

A possible ceratopsid tooth from the Upper Cretaceous of Kyushu, Japan

Makoto Manabe¹, Takanobu Tsuihiji², Yuka Miyake³ and Toshifumi Komatsu⁴

¹ Department of Geology and Paleontology, National Museum of Nature and Science,
4–1–1 Amakubo, Tsukuba, Ibaraki 305–0005, Japan

² Department of Earth and Planetary Science, The University of Tokyo,
7–3–1 Hongo, Bunkyo-ku, Tokyo 113–0033, Japan

³ Satsumasendai City Board of Education, 1457–10 Imuta, Kashima, Satsumasendai,
Kagoshima 896–1392, Japan

⁴ Faculty of Advanced Science and Technology, Kumamoto University,
2–39–1 Kurokami, Chuo-ku, Kumamoto 860–8555, Japan

Abstract A fragmentary tooth is reported from the Campanian section of the Upper Cretaceous Himenoura Group on Shimokoshikishima Island of Kyushu, Japan. The tooth specimen is identified as the medial root of a ceratopsid dinosaur. If this identification is correct, it represents a rare example of the clade in Asia.

Key words: Ceratopsidae, Dinosauria, Himenoura Group, Campanian, Kyushu, Japan

Introduction

Ceratopsians were one of the most successful clades of dinosaurs in North America and Asia during the Cretaceous Period (e.g., Dodson *et al.*, 2004; You and Dodson, 2004). Ceratopsians, especially ceratopsids, are characterized by derived and diversified characters especially in the skull such as the distinctive frill, horns and beak (Dodson, 1996). Ceratopsidae, including the well-studied taxon *Triceratops*, is known for its complex dental battery, i.e., cheek teeth stacked and overlapped together into a single functional slicing block in each jaw. The structure of their dental battery is significantly different from that of hadrosaurids, reflecting their independent acquisitions; i.e., the grinding surfaces are nearly vertical in ceratopsids and more horizontal in hadrosaurids. In ceratopsids, the root of each cheek tooth is transversely bifurcated and overlaps the crown of the succeeding tooth (Hatcher *et al.*, 1907; Brown and Schlaikjer, 1940). Bifurcated roots are only known in Ceratopsidae within dinosaurs (e.g. Sereno, 1984). Ceratopsidae had been reported only from

North America until Xu *et al.* (2010) described *Sinoceratops zhuchengensis* from the Upper Cretaceous of China, demonstrating the presence of this clade in Asia. However, remains of ceratopsids are still very scarce in Asia with *S. zhuchengensis* being the only definite Asian ceratopsid. In the present study, a fragmentary element found from the Campanian section of the Himenoura Group on Shimokoshikishima Island in Japan is described. This specimen is identified as a part of the medial root of a ceratopsid. If the identification is sustained, it would represent the first specimen of Ceratopsidae, or its close out-group, reported from Japan.

Materials and Methods

An isolated and fragmentary tooth root found in Kashima on Shimokoshikishima Island (KMSP-100117). The specimen was CT-scanned on the TESCO TXS320-ACTIS micro CT scanner at the National Museum of Nature and Science, Tokyo, Japan.

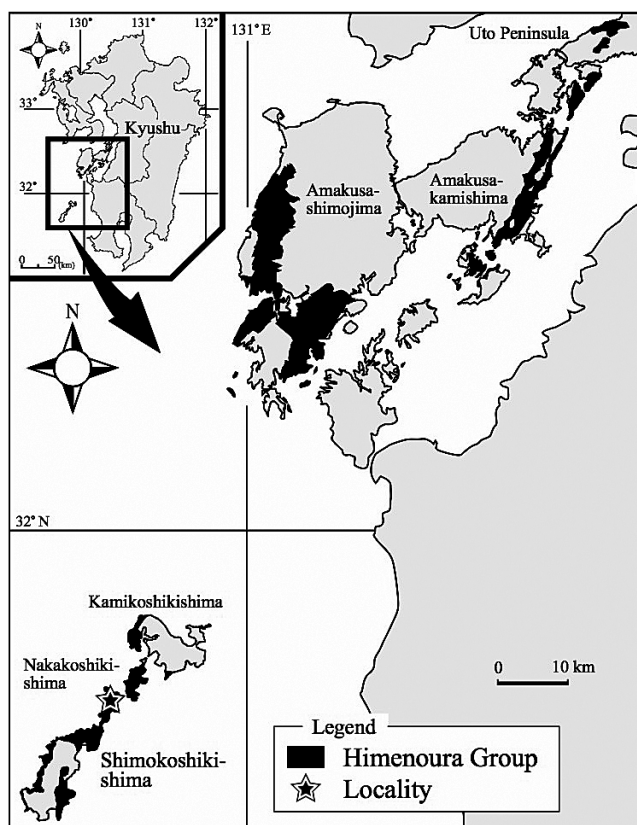


Fig. 1. Map showing the Upper Cretaceous Himenoura Group in southwest Kyushu, Japan (modified from Tashiro, 1976 and Komatsu *et al.*, 2008) with a star indicating the locality of KMSP-100117.

Institutional Abbreviations

KMSP, Faculty of Science, Kumamoto University, Japan; NSM PV, Vertebrate Paleontology Collection, National Museum of Nature and Science, Japan.

Geological Setting

The specimen (KMSP-100117) was collected in the Kashima area on Shimokoshikishima Island (Fig. 1). The Imuta Formation (Amano, 1957; Tashiro and Noda, 1973) or “Formation U-III” (Tashiro, 1976; Kanoh *et al.*, 1989) of the Himenoura Group is exposed in this area. The age of this formation has been inferred as Campanian (Kanoh *et al.*, 1989), Campanian to Maastrichtian (Tashiro and Noda, 1973), or early Maastrichtian (Tashiro, 1976) based on its

bivalve assemblages. Miyake *et al.* (2012) and Komatsu *et al.* (2014) reported middle Campanian inoceramids characterized by *Sphenoceras schmidtii* in the upper part of the “Formation U-II” underlying the “Formation U-III” in southern Kashima area. Aramaki *et al.* (2013) also reported abundant Santonian to middle Campanian radiolarian assemblages consisting of *Amphipyndax stocki* and *Dictyomitra koslovae* in the “Formation U-IV” overlying the “Formation U-III” on Nakakoshikishima Island. Based on these data, Aramaki *et al.* (2013) and Komatsu *et al.* (2014) inferred the age of the “Formation U-III” to be middle Campanian.

The specimen was found in a black, sandy mudstone bed of less than 1 m thickness interpreted as the back marsh deposit in the fluvial systems (Fig. 2), and co-occurred with isolated bones such as an infraorbital of a fish, fragmen-

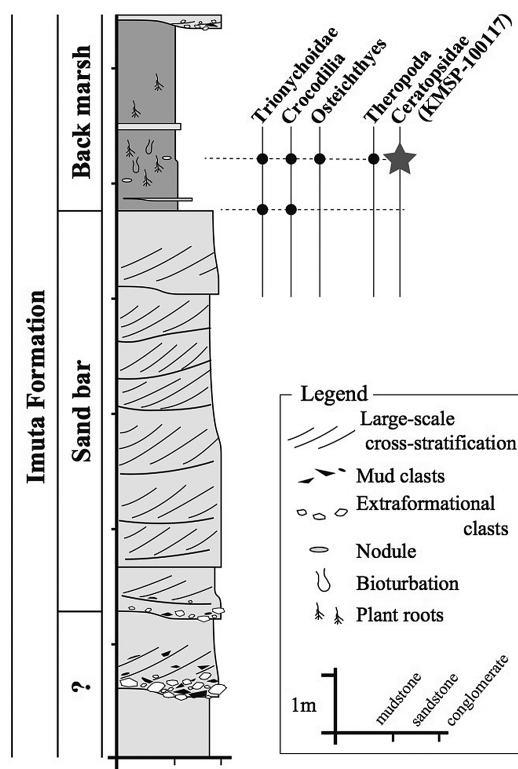


Fig. 2. Schematic profile of the Imuta Formation with stratigraphic occurrence of vertebrate fossils in Kashima of Shimokoshikishima Island modified from Ohashi *et al.* (2009), Miyake *et al.* (2012), Tsuihiji *et al.* (2013) and Komatsu *et al.* (2014).

tary carapaces of trionychoid turtles, crocodilian scutes and tooth, and a fragmentary rib and teeth belonging to theropods (e.g., Miyake *et al.*, 2012; Tsuihiji *et al.*, 2013).

Results

The specimen (KMSP-100117) is an isolated, fragmentary tooth element (Fig. 3) identified herein as a part of a plate-like root of a tooth continuing from the crown. It is approximately square and thin, and is 12.1 mm in the maximum width, 8.6 mm in height, and 3.7 mm in thickness. One side of the element is generally convex and the other side is concave. The convex side of the specimen bears an oblique ridge that bounds a deep depression on one side and a shallow oval

depression on the other (Fig. 4a). On the opposite, concave side, the central part is especially deeply excavated (Fig. 4b). This excavation is likely to have formed due to resorption from the succeeding tooth. These morphological features are very similar to a basal part of the lingual (medial) root of the maxillary tooth in ceratopsids. Here comparison was made with an isolated ceratopsid tooth collected from the Hell Creek Formation in South Dakota (NSM PV 23806; Figs. 3d, 4d, e, f). NSM PV 23806 is identified as a maxillary tooth because the primary ridge on the crown is only moderately developed, and the root on the side of the enameled surface of the crown is more robustly developed than the other root (e.g., Hatcher *et al.*, 1907; Mallon and Anderson, 2014). In addition, the specimen is derived from the left side because the primary ridge is offset distally on the maxillary tooth in ceratopsids (Mallon and Anderson, 2014). In the specimen, the lingual aspect of the lingual root bears a depression that is bounded mesially (anteriorly) by an oblique low ridge. Between this ridge and the mesial margin of the root is also depressed. The labial (lateral) or deep side of this root is deeply excavated. All the morphological features preserved in KMSP-100117 are shared with NSM PV 23806, suggesting that the former belongs to a ceratopsid or a closely-related taxon (see Discussion below). In addition, KMSP-100117 is similar in size to the corresponding part of NSM PV 23806.

Discussion

Ceratopsidae is the major derived clade of Ceratopsia (e.g., Dodson *et al.*, 2004). For a long time, the fossil record of this clade had been restricted to North America, leading to the notion that it originated and evolved in this continent (e.g., Dodson *et al.*, 2004). Recently, however, remains of ceratopsids, or their close outgroup, have been found in Asia. First, *Turanoceratops tardabilis* found from the Upper Cretaceous of Uzbekistan was reported as a ceratopsid by Sues and Averianov (2009). However, Farke *et al.*



Fig. 3. KMSP-100117 in lingual (a), labial (b) and basal (c) views. KMSP-100117 is superimposed on a digitally rendered image of a ceratopsid tooth NSM PV 23806 (d).

(2009) argued that *T. tardabilis* is the sister taxon of Ceratopsidae, and this hypothesis is supported by more recent phylogenetic analyses, which either supports this interpretation (Brown and Henderson, 2015) or places it as a part of an unresolved polytomy with Ceratopsidae and *Zuniceratops christopheri* (e.g., McDonald, 2011; Lund *et al.*, 2016). Xu *et al.* (2010) described *Sinoceratops zuchengensis* from the Upper Cretaceous of Shandong, China, as a true ceratopsid and this has been supported by recent phylogenetic analyses (e.g., McDonald, 2011; Lund *et al.*, 2016), making *Sinoceratops* the only currently-known ceratopsid in Asia. The tooth roots of Ceratopsidae and *T. tardabilis* are bifurcated (Sues and Averianov, 2008), indicating that this feature is not an synapomorphy for Ceratopsidae, but rather diagnoses a more inclusive

clade. Assuming that identification of KMSP-100117 as the lingual branch of a bifurcated tooth root is sustained, this specimen represents a rare example of Ceratopsidae or its close out-group from Asia and the first report from Japan. Whereas dinosaur remains have been increasingly common in the Lower Cretaceous of Japan (e.g., Saegusa and Ikeda, 2014; Azuma *et al.*, 2016), the Upper Cretaceous counterpart has yielded relatively scarce specimens. However, the present finding, together with the previous report on a theropod tooth (Tsuihiji *et al.*, 2013), suggests that a potentially diverse dinosaurian fauna existed in the present Shimokoshikishima Island during the deposition of sediments of the Himenoura Group and that it could provide important information on dinosaurian paleogeography and evolution in Asia in the Campanian.



Fig. 4. KMSP-100117 in lingual (a), labial (b) and basal (c) views; A digitally rendered image of NSM PV 23806 lingual view (d), labial view of the lingual root (e) and basal view (f); groove (gr), oval depression (od) and cross-sectional view corresponding to (c) (cs).

Acknowledgments

The authors admire the skillful preparation of the specimen performed by Masatoshi Okura of Konan City, Aichi Prefecture. We thank Dr. Michael J. Ryan of Cleveland Museum of Natural History for his comments that greatly improved the manuscript. The specimen was CT-scanned by Chisako Sakata at National Museum of Nature and Science, Japan. Fossil studies were logistically supported by the Kashima Branch office of the City of Satsuma Sendai and also by the Department of Education of the city. This study was in part financially supported by a Grant-in-Aid from the Japan Society for Promotion of Science (16K05593 to Komatsu).

References

- Amano, M. (1957). Upper Cretaceous molluscan from Shimo-Koshikijima. Kyushu. *Kumamoto Journal of Science, ser. B, sec. 1*, 2: 63–86.
- Aramaki, M., Komatsu, T., Miyake, Y., Takahashi, O. and Tsutsumi, Y. (2013). Radiolarians from the Upper Cretaceous Himenoura Group, Nakakoshiki-jima Island, Kagoshima Prefecture, Japan. *Journal of the Geological Society of Japan*, 119: 45–50. (In Japanese with English abstract)
- Azuma, Y., Xu, X., Shibata, M., Kawabe, S., Miyata, K. and Imai, T. (2016). A bizarre theropod from the Early Cretaceous of Japan highlighting mosaic evolution among coelurosaurians. *Scientific Reports*, 6: 20478. doi: 10.1038/srep20478
- Brown, B. and Schlaikjer, E. M. (1940). A new element in the ceratopsian jaw the additional notes on the mandible. *American Museum Novitates*, 1092: 1–13.
- Brown, C. M. and Henderson, D. M. (2015). A new horned dinosaur reveals convergent evolution in cranial

- ornamentation in Ceratopsidae. *Current Biology*, **25**: 1641–1648.
- Dodson, P. (1996). The Horned Dinosaurs. 346 pp. Princeton University Press, Princeton, NJ.
- Dodson, P., Forster, C. A. and Sampson, S. D. (2004). Ceratopsidae. In: Weishampel, D., Dodson, P. and Osmólska, H. (Eds.), The Dinosauria, 2nd ed. University of California Press, Berkeley and Los Angeles, pp. 494–513.
- Hatcher, J. B., Marsh, O. C. and Lull, R. S. (1907). The Ceratopsia. *Monographs of the United States Geological Survey*, **49**: 1–300.
- Kanoh, M., Toshimitsu, S. and Tashiro, M. (1989). Stratigraphy and depositional facies of the Himenoura Group in the Koshikijima Island, Kagoshima Prefecture. *Research Reports of the Kochi University, Natural Science*, **38**: 157–172. (In Japanese with English abstract)
- Komatsu, T., Miyake, Y., Manabe, M., Hirayama, R., Yabumoto, Y. and Tsuihiji, T. (2014). Stratigraphy, fossils and depositional environments of the Upper Cretaceous Himenoura Group on the Koshikijima Islands. *Journal of the Geological Society of Japan*, **120**: S19–S39. (In Japanese)
- Komatsu, T., Ono, M., Naruse, H. and Kumagae, T. (2008). Upper Cretaceous depositional environments and bivalve assemblages of far-east Asia: The Himenoura Group, Kyushu, Japan. *Cretaceous Research*, **29**: 489–508.
- Lund, E. K., O'Connor, P. M., Loewen, M. A. and Jinnah, Z. A. (2016). A new centrosaurine ceratopsid, *Machairoceratops cronusi* gen et sp. nov., from the Upper Sand Member of the Wahweap Formation (middle Campanian), Southern Utah. *PLoS ONE*, **11**(5): e0154403. doi:10.1371/journal.pone.0154403.
- McDonald, A. T. (2011). A subadult specimen of *Rubeosaurus ovatus* (Dinosauria: Ceratopsidae), with observations on other ceratopsids from the Two Medicine Formation. *PLoS ONE*, **6**(8): e22710. doi:10.1371/journal.pone.0022710.
- Mallon, J. C. and Anderson, J. S. (2014). The functional and palaeoecological implications of tooth morphology and wear for the megaherbivorous dinosaurs from the Dinosaur Park Formation (Upper Campanian) of Alberta, Canada. *PLoS ONE*, **9**(6): e98605. doi:10.1371/journal.pone.0098605.
- Miyake, Y., Aramaki, M., Komatsu, T., Takahashi, O., Shigeta, Y., Manabe, M., Tsuihiji, T., Hirayama, R., Yabumoto, Y. and Ohashi, T. (2012). Vertebrate fossils and geologic age of the Cretaceous Himenoura Group in the Shimokoshiki-jima Island, Kagoshima, Kyushu, Japan. *Proceedings of the Nishinohon Branch, Geological Society of Japan*, **162**: O-07. (In Japanese with English abstract)
- Ohashi, T., Hirasawa, T., Tsuihiji, T., Kusuhashi, N., Kondo, K., Komatsu, T. and Manabe, M. (2009). A new vertebrate fossil site in fluvial deposits of the Late Cretaceous Himenoura Group in southwest Japan. In: Organizing and Scientific Committee of the IGCP Symposium (Ed.), Abstracts and Post-symposium Field Excursion Guidebook, 4th International Symposium of the International Geoscience Programme Project no. 507. pp. 70–71.
- Saegusa, H. and Ikeda, T. (2014). A new titanosauriform sauropod (Dinosauria: Saurischia) from the Lower Cretaceous of Hyogo, Japan. *Zootaxa*, **3848**: 1–66.
- Sereno, P. C. (1984). The phylogeny of the Ornithischia: a reappraisal. In: Reif, W.-E. and Westphal, F. (Eds.), Third Symposium on Mesozoic Terrestrial Ecosystems, Short Papers. Attempto Verlag, Tübingen, pp. 219–226.
- Sues, H. D. and Averianov, A. (2009). *Turanoceratops tardabilis*—the first ceratopsid dinosaur from Asia. *Naturwissenschaften*, **96**: 645–652.
- Tashiro, M. and Noda, M. (1973). The geological age of the “Himenoura Group,” Kyushu, Japan. *Journal of the Geological Society of Japan*, **79**: 465–480. (In Japanese with English abstract)
- Tashiro, M. (1976). Bivalve faunas of the Cretaceous Himenoura Group in Kyushu. *Palaeontological Society of Japan, Special Papers*, **19**: 1–102.
- Tsuihiji, T., Komatsu, T., Manabe, M., Miyake, Y., Aramaki, M. and Sekiguchi, H. (2013). Theropod tooth from the Upper Cretaceous Himenoura Group in the Koshikijima Islands, Southwestern Japan. *Paleontological Research*, **17**: 39–16.
- Xu, X., Wang, K., Zhao, X. and Li, D. (2010). First ceratopsid dinosaur from China and its biogeographical implications. *Chinese Science Bulletin*, **55**: 1631–1635.
- You, H. and Dodson, P. (2004). Basal Ceratopsia. In: Weishampel, D., Dodson, P. and Osmólska, H. (Eds.), The Dinosauria. 2nd ed. University of California Press, Berkeley and Los Angeles, pp. 478–493.