Nat. Hist. Res., Vol. 9 No. 1: 1 − 13, March 2006

MIS15-16 Pollen Assemblages from 23 m Iioka Section, NE Boso Peninsula, Central Japan: Validity Check for Choshi Core Pollen Signals

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Abstract This paper presents Middle Pleistocene pollen assemblages from the Iioka section (IOK) covering the upper Yokone and lower Kurahashi Formations of the Inubo Group (equivalent of the Kazusa Group), for validity check of the contemporary Choshi-core pollen record. The Iioka section, located on the western side of the Iioka upland, NE Boso Peninsula, is defined by the marker tephras Kh4a (Ks15) at the top and Yk12 (Ch2) near the bottom. This section is time equivalent to the 107-127 m (MIS15-16) of the 250 m Choshi core (CHOSHI-1), which was recovered from the eastern side of the Iioka upland penetrating MIS11-25. Results of pollen analyses for the Iioka section indicate boreal conifer forest of *Picea, Betula, Artemisia*, ferns, *etc* around Yk12, followed by a massive phase of temperate conifer forest of *Cryptomeria*, T-C-C and *Sciadopitys* around Kh3b-c, as well as a small return of boreal forest around Kh4a. This reproduces the corresponding CHOSHI-1 pollen stratigraphy, supporting the continuity of the Choshi core below Ks15. The IOK result also shows that the CHOSHI-1 pollen signals have a regional extent with more nearshore environments, supporting the terrestrial-palaeoclimate proxy use of the alternation between temperate and boreal conifers.

Key words: Boso Peninsula, Choshi core, Inubo Group, palynology, palaeoclimate, Middle Pleistocene, tephrochronology.

The Middle Pleistocene has been the focus for palaeoclimatological studies because of the extreme glaciations and interglaciation in MIS16, 12 and 11 (Droxler *et al*., 2003) (Fig. 1), climate revolution from 41-kyr obliquity cycle to 100-kyr eccentricity cycle around 700 ka (Shackleton *et al*., 1990) and millennial-scale variations detected in some Middle Pleistocene records (Oppo *et al*., 1998; McManus *et al*., 1999; Tzedakis *et al*., 2003). The Boso Peninsula (35° N; 140° E) is one of the appropriate research areas to the paleoclimatological scopes, because thick Quaternary deposits (the Kazusa-Shimosa Groups) permit high-resolution analyses for obtaining fossil pollen data for the reconstruction of terrestrial palaeoclimate conditions. The Pleistocene of the Boso Peninsula also receives a well-established chronostratigraphy based on tephro-, bio-, isotope- and sequence-stratigraphical studies (Kanto Quaternary Research Group, 1980; Machida *et al*., 1980; Okada and Niitsuma, 1989; Ito, 1994; Masuda, 1997; Pickering *et al*., 1999; Nakazato, 2001). In contrast, many pollen sequences of the Middle Pleistocene lack independent timescales where pollen data have been consumed as chronological scales (Wijmstra and Groenhart, 1983; Mommersteerg

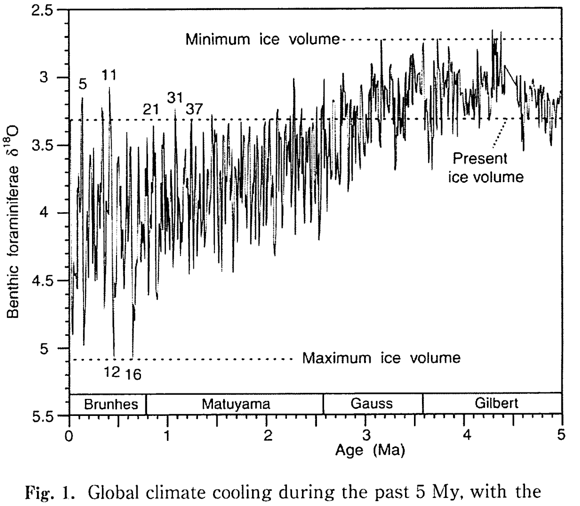

Fig. 1. Global climate cooling during the past 5 My, with the Middle Pleistocene containing climate extremes of MIS11, 12 and 16 (data from benthic foraminifer $\delta^{18}O$ from ODP Site 849; Mix *et al*., 1995).

et al., 1995; Tzedakis *et al.*, 1997; Okuda *et al.*, 2001, 2002a).

Prior palynological studies in the Boso Peninsula have been restricted to the last decades. A few pollen records (Onishi, 1969; Chisaka and Kase, 1979; Kase, 2001; Okuda *et al.*, 2002b) were unfortunately in low resolution and/or fragmentary due to changeable sandy lithofacies. Hence the pollen-climate relation remained uncertain in the Boso Peninsula particularly prior to MIS5. Although preliminary pollen analyses (*e.g.*, Kase, 2001) detected coniferous pollen assemblages including *Picea*, their climate inference remained obscure because such conifer pollen abundance can simply result from long-distance transport under hemipelagic environments (see Yamanoi, 1992, 1993).

A breakthrough for such palynological limitations was brought from the CHOSHI-1 pollen profile from the Choshi core (data published in Okuda *et al.*, 2006). The Choshi core was originally a 255 m-long muddy corelog drilled in 1998 by the Ocean Research Institute, University of Tokyo from the marginal slope of the Kazusa forearc basin. Since the core site has been free from violent turbidity currents, the corelog received homogeneous lithology consisting of polliniferous clay/silt except the top 19 m (El-Masry, 2002). Geologically, the Choshi core penetrated the upper part of the Inubo Group, which is equivalent to the Kazusa Group to part of the Shimosa Group. Our CHOSHI-1 pollen record, anchored by tephrochronology and $\delta^{18}O$ stratigraphy, provided quasi-continuous palynostratigraphy of 400-780 ka with five sets of alternation between temperate conifers (mainly *Cryptomeria*) and boreal conifers (mainly *Picea*) (Fig. 2a), which were comparable to MIS11-19 glacial/interglacial cycles.

Concerning the CHOSHI-1 record, two questions remained critical: (1) temporal and (2) spatial extents of the pollen variations, which hindered converts from the pollen to palaeoclimate (see Okuda *et al.*, 2006).

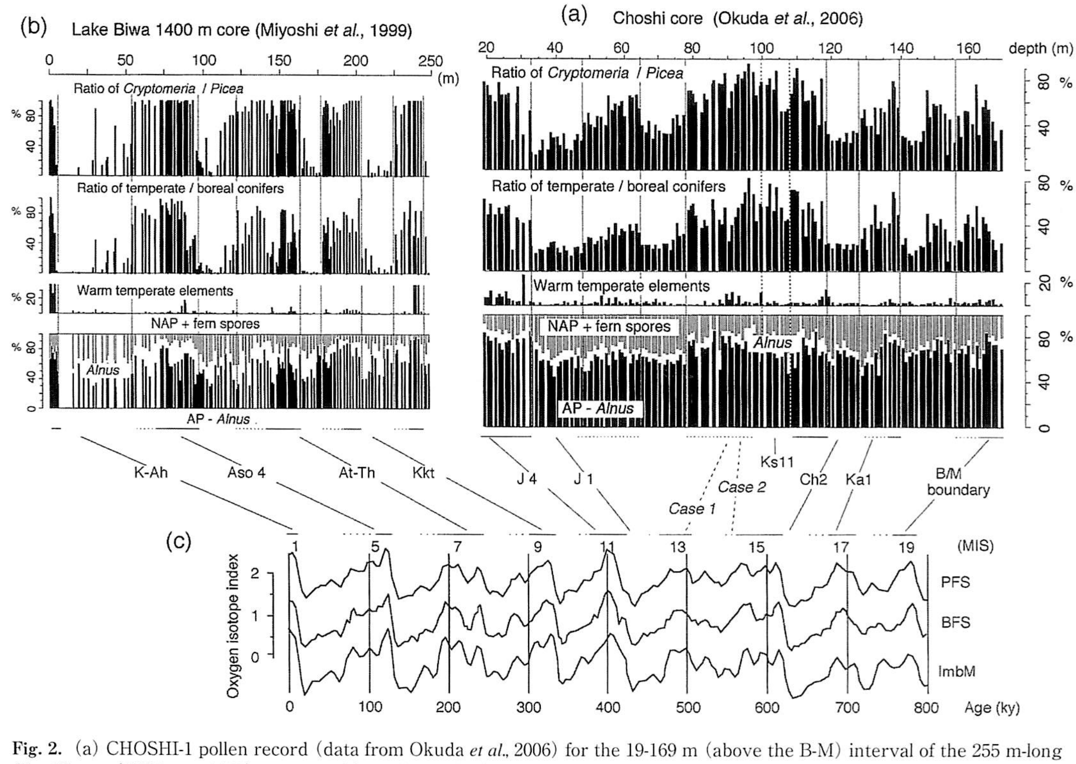

Fig. 2. (a) CHOSHI-1 pollen record (data from Okuda *et al.*, 2006) for the 19-169 m (above the B-M) interval of the 255 m-long Choshi core (El-Masry, 2002), recovered from the Inubo Group in the NE Boso Peninsula, central Japan. Temperate conifers denote *Cryptomeria*, T-C-C (Taxaceae-Cephalotaxaceae-Cupressaceae) and *Sciadopitys*. Boreal conifers denote *Picea*, *Abies*, *Pinus* (mainly *P.* subgen. *Haploxylon*) and *Tsuga* (mainly *T. diversifolia*). Warm-temperate elements denote *Castanopsis* and *Quercus* subgen. *Cyclobalanopsis*. AP and NAP denote arboreal and non-arboreal pollen, respectively. (b) Lake Biwa pollen record (redrawn from Miyoshi *et al.*, 1999) from the 250 m T-bed of the 1400 m core (Takemura, 1990). (c) External $\delta^{18}O$ stacks during the past 800 ky (compilation after Berger and Wefer, 2003). PFS and BFS denote stacks of planktonic and benthic foraminifer $\delta^{18}O$ records. ImbM denotes the SPECMAP stack (Imbrie *et al.*, 1984) with age adjusted to the algorithm operating on Milankovitch input (Mila 1000) (Berger *et al.*, 1996).

The first question has been given an answer by referring to the Lake Biwa pollen record (Miyoshi *et al.*, 1999) from the top 250 m of the 1400 m core (Takemura, 1990; Meyers *et al.*, 1993) (Fig. 2b). That is the standard pollen profile for the past 430,000 years (MIS1-12) with dozens anchor points based on tephrostratigraphy from the parallel Takashima-oki core (Yoshikawa and Kuwae, 2001). The integration of the Lake Biwa and CHOSHI-1 pollen records showed the consistency with external δ^{18}O stacks (Fig. 2c) throughout the Brunhes chron. In contrast, the second question (spatial extents of the CHOSHI-1 pollen variations) has remained unsolved due to the lack of time-equivalent pollen records. This problem was not negligible because conifer-rich assemblages only in hemipelagic environments could be the result of long-distance transport. For example, many offshore pollen records were dominated by *Pinus* (Shimakura, 1970; Suc, 1984; Yamanoi, 1992), which is easily wind-blown from distant uplands and disturbs palaeoclimate signals (Chaloner and Muir, 1968; Traverse, 1988).

There was also the third geological problem that implied a sediment discontinuity around 105-110 m of the Choshi core. The discontinuity was initially suggested by assuming the extension of the Nagahama unconformity, which lay below the Ks15 tephra denuding the Chonan, Kakinokidai and Kokumoto Formations in the western Boso Peninsula (Machida *et al.*, 1980) (Fig. 3a). In the east, this unconformity pinched out into the muds of the Kurahashi Formation, but it was difficult to deny the possibility of invisible hiatuses in the Choshi area. In the Inubo Group, the stratigraphic distance between tephras Kh4a (Ks15) and Yk12 (Ch2) is anomalously small in the eastern side of the Iioka upland (Fig. 3b), and Sakai (1990) drew his local tephras Kh2 and Kh3 as if missing in the eastern side (see Nakazato *et al.*, 2003). This logically permitted a possible sediment lack in the Choshi core stratigraphy.

In order to address these issues, this paper provides a pollen profile from the Iioka section (IOK), located in the opposite side of the Iioka upland (see Fig. 4). This 23 m section is defined by tephra Kh4a (Ks15) at the top, with Kh3c (Ks17) at 11.5 m, Kh3b (Ks18) at 13 m and Yk12 (Ch2) at 19.5 m in descending order, being time-equivalent to the 107-127 m of the Choshi-core stratigraphy (Okuda *et al.*, 2006). When Sakai's (1990) interpretation was right, the pollen spectra from Iioka would not agree with the corresponding CHOSHI-1 pollen stratigraphy, but would provide some extra signals that was not recorded in the Choshi core. Similarly, if the CHOSHI-1 record contained abundant

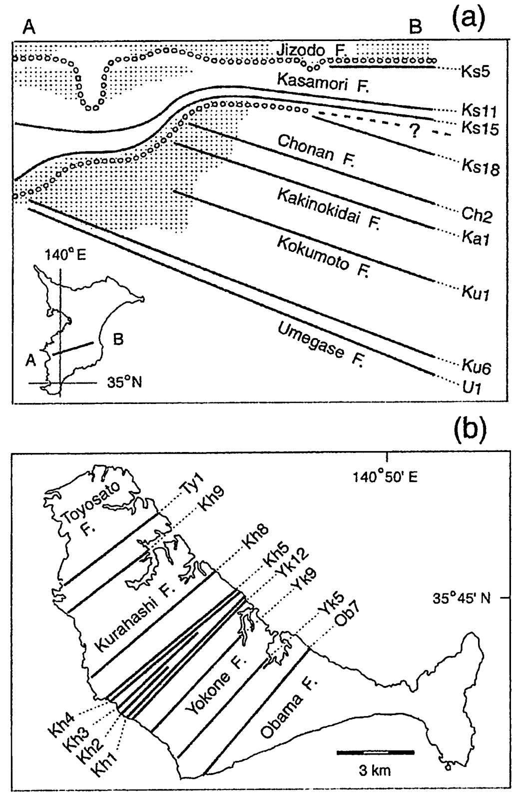

Fig. 3. (a) Schematic geological section of the Kazusa Group (E-W direction), with the Nagahama unconformity shown below tephra Ks15 (Machida *et al.*, 1980). (b) Marker tephra distribution in the Inubo Group, NE Boso Peninsula, Japan (simplified after Sakai, 1990). The tephrostratigraphy between Kh4 and Yk12 has been questioned by Nakazato *et al.* (2003).

exotic pollen as a consequence of the hemipelagic location, the IOK pollen signals, formed at a more nearshore site, would be significantly different from the Choshi core pollen signals.

Geological Setting of the Inubo Group, with Lithostratigraphy of the Iioka Section and the Choshi Core

The Inubo Group was initially termed for the Plio-Pleistocene (500-600 m thick) of marine origin in the northeasternmost Boso Peninsula (Ozaki, 1958) (Fig. 5a). These strata have received few geological studies (Matoba, 1967; Niitsuma, 1970; Nishida, 1980) compared with intense studies on the Kazusa Group in the central Boso Peninsula. Recently, a comprehensive work by Sakai (1990) redefined the lithostratigraphy of the Choshi area based on litho-, tephro-, magneto- and radiolarian stratigraphies, subdividing the Inubo Group into the Naarai, Kasuga, Obama, Yokone,

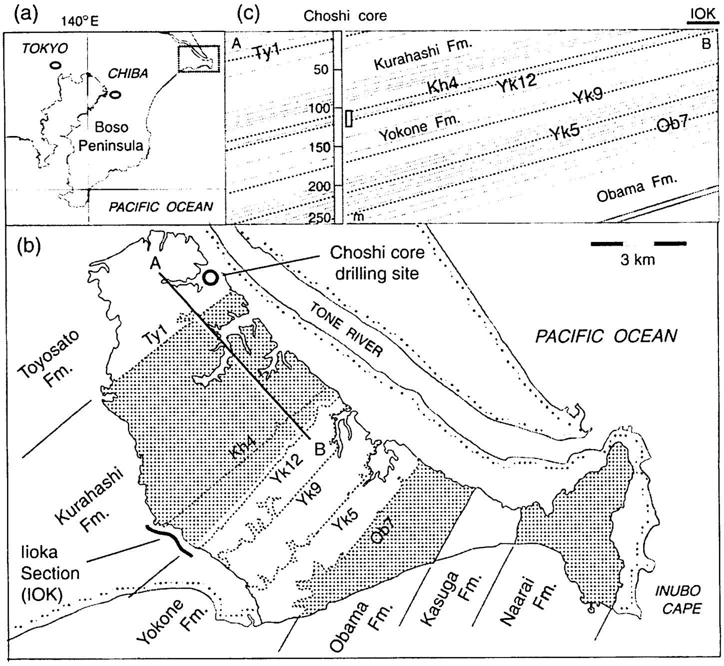

Fig. 4. (a) Locality of the Choshi area. (b) Geological map for the Inubo Group (after Sakai, 1990), with localities of the Choshi-core drilling site (El-Masry, 2002; Okuda *et al.*, 2006) and the Iioka section (this study). (c) Schematic geological section of the Inubo Group with representative marker tephras. An open rectangle along the corelog denotes the time-equivalent interval of the Choshi core (107-127 m) to the Iioka section (IOK).

Kurahashi and Toyosato Formations from the base upwards. Today the Inubo Group is time equivalent to the Kazusa (and basal part of Shimosa) Groups based on abundant marker tephras (Na2-5, Kg1-4, Ob1 and 3-7, Yk1-12, Kh1-9 and Ty1-3), spanning from the early Middle Pleistocene (>0.4 Ma) to the late Pliocene (<3-4 Ma) (Sakai, 1990; Takayama *et al.*, 1995) (Fig. 5b). The Brunhes-Matuyama (B-M) palaeomagnetic boundary has been recognised in the midst of the Yokone Formation, as well as the Olduvai subchron placed in the upper part of the Kasuga Formation. Lithologically, the Inubo Group consists of hemipelagic mudstone unlike the turbidite-rich Kazusa Group. Particularly the Yokone Formation consists of fine-grained materials deposited in offshore environments, whereas the Kurahashi Formation becomes sandy in the upper part, as the consequence of progradation near the top of the Inubo Group. The uppermost Toyosato Formation consists of massive sand/silt (Sakai, 1990).

The Iioka section, located in Iioka-cho, Asahi-shi, Chiba prefecture (35° 43'0-10"N; 140° 42'30-50"E; 5-10m a.s.l.) (see Fig. 4), consists of roadside outcrops of 23m in the total height. This section is bracketed by marker tephras Kh4a at the top (0m) and Yk12 near the bottom (19.5m), spanning the upper Yokone and lower Kurahashi Formations (see Fig. 5). Two more marker tephras Kh3b and Kh3c are interbedded at 13 m and 11.5 m from the top, respectively. These correlate the Iioka section with the 107-127 m of the Choshi core. Tephrostratigraphically, the Kh4a, Kh3c, Kh3b, Yk12 are counterparts of Ks15, Ks17, Ks18 and Ch2 of the Kazusa Group based on refractive indices and heavy-mineral compositions (Nakazato *et al.*, 2003). Lithologically, the Iioka section consists of olive-grey coloured clay/silt. The sediments are very massive, except for fine-grained sands forming thin, obscure bands above Kh3c. Pumice fractions and small (< 1cm) mollusk shells are scattered above and below Kh3b-c, though they are far from abundant through the section.

The Choshi core (255m long altogether) was recovered from morito-cho, Choshi-shi, Chiba prefecture (35° 46'44"N; 140° 43'53"E). This core received multi-proxy analyses including bulk density, sand contents, electric resistivity, total organic carbon (TOC), magnetic susceptibility (MS), carbon/oxygen isotopes ($\delta^{18}O$, $\delta^{13}C$), foraminifer and diatom abundance, *etc* (El-Masry, 2002). The Brunhes-Matuyama (B-M) palaeomagnetic boundary was placed in 162-169 m centred in 168 m, and the whole corelog penetrated MIS11-25 (ca. 395-925 ka) (El-Masry, 2002; Kameo *et al.*, 2006). Lithologically, the core consisted of olive-grey coloured silt/clay of the Kurahashi, Yokone and Obama Formations, except the top 19 m with abundant coarse-sands/gravels of the Toyosato and Katori Formations. In order to escape the *Metasequoia* flora surviving in the Early Pleistocene, the upper portion of the Choshi core above the B-M (*i.e.*, 19-169 m) was analysed for the CHOSHI-1 pollen record (Okuda *et al.*, 2006). The lithology resembled that of the Iioka section except for abundant granule/pebble-sized pumice scattered. Tephras Kh4a, Kh3b and Yk12 were observed at 107.5 m, 111.6 m and 123.8 m of the Choshi core, respectively (El-Masry, 2002).

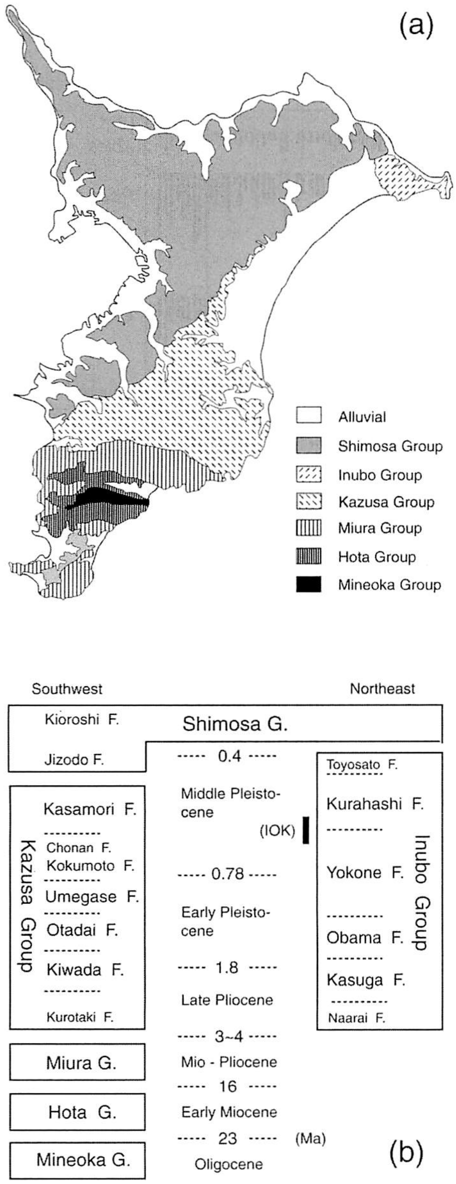

Fig. 5. The Neogene-Quaternary of the Boso Peninsula. (a) Regional geological map of Chiba prefecture, showing the Inubo Group in the northeast. (b) Schematic columnar section for the Neogene-Quaternary of the Boso Peninsula (compiled after Editorial Committee of Kanto, 1986; Sakai, 1990). A filled rectangle denotes the time range of the Iioka section (IOK).

Materials and Methods

The field survey was performed in 2003 March with tephra researches conducted by the second and the third authors. Sediment samples for pollen analysis were collected from 45 horizons by the first author. The sampling interval was generally 50 cm and each sample was 1-2 cm^3 in size. The samples were pretreated and analysed in the pollen laboratory at the Natural History Museum and Institute, Chiba.

The pretreatment method for pollen analyses followed the standard KOH-acetolysis method (Moore *et al.*, 1991) with inert plastic microspheres added for absolute counts (Ogden III, 1985). The sediment samples were milled and bathed in a 10% HCl solution overnight to remove any calcium carbonate. After excess HCl was rinsed off, the samples were boiled in a 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 $ZnCl_2$ solution. The samples were finally acetolysed and mounted in glycerol solution. More than 200 grains of arboreal pollen (AP) except *Alnus* were counted for each sample, forming the sum for percentage calculations. Percentages for *Alnus* itself as well as non-arboreal pollen (NAP) and pteridophyte spores were based on the same sum (AP minus *Alnus*) to enable comparisons with the CHOSHI-1 and Lake Biwa pollen records.

Results

Results of the pollen analysis for the Iioka section were shown in Figure 6. Averages of 5000-8000 grain s/cm^3 of AP minus *Alnus* were yielded from the analysed samples (with the maximum of 29,000 grain s/cm^3), which were substantially high for marine environments. *Pinus* did not become dominant throughout the analysed section. The dominant taxa were *Cryptomeria*, Taxaceae-Cephalotaxaceae-Cupressaceae (T-C-C) and *Picea*, associated with *Abies*, *Tsuga*, *Pinus*, *Sciadopitys*, *etc*. The *Pinus* and the *Tsuga* contained a lot of *P.* subgen. *Haploxylon* and *T. diversifolia* pollen-types, which are today the elements of boreal coniferous forest in northern Japan (Nakanishi *et al.*, 1983). The *Fagus* belongs to *F. crenata* based on the pollen morphology, but palaeobotanically could contain extinct beeches of *F. japonica*, *F. hayatae* and/or *F. microcarpa* when prior works for the Osaka Group (Tai, 1973) are considered. *Carya* and *Liquidambar*, which have been extincted from Japan (Nasu, 1980), sporadically occurred throughout the sequence. They logically originated from some reworked materials. *Lagerstroemia* was absent throughout the section.

Three local pollen zones IOK1-3 were recognized based on the variations among the dominant taxa (*Cryptomeria*, T-C-C, *Picea*, *Artemisia*, monolete ferns, *etc*) as well as the pollen (and spore) concentrations.

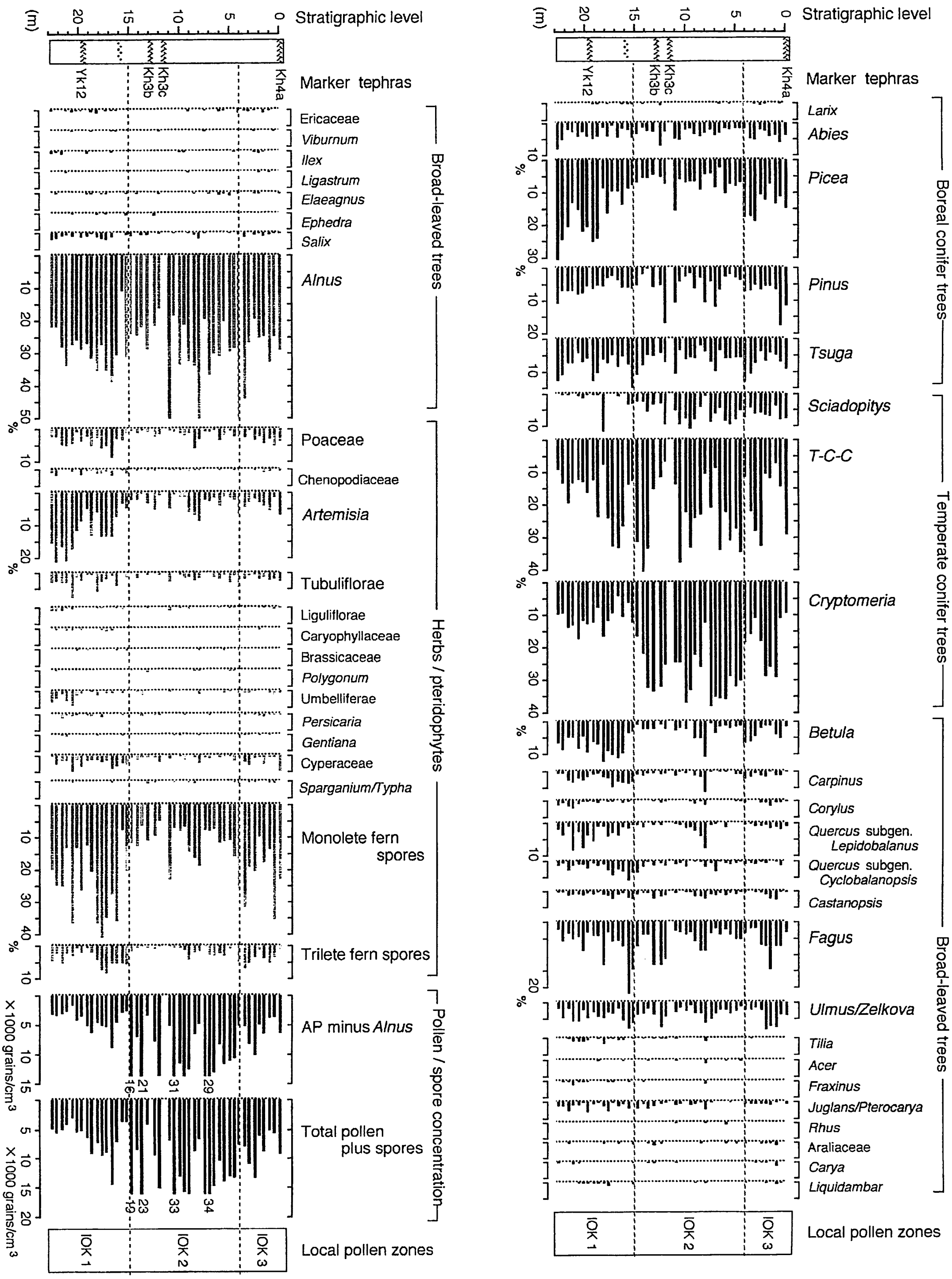

Fig. 6. Results of the relative and absolute pollen analyses for the Iioka section, NE Boso Peninsula. Arboreal pollen except *Alnus* forms the sum for percentage calculations. Percentages of *Alnus*, herbs and pteridophyte are also based on the same sum to enable the comparison with the CHOSHI-1 (Okuda *et al.*, 2006) and Lake Biwa (Miyoshi *et al.*, 1999) pollen records.

1. IOK1 (15-22.8 m)

Zone IOK1 was characterised by abundant *Picea*, *Betula*, *Artemisia* and ferns (monolete and trilete types). *Pinus*, *Tsuga*, *Quercus* subgen. *Lepidobalanus*, Poaceae, Tubuliflorae and Umbelliferae were main associates. Pollen concentrations remained low in this zone (3000-6000 grains/cm^3 for AP minus *Alnus*), suggesting lower forest density. The reconstructed vegetation of zone IOK1 was boreal (or subarctic) coniferous forest with *Artemisia* and/or pteridophytes around the spruce forest.

2. IOK2 (4-15 m)

Zone IOK2 was characterised by dominant *Cryptomeria* and T-C-C replacing the boreal elements. The regular abundance of *Sciadopitys* was also characteristic, differentiating the IOK2 from the IOK1. Higher pollen concentrations (reaching 15,000-30,000 grains/cm^3 for AP minus *Alnus*) indicated higher forest density, coupled with the simultaneous decreases in open-space elements (ferns, *Artemisia*, Tubuliflorae, Poaceae, *etc*). The reconstructed vegetation of zone IOK2 was dense forest of temperate conifers such as *Cryptomeria*, T-C-C and *Sciadopitys*. This zone had irregular peaks of *Picea* and *Pinus* in 11-12 m as well as *Betula*, *Carpinus*, *Quercus*, *Fagus*, *etc* in 7-9 m, possibly being subdivided under higher resolution.

3. IOK3 (0-4 m)

Zone IOK3 was a less distinct pollen zone than the IOK1-2, but was recognised by a return of *Picea* replacing *Cryptomeria*. The *Pinus* (probably *P. Haploxylon*), herbs (*Artemisia*, Poaceae, *etc*) and ferns were also main associates. A feature of this zone was the persistence of *Sciadopitys*, so the temperate forest was not completely replaced by the returning boreal forest. The reconstructed vegetation of zone IOK3 was boreal and temperate mixed conifer forest. The lower pollen concentrations (<10,000 grains/cm^3 for AP minus *Alnus*) with returns of herbs and pteridophytes indicated reduction of forest density.

Discussion

1. Terrestrial-environmental signals in the IOK and CHOSHI-1 records

The significance of the IOK record is the consistency with the corresponding interval of the CHOSHI-1 record (Fig. 7). Around tephra Yk12, lower ratios of *Cryptomeria*/*Picea*, temperate/boreal conifers and AP/NAP-plus-spores are observed in the IOK and CHOSHI-1. Around tephra Kh3b, increases in the *Cryptomeria*/*Picea*, temperate/boreal conifers and AP/NAP-plus-spores are shared by the two profiles. Comparisons with multiproxy data from the Choshi core (δ^{18}O, δ^{13}C, magnetic susceptibility, planktonic foraminifera) (see Fig. 7) indicates glacial environments to zone IOK1, whereas an interglacial environ-

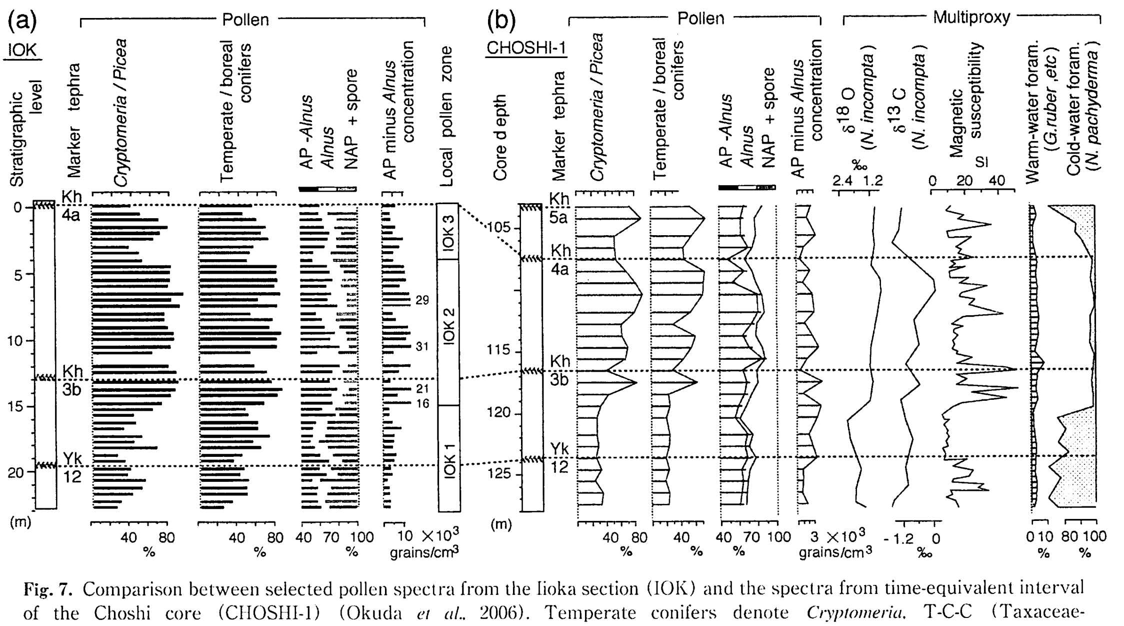

Fig. 7. Comparison between selected pollen spectra from the Iioka section (IOK) and the spectra from time-equivalent interval of the Choshi core (CHOSHI-1) (Okuda *et al.*, 2006). Temperate conifers denote *Cryptomeria*, T-C-C (Taxaceae-Cephalotaxaceae-Cupressaceae) and *Sciadopitys*. Boreal conifers denote *Picea*, *Abies*, *Pinus* (mainly *P.* subgen. *Haploxylon*) and *Tsuga* (mainly *T. diversifolia*). Multiproxy records (δ^{18}O, δ^{13}C, MS, foram composition, *etc*) are from El-Masry (2002).

ment is given to zone IOK2. Pollen concentrations show a similar pattern between the two profiles. Concerning the concentration levels, the IOK record shows 3-10 times higher pollen/spore concentrations than the Choshi core, which is consistent with the nearshore location of the Iioka site. The averaged concentrations of 5000-20,000 grains/cm^3 are significantly high compared with the prior Sakata record (Okuda *et al.*, 2002b), which originated from a lagoonal environment of MIS9 interglacial but the pollen concentration hardly reached 1000 grains/cm^3. It deserves attentions that the IOK record shares the same signals with the Choshi core. This supports that the CHOSHI-1 palynoflora represents terrestrial environments rather than reflecting noise-like exotic pollen transported from distant areas.

2. Orbital-scale continuity of the Choshi core below Ks15

The consistency between the IOK and CHOSHI-1 pollen records denies differential sedimentation in the east and west sides of the Iioka upland. This certainly attenuates the sediment lack hypothesis for the Choshi core in at least orbital scales (10-100 kyr in this context). The problematic tephras Kh2 and Kh3 shown by Sakai (1990) may possibly result from double recognition of Kh1, which may appear repeatedly along the study route due to undulating bedding planes (see Nakazato *et al.*, 2003). We note that the present IOK result support the sediment continuity of the Choshi core between tephras Kh4 and Yk12. In other words, no hidden stadial phase exists below Kh4 (*i.e.*, Ks15), unlike the assumption of hiatus (El-Masry, 2002) that is invisible but comparable to the Nagahama unconformity of the Kazusa Group.

3. Palaeoclimate proxy use of the temperate/ boreal conifer alternation

Figure 7 also shows a relation between palaeoclimate (glacial/interglacial cycles) and pollen variations between temperate conifers (mainly *Cryptomeria*) and boreal conifers (mainly *Picea*). The $\delta^{18}O$ has been known as a proxy of the 100-kyr glacio-eustasy cycle in the Kazusa Group (Pickering *et al.*, 1999), and the foraminifer composition showed abundant cold-water species *N. pachyderma* during the zone IOK1 (El-Masry, 2002) (Fig. 7). These give stadial features to the boreal conifers, while giving interstadial features to the temperature conifers. At present, geographical isolation between *Picea* sp. and *Cryptomeria japonica* is apparent in surface pollen spectra (Fig. 8). In this latitude-altitude diagram, *Picea* pollen is restricted to Hokkaido and the mountains of central Honshu, whereas *C. japonica* is common in the temperate zones of Honshu, Shikoku and Kyushu islands. The border of the two major pollen types was recognised around 7-8℃ in mean annual temperature (Okuda *et al.*, 2006), which is close to the Kuromatsunai line in southwestern Hokkaido. It is also true that the distribution of natural *C. japonica* forest is constrained by high rainfalls (>1800mm/y) (Tsukada, 1982, 1986). The abundant *Cryptomeria* in the Pleistocene palynoflora would also reflect increased rainfall during interglacials, which has widely been observed in the monsoon regions (An *et al.*, 1991; Tada *et al.*, 1999; Zhou *et al.*, 2001). In the Late Pleistocene, the temperate-conifer phase in MIS5 and the boreal-conifer phase in MIS2-4 have been common in numerous pollen records from Japanese archipelago (Yasuda, 1982; Tsukada, 1983; Tsuji *et al.*, 1984; Heusser, 1990; Oshima *et al.*, 1997; Takahara and Kitagawa, 2000; Yasuda, 2002; Miyake *et al.*, 2005; Iriya *et al.*, 2005).

4. Time ranges of the Iioka section

Based on the above geochemical and ecological evidence, the temperate-conifer phase of zone IOK2 correlates with MIS 15, whereas the boreal-conifer phase of zone IOK1 correlates with MIS16. This means that the Iioka section covers at least 600-630 ka (calibration target from Bassinot *et al.*, 1994). The boreal and temperate mixed phase of zone IOK3 may represent MIS14 glacial but may reflect MIS15b/d stadials, obscuring the upper limit of the time range. This chronological problem concerns the eruption age of tephra Kh5a (at 103.5 m of the Choshi core, see Fig. 7), which is equivalent to widespread marker tephra Ks11 (Kb-Ks or Sakura) found in many parts of Japan (Yoshikawa and Mitamura, 1999; Shirai, 2001; Suzuki, 2003; Nagahashi *et al.*, 2004), requiring further researches.

Conclusions

The Iioka (IOK) pollen record, which spanned at least 600-630 ka (MIS15-16) based on the tephrostratigraphy bracketed by Kh4a (Ks15) and Yk12 (Ch2), reproduced the corresponding interval of the Choshi core pollen profile. Since the IOK record was deposited in the nearshore environment in the western side of the Iioka upland, the data reproduction supported the regional extent of the CHOSHI-1 pollen signals, as well as a relation between the pollen and terrestrial climate. The IOK results also showed the evidence against the possible hiatus below Kh4a (Ks15) in the

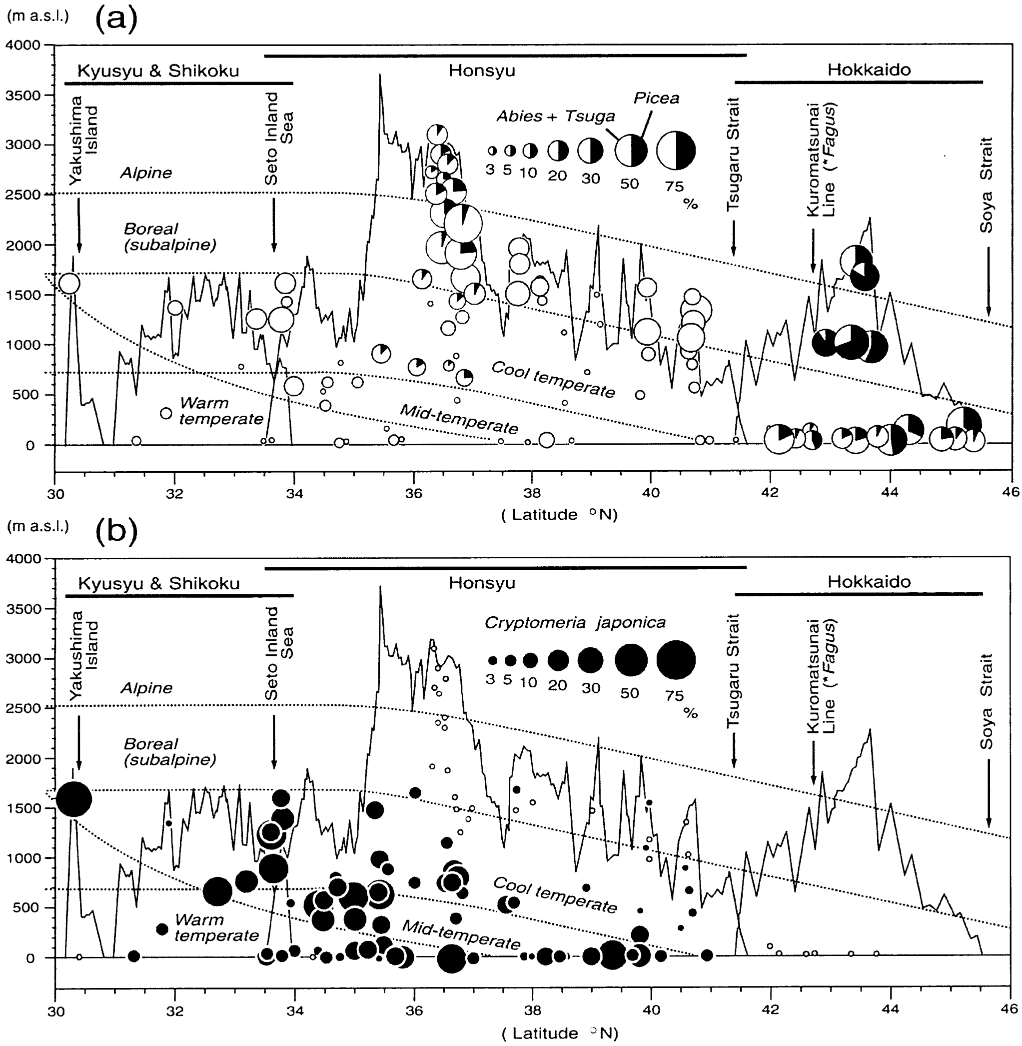

Fig. 8. Latitude-altitude diagrams based on surface pollen spectra of the Japanese archipelago (redrawn after Tsukada, 1986, 1988). (a) *Picea* (*Abies* plus *Tsuga* added). (b) *Cryptomeria japonica*.

Choshi core, strengthening the sediment continuity of the Choshi corelog particularly in 105-125 m. The palaeoclimate proxy use of the temperate/boreal conifer alternation was also supported with the aid of multiproxy records (δ^{18}O, *N. pachyderma, etc*) as well as the comparison with surface pollen spectra. These means that a quasi-continuous MIS11-19 biostratigraphy emerges from the Choshi core, and that the combination with Lake Biwa record provides the standard reference section for the past 780 ka.

Acknowledgements

This work was supported by a promotion fund of the Grant-in-Aids for Scientific Research from MEXT to M. O. (No. 15740311). The IOK and CHOSHI-1 pollen records are the products from a research project of the Natural History Museum and Institute, Chiba, entitled Vegetation and environmental history of the Boso Peninsula. The Choshi core itself was the product of the Boso Drilling Program (BDP) organized by the Ocean Research Institute, University of Tokyo.

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(Accepted 7 February 2006)

銚子地域飯岡露頭における酸素同位体比ステージ（MIS）15-16の化石花粉群とその意義
—銚子コア花粉信号の信頼度チェック—

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鮮新—更新統犬吠層群（上総層群相当層）の一部が露出する房総半島北西部飯岡露頭に対して花粉分析をおこない，東大海洋研掘削の 250 m 銚子コアからの花粉層序との比較およびデータ検証に用いた．これは平成 15-17 年度文部科学省科研若手研究 B（課題番号 15740311；代表者奥田）の成果であると同時に，千葉中央博総合研究「房総の植生変遷と環境変動」の成果の一部である．飯岡露頭は層厚 23 m の海成粘土層からなり，上から順に MIS15-16 の指標テフラ Kh4a（Ks15）・Kh3c（Ks17）・Kh3b（Ks18）・Yk12（Ch2）を挟み，250 m 銚子コアの深度 107-127 m 部分に相当する．飯岡露頭の調査意義は以下 2 点に纏められる：（1）銚子コア地点より当時の陸域に近接していたことから，銚子コア中の化石花粉群組成の陸上環境に対する相関度の検証に役立つ；（2）銚子コア Kh4a 直下に存在が示唆されていた万年オーダーの堆積間隙の検証に役立つ．

飯岡露頭の花粉分析結果は以下のようであった．Yk12 付近ではトウヒ属・カバノキ属・ヨモギ属・シダ胞子を中心とする北方系針葉樹林が優先し，Kh3b-c 付近ではスギ属・コウヤマキ属・ヒノキ科等よりなる温帯性針葉樹林が優先し，Kh4a 付近において上記北方系要素の再増が示された．以上が銚子コア相当部の花粉層序（Okuda *et al.*, 2006）と概ね調和であることから，（1'）銚子コア中の花粉信号は最寄りの陸上植生変遷の有意な反映であり遠距離飛来性花粉による歪みはさほどでは無いことが指示された．これは銚子

コア中の北方系／温帯性針葉樹花粉群の周期的な交代が万年単位の古気候変動（おそらく氷期間氷期サイクル）の指標となり得ることを意味する．また（2'）銚子コア Kh4a-Kh3 間（深度 110-115 m 付近）の万年単位での連続性が支持された．これは同コア Kh4a (Ks15) 直下における小寒冷期の存在の可能性を否定し，銚子コアにおけるプロキシーベースの編年構築の有意性を強めている．