Early Pleistocene Plant Biostratigraphy of the Shobudani Formation, Southwest Japan, with Reference to Extinction of Plants¹⁾

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Plant macrofossil assemblages from the Shobudani Formation in the northern part of Hashimoto City, Wakayama Prefecture, are described. 221 taxa including 21 extinct plants are identified. Six assemblage zones, SB-I to SB-VI in ascending order, are established. The zones SB-II and SB-V are characterized by the occurrence of the members belonging to subarctic and cool-temperate elements indicative of a cool climate. The zones SB-I, SB-III, SB-IV and SB-VI are characterized by the occurrence of the members belonging to warm-temperate and/or subtropical elements associated with some cool-temperate elements, suggesting warm climatic conditions. The coexistence of the members attributed to both subtropical and cool-temperate elements in the zone SB-III suspects warm winters and cool summers. A scarcity of the members belonging to the cool-temperate elements associated with common subtropical and warm-temperate elements in the zone SB-VI indicates warmer summer conditions than in the zone SB-III. Based on the mode of the occurrence of fossil plants, the Shobudani Formation is thought to be early Pleistocene in age. The late early-Pleistocene extinction of *Cyclocarya paliurus*, *Pterocarya* aff. *stenoptera*, and *Picea koribai* is assumed to a lowering of the winter temperatures. In respect to the extinction of *Metasequoia glyptostroboides* from the area, a warming of the summer climate and a change in topography together with repeated changes in overall climatic deterioration are suspected.

I. Introduction

Plio-Pleistocene floral change in Japan is characterized by the elimination of Tertiary elements and the occurrence of modern elements. This change was described first by MIKI (1948) from the Osaka Group and other correlative strata in and around the Kinki District. Later, many researchers re-examined his localities based on detailed stratigraphical studies of the Osaka Group, e.g., HUZITA (1954), ITHARA (1960), and KOKAWA (1961). Among them, ITHARA (1960) reported that the elimination of *Metasequoia* from the Osaka Group was contemporaneous within the area, and he made an attempt to divide the

group into the upper and lower parts based on that evidence.

The Plio-Pleistocene Shobudani Formation is distributed along the Kinokawa River in Wakayama Prefecture and the Yoshino River in Nara Prefecture (KAWADA, 1939 ; SHIIDA and KOKAWA, 1954 ; SANGAWA, 1977). It consists mainly of fluvial sediments and yields many well-preserved plant macrofossils (MIKI, 1941a, 1948, 1950, 1957 ; SHIIDA and KOKAWA, 1954). The formation is thought to be correlated with the Osaka Group (SANGAWA, 1977). The type-specimen of the genus *Metasequoia* was described first from the formation by MIKI (1941a), and later the living plant identical to the fossil specimen

- 1) Received February 28, 1989. Accepted October 7, 1989. Partly presented at the Annual Meetings of the Ecological Society of Japan on March 31, 1985 and the Japan Association for Quaternary Research on August 27, 1987.
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Fig. 1 Map showing the area studied and the location of the sites
Each site number corresponds to that in Fig. 2.

was discovered in China (HU and CHENG, 1948).

In this paper, plant macrofossil assemblages in the Shobudani Formation in the northern part of Hashimoto City, Wakayama Prefecture, are described. An attempt has been made to obtain biostratigraphical and palaeoecological implications of the area.

II. Stratigraphy

The study area is located around Miyukitsuji and Shobudani, Hashimoto City, and Tahara, Koyaguchi-cho, Ito-gun, Wakayama Prefecture (Fig. 1). The Shobudani Formation in the area is about 100 meters thick, unconformably overlies the Sanbagawa crystalline schists, and is overlain unconformably by terrace deposits. The formation is mainly bounded on the north by faults and contacts with the Cretaceous Izumi Group.

The lower part of the formation consists of an alternation of silt and subangular-angular pebbles, and the upper part mainly consists of subrounded pebble-cobbles around Miyukitsuji, although in areas around Shobudani and Tahara it consists of an alternation of subangular-

angular pebble-cobbles and silt (Fig. 2). Because of the difference in the facies, SANGAWA (1977) segregated the upper part from the formation and referred to it as the Gojo Formation. However, the deposits of the formation inter-finger locally with those of the Shobudani Formation within the study area. In this paper, therefore, the lower and the upper part of the formation is designated here as the lower and the upper member, respectively.

There are six volcanic ash layers, Sh1~Sh6, in ascending order in the area, of which Sh1 and Sh 6 were confirmed by fission-track data of 2.07 ± 0.36 Ma and 0.93 ± 0.21 Ma, respectively (SUZUKI, 1988). In his report, however, the former ash layer is referred to as the Miyukitsuji tuff layer and the latter as the Jizoji tuff layer.

Plant macrofossils are obtained from every peaty layer at all of the sites with the exception of the site 19. There are at least three kinds of peaty sediments from which plant macrofossils are found. The differences in character of the matrix seem to be influenced by depositional conditions under which they have been formed. The one of these is interbedded within stratified

Fig. 2 Columnar sections at site 1 to 22
Each site number corresponds to that in Fig. 1. Sh1~Sh6 : volcanic ash layer, P1~P41 : peaty layer.

Table 1 Systematic list of plant fossils from the Shobudani Formation

Characeae	Charophyta	Chloranthaceae
Characeae, os.		<i>Chloranthus</i> sp., e.
	Bryophyta	Juglandaceae
Bryopsida, gp.		<i>Pterocarya rhoifolia</i> SIEB. et ZUCC., e.
	Pteridophyta	* <i>Pterocarya</i> aff. <i>stenoptera</i> C.DC., e.
Selaginellaceae		* <i>Cyclocarya paliurus</i> (BATAL.) ILJINSK., e.
<i>Selaginella remotifolia</i> SPRING, ms.		* <i>Juglans megacineria</i> MIKI ex CHANEY, e.
* <i>Selaginella</i> sp. a, ms.		Betulaceae
* <i>Selaginella</i> sp. b, ms.		<i>Carpinus</i> cf. <i>tshonoskii</i> MAXIM., f.
Isoetaceae		<i>Carpinus cordata</i> BL., f.
<i>Isoetes</i> cf. <i>japonica</i> A.BR., ms.		<i>Ostrya japonica</i> SARG., f.
	Gymnospermae	<i>Corylus</i> sp., f.
Cephalotaxaceae		<i>Betula maximowicziana</i> REGEL., f.
<i>Cephalotaxus harringtonia</i> (KNIGHT) K.KOCH, s.		<i>Betula platyphylla</i> SUKATSCHEV, f, fb.
Pinaceae		<i>Betula grossa</i> SIEB. et ZUCC., fb.
<i>Abies</i> spp., l, sh.		<i>Alnus</i> cf. <i>japonica</i> (THUNB.) STEUD., fb, f, i, mi.
* <i>Pseudotsuga subrotunda</i> MIKI, c.		<i>Alnus</i> subgen. <i>Alnaster</i> , f.
<i>Pseudotsuga</i> spp., s, l, sh.		Fagaceae
<i>Tsuga sieboldii</i> CARR., c.		<i>Fagus crenata</i> BL., cu.
<i>Tsuga</i> spp., s, l, sh.		* <i>Fagus</i> aff. <i>hayatae</i> PALIB. ex HAYATA, cu.
<i>Picea jezoensis</i> (SIEB. et ZUCC.) CARR., l.		<i>Fagus</i> spp., f.
<i>Picea</i> cf. <i>polita</i> (SIEB. et ZUCC.) CARR., l.		<i>Quercus</i> subgen. <i>Lepidobalanus</i> , cu.
<i>Picea maximowiczii</i> REGEL, c.		<i>Quercus</i> spp., f, mi, b.
* <i>Picea koribai</i> MIKI, c, l.		Ulmaceae
<i>Picea</i> sect. <i>Eupicea</i> , c, s, l, sh, g.		<i>Zelkova</i> sp., f.
<i>Pinus koraiensis</i> SIEB. et ZUCC., s.		* <i>Hemiptelea mikii</i> MINAKI, f.
<i>Pinus</i> subgen. <i>Haploxylon</i> , l, sb.		Moraceae
Pinaceae, b.		<i>Fatoua villosa</i> (THUNB.) NAKAI, f.
Taxodiaceae		<i>Morus</i> sp., e.
<i>Cryptomeria japonica</i> (L. f.) D.DON, c, s, l, sh, mi.		<i>Broussonetia</i> sp., e.
* <i>Cunninghamia</i> sp., c, s, l, sh.		<i>Ficus</i> cf. <i>pumila</i> L., f.
* <i>Metasequoia glyptostroboides</i> HU et CHENG, c, s, l, sb, b.		Urticaceae
Cupressaceae		<i>Pilea</i> spp., f.
<i>Thuja</i> sp., sh.		<i>Pellionia</i> sp., f.
<i>Chamaecyparis pisifera</i> (SIEB. et ZUCC.) ENDL., c, s, sh, mi.		<i>Boehmeria</i> spp., f.
<i>Juniperus</i> spp., s.		Polygonaceae
	Angiospermae	<i>Polygonum</i> cf. <i>filiforme</i> THUNB., f.
Sparganiaceae		<i>Polygonum</i> cf. <i>maackianum</i> REGEL, f.
<i>Sparganium</i> spp., f.		<i>Polygonum pubescens</i> BL., f.
Potamogetonaceae		<i>Polygonum</i> spp., f.
<i>Potamogeton distinctus</i> A.BENN., f.		Phytolaccaceae
<i>Potamogeton cristatus</i> REGEL et MAACK, f.		<i>Phytolacca japonica</i> MAKINO, s.
<i>Potamogeton oxyphyllus</i> MIQ., f.		Caryophyllaceae
Najadaceae		<i>Stellaria diversiflora</i> MAXIM., s.
<i>Najas minor</i> ALL., s.		<i>Stellaria alsine</i> GRIMM, s.
<i>Najas japonica</i> NAKAI, s.		Caryophyllaceae, s.
<i>Najas graminea</i> DEL., s.		Nymphaeaceae
Alismataceae		<i>Nuphar</i> sp., s.
<i>Alisma</i> sp., f.		Ceratophyllaceae
<i>Caldesia reniformis</i> (D.DON) MAKINO, f.		<i>Ceratophyllum demersum</i> L., f.
<i>Sagittaria</i> sp., f.		Ranunculaceae
Gramineae		<i>Ranunculus</i> spp., f.
Gramineae, gl.		<i>Batrachium</i> sp., f.
Cyperaceae		<i>Isopyrum trachyspermum</i> MAXIM., s.
<i>Cyperus</i> spp., f.		<i>Isopyrum</i> sp., s.
<i>Scirpus</i> cf. <i>mitsukurianus</i> MAKINO, f.		Berberidaceae
<i>Scirpus</i> cf. <i>wichurae</i> BOECKLER, f.		<i>Berberis</i> spp., spn.
<i>Scirpus</i> cf. <i>juncoides</i> ROXB., f.		Menispermaceae
<i>Scirpus</i> spp., f.		<i>Sinomenium</i> aff. <i>acutum</i> (THUNB.) REHD. et WILS., e.
<i>Fimbristylis</i> sp., f.		Magnoliaceae
<i>Eleocharis</i> sp., f.		<i>Magnolia obovata</i> THUNB., s.
<i>Carex</i> cf. <i>dickinsii</i> FR. et SAV., f.		<i>Magnolia</i> sp., s.
<i>Carex</i> sect. <i>Carex</i> , f.		Lauraceae
<i>Carex</i> spp., f.		* <i>Cinnamomum macropodum</i> MIKI, s.
Cyperaceae, f.		cf. <i>Lindera</i> sp., s.
Eriocaulaceae		Lauraceae, s.
<i>Eriocaulon</i> spp., s.		Papaveraceae
Commelinaceae		<i>Macleaya cordata</i> (WILLD.) R.BR., s.
<i>Aneilema keisak</i> HASSK., s.		<i>Corydalis</i> cf. <i>incisa</i> (THUNB.) PERS., s.
Pontederiaceae		<i>Corydalis</i> cf. <i>pallida</i> (THUNB.) PERS., s.
<i>Monochoria korsakowii</i> REGEL et MAACK, s.		<i>Corydalis</i> sp., s.
Juncaceae		Saxifragaceae
<i>Juncus</i> spp., s.		<i>Chrysosplenium</i> cf. <i>macrostemon</i> MAXIM., s.
		<i>Chrysosplenium</i> sp., s.
		<i>Schizophragma</i> aff. <i>hydrangeoides</i> SIEB. et ZUCC., f.
		<i>Hydrangea</i> spp., s.
		<i>Deutzia</i> sp., f.

Asterisk indicates taxon which is extinct or no longer represented in Japan.

Abbreviations of the fossil part : b : bud, c : cone, cu : cupule, e : endocarp, f : fruit, fb : fruiting bract,

- Hamamelidaceae
**Hamamelis parrotioides* MIKI, f.
Corylopsis sp., f.
Hamamelidaceae, s.
- Rosaceae
Stephanandra cf. *incisa* (THUNB.) ZABEL, s.
Kerria japonica (THUNB.) DC., s.
Duchesnea chrysantha (ZOLL. et MORITZ.) MIQ., f.
Potentilla spp., f.
Rubus buergeri MIQ., e.
Rubus spp., e.
Agrimonia sp., f.
Rosa sect. *Synstylae*, f.
Rosa sp., e.
**Prunus* cf. *salicina* LINDL., e.
**Prunus* cf. *triloba* LINDL., e.
Prunus subgen. *Cerasus*, e.
Crataegus sp., e.
- Leguminosae
Wisteria sp., f, b.
Leguminosae, f.
- Oxalidaceae
Oxalis sp., s.
- Rutaceae
Zanthoxylum piperitum (L.) DC., s.
Zanthoxylum schinifolium SIEB. et ZUCC., s.
Zanthoxylum ailanthoides SIEB. et ZUCC., s.
Zanthoxylum sp., s.
Evodia glauca MIQ., s.
Phellodendron amurense RUPR., s.
- Euphorbiaceae
Acalypha australis L., s.
Sapium japonicum (SIEB. et ZUCC.) PAX et HOFFM., s.
**Sapium sebiferum* (L.) ROXB. var. *pleistoceaca* MIKI, s.
Euphorbia sp., s.
**Aleurites cordata* (THUNB.) R.BR. ex STEUD., s.
Euphorbiaceae, s.
- Aquifoliaceae
**Ilex* aff. *cornuta* LINDL., e, l.
- Staphyleaceae
Staphylea bumalda (THUNB.) DC., s.
**Staphylea* sp., s.
- Aceraceae
Acer cf. *palmatum* THUNB., f.
Acer ginnata MAXIM., f.
Acer mono MAXIM., f.
Acer rufoinerve SIEB. et ZUCC., f.
Acer diabolicum BL., f.
Acer cf. *cissifolium* (SIEB. et ZUCC.) K.KOCH, f.
Acer spp., f.
- Hyppocastanaceae
Aesculus turbinata BL., f, s.
- Sabiaceae
Sabia japonica MAXIM., m.
Meliosma sp., e.
- Balsaminaceae
Impatiens sp., s.
- Rhamnaceae
Berchemia sp., e.
Rhamnus sp., e.
- Vitaceae
Vitis spp., s.
Ampelopsis brevipedunculata (MAXIM.) TRAUTV., s.
- Tiliaceae
Tilia spp., f.
- Actinidiaceae
Actinidia cf. *rufa* (SIEB. et ZUCC.) PLANCH., s.
Actinidia arguta (SIEB. et ZUCC.) PLANCH. ex MIQ., s.
Actinidia polygama (SIEB. et ZUCC.) MAXIM., s.
Actinidia sp., s.
- Theaceae
Stewartia cf. *monadelphae* SIEB. et ZUCC., f, s.
Cleyera japonica THUNB., s.
- Guttiferae
Triadenum japonicum (BL.) MAKINO, s.
Sarothra sp., s.
Hypericum sp., s.
- Violaceae
Viola spp., s.
- Flacourtiaceae
Idesia polycarpa MAXIM., s.
- Stachyuraceae
Stachyurus praecox SIEB. et ZUCC., s.
- Thymelaeaceae
Wikstroemia spp., s.
- Elaeagnaceae
Elaeagnus spp., e.
- Lythraceae
Lagerstroemia sp., f.
- Onagraceae
Trapa sp., f.
Ludwigia ovalis MIQ., s.
Ludwigia sp., s.
- Haloragaceae
Haloragis micrantha (THUNB.) R.BR., f.
- Araliaceae
Aralia elata (MIQ.) SEEM., e.
Aralia cf. *cordata* THUNB., e.
Acanthopanax sp., e.
- Umbelliferae
Hydrocotyle sp., f.
Umbelliferae, f.
- Cornaceae
Cornus controversa HEMSLE., e.
Cornus brachypoda C.A.MEY., e.
**Cornus* aff. *mas* L., e.
- Ericaceae
Tripetaleia sp., s.
Rhododendron sp., s.
Enkianthus sp., f.
- Primulaceae
Lysimachia subgen. *Lysimachia*, s.
Lysimachia subgen. *Palladia*, s.
- Symplocaceae
Symplocos sect. *Palura*, e.
- Styracaceae
Styrax japonica SIEB. et ZUCC., s.
Styrax obassia SIEB. et ZUCC., s.
**Styrax* cf. *microcarpa* MIKI, s.
Pterostyrax hispida SIEB. et ZUCC., f.
- Oleaceae
Chionanthus retusus LINDL. et PAXT., e.
Fraxinus aff. *mandshurica* RUPR., f.
- Verbenaceae
Verbena officinalis L., f.
Callicarpa sp., e.
Premna japonica MIQ., f.
Clerodendrum trichotomum THUNB., e.
- Labiatae
Ajuga spp., f.
Mosla cf. *punctulata* (J.F.GMEL.) NAKAI, f.
Mosla cf. *dianthera* (HAMILT.) MAXIM., f.
Lycopus sp., f.
Clinopodium sp., f.
- Labiatae, f.
- Solanaceae
Solanaceae, s.
- Pedaliaceae
Trapella sinensis F.W.OLIV., f.
- Caprifoliaceae
Sambucus sieboldiana BL. ex GRAEBN., e.
Viburnum furcatum BL., e.
Viburnum plicatum THUNB., e.
Viburnum sect. *Odontotinus*, e.
Weigela sp., s.
- Valerianaceae
Patrinia sp., f.
- Campanulaceae
Lobelia chinensis LOUR., s.
- Compositae
Siegesbeckia sp., f.
Lapsana sp., f.
Compositae, f.

g : gall, gl : glume, gp : gametophyte, i : infructescence, l : leaf, m : mesocarp, mi : malein-florescence, ms : macrospore, os : oospore, s : seed, sb : short branch, sh : shoot, spn : spine

The name of the extant plant is mainly followed by OHWI (1965).

sands or sandy silt, the second is unstratified and laterally well continued peaty silt, and the last one is a laminated lignitic silt.

III. Method

Although some larger plant macrofossils were collected from the outcrop at the site, samples of a known volume of more than 250 cm³ were macerated in water and then passed through 2 mm, 1 mm, 0.5 mm, and 0.25 mm mesh sieves. The fractions were examined under a binocular microscope. They were picked out and counted. The lignitic silt was left in 8% potassium hydroxide and then neutralized with hydrochloric acid before applying a sieve.

All specimens obtained have been preserved in 70% alcohol and stored in the Osaka City University.

IV. Result

Fossil plants representing the Shobudani Formation are now found to include 221 taxa, i.e., 128 of them are woody, 93 represent herbaceous (Table 1). Systematically the woody taxa are composed of 20 gymnosperms and 108 angiosperms, while the herbaceous taxa comprised of 1 charophytes, 1 bryophytes, 4 pteridophytes, and 87 angiosperms. Fossil plants which are either extinct or no longer represented in Japan include 19 woody and 2 herbaceous. Based on the sequential record of the occurrence the Shobudani Formation in this area is divided into six assemblage zones labelled as SB-I to SB-VI, starting from the base (Fig. 3). They are characterized as follows:

SB-I (P-1 and 2)

This lowest zone is characterized by the occurrence of *Cunninghamia* sp., *Ilex* aff. *cornuta* and *Phytolacca japonica* belonging to the warm temperate elements. *Metasequoia glyptostroboides*, *Hamamelis parrotioides* and *Morus* sp. are well represented. Among herbaceous plants, *Batrachium* sp. is included in this zone.

SB-II (P-3 to 5)

This zone is characterized by the dominance of *Picea* sect. *Eupicea* including *P. maximowiczii*, *Betula maximowicziana* and *Picea jezoensis* belonging to the cool-temperate and subarctic

elements. *Tsuga* spp. and *Abies* spp. are also dominant. On the other hand, warm-temperate elements are virtually absent. Only two species of extinct members, i.e., *Metasequoia glyptostroboides* and an unknown species of *Selaginella* that is tentatively designated here as *S. sp. a*, occur in this zone. *Metasequoia* is well marked with its short branches. Among herbaceous plants a species of *Scirpus*, here tentatively designated as *S. sp. a*, and a species of *Carex* designated as *C. sp. l* are exclusively found only in this zone.

SB-III (P-6 to 23, 27 to 30, and 34)

This zone is characterized by the occurrence of *Evodia glauca*, *Sapium sebiferum* var. *pleistoceaca*, *Premna japonica*, *Lagerstroemia* sp., *Actinidia* cf. *rufa* and *Ficus* cf. *pumila*. They or their close allies are now found from subtropical to borders of warm temperate latitudes in the greatest abundance. At warm temperate latitudes, they are confined to the coastal areas. For the sake of convenience in this paper, they are designated as the subtropical elements. The members belonging to the warm-temperate elements such as *Cunninghamia* sp., *Cyclocarya paliurus*, *Pterocarya* aff. *stenoptera*, *Ilex* aff. *cornuta*, *Cinnamomum macropodum* and *Ludwigia ovalis*, and those of the cool-temperate elements such as *Picea* sect. *Eupicea*, *Chamaecyparis pisifera*, *Stewartia* cf. *monadelphica*, *Phellodendron amurense* and *Fagus crenata* occur together with the members belonging to the subtropical elements just mentioned. It would be of value to note that some cones belonging to the genus *Picea* sect. *Eupicea* are distinct from those of any modern Japanese species. These are shown in Figs. 2~4 of Plate I.

Many kinds of extinct plants occurred in this zone. Among them, *Metasequoia* occurs in almost all of the peaty layers, while *Juglans megacineria* is scarce.

Conifers are well represented. *Picea* sect. *Eupicea* other than *P. koribai*, *Cryptomeria japonica*, *Cunninghamia* sp., *Pseudotsuga* spp., *Tsuga* spp. and *Abies* spp. are found to occur mainly in stratified sand or sandy silt layers. On the other hand, *Picea koribai* and *Metasequoia* are recorded commonly also in unstratified peaty silt layers associated with abundant aquatic and/or semi-aquatic plants.

Number of fossils counted: ●: 1/100cm², ○: 2-10/100cm², ⊙: >11/100cm².

Fig. 3 Stratigraphic distribution of selected plant macrofossils

Asterisk indicates taxon which is extinct or no longer represented in Japan.

Picea sect. *Eupicea* in this figure represents other than *P. koribai* and *P. polita*.

Parentheses for each taxon indicates the fossil part. Abbreviations are the same as indicated in Table 1.

Letter subsequent to each taxon indicates the range of its present distribution : S : subtropical, W : warm-temperate, C : cool-temperate, SA : subarctic

Closed circles : woody, open circles : herbaceous + indicates occurrence of plant parts other than mentioned in the parenthesis.

Well-represented broad-leaved trees are *Morus* sp., *Hamamelis parrotioides* and *Styrax japonica*.

SB-IV (P-24 to 26, 31 to 33, and 35)

The members attributed to subtropical elements are not recorded. Some members belonging to the warm-temperate elements such as *Broussonetia* sp. and *Cunninghamia* sp. occur. *Chamaecyparis pisifera* belonging to the cool-temperate elements is well represented. Extinct plants are scarce. *Metasequoia* is found less frequently than in the preceding zone. The uppermost occurrences of both *Metasequoia* and *Picea koribai* are in the peaty layer P-26. Among herbaceous plants *Batrachium* sp. is well-represented, and *Haloragis micrantha* is recorded only in this zone.

SB-V (P-36 and 37)

The members belonging to cool-temperate and subarctic elements are dominant. In the peaty layer P-36, *Picea jezoensis*, *Betula maximowicziana* associated with abundant aquatic plants such as Characeae, *Potamogeton* spp., *Najas* spp., *Trapa* sp. and *Trapella sinensis* are recorded, while in the layer P-37 abundant leaves of *Picea* cf. *polita* and *Pinus* subgen. *Haploxylon* including *P. koraiensis* with well-preserved fruits and fruiting bracts of *Betula platyphylla* are found. Extinct plants are not recorded except *Selaginella* sp. a.

SB-VI (P-38 and 41)

This uppermost zone is characterized by the occurrence of *Ficus* cf. *pumila* and *Actinidia* cf. *rufa* belonging to the subtropical elements and *Cunninghamia* sp. belonging to the warm-temperate elements. The occurrence of members belonging to the cool-temperate elements is rare. The only representative of them is one seed of *Chamaecyparis pisifera* in the peaty layer P-40. Some extinct plants as *Cunninghamia* sp. and *Fagus* aff. *hayatae* occur in abundance.

V. Discussion

1. Floral and climatic implications

As was described in the preceding chapter, the fossil assemblage zones both for SB-II and SB-V are mainly characterized by the dominance of the members belonging to the cool-temperate and subarctic elements, implying that climatic conditions are thought to have been cool. On the contrary, the zones SB-I, SB-III, SB-IV, and

SB-VI are for the most part characterized by the occurrence of the members belonging to the warm-temperate and/or subtropical elements associated with some members belonging to the cool-temperate elements, suggesting that the overall climate was warmer as compared with that during zones SB-II and SB-V.

During the zone SB-II, the fossil assemblage suggests that the climate may have been colder than during the zone SB-I. The occurrence of many well-preserved cones for *P. maximowiczii* associated with abundant leaves for *Picea* sect. *Eupicea* suggests that the species played an important part in the local forests. In the same zone, no cones for *P. jezoensis* are found but the occurrence of its leaves indicates that the species may be occurred at higher altitudes.

During the zone SB-III, the presence of the members belonging to the subtropical and warm-temperate elements suggests that the climate was warmer than the preceding cold phase. However, many plants belonging to the cool-temperate elements are also existed during this zone. It is, then, likely that the climatic conditions are thought to have been mild and oceanic.

The coexistence of the plants attributed to both subtropical and cool-temperate elements in fossil assemblages has also been often recorded from the Osaka Group (e.g., MIKI, 1948 ; MINAKI *et al.*, 1981). These workers have been assumed that these plants may have occurred within a nearby vegetation under mild and oceanic climatic conditions. Fossil flora represented in the zone SB-III is thought to be comparable with those obtained by them in terms of depositional environments. As the matter of fact, the unstratified peaty silt layers yielded abundant and well-preserved plant macrofossils belonging to the cool-temperate elements associated with those of subtropical and/or warm-temperate elements. These sediments are assumed to have been deposited under a deeper and less turbulent water, and included many plant materials and minerals from nearby areas.

The members belonging to the subtropical elements such as *Actinidia* cf. *rufa*, *Ficus* cf. *pumila*, *Premna japonica* and *Evodia glauca* repre-

sented in the zone SB-III occur along coast of present southwestern Japan, where warm and humid winters prevailed. The members attributed to the cool-temperate elements as *Picea* sect. *Eupicea* and *Betula maximowicziana*, on the other hand, require cool summers. The intermingling of these plants is thought to represent an ecotone between these fossil plants in the coastal area. In other words, the flora suggests that mild and oceanic climatic conditions may have been prevailed.

During the zone SB-IV, a warm and mild climate prevailed as indicated by the occurrence of the members belonging to the warm temperate elements such as *Cunninghamia* sp. and *Broussonetia* sp.. However, the lack of the members belonging to the subtropical elements indicates that the winter climate was colder than the preceding zone. During the zone SB-V, the climate became much colder than the preceding zone. The occurrence of the members belonging to the subarctic and cool-temperate elements associated with many aquatic plants in the peaty layer P-36 indicates that the members attributed to the subarctic and cool-temperate elements as *Picea jezoensis* and *Betula maximowicziana* inhabited in local forests.

During the zone SB-VI, the occurrence of the members belonging to both subtropical and warm-temperate elements, such as *Ficus* cf. *pumila* and *Cunninghamia* sp. indicative of warmer conditions, indicate a climatic amelioration again. However, the members attributed to the cool-temperate elements are rarely found. In practice, only one seed of *Chamaecyparis pisifera* was recorded from the peaty layer P-40. Then, it seems to likely that the tree may have been inhabited at higher places. The summer climates during this zone are assumed to have been warmer than during the zone SB-III, and then, the range of annual temperatures might have been wider than the zone SB-III. The occurrences of limited members belonging to the cool-temperate elements seem rather due to high summer temperatures.

2. Stratigraphic correlation with the Osaka Group

The volcanic ashes in the Shobudani Forma-

tion are rare and weathered. Thus, the direct correlation with those of the Osaka Group is difficult. The formation is, however, distributed just beside the Osaka Group, then the mode of occurrence of the fossil plants from both areas can be compared with respect to a correlation.

Fig. 4 shows the stratigraphic distribution of selected plant macrofossils in common both from the Osaka Group and the Shobudani Formation. In the instance of the Osaka Group, however, three genera as *Liquidambar*, *Pseudolarix* and *Glyptostrobus* that are not known so far from the Shobudani Formation in the study area are added. As shown in the figure, the mode of occurrence from the Shobudani Formation is similar to that from the Osaka Group, i.e., 1) *Fagus crenata* and *Cryptomeria* are recorded from a later stage of the lower part of the Osaka Group onward, while they are represented during the zones SB-III to SB-IV of the Shobudani Formation. 2) *Juglans megacrinerea*, *Pterocarya* aff. *stenopectera*, *Cyclocarya paliurus*, *Metasequoia glyptostroboides* and *Picea koribai* became extinct from the lower part of the Osaka Group as represented respectively in the sequential order of termination. The same is true to the zones SB-III and SB-IV of the Shobudani Formation. Among them, it is worth to mention that the last record of both *Metasequoia* and *Picea koribai* was in the Ma 2 marine clay of the Osaka Group, while these are presented during the zone SB-IV. 3) *Cunninghamia* and *Fagus* aff. *hayatae* are well extended to the upper part of the Osaka Group in one hand, they are represented during the zone SB-VI on the other.

Based on these evidences, the zones from SB-I to SB-V are correlated with the lower part of the Osaka Group and the zone SB-VI is correlated with the lowest part of the upper part of the group. The age of the Shobudani Formation in the study area is assumed to early Pleistocene, which corresponds approximately to the ages obtained by fission track data (SUZUKI, 1988).

3. Plant extinction from the area and its causes

As noted in the preceding chapter, some plant species became extinct during the zones SB-III to SB-IV from the area studied and also from the

Fig. 4 Stratigraphic distribution of the selected plant macrofossils from the Osaka Group and the Shobudani Formation

Tuff layers : Ks : Kasuri Tuff, Az : Azuki Tuff, Pi : Pink Tuff, Y : Yellow Tuff, Sn : Senriyama Tuff, Fu : Fukuda Tuff, Ha : Habutaki Tuff, Tc : Tsuchimaru Tuff, Ms : Misaki Tuff

Closed circles in the record from the Osaka Group are cited from FUKAKUSA RESEARCH GROUP (1962), ITIHARA (1960), ITIHARA *et al.* (1966, 1975), KOKAWA (1961), KOMYOIKE RESEARCH GROUP (1971), MIKI (1941b, 1948, 1950, 1954, 1955, 1957), MIKI *et al.* (1957), MOMOHARA *et al.* (1986), NIREI (1968), NISHIYAMA RESEARCH GROUP and EARTH SCIENCE CLUB OF KATSURA HIGH SCHOOL, KYOTO (1970), YOKOYAMA and NAKAGAWA (1984), and YOSHIKAWA (1973). Open circles are unpublished records from the Osaka Group in the Sennan District.

The uppermost occurrence of *Cunninghamia* from the Osaka Group is cited from NASU (1972) and MIZUNO and MINAKI (1986).

Osaka Group almost contemporaneously. Among them, *Cyclocarya paliurus* and *Pterocarya aff. stenoptera* are now represented in warm temperate latitudes of southeastern China. These species are assumed to have been flourished under warm and oceanic climatic conditions, especially during the zone SB-III, and probably have had a history back behind to Pliocene as were recorded in the Osaka Group. Only two cold phases, zones SB-II and SB-V, are noted in the Shobudani Formation. The plant macrofossil

records (e.g., KOKAWA, 1961 ; IBARAGI RESEARCH GROUP, 1966) and pollen records (TAI, 1973) from the Osaka Group, however, have been noted a few climatic deteriorations existed during the late early-Pleistocene. Some members belonging to the warm-temperate elements might have been exterminated due to a decrease in winter temperatures, for which it has not been clearly recognized during the zones SB-III and SB-IV.

Genus *Picea* is now widely distributed from cool-temperate to subarctic latitudes of the

Northern Hemisphere. One extinct species recognized by MIKI (1948), *Picea koribai*, however, seems to have been inhabited under warmer conditions than modern *Picea* because the species is co-occurred always with the members belonging to subtropical and/or warm-temperate elements, where the sediment is unstratified peaty silt. It is likely that *Picea koribai* became extinct in the same way as the members belonging to the warm-temperate elements did, i.e., the repeated gradual climatic deteriorations during the zone SB-IV led eventually to the termination of the species from the area.

With regard to *Metasequoia glyptostroboides*, the extinction of it can not be explained only by a lowering of winter temperatures. The common occurrence of it associated with the members attributed to the subarctic and cool-temperate elements in the zone SB-II suggests that the species was common during the cold phase. Additional fossil records from the Osaka Group support this suggestion, i.e., *Metasequoia* occurs associated with *Pinus koraiensis* and other members belonging to the cool-temperate elements from Ibaragi (IBARAGI RESEARCH GROUP, 1966) and from Kantengoya (KOKAWA, 1961) in the Osaka district. The species should have had a much wider distribution across several different vegetation zones than it now has in China.

Two possible causes may be explained on the extinction of *Metasequoia*. The first is a rise in summer temperatures. As had been indicated by the constituents of the plant macrofossils, the zone SB-VI suggests warmer summers, in other words, less oceanic than the zone SB-III. Thus, the members belonging to the cool-temperate elements as *Chamaecyparis pisifera* and *Picea* could not have been grown on lowlands associated with the members belonging to the subtropical and/or warm-temperate elements. *Metasequoia* may be susceptible to summer warmth rather than winter coldness, although overall climatic deteriorations during the zone SB-IV may not be negligible.

The second is changes in topographical features reflected on the facies of the deposits. The size of gravels was coarser in the upper member than in the lower member. SANGAWA (1977) mentioned

that surrounding hills and mountains had uplifted when the upper member was formed and that from there these coarse gravels were derived. This uplift combined with a change in climate must have related to change in topography of the sedimentary basin, leading to an extermination of some plants including *Metasequoia*.

SUZUKI (1977) has noted that the extinction of *Metasequoia* could not be explained only by a lowering of winter temperatures based on freezing experiments carried out by SAKAI (1971), and suspected that a competition with *Cryptomeria* together with a change in topography may induce the termination. His suspicion is hard to believe because a different kind of sediments from which both genera are recorded is noted. *Metasequoia* occurred abundantly in unstratified peaty silt, whereas *Cryptomeria* is found mainly in stratified sandy layers. Therefore, the former genus may have had its habitat in a lower area than the latter.

Acknowledgement

We are grateful to Dr. A. SANGAWA, Geological Survey of Japan, Dr. M. ITIHARA, Dr. S. YOSHIKAWA and Mr. M. MITAMURA, the Osaka City University, Mr. N. IKAWA, Kawasaki Geological Engineering Co. Ltd., and Dr. M. MINAKI, the University of Marketing and Distribution Sciences, for their valuable suggestions. We are indebted to the third-year students, Department of Biology, Osaka City University in 1981, 1982, 1983, and 1984, who collected many of the specimens for this study.

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菖蒲谷層の前期更新世植物化石層序と植物群の絶滅過程

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(要 旨)

和歌山県橋本市北部の菖蒲谷層の大型植物化石群を記載した。絶滅した21分類群を含む220分類群を同定し、下位よりSB-I～SB-VIの6分帯を設けた。SB-II帯とSB-V帯は、亜寒帯に分布する分類群と冷温帯に分布する分類群を含むことから、寒冷と考えられ、一方、SB-I帯とSB-III帯、SB-IV帯、SB-VI帯は、冷温帯に分布する分類群と亜熱帯や暖温帯に分布する分類群を含むことから、温暖な気候が考えられる。このうち、SB-III帯では亜熱帯に分布する分類群と冷温帯に分布する分類群が共存し、冬期は温暖で夏期が冷涼な海洋性気候が考えられる。SB-VI帯では、亜熱帯や暖温帯に分布する分類群が普通で、冷温帯に分布する分類群は稀なことから、SB-III帯よりも夏期の気温が高かったと考えられる。メタセコイアを含む植物群の消滅と出現の層位から、調査地域の菖蒲谷層は前期更新世に対比する

ことができる。サイクロカリア、シナサワグルミ近似種、オオバラモミの前期更新世後半の絶滅は、冬期の気候の寒冷化が原因と考えられる。メタセコイアの絶滅の原因として、冬期の漸移的な寒冷化に加えて、夏期の気候の温暖化と生育地の古地形の変化を考えた。

地名・地層名

Hashimoto City	橋本市
Ito-gun Koyaguchi-cho	伊都郡高野口町
Miyukitsuji	御幸辻
Shobudani	菖蒲谷
Tahara	田原
Jizoji tuff layer	地藏寺火山灰層
Miyukitsuji tuff layer	御幸辻火山灰層

Plate I Plant macrofossils from the Shobudani Formation (specimen number stored at the Osaka City University is in parentheses)

1. *Picea koribai*, cone, P-34 (AM214-1b-1).
 - 2~4. *Picea* sect. *Eupicea*, cones, 2. P-15 (AM195-13-1), 3. P-12 (AM192-67-1), 4. P-15 (AM195-6-1).
 5. *Picea maximowiczii*, cone, P-5 (AM185-3-1)
 - 6,7. *Pinus koraiensis*, seeds, P-37 (AM217-2-1, 2)
 8. *Pseudotsuga subrotunda*, cone, P-7 (AM187-2c-1)
 9. *Tsuga sieboldii*, cone, P-15 (AM195-10c-1)
 10. *Metasequoia glyptostroboides*, cone, P-14 (AM194-6-1)
 11. *Chamaecyparis pisifera*, cone, P-15 (AM195-1c-1)
 12. *Cryptomeria japonica*, cone, P-15 (AM195-2c-1)
 13. *Betula platyphylla*, fruiting bract, P-37 (AM217-1a-1)
 14. *Betula maximowicziana*, fruit, P-15 (AM195-35-1)
 15. *Fagus crenata*, cupule, P-15 (AM195-27a-1)
 16. *Fagus* aff. *hayatae*, cupule, P-41 (AM221-2a-1)
 17. *Ficus* cf. *pumila*, fruit, P-23 (AM203-83-1)
 18. *Cyclocarya paliurus*, endocarp, P-23 (AM203-56-1)
 19. *Pterocarya* aff. *stenoptera*, endocarp, P-14 (AM194-14-1)
 20. *Cinnamomum macropodum*, seed, P-18 (AM198-16-1)
 21. *Sabia japonica*, mesocarp, P-29 (AM209-30-1)
 22. *Actinidia* cf. *rufa*, seed, P-14 (AM194-27-1)
 23. *Evodia glauca*, seed, P-14 (AM194-42-1)
 24. *Premna japonica*, fruit, P-23 (AM203-2-1)
 25. *Acalypha australis*, seed, P-23 (AM203-12-1)
 26. *Polygonum pubescens*, fruit, P-30 (AM210-5-1)
 27. *Siegesbeckia* sp., fruit, P-27 (AM207-105-1)
- thin line=1 cm, thick line=1 mm.