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Plant fossils from the Arimine Formation (Oxfordian, Jurassic) of the Tetori Group in Arimine, Toyama Prefecture, Central Japan

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Abstract. *Ptilophyllum* sp. and *Zamites brevipennis* are newly described from the middle Oxfordian Arimine Formation in Arimine area, Toyama Prefecture, Central Japan. These two species characterize the vegetation of the Eurosinian paleophytogeographic province where a climate with dry season(s) prevailed. This finding, as well as the presence of a Kaizara Flora, suggests that Eurosinian-type vegetations continuously flourished during the late Bathonian to Oxfordian on the land of the Tetori Group. We also infer that Tetori-type floras first appeared during the Tithonian in the Tetori Group.

Key words: Arimine Formation, Oxfordian, *Ptilophyllum*, Tetori Group, Tetori-type flora, *Zamites*

Introduction

The paleophytogeographic provinces were largely divided into the Siberian and Eurosinian provinces in Eastern Asia during the Middle Jurassic to Early Cretaceous period (Vakhrameev, 1987, 1991). The Siberian province, located north of the Eurosinian province, was characterized by a warm-temperate climate. The vegetation of the Siberian province was characterized by broad-leaved gymnosperms (e.g. *Podozamites*, *Dictyozamites* and *Neozamites*), Ginkgoales, Czekanowskiales, and diverse pteridophytes such as Dicksoniaceae and Osmundaceae (Vakhrameev, 1987, 1991). In contrast, the Eurosinian province laid within a subtropical to tropical belt in which a seasonally dry climate mainly prevailed after the Bathonian (Vakhrameev, 1987, 1991). In the Eurosinian province, microphyllous gymnosperms flourished, such as *Otozamites* and *Ptilophyllum* (Bennettitales), *Brachyphyllum*, *Pagiophyllum*, and cheirolepidiaceous genera (Coniferales) (Vakhrameev, 1987, 1991). The genus *Zamites* (Bennettitales) was also unique to the Eurosinian province (Vakhrameev, 1987, 1991). The boundary between the two provinces was placed at the line connecting the middle part of Sikhote-alin and the southern margin of the Baikal region at the beginning of the Oxfordian (Vakhrameev, 1987, 1991), while its position fluctuated during the Middle to Late Jurassic (Vakhrameev, 1987, 1991).

Such a phytogeographic scheme is generally applicable in Japan, where Siberian-type and Eurosinian-type vegetations are represented by Tetori-type and Ryoseki-type floras, respectively (Kimura, 1987, 1988, 2000). Tetori-type floras have been reported only from the Tetori Group distributed in the Hokushinetsu District (Figure 1), in the Inner Zone of Central Japan (Kimura, 1958, 1975, 1987, 1988; Kimura and Sekido, 1976; Yabe *et al.*, 2003), whereas Ryoseki-type floras have been reported from Northeast Japan and the Outer Zone of Southwest Japan (Kimura, 1987, 1988, 2000; Kimura and Ohana, 1988a, b, 1989; Kimura *et al.*, 1991). It has long been recognized that

Tetori-type floras continuously flourished in the Tetori Group during the Middle Jurassic to the Early Cretaceous (Kimura, 1987, 1988, 2000). However, this interpretation is markedly different from observations in Eurasia of Eurosinian-type vegetations in the far northern region compared to the Tetori Group area during the Middle to Late Jurassic (Vakhrameev, 1987, 1991). Vakhrameev (1991) attempted to reconcile this discrepancy by hypothesizing that the Late Jurassic Tetori-type flora represents a vegetation type of the continental margin with high precipitation.

The “Kuzuryu Flora” (Kimura, 1958) constitutes the basis for the “Middle to Late Jurassic Tetori-type flora”, and was proposed to comprise plant fossil assemblages from Hakogase, Kowashimizu, Mochiana, Ushimaru, and Wakogo localities (Figure 1), where the Bajocian to Oxfordian “Kuzuryu Subgroup” of the Tetori Group is outcropped (Kimura, 1958; Maeda, 1961a). However, stratigraphic revisions of these plant-bearing sediments have been conducted in the last 15 years based on ammonoids (Sato *et al.*, 2003, 2008; Sato and Yamada, 2005) and radiometric dating (Kusuhashi *et al.*, 2006; Kawagoe *et al.*, 2012). As a result, it is now accepted that the sediments are younger than Tithonian (Yamada and Uemura, 2008; Figure 2).

In addition, we reported a late Bathonian to Callovian Kaizara Flora from the Kaizara Formation in the Kuzuryu/Itoshiro area, Fukui Prefecture (Figures 1, 2), whose age was confirmed by ammonoids occurring along with the plants (Yamada and Uemura, 2008). The Kaizara Flora was classified as Eurosinian type by its abundant occurrence of bennettitalean *Otozamites* and *Ptilophyllum* (Yamada and Uemura, 2008). This result showed that the Tetori-type flora would have appeared after the Oxfordian in the Tetori Group area, but the exact age of its appearance has not been determined. Our data also implied that the floristic trends were shared between Eurasia and Japan in the Middle to Late Jurassic period, but this implication should be further tested by locating the Oxfordian plants from the Tetori Group.

In this study, two plants are reported from the middle Oxfordian Arimine Formation in the Arimine area, Toyama Prefecture (Figures 1, 2). Although only two species were recognized, they provide sufficient evidence to infer that a Tetori-type flora was not present during this period in the Tetori Group.

Material and geological settings

Plant fossils were collected from locality AR0021 in Arimine, Toyama City, Toyama Prefecture (Figure 1). All specimens are stored in the Palaeobotanical Collections of the National Museum of Nature and Science, Tsukuba (NSM PP).

In this locality, the lower part of the Arimine Formation is outcropped, consisting of fine-to-medium sandstones of shallow marine origin (Sato and Yamada, 2014). The middle Oxfordian age was inferred by the simultaneous occurrence of the ammonoid genera, *Perisphinctes* (*Kranaosphinctes*), *P.* (*Dichotomosphinctes*), and *Ochetoceras* (Sato and Yamada, 2014). Details on the collection site are available in Sato and Yamada (2014).

Systematic palaeobotany

Class Bennettiopsida

Order Bennettitales Engler, 1892

Family uncertain

Genus ***Ptilophyllum*** Morris, 1840

Type species.—*Ptilophyllum acutifolium* Morris, 1840.

Ptilophyllum sp.

Figure 3A, B

Ptilophyllum sp. A. Yamada and Uemura, 2008, p. 10, fig. 5D–F.

Specimens examined.—NSM PP-9925.

Description.—One specimen of compound leaf was collected whose apex and base were not preserved. Leaf fragment is 2.8 cm wide by 2.6 cm long. Rachis is ca. 1.3 mm wide and bears leaflets on the adaxial side. Angles between the rachis and leaflets range between 50 and 55 degrees. Leaflets are 12.7–15.7 mm long by 2.1–2.9 mm wide. Leaflet apices are obtusely pointed. Leaflet bases are slightly contracted on the acroscopic side, but decurrent on the basiscopic side. Veins run almost parallel and do not diverge acropetally. Concentration of veins ranges from 41.6 to 47.6 per cm, although veins could be observed in only two leaflets.

Remarks.—Distinction among "cycadophyte" foliar genus *Otozamites*, *Ptilophyllum* and *Zamites* is sometimes difficult when epidermal characters are not available. However, it is suggested that genus *Ptilophyllum* could be distinguished from the other two genera by decurrent basiscopic bases of leaflets and veins not diverging acropetally (Rees and Cleal, 2004; McLoughlin and Pott, 2009).

The obtained specimen could not be distinguished in leaf shape and leaflet vein concentration from *Ptilophyllum* sp. A from the Callovian Kaizara Formation in Kuzuryu/Itoshiro area, Fukui Prefecture (Yamada and Uemura, 2008). As reported in Yamada and Uemura (2008), *Ptilophyllum* sp. A, as well as our specimen, can be assigned either to *P. cutchense* Morris (1840) emend. Bose and Kasat (1972) or to *P. chosiense* Kimura, Okubo and Miyahashi (1991). However, specific assignment is not possible without the epidermal characteristics.

Genus ***Zamites*** Brongniart, 1828

Type species.—*Zamites gigas* (Lindley *et* Hutton, 1837) Morris, 1841 emend. Harris, 1969.

Zamites brevipennis (Oishi) Takimoto, Ohana and Kimura, 2008

Figure 3C–E

Pseudoctenis brevipennis Oishi, 1940, p. 322, pl. 28, figs. 5, 6; Kimura and Ohana, 1988b, p. 157, pl. 14, fig. 1, text-fig. 20a, b.

Zamites sp. A. Kimura and Ohana, 1988a, p. 124, pl. 7, figs. 4, 5.

Zamites sp. B. Kimura and Ohana, 1988a, p. 124, text-fig. 14.

Zamites sp. D. Kimura and Ohana, 1989, p. 15, pl. 1, fig. 5.

Zamites brevipennis (Oishi) Takimoto, Ohana and Kimura, 2008, p. 135, fig. 5.1–5.3.

Specimens examined.—NSM PP-9926 (Figure 3C), NSM PP-9927 (Figure 3D), NSM PP-9928 (Figure 3E), NSM PP-9929.

Description.—Two fragments of compound leaves (Figure 3C, D) and two detached leaflets (Figure 3E, NSM PP–9929) were collected. Both leaves lacked the apical and basal parts, as well as leaflets on the right side (Figure 3C, D). Leaves are more than 9 cm long (Figure 3C, D). Rachis is slender (i.e., 2.0–2.5 mm wide) and bears leaflets on the upper-lateral side at 75–80 degrees (Figure 3C, D). Leaflets are ca. 4.5 cm long by 1.2–1.3 cm wide (Figure 3C–E) and slightly overlap with adjacent ones (Figure 3C, D). Leaflet apices are obtuse (Figure 3D). Leaflet bases are equally contracted to two-thirds of the widest part (Figure 3C, D) and thickened to form a crescentic elevation (Figure 3C). Upper margins of leaflets are straight. Lower margins of leaflets are almost straight, but start to curve at the apical one-third of each leaflet (Figure 3D). Veins run almost parallel without anastomosis, and fork several times. Concentrations of veins range from 15 to 22 per cm (Figure 3C, E).

Remarks.—These specimens were classified as *Zamites brevipennis*, which was originally described from the Oxfordian Tochikubo Formation, Fukushima Prefecture, northeastern Japan, based on the slender rachis, short leaflets with obtuse apex and equally contracted base, crowded veins, and crescentic elevation at the base of the leaflets (Oishi, 1940; Takimoto *et al.*, 2008). *Zamites brevipennis* is unique in that the leaflets are short relative to the width, as denoted by the specific epithet. *Zamites carruthersii* Seward from the Berriasian of English Wealden (Watson and Sincock, 1992) is another species with short leaflets, but the leaflets are attached to a rachis by a narrow attachment without thickening in *Z. carruthersii*.

Zamites-type leaves were classified as the bennettitalean morphogenus *Pterophyllum* or the cycadalean morphogenus *Pseudoctenis* when epidermal characteristics were unavailable (Harris, 1964, 1969). Two *Zamites*-type leaves have been reported from the Tetori Group, i.e., *Pseudoctenis* sp. from the Callovian Kaizara Formation in the Kuzuryu/Itoshiro area, Fukui Prefecture (Yamada and Uemura, 2008), and *Pterophyllum pachyrachis* (Oishi) Kimura and Ohana (1987) from the Tithonian to Berriasian Yambara Formation in the Eastern Izumi area, Fukui Prefecture (Oishi, 1940; for stratigraphic horizon of the specimen, see Yamada and Uemura, 2008). Both species have thick rachis of ca. 1 cm diameter and long leaflets; thus, they are clearly different from *Z. brevipennis*.

Discussion

It had been widely accepted that Tetori-type floras continuously flourished during the Middle Jurassic (the Bajocian) to Early Cretaceous in the Tetori Group (Kimura, 1958, 1975, 1987, 1988; Yabe *et al.*, 2003). However, this interpretation contradicted the palaeobotanical data indicating that the Eurosinian-type vegetations incurred far northward in Eurasia beyond the land of the Tetori Group during the Middle to Late Jurassic (Vakhrameev, 1987, 1991). Recent stratigraphic and palaeobotanical studies suggested that the Tetori-type flora should have appeared after the Oxfordian (Yamada and Uemura, 2008), but it remains to be clarified when the Tetori-type flora first appeared.

In this study, *Ptilophyllum* sp. and *Zamites brevipennis* are described from the Oxfordian Arimine Formation of the Tetori Group distributed in Arimine area, Toyama Prefecture (Figure 1). This is the first report of Oxfordian plants from the Tetori Group. These two genera are considered as indices of a climate with dry season(s) (Ziegler *et al.*, 1993, 1996; Rees *et al.*, 2000) that prevailed in the Eurosinian province during the Middle Jurassic to Early Cretaceous (Vakhrameev, 1987, 1991). In contrast, these plants have not been reported to date from any flora of the Siberian province, including Tetori-type floras (Kimura, 1987, 1988; Vakhrameev, 1987, 1991).

Since the plant specimens used in this study were fossilized in shallow marine deposits, they possibly reflect the coastal vegetation only. However, post-Tithonian marine deposits of the Tetori Group include index species of the Siberian-type floras and do not contain these indices of a drier climate (Yamada and Uemura, 2008; T. Yamada, unpublished data). Therefore, it is likely that the typical Tetori-type flora did not flourish during the Oxfordian on the land of the Tetori Group. The Eurosinian-type vegetation is successively present from the late Bathonian to Oxfordian, although more plant fossils should be collected to develop a more comprehensive image of the Oxfordian flora of the Tetori Group.

Two Eurosinian-type floras were reported from the Oxfordian of Northeast Japan: one from the Tochikubo Formation of the Somanakamura Group in Fukushima Prefecture (Kimura and Ohana, 1988a, b; Takimoto *et al.*, 2008) and the other from the Oginohama Formation of the Ojika Group in Miyagi Prefecture (Kimura and Ohana, 1989). The plant fossil assemblage of the Arimine Formation is too incompletely clarified to compare to those of the Oginohama and Tochikubo formations in species-by-species manner, but it should be noted that *Z. brevipennis* commonly occurs from all of these formations (Oishi, 1940; Kimura and Ohana, 1989; Takimoto *et al.*, 2008). The common occurrence may imply that floristic barrier was weak, if present, which separated the lands of these three formations. Whatever the case may be, plant fossils from the Arimine Formation add an evidence that an Eurosinian-type flora was prevailed also in the Inner Zone of Southwest Japan, resolving the discrepancy in the Oxfordian floras between Japan and the Eurasian region of East Asia (Vakhrameev, 1987, 1991).

The oldest plant assemblages of the Tetori-type flora are those from the Tithonian Ushimaru Formation distributed in the Shokawa area of Gifu Prefecture (Kimura, 1958; Maeda, 1961b; Yamada and Uemura, 2008; Figures 1, 2). An almost coeval assemblage of the Tetori-type flora was also reported from the Tithonian Ashidani Formation in Eastern Izumi, Fukui Prefecture (Kimura, 1958; Yamada and Uemura, 2008; Figures 1, 2). In summary, plant fossils from the Oxfordian Arimine Formation suggest that Tetori-type floras appeared after the Tithonian on the land of the Tetori Group. The Eurosinian-type flora disappeared during the late Oxfordian to Tithonian when the deposition was interrupted in the Tetori Group (Sato and Yamada, 2014).

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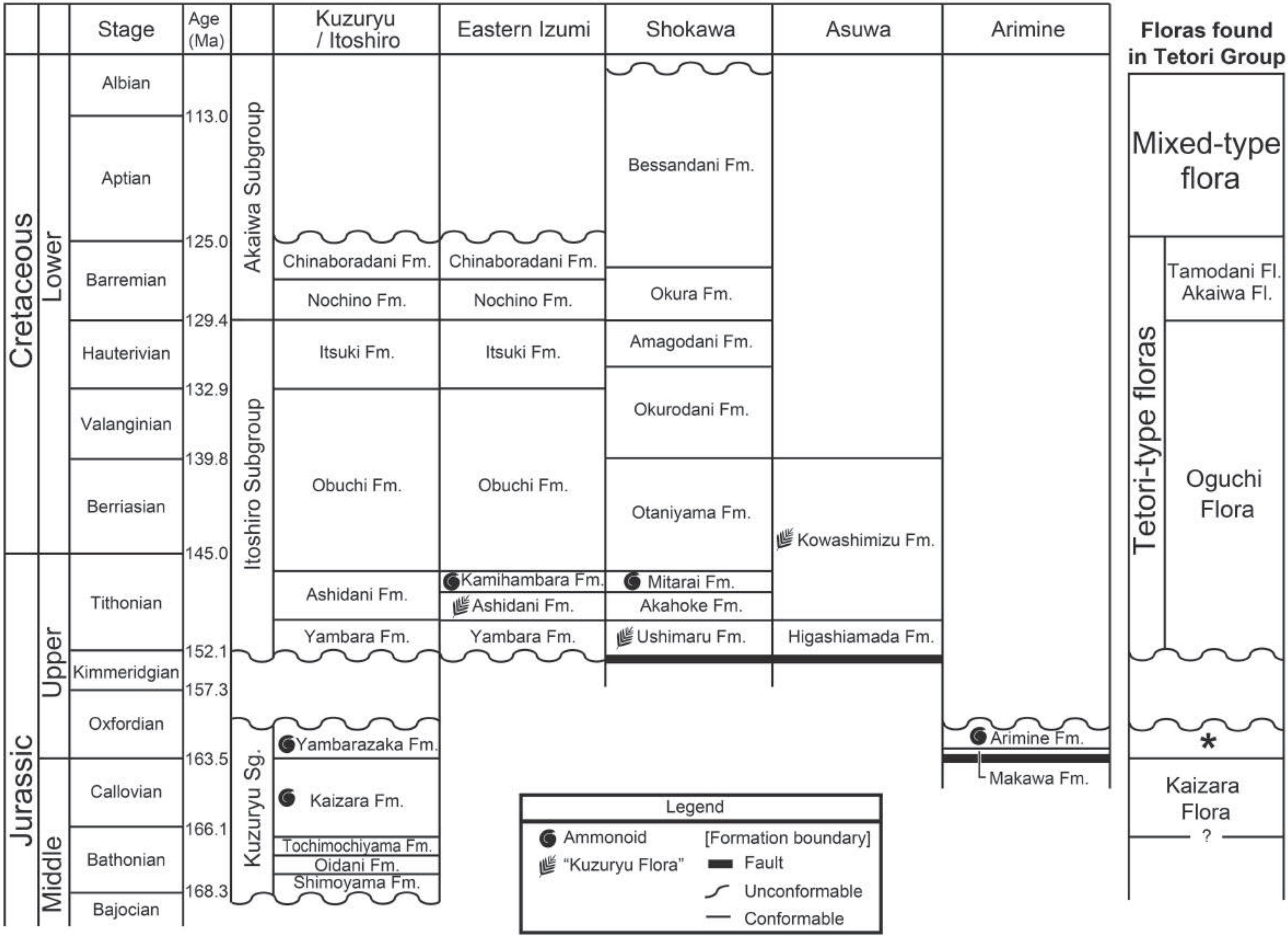
Figure legends

Figure 1. Distribution of the Tetori Group (shaded) based on Maeda (1961b) and the fossil locality (AR0021) in Arimine area. Numbers indicate fossil localities of the "Kuzuryu Flora" and the Kaizara Flora: 1, Ushimaru: 2, Hakogase and Mochiana: 3, Kaizara: 4, Shimoyama: 5, Wakogo: 6, Kowashimizu. As, Asuwagawa River; Jg, Joganjigawa River; Jz, Jinzugawa River; Kz, Kuzuryugawa River; Sg, Shogawa River; Td, Tedorigawa River.

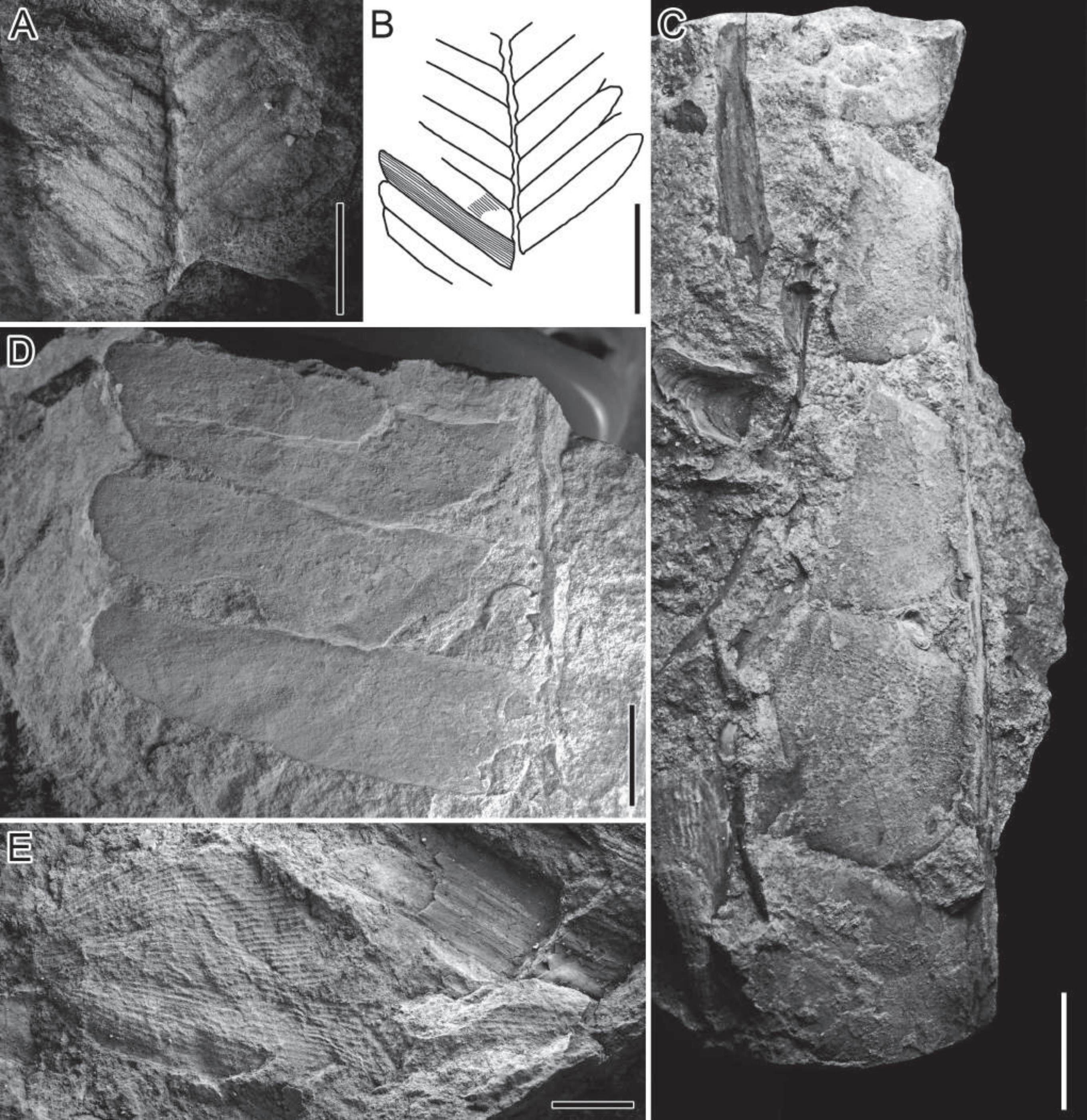
Figure 2. Current interpretations of stratigraphic horizons bearing the "Kuzuryu Flora," modified from Yamada and Uemura (2008). Stratigraphic ranges of floras reported from the Tetori Group are summarized in the rightmost column based on Yabe *et al.* (2003) and Yamada and Uemura (2008) (asterisk indicates the plant fossil assemblage from the Arimine Formation). The stratigraphy in Wakogo, Managawa (#5 in Figure 1) is not shown because it has yet to be precisely revised. However, radiometric dating suggests that the plant-bearing horizon in Wakogo is younger than the Tithonian (Kawagoe *et al.*, 2012). Fm, Formation; Fl, Flora.

Figure 3. Plant fossils from the Arimine Formation. **A, B**, *Ptilophyllum* sp.; A, NSM PP-9925; B, line drawing of A. **C–E**, *Zamites brevipennis*; C, compound leaf, NSM PP-9926; D, compound leaf, NSM PP-9927; E, detached leaf, NSM PP-9928. Scale bars indicate 1 cm.

50 km
136°28'E
36°29'N
Sg
Jz
Jg
Td
Arimine
AR0021
Shiramine
Takinamigawa
As
6
Asuwa
Kz
1
Shokawa
4
3
Kuzuryu / Itoshiro
5
2
Managawa
Eastern Izumi
1000 km



Stage
Age (Ma)
Kuzuryu / Itoshiro
Eastern Izumi
Shokawa
Asuwa
Arimine
Floras found in Tetori Group
Cretaceous
Lower
Jurassic
Upper
Middle
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Tithonian
Kimmeridgian
Oxfordian
Callovian
Bathonian
Bajocian
113.0
125.0
129.4
132.9
139.8
145.0
152.1
157.3
163.5
166.1
168.3
Akaiwa Subgroup
Itoshiro Subgroup
Kuzuryu Sg.
Chinaboradani Fm.
Nochino Fm.
Itsuki Fm.
Obuchi Fm.
Ashidani Fm.
Yambara Fm.
Yambarazaka Fm.
Kaizara Fm.
Tochimochiyama Fm.
Oidani Fm.
Shimoyama Fm.
Chinaboradani Fm.
Nochino Fm.
Itsuki Fm.
Obuchi Fm.
Kamihambara Fm.
Ashidani Fm.
Yambara Fm.
Bessandani Fm.
Okura Fm.
Amagodani Fm.
Okurodani Fm.
Otaniyama Fm.
Mitarai Fm.
Akahoke Fm.
Ushimaru Fm.
Kowashimizu Fm.
Higashiamada Fm.
Arimine Fm.
Makawa Fm.
Mixed-type flora
Tetori-type floras
Tamodani Fl.
Akaiwa Fl.
Oguchi Flora
*
Kaizara Flora
?
Legend
Ammonoid
"Kuzuryu Flora"
[Formation boundary]
Fault
Unconformable
Conformable


A
B
C
D
E