Vol. 85 No. 5 pp. 969–976 ACTA GEOLOGICA SINICA (English Edition) Oct. 2011

A New Iguanodontian Dinosaur from the Lower Cretaceous Khok Kruat Formation, Nakhon Ratchasima in Northeastern Thailand

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Abstract: Here we report a new iguanodontian dentary found from the Lower Cretaceous Khok Kruat Formation, Nakhon Ratchasima, northeast Thailand. A unique character, which is an elongated and flat shape of the dentary ramus, makes it possible to assign the specimen to the new genus of non-hadrosaurid iguanodontian, *Ratchasimasaurus suranareae gen. et sp. nov.* *R. suranareae* shows both primitive and derived characters, such as a caudally inclined coronoid process and alveolar trough with a primitive crown impression, and a derived buccal shelf between tooth row and coronoid process. The discovery of a new iguanodontian from the Indochina Terrene, considering that the previously reported "*Probactrosaurus*-like" iguanodontian, points out a great diversity of this group in the late Early Cretaceous in Thailand, and corresponds to the Asian iguanodontian diversity at that time.

Key words: *Ratchasimasaurus*, iguanodontia, dentary, Early Cretaceous, Thailand

1 Introduction

Iguanodontia is one of the best-known and studied dinosaur groups since Mantell (1825) reported *Iguanodon*, which was one of the members of Dinosauria when Owen (1842) established this group. A stem-based taxon, Iguanodontia, is defined as all euornithopods closer to *Edmontosaurus* than to *Thescelosaurus* (Norman, 2004). The clade Iguanodontoidea is amended to a stem-based taxon defined as all Iguanodontia closer to *Edmontosaurus* than to *Camptosaurus* (Norman, 2004), although Sereno (1986) explained it as a node-based as *Iguanodon* and all more derived iguanodontians. Non-hadrosaurid iguanodontians are, therefore, a paraphyletic iguanodontian group closer to Hadrosauridae (Fig. 1; Norman, 2004). In recent analysis of You and Li (2009), the clade of Hadrosauroidea is covered that of Hadrosauridae in Norman (2004). And then, they gave the clade name Hadrosauriformes for the more derived non-hadrosaurid iguanodontian than *Iguanodon* and considered *Ouranosaurus* as a sister taxon of this clade. Although Macdonald et al. (2010a) also analyzed basal non-hadrosaurid iguanodontians, *Ouranosaurus* was included in Hadrosauriformes. Prieto-Márquez (2010) redefined

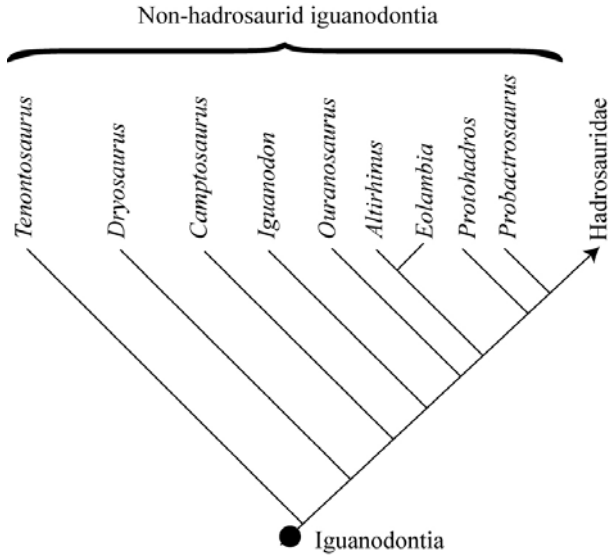

Fig. 1. Phylogeny of non-hadrosaurid iguanodontian (modified from Norman, 2004).

Hadrosauridae as the most recent common ancestor of *Hadrosaurus foulkii*, *Edmontosaurus regalis, Saurolophus osborni* and *Lambeosaurus lambei* and all of its descendants. Interestingly, in his analysis, several hadrosaurids in Norman (2004) are excluded from Hadrosauridae. Instead, he uses Hadrosauroidea for a clade

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including derived non-hadrosaurid iguanodontians in Norman (2004) and derived hadrosauriformes in You and Li (2009).

Basal iguanodontians, such as *Dryosaurus* and *Camptosaurus,* evolved in Euroamerica during the Middle to Late Jurassic. During the Early Cretaceous iguanodontian evolution shifted to Asia, with the exception of *Iguanodon* (Norman, 2004). Derived non-hadrosaurid iguanodontians mainly have been discovered in China (Table 1), although more basal forms have been reported from and added new information in Europe and North America (MacDonald et al., 2010a and b). Buffetaut et al. (1998, 2005, 2006) briefly reported several iguanodontian materials from the Early Cretaceous of Thailand and discussed a close relationship between the Thai iguanodontian and *Probactrosaurus gobiensis* (Norman, 2002).

Here described is one iguanodontian dentary from the Lower Cretaceous Khok Kruat Formation in Nakhon Ratchasima, northeastern Thailand (Fig. 2). This dentary was discovered by a local farmer near a pond in Khok Kruat Subdistrict where there is a small outcrop of the Khok Kruat Formation exposed. This formation is 430-700 m in thinkness and consists of siltstone, mudstone, sandstone and conglomerate, including calcareous nodules (Meesook et al. 2002) and is predominantly a fluvial deposit (Racey, 2009). The age of this formation has not been determined yet because of lack of any crucial fossils to date. Hasegawa, et al. (2010) pointed out a possibility of Barremian age based on magnetostratigraphic data from the overlying Phu Thok Formation. However, no direct information from the Khok Kruat Formation was obtained for its age. Traditionally, a Aptian-Albian age is believed for the formation by means of palynology and vertebrate fossil records, and the age of overlying Maha Sarakham Formation (Sattayarak et al. 1991; Buffetaut et al. 2006; Racey and Goodall, 2009). We follow the Aptian age determination in this study.

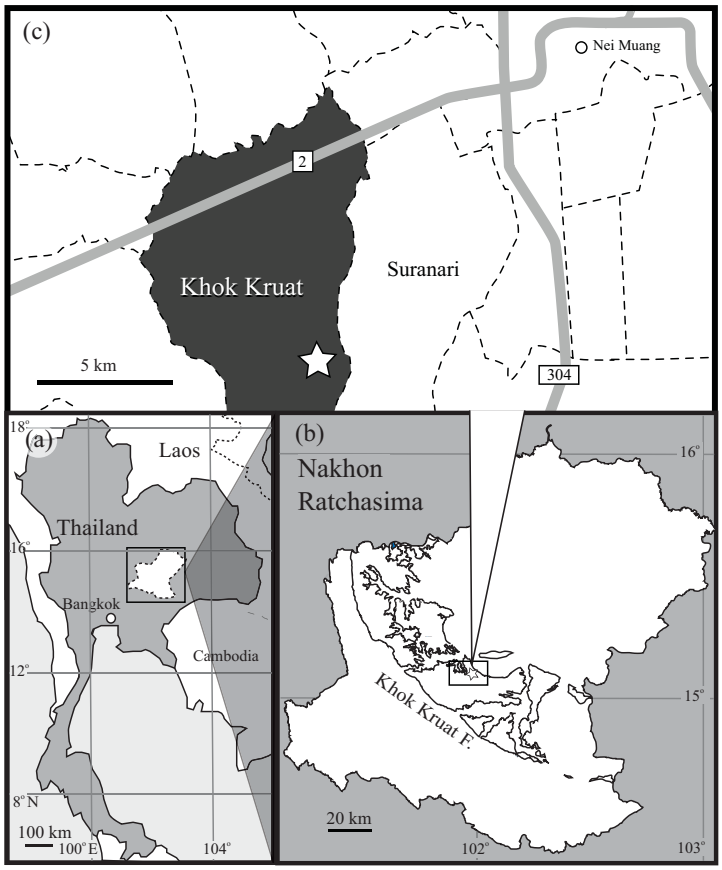

Fig. 2. The map of the locality and distribution of the Lower Cretaceous Khok Kruat Formation in Nakhon Ratchasima.
(a), Map of Thailand ; (b), the Khok Kruat Formation in Nakhon Ratchasima Province ; (c), Enlarged locality map with subdistrict boundaries. Star mark: the locality.

Vertebrate remains from this formation have been well known, such as hybodont sharks (Cuny et al. 2003), fishes and turtles (Tong et al. 2005, 2006), a neosuchian crocodyliform (Lauprasert et al. 2009), pterosaur and dinosaurs (Buffetaut and Suteethorn 1992; Buffetaut et al. 2005, 2006). The primitive ceratopsian *Psittacosaurus sattayaraki* was the first described dinosaur from this formation (Buffetaut and Suteethorn, 1992).

Except for *P. sattayaraki*, other dinosaurs were just briefly mentioned and have not been fully described because of disarticulated and fragmented materials (Buffetaut et al. 2003, 2005, 2006; Shibata et al. 2008). Although the dentary in this study was isolated with no associated teeth and bones morphological features make it possible that a new taxon of Iguanodontia from Thailand be erected.

2 Systematic Paleontology

Dinosauria Owen, 1842
Ornithischia Seely, 1887
Ornithopoda Marsh, 1881
Iguanodontia Dollo, 1888
Ratchasimasaurus gen. nov.

Etymology: "*Ratchasima*" is a short name of the city of Nakhon Ratchasima.

Diagnosis: as for only species (see below)

Type species: *Ratchasimasaurus suranareae* gen. et sp. nov.

Table 1 Occurrence of non-hadrosaurid iguanodontians in the Early Cretaceous

Taxa	Age	Occurrence	Reference
Kukufeldia tilgatensis	Valanginian	England (W. Sussex)	MacDonald et al. (2010a)
Mantellisaurus atherfieldensis	Valanginian-Aptian	Europe	Norman (1986) and Paul (2006)
Iguanodon bernissartensis	late Barremian	Europe	Norman (1980)
Iguanacolossus fortis	? early Barremian	USA (Utah)	MacDonald et al. (2010b)
Dakotadon lakotaensis	Barremian	USA (South Dakota)	Paul (2008)
Jinzousaurus yangi	Barremian	China (Liaoning)	Wang and Xu (2001)
Probactrosaurus gobiensis	Barremian	China (Inner Mongolia)	Norman (2002)
Lanzhousaurus magnidens	Early Cretaceous	China (Gansu)	You et al. (2005)
Fukuisaurus tetoriensis	Barremian-Aptian	Japan	Kobayashi and Azuma (2003)
Hippodraco scutodens	late Barremian-early Aptian	USA (Utah)	Macdonald et al. (2010b)
Equijubus normani	Barremian-Albian	China (Gansu)	You et al. (2003b)
Ratchasimasaurus suranareae	**Aptian**	**Thailand**	**this study**
Ouranosaurus nigeriensis	Late Aptian	Niger	Taquet (1976)
Muttaburrasaurus langdoni	Albian	Australia	Bartholomai and Molnar (1981)
Probactrosaurus mazongshanensis	Albian	China (Gansu)	Lü (1997)
Penelopognathus weishampeli	Albian	China (Inner Mongolia)	Godefroit et al. (2005)
Jintasaurus meniscus	?Albian	China (Gansu)	You et al. (2009)
Nanyangosaurus zhugeii	?Albian	China (Henan)	Xu et al. (2000)
Altirhinus kurzanovi	Late Albian	Mongolia	Norman (1998)

Etymology: "*suranareae*" comes from a heroine Thao Suranaree, who saved the city of Nakhon Ratchasima from the rebel army in 19th century.

Holotype: NRRU-A2064, a complete left dentary with no teeth, housed in the Northeastern Research Institute of Petrified Wood and Mineral Resources, Nakhon Ratchasima Rajabhat University, Thailand.

Locality and horizon: The discovery site, where the Lower Cretaceous (Aptian) Khok Kruat Formation is distributed, is located in Khok Kruat Subdistrict, Muang Nakhon Ratchasima, Nakhon Ratchasima Province of NE Thailand (Fig. 2).

Diagnosis: A proportionally elongated and flat dentary with a high ratio of length /height of a dentary (> 6) and combination of following characters: dorsoventrally compressed shape of dentary ramus; caudally inclined coronoid process; buccal shelf present; alveolar trough with a tooth crown shape; a short diastema exists.

3 Descriptions

The left dentary is almost completely preserved in shape without teeth. The length of dentary is 198.1 mm and the height of the coronoid process is 50.7 mm (Fig. 3). There is a horizontally running crack on the rostral part of dentary (Fig. 4). According to X-Ray Computed Tomographic sections (Fig. 4), no major breakage is visible from middle to caudal part of this dentary. It is unknown that if this is a immature or mature individual because only one dentary was discovered from the site. Even so, considering that there is no clear ontogenetic change of dentary morphology on Iguanodontian without a size and number of tooth (Carpenter, 1994; Horner and Currie, 1994), the morphological characters of NRRU-A2064 are effective to identify a taxon.

In lateral view (Fig. 3a), the dentary ramus is proportionally elongated and runs straight but a lateral edge of the dentary ramus is distinct and slightly bends down. The tooth eruption edge runs almost parallel with that of the dentary ramus. The dentary terminates rostrally at a flat and thin attachment region for a predentary. The ratio of length (from the rostral to the caudal margin) /height (at the middle of the dentary length) of the dentary is 6.9. The groove for the predentary runs anteroventrally. A diastema, which is a toothless space between that groove and the first alveolus, is existent. The ratio of diastema to dentary lengths of 0.934 is short (Kubota and Kobayashi, 2009). The flat most-rostral part of dentary shows a slightly bending dorsally close to a symphysis. Caudally, the dentary ramus becomes dorsoventrally thicker. The coronoid process is raised at caudal-most and inclined caudally. It is an almost complete in shape and has a slight expansion at the dorsal end. The height of it is relatively low. A suture for the surangular can be seen at the caudal edge of it. In dorsal view (Fig. 3b), it indicates a weak "S-shape" from the rostral to caudal ends with almost same width. The tooth row is bended medially with bow-shape and ended at the slightly anterior to a center of the coronoid process apex. 18 alveoli are recognizable and large sized ones are positioned around the center of the tooth row. The caudal-most alveolus is separate from the coronoid process. For that reason, there is a well-developed buccal shelf exist with more than five foramina. In medial view (Fig. 3c), there is no alveolar parapet preserved. The shallow alveoli are molded to the shape of tooth root and crown, but not just groove. The attachment for the prearticular is flanged medially. In ventral view (Fig. 3d), the flat rostral part of dental ramus becomes more rounded to caudally. There are four foramina preserved on the ventral surface and five small and one large ones along with the attachment for predentary.

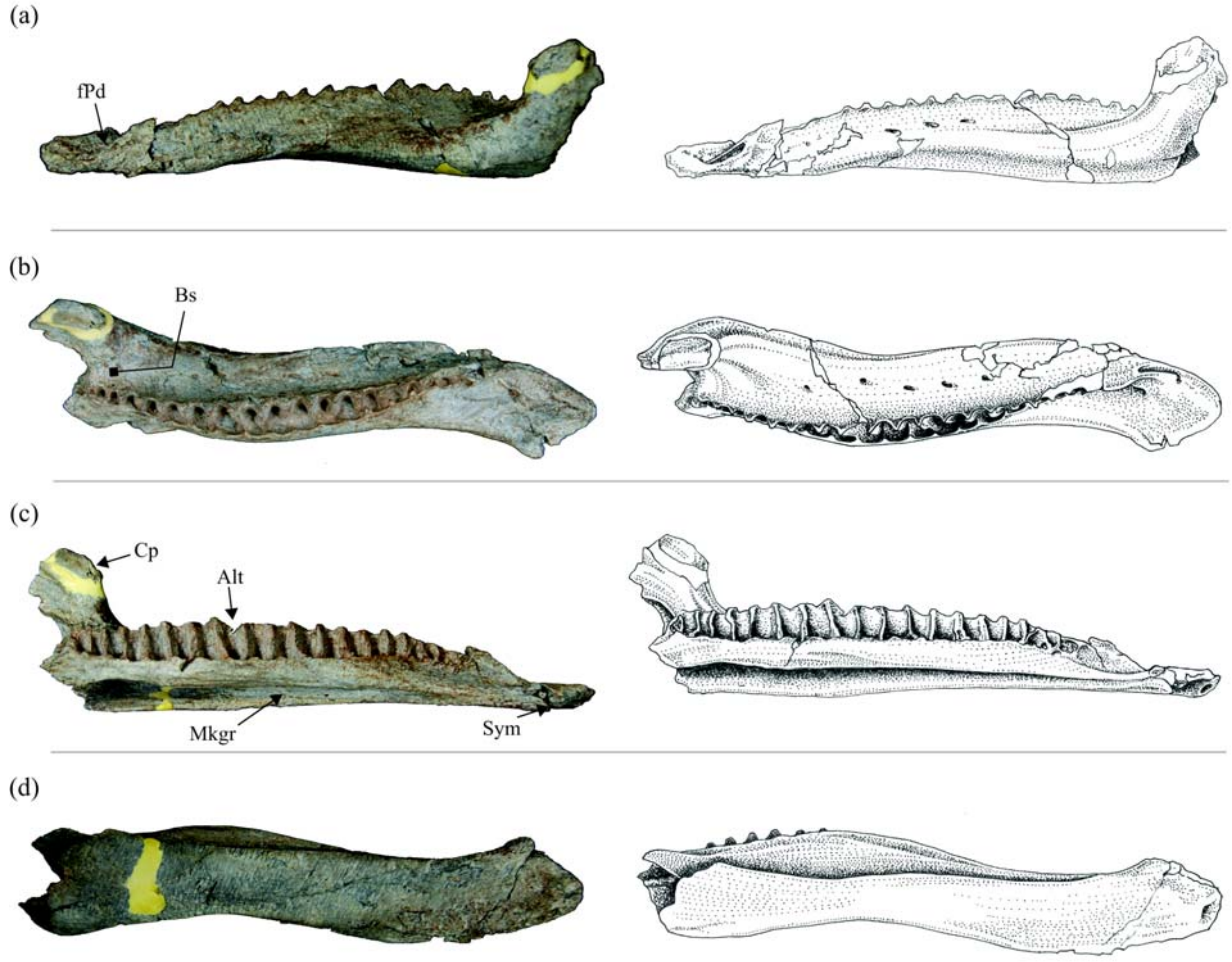

Fig. 3. Photos (left) and sketches (right) of a left dentary of *Ratchasimasaurus suranareae* gen. et sp. nov. (NRRU-A2064).
(a), Dorsal ; (b), Medial; (c), Ventral; (d), Lateral views; Alv., alveolar trough; Bs, buccal shelf; Cp, coronoid process; fPd, facet for predentary; Mkgr, Meckelian groove; Sym, symphysis; Scale bar: 10 cm

4 Comparison

Although no teeth are preserved, which generally show distinct characters on iguanodontians, morphological features of NRRU-A2064 indicate unique, and mixed primitive and derived non-hadrosaurid iguanodontian characters. According to Norman (2004), the straight dentary ramus, a tooth crown shaped alveolar trough and caudally inclined coronoid process without dorsal expansion indicate that NRRU-A2064 is certainly close to *Iguanodon bernissartensis* and *Ouranosaurus nigeriensis*. Furthermore, assuming from CT scanning images, this dentary might have born one replacement tooth (Fig. 4). On the other hand, the buccal shelf between the coronoid process and the caudal end of tooth row of NRRU-A2064 are occurred in derived non-hadrosaurids, such as *Protohadros byradi* (Head, 1998), *Altirhinus kurzanovi* (Norman, 1998) and more derived species.

An autapomorphic character of NRRU-A2064 is an elongated and flat dentary ramus. To express an elongation of dentary, we attempted to show a ratio between length of dentary and height at the middle of dentary length (abbreviated in RD in this paper). To examine other iguanodontians, measurements were made from the literature, in the case where dorsal and lateral views were

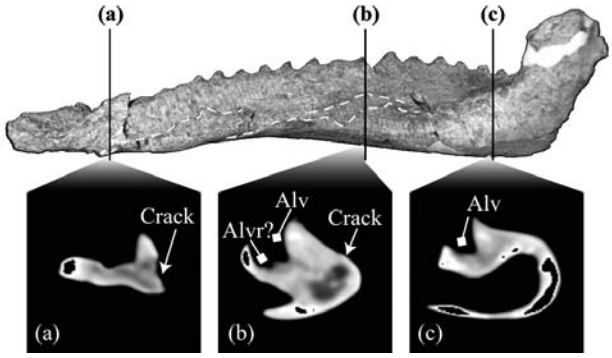

Fig. 4. X-Ray CT-scanning images of holotype (NRRU-A2064).
Alv., alveolar trough; Alvr., alveolar trough for replacement tooth; Dashed lines, cracks.

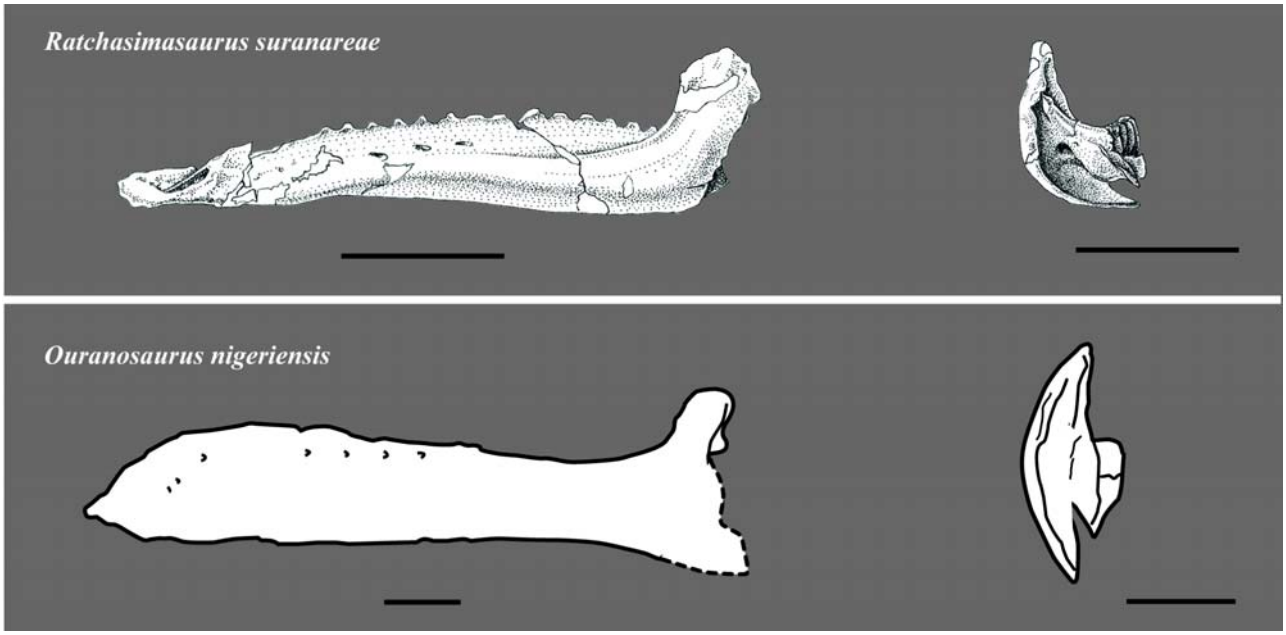

Fig. 5. Comparison of *Ratchasimasaurus suranareae* gen. et sp. nov. with *Ouranosaurus nigeriensis* (modified from Taquet, 1976). Lateral (left) and caudal (right) views. Scale bars: 5 cm.

shown (Table 2). Accordingly, the only RDs of NRRU-A2064 and *O. nigeriensis,* having an elongated dentary in non-hadrosaurid iguanodontian, are over 6. The rostrally deep dentary of *O. nigeriensis*, however, are different from rostrally narrowing and flat on NRRU-A2064. In addition, a dorsoventrally compressed dentary of NRRU-A2064 is an autapomorphic character in Iguanodontia. Except for NRRU-A2064, Iguanodontia generally has a mediolaterally-compressed dentary, such as one of *O. nigeriensis* (Fig. 5). Taking into consideration that these above-mentioned characters of NRRU-A2064, it is concluded that this is a new taxon of basal non-hadrosaurid iguanodontian, *Ratchasimasaurus suranareae*

Table 2 Comparison of RD* in non-hadrosaurid iguanodontians

Taxon	RD*	Reference
Dryosaurus lettowvorbecki	4.8	MBR 1351
Camptosaurus	4.2	Gilmore (1909, Fig. 8)
Iguanodon atherfieldensis	5.8	Norman (1986,Fig.19)
Probactrosaurus gobiensis	4.6	Norman (2002, Fig.12)
Fukuisaurus tetoriensis	3.4	FPDM-V40-9
Equijubus normani	4.7	You, et al. (2003b, Fig. 1)
Ratchasimasaurus suranareae	**6.9**	**NRRU-A2064**
Ouranosaurus nigeriensis	6.0	Taque (1976)
Penelopognathus weishampeli	4.6	Godefroit, et al. (2005)
Altirhinus kurzanovi	5.4	Norman (1998, Fig.16)
Lanzhousaurus magnidens	5.8	You, et al. (2005, Fig. 1)
Shuangmiaosaurus gilmorei	4.9	You, et al. (2003a, Fig.2)
Eolambia caroljonesa	4.8	Kirkland (1998, Fig. 6)
Protohadros byrdi	4.6	Head (1998, Fig. 11)

*The ratio of length (from the rostral to the caudal margin) /height (at the middle of the dentary length) of the dentary.

5 Discussion

Iguanodontians in Thailand have been known only from the Khok Kruat Formation in the Khorat Group, although theropods, sauropods and other ornithopods have been known from this group (Buffetaut, et al. 2005). According to Buffetaut, et al. (2005), the reported left maxilla with triangular shape of outline, a distinct jugular process and morphology of teeth resemble those of *Probactrosaurus gobiensis*. On the other hand, Shibata, et al. (2008) briefly reported a maxilla, dentary and jugal of an iguanodontian, and implied a basal position of that iguanodontian to *P. gobiensis*. Shibata, et al. (2008) mentioned, in addition, that the maxilla is a totally different shape from that of Buffetaut, et al. (2005). Though more detailed descriptions are needed on those two maxillae, there might have been two different iguanodontians in this formation. Comparing the dentary of Shibata, et al. (2008) and *R. suranareae*, the lateromedially compressed dentary ramus as well as other iguanodontians designates a distinctive dissimilarity to a dorsoventrally compressed one of *R. suranareae*.

Iguanodontians in the Late Jurassic were restricted in distribution to Africa, Europe and America (Norman, 2004). Afterwards, in the Early Cretaceous, non-hadrosaurid iguanodontians were greatly diverse and spread into Asia and Australia (Table 1; Head and Kobayashi, 2001; Norman, 2004), however most come from the late Early Cretaceous of Asia (Table 1). According to Russell (1993) and Barrett, et al. (2002), Asian isolation seems to be over and dinosaur faunal invasion from other Laurasian areas to East Asia began during the Early Cretaceous. Focusing on the iguanodontian biogeography, it could be said that a similar biogeographical trend occurred in Asia (Barrett et al., 2002). Recent discoveries

from England and North America (MacDonald et al., 2010a and b) suggest the early Early Cretaceous iguanodontian diversity in those places. At the time, the existence of *Jinzhousaurus yangi* from Liaoning Province in northeast China (Wang and Xu, 2001) indicates that iguanodontians invaded into East Asia in the Barremian. Iguanodontians, however spread out all over the Asian continent in the Aptian (Table 1) and reached the Indochina Terrane, where the southeastern part of the Asian continent was at that time and Thailand is at present (Metcalfe, 2009). In addition, taking into account that the Khok Kruat Formation has yielded two possible different iguanodontians (Buffetaut et al., 2005; Shibata et al., 2008), it is assumed that several lineages of iguanodontians might have entered Southeast Asia at that time or their arrival at this region might have occurred before Aptian age and then have diversified in situ. Although additional discoveries are needed to discuss in detail on their phylogenetic position, it is important that an appearance of Thailand non-hadrosaurid iguanodontians corresponds with the Asian iguanodontian diversity of late Early Cretaceous (Table 1).

6 Conclusions

A new non-hadrosaurid iguanodontian dentary from Thailand indicates the presence of a new species, *Ratchasimasaurus suranareae*. Despite discovering of only one isolated dentary, the strongly elongated and dorsoventrally compressed dentary ramus is distinguishable from any other iguanodontians. Compared to other iguanodontians from Thailand, this specimen might be a different species. Morphologically unique characters of *R. suranareae* imply that iguanodontians diversified in the Early Cretaceous, not only in the East but also in Southeast Asia.

Acknowledgements

This work is one of the Japan-Thailand Dinosaur Project 2007-2009, which is a collaborative research project between the Fukui Prefectural Dinosaur Museum (FPDM) and the Northeastern Research Institute of Petrified Wood and Mineral Resources, Nakhon Ratchasima Rajabhat University (NRRU). We thank to members of this project, who are Dr. Yoshikazu Noda, Mr. Atsushi Yabe, Mr. Keiichi Kojima and Dr. Kazuo Terada (FPDM), Dr. Yupa Thasod, Dr. Rattanaphorn Hanta, Mr. Jaroon Duangkrayom, Miss Krongkaew Jenjitpaiboon, Miss Supatra Boonlampoo, Miss Wanida Khonchoho (NRRU), Miss Nareerat Boonchai (Jilin University, China), Dr. Toru Sekiya (Zigong Dinosaur Museum, China), Mr. Hirokazu Yukawa (Okayama University, Japan). Special thanks to Professor Dong Zhiming (Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences) for advising and encouraging us at the site, and Dr. Lü Junchang (Institute of Geology, Chinese Academy of Geological Sciences) and Mr. Joshua Bonde (University of Nevada, Las Vegas) for revising this paper. Support was by Fukui Prefecture Government, Japan and Nakhon Ratchasima Rajabhat University, Thailand.

Manuscript received June 11, 2010
accepted Nov. 15, 2010
edited by Jiang Shaoqing

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