

Chondrichthyan Remains from the Akasaka Limestone Formation (Middle Permian) of Gifu Prefecture, Central Japan

Haruka YAMAGISHI¹⁾ & Tsuyahiko FUJIMOTO²⁾

Abstract. Over 30 isolated teeth and several scales of sharks were found by using a formic acid process on the rocks from the Middle Permian of the Akasaka Limestone Formation (ALF), Gifu Prefecture, Central Japan. Most of these teeth were assignable to the hybodont genus, *Lissodus*. The remaining were cladodont teeth, including one specimen assignable to the ctenacanthid *Glikmanius occidentalis*. All scales obtained in this study were of the hybodontid type. The occurrence of *Lissodus* in the ALF is not only the first Middle Permian record in the world; but also the fifth and oldest record in Asia. Despite the fact that most records of Permian *Lissodus* are derived from nonmarine sediments, *Lissodus* from the ALF is derived from an oceanic environment; the ALF is recognized as a carbonate build-up deposited on ancient mid-ocean seamounts. This finding may aid in tracing the route of the divergence of *Lissodus* to a mid-ocean environment. In addition, morphological features of the specimens from the ALF resemble those of the Middle Triassic species *Lissodus cristatus* than those of the Paleozoic species. These specimens from the ALF are important to consider the status of the Paleozoic species of this genus.

Key words: Chondrichthyes, *Lissodus*, *Glikmanius*, Akasaka Limestone Formation, Permian

Introduction

The Akasaka Limestone Formation (ALF; Middle to Upper Permian) yielding the chondrichthyan fauna described here is a component of the Permian mid-ocean seamount deposits of Panthalassa associated with the accretionary complex in Central Japan. It is distributed as an isolated limestone mass surrounded by noncalcareous clastic facies in the southwestern part of the Mino Terrane. The ALF contains abundant and well-preserved Permian shallow marine fossils (e.g., Ishii *et al.*, 1981; Isozaki *et al.*, 1990; Ozawa & Nishiwaki, 1992; Isozaki & Ota, 2001).

The occurrence of chondrichthyan remains in the ALF was previously reported by Goto *et al.* (1988), Goto (1996), and Yokoi (2000). The teeth reported as *Symmorium* sp. by Goto *et al.* (1988) and Goto (1996) were reassigned to *Glikmanius occidentalis* by Ginter *et al.* (2005). However, a detailed description and taxonomical comparison were not provided in those previous reports. This paper provides a systematic description and comparison of the chondrichthyan teeth from the ALF, particularly focusing on *Lissodus*.

Materials and methods

The specimens described in this paper were obtained from bedded black coaly limestone at the quarry in Kinshozan, Ogaki-City, Gifu Prefecture. This limestone bed is situated beneath the *Colania gifuensis*-concentrated bed, in the *Colania amicula*-*C. gifuensis* zone of the Middle Member (Ozawa & Nishiwaki, 1992).

By applying an acid preparation technique generally used for microfossils, it was possible to obtain extremely small hard parts of sharks which may have been missed in the past (e.g. Thies, 1995; Johns *et al.*, 1997; Tanimoto & Fujimoto, 2000). The limestones were processed using a 5% formic acid solution in order to isolate the chondrichthyan remains. Next, they were coated with resin for reinforcement and studied using a binocular microscope. Some of these specimens were photographed using scanning electron microscopy (Hitachi S-2400S at the Department of Earth and Planetary Science, Graduate School of Science, University of Tokyo; Hitachi S-2250N at the University Museum, University of Tokyo).

Systematics and terminology for tooth morphology followed Cappetta (1987) and Duffin & Ginter (2006); the terminology for the morphology of dermal denticles followed Johns *et al.* (1997). All specimens described in this paper are deposited in the Kanagawa Prefectural Museum of Natural History (KPMNH), Japan.

¹⁾ 1782-2 Toyodahongo, Hiratsuka, Kanagawa 254-0087, Japan
〒254-0087 神奈川県平塚市豊田本郷 1782-2

²⁾ Rm.7, 1F, Asano No.3 Bldg, 3-101 Tsukizutecho, Ogaki, Gifu
503-0854, Japan
〒503-0854 岐阜県大垣市築捨町 3 丁目 101 第 3 浅野ビル 1
階 7 号室

Class Chondrichthyes Huxley, 1880
 Subclass Elasmobranchii Bonaparte, 1838
 Cohort Euselachii Hay, 1902
 Order Ctenacanthiformes Glikman, 1964
 Family indet.

Genus Glikmanius Ginter *et al.*, 2005
Glikmanius occidentalis (Leidy, 1859)
 (Fig. 1 A–F)

Material: KPM-NNV 000289. A tooth from the Middle Member of the ALF.

Locality: Quarry in Kinshozan, Ogaki-City, Gifu Prefecture.

Range: *C. amacula*–*C. gifuensis* zone of the Middle Permian (Ozawa & Nishiwaki, 1992).

Description: Tooth with triangular principal cusp; probably one pair of lateral cusps (lack one of them). Cross section of principal cusp almost flat labially; convex lingually. Principal cusp with cutting edge; many fine striae particularly on lingual face. Cusps connected at their base. Base reniform with obvious basolabial depression; two rounded projections at basolabial shelf; two buttons at orolingual side.

Remarks: In this study, 7 cladodont teeth (KPM-NNV 000272, 000288, 000298, 000302–000305) were obtained in addition to the aforementioned specimen, but they are poorly preserved for determination of their taxonomy.

Order Hybodontiformes Glikman, 1964
 Superfamily Hybodontoidea Owen, 1846
 Family Lonchidiidae Herman, 1977
 Genus *Lissodus* Brough, 1935

Lissodus sp.
 (Fig. 2 A–L)

Material: KPM-NNV 000261–000271, 000273–000283, 000290–000297, 000299–000301. 33 isolated teeth from the Middle Member of the ALF.

Locality: Quarry in Kinshozan, Ogaki-City, Gifu Prefecture.

Range: *C. amacula*–*C. gifuensis* zone of the Middle Permian (Ozawa & Nishiwaki, 1992).

Description: Teeth with non-striated crown with low pointed main cusp; obvious occlusal crest; prominent crown shoulder; labial protuberance. Labial protuberance supported by labial root buttress. Crown not expanded mesio-distally. Mesio-distal length of crown up to 2 mm long. Crown-root junction strongly incised around entire crown. Root lingually projected; labially hollow; occasionally labial face with row of foramina under crown-root junction.

Most specimens (presumed laterals) crown shape chevroned in labial view (Fig. 2 C, I). Crown with lateral cusps (Fig. 2 A, B), or crenulated occlusal ridge (Fig. 2 I, J) in some teeth. Crown with almost no or very low cusp; crown shape oval to



Fig. 1. A–F: Tooth of *Glikmanius occidentalis* from the ALF, Gifu prefecture, Japan; KPM-NNV 000289. A, labial view; B, lingual view; C, basal view; D, occlusal view; E–F, lateral view. Scale bar = 5 mm.

rounded triangular in occlusal view (Fig. 2 E, F) in some teeth (presumed posterior). Some teeth (presumed anterior) with labial protuberance; occlusal crest stronger than other teeth; crown triangular in labial, lingual, and occlusal view (Fig. 2 K, L). Accessory cusplets (or pieces of longitudinal ridges) in some specimen (Fig. 2 A, B, I, and L).

Comparisons: The morphology and heterodonty pattern of these teeth resemble those of the family Lonchidiidae, particularly the genus *Lissodus*.

Rees & Underwood (2002) revised the family Lonchidiidae and its component genera including *Lissodus*. They restricted the range of *Lissodus* within the Mesozoic. All the Paleozoic specimens, which had been assigned to the genus *Lissodus* by Duffin (1985), were re-assigned to the Paleozoic Genera 1 and 2 (Hybodontoidae incertae familiae) by Rees & Underwood (2002). However, in terms of their morphology, Akasaka specimens resemble the Mesozoic *Lissodus* more than the Paleozoic Genera 1 and 2. Paleozoic Genus 1 (e.g., “*Lissodus*” *zideki* Johnson, 1981; “*Lissodus*” *lacustris* Gebhardt, 1988) differs from Akasaka specimens because members of this genus have pointed, strongly labially inclined cusp, triangular to “diamond-shaped” teeth in occlusal view (as some teeth also have a lingual protuberance), and the labial side of the crown divided in two concave parts by the protuberance. Moreover, Paleozoic Genus 2 (e.g., “*Lissodus*” *wirkworthensis* Duffin, 1985) differs from Akasaka specimens by having a mesio-distally expanded crown with an extremely strong crown shoulder, frequent presence of strong accessory cusplets, and ornamentation of coarse folds.

The general morphology of the teeth from the ALF is similar to *Lissodus cristatus* Delsate et Duffin, 1999 from the Anisian (Middle Triassic) of Moersdorf, Luxembourg. However, *L. cristatus* differs from Akasaka specimens by having the obvious longitudinal ridge surrounding the tooth labially and lingually at the crown shoulder and the presence of a coarse vertical ridge ascending the crown on the crest of the labial protuberance.

Remarks: Rees & Underwood (2002) restricted the range of the genus *Lissodus* within the Mesozoic; the Paleozoic teeth assigned to the genus *Lissodus* were fallen into two groups, which were left in open nomenclature. Recently, Fischer *et al.* (2010) argued against this opinion and re-classified the two genera of Paleozoic teeth into the genus *Lissodus*.

Until date, only 4 occurrences of the genus *Lissodus* have been reported from modern Asia: *L. xinshuiensis* from Changhsingian (uppermost Permian) in the Changxing Formation, South China (Wang *et al.*, 2007); *L. cf. cristatus* Delsate et Duffin, 1999 from Dienerian to lower Smithian (Lower Triassic) in the Zhitkov Formation, Abrek Bay area, South Primorye (Yamagishi, 2009); *Lissodus* sp. from Spathian (Lower Triassic) in the Taho Formation, Ehime prefecture, southwestern Japan (Goto *et al.*, 2010); and *L. indicus* (Yadagiri, 1986) from Middle to Upper Jurassic in the Kota Formation, Andhra Pradesh, India (Yadagiri, 1986; Prasad *et al.*, 2004). The Akasaka specimens described in this paper denote the fifth and oldest occurrence of the genus *Lissodus* in Asia.

The stratigraphic range of *Lissodus* is from Famennian (Late Devonian) to Late Cretaceous (Duffin, 2001; Ginter *et al.*, 2002). Previously, several authors reported the occurrence of *Lissodus* from the Permian: *L. zideki* from the upper Admiral to the middle Lueders Formation (Lower Permian), Wichita Group, Texas, USA (Johnson, 1981; Duffin, 1985); *L. sp.* from the Meisenheim Formation (Lower Permian), Niedermoschel, Saar-Nahe Basin, Germany (Hampe, 1996); *L. xinshuiensis* from Changhsingian (uppermost Permian) in the Changxing Formation (see above); and *L. sardiniensis* from Gzhelian-Asselian (latest Carboniferous–earliest Permian) in the Guardia Pisano Basin, Sardinia, Italy (Fischer *et al.*, 2010). This report of *Lissodus* from the ALF marks its first recorded occurrence in the Middle Permian.

Although the ALF, which yields *Lissodus*, and the Changxing Formation, which yields *L. xinshuiensis*, are marine sediments, the former was located in a mid-ocean environment. *L. zideki* from the Wichita Group appeared in nonmarine sediments (Johnson, 1981). Both *L. sardiniensis* from the lacustrine limestone of Guardia Pisano and *L. sp.* from the Meisenheim Formation appeared in nonmarine sediments (Fischer *et al.*, 2010).

Although *Lissodus* is probably known as euryhaline and occurs in both terrestrial and marine sediments (Duffin, 1985), its occurrence in the ALF suggests that *Lissodus* inhabited various environments, including the mid-ocean already in the Permian. In order to explain this result, it is necessary to trace the route of their divergence to a mid-ocean environment or to confirm whether the Permian teeth known as *Lissodus* contain several Paleozoic taxa.

Family indet.

(Fig. 2 M)

Material: KPM-NNV 000284–000287. 4 isolated scales from the Middle Member of the ALF.

Locality: Quarry in Kinshozan, Ogaki-City, Gifu Prefecture.

Range: *C. amacula*–*C. gifuensis* zone of the Middle Permian (Ozawa & Nishiwaki, 1992).

Description: Scales with low blunt crown; robust root; without development of pedicle. Crown vertical ridges coarse; may bifurcate near base of crown.

Remarks: Within a species, the morphology of the scales is highly variable according to body region. Moreover, the scales show important morphological differences among specimens of different sizes in the same region of the body (e.g., Reif, 1973). Thus, scales have been considered as a taxonomically obscure material for identification (Reif, 1985; Cappetta, 1987) and are described here without interpretation of taxonomy.

Reif (1978) divided the morphological type of scales in fossil sharks into the placoid, hybodontid, and ctenacanthid types. The scales of the ALF are not similar to the ctenacanthid type which are curved in a posterior direction, having an extremely thin crown and basal plate, and a well-developed neck region. Akasaka specimens may be assignable to the hybodontid type; the scales of hybodontid type have been found in Rhaetian,

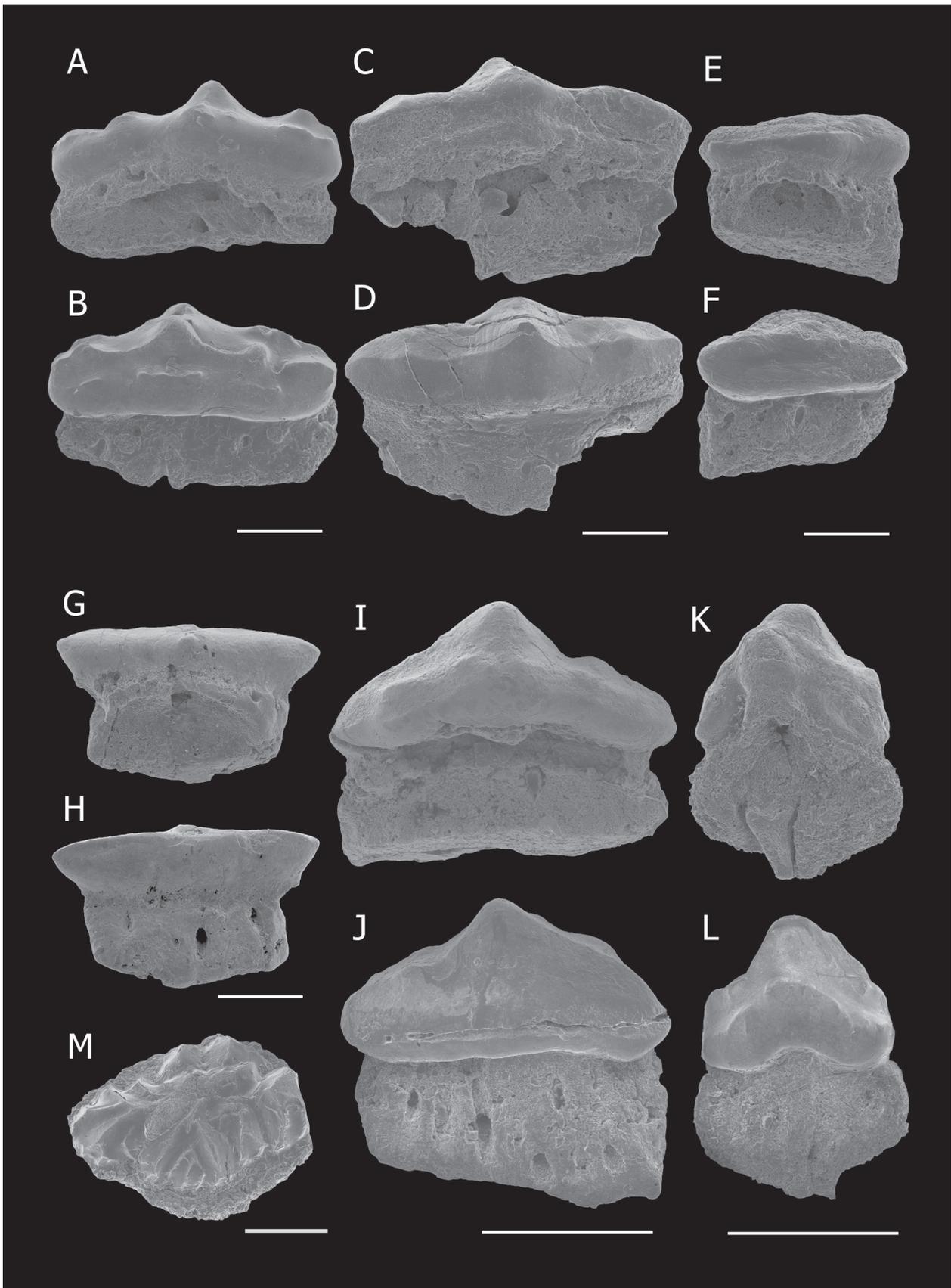


Fig. 2. A–L: Teeth of *Lissodus* sp. from the Akasaka Limestone Formation, Gifu prefecture, Japan. A–B: KPM-NNV 000278; A, labial view; B, lingual view. C–D: KPM-NNV 000279; C, labial view; D, lingual view. E–F: KPM-NNV 000280; E, labial view; F, lingual view. G–H: KPM-NNV 000275; G, labial view; H, lingual view. I–J: KPM-NNV 000299; I, labial view; J, lingual view. K–L: KPM-NNV 000270; K, labial view; L, lingual view. M: Scale from the ALF; KPM-NNV 000287. Scale bar = 500 μ m (A–H, M), 1 mm (I–L).

Jurassic and Cretaceous hybodontoid sharks (Reif, 1978). In addition, the scales of *Lissodus africanus* (Early Triassic) are of the hybodontid type (Duffin, 1985).

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摘 要

Yamagishi H. & T. Fujimoto, 2011. Chondrichthyan remains from the Akasaka Limestone Formation (Middle Permian) of Gifu Prefecture, Central Japan. *Bull. Kanagawa prefect. Mus. (Nat. Sci.)*, (40): 1-6. (山岸 悠・藤本艶彦, 2011. 岐阜県赤坂石灰岩累層から産出した軟骨魚類化石. 神奈川県立博物館研究報告 (自然科学), (40): 1-6.)

金生山 (岐阜県大垣市) の赤坂石灰岩累層中部層 (中部ペルム系) から、石灰岩の蟻酸処理によって、軟骨魚類の微細な歯および鱗の化石を抽出した。

得られた歯化石のうち7点は *cladodont* と呼ばれる古生代に生息した軟骨魚類に特有の形態を持ち、うち1標本はクテナカントゥス類の *Glikmanius occidentalis* に同定される。その他の歯化石は、中生界からの産出記録が多いヒボダス類の属 *Lissodus* に同定される。また鱗化石は、中生界から多産する *hybodontid type* と呼ばれる形態のものであった。中部ペルム系からの *Lissodus* の報告は本例が初めてであり、かつアジア地域においては現時点で最も古い産出記録となる。また、ペルム紀におけるヨーロッパや北米の他産地が非海成層であるのに対し、赤坂石灰岩累層は古海山頂部起源の石灰岩で、遠洋性堆積物であることから、遠洋域での本属の放散を辿る上で貴重な産出例であると考えられる。

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