

Arata Momohara* and Kiyohide Mizuno** : Habitat of Plants in the Late Pliocene Sedimentary Basin on Awaji Island, Central Japan

百原 新*・水野清秀** : 淡路島の後期鮮新世堆積盆地における植物の生育地

Abstract Late Pliocene plant macrofossil assemblages on Awaji Island, central Japan, were studied to reconstruct the habitat of plants and to complement the upper Pliocene biostratigraphy of the Osaka Group. The lower part of the Atago Formation yields many plants extinct from Japan and includes *Choerospondias axillaris* and *Reevesia* sp. that characterize the basal part of the Osaka Group in the Sennan area. Stratigraphic occurrence of plant fossils in the upper Pliocene on Awaji Island is very similar to that in the Sennan area. Sedimentary facies of fossil bearing beds were classified into three types, i.e., peat, massive silt, and stratified sand, and occurrence of plant taxa was compared between these types to reconstruct their habitat. *Glyptostrobus pensilis*, *Trapa* and Nymphaeaceae included in peat were growing in backmarshes in an alluvial plain. Plants common in massive silt, such as *Metasequoia glyptostroboides*, *Stewartia monadelphica*, *Sequoia* sp., and *Pseudolarix amabilis*, composed forests in wetlands and on sandbanks in an alluvial plain. Plants common in stratified sand, such as *Picea* sect. *Picea*, *Buxus microphylla*, and *Fagus microcarpa*, grew on fans and mountain slopes around a sedimentary basin.

Key Words : Biostratigraphy, Late Pliocene, Osaka Group, Plant macrofossil assemblages, Sedimentary facies

要 旨 これまでの大阪層群の上部鮮新統植物化石層序を補足するとともに、当時の植物の生育地を復元するために、淡路島の大型植物化石群を検討した。淡路島の大阪層群の基底部を構成する愛宕累層下部からは、日本からの絶滅種が多産する。この中には、泉南地域の大阪層群の基底部を特徴づけるチャンニンモドキやチャセンギリ属が含まれる。淡路島の上部鮮新統での植物化石の層位的産出状況は、泉南地域とよく類似している。植物の生育地を復元するために、植物化石群含有層の堆積相を泥炭層、塊状シルト、葉理の発達した砂層の3つに区分し、化石の産出状況を比較した。泥炭層に含まれるスイショウ、ヒシ属、スイレン科は沖積平野の後背湿地に生育し、塊状シルトに多く含まれるメタセコイア、ヒメシャラ、セコイア属、イヌカラマツは沖積平野の自然堤防とその周辺の湿地に分布していた。一方、葉理の発達した砂層内に多く含まれるトウヒ属バラモミ節、ツゲ、ヒメブナは堆積盆地周辺の扇状地や山地斜面に生育していたと考えられる。

キーワード : 大型植物化石群、大阪層群、後期鮮新世、生層序、堆積相

Introduction

Changes in the geographical distribution of plants in and around a sedimentary basin induced by environmental changes caused extinction and evolution of plants. Momohara (1994) showed that the habitat of respective plant species in and around a sedimentary basin was affected by the uplift of surrounding mountains and the relative sea level changes that continued since the late Pliocene. Plants living in the lowland,

such as *Metasequoia glyptostroboides*, became extinct from Japan probably due to the geomorphological changes in the last phase of the early Pleistocene in addition to the climatic deterioration (Momohara *et al.*, 1990). Reconstruction of past geomorphology and habitat of plants in and around a sedimentary basin is, thus, complementary to discuss floral changes since the late Pliocene.

Reconstruction of past plants' habitat is usually

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based on the present ecology of extant plants. This analogy is, however, problematic for plants extinct from Japan. The flora of the late Pliocene includes abundant taxa extinct from Japan (Miki, 1948; Itihara, 1961; Momohara, 1992). Most of them are now confined to limited areas in China, and their relict status hardly represent their past ecological preference. The natural vegetation in China has mostly been damaged through the long human history, and an analogical argument based on plants in present lowland areas is impracticable due to the extensive and continued human activities. Besides, the late Pliocene flora includes many fossil species, and the ecology of their nearest living relatives is not necessarily the same as that of the fossil species.

Though ecology of present plant species is not applicable as an environmental indicator of fossil taxa, the spacial distribution of fossils in a sedimentary basin and a study of the depositional environments of fossil assemblages serve as keys for the reconstruction of past habitat of fossil plants. Suzuki (1976) compared the species composition of fossil assemblages with their distribution in the late Miocene and Pliocene sedimentary basin in Aizu Prefecture, northern Japan, and reconstructed the special and temporal change of plant communities in the sedimentary basin. Momohara (1994) recognized two kinds of sedimentary facies in fluvial deposits of the Osaka Group that include plant macrofossil assemblages, unstratified peaty silts with more or less autochthonous plants and well-stratified sandy sediments with plants transported from wide areas. Difference of the species composition between these two types of sedimentary facies partly reflects the distributional pattern of plant species in the sedimentary basin. Fossil assemblages in unstratified silt should consist of plants that have grown in and around the backmarsh in an alluvial plain, and those in sandy sediment should include plants growing on mountains far from the area of deposition (Momohara, 1994).

In this study, we will describe plant macrofossil assemblages in the late Pliocene of the Osaka Group on Awaji Island and will reconstruct habitat of plants from the sedimentary facies. The Osaka Group distributed in central Japan consists mainly of fluvial, lacustrine, and marine sediments that were deposited

continuously since the late Pliocene to the middle Pleistocene (Itihara, 1961). The magnetostratigraphy and the tephrostratigraphy of this group have been examined in detail, and the most detailed plant macrofossil biostratigraphy has been established among the Plio-Pleistocene strata in the world (Itihara, 1961; Momohara, 1994). The lowermost part of the Osaka Group, i.e., upper Pliocene, is distributed widely on Awaji Island (Mizuno, 1993), west of the Osaka Bay, and in the Sennan area, east of the bay (Fig. 1, Itihara *et al.*, 1975). Miki (1948, 1950, 1952, 1957 and 1960) reported plant macrofossil localities on Awaji Island, but did not describe locations or stratigraphy in detail. Our study aims to complement the plant biostratigraphy of the Osaka Group with materials from Awaji Island.

Litho- and tephrostratigraphy of the Osaka Group on Awaji Island

On Awaji Island the Osaka Group is composed of fluvial sediments including gravel, sand, and silt (Mizuno, 1993). The Osaka Group on the island is divided into northern (areas A–C in Fig. 1), middle (areas D–O), and southern (areas P and Q) parts. Because this group is distributed in isolated areas, stratigraphic subdivisions and volcanic ash layers in each area are named separately (Fig. 2, Mizuno, 1993).

The Osaka Group in the northern part of the island (areas A–C) reaches about 600m thick and is divided into the Toshima and Kariya Formations in the ascending order (Fig. 2, Mizuno, 1993). The Toshima Formation is divided into a lower part, mainly composed of alternating beds of sand and silt with occasional gravelly sediments and an upper part, consisting of overwhelming sand and gravel. The Kariya Formation is divided into a lower part of alternating beds of sand and silt and an upper part of sand and gravel.

The Osaka Group is widely distributed in the middle part of the island (areas D–O). It is about 450 m thick and is divided into the Atago and Goshiki-hama Formations in the ascending order. The Atago Formation is divided into a lower part mainly of gravel, a middle part of alternating beds of sand and silt, and an upper part mainly of sand and gravel. The Goshiki-hama Formation consists of well-sorted pebble-cobble

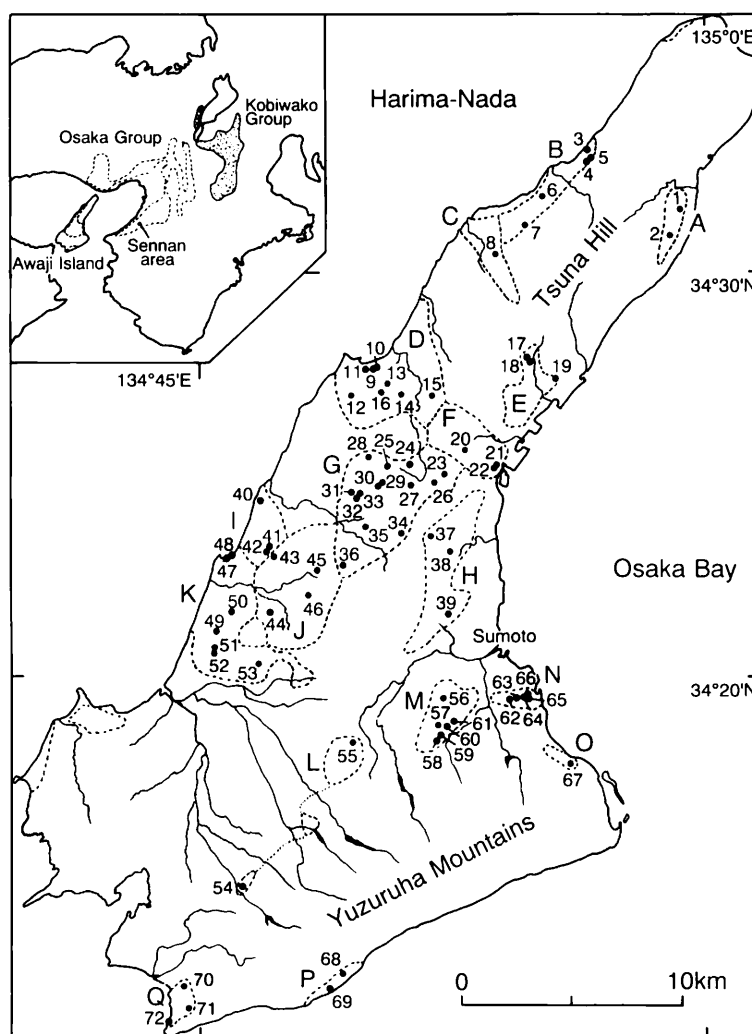


Fig. 1 Fossil localities (1–72) and the distribution of the Osaka Group (areas A – Q enclosed by broken line) on Awaji Island. (Ithihara *et al.*, 1975)

layers with prevalent silt and clay layers, and its gravel layers characteristically include abundant crystalline schist.

Based on volcanic ash layers and composition of gravel layers, the Osaka Group of the middle and the northern parts of the island can be correlated with each other (Mizuno, 1993). The Asano 1 Volcanic Ash Layer in the Toshima Formation corresponds to the Sako Volcanic Ash Layer of the Atago Formation, and the Asano 2 Volcanic Ash Layer to the Shitoori Volcanic Ash Layer (Fig. 2). The lower part of the Toshima Formation corresponds to the middle part of the Atago Formation, and the upper part of the

Toshima Formation to the upper part of the Atago Formation. The Kariya Formation can be correlated with the Goshikihamama Formation based on the existence of crystalline schist in the gravel layers (Mizuno, 1993).

The Osaka Group in the southern part of the island (areas P and Q), named Yudani Formation, is more than 100m thick and mainly consists of sand and gravel (Fig. 2; Mizuno, 1993). The stratigraphic position of this formation is uncertain because of the lack of volcanic ash layers in this formation.

Some volcanic ash layers in the Osaka Group on Awaji Island can be correlated with those in the

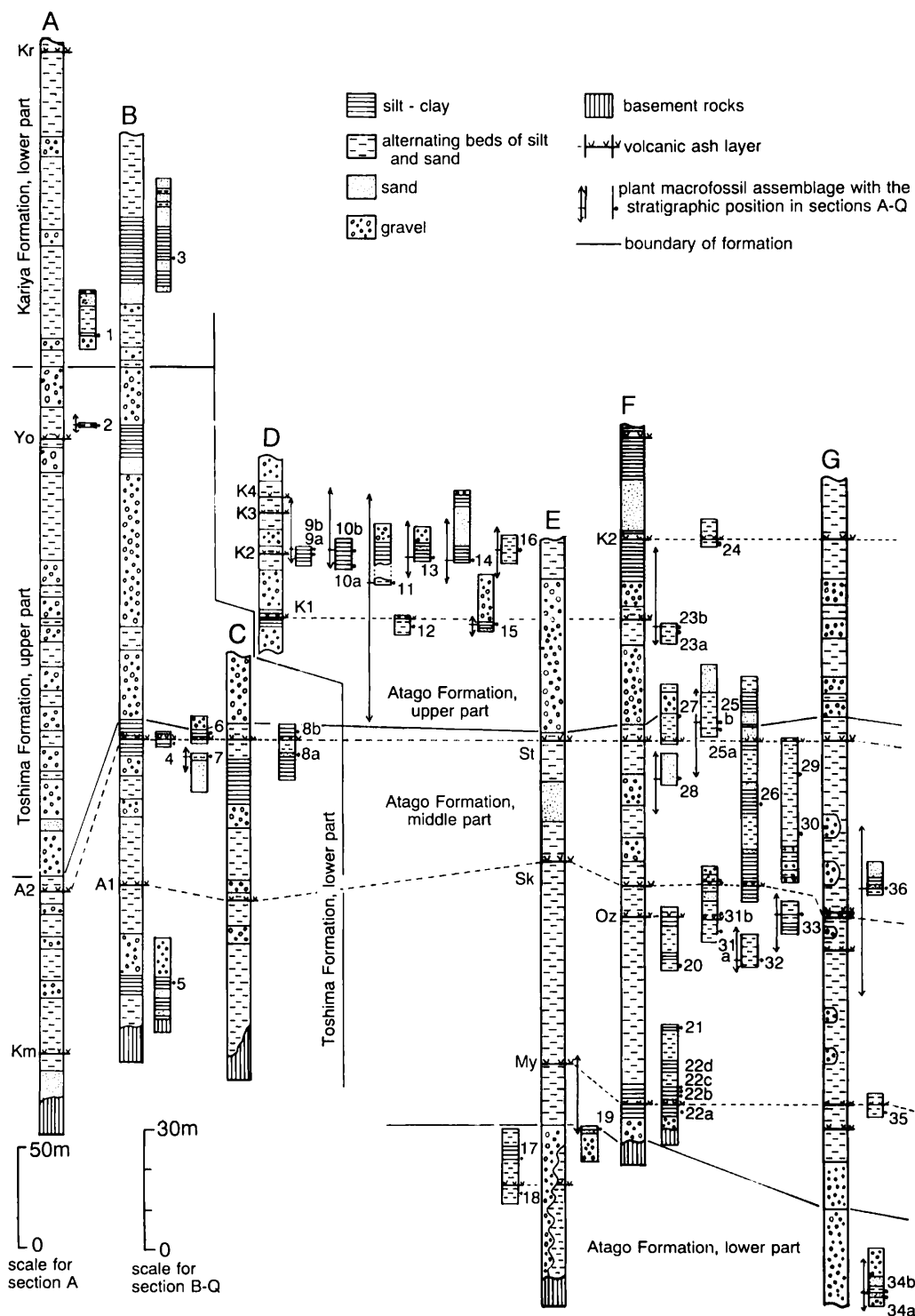
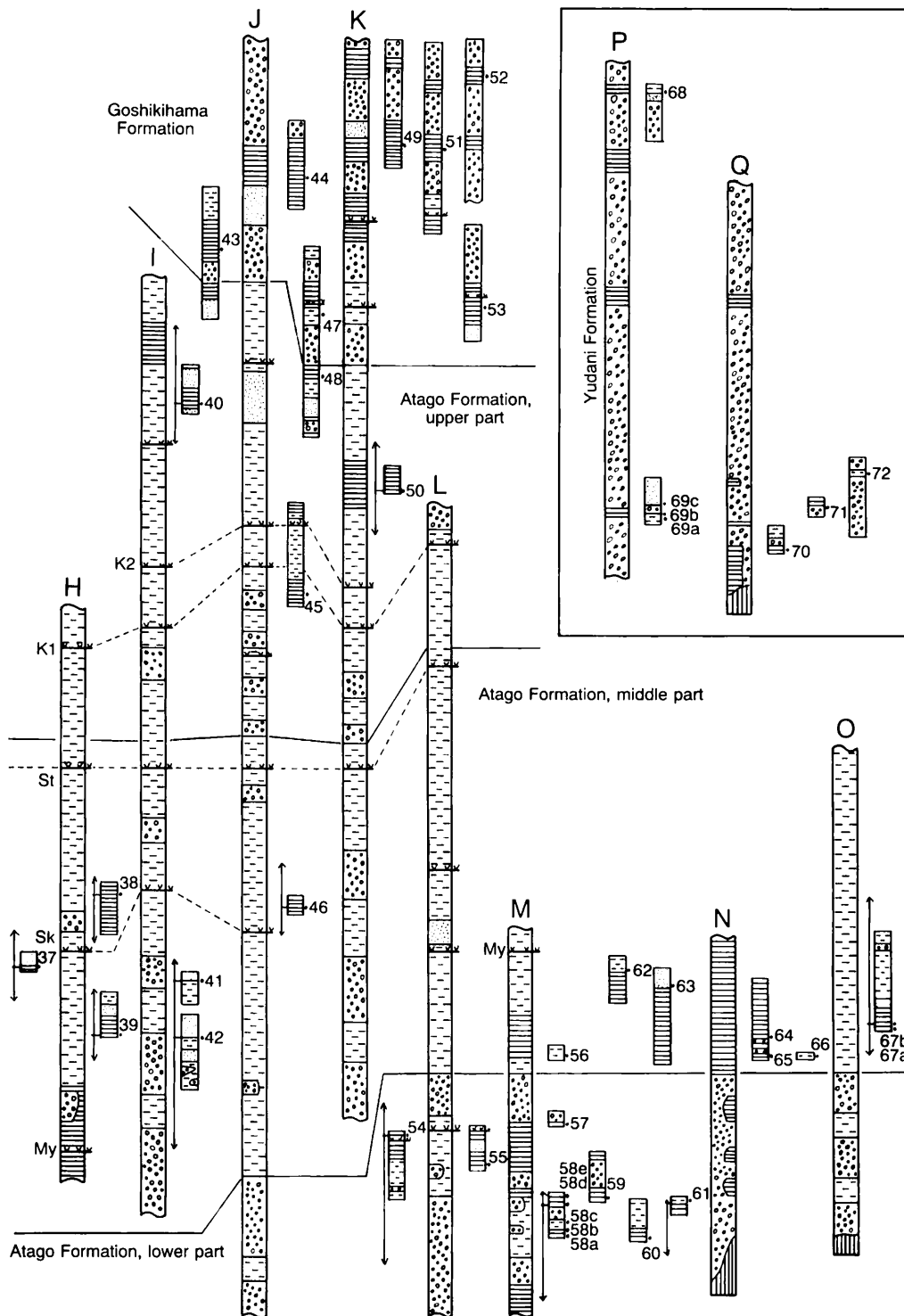


Fig. 2 Standard columnar sections of the Osaka Group in areas A-Q (following Mizuno, 1993) and columnar sections of the fossil localities (1-72). The arrow at the left hand of columnar section indicates the stratigraphic position of plant macrofossil assemblages at localities without volcanic key beds. Volcanic ash layers Km: Kamaguchi Volcanic Ash, A1: Asano 1 Volcanic Ash, A2: Asano 2 Volcanic Ash, Yo: Yokoyama Volcanic Ash, Kr: Kuruma Volcanic Ash, My: Myojin Volcanic Ash, Oz: Uji Volcanic Ash, Sk: Sako Volcanic Ash, St: Shitori Volcanic Ash, K1: Kenjogaoka 1 Volcanic Ash, K2: Kenjogaoka 2 Volcanic Ash, K3: Kenjogaoka 3 Volcanic Ash, K4: Kenjogaoka 4 Volcanic Ash.



Osaka Group of the Sennan area and with those in the Kobiwako Group (Fig. 3; Mizuno, 1992). Between Awaji Island and the Sennan area, the Sako Volcanic Ash Layer is correlated with the Habutaki II Volcanic

Ash Layer, the Shitoori Volcanic Ash Layer with the Asashiro Volcanic Ash Layer, the Yokoyama Volcanic Ash Layer with the Shinnoike Volcanic Ash Layer, and the Kuruma Volcanic Ash Layer with the

Stratigraphy	Yudani Form.	Atago Formation												Goshikiham Formation
		lower part			middle part						upper part			
Volcanic ash layers						Mojin		Sako (Asano 1)		Shitoori (Asano 2)		Kenjozaka 1	Yokoyama	Kuruma
Plant macrofossil assemblages	68	58a,b	17	19	22a	5	20	30	4	6	12	9a,b	2	1, 3
	69a,b	58c,d	18	56	35	21	31a,b	36	7	8b	15	10a,b	40	43, 44
	69c	58e	34a,b	64	62	22b,c	32	38	8a	25a,b	23a,b	11	48	47
	70	59	54	65	63	22d	33	46	26	27	45	13	50	49
	71	60	55	66		39	37		28			14		51
	72	61	57	67a,b		42	41		29			16		52
												24		53
<i>*Taiwania cryptomerioides</i>	1													
<i>Melia azedarach</i>	2													
<i>*Choerospondias axillaris</i>		3												
<i>*Reevesia</i> sp.			1											
<i>*Fortunearia sinensis</i>				5										
<i>*Liquidambar</i> sp.	1	2	1	1		1								
<i>*Melliodendron xylocarpum</i>	1					1								
<i>*Keteleeria</i> sp.		2		1			1							
<i>Quercus</i> subgen. <i>Cyclobalanopsis</i>		1		1			1							
<i>*Fagus microcarpa</i>	1	3	1	2		1	2							
<i>*Quercus</i> sect. <i>Cerris</i>	1	1	1	3	1			1						
<i>*Sequoia</i> sp.	1	5	1	3	2	1	3		2	1	1			
<i>Stewartia monadelph</i>	3	4	4	4	1		2	1	2		1			
<i>*Glyptostrobus pensilis</i>		1	1	1					2	2		1		
<i>*Pseudolarix amabilis</i>	3	3	2	1		1	2		2		1	3	2	
<i>Buxus microphylla</i>		2	2	2	3	1	1		2				1	
<i>Picea</i> sect. <i>Picea</i>	2	3	1	3	2	1	2	1	1	1		1	1	
<i>*Metasequoia glyptostroboides</i>	3	2	2	1				2	2	3	1	4	3	5
<i>*Cinnamomum macropodum</i>		1					1			1		1		2
<i>Acer diabolicum</i>						1								
<i>*Hamamelis parrotioides</i>								1			1	1		3
<i>Pinus</i> subgen. <i>Haploxylon</i>									1					
<i>Alnus japonica</i>										1	2			
<i>Phellodendron amurense</i>										1		1		
<i>*Cyclocarya paliurus</i>											1	1		
<i>Corylus heterophylla</i>											1	2	1	
Volcanic ash layers in the Sennan area and (Kobiwako Group)								Habutaki II (Hozoin II)		Asashiro		(Hazama)	Shinnoike	Fukuda (Gokenjaya)
Magnetostratigraphy														
Age (Ma)														

Fig. 3 Stratigraphic occurrence of selected plant taxa and correlation of volcanic ashes with those in the Osaka Group in Sennan Area and the Kobiwako Group. Plant macrofossil assemblages in the lower and upper parts of the Toshima Formation are included in the middle and upper parts of the Atago Formation, respectively. The assemblages in the lower part of the Kariya Formation are included in the Goshikiham Formation. Taxa with an asterisk are plants extinct from Japan. Numbers in each taxon indicate the number of fossil assemblages within each horizon. Magnetostratigraphy follows Mizuno (1992).

Table 1 Systematic list of plant fossils from the Osaka Group on Awaji Island.

Parts of plant fossils are shown in the parentheses: b: bud, c: cone, cs: cone scale, cu: cupule, e: endocarp, f: fruit, fs: fruiting scale, i: infructescence, l: leaf, s: seed, sh: shoot.

Asterisks indicate taxa extinct or no longer present in Japan.

Cephalotaxaceae	Leguminosae
<i>Cephalotaxus</i> sp. (s)	<i>Wisteria floribunda</i> (Willd.) DC. (f, b)
Cupressaceae	Leguminosae (f)
<i>Chamaecyparis pisifera</i> (Sieb. et Zucc.) Endlicher (sh, s)	Euphorbiaceae
Taxodiaceae	* <i>Aleurites cordata</i> R. Br. (s)
* <i>Metasequoia glyptostroboides</i> Hu et Cheng (c, s, l, sh)	<i>Euphorbia</i> sp. (s)
* <i>Glyptostrobus pensilis</i> (Staunt.) Koch. (c, s, sh, l)	* <i>Sapium sebiferum</i> Roxb. (s)
* <i>Cunninghamia</i> sp. (c, l)	Rutaceae
* <i>Sequoia</i> sp. (c, s, sh)	<i>Phellodendron amurense</i> Rupr. (s)
* <i>Taiwania cryptomerioides</i> Hayata (c)	<i>Zanthoxylum ailanthoides</i> Sieb. et Zucc. (s)
Pinaceae	<i>Zanthoxylum piperitum</i> (L.) DC. (s)
* <i>Keteleeria</i> sp. (c, l)	Meliaceae
* <i>Picea koribai</i> Miki (c, l)	<i>Melia azedarach</i> L. (e)
<i>Picea</i> sect. <i>Picea</i> (c, l)	Anacardiaceae
<i>Pinus</i> subgen. <i>Diploxylon</i> (c)	* <i>Choerospondias axillaris</i> (Roxb.) Burtt et Hill (e)
<i>Pinus</i> subgen. <i>Haploxylon</i> (l)	Aceraceae
* <i>Pseudolarix amabilis</i> (Nelson) Rehd. (cs, s, sh, l)	<i>Acer diabolicum</i> Blume ex K. Koch (f)
* <i>Pseudotsuga subrotunda</i> Miki (c)	<i>Acer</i> cf. <i>mono</i> Maxim. (f)
Juglandaceae	<i>Acer</i> sp. (f)
* <i>Cyclocarya paliurus</i> (Batal.) Iljinsk. (f)	Sabiaceae
* <i>Juglans megacineria</i> Miki (f)	<i>Meliosma</i> sp. (e)
* <i>Pterocarya stenoptera</i> C. DC. (f)	<i>Sabia japonica</i> Maxim. (e)
Salicaceae	Staphyleaceae
<i>Salix</i> sp. (f)	<i>Staphylea bumalda</i> (Thunb.) DC. (s)
Betulaceae	Buxaceae
<i>Alnus japonica</i> (Thunb.) Steud. (i, fs, f)	<i>Buxus microphylla</i> Sieb. et Zucc. (l)
<i>Carpinus tschonoskii</i> Maxim. (f)	Rhamnaceae
<i>Corylus heterophylla</i> Fisch. (f)	<i>Berchemia</i> sp. (e)
Fagaceae	* <i>Paliurus nipponicus</i> Miki (f)
* <i>Fagus microcarpa</i> Miki (cu, f)	Vitaceae
<i>Quercus aliena</i> Blume (cu)	<i>Vitis</i> sp. (s)
<i>Quercus</i> (b, f)	Sterculiaceae
<i>Quercus</i> subgen. <i>Lepidobalanus</i> (cu, f)	* <i>Reevesia</i> sp. (f)
* <i>Quercus</i> sect. <i>Cerris</i> (cu)	Lythraceae
<i>Quercus</i> subgen. <i>Cyclobalanopsis</i> (cu)	<i>Lagerstroemia</i> sp. (f)
Ulmaceae	Trapaceae
<i>Zelkova</i> sp. (f)	<i>Trapa incisa</i> Sieb. et Zucc. (f)
Polygonaceae	* <i>Trapa</i> sp. (f)
<i>Polygonum</i> sp. (f)	Alangiaceae
Magnoliaceae	<i>Alangium</i> sp. (e)
<i>Magnolia praecocissima</i> Koidz. (s)	Cornaceae
Schisandraceae	<i>Benthamidia japonica</i> Hara (e)
<i>Schisandra repanda</i> (Sieb. et Zucc.) Radlk. (s)	<i>Cornus controversa</i> Hemsley (e)
Lauraceae	<i>Cornus macrophylla</i> Wall. (e)
* <i>Cinnamomum macropodum</i> Miki (s)	Araliaceae
Menispermaceae	<i>Aralia elata</i> (Miq.) Seemann (e)
<i>Sinomenium acutum</i> (Thunb.) Rehd. et Wilson (s)	Ericaceae
Nymphaeaceae	<i>Enkianthus</i> sp. (f)
<i>Brasenia schreberi</i> J.F. Gmel. (s)	Styracaceae
* <i>Euryale</i> sp. (s)	* <i>Meliiodendron xylocarpum</i> Hand.-Mazz. (e)
<i>Nuphar</i> sp. (s)	<i>Styrax japonica</i> Sieb. et Zucc. (s)
Ceratophyllaceae	<i>Styrax</i> sp. (s)
<i>Ceratophyllum demersum</i> L. (f)	Symplocaceae
Actinidiaceae	<i>Symplocos</i> sp. (f)
<i>Actinidia rufa</i> (Sieb. et Zucc.) Planch. (s)	Verbenaceae
<i>Actinidia</i> sp. (s)	<i>Callicarpa</i> sp. (e)
Theaceae	<i>Clerodendrum trichotomum</i> Thunb. (e)
<i>Eurya</i> sp. (s)	Caprifoliaceae
<i>Stewartia monadelphica</i> Sieb. et Zucc. (f)	<i>Viburnum</i> sp. (e)
Hamamelidaceae	Alismataceae
* <i>Fortunaria sinensis</i> Rehd. et Wils. (f, s)	<i>Sagittaria</i> sp. (f)
* <i>Hamamelis parrotioides</i> Miki (f, s)	Sparganiaceae
* <i>Liquidamber</i> sp. (f)	<i>Sparganium</i> sp. (e)
Saxifragaceae	Cyperaceae
<i>Schizophragma hydrangeoides</i> Sieb. et Zucc. (f)	<i>Carex</i> sect. <i>Carex</i> (f)
Rosaceae	<i>Carex</i> spp. (f)
<i>Crataegus</i> sp. (e)	<i>Scirpus</i> cf. <i>juncoides</i> Roxb. (f)

Table 2 List of plant macrofossils with the location and sedimentary facies types of the plant fossil bearing bed. Abbreviations for plant parts are in Table 1.
Abundance in plant macrofossil assemblages are indicated after the parentheses; A: abundant, C: common. Sedimentary facies; S: stratified sand, M: massive silt, P: peat.

fossil assemblage number	latitude, longitude	altitude (m)	sedimentary facies	taxa
1	34°30'49"N, 134°59'05"E	30	M	<i>Euryale</i> sp. (s)
2	34°31'32"N, 134°59'16"E	30		<i>Metasequoia glyptostroboides</i> (c); <i>Quercus aliena</i> (cu)
3	34°32'48"N, 134°56'27"E	25		<i>Vitis</i> sp. (s); <i>Styrax japonica</i> (s)
4	34°32'26"N, 134°56'32"E	30	M	<i>Glyptostrobus pensilis</i> (cs, sh); <i>Sequoia</i> sp. (c, s, sh); <i>Meliosma</i> sp. (e)
5	34°32'28"N, 134°56'43"E	40	S	<i>Pseudolarix amabilis</i> (cs), C; <i>Pterocarya stenoptera</i> (f); <i>Quercus aliena</i> (cu), A; <i>Liquidambar</i> sp. (f); <i>Schizophragma hydrangeoides</i> (f); <i>Acer diabolicum</i> (f); <i>Meliosma</i> sp. (e); <i>Buxus microphylla</i> (l); <i>Berchemia</i> sp. (e); <i>Meliidendron xylocarpum</i> (f); <i>Symprocos</i> sp. (f); <i>Callicarpa</i> sp. (e); <i>Carex</i> sp. (f)
6	34°31'56"N, 134°55'19"E	62	M	<i>Glyptostrobus pensilis</i> (c, s); <i>Sequoia</i> sp. (c, s, sh), A
7	34°31'28"N, 134°55'15"E	100	M	<i>Quercus aliena</i> (cu, f), A; <i>Stewartia monadelpha</i> (f); <i>Zanthoxylum ailanthoides</i> (s); <i>Buxus microphylla</i> (l)
8a	34°30'30"N, 134°53'55"E	70	S	<i>Chamaecyparis pisifera</i> (sh, s), C; <i>Cunninghamia</i> sp. (l); <i>Metasequoia glyptostroboides</i> (l, sh); <i>Sequoia</i> sp. (sh); <i>Picea</i> sect. <i>Picea</i> (l); <i>Pseudolarix amabilis</i> (l); <i>Pinus</i> subgen. <i>Haploxylon</i> (l); <i>Salix</i> sp. (f); <i>Wisteria floribunda</i> (b); <i>Buxus microphylla</i> (l); <i>Callicarpa</i> sp. (e); <i>Carex</i> sp. (f)
8b	34°30'33"N, 134°53'56"E	88	M	<i>Metasequoia glyptostroboides</i> (c, s); <i>Juglans megacarinata</i> (f); <i>Quercus</i> sp. (f); <i>Magnolia praecoxissima</i> (s); <i>Cinnamomum macropodium</i> (s); <i>Phellodendron amurense</i> (s), C; <i>Zanthoxylum ailanthoides</i> (s); <i>Zanthoxylum piperitum</i> (s); <i>Styrax japonica</i> (s), C
9a	34°27'41"N, 134°50'14"E	10	S	<i>Cinnamomum macropodium</i> (s)
9b	34°27'41"N, 134°50'14"E	10	S	<i>Metasequoia glyptostroboides</i> (c)
10a	34°27'41"N, 134°50'17"E	10	M	<i>Ceratophyllum demersum</i> (s); <i>Sparganium</i> sp. (e), A; <i>Scirpus cf. juncoides</i> (f)
10b	34°27'41"N, 134°50'17"E	10	M	<i>Metasequoia glyptostroboides</i> (c), C; <i>Wisteria floribunda</i> (b); <i>Aleurites cordata</i> (s); <i>Styrax japonica</i> (s)
11	34°27'36"N, 134°49'57"E	20	M	<i>Glyptostrobus pensilis</i> (c); <i>Euryale</i> sp. (s); <i>Nuphar</i> sp. (s); <i>Trapa</i> sp. (f); <i>Sparganium</i> sp. (f)
12	34°26'52"N, 134°49'30"E	45	S	<i>Alnus japonica</i> (l)
13	34°27'26"N, 134°50'40"E	25	S	<i>Metasequoia glyptostroboides</i> (c), A; <i>Pseudolarix amabilis</i> (sh); <i>Quercus aliena</i> (cu); <i>Quercus</i> sp. (f); <i>Magnolia</i> sp. (s); <i>Wisteria floribunda</i> (b); <i>Euphorbia</i> sp. (s); <i>Phellodendron amurense</i> (s); <i>Benthamidia japonica</i> (e), C; <i>Styrax japonica</i> (s)
14	34°27'10"N, 134°50'54"E	50	M	<i>Zeikova</i> sp. (f), C
15	34°27'04"N, 134°52'02"E	30	M	<i>Pseudolarix amabilis</i> (cs, sh), C; <i>Cyclocarya paliurus</i> (f); <i>Alnus japonica</i> (fs); <i>Carpinus tschonoskii</i> (f); <i>Corylus heterophylla</i> (f), C; <i>Hamamelis parrotioides</i> (f, s); <i>Styrax japonica</i> (s)
16	34°27'03"N, 134°50'26"E	32	M	<i>Metasequoia glyptostroboides</i> (c); <i>Pseudolarix amabilis</i> (sh); <i>Corylus heterophylla</i> (f); <i>Cornus macrophylla</i> (e)
17	34°27'49"N, 134°54'45"E	90	M	<i>Sequoia</i> sp. (c, s, sh), C; <i>Carex</i> sect. <i>Carex</i> (f)
18	34°27'45"N, 134°54'48"E	85	P	<i>Glyptostrobus pensilis</i> (c, sh), A; <i>Trapa</i> sp. (f), C; <i>Euryale</i> sp. (s); <i>Styrax</i> sp. (s)
19	34°27'19"N, 134°55'44"E	30	S	<i>Metasequoia glyptostroboides</i> (c); <i>Sequoia</i> sp. (sh); <i>Picea koribai</i> (l); <i>Quercus</i> sp. (f); <i>Buxus microphylla</i> (s); <i>Viburnum</i> sp. (e)
20	34°25'35"N, 134°52'56"E	30	S	<i>Sequoia</i> sp. (c); <i>Pseudolarix amabilis</i> (cs); <i>Picea</i> sect. <i>Picea</i> (l); <i>Quercus aliena</i> (cu), A; <i>Quercus</i> sp. (f); <i>Stewartia monadelpha</i> (f), C; <i>Wisteria floribunda</i> (b); <i>Enkianthus</i> sp. (f); <i>Styrax japonica</i> (s)
21	34°25'06"N, 134°53'56"E	40	M	<i>Paliurus nipponicus</i> (f)
22a	34°25'07"N, 134°53'54"E	40		<i>Picea</i> sect. <i>Picea</i> (c)
22b	34°25'07"N, 134°53'54"E	40		<i>Trapa</i> sp. (f), C
22c	34°25'07"N, 134°53'54"E	40		<i>Fagus</i> sp. (f)
22d	34°25'07"N, 134°53'54"E	40		<i>Picea</i> sect. <i>Picea</i> (c)
23a	34°24'59"N, 134°52'25"E	95	M	<i>Quercus aliena</i> (cu)
23b	34°24'59"N, 134°52'25"E	95	M	<i>Sequoia</i> sp. (s, sh); <i>Quercus</i> subgen. <i>Lepidobalanus</i> (cu); <i>Stewartia monadelpha</i> (f); <i>Styrax japonica</i> (s)
24	34°25'09"N, 134°51'16"E	85	S	<i>Metasequoia glyptostroboides</i> (c); <i>Pseudolarix amabilis</i> (cs, sh), C; <i>Picea koribai</i> (l), C; <i>Picea</i> sp. (sh); <i>Cyclocarya paliurus</i> (f); <i>Carpinus tschonoskii</i> (f); <i>Corylus heterophylla</i> (f); <i>Quercus aliena</i> (cu), A; <i>Quercus</i> sp. (f); <i>Hamamelis parrotioides</i> (f, s); <i>Acer</i> sp. (f); <i>Aralia elata</i> (e)
25a	34°25'10"N, 134°50'35"E	80	M	<i>Glyptostrobus pensilis</i> (c, s, sh); <i>Alnus japonica</i> (l); <i>Trapa incisa</i> (f)
25b	34°25'10"N, 134°50'35"E	80	S	<i>Metasequoia glyptostroboides</i> (c); <i>Callicarpa</i> sp. (e)
26	34°24'47"N, 134°51'55"E	75	M	<i>Metasequoia glyptostroboides</i> (l); <i>Pseudolarix amabilis</i> (cs, sh); <i>Carpinus tschonoskii</i> (f); <i>Quercus aliena</i> (cu); <i>Quercus</i> sp. (f); <i>Stewartia monadelpha</i> (f); <i>Styrax japonica</i> (s)
27	34°24'39"N, 134°51'21"E	75	S	<i>Metasequoia glyptostroboides</i> (l); <i>Picea</i> sect. <i>Picea</i> (l); <i>Actinidia rufa</i> (s); <i>Wisteria floribunda</i> (b); <i>Styrax japonica</i> (s)
28	34°25'24"N, 134°50'05"E	100	S	<i>Cephalotaxus</i> sp. (s)
29	34°24'50"N, 134°50'21"E	110	M	<i>Glyptostrobus pensilis</i> (sh); <i>Ceratophyllum demersum</i> (f); <i>Trapa incisa</i> (c), A; <i>Sparganium</i> sp. (f)
30	34°24'47"N, 134°50'17"E	110	S	<i>Sinomenium acutum</i> (s)
31a	34°24'32"N, 134°49'34"E	130	S	<i>Alangium</i> sp. (e)
31b	34°24'32"N, 134°49'34"E	130	S	<i>Sequoia</i> sp. (c, sh); <i>Cinnamomum macropodium</i> (s); <i>Stewartia monadelpha</i> (f); <i>Aleurites cordata</i> (s); <i>Clerodendrum trichotomum</i> (e)
32	34°24'24"N, 134°49'46"E	120	S	<i>Keteleeria</i> sp. (c, l); <i>Picea</i> sect. <i>Picea</i> (c); <i>Pseudolarix amabilis</i> (cs); <i>Fagus microcarpa</i> (cu); <i>Alangium</i> sp. (e); <i>Styrax</i> sp. (s)
33	34°24'31"N, 134°49'48"E	130	S	<i>Quercus aliena</i> (cu); <i>Quercus</i> subgen. <i>Cyclobalanopsis</i> (cu); <i>Quercus</i> sp. (f); <i>Aleurites cordata</i> (s); <i>Buxus microphylla</i> (s); <i>Trapa</i> sp. (f); <i>Styrax japonica</i> (s)
34a	34°23'33"N, 134°50'58"E	150	M	<i>Pseudolarix amabilis</i> (cs), C; <i>Stewartia monadelpha</i> (f)
34b	34°23'33"N, 134°50'58"E	150	M	<i>Metasequoia glyptostroboides</i> (c); <i>Pseudolarix amabilis</i> (cs), C; <i>Quercus</i> subgen. <i>Lepidobalanus</i> (cu); <i>Stewartia monadelpha</i> (f); <i>Staphylea bumalda</i> (s); <i>Leguminosae</i> (f)
35	34°23'42"N, 134°49'56"E	95	M	<i>Sequoia</i> sp. (c); <i>Stewartia monadelpha</i> (f); <i>Buxus microphylla</i> (l)

assem. number	latitude, longitude	alt. (m)	sed. facies	taxa
36	34°22'50"N, 134°49'16"E	128	M	<i>Metasequoia glyptostroboides</i> (l); <i>Quercus aliena</i> (cu); <i>Quercus</i> sect. <i>Cerris</i> (cu), C; <i>Quercus</i> sp. (f); <i>Schisandra repanda</i> (s); <i>Nupher</i> sp. (s); <i>Stewartia monadelpha</i> (f); <i>Hamamelis parrotioides</i> (f, s); <i>Meliosma</i> sp. (e); <i>Styrax japonica</i> (s)
37	34°23'26"N, 134°51'49"E	60	P	<i>Trapa incisa</i> (f); <i>Trapa</i> sp. (f); <i>Brasenia schreberi</i> (s)
38	34°23'05"N, 134°52'28"E	30	S	<i>Picea</i> sect. <i>Picea</i> (c, s)
39	34°21'31"N, 134°52'27"E	60		<i>Quercus</i> subgen. <i>Lepidobalanus</i> (cu)
40	34°24'21"N, 134°46'48"E	30	S	<i>Vitis</i> sp. (s)
41	34°23'09"N, 134°46'59"E	50	M	<i>Sequoia</i> sp. (c, s); <i>Fagus microcarpa</i> (cu); <i>Quercus aliena</i> (cu); <i>Styrax japonica</i> (s)
42	34°23'04"N, 134°46'58"E	55	M	<i>Sequoia</i> sp. (c, s, sh), A; <i>Fagus microcarpa</i> (cu); <i>Aleurites cordata</i> (s); <i>Sapium sebiferum</i> (s); <i>Meliosma</i> sp. (e); <i>Cornus controversa</i> (e); <i>Styrax japonica</i> (s), A
43	34°23'00"N, 134°47'11"E	40	M	<i>Metasequoia glyptostroboides</i> (c), C; <i>Styrax japonica</i> (s)
44	34°21'33"N, 134°47'01"E	50	M	<i>Metasequoia glyptostroboides</i> (c), A; <i>Styrax japonica</i> (s), C; <i>Hamamelis parrotioides</i> (f, s), C; <i>Wisteria floribunda</i> (b)
45	34°22'33"N, 134°48'38"E	85	S	<i>Metasequoia glyptostroboides</i> (c)
46	34°21'59"N, 134°48'14"E	50	M	<i>Metasequoia glyptostroboides</i> (c)
47	34°22'53"N, 134°45'49"E	1	S	<i>Metasequoia glyptostroboides</i> (c)
48	34°22'55"N, 134°45'52"E	1	S	<i>Metasequoia glyptostroboides</i> (sh); <i>Picea</i> sect. <i>Picea</i> (l); <i>Pseudolarix amabilis</i> (cs); <i>Euphorbia</i> sp. (s); <i>Buxus microphylla</i> (l)
49	34°21'12"N, 134°45'30"E	50	M	<i>Cinnamomum macropodium</i> (s); <i>Paliurus nipponicus</i> (f)
50	34°21'36"N, 134°45'51"E	25	S	<i>Metasequoia glyptostroboides</i> (c); <i>Pseudolarix amabilis</i> (cs, sh, s), A; <i>Quercus</i> subgen. <i>Lepidobalanus</i> (cu); <i>Corylus heterophylla</i> (f); <i>Crataegus</i> sp. (e)
51	34°20'42"N, 134°45'28"E	50	M	<i>Metasequoia glyptostroboides</i> (c), A; <i>Polygonum</i> sp. (f); <i>Cinnamomum macropodium</i> (s); <i>Hamamelis parrotioides</i> (e, s); <i>Wisteria floribunda</i> (b); <i>Styrax japonica</i> (s), C; <i>Symplocos</i> sp. (e)
52	34°20'38"N, 134°45'28"E	50	M	<i>Sagittaria</i> sp. (f); <i>Carex</i> sect. <i>Carex</i> (f); <i>Carex</i> sp. (f)
53	34°20'19"N, 134°46'46"E	25	M	<i>Metasequoia glyptostroboides</i> (c, b), C; <i>Hamamelis parrotioides</i> (f, s), C; <i>Wisteria floribunda</i> (f, b); <i>Vitis</i> sp. (s); <i>Styrax japonica</i> (s); <i>Scirpus cf. juncoides</i> (f)
54	34°14'45"N, 134°46'16"E	75	M	<i>Liquidambar</i> sp. (f)
55	34°18'21"N, 134°49'33"E	50	M	<i>Metasequoia glyptostroboides</i> (c); <i>Stewartia monadelpha</i> (f); <i>Magnolia</i> sp. (s); <i>Buxus microphylla</i> (l)
56	34°18'28"N, 134°52'24"E	15	M	<i>Keteleeria</i> sp. (l); <i>Euryale</i> sp. (s), C; <i>Nupher</i> sp. (s); <i>Fortunearia sinensis</i> (s); <i>Sapium sebiferum</i> (s); <i>Trapa incisa</i> (f); <i>Trapa</i> sp. (f)
57	34°18'41"N, 134°52'05"E	50	S	<i>Picea</i> sect. <i>Picea</i> (cs, l); <i>Carpinus tschonoskii</i> (f); <i>Fagus microcarpa</i> (cu, f), C; <i>Quercus</i> sect. <i>Cerris</i> (cu); <i>Stewartia monadelpha</i> (f); <i>Buxus microphylla</i> (l); <i>Reevesia</i> sp. (f)
58a	34°18'22"N, 134°52'08"E	100	M	<i>Cunninghamia</i> sp. (c, l); <i>Sequoia</i> sp. (c, s, sh), C; <i>Keteleeria</i> sp. (c); <i>Fagus</i> sp. (f); <i>Quercus</i> subgen. <i>Cyclobalanopsis</i> (cu); <i>Stewartia monadelpha</i> (f), C; <i>Choerospondias axillaris</i> (s); <i>Alangium</i> sp. (e); <i>Carex</i> sect. <i>Carex</i> (f); <i>Carex</i> sp. (f)
58b	34°18'22"N, 134°52'08"E	100	M	<i>Sequoia</i> sp. (c), C; <i>Picea</i> sect. <i>Picea</i> (c); <i>Cinnamomum macropodium</i> (s); <i>Choerospondias axillaris</i> (e); <i>Alangium</i> sp. (e)
58c	34°18'22"N, 134°52'08"E	100	S	<i>Metasequoia glyptostroboides</i> (c), C; <i>Sequoia</i> sp. (c); <i>Picea</i> sect. <i>Picea</i> (c); <i>Pinus</i> subgen. <i>Diploxylon</i> (c); <i>Pseudotsuga subrotunda</i> (c); <i>Fagus microcarpa</i> (cu); <i>Liquidambar</i> sp. (f), C; <i>Choerospondias axillaris</i> (e); <i>Acer</i> sp. (f); <i>Trapa</i> sp. (f)
58d	34°18'22"N, 134°52'08"E	100	P	<i>Glyptostrobus pensilis</i> (c)
58e	34°18'22"N, 134°52'08"E	100	S	<i>Keteleeria</i> sp. (c); <i>Fagus microcarpa</i> (cu); <i>Meliosma</i> sp. (e); <i>Carex</i> sp. (f)
59	34°18'32"N, 134°52'09"E	63	S	<i>Sequoia</i> sp. (s, sh); <i>Pseudolarix amabilis</i> (cs); <i>Stewartia monadelpha</i> (f); <i>Buxus microphylla</i> (l)
60	34°18'41"N, 134°52'20"E	80	M	<i>Pseudolarix amabilis</i> (sh); <i>Stewartia monadelpha</i> (f)
61	34°18'55"N, 134°52'33"E	40	S	<i>Metasequoia glyptostroboides</i> (c); <i>Sequoia</i> sp. (c); <i>Picea koribai</i> (c); <i>Picea</i> sect. <i>Picea</i> (l); <i>Pseudolarix amabilis</i> (cs, l); <i>Fagus microcarpa</i> (cu), A; <i>Quercus aliena</i> (cu); <i>Quercus</i> sect. <i>Cerris</i> (cu); <i>Stewartia monadelpha</i> (f), C; <i>Liquidambar</i> sp. (f), C; <i>Buxus microphylla</i> (l); <i>Styrax japonica</i> (s)
62	34°19'26"N, 134°54'14"E	45	S	<i>Sequoia</i> sp. (c); <i>Buxus microphylla</i> (l)
63	34°19'25"N, 134°54'23"E	45	S	<i>Picea</i> sect. <i>Picea</i> (l, sh), A; <i>Juglans megacineria</i> (f); <i>Quercus</i> sect. <i>Cerris</i> (cu); <i>Buxus microphylla</i> (l)
64	34°19'30"N, 134°54'35"E	40	S	<i>Sequoia</i> sp. (c); <i>Picea</i> sect. <i>Picea</i> (c); <i>Pseudotsuga subrotunda</i> (c); <i>Fagus microcarpa</i> (cu); <i>Quercus</i> subgen. <i>Cerris</i> (cu); <i>Stewartia monadelpha</i> (f); <i>Fortunearia sinensis</i> (s)
65	34°19'28"N, 134°54'38"E	40	S	<i>Picea koribai</i> (c); <i>Picea</i> sect. <i>Picea</i> (l, cs); <i>Carpinus</i> sp. (f); <i>Fagus</i> sp. (f); <i>Stewartia monadelpha</i> (f), A; <i>Fortunearia sinensis</i> (s); <i>Styrax japonica</i> (s)
66	34°19'30"N, 134°54'39"E	40	M	<i>Glyptostrobus pensilis</i> (c, sh); <i>Sequoia</i> sp. (s)
67a	34°17'55"N, 134°56'02"E	20	M	<i>Pseudolarix amabilis</i> (cs, sh), C; <i>Quercus</i> sect. <i>Cerris</i> (cu); <i>Carpinus tschonoskii</i> (f); <i>Stewartia monadelpha</i> (f), A; <i>Fortunearia sinensis</i> (e, s), A; <i>Liquidambar</i> sp. (f); <i>Buxus microphylla</i> (l); <i>Vitis</i> sp. (s); <i>Symplocos</i> sp. (e)
67b	34°17'55"N, 134°56'02"E	20	S	<i>Sequoia</i> sp. (c); <i>Fagus microcarpa</i> (cu); <i>Quercus</i> subgen. <i>Cyclobalanopsis</i> (cu); <i>Quercus</i> sect. <i>Cerris</i> (cu); <i>Quercus</i> sp. (f); <i>Actinidia rufa</i> (s); <i>Eurya</i> sp. (s); <i>Stewartia monadelpha</i> (f); <i>Fortunearia sinensis</i> (f, s); <i>Zanthoxylum</i> sp. (s); <i>Vitis</i> sp. (s); <i>Styrax japonica</i> (s)
68	34°12'35"N, 134°49'16"E	60	M	<i>Metasequoia glyptostroboides</i> (c); <i>Taiwania cryptomerioides</i> (c); <i>Pseudolarix amabilis</i> (cs, sh); <i>Pterocarya stenoptera</i> (f), C; <i>Magnolia praecox</i> (s); <i>Acer cf. mono</i> (f); <i>Acer</i> sp. (f); <i>Lagerstroemia</i> sp. (f); <i>Cornus controversa</i> (e); <i>Symplocos</i> sp. (e)
69a	34°12'13"N, 134°48'53"E	5	M	<i>Melia azedarach</i> (e); <i>Styrax japonica</i> (s)
69b	34°12'13"N, 134°48'53"E	5	M	<i>Metasequoia glyptostroboides</i> (c); <i>Magnolia</i> sp. (s), C; <i>Actinidia</i> sp. (s); <i>Stewartia monadelpha</i> (f); <i>Wisteria floribunda</i> (b); <i>Sapium sebiferum</i> (s); <i>Zanthoxylum ailanthoides</i> (s); <i>Melia azedarach</i> (e); <i>Sabia japonica</i> (e); <i>Ampelopsis</i> sp. (s); <i>Styrax japonica</i> (s)
69c	34°12'13"N, 134°48'53"E	5	S	<i>Magnolia</i> sp. (s)
70	34°12'16"N, 134°44'28"E	30	M	<i>Sequoia</i> sp. (s); <i>Picea</i> sect. <i>Picea</i> (c, l); <i>Pseudolarix amabilis</i> (sh); <i>Quercus aliena</i> (cu); <i>Stewartia monadelpha</i> (f); <i>Styrax japonica</i> (s)
71	34°11'49"N, 134°44'37"E	25	S	<i>Picea</i> sect. <i>Picea</i> (l); <i>Fagus microcarpa</i> (cu); <i>Quercus</i> sect. <i>Cerris</i> (cu)
72	34°11'25"N, 134°44'01"E	10	S	<i>Metasequoia glyptostroboides</i> (c); <i>Pseudolarix amabilis</i> (sh); <i>Quercus</i> sect. <i>Cerris</i> (cu); <i>Stewartia monadelpha</i> (f), C; <i>Liquidambar</i> sp. (f); <i>Aleurites cordata</i> (s); <i>Meliosma</i> sp. (e); <i>Meliiodendron xylocarpum</i> (f)

Fukuda Volcanic Ash Layer (Mizuno, 1992). With the Kobiwako Group, the Kenjogaoka I Volcanic Ash Layer is correlated with the Hazama Volcanic Ash Layer (Mizuno *et al.*, in press).

Materials and methods

We found 89 plant macrofossil assemblages at 72 localities (Figs. 1, 2, Table 1). At localities without volcanic key beds, we correlated plant macrofossil assemblages with the standard columnar section of each area based on the continuity of lithofacies and the local geological structure.

Most plant macrofossils were collected directly from the outcrops. As for macrofossil bearing beds without macroscopic plant parts (fossil assemblages 8a, 24 and 27), plant macrofossils were obtained by sieving of sediments. We did not sieve sediments at most other fossil bearing beds, because this study mainly aimed to clarify arboreal plant fossils that can be obviously recognized at the outcrops. Plant macrofossils are preserved in 70% alcohol and are deposited in the Faculty of Horticulture, Chiba University.

Results

Stratigraphic occurrence of plants

From 89 fossil assemblages, 14 coniferous and 70 angiospermous taxa have been obtained (Tables 1, 2). Among the 84 taxa obtained, 26 taxa (31%) are extinct from Japan. They are common in the horizon lower than the Sako Volcanic Ash Layer in the Atago Formation and in the Yudani Formation (Fig. 3). *Choerospondias axillaris* and *Reevesia* sp. are confined in the lower part of the Atago Formation. *Fortunearia sinensis*, *Liquidambar* sp., *Meliiodendron xylocarpum*, *Keteleeria* sp., and *Fagus microcarpa* occur only in the horizon lower than the Sako Volcanic Ash Layer. *Sequoia* sp., *Pseudolarix amabilis*, and *Glyptostrobus pensilis* common in the middle part of the Atago Formation disappeared in the upper part of the same formation. In horizons upper than the Sako Volcanic Ash Layer, *Hamamelis parrotioides*, *Pinus* subgen. *Haploxylon*, *Alnus japonica*, *Phellodendron amurense*, *Cyclocarya paliurus*, and *Corylus heterophylla* appear, and *Metasequoia glyptostroboides* occurs more commonly than in the lower horizon. Fossil

assemblages in the Goshikiham Formation include *Metasequoia glyptostroboides*, *Cinnamomum macropodum*, and *Hamamelis parrotioides*.

Fossil assemblage in the Yudani Formation includes plants extinct from Japan, such as *Taiwania cryptomerioides*, *Meliiodendron xylocarpum*, *Pseudolarix amabilis*, and *Sequoia* sp., and its composition is similar to those in the middle and lower parts of the Atago Formation.

Sedimentary facies of fossil bearing beds

Most plant macrofossil assemblages are included in the sandy and silty sediments of the alternating beds of silt and sand, but not in the gravel layers. The sedimentary facies of 82 plant macrofossil assemblages can be classified into three types (Table 2).

The first type is peat layers with high organic contents and includes three fossil assemblages (18, 37, and 58d). These peat layers are made of undecomposed plant parts including roots, shoots, and reproductive organs of herbs and arbors. The fossil bearing beds of assemblages 18 and 58d are woody peat of compacted leaves and shoots of *Glyptostrobus pensilis*, and overlie massive silt conformably. The organic contents of the sediments increase gradually from the massive silt to the woody peat.

The second type is massive silt layers often showing horizontal continuity and includes 43 fossil assemblages. In this facies type, plant remains are scattered uniformly in the silt and are very poorly sorted according to their size. The massive silt layers near the basement rocks are sometimes ill-sorted and include sand particles.

The third type is plant fossil layers included in stratified sandy sediments and includes 36 plant macrofossil assemblages. Fossil remains and sediments are well-sorted according to the size: larger fruits and woods in coarser sands, and leaves and smaller seeds in finer ones.

Sedimentary facies and the occurrence of plant taxa

We selected 17 taxa included in more than six assemblages to clarify correlation between the sedimentary facies and the occurrence of plant taxa (Table 3). Based on the sedimentary facies, 17 taxa

Table 3 Occurrence of selected plant taxa in three sedimentary facies types. Nymphaeaceae includes *Brasenia schreberi*, *Euryale* sp., and *Nuphar* sp. *Picea* sect. *Picea* includes *Picea koribai*.

taxa	sedimentary facies of fossil bearing beds			presumed habitat
	peat (3)	massive silt (43)	stratified sand (36)	
<i>Glyptostrobus pensilis</i>	2	6		alluvial plain (swamp)
Nymphaeaceae	2	4		alluvial plain (swamp)
<i>Trapa</i>	2	4	2	alluvial plain (swamp)
<i>Styrax japonica</i>	1	15	8	alluvial plain (swamp – riverbank)
<i>Metasequoia glyptostroboides</i>		14	12	alluvial plain (wetland – riverbank)
<i>Stewartia monadelphica</i>		13	9	alluvial plain (wetland – riverbank)
<i>Sequoia</i> sp.		11	9	alluvial plain (wetland – riverbank)
<i>Pseudolarix amabilis</i>		9	11	alluvial plain (wetland – riverbank)
<i>Quercus aliena</i>		6	6	alluvial plain (wetland – riverbank)
<i>Wisteria floribunda</i>		5	4	alluvial plain (wetland – riverbank)
<i>Hamamelis parrotioides</i>		5	1	alluvial plain (wetland – riverbank)
<i>Cinnamomum macropodum</i>		4	2	alluvial plain (wetland – riverbank)
<i>Picea</i> sect. <i>Picea</i>		2	15	fan and mountain slope
<i>Buxus microphylla</i>		4	10	fan and mountain slope
<i>Fagus microcarpa</i>		2	8	fan and mountain slope
<i>Quercus</i> sect. <i>Cerris</i>		2	6	fan and mountain slope
<i>Liquidambar</i> sp.		2	4	fan and mountain slope

are classified into three groups. The first group is composed of *Glyptostrobus pensilis*, Nymphaeaceae, *Trapa*, and *Styrax japonica* occurring in peat and massive silt. The second group consists of taxa common in massive silt layers, i.e., *Metasequoia glyptostroboides*, *Stewartia monadelphica*, *Sequoia* sp., *Pseudolarix amabilis*, *Quercus aliena*, *Wisteria floribunda*, *Hamamelis parrotioides*, and *Cinnamomum macropodum*. The third group includes *Picea* sect. *Picea*, *Buxus microphylla*, *Fagus microcarpa*, *Quercus* sect. *Cerris*, and *Liquidambar* sp., occurring commonly in stratified sand but rarely in massive silt.

Discussion

Comparison of biostratigraphy in and around Awaji Island

The stratigraphic occurrence of extinct taxa from Japan on Awaji Island is similar to that in the Sennan area. In the Sennan area, *Reevesia* sp. and *Choerospondias axillaris* occur only in the basal horizon of the Osaka Group lower than the Tsuchimaru I Volcanic Ash Layer (Momohara, 1992). *Fortunearia sinensis* and *Keteleeria* sp. became extinct below the Mizuma II Volcanic Ash Layer, and *Liquidambar* sp., *Meliodendron* sp. and *Sequoia* sp. disappeared at about the Habutaki II Volcanic Ash Layer. *Pseudolarix*

amabilis became extinct at about the Shinnoike Volcanic Ash Layer. In the horizons between the Shinnoike Volcanic Ash Layer and Fukuda Volcanic Ash Layer, *Glyptostrobus pensilis*, *Metasequoia glyptostroboides*, *Picea koribai*, *Cinnamomum macropodum*, and *Hamamelis parrotioides* occur commonly (Momohara, 1992). According to the correlation of Habutaki II, Asashiro, Shinnoike, and Fukuda Volcanic Ash Layers with volcanic ashes on Awaji Island (Fig. 3), *Keteleeria* sp. and *Sequoia* sp. lingered on in more younger ages on Awaji Island than in the Sennan area.

The Yudani Formation can be correlated with the basal horizon of the Osaka Group in the Sennan area. Because *Taiwania cryptomerioides* occurs in fossil assemblage 68 in the upper part of the Yudani Formation in area P (Fig. 2), *Taiwania cryptomerioides* is confined below Tsuchimaru I Volcanic Ash Layer in the basal horizon of the Osaka Group in the Sennan area. The occurrence of *Liquidambar* sp. and *Meliodendron xylocarpum* in the Yudani Formation indicates correlation with horizons below Sako Volcanic Ash Layer in the Atago Formation.

Sedimentary environment of plant macrofossil assemblages

The Osaka Group on Awaji Island has the sedimen-

tary facies of an alluvial plain or a fan. The alternating beds of silt and sand dominating in the Osaka Group of this island show sedimentary facies of an alluvial plain where sandy meandering channels are developing (Walker, 1984). The often-stratified sandy sediments are channel-fill deposits or flood deposits over banks. Massive silty and clayey sediments are backmarsh deposits of rivers. Gravel layers characteristically deposit in a fan or along a large river. The gravel layers in the Atago, Toshima, and Yudani Formations consist of poorly-sorted subangular or subrounded gravel with occasional discontinuous silty layers, and their composition is greatly influenced by the basement rocks around the sedimentary basin (Mizuno, 1993). These characteristics of the gravel deposits correspond to those of the distal end of a fan where braided channels are developing. On the contrary, the gravel layers in the Goshikiham Formation are composed of well-sorted gravel and commonly include crystalline schist not found in the present basement rocks on Awaji Island (Mizuno, 1993). This schist is derived from areas of the Sanbagawa metamorphic belt now distributed along the Kinokawa River in Wakayama Prefecture and the Yoshino River in Tokushima Prefecture. In the late Pliocene, Sanbagawa schist was probably exposed on land to the south of the present Awaji Island. The sedimentary facies and the existence of long-transported gravel in the Goshikiham Formation indicate deposition in a large river system. Plant macrofossil assemblages included in the alternating beds of sand, silt and clay were thus deposited in an alluvial plain or at the distal end of a fan.

Among the three types of sedimentary facies of plant bearing beds, the undecomposed peat is usually formed in waterlogged environment such as fen and bogs. The high carbon contents and the lack of coarser sand particles transported by flooding water in the matrix indicates peat formation from plants growing in situ with occasional inclusion of floating allochthonous fruits and seeds. Plant macrofossil assemblages in the peat can thus be interpreted as backmarsh deposits and autochthonous origins.

Plant macrofossil assemblages in massive silt were also deposited in the backmarsh of a river. The finer matrix without stratification and the uniform distribu-

tion of fossils in the sediments reflect deposition under a gentle flow or without a water flow. Size of plant remains transported in water is correlated well with the grain size of the matrix (Momohara & Yoshikawa, 1997). A poor correlation between fossil size and the grain size of the matrix composing the massive silt shows that most plant parts were not transported in water, but were floated down over the water surface. In such a case most plant remains are derived from plants growing around the place of deposition in the backmarsh. Fossil assemblages in the massive silt should thus reflect paleovegetation on wetlands and riverbanks in an alluvial plain.

On the contrary, plant fossil layers within stratified sand were deposited under a high-energy water flow. Stratified sand composes channel-fill deposits or flood deposits over banks. Plant fossils in these fossil layers are mostly transported from the upstream watershed. In channel fill deposits, size and shape of plant remains are correlated well with the grain size of the sediment matrix (Momohara & Yoshikawa, 1997). Fossil assemblages of this type should thus reflect regional paleovegetation including fans and mountain slopes along an alluvial plain.

Plant habitat in the late Pliocene sedimentary basin

Taxa found in the peat probably grew in the most aqueous environment (Table 3). The abundant occurrence of shoots and cones of *Glyptostrobus* together with *Trapa* and Nymphaeaceae indicates that *Glyptostrobus pensilis* were growing in shallow water. *Glyptostrobus pensilis* is now distributed in swampy areas of a delta in south China and develops respiratory roots above the water surface (Fu, 1992). A few *Syrax* seeds in a peat layer with *Glyptostrobus* were probably derived from drier areas such as riverbanks, because they float well.

Taxa common in the massive silt must have grown in and around the backmarsh where their seeds, fruits, or leaves could easily be transported into the area of deposition by a gentle stream or wind. Sandbanks or mounds and wetlands around them interspersed in an alluvial plain probably offered habitat for these plants. Fruits and seeds of plants growing in these areas, which were susceptible to flood, must also have

been transported by flooding water and were deposited also in stratified sand (Table 3). Among the plants in the massive silt (Table 3), *Styrax japonica*, *Metasequoia glyptostroboides*, *Sequoia* sp., and *Wisteria floribunda* are now growing in and around the wetland. *Styrax japonica* and *Wisteria floribunda* are very common around the wetland in alluvial plains in Japan. The habitat of *Metasequoia glyptostroboides* in southwest China is confined to the wetland in valley bottoms (Chu & Cooper, 1950; Momohara *et al.*, 1993), and *Sequoia sempervirens* is growing in the wet places along rivers in the west coast of North America (Li, 1953). On the other hand, *Stewartia monadelpa* and *Quercus aliena* are now distributed in mountains and hills in Japan, and *Pseudolarix amabilis* is distributed in hilly regions including limestone areas in central and south China (Fu, 1992; Momohara *et al.*, 1993). The habitat of these three taxa extended to alluvial plains in the Pliocene, and is different from their present distribution. Extinct species of *Cinnamomum macropodium* and *Hamamelis parrotioides* also grew in alluvial plains.

Plants common in the stratified sand but rare in the massive silt probably grew on fans and mountain slopes far from the area of deposition in an alluvial plain. *Picea* sect. *Picea*, *Buxus microphylla*, *Fagus microcarpa*, *Quercus* sect. *Cerris*, and *Liquidambar* sp. mainly grew on fans and mountain slopes. These plants may have grown also in an alluvial plain, because they are included in the massive silt. Their rare occurrence in the massive silt may, however, indicate occasional inclusion of floating plant remains after floods. *Picea* sect. *Picea* is now distributed mainly in rocky areas in east Asia, e. g., *P. bicolor* in central Honshu (Note *et al.*, 1998). *Picea* sect. *Picea* is also distributed in wetlands in an alluvial plain, e. g., *Picea glehnii* in Hokkaido (Note *et al.*, 1998). Fossils of *Picea* sect. *Picea* occurred from massive silt in the Osaka Group and was assumed to have been a component of forests in an alluvial plain in cooler stages of the Pleistocene (Momohara, 1992). *Picea* sect. *Picea* on Awaji Island preferred fan and mountain slopes in the Pliocene rather than an alluvial plain as its habitat.

Plant habitat assumed in this paper is consistent with that in the Neogene Aizu sedimentary basin clarified by Suzuki (1976). Suzuki (1976) examined the

species composition of plant macrofossil assemblages and their spacial and temporal distribution in a late Miocene and Pliocene sedimentary basin in Aizu Prefecture, northern Japan. He considered coexistence of species in fossil assemblages and the present habitat of fossil species and their modern relatives as important criteria to reconstruct past plant communities. In the Pliocene sedimentary basin, *Glyptostrobos* inhabited the most aqueous environment with *Alnus japonica* and *Phragmites*, *Metasequoia*, *Styrax*, *Buxus*, and *Stewartia* grew in the drier habitat in the lowland, and *Picea koribai*, *Pseudolarix*, and *Fagus microcarpa* occupied mountain slopes (Suzuki, 1976). Among them, habitats of *Glyptostrobos*, *Metasequoia*, *Styrax*, *Stewartia*, *Picea koribai*, and *Fagus microcarpa* clarified by Suzuki (1976) are comparable with those assumed in this paper.

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本書は、森林の環境に関心をもつ人だけでなく、地球人として森林と環境のかかわりに関心をもってもらいたいあらゆる人を対象に執筆・編集されている。森林総合研究所を中心にした中堅・若手の研究者が執筆にあっている。1項目2ページで100項目200ページ、それぞれの項目を得意とする研究者が担当している。それに加えて、平易なです・ます体で語られ、項目ごとに親しみやすい題目が付けられているので、読者の興味のあるところから読みはじめることができる。

そうは言っても、ただ項目の羅列だけなら辞書同然であるが、本書はそうではない。環境問題と森林、気候変動と森林、日本の森林の変遷と現状、森林が守る私たち

の生活環境の4つのおおきな部分に分かれており、ストーリー性を失っていない。そのストーリー性とは、今日の地球環境問題を理解するための緑の生態系、自然・人類の歴史における緑の生態系、現代社会史における緑の生態系といった具合である。

編集・発行にあっている林業技術協会、執筆者の大半が所属する森林総合研究所とは、いったいどういうことをしているところなのか。それをアピールする目的も本書にはあるようだ。そういう視点も忘れずに読んでみると、一層おもしろくなるかも知れない。

(辻 誠一郎)