PHYSICAL CONDITION INDICATED BY THE FLORAS

During these several decades it has been accepted by various authors that certain foliar physiognomic characters of woody dicotyledons are useful as climatic indicators. Bailey and Sinnot (1916) were the first authors who revealed that there is a general correlation between easily observable leaf characters of dicots and the climatic conditions under which they grow from the tropics to the tundra. They (Bailey and Sinnot, 1915) also recognized the importance of these correlative relationships to analysis of past climate on the basis of fossil leaf characters, wholly independent of the taxa to which the leaves belong. Thereafter, various Tertiary paleobotanists (e.g., Chaney and Sanborn, 1933 ; MacGinitie, 1941 ; Wolfe and Hopkins, 1967) use physiognomic analysis of leaf floras (assemblages) to paleoclimatic interpretations, although there is an objection to its application (Dolph and Dilcher, 1979, 1980).

Among the most useful morphologic characters of broad-leaved foliage are type of margin (entire or non-entire), texture (leathery or papery), size (megaphyllous or microphyllous), type of apex (presence of drip point) and venation (pinnate or palmate). Considering those characters with mode of fossil preservation, the most reliable leaf character for paleoclimatic studies is the nature of leaf margin of woody dicots. The proportion of entire-margined leafed dicot species shows major differences in comparing forest vegetations ranging from the tropical lowland to the lowland subarctic, as well as the cool and frigid uplands.

Through the compilation of analyses of woody vegetations and climatic data in the humid to mesic forests of East Asia, a clearcut correlation between the percentage of dicot tree species with entire leaf margins and mean annual temperature was recently well documented by Wolfe (1978, 1979), as shown in Fig. 20. Thus, we can estimate the paleotemperature indicated by the fossil flora, applying the percentage of the entire margined leaf species to Wolfe's correlation of the extant forests. The paleotemperatures of the respective floras here studied are calculated as shown in Table 50.

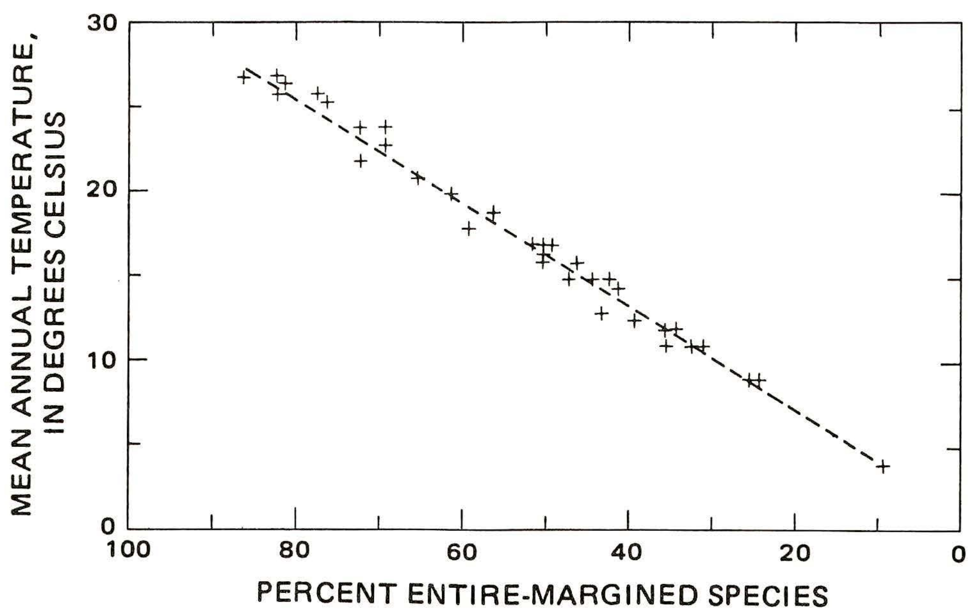

Fig. 20. Relation between percent of entir-margined species and mean annual temperature. After Wolfe (1978)

Table 50. Proportion of entire-margined broad-leaved species and its corresponding mean annual temperature

	Seto	Lower Itahana	Sashikiri		Upper Itahana
No.	22/62	17/47	30/88		21/65
%	35.48	36.17	34.09		32.31
°C	12.6	12.8	12.2		11.6
	Yagii	Chausuyama	Kouwa	Ohoka	Kabutoiwa
No.	20/60	9/25	6/15	10/34	24/94
%	33.33	36.00	40.00	29.41	25.53
°C	11.9	12.8	14.0	10.6	9.6

The temperature of 12.6°C indicated by the flora in the Seto porcelain clay Formation seems slightly lower than that expected from the species composition, because nearly one-fifth of the flora is taken up by evergreen broad-leaved species. The discrepancy may have resulted from the fact that dicot species recorded only by seed or fruit are added in the leaf floristic list. According to the climatic table (Japan Meteorol. Agency, 1982), this paleotemperature corresponds to 12.5°C of Soma along the coast of Fukushima Prefecture, and 12.5°C of inland Iwamura, Shiratori and Kera of Gifu Prefecture, at 547 m, 372 m and 450 m above sea level respectively. The northern limit of *Castanopsis cuspidata* var. *sieboldii* or evergreen *Quercus* is restricted by roughly 12°C mean annual temperature line passing north of Soma (K. Yoshioka, 1954, 1956). The modern cool temperate forest begins from altitudes of about 700 -800m upward in Gifu Prefecture.

The mean annual temperature of 12.8°C for the Lower Itahana florule is close to 12.5°C of Nakanojo, 13.1°C of Azuma in Gunma Prefecture, at 350 m and 295 m above sea level respectively. The value 12.7°C of Ozawa in Tokyo is also close to that of the Lower Itahana. The upper limit of the modern evergreen broad-leaved forest in these region of the Kwanto Mountains is about 500 m above the sea. The mean annual temperature shown by the Lower Itahana florule is found along the coast of Fukushima Prefecture as 13.1°C of Hirono, 12.9°C of Tomioka, 12.8°C of Namie, 12.5°C of Haramachi, 12.5°C of Soma. These areas correspond to the northern marginal region of the evergreen broad-leaved forest.

As the Ogawa Formation is considered to have been deposited in the coastal lowland open to the north, the mean annual temperature of 12.2°C for the Sashikiri flora approximates to the present temperature in several places of Yamagata Prefecture along the coast of the Japan Sea, namely, in Sakata (12.2°C) and Tsuruoka (12.3°C). In these areas the warm temperate evergreen broad-leaved forest develops only along the coast. The corresponding temperatures are found also in the similar coastal environment open to the north in the Toyama Plain, as exemplified by 12.4°C of Soyama at 220 m above the sea. In Ishikawa Prefecture, 12.2°C of Yanagida at 100 m above the sea in northern Noto Peninsula and 12.4°C of Onnabara at 300 m at the mountain-foot of Mt. Hakusan correspond to the value of the Sashikiri flora. The modern cool temperate forest in Hokuriku district begins upward from about 300 m above the sea in Noto Peninsula and from 350 m above the sea in an inland area.

The value 11.9°C for the Yagii flora is close to 12.2°C of Sendai and 11.8°C of Matsushima in Miyagi Prefecture. The evergreen broad-leaved forest develops narrowly along the coast and at the south of Sendai City. In an inland area, the mean annual temperature of Ashino near Kuroiso in Tochigi Prefecture and Urayama near Chichibu in Saitama Prefecture, are 11.9°C and 12.2°C at 250 m and 410 m above the sea respectively. The modern cool temperate forest begins from about 350 m around Kuroiso and from about 500 m around the Chichibu basin.

The values close to 11.6°C for the upper Itahana florule are found at the following areas: 11.8°C of Minakami and 11.5°C of Ikaho, Gunma Prefecture, 500 m and 630 m above sea level respectively, 11.7°C of Kuroiso at 343 m and 11.5°C of Kawaji at 520 m, Tochigi Prefecture. The cool temperate forest begins upward from about 450 m around Minakami and sometimes descend till about 350 m in Kuroiso area.

Corresponding to 12.8°C for the Chausuyama flora are the mean annual temperatures of Fuya (12.7°C), Murakami (12.8°C) and Minamisabashi (12.7°C) in coastal plain of northern Niigata Prefecture, and of the region about 180-200 m above the sea in Toyama Prefecture, and of Torigoe (12.7°C) at 180 m above the sea of Ishikawa Prefecture. The lower limit of the modern *Fagus* forest is at the altitudes of 200 m-300 m in the middle to northern coastal area of Niigata Prefecture, and is generally at 350 m above the sea in an inland area of Toyama and Ishikawa Prefectures.

The Kouwa flora may be unsuited for the physiognomic analysis of paleotemperature, because this assemblage comprises only 15 species of broad-leaved species identified by reproductive organs. Calculated for reference, the Kouwa flora shows 14.0°C in the mean annual temperature. Corresponding values are found in Shimodate (14.1°C), Makabe (14.2°C) and Shimozuma (14.2°C), at altitudes of 30 m to 60 m in the west of Mt. Tsukuba of Ibaragi Prefecture, or in Mito (13.8°C) and Tsuchiura (14.3°C) of Ibaragi Prefecture.

The mean annual temperature 10.6°C for the Ohoka flora corresponds to 10.7°C of Hirosaki in the Tsugaru Plain and 11.0°C of Fukaura at the western coast of Aomori Prefecture. These areas are occupied now by the cool temperate forest.

As the Kabutoiwa flora probably represents an upland vegetation, the value 9.6°C of this flora is found in the following upland areas of Nagano Prefecture : Koumi (9.7°C) at an altitude of 870 m, Nojiri (9.8°C) at 659 m, Fujimi (9.7°C) at 952 m, Kiso (9.5°C) at 980 m, Otaki (9.8°C) at 924 m and Hiraya (9.6°C) at 920 m. The southern parts of the Hiyama Province of Hokkaido can be placed in this category. These areas are included in the cool temperate *Fagus* forest zone.

The above discussion is concluded that there is no discrepancy in the floristic composition between the fossil floras described here and the extant forests which inhabit under the present-day climate approximating paleotemperatures indicated by the respective floras.

The mean annual paleotemperatures indicated by the fossil floras (Tab. 50) are plotted at their time-stratigraphic positions in 4 regions of Central Honshu (Fig. 21). The open circle represents the lowland flora, while the solid circle represents the inland and/or upland flora. Inferred the altitude of depositional basin, the mean annual paleotemperature at the sea level is calculated for inland floras by using a altitudinal temperature gradient (0.55°C/100m) ; the resultant value is indicated by an open circle together on the side of the original.

The altitude of deposition of the Kabutoiwa Formation was inferred from the relief map of the latest stage of the Tertiary (Japan Assoc. Quatern. Res. ed., 1977). It was probably at about 350 m. The probable paleotemperature at the sea level was 11.5°C for the Kabutoiwa flora. The Seto porcelain clay Formation is considered to have been deposited in inland close to hilly mountains, judging from the paleogeography, a great quantities of well-sorted coarse-grained silica sands and rich valley elements in the flora. The probable paleotemperature in the lowland was estimated as 13.0°C for the Seto porcelain clay flora.

Wolfe (1979) revealed temperature parameters of humid to mesic forests of Eastern Asia. All the Late Miocene and Pliocene floras from central Honshu range from 9°C to about 13°C in estimated mean annual temperature and were composed mainly of broad-leaved tree species. Accordingly, these fossil floras belong to the microthermal vegetation designated by Wolfe. Based on Wolfe's parameters, together with the floristic composition of each fossil flora, Late Miocene and Pliocene vegetations in central Honshu correspond to the following forest types. The Seto porcelain clay leaf flora belongs presumably to the Mixed broad-leaved evergreen and coniferous or Mixed Broad-leaved Evergreen and Deciduous forest ; mean annual range of temperature was about 25°C with the cold month mean temperature of about 1°C. The Lower Itahana florule and Yagii and Sashikiri floras seem to represent a Mixed Mesophytic forest with the mean annual temperature of above 12°C. The Upper Itahana florule belongs to the Mixed Broad-leaved Deciduous forest having mean annual temperature less than 12°C. The

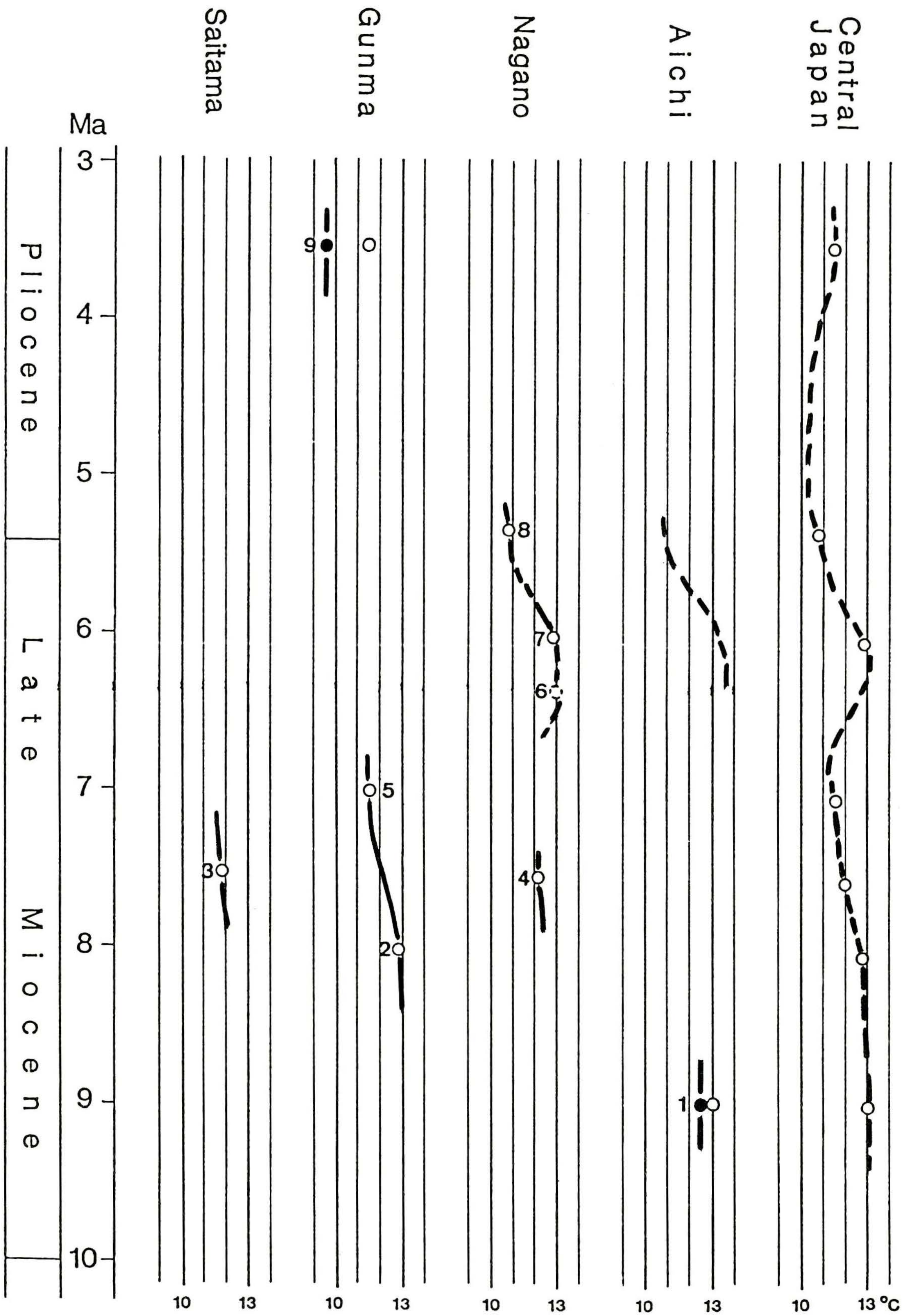

Fig. 21. Inferred Late Miocene to Pliocene climatic regimes for central Honshu, based on percentages of fossil species having broad-leaved entire-margined leaves. Open circles indicate lowland floras and solid circles show inland or highland fleras.

1: Seto 2:Lower Itahna 3: Yagii 4: Sashikiri 5: Itahana 6: Bodaira 7: Chausuyama 8: Ohoka 9: Kabutoiwa

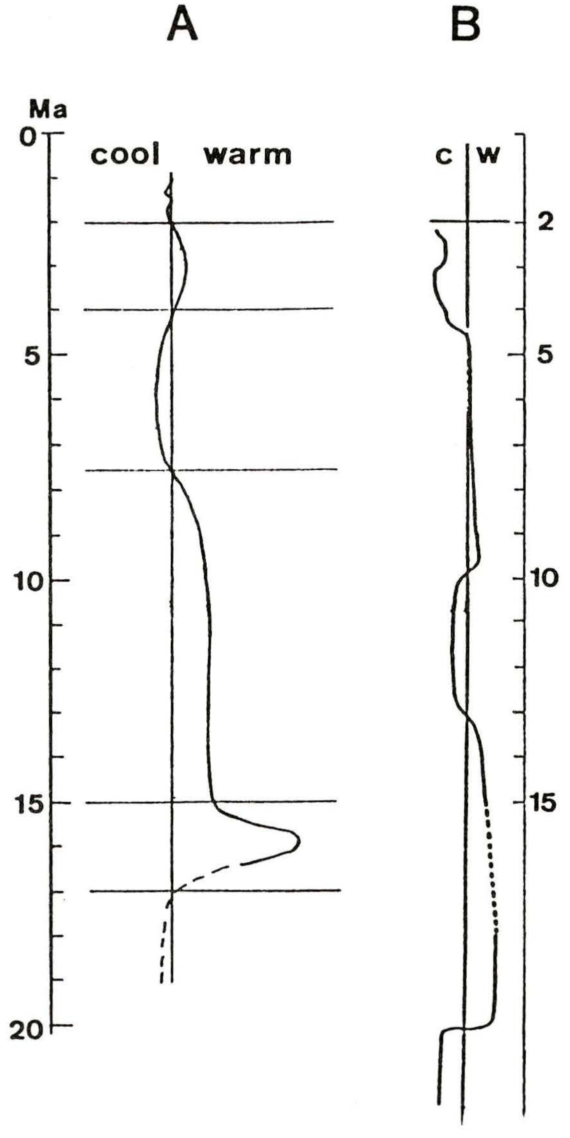

Fig. 22. Neogene climatic trends in the oil-bearing regions of Honshu, Japan.
A: Yamanoi (1986) B: Shimazaki et al. (1973)

Chausuyama flora represents the Mixed Broad-leaved Evergreen and Coniferous forest with higher than 1°C in the cold month mean temperature. The Ohoka flora belongs to Mixed Broad-leaved Deciduous forest, with the cold month mean temperature of lower than −2°C. The Kabutoiwa flora belongs to the Mixed Mesophytic forest with the mean annual temperature of 9.5°C.

Collecting the paleotemperatures on the lowland of 4 regions into one column, climatic changes of central Honshu during Late Tertiary time are shown in the most right column of Fig. 21. Early Late Miocene temperature indicating nearly 13°C gradually decreased toward the end of the Pliocene, although some fluctuations are found within about 2-3°C. Two slightly warming intervals are confirmed during the Latest Miocene (6 Ma) and the middle

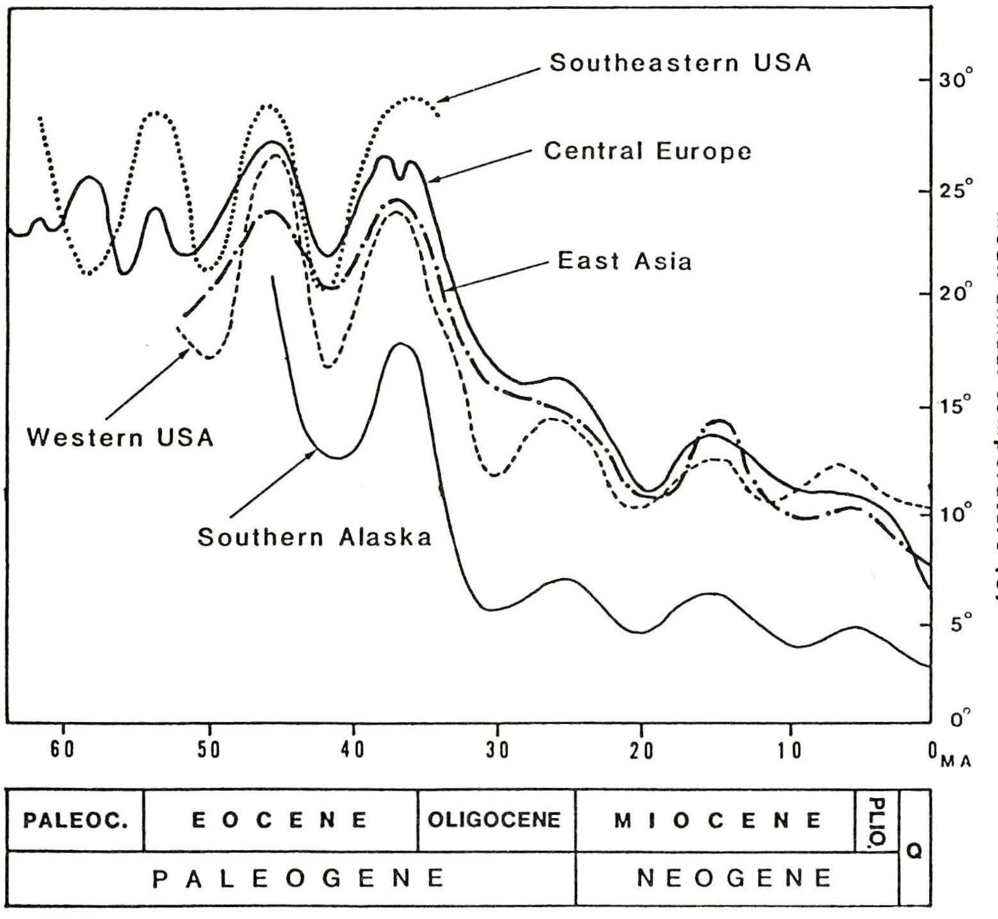

Fig. 23. Climatic changes in the Northern Hemisphere for Cenozoic time. (after T. Tanai, 1984)

Pliocene (about 3.5 Ma).

Neogene climatic changes on land of Japan have been discussed by several authors, based on leaf floras (Tanai & Huzioka, 1967; Tanai 1984; Uemura, 1988) and pollen assemblages (Shimazaki et al., 1972; Yamanoi, 1986). Most of their studies described only the relative changes of climate, showing the warmer or cooler than the present climate. For instance, Neogene climatic changes in Japan Sea side of northeastern Honshu are illustrated by Shimazaki et al. (1972) and Yamanoi (1986), based principally on pollen assemblages of marine sediments (Fig. 22). The former illustrated early Late Miocene climate slightly warmer than at the present gradually became cooler toward the Late Pliocene, while the latter considered it became coolest at the end of the Late Miocene. But both of them described a warming episode during early Late Pliocene (about 3 Ma). Generally, the climatic analysis based on pollen contains an important problem to resolve: pollen assemblage was represented by a mixture of palynomorphs whose plants inhabited widely from the lowland to montane area. Pollen assemblage, especially from the marine sediments, needs to be analyzed in the sense of forest composition for climatic consideration.

The changes of the mean annual temperatures through the Tertiary in the Northern Hemisphere were recently summarized by leaf floras by Tanai (1984) as shown in Fig. 23. Late Miocene temperatures of East Asia illustrated by him are somewhat lower than those of central Honshu, although the general temperature trends are consistent except for minor fluctuation intervals. Such difference in paleotemperatures is probably due to the fact that the climatic analysis for East Asia by Tanai (1984) was probably based mainly on the physiognomic data of Neogene leaf floras of northeastern Honshu and Hokkaido. If these differences of paleotemperatures between Tanai's and my conclusions is accepted, the mean annal temperatures of central Honshu are inferred to have been usually higher with 2-3°C than those of northern Honshu during Late Miocene and Pliocene time.

Wolfe and Poore (1981) summarized the climatic trends of the Tertiary on the basis of marine microfossil assemblages and land flora of the Northeastern Pacific, considering together with the isotopic data of marine fossils. The temperature trends of the central Honshu of Japan are well consistent with those of the Northeastern Pacific region. The warming intervals at the middle and late parts of the Late Miocene and at middle Pliocene are in accord rather with these inferred by marine fossils of the northeastern Pacific.

It may be concluded that the Late Miocene through Pliocene temperature fluctuations consistently occurred around the northern Pacific regions, representing one of worldwide climatic events.