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Journal of Geosciences, Osaka City University
Vol. 32, Art. 4, p. 91-121
March, 1989

Stratigraphical Subdivision and Pollen Zonation of the Middle and Upper Pleistocene in the Coastal Area of Osaka Bay, Japan

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(with 16 Figures and 2 Tables)

Abstract

In this study, the author clarified a standard stratigraphical succession ranged from Ma8 bed of the Osaka Group to the Nanba Formation in the offshore areas of Senshu and Kobe Port and onshore areas of Senshu, Osaka Port and Amagasaki City by means of pollen Stratigraphy, tephrochronology and absolute dating. The standard stratigraphical succession extending from the bottom of the sea to ca. 200 m. depth in Osaka Bay, which intercalates ten marine or brackish clay beds, four volcanic ash layers and thirteen volcanic glass horizons, is divided into four pollen zones namely *Haploxylon* Z., cf. *Pseudotsuga* Z., *Lagerstroemia* Z. and *Celtis-Aphananthe* Z. and is subdivided thirteen pollen assemblage zones (P1 to P15).

Stratigraphical successions in lowland and upland areas of Osaka City, Higashi-Osaka City and Itami City are also reexamined by means of the same methods.

The results of a synthetic correlation between submarine stratigraphical successions and lowland and upland ones from the Middle Pleistocene to the Holocene are summarized in this paper. And then, on the basis of the standard stratigraphical succession, several problems concerning the correlation and subdivision are discussed.

I. Introduction

Osaka sedimentary Basin is filled by late Cenozoic sediments and surrounded by moutainous ares of basement rocks. The Basin itself is geomorphologically divided into hilly lands, terracelike uplands, lowlands and the bottom of Osaka Bay.

In the hilly areas, the Pliocene-Pleistocene Osaka Group is divided into the Sennan Formation (lowermost part), the Kokubu Formation (lower part) and the Senpoku Formation (upper part) in ascending order. The Senpoku Formation is composed of alternations of marine clay beds (Ma3, Ma4,···Ma9 and Ma10 beds in ascending order) and freshwater sediments (ITIHARA, M. *et al.*, 1975).

In the upland areas, Middle and Upper Pleistocene Terrace deposits are distributed, and divided into High (the Harima and Kiyotani Formations), Middle (the Uemachi Formation) and Low (the Itami Formation) ones basing on the height of depositional surface above riverbed and the weathering degree (ITIHARA, M., 1960). The Uemachi Formation is interbeded with a marine bed in Uemachi, Hirakata and Akashi areas.

Under the ground in the lowland areas, late Cenozoic sediments are developed and are divided into five stratigraphic units, the Alluvial formation, "the Upper Pleistocene formations", the Osaka Group, "the Infra-Osaka Group (early Pliocene)" and the Kobe Group (Miocene) in descending order on the basis of deep drillings namely OD-1,··· OD-9 (IKEBE, N. *et al.*, 1970). Recently, YOSHIKAWA, S. *et al.* (1987) reveal that "the Infra-Osaka Group" and the Kobe Group in the OD-1 and OD-2 cores are assigined to the lower and lowermost parts of Osaka Group from lithologic and pollen stratigraphic data and a fission-track date. The information about "the Upper Pleistocene formations" is insufficient, and the stratigraphic correlation between Upper Pleistocene formations in upland and lowland areas is still open to discussion.

"The Upper Pleistocene formations", which are ranged from the upper limit of Ma10 bed to the lower limit of the Alluvial formation (Nanba Formation), intercalates two marine clay beds, namely Ma11 and Ma12 beds at OD-1 site in Osaka Port (IKEBE, N. *et al.*, 1970). Ma12 bed under the ground in the onshore areas is inferred to be correlated with the Itami clay bed in Itami upland (HUZITA, K. and MAEDA, Y., 1971) and the middle and upper parts of the Uemachi Formation in Uemachi upland (FURUTANI, M., 1978).

The informations about late Cenozoic sediments under the bottom of Osaka Bay, has been insufficient, with the exception of that about the Alluvial formation. Recently, the lithologic and pollen successions of the strata ranged from Ma12 bed to Alluvial formation in the "Port Island" of Kobe Port, were reported by FURUTANI, M. *et al.* (1983). HUZITA, K. and MAEDA, Y. (1984) also published the results of their research on the strata ranged from Ma10 bed to Alluvial formation in the same area. From 1981 to 1983 a synthetic research on the submarine strata ranged from the bottom of the sea to ca. 400 m. depth in offshore area of Senshu was carried out by NAKASEKO, K. *et al.* (1984). They suggested that the strata ranged from the Osaka Group to the Alluvial formation is divided into the Sennan-oki Formation and the Kukojima Formation in ascending order. After then, SUGANO, K. *et al.* (1986) suggested that "Akagashi bed" in the Kukojima Formation is correlative with Ma9 bed in Minato-B site near OD-1 site, but the correlation between the Sennan-oki and Kukojima Formations and OD-1 column is still an outstanding question.

In this paper, on the basis of lithological and pollen analytical investigations of the strata ranged Middle Pleistocene to Holocene in offshore and onshore areas of Osaka Bay, stratigraphical subdivision and pollen zonation are described in detail. Besides the stratigraphical successions are standardized and a synthetic correlation between coastal and inland areas is discussed.

II. Methods of study

1. Investigated areas and sites

Columnar sections and pollen diagrams are represented by boring core samples which were almost obtained by surveys for foundation works in eight areas surrounding

Osaka Bay. These areas which include thirty three sites in total are shown in Fig. 1. Ow1 site is the same locality as that of OD–1 in which IKEBE, N. *et al.* (1970) standardized the stratigraphical succession under the ground of Osaka Plain. On6 site is the stratotype of the Uemachi Formation (Middle terrace deposits).

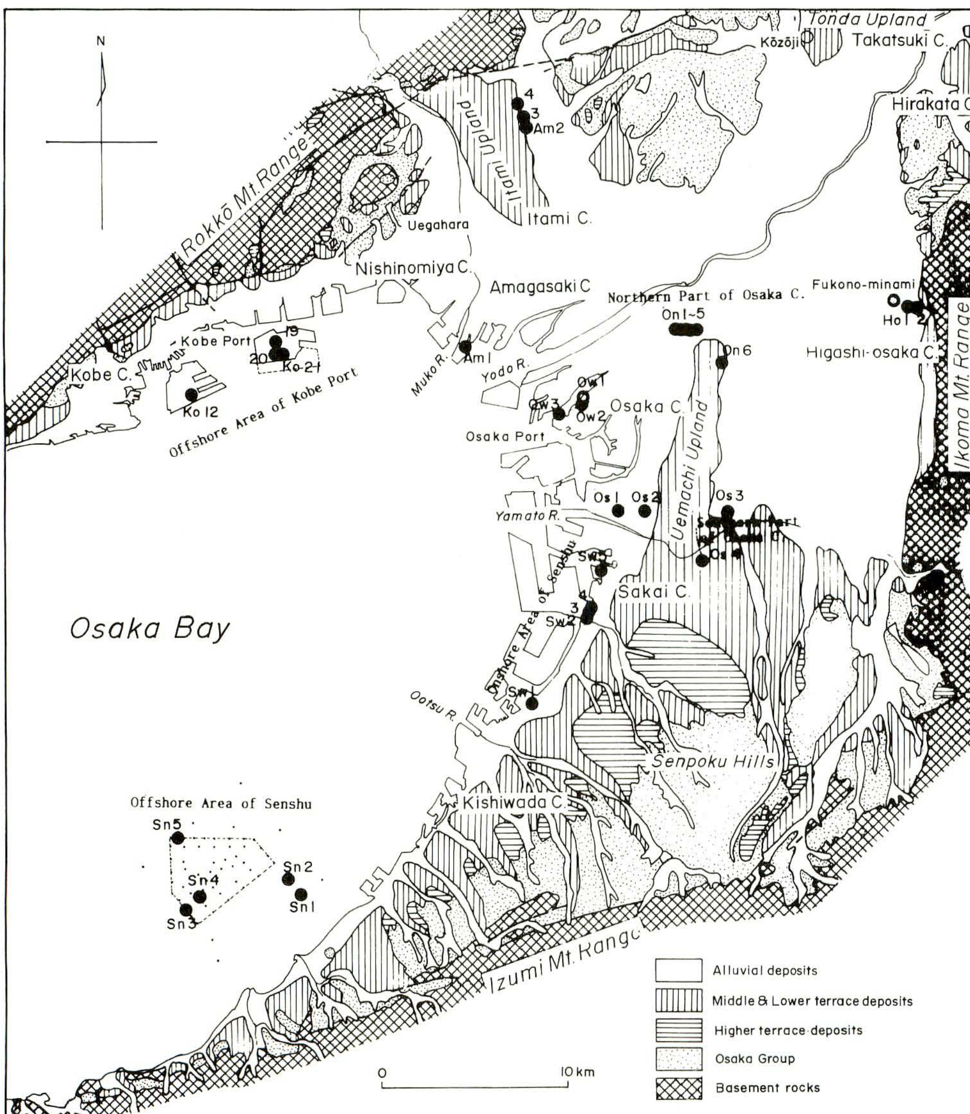


Fig. 1. Geologic map and investigated sites (simplified after ITIHARA *et al.*, 1966). Ko: Offshore of Kobe Port, Am: Onshore and inland in Amagasaki and Itami City, On: Lowland and upland in northern part of Osaka City, Ow: Onshore of Osaka Port, Os: Lowland and upland in southern part of Osaka and Sakai City, Sw: Onshore of Senshu area, Sn: Offshore of Senshu area.

2. Preparation

The procedure to preparate pollen slide samples for microscopic work is as follows: Dispersion by KOH solution, wet-sieving by 125 meshes (1/8 mm.), extraction of colloids, extraction of silicates, floatation of plant residues by heavy solution (gravity=1.85), dehydration by acetolysis method and mounting of slide. So far, the extraction of colloidal clay grains smaller than pollen grains was a troublesome process in pollen analytical technique. The author made use of the vibrating micro-mesh filter which is possible to eliminate completely fine grains smaller than 5 μm. size in short time for this process.

3. Pollen zonation and correlation

Pollen grains which are produced by trees and grasses are supplied from vegetations in river basins of hinterlands behaving like as silt grains (MULLER, J., 1959). Vegetational change caused by climatic change is shown as compositional change of pollen assemblage in sediments. Zonation of pollen compositional transition means to divide stratigraphic successions into characteristic pollen assemblage zones. In the case of the same sedimentary basin, each pollen compositional transition is expected to correspond to that in the different areas, so that the stratigraphic correlation is possible by means of pollen assemblage zones. For example, the Nanba Formation was divided into six pollen assemblage subzones which are correlative with the corresponding subzones in different three areas on the basis of characteristic dominant taxa (FURUTANI, M., 1979). Besides, volcanic glass horizon (Yoko-oji volcanic ash layer) were recognized in a pollen subzone. Furthermore, FURUTANI, M. (1984) showed that fourteen pollen assemblage zones ranged from the upper Osaka Group to the Nanba Formation are correlative with the corresponding zone in ten sites in offshore area of Senshu.

III. Stratigraphical subdivision and pollen zonation

1. Osaka Port area

In Ow1 (OD-1; bored 907 m.) site, the Osaka Group ranged in depth from 115 m. to 690 m. is interstratified with eleven marine clay beds which are correlated with Ma0, Ma1,...Ma10 beds of the standard succession in hilly lands (IKEBE, N. *et al.*, 1970). The deposits between the upper limit of Ma10 bed and the lower limit of the Nanba Formation which were named "Upper Pleistocene formations" by them, are interstratified with two marine clay beds namely Ma11 and Ma12 beds.

TAI, A. (1966a; 1966b) divided the Osaka Group in Ow1 site into two pollen fossil zones i.e., *Metasequoia* Zone and *Fagus* Zone. Furthermore, Fagus Zone which is equivalent to Ma3 to Ma10 beds was subdivived into four subzones i.e., E (including Ma3 bed and Ma4 bed), F (including Ma5 bed and Ma6 bed), G (including Ma7 bed and Ma8 bed) and H (including Ma9 bed) subzones (TAI, A., 1973).

In Ow2 (Minato-B; bored 465 m.) site, its geologic column is correlated with the strata ranged from Ma3 bed to Ma12 bed in Ow1 site. "Azuki Tuff" interbeded in

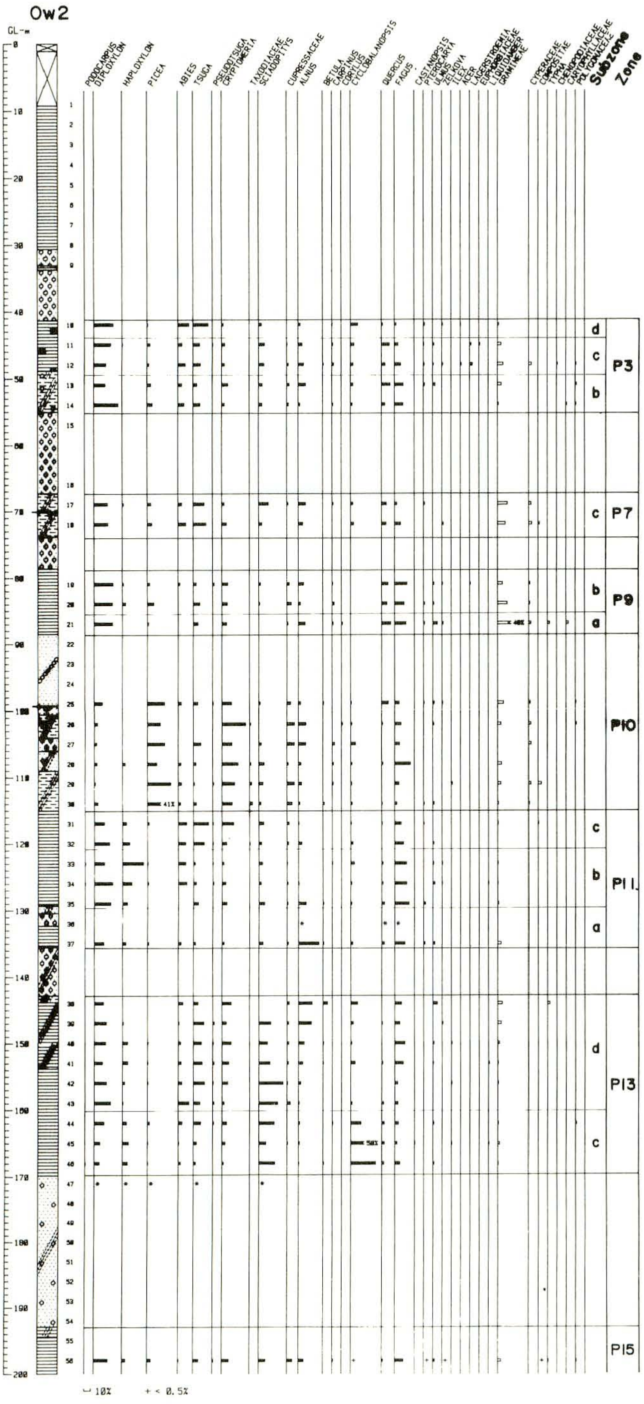


Fig. 2. Pollen diagram and zonation in site Ow2 in onshore of Osaka Port.

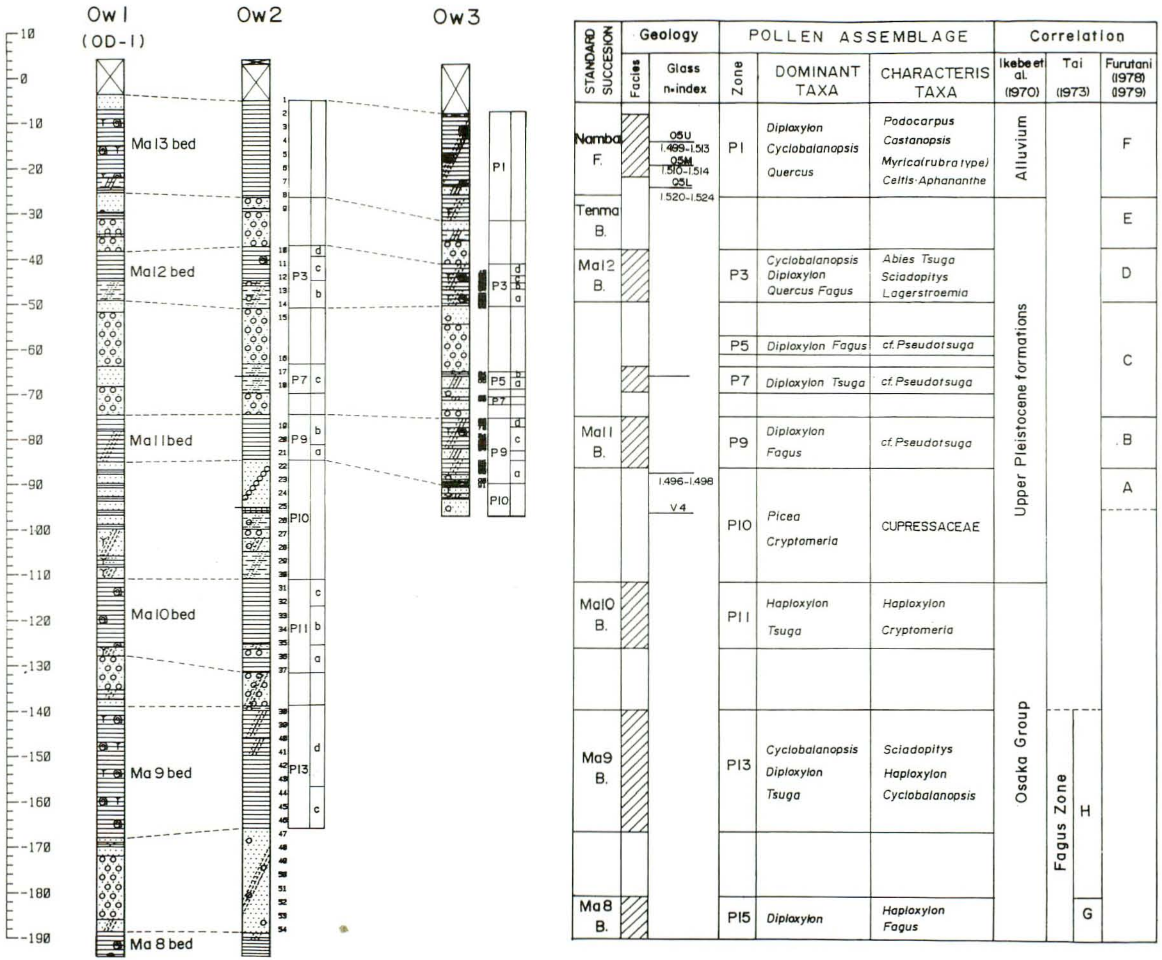


Fig. 3. Lithologic and pollen successions in onshore of Osaka Port.

Ma3 bed is discovered in depth 412.6 m. A marine bed was newly revealed between Ma11 bed and Ma12 bed, and a volcanic ash layer (V4) was recognized between Ma10 bed and Ma11 bed (SUGANO, K. *et al.*, 1986). The strata range from Ma8 bed to Ma12 bed are divided seven pollen assemblage zones namely from P15 Zone to P3 Zone as shown in Fig. 2. P13 Zone is particularly characterized by the dominace of *Cyclobalanopsis* in its lower part, and is equivalent to Ma9 bed in Ow1 site. P10 Zone is equivalent to fresh water deposits between Ma10 bed and Ma11 bed, and is characterized by the appearance of *Picea* and *Cryptomeria*. P7 Zone is equivalent to a marine bed between Ma11 bed and Ma12 bed.

In Ow3 site, Ma11 bed and Ma12 bed are correlated with ones in Ow1 site. The volcanic glass horizons are discovered in the middle and lower parts of Ma11 bed and in the lower and middle parts of Nanba Formation (FURUTANI, M., 1978). The strata which range from fresh water deposits below Ma11 bed to the Nanba Formation are divided into six pollen assemblage zones. P9 and P3 Zones in this site are correlative with the corresponding zones in Ow2 site as shown in Fig. 3.

The pollen assemblages in the above-mentioned three sites, indicated that P15, P13 and P11 Zones are characterized by the continuous appearance of *Haploxylon,* P9, P7 and P5 Zones are characterized by the appearance of cf. *Pseudotsuga,* P3 Zone is characterized by the appearance of *Lagerstroemia* and Euphorbiaceae (cf. *Sapium*) and P1 Zone is characterized by the appearance of *Castanopsis, Myrica* (*M. rubra* type) and *Celtis-Aphananthe*. Besides, the dominance of *Cyclobalanopsis* is recognized in P13, P3 and P1 Zones.

2. Onshore area of Senshu

In the coastal area of Senshu, the deposits above 60 m. depth under the ground which is composed of alternating beds of sand, gravel and clay, are interstratified with six marine beds. The uppermost marine bed is correlative with the Nanba Formation. The strata which are ca. 100 m. in maximum thickness are typically divided into eight pollen assemblage zones in Sw3 and Sw5 sites as shown in Fig. 4a, b.

The characteristics of pollen assemblages in P1, P3, P9, P10 and P13 Zones are identical with those of the corresponding zones in Ow2 site. P4 Zone between P5 Zone and P3 Zone is characterized by the appearance of *Cryptomeria* and *Picea*. From P15 Zone to P3 Zone, remarkable taxa in pollen assemblages are *Haploxylon* (P15 $\sim$ P11 Zones), cf. *Pseudotsuga* (P9 $\sim$ P5 Zones) and *Lagerstroemia* (P3 Zone) in the same way as zones in Ow2 and Ow3 sites as shown in Fig. 5.

3. Offshore area of Senshu

The deposits from the bottom of the sea down to ca. 400 m. depth are interstratified with fourteen marine or brackish clay beds, which were named the Senshu-Oki Group by NAKASEKO, K. *et al.* (1984) in offshore area of Senshu. They identified a volcanic ash layer at 190.5 m. depth in 56–9 site and one at 332.2 m. depth in Sn1 (57–30) site as "Azuki Tuff" in the Senshu-Oki Formation by means of X-ray and EDX analysis.

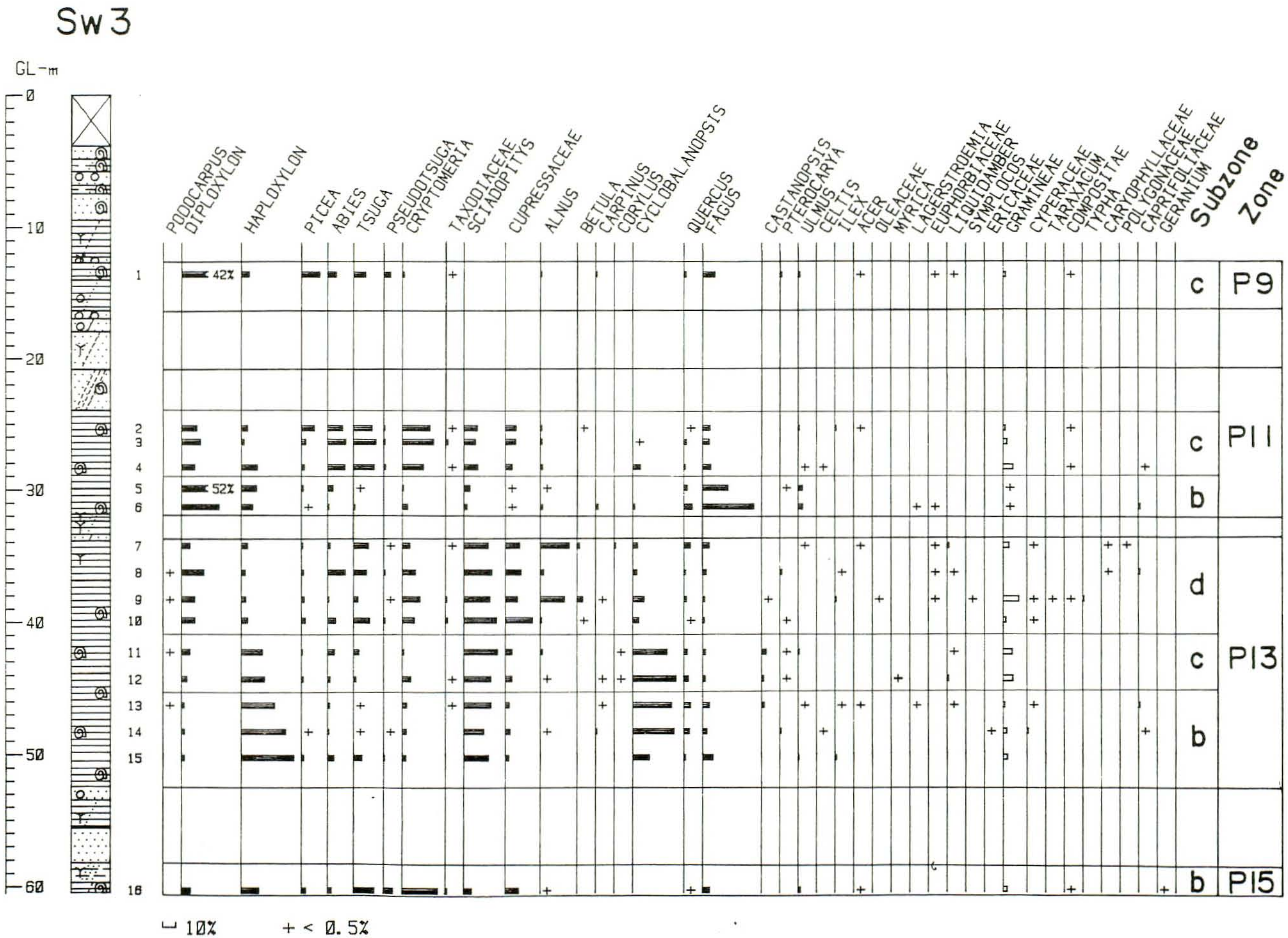


Fig. 4a. Pollen diagram and zonation in Sw 3 site in onshore of Senshu.

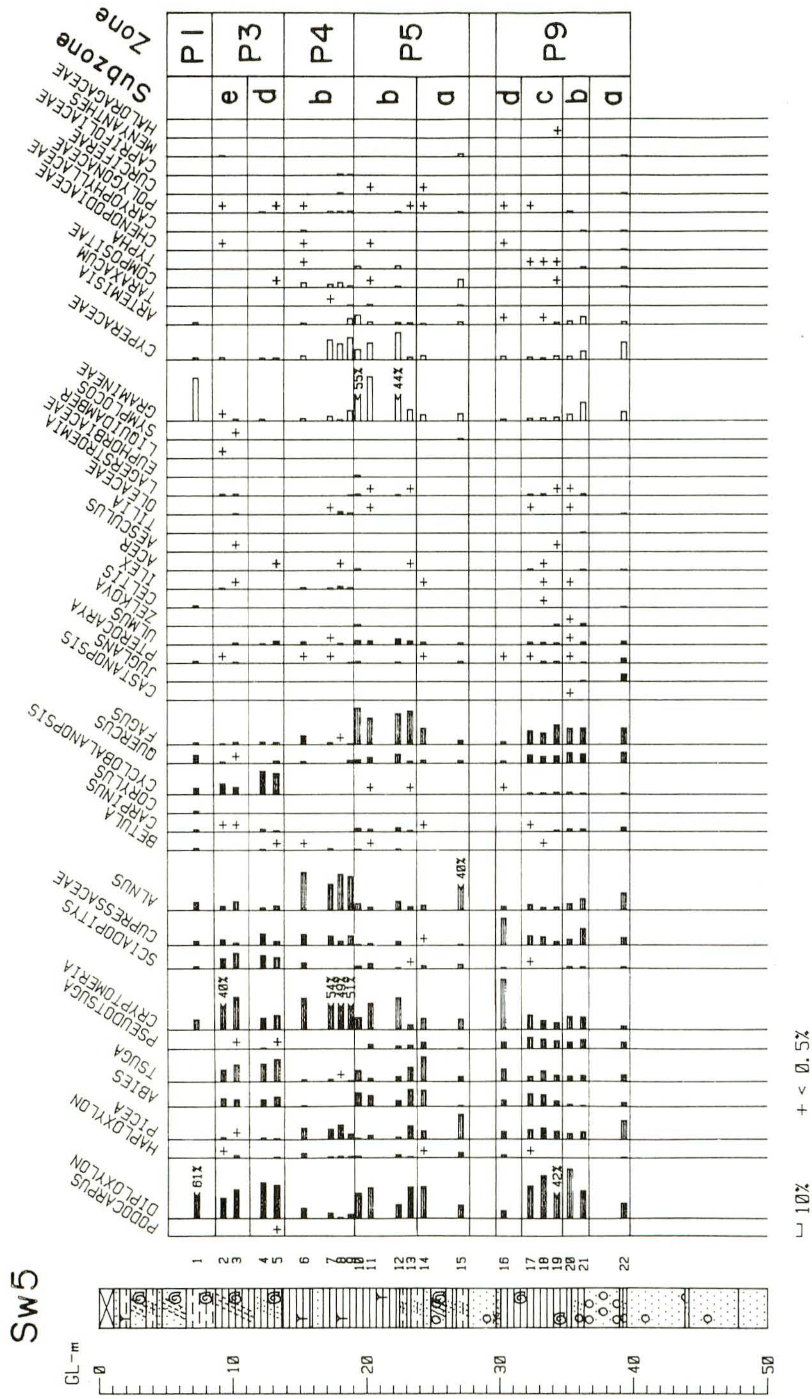


Fig. 4b. Pollen diagram and zonation in Sw5 site in onshore of Senshu.

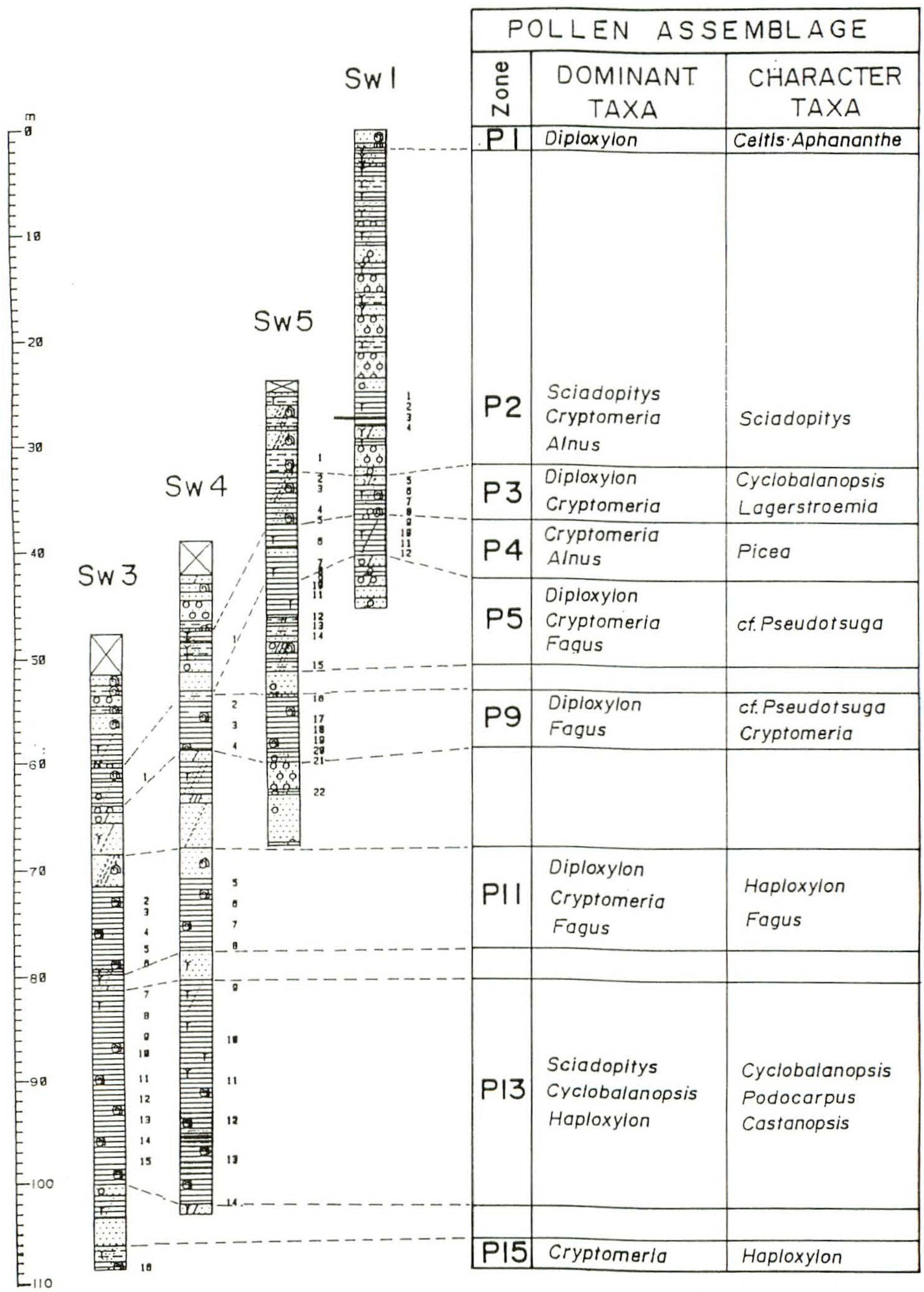


Fig. 5. Lithologic and pollen successions in onshore of Senshu.

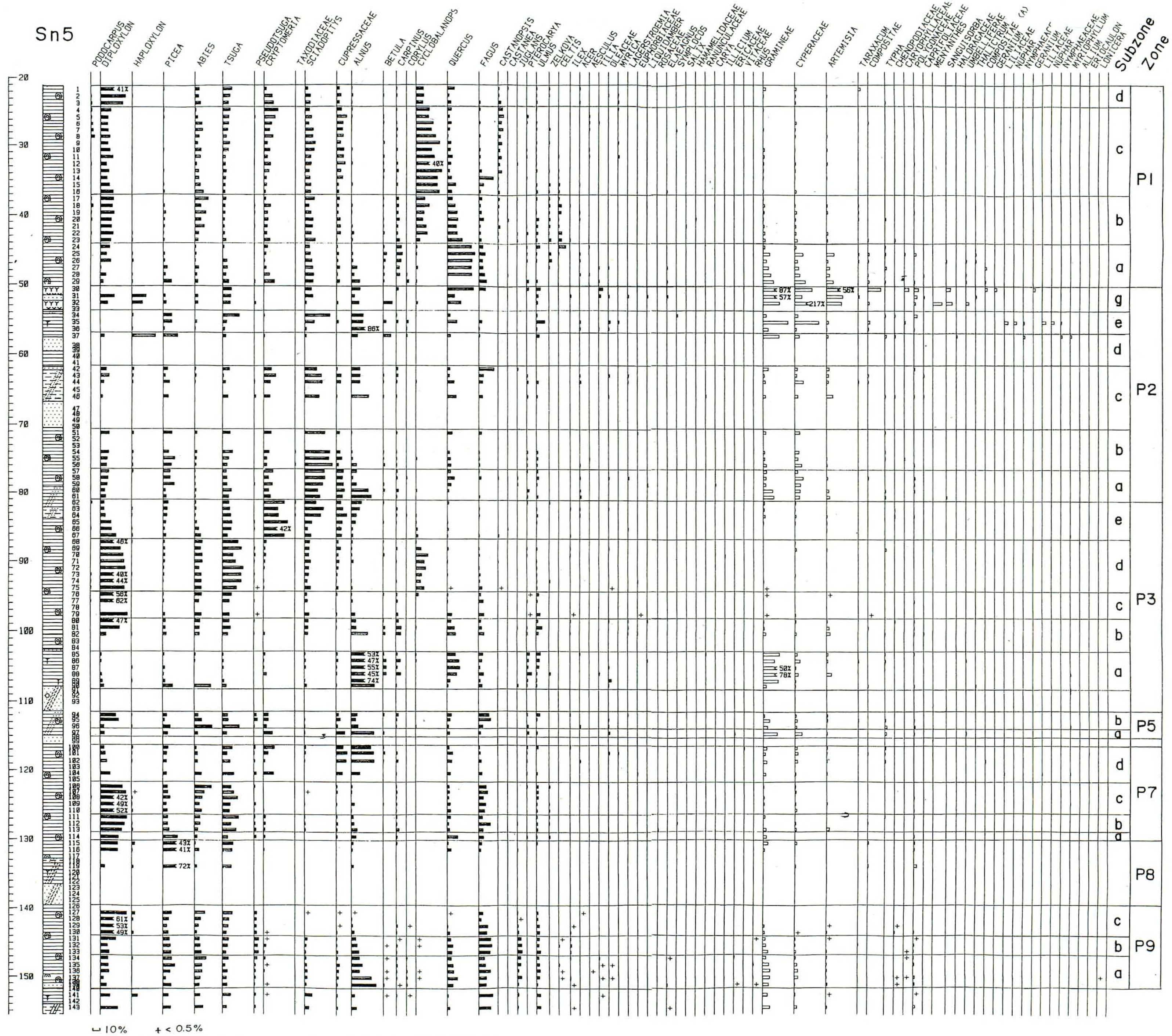


Fig. 6. Pollen diagram and zonation in Sn5 site in offshore of Senshu.

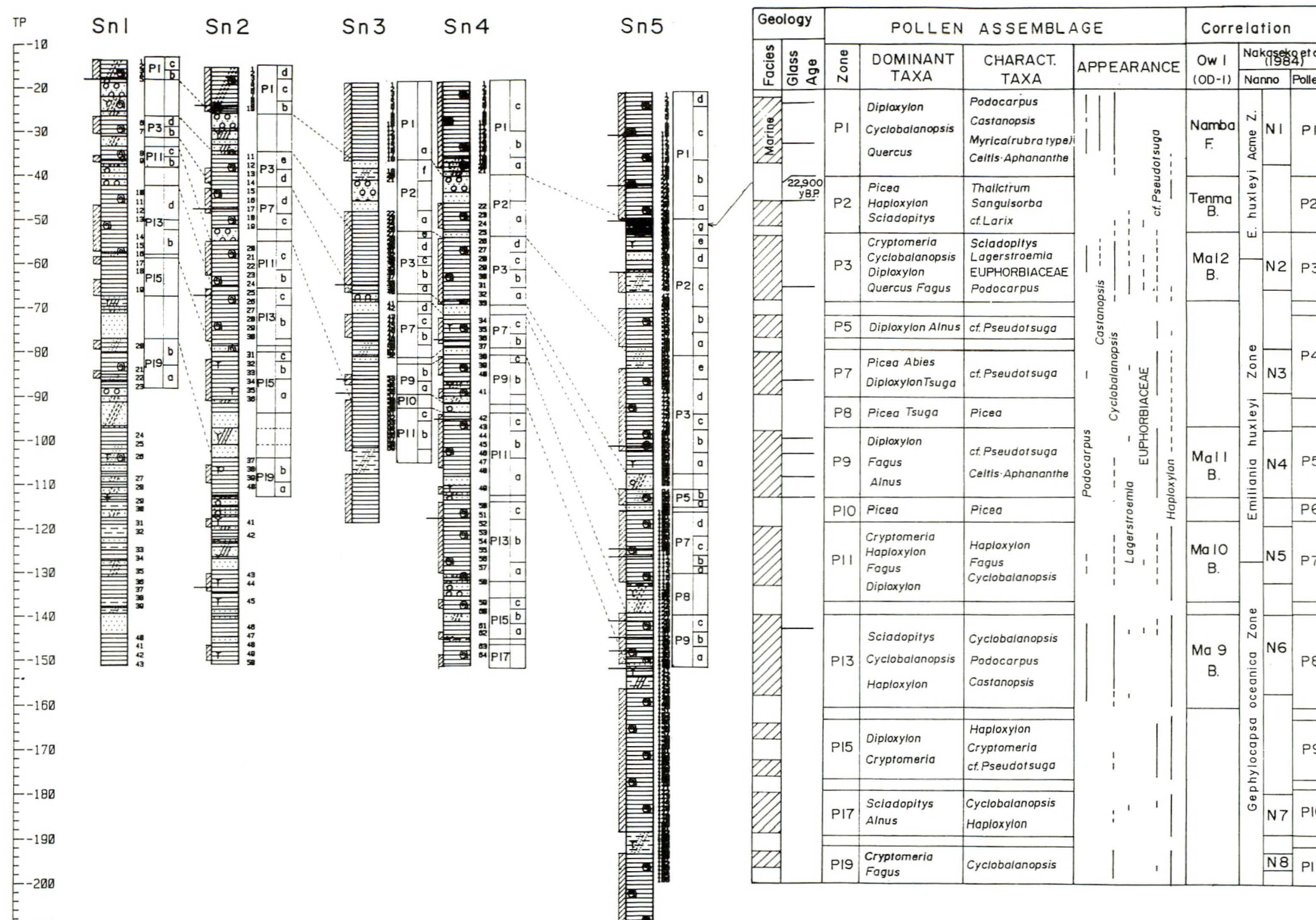


Fig. 7. Lithologic and pollen successions in offshore of Senshu.

The Kukojima Formation which was inferred to cover uncomformably the Sennan-Oki Formation, was divided eleven lithologic units namely from "Basal conglomerates" to "Akahoya bed", and was subdivided eight nannofossil zones i.e., from N1 to N8 Zones by them. *Emiliania huxleyi* first appears in the middle horizon of N5 Zone and *Pseudoemiliania lacunosa* last occurs in the middle horizon of N8 Zone (OKAMURA, M. and YAMAUCHI, M., 1984).

The strata ranged from the bottom of the sea to ca. 135 m. depth in Sn5 (57–30) site, which are interstratified with seven marine or brackish clay beds, are divided into seven pollen assemblage zones namely from P9 Zone to P1 Zone as shown in Fig. 6. On the basis of close investigations in the five sites, it is concluded that the strata range from the bottom of the sea to ca. 210 m. depth which are interstratified twelve marine or brackish clay beds, are divided thirteen pollen assemblage zones as shown in Fig. 7. The characteristics of pollen assemblages in P1, P3, P9, P10, P13 and P15 Zones are identical with the corresponding zones in Ow2 site. P5 and P7 Zones are characterized by the appearance of cf. *Pseudotsuga*. P2 Zone between P3 Zone and P1 Zone is characterized by the dominance of *Picea*. From P19 Zone to P1 Zone, remarkable taxa in pollen assemblages are *Haploxylon* (P19～P11 Zone), cf. *Pseudotsuga* (P9～P5 Zone), *Lagerstroemia* (P3 Zone) and *Celtis-Aphananthe* (P1 Zone) in the same way as zones in Ow2 and Ow3 sites.

4. Offshore area of Kobe

In the reclaimed islands in offshore area of Kobe Port, the deposits above ca. 160 m. depth under the bottom of the sea, are interstratified with six marine or brackish clay beds. Three volcanic ash layers (V1～V3) and nine volcanic glass horizons (G1～G9) are recognized in those strata in Ko 21 site as shown in Table 1. Thirteen radiocarbon dates, which range from 14,050±280 y.BP to 55,700±3,300 y.BP, are determined by means of accelerator method and β-counting method in Ko21 site as shown in Table 2.

The strata range from the bottom of the sea to ca. 160 m. depth are divided into seven pollen assemblage zones. Pollen zonation from P3 Zone to P9 Zone in Ko19 site is shown in Fig. 8. The characteristics of pollen assemblages in P1 Zone and P3 Zone are identical with the corresponding zones in Ow2 and Ow3 site. P5, P7 and P9 Zones are characterized by the appearance of cf. *Pseudotsuga*. In these three zones, P9 Zone is most similar to the corresponding Zone which is equivalent to Ma11 bed in Ow3 site. Furthermore, G8 and G9 volcanic glass horizons are correlative with the volcanic glass horizons in the middle and lower parts of Ma11 bed in Ow3 site from the data of glass refractive index (1.498–1.501).

Pollen assemblages in Ko12, Ko19 and Ko20 sites, are similar to the corresponding zones in Ko21 site as shown in Fig. 9. It should be notice that the deposits being equivalent to P2 Zone which is interstratified with a thin marine bed, are characterized by the dominance of *Sciadopitys* in their lower part and characterized by the dominance of subarctic forest pollens including *Haploxylon* and *Picea* in their upper part.

Table 1. Volcanic ash layers and volcanic glass horizons in Ko21 site. Shape of glass is as follows: H-type is consisted large broken bubble wall, T-type is consisted fibrous bubble, H-type is intermediate between H and T types after YOSHIKAWA, S. (1984).

Name	Depth TP - m.	Specimen	Refract. index	Shape
G 1	29.15- 29.45	glass	1.509 - 1.513	H
G 2	35.15- 35.45	glass	1.497 - 1.501	H
G 3	37.15- 37.40	glass	1.499 - 1.501	H
V 1	96.40- 96.42	ash	1.514 - 1.516 1.534 - 1.544	C~H
V 2	97.37- 97.39	ash	1.513 - 1.519	C~H
G 6	116.15-116.45	glass	1.498	C
V 3	125.10-125.13	ash	1.504 - 1.510	T
G 7	128.95-128.98	glass	1.495 - 1.499	H
G 8	153.15-153.18	glass	1.498 - 1.500	H
G 9	156.35-156.38	glass	1.498 - 1.501	H

Table 2. Radiocarbon dates in Ko21 site.

Specimen No.	Depth TP - m.	Radiocarbon date (yr.BP)	Dating No.
1	34.15- 34.45	14,050± 280	NUTA-246
2	35.15- 35.40	19,010± 410	NUTA-247
2'	35.15- 35.40	15,030± 210	I- 13950
3	38.15- 38.45	24,190± 790	NUTA-248
4	41.15- 41.20	25,170± 650	NUTA-249
4'	41.15- 41.20	24,060±1,400	I- 13951
5	49.15- 49.45	25,370± 680	NUTA-250
5'	49.15- 49.45	25,090±1850	I- 13592
6	55.15- 55.45	25,730± 630	NUTA-251
7-1 7-2	63.15- 63.45 63.15- 63.45	50,600±2,400 55,700±3,300	NUTA-398 NUTA-252
8-1 8-2	69.15- 69.45 69.15- 69.45	37,000±2,600 40,500±3,600	NUTA-399 NUTA-253

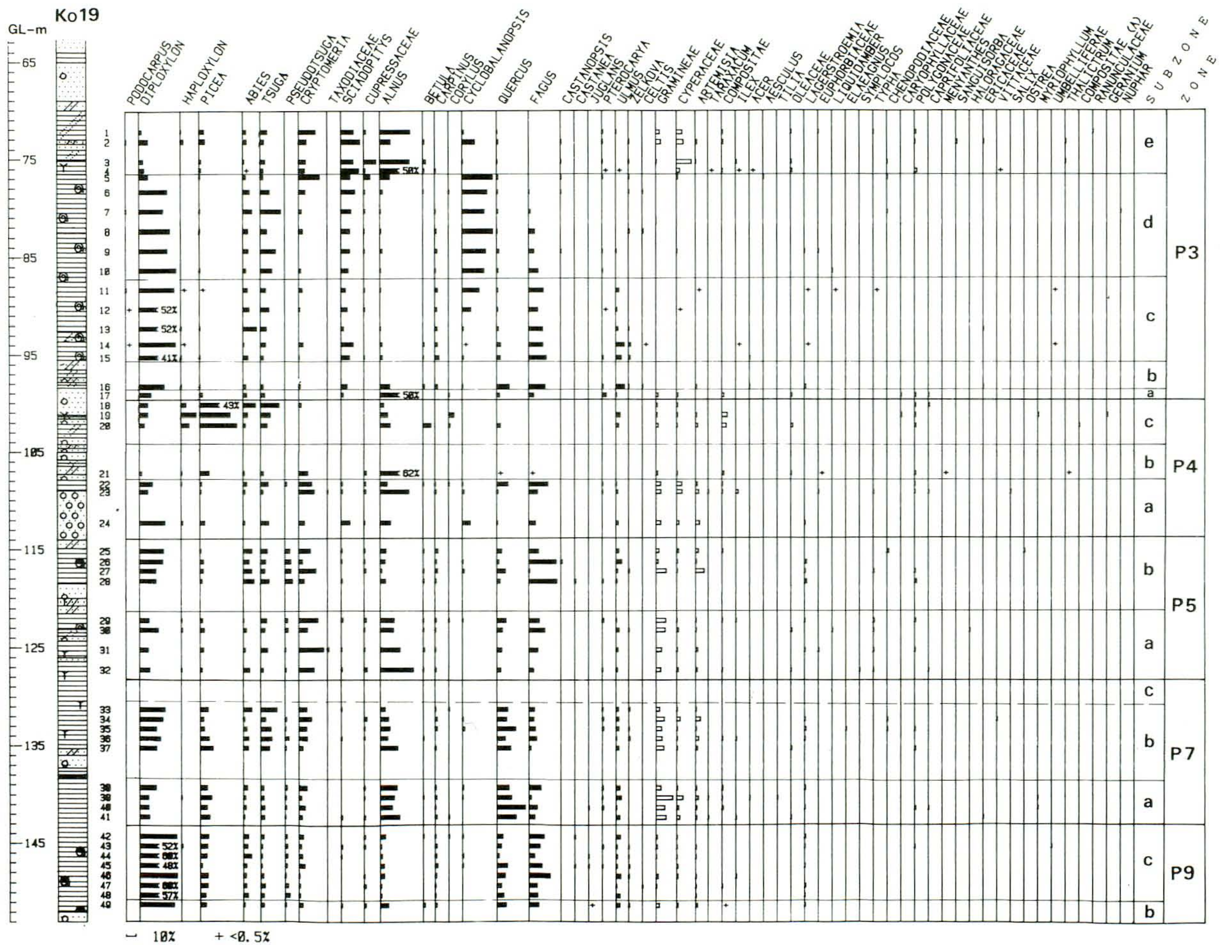
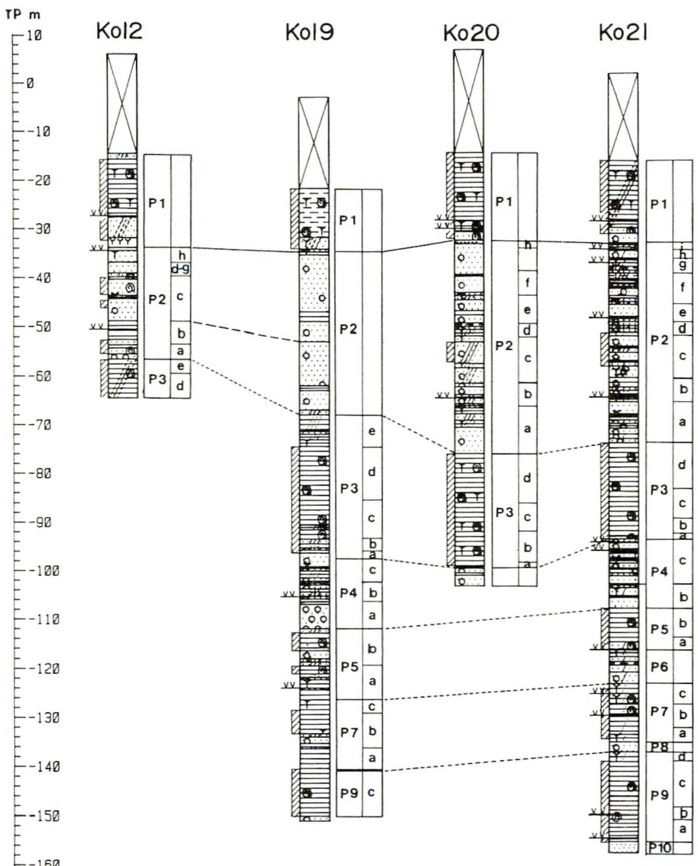


Fig. 8. Pollen diagram and zonation in site Ko19 in offshore of Kobe Port.



Geology					POLLEN ASSEMBLAGE			Correlation	
Facies	DIATOM Zone	DIATOM Ecology	Tuff, Glass (n=index)	Age (^{14}C y.BP)		DOMINANT TAXA	CHARACTERIS TAXA	Watanabe et al. (1983)	Huzita-Maeda (1984)
	D1	Ma>Br	G1 1.509-1.513	14,050	P1	*Diploxylon*, *Cyclobalanopsis*, *Quercus*	*Podocarpus*, *Castanopsis*, *Myrica(rubra type)*, *Celtis-Aphananthe*	Alluvial clay	Uppermost M.
	D2	Fr	G2 1.497-1.501, G3 1.499-1.501, G4	19,010, 24,190, 25,170, 25,370	P2	*Haploxylon*, *Picea*, *Tsuga*, *Quercus*	cf. *Larix* *Betula*, *Myrica(gale type)*, *Sanguisorba*, *Geranium*, *Menyanthes*	Upper Dilluvial alternation	Upper M. intercalated Ma12 B.
	D3	Ma>Br		25,730		*Sciadopitys*, *Cryptomeria*	*Betula*, *Juglans*		
	D4	Fr	G5	55,700		*Sciadopitys*, *Alnus*	*Lagerstroemia*, EUPHORBIACEAE		
	D5	Ma>Br	1.514-1.516, 1.534-1.544, V1		P3	*Diploxylon*, *Abies*, *Tsuga*	*Cyclobalanopsis*, *Sciadopitys*, *Lagerstroemia*, EUPHORBIACEAE	Dilluvial clay	
	D6	Fr	V2 1.513-1.519		P4	*Picea*, *Alnus*	*Betula* *Geranium*, COMPOSITAE, *Haploxylon*	Lower Dilluvial alternation	Middle M. intercalated Ma11 B.
	D7	Br>Ma>Fr	G6		P5	*Diploxylon*, *Cryptomeria*	cf. *Pseudotsuga*, *Celtis-Aphananthe*		
	D9	Br>Ma>Fr	V3 1.504-1.510, G7		P7	*Diploxylon*, *Picea*, *Tsuga*	cf. *Pseudotsuga*, *Picea*		
	D11	Br>Ma>Fr	G8 1.498-1.500, G9 1.498-1.501		P9	*Diploxylon*, *Alnus*, *Fagus*	cf. *Pseudotsuga*, *Picea*, *Cryptomeria*		Lower M. intercalated Ma10 B.
					P10	*Picea*	*Picea*		

Fig. 9. Lithologic and pollen successions in offshore of Kobe Port.

5. Onshore area of Amagasaki

In the coastal area of Amagasaki, the deposits above ca. 65 m. depth under the ground, are composed of Ma12 bed, the Tenma Formation and the Nanba Formation (FURUTANI, M., 1978). They are divided into three pollen assemblage zones i.e. P1, P2 and P3 Zones.

IV. Standard stratigraphy in the coastal areas

1. Marine and brackish beds

As mentioned above, marine and brackish beds which fill the role of key marker in the case of subdivision and correlation are interstratified with freshwater deposits. These beds are as follows; six beds ranging from Ma8 bed to the Nanba Formation exist in onshore area of Osaka Port, six beds exist in onshore area of Senshu, twelve beds exist in offshore area of Senshu, six beds exist in offshore area of Kobe Port and two beds exist in onshore area of Amagasaki.

Ma9 bed, Ma10 bed, Ma12 bed and the middle part of the Nanba Formation are abundant in marine microfossils in Ow2 site (SUGANO, K. *et al.*, 1986). On the other hand, in offshore area of Kobe Port four beds with the exception of Ma12 bed and the Nanba Formation are rich in brackish and freshwater diatoms.

Pollen assemblage zones i.e., P15, P13, P11, P9, P7, P3 and P1 Zones are equivalent to brackish or marine beds in those areas. P5 Zone is also equivalent to a brackish bed in offshore area of Kobe Port.

2. Volcanic ash and absolute age

Although more than twelve volcanic ash layers or glass horizons are recognized in the strata in onshore and offshore areas, traceable ones are limited to two or three as shown in fig. 10. A volcanic glass horizon in the lower part of Ma11 bed in Ow3 site is correlative with G9 horizon in Ko21 site and a horizon in the lowermost part of a maine bed being equivalent to P9 Zone in Sn5 site. A volcanic ash layer in the middle part of a marine bed between Ma11 bed and Ma12 bed in Ow2 site is correlative with V3 layer in Ko21 site and a horizon in the middle part of a marine bed being equivalent to P7 Zone in Sn5 site. G3 glass horizon in Ko21 site is correlative with a glass horizon in coaly bed which was determined as 22,900$\pm$2,070 y.BP by radiocarbon dating, being equivalent to g Subzone in P2 Zone in Sn5 site. G3 glass horizon in Ko21 site is correlative with Heian-jingu volcanic ash layer (YOSHIKAWA, S. *et al.*, 1986) judging from refractive index of glass and its absolute age. G1 glass horizon in Ko21 site which is correlative with Yoko-oji volcanic ash layer (YOSHIKAWA, S. *et al.*, 1986) is widely distributed in the middle lower part of the Nanba Formation.

The first appearance of *Emiliania huxleyi*, which is assigned to an age of 270,000 y.BP, was recognized in the middle horizon of a marine bed which is equivalent to P11 Zone in offshore area of Senshu (NAKASEKO, K. *et al.*, 1986). Radiocarbon dates of the

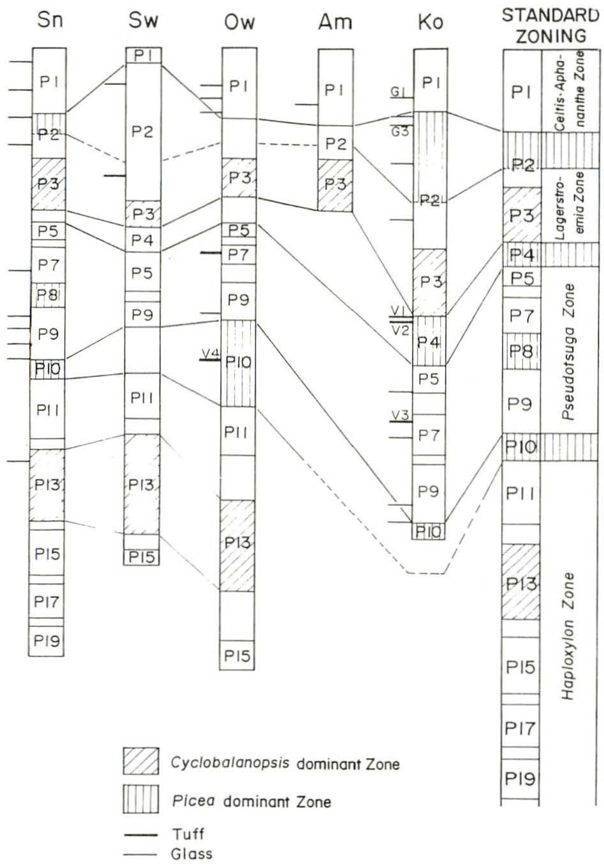


Fig. 10. Correlation by pollen zones in offshore and onshore areas in Osaka Bay.

deposits corresponding to P2 Zone in offshore area of Kobe Port, are determined as the details are described later.

3. Pollen stratigraphy

According to pollen stratigraphical study, four remarkable taxa are found in Middle and Late Pleisticene and Holocene deposits in the coastal area of Osaka Bay. They are *Haploxylon,* cf. *Pseudotsuga, Lagerstroemia, Celtis-Aphananthe.* It is possible to divide the deposits into four stratigraphical zones besed on their characteristic appearances as shown in Fig. 10. *Haploxylon* in zones ranged from P11 Zone to P19 Zone should be distinguished from the same genus of subarctic forest element, whereas *Haploxylon* in P10 Zone, P4 Zone and the upper part of P2 Zone should be excepted from these zones because of the dominance of subarctic forest pollens e.g. *Picea.* The former *Haploxylon,* which increase together with warm temperate forest pollens e.g. *Cyclobalanopsis,* is assumed to correspond to *Pinus* subgen. *Haploxylon armandi* (MINAKI, M., 1983), and the

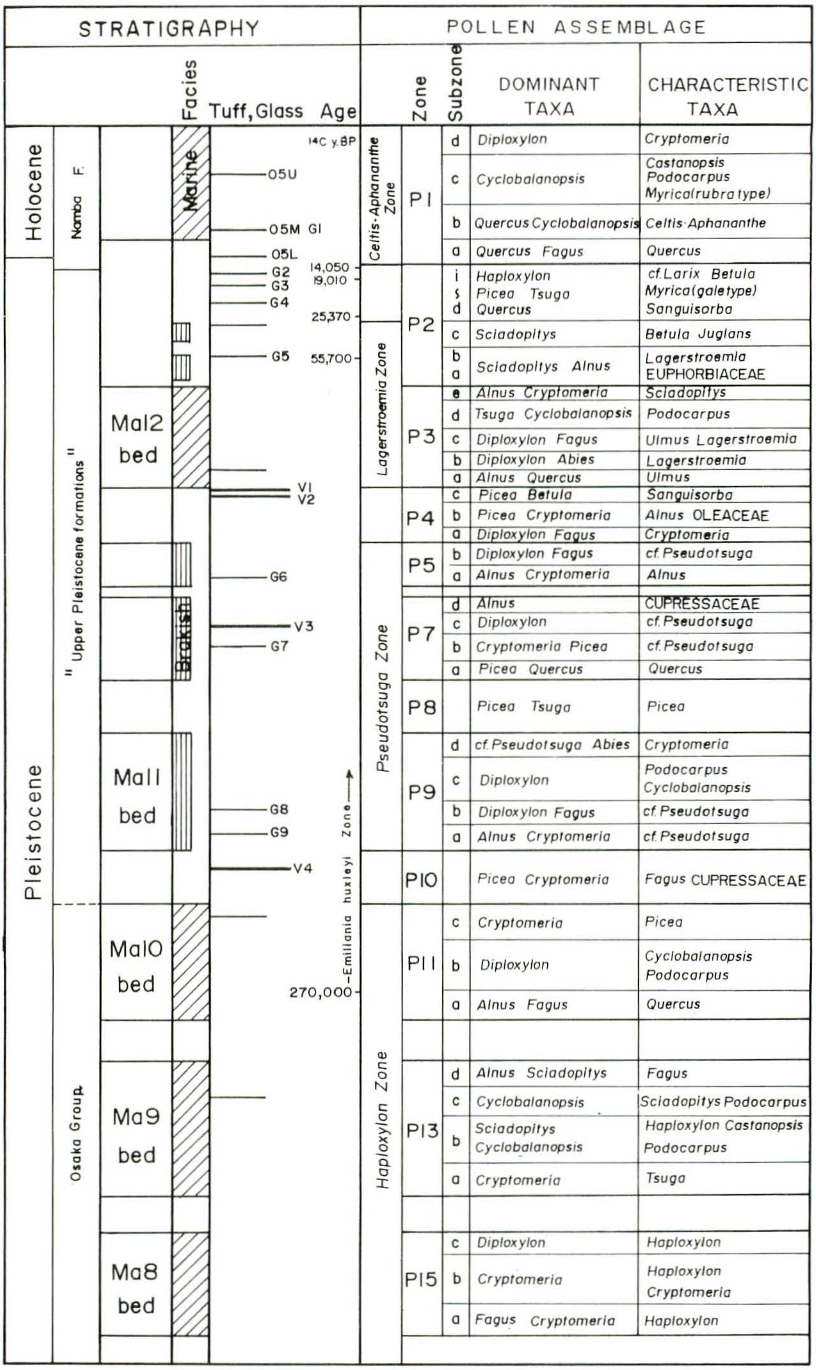


Fig. 11. Standard succession in offshore and onshore areas in Osaka Bay.

latter is assumed to correspond to *Pinus* subgen. *Haploxylon koraiensis*.

P13 Zone which is equivalent to Ma9 bed in Ow2 site is characterized by the remarkable dominance of *Cyclobalanopsis* in its lower part. P3 Zone and P1 Zone are also characterized by the dominance of *Cyclobalanopsis* accompanied by *Podocarpus* and *Castanopsis* in their middle part.

On the basis of the above mentioned evidences in lithology, chronology and pollen stratigraphy, it is possible to correlate twelve pollen assemblage zones with those in five coastal areas of Osaka Bay. The standard stratigraphy from the Middle Pleistocene to the Holocene is summarized as shown in Fig. 11.

V. Stratigraphic correlation

1. Stratigraphic correlation between coastal areas and inland areas

Stratigraphic subdivision and pollen zonation in inland areas was studied in the Uemachi upland (On6 site) and the Itami upland (Am2 ~ 4 sites) by FURUTANI, M. (1978), in the Kawachi lowland (Ho1 and 2 sites) by FURUTANI, M. (1979) and is newly studied in the southern part (Os1 ~ 3 sites) and in the northern part (On 1 ~ 5 sites) of Osaka City by means of the same method.

The results of pollen zonation and stratigraphic correlation between coastal areas and inland areas are summarized as shown in Fig. 12.

Several problems on stratigraphic subdivision and correlation are discussed as followings.

1-1. The uppermost part of Osaka Group, the Middle Pleistocene

Ma9 bed under the bottom of Osaka Bay is particularly characterized by the dominance of warm temperate forest pollens including *Podocarpus, Castanopsis* and *Cyclobalanopsis*. Ma9 bed should be taken notice as a remarkable marine key bed in the upper part of Osaka Group, because of its pollen assemblage.

On the other hand, MIKI, S. *et al.* (1957) reported the warm temperate forest plant remains composed of *Myrica rubra, Quercus* subgen. *Cyclobalanopsis glauca, Q. phillyraeoides, Distyllium racemosum, Sciadopitys verticilata* and so on at Uegahara in Nishinomiya hills. In Hirakata hills, the plant remains composed of *Quercus* subgen. *Cyclobalanopsis gilva, Syzygium buxifolium* and so on were found in Shinkori bed (TAKAYA, Y. and ITIHARA, M., 1961) and a pollen composition including *Cyclobalanopsis* were reported in the same bed (TAI, A., 1963). ITIHARA, M. *et al.* (1966) correlated "*Syzygium* bed" in Hirakata hills with Ma8 bed in the Osaka Group.

The pollen composition in Ma9 bed (P13 Zone) in coastal areas is similar to the composition of plant remains at Uegahara namely "*Syzygium* Flora" (KOKAWA, S., 1961), whereas the pollen composition in Ma8 bed (P15 Zone) under the ground is characterized by the dominance of *Fagus* and *Cryptomeria*. Accordingly, the horizon of "*Syzygium* Flora" is not correlated with Ma8 bed, but with Ma9 bed under the ground.

The pollen compositions of P14 Zone between Ma8 bed and Ma9 bed and of P10

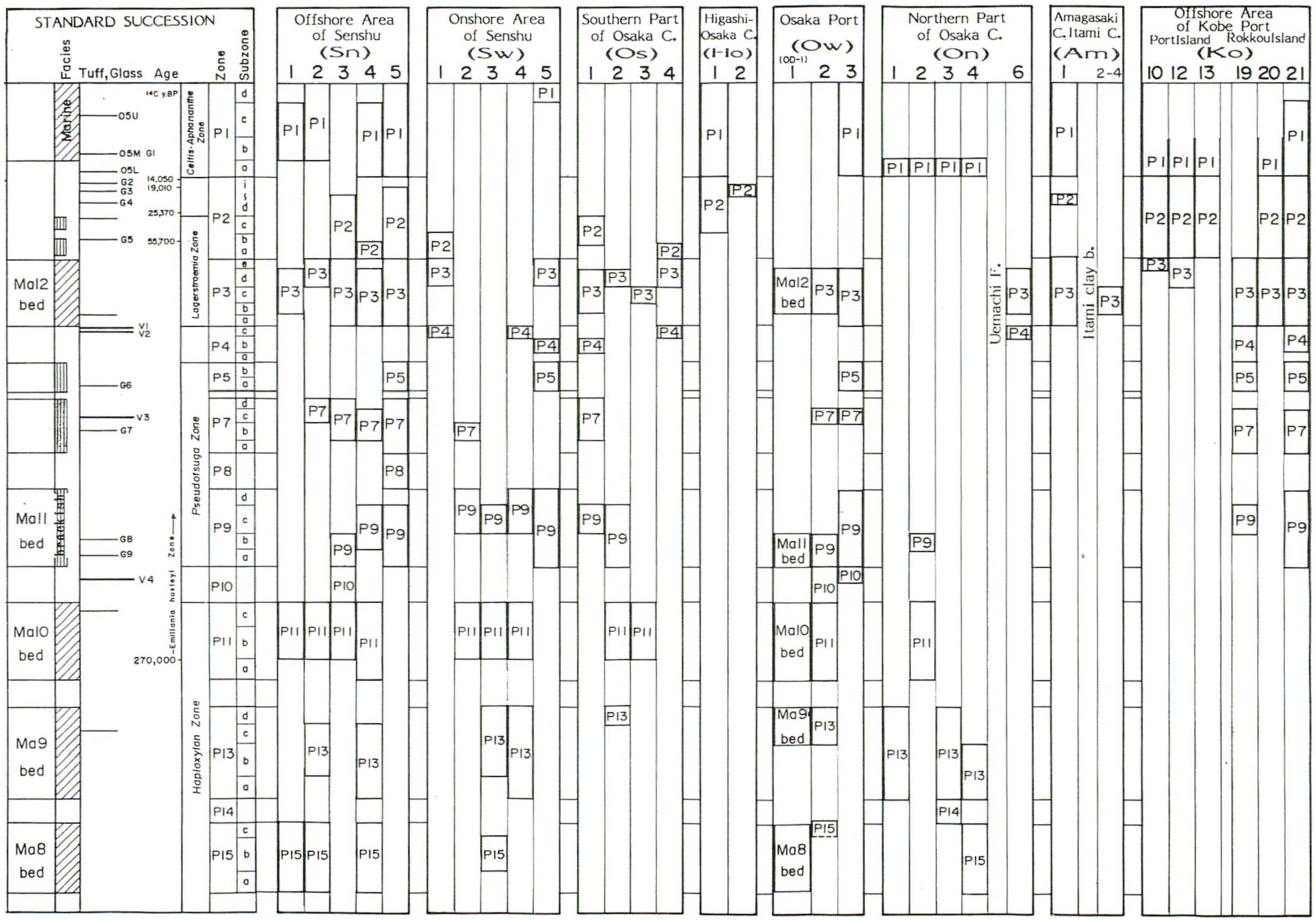


Fig. 12. Correlation by pollen assemblage zones between submarine and lowland and upland in coastal areas of Osaka Bay.

Zone between Ma10 bed and Ma11 bed are composed of subarctic and cool temeprate forest pollens which may be correlative with "Kitashinoda Cold Age" (Komyoike Research Group, 1971) and "Hojyo Cold Age" (ITIHARA, M. *et al.*, 1986).

1–2. Ma11 bed

Ma11 bed which was included in "Upper Pleistocene formations" was usually proposed to correlate with the High terrace deposits.

In offshore areas of Kobe Port and Senshu, the strata between the upper limit of Ma11 bed and the lower limit of Ma12 bed interstratify two brackish or marine clay beds which are equivalent to P7 Zone and P5 Zone. Ma11 bed and these two marine beds in Senshu are similar to those in Kobe Port in thickness and sedimentary facies respectively. Therefore these marine beds should be discriminated stratigraphically one another. The author proposes to name the three beds Ma11(1) bed, Ma11(2) bed and Ma11(3) bed in ascending order.

The High terrace deposits, which are widely developed in Akashi and Harima hills, are suggested to intercalate a marine bed namely Takatsukayama clay bed or Akasaka clay bed. However the pollen composition of the marine bed is not similar with one of Ma11(1) ~ Ma11(3) beds. The correlation of the High terrace deposits between hilly area and coastal area should be dscussed later.

1–3. Middle terrace deposits

The Uemachi Formation in the Uemachi upland where is stratotype of the Middle terrace deposits is lithologically subdivided into the lower gravel, the middle marine clay and the upper silty sand members (FURUTANI, M., 1978).

ITIHARA, M. (1960) clarified the compositional transition of plant remains changed from subarctic forest remains in the lower part to temperate forest remains in the middle marine part in the Hirakata formation. In the same manner, KOKAWA, S. (1961) reported the plant remains including *Pinus* subgen. *Haploxylon koraiensis, Menyanthes trifoliata* and so on in the lower part of Uemachi Formation in southern part of Osaka City.

The lower gravel member of the Uemachi Formation unconformably covers Ma11 bed and the upper part of Osaka Group, and its pollen assemblage is characterized by the dominance of subarctic forest pollens in northern (On6 site) and southern (Os1, 4 sites) parts of Osaka City.

The fresh water deposits which is equivalent to P4 Zone between Ma11(3) bed and Ma12 bed under the bottom of Osaka Bay is correlative with the lower member of Uemachi Formation, because of the remarkable dominance of subarctic forest pollens and the correlation a characteristic volcanic ash layer between V2 layer in Ko21 site and a volcanic ash layer (FURUTANI, M., 1978) as newly naming Morinomiya volcanic ash layer in On6 site.

Ma12 bed under the bottom of Osaka Bay which is characterized by the appearance of *Cyclobalanopsis* and *Lagerstroemia* is correlative with the middle marine clay member of Uemachi Formation, and both the marine beds were deposited in the same period by

Uemachi Transgression estimated at ca. 130,000 y.BP.

The upper member of Uemachi Formation which is characterized by the dominance of cool temperate forest pollens including *Sciadopitys* as shown in Fig. 13. The pollen assemblage is correspondingly found in the brackish or fresh water deposits above Ma12 bed under the bottom of Osaka Bay. The radiocarbon dates in the fresh water deposits being equivalent to b Subzone in P2 Zone are 55,700±3,300 y.BP and 50,600±2,400 y.BP. These deposits are unconformably covered by the Low terrace deposits which are determined radiocarbon dates younger than 25,730±630 y.BP.

The paleoclimatic change in an interval ranged from Ma11(1) bed to the Nanba Formation is shown basing on pollen assemblage in Fig. 14 and it is revealed that the climatic transition through the Middle terrace period changed from subarctic (c Subzone in P4 Zone) to warm temperate (d Subzone in P3 Zone) and cool temperate (a and b Subzone in P2 Zone).

1–4. Low terrace deposits

The Tonda Formation (Low terrace deposits) which is typically distributed in Settsu-Tonda upland in Takatski City interbeds a coaly clay including cool temperate forest remains and Heianjingu volcanic ash layer (YOSHIKAWA, S. *et al.*, 1986). And a radiocarbon date of this coaly clay was determined as 26,000±800 y.BP (ITIHARA, M. and KIGOSHI, K., 1962).

On the other hand, Itami clay bed and Itami gravel bed had been correlated with the Low terrace deposits (HUZITA, K. and MAEDA, Y., 1971), but it was revealed that they should be correlated with the Middle terrace deposits by means of pollen stratigraphy (FURUTANI, M., 1978).

The deposits which are correlative with the Low terrace deposits are thickly and widely developed under the bottom of Osaka Bay in offshore area of Kobe Port as shown in Fig. 15. Radiocarbon dates of these deposits are determined as 25,730±630 y.BP～25,090±850 y.BP in their lower member, and 24,060±1,400 y.BP～14,050±280 y.BP in their upper member.

The pollen assemblages which include *Sciadopitys* and *Cryptomeria* in the lower member being equivalent to c～e Subzone in P2 Zone show the cool temperate climate, and which include *Picea*, cf. *Larix* and *Geranium* and so on in the upper member being equivalent to f～i Subzone show the subarctic one. On the basis of these pollen assembalge, paleoclimatic change is shown in Fig. 14.

The Lower member interstratifies a marine deposit which is equivalent to c Subzone, and this marine bed shows the sea level rising before or after 26,000 y.BP. The correspondence of plant fossil composition and radiocarbon dates of Tonda gravels with those of the marine bed lead to a conclusion that the Low terrace deposits in inland areas are mostly resulted from this rising of sea level.

The cool temperate forest elements e.g., *Fagus, Cryptomeria* and *Sciadopitys*, are not found, but only *Betula* and *Myrica* (*M. gale* type) appear in g and i Subzone in P2 Zone. Temporary appearance of the cool temperate forest elements in the upper part

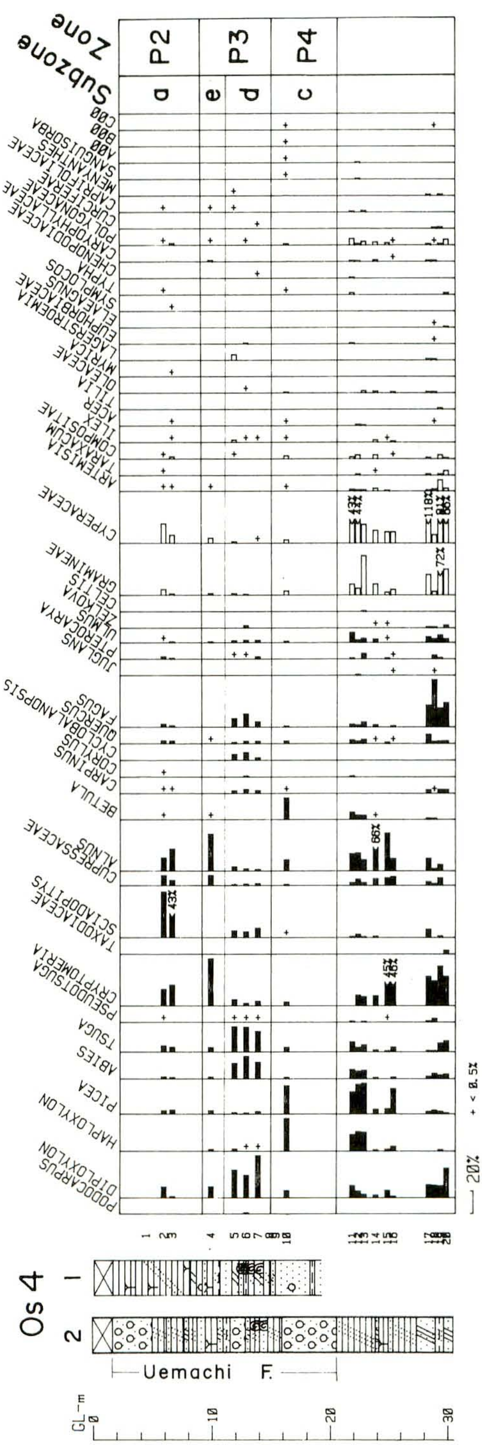


Fig. 13. Pollen diagram and zonation in Os4 site in Uemachi upland in the southern part of Osaka City.

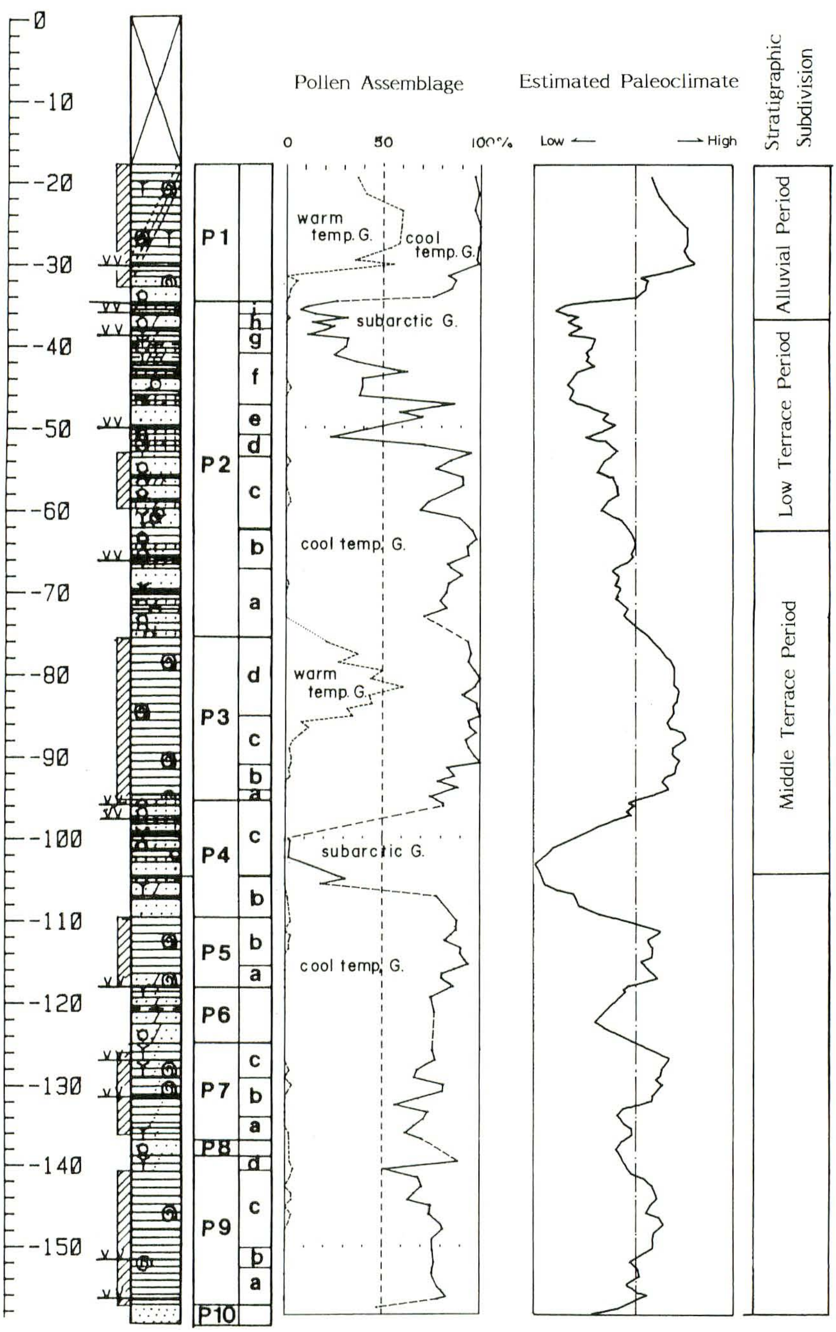


Fig. 14. Total diagram of pollen assemblage and estimated paleoclimatic change in site Ko21 in offshore of Kobe Port.

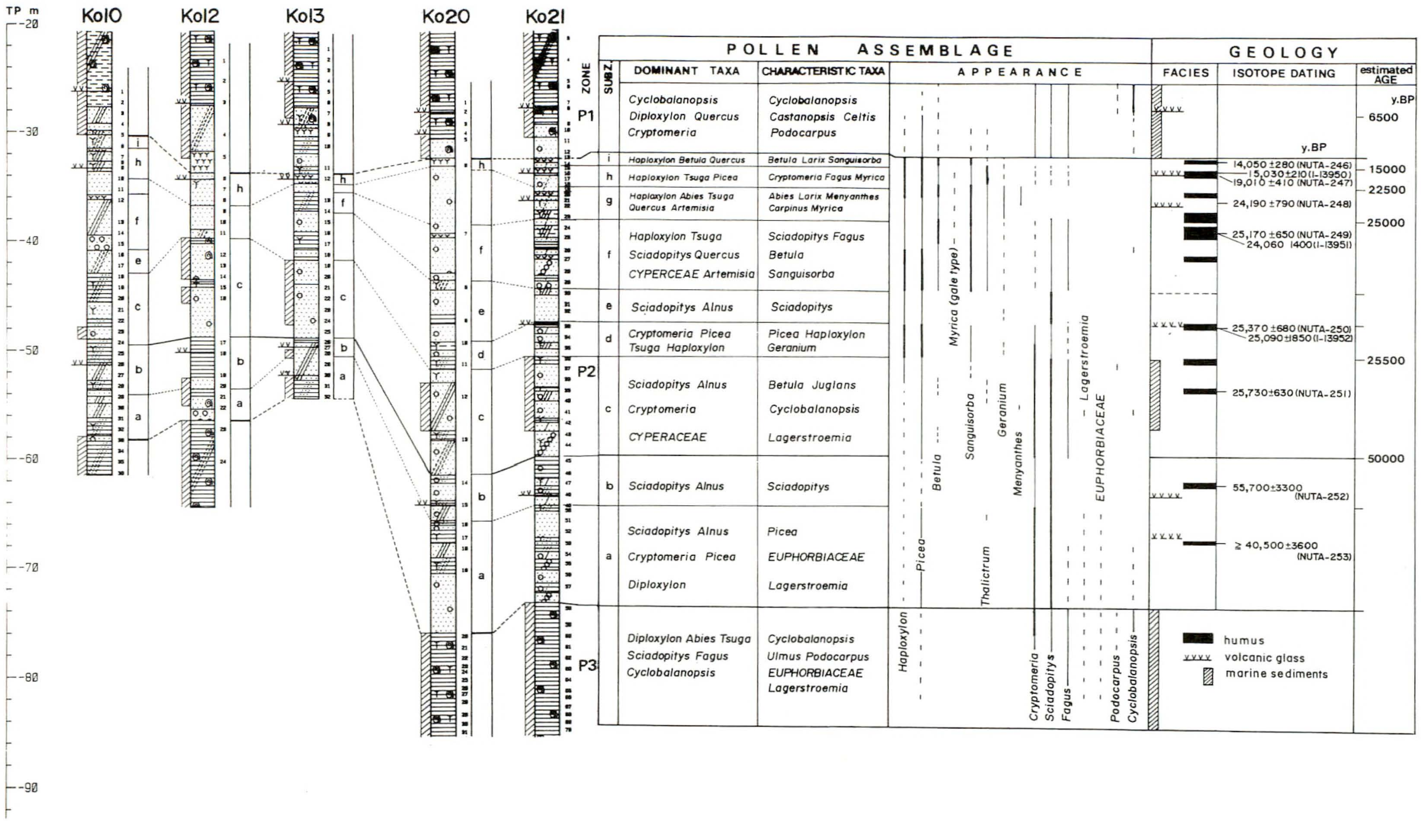


Fig. 15. Lithologic succession and change of pollen assemblage with absolute dates ranged from Ma12 bed to the Nanba Formation in offshore of Kobe Port.

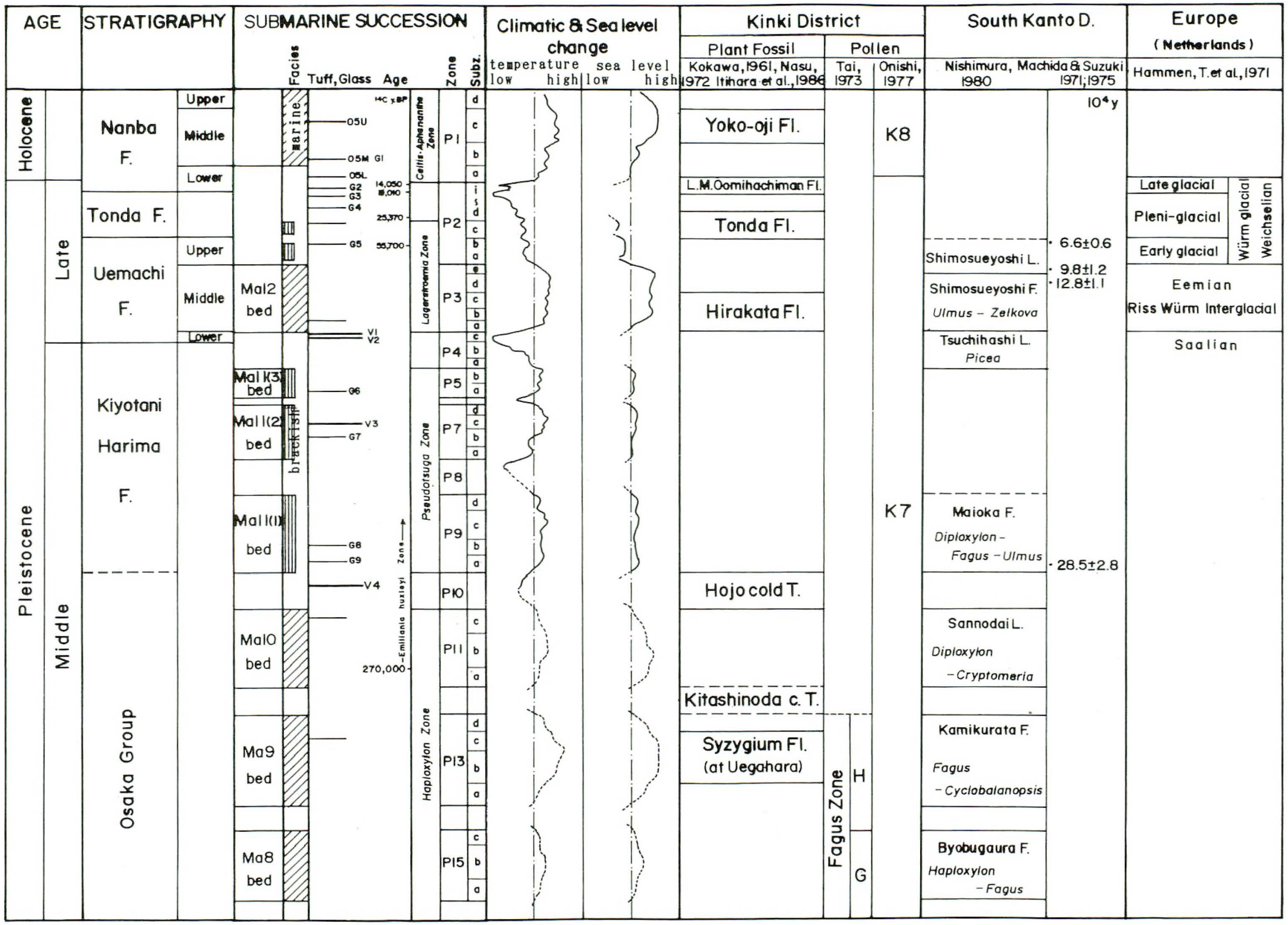


Fig. 16 Stratigraphic correlation between Kinki and South Kanto Districts since Middle Pleistocene to Holocene.

of h Subzone is inferred to be a climatic improvement, because the base of the Alluvial formation (Namba Formation) is estimated at about 22,500 y.BP in age.

2. Correlation between Kinki and South Kanto District

Since the Middle Pleistocene, in Kinki District, the strata under the bottom of Osaka Bay which are interstratified with ten marine or brackish beds ranged from Ma8 bed to the Namba Formation, have been accumulated. The strata consist of five stratigraphic units and are divided into four pollen zones, twelve pollen assmeblage zones and fourty one subzones. The paleoclimatic change and the sea level change in submarine succession of Osaka Bay are summarized in Fig. 16.

ONISHI, I. (1977) divided the Pliocene and Pleistocene strata into seven pollen zones in central and southwest Japan, and correlated the strata ranged from Ma6 bed to Terrace deposits in Kinki District with the uppermost part of the Kazusa Group and the Sagami Group in Kanto District by *Cryptomeria* Zone (K7 Z.).

NISHIMURA, S. (1980) subdivided the Middle and Upper Pleistocene ranged from the Naganuma Formation to the Musashino Loam Formation into nine pollen assemblage zones in South Kanto District. As shown in Fig. 16, the change of pollen assemblage from the Byobugaura Formation to the Shimosueyoshi Formation is meaningfully corresponded with one in Kinki District. *Haploxylon* Zone is correlative with *Haploxylon-Fagus* Zone, *Fagus-Cyclobalanopsis* Zone and *Diploxylon-Cryptomeria* Zone, and particularly the Kamikurata Formation is characterized by the dominance of *Cyclobalanopsis* such as Ma9 bed. Cf. *Pseudotsuga* Zone is correlative with *Diploxylon-Fagus-Ulmus* Zone appearing cf. *Pseudotsuga* in the Maioka Formation which is determined as 285,000±28,000 y.BP by fissiontrack dating. P4 Zone is correlative with *Picea* Zone in the Tsuchihashi Loam Formation. *Lagerstroemia* Zone is correlative with *Ulmus-Zelkova* Zone appearing *Lagerstroemia* in the Shimosueyoshi Formation which was determined as 128,000±11,000 y. BP by fission-track dating.

Acknowledgements

The author wishes to thank Prof. emeritus M. ITIHARA of Osaka City University for his valuable advice and critical reading of the manuscript. The author is also much indebted to Dr. S. YOSHIKAWA of Department of Geosciences, Osaka City University for his advice and help with tephrostratigraphical study, Prof. N. NAKAI and Dr. T. NAKAMURA of Nagoya University for their helps with radiocarbon determination, Dr. K. NAKASEKO and Prof. emeritus K. TANIMOTO of Kobe University for their helps with the study in offshore areas.

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