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Late Miocene Plants from Onbara in Northern Okayama Pref., Southwestern Honshu, Japan

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Abstract Plant megafossils from the Late Miocene Ningyo-toge Formation are recorded, based on the new materials including 36 species. The Onbara florule is now known to include 56 species in 36 genera and 20 families. Most of the components are members of temperate slope forests, and have already been recorded from other "Mio-Pliocene" floras in areas on the border between Tottori and Okayama prefectures. These floras including the Onbara florule indicate the ages within the Late Miocene from their floristic similarity and stratigraphic evidences.

Introduction

Plant-bearing sediments of late Neogene time are distributed in Ningyo-toge and its vicinity to the west and north, on the border between Tottori and Okayama prefectures. Many geological and paleobotanical studies have been made on these plant-bearing sediments, since uranium-bearing deposits were discovered in 1955 (YAMADA, 1961). TANAI and ONOE (1961) described the Hoki flora and assigned its age ranging from the Late Miocene to Early Pliocene. Their Hoki flora consists of three florules from separate areas, the Mitoku, Onbara and Ningyo-toge florules. Subsequently, well-preserved plants were found from Tatsumitoge (YAMANA *et al.*, 1967; TOKUNAGA and ONOE, 1969), and were studied taxonomically and floristically by OZAKI (1979, 1980a, 1980b, 1981). Most recently, AKAGI *et al.* (1984) reported plant assemblages from north of Mitoku.

The knowledge of the "Mio-Pliocene" floras in these areas is important as the Mio-Pliocene floras are scarcely known from southwestern Japan, in contrast to those in central and northern Japan. Furthermore, as TANAI and ONOE (1961) and TANAI (1961) stated, these floras are important in assessing late Neogene floristic change in Japan.

The present report concerns the plant megafossils collected from Onbara. Although many of them have already been recorded by TANAI and ONOE (1961) and others, this report provides further informations on the diverse Late Miocene floras in these areas, including newly recorded plants, taxonomic changes and a brief comparison with other floras.

Plant fossils were collected from the diatomaceous mudstone beds at the roadside exposure by Onbara-ike (storing reservoir) at Onbara, from which T. ONOE also

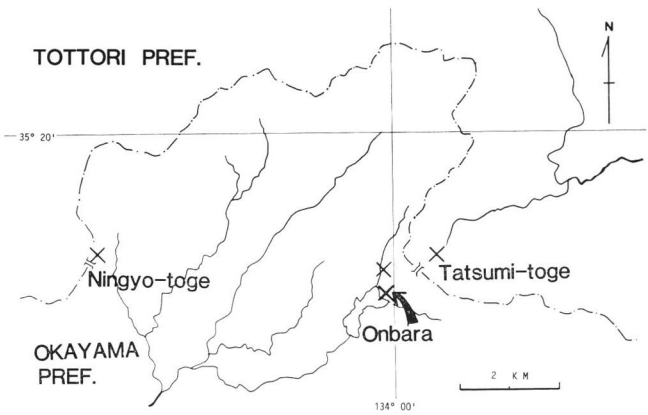

Fig. 1. Map showing fossil localities. An arrow indicates the present collecting site.

found a few plants (Fig. 1). However, almost all specimens on which TANAI and ONOE (1961) based were from a small valley exposure 500 m north of the present collecting site (T. ONOE, pers. comm.; cf. FUJIWARA *et al.*, 1957). These plant-bearing beds are in the Onbara Mudstone Member of the Ningyo-toge Formation (FUJIWARA *et al.*, 1957; revised by FUJITA, 1972). The Onbara Mudstone Member is about 70 m in thickness, and is composed of conglomerate, sandstone, mudstone and dacitic tuff. It is considered to have deposited in a fresh water lake that was formed by the damming of the drainage by the dacite lavas (FUJITA, 1972). The Ningyo-toge Formation unconformably overlies the Mesozoic granitic rocks and is conformably overlain by the Togo Formation consisting mainly of effusive volcanic rocks (YAMADA, 1961; FUJITA, 1972).

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Enumeration of Plants

Listed herewith are 36 species, including 6 conifers, 27 dicotyledons and 3 incertae sedis, which are recognized in the present collection form Onbara. The original references are given for all named taxa, and a few subsequent references and brief remarks are added to some. The classification of the dicotyledons is that of TAKHTAJAN (1980). All of the specimens are deposited in the Paleobotanical Collections, Department of Geology, National Science Museum, Tokyo: NSM-PP 10107–10114, 10143–10181. Loc. Onbara, Kamisaibara-mura, Tomata-gun, Okayama Pref.; Onbara Mudstone Member, Ningyo-toge Formation (Late Miocene).

Family Taxodiaceae

Taiwania japonica TANAI et ONOE (Fig. 7). *Taiwania japonica* TANAI et ONOE, 1961, p. 19, pl. 1, fig. 4. A leafy twig having small triangular leaves is found in the present collection. The species was reported from the Mitoku florule, but is relatively rare among the Late Miocene floras of Japan. NSM-PP 10145.

Family Cupressaceae

Thuja nipponica TANAI et ONOE. *Thuja nipponica* TANAI et ONOE, 1961, p. 19, pl. 1, fig. 11a, b. NSM-PP 10151b.

Family Pinaceae

Abies ugoensis HUZIOKA et UEMURA (Fig. 5). *Abies ugoensis* HUZIOKA et UEMURA, 1973, p. 697, pl. 1, figs. 1–5; OZAKI, 1979, p. 35, pl. 1, figs. 1–4. A single winged seed is recognized. This species is common in the Late Miocene floras of Japan. *A. protofirma* TANAI (cone-scale) and this species (winged seed) are related to the modern *A. firma* SIEB. et ZUCC. NSM-PP 10143a.

Picea ugoana HUZIOKA. *Picea ugoana* HUZIOKA, 1964, p. 62, pl. 1, figs. 17–21; Ozaki, 1979, p. 36, pl. 1, figs. 19, 20. NSM-PP 10144.

Pinus palaeopentaphylla TANAI et ONOE. *Pinus palaeopentaphylla* TANAI et ONOE, 1961, p. 18, pl. 1, fig. 12 (excluding figs. 8, 10). NSM-PP 10146a.

Tsuga sp. A few detached needle leaves are found. NSM-PP 10180b.

Family Lauraceae

Lindera paraobtusiloba HU et CHANEY. *Lindera paraobtusiloba* HU et CHANEY, 1938, p. 43, pl. 8, figs. 1–3, pl. 20, fig. 4; Ozaki, 1980a, p. 36, pl. 3, figs. 8, 9. NSM-PP 10167.

Lindera sp. Some fragmentary leaves are found, which show the general resemblance to *L. miyataensis* HUZIOKA et UEMURA. NSM-PP 10168.

Family Fagaceae

Castanea miocrenata TANAI et ONOE (Fig. 14). *Castanea miocrenata* TANAI et ONOE, 1961, p. 30, pl. 5, figs. 1–4; OZAKI, 1979, p. 52, pl. 6, fig. 1. This species is distinct in its marginal teeth from the Early and Middle Miocene species *C. miomollissima* HU et CHANEY, and is one of the characteristic species in the Late Miocene floras of Japan. NSM-PP 10154b, 10162, 10163.

Castanea sp. (Fig. 13). A single cupule with numerous spines is present. It encloses one nut which is 9 mm long and 12 mm wide and has a projection (remnant of the style) at the apex. This cupule is probably related to *C. miocrenata* because of their co-occurrence. Since the specimen is highly compressed longitudinally, the exact affinity is uncertain. NSM-PP 10164a.

Fagus palaeojaponica TANAI et ONOE (Fig. 4). *Fagus palaeojaponica* TANAI et ONOE, 1961, p. 35, pl. 7, figs. 3–5; OZAKI, 1979, p. 52, pl. 6, fig. 7 (see discussion). NSM-PP 10107.

Fagus stuxbergi (NATHORST) TANAI (Figs. 11, 12). *Quercus stuxbergi* NATHORST, 1883, p. 44, pl. 3, figs. 18–20, pl. 4, figs. 4–9 (excluding figs. 1–3). *Fagus stuxbergi* (NATHORST) TANAI, 1976, p. 296, pl. 1, figs. 4, 5, 8, 10, text-fig. 2g–j; OZAKI, 1979, p. 53, pl. 6, figs. 2–6. *Fagus palaeocrenata* OKUTSU, TANAI, 1960, p. 197, pl. 23, figs. 2–7, 9–11. Many leaves and one cupule were collected. This species is one of the dominant and characteristic plants of Late Miocene floras in Japan. NSM-PP 10109a, 10110–10113, 10165, 10179b.

Fagus cf. ***F. japonica*** MAXIM. (Fig. 3). Compare: *Fagus japonica* MAXIMOWICZ, 1886, p. 101. A single cupule having a long slender stalk and scaly prickles is comparable with that of the modern *F. japonica* MAXIM. of Japan. The relationship to *F. palaeojaponica* is not yet certain. The cupula previously described in association with the leaves of *F. palaeojaponica* (mostly described under the name of *F. protojaponica* K. SUZUKI in the previous literature) distinctly differ from the present cupule (see HUZIOKA & UEMURA, 1973). Fossil cupula identical or related to those of the modern *F. japonica* are rare in the Neogene and even in the Pleistocene. This Onbara specimen is the oldest reliable record of this type of cupule. NSM-PP 10108.

Quercus protoaliena OZAKI. *Quercus protoaliena* OZAKI, 1979, p. 54, pl. 7, figs. 1, 2, OZAKI (1979) made a revision for the leaves described under the name of *Q. miocrispula* and related species, and

established this species. *Q. protoaliena* is common in the Late Miocene floras of Japan. NSM-PP 10114, 10154b, 10166.

Family Betulaceae

Betula onbaraensis TANAI et ONOE. *Betula onbaraensis* TANAI et ONOE, 1961, p. 25, pl. 4, figs. 1, 2, text-fig. 2, TANAI and ONOE (1961) established this species based on the leaves from Onbara. This species is common in the present collection. NSM-PP 10155–10157, 10159b (?).

Betula protoglobispica TANAI et ONOE (Fig. 9). *Betula protoglobispica* TANAI et ONOE, 1961, p. 24, pl. 3, figs. 1, 2; OZAKI, 1979, p. 47, pl. 5, fig. 5 (see discussion). NSM-PP 10152, 10154a, 10153 (?).

Betula sp. A single specimen may represent a leaf produced by a young tree, showing some resemblance to those of *Betula protoglobispica* and its related species. NSM-PP 10158.

Carpinus heigunensis HUZIOKA. *Carpinus heigunensis* HUZIOKA, 1938, p. 149, text-fig. 1; OZAKI, 1979, p. 48, pl. 3, fig. 9, pl. 4, figs. 5–9 (see discussion). This species is common in the present collection, represented by one involucre and some leaves. NSM-PP 10147–10149.

Carpinus subcordata NATHORST. *Carpinus subcordata* NATHORST, 1883, p. 39, pl. 2, figs. 13–18, 20; TANAI & ONOE, 1961, p. 27, pl. 4, fig. 11; OZAKI, 1979, p. 50. pl. 3, fig. 8, pl. 5, fig. 4. NSM-PP 10150.

Carpinus sp. A single leaf is similar to that of "*C. miocenica* TANAI" by TANAI and ONOE (1961). However, *C. miocenica* has not yet been published validly. NSM-PP 10151a.

Family Juglandaceae

Pterocarya sp. (Fig. 6). A single leaflet is similar to that of *Pterocarya* sp. described by OZAKI (1979, p. 40, pl. 2, figs. 8, 10). At first glance the Onbara specimen is similar to the leaflets described as *P. nipponica* and *Juglans* sp. by TANAI and ONOE (1961). However, the leaflets of the latter two species have craspedodromous secondary veins at least on one side of the lamina, and probably represent those of a species of *Carya*. NSM-PP 10161.

Family Theaceae

Stewartia submonadelpha TANAI et ONOE. *Stewartia submonadelpha* TANAI et ONOE, 1961, p. 53, pl. 18, fig. 6; OZSKI, 1980b, p. 22, pl. 1, figs. 1, 3, 4. NSM-PP 10146b, 10176.

Family Salicaceae

Salix k-suzukii TANAI (Fig. 10). *Salix k-suzukii* TANAI, 1961, p. 269, pl. 4, fig. 12. This species is commonly present in the Late Miocene floras of northern Honshu. NSM-PP 10159a.

Family Clethraceae

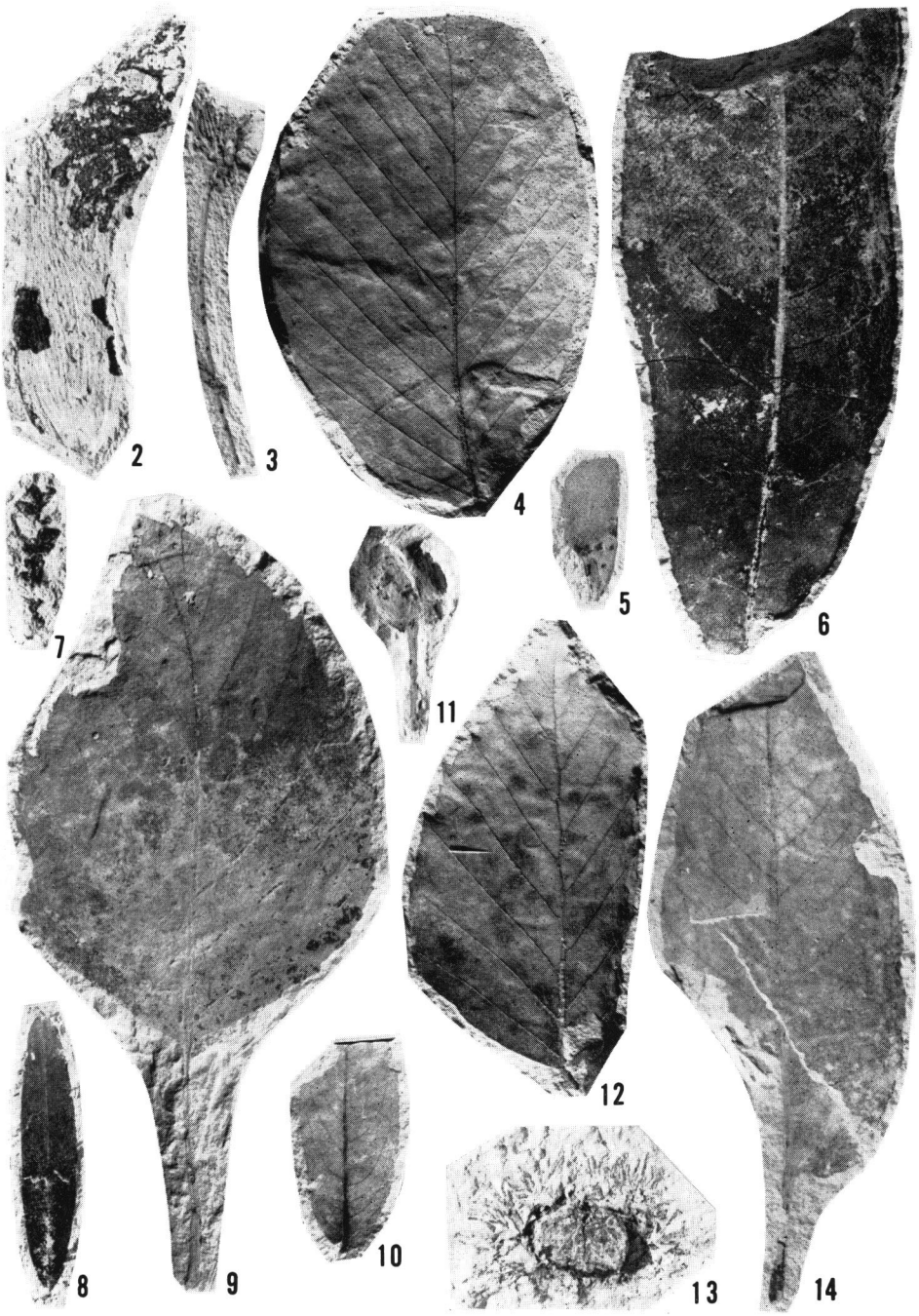
Clethra maximoviczi NATHORST. *Clethra maximoviczi* NATHORST, 1883, p. 51, pl. 11, figs. 18–20; OZAKI, 1980b, p. 36, pl. 2, fig. 5, pl. 3, fig. 5. The leaf of *Euonymus palaeosieboldianus* TANAI et ONOE (1961) has craspedodromous or rarely semicraspedodromous secondary veins and sharply pointed marginal teeth, and probably belongs to this species. NSM-PP 10175.

Family Rosaceae

Prunus protossiori TANAI et ONOE. *Prunus protossiori* TANAI et ONOE, 1961, p. 44, pl. 13, figs. 6, 7; OZAKI, 1980a, p. 43, pl. 4, figs. 11, 12. NSM-PP 10143b.

Sorbus palaeojaponica MURAI. *Sorbus palaeojaponica* MURAI, 1969, p. 61, pl. 3, fig. 6; OZAKI, 1980a, p. 47, pl. 5, figs. 6, 7, text-fig. 6D. NSM-PP 10169-10171.

Figs. 2–14. Fossil leaves and fruits from the Onbara locality. All figures in natural size except for figs. 2 (×1.4) and 14 (×0.8). 2, *Acer ezoanum* OISHI et HUZIOKA, NSM-PP 10173; 3, *Fagus* cf. *F. japonica* MAXIM., NSM-PP 10108; 4, *Fagus palaeojaponica* TANAI et ONOE, NSM-PP 10107; 5, *Abies ugoenisis* HUZIOKA et UEMURA, NSM-PP 10143a; 6, *Pterocarya* sp., NSM-PP 10161; 7, *Taiwania japonica* TANAI et ONOE, NSM-PP 10145; 8, *Lespedeza tatsumitogensis* OZAKI, NSM-PP 10160; 9, *Betula protoglobispica* TANAI et ONOE, NSM-PP 10152; 10, *Salix k-suzukii* TANAI, NSM-PP 10159a; 11, 12, *Fagus stuxbergi* (NATHORST) TANAI, NSM-PP 10110, 10113; 13, *Castanea* sp., NSM-PP 10164a; 14, *Castanea miocrenata* TANAI et ONOE, NSM-PP 10162.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Family Fabaceae (Leguminosae)

Gleditsia miosinensis HU et CHANEY. *Gleditsia miosinensis* HU et CHANEY, 1938, p. 52, pl. 26, fig. 6, 7; OZAKI, 1980a, p. 52, fig. 13. NSM-PP 10109b.

Leguminosites sp. A single fragmentary pod, showing a resemblance to that of *Cladrastis*, is found. NSM-PP 10172.

Lespedeza tatsumitogensis OZAKI (Fig. 8). *Lespedeza tatsumitogensis* OZAKI, 1980a, p, 54, pl. 7, fig. 16, text-fig, 9B. A narrow elliptic leaflet with abruptly pointed apex and short and thick petiolule is identical to this species. *L. tatsumitogensis* is characterized by densely- and regularly-arranged acute secondary veins, together with ramifying tertiary veins parallel to the secondary veins. NSM-PP 10160.

Family Aceraceae

Acer ezoanum OISHI et HUZIOKA (Fig. 2). *Acer ezoanum* OISHI et HUZIOKA, 1943, p. 98, pl. 10, figs. 1–3, pl. 11, figs. 1–4, pl. 12, figs. 1, 2; TANAI, 1983, p. 320, pl. 4, fig. 1, pl. 6, figs. 1, 4–6, pl. 7, figs. 1–3, 5–8. *Acer yabei* ENDO, 1950, p. 13, pl. 3, fig. 7. A large samara, although incomplete, is easily identifiable to this species by distinctive features of the seed. TANAI (1983) made a comprehensive revision of Tertiary *Acer* from East Asia, in which he placed *A. yabei* into synonymy of *A. ezoanum* OISHI et HUZIOKA on account of the close resemblance to the modern *A. saccharinum* L. of North America and the co-occurrence. NSM-PP 10173.

Acer palaeorufinerve TANAI et ONOE. *Acer palaeorufinerve* TANAI et ONOE, 1961, p. 49, pl. 16, figs. 2, 3. NSM-PP 10164b.

Acer yamanae TANAI et OZAKI. *Acer yamanae* TANAI et OZAKI, 1977, p. 588, pl. 3, fig. 1, 7–11, text-fig. 5F, G, text-fig. 6E, F; TANAI, 1983, p. 337, pl. 12, figs. 1–3, 6. NSM-PP 10174.

Family Aquifoliaceae

Ilex sp. Three fragmental, entire-margined leaves are recognized. NSM-PP 10177.

Incertae sedis

Three entire-margined dicot species are present. They are listed only with their registered numbers, due to the fragmental nature or ill-presevation of fossils.

Phyllites sp. 1. NSM-PP 10179a.

Phyllites sp. 2. NSM-PP 10180a.

Phyllites sp. 3. NSM-PP 10181.

Composition of the Onbara Florule

The Onbara florule was reported by TANAI and ONOE (1961), in which they listed 36 species representing 26 genera and 18 families. The term Onbara florule is followed here, since the stratigraphic horizons between the presenty collecting site and that of TANAI and ONOE (1961) are close within the Onbara Mudstone Member. Newly recognized species to the Onbara florule are: *Taiwania japonica*, *Abies ugoensis*, *Picea ugoana*, *Tsuga* sp., *Lindera paraobtusiloba*, *L.* sp., *Castanea* sp., *Fagus* cf. *F. japonica*, *Betula* sp., *Carpinus subcordata*, *Pterocarya* sp., *Stewartia submonadelpha*, *Salix k-suzukii*, *Prunus protossiori*, *Sorbus palaeojaponica*, *Gleditsia miosinensis*, *Leguminosites* sp., *Lespedeza tatsumitogensis*, *Acer palaeorufinerve*, *A. ezoanum*, *Clethra maximoviczi* and *Ilex* sp. Most of the above specifically identified taxa have been recorded from the Mitoku, Tatsumi-toge or Ningyo-toge areas. Three species, *Salix k-suzukii*, *Acer ezoanum* and *Fagus* cf. *F. japonica* are new to the Mio-Pliocene floras in Tottori and Okayama prefectures.

The Onbara florule is now known to include 56 species in 36 genera and 20 families,

Table 1. List of families and species of the Onbara florule.

Taxodiaceae
Cunninghamia protokonishii TANAI et ONOE
Taiwania japonica TANAI et ONOE
Cupressaceae
Thuja nipponica TANAI et ONOE
Pinaceae
Abies protofirma TANAI
Abies ugoensis HUZIOKA et UEMURA
Larix onbaraensis TANAI et ONOE
Picea ugoana HUZIOKA
Pinus palaeopentaphylla TANAI et ONOE
Pseudolarix japonica TANAI et ONOE
Tsuga sp.
Lauraceae
Lindera paraobtusiloba HU et CHANEY
Lindera sp.
Sassafras yabei ENDO et OKUTSU
Hamamelidaceae
Hamamelis protojaponica TANAI et N. SUZUKI
Ulmaceae
Ulmus protolaciniata TANAI et ONOE
Zelkova ungeri (ETT.) KOVATS
Fagaceae
Castanea miocrenata TANAI et ONOE
Castanea sp.
Fagus palaeojaponica TANAI et ONOE
Fagus stuxbergi (NATHORST) TANAI
Fagus cf. *F. japonica* MAXIM.
Quercus miocrispula HUZIOKA
Quercus protoaliena OZAKI
Quercus protodentata TANAI et ONOE
Quercus protoserrata TANAI et ONOE
Betulaceae
Alnus miojaponica TANAI
Alnus protohirsuta ENDO
Betula onbaraensis TANAI et ONOE
Betula protoglobispica TANAI et ONOE
Betula sp.
Carpinus heigunensis HUZIOKA
Carpinus nipponica ENDO
Carpinus stenophylla NATHORST
Carpinus subcordata NATHORST
Carpinus sp.
Juglandaceae
Carya sp.
Pterocarya sp.
Theaceae
Stewartia submonadelpha TANAI et ONOE
Salicaceae
Salix k-suzukii TANAI
Clethraceae
Clethra maximowiczi NATHORST
Ericaceae
Tripetaleia pseudopaniculata TANAI et ONOE
Buxaceae
Buxus protojaponica TANAI et ONOE
Rosaceae
Sorbus palaeojaponica MURAI
Prunus protossiori TANAI et ONOE
Fabaceae (Leguminosae)
Gleditsia miosinensis HU et CHANEY
Leguminosites sp.
Lespedeza tatsumitogensis OZAKI
Wisteria fallax (NATHORST) TANAI et ONOE
Aceraceae
Acer ezoanum OISHI et HUZIOKA
Acer palaeorufinerve TANAI et ONOE
Acer rotundatum HUZIOKA
Acer yamanae TANAI et OZAKI
Aquifoliaceae
Ilex sp. (TANAI & ONOE, 1961)
Ilex sp.
Rhamnaceae
Paliurus nipponicus MIKI
Caprifoliaceae
Lonicera protojaponica TANAI et ONOE

combining the results of TANAI and ONOE (1961) and present study (Table 1). The floristic composition is basically the same as that having been pointed out by TANAI and ONOE (1961). The following is a brief summary of the Onbara florule including the present additions.

The Betulaceae (10 species) and Fagaceae (9 species) are codominant in number of species, followed by the Pinaceae (7 species) and Aceraceae (4 species). In relative

abundance, *Fagus stuxbergi* is the most common species, followed by *Quercus protoaliena*, *Betula onbaraensis*, *Carpinus heigunensis* and *Castanea miocrenata*. Of the 10 conifers, there are two deciduous conifers, *Larix onbaraensis* and *Pseudolarix japonica*. All dicotyledons, except for *Buxus protojaponica*, are deciduous representatives, judging from the similar living relatives and leaf textures of the fossil leaves.

The Onbara florule is characterized by the dominance of deciduous broad-leaved trees, with common association of coniferous trees. The living relatives of most of the Onbara species are found in the montane forests of temperate zone in central and southern Japan. The Onbara florule includes genera which do not grow naturally in the present-day forests of Japan: *Sassafras*, *Pseudolarix* and possibly *Carya*. General absence of typically swamp inhabitants is in accordance with the conclusion of TANAI and ONOE (1961) that the Onbara plants are largely represented by the members of a slope association.

Concluding Remarks

The Onbara florule is closely similar to the plant assemblages from Mitoku (TANAI and ONOE, 1961; AKAGI *et al.*, 1984) and Tatsumi-toge (OZAKI, 1981). Of the 56 Onbara species, 30 are common to Mitoku and 32 to Tatsumi-toge. The Onbara florule has fewer species (18 species) common to the Ningyo-toge florule which shows more temperate aspect in its floristic composition.

The Ningyo-toge florule is characterized by the dominance of *Fagus stuxbergi*, together with the common occurrence of many temperate deciduous trees and of conifers (TANAI and ONOE, 1961). Furthermore, as the Ningyo-toge florule contains no typically warm or southern elements and exotic genera, TANAI (1961) regraded it to belong his Shinjo-type flora (Early Pliocene). However, TOKUNAGA and ONOE (1969) subsequently reported the occurrences of two exotic genera of *Sassafras* and *Parrotia* and a Miocene species "*Alangium aequalifolium*". Stratigraphic evidence based on a number of prospecting borings for the concealed uranium ores reveals that the plant-bearing sediments in Onbara are nearly correlative to those in Ningyo-toge (FUKUOKA and KUBO, 1969; FUJITA, 1972). Therefore, the floristic differences between the Onbara and Ningyo-toge florules are probably due to the environmental and sedimentary factors, especially those of the condition of nearby hinterland. Such differences have often been recognized among the Late Miocene plant assemblages in Northeast Honshu (HUZIOKA and UEMURA, 1974, and others).

Stratigraphically, the Mitoku and Tatsumi-toge assemblages occur in the lower horizon and the Onbara and Ningyo-toge in the upper (OZAKI, 1981). Although there is a slight difference between them in components such as warm inhabitants and exotic elements, all these plant assemblages are essentially the same in their floristic characters. They are inclusive in the Mitoku-type flora of TANAI (1961) or the Hoki flora collectively of TANAI and ONOE (1961), representing the ages within the Late Miocene.

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