[Original report]

# Fossil fern fronds from the early Pleistocene Kobiwako Group in Minakuchi, Shiga Prefecture, central Japan

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## Abstract

Fossil fern fronds of three taxa occur in the early Pleistocene Kobiwako Group in Minakuchi, Shiga Prefecture, central Japan. All fern fossils are impressions of sterile fronds, and they are described in terms of their morphological features : division of blades, forms of pinna and pinnule, and types of venation. The three taxa identified are *Thelypteris* cf. *T. palustris* (Salisb.) Schott, *Onoclea* cf. *O. sensibilis* L. var. *interrupta* Maximowiczi, and Polypodiales, and these ferns constitute important specimens among the sparse records of early Pleistocene fossil ferns in Japan.

Fossil fern fronds were preserved in their growing position by a volcanic ash fall and were found in a tuffaceous peaty-silt bed just below the base part of the Hazama ash layer (c.a. 2.3 Ma), occurring together with *Aristolochia*, *Acer*, and *Ilex*, as well as fossil leaves of Cyperaceae. The ferns were growing in an open back-marsh or swamp habitat around a forested area.


Key words : fossil fern, sterile frond, Kobiwako Group, early Pleistocene, paleo-ecology

## Introduction

Ferns are seedless vascular plants, which reproduce through the production of spores. Ferns (Lycophytes and Monilophytes) were globally common in the Carboniferous, and declined after the Jurassic, however, Monilophytes had the variety of species and ecology in the Cenozoic (Willis and Mcelwain, 2002 ; Collinson, 2002). Fossil ferns are not rare in the Tertiary floras of Japan, although their diversity and frequency are generally low (Table 1). Fossil fronds of *Osmunda* and *Onoclea* are frequently found in Japanese Eocene to Miocene floras (e.g. Matsuo, 1953 ; Tanai, 1970 ; Ishida, 1970 ; Matsumoto and Nishida, 2003) : a famous example is the high abundance of fossil fern fronds in the Eocene *Woodwardia* Sandstone of the Ikushunbetsu Formation (Oishi and Huzioka, 1941). Many previous studies of fossil ferns from the Eocene to Miocene focused on their morphological features for classification. However, study of the mode of occurrence and the depositional facies of sediments that include the fossil ferns are necessary to reconstruct the paleo-ecology and paleo-environment of the fossil ferns (Collinson, 2002).

Fossil fern records from the Japanese Plio-Pleistocene are rare, but include fossil fronds of *Osmunda* from the Pliocene Kabutoiwa Formation (Ozaki, 1991), extant fern taxa (*Davallia*, *Blechnum*, *Polystichum*, *Woodsia*, and *Athyrium* ) from the Pleistocene Shiobara flora (Onoe, 1989), and fossil fronds of *Pteridium* from the Middle Pleistocene Katata and Kawanishi Formations in central Japan (Miki, 1948).

Several fossil fern fronds that were discovered from the early Pleistocene Kobiwako Group on the riverbed of the Yasu River in Minakuchi, Koka City,

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Table 1. List of fossil ferns from the Cenozoic floras in Japan.

| Fossil fern | Locality & stratum | Age | Reference |
|---|---|---|---|
| Selaginellaceae | | | |
| *Selaginella* sp. | Sashikira | Miocene | Ozaki (1991) |
| Equisetaceae | | | |
| *Equisetum ezoense* Endo | Yubari | Eocene | Endo (1968) |
| *E. arcticum* Heer | Yubari, Harutori, Kobe | Eocene, Oligocene | Huzioka & Kobayashi (1961), Tanai (1970), Yamamoto & Yonesaka (1999) |
| *E. kitamurae* Kon'no | Kotsuki | Oligocene | Matsuo (1971) |
| *Equisetum* sp. | Takashima, Kiwado, Aniai, Hiyoshi, Kani, Daijima, Kamigo, Mizunami | Eocene, Oligocene, Miocene | Huzioka (1963, 1964), Matsuo (1967), Huzioka & Koga (1981), Ina (1992), Uemura *et al.* (1999) |
| Osmundaceae | | | |
| *Osmunda sachalinensis* Kryshtofovich | Harutori | Eocene | Tanai (1970) |
| *O. regalis* Linnaeus | Yubari | Eocene | Endo (1968) |
| *O. japonica* Thunberg | Ikushunbetu, Aniai, Hiyoshi, Kani | Eocene, Miocene | Oishi & Huzioka (1941), Huzioka (1964), Ina (1992) |
| *O kuragatakensis* Matsuo | Kuragatake | Miocene | Matsuo (1953) |
| *O. bromeliaefolioides* Matsuo | Tsumenomori | Miocene | Matsuo (1953) |
| *O. tsunenomoriensis* Matsuo | Kammachi, Oguni, Mizunami, Aizu | Miocene | Matsuo (1953), Suzuki (1961), Huzioka & Koga (1981), Ina (1992) |
| *O. lignita* (Giebel) Stur | Oguni | Miocene | Huzioka & Koga (1981) |
| *Osmunda* cf. *O. Japonica* Thunberg | Miyata, Kabutoiwa | late Miocene, Pliocene | Huzioka & Uemura (1973), Ozaki (1991) |
| *O. shimokawaensis* Matsumoto & Nishida | Shimokawa | late Middle Miocene | Matsumoto & Nishida (2003) |
| *O. cinnamomea* Linnaus | Shimokawa | late Middle Miocene | Matsumoto & Nishida (2003) |
| *Osmunda* sp. | Kobe | Oligocene | Yamamoto & Yonesaka (1999) |
| *Plenasium lignitum* (Giebel) Squinabol | Takashima, Ube, Notonakajima | Eocene, Miocene | Matsuo (1963,1967), Huzioka & Takahashi (1970) |
| *Plenasium* sp. | Kishima, Daijima | Eocene, Miocene | Huzioka (1963), Matsuo (1971) |
| Lygodiaceae | | | |
| *Lygodium mioscandes* Matsuo | Notonamajima | Miocene | Matsuo (1963) |
| *Lygodium* sp. | Daijima | Miocene | Huzioka (1963) |
| Salviniaceae | | | |
| *Salvinia natans* (L.) Allioni | Sakito | Eocene | Mastuo (1970) |
| *S. kryshtofovichiana* (Florin) Shaparenko | Takashima, Kamigo, Sakipenpetsu | Eocene, Miocene | Matsuo (1967), Tanai (1971), Huzioka & Koga (1981) |
| *Salvinia* cf. *S. natans* (L.) Allioni | Itahana, Aizu | Miocene | Suzuki (1961), Ozaki (1991) |
| *S. floriniana* Huzioka & Takahashi | Oguni, Shimonoseki | Miocene | Huzioka & Takahashi (1973), Huzioka & Koga (1981) |
| *S. psudoformosa* Oishi & Huzioka | Aniai, Hiyoshi, Kani | Miocene | Huzioka (1964), Ina (1992) |
| *Salvinia* sp. | Daijima, Iki | Miocene | Huzioka (1963), Hayashi (1975) |
| Dennstaedtiaceae | | | |
| *Dennstaedtia nipponica* Oishi & Huzioka | Ikushunbetu, Harutori | Eocene | Oishi & Huzioka (1941), Tanai (1970) |
| *Microlepia* sp. | Iki | Miocene | Hayashi (1975) |
| *Pteridium aquilinum* Kuhn | Katata, Kawanishi | Pleistocene | Miki (1948) |
| Pteridaceae | | | |
| *Acrostichum ubense* Huzioka | Ube | Eocene | Huzioka & Takahashi (1970) |
| *Pteris mioinequalis* Matsuo | Notonakajima, Oguni | Miocene | Matsuo (1963), Huzioka & Koga (1981) |
| *Pteris* sp. | Daijima | Miocene | Huzioka (1963) |
| Aspleniaceae | | | |
| *Asplenium* sp. | Kamigo, Sashikira | Miocene | Huzioka & Koga (1981), Ozaki (1991) |
| Thelypteridaceae | | | |
| *Lastrea kushiroensis* Tanai | Harutori | Eocene | Tanai (1970) |
| *Cyclosorus aizuensis* Suzuki | Aizu | Miocene | Suzuki (1961) |
| *Cyclosorus* sp. | Kani | Miocene | Ina (1992) |
| Woodsiaceae | | | |
| *Diplazium* sp. | Sashikira, Chausuyama | Miocene | Ozaki (1991) |
| *Athyrium delicatulum* Oishi & Huzioka | Ikushunbetu | Eocene | Oishi & Huzioka (1941) |
| *Athyrium* sp. | Noroshi | Miocene | Ishida (1970) |
| *A. yokoscense* (Franchet & Savatier) Christ | Shiobara | Pleistocene | Onoe (1989) |
| *Woodsia manchuriensis* Hooker | Shiobara | Pleistocene | Onoe (1989) |
| *W. polystichoides* Eaton | Shiobara | Pleistocene | Onoe (1989) |
| *Cornopteris* sp. | Chausuyama | Miocene | Ozaki (1991) |
| Blechnaceae | | | |
| *Woodwardia sasae* Oishi & Huzioka | Harutori | Eocene | Tanai (1970) |
| *W. japonica* var. *eocenica* | Yubari | Eocene | Endo (1968) |
| *W. decurrens* Oishi & Huzioka | Ikushunbetu | Eocene | Oishi & Huzioka (1941) |
| *W. endoana* Oishi & Huzioka | Ikushunbetu | Eocene | Oishi & Huzioka (1941) |
| *Woodwardia* sp. | Oguni, Chausuyama, Kobe | Oligocene, Miocene | Huzioka & Koga (1981), Ozaki (1991), Yamamoto & Yonesaka (1999) |
| *Blechnum amabile* Makinio | Shiobara | Pleistocene | Onoe (1989) |
| Onocleaceae | | | |
| *Onoclea hebraidica* (Forbes) Gardner & Ettingshausen | Harutori | Eocene | Tanai (1970) |
| *O. sensibilis* Linnaus | Ikushunbetu | Eocene | Oishi & Huzioka (1941) |
| *Onoclea* sp. | Kobe | Oligocene | Yamamoto & Yonesaka (1999) |
| *Onoclea* sp. | Noroshi | Miocene | Ishida (1970) |
| Dryopteridaceae | | | |
| *Ctenitis* sp. | Kani | Miocene | Ina (1992) |
| *Dryopteris uttoensis* Huzioka | Utto, Kamigo | Miocene | Huzioka (1963), Huzioka & Koga (1981) |
| *Dryopteris* sp. | Kani, Daijima, Mizunami | Miocene | Huzioka (1963), Ina (1992) |
| *Polystichum tripteron* (Kunze) Presl | Shiobara | Pleistocene | Onoe (1989) |
| Davalliaceae | | | |
| *Davallia mariesii* Moore | Shiobara | Pleistocene | Onoe (1989) |

Shiga Prefecture, central Japan are the subject of this paper. Three fern taxa, *Thelypteris* cf. *T. palustris* (Salisb.) Schott, *Onoclea* cf. *O. sensibilis* L. var. *interrupta* Maximowiczi, and Polypodiales fam., gen. *et* sp. indet., are included the first fossil records of two taxa from the Pleistocene in Japan. These fossil fronds were extracted from several blocks of massive and tuffaceous peaty silt just below the basal part of an ash layer. Therefore, the mode of occurrence and the distribution in the sediment could be observed in detail.

In this study, we describe the morphological features and the occurrence of these fossil fern fronds from the early Pleistocene Kobiwako Group in central Japan, and discuss the paleo-ecology of these ferns considering the composition of the accompanying plant macrofossil assemblage.

## Geological Setting and locality

The Plio-Pleistocene Kobiwako Group is located in the Omi and Ueno basins, central Japan. It consists of lacustrine and fluvial sediments deposited in and around the Paleo-Lake Biwa. The sediments are composed of clay, sand and gravel, and are interleaved with many volcanic ash and peat layers (Kawabe, 1989). The stratigraphic sequence of lithofacies, tephrochronology, and paleomagnetism are well established for this group (Hayashida and Yokoyama, 1983 ; Yoshikawa, 1984 ; Suzuki, 1988 ; Kawabe, 1989).

The fossil ferns were recovered from the riverbed of the Yasu River in Minakuchi, Koka City, Shiga Prefecture. The locality is about 70 meters

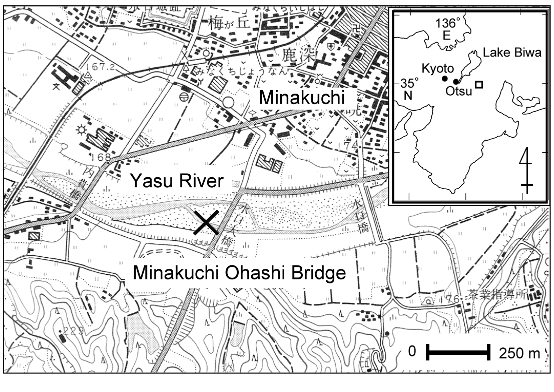


Fig. 1. Locality map of Minakuchi area, Shiga Prefecture, from the topographical map sheet " Minakuchi" scale 1 : 25,000 published by the Geospatial Information Authority of Japan.

downstream of the Minakuchi- Ohashi Bridge (Fig. 1). The strata are composed mainly of peaty silt, intercalated with volcanic ash, clay, and fine to medium grained sand, and the thickness is about nineteen meters (Fig. 2). The Komazuki ash layer is in the upper part of the sediments, and the Hazama ash layer lays below the Komazuki ash layer about 5 m, corresponding to the lower part of the Gamo Formation in this region (Kobiwako Research Group, 1977 ; Kawabe, 1981). Three silt layers contain many fossil wood material preserved in a coal-like, compressed status. Proboscidean footprint fossils are included in the lowest clay layer.

The Hazama and Komazuki volcanic ash layers including the strata are present in the lower of the Mushono ash layer (Kawabe, 1981; Yoshikawa, 1984). Fission track dating of the Mushono ash layer that overlies the Hazama ash layer gave an age of 2.27 ± 0.44 Ma (Suzuki, 1988). However, the Mushono ash layer is correlated to the Koyashiro ash in the Tokai Group, the Shiraiwa ash in the Kakegawa Group, and the Kyp-NA 11-Jwg 4 ash layers in the Niigata region, the latter of which, has been recently dated to around 2.35Ma (Kurokawa *et al*., 2004). The magnetostratigraphic polarity zone is Matsuyama Reversed Chron (Hayashida and Yokoyama, 1983). The age of the fossil fern fronds is therefore estimated to be about 2.3 Ma, the early Pleistocene.

## Materials and Methods

Several blocks containing c.a. 50 fragments of fossil fern fronds were extracted from the lower boundary of the Hazama ash layer (Fig. 2).

The important criteria for the classification of ferns are the shapes and positions of sori (on fertile fronds). However, because we were unable to find sporangia and sori on the undersurface of the fronds using microscopy, all fossil fern fronds in this study are impression fossils of sterile fronds. Therefore, the fossil fern fronds herein were classified using other morphological features, namely the basis of division of blades, the characteristics of the rachises and pinnal axes, the forms of pinnae and pinnules, and types of venation. The classification follows the system by Smith *et* al. (2006) and Yonekura (2012). The ecology and distribution of the extant species is based on Iwatsuki (1992).

We observed the mode of occurrence of the fossil fern fronds in the extracted blocks, each of

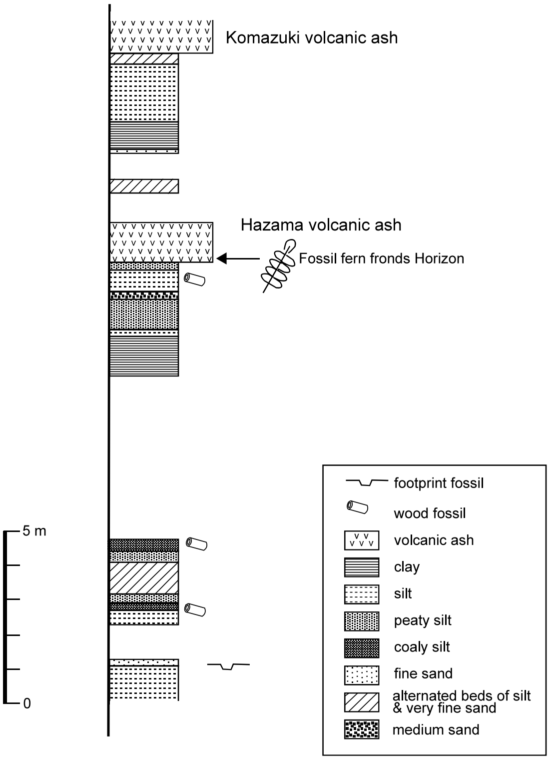


Fig. 2. Columnar section of the Gamo Formation showing the horizon of fossil fern fronds at the bed of the Yasu River in Minakuchi, Shiga Prefecture.

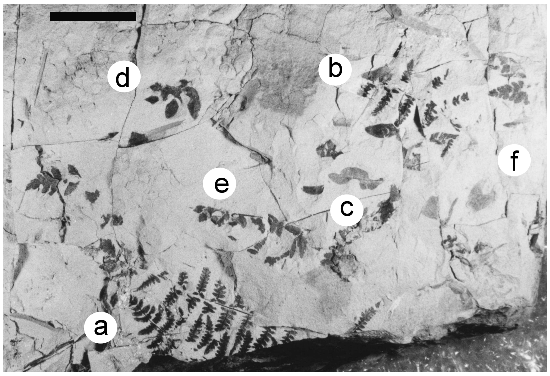


Fig. 3. Occurrence of fossil fern fronds from the early Pleistocene Kobiwako Group in Minakuchi, Shiga Prefecrure. Scale bar is 5 cm.

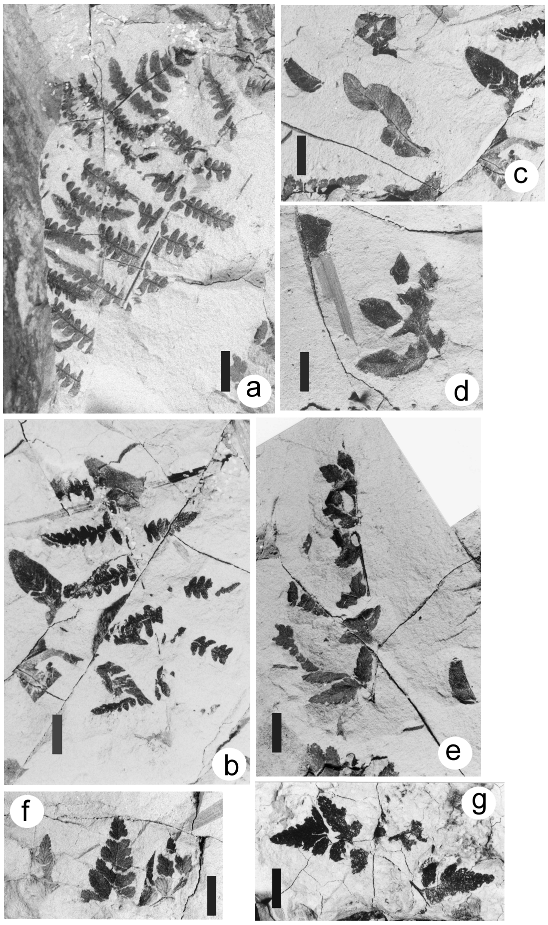


Fig. 4. Three fossil fern fronds from the early Pleistocene Kobiwako Group. a, b : *Thelypteris* cf. T. *palustris*. c,d : *Onoclea* cf. O. *sensibilis* var.*interrupta*. e, f, g : Polypodiales. Scale bars are 1 cm.

which were 80 cm long and 40 cm wide (Fig. 3), and considered the paleo-environment, based on the composition of the plant macrofossil assemblage with ferns.

The fossil specimens collected for this study have been deposited in the Lake Biwa Museum.

## Result

### 1) Systematic description

Three fossil fern taxa from the early Pleistocene Kobiwako Group are identified and described below :

Class Polypodiales

Family Thelypteridaceae Smith

Genus *Thelypteris* Schmidel

*Thelypteris* cf. *T*. *palustris* (Salisb.) Schott

(Fig. 4-a, b ; Fig. 5)

Description: impression fossil, defective, sterile frond with the lower part absent. Rachis stout, subulate shape, 123 mm long and 0.6 mm wide, slightly curved. Simply pinnate, 10 to 11 pinnae pairs arranged in alternate branching pattern along proximal part and in opposite branching pattern along distal part of frond; pinnatisect shape, pinnatilobate at upper part of frond, chartaceous texture ; parted or sected lobation and caudate at apical part, pinnae 10 to 28 mm long and 6 to 7 mm wide, maximum width 9.7 mm near rachis ; pinna rachises spine-like, smoothly curved toward apex, 90° to 70° branching angles from rachis in middle part of frond, pinnae spaced at intervals of 5 to 14 mm, with wider intervals toward proximal part of rachis. 10 to 13 pinnule pairs on each pinna rachis, alternate to opposite arrangement; frond margin entire, enrolled on underside, acute to obtuse at apical part; midvein irregularly sinuous, separate from a pinna rachis (Fig. 5 a); upper secondary veins more acute than lower, branching and forking to enter pinnule margin, with free vein ending type (Fig. 5 b).

Remarks : Although the pinnules of the entire margin are enrolled to the underside, a characteristic of fertile fronds, the sporangia and sori were not found on the underside surface of the fronds using microscopy. This fossil species is smaller than the modern species *Thelypteris palustris* (Salisb.) Schott., although the fossil fronds have frond shape and venation type of *T. palustris*. The modern species is distributed in temperate zone of the world, including Hokkaido to Kyushu in Japan (Iwatsuki, 1992), and grows in open marsh or swamp habitats.

Collections : LBM0112000831, 833, 834, 840, 856, 863

Family Onocleaceae

Genus *Onoclea* Linnaeus

*Onoclea* cf. *O. sensibilis* L. var. *interrupta* Maximowiczi

(Fig. 4-c, d ; Fig. 6)

*Onoclea sensibilis* L. fossils Newberry, Oishi and Huzioka, 1941, Jour. Fac. Sci. Hokkaido Univ. ser.4, vols.6, P.184-185, pl. XLI (III), figs.1, 1a, 2, 2a.

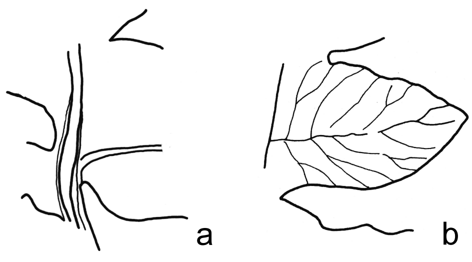


Fig. 5. Illustration of fossil *Thelypteris* cf. *T. palustris*. a: pinnule midveins separate from pinna rachis. b: pinnule venations are branching and forking to enter the frond margin, with free vein ending type.

Description : defective impression fossil, distal and middle parts of sterile fronds. Frond simple and lobed, herbaceous texture. Middle part of rachis about 0.3 mm wide and straight. Parted lobation, frond alate along rachis. Pinna rachises slender, gently curved towards apex, attached to rachis at 60° at distal part and 90° at middle part, arranged in opposite branching pattern. Pinnules nallowly elliptic in shape, 32.4 mm long and 11.5 mm wide, with acute apical section, and rounded apex. Entire margin of pinna smooth, vein leaving pinna rachis at angle of 30° to 40° , branching dichotomously three or four times, joining neighbor veins and forming regular pentagonal netted venation (Fig. 6a). Marginal ultimate veins ending in loops (Fig. 6b).

Remarks: This fossil species has a general frond shape similar to that of *Osmunda japonica*. *O. japonica* has the dichotomous branching type of venation and veins that directly enter the finely serrated edge. In this fossil species, the venation type is repeatedly branching dichotomously, joining and forming a pentagonal reticulate venation, not free veins type, and is also different to those of the Polypodiaceae, which has complicated reticulate venation.

The fossil *Onoclea sensibilis* occurs in the Eocene *Woodwardia* sandstone of Hokkaido (Oishi and Huzioka, 1941). *O. hebraidica* (Forbes) Gardner and Ettingshausen has been reported from the Oligocene Kushiro coalfield, known as the Harutori specimens (Tanai, 1970). Also *Onoclea* sp. occurs from the Miocene Noto Group (Ishida, 1970).

Living *Onoclea sensibilis* is distributed from Hokkaido to Kyushu in Japan, as well as northeast China, south Sakhalin, the south Kurile Islands and east Siberia. Its habitat is wet, humid sunny areas of foothills, low lying-hills and lowlands (Iwatsuki, 1992).

Collections : LBM0112000836, 838, 854

Polypodiales fam., gen. *et* sp. indet.

(Fig. 4e-d ; Fig. 7)

Description: impression fossil, sterile frond. Defective in distal and proximal parts of frond. Frond bipinnatiparted shape, anadromous branching, herbaceous to thin chartaceous texture; middle part of rachis, smoothly curved, about 100 mm long and 0.8 mm wide, alate frond at both sides of rachis ; pinnae triangular, with acute angle at distal part, cleaved to parted at proximal part. Pinnae commonly connect to rachis, but isolated examples show short petiole at basal part ; pinna rachis slender or stout at joining part on rachis and with petiole at basal part, leaving at angle of 50° to 60° from rachis, 100° at basal part ; pinnules narrowly ovate to narrowly elliptic, margin with fine serration ; midvein thin, dividing into two to three pairs at basal part of pinnules, branching dichotomously and zigzagging at apical part ; lateral vein dichotomously branching one to three times (Fig. 7a), and reaching to serrate margin, with free vein ending type (Fig. 7b).

Remarks: this fossil species is characterized by pinnae of various shapes and the joining stele of rachises from the distal to proximal parts. The rachises with a wing, pinnules with pointed, fine serration, and the repetitive dichotomous branching of the fossil species are morphological characters similar to those of Woodsiaceae and Dryopteridaceae.

Collections : LBM0112000823, 835, 842, 843, 865, 867

2) Occurrence of the fossil fern fronds

The sediments of the locality are composed mainly of silt and sand intercalated with two exposed volcanic ash layers, the Komazuki and Hazama ash layers (Fig. 2, Tamura *et al*., 1977; Kawabe, 1981). They dip roughly to the northwest at an angle of 23 to 25 degrees. The Hazama ash layer consists of two units ; the lower part comprises of a massive bedded, ash fall deposit, and the upper part comprises of a tuffaceous silty-ash flow deposit. The horizon of the fossil fern bed is situated within the massive tuffaceous peaty silt just below the basal part of the Hazama ash layer.

Fossil fern fronds are contained in the top part of the massive tuffaceous peaty silt. The ferns are in an excellent state of preservation as evidenced by the fact that they are not lacking any pinnules or pinnae (Fig. 3). The roots of the ferns were not found. Many rachises are orientated in a similar direction on the bedding planes. There are almost no fragments of other leaves except for fern fronds and monocotyledonous leaves. The average density of fossil fern fronds on the sedimentary plane was about one fossil frond per 100 cm$^2$. The fronds recovered were partly covered by sediment, which was removed to allow study. The fronds were not flattened but retained their original three dimensional states, with example of fronds overlapping each other and fronds with a crinkled texture.

3) Seed plant macrofossil recovered with the fern fronds

In the plant macrofossils of the massive tuffaceous peaty silt, four angiospermae were identified in addition to the three fern taxa ; *Thelypteris* cf. *T. palustris*, *Onoclea* cf. *O. sensibilis* var. *interrupta*, and Polypodiales (Table 2; Fig. 8). The plant macrofossils assemblage consisted of only a few taxa including a leaf of *Aristolochia*, which is herbaceous liane plant. Many leaves of monocotyledonous Cyperaceae, a typical wetland plant, occurred next to the fern fronds. While a fossil leaf of *Ilex* was identified representing broadleaf-trees, conifer fossils were not found. Additionally,

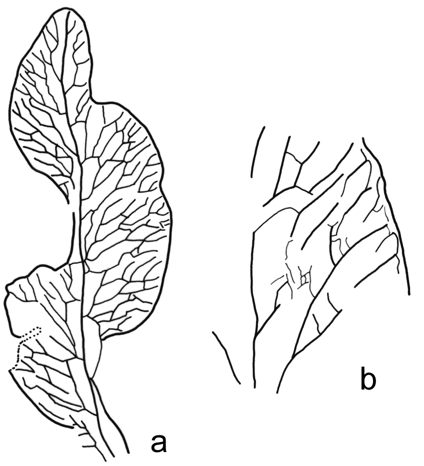


Fig. 6. Illustration of fossil *Onoclea* cf. *O. sensibilis* var. *interrupta*. a : pinna margin is smooth entire, and vein leaving pinna rachis at angle of 30° to 40°, branching dichotomously three or four times, joining neighbor veins and forming regular pentagonal netted venation. b : marginal ultimate veins ending in loops.

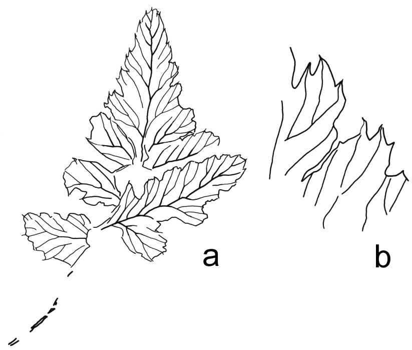


Fig. 7. Illustration of fossil Polypodiales. a : midvein dividing into two to three pairs at the basal part of pinnules, branching dichotomously and zigzagging at the apical part, and lateral vein dichotomously branching one to three times. b : lateral vein reaching to serrate margin, with free vein ending type.

fossil fruit of *Acer* occurred with the other fossil leaves.

## Discussion - paleoecology of the fossil ferns.

Generally plants that have thin leaves, such as herbs and aquatic-plants, or fern fronds, don't readily fossilize. However, plants growing in wetlands are commonly preserved as fossils, because they are deposited underwater in sediments low or absent in oxygen. Some types of fossil ferns that grew in wetlands are recognized at certain horizons, for example, *Equisetum* is often found *in situ* at certain horizon in the Eocene, Oligocene, and Miocene in Japan (Uemura *et al*., 1999; Yamamoto and Yonesaka, 1999), as are found of the water fern *Salvinia* (Suzuki, 1961; Ina, 1992). However, fossil fern fronds are rarely included in plant macrofossil assemblages deposited in marsh and swamp environments during the Pliocene to Pleistocene in Japan.

In this study, three fossil fern fronds were recovered from the tuffaceous peaty silt layers under the Hazama ash layer. The Hazama ash layer consists of two units ; the lower part is a massive bedded, ash fall deposit, and the upper part is a tuffaceous silt- ash flow deposit. The basal part of the ash fall deposit covered the tuffaceous peaty silt containing the fossil fern fronds. Although the preserved fronds are partly drift-covered by sediment, they are not intermingled with many other plants, such as conifers or broad-leaves trees. The fern fronts are good preserved and high frequency of the occurrence. Therefore, the preservation of fern fronds is autochthonous, or nearby the original habitat of the ferns. It was possible no forest consists of conifers and broad-leaves trees around the depositional area. This indicates that the depositional environment was a stagnant water body, such as a marsh or swamp, a scenario supported by the presence of the wetland plant Cyperaceae. Because the lianoid *Aristolochia* grows in the riverbank, it is suggested that the environment of depositional area is the back-marsh or swamp nearly a river. This corresponds to the habitat of extant species of these genera. *Thelypteris* and *Onoclea*, which grow in is sunny and open flat areas around marshes or swamps (Iwatsuki, 1992). Therefore, the fossil ferns of *Thelypteris* and *Onoclea* were probably growing in an open flat area around a swamp and marsh, and were buried *in situ* by a tuffaceous silty-ash flow deposit.

The fossil plant assemblage from the early Pleistocene Kobiwako Group consists of conifers, broadleaf trees and herbs, such as *Pinus*, *Picea*,

Table 2. List of plant macrofossils recovered with the fern fronds from the bed of the Yasu River in Minakuchi, Shiga Prefecture.

| Fossil Plants | Part |
|---|---|
| Polypodiales | |
| *Thelypteris* cf. *T. palustris* (Salisb.) Schott | frond |
| *Onoclea* cf. *O.* sensibilis L. var. *interrupta* Maxim. | frond |
| Polypodiales fam., gen. *et* sp. *indet*. | frond |
| | |
| Angiospermae | |
| Cyperaceae | leaf |
| *Acer* sp. | seed |
| *Ilex* sp. | leaf |
| *Aristolochia debilis* Sieb. *et* Zucc. | leaf |

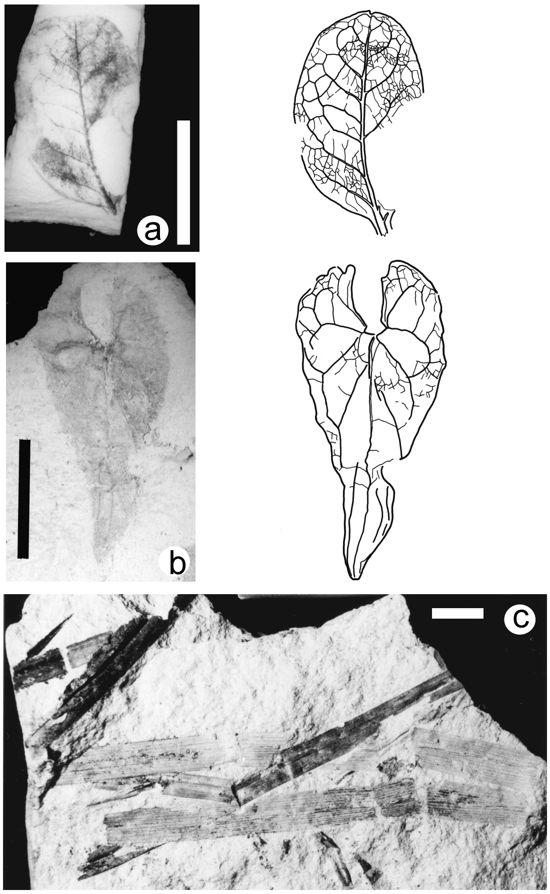


Fig. 8. Photographs and illustrations of plant macrofossils recovered with the fern fronds. Scale bar is 1 cm, a : *Ilex* sp., b : *Aristolochia* sp., C : Cyperaceae.

*Metasequoia*, *Glyptostrobus*, *Cunninghamia*, *Salix*, *Juglans*, *Alnus*, *Quercus*, *Liquidambar*, *Acer*, *Cyperus*, *Scirpus*, *Polygonum* and *Trapa* (Kobiwako Research Group, 1977; Kida, 1997). A wetland forest dominated by *Metasequoia*, *Glyptostrobus* and *Alnus* with the herbaceous *Cyperus* and *Scirpus*, was present in and around marshes and swamps (Yamakawa *et al*., 2008). Fossil fern are not found in these assemblages, but it seems probable that ferns were growing in and around the wetland forest floor.


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