群馬県立自然史博物館研究報告(14)：11－20，2010
Bull.Gunma Mus.Natu.Hist.(14)：11－20，2010



Original Article

# Fine sculptures on a tooth of *Spinosaurus* (Dinosauria, Theropoda) from Morocco

HASEGAWA Yoshikazu[1], TANAKA Gengo[1], TAKAKUWA Yuji[1] and KOIKE Satoshi[2]

[1]*Gunma Museum of Natural History:*
*1674-1 Kamikuroiwa, Tomioka, Gunma 370-2345, Japan*
(*hasegawa@gmnh.pref.gunma.jp; tanaka@gmnh.pref.gunma. jp;*
*takakuwa@gmnh.pref.gunma.jp*)
[2]*KEYENCE: 4-12-6 Higashi-Shinagawa, Shinagawa-ku, Tokyo 140-0002, Japan*
(*koikes@sales.keyence.co.jp*)

Abstract：Here we report fine sculptures developed over the crown of an isolated tooth identifiable to *Spinosaurus* from Morocco. It is difficult to observe the fine sculptures in detail in most theropod teeth because the surface of the teeth usually experience wears in life and also ablation in the process fossilization. The micro-structures described herein significantly differ from the ones previously reported in the literature. Some possilble spinosaurids teeth previously reported is more likely to be from a crocodile.

Key Words：tooth crown surface sculptures, Spinosaurus, Theropoda, Mesozoic reptile, Cretaceous, Africa, Morocco

## Introduction

*Spinosaurus* was originally described by Stromer(1915)as an extraordinary specialized theropod dinosaur from the mid Cretaceous of Egypt. Closely related species have been reported from the U.K.(Charing and Milner, 1986, 1987), Portugal (Buffetaut, 2007), Tunisia(Buffetaut and Ouaja, 2002), Niger (Sereno et al., 1998), Morocco(Russel, 1966), Thailand (Kobayashi et al., 1962; Buffetaut, 1986), China(Hou et al., 1975; Buffetaut et al., 2008), Japan(Hasegawa et al., 2003), Brazil(Sues et al., 2002; Medeiros, 2006), and Argentina (Salgado et al., 2009).

Although many material identifiable to *Spinosaurus* have been known from Morocco, there are not much information available in literature(Buffetaut, 1989; Russell, 1996; John et al., 2003). Buffetaut(1989)assigned *Spinosaurus* from Morocco to *Spinosaurus* cf. *áegyptiacus*, and Russell(1996) subsequently gave a new name *S. maroccanus* to them. The holotype specimen of the *S. maroccanus* consists of cervical vertebra(NMC 5079), and does not include any description about the tooth.

Based upon the studies on *Baryonyx*(Charig and Milner, 1986 and 1997), spinosaurid theropods are considered as a fish eater with the stomach contents evidence and some similarities in the jaw morphology with semi-aquatic crocodiles. Many crocodiles have conically-shaped teeth with striations over the crown. There are also reports of crocodiles from the same formation. We therefore should be very careful of identifying isolated teeth from the formation. It is also impossible to classify an isolated tooth into a species level. Not enough information is currently available to discuss the validity of identifying spinosaurids and crocodiles based upon isolated teeth. In this paper, we consider that the tooth is unique in morphology enough to be identified as *Spinosaurus* sp., but we are aware of the fact our classification conclusion is subject to future scrutiny, when there are enough information available for inter- and/or intra-specific variations of the teeth morphology of spinosaurs and crocodiles in the future.

Many *Spinosaurus*-like teeth are available for sale in international fossil trade markets. One of the authors(Y.H.) acquired a relatively well-preserved specimen labeled as *S. maroccanus* from the Kem Kem Beds of Morocco at an international fossil trade show in Tuscon, Arizona in February, 2008. It lacks the apex of the crown by about 25% estimated based on more complete teeth. The root is not completely preserved. The root does not show any sign of resorption due to tooth replacement. It is highly likely that the tooth was broken off from the jaw either in life or after death. Apart from that, the surface of the crown is well preserved with micro sculptures.

Despite the fact that the holotype specimen of the type species of *Spinosaurus*(Stromer, 1915)was lost during the World War II, the species has been incorporated in many phylogenetic and morphological studies based on additional material and/or material from closely related species(Buffetaut, 2007; Buffetaut and Ingavat, 1986; Hone et al., 2010; Kellner and Mader, 1997; Medeiras, 2006; Salgado et al., 2009; Sues et al., 2002). In carnivorous dinosaurs, serrations of various shape and sizes are developed along the mesial and distal edges(Currie et al., 1990). Morphology of serrations including each denticle can be used for classification of the therpods in some cases(Currie et al., 1990). There is not much detailed information about their peculiar teeth of spinosaurids to date.

Charing and Milner(1997)firstly mentioned about the characteristic mark of fine micro-sculpture on the surface of

受付：2010年1月8日，受理：2010年3月9日

tooth crown of *Spinosaurus*. Hasegawa et al.(2003) firstly reported tooth crown ornamentations on an isolated tooth from the Early Cretaceous Sebayashi Formation of Japan and it argued a possible affinity of the tooth to the spinosaurids. A similar tooth crown sculpture was reported in *Siamosaurus* from the late Jurassic Sao Khua Formation of Thailand (Buffetaut and Ingavat, 1986). Hasegawa et al.(2003) described the Japanese specimen possibly similar to *Siamosaurus*. The tooth specimen reported in the present study is significantly different in our knowledge from all the teeth specimens figured in the studies listed earlier. Our intention in this paper is that we give a short description of a well-preserved tooth and we hope to draw scientists' attention to the interesting morphology.

## Description

Superorder Saurichia Seeley, 1888
Suborder THEROPODA Marsh, 1881
Superfamily Spinosauroidea Stromer, 1915
*Spinosaurus* sp.
Plates I-IV

An isolated tooth from the Kem Kem Bed of Morocco (GMNH-FV. 2400) lacks the apex of the crown for about 25% of the total length of the crown. The root is broken off, but the root does not show any sign of resorption in the preserved part. Total length of the tooth is 80 mm, the height of dental crown is 50 mm, the maximum anteroposterior length of the dental crown is 33mm, the maximum bucco-lingual length is 30 mm, as preserved. It is one of the largest teeth reported from the formation to our knowledge. The anteroposterior length of GMNH-FV. 2400 is similar in size to the 4th tooth of lower left of *Spinosaurus áegyptiacus* figured in Storomer (1915).

The anterior and posterior side can be identified according to the curvature of the crown. The lateral side of the crown should be almost perpendicular to the anterior and posterior axis. One lateral side is straighter than the other one. We assume that the straighter side faces to the inside of the mouth. The tooth comes originally from the right lower jaw or left upper jaw. For the clarity of the argument in the paper, we tentatively identify the tooth from the right lower jaw. The anterior and posterior carinae are most outstanding ridges on the crown, but strong striations run longitudinally on the crown. The number of striations gradually decreases from the base to the apex. The striations are well developed more in anterior and posterior sides than those of lateral sides. The distance between neighboring two striations ranges from 1 mm to 5 mm. The carinae and striations are elevated like a ridge. The spaces between the ridges are low areas or valleys where numerous irregular, elongated granular structures are developed. These irregular morphology look like a twisted rope or undulating rope. These structures look as if the many streams ran down from the ridge to the valley and curved the surface in to the irregular shape. The structures look like the eroded terrain formed by a flow from the apex of the crown to the base. The surface structures are relatively less preserved in the apex of the crown, most likely because of more wear towards the apex in predation. In anterior and posterior views, the tooth crown is almost straight. In lateral views, the tip of mesial side slightly tilts posteriorly. The cross-section of the tooth is sub-ellipsoidal with longer in the anterioposterior axis. , The pattern of the surface of enamel structure of GMNH-FV. 2400 cannot be compared with *Spinosaurus áegyptiacus* because the detail tooth surface morphology is not available in Storomer (1915).

## Discussion

Many teeth of the holotype (BMNHR995) of *Baryonyx walkezi* have short crown and extremely long root, and these teeth develop pronounced striations on the surface of the crown. The denticles of mesial carina are typical in morphology as a theropod. GMNH-FV. 2400 is different from *Baryonyx* in the morphology of the serrations. The granular texture is developed on the surface of enamel. The granular structure is quite different from GMNH-FV. 2400 as it runs more oblique to the axis of the crown in *Baryonyx walkezi* (Charig and Milner, 1999). The teeth of *Siamosaurus* from Thailand and ?*Siamosaurus* from Japan are not preserved with crown surface structure in detail. It is therefore difficult to make comparison to GMNH-FV. 2400.

Long and rather straight teeth with straitions can be found in many marine reptiles such as ichthyosaurus, elasmosaurus, mosasaurus, and crocodiles. If they are isolated from the jaw bone, a fossil crocodile tooth like *Brachychampsa montana* (Fig. 1) and a mosasaur like *Mosasaurus* (Fig. 2) could be misidentified as a spinosaur tooth. Salgado, L. et al.(2009) reported a tooth possibly identified as possibly Spinosauridae from cerro Lisndro Formation RioNegro, Patagonia, Argentina. The tooth has coarsely serrated carinae, sevearl ridges in the base of the crown in lateral sides, it is a sub-circular in cross-section. Similar teeth are reported as crocodyliformus *Hamadasuchus* cf. *nebouli* from Morocco (Fig. 3). We would assign the ?Spinosaurid tooth reported by Salgado et al. (2009) to a *Hamadasuchus*.

Hone et al.(2010) reported *Baryonychines* from Henan Province in China. This was the first report of *Baryonychines* from Asia. The crown is laterally compressed with serrations developed along the anterior and posterior keels, and the smooth enamel surface on buccolinhual sides. GMNH-FV. 2400 is clearly different from the *Baryonychines*.

A crown surface sculpture observed in GMNH-FV. 2400 is also seen in some whales (Beneden, 1867; Kellogg, 1936; Fitzgerald, 2006). Long conical, striated teeth independently evloved in spinosaurid theropods, crocodiles, mosasaurs, plesiosaurs, ichthyosaurs, and even in whales. This tooth morphology may have some functional advantages in feeding in aquatic environments

## Acknowledgements

We are grateful to Drs. Manabe Makoto, Kohno Naoki, Tsuihiji Takanobu and Tanoue Kyo (Natural Science Museum, Tokyo) and Ichijo Masatoshi and Yamashita Yosuke (Hankikaku 21) for drawing our attention to many important references. Many thanks to Ms. Yanoma Chikako for document management.

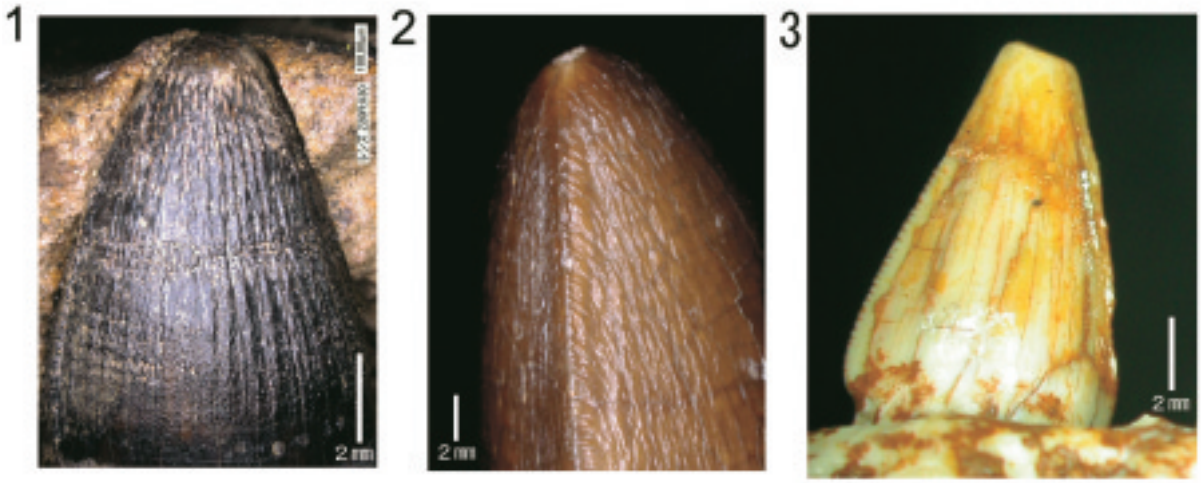



Fig. 1 *Brachychampsa montana*. Short conical cone-shped crown has about ten striations in a lateral side. The serrations on the carinae are globular.

Fig. 2 *Mosasaurus* sp. from Morocco. The ornamentation found on a part of the anterior margin is similar to that of *Spinosaurus* sp.

Fig. 3 *Hamadasuchus* cf. *rebouli* from Morocco（GMNH-PV.2398）. The theropod-like serrations develops along the anterior and posterior carinae.

## References


Amiot, R., E. Buffetaut, C. Lecuyer, L. Boudad, S. Hutt, J. Y. Mo, V. Suteethorn, S. Sweetman, H. Tong, X. Wang and Z. Fusong（2008）: Were some dinosaurs aquatic? In Mazin J.-M., Pouch J., Hantzpergue P. and Lacombe V.（ed.）Mid-Mesozoic Life and Environments. Cognac, France（June 24th - 28th 2008）.

Beneden D.-J. Van 1867. Recherches sur les Squalodons, supplement. *Memoires de l'Académie Royale des Sciences. Des letres et des beaux-arts de Belgique Extrait du tome* XXXVII:3-15, Pl. 1.

Buffetaut, E.（1986）: Unusual theropod dinosaur teeth from the upper Jurassic of Phu Wiang, northeastern Thailand. *Revue de Paléobiologie*, 5（2）: 217-220.

Buffetaut, E.（1989）: New remains of the enigmatic dinosaur *Spinosaurus* from the Cretaceous of Morocco and the affinities between *Spinosaurus* and *Baryonyx*. *Neues Jahrbuch für Geologie und Paläontologie Mh. H.2*, 2: 79-87.

Buffetaut, E.（1992）: Remarks on the Cretaceous theropod dinosaurs *Spinosaurus* and *Baryonyx*. *Neues Jahrbuch für Geologie und Paläontologie Mh. H.2*, 2: 88-96.

Buffetaut, E.（2007）: The spinosaurid dinosaur *Baryonyx*（Saurischia, Theropoda）in the early Cretaceous of Portugal. *Geological Magazine*, 144（6）: 1021-1025.

Buffetaut, E.（2008）Spinosaurid teeth from the late Jurassic of Tengaduru, Tanzania, with remarks on the evolutionary and biogeographical history of the Spinosauridae. In Mazin, J.-M., Pouch, J., Hantzpergue, P. and Lacombe, V.（ed.）Mid-Mesozoic Life and Environments, pp.26-28. Cognac, France（June 24th - 28th 2008）.

Buffetaut, E. and Ouaja, M.（2002）: A new specimen of *Spinosaurus*（Dinosauria, Theropoda）from the lower Cretaceous of Tunisia, with remarks on the evolutionary history of the Spinosauridae. *Bulletin de la Société géologique de France*, 173（5）: 415-421.

Buffetaut, E. and Ingavat, R.（1986）: Unusual theropod dinosaur teeth from the upper Jurassic of Phu Wiang, northeastern Thailand. *Revue de Paléobiologie*, 5: 217-220.

Buffetaut, E., Suteethorn, V., Tong, H. and Amiot, R.（2008）: An early Cretaceous spinosaurid theropod from southern China. *Geological Magazine*, 145（5）: 745-748.

Buffetaut, E., Suteethorn, V., Loeuff, L., Khansubha, J. S., Tong, H. and Wongko, K.（2005）: The dinosaur fauna from the Khok Kruat Formation（Early Cretaceous）of Thailand. In Wannakao, L., Youngme, W., Srisuk, K. and Lertsirivorakul R.（ed.）Proceedings of the International Conference on Geology, Geotechnology and Mineral Resources of Indochina, p.575-581. Khon Kaen, Khon Kaen University.

Buffetaut, E., Suteethorn, V. and Tong, H.（2006）: Dinosaur assemblages from Thailand: a comparison with Chinese faunas. In Lü, J., Kobayashi, Y., Huang, D. and Lee, Y. N.（ed.）Papers from the 2005 Heyuan International Dinosaur Symposium, p.19-37. Beijing, Geological Publishing House.

Canudo, J. I., Gasulla, J. M., Gómez-Hernandez, D., Ortega, F., Sanz, J. L. and Yagüe, P.（2008）: First evidence of isolated teeth referred to Spinosauridae（Theropoda）feom the lower Aptian（lower Cretaceous）of Europe: *Arcillas de Morella Formation*（*Spain*）. *Ameghiniana* 45: 649-662.

Carrano, M., Benson, R. and Sampson, S.（200）: The phylogeny of Megalosauroids（Dinosauria: Theropoda）with implications for the evolution of North African paleoecosystems. First International Congress on North African Vertebrate Palaeontology, p.21-22. Marrakech, Morocco（May 25th - 27th 2009）.

Charig, A. J. and A. C. Milner（1986）: *Baryonyx*, a remarkable new theropoddinosaur. *Nature*, 324: 359-361.

Charig, A. J. and Milner, A. C.（1997）: *Baryonyx walkeri*, a fish-eating

dinosaur from the Wealden of Surrey. *Bulletin of the Natural History Museum, London Geology Series*, 53(1): 11-70.

Currie, P. R. J., Keith, R. Jr J. and Sloan, R. E.(1990): Theropod teeth from the Judith River Formation of southern Alberta, Canada. Dinosaur Systematics, p. 107-125, Cambridge University Press.

Dal Sasso, C., Maganuco, S. and Cioffi, A.(2009): A neurovascular cavity within the snout of the predatory dinosaur *Spinosaurus*. First International Congress on North African Vertebrate Palaeontology, p.22-23. Marrakech, Morocco(May 25th - 27th 2009).

Fitzgerald, E. M. G.(2006): A bizarre new toothed mysticete (Cetacea) from Australia and the early evolution of between whales. *Proceedings of the Royal Society, Biological Sciences,* 273: 2955-2963.

Hasegawa, Y., Buffetaut, E., Manabe, M. and Takakuwa, Y.(2003): A Possible spinosaurid tooth from the Sebayashi Formation (lower Cretaceous), Gunma, Japan. *Bulletin of the Gunma Museum of Natural History*, 7: 1-5.

Heckeberg, N.(2009): About the lifetime of a spinosaur tooth - new histologic investigation of tooth formation rates. *Journal of Vertebrate Paleontology*, 29(3): 112A.

Hendrickx, C. and Buffetaut, E.(2008): Functional interpretation of spinosaurid quadrates(Dinosauria: Theropoda)from the Mid Cretaceous of Morocco. 56th Annual Symposium of Vertebrate Palaeontology and Comparative Anatomy. Dublin(September 2nd - 6th 2008).

Holtz, T. R. Jr.(1998): *Spinosaurs* as Crocodile mimics. *Science*, 282: 1276-1277.

Hone, D. W. E., Xu, X. and Wang D.-Y.(2010): A probable Baryonychine (Theropoda: Spinosauridae)tooth from the upper Cretaceous of Henan Province, China. *Vertebrata PalAsiatica*, 48(1): 19-26.

Hou L.-H., Yeh H.-K'. and Zhao X.-J.(1975): Fossil reptiles from Fusui, Kwangshi. *Vertebrata PalAsiatica*, 13: 23-33.

Johan, S., Bode, R, Lydsberg, P., Medenbach O. and Lierl H.-J.(2003): Marokko Lond der schönen Mineralien und Fossilien. Rainer Bode, pp. 514.

Kellner, W. A. A. and B. J. Mader(1997): Archosaur teeth from the Cretaceous of Morocco. *Journal of Paleontology*, 71(3): 525-527.

Kellogg R. (1936) A review of the Archaeoceti, 366p., pls.34. Carnegie Institute.

Kobayashi, T., Takai, F. and Hayami, I.(196): On some Mesozoic fossils from the Khorat Shorat Series of East Thailand and a note on the Khorat Series. *In* Kobayashi, T.(ed.)*Geology and Palaeontology of Southeast Asia*, p.119-133. Tokyo, University of Tokyo Press.

Larsson, H. C. E. and Sues, H-D.(2007): Cranial osteology and phylogenetic relationships of *Hamadasuchus rebouli*(Crocodyliformes: Mesoeucrocodylia)from the Cretaceous of Morocco. *Zoological Journal of the Linnean Society*, 149: 533-567.

Machado, E., Azevedo, S., Carvalho, L., Henriques, D., and Kellner, A. (2009): A new spinosaurid from the Cretaceous Alcantara Formation (Maranhao), northeastern Brazil. *Journal of Vertebrate Paleontology*, 29(3): 138A.

Machado E. B. and Kellner, A. W. A.(2005): Notas Sobre Spinosauridae (Theropoda, Dinosauria). *Anuário do Instituto de Geociências-UFRJ*,28(1): 158-173.

Pérez-Moreno, B. P., Sanz, J. L., Buscalioni, A. D., Moratalla, J. J., Ortega, F. and Rasskin-Gutman, D.(1994): A unique multitoothed ornithomimosaur dinosaur from the Lower Cretaceous of Spain. *Nature*, 370(6488): 363-367.

Rayfield, E. J., Milner, A. C., Xuan, V. B. and Young, P. G.(2007): Functional morphology of spinosaur 'Croccodile-mimic' dinosaurs. *Journal of Vertebrate paleontology*, 27(4): 892-901.

Remington, K.(1936)A reviews of the Archaeoceti. *Carnegie Institution of Washington, Pub*.No.482, 366pp. Pls. 32.

Richard O.(1851)Monograph on the fossil Reptilia of the Cretaceous formations. Part I. Palaeontographical Society Monographs 1851, 118pp.

Salgado L., Canudo J. I., Garrido A. C., Ruiz-Omeñaca J. I., Garcia R. A., de la Fuente M. S., Barco J. L. & Bollati R. 2009. Upper Cretaceous vertebrates from El Anfiteatro area, Río Negro, Patagonia, Argentina. *Cretaceous Research*, 30(3): 767-784.

Sasso, C. D., Maganuco, S., Buffetaut, E. and Mendez, M. A.(2005): New information on the skull of the enigmatic theropod *Spinosaurus*, with remarks on its size and affinities. *Journal of Vertebrate Paleontology*, 25(4): 888-896.

Sereno, P. C., Beck, A. L., Dutheil, D. B., Gado, B., Larsson, H. C. E., Lyon, G. H., Marcot, J. D., Rauhut, O.W. M., Sadleir, R. W., Sidor, C. A., Varricchio, D. D., Wilson G. P. and Wilson J. A.(1998): A long-snouted predatory dinosaur from Africa and the evolution of Spinosaurids. *Science*, 282(5392): 1298-1302.

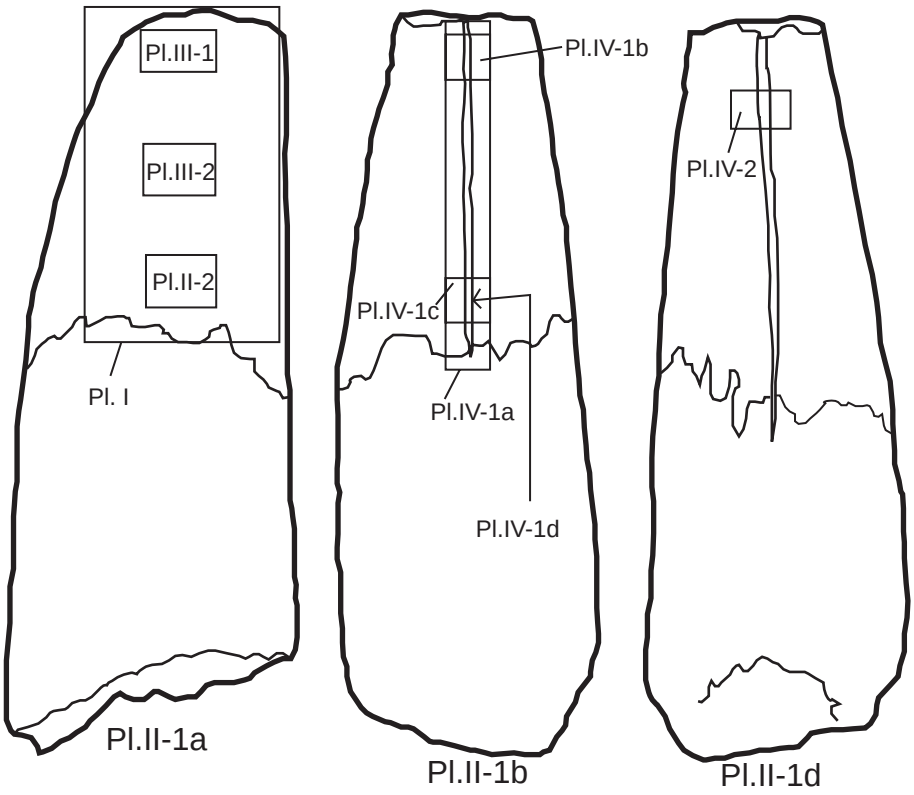
Smith J. B., Matthew, L. C., Helmut, M. and Kenneth L. J.(2006): New information regarding the holotype of *Spinosaurus aegyptiacus* Stromer, 1915. *Journal of Paleontology*, 80(2): 400-406.

Storomer, E.(1915): Ergebnisse der Forschungsreisen Prof. E. Stromers in den Wüsten Ägyptens. Wirbeltier-Reste der Baharîje-Stufe(unterstes Cenoman). 3. Das Original des Theropoden *Spinosaurus aegyptiacus* nov. gen. spec. *Abhandlungen der Königlichen Bayerischen Akademie der Wissenschaften, Mathematisch-physikalische Klasse*, 28(3): 1-32.

Sues, H.-D., Frey, E. Martill, D. M. and Scott, D. M.(2002): Irritator challengeri, a spinosaurid(Dinosauria: Theropoda)from the lower Cretaceous of Brazil. *Journal of Vertebrate Paleontology*, 22(3): 535-547.

Taquet, P.(1984): A curious specialization of the skull of some Cretaceous carnivorous dinosaurs: the long and narrow snout of spinosaurids. *Comptes Rendud del'Académie des Sciences, Paris, Series II*, 299(5): 217-222.

Taquet, P. and Russell, A. D.(1998): New data on spinosaurid dinosaurs from the early Cretaceous of the Sahara. *Comptes Rendud del'Académie des Sciences, Paris, Series II*, 327: 347-353.




Explanation of plates

＊1. We studied the *Spinosaurus* teeth（GMNH-FV. 2400）with a digital microscope（KEYENCE VHX-1000）by x30 magnifications（100,000,000 pixels）.

Pl. I: *Spinosaurus* sp. in lingual view, magnified from pl. II-1a

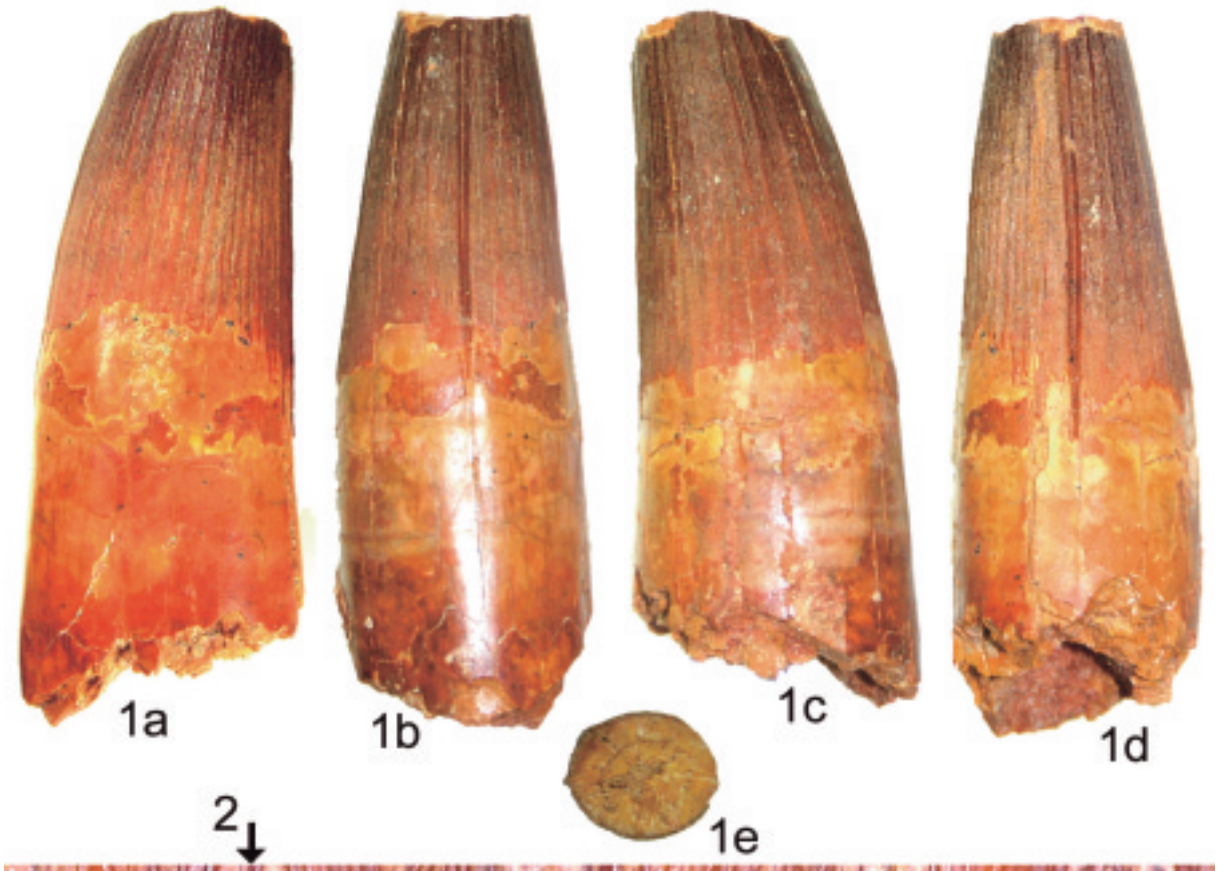
Pl. II-1: *Spinosaurus* sp.（x 1）. 1a, in lingual view. 1b, in anterior view. 1c, in labial view. 1d, in poseterior view. 1e, in cross-sectional view from the base
Pl. II-2: A magnified view of the basal crown in lingual view.

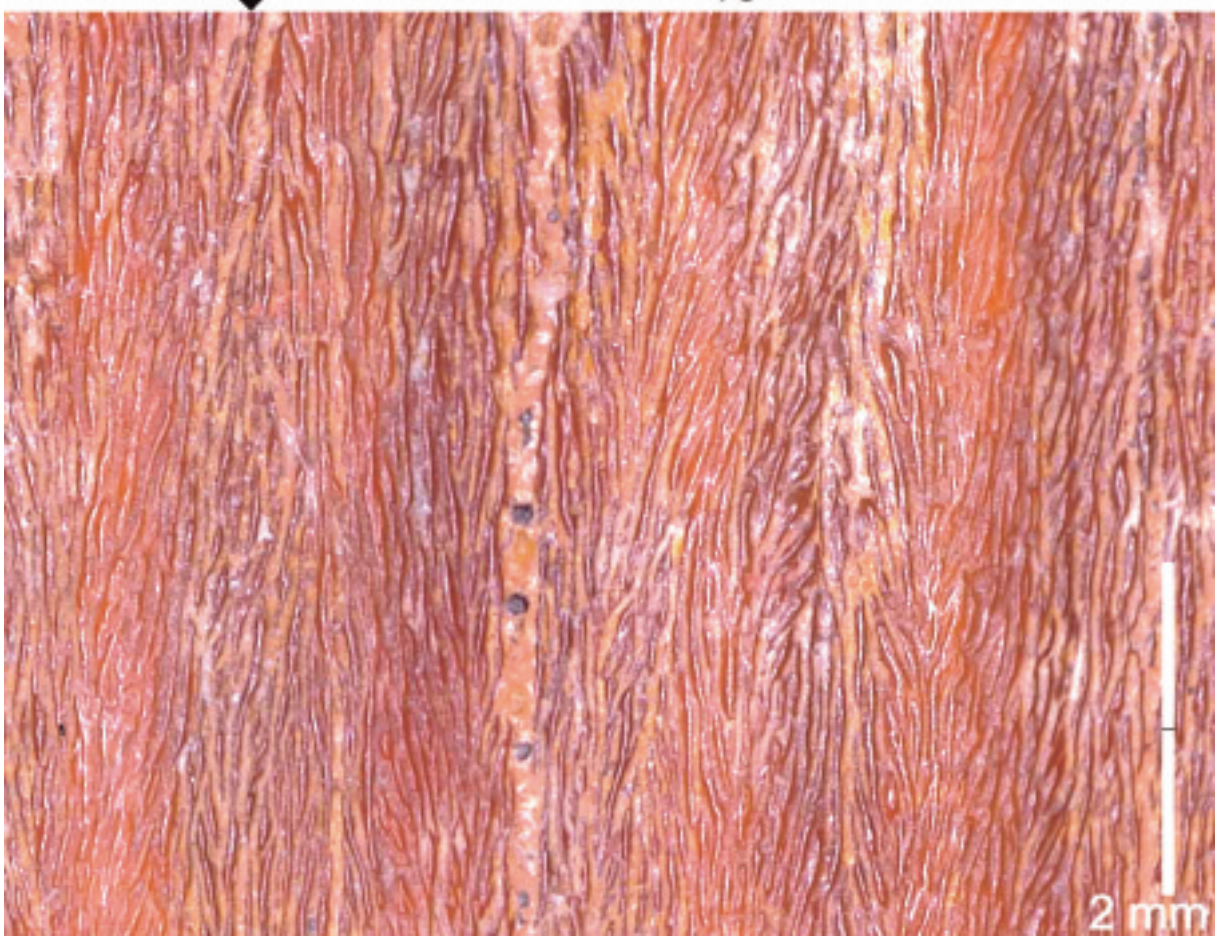
Pl. III-1: A magnified view of the apxial crown in lingual view. The Enamel is slightly worn away in comparison to the basal crown shown in Pl. II-2.
Pl. III-2: A magnified view of the mid crown in lingual view.

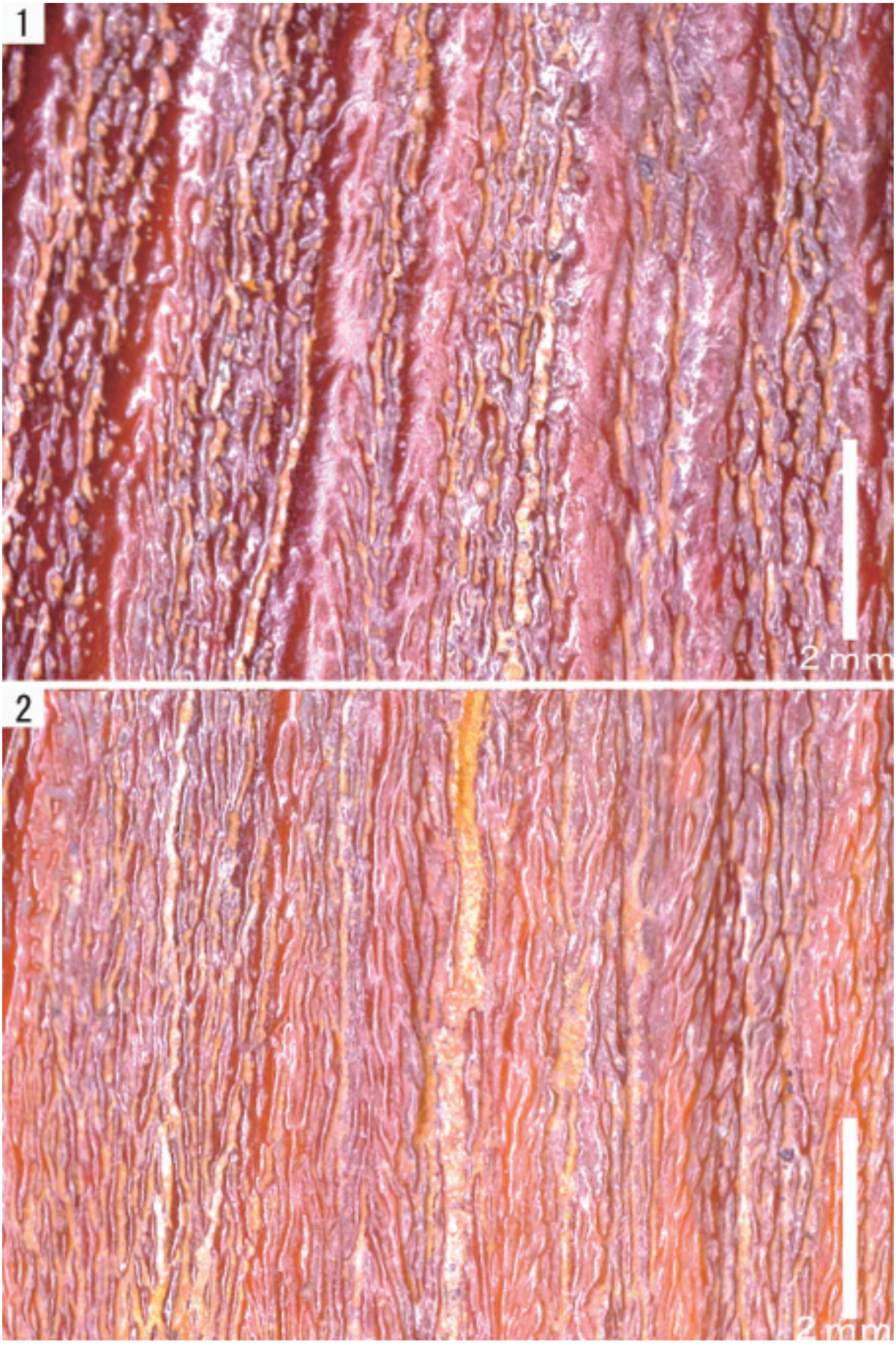
Pl. IV-1a: A magnified view of the anterior carina.
Pl. IV-1b: The apical area manified in the anterior carina. Sculputures are worn in comparison to the more basal area along the carina（Po. IV-1c and d）

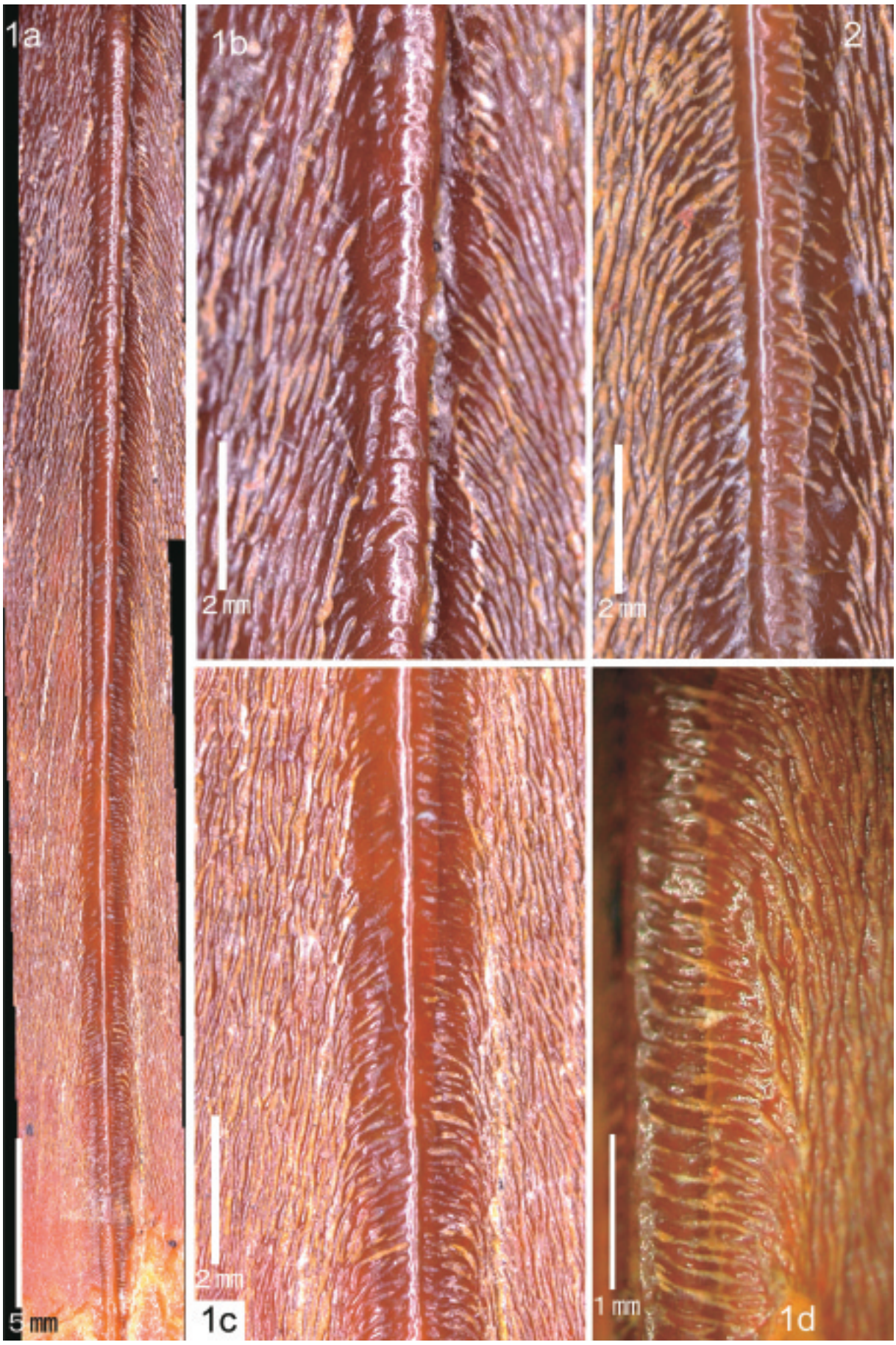
Pl. IV-1c: The basal area manified in the anterior carina. The carina descends down to the valley with numrous small rigdes which look like the ribs of a snake in dorsal view.
Pl. IV-1d: A slightly lateral view of Pl. IV-1c. Each denticle descends down to forming valley between the neighboring ridges.
Pl.IV-2: A magnified view of the posterior carina. The structure is almost the same as in the anterior carina.


5 mm


1a
1b
1c
1d
1e
2


2 mm


1
2 mm
2
2 mm


1a
5 mm
1b
2 mm
2
2 mm
2 mm
1c
1 mm
1d

# スピノサウルスの歯冠表面にみられる微細彫刻

長谷川善和[1]・田中源吾[1]・髙棊祐司[1]・小池　智[2]

[1]群馬県立自然史博物館：〒370-2345 群馬県富岡市上黒岩1674-1
（hasegawa@gmnh.pref.gunma.jp; tanaka@gmnh.pref.gunma.jp; takakuwa@gmnh.pref.gunma.jp）
[2]キーエンス：〒140-0002 東京都品川区東品川4-12-6（koikes@sales.keyence.co.jp）

**要旨：**モロッコ産Spinosaurusの歯冠表面に微細な彫刻が発達していることが判った．多くの遊離した単一の歯は生前に歯を使用することによる摩耗，死後に地層に埋没するまでの過程での物理的磨滅などにより歯の微細な構造が消失していて観察が難しい．これまで報告された世界各地のSpinosaurus類の歯の特長はいずれも細かい点で異なるが、一部はワニなどの可能性が高い．

**キーワード：**歯冠彫刻，スピノサウルス，獣脚類，中生代爬虫類，白亜紀，アフリカ，モロッコ