

Middle Miocene Plants from Marine Sediments in Tatsugoroshi of Hitachiota, Ibaraki Prefecture, Japan

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Abstract Plant megafossils from the early Middle Miocene marine sediments in Tatsugoroshi of Hitachiota, north-central part of Ibaraki Prefecture are described. The plant-bearing siltstone and sandstone beds are in the Tatsukuroiso Mudstone Member of the Higashikanasayama Formation, and is assigned to the lower part of the *Denticulopsis lauta* zone in the diatom biostratigraphy. Total 17 types of plant megafossils are briefly described, and floral characters of the Tatsukuroiso assemblage are compared with the Daijima-type floras of late Early and earliest Middle Miocene. The assemblage has some common elements to the Daijima-type floras, but unusually includes many leaves of *Fagus antipofii*. Co-occurred marine molluscs, echinoid and siliceous sponge indicate the Tatsukuroiso Mudstone Member has deposited in relatively deep-sea environments. The Tatsugoroshi plant megafossil assemblage represents one of the plant taphocoenosis examples preserved in marine sediments.

Key words: Plant megafossils, Middle Miocene, marine sediments, taphonomy, Ibaraki Prefecture.

Introduction

Miocene marine sediments in Japan frequently contain terrestrial plant megafossils. These fossil plants provide important additions to the Miocene floras of Japan, because they are well-constrained bio- and chronostratigraphically by marine invertebrates and microfossils. In addition, these plant megafossils play a certain role for the palynostratigraphy of marine sediments, in inferring the taxonomy of source plants and vegetations. Apart from these points of view, plant megafossils in marine sediments are the subject for various taphonomic processes of terrestrial plants. However, studies on the plant megafossils from marine sediments have been insufficiently made in Japan, except for preliminary accounts by Uemura and Yasuno (1991), Yabe (1999), Uemura (2004), and others.

In this paper, we describe the Middle Miocene

plant megafossils preserved in deep-sea sediments from Tatsugoroshi of Hitachiota City (former Suifu-mura), north-central part of Ibaraki Prefecture. Although the plant megafossil collection is small in size, these fossil plants present some aspects on an early Middle Miocene flora and vegetation in Japan, and on plant taphocoenosis.

Geological Setting

Miocene clastic and volcanoclastic rocks widely crop out in the north-central part of Ibaraki Prefecture. The geology and stratigraphy in this area have been studied by Otsuki (1975), Amano *et al.* (1989) and Yoshioka *et al.* (2001). Plant megafossils are found from the Tatsukuroiso Mudstone Member of the Higashikanasayama (Conglomerate) Formation (Otsuki, 1975). Although Otsuki (1975) proposed this Member

with the type section at “Tatsukuroiso”, the correct geographic name of “Tatsukuroiso” is Tatsugoroshi (Amano & Takahashi, 1984). In the following lines, we use Tatsukuroiso in reference to the stratigraphic unit, and Tatsugoroshi to geographic name.

The Higashikanasayama Formation consists of thick, poorly sorted conglomerate beds showing fan delta deposits (Amano *et al.*, 1989; Yoshioka *et al.*, 2001), and crops out in the Tanakura Shear Zone, a major tectonic belt in Japan being bounded by the pre-Tertiary basement provenance.

The Tatsukuroiso Mudstone Member is made up mainly of siltstone, with intercalated fine- to coarse-grained sandstone and conglomerate beds. It grades laterally to the Higashikanasayama (Conglomerate) Formation. Maximum thickness of the Member attains up to 300 m (Y. Kikuchi, unpublished data). Marine fossils contained in this Member are diatoms, molluscs such as *Solemya tokunagai* and *Delectopecten peckhami*, and echinoid of *Pourtalesia* (Kikuchi and Nikaido, 1986). Furthermore, fossil siliceous sponge of uncertain affinity, *Makiyama chitanii*, is common in siltstone.

Plant megafossils are collected from the middle part of the Tatsukuroiso Mudstone Member at Tatsugoroshi (Fig. 1). They are scattered in bedded or massive, whitish-yellow to whitish gray, bioturbated tuffaceous siltstone. Thin

lenticular sandstones are interbedded with siltstones. Biotite crystals are common in the matrix of siltstone and sandstone. Many leaves, shoots, and fruits, together with small wood fragments, are preserved in parallel to the bedding plane. Occasionally, these plant organs are also preserved obliquely or perpendicular to the bedding plane. Preservation of plant megafossils is moderate in siltstones being visible in tertiary venation of the leaves, and very poor in sandstones. Beside of identifiable plants, many fragmented leaves with supposedly thin texture are present.

Otsuki (1975) reported a diatom assemblage of the *Denticulopsis lauta* Zone of Koizumi (1973) from the Tatsukuroiso Mudstone Member without giving any detail of the assemblage. The diatom assemblage, detected from the siltstone matrix of the plant megafossil specimen from Tatsugoroshi, is assigned to the lower part of *Denticulopsis lauta* Zone of Akiba (1986), indicating early Middle Miocene in age (see Appendices).

Taxonomic Composition

Among the 56 identifiable plant megafossils, we recognize 17 types of plant megafossils in the Tatsukuroiso Mudstone Member. The majority of species are dicotyledonous angiosperms. Gymnosperms are represented by six types of conifers, but no ferns and monocotyledons were recovered. All the specimens are kept in the Pale-

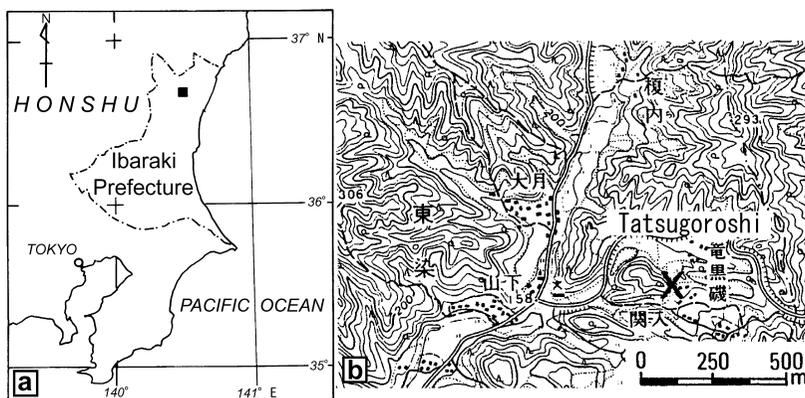


Fig. 1. Map showing the location of Tatsukuroiso in the north-central part of Ibaraki Prefecture (a), and fossil plant locality (b; base map adopted ‘Machiya’, scale 1 : 25,000, Geographical Survey Institute of Japan).

obotanical Collections, National Science Museum, Tokyo (NSM-PP).

Family Pinaceae

Pinus sp. cf. *P. oishii* Ishida

(Fig. 2B–E)

Compare: *Pinus oishii* Ishida, 1970. Mem. Fac. Sci., Kyoto Univ., ser. Geol. Miner., 37, p. 62, pl. 1, figs. 17, 18; pl. 2, figs. 1, 2.

Two *Pinus* species of two-needled type have been recorded from the Miocene of Japan: *Pinus miocenica* Tanai and *P. oishii* Ishida. From Tatsugoroshi three fragmentary needle leaves, one disarticulated winged seed, one male cone and one twig with marks of detached fascicles are recognized. The needle leaves are fragmentary, but their width exceeds 1 mm, probably indicating long and narrow leaves like *Pinus oishii*. Combined with features and size in both the winged seed and the male cone, present specimens are compared with this species.

Pinus oishii and *P. miocenica* are common in the Daijima-type floras of late Early to earliest Middle Miocene age and in Middle Miocene shallow marine sediments of Japan. *P. oishii* is distinct from two modern species in Japan, *P. densiflora* Sieb. et Zucc. and *P. thunbergii* Parlatore (Ishida, 1970).

Collection: NSM-PP 11516–11519.

cf. *Picea* sp.

(Fig. 2I)

A single cone, 7.5 cm long (estimated) and 2.0 cm wide, probably represents that of *Picea*, judging from the persistent nature of cone-scales which abruptly curving up in the longitudinal section. As this specimen represents the inner mold, more details of cone-scales are not visible.

Collection: NSM-PP 11520.

Family Taxodiaceae

Cryptomeria sp.

(Fig. 2F)

A single leafy shoot is similar to shoots of *Taiwania*, which also recognized from Tatsugoroshi. However, it is referred to the genus *Cryptomeria* in blunt apex and incurved nature of the leaves.

The genus *Cryptomeria* is common in the Late Miocene and younger age in Japan, but rare in the Middle Miocene.

Collection: NSM-PP 11514.

Cunninghamia protokonishii Tanai et Onoe

(Fig. 2G, H)

Cunninghamia protokonishii Tanai et Onoe, 1961. Rep. Geol. Surv. Japan, (187), p. 18, pl. 1, fig. 1.

Four shoots and one detached leaves are recognized. Spirally arranged leaves are flattened, having low, minute, blunt teeth in leaf margin. This species is common throughout the Neogene Tertiary in Japan, though it is not abundant in the numerical occurrence in each fossil assemblage.

Collection: NSM-PP 11521, 11522, 11543.

Taiwania japonica Tanai et Onoe

(Fig. 2J, 4F)

Taiwania japonica Tanai et Onoe, 1961. Rep. Geol. Surv. Japan, (187), p. 19, pl. 1, fig. 4.

Four leafy shoots having long triangular leaves are recognized. Some leafy shoots of *Taiwania*, especially those produced in younger trees, are similar to those of *Cryptomeria*. Leafy shoots produced in mature trees, however, are easily distinguished from *Cryptomeria* even in the gross morphological features.

Collection: NSM-PP 11523, 11524, 11525a.

Family Cupressaceae

Thuja nipponica Tanai et Onoe

(Fig. 2A)

Thuja nipponica Tanai et Onoe, 1961. Rep. Geol. Surv. Japan, (187), p. 19, pl. 1, figs. 11a, b. — Huzioka & Uemura, 1972. Bull. Natn. Sci. Mus., Tokyo, 16, p. 703, pl. 3, figs. 12–14 (see supplementary description).

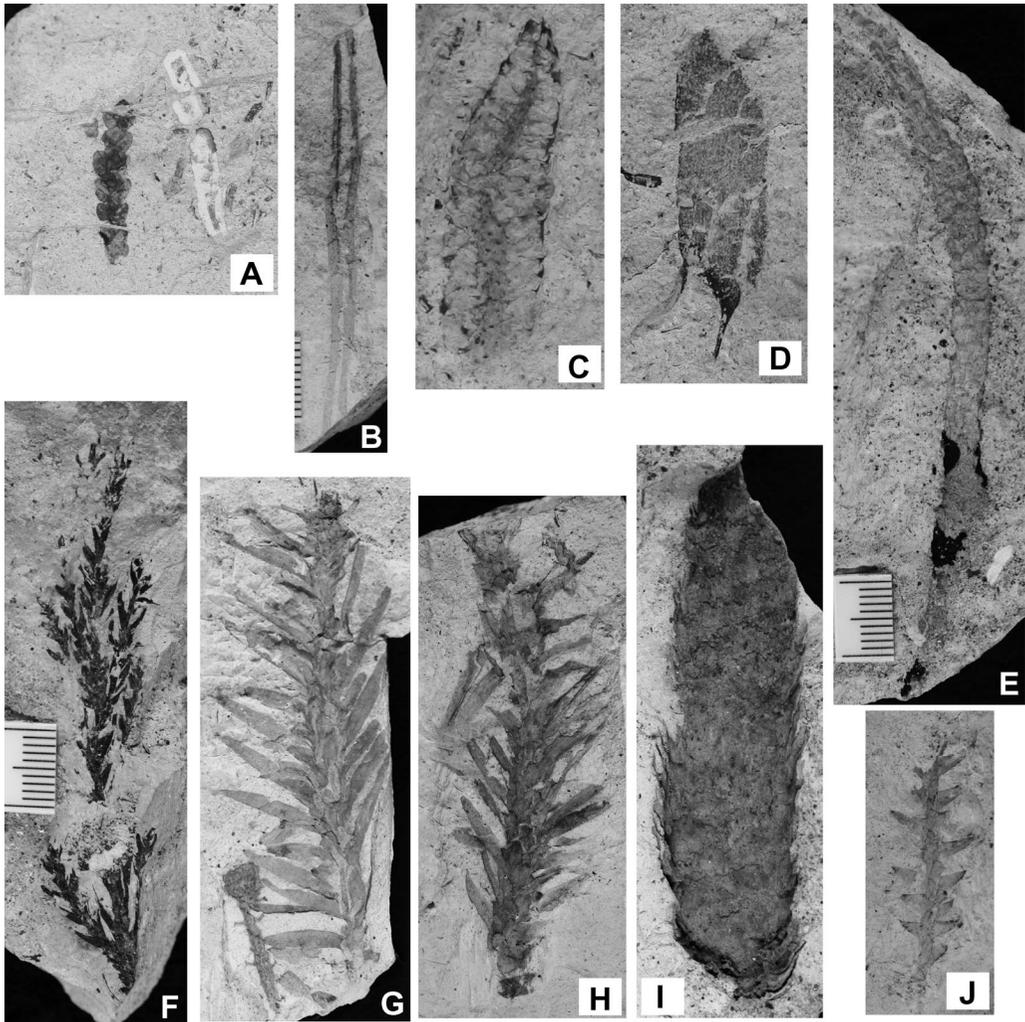


Fig. 2. Fossil conifers. **A**, *Thuja nipponica* Tanai et Onoe, NSM-PP 11526, note white, fragmented tube-like siliceous sponge of Makiyama, $\times 2$. **B**, *Pinus* sp. (two-needled type), NSM-PP 11516. **C**, *Pinus* sp. (pollen cone), NSM-PP 11518, $\times 2$. **D**, *Pinus* sp. (winged seed), NSM-PP 11517, $\times 2$. **E**, *Pinus* sp. (twig), NSM-PP 11519. **F**, *Cryptomeria* sp., NSM-PP 11514. **G**, **H**, *Cunninghamia protokonishii* Tanai et Onoe, NSM-PP 11522, 11521. **I**, Pinaceae cone, NSM-PP 11520. **J**, *Taiwania japonica* Tanai et Onoe, NSM-PP 11523. (All figures in natural size unless otherwise indicated).

A single fragmentary shoot is referred to this species, which is also common throughout the Neogene Tertiary, as is the case of *Cunninghamia protokonishii*.

Collection: NSM-PP 11526.

Family Lauraceae

Cinnamomum lanceolatum (Unger) Heer

(Fig. 3A)

Cinnamomum lanceolatum (Unger) Heer, 1856.

Fl. Tert. Herv., 2, p. 86, pl. 93, figs. 6–11. — Huzioka, 1963. Tert. Fl. Japan, 1, p. 201, pl. 33, figs. 6–8.

One nearly complete and an incomplete lance-

olate leaves have the supra-basal tri-veins. Although this species is a form species having *Cin-namophyllum* type leaves in the Lauraceae, it is one of the representative elements of the Daijima-type floras of late Early to earliest Middle Miocene age in Japan.

Collection: NSM-PP 11525b, 11528.

Family Ulmaceae

Ulmus longifolia Unger

(Fig. 3C, D)

Ulmus longifolia Unger, 1847. Chlor. Prot., p. 101, pl. 26, figs. 5, 6. —Huzioka, 1963, Tert. Fl. Japan, 1, p. 199, pl. 32, figs. 6, 7.

Two leaves showing a stout primary and secondary veins, with doubly or often simply serrated margin. This European species is well represented in the Miocene floras of Japan, but future revisions, including both leaves and samaras, are needed. Although described throughout the Miocene of Japan, this species is commonly found in the Daijima-type floras.

Collection: NSM-PP 11541a, b.

Family Fagaceae

Fagus antipofii Heer

(Figs. 4A, C, D)

Fagus antipofii Heer, in Abich, 1859. Mem. Acad. Imp. Sci. St.-Petersbourg, 6th ser., 9, p. 527, pl. 8, fig. 2. —Huzioka, 1964, p. 78, pl. 8, figs. 5–7. —Tanai, 1974. Birbal Sahni Inst. Palaeobot. Spec. Publ., (1), p. 66, pl. 3, figs. 1–6; p. 74.

This species was originally described by Heer from the Oligocene of Kirgiz Steppe in Kazakhstan, and has subsequently been reported from many localities in so-called Arctic regions, and central and eastern Asia. These leaves attributed to this species have commonly obtuse craspedodromous teeth, the feature differing from the Heer's original specimen. Although the revision is needed, we identified the fossil leaves from Tatsugoroshi to this species, following Huzioka (1964) and Tanai (1974).

In Honshu of Japan, this species is common or abundant in the Aniai-type floras of early Early Miocene age, while it is rare or absent in the Daijima-type floras of late Early to earliest Middle Miocene age. In the northward areas, such as Hokkaido and Sakhalin, this species is common in the late Early to early Middle Miocene. This species is sporadically reported from marine Middle Miocene sediments in Honshu (Uemura, 2004; Uemura & Yasuno, 1991).

Collection: NSM-PP 11530b, 11532-11536, 11540, 11549.

Fagus ? sp.

(Fig. 3G)

A cupule-like fruit with incomplete stalk, 9 mm long and 6 mm wide, shows the inner mold. This fruit perhaps represents *Fagus* in having cupule valves, but further details like appendages (prickles) on the cupule valve are unrecognized.

Collection: NSM-PP 11545.

cf. *Pasania* sp.

(Fig. 3B)

A single incomplete, entire-margined leaf is similar to evergreen members of the Fagaceae, in having thick primary and secondary veins, short to medium intersecondary veins, thick tertiary veins perpendicular to the secondaries, and thick petiole. Such venational features are most likely to the leaves produced by *Pasania*.

Collection: NSM-PP 11531.

Family Betulaceae

Carpinus sp.

(Fig. 3F)

Five incomplete leaves are referred to *Carpinus* in these features: craspedodromous venation, compound teeth with usually two subsidiaries, and sharp narrow-triangular teeth shape (concave-convex) with a centrally running tertiary vein.

Collection: NSM-PP 11529, 11530a.

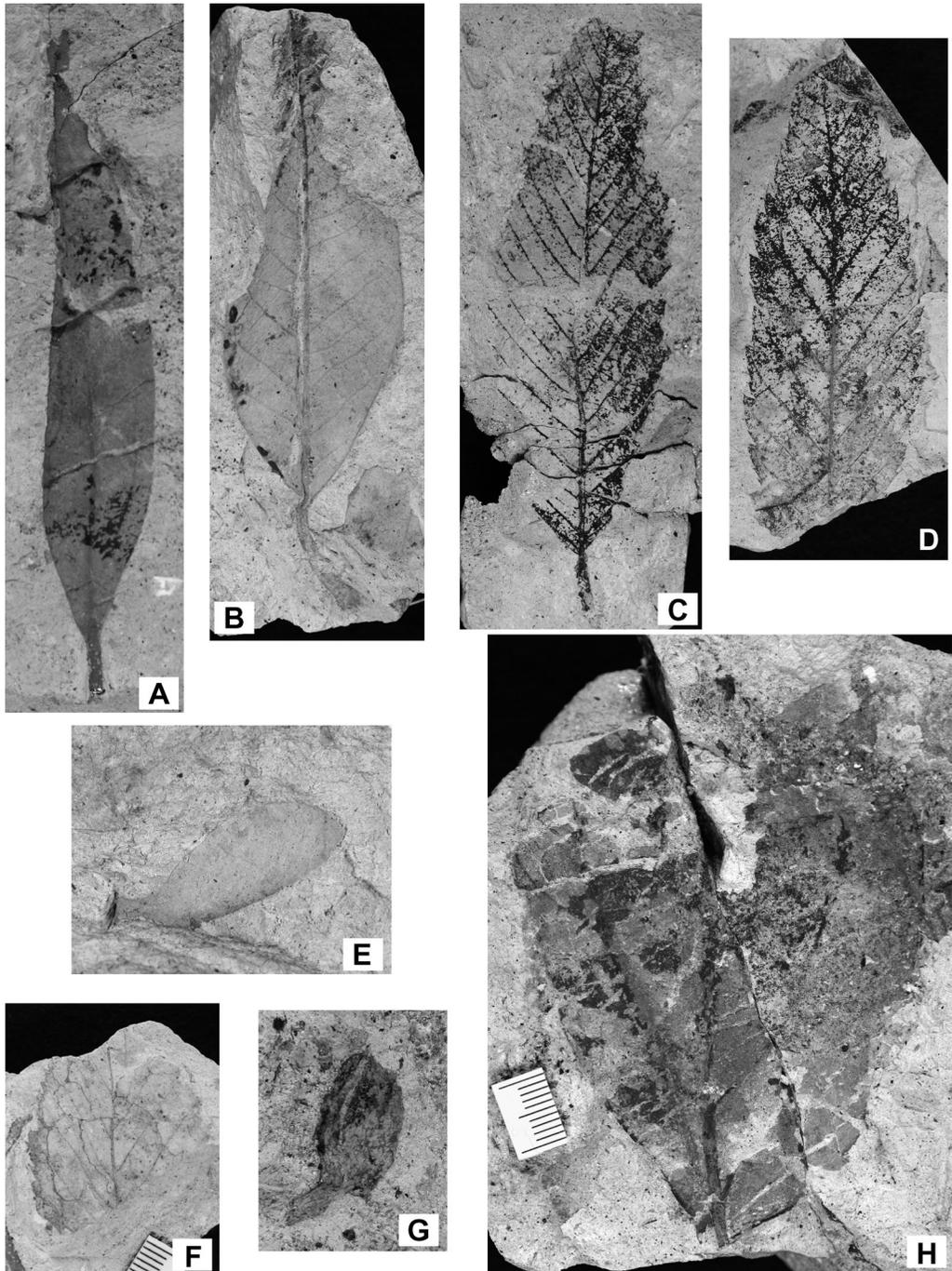


Fig. 3. Fossil angiosperm leaves and fruits. **A**, *Cinnamomum lanceolatum* (Unger) Heer, NSM-PP 11528. **B**, *Pasania* sp., NSM-PP 11531. **C**, **D**, *Ulmus longifolia* Unger, NSM-PP 11541a, b. **E**, *Acer* sp. (samara), NSM-PP 11527, $\times 2$. **F**, *Carpinus* sp., NSM-PP 11530a. **G**, *Fagus* ? sp. (cupule), NSM-PP 11545. **H**, *Dicotyophyllum* sp. (*Mucuna* ?), NSM-PP 10544. (All figures in natural size, unless otherwise indicated).

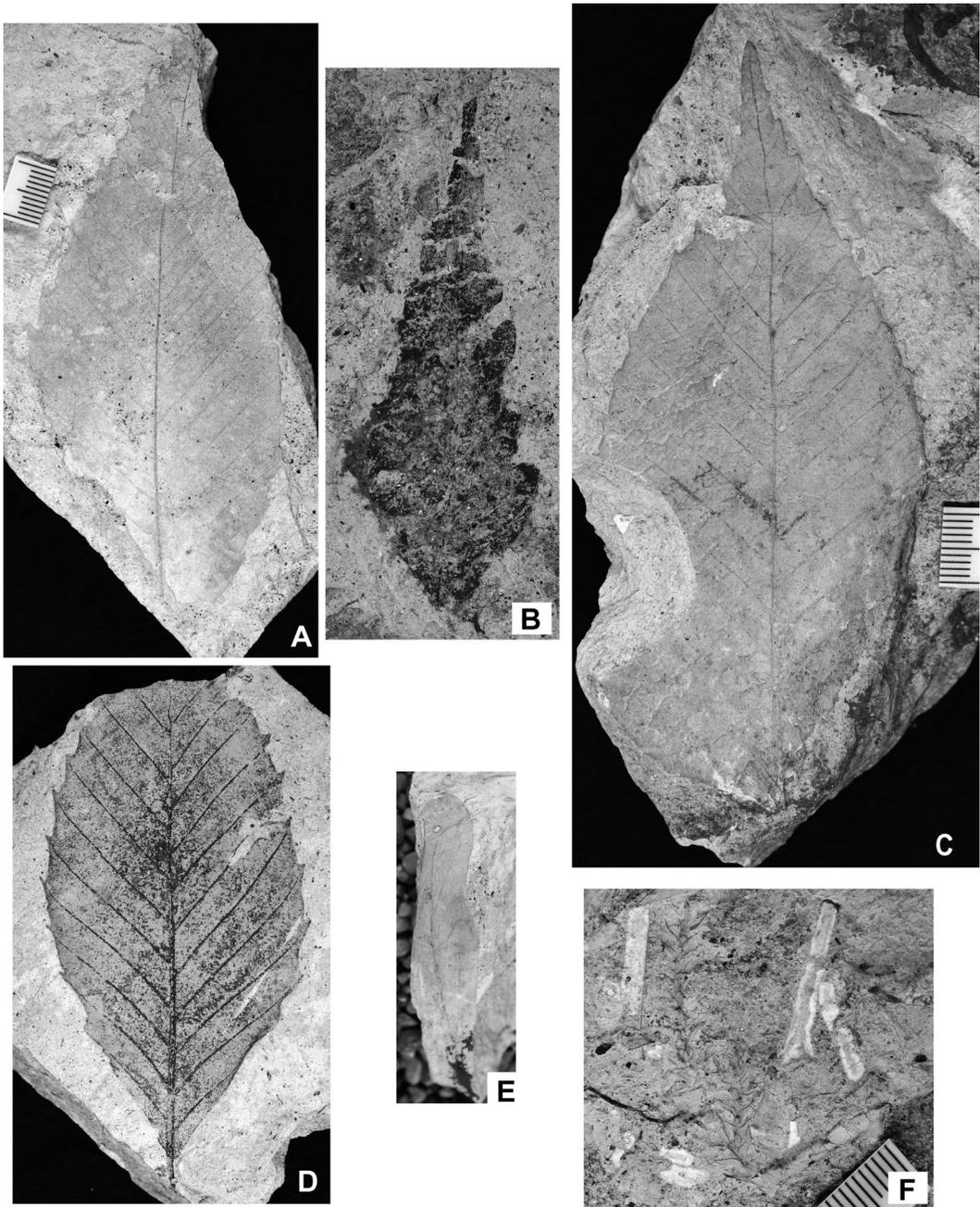


Fig. 4. Fossil angiosperm leaves and coniferous shoot. **A, C, D**, *Fagus antipofii* Heer, NSM-PP 11533, 11532, 11540; **A**, $\times 0.8$. **B**, *Dicotylophyllum* sp. (Sapindaceae ?), NSM-PP 11546. **E**, *Dicotylophyllum* sp. (*Daphne* ?). **F**, *Taiwania japonica* Tanai et Onoe, note fragments of sponge of *Makiyama*, NSM-PP 11525, $\times 1.3$. (All figures in natural size unless otherwise indicated).

Family Leguminosae

cf. *Cladrastis* sp.

A single incomplete, entire-margined specimen (lacking upper part) perhaps represents a legume leaflet in having inequilateral outline and thick and short petiolule with many perpendicular grooves. In general venation features, it is similar to *Wisteria* and *Cladrastis*, the latter more likely in having numerous secondary veins.

Collection: NSM-PP 11538.

Family Aceraceae

Acer sp.

(Fig. 3E)

A single samara, though lacking the attachment scar and some part of nutlet, is similar to that of section *Macrantha* of *Acer* in the nutlet-wing attachment and supposed globose nutlet.

Collection: NSM-PP 11527

Dicotyledonae (Magnoliidae) incertae sedis

Beside above noted species, there are, at least, three other types of dicotyledonous angiosperms. They are too poor in preservation to give a taxonomic account. Because they contribute to the floral and paleoclimatic interpretations, we only list their presence in the assemblage.

Dicotylophyllum sp. (*Daphne* ?) (Fig. 4E). *Collection*: NSM-PP 11539.

Dicotylophyllum sp. (cf. Sapindaceae) (Fig. 4B). *Collection*: NSM-PP 11546.

Dicotylophyllum sp. (*Mucuna* ?) (Fig. 3H). *Collection*: NSM-PP 11544.

Comparison with the Daijima-type floras

In Japan and its surrounding areas, the Daijima-type floras of late Early to earliest Middle Miocene age are widely known (Tanai, 1961, 1992). These Daijima-type floras include many warm-temperate and some subtropical genera. In the western and northwestern areas contiguous to Tatsugoroshi, namely, west to the Tanakura Shear Zone, the Daijima-type floras have been known

(Nathorst, 1888; Tanai, 1961; Horiuchi, 1996; Horiuchi & Takimoto, 2001). These floras come from fluvio-lacustrine deposits of the Kitatake and Asakawa formations. The floras from both formations contain such characteristic plants in the Daijima-type floras as *Liquidambar miosinica*, *Comptonia naumanni*, *Parrotia pristina*, *Podogonium* and *Paliurus*. However, they include less numbers of evergreen dicots compared with other Daijima-type floras.

The Tatsugoroshi assemblage from the Tatsukuroiso Mudstone Member contains *Cinnamomum lanceolatum*, *Pinus oishii* and cf. *Pasania* sp., which are common to the Daijima-type floras. However, the assemblage lacks many representative elements of the Daijima-type floras. On the other hand, the abundant occurrence of *Fagus antipofii* in the Tatsugoroshi assemblage is worthy to note. The species is one of the common elements in the Aniai-type floras of early Early Miocene age, which represent more cool temperate genera composed mainly of diverse deciduous dicots.

Non-marine beds containing the Daijima-type floras are conformably overlain by shallow marine beds in many localities of Japan, which contain a warm molluscan fauna called as the Arcid-Potamid Fauna or the Kadonosawa Fauna (Noda, 1973; Chinzei, 1986; Ogasawara, 1994). Such fauna was reported from the upper part of the Asakawa Formation and its equivalent formations in the western and northwestern areas to Tatsugoroshi (Noda *et al.*, 1994). As the Tatsukuroiso Mudstone Member is nearly correlative with the Arcid-Potamid Fauna bearing formations, the difference in the floral composition between the Tatsugoroshi assemblage and the Daijima-type floras in the Asakawa and more older Kitatake formations is due largely to different manner in deposition and taphonomic process.

Depositional Environment and Vegetation

Plant-bearing siltstone and sandstone beds of the Tatsukuroiso Mudstone Member grade laterally into the fan delta deposits of the Hi-

gashikanasayawa Formation. Kikuchi and Nikaido (1985) recovered an abyssal echinoid of *Pourtalesia*, together with offshore molluscan fossils of poor diversity and siliceous sponge of *Makiyama*. As Kikuchi and Nikaido (1985) pointed out, plant-bearing beds have accumulated in relatively deep-sea environment. Overall fan deltaic conglomerates of the Higashikanasayama Formation may indicate that the Tatsukuroiso Mudstone Member have deposited in a deep sea fan delta environment.

The plant megafossil assemblage from Tatsugoroshi is allochthonous, and all plant organs were transported into marine depositional site. The assemblage is rich in conifers. All of six types of conifer are evergreen, and their shoots or cone have a persistent texture. Among the dicotyledonous angiosperms, *Acer* is a fruit with wing (samara) and remaining 10 types are leaf or leaflet remains. Two genera (*Cinnamomum* and *Pasania*) are evergreen, and two of *Dicotylophylum* (cf. *Daphe*? and cf. Leguminosae?) have a thick texture. Several deciduous leaves of the Tatsugoroshi assemblage, such as *Ulmus* and *Fagus*, have a relatively resistant texture. The above evidence, however, does not mean that only resistant plant organs have been preserved in sediments, because there are *Carpinus*, cf. *Cladrastis* and many unidentifiable leaf fragments with thin texture.

Suggested paleogeographic reconstruction in and around the Tanakura Shear Zone (Amano *et al.*, 1989; Y. Kikuchi unpublished data) indicate that most of plant organs of the Tatsugoroshi assemblage have not received a long-distance transportation from source vegetation(s) into the depositional site. A rare occurrence of freshwater diatoms (see appendix) may suggest the absence of a large and long river system at the time of deposition. Although the Tatsugoroshi assemblage represents one of the complex plant taphonocoenoses, two-needled *Pinus*-rich nearby coastal stands were probably present on account of common leaf occurrence associated by other organs, such as male cone, winged seed and twig. The fact that the two-needled *Pinus* is more com-

mon in the marine formations with the Arcid-Potamid Fauna (Shicchi *et al.*, 2001; Uemura unpublished data) is consistent with this interpretation. Regarding the unusual and abundant occurrence of *Fagus antipofii*, it is premature to assume its inhabitance.

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References

- Akiba, F., 1986. Middle Miocene to Quaternary diatom biostratigraphy in the Nankai Trough and Japan Trench, and modified Lower Miocene through Quaternary diatom zones for middle-to-high latitudes of the North Pacific. *In*, Kagami, H. *et al.*, Initial Rep. DSDP, **87**: 393–481.
- Amano, K. & H. Takahashi, 1984. [Tertiary Geology around Tanakura Shear Zone]. *In*, [Geological and Geophysical Research on Tanakura Shear Zone], pp. 6–9. Dept. Earth Sci., Fac. Sci., Ibaraki Univ., Mito. (In Japanese.)
- Amano, K., S. Koshiya, H. Takahashi, H. Noda & K. Yagishita, 1989. Tectonics and sedimentation in Tanakura Shear Zone. *In*, Excursion Guidebook, 96th Ann. Meet. Geol. Soc. Japan, pp. 55–86, pl. 1. Geol. Soc. Japan, Tokyo. (In Japanese.)
- Chinzei, K., 1986. Faunal succession and geographic distribution of Neogene molluscan faunas in Japan. *Palaeont. Soc. Japan, Spec. Pap.*, (29): 17–32.
- Horiuchi, J., 1996. Neogene floras of the Kanto District. *Sci. Rep. Inst. Geosci., Univ. Tsukuba*, sec. B, **17**: 109–208.
- Horiuchi, J. & H. Takimoto, 2001. Plant mega-fossils from the late Early to early Middle Miocene Asakawa Formation at Inuboe Pass, Ibaraki Prefecture, Kanto District, Japan. *Bull. Ibaraki Nat. Mus.*, (4): 1–32, pls. 1–10.
- Huzioka, K., 1964. The Aniai flora of Akita Prefecture, and the Aniai-type floras in Honshu, Japan. *J. Mining Coll. Akita Univ.*, ser. A, **3**(4): 1–105, pls. 1–18.

- Ishida, S., 1970. The Noroshi flora of Noto Peninsula, central Japan. *Mem. Fac. Sci., Kyoto Univ.*, ser. Geol. Miner., **37**: 1–112, pls. 1–22.
- Kikuchi, Y. & A. Nikaido, 1985. The first occurrence of abyssal echinoid *Pourtalesia* from the Middle Miocene Tatsukuroiso Mudstone in Ibaraki Prefecture, north-eastern Honshu, Japan. *Ann. Rep. Inst. Geosci., Univ. Tsukuba*, (11): 32–34.
- Koizumi, I., 1973. The stratigraphic ranges of marine planktonic diatoms and diatom biostratigraphy in Japan. *Geol. Soc. Japan Mem.*, (8): 35–44.
- Nathorst, A. G., 1888. Zur fossilen Flora Japan's. *Palaeont. Abh.*, **4**: 197–250, pls. 17–30.
- Noda, H., 1973. Geological significance of *Anadara (Hataiarca) kakehataensis* Hatai and Nisiyama in the Arcid-Potamid Fauna in Japan. *Sci. Rep. Tohoku Univ.*, 2nd ser., Spec. Vol., (6): 205–215, pl. 18.
- Noda, H., Y. Kikuchi & A. Nikaido, 1994. Middle Miocene molluscan fauna from the Tamagawa Formation in Ibaraki Prefecture, northern Kanto, Japan—Arcid-Potamid Fauna in the Tanakura Tectonic Zone. *Sci. Rep., Inst. Geosci., Univ. Tsukuba*, sec. B, **15**: 81–102.
- Ogasawara, K., 1994. Neogene paleogeography and marine climate of the Japanese Islands based on shallow-marine molluscs. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, **108**: 335–351.
- Otsuki, K., 1975. Geology of the Tanakura Shear Zone and adjacent area. *Contr., Inst. Geol. Paleont., Tohoku Univ.*, (76): 1–71. (In Japanese with English abstract.)
- Shicchi, Y., M. Matsumoto & K. Uemura, 2001. Plant megafossil assemblage from the Nishikurosawa Formation in the southern part of the Oga Peninsula, Akita Prefecture. Abstracts with Programs, 150th Regular Meeting, Palaeont. Soc. Japan, 2001: 53. (In Japanese.)
- Tanai, T., 1961. Neogene floral change in Japan. *J. Fac. Sci., Hokkaido Univ.*, ser. 4, **11**: 119–398, pls. 1–32.
- Tanai, T., 1974. Evolutionary trend of the genus *Fagus* around the northern Pacific basin. *Birbal Sahani Inst. Palaeobot., Spec. Publ.*, (1): 62–83, pls. 1–5.
- Tanai, T., 1992. Tertiary vegetational history of East Asia. *Bull. Mizunami Fossil Mus.*, (19): 125–163. (In Japanese with English abstract.)
- Uemura, K. & T. Yasuno, 1991. Miocene plants from the Komegawaki Formation, Fukui Prefecture, Central Japan. In, Prof. S. Miura Mem. Vol., p. 43–54, Commem. Assoc. Prof. S. Miura's Retirement, Fukui. (In Japanese with English abstract.)
- Uemura, K., 2004. Miocene plant megafossils from Nonosawa, Tadami-cho, Fukushima Prefecture. In, Editorial Board of the History of Tadami-cho (ed.), The History of Tadami-cho, Vol. 1, pp. 61–74. Tadami-cho (Fukushima Prefecture). (In Japanese.)
- Yabe, A., 1999. Taphonomy of the plant megafossils from marine bed: Deltaic deposits from the Lower Miocene of Joban Area, Northeast Honshu, Japan. *Mem. Geol. Soc. Japan*, (54): 185–195. (In Japanese with English abstract.)
- Yanagisawa, Y. & F. Akiba, F., 1998. Refined Neogene diatom biostratigraphy for the northwest Pacific around Japan, with an introduction of code numbers for selected diatom biohorizons. *J. Geol. Soc. Japan*, **104**: 395–414.
- Yoshioka, T., F. Takizawa, M. Takahashi, K. Miyazaki, Y. Banno, Y. Yanagisawa, Y. Takahashi, K. Kubo, Y. Seki, M. Komazawa & T. Hiroshima, 2001. Geology of the 1:200,000 Mito Quadrangle. 1 geological map with explanation. Geological Survey of Japan, Tsukuba.

Appendix 1. Diatoms from the Tatsukuroiso Mudstone Member (By Fumio Akiba, Diatom Minilab Ltd., 632–12, Iwasawa, Hanno, Saitama Prefecture, 357–0023 Japan)

As mentioned in the text, Otsuki (1975) reported that the Tatsukuroiso Mudstone Member belongs to the *Denticulopsis lauta* Zone of Koizumi (1973), which was subsequently divided into three zones by Akiba (1986): the *D. praelauta*, the *D. lauta* and the *D. hyalina* zones in ascending order, which range from 16.3 through 13.1 Ma (Yanagisawa & Akiba, 1998). One of the samples of which the fossil plants being reported in this paper was examined, therefore, to clarify more precise age assignment and also depositional environment of the stratum. The sample was processed and diatoms were counted according to the methods of Akiba (1986), and the diatom zonation and ages of the zones and bioevents of diatoms are followed to Akiba (1986) and Yanagisawa and Akiba (1998), respectively.

The sample contained common diatoms, and their preservation was rather poor in that most diatom valves, except for smaller valve of *Denticulopsis* species, were fragmented. The assemblage was characterized by dominances of *Denticulopsis praelauta* (45%) and *Thalassionema nitzschioides* (29%), and includes such rare taxa as *Actinoptychus senarius*, *Coscinodiscus lewsianus* and *Denticulopsis lauta* and others (Appendix 2). The presence of *D. lauta* and the lack of *D. hyalina* indicate the sample can safely be assigned to

the lower Middle Miocene *D. lauta* Zone (NPD4A; 15.9–14.9 Ma), and the occurrence of *D. praelauta* in this sample further restricts its age to be within a very short time interval of 15.9–15.7 Ma, as above the first occurrence of *D. lauta* (D40: 15.9 Ma) and below the last occurrence of *D. praelauta* (D41: 15.7 Ma).

The dominance of pelagic planktonic diatoms

and very little occurrence of either marine benthic or non-marine diatoms in the sample suggest that it was deposited at an offshore deep environment, though the rare occurrences of diatoms of the latter habitats were not expected before the analysis, because probable river currents transporting the plant fossils could add those diatoms to the assemblage.

Appendix 2. Fossil diatoms from the Tatsukuroiso Mudstone Member of the Higashikanasayama formation, Ibaraki Prefecture, Japan.

DIATOM ZONE (NPD code number)		NPD 4A
ABUNDANCE		Common
Approximate number of diatom valves per slide		2400
PRESERVATION		Poor
MARINE DIATOMS		
* p	<i>Actinocyclus ingens</i> Rattray	1
b	<i>A. octonarius</i> Ehenberg	1
p	<i>A.</i> spp.	1
b	<i>Actinoptychus senarius</i> (Ehrenberg) Ehrenberg	5
b	<i>Arachnoidiscus</i> sp.	+
* p	<i>Azpeitia endoi</i> (Kanaya) Sims et Fryxell	1
p	<i>A.</i> sp.	+
* p	<i>Cavitatus linearis</i> (Sheshukova) Akiba et Yanagisawa	+
* p	<i>C. miocenicus</i> (Schrader) Akiba et Yanagisawa	1
b	<i>Cocconeis</i> spp.	+
* p	<i>Coscinodiscus lewsianus</i> Gréville	+
p	<i>C. marginatus</i> Ehrenberg	+
p	<i>C. oculus-iridis</i> Ehrenberg	+
p	<i>C. radiatus</i> Ehrenberg	+
* p	<i>C. symbolophorus</i> Grunow s. l.	+
p	<i>C.</i> spp.	1
* b	<i>Delphineis miocenica</i> (Schrader) Andrews	+
b	<i>D.</i> spp.	+
* p	<i>Denticulopsis lauta</i> (Bailey) Simonsen	3
* p	<i>D. praelauta</i> Akiba et Koizumi	45
b	<i>Grammatophora</i> spp.	+
* p	<i>Hemiaulus</i> cf. <i>polymorphus</i> Grunow	+
b	<i>Isthmia</i> sp.	+
* p	<i>Medialia splendida</i> Sheshukova	2
b	<i>M. sol</i> (Ehrenberg) Kützing	+
b	<i>Paralia sulcata</i> (Ehrenberg) Cleve	+
* b	<i>Rhaphoneis elegans</i> Pantocsek	+
b	<i>R.</i> sp.	1
* p	<i>Rhizosolenia miocenica</i> Schrader	+
p	<i>R.</i> spp.	2
* p	<i>Rouxia</i> sp.	+
p	<i>Stephanopyxis</i> spp.	3
p	<i>Thalassionema nitzschioides</i> (Grunow) H. et M. Peragallo	29
* p	<i>Thalassiosira mizunamiensis</i> Yanagisawa	1
p	<i>Thalassiothrix longissima</i> Cleve et Grunow	+
* p	<i>Trochosira spinosa</i> Kitton	+
NONMARINE DIATOMS		
p	<i>Aulacoseira granulata</i> (Ehrenberg) Simonsen s. l.	+
Total number of diatoms counted		100
Resting spores of <i>Chaetoceros</i>		10
Number of taxa recognized		37

*; extinct, p; planktonic, b; benthic.