Middle Pleistocene Pollen Assemblages and their Implications for the Yabu Formation, Boso Peninsula, Central Japan

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Palynological results from the lower part of the Sakata section (35°20′42″N, 139°53′02″E; 20 m a.s.l.), belonging to the Yabu Formation (Marine Isotope Stages 9–8) of the Pleistocene Shimosa Group, show good agreements with sedimentological facies changes. A muddy lagoonal unit provides well-diversified pollen assemblages with abundant conifers and consistently high pollen concentrations. By contrast, a sandy shoreface unit provides possibly exotic assemblages with low pollen concentrations and poor floral diversity. The dominant taxon in the lagoonal unit is Picea (spruce) associated with Abies, Pinus, Tsuga, Betula, Fagus, Cupressaceae, etc. The corresponding abundance of Alnus and herbs (mainly Artemisia) indicates the vicinity of the coast. Therefore, the coniferous assemblages do not consist of exotic pollen transported over long distances, but indicate the spread of boreal conifer forest in the Boso Peninsula during cold stages near the end of Stage 9 or Stage 8. This is equivalent to Picea-dominated subarctic to cool-temperate conifer forest reconstructed for the Stage 4 glacial in the Sagami region, Kanagawa Prefecture.

Key words: Boso Peninsula, Middle Pleistocene, Paleo-Tokyo Bay, palynology, Shimosa Group

I. Introduction

The Shimosa Group comprises Middle to Late Pleistocene strata with good time control, which is located in the Boso Peninsula, central Japan (Okazaki et al., 2001a). A large number of studies has identified sedimentary environments of the Shimosa Group (littoral/neritic to terrestrial), recognising distinct depositional sequences as the consequence of glacio-eustatic sea level changes (e.g., Tokuhashi and Kondo, 1989; Murakoshi and Masuda, 1992; Okazaki and Masuda, 1992; Masuda, 1994; Nishikawa and Ito, 1997). The depositional sequences have been tephrochronologically correlated with Marine Isotope Stages 11 to 5 (Kanto Quaternary Research Group, 1980; Nakazato et al., 1989; Masuda, 1997; Nakazato, 2001). Palynological studies for the Shimosa Group can provide age-secured vegetation histories and climate proxy curves for the Middle to Late Pleistocene. There are many Pleistocene pollen records derived mainly from Mediterranean lacustrine deposits (e.g., Wijmstra and Smit, 1976; Tzedakis et al., 1997; Okuda et al., 2001, 2002), but most of them lack reliable age controls, making it difficult to establish unambiguous land-marine correlations especially for pre-Eemian interglacials and interstadials. Sandy facies and inorganic sediment properties have hindered palynological approaches to the Shimosa Group. A few published studies are available for the underlying Kazusa Group, which consists of more muddy (hemi) pelagic...
strata of the earlier Plio-Pleistocene (e.g., Onishi, 1969; Kase, 2001). These yielded pollen assemblages dominated by *Pinus* and other Pinaceae throughout the sequences. Predominantly coniferous marine pollen assemblages do not permit reliable reconstruction for paleovegetation and terrestrial environments, because some saccate pollen of conifers is buoyant and can easily be over-represented in offshore sediments (Chaloner and Muir, 1968; Shimakura, 1970; Heusser, 1990; Yamanoi, 1992). Such assemblages are mainly composed of exotic conifer pollen from distant uplands, and frequently dominate pelagic sediments while bearing no positive relations to terrestrial environmental changes (Traverse, 1988). In some cases, exclusion of exotic conifer pollen from total pollen sums leads to meaningful paleoclimate reconstruction (Yamanoi, 1993). However, this approach inevitably excludes boreal conifer pollen also, which characterises glacial flora in Japan (Tsukada, 1983, 1988) and is a useful indicator of glacial environments.

Unlike the Kazusa Group, the Shimosa Group is generally littoral to neritic, having been deposited in half-closed Paleo-Tokyo Bay, which occupied almost all the Kanto Plain in warm stages of the late Pleistocene (Yabe, 1931; Kikuchi, 1980). This means that the Shimosa Group is relatively free from problematic exotic pollen and is useful for reconstruction of paleovegetation and terrestrial environments in the Boso Peninsula despite its marine origin.

This paper presents palynological results from the Sakata section of the Pleistocene Shimosa Group. The major part of the section is tephrachronologically correlated with the Yabu Formation to the Kamiizumi Formation (Stages 9–7). Sedimentological and paleontological studies have given shallow marine environments (shoreface, lagoon, tidal flat, etc.) to the Sakata sediments (Okazaki et al., 2000). Particularly the lagoonal deposits are fine with macroscopic charcoal fragments, and are suitable for palynological approaches.

**II. Geological setting**

The Sakata section is located in the western Kisarazu Upland, westernmost Boso Peninsula, central Japan (Fig. 1). This is a continuous 40 m-high outcrop and contains at least two sedimentary cycles. Based on interbedding of a key marker tephra (Km2) (Nakazato and Sato, 1988; Sato, 2000), the 20–23 m interval of the section is correlated with the Kamiizumi Formation (Stage 7). As there are no unconformities observed below the Km2 tephra, the lower 0–20 m interval is assigned to the Yabu Formation (Stages 9–8). It frequently occurs that the key marker tephras of the Yabu Formation (Yb0–Yb5) are not found in the western part of the Kisarazu Upland (Okazaki et al., 2000).

Below the Km2 tephra, sedimentary facies VIII and IX have been recognised from the base upward (see Fig. 2). Facies VIII consists of alternating beds of silt and coarse sand. Distinct forset beddings and planar stratification suggest strong wave influence. *Ruditapes philippinarum* are abundant in shell beds, and poor preservation of molluscan shells with abundant fragments suggests sediment reworking from the surrounding (more oceanic) environments. As a result, facies VIII represents shoreface deposits influenced by strong waves and longshore currents (Okazaki and Masuda, 1992; Okazaki et al., 2000). A sedimentological study has reported the existence of similar modern environments in the inner-bay side along the Futtu Spit, which projects from the western coast of Boso Peninsula and marks the mouth of present-day Tokyo Bay (Kayanne, 1991).

Sedimentary facies IX consists of almost homogeneous clay/silt. Thin, very fine sand layers are frequently intercalated with wave ripple lamination. The sediments are relatively dark in colour and contain macroscopic charcoal fragments. Clayey layers rarely yield autochthonous *Ruditapes philippinarum*. Inferred sedimentary environments of facies IX are calm, small-scale lagoons sheltered by barrier islands (Okazaki et al., 2000).

Above the Km2 tephra, coarse sands of beach deposits are overlain by fluvial deposits with erosional bases. As no key marker tephras are found, this fluvial deposits are tentatively correlated with the Kiyokawa Formation (Stage 7) based on estimated contour maps of formation.
bases (Okazaki et al., 2001b).

III. Materials and methods

Sampling for pollen analyses was performed in July 2001 when 54 sediment samples of clay/silt were collected from the Sakata section below the Km2 tephra. In the facies IX interval (13–19 m), the sampling was done every 50 cm. The facies VIII interval (0–13 m) was sandy, but no crucial sampling gaps occurred because the coarse sand was frequently interbedded with thin silt/clay layers. The sample sizes were 5–10 g in facies IX and 20–50 g in facies VIII. The samples were analysed in the pollen laboratory of the Natural History Museum and Institute, Chiba (Japan).

Pretreatment for pollen analyses followed the method of Moore et al. (1991). Inert plastic microspheres (NEM-002 and 003, Du Pont) were added for absolute counts (Ogden III, 1985). The sediment samples were milled and bathed in 10% HCl solution overnight to remove any calcium carbonate. After excess HCl was rinsed off, the samples were boiled in 10% KOH solution for 10 minutes to remove humic acids. The resulting suspension was cleaned by repeated centrifugation and decanting to remove clay-sized particles. Fossil pollen was extracted from heavier particles by heavy liquid flotation using ZnCl₂ solution. Finally, the samples were acetolysed and mounted in glycerol solution. More than 200 pollen grains from terrestrial trees and herbs (excluding Alnus and wetland herbs) were counted for each sample, and used for pollen sums and percentage calculations. As abundant Alnus pollen can originate from local swamp forest, its percentages have been calculated separately when Alnus is extremely high in frequencies (e.g., Iwauchi and Hase, 1992). Percentages for Alnus and wetland herbs were calculated based on the total pollen sum including Alnus and wetland herbs themselves.

IV. Results and establishment of pollen zones

Selected results from pollen analyses are shown in Figure 2. In the 0–13 m interval, the
Fig. 2 Pollen assemblages for the lower units of Sakata section, Boso Peninsula, central Japan. *Alnus* and wetland herbs are excluded from the pollen sums for the purpose of percentage calculations. The term T–C–C means Taxaceae–Cephalotaxaceae–Cupressaceae. The lithological column is after Okazaki et al. (2000). The sampled section is marked by a key marker tephra (Km2) at the top, which belongs to the lower part of the Kamiizumi Formation (Marine Isotope Stage 7) (Sato, 2000). The absence of unconformities below the Km2 tephra allows to correlate the underlying unit (0–20 m) with the Yabu Formation (Stages 9–8).
Fig. 3 Photomicrographs of major pollen types (scale: 30μ)
pollen concentration is low with poor pollen preservation. Several clayey samples do not provide sufficient pollen counts. By contrast, the 13-19 m interval provides consistently high pollen concentrations. Fifty-eight pollen and spore types are identified. Photomicrographs of 21 main pollen and spore types are shown in Figure 3. Minor taxa not shown in Figure 2 include Araliaceae, Styrax, Myrica, Elaeagnus, Polygonum, Fabaceae, Ranunculaceae, Valerianaceae, Thalictrum, Menyanthes, Lythrum, Geranium, Scabiosa and Epilobium. All these minor taxa are less than 1% in total pollen assemblages. Calculated pollen concentrations (grains/g) are based on dry sample weight. Five local pollen zones (SK1, 2, 3, 4 and 5) are established from the base upwards, on the basis of percentage variations in major taxa (Picea, Abies, Pinus, Tsuga, Betula, Poaceae, Artemisia, etc.) as well as total concentration changes. Zones SK1-4 and zone SK5 correspond to facies VIII and IX, respectively (Okazaki et al., 2000).

1. **SK1 (0–3 m)**
   Zone SK1 is generally dominated by *Picea* and *Alnus*, although higher resolution could provide finer zonation. *Abies, Pinus, Tsuga, Betula, Poaceae, Artemisia, etc.* occur at low levels. Herb taxa (*Artemisia, etc.*) and fern spores are abundant. Total pollen concentrations are less than 100 grains/g.

2. **SK2 (3–5 m)**
   Zone SK2 is dominated by *Picea* with decreased palynofloral diversity. *Picea* reaches 70% and all angiosperm taxa decrease. Two spectra show high pollen concentrations (200–400 grains/g). However, the high concentrations are not stable and a few clayey layers around 4.5 m at stratigraphic level do not contain sufficient amounts of pollen despite their fine grain sizes.

3. **SK3 (5–9 m)**
   *Picea* values are close to 50% and broad-leaved trees (*Quercus, Ulmus/Zelkova, etc.*) and herb taxa (*Poaceae, Artemisia, Asteraceae subfam. Tubuliflorae, etc.*) occur regularly. *Alnus* and monolectic fern spores increase. Total pollen concentrations are consistently low (<100 grains/g).

4. **SK4 (9–12 m)**
   SK4 is a somewhat unstable zone defined by abundant Poaceae at the expense of *Picea*. *Betula* values are also high. *Alnus* shows the highest percentage in the record (58%). Total pollen concentrations are less than 100 grains/g.

5. **SK5 (12–19 m)**
   Zone SK5 differs from zones SK1-4 by consistently high pollen concentrations (300–1,000 grains/g). Pollen preservation is significantly better than in zones SK1–4. In the relative diagram, SK5 is a stable, almost homogeneous zone with high pollen diversity. The dominant taxon (*Picea*) is present at low frequencies (20–40%), and is associated with abundant *Abies, Pinus* (Haploxylon and Diploxylon), *Tsuga, Betula, Quercus* and *Ulmus/Zelkova, etc.* The occurrence of *Fagus* and *Cryptomeria* is characteristic. *Quercus* pollen consists of both deciduous and evergreen types. *Artemisia, Alnus* and monolectic fern spores are consistently abundant.

V. **Discussion and conclusions**

A general feature of our results is abundant *Picea* throughout the sequence. Particularly in zone SK5, *Picea* is consistently dominant in the terrestrial pollen assemblages. This is consistent with a single pollen spectrum from the Yabu Formation (Onishi, 1969). We note that abundant *Alnus* also characterises the Sakata record. *Pinus* values are low and herb taxa (*Artemisia, Poaceae and Tubuliflorae*) are abundant throughout the sequence. *Pinus* pollen is basically long-transported and dominates pollen assemblages in deep-sea sediments (Chaloner and Muir, 1968). By contrast, abundant *Alnus* pollen occurs only relatively close to the locus of production. This is also true of herb pollen unless there are significant river influences (Matsushita, 1981, 1982). Sedimentological and paleontological studies have suggested that Sakata was under lagoonal environments during the facies IX period (Okazaki et al., 2000). All these evidences are in agreement, indicating a very shallow marine origin for the Sakata sediments (<10–20 m water depth). Sakata belongs to depositional zone a or possibly the upper part
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of zone β which were defined by Traverse (1988) in the vicinity of the coast (Fig. 4). In such shallow marine sediments, conifer pollen transported over long distances is rarely dominant, unlike results seen in deep-sea deposits. We therefore consider that the conifer-rich SK5 assemblages reflect paleovegetation at that time and suggest the spread of *Picea* (spruce) forest in the Boso Peninsula. In the modern vegetation, typical *Picea* forest with *Abies*, *Pinus*, *Tsuga* and *Betula* occupies subarctic zones in Hokkaido (Nakanishi et al., 1983). Zone SK5 represents a cold stage in the regressive phase of the Yabu Formation (near the end of Stage 9 or Stage 8).

For the Boso Peninsula, there are no previous pollen data that definitely represent the Stage 8 glacial, but our knowledge of younger periods supports the above arguments. In the last glacial, abundant *Picea* occurs frequently in pollen records from central Japan (Palynological Research Group for Nojiri-ko Excavation, 1980; Tsukada, 1983; Nasu, 1992; Oshima et al., 1997). Particularly the Stage 4 flora dominated by *Picea* have been reported from Eda, Yokohama, Kanagawa Prefecture (Tsuji, 1983). Based on pollen and macroscopic plant analyses with fission track ages, Tsuji et al. (1984 a) indicated subarctic to cool-temperate conifer forest of mainly *Picea maximowiczii* spread in the Sagami region between ca. 55,000 - 50,000 yrs BP. This forest was associated with *Pinus*, *Tsuga*, *Cryptomeria*, *Ainus*, etc. and is similar to our SK5 flora. The knowledge of Stage 2 remains somewhat fragmentary in the Kanto district (Uchiyama, 1998), but in some cases the Stage 2 flora are characterised by high pollen frequencies of *Pinus* subgenus *Haploxylon* (Sakaguchi, 1978; Tsuji et al., 1984 b; Suzuki et al., 1993), which appear relatively different from our results. In the marine realm, many oxygen isotope records indicate that Stage 8 had significantly lower δ18O values (i.e., was warmer) than Stage 2 and was similar to Stage 4 (Imbrie et al., 1984; Shackleton, 1987; Raymo, 1997). It remains uncertain whether zone SK5 covers the glacial extreme of Stage 8 because lagoons persisted at Sakata against lowered sea level. Nevertheless, the consistence with the last glacial flora in the southern Kanto district supports the presence of *Picea* forest in the Boso Peninsula during cold stages in the Middle Pleistocene. Consequently, the pollen analysis on the fine lagoonal deposits results in a success, ultimately expecting more continuous vegetation and climate histories provided from the Shimosa Group when proper sites and sediment materials are selected.

Unlike the more informative SK5 flora, the pollen assemblages from zones SK1-4 need careful interpretation. The pollen concentrations are very low even in clayey layers and the lithology is not homogeneous. These zones may represent exotic palynoflora. The occurrence of *Carya*, which has been extincted by the end of Pliocene, may indicate sediment reworking from Tertiary-age basement rocks (e.g., Shimakura, 1970). The paleoenvironment
of zones SK1–3 (facies VIII) reconstructed sedimentologically and paleontologically was shoreface (Okazaki et al., 2000). It is possible that the Sakata area was influenced by long-shore currents and experienced active sediment reworking from more oceanic floors with abundant exotic conifer pollen. Two spectra with high pollen concentrations occur in zone SK2, but these appear to be less meaningful because the high concentration is not consistent, interrupted by almost barren (devoid of pollen) sediments around 4.5 m at stratigraphic level.

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References


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房総半島西部、下総層群蓄層堆積物中の化石花粉群集とその意義

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〔要 旨〕

房総半島西部坂田に分布する下総層群蓄層に対して花粉分析を行った結果、堆積層変化との非常によい相関が示された。泥質のラグーン堆積物からは、おもに針葉樹による多様な花粉群集が産し、花粉絶対量も安定して高かったのに対し、砂質の外浜堆積物からの花粉群集はおそらく異地性で、花粉絶対量もまた群集としての多様性も低かった。ラグーン堆積物中の優占分類群はトウヒ属で、モミ属・マツ属・ツガ属・カバノキ属・ブナ属・ヒノキ科などを伴っていた。同時に、ハンノキ属とヨモギ属などの草本が多産し、陸域に近い浅海性の堆積環境が推定される。これらの結果は、上記の針葉樹花粉群集が、いわゆる遠距離飛来花粉を反映している可能性がきわめて低く、むしろトウヒ属を中心とする針葉樹林がステージ9の終わりからステージ8にかけて房総半島に拡大したことを示唆している。これは神奈川県相模地域のステージ4堆積物から亜寒帯—冷温帯性トウヒ林が復元されている事実とも整合的である。

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