Description of Theropod Teeth from the Upper Cretaceous Judith River Formation in Montana, U.S.A.

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Abstract

Five theropod teeth from the Campanian Judith River Formation in Montana, USA are described. The specimens come from Site 1, a bonebed in mudstone layer near Winifred, Fergus County, north-central Montana. Horizontal sections of two specimens are D-shaped, whereas the other three are lenticular. Hence former two specimens are tyrannosauroid premaxillary teeth. Latter three specimens are maxillary or dentary teeth of tyrannosauroids because their sizes show that they are of large North American theropods in the Late Cretaceous. Also, denticles of these three teeth on the distal carina are as large as those on the mesial carina, which excludes teeth of Dromaeosauridae, whose denticles on dental carina are larger than those on mesial carina.

Key Words: Theropoda, dentition, Late Cretaceous, Judith River Formation

Introduction

A nonmarine clastic wedge in Montana, U.S.A. and southern Alberta, Canada was formed to the west of the Western Interior Seaway in the Late Cretaceous (Eberth, 1997). In Montana, the Campanian Judith River Formation deposited along the Western Interior Seaway and the Two Medicine Formation inland (Rogers, 1998). The Judith River Formation has been well known for the occurrence of abundant disarticulated vertebrate fossils including dinosaurs (Sahni, 1972; Eberth, 1997; Weishampel et al., 2004).

In 1991, total of 220 fossil vertebrate specimens were collected from the Judith River Formation at a site named Site 1 in north-central Montana, U.S.A. (Fig. 1; Suzuki, 1993). Although the taphonomy of the bonebed at Site 1 has been analyzed including three-dimensional distribution of vertebrate specimens (Suzuki, 1993; Kawaguchi, 2013), none of the collected specimens have been described in detail. In this study, five tooth specimens among the collected elements are described to clarify their taxonomic affinities.

Geological Settings

Along the western margin of the Western Interior Seaway were coastal and alluvial plains in the Cretaceous (Everhart, 2005; Gates et al., 2010). In north-central Montana, nonmarine sequence of the middle-upper Campanian Judith River Formation overlies the middle Campanian Clagett Shale and is overlain by upper Campanian Bearpaw Formation, both of which are composed of marine sediments (Eberth, 1997; Gates et al., 2010). The Judith River Formation correlates with the Oldman Formation in southern Alberta, Canada, which also deposited along the Western Interior Seaway (Eberth, 1997). To the west of the Judith River Formation, which was more inland in the Late Cretaceous, lies the middle-upper Campanian Two Medicine Formation (Rogers, 1998).

The Judith River Formation, along with its lithostratigraphic equivalent the Oldman Formation, has yielded numerous concentrated and disarticulated vertebrate fossils including dinosaurs (Eberth, 1997). Dinosaur remains from the Judith River Formation comprise those of theropods,

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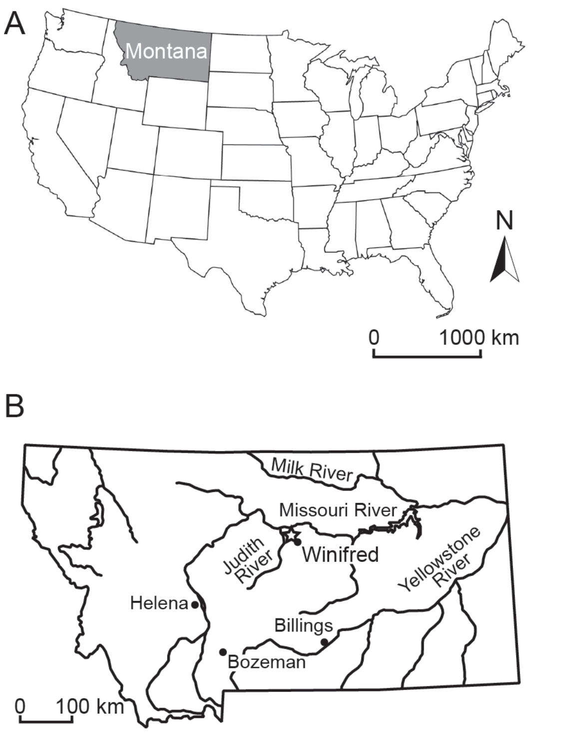

Figure 1. Locality of studied specimens. (A) Map of U.S.A. (B) Map of Montana. Star indicates Site 1.

ankylosaurs, ornithopods, pachycephalosaurs, and ceratopsians (Weishampel et al., 2004).

Two hundred twenty vertebrate fossils have been collected in 1991 from a bonebed in a mudstone layer near Winifred, Fergus County, north-central Montana, which was named Site 1 (Fig. 1B; Suzuki, 1993). The elements were concentrated within the area of 10 m in north-south direction and 14 m in east-west direction. Sizes of vertebrate fossils range from several millimeters to 1 m and large elements are considered to be of hadrosaurids (Kawaguchi, 2013). None of the specimens were articulated, indicating allochthonous preservation. The bonebed also includes freshwater bivalves (Suzuki, 1993).

Materials and Methods

Terminology used in this paper is shown in Figure 2. Five theropod tooth specimens, KMNH VP 000,026 - KMNH VP 000,030 from Site 1 were analyzed in this study (Fig. 3). They are housed at the Kitakyushu Museum of Natural History and Human History in Kitakyushu, Fukuoka Prefecture, Japan.

The overall morphology of the studied specimen was first documented. Five measurements of tooth specimens were taken. In this study, apical length (AL), crown base length (CBL), crown base width (CBW), height of the crown (CH), and the angle of the crown (CA) were measured (Fig. 2). The density of denticles (i.e. number of denticles/mm) along carinae was also examined. Casts of the five specimens were produced and partially ground to observe the horizontal cross-section of the specimens.

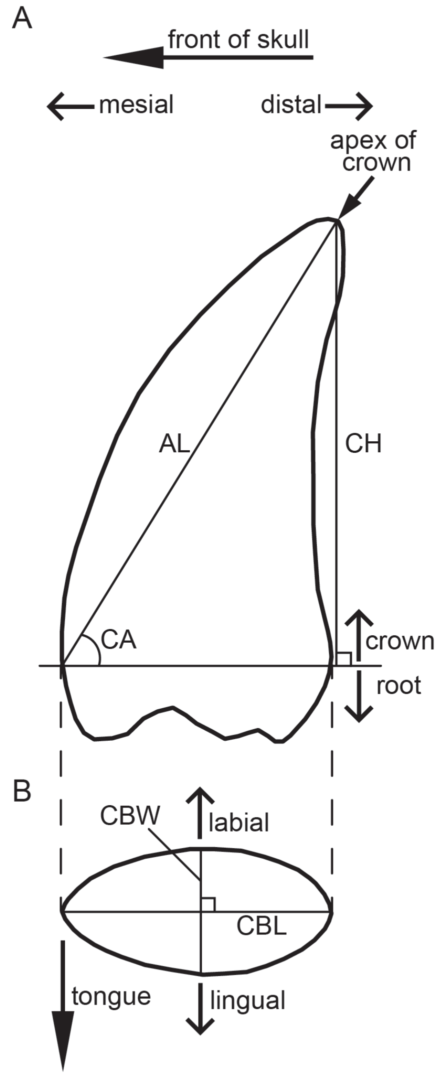

Figure 2. Dental terminology and measurements taken. Schematic diagram of a theropod tooth is shown. (A) Dentary tooth in labial view. (B) Dentary tooth in basal view. Abbreviations: AL, apical length; CA, angle of crown; CBW, crown base width; CBL, crown base length; CH, height of crown.

Systematic Paleontology

Theropoda Marsh, 1881

Tetanurae Gauthier, 1986

Coelurosauria von Huene, 1914

Tyrannosauroidea Walker, 1964

Tyrannosauroidea indet.

Figure 3

Description

All teeth are roughly conical and are recurved (Figs. 3, 4). The roots are only partially preserved. Since all five specimens have worn surfaces in the apical region, they were functional teeth. KMNH VP 000,026 and KMNH VP 000,027 have two lingual or caudal carinae, which are on a plane perpendicular to rostrocaudal axis of the skull. KMNH VP 000,028, KMNH VP 000,029, and KMNH VP 000,030 have a mesial and a distal carina aligned on a plane parallel to rostrocaudal axis of the skull. Denticles develop on carina. In each specimen, the denticles are approximately of the same size.

Measurements are shown in Table 1. In addition to the dental morphology owing to the positions of the carinae, KMNH VP 000,026 and KMNH VP 000,027 can be distinguished from KMNH VP 000,028, KMNH VP 000,029, and KMNH VP 000,030 by the size range, with the former two being smaller than the latter three. CA is approximately 60

Figure 3. Photographs of studied specimens in mesial/labial views. (A) KMNH VP 000,026. (B) KMNH VP 000,027. (C) KMNH VP 000,028. (D) KMNH VP 000,029. (E) KMNH VP 000,030. Note that labial side is to the left in A and B, and mesial side to the right in C-E. Scale bars: 20 mm.

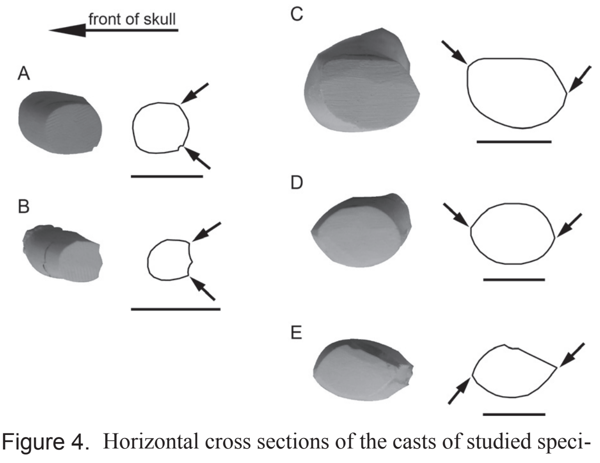

Figure 4. Horizontal cross sections of the casts of studied specimens. (A) KMNH VP 000,026. (B) KMNH VP 000,027. (C) KMNH VP 000,028. (D) KMNH VP 000,029. (E) KMNH VP 000,030. In each specimen, photograph in occlusal view is to the left and the outline of the horizontal section is to the right. Arrows associated with the outlines indicate the carinae. Scale bars: 20 mm.

specimen no.	CH (mm)	AL (mm)	CA (degrees)	CBL (mm)	CBW (mm)	no. of denticles/ mm	
KMNH VP 000,026	32.9	39.0	58	21.0	12.7	4 (r)	5 (l)
KMNH VP 000,027	25.4	28.9	61	14.0	8.5	8 (r)	7 (l)
KMNH VP 000,028	50.9	55.6	66	22.3	17.7	6 (m)	6 (d)
KMNH VP 000,029	42.1	48.0	61	23.2	17.1	5 (m)	5 (d)
KMNH VP 000,030	39.3	45.8	59	23.6	16.8	6 (m)	5 (d)

Table 1. Measurements of five theropod tooth specimens. See text and Figure 2 for definition of CH, AL, CA, CBL, and CBW. Abbreviations: d, distal carina; l, left carina in occlusal view; m, mesial carina; r, right carina in occlusal view.

degrees, ranging from 57.5 degrees in KMNH VP 000,026 and 66.4 degrees in KMNH VP 000,028. The lower CA is, more recurved a tooth is. KMNH VP 000,026, therefore, is most recurved among the five specimens. In terms of the density of denticles along carina, the numbers of denticles per 1 mm on the two carinae are roughly the same in all specimens.

Horizontal sections of KMNH VP 000,026 and KMNH VP 000,027 are D-shaped, owing to the two carinae on the lingual surface (Fig. 4A, B). On the contrary, horizontal sections of KMNH VP 000,028, KMNH VP 000,029, and KMNH VP 000,030 are lenticular, for they have a mesial and distal carina (Fig. 4C-E).

Discussion and Conclusion

The conical morphology of the studied specimens shows that they are the teeth of carnivorous vertebrates. Among the toothed carnivorous terrestrial vertebrates from the Judith River Formation including crocodiles, pterosaurs, theropods, champsosaurids, and mammals, only theropod teeth have denticles (Eberth, 1997; Gates et al., 2010). Therefore, all five teeth studied pertain to Theropoda.

In Theropoda, Tyrannosauroidea, Ornithomimosauria, Oviraptorosauria, Troodontidae, and Dromaeosauridae have been discovered from the Judith River Formation (Weishampel et al., 2004; Gates et al., 2010). Among these taxa, D-shaped horizontal section can only be seen in premaxillary teeth of Tyrannosauroidea, owing to the two lingual carinae (Holtz, 2004). Hence KMNH VP 000,026 and KMNH VP 000,027 are tyrannosauroid premaxillary teeth. The sizes of KMNH VP 000,028, KMNH VP 000,029, and KMNH VP 000,030 show that they are of large theropods. Carinae of dromaeosaurid teeth are serrated, but denticles on the distal carina are distinctly larger than those on the mesial carina (Currie et al., 1990). In KMNH VP 000,028, KMNH VP 000,029, and KMNH VP 000,030, denticles on the distal carina, in contrast, are as large as those on the mesial carina. Ornithomimosaurs and oviraptorosaurs are toothless (Makovicky et al., 2004; Osmólska et al., 2004). Troodontids are small theropods. CBL of troodontid teeth does not exceed 20 mm (Holtz et al., 1998). The size and morphology of KMNH VP 000,028, KMNH VP 000,029, and KMNH VP 000,030 do not coincide with those of the above taxa other than Tyrannosauroidea. Therefore, KMNH VP 000,028, KMNH VP 000,029, and KMNH VP 000,030 are either maxillary or dentary teeth of Tyrannosauroidea.

Among the 220 vertebrate elements from Site 1, KMNH VP 000,026 - KMNH VP 000,030 are the only carnivorous teeth collected (Kawaguchi, 2013), all of which are of large theropods. Lack of small carnivores may be the result of preservation bias.

In conclusion, KMNH VP 000,026 and KMNH VP 000,027 are tyrannosauroid premaxillary teeth, and KMNH VP 000,028, KMNH VP 000,029, and KMNH VP 000,030 are tyrannosauroid maxillary or dentary teeth. Tyrannosauroids from the Judith River Formation include *Albertosaurus*, *Gorgosaurus* and other tyrannosaurids whose generic affinity is not yet known (Gates et al., 2010). Further studies may clarify the taxonomy of these specimens.

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