Vegetational History of the Area around Kashira Island in the Inland Sea, Okayama Prefecture, Western Japan

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Abstract Kashira Island is situated in the Inland Sea, near Hinase town, Okayama Prefecture. The 44-m core consisted of clay, sandy clay, gravel with sand, humus and tephra (Aira : 2,540-2,390 cm depth, Akahoya : 1,900-1,890 cm depth). The humus portion (2,368-2,360 cm depth) was dated to $21,100 \pm 400$ yr B.P. by the ^{14}C -dating method.

Pollen analysis revealed the core to consist of nine pollen and two barren zones. Layers containing *Lagerstroemia* pollen, the important index taxa for the warm period, were regarded as sediments of the warm period. This core may contain the sediments of four warm (KS-9, 8, 6, 4-1) and three cold periods (KS-7, 5 and BZ-2, 1). KS-4-1 represent the post glacial period.

Key words pollen analysis, cold and warm period cycle, *Lagerstroemia*

I. Introduction

Many pollen analyses have been carried out in the Chugoku Mountains by palynologists such as Yamazaki (1943), Nakamura (1959) and Miyoshi and Yano (1986), and the vegetational history and climate changes have been well clarified. However, moors and marshes are very rare near the coast of the Inland Sea, because of warm weather and little annual rainfall. Furthermore, most swampy places have been changed to paddy fields and lands for housing. There are a few palynological works, such as those of Furutani (1989) and Miyoshi (1994a).

This background was considered in relation to

a geological survey for harbor construction by Fukken Research and Planning Corporation, Okayama. The purpose of this study was to clarify the vegetational history around Kashira Island.

II. Site description

Kashira Island is situated about 4 km from Hinase town, Okayama Prefecture (coordinates $34^{\circ}41'\text{N}$, $134^{\circ}17'\text{E}$) in the Inland Sea, western Japan (Fig. 1). Some meteorological data for the island are as follows: annual temperature, 15.1°C ; lowest monthly mean temperature, 4.5°C (Jan); highest monthly mean temperature, 26.8°C (Aug); total annual precipitation, 1,231.9 mm.

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Fig. 1 Map giving the position of the drilling point.

The climate is warm and little annual rainfall and it is known as having the climatic type termed Seto-uchi (the Inland Sea) (Hada, 1996). On Kashira Island, secondary forest of *Pinus densiflora* is dominant, although a number of *P. densiflora* have died because of weevil infection. In the southern part of the island there are some small forests dominated by *Pinus thunbergii*, *P. densiflora*, *Cinnamomum comphora* and *Mallotus japonicus*. In the northern part of the island there are tangerine orchards and some forests dominated by *Celtis sinensis*, *Cinnamomum japonicum* and *Eurya japonica* (Hada, 1975). Around the drilling site the present dominant species is *P. densiflora*.

III. Material and Methods

The 44-m core sample was collected in October 1994. The drilling site is approximately 300 m from the seashore and at a 4.27 m water depth. From the bottom to the surface there are six kinds of sediments: clay (4,375–4,090 cm, 3,300–2,985 cm, 2,300–0 cm), humus (2,390–2,300 cm), sandy clay (3,700–3,570 cm, 2,600–2,540 cm), sand (2,670–2,600 cm), gravel with sand (4,090–3,700 cm, 2,985–2,670 cm), gravel with sandy clay (3,570–3,300 cm) and tephra (Aira: ca. 25,000 yr B.P. 2,540–2,390 cm, and Akahoya: ca. 6,300 yr B.P. 1,900–1,890 cm). One sample for ^{14}C -dating was taken from the humus at the depth of 2,368–2,360 cm.

The core was cut at 5-cm intervals and each piece was put in a vinyl bag, and kept at -20°C until needed for laboratory studies. The samples for pollen analysis were obtained at intervals of 30–40 cm. The samples used for the pollen analysis were 3 cm in thickness. The sample for ^{14}C -dating was dried in a hot-air drier and sent to the Kyushu Environment Management Association at Fukuoka. Fossil pollen and spores were extracted by boiling in 10% KOH solution and by applying mineral separation with ZnCl_2 solution (s.g. 1.78). The samples were subsequently treated with 40% HF and then with Erdtman's acetolysis method. In making the slides the treated materials were mounted in glycerine jelly. Samples for scanning electron microscope were fixed with 2% osmium tetroxide after acetolysis, then dehydrated with 99.5% ethanol and substituted with xylene. The samples were put on the stand of an ion sputtering apparatus and spattered with gold-palladium for about five minutes and then observed with the high-resolution scanning electron microscope (HR-SEM: JEOL-890).

In the pollen diagram, percentages for each taxon were calculated for the sum-total of the AP (arboreal pollen). At least 500 pollen grains were counted per level. However *Alnus* pollen was excluded from the summed arboreal pollen, because the high frequencies and fluctuations of

Alnus pollen, considered to be derived mainly from *Alnus* thickets which are abundant on wet land, affect the frequencies of other upland arboreal taxa. The pollen of *Buxus*, *Ilex*, *Elaeagnus*, *Ligustrum*, *Clethra*, Ericaceae and *Weigela*, which are regarded as bushes, are excluded from the summed arboreal pollen.

IV. Results

1. Dating

^{14}C -dating yielded the age of $21,100 \pm 400$ yr B.P. (at the depth of 2,368–2,360 cm, KEEA-52).

Two tephra layers corresponded to widespread late Quaternary tephra deposited at 6,300 yr B.P. (1,900–1,890 cm, Akahoya) and 25,000 yr B.P. (2,540–2,390 cm, Aira) based on an estimate using lithologic characters (Table 1).

2. Analytical results

Seventy-eight varieties of fossil pollen and spores were detected. These were divided into AP (arboreal pollen), NAP (non-arboreal pollen) and FS (fern spores), as described below. The genus order follows the classification of Ohwi and Kitagawa (1992).

AP: *Podocarpus*, *Abies*, *Tsuga*, *Picea*, *Pinus* (*Diploxylon*), *Pinus* (*Haploxylon*), *Sciadopitys*, *Cryptomeria*, Cupressaceae, *Ephedra*, *Salix*, *Myrica*, *Platycarya*, *Pterocarya*, and/or *Juglans*, *Carya*, *Carpinus*, *Corylus*, *Betula*, *Alnus*, *Fagus*,

Table 1 The characteristics of volcanic glass from Kashira Island.

Tephra	Refractive index	Morphology of volcanic glass	Color of volcanic glass
K-Ah (Machida & Arai, 1992)	1.508–1.516	bubble wall type & pumice type	transparency & light-brown
Kashira Is. (1,900–1,890 cm)	1.505–1.509	bubble wall type & pumice type	transparency & light-brown
AT (Machida & Arai, 1992)	1.498–1.501	bubble wall type & pumice type	transparency
Kashira Is. (2,540–2,390 cm)	1.499–1.503	bubble wall type & pumice type	transparency

Fig. 2 Stratigraphic sequence and pollen (AP) diagram from Kashira Island.

Fig. 3 Stratigraphic sequence and pollen (AP and NAP) diagram from Kashira Island.

Cyclobalanopsis, *Lepidobalanus*, *Castanea*, *Castanopsis*, *Ulmus* and/or *Zelkova*, *Celtis* and/or *Aphananthe*, *Euptelea*, *Liquidamber*, *Sapium*, *Buxus*, *Ilex*, *Acer*, *Aesculus*, *Tilia*, *Elaeagnus*, *Lagerstroemia*, *Corunus*, *Clethra*, Ericaceae, *Symplocos*, *Styrax*, *Ligustrum*, *Fraxinus*, *Weigela*

NAP: *Typha*, Gramineae, Cyperaceae, *Eriocaulon*, Liliaceae, *Persicaria* and other Polygonaceae, Chenopodiaceae, Caryophyllaceae, *Thalictrum* and other Ranunculaceae, *Sanguisorba*, *Geranium*, *Impatiens*, *Viola*, *Haloragis*, Umbelliferae, *Menyanthes* and other Gentianaceae, *Lonicera*, Labiatae, *Scabiosa*, *Artemisia* and other Compositae.

FS: monolete type, trilete type, Lycopodiaceae, Osmundaceae.

The pollen analytical data are plotted in Fig. 2, except for *Alnus*, shrubs, herbs and ferns. The appearance tendencies of the main pollen types are shown below. The pollen of the temperate conifers, such as *Abies* and *Tsuga*, were dominant at the depth of 4,400–4,200 cm. *Pinus* (*Diploxylon*) pollen increased to 5–60% at the depth of 0–550 cm but accounted for less than 30% at other depths. The pollen of the subarctic conifers, such as *Pinus* (*Haploxylon*), increased at the depth of 2,300–550 cm and rarely appeared at other depths. The pollen of the temperate conifers, such as *Cryptomeria*, *Sciadopitys* and Cupressaceae, showed a marked increase at the depth of 3,650–3,350 cm while being minimal at other depths. *Carpinus* pollen accounted for 5–15% below 1,860 cm but showed a very low percentage. *Betula* pollen increased markedly at the depth of 2,550–2,300 cm but was low at other depths. The pollen of the cool temperate deciduous broad-

leaved tree, such as *Fagus*, increased to 10–30% at the depth of 4,400–4,200 cm while being less than 15% at other depths. *Lepidobalanus* pollen was dominant, at 10–15%, at depth lower than 1,860 cm but was less than 15% above 1,860 cm. *Ulmus* and/or *Zelkova* pollen are dominated, at 5–45%, below the depth of 1,860 cm but then diminished to very low percentages. *Celtis* and/or *Aphananthe* pollen were slightly increased at the depth of 2,300–1,860 cm, were low above 1,860 cm, and minimal below 2,990 cm. The pollen of the warm temperate deciduous broad-leaved trees, such as *Lagerstroemia* and *Sapium*, were detected only at the depth lower than 2,990 cm. This was especially true of *Lagerstroemia* pollen, which was detected at very high percentages. In contrast, the pollen of the warm temperate evergreen broad-leaved trees, such as *Cyclobalanopsis* and *Castanopsis*, were associated with very high percentages at the depth above 2,170 cm.

Alnus pollen was characteristically found at the depth below 2,300 cm. Among the herbs, *Typha* pollen was increased at 3,300–3,400 cm but was minimal at other depths. Gramineae pollen was dominant at the depths of 3,750–2,170 cm but accounted for less than 10% at other depths. Cyperaceae pollen was dominant at the depth of 3,650–2,300 cm but comprised less than 10% at other depths. *Sanguisorba*, Umbelliferae and other Compositae pollen showed a marked increase at the depth of 2,550–2,300 cm but were negligible at other depths. *Artemisia* pollen was dominant below 2,170 cm but at a very low percentage. The monolete spore type was dominant at the depths of 3,650–3,350 cm and 2,550–2,170 cm but constituted less than 10% at other depths.

The trilete spore type was increased at the depths of 2,550–2,300 cm and 550–0 cm.

3. Palynological zonation

1) Zone KS-9

Zone KS-9 was characterized by dominance of the pollen of the warm-temperate elements, such as *Lagerstroemia* and *Cyclobalanopsis*. Among the deciduous broad-leaved elements, *Fagus*, *Lepidobalanus*, *Ulmus* and/or *Zelkova* and *Carpinus* pollen were detected at high percentages. Among the coniferous elements, percentages of pollen were high (5–20%) for *Abies*, *Tsuga* and *Pinus* (*Diploxylon*). About the other pollen, percentages for *Alnus* and *Artemisia* pollen were high.

2) Barren zone-2

No fossil pollen grains were found in barren zone-2, presumably because the sediments are derived mainly from sand and gravel. The separation of zones KS-9 and barren zone-2 reflected the appearance and disappearance of fossil pollen grains characteristic of zone KS-9.

3) Zone KS-8

This zone is composed of only two samples. The warm-temperate element of *Lagerstroemia* pollen reached a high percentage, while that for *Cyclobalanopsis* pollen was low. The pollen of the deciduous broad-leaved elements, such as *Fagus*, *Lepidobalanus* and *Ulmus* and/or *Zelkova*, had percentages of 3 to 10%. Some increments in *Artemisia* and *Alnus* pollen were also recognizable about the other pollen. The zonal line (3,750 cm) between barren zone-2 and 8 was demarcated by the sudden appearance of fossil pollen grains in zone KS-8.

4) Zone KS-7

This zone was characterized by dominance of the pollen of the temperate coniferous elements, such as *Sciadopitys* and *Cryptomeria*. Among the broadleaved elements, percentages for *Carpinus*, *Lepidobalanus* and *Ulmus* and/or *Zelkova* pollen were high. *Alnus*, *Typha*, Gramineae, Cyperaceae, *Artemisia* pollen and the monolet spore type were dominant about the other pollen. The division of zones KS-8 and 7 was determined by increased *Sciadopitys* and *Cryptomeria* pollen and decreased *Lagerstroemia* pollen.

5) Zone KS-6

Zone KS-6 was characterized by the pollen of the warm-temperate elements, such as *Lagerstroemia* and *Cyclobalanopsis*, though the percentages of these pollen grains were low. Among the deciduous broad-leaved elements, percentages for *Lepidobalanus*, *Ulmus* and/or *Zelkova* and *Carpinus* pollen were high. The separation between KS-7 and 6 was based on decreased *Sciadopitys* and *Cryptomeria* pollen and increased *Lepidobalanus* pollen in zone KS-6.

6) Barren zone-1

There were no pollen grains in this zone, like barren zone-2. The separation of zone KS-6 and barren zone-1 was determined by the appearance and disappearance of the aforementioned pollen in zone KS-6.

7) Zone KS-5

This zone was characterized by dominance of the pollen of the subarctic elements, such as *Pinus* (*Haploxylon*) and *Betula*, and the cool-temperate elements, such as *Lepidobalanus*. *Alnus*, Gramineae, Cyperaceae, *Sanguisorba*, Umbelliferae, *Artemisia* and other Compositae pollen and

monolete and trilete spore types were dominant about the other pollen. The separation of zones KS-6 and 5 was based on the sudden appearance of *Pinus* (*Haploxylon*), *Betula* and *Lepidobalanus* pollen in zone KS-5.

8) Zone KS-4

The pollen of the cool-temperate elements, such as *Lepidobalanus*, peaked in zone KS-4. The pollen of other deciduous broad-leaved elements, such as *Fagus* and *Ulmus* and/or *Zelkova*, were also abundant. The NAP is dominated by Gramineae, *Artemisia* pollen and the monolete spore type. The separation of zones KS-5 and 4 was determined by decreased *Pinus* (*Haploxylon*) and *Betula* pollen and increased the deciduous broad-leaved elements.

9) Zone KS-3

The pollen of the cool-temperate elements, such as *Lepidobalanus*, *Fagus*, *Ulmus* and/or *Zelkova* and *Carpinus*, and of the warm-temperate elements, such as *Cyclobalanopsis* and *Castanopsis*, were dominant in this zone. The NAP showed the lowest percentage. The separation of zones KS-4 and 3 was based on increased *Pinus* (*Diploxylon*) pollen and the evergreen broad-leaved elements.

10) Zone KS-2

The pollen of the warm-temperate elements, such as *Cyclobalanopsis* and *Castanopsis*, peaked this zone. The NAP showed the lowest percentage. The separation of zones KS-3 and 2 was based on decreased the deciduous broad-leaved elements and markedly increased the evergreen broad-leaved elements.

11) Zone KS-1

Percentage for *Pinus* (*Diploxylon*) pollen

showed a sudden increase. *Cyclobalanopsis* and *Castanopsis* pollen were also dominant. The pollen of NAP, such as Gramineae, Cyperaceae, *Artemisia* and spores of Pteridophyta, were slightly increased. The separation of zones KS-2 and 1 was determined by a sudden increase in *Pinus* (*Diploxylon*) pollen.

V. Discussion

1. The pollen zones

We found the core to be divisible into nine pollen and two barren zones. In Osaka Bay, ca. 100 km to the east of Kashira Island (Furutani, 1989), Lake Mikata, ca. 170 km to the east-northeast of Kashira Island (Morita, 1994) and Lake Biwa, ca. 180 km to the northeast of Kashira Island (Miyoshi, 1994b), *Lagerstroemia* pollen is detected in the warm periods. Similar are obtained in the present study. Zones KS-9, 8 and 6 represent the warm periods, zone KS-4, 3, 2 and 1 the post glacial period, zone KS-8 and 5 and barren zones-1 and 2 the cold periods. In this core, the sediments of four warm and three cold periods are detected.

Zone KS-9 is the warm period, since *Lagerstroemia* pollen of the warm-temperate elements appears. Furthermore, Tsuji (1980), Miyoshi *et al.* (1991) and Morita (1994) reported that *Lagerstroemia* pollen appeared with *Fagus* pollen in the warm period. As we obtained similar results, this zone can be regarded as representing the warm period.

In barren zone-2 and 1, the fossil pollen can not be recognized. These zone consist mainly of sand and gravel, most probably relating to the regression during the cold period (Itano *et al.*,

1994). Such continental sediments sometimes have no fossil pollen grains (Itano *et al.*, 1994; Yamanaka, 1984). Therefore, barren zone-2 and 1 are the cold period.

In zone KS-8, *Lagerstroemia* pollen of the warm-temperate element markedly increases, whereas the percentage of *Cyclobalanopsis* pollen is low. This zone is the warm period.

In zone KS-7, *Lagerstroemia* pollen of the warm-temperate element is absent, *Cryptomeria* and Cupressaceae pollen are abundant. This zone and be regarded as the cold period.

Zone KS-6 is characterized by the pollen of the warm-temperate elements, such as *Lagerstroemia* and *Cyclobalanopsis*. However, the percentages of these types of pollen are low and those of the deciduous broad-leaved elements are dominant. This zone is regarded as the warm period.

In zone KS-5, the cool-temperate elements, such as *Pinus* (*Haploxylon*), *Betula* and *Lepidobalanus*, are dominant. From ¹⁴C-dating and tephra, this period is presumed to be the last full glacial period. Peat and humus accumulate above Aira volcanic ash in the Inland Sea. The pollen of wet land plants, such as *Alnus*, Gramineae and Cyperaceae, are abundant in this layer. Therefore, in the region of the Inland Sea, wet land may have existed at the end of the full glacial period. Subsequently, the clay accumulated because of transgression during the post glacial period. In this zone, there are few *Myrica* pollen grains, probably representing *M. gale* growing on the wet land in Hokkaido and the northern part of Honshu.

Zone KS-4 is observed to be a transitional stage from the subarctic to the cool-temperate forests.

Deciduous broad-leaved elements, such as *Lepidobalanus*, are dominant in this zone. This period is the early stage of the post glacial period, pollen zone R-I in the Japanese pollen zone system (Tsukada, 1963). *Lepidobalanus* pollen from this zone was observed using SEM and was identified using the pollen key for *Lepidobalanus* by Fujiki *et al.* (1996). Most of the *Lepidobalanus* pollen grains were of the *Quercus dentata* type (Photo 1).

Zone KS-3 is characterized by a sudden increase in the warm-temperate elements. From tephra, this period is assumed to be the early stage of the Jomon transgression and to correspond with the lower part of pollen zone R-II.

In zone KS-2, the warm-temperate elements, such as *Cyclobalanopsis* and *Castanopsis*, show a marked dominance. This period is assumed to represent the later stage of the Jomon transgression and to correspond with the upper part of pollen zone R-II. *Cyclobalanopsis* pollen from this zone was observed using SEM and was identified using the pollen key for *Cyclobalanopsis* by Fujiki and Miyoshi (1995). Most of the *Cyclobalanopsis* pollen grains were of the *Quercus glauca* type (Photo 1).

In zone KS-1, secondary forest elements, such as *Pinus* (*Diploxylon*) (ex. *P. densiflora*), increase rapidly. Hence this zone is recognized as a period in which the human impact on natural vegetation became evident.

From the pollen composition, four warm and three cold pollen zones were divided. These meanings of Quaternary chronicle become the subject of study for the future.

Photo 1 Fossil pollen of species from the subgenus *Cyclobalanopsis* and *Lepidobalanus*.
General view $\times 2,000$ (white line corresponds to $10\ \mu\text{m}$). Surface detail $\times 10,000$ (white line corresponds to $1\ \mu\text{m}$).
1a-b *Q. glauca* type fossil pollen
2a-b *Q. dentata* type fossil pollen

2. Significant *Lagerstroemia* in the warm periods

Lagerstroemia pollen has been demonstrated during the warm periods (Tsuiji, 1980; Furutani, 1989; Morita, 1994; Miyoshi, 1994b). At present, in Japan, *Lagerstroemia* (*L. subcostata* and *L. subcostata* var. *fauriei*) is distributed only in Yakushima Island, Tanegashima Island and Okinawa (Horikawa, 1972). In zone KS-9 of the warm period, the pollen of warm-temperate taxa, such as *Lagerstroemia* and *Cyclobalanopsis*, are detect-

ed. The paleoclimate of zone KS-9 was warmer than the present climate because pollen of *Lagerstroemia*, which does not grow naturally around Kashira Island, was found. However, the pollen of Pinaceae and cool-temperate elements, such as *Lepidobalanus*, *Fagus*, *Ulmus* and/or *Zelkova* and *Carpinus*, are detected with those of the warm-temperate elements.

The warm-temperate elements are able to survive in winter and the cool-temperate elements are able to survive in summer. Hence the paleo-

climate may have been relatively cool in the summer and warm in the winter, and thus different from the present climate.

VI. Conclusions

The 44-m core from Kashira Island used for pollen analysis showed nine pollen and two barren zones. Layers with *Lagerstroemia* pollen were regarded as the sediments of the warm periods. Four warm and three cold pollen zones were divided. These meanings of Quaternary chronicle become the subject of study for the future.

Lagerstroemia pollen was found with those of the cool-temperate elements, such *Lepidobalanus*, *Carpinus*, *Ulmus* and/or *Zelkova* and Pinaceae. Hence, the paleoclimate may have been relatively cool in the summer and warm in the winter, and thus different from the present climate.

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瀬戸内海・頭島（岡山県日生町）周辺の花粉分析による 植生変遷史の研究

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岡山県日生町にある頭島で採取された 44 m ボーリングコアの花粉分析を行った。このコアは粘土・砂質粘土・砂・礫・腐植土・火山灰から成る。2,368-2,360 cm で $21,100 \pm 400$ yr B.P. という ^{14}C 年代測定結果が得られ、1,900-1,890 cm でアカホヤ火山灰、2,540-2,360 cm で姶良火山灰が確認されている。

分析の結果、9 花粉帯と 2 無化石帯が認められた。サルスベリ属の花粉が出現する層を温暖期、化石花粉の出現しない層は寒冷期と考えると、このコアは 4 回の温暖期 (KS-9, 8, 6, 4-1) と 3 回の寒冷期 (KS-7, 5, BZ-2, 1) に堆積したものである。KS-4~1 は後氷期である。

キーワード 花粉分析, 寒・暖期サイクル, サルスベリ属

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