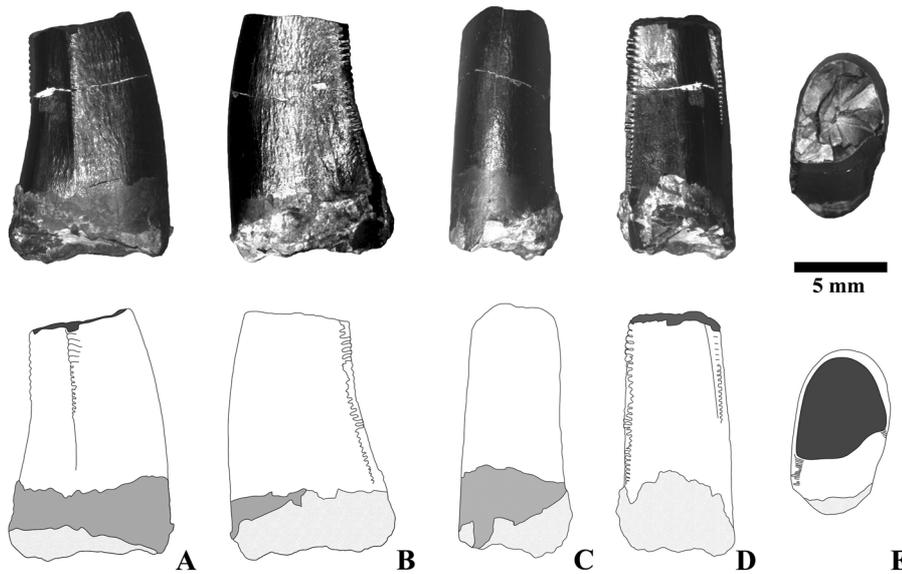
**Fig. 2.** Geological columnar section of the site indicating fossil bearing horizons.

neighboring serrations in both carinae. Hollow pockets between neighboring serrations are present, which may be cellae that trap and hold grease and meat debris, and which possibly facilitated an infectious bite (Alber, 1997). Serrations of the distal carina are saddle shaped and those of the mesial have the shape of a simple cube. Twenty eight and eighteen denticles are preserved in the distal and mesial carina, respectively. The denticles trend toward decreasing size in the direction of the base. Mean serration densities are 15.8/5 mm (DAVG, average distal denticle density, *sensu* Smith, 2005) and 17.6/5 mm (MAVG, average mesial denticle density), which suggests that the mesial denticles are smaller than the distal. The denticle size density index

(DSDI) is 1.11. In the distal carina, denticles are thicker mesiodistally than from the apex to the base of tooth and curve only slightly towards the apex of the tooth, but they are almost as high as they are long in the mesial carina.

#### 4. DISCUSSION

It is not certain whether KIGAM VP 200504 came from a juvenile or an adult, but its small size is consistent with the small sizes of the premaxillary teeth of all basal tyrannosauroids (Table 1). If from an adult, this tooth supports the evidence that basal tyrannosauroids were relatively small animals, and Holtz (1994) and Manabe (1999) have



**Fig. 3.** KIGAM VP 200504 in mesial (A), distal (B), labial (C), lingual (D), and occlusal (E) views.

**Table 1.** Basal tyrannosauroid's premaxillary teeth

	Perservation	Crown height	Lingual ridge	D-shape in cross section	References
<i>Bagaraatan</i>	not preserved				Osmolska, 1996
<i>Dryptosaurus</i>	not preserved				Cope, 1866; Carpenter et al., 1997
<i>Appalachiosaurus</i>	isolated tooth	~18 mm without root	yes	yes	Carr et al., 2005
<i>Eotyrannus</i>	two preserved in the right premaxilla	~25 mm with root	no	yes	Hutt et al., 2001
<i>Dilong</i>	in situ		no	yes	Xu et al., 2004
<i>Korean tooth</i>	isolated tooth	~18 mm without root*	yes	yes	This study
<i>Japanese tooth</i>	isolated tooth	~11 mm without root	no	yes	Manabe, 1999
<i>Stokesosaurus</i>	one preserved in the right premaxilla	~22 mm with root	no	sub-cylindrical	Madsen, 1974
<i>Aviatyrannis</i>	several isolated teeth	4~10mm without root	yes	yes	Zinke, 1998; Rauhut, 2000; Rauhut, 2003
<i>Guanlong</i>	in situ	~10 mm with root	yes	yes	Xu et al., 2006

\*estimated.

suggested that the group attained giant size mainly in the Late Cretaceous.

KIGAM VP 200504 is the first substantial evidence from Korea that can be attributed to the Tyrannosauoidea. Previously, all confirmed Asian basal tyrannosauroids had been discovered from China (*Dilong* and *Guanlong*, Xu et al., 2004, 2006) and Mongolia (*Bagaraatan*, Osmolska, 1996). One exception is an isolated premaxillary tooth identified as a tyrannosaurid from the Jobu Formation (Valanginian~Aptian) in Japan (Manabe, 1999). However, it could be a non-tyrannosaurid tyrannosauroid premaxillary tooth because of its small size (11 mm in tooth crown height) and its lower stratigraphic position than the first appearance of tyrannosaurid material at the Albian-Cenomanian boundary in Utah (Kirkland et al., 1997). Also, the key character to assign the specimen to the Tyrannosauridae was the “D-

shaped” cross-section of the tooth, however, this feature is a character common in non-tyrannosaurid tyrannosauroids as well as in tyrannosaurids (Table 1).

KIGAM VP 200504 is different from the Japanese specimen (IBEF VP 001) in having a distinct lingual ridge on the lingual surface and lower average denticle density (3.34 denticles per 1 mm). Other tyrannosauroids from the Early Cretaceous are *Dilong paradoxus* from the Yixian Formation (Valanginian~Barremian) in China (Xu et al., 2004) and *Eotyrannus lengi* from the Wessex Formation (Barremian) in England (Hutt et al., 2001). The premaxillary teeth of *Dilong* and *Eotyrannus* differ from KIGAM VP 200504 in having no such lingual ridge.

Identification of KIGAM VP 200504 as a tyrannosauroid is important for insight into tyrannosauroid paleobiogeography and evolution. Tyrannosauoidea included *Guanlong*,

*Aviatyrannis*, *Stokesosaurus*, *Dilong*, *Eotyrannus*, *Appalachiosaurus*, *Dryptosaurus*, *Bagaraatan*, and Tyrannosauridae (*sensu* Holtz, 2004). The oldest confirmed tyrannosauroid, *Guanlong wucaii* from the Oxfordian Shishugou Formation of China (Xu et al., 2006), is the most ancient known member of the lineage that led to *Tyrannosaurus rex* more than 90 million years later (Holtz, 2006). With discovery of this new Korean specimen, early tyrannosauroid biogeography appears more complex than previously thought (Hutt et al., 2001; Rauhut, 2003). After the first tyrannosauroid appeared in the early Late Jurassic in China, basal forms apparently dispersed to North America (*Stokesosaurus* in USA) and to Europe (*Aviatyrannis* in Portugal) during the Late Jurassic. Such basal Jurassic tyrannosauroids are succeeded by Early Cretaceous taxa in Asia (*Dilong*, the Korean and Japanese specimens) and Europe (*Eotyrannus*). These Early Cretaceous representatives indicate that basal tyrannosauroids were more widespread than tyrannosaurids in the Late Cretaceous. The Korean specimen indicates that after an Asian origin of tyrannosauroids, there was a subsequent Asian diversification of the group. Towards the end of the Late Cretaceous, however, tyrannosaurids were distributed only in Asia and North America (Carpenter, 1992; Holtz, 2004).

**ACKNOWLEDGMENTS:** For the fieldwork in 2005, I am deeply indebted to Drs. Y.-B. Kim, Y.-S. Lee, B.-C. Kim, and K.-Y. Song of KIGAM. I am grateful for the geological columnar section made by Dr. B.-C. Kim. I am also indebted to two anonymous reviewers for their comments and suggestions on the original manuscript. This work was supported mainly by the Cultural Heritage Administration, Korea.

## REFERENCES

- Abler, W.L., 1992, The serrated teeth of tyrannosaurid dinosaurs, and biting structures in other animals. *Paleobiology*, 18, 161–183.
- Abler, W.L., 1997, Tooth serrations in carnivorous dinosaurs. In: Currie, P.J. and Padian, K. (eds.), *Encyclopedia of dinosaurs*. Academic Press, p. 740–743.
- Carpenter, K., 1992, Tyrannosaurids (Dinosauria) of Asia and North America. In: Mather, N.J. and Chen, P.-J. (eds.), *Aspects of non-marine Cretaceous Geology*. China Ocean Press, Beijing, p. 250–268.
- Carpenter, K., Russell, D., Baird, D. and Denton, R., 1997, Redescription of the holotype of *Dryptosaurus aquilunguis* (Dinosauria: Theropoda) from the Upper Cretaceous of New Jersey. *Journal of Vertebrate Paleontology*, 17, 561–573.
- Carr, T.D., Williamson, T.E. and Schwimmer, D.R., 2005, A new genus and species of tyrannosauroid from the Late Cretaceous (middle Campanian) Demopolis Formation of Alabama. *Journal of Vertebrate Paleontology*, 25, 119–143.
- Chang, K.H., 1988, Cretaceous strata. In: Lee, D.S. (ed.), *Geology of Korea*. Geological Society of Korea, Kyohak-Sa, p. 175–194.
- Choi, D.K., 1985, Spores and pollen from the Gyeongsang Supergroup, southeastern Korea and their chronologic and paleoecologic implications. *Journal of Paleontological Society of Korea*, 1, 33–50.
- Choi, D.K., 1989, Palynology of the Geoncheonri Formation (Lower Cretaceous), Geoncheon-Ahwa area, Korea. *Journal of Paleontological Society of Korea*, 5, 1–27.
- Choi, H.I., 1986, Fluvial plain/lacustrine facies transition in the Cretaceous Sindong Group, south coast of Korea. *Sedimentary Geology*, 48, 295–320.
- Cope, E.D., 1866, Discovery of a gigantic dinosaur in the Cretaceous of New Jersey. *Proceedings of the Academy of Natural Sciences of Philadelphia*, 18, 275–279.
- Currie, P.J., Rigby, J.K. and Sloan, R.E., 1990, Theropod teeth from the Judith River Formation of southern Alberta, Canada. In: Carpenter, K. and Currie, P.J. (eds.), *Dinosaur systematics: approaches and perspectives*. Cambridge University Press, Cambridge, p. 107–125.
- Dong, Z., Paik, I.S. and Kim, H.J., 2001, A preliminary report on a sauropod from the Hasandong Formation (Lower Cretaceous), Korea. In: Deng, T. and Wang, Y. (eds.), *Proceedings of the 8th Annual Meeting of the Chinese Society of Vertebrate Paleontology*. Beijing, China Ocean Press, p. 41–53.
- Fiorillo, A.R. and Currie, P.J., 1994, Theropod teeth from the Judith River Formation (Upper Cretaceous) of south-central Montana. *Journal of Vertebrate Paleontology*, 14, 74–80.
- Holtz, T.R.Jr., 1994, The phylogenetic position of the Tyrannosauridae: implications for theropod systematics. *Journal of Paleontology*, 68, 1100–1117.
- Holtz, T.R.Jr., 2004, Tyrannosauroidae. In: Weishampel, D.B., Dodson, P. and Osmolska, H. (eds.), *The Dinosauria* (2nd edition). University of California Press, Berkeley, p. 111–136.
- Holtz, T.R.Jr., 2006, A Jurassic tyrant is crowned. *Nature*, 439, 665–666.
- Huene, F. von., 1914, Das natürliche system der Saurischia. *Zentralblatt für Mineralogie, Geologie, Palaeontologie*. B., 154–158.
- Hutt, S., Naish, D., Martill, D.M., Barker, M.J. and Newbery, P., 2001, A preliminary account of a new tyrannosauroid theropod from the Wessex Formation (Early Cretaceous) of southern England. *Cretaceous Research*, 22, 227–242.
- Kim, J.Y., Kim, K.-S. and Pickerill, R.K., 2002, Cretaceous non-marine trace fossils from the Hasandong and Jinju formations of the Namhae area, Kyongsangnamdo, Southeast Korea. *Ichnos*, 9, 41–60.
- Kirkland, J.I., Britt, B., Burge, D.L., Carpenter, K., Cifelli, R., Decourten, F., Eaton, J., Hasiotis, S. and Lawton, T., 1997, Lower to Middle Cretaceous dinosaur faunas of the central Colorado plateau: a key to understanding 35 million years of tectonics, sedimentology, evolution and biogeography. *BYU Geology Studies*, 42, 69–103.
- Lee, Y.S., Nishimura, S. and Min, M.D., 1996, Paleomagnetotectonics of East Asia in the Proto-Tethys Ocean. *Tectonophysics*, 270, 157–166.
- Lee, Y.-N., 2003, Dinosaur bones and eggs in South Korea. *Memoirs of the Fukui Prefectural Dinosaur Museum*, 2, 113–121.
- Lee, Y.-N., 2007, New theropod teeth from Juji Island (Hasandong Formation), Daedo-ri, Hadong County, South Gyeongsang Province. *Journal of the Geological Society of Korea*, 43, 151–166.
- Lee, Y.-N., Yang, S.Y. and Park, E.J., 1997, Sauropod dinosaur remains from the Gyeongsang Supergroup, Korea. *Journal of the Paleontological Society of Korea*, Special Publication, 2, 103–114.
- Lim, J. D., Martin, L. D. and Baek, K. S., 2002, The first megalosaurid tooth from South Korea. *Current Science*, 82, 326–328.
- Madsen, J.H.Jr., 1974, A new theropod dinosaur from the Upper Jurassic of Utah. *Journal of Paleontology*, 48, 27–31.
- Manabe, M., 1999, The early evolution of the Tyrannosauridae in

- Asia. *Journal of Paleontology*, 76, 1176–1178.
- March, O.C., 1881, Classification of the Dinosauria. *American Journal of Science* (Series. 3), 23, 81–86.
- Osborn, H.F., 1905, *Tyrannosaurus* and other Cretaceous carnivorous dinosaurs. *Bulletin of the American Museum of Natural History*, 21, 259–265.
- Osmolsak, H., 1996, An unusual theropod dinosaur from the Late Cretaceous Nemegt Formation of Mongolia. *Acta Palaeontologica Polonica*, 41, 1–38.
- Otofujii, Y., Matsuda, T. and Nohda, S., 1985, Opening mode of the Japan Sea inferred from the palaeomagnetism of the Japan Arc. *Nature*, 317, 603–604.
- Paik, I.S., Kim, H.J., Park, K.H., Song, Y.S., Lee, Y.I., Hwang, J.Y. and Huh, M., 2001, Palaeoenvironments and taphonomic preservation of dinosaur bone-bearing deposits in the Lower Cretaceous Hasandong Formation, Korea. *Cretaceous Research*, 22, 627–642.
- Park, E.J., Yang, S.Y. and Currie, P.J., 2000, Early Cretaceous dinosaur teeth of Korea. *Journal of the Paleontological Society of Korea*, Special Publication, 4, 85–98.
- Rauhut, O.W.M., 2000, The dinosaur fauna from the Guimarota mine. In: Martin, T. and Krebs, B. (eds.), *A Jurassic Ecosystem*. Verlag Dr. Friedrich Pfeil, Munich, p. 75–82.
- Rauhut, O.W.M., 2003, A tyrannosauroid dinosaur from the Upper Jurassic of Portugal. *Palaeontology*, 46, 903–910.
- Sano, Y., Terada, K. and Park, E.J., 2002, Ion microprobe dating of dinosaur tooth: implications for high-level lead exposure. *Goldschmidt Conference Abstract*, p. A666.
- Smith, J.B., 2005, Heterodonty in *Tyrannosaurus rex*: implications for the taxonomic and systematic utility of theropod dentitions. *Journal of Vertebrate Paleontology*, 25, 865–887.
- Upchurch, P., Barrett, P.M. and Dodson, P., 2004, Sauropoda. In: Weishampel, D. B., Dodson, P. and Osmolsaka, H.(eds.), *The Dinosauria* (2nd edition). University of California Press, Berkeley, p. 259–322.
- Xu, X., Norell, M.A., Kuang, X., Wang, X., Zhao, Q. and Jia, C., 2004, Basal tyrannosaurioids from China and evidence for protofeathers in tyrannosauroids. *Nature*, 431, 680–684.
- Xu, X., Clark, J.M., Forster, C.A., Norell, M.A., Erickson, G.M., Eberth, D.A., Jia, C. and Zhao, Q., 2006, A basal tyrannosauroid dinosaur from the Late Jurassic of China. *Nature*, 439, 715–718.
- Yang, S.Y., 1982, Geology around the type-locality of *Trigonioides* (s.s.) *kodairai* and age of the Nagdong Subgroup. *Journal of the Geological Society of Korea*, 18, 67–72.
- Yi, M.S., Cho, B.H. and Chi, J.M., 1994, Palynomorphs from the Jinju Formation in the Euseong area, Korea. *Journal of the Paleontological Society of Korea*, 10, 41–56.
- Yun, C.S. and Yang, S.Y., 1997, Dinosaur eggshells from Hasandong Formation, Gyeongsang Supergroup, Korea. *Journal of the Paleontological Society of Korea*, 13, 21–36. (in Korean with English abstract)
- Zinke, J., 1998, Small theropod teeth from the Upper Jurassic coal mine of Guimarota (Portugal). *Paläontologische Zeitschrift*, 72, 179–189.

---

Manuscript received September 27, 2007

Manuscript accepted March 19, 2008