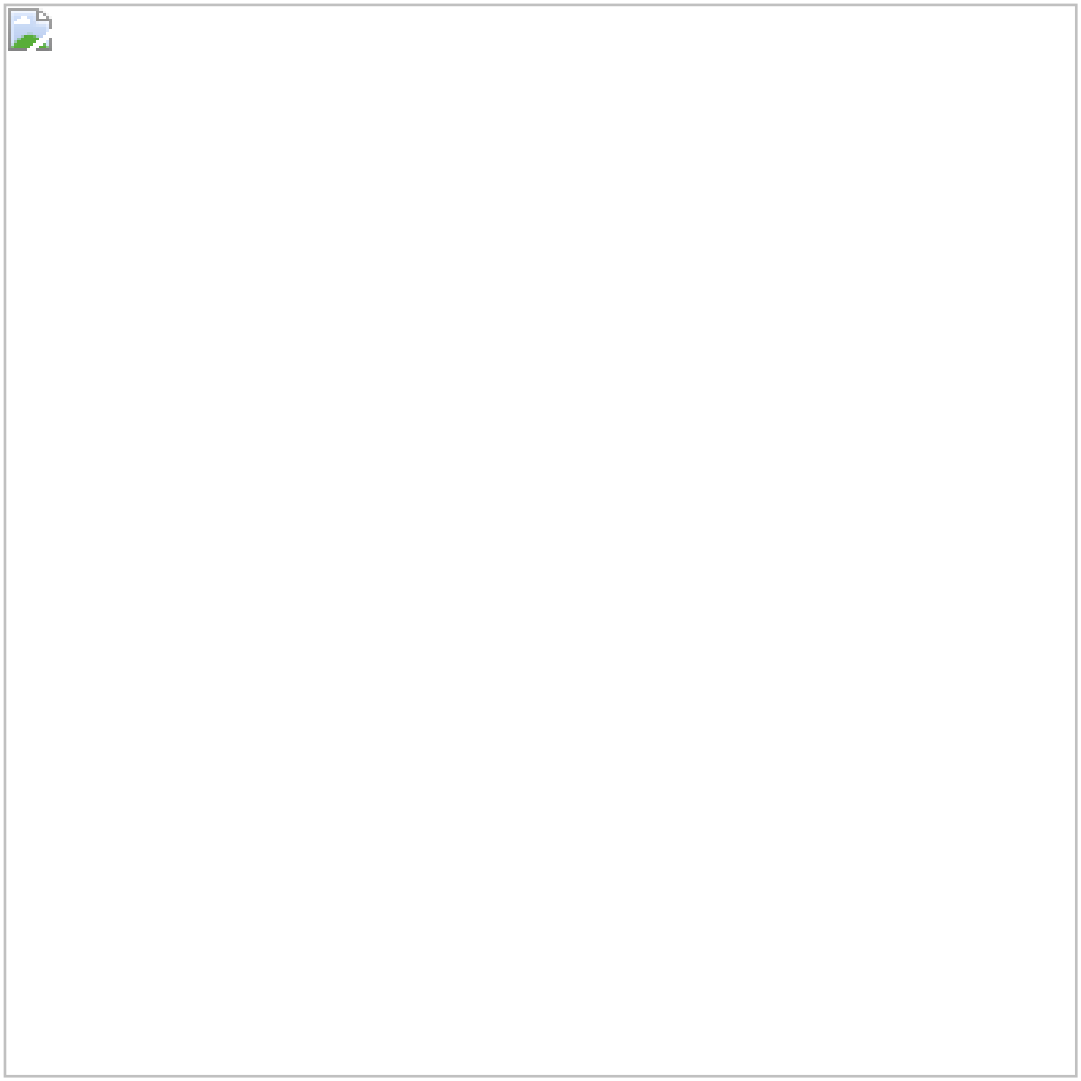

A New Species of the Genus Adocus (Adocidae, Testudines) from the Lower Cretaceous of Southwest Japan

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Source: Paleontological Research, 19(1) : 26-32

Published By: The Palaeontological Society of Japan

URL: https://doi.org/10.2517/2014PR026

Paleontological Research, vol. 19, no. 1, pp. 26–32, January 1, 2015

doi:10.2517/2014PR026

A new species of the genus *Adocus* (Adocidae, Testudines) from the Lower Cretaceous of Southwest Japan

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Received July 22, 2013; Revised manuscript accepted June 1, 2014

Abstract. ***Adocus sengokuensis*** **sp. nov. is described on the basis of disarticulated shell elements (nuchal, first peripherals, left fourth peripheral, left second costal, left hyoplastron, and right hypoplastron) collected from a lacustrine mudstone of the Lower Cretaceous Sengoku Formation, Kanmon Group in Miyawaka City, Fukuoka Prefecture, Japan.** ***A. sengokuensis*** **is characterized by its small size with a carapace estimated at only 29 cm long, a trapezoidal cervical scale greater in width than length, and a narrow lateral projection of the first pleural scale of the fourth peripheral. Small size and wide cervical scale suggest that this new species is the most basal taxon of the genus** ***Adocus*****.**

Key words: Adocidae, *Adocus sengokuensis*, Early Cretaceous, fossil turtle, Japan, Trionychoidea

Introduction

The genus *Adocus* of moderate to large-sized semiaquatic turtles has widely been recorded from the Cretaceous to the Paleogene of Asia and North America (e.g. Hutchison, 2000; Hirayama *et al*., 2000; Danilov *et al.*, 2011, 2013). This genus is easily distinguishable from other turtles even in isolated shell materials by its characteristic wide overlapping of the marginal scales onto the costal plates. At least seven valid species have been described (Hirayama, 2002; Danilov *et al.*, 2011). Occurrence of *Adocus* from the Lower Cretaceous Kitadani Formation of Japan (Barremian to Aptian, *Adocus* sp., Hirayama, 2002) suggests that the genus *Adocus* appeared first in Asia. Nonetheless, these materials are rather poorly documented, making it difficult to discuss systematic positions within this genus at the species level.

In this study, we report new materials of *Adocus* from the Lower Cretaceous Sengoku Formation of the Kanmon Group in Miyawaka City, Fukuoka, Kyushu, Western Japan (Figure 1). We describe these materials as a new species and discuss its systematic implications for understanding the early history of this genus.

Geological setting

The Lower Cretaceous Kanmon Group distributed in northern Kyushu to western Honshu of Southwest Japan is stratigraphically divided into the lower Wakino and the upper Shimonoseki subgroups (Figure 1; Matsumoto, 1951). The Wakino Subgroup is mainly composed of black shale, conglomerate, sandstone, purple siltstone, and acid tuff, and contains abundant fresh-water mollusks (Ota, 1960). It consists of the Sengoku, Nyoraida and Wakamiya formations in ascending order (Ota, 1953). The Sengoku Formation yields a number of vertebrate fossils such as dinosaurs, crocodiles, fishes, and turtles (Okazaki, 1992, 1994). Turtle remains occur from the upper part of the Sengoku Formation that is interpreted as marginal lacustrine deposits by lithofacies, fossil assemblages and sedimentary structures (Seo *et al*., 1994). The Sengoku Formation has been correlated with the upper Barremian by freshwater molluscan fossils including *Trigonioides* and *Plicatounio* (Hase, 1960; Ota, 1960; Matsumoto *et al*., 1982; Kozai *et al*., 2005). The radiometric age of this formation has not been dated yet.

The upper Shimonoseki Subgroup, composed of volcaniclastic and terrestrial sediments, consists of the Shiohama, Kitahikoshima and Sujigahama formations in ascending order (Matsumoto, 1951). Although there are

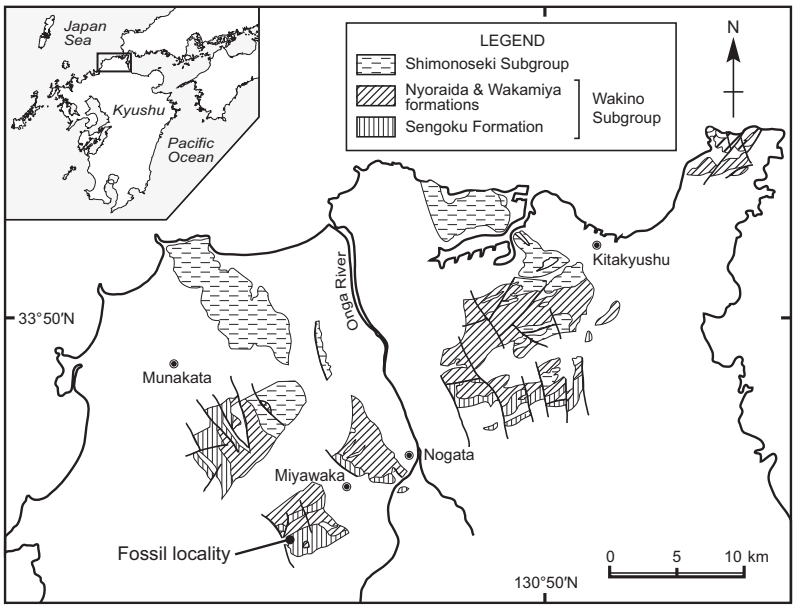

Figure 1. Fossil locality of the present materials and the distribution of the Kanmon Group in the northern part of Kyushu, Southwest Japan (modified from Hase, 1960).

few index fossils, the Shimonoseki Subgroup is assigned to the Albian by K-Ar ages and magnetostratigraphic data from andesite and dacite in the Kitahikoshima Formation (Shibata *et al*., 1978; Imaoka *et al*., 1993; Matsuura, 1998).

Materials and methods

The assemblage of specimens described (KMNH VP 000,024, housed in the Kitakyushu Museum of Natural History and Human History, Kitakyushu City, Fukuoka Prefecture, Japan) was collected by Mr. Masahiro Sato in 1994, from a riverside outcrop in the Sengoku gully of Miyawaka City, Fukuoka Prefecture, Japan. These materials comprise seven isolated shell elements (Figure 2). They can be considered to be derived from a single individual because: 1) all elements are different from each other in position of the shell, 2) the seven elements are not very different from one another in size, 3) these materials occurred together within a small block of about 20 cm span, 4) the matrix consists of lacustrine mud where physical transport of coarse clastic particles and shell materials are less likely, and 5) the ornamentation on the shell surface is very well preserved.

Terminology for the shell morphology follows Zangerl (1969). The carapace and plastron lengths are estimated mainly on the basis of *Adocus punctatus* (Hay, 1908). Our studies on the shell reconstruction and the determination of the systematic position refer to published data on the following taxa of trionychoids: *Adocus aksary* Nessov in Nessov and Krasovskaya, 1984 (Syromystnikova and Danilov, 2009); *A. amtgai* Narmandakh, 1985; (Sukhanov and Narmandakh, 2006); *A. beatus* Leidy, 1865 (Hay, 1908); *A. bossi* Gilmore, 1919 (Gilmore, 1919); *A. inexpectatus* Danilov *et al.*, 2013 (Danilov *et al*., 2013); *A. kirtlandius* Gilmore, 1919 (Gilmore, 1919); *A. punctatus* Marsh, 1890 (Hay, 1908); *A. dzhurtsensis* Syromyatnikova and Danilov, 2009 (Syromyatnikova and Danilov, 2009); *Adocus* sp. from Katsuyama in Fukui, Japan (Hirayama, 2002).

In addition to the genus *Adocus*, we used an unnamed trionychoid from the Kuwajima Formation of "Kasekikabe", Shiramine, Ishikawa Prefecture and *Ferganemys verzilini* as important outgroup taxa (Hirayama, 2000; Hirayama *et al*., 2000).

Systematic paleontology

Order Testudines Batsch, 1788
Suborder Cryptodira Cope, 1868b
Superfamily Trionychoidea Fitzinger, 1826
Family Adocidae Cope, 1870
Genus *Adocus* Cope, 1868a
Adocus sengokuensis sp. nov.

Figures 2, 3

Diagnosis.—A species of *Adocus* characterized by small shell size less than 30 cm long shell, wide and trap-

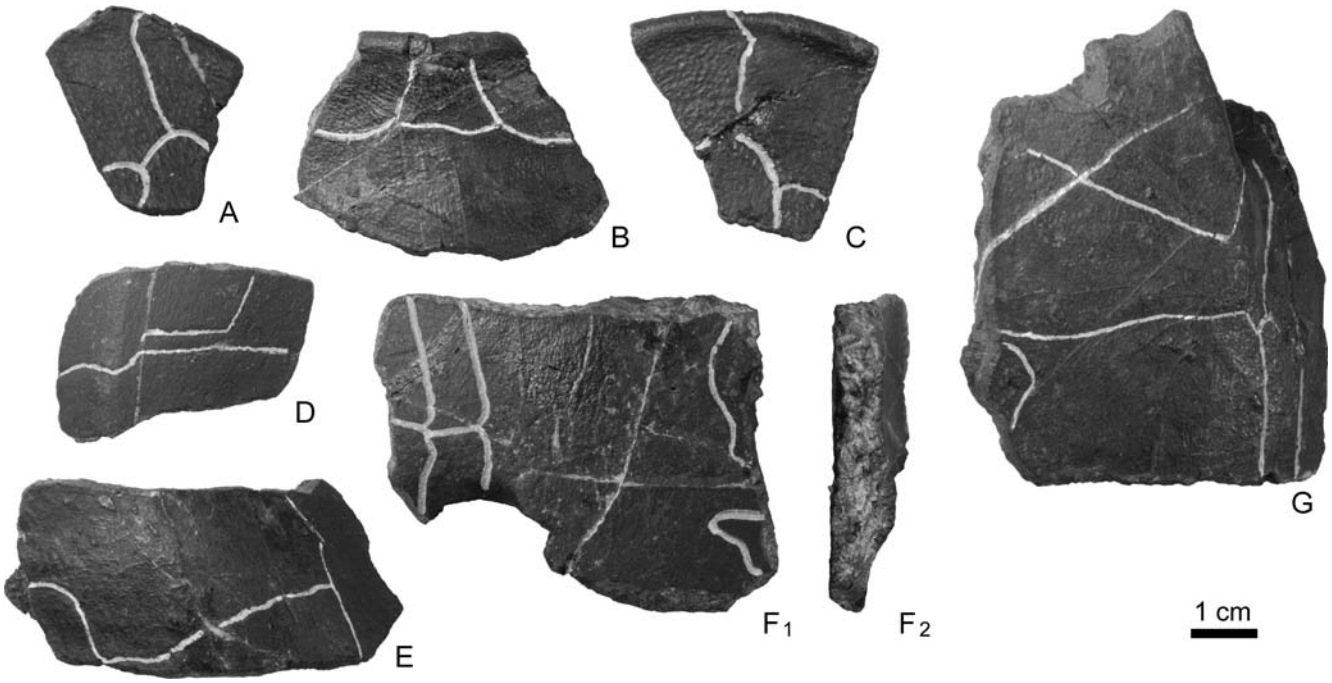

Figure 2. *Adocus sengokuensis* sp. nov., holotype, KMNH VP 000,024. **A–E**, dorsal views of carapace; A, left first peripheral; B, nuchal; C, right first peripheral; D, left fourth peripheral; E, left second costal; **F**, **G**, plastron; F_1, ventral view of right hypoplastron; F_2, medial view of right hypoplastron; G, ventral view of left hyoplastron. Scale sulci are filled with grey.

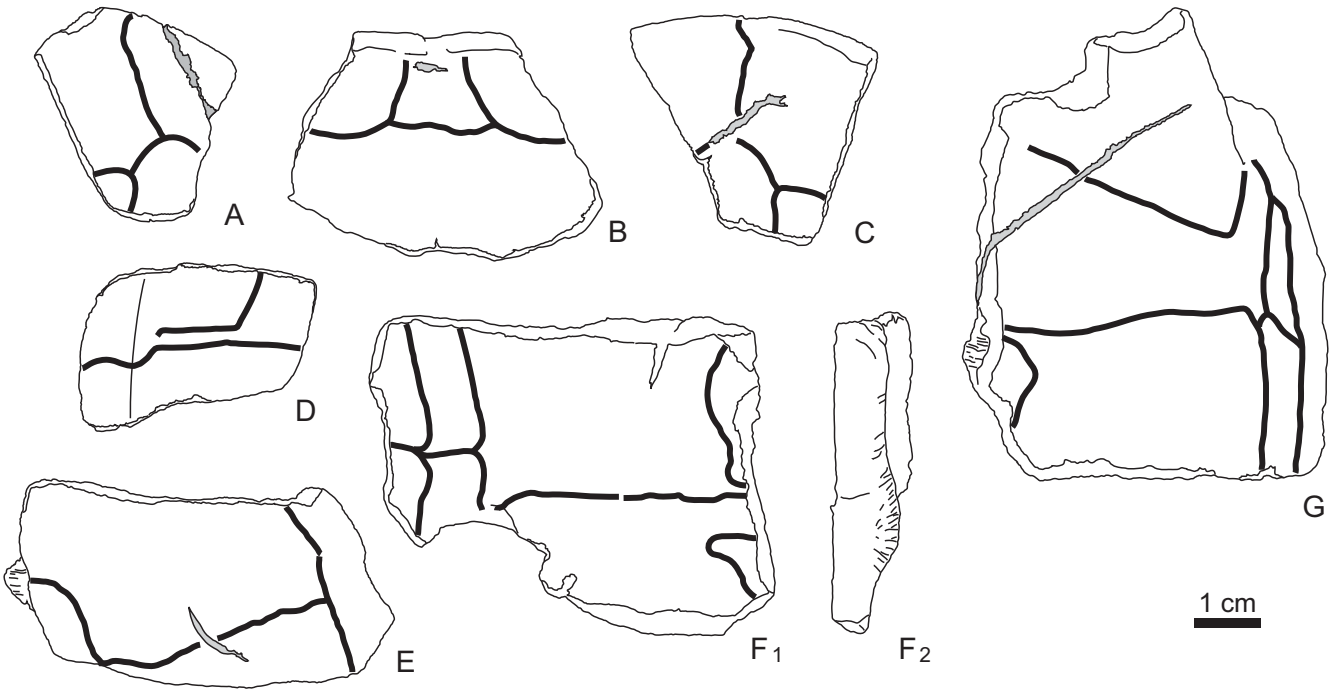

Figure 3. Line drawings of *Adocus sengokuensis* sp. nov., holotype, KMNH VP 000,024. **A–E**, dorsal views of carapace; A, left first peripheral; B, nuchal; C, right first peripheral; D, left fourth peripheral; E, left second costal; **F**, **G**, plastron; F_1, ventral view of right hypoplastron; F_2, medial view of right hypoplastron; G, ventral view of left hyoplastron. Scale sulci are drawn with bold lines.

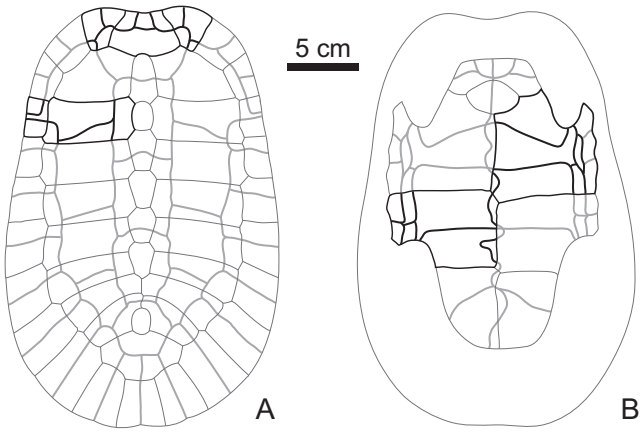

Figure 4. Shell reconstruction of *Adocus sengokuensis* sp. nov. **A**, dorsal view; **B**, ventral view. Scale sulci are drawn with black and gray thick lines. Black lines (thick and thin) are based on preserved elements. Gray lines (thick and thin) are based on *A. punctatus* (after Hay, 1908).

Table 1. Measurements in mm of shell elements of KMNH VP 000,024.

Material	Maximum length (mm)	Maximum width (mm)
Nuchal	30.8	46.0
Peripheral I (L)	30.7	30.3
Peripheral I (R)	33.3	37.0
Peripheral IV (L)	28.4	23.8
Costal II (L)	27.4	–
Hyoplastron (L)	68.6	40.9
Hypoplastron (R)	41.3	39.5
Cervical scale	13.5	14.9

ezoidal cervical scale, a narrow lateral projection of first pleural scale bordered by fourth and fifth marginals on the fourth peripheral.

Holotype.—KMNH VP 000,024: seven disarticulated shell elements attributed to a single individual, including nuchal, right and left first peripherals, left fourth peripheral, left second costal, left hyoplastron, and right hypoplastron.

Type Locality.—Sengoku gully, Miyawaka City, Fukuoka Prefecture, Kyushu Island, Japan.

Occurrence.—Upper part of the Sengoku Formation, Wakino Subgroup, Kanmon Group (Early Cretaceous, estimated as late Barremian in age).

Etymology.—Named after the type locality of the holotype and the Sengoku Formation, Sengoku gully.

Description.—Although materials are more or less slightly deformed, lengths of the carapace and plastron of *A. sengokuensis* are approximately estimated as 29 and 21 cm long, respectively (Figure 4). The holotype is considered to be mature because there is no supposed fontanel between shell elements as seen in juvenile or young individuals. Shell surface shows sculpture with fine and regular pits characteristic of *Adocus* and *Ferganemys* (Danilov *et al.*, 2013). Scale sulci are shallower and narrower than in terrestrial turtles such as nanhsiungchelyids. Measurements of each element are shown in Table 1.

Carapace. The nuchal is roughly hexagonal in shape, although it is somewhat asymmetrically deformed by postmortem diagenesis. The anterior free edge is thickened, upturned, and weakly emarginated posteriorly. The nuchal and the first right and left peripherals form a shallow nuchal notch. The suture between the nuchal and the first neural is short. The cervical scale is wide and trapezoidal in shape and expands posteriorly. The maximum width (14.9 mm) is larger than the maximum length (13.5 mm).

The left second costal plate is remarkably folded in the middle part by deformation, judging from the observation of a cross-sectional view. The thoracic rib head is weakly developed, and is elongated in an anteroposterior direction. Ventral surface of the second costal is very smooth and flat, and rib thickening is not recognized. The thickness of the costal increases towards the proximal end in cross-section. The marginal sulcus runs on the distal-posterior surface, and the fifth marginal clearly overlaps onto the second costal, whereas the fourth marginal does not reach there.

The pair of the first right and left peripherals is nearly complete. The fourth peripheral is longer than it is wide. Their scale sulci indicate that the first vertebral and pleural scales clearly overlap onto the first peripheral. The first vertebral scale has a wide anterior end. The fourth marginal is restricted to the anterior half of the fourth peripheral. Thus, overlapping of marginals onto the costals begins with the fifth marginal. The first pleural has a narrow lateral projection bordered by the fourth and fifth marginals on the fourth peripheral. The first pleural scale reaches the free edge of the fourth peripheral because of the narrow emargination between the fourth and fifth marginals.

Plastron. The right hyoplastron and left hypoplastron are preserved. The hyoplastron is longer than the hypoplastron. The curved suture line between the epiplastron and hyoplastron does not form the hinge structure. The borderline between the entoplastron and hyoplastron suggests that the entoplastron has a wide oval shape. The medial part of the hypoplastron is dorsally thickened like a shallow ridge, especially on the posterior area from the

Table 2. Comparisons of shell characters in *Adocus*. *A. beatus* is treated as representative of North American taxa.

Characters	*A. aksary*	*A. amtgai*	*A. beatus*	*A. inexpectatus*	*A. sengokuensis* sp. nov.	*Adocus* sp. (Katsuyama)
Carapace length	40 cm	40 cm	50 cm	35 cm	29 cm	37 cm
Cervical scale	narrow	narrow	narrow	?	wide	narrow
Beginning of marginal overlapping onto the costals	marginal 5	marginal 3 or 4	marginal 5	marginal 4	marginal 5	marginal 5
Distinctly narrow emargination of the posterior border of marginal 4	absent	absent	absent	absent	present	absent
Medial part of hypoplastron	flat	flat	flat	flat	thickened	thickened

buttress to midline. The pectral scale becomes broader into the median suture, although the humero-pectral sulcus is restricted in the hyoplastron. The median sulcus is strongly sinuous. Three pairs of inframarginals are recognized as in other species of *Adocus*.

Discussion

KMNH VP 000,024 is assigned to the Adocidae based on the presence of the following synapomorphies: shell sculpturing with regular and fine pits, shallow and narrow scale sulci, weakly developed rib heads, and very flat ventral surface of costals (Syromyatnikova and Danilov, 2009; Danilov *et al*., 2011). Furthermore, the left second costal in the present material (Figures 2D and 3D) is clearly overlapped by the fifth marginal, which has been regarded as an autoapomorphic character of the genus *Adocus* (Hirayama, 2002; Syromyatnikova and Danilov, 2009; Danilov *et al*., 2011). Thus, KMNH VP 000, 024 is identified as *Adocus*.

A. sengokuensis differs from the other species of this genus in having the smallest shell size, a cervical scale wider than it is long, and a narrow distal projection of the first pleural scale on the fourth peripheral (Table 2).

The shell length of *A. sengokuensis* is estimated as smaller than 30 cm long, whereas those in the Late Cretaceous and Paleogene species, including *A. aksary*, *A. amtgai*, *A. beatus*, *A. bossi*, *A. inexpectatus*, and *A. kyzirkmensis*, have been more than 35 cm in length (Gilmore, 1919; Danilov *et al*., 2013). In addition, the Early Cretaceous *Adocus* sp. from the Kitadani Formation of the Tetori Group in Katsuyama, Fukui, Japan, appears to be larger than *A. sengokuensis* (*ca*. 37 cm long; Hirayama, 2002). On the other hand, estimated shell length of an unnamed trionychoid taxon from the Lower Cretaceous Kuwajima Formation of the Tetori Group and *Ferganemys*, a primitive adocid from the Early Cretaceous of Central Asia, are less than 30 cm long (Hirayama, 2000; Hirayama *et al*., 2000; Syromyatnikova, 2011). This character distribution suggests that the small shell size of *A. sengokuensis* is a plesiomorphic state among the genus *Adocus* as well as the trionychoids. The shell size may have gradually become larger in *Adocus* during the Cretaceous.

A. sengokuensis is unique in the possession of a wide cervical scale within the genus *Adocus* (Figures 2B and 3B). The cervical is narrow and trapezoidal or rectangular in most species of this genus such as *A. beatus*, *A. bossi*, *A. aksary*, *A. amtgai* and *A.* sp. from the Lower Cretaceous Kitadani Formation of Fukui, Japan, or absent in *A.* sp. from the Upper Cretaceous Tamagawa Formation of Kuji, Iwate, Japan (Table 2; Hirayama, 2002; Syromyatnikova and Danilov, 2009; Hirayama *et al*., 2010; Danilov *et al*., 2013). As cervical shape is relatively stable through ontogenetic growth in living turtles (Hirayama, personal observation), this feature has been used as one of the informative character states in turtle taxonomy since the later 19th century (e.g. Boulenger, 1889). In other trionychoids such as the nanhsiungchelyids and *Ferganemys*, as well as an unnamed trionychoid from the Lower Cretaceous Kuwajima Formation of Shiramine, Ishikawa, Japan (Hirayama, 2000; Sukhanov *et al*., 2008; Syromyatnikova, 2011), the cervical scale is wider than it is long. Thus, the wide cervical scale in *A. sengokuensis* is considered as a plesiomorphic condition for *Adocus*. A narrow distal projection of the first pleural scale bordered by the fourth and fifth marginals of the fourth peripheral plate in *A. sengokuensis* seems quite unique in *Adocus* as well as the other turtles (Figures 2D and 3D). Other species of this genus have no similar lateral projection of the first pleural. Thus, this character is considered as an autoapomorphic character of this taxon. Based on the above characters, KMNH VP 000,024 is distinguished from its congeners.

In conclusion, new adocid materials from the Lower Cretaceous Sengoku Formation of Miyawaka, Fukuoka, Japan, are described as the most basal species of the genus *Adocus*, *A. sengokuensis*. This species is distinguished from its congeners in the possession of two ple-

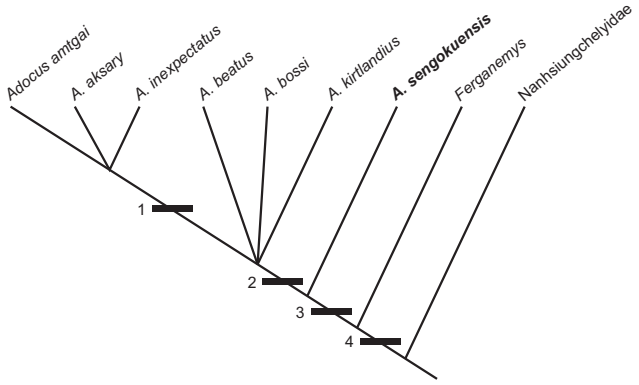

Figure 5. Phylogenetic tree showing relationships of *Adocus* and *Ferganemys* (Adocidae), modified from Danilov *et al.* (2013). Synapomorphic characters at each node are as follows: 1) marginal scale overlapping costals begins from third or fourth marginal, 2) cervical scale longer than it is wide, 3) fifth and posterior marginals overlapping onto costals, 4) shell sculpturing with fine pits or dots, reduced proximal head of thoracic rib, and large semicircular facet for ischium on xiphiplastron.

siomorphic characters such as small shell size and wider cervical scale, and one autoapomorphic character, a narrow lateral projection of the first pleural of the fourth peripheral. With reference to the recent results of cladistic analysis for *Adocus*, *A. sengokuensis* appears to be the most plesiomorphic taxon within the genus in lacking two synapomorphies: marginal scale overlapping costals beginning with the third or fourth (Figure 5, node 1; e.g. Syromyatnikova and Danilov, 2009; Danilov *et al.*, 2013), and a cervical scale longer than it is wide (node 2; see above). Further research on turtles in the Late Jurassic and Early Cretaceous turtles from Asia will shed light on the origin and early evolution of the superfamily Trionychoidea.

Acknowledgements

We are especially grateful to Masahiro Sato for collecting this specimen of the new species of the genus *Adocus*. We also thank Yoshitaka Yabumoto and Tomoyuki Ohashi (Kitakyushu Museum of Natural History and Human History) for kind help on specimen examination, and Yoichi Azuma and Masateru Shibata (Fukui Prefectural University/FPDM) for allowing access to comparative specimens. We also thank I. G. Danilov (Zoological Institute, Russian Academy of Sciences) and E. G. Gaffney (American Museum of Natural History) for examination of comparative fossil turtles, and W. G. Joyce (University of Tübingen) and Eric McEver (New York University) for kindly correcting our manuscript.

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