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

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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 outgroup, 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.

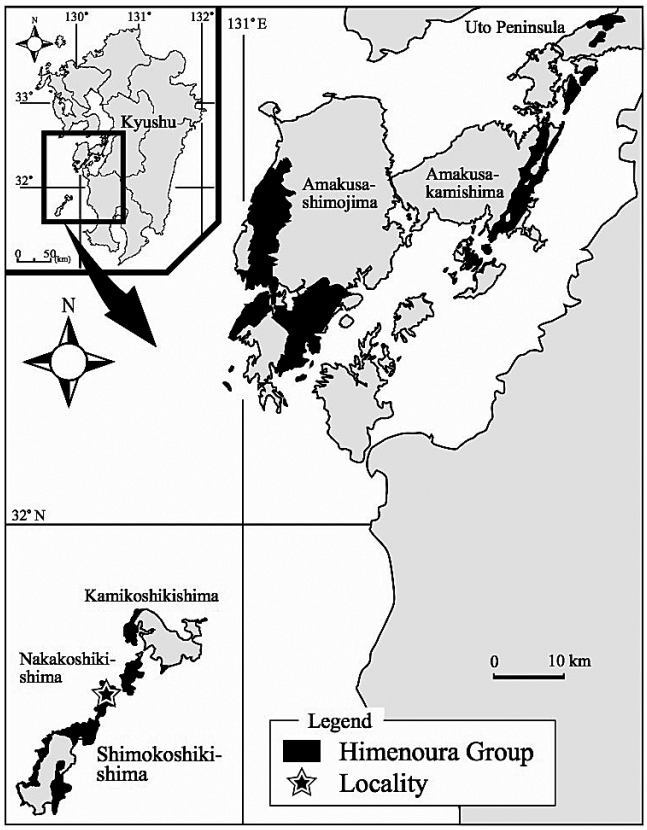

Fig. 1. Map showing the Upper Cretaceous Himenoura Group in southwest Kyushu, Japan (modified from Tashiro, 1976 and Komatsu *et al.*, 2008) with a star indicating the locality of KMSP-100117.

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 *Sphenoceramus schmidti* 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-

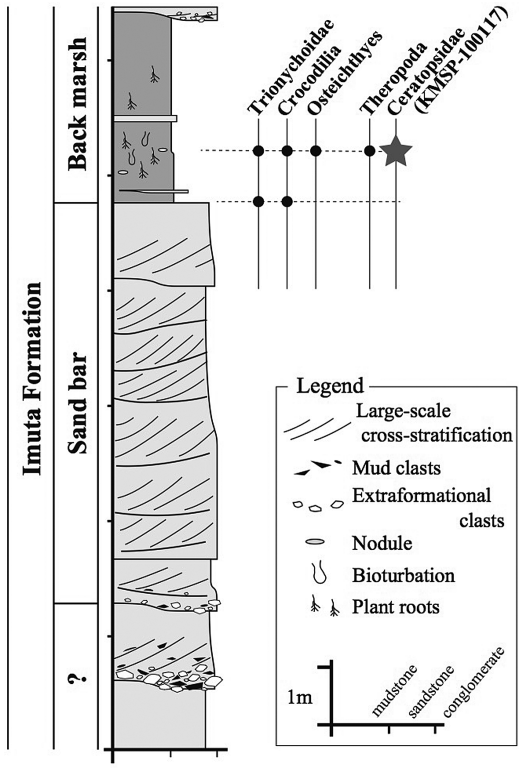

Fig. 2. Schematic profile of the Imuta Formation with stratigraphic occurrence of vertebrate fossils in Kashima of Shimokoshikishima Island modified from Ohashi *et al.* (2009), Miyake *et al.* (2012), Tsuihiji *et al.* (2013) and Komatsu *et al.* (2014).

tary carapaces of trionycoid 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 outgroup 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.

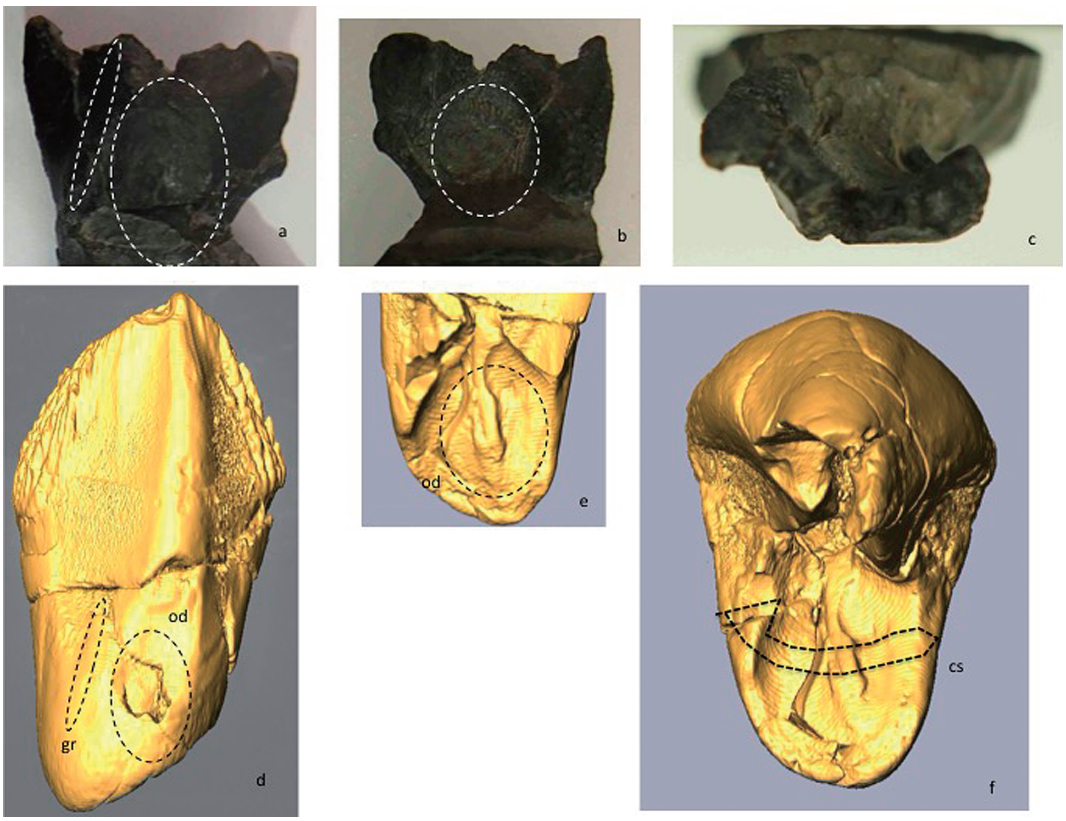

Fig. 4. KMSP-100117 in lingual (**a**), labial (**b**) and basal (**c**) views; A digitally rendered image of NSM PV 23806 lingual view (d), labial view of the lingual root (e) and basal view (f); groove (gr), oval depression (od) and cross-sectional view corresponding to (c) (cs).

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