Quaternary International xxx (2015) 1–13

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Stages of major floral change in Japan based on macrofossil evidence and their connection to climate and geomorphological changes since the Pliocene

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ARTICLE INFO

Article history:
Available online xxx

Keywords:
Climate change
Floral change
Geomorphological change
Plant extinction
Plant macrofossil
Plio-Pleistocene

ABSTRACT

In the present study, the plant macrofossil stratigraphy of the Plio–Pleistocene sedimentary basins of Japan is reviewed, and the process of development of modern flora is discussed. Taxa endemic to the modern flora of central and south China became extinct, while plants that have been dominant in the recent cool-temperate and subarctic zones of Japan increased and/or emerged after the Late Pliocene. The floral change was stepwise, and the events were concentrated in transition periods of climatic fluctuation and/or in a downward shift of the glacial climate. These events are represented by the last occurrence of exotic taxa at 3.35 Ma, 2.9 Ma, 2.7–2.5 Ma, 1.2 Ma, 0.9 Ma, 0.5 Ma, and in the Late Pleistocene. Local extinctions occurred earlier in northern and inland basins, and the first appearance of plants dominant in modern cool-temperate and subarctic forests was dependent on the topography of mountains surrounding the basin. Geomorphological changes that were accompanied by mountain uplifts and sea level changes occurred in and around sedimentary basins during stage of floral changes. These alterations, along with climate changes, likely changed the habitats and migration routes of plants, which ultimately resulted in their extinction.

1. Introduction

Global climate deterioration and drastic environmental changes between glacial and interglacial stages have affected terrestrial ecosystems and biodiversity since the Late Pliocene. As a consequence of extinction, migration, and speciation of plants in response to changing environments at global and/or regional scales, the diversity of regional floras has changed, and these changes are reflected in modern plant distribution patterns. Research on European profiles has clarified the history of vegetation changes and decreased floral diversity in recurring glacial stages since the Late Pliocene (Reid and Reid, 1915; Zagwijin, 1960; van der Hammen et al., 1971; Tzedakis et al., 2006). In continental East Asia, the winter monsoon that prevailed during glacial stages diminished vegetation cover, as is shown in the loess–paleosol sequence of north China (Kukla, 1987; Sun et al., 2010). The glacial climate also eliminated thermophilous taxa in regional vegetation from the Lake Baikal region (Miyoshi et al., 2002) and north China (Liu et al., 2002).

The Japanese Islands have been isolated from the Eurasian continent since the early Late Pliocene (Kitamura and Kimoto, 2006) and have been influenced by changing monsoon climates (Tada, 2004). The early Late Pliocene flora in central Japan was rich in taxa that are endemic to central and south China (Miki, 1948). These taxa subsequently became extinct, and elements that are dominant in the present cool-temperate and subalpine forests of Japan have increased and/or emerged since the Late Pliocene (Miki, 1938, 1948; Momohara, 1994). The floral change was stepwise (Momohara, 1994), and the events were concentrated in transition periods of climatic fluctuation and a downward shift of the glacial climate shown in marine oxygen isotope curves (Momohara, 2011), as well as during stages of mountain uplift in central Japan (Momohara, 1994). The plant macrofossil data and stratigraphic information increasing in this area illuminate the detailed process of floral changes accompanied by global climate change events and regional tectonic movements. Age control of stratigraphic data has been refined by using widespread tephra beds correlated to paleomagnetic events and calcareous nanoplankton datum planes (Sato et al., 1999), and recent progress in tephrochronology has promoted the correlation of sediments between sedimentary

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http://dx.doi.org/10.1016/j.quaint.2015.03.008
1040-6182/

basins in central and western Japan (Machida, 1999; Satoguchi and Nagahashi, 2012). These methods make it possible to trace changes in the spatial and temporal distributions of plants in Japan.

In this study, which utilizes tephro- and magneto-stratigraphy, the ages of plant macrofossil assemblages from sedimentary basins in and around the Kinki District (Fig. 1) are defined based on more refined age control than that used in previous studies (Momohara, 1994, 2010, 2011). Plant biostratigraphy in the sedimentary basins in Japan is also reviewed to reconstruct the process of spatial and temporal changes of flora in Japan. The climatic and geomorphological changes discussed are based on detailed geological information to clarify the cause of plant extinction and the process leading to the development of the modern Japanese flora.

2. Geological and geographical outlines of the Plio-Pleistocene sedimentary basins

Formations of sedimentary basins that began to subside in the latest Late Miocene and Pliocene are distributed in hills surrounding the present basins in Japan (Fig. 1). Most of the plant macrofossils in the formations are fruits and seeds obtained mainly from sediments that were deposited in fluvio-lacustrine systems and occasionally from marine sediments. Their ages have been determined based on magneto- and tephrostratigraphy in a coastal basin along the Sea of Japan in the central Niigata Prefecture, and in inland basins surrounded by mountain ranges in west Fukushima Prefecture, the central Kinki District, and central and south Kyushu Island. Among these, the finest plant biostratigraphy was developed in the Kinki District based on assemblages obtained by sieving sediments (Momohara et al., 1990; Momohara, 1992), whose age control was provided by correlation to many widespread tephra beds (Fig. 2; Satoguchi and Nagahashi, 2012).

The Yamato Group in the Aizu Basin, an inland basin in west Fukushima Prefecture, is composed of fluvio-lacustrine sediments. The deposits formed between 5.4 Ma in the Early Pliocene and the early Middle Pleistocene, and they are more than 1500 m thick (Suzuki and Manabe, 1982). The fossil flora was studied intensively by Suzuki and Manabe (1982) using detailed magneto- and tephrostratigraphy as well as Middle and Late Pleistocene terrace deposits in and around the basin (Suzuki and Takeuchi, 1989).

The Uonuma Group crops out in the hills of central Niigata Prefecture and is composed of fluvial and marine sediments that were deposited in a coastal basin along the Sea of Japan. The deposits formed between 2.5 Ma and 0.7 Ma and are more than 1500 m thick (Kazaoka, 1988). The abundant tephra beds that are distributed continuously within the sedimentary basin and widespread in other basins (Satoguchi and Nagahashi, 2012) are useful for stratigraphic correlation of macrofossil assemblages. Marine sediments deposited during interglacial transgressions have been partly correlated to marine isotope stages (Urabe et al., 1995). Stratigraphic data of fruit and seed assemblages in the group have been accumulated by NFPRG and NPRG (1983) and Momohara (1988).

Inland sedimentary basins were developed in and around the central Kinki District near Osaka Bay and to the east of Ise Bay. The basins include the Shobudani Formation, deposited along the Median Tectonic Line, and the Osaka, Kobiwako, and Tokai Groups that are arranged from west to east in the north of the Median Tectonic Line (Fig. 1). The age of the sediment has been correlated using tephra beds spread within and/or among basins and magneto-stratigraphy (Fig. 2; Itihara, 1993; Satoguchi and Nagahashi, 2012). The Shobudani Formation is composed of fluvial sediments about 200 m thick that were deposited in a narrow basin along the Median Tectonic Line between the Late Pliocene and Middle Pleistocene (Mizuno and Momohara, 1993). The Osaka Group is distributed in the Harima, Osaka, Kyoto, and Nara Basins, and its maximum thickness in Osaka Bay has been estimated at 1500–2000 m (Itihara, 1993). The lower part of the group consists of fluvio-lacustrine sediments deposited between ca. 3.5 and 1.25 Ma, and the upper part is alternating non-marine and marine sediments that have been correlated with glacial–interglacial stages from MIS 37 (ca. 1.24 Ma) to the present (Yoshikawa and Mitamura, 1999). The Kobiwako Group is distributed in the Omi, Koga, and Iga Basins. It consists of 1500 m thick fluvio-lacustrine deposits, ranging between 4.2 and 0.4 Ma, occurring in hilly areas. The Tokai Group consists of more

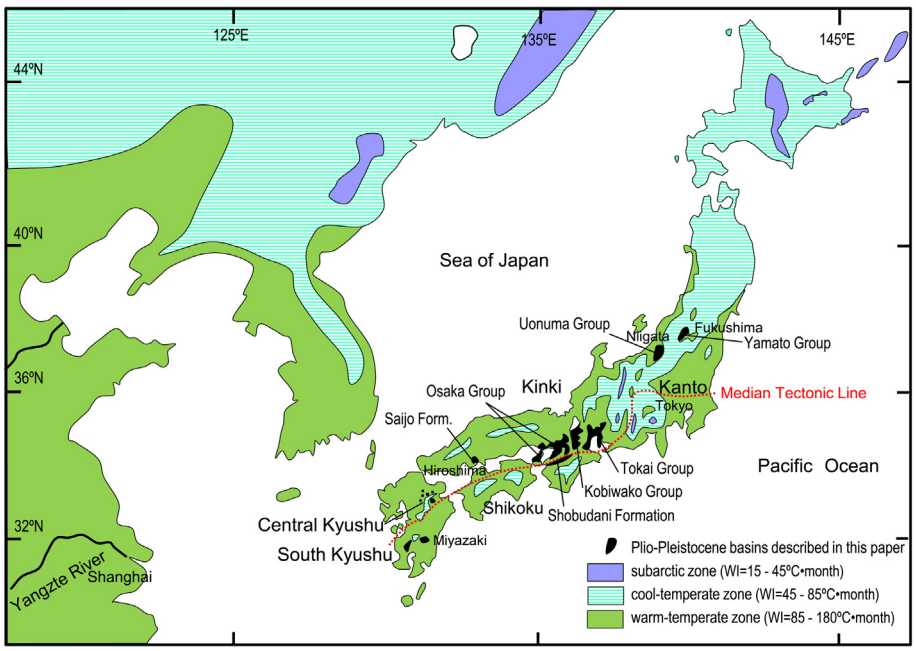

Fig. 1. Climatic zones in and around Japan based on the warmth index by Kira (1991) and distribution of the Plio-Pleistocene basins described in this paper.

Please cite this article in press as: Momohara, A., Stages of major floral change in Japan based on macrofossil evidence and their connection to climate and geomorphological changes since the Pliocene, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2015.03.008