Minoru Tsukagoshi[1]: **Recent progress in paleobotanical and geological studies of *Pinus trifolia* flora**

Abstract The Tokiguchi and Seto Porcelain Clay Formations of the Tokai Group that are distributed in central Japan are characterized by the occurrence of *Pinus trifolia* Miki and many exotic, warm temperate taxa with such as the extinct genus *Hemitrapa*. Dr. Shigeru Miki described *P. trifolia* and many fossil species from the flora of these formations along with a new genus, *Metasequoia*. This paper reviews paleobotanical, stratigraphic, and sedimentological research of the porcelain clay formations since Miki's work. The age of *P. trifolia* flora is now correlated to the latest middle Miocene to early late Miocene (10–12 Ma) based on fission track dating of the tephras.
Key words: *Pinus trifolia* flora, Seto Porcelain Clay Formation, Shigeru Miki, Tokiguchi Porcelain Clay Formation

Introduction

Shigeru Miki (1901–1974) is known as a pioneer of late Cenozoic paleobotany and carpology in Japan. In 1941, Dr. Miki established the new genus *Metasequoia* in a paper titled "On the change of flora in Eastern Asia since Tertiary Period (I). The clay or lignite beds flora in Japan with special reference to the *Pinus trifolia* beds in Central Hondo" (Miki, 1941). As indicated by this somewhat long title, the paper mainly describes the flora from *P. trifolia* beds, not merely presenting a description of *Metasequoia*. Here he described species belonging to 37 families and 62 genera including two extinct genera, *Metasequoia* and *Hemitrapa,* from the "*Pinus trifolia* bed" in the Seto and Tokiguchi Porcelain Clay Formations from locations northeast of Nagoya, central Japan. Dr. Miki continued to study the "*P. trifolia* bed" after the publication of his monograph and published a revised floral list of 41 families, 89 genera, and 116 species with some brief taxonomic revisions (Miki, 1963; Table 1).

After Dr. Miki's death in 1974, many Japanese paleobotanists and geologists re-engaged in the study of the flora and geology of the *P. trifolia* bed. The age of the bed that Miki (1941) originally assigned to the lower Pliocene was reexamined using fission track analysis. Additional floral and biostratigraphic research has provided more information on the flora and palaeoenvironment of the *P. trifolia* bed. This paper reviews the progress of the research on the *P. trifolia* beds and their flora following Miki's (1941) establishment of the genus *Metasequoia*.

Pinus trifolia Miki and *P. trifolia* flora

Pinus trifolia Miki (1939) was described from the Seto Porcelain Clay Formation and the Tokiguchi Formation prior to the monograph on the flora of the "*P. trifolia* beds" (Miki, 1941). The genus *Pinus* L. that is distributed throughout Japan includes the two-leaved subgenus *Diploxylon* and the five-leaved *Haploxylon*. *Pinus trifolia* is an extinct pine that has three leaves on each short shoot as the specific epithet suggests. Miki (1939) described and presented many parts of *P. trifolia* including seed cones, pollen cones, leaves, shoots with leaf scars, seeds, and pollen with some important characters of the taxon, phyllotaxis of the cone that includes 8 and 13 conjugated rows, and abscission scars at the base of cone to reconstruct the whole plant and its ecology (Fig. 1). This description represented his idea of paleobotanical research that was based on a whole plant concept and signified the importance of research on the morphology of compression fossils. Based on these characters, he assigned *P. trifolia* to section *Taeda*, including the extant pines in western America such as *Pinus coulteri* D. Don and *P. sabiniana* Dougl. Dr. Miki must have been intrigued by the exotic morphology of *P. trifolia,* which probably induced him to concentrate on the research of the flora of *P. trifolia* beds. Syntypes of *P. trifolia* are now kept in the Osaka Museum of Natural History (Kokawa et al., 2006). Following Miki's (1939) initial description, *P. trifolia* remains have been found from five formations and three groups that extend from the Paleogene to late Miocene (Table 2).

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Table 1 Revised list of the taxa identified in the *Pinus trifolia* beds in the Seto-Tajimi district (Miki, 1963)

Osmundaceae	*Osmunda japonica* Thunb.		*Sapium sebiferm* Roxb. var.
Cephalotaxaceae	*Cephalotaxus biumbonata* Miki	Buxaceae	*Buxus japonica* Muell
Taxodiaceae	*Cunninghamia konishii* Hayata	Anacardiaceae	*Poupartia polymeris* Miki
	Glyptostrobus pensilis Koch.	Rutaceae	*Fagara ailanthoides* Engl.
	Metasequoia japonica (Endo) Miki *1	Meliaceae	*Melia* cf. *japonica* G. Don
	Sequoia sempervirens Endl. *2	Staphyleaceae	*Euscaphis japonica* Kant.
	Sequoiadendron cf. *chaneyi* Axel. *3	Aceraceae	*Acer buergerianum* Miq.
Pinaceae	*Abies* sp.		*Acer diabolicum* Bl.
	Keteleeria davidiana Beiss.		*Acer palmatum* Thunb.
	Keteleeria robusta Miki		*Acer rubrum* L. var.
	Picea koribai Miki	Sabiaceae	*Meliosma radiocosta* Miki
	Picea latibracteata Miki		*Meliosma rigida* S. et Z.
	Pinus armandi Fr.		*Sabia japonica* Miki
	Pinus fujiii (Yasui) Miki	Rhamnaceae	*Berchemia racemosa* S. et Z.
	Pinus trifolia Miki		*Paliurus nipponica* Miki
	Pseudolarix kaempferi Gord.	Vitaceae	*Cayratia megasperm* Miki
	Pseudotsuga subrotunda Miki		*Cayratia orbitalis* Miki
	Tsuga longibracteata Cheng		*Tetrastigma tazimiensis* Miki
	Tsuga oblonga Miki		*Vitis brachypoda* Miki
Salicaceae	*Salix* sp.		*Vitis rabruscoida* Miki
Juglandaceae	*Carya ovatocarpa* Miki		*Vitis rotundata* Miki
	Carya striata Miki	Tiliaceae	*Tilia costata* Miki
	Carya venticosa Unger	Theaceae	*Camellia sasanqua* Thunb.
	Juglans megacinerea Chaney		*Stewartia obovata* Miki
	Pterocarya paliurus Batal		*Schima plioceca* Miki
Betulaceae	*Alnus japonica* S. et Z.	Hydrocaryaceae	*Eotrapa tetrasepala* Miki
	Betula adstigmata Miki		*Hemitrapa trapelloidea* Miki
	Carpinus carpinoides Mak.		*Trapa maximowiczii* Korsh.
	Corylus ligniatus Miki		*Trapa pulvinipoda* Miki
	Ostrya stenocarpa Miki	Lythraceae	*Lagerstroemia* sp.
Fagaceae	*Castanopsis oligospina* Miki	Elaeagnaceae	*Elaeagnus* sp.
	Cyclobalanopsis sp.	Alangiaceae	*Alangium begoniifolium* (Roxb.) Baill.
	Fagus japonicoides Miki		*Alangium macrocarpum* Miki
	Fagus ferruginea Ait.	Nyssaceae	*Nyssa pachycarpa* Miki
	Lithocarpus glabra Nakai		*Nyssa rugosa* Miki
	Quercus chenii Nakai		*Nyssa sylvatica* Marsh.
	Quercus rubroidea Miki		*Paleodavidia multipterium* Miki *4
Ulmaceae	*Zelkova* cf. *ungeri* Kovats.	Cornaceae	*Benthamia japonica* S. et Z.
Nymphaeaceae	*Brasenia schreberi* Gmel.		*Cornus controversa* Hemsl.
	Eoeuryale brasenioides Miki	Ericaceae	*Enkianthus* sp.
	Nuphar akashiensis Miki		*Pieris japonica* Don
Magnoliaceae	*Magnolia salicifolia* Max.		*Rhododendron ovatocarpa* Miki
	Michelia sp.	Styracaceae	*Melliodendron nipponicum* Miki
	Schizandra megasperma Miki		*Rehderodendron elliptica* Miki
Menispermaceae	*Sinomenium acutum* Rehd. et Wils.		*Styrax laevigata* Miki
	Stephania periporosa Miki		*Styrax rugosa* Miki
Lauraceae	*Benzoin citrodorum* S. et Z.		*Styrax obassioidea* Miki
	Benzoin umbellatum Rehd.	Symplocaceae	*Symplocos myrtacea* S. et Z.
	Machilus sp.		*Symplocos lancifolia* S. et Z.
Hamamelidaceae	*Corylopsis* sp.		*Symplocos tricarpa* Miki
	Distylopsis parrotioides Miki	Trapellaceae	*Trapella lissa* Miki
	Fortunearia sinensis Rehd. et Wils.		*Trapella primaria* Miki
	Liquidambar cf. *formosana* Hance	Oleaceae	*Fraxinus japonica* Bl.
Eucomiaceae	*Eucommia ulmoides* Oliv.		*Syringa* sp. ?
Legminosae	*Gleditschia* cf. *macrocantha* Desf.	Caprifoliaceae	*Viburnum japonicum* Sp.
	Wisteria ligniata Miki		*Trichosanthes kirilowii* Max.
Euphorbiaceae	*Aleurites fordioides* Miki	Cusurbitaceae	*Lissopepon melothroidea* Miki
	Mallotus protojaponics Miki	Graminiae	*Bambusoidea nipponica* Miki

*1: *Metasequoia japonica* was listed, but *M. disticha* was not. The reason is unknown. *2: *Sequoia sempervirence* Endl. was transferred to *S. couttisie* Heer by Miki (1965). *3: *Sequoiadendron* cf. *chaneyii* Axel. was transferred to *S. primarium* Miki by Miki (1965). *Sequoiadendron primarium* Miki was transferred to *Protosequoia primaria* (Miki) Miki by Miki (1969). *4: *Paleodavidia multipterium* Miki was transferred to *Melliodendron multistriatum* (Miki) Miki by Miki (1968).

Table 2 Localities and the age of *Pinus trifolia* in Japan

Prefecture	Group and formation	Age	Reference
Saitama	Yagii Formation	late Miocene	Ozaki (1991), Nirei & Akiyama (2008)
Gifu	Toki Sand and Gravel Formation	late Miocene	Tsukagoshi & TCRG (1998), TCRG (1999)
Gifu	Tokiguchi Porcelain Clay Formation	latest middle Miocene to early late Miocene	Miki (1941)
Aichi	Seto Porcelain Clay Formation	latest middle Miocene to early late Miocene	Miki (1941)
Ibaraki	Kanazawa Group	middle Miocene	Omori & Tanaka (1965)
Nagano	Bessho Formation	middle Miocene	Omori & Tanaka (1965)
Hyogo	Kobe Group	Eocene to Oligocene	Ohga (1960)
Kyushu	Unknown	Paleogene	Miki (1972)

As the result of the studies on the fossil floras from Kinki and the adjacent districts of central Japan, Miki (1948) classified the fossil assemblages into seven biostratigraphic units including the "*P. trifolia* bed", "*Metasequoia* bed", "*Paliurus* bed", "*Cryptomeria* bed", "*Larix* bed", "*Sapium* bed", and "*Aphananthe* bed" in ascending order. Miki (1948) assigned the *P. trifolia* bed to the lower Pliocene, because the *P. trifolia* bed included abundant remains of species that are extinct from Japan including *Metasequoia* and *Hemitrapa*. He assigned the *Metasequoia* bed to the upper Pliocene, the *Paliurus*, *Cryptomeria*, *Larix,* and *Sapium* beds to the Pleistocene, and the *Aphananthe* bed to the Recent. The biostratigraphic classification and age of the units was based on the percentage of extinct species and geology of each bed including the elevation and sedimentary environments of the horizon. This system of classification was based on Miki's (1948) belief that climate and sea-level change played important roles in shaping the composition of fossil flora. Minaki (1989) re-examined the stratigraphic positions of the Pleistocene *Paliurus*, *Cryptomeria*, *Larix*, and *Sapium* beds and indicated that these beds were formed in response to glacial and interglacial cycles during the middle and late Pleistocene. Although his stratigraphic correlation needs revision, Miki's (1948) classification of the beds represented a milestone for late Cenozoic paleobotany and plant biostratigraphy in Japan. Because Miki's (1948) seven beds indicated biostratigraphic units, Kokawa (1961) reconsidered them as floral units and referred to each bed as a "flora". For example, the *P. trifolia* beds were now referred to as the *P. trifolia* flora.

Among the Neogene floras that were subdivided into six types based on floristic composition, Tanai (1961) assumed the *P. trifolia* flora to have a close similarity to the late Miocene Mitoku-type flora. The Mitoku-type flora is characterized by possessing a rich diversity of extant type cool-temperate deciduous taxa, differentiation of the local flora, and the occurrence of some genera that are now extinct in Japan. Although the *P. trifolia* flora includes more exotic and warm elements compared to the Mitoku-type floras in northeastern Japan, Tanai (1961) assigned this flora to a type of the Mitoku-type flora based on the floristic composition and stratigraphic position on middle Miocene marine sediments.

Nasu (1972) reported on the palynoflora of the Seto Porcelain Clay Formation. He suggested a warm paleoclimate with frequent rain based on the scarcity of conifer pollen, the dominance of evergreen *Quercus* pollen, and the occurrence of *Nyssa* and *Carya* pollen.

Ozaki (1991) described a rich leaf flora of 31 families, 49 genera, and 62 species from a locality in the Seto Porcelain Clay Formation. His numerical analyses illustrated the abundance of evergreen trees including evergreen *Quercus* and *Cinnamomum* as well as rich warm-temperate elements such as *Paliurus* that showed affinity with the modern warm-temperate broad-leaved forests in north-central Japan.

Recently Momohara & Saito (2001) reported on the composition of the plant macrofossils from the Tokiguchi Porcelain Clay Formation in Tajimi City and discussed the floral and vegetation change. They reported 124 woody plants, 18 vines, and 48 herbs from 13 assemblages at different horizons. During the deposition of the lower horizon, the plant macrofossils were constituents of wetlands and forests. The forest was composed mainly of deciduous broad-leaved trees mixed with conifers and evergreen broad-leaved trees. During the deposition of the upper horizon, the watershed expanded to include higher mountains, from which the cool-temperate elements were derived.

Geology and plant biostratigraphy of the formations bearing *Pinus trifolia*

The porcelain clay formations yielding *P. trifolia* remains consist of the basal part of the fluvial and lacustrine deposits of the Tokai Group that are distributed

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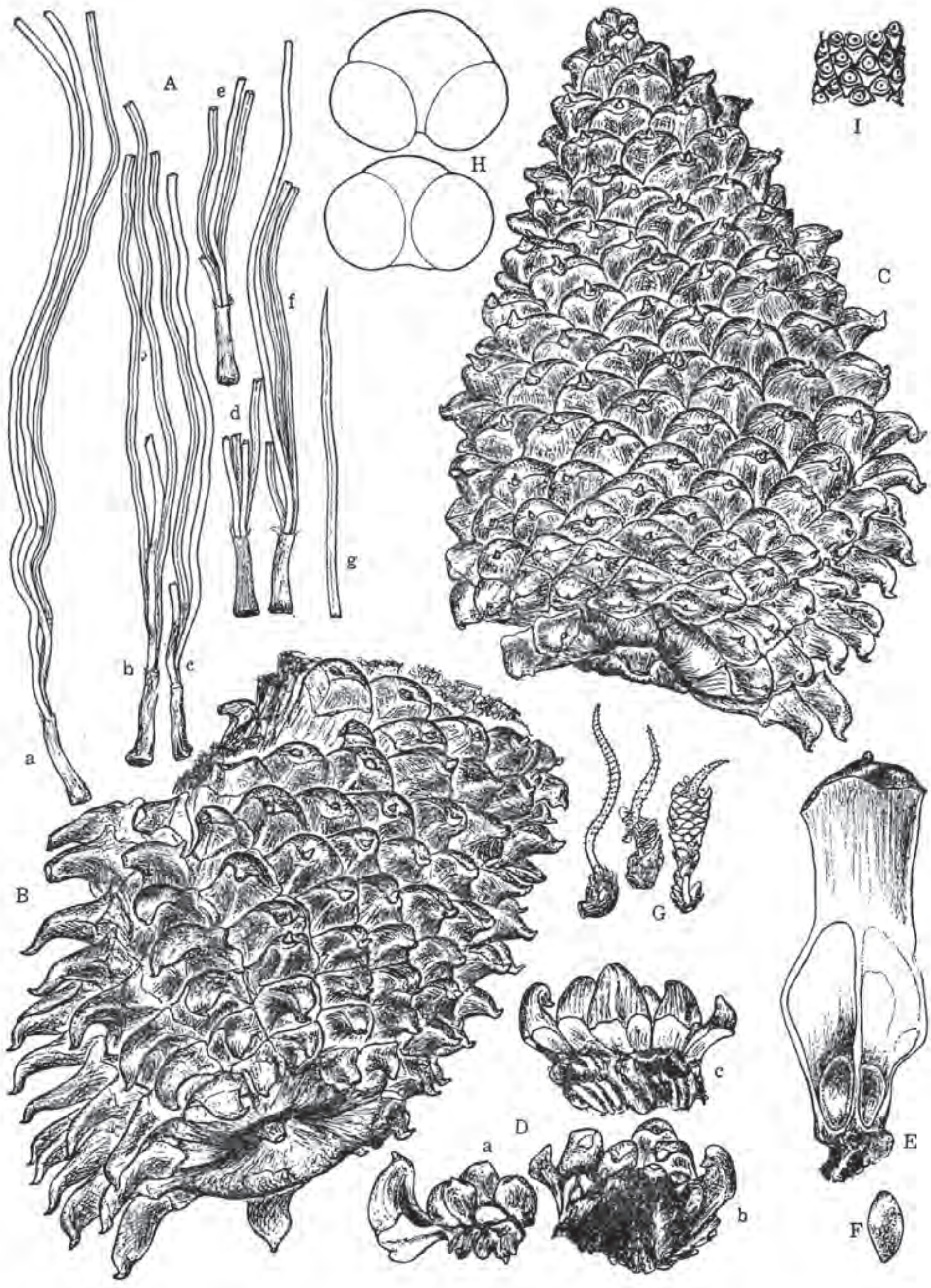


Fig. 3. A Fascicled leaves ×1: *a–c* 3-needled in a fascicle, *d–f* 4-needled in a fascicle, *g* terminal part of a leaf. B–C Cones ×⅔: B from Itirizuka, C from Hatagoya. D Remained part of cones with a few scales on the branch ×1, *c* dorsal view of *b*. E Cone scale with seeds ×1. F Seed ×1. G Male cones ×1. H Pollen from the male cones, sculpture omitted ×334. I The scars of a young shoot ×1.

Fig. 1 Figures from the original description of *Pinus trifolia* Miki (Miki, 1939).

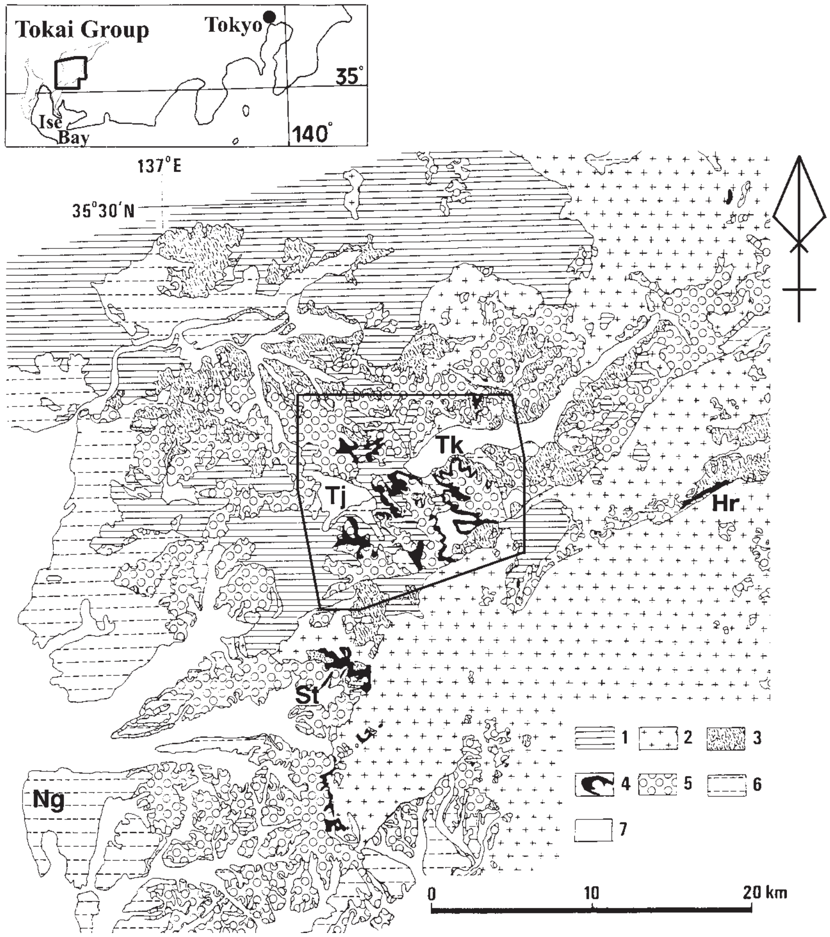
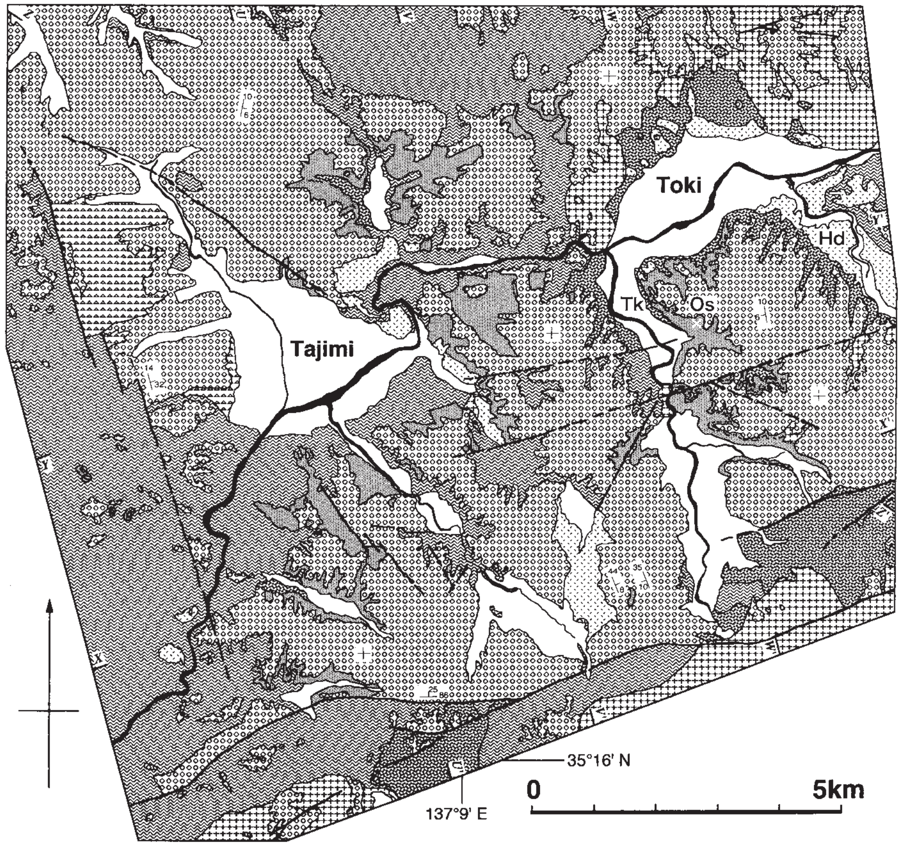


Fig. 2 Outline of the geology of the Tokai Group east of Nagoya (modified from TCRG, 1985). — 1: Mesozoic sedimentary complex, 2: Granite and Nohi Ryolite, 3: Mizunami Group, 4: Seto and Tokiguchi Porcelain Clay Formation, 4: Yadagawa and Toki sand and gravel Formation, 5: Terrace deposits, 6: Alluvium. Ng, Nagoya City; St, Seto City; Tj, Tajimi City; Tk, Toki City; Hr, Hara in Yamaoka Town, Ena City. The enclosed area is shown in Fig. 3.

in and around Ise Bay (Todo Collaborative Research Group (TCRG), 1985; Fig. 2). The Tokai Group east of Nagoya in Aichi Prefecture is divided into the Seto Porcelain Clay Formation and the Yadagawa Formation. The Seto Porcelain Clay Formation is composed mainly of clay and sand and is overlain conformably by the sand and gravel of the Yadagawa Formation (Figs. 2, 5).

The Tokai Group in Tajimi and Gifu Prefecture is classified as the Tokiguchi Porcelain Clay Formation and the Toki Sand and Gravel Formation (TCRG, 1985, 1999; Figs. 2–5). The Tokiguchi Porcelain Clay Formation is composed of interbedded sand, silt, and clay that ranges from 10 to 30 m thick and lies unconformably over the early to middle Miocene Mizunami Group, granite, and Mesozoic chert. The Tokiguchi Porcelain Clay Formation is overlain conformably by the Toki Sand and Gravel Formation that consists of gravel that is up to 40 m thick and is intercalated by mud layers (TCRG, 1999; Fig. 3). The Toki Sand and Gravel Formation is also found in a remote basin of the Ena area, 30 km northeast of Tajimi City (Fig. 5). A porcelain clay formation called the Hara Formation is distributed in a small sedimentary basin in and around Hara and is correlated with the Tokiguchi Porcelain Clay Formation (TCRG, 1982, 1985; Fig. 2). In this paper the Tokiguchi Porcelain Clay Formation is treated as the formation including the Hara Formation.

Of the 12 localities containing *P. trifolia* remains that are indicated by Miki (1941), six localities from Aichi Prefecture are assigned to the Seto Porcelain Clay Formation and six from Gifu Prefecture are assigned to the



Geological Age	Stratigraphic Units		Marks	Remarks
Holocene	(Alluvium)			
Pleistocene	(Talus & fan dep.) (Terrace dep.)			
Pliocene to latest Middle-early Late Miocene	Tokai Group	Toki Sand and Gravel F.		Ohhari Volcanic Ash Hida Volcanic Ash
		Tokiguchi Porcelain Clay F.		Oroshi Volcanic Ash
Early to Middle Miocene	Mizunami Group			
Late Cretaceous to Paleogene	Ryoke Granite	Nohi Rhyolites		Andesite dyke
Triassic to Jurassic	Mino Sedimentary Complex			

Fig. 3 Geologic map and stratigraphic relationship of Toki and vicinity (modified from TCRG, 1999). — The symbols used in the stratigraphic scheme are the same as those used in the geological map. Tk: Tokiguchi, Os: Osusawa (white x), Hd: Hida.

Tokiguchi Porcelain Clay Formation, although some of the horizons at some localities might be included in the Toki Sand and Gravel Formation. The horizon of the Osusawa locality, south of Tokiguchi, from which Miki (1941) described *Metasequoia disticha* (Heer) Miki and *M. japonica* (Endo) Miki is included in the Tokiguchi Porcelain Clay Formation (Fig. 3) along with the Hatagoya locality, from which Miki (1939) described *P. trifolia*.

The age of the Tokiguchi Porcelain Clay Formation and the Toki Sand and Gravel Formation was recently determined to be 10–12 Ma (latest middle Miocene to early late Miocene) based on the fission track age of the tephras (TCRG 1999; Fig. 5). The fission-track age for the Oroshi tephra in the upper part of the Tokiguchi Porcelain Clay Formation is 10 ± 0.4 Ma (Yoshida et al., 1997b). The unnamed tephra of the lower part of the Tokiguchi Porcelain Clay Formation has a fis-

Fig. 4 Tokiguchi Porcelain Clay Formation of Nakayama Mine near Tajimi City and Toki City. The whitish gray layers are composed of clay, silt, and sand. The black layers are composed of accumulations of compressed plant fossils (mainly shoots).

sion-track age of 9.7 ± 0.4 Ma (Ando et al., 1999). The Hida tephra in the lower part of the Toki Sand and Gravel Formation has a fission-track age of 11.1 ± 0.6 Ma (Yoshida et al., 1997b). The fission track age of the Nishizono tephra in the Seto Porcelain Clay Formation is 12.2 ± 0.6 Ma, the latest middle Miocene (Yoshida et al., 1997a).

The paleoenvironment and sedimentary processes in and around the basin were reconstructed based on a sedimentary facies analysis of the Tokai Group. Nakayama (1991, 1999) studied the sedimentary facies of the Seto Prcelain Clay Formation and reconstructed the depositional environment including an alluvial fan and a lake. Nakayama (1994) clarified the deposition of the Seto Porcelain Clay Formation in small collapse basins that were less than 4 km^2 in area closed by faults and discussed the change in paleogeography in and around the basin of the Tokai Group from the late Miocene to Pleistocene.

Saneyoshi et al. (2000) re-examined the depositional environment of the Tokiguchi Porcelain Clay Formation in Tajimi City and suggested an immature sandy braided fluvial system with areas of swamp and ponds that developed near the mountain slopes. Nakajima et al. (2004) studied and reconstructed the depositional processes of the Tokiguchi Porcelain Clay Formation in Tajimi City. The results indicated that the fluvial systems were dominated by sand and mud that were deposited in the river channels and adjacent swamps.

The plant fossils from the Toki Sand and Gravel Formation in this area include *P. trifolia* and *Hemitrapa trapelloidea* Miki, that are the characteristic elements of the *P. trifolia* flora (Tsukagoshi & TCRG, 1998; TCRG, 1999). The floral composition indicates affinity to the Toki Sand and Gravel Formation and the Tokiguchi Porcelain Clay Formation. The geological conformity of both formations and a fission track age of 11.1 ± 0.8 Ma of the Hida tephra support the floristic affinity of both formations (Fig. 5). However, the Toki Sand and Gravel Formation includes Pliocene sediments of the middle Pliocene Ohhari tephra with an age of 3.8 ± 0.3 Ma (Yoshida et al., 1997b). The Nakatsugawa I & II tephras in the Toki Sand and Gravel Formation in the Ena area has an age of 4.3 ± 0.2 Ma and is correlated with the Togo tephra in the Yadagawa Formation in and around the Seto area (Nakayama et al., 1994). These data indicate deposition of the upper part of the Toki Sand and Gravel Formation occurred during the Pliocene. The age of the uppermost contact of the Toki Sand and Gravel Formation is estimated to be 1.5 Ma based on the sedimentation rate between the Ohhari and Hida tephras (TCRG, 1999). It is considered that

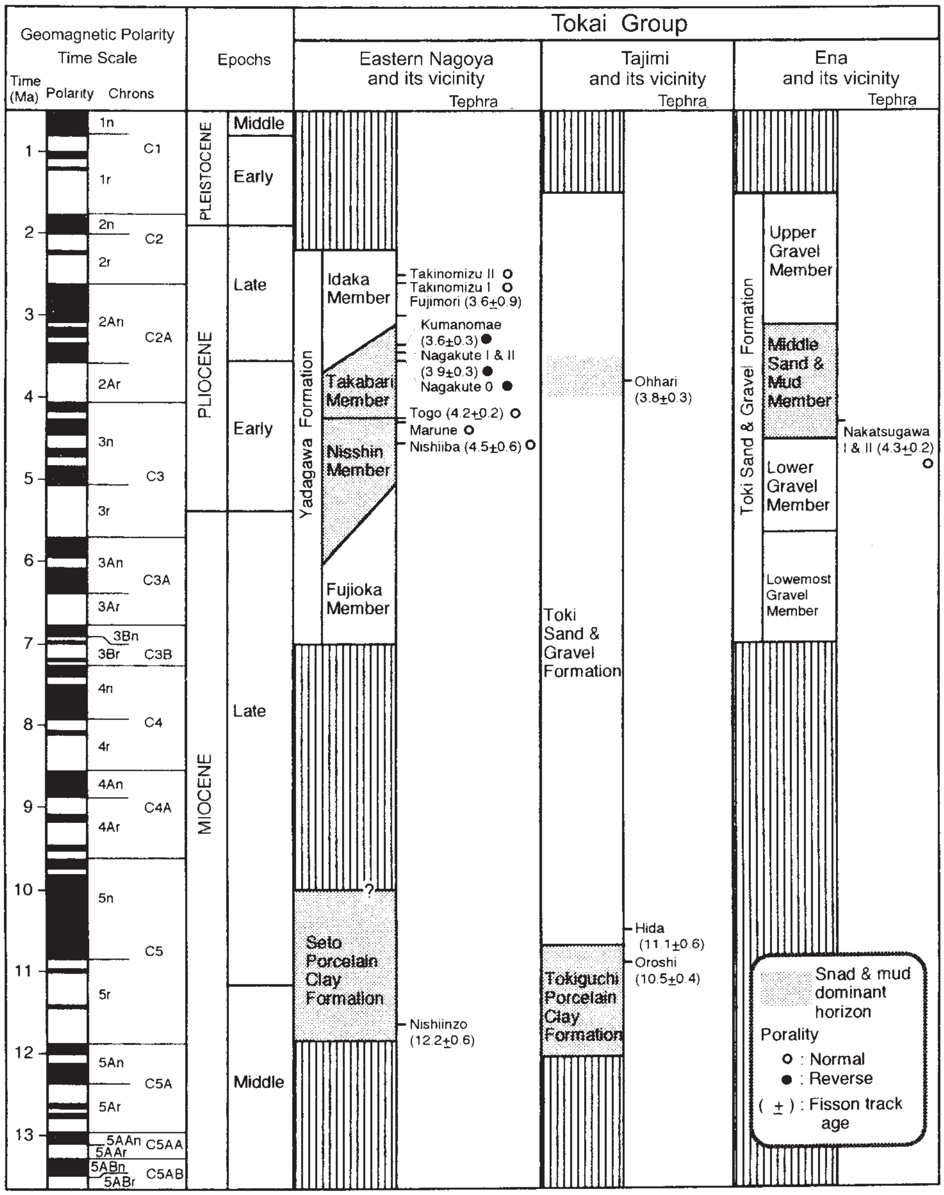


Fig. 5 Stratigraphy and age of the Tokai Group in Aichi and Gifu Prefectures (modified from TCRG, 1999).

the Toki Sand and Gravel Formation was deposited over a long period of time from the early late Miocene to the Pleistocene.

The floras of latest middle Miocene to early late Miocene that are contemporaneous with the floras of the Seto and Tokiguchi Porcelain Clay Formations and are rarely reported either from Japan or east Asia. The *P. trifolia* flora includes well-preserved of fruit, seed, and leaf compressions that are essential for the reconstruction of whole plants and the recognition of Neogene floral and vegetation change in east Asia. Additional research on the taxonomy and floral composition of the *P. trifolia* flora is necessary to clarify the floristic development in this area. However, some new genera and species proposed by Dr. Miki are still *nomen nudum* in the sense of the present *International Code of Botanical Nomenclature*, such as *Distylopsis parottioides* nomen nudum, *Lissopepon melothroidea* nomen nudum, *Schima plioceaca* nomen nudum, etc. Therefore, it is important that Miki's plant fossil that are stored in the Osaka Museum of Natural History first be re-examined and re-named following the guidance provided in the ICBN.

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