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The first basal neoceratopsian dinosaur from the Lower Cretaceous Kanmon Group in Kyushu, southwestern Japan

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Abstract. **An isolated tooth specimen from the Lower Cretaceous Kanmon Group in Kyushu Island, southwestern Japan was initially identified as a hadrosaurid. It is reidentified herein as a neoceratopsian tooth based on the presence of a wide and prominent primary ridge on the crown, a shallow indentation on the right side of the primary ridge in non-occlusal view, and a horizontally oriented cingulum at the base of the crown. The poorly developed cingulum and shallow indentation suggest that it does not pertain to a ceratopsid, but is only referable to a basal neoceratopsian. This represents the first basal neoceratopsian specimen from the Lower Cretaceous of Kyushu Island.**

Key words: dentition, Early Cretaceous, East Asia, Kanmon Group, Kyushu, Neoceratopsia

Introduction

Ceratopsia was one of the dominant herbivorous dinosaur clades in the Cretaceous terrestrial ecosystems of Asia and western North America (Dodson *et al*., 2004; You and Dodson, 2004; Makovicky, 2012). Within Ceratopsia, Neoceratopsia thrived throughout the Cretaceous. Within Dinosauria, neoceratopsians are diagnosed, in part, by having a very large head relative to body size, a predentary and a keeled rostral forming a deep 'beak', a caudodorsally oriented parietosquamosal frill, ovate maxillary and dentary tooth crowns in non-occlusal view, and maxillary teeth with prominent primary ridge (Sereno, 1986). Recent discoveries of European and Korean basal neoceratopsians show that the distribution of basal Neoceratopsia in Eurasia was wider than previously thought (Godefroit and Lambert, 2007; Lindgren *et al*., 2007; Lee *et al*., 2011). The occurrence of neoceratopsian specimens from the Lower Cretaceous Sasayama Group, Hyogo Prefecture, Japan (Saegusa *et al*., 2009), and the Upper Cretaceous Himenoura Group, Kagoshima Prefecture, Japan (Manabe, pers. comm., 2013) demonstrates that neoceratopsian distribution extended to the eastern margin of the Eurasian continent.

A tooth specimen was collected from the Lower Cretaceous Kanmon Group in Fukuoka Prefecture, Kyushu, southwestern Japan in 1991. Although it was originally reported as a hadrosaurid tooth (Okazaki, 1994), it has not been described in detail. In this study, we reexamined the specimen to clarify its affinity and concluded that it does not pertain to a hadrosaurid, but rather to a basal neoceratopsian, possibly referable to a new taxon. This represents the first basal neoceratopsian specimen from the Lower Cretaceous of Kyushu.

Institutional abbreviations.—**IG**, Institute of Geology, Chinese Academy of Geological Sciences, Beijing, China; **KMNH**, Kitakyushu Museum of Natural History and Human History, Kitakyushu, Japan; **ROM**, Royal Ontario Museum, Toronto, Canada; **SBEI**, Shiramine Board of Education, Ishikawa.

Geological setting

Outcrops of the Lower Cretaceous Kanmon Group are distributed in Fukuoka Prefecture, northern Kyushu Island and Yamaguchi Prefecture, western Honshu Island, Japan (Figure 1; Ota *et al*., 1979; Nakae *et al*., 1998). The Wakino and Shimonoseki subgroups compose the lower and upper parts of the Kanmon Group, respectively. The Wakino Subgroup consists of non-marine deposits and is 1,000 to 1,200 m thick (Ota *et al*., 1979). Its age is considered to be Hauterivian to Barremian (Ota, 1981; Matsumoto *et al*., 1982). In central Kitakyushu City, Fukuoka Prefecture, the Dobaru,

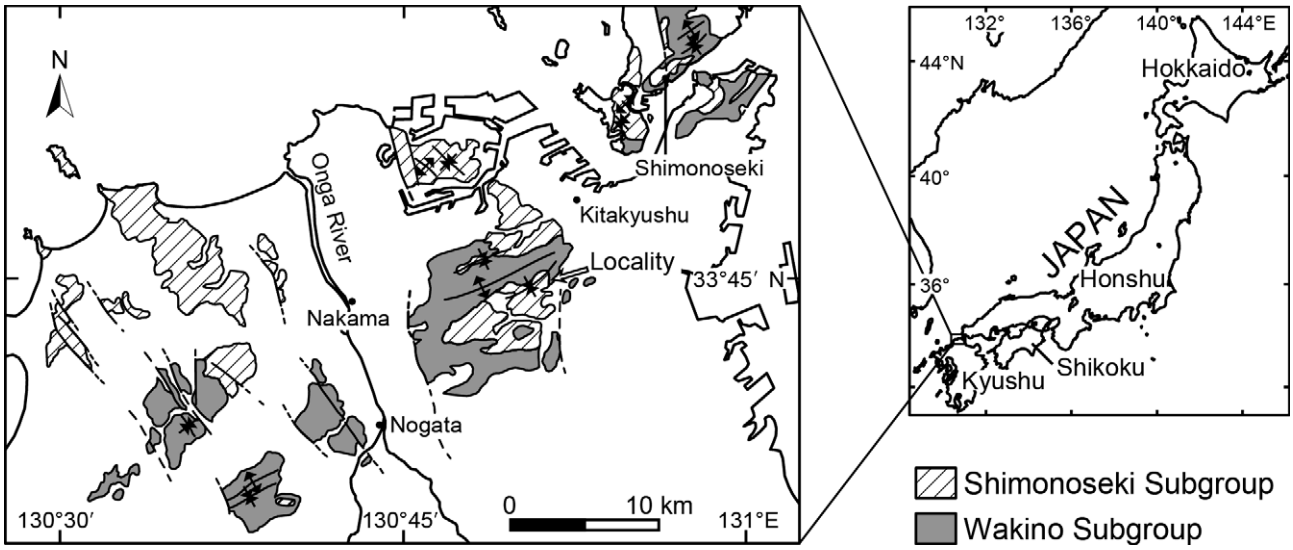


Figure 1. Distribution of the Wakino and Shimonoseki subgroups of the Kanmon Group in Kitakyushu City and its vicinity. Arrow indicates the locality where the neoceratopsian tooth described in this paper (KMNH VP 000,025) was collected. Modified after Nakae *et al*. (1998).

Takatsuo, Gamo, and Kumagai formations comprise the Wakino Subgroup in ascending order (Nakae *et al*., 1998). Vertebrate fossils including freshwater fishes, turtles, crocodiles, and dinosaurs have been reported from the Wakino Subgroup in Fukuoka Prefecture since the 1950s (Ota, 1955; Uyeno, 1979; Okazaki, 1992, 1994; Yabumoto, 1994).

The specimen described in this paper (KMNH VP 000,025) was collected by Takayoshi Harada from a siltstone bed exposed in a roadside outcrop of the Gamo Formation in Kokuraminami-ku, Kitakyushu City in 1991 (Figure 1; Okazaki, 1994; Nakae *et al*., 1998). The Gamo Formation is composed of conglomerate, sandstone, and mudstone layers yielding freshwater gastropods and osteichthyes (Ota *et al*., 1979; Yabumoto, 1994; Nakae *et al*., 1998). The specimen was recovered from a tuffaceous siltstone layer, considered to be a lacustrine deposit, along with theropod and unidentified 'reptile' teeth (Okazaki, 1994).

Systematic paleontology

Order Ornithischia Seeley, 1887
Suborder Ceratopsia Marsh, 1890
Infraorder Neoceratopsia Sereno, 1986

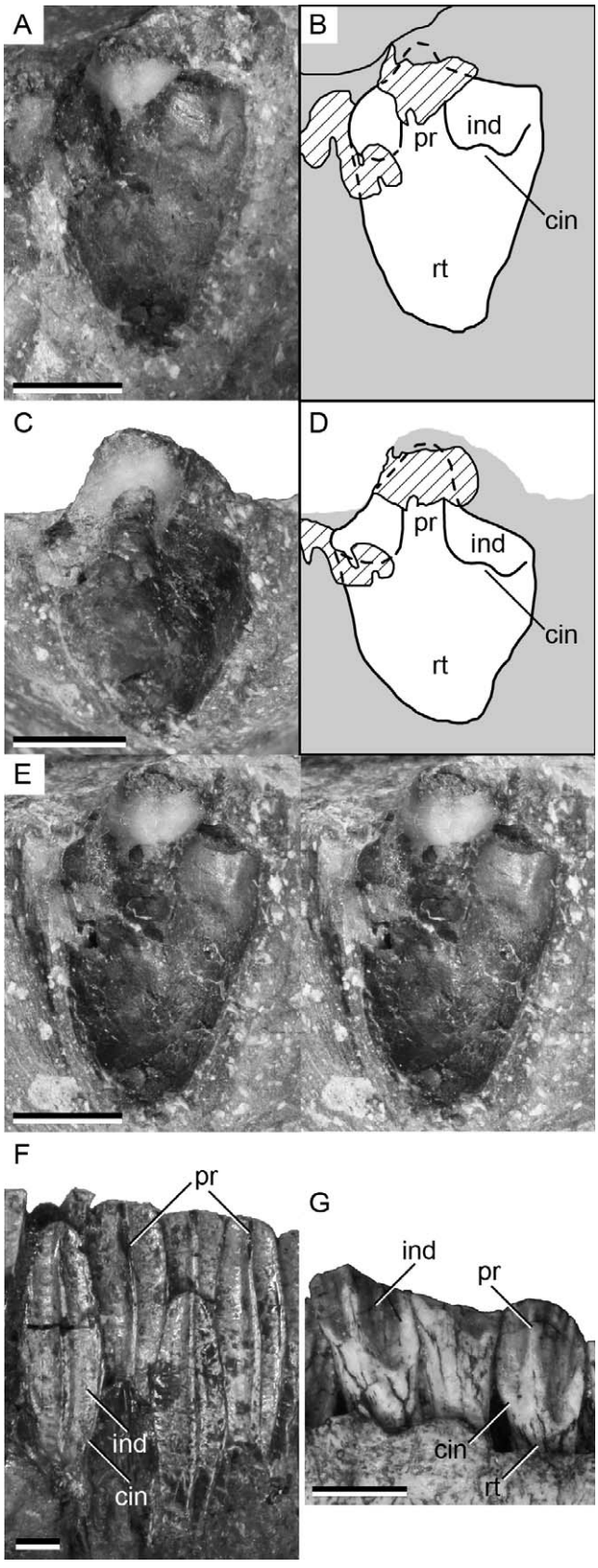
Neoceratopsia indet.

Figure 2

Material.—KMNH VP 000,025, a partial maxillary or dentary tooth (Figure 2).

Description.—KMNH VP 000,025 is either an isolated maxillary or isolated dentary tooth (Figure 2A, B). The specimen is still partially embedded in the matrix (preparation was halted to prevent further damage), and only its non-occluding side is exposed. The basal portion of the crown and upper portion of the root are preserved. The preserved crown is semicircular in non-occlusal view. The exposed crown measures 8.7 mm in rostrocaudal length and 6.4 mm in apicobasal height. Enamel is not preserved. The primary ridge is high and semicircular in horizontal section (Figure 2C–E), with a width of 2.2 mm or 25 percent of the crown. It is located to the left of the midline in non-occlusal view. Secondary ridges are not preserved. The cingulum is poorly developed except where the primary ridge reaches the base of the crown (Figure 2E) and expands mesiodistally along the right lobe. The cingulum stretches horizontally along the basal margin of the crown and is sinuous at the base of the right lobe. There is a shallow indentation on the right side of the primary ridge that occupies most of the right lobe of the crown in non-occlusal view and is bounded basally by the cingulum. Any indentation which might be located on the left side of the primary ridge is obscured by consolidants used to stabilize the tooth.

KMNH VP 000,025 was originally identified as a hadrosaurid tooth by Okazaki (1994). However, the maxillary and dentary crowns of hadrosaurids are lanceolate in non-occlusal view with a V-shaped cingulum on the basal part of the crown (Figure 2F), whereas the crown of KMNH VP 000,025 is semicircular (non-lanceolate) and the cingulum is horizontal, forming a wide crown base



(Norman and Weishampel, 1990; Norman, 2004; Tanoue *et al*., 2009). This precludes assigning KMNH VP 000,025 to the lanceolate iguanodontian maxillary teeth known from the Lower Cretaceous Kuwajima Formation, Tetori Group (SBEI 172; Manabe and Barrett, 2000). In addition, maxillary and dentary crowns of iguanodontians, including hadrosaurids, lack indentations in the mesial and distal lobes (Godefroit and Lambert, 2007). The maxillary and dentary teeth of the basal iguanodontian, *Zalmoxes*, do have a horizontal cingulum at the base of the crown, but, unlike KMNH VP 000,025, its maxillary tooth lacks a primary ridge and the width of the primary ridge relative to the mesiodistal length of the dentary tooth crown is much narrower (Weishampel *et al*., 2003). Moreover, maxillary and dentary tooth crowns of non-iguanodontian ornithopods including *Orodromeus*, *Jehosaurus*, *Hypsilophodon*, *Bugenasaura*, *Gasparinisaura*, *Parksosaurus*, *Thescelosaurus*, and *Anabisetia* narrow basally to form a distinctive neck between crown and root (Parks, 1926; Galton, 1974, 1995; Coria and Salgado, 1996; Coria and Calvo, 2002; Norman *et al*., 2004; Butler *et al*., 2008; Barrett and Han, 2009). The crown of KMNH VP 000,025, in contrast, is confluent with the root (Figure 2A), a condition seen in the maxillary and dentary teeth of some basal neoceratopsians (Figure 2G; Tanoue *et al*., 2009).

We reidentify KMNH VP 000,025 as a neoceratopsian tooth based on the coexistence of a wide and prominent primary ridge, a shallow indentation to the right of the primary ridge in non-occlusal view, and a horizontally oriented cingulum at the base of the crown (You and Dodson, 2004; Godefroit and Lambert, 2007; Tanoue *et al*., 2009). KMNH VP 000,025 cannot be assigned to Psittacosauridae because its primary ridge is prominent, not low as in that taxon (Tanoue *et al*., 2009; Makovicky, 2012). The poorly developed cingulum and shallow indentation on the right side of the primary ridge suggest that KMNH VP 000,025 does not belong to a ceratopsid, but is only referable to a basal neoceratopsian (Tanoue *et al*., 2009).

Figure 2. Comparison of KMNH VP 000,025 with hadrosaurid and basal neoceratopsian teeth. **A**, **C**, photographs of KMNH VP 000,025 in non-occlusal (**A**) and oblique basal (**C**) views; **B**, **D**, interpretative outlines of KMNH VP 000,025 in non-occlusal (**B**) and oblique basal (**D**) views (hatched areas are obscured by consolidant); **E**, stereo pair of KMNH VP 000,025 in non-occlusal view; **F**, left dentary teeth of hadrosaurid *Corythosaurus casuarius* (ROM1947) in lingual view; **G**, right maxillary teeth of basal neoceratopsian *Auroraceratops rugosus* (IG-2004-VD-001) in labial view (inverted). Abbreviations: cin, cingulum; ind, indentation; pr, primary ridge; rt, root. Scale bars = 5 mm.

Discussion and conclusions

KMNH VP 000,025 has a poorly developed cingulum and a shallow indentation on the non-occlusal side of the crown that is distinctive of the maxillary and dentary teeth of Early Cretaceous East Asian basal neoceratopsians, including *Liaoceratops yanzigouensis* (Tanoue *et al*., 2009, fig. 7C, E), *Archaeoceratops oshimai* (Tanoue *et al*., 2009, fig. 8C–E), *A. yujingziensis* (You *et al*., 2010, fig. 3.4B, C), *Auroraceratops rugosus* (Tanoue *et al*., 2009, fig. 9C, E), *Helioceratops brachygnathus* (Jin *et al*., 2009, figs. 2d, 3d, 3e), and *Yamaceratops dorngobiensis* (Makovicky and Norell, 2006, fig. 15A, B). In contrast, the maxillary and dentary teeth of neoceratopsians in the Late Cretaceous, including *Protoceratops andrewsi*, *Leptoceratops gracilis*, and ceratopsids, have a well developed cingulum and deep indentations on the mesial and distal sides of the primary ridge (Tanoue *et al*., 2009). KMNH VP 000,025 is large compared to the teeth of most known basal neoceratopsians in the Early Cretaceous, but the teeth of *Auroraceratops rugosus* are comparable in size (Figure 2G; Tanoue *et al*., 2009). A unique character of KMNH VP 000,025 is the presence of a sinuous basal margin of the crown on the right side of the primary ridge in non-occlusal view (Figure 2A, B) that may be autapomorphic of a new taxon. Some maxillary teeth of *Leptoceratops gracilis* also have a sinuous basal margin due to the presence of a notch (Tanoue *et al*., 2009, fig. 10B), but KMNH VP 000,025 lacks this feature.

A theropod tooth is the only other dinosaur specimen from the Kanmon Group which has been described (Okazaki, 1992). KMNH VP 000,025 is the first basal neoceratopsian specimen to be recovered from the Lower Cretaceous deposits in Kyushu, including the Kanmon Group. The presence of both ornithischian and saurischian dinosaurs in the group implies that it probably contains a paleodiversity on par with other specimen-rich Early Cretaceous Asian dinosaur-bearing localities. Additionally, KMNH VP 000,025 likely represents a new neoceratopsian taxon, thus adding to the steadily increasing, known diversity of these dinosaurs from the Cretaceous of Japan.

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