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Age and paleoclimatic implication of middle to upper Miocene plant-bearing strata in the southern Kanazawa area, Ishikawa Prefecture, central Japan, based on refined Neogene palynostratigraphy in the Hokuriku district

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Abstract

13–8 Ma (middle to late Miocene) is a key period for understanding how the unique vegetation was established in Japan. Palynostratigraphy is useful for estimating the ages of plant-bearing strata deposited in shallow-marine and non-marine environments, but has low temporal resolution for this key period in Japan. We compiled Neogene and early Quaternary palynological records for the Hokuriku district of central Japan to clarify palynostratigraphic events that may improve the temporal resolution. Our results showed that palynoassemblages changed considerably during 10–6.4 Ma in the Hokuriku district, following a relatively stable period during 13–10 Ma. We found that evergreen *Quercus* abundance increased at 11.5–10 Ma. We used these palynostratigraphic signatures, along with other biostratigraphic markers, to infer the ages of the Miocene plant-bearing Saikawa and Koderayama Formations in the southern Kanazawa area of Ishikawa Prefecture in the Hokuriku district. The ages of the Saikawa and Koderayama Formations were inferred as approximately 13 and 10–6.4 Ma, respectively. The palynoflora of the Koderayama Formation shows floristic similarity to that of present south China, implying that the unique flora of Japan established after the age of the Koderayama Formation.

KEYWORDS

Hokuriku district, Kanazawa, Miocene, Neogene Pollen Zone, Palynostratigraphy, Saikawa

1 | INTRODUCTION

Today, Japan is a biodiversity hotspot that harbors numerous endemic plant species (Mittermeier et al., 2005). Late Miocene Mitoku-type flora (8–6 Ma) is the most recent archetype of present-day Japanese vegetation (Tanai, 1961), but how this flora was established remains unclear. Recently, it has been suggested that some species of the middle Miocene Daijima-type flora (17–16 Ma) helped shape the modern Japanese vegetation (e.g., Yabe & Nakagawa, 2018; Yamada & Yamada, 2018). However, vegetation in the interval between the Daijima- and Mitoku-type floras is poorly understood (Tanai, 1961, 1991), except for a few examples in Aichi and Gifu Prefectures (Miki, 1941; Momohara & Saito, 2001). This insufficiency is largely due to lack of precise ages for plant-bearing strata in this interval.

Palynostratigraphy can be correlated with biostratigraphies of marine microfossils because pollen and spores are abundant in offshore deposits (Traverse, 1988). As plant macrofossils are usually found in shallow marine and non-marine deposits for which marine biostratigraphic markers are often unavailable, such integrated biostratigraphies allow the ages of these plant-bearing strata to be estimated. Yamanoi (1989a, 1992a, 1998) proposed six palynostratigraphic zones for the Neogene in Japan (NP-1–NP-6), which could be related to macrofossil flora as well as global climatic trends (Yamanoi, 1989a, 1992a, 1998; Saito, 2008). However, the temporal resolution is insufficient for the NP-3 zone, which spans 13–6.5 Ma (Yamanoi, 1989a, 1992a; Saito, 2008), the key period for establishment of the current Japanese vegetation. Wang et al. (2001) reported detailed palynostratigraphy of the Himi area, Toyama Prefecture, in the Hokuriku district of Central Japan (Figure 1). They noted that the transition from NP-3 to NP-4 type palynoassemblages should have occurred at 9–6.4 Ma in the Himi area. This finding indicates that the NP-3 zone can be divided into two subzones, but the applicability of this subdivision to other areas has not yet been tested.

Recently, we revised the Neogene stratigraphy of the southern Kanazawa area (Figure 1) of Ishikawa Prefecture in the Hokuriku district (Yamada et al., 2017). We identified two plant-bearing stratigraphic units that may fill the gap in plant macrofossil records, i.e., the middle to upper Miocene Saikawa and Koderayama Formations. However, the age of the Koderayama Formation has not been precisely determined, as it does not yield any marine microfossils associated with stratigraphic indices (Yamada et al., 2017). In addition, the Saikawa Formation is correlated with the CN5a zone of calcareous nannofossil biostratigraphy (Takayama et al., 1988), but this biozone spans a long period of about 1.7 Ma (Okada and Bukry, 1980).

In this study, we compiled Neogene and early Quaternary palynological records from the Hokuriku district of Central Japan to improve the temporal resolution of the NP zones. The compiled records were correlated to biostratigraphies of marine microfossils and tephrostratigraphy. We propose several palynological events for stratigraphic use, which are applicable at least to sediments in this district. We also analyzed the pollen and spore assemblages of middle to upper Miocene sediments exposed in the Saikawa section (Yamada et al., 2017) of Okuwa, in the southern Kanazawa area (Figure 1). We applied the newly identified palynological signatures to these palynoassemblages to infer the ages of the Saikawa and Koderayama Formations.

2 | GEOLOGICAL SETTING

2.1 | Geology in the southern Kanazawa area

In the southern Kanazawa area, the Neogene and Quaternary strata strike in the NE–SW direction and dip northwestwardly at approximately 20°. The Neogene deposits are of marine origin, as indicated by the presence of marine microfossils and mollusks (Ogasawara, 1976; Sasaki and Ogasawara, 1986; Yanagisawa, 1999a, b; Yamada et al., 2017). Most of the Quaternary strata were deposited in shallow marine, but some could be non-marine (Nirei, 1969; Kaseno, 1996).

The Neogene deposits in this area are classified into the Iozen (older than 16.9 Ma), Sunagozaka (16.9–16.7 Ma), Nanamagari (16.7–16.6 Ma), Asagaya (16.6–15.8 Ma), Shimoaraya (15.8–15.6 Ma), Yamashina (15.6–15.4 Ma), Saikawa (13.5–11.8 Ma), and Koderayama Formations (younger than 11.8 Ma) in ascending order (Ogasawara, 1976; Sasaki and Ogasawara, 1986; Yanagisawa, 1999a, b; Yamada et al., 2017). Sedimentary hiatuses occurred between the Yamashina and Saikawa Formations, and between the Saikawa and Koderayama Formations (Yamada et al., 2017; see below for details). The Pleistocene (1.72–0.85 Ma) Omma Formation unconformably overlies the Neogene deposits (Kitamura et al., 1994; Okubo, 1999; Kitamura and Kimoto, 2007). The Omma Formation is conformably (Nirei, 1969; Kaseno, 1996) or unconformably (Ichihara et al., 1950) overlain by the Utatsuyama Formation. The precise age of the Utatsuyama Formation has not been determined, but it must be older than 0.4 Ma, as the Utatsuyama

Formation is overlain by volcanic deposits from Mt. Tomuro, which erupted at that time (Kaseno, 1996).

2.2 | Stratigraphy of Miocene sediments in the Saikawa section

In the studied part of the Saikawa section of Okuwa in the southern Kanazawa area (Figure 1a, b), the Miocene sediments consist of the Yamashina, Saikawa, and Koderayama Formations (Figure 1c, d). The Koderayama Formation is in contact with the overlying Omma Formation by a low-angle unconformity (Kitamura, 1997; Yamada et al., 2017).

The Yamashina Formation consists of bluish grey mudstone deposited in offshore environments. It reaches a thickness of 210 m in this section. Pumices and charcoals are commonly present in the upper member of this formation. The last occurrence of the index diatom *Denticulopsis okunoi* (D43, 15.4 Ma) is in the upper part of the Yamashina Formation (Yamada et al., 2017).

The 23-m-thick Saikawa Formation is a shallow marine sediment composed of medium to coarse tuffaceous sandstones. It contains abundant charcoalified wood fragments and pumices of pebble size. The boundary between the Yamashina and Saikawa Formations is ambiguous in the studied section due to intense bioturbation. Diatom biozones could not be assigned, as only reworked assemblages were obtained (Yamada et al., 2017), but calcareous nannofossils of CN5a (13.5–11.8 Ma, Okada and Bukry, 1980) have been reported in this formation (Takayama et al., 1988).

The Koderayama Formation (25 m thick) is mainly composed of fine sandstones rich in sulfur and carbonaceous materials, suggesting a stagnant sedimentary environment such as an inner bay. The underlying Saikawa Formation was eroded and covered with a granule conglomerate bed approximately 70 cm thick. Climbing ripples with a symmetrical crest are often observed in the fine sandstone. At the base of each sandstone bed, a thin (5–10 cm) granule- to pebble-sized conglomerate layer is present. Plant fragments, such as woods, cones, and fruits, are abundant in this layer. Calcareous microfossils and diatoms have not been obtained from this formation (Yamada et al., 2017).

3 | MATERIALS AND METHODS

3.1 | Compilation of previous palynological records from the Hokuriku district

We compiled published palynological datasets to reconstruct the palynological transitions of 17–2 Ma in the Hokuriku district. These datasets include observations from the Noto, Kanazawa and Daishoji areas of Ishikawa Prefecture, the Himi area of Toyama Prefecture, and the Tokamachi area of Niigata Prefecture (Figure 1b). Numerous palynological reports are available for this district, but we used only those with well-defined ages (see below for details). Palynological records are concentrated around 17–16.7 Ma in this district (e.g., Yamanoi, 1989b, 1992b; Yamanoi & Tsuda, 1986), a period characterized by the widespread Arcid-Potamid-type molluscan assemblage (Yanagisawa & Watanabe, 2017a, b). As palynological characters do not differ greatly among these 17–16.7 Ma records, those from Ishikawa Prefecture were used as representative records of this period.

We selected seven major taxa for evaluation, i.e., Cupressaceae, *Tsuga*, *Liquidambar*, *Fagus*, deciduous *Quercus* (section *Quercus*), evergreen *Quercus* (subgenus *Cyclobalanopsis*), and *Carya*. We calculated their percentages among all taxa, including Pinaceae. We followed Eckenwalder's (1976) circumscription of Cupressaceae, which includes Taxodiaceae and Cupressaceae *sensu* Pilger (1926), as the monophyly of Taxodiaceae is not supported by molecular phylogenetic studies (e.g., Brunsfeld et al., 1994; Gadek et al., 2000). However, no firm records of Cupressaceae *sensu* Pilger (1926) were obtained in the Hokuriku district, so the Cupressaceae in this study include only genera previously assigned to Taxodiaceae.

We set the time intervals for each route according to available age markers, such as biozones of diatoms and calcareous nannoplankton, and radiometric ages of tephras. We averaged the percentage values if more than two samples were available for a given time interval. Details of the datasets and age markers used for this study are provided below.

3.1.1 | Noto area

Palynological data are available for the following routes (Figure 1b): Hojuji, Horyu, Okada–1 (Fuji & Kawai, 1982), Okada–2, Wakayama (Fuji & Hori, 1990), and Kawaura (Yamanoi, 1989b) in Suzu City; and Tokunari (Yamanoi, 1989b) and Tsukada

(Fuji, 1972) in Wajima City. Pollen-bearing strata along these routes are classified into the Higashiinnai (16.8–16.7 Ma), Hojuji (16.7–15.8 Ma), Awagura (15.8–15.6 Ma), Iida (15.6–12.9 Ma), and lower to middle parts of the Iiduka (12.9–9.5 Ma) Formations, ordered from oldest to most recent (Yanagisawa, 1999c; Yoshikawa et al., 2002), as well as into the Tsukada Formation (12.2–11.6 Ma) which is coeval with the lower part of the Iiduka Formation (Yanagisawa, 2012) (Figure 2).

On the Horyu, Okada–1, and Okada–2 routes, where the Iiduka Formation outcrops, palynological (Fuji & Hori, 1990; Fuji & Kawai, 1982) and diatom (Yanagisawa, 1999c) data are available for the same horizons, so the ages of the palynoassemblages can be inferred based on Neogene North Pacific Diatom Biohorizons (Watanabe & Yanagisawa, 2005; Yanagisawa & Akiba, 1998). Three sampling horizons of Fuji & Kawai (1982) are located between D51 (12.7 Ma) and D55 (11.4 Ma), and five between D55 and D56 (10 Ma), in Horyu; three between D51 and D55, five between D55 and D55.8 (10.1 Ma), and three between D55.8 and D57 (9.5 Ma) are present in Okada–1 (Figure 2). Fuji & Hori (1990) also reported palynoassemblages from Okada–2, including six sampling horizons between D55.8 and D57 and three between D59 (9.3 Ma) and D66 (8.4 Ma) (Figure 2).

Along other routes, the percentages of the selected taxa were averaged for each formation (Figure 2): three samples were averaged for the Higashiinnai Formation in Tokunari (Yamanoi, 1989b), along with five for the Hojuji Formation in Hojuji (Fuji & Kawai, 1982), one for the Hojuji Formation in Kawaura (Yamanoi, 1989b), six for the Hojuji Formation, five for the Awagura Formation, seven for the Iida Formation in

Wakayama (Fuji and Hori, 1990), and 16 for the Tsukada Formation in Tsukada (Fuji, 1972).

In the Noto area, palynological studies have been conducted for the Wakura (Fuji, 1969a), Yamatoda (Fuji, 1969b; Yamanoi, 1989b), Hijirikawa (Fuji, 1969c), and Oginoya (Fuji, 1969c) Formations. However, these datasets were not used in our analysis due to uncertainty regarding the inferred ages.

3.1.2 | Kanazawa area

At sites along the Asano River, Yamanoi (1992b) collected two palynological samples from the Sunagozaka Formation, as well as one from the Nanamagari Formation, five from the Asagaya Formation, one from the Yamashina Formation, and one from the Saikawa Formation (Figure 2; see also 2.1. for details of the stratigraphy). Yamanoi (1992b) also analyzed two samples from the Saikawa Formation that outcrops in the Saikawa section (Figures 1b and 2). Percentages of the selected taxa were averaged for each formation. The results of our own palynological analyses were not included in this data compilation nor used for prior age estimates.

3.1.3 | Daishoji area

Yamanoi (1992b) collected eight samples from the Kawaminami Formation, along with two from the Hosotsubo Formation, two from the Daishoji Formation, and one from the

Kasanomisaki Formation (Figure 2). The Kawaminami Formation contains the Arcid-Potamid molluscan assemblage (Bito et al., 1980), which has an estimated age of 17–16.7 Ma (Yanagisawa & Watanabe, 2017a, b). Planktonic foraminifera of the N8 to N9 biozones (17–14.5 Ma; Hilgen et al., 2012; Hoshi et al., 2019) have been reported in the Hosotsubo and Daishoji Formations (Nakagawa & Chiji, 1988), while calcareous nannofossils of CN4 (14.9–13.5 Ma; Okada and Bukry, 1980) were obtained from the Daishoji Formation (Bito et al., 1980). Therefore, the age of the Daishoji Formation is estimated as 14.9–14.5 Ma in this study. The Kasanomisaki Formation unconformably overlies the Daishoji Formation (Bito et al., 1980). The exact age of the Kasanomisaki Formation has not been clarified, but is estimated as approximately 14–13 Ma (Fujii et al., 1992) based on the occurrence of NPD4B diatoms (Itoh & Ito, 1989). This estimate is consistent with the K-Ar age of 13.2–12.4 Ma obtained from volcanic rocks in the Amagozenmisaki Formation (Higashino & Shimizu, 1987), which unconformably overlies the Kasanomisaki Formation. Percentages of the selected taxa were averaged for each formation.

3.1.4 | Himi area

In this area, horizons of pollen samples (Wang et al., 2001) are strongly correlated with diatom biozones or tephras (Watanabe, 2002a, b). More recently, Satoguchi et al. (2005) refined the ages of these tephras. Accordingly, the sampling horizons of Wang et al. (2001) were classified into 11 time intervals, namely 13.0–12.7 (6 samples), 12.7–11.4

(4), 11.4–10.0 (2), 10.0–9.2 (1), 6.4–5.5 (6), 5.5–4.4 (4), 4.4–3.4 (8), 3.4–3.0 (6), 3.0–2.9 (4), 2.9–2.7 (6), and 2.7–2.0 Ma (7), with a depositional hiatus at 9.2–6.4 Ma (Figure 2). Average pollen percentages were calculated for each time interval.

3.1.5 | Tokamachi area

Pollen fossils were reported from a late Miocene to Pleistocene succession, which is frequently intercalated with volcanic ash layers (Yamanoi & Nitobe, 1970). Radiometric ages have been determined for numerous ash layers in this area (e.g., Kurokawa & Ohashi, 2005; Satoguchi, 1997). The names of the ash layers used by Yamanoi & Nitobe (1970) differ from those of the Niigata Volcanic Ash Research Group (1983), which forms the basis for tephrochronological studies. We referred to Yanagisawa et al. (1985) and Takeuchi et al. (2000) to correlate the ash layer names between these two sources. In addition, we confirmed the stratigraphic relationships among the horizons of pollen samples and ash layers by overlaying the route maps of Yamanoi & Nitobe (1970) onto the geological maps of Yanagisawa et al. (1985) and Takeuchi et al. (2000).

In total, 3 sampling horizons of Yamanoi & Nitobe (1970) were located between the tuff layers of Kiwadahara (6.2 Ma) and Isg-c (5.4 Ma), 11 between Isg-c and Itayama (4.1 Ma), 8 between Itayama and Akakura (3.3 Ma), 19 between Akakura and Chitose (2.9 Ma), and 11 between Chitose and Isgp (2.2 Ma; Figure 2). Percentages of the selected taxa were averaged over each time interval. Yamanoi & Nitobe (1970) did not distinguish between deciduous and evergreen *Quercus* pollen. Therefore, their *Quercus* data were not incorporated into the reconstruction of palynological trends in the Hokuriku district, but the average percentages of total *Quercus* are shown in Figure 3 (dashed brown lines) for reference.

3.2 | Preparation and analysis of palynological samples

Previously, we collected 71 samples at 1–2.5 m intervals from sediments outcropped in the Saikawa section for diatom analyses (Yamada et al., 2017). We conducted palynological analyses of some of these samples (Figure 1c, d), i.e., two samples from the upper member of the Yamashina Formation (017L and 017Q), three from the Saikawa Formation (015A, 014A and 012A), and eight from the Koderayama Formation (009U, 008A, 007A–007D, 006A, and 006D). However, we could not obtain sufficient number of pollen grains from 007B–007D. The Koderayama Formation contacts the overlying Omma Formation via a low-angle unconformity, and the lower part of the Omma Formation consists mainly of clastics reworked from the Koderayama Formation. The sedimentary environments and lithofacies of the two formations are similar to each other (Kitamura, 1997; Yamada et al., 2017). As a result, it is often difficult to distinguish between them, certainly around the possible boundary. Sample 006D represents the uppermost palynomorph-bearing horizon in this section that can be certainly assigned to the Koderayama Formation.

Crushed samples were sieved through a 60-mesh screen. Carbonaceous materials were separated through centrifugation of the powdered material in $ZnCl_2$ solution with specific gravity of 2.2. The transparency of carbonaceous materials was increased through successive oxidization with 10% HNO_3 (10 minutes) and 10% KOH (10 minutes). After these chemical treatments, carbonaceous materials were briefly rinsed with distilled water and mounted onto glass slides with glycerin jelly. All glass slides were stored at the National Museum of Nature and Science, Tokyo, Japan.

For each sample, 200 grains of pollen and spores were counted. Pinaceae pollen tends to be overrepresented, especially in marine sediments (Traverse & Ginsburg, 1966), but Pinaceae accounted for less than 25% of the total pollen and spores in each sample. Therefore, we did not exclude Pinaceae pollen from the sum of pollen and spores in this study. Pollen and spore taxa accounting for less than 2% for all samples were grouped as “others”, including *Larix*, *Podocarpus*, Poaceae, *Engelhardia*, *Gossypium*, Ericaceae, and *Artemisia*.

The pollen taxa were classified into four categories according to the climatic preferences of extant species distributed in the northern hemisphere, i.e., those distributed in tropical to temperate, subtropical mountainous and temperate, temperate to subarctic, and tropical to subarctic regions. The percentages of constituent taxa were summed for each category. Since the exact affinities of identified pollen taxa remain unclear, the distributions of all northern hemisphere species were considered for each genus. Distribution data were obtained from “Plants of the World Online” (POWO, 2019) and “The Gymnosperm Database” (Earle, 1997). These data were cross-checked using the literature on gymnosperm taxa (Debreczy & Rácz, 2011); *Liquidambar* (Hoy & Parks, 1994); *Alnus* (Sakalli, 2017); *Betula* (Jiang, 1990); *Carpinus* (He et al., 2020);

Corylus (Whitcher & Wen, 2000); *Castanea* (Mellano et al., 2012); *Fagus* (Fang & Lechowicz, 2006); *Lithocarpus* (Chen et al., 2018); deciduous *Quercus* (Yan et al., 2019); evergreen *Quercus* (Denk & Grim, 2010); *Carya* (Zhang et al., 2013); *Juglans* (Aradhya et al., 2007); *Pterocarya* (Song et al., 2020); *Ulmus* and *Zelkova* (Fragnièr et al., 2021); *Salix* (Wu et al., 2015); *Tilia* (Pigott, 2012); and *Rhus* (Miller et al., 2001). Genera in "others" were not included in this climatic classification.

4 | RESULTS

4.1 | Palynological transitions during 17–2 Ma in the Hokuriku district

Palynological transitions in the Hokuriku district were reconstructed for the period 17.0–2.0 Ma. A deficiency in palynological records occurred between 8.4–6.4 Ma, likely because of insufficient availability of sediments from this period. In addition, 9–8.4 Ma is represented only by records from the Iiduzka Formation in the Noto area (Fuji & Hori, 1990) (Figure 3).

For Cupressaceae, average percentages ranged from 2.3–10.5% before 9 Ma, and rose to 6.4–18.1% after 6.4 Ma (Figure 3). Average levels of *Tsuga* pollen increased to 8.5% at approximately 13 Ma, remained at around 5% during 13–10 Ma, decreased to approximately 3 % at 10–9 Ma, and then rose to > 5% after 6.4 Ma (Figure 3). A similar trend to *Tsuga* was observed for *Fagus* (Figure 3), which increased gradually until approximately 13 Ma, decreased very slightly during 13–9 Ma, and increased markedly after 6.4 Ma (i.e., average of 1.5–6.6% before 9 Ma vs. 13.2–25.4% after 6.4 Ma).

Liquidambar and *Carya* exhibited decreasing tendencies during 17.0–2.0 Ma. Their pollen levels dropped considerably around 16.5 Ma, but increased gradually from 14 to 13 Ma. *Liquidambar* fell at approximately 12 Ma and remained at low levels (approximately 2.5%) until 9 Ma, while *Carya* averaged around 5% during 13–9 Ma. *Liquidambar* and *Carya* occurred less frequently after 6.4 Ma and their average percentages were < 1% after approximately 3.0 Ma. However, a slight revival of *Liquidambar* was recorded during 4.4–3.4 Ma in the Himi area (Figure 3), which may correspond to the *Liquidambar* zone of Onishi (1978).

Deciduous *Quercus* increased during 17–10 Ma, with a substantial rise at 11.5–10 Ma, then decreased slightly at 10–9 Ma. Pollen representation of deciduous *Quercus* (1.3–3.2%) in the Himi area (Wang et al., 2001), as well as the total *Quercus* levels (5.5–12.6%) in the Tokamachi area (Yamanoi & Nitobe, 1970) (Figure 3), suggest that deciduous *Quercus* decreased further after 9 Ma. Evergreen *Quercus* exhibited an increasing trend until 10 Ma after a drop-off at 16.5 Ma. Proportion of evergreen *Quercus* increased most at 11.5–10 Ma, and decreased again at approximately 10 Ma. After 6.4 Ma, percentages of evergreen *Quercus* decreased to < 3.8% in the Himi area, consistent with low levels of total *Quercus* in the Tokamachi area (Figure 3).

4.2 | Palynoassemblages in the Saikawa section

Despite the changes in pollen representations, the constituent taxa did not differ among palynoassemblages from the Yamashina, Saikawa, and Koderayama Formations

(Figures 4 and 5). Cupressaceae represented < 5%, and each genus of Pinaceae accounted for < 10%, in all horizons, except for *Pinus* in 017Q of the Yamashina Formation (12.5%). No consistent tendencies were apparent for Cupressaceae, *Abies*, *Larix* (< 2%), *Picea*, or *Pinus*, while *Tsuga* increased in the upper part of the Koderayama Formation, with percentages of 9% and 8.5% in 006A and 006D, respectively, and < 4% in other horizons (Figure 4).

Fagus accounted for 6% of pollen recorded in the Yamashina Formation (017L, 017Q) and 5% in the lower part of the Saikawa Formation (015A). This level increased to 10.5% in the middle horizon of the Saikawa Formation (014A), and to 14.5–26.5% in the upper horizons of the Saikawa (012A) and Koderayama Formations (Figure 4). In contrast, deciduous and evergreen *Quercus* decreased from 007A within the Koderayama Formation, although this trend was more prominent for evergreen *Quercus*. These taxa peaked in 014A of the Saikawa Formation. Evergreen *Quercus* was most abundant (approximately 25%) among all identified taxa throughout the Yamashina and Saikawa Formations (Figure 4).

Liquidambar accounted for 3–7% of pollen in the Yamashina and Saikawa Formations and lower part of the Koderayama Formation (009UA, 008A). It decreased to 0–2% in the middle to upper part of the Koderayama Formation (007A, 006A, 006D) (Figure 4). *Carya* levels were highest in 008A of the Koderayama Formation (6.5%), and were 0.5–3.5% in other horizons (Figure 4).

Carpinus accounted for 2.5–4.5% of pollen in the Yamashina and Saikawa Formations. The percentage of this genus increased to 7% in the lower part of the

Koderayama Formation and its highest level (18%) was recorded in the uppermost horizon (006D) (Figure 4).

5 | DISCUSSION

5.1 | Palynological signatures with stratigraphic applicability in the Hokuriku district

Six pollen zones have been proposed for the Neogene of Japan (NP-1–NP-6) (Yamanoi, 1989a, 1992a, 1998), and the time spans and diagnostic events of these zones were modified in subsequent studies (Wang et al., 2001; Saito, 2008). In the period subjected in this study (17–2 Ma), pollen assemblages could be assigned to zones NP-2–NP-6 (Yamanoi, 1989a, 1992a; Wang et al., 2001; Saito, 2008). The NP-2 zone (17–13 Ma) is characterized by abundant *Liquidambar*, evergreen *Quercus*, and *Carya*, which favor a subtropical to warm temperate climate. NP-3 (13–6.5 Ma) assemblages exhibit high levels of Cupressaceae and *Fagus*, while evergreen *Quercus* decreases within this zone. *Liquidambar* and *Carya* are commonly found. The palynoassemblages suggest a cooler climate for NP-3 than NP-2. The NP-4 zone (6.5–5.5 Ma) is represented by abundant Cupressaceae and *Fagus*, contrasting the further decrease of evergreen *Quercus*. *Liquidambar* and *Carya* were also decreased. A cold temperate climate is assumed for NP-4. Then, NP-5 (5.5–3.0 Ma) is characterized by the abundance of *Cathaya* (Pinaceae). Increases of *Liquidambar* and evergreen *Quercus* also occurred in this zone, but *Fagus* remains dominant. The abundant taxa suggest a slightly warmer climate in

NP-5 than NP-4. The NP-6 zone (3.0–1.8 Ma) is less well characterized than the other zones, as the NP-5 and the NP-6 assemblages are similar. However, fluctuations in the abundances of Cupressaceae and *Cathaya* are commonly observed in this zone.

Palynological characteristics of the NP assemblages could be correlated with global climatic trends (Yamanoi, 1989a, 1992a, 1998; Wang et al., 2001; Saito, 2008). For example, the NP-2 zone corresponds to a high-temperature period around the Miocene Climatic Optimum, and NP-3 assemblages reflect a period of global cooling beginning around 14 Ma (Miller et al., 1991; Zachos et al., 2001; Holbourn et al., 2013). A subsequent cooling period should have driven the transition from NP-3 to NP-4 assemblages. The change from NP-4 to NP-5 coincides with global warming beginning at 5.55 Ma (Vidal et al., 2002). The NP zones are generally consistent with vegetational changes inferred from plant macro-remains (Yamanoi, 1989a, 1992a, 1988; Wang et al., 2001; Saito, 2008); NP-2 corresponds to the period of the Daijima-type flora (Tanai, 1961) and NP-4 to the Mitoku-type flora (Tanai, 1961).

Our compilation of palynological records in the Hokuriku district indicated diagnostic events in the NP zones (Yamanoi, 1989a, 1992a, 1988; Saito, 2008), including decreases in *Liquidambar*, evergreen *Quercus*, and *Carya* at the base of the NP-2 zone, a reduction of evergreen *Quercus* at the NP-2/NP-3 boundary, and an increase of *Fagus* at 14–13 Ma (Figure 3). Long-term decreasing trends of *Liquidambar* and *Carya* were also evident after 16.5 Ma (Figure 3), as suggested in previous studies (Yamanoi, 1989a, 1992a, 1988; Saito, 2008). In addition to these conventional diagnostic events, our results demonstrate increases in *Tsuga*, *Liquidambar*, and *Carya* around the NP-2/NP-3 boundary, as well as increases in deciduous and evergreen *Quercus* at 11.5–10 Ma (Figures 3 and 6). A *Tsuga* increase is recorded for the NP-2/NP-3 transition in the Daijima and Nishikurosawa Formations of the Oga Peninsula, northeast Japan (Wang & Yamanoi, 1996). In these sediments, *Liquidambar* also increased slightly in the early NP-3, after decreasing in the late NP-2 (Wang & Yamanoi, 1996). These trends have not attracted any attention, but our compilation recalls their stratigraphic importance. Meanwhile, an increase in evergreen *Quercus* at 11.5–10 Ma was reported in the Himi area, and it was pointed out that a warming event could have triggered this signature (Wang et al., 2001; see below for details). Palynological trends throughout the Hokuriku district support their inference.

Although palynological data are unavailable for the period 8.4–6.4 Ma, which corresponds to the mid-NP-3 to earliest NP-4 periods, percentages differ markedly between post-6.4 Ma and pre-8.4 Ma for all taxa (Figure 3). The change from NP-3 to NP-4 type representations appear to have begun no earlier than 10 Ma except for *Fagus*; Cupressaceae and *Tsuga* increased between 10–9.5 and 9.5–9.2 Ma, while *Liquidambar*, deciduous and evergreen *Quercus*, and *Carya* decreased between these intervals (Figures 3 and 6). Records for 9.2–8.4 Ma are available only for the Iiduzka Formation in the Noto area (Figure 2), but the same trends are evident in these records (Figure 6).

During the Middle Miocene Climatic Transition (MMCT), considerable cooling occurred at 13.9 and 13.1 Ma, subsequently, the temperature decreased gradually in a stepwise manner until 8.4 Ma (Miller et al., 1991; Holbourn et al., 2013). In addition, a temperature warming was recorded at 10.8–10.7 Ma, at least in the western Pacific region (Holbourn et al., 2013). This warm period was supported by molluscan assemblages observed in Japan (Ozawa et al., 1995; Inoue et al., 1997). The increase in evergreen *Quercus*, which prefers a warm climate (Yan et al., 2019), at 11.5–10 Ma (Wang et al., 2001; this study), is consistent with these climatic records. The NP-3 type vegetation could tolerate the climatic change during 13–10 Ma, but the transition to the NP-4 type would have started with further change during 10–8.4 Ma. A similar transition, i.e., a decrease in evergreen broad-leaved species along with an increase in cool temperate species, was recorded at approximately 9.5 Ma for macrofossil assemblages from the Tokiguchi Formation of Gifu Prefecture, southern Central Japan (Momohara and Saito, 2001). Although they argued that the transition might have been caused by local topographic or provenance changes rather than by climatic change, it would be worth exploring whether climatic change is involved in this case.

The Neogene deposits of Hokuriku district have been studied intensively by incorporating marine microfossil biostratigraphies (e.g., Yanagisawa, 1999a–c). Many palynological studies have also been conducted in this district (e.g., Fiji & Hori, 1990; Yamanoi, 1989b). Therefore, there is a strong basis for using the Hokuriku district to establish the Neogene palynolostratigraphic standard of Japan with refined age resolution. Our compilation actually showed novel palynological signatures for stratigraphic use, and strengthened the previously proposed palynological events. Yamanoi (1989b) noted possible observer bias in the palynological records of the Noto area, but the signatures described above have been recorded in multiple routes in the Hokuriku district, including the Noto area, irrespective of the observer. Nevertheless, our compilation revealed some problems. Palynological data are missing for 8.4–6.4 Ma, although sediments from this interval were present in the Noto (Yoshikawa et al., 2002) and Yatsuo (Nakajima et al., 2019) areas. In addition, many reported palynological records (e.g., Fuji, 1969a–c) could not be used for data compilation due to uncertain ages. However, their ages could be determined using marine microfossils or tuffs, judging from geological descriptions in the palynological literature. These unexploited resources should be used in future studies to improve the palynostratigraphic age resolution.

5.2 | Age of the Yamashina and Saikawa formations

Samples from 017L and 017Q of the Yamashina Formation yielded diatoms indicating the 4A5 interval (15.4–15.2 Ma) of the NPD4A zone (Yamada et al., 2017). Palynoassemblages of these horizons represent NP-2 (17–13 Ma), as suggested by low *Fagus* and high evergreen *Quercus* abundance (Figure 4). Therefore, the age of the Yamashina Formation based on palynoassemblage analysis is consistent with that based on diatom biostratigraphy.

The age of the Saikawa Formation is estimated as 13.5–11.8 Ma (Yamada et al., 2017) based on calcareous nannoplankton (Takayama et al., 1988) of CN5a (Okada & Bukry, 1980). The 015A palynoassemblage of the Saikawa Formation shows characteristics of the NP-2 zone, including low *Fagus* and high evergreen *Quercus* levels. However, *Liquidambar* and *Fagus* increase upwards from 015A to 012A, as evident for the NP-2/NP-3 transition (14–13 Ma) in the Hokuriku district (Figure 3). Although there is no obvious increase in *Carya*, a slight increase in *Tsuga* is observed in the Saikawa Formation (Figure 4), which also characterizes the NP-2/NP-3 transition period (Figure 3). Therefore, the age of the Saikawa Formation could be estimated as approximately 13 Ma, when CN5a overlaps with the NP-2/NP-3 transition period.

In the Hokuriku district, uplift events were promoted by east-west compressional stress at 15–13 Ma. The compressional stress weakened after 13 Ma. As a result, sedimentation paused between 14.5 and 13 Ma in the Yatsuo area of Toyama Prefecture (Figure 1b), which is now recognized as the Arayama Unconformity (Nakajima et al., 2019). In the southern Kanazawa area, sedimentation also ceased between approximately 15 and 13 Ma, i.e., at the unconformity between the Yamashina and Saikawa Formations. This finding indicates that the same tectonic scheme controlled basin development in the Yatsuo and southern Kanazawa areas.

5.3 | Age of the Koderayama Formation

The Koderayama Formation is comprised of shallow marine sediment interposed between the Saikawa and Omma Formations (Yamada et al., 2017). It has been included in the Omma Formation in some studies (Tsukawaki & Okawara, 1996; Tsukawaki & Ooji, 2008), but sediments in part of the Koderayama Formation were sufficiently consolidated for boring bivalves to form shelters before deposition of the Omma Formation began (Kitamura, 1997). The basal part of the Omma Formation in the

Saikawa section is younger than 1.72 Ma, based on tephrostratigraphy and calcareous nannoplankton biostratigraphy (Okubo, 1999). Meanwhile, endocarps of *Carya* occur in the Koderayama Formation (Yamada et al., 2017), and this genus became extinct before 2.7 Ma in Japan (Momohara, 1989). Accordingly, a sedimentary hiatus of > 1 Ma should be present between these formations. The Koderayama Formation, in turn, erodes the Saikawa Formation, suggesting an unconformable relationship between the two formations. However, the age of the Koderayama Formation has not been determined due to its lack of biostratigraphically informative microfossils (Yamada et al., 2017).

In the Koderayama Formation, the palynoassemblages have different representations of marker taxa in the lower three (009A, 008A, 007A) and the upper two (006A, 006D) horizons (Figures 4 and 6). The palynoassemblages from the lower horizons have the NP-3 type percentages for *Tsuga*, *Liquidambar*, deciduous and evergreen *Quercus*, and *Carya* (Figure 6). By contrast, the percentages of *Tsuga*, *Liquidambar*, and *Carya* are NP-4 type values in the upper horizons, while deciduous and evergreen *Quercus* decrease within the range of the NP-3 type values (Figure 6). The percentages of *Fagus* reach the NP-4 type range in both the lower and upper horizons (Figure 6). However, the palynoassemblages of both horizons clearly differ from the NP-4 ones in the low representation of Cupressaceae (Figure 6) (Wang et al., 2001; Saito, 2008). *Cathaya* is absent in the Koderayama Formation, contrary to the occurrence from the NP-4 deposits in the Himi area (Wang et al., 2001).

These characters suggest that the Koderayama Formation records the transition from

NP-3 to NP-4 type vegetation. Our palynological compilation suggests that the NP-3/NP-4 transition started no earlier than 10 Ma in the Hokuriku district (see section 5.1 for details). However, no data are available on how long and fast the transition progressed, due to the lack of palynological records for 8.4–6.4 Ma. Therefore, we tentatively assigned 10–6.4 Ma age to the Koderayama Formation in this study.

5.4 | Floristic implications of palynoassemblages in the Saikawa section

In the palynoassemblages of the Saikawa section (Figures 4 and 5), all angiosperm taxa are deciduous broad-leaved trees, except for evergreen broad-leaved *Lithocarpus* and *Quercus* subgenus *Cyclobalanopsis*, and for both evergreen and deciduous broad-leaved *Rhus*. Gymnosperm taxa are evergreen needle-leaved trees, although a few Cupressaceae grains might be classified as deciduous *Metasequoia*. In general, tropical to temperate genera decrease upwards, while temperate and subtropical mountainous genera increase upwards (Figures 4 and 7). These tendencies are consistent with the global cooling trend during the MMCT.

The most prominent feature in these palynoassemblages is the coexistence of *Fagus* and evergreen *Quercus* (Figures 4 and 6). In present Japan, their distributions do not overlap, since *Fagus* favors cooler conditions (Fujita, 1987). By contrast, in the subtropical mountainous areas of present south China, *Fagus* occurs with evergreen *Quercus*. These Chinese *Fagus* (*F. engleriana*, *F. hayatae*, *F. longipetiolata*, and *F. lucida*) are also associated with evergreen *Tsuga* and *Lithocarpus*, as well as deciduous

Liquidambar, *Betula*, *Carpinus*, and *Tilia* (Fang et al., 1996; Cao & Peters, 1997; Wang et al., 2005; Fang & Lechowicz, 2006), like the palynoassemblages from the Saikawa section (Figure 4). Ancestral forests with mixed beech and evergreen trees appeared no later than the Oligocene in China (Liu et al., 1998) and became widespread after the early Miocene in south to east China under a subtropical to warm temperate climate (Sun & Wang, 2005). They spread along the Pacific coast to Japan in the middle Miocene, as also pointed out for the Daijima-type (i.e., NP-2) flora and subtropical forests of the south China (Tanai, 1961; Yang et al., 2018). As the climate cooled and dried during the MMCT in East Asia (Jiang & Ding, 2008), the beech forests retracted southwardly in China (Sun & Wang, 2005; Pound et al., 2012), while they persisted in Japan, as the NP-3 type flora suggests. The distribution of extant Chinese *Fagus* correlates with high winter temperatures (Fang & Lechowicz, 2006), while the moisture deficit determines the northern limit of the distribution (Cao et al., 1995). Global cooling and aridification forced by a weakening monsoon (Sun & Wang, 2005; Jiang & Ding, 2008) would have promoted the retraction of beech forests, while the coastal position of Japan might ameliorate such deterioration.

The palynological records in Japan are sparse for the middle to late NP-3. As a result, it is unclear when and how the tropical beech forests disappeared from Japan. Our palynological data help to fill this data paucity and suggest the persistence of beech forests in the time of the Koderayama Formation. In other words, floristic turnover to the present Japanese vegetation should have happened after the age of the Koderayama Formation. However, it is not clear whether the NP-3 species adapted to the cooler, drier climate and were the ancestors of the present Japanese species. Infrageneric-level taxonomic studies of Neogene pollen are necessary to understand the role pre-MMCT taxa played in shaping the present flora of Japan and adjacent regions. The abundant plant remains in the Saikawa and Koderayama Formations (Yamada and Yamada, 2014; Yamada et al., 2017) would also be useful for tracing these processes.

6 | CONCLUSIONS

We compiled published palynological records from the Hokuriku district to improve temporal resolution within the NP-3 zone (13–6.5 Ma). We also reported palynoassemblages from the Saikawa and Koderayama Formations in the southern Kanazawa area, and estimated their ages based on the refined palynostratigraphy. From the results, we reached the following conclusions.

1. In the Hokuriku district, the transition from NP-3 to NP-4 palynoassemblages occurred during 10–6.4 Ma. Evergreen *Quercus* increased at 11.5–10 Ma. An increase in *Tsuga* marked the NP-2/NP-3 boundary. These palynological events would be relevant to other NP-3 deposits in Japan, as they were likely driven by global climatic changes.
2. Palynoassemblages suggest that the Saikawa Formation correlates with the NP-2/NP-3 transition period, dating to approximately 13 Ma.
3. The Koderayama Formation is correlated with the NP-3 zone. Its age can be

narrowed to 10–6.4 Ma, as the palynoassemblages of this formation have intermediate characteristics between NP-3 and NP-4 assemblages.

4. The palynoflora of the Koderayama Formation were similar to extant tropical flora of south China in the coexistence of *Fagus* and evergreen *Quercus*, implying that the floristic turnover to the present Japanese flora might have happened after this age.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

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Figure legends

FIGURE 1 Maps showing the localities studied. (a, b) Locations of the Neogene and Quaternary palynoassemblages analyzed in this study (solid circles). The location of the Yatsuo area is also indicated (diamond). The dashed rectangle in (a) is enlarged in (b). (c, d) Geological map of the Saikawa section of Okuwa in the southern Kanazawa area of Ishikawa Prefecture. Palynological samples were collected along the route indicated by the red line, with details shown in (d).

FIGURE 2 Stratigraphic horizons of the palynological records used in this study (see main text for details). Colors of the stratigraphic columns correspond to those in Figure 3.

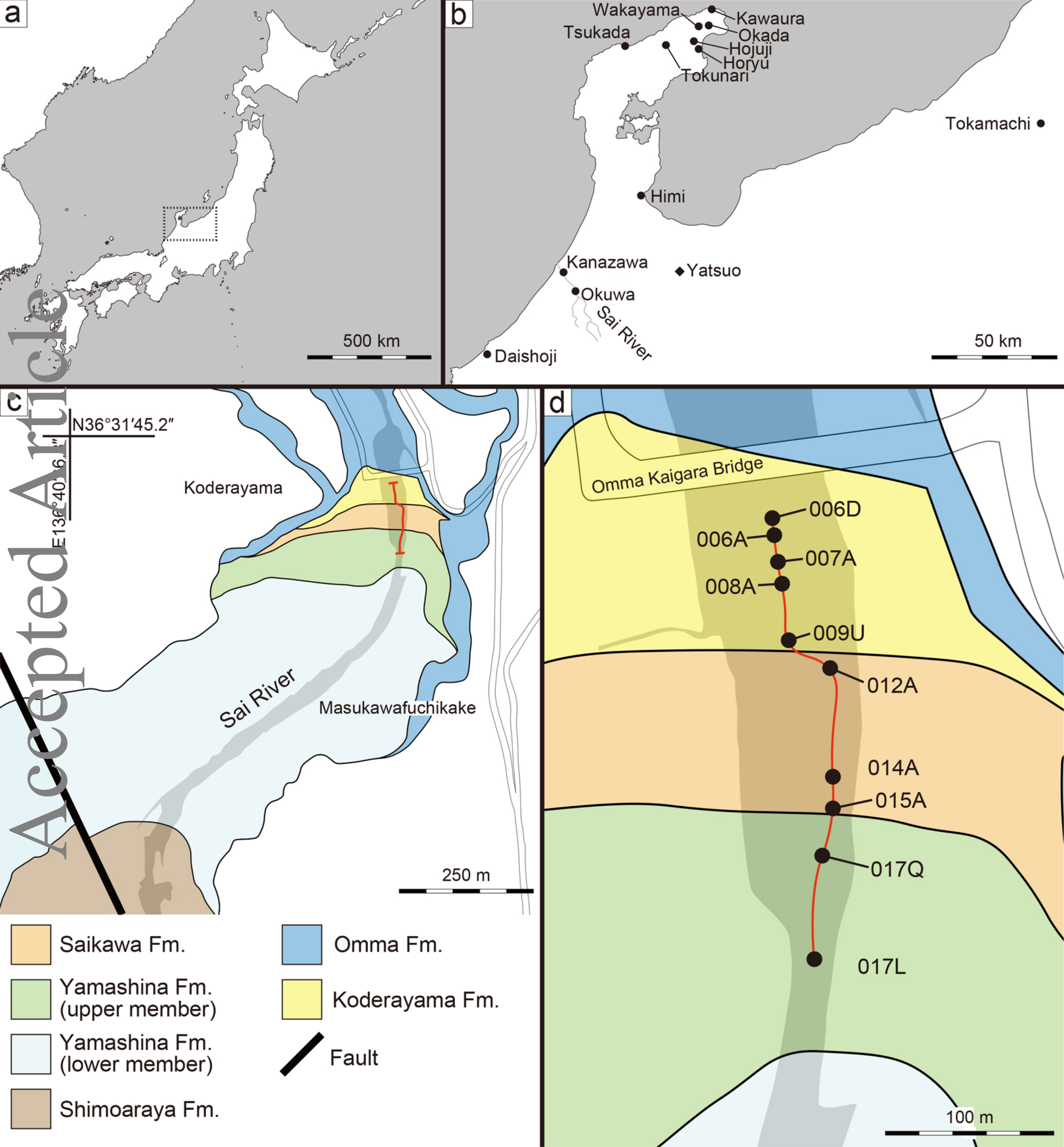
FIGURE 3 Palynological transitions of selected taxa during 17–2 Ma in the Hokuriku district. Neogene palynostratigraphies are shown along with diatom (Yanagisawa & Akiba, 1998; Watanabe & Yanagisawa, 2005) and calcareous nannoplankton (Okada & Bukry, 1980) biostratigraphies. Standard palynostratigraphies of Japan and the Himi area are based on Yamanoi (1992a) and Wang et al. (2001), respectively. When palynological records from only one route are available, the average value is indicated with a dashed black line. Dashed brown lines for deciduous (D.) and evergreen (E.) *Quercus* indicate the total abundance of *Quercus* in the Tokamachi area. Ps, Pleistocene.

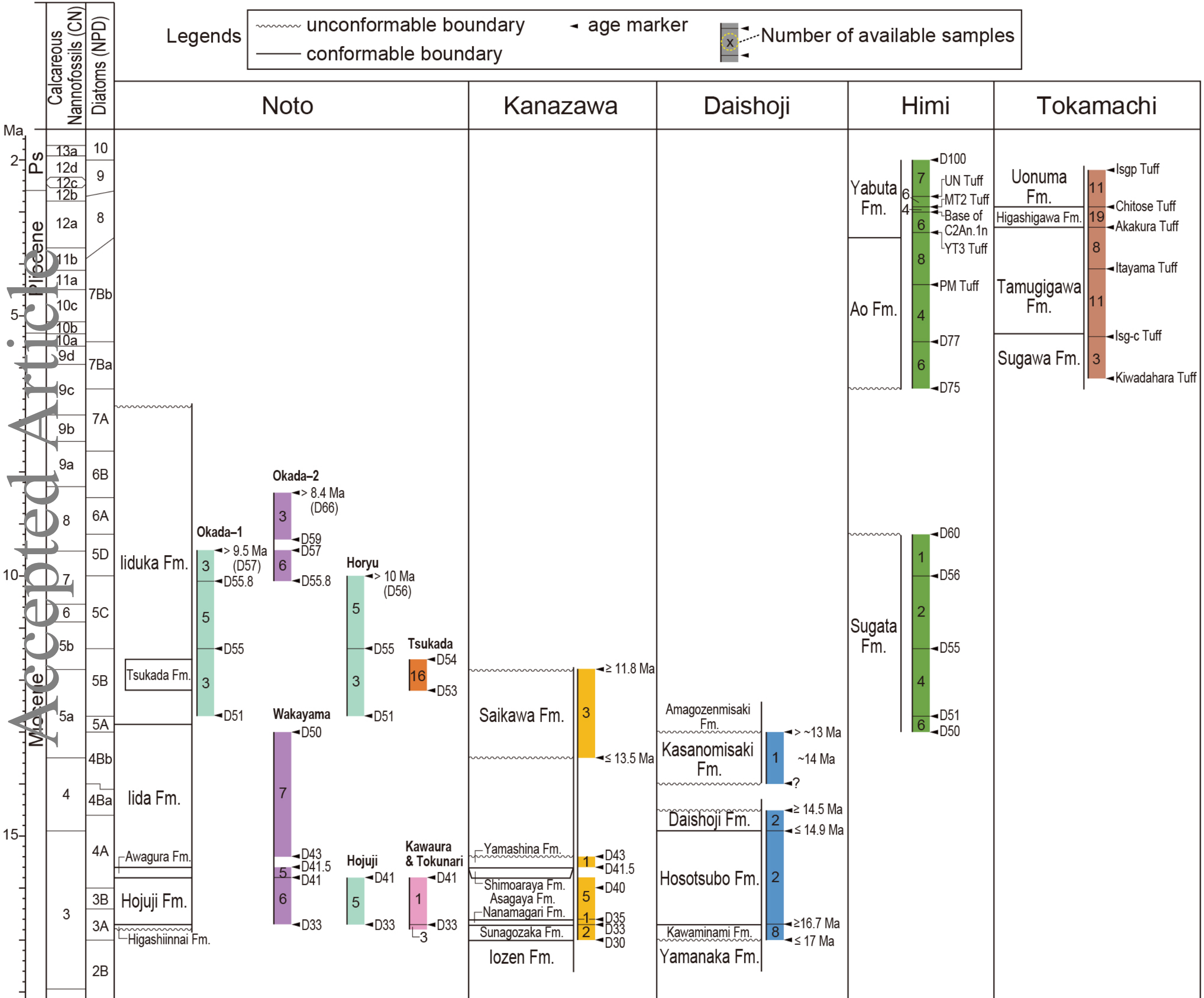
FIGURE 4 Percentages of pollen taxa in the Saikawa section. The stratigraphic column on the left shows sampling horizons and their lithological features. Distributions are indicated above taxon names, according to their climatic preferences. An open box indicates a mountainous distribution.

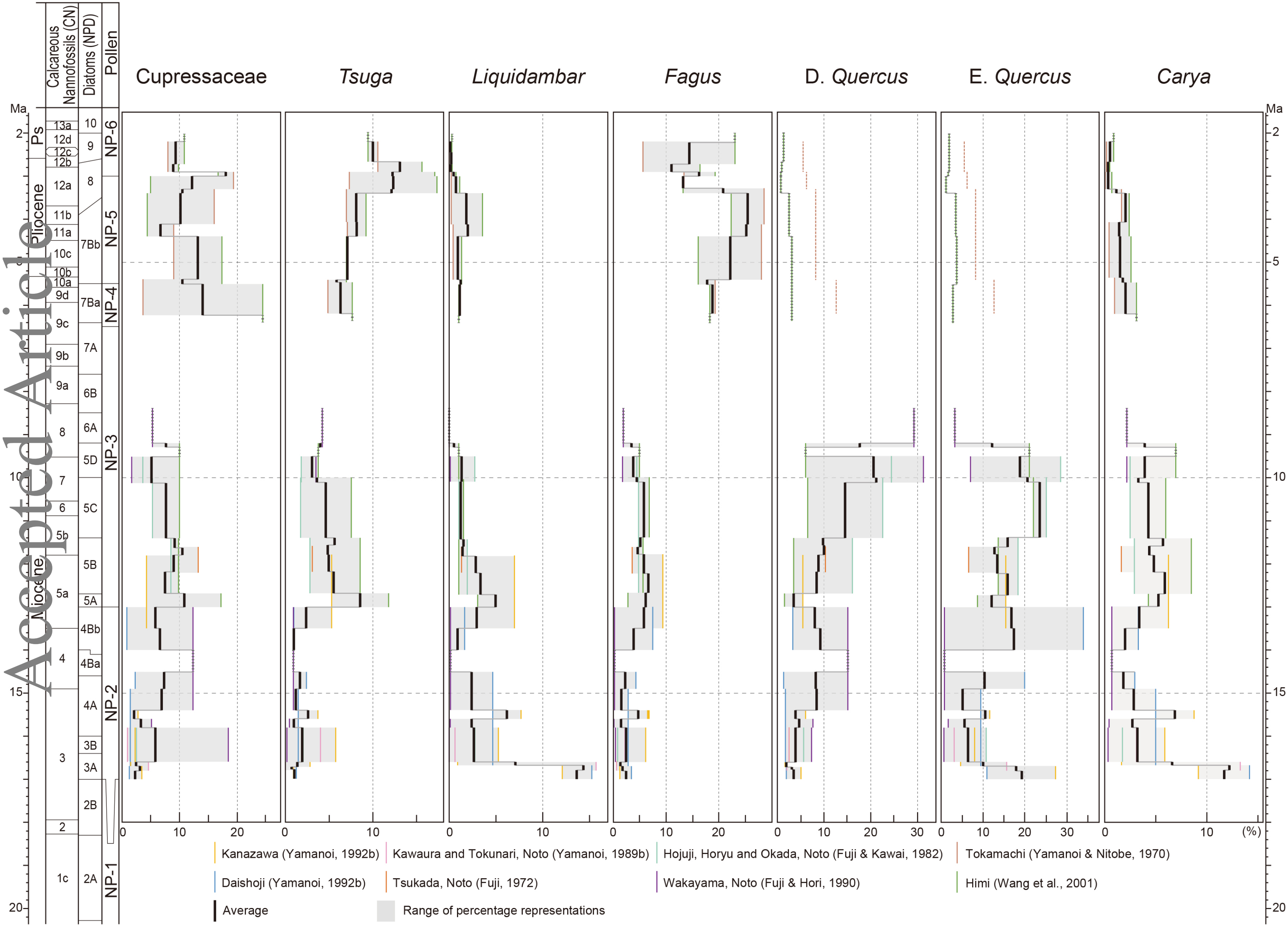
FIGURE 5 Pollen grains from the Koderayama Formation. (a) Cupressaceae, 006A. (b) *Tsuga*, 006A. (c) *Liquidambar*, 009U. (d) *Carpinus*, 007A. (e) *Fagus*, 007A. (f) *Lithocarpus*, 008A. (g) Deciduous *Quercus*, 006D. (h) Evergreen *Quercus*, 009A. (i) *Carya*, 007A. Scale bars, 10 μm.

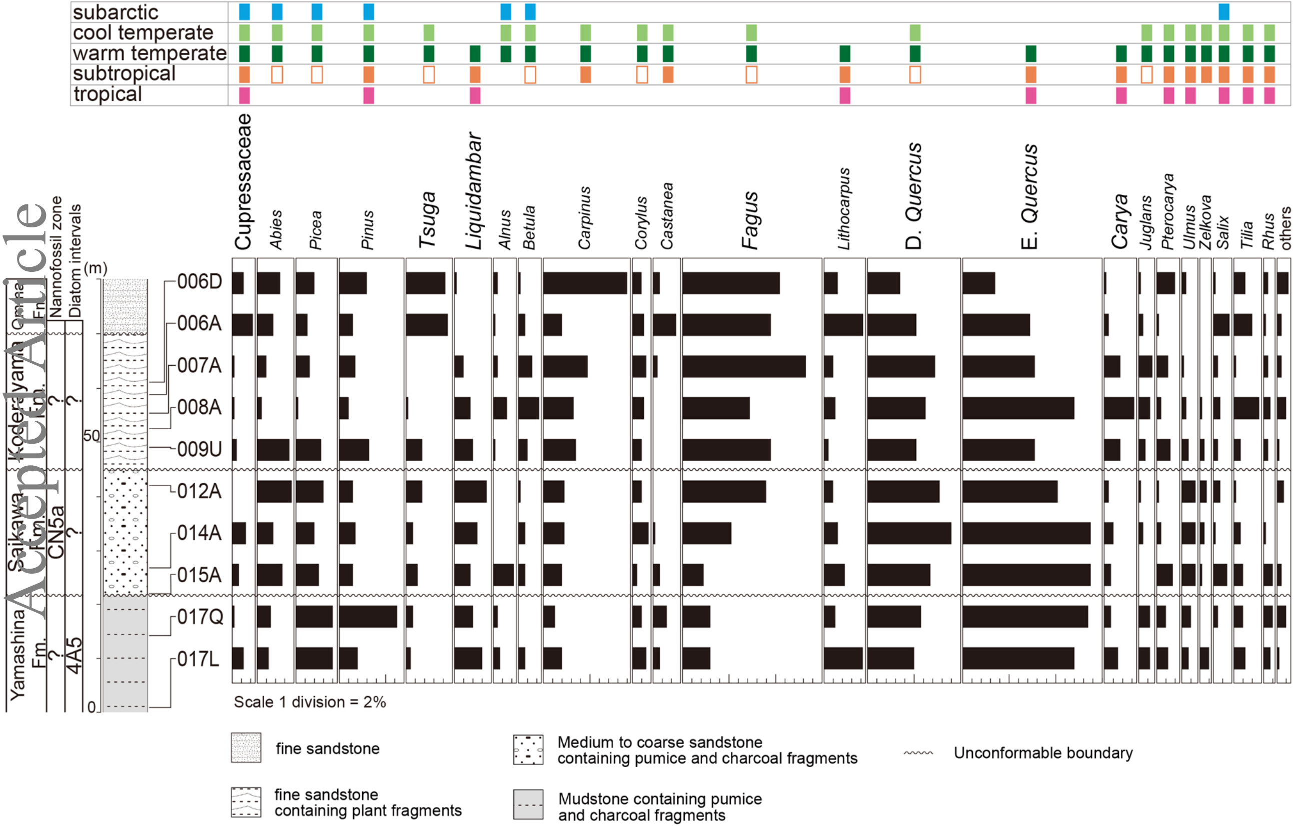
FIGURE 6 Comparison between the pollen representations in the Koderayama Formation and palynological transitions in Hokuriku district during the latest NP-2 to NP-4 zones. For each taxon, the average and range of percentages are indicated by the solid line and shaded box, respectively.

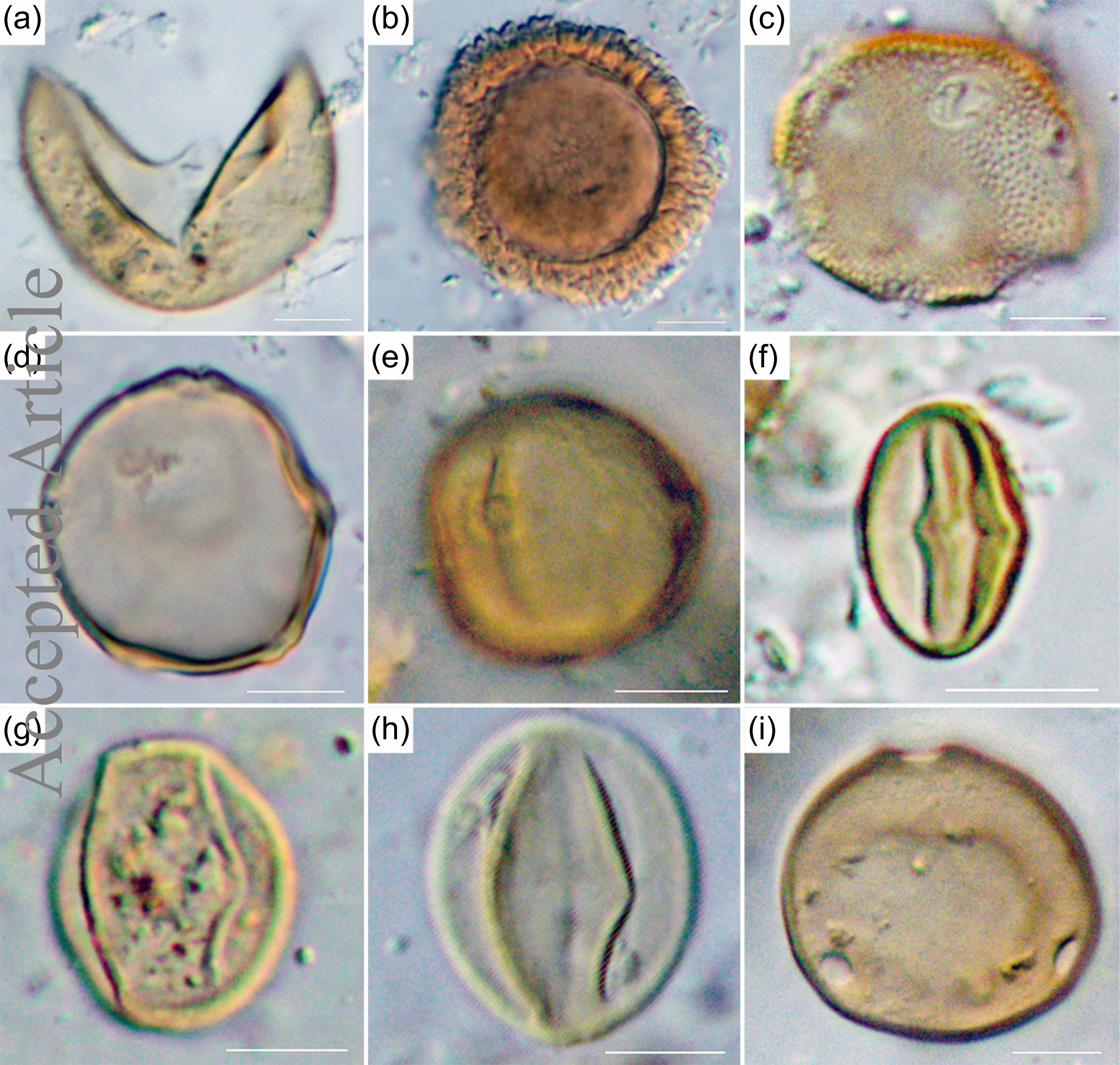
FIGURE 7 Transition in climatic preferences of pollen taxa in the Saikawa section. Changes across a formation boundary are indicated by dashed lines.

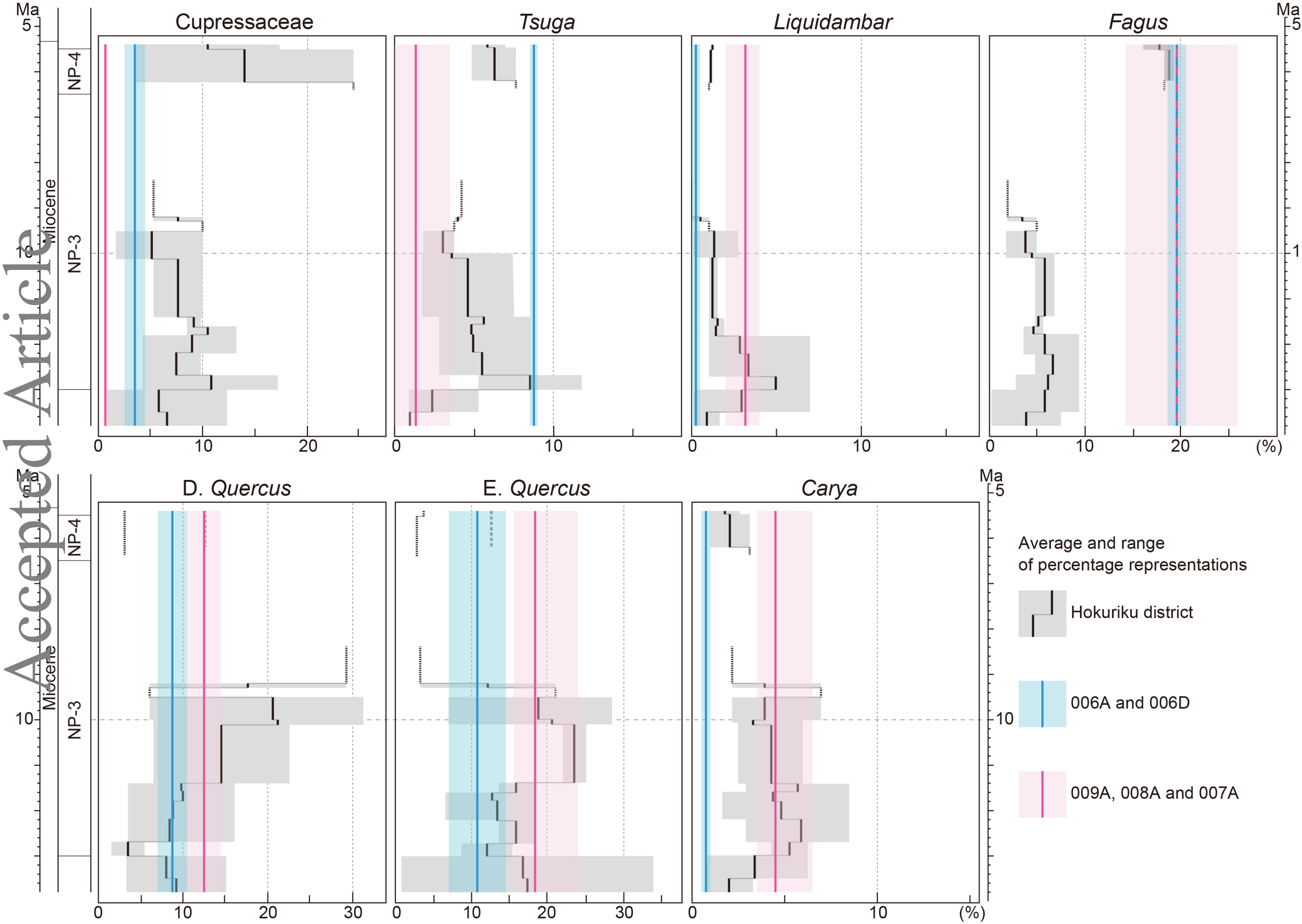

a
500 km
b
Wakayama
Kawaura
Okada
Hojuji
Horyu
Tsukada
Tokunari
Tokamachi
Himi
Kanazawa
Yatsuo
Okuwa
Sai River
Daishoji
50 km
c
N36°31′45.2″
E136°40′6.″
Koderayama
Sai River
Masukawafuchikake
250 m
d
Omma Kaigara Bridge
006D
006A
007A
008A
009U
012A
014A
015A
017Q
017L
100 m
Saikawa Fm.
Yamashina Fm. (upper member)
Yamashina Fm. (lower member)
Shimoaraya Fm.
Omma Fm.
Koderayama Fm.
Fault

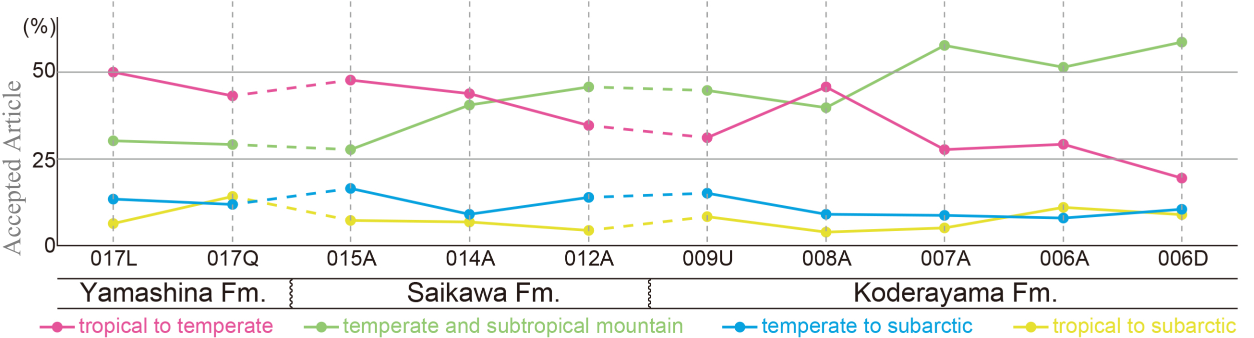

Legends
unconformable boundary
conformable boundary
age marker
x
Number of available samples
Calcareous Nannofossils (CN)
Diatoms (NPD)
Ma
2
5
10
15
Ps
Pliocene
Miocene
13a
12d
12c
12b
12a
11b
11a
10c
10b
10a
9d
9c
9b
9a
8
7
6
5b
5a
4
3
10
9
8
7Bb
7Ba
7A
6B
6A
5D
5C
5B
5A
4Bb
4Ba
4A
3B
3A
2B
Noto
Kanazawa
Daishoji
Himi
Tokamachi
Iiduka Fm.
Tsukada Fm.
Iida Fm.
Awagura Fm.
Hojuji Fm.
Higashiinnai Fm.
Okada–1
> 9.5 Ma (D57)
D55.8
D55
D51
Okada–2
> 8.4 Ma (D66)
D59
D57
D55.8
Horyu
> 10 Ma (D56)
D55
D51
Tsukada
D54
16
D53
Wakayama
D50
D43
D41.5
D41
D33
Hojuji
D41
D33
Kawaura & Tokunari
D41
D33
3
Saikawa Fm.
Yamashina Fm.
Shimoaraya Fm.
Asagaya Fm.
Nanamagari Fm.
Sunagozaka Fm.
Iozen Fm.
≥ 11.8 Ma
≤ 13.5 Ma
D43
D41.5
D40
D35
D33
D30
Amagozenmisaki Fm.
Kasanomisaki Fm.
Daishoji Fm.
Hosotsubo Fm.
Kawaminami Fm.
Yamanaka Fm.
> ~13 Ma
~14 Ma
?
≥ 14.5 Ma
≤ 14.9 Ma
≥16.7 Ma
≤ 17 Ma
Yabuta Fm.
Ao Fm.
Sugata Fm.
D100
UN Tuff
MT2 Tuff
Base of C2An.1n
YT3 Tuff
PM Tuff
D77
D75
D60
D56
D55
D51
D50
Uonuma Fm.
Higashigawa Fm.
Tamugigawa Fm.
Sugawa Fm.
Isgp Tuff
Chitose Tuff
Akakura Tuff
Itayama Tuff
Isg-c Tuff
Kiwadahara Tuff


Ma
Calcareous Nannofossils (CN)
Diatoms (NPD)
Pollen
Cupressaceae
Tsuga
Liquidambar
Fagus
D. Quercus
E. Quercus
Carya
Ps
Pliocene
Miocene
13a
12d
12c
12b
12a
11b
11a
10c
10b
10a
9d
9c
9b
9a
8
7
6
5b
5a
4
3
2
1c
10
9
8
7Bb
7Ba
7A
6B
6A
5D
5C
5B
5A
4Bb
4Ba
4A
3B
3A
2B
2A
NP-6
NP-5
NP-4
NP-3
NP-2
NP-1
2
5
10
15
20
0
10
20
30
(%)
Kanazawa (Yamanoi, 1992b)
Kawaura and Tokunari, Noto (Yamanoi, 1989b)
Hojuji, Horyu and Okada, Noto (Fuji & Kawai, 1982)
Tokamachi (Yamanoi & Nitobe, 1970)
Daishoji (Yamanoi, 1992b)
Tsukada, Noto (Fuji, 1972)
Wakayama, Noto (Fuji & Hori, 1990)
Himi (Wang et al., 2001)
Average
Range of percentage representations


subarctic
cool temperate
warm temperate
subtropical
tropical
Cupressaceae
Abies
Picea
Pinus
Tsuga
Liquidambar
Alnus
Betula
Carpinus
Corylus
Castanea
Fagus
Lithocarpus
D. Quercus
E. Quercus
Carya
Juglans
Pterocarya
Ulmus
Zelkova
Salix
Tilia
Rhus
others
Yamashina Fm.
Saikawa Fm.
Koderayama Fm.
Omma Fm.
Nannofossil zone
Diatom intervals
CN5a
4A5
?
(m)
50
0
006D
006A
007A
008A
009U
012A
014A
015A
017Q
017L
Scale 1 division = 2%
fine sandstone
fine sandstone containing plant fragments
Medium to coarse sandstone containing pumice and charcoal fragments
Mudstone containing pumice and charcoal fragments
Unconformable boundary


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)


Ma
5
10
Miocene
NP-4
NP-3
Cupressaceae
Tsuga
Liquidambar
Fagus
0
10
20
(%)
D. Quercus
E. Quercus
Carya
30
Average and range
of percentage representations
Hokuriku district
006A and 006D
009A, 008A and 007A


(%)
50
25
0
Accepted Article
017L
017Q
015A
014A
012A
009U
008A
007A
006A
006D
Yamashina Fm.
Saikawa Fm.
Koderayama Fm.
tropical to temperate
temperate and subtropical mountain
temperate to subarctic
tropical to subarctic