PRELIMINARY REPORT ON THE LATE CENOZOIC PLANT FOSSILS FROM THE AREA NORTH OF KAGOSHIMA CITY, SOUTH KYUSHU, JAPAN

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By

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I. Introduction and Acknowledgments

Through the geological studies of the present area (Fig. 1) carried on by the members of the Institute of Earth Sciences, Kagoshima University for the past decade of years[1] three consecutive formations are discriminated and recognized to bear rather rich plant fossils. In this article, some remarks on the fossil localities are given and the floral composition and paleoecology of these plant fossils from the three formations are discussed respectively and also compared with each other. Although some of the plant fossils from the present area have been briefly treated by a few authors (ENDO, 1939; MIKI and KOKAWA, 1962; ONOE, 1972), the details have been remained unknown to date.

Before going further, the writers wish to express their deep gratitude to Professor Hidekuni MATSUO of the Department of Geology, Kanazawa University, for kindly introducing the senior writer to the paleobotanical study. Particular appreciation is due to Dr. Kotora HATAI, Professor Emeritus of the Tohoku University, for his contiguous encouragements. Acknowledgments are also due to Dr. Hiroyuki ÔTSUKA and Mr. Kimihiko ÔKI of the Kagoshima University, for their valuable advices and suggestions.

II. Outline of Geology

The geology of the present area where the fossil specimens were collected is characterized by the dominance of andesitic volcanic products of various ages ranging from the Late Tertiary to the Late Pleistocene. As the result of field studies these were classified into three groups of volcanics, namely, the older andesites, middle andesites, and the younger andesites and pyroclastic flow deposits. Between the

1) The results of studies will be published in detail in the near future.

three, rather thin sedimentary formations are developed with plant fossils and sometimes with animal fossils as well. The stratigraphic succession in the present area can be roughly compiled as follows (the fossil locality numbers are also shown in the table 1):

Table 1. Stratigraphic relations between the three, fossil-bearing formations.

Younger Andesites and Pyroclastic Flow Deposits		
Younger Sedimentary Formation[1] ("B Formation" in the text) with plant and partially with animal[2] fossils		[Loc. Nos. 12–14]
Middle Andesites		
Older Sedimentary Group[3] with plant fossils	Upper Formation[4] ("A-2 Formation" in the text)	[Loc. Nos. 7–11]
	Lower Formation[5] ("A-1 Formation" in the text)	[Loc. Nos. 1–6]
Older Andesites		

The older andesites show the isolated distributions in the areas east of Nagano village, Satsuma-chō and surrounding the Imuta Lake. This is exclusively represented by partially propyritized two-pyroxene andesite. The middle andesites include wide variety of andesite bodies ranging in lithology from dacite to pyroxene andesite and also rather widely ranging in age. These are distributed in the area closer to the coast of Kagoshima Bay. The Younger Andesites and Pyroclastic Flow Deposits overlies the Younger Sedimentary Formation in the present area. The former ones, represented by the basaltic andesites, is rather sporadical in distribution while the latter covers most of the lowland area between the mountainous volcanic rock bodies.

III. Fossil Localities and Mode of Occurrence

The 14 fossil localities where the specimens treated in the present article were

1) This formation, overlain by the marine fossiliferous formation (the Yoshidamura Shell Bed), has long been known to occur abundant plant fossils. ENDO (1939) descriminated seven species from the present formation and stated that from the abundant occurrence of *Fagus crenata* outnumbering of others partaking over 90% of the total specimens examined, the original forests can be regarded as almost pure beech forests. He also stated that the climatic condition cooler than that of the present time in the present area can be infered from the fact that "the tree *Fagus crenata* is now exist in the mountains of Kyushu and is growing at the altitude of about 1000 m or more." ONOE (1972) listed 15 species from one of the localities studied by ENDO (1939) and gave support to the ENDO's opinion.
2) Shikama, 1967.
3) This has been known by the name of the "Nagano Formation" without any published definition and sometimes confused with the younger plant beds. Through the detailed field study, two consecutive formations with a slight unconformity were recognized in the so-called Nagano Formation. The plant fossils from the "Nagano Formation" were assumed by ONOE (1972) to represent the age of extinction of *Metasequoia* recognized in the Kinki District.
4) The Tabira Formation (HASHIMOTO, 1965 MS) and the Ômura Formation (MAENO, 1965 MS).
5) The Nagano Formation (HASHIMOTO, 1965 MS) and the Imuta Formation (MAENO, 1965 MS).

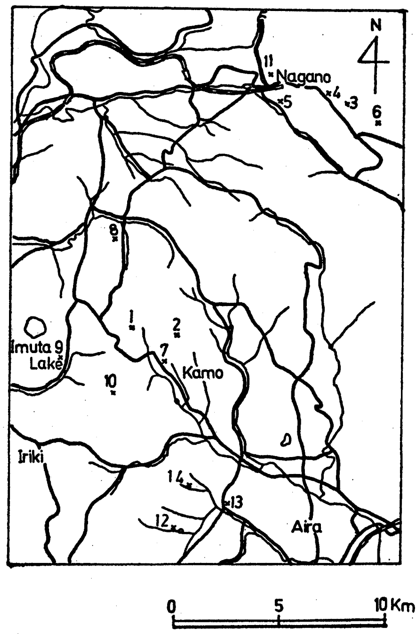

Fig. 1. Map showing the fossil localities.

collected are shown in the fig. 1, and the stratigraphic horizons of them are in the table 1.

The detailed locations of them are listed below with the lithofacies and the mode of occurrence of fossils.

I. Lower Formation of the Older Sedimentary Group (A–1)

Loc. No. 1: Between Nakahara and the Matsukawauchi Pass, Kamō-chō, Kagoshima Pref.

Lithofacies: Alternation of yellowish brown colored tuffaceous sandstone and shale.

Mode of Occurrence: Well-preserved on the bedding planes of shale. Rich in number of species and of individuals. Most of the representative species of the A–1 Formation including the large-sized specimens of the genus *Fagus* occur abundantly.

Loc. No. 2: Between Hiuto and the Nishikawauchi Pass, Kamō-chō, Kagoshima Pref.

Lithofacies: Loose tuffaceous sandstone.

Mode of Occurrence: Owing to the lithofacies, only a small number of the ill-preserved specimens were collected.

Loc. No. 3: Shironida, Nagano, Satsuma-chō, Kagoshima Pref.

Lithofacies: Hard tuffaceous sandstone.

Mode of Occurrence: Very well-preserved. Rich in number of species and of individuals. Most of the representative species of the A–1 Formation were collected.

Loc. No. 4: Kanayama village, Satsuma-chō, Kagoshima Pref.
Lithofacies: Dark grey colored shale.
Mode of Occurrence: Well-preserved. Poor in number of species. *Metasequoia* predominates.

Loc. No. 5: Yakushi, Satsuma-chō, Kagoshima Pref.
Lithofacies: Dark grey colored shale.
Mode of Occurrence: Well-preserved on the bedding planes. Aceraceae predominates.

Loc. No. 6: Chayanishi, Satsuma-chō, Kagoshima Pref.
Lithofacies: Grey to yellow colored shale.
Mode of Occurrence: Well-preserved. Poor in number of species. *Metasequoia* predominates.

II. Upper Formation of the Older Sedimentary Group (A–2)

Loc. No. 7: Yashiro,[1] Kamō-chō, Kagoshima Pref.
Lithofacies: Diatomaceous shale.
Mode of Occurrence: Very rich in number of individuals but rather few in number of species. The specimens of the genus *Quercus* are found quite often. Perfect specimens are scarecely found because the rocks are strongly sheared.

Loc. No. 8: Takigi,[2] Kedōin[3]-chō, Kagoshima Pref.
Lithofacies: tuffaceous shale and sandstone.
Mode of Occurrence: Well-preserved in shale. Considerable number of species, most of which shows the warm and humid climate.

Loc. No. 9: Sazarashi,[4] Kedōin-chō, Kagoshima Pref.
Lithofacies: Diatomite.
Mode of Occurrence: Poor in number both of species and of individuals.

Loc. No. 10: Shintometōge, Kedōin-chō, Kagoshima Pref.
Lithofacies: Diatomite.
Mode of Occurrence: Poor in number both of species and of individuals.

Loc. No. 11: Naganochōba, Nagano, Satsuma-chō, Kagoshima Pref.
Lithofacies: Diatomite.
Mode of Occurrence: Well-preserved. Perfect specimens were collected quite often. Rich in number of species and individuals. The specimens of the genus *Fagus* are predominant.

1) 社野
2) 龍間
3) 祁答院
4) 砂石

Family Name	Specific Name	Japanese Name	Formation & Locality Number: A — 1						A — 2					B			Habit	Margin	Habitat	Vertical Distribution	Climate	Present Distribution
			1	2	3	4	5	6	7	8	9	10	11	12	13	14						1 2 3 4 5 6 7 8 9 10
Osmundaceae	*Osmunda japonica* THUNBERG	Zenmai		R																		*******
Taxaceae	*Taxus cuspidata* SIEBOLD et ZUCCARINI (Pl. 1, fig. 1)	Araragi	R								R			C			t-n-e			sl-mo	c	******
	Cfr. *Torreya nucifera* SIEBOLD et ZUCCARINI													C			t-n-e			sl	c	****
Pinaceae	*Abies firma* SIEBOLD et ZUCCARINI	Momi												C			t-n-e			sl	c	****
	Pinus cfr. *thunbergii* PARLATORE (Pl. 1, fig. 2)	Kuromatsu													C		t-n-e		c	l-sl	c	**** *
Taxodiaceae	*Cunninghamia protokonishii* TANAI et ONOE (Pl. 1, fig. 3)		C		C								R				t-n-e			mo	w	*
	Metasequoia cfr. *occidentalis* (BEWBERY) CHANEY (Pl. 1, figs. 4, 5)		A							R							t-n-d		m-st	sl	w	*
	Taxodium cfr. *disthicum* ENDLICHER									C	R	C					t-n-d				w	
	Sequoia sp. (Pl. 1, fig. 6)				A	A											t-n-d			mo	w	*
	Cryptomeria japonica D. DON (Pl. 1. fig. 7)	Sugi											C				t-n-e			sl	c	***
Cupressaceae	Cfr. *Thujopsis dolaborata* SIEBOLD et ZUCCARINI	Asunaro												C			t-n-e				c	****
Salicaceae	*Salix* sp.									R							t-b-d	s	m-st	l-sl	c	
	Populus sp.									R							t-b-d	s		sl-mo	c	
Mylicaceae	*Myrica rubra* SIEBOLD et ZUCCARINI	Yamamomo								R							t-b-d	e		sl	c	***
Betulaceae	*Alnus firma* SIEBOLD et ZUCCARINI	Yashabushi					R						R				s-b-d	s		sl	c	****
	Alnus hirsuta TURCZANINOW	Yamahannoki		R													t-b-d	s		sl	c	*****
	Alnus sp.			R													t-b-d	s		sl	c	
	Carpinus carpinoides MAKINO	Kumashide								C					R		t-b-d	s		sl	c	****
	Ostrya japonica SARGENT (Pl. 1, fig. 8)	Asada								R							t-b-d	s		sl	c	***** **
Fagaceae	*Castanea crenata* SIEBOLD et ZUCCARINI	Kuri								R							t-b-d	s		sl	c	
	Fagus crenata BLUME (Pl. 1, figs. 9-11)	Bunanoki	A		C				C		C	C	A	A		C	t-b-d	s		sl-mo	c	****
	Fagus hayatae PALIB (Pl. 1. fig. 12)	Taiwanbuna														C	t-b-d	s		sl-mo	c	*
	Fagus japonica MAXIMOWICZ	Inubuna							C								t-b-d	s		sl-mo	c	****
	Quercus acuta THUNBERG	Akagashi														R	t-b-e	s		sl	w	
	Quercus glauca THUNBERG (Pl. 2, fig. 1)	Arakashi												A	C		t-b-e	s	c	l-sl	w	*****
	Quercus stenophylla MAKINO	Urajirokashi												R			t-b-e			sl	w	***
	Quercus aliena BLUME	Narakashiwa							A								t-b-d	s		sl	c	***
	Quercus crispula BLUME	Misunara							R								t-b-d	s		sl	c	**** **
	Quercus dentata THUNBERG	Kashiwa							A								t-b-d	s		sl	c	***
	Quercus serrata THUNBERG	Hahaso							A								t-b-d	s	st	l-sl	c	**** ***
Ulmaceae	*Celtis* sp.	Enoki	R														t-b-d			sl	c	
	Zelcova serrata MAKINO (Pl. 2. figs. 2,3)	Keyaki			C									A	A		t-b-d	s		l-sl	c	*****
	Ulmus parvifolia JACQUIN	Akinire					R										s-b-d	s	st	l-sl	c	** **
Magnoliaceae	*Magnolia kobus* DE CANDOLLE	Kobushi													C		t-b-d	e	c	l-sl	w	**** *
Lauraceae	*Actinodaphne acuminata* MEISSN	Baribarinoki													C		t-b-e	e	c	l-sl	w	****
	Cinnamomum japonicum SIEBOLD et ZUCCARINI	Yabunikkei													A		t-b-e	e	c	l-sl	w	********
	Cinnamomum cfr. *lanceolatum* HEER (Pl. 2, fig. 4)		R														t-b-e	e		l-sl	w	
	Machilus japonica SIEBOLD et ZUCCARINI	Hosobatabu													A		t-b-e	e	c	l-sl	w	********
	Machilus sp.														C		t-b-e	e	c	l-sl	w	
	Litsea glauca SIEBOLD	Shirodamo													A		t-b-e	e	c	l-sl	w	****
Hamamelidaceae	*Liquidambar formosana* HANCE (Pl. 2, fig. 5)	Hû			C					C							t-b-d	s	m-st	sl	w	* *
Rosaceae	*Sorbus* sp.		C							R					R		s-b-d	s		mo		
Leguminosae	*Leguminosites* sp.												R				h-b-d	e		l-mo		
Simarubaceae	*Ailanthus* sp.									R							t-b-d	e		l-sl	w	
	Rhus silvestris SIEBOLD et ZUCCARINI	Yamahaze														R	s-b-d	e		l	w	*****
	Rhus succedanea LINNE	Ryukyuhaze													R		s-b-d	e		sl	w	***** *

	Machilus sp.				C	t- b- e	e	c	l-sl	w	
	Litsea glauca SIEBOLD	Shirodamo			A	t- b- e	e	c	l-sl	w	****
Hamamelidaceae	*Liquidambar formosana* HANCE (Pl. 2, fig. 5)	Hû	C	C		t- b- d	s	m-st	sl	w	* *
Rosaceae	*Sorbus* sp.		C	R	R	s- b- d	s		mo		
Leguminosae	*Leguminosites* sp.			R		h- b- d	e		l-mo		
Simarubaceae	*Ailanthus* sp.			R		t- b- d	e		l-sl	w	
Anacardiaceae	*Rhus silvestris* SIEBOLD et ZUCCARINI	Yamahaze			R	s- b- d	e		l	w	*****
	Rhus succedanea LINNE	Ryukyuhaze			R	s- b- d	e		sl	w	***** *
	Rhus trichocarpa MIQ.	Hazenoki		R		s- b- d	e		sl	w	****
Aceraceae	*Acea pictum* THUNBERG (Pl. 2, fig. 6)	Itayakaede	C C	C		t- b- d	e		sl	c	***** **
	Acer palmatum THUNBERG (Pl. 2, fig. 7)	Takaomomiji	R R		R	t- b- d	s		sl	c	**** *
	Acer rufinerve SIEBOLD et ZUCCARINI	Urihadakaede	R R R			t- b- d	s		sl	c	****
	Acer sp.				R	t- b- d	s		sl	c	
Vitaceae	*Vitis* sp.		R			v- b- d	s		sl	c	
Tiliaceae	*Tilia* sp.				R	t- b- d	s		sl	c	
Theaceae	*Camellia japonica* LINNE	Tsubaki		R		t- b- e	s		sl	w	**
	Clyera japonica THUNBERG	Sakaki			C	s- b- e	e		sl	w	***
	Stewartia sp.			R		s- b- d	s		sl	w	
Elaeagnaceae	*Elaeagnus* sp.				R	s- b- e			l		
Halorrhagaceae	*Myriophyllum spicatum* LINNE (Pl. 2, fig. 8)	Kingyomo			C			m-st			
Cornaceae	*Cornus* sp.				C	s- b- d	s		sl	c	
Ericaceae	*Vaccinum* sp.				C	s- b- d	e		sl	w	
	Rhododendron sp.				R	s- b- d	e		sl	w	
Ebenaceae	*Diospyro kaki* LINNE	Kaki			R	t- b- d	e		sl	w	
Oleaceae	*Osmanthus* sp.				R	t- b- e	s		l-sl	w	
Caprifoliaceae	*Lonicera japonica* THUNBERG	Suikazura			R	t- b- e	e		l-sl		
	Viburnum sp.			R		t- b- d	s		l-sl	c	

Abbreviations:

Mode of occurenec:
A abundant(more than 10 specimens), C common(more than 3 specimens),
R rare (less than 3 specimens)

Habit:
t tree, s small tree or shrub, v vine, h herb, n needle-leaf, b broad-leaf,
e evergreen leaf, d deciduous leaf

Margin:
s serrate, e entire

Habitat:
m marsh, st stream side, c coastal plain

Vertical distribution:
l lowland, sl slope, mo montane

Present distributon:
1 Hokkaido, 2 Northern Honshû, 3 Central Honshû, 4 Southern Honshû,
5 Shikokn & Kyûshû, 6 Loochoo Island & Formosa, 7 Korea,
8 Northern part of China, 9 Southern part of China, 10 North America

Climate:
c cool temperate forest zone, w warm forest zone

Table 2. Systematic list of species

III. Younger Sedimentary Formation (B)

Loc. No. 12: Sagezuru[1], Yoshida-mura, Kagoshima Pref.

Lithofacies: Tuffaceous siltstone.

Mode of Occurrence: Very well-preserved on the bedding planes. Very abundant specimens of various species including those of the genus *Zelcova* and *Quercus* were collected. Seeds and leaf twigs of some needle-leaved trees are also found.

Loc. No. 13: Kuwanomaru, Yoshida-mura, Kagoshima Pref.

Lithofacies: Massive, brown colored tuffaceous siltstone.

Mode of Occurrence: Very abundant, but ill-preserved.

Most of the Lauraceae specimens treated in the present article was collected at this locality.

Loc. No. 14: Shiosoba[2], Yoshida-mura, Kagoshima Pref.

Lithofacies: Tuffaceous sandstone.

Mode of Occurrence: Ill-preserved. The specimens derived from this locality are characterized by the frequent occurrence of the herbal species.

IV. Floral Composition

The plant fossil species examined are listed systematically in the table 2. Paleontological study has resulted in the recognition of 65 species, 48 genera and 28 families. With a few exceptions, most of the families are recognized to be the ones widely distributed in the cool-temperate and the warm forest zones in the northern hemisphere at present. The families represented by the larger number of species are Fagaceae (11 species of 3 genera), Betulaceae (5 species of 3 genera), Lauraceae (6 species of 4 genera) and Taxodiaceae (5 species of 5 genera). The number of individual specimens, being rather variable locally, predominates in the families Fagaceae and Lauraceae.

As shown in the table 2, the most species identified is known to live in the Japanese Islands except for the three extinct species, *Cunninghamia protokonishii*, *Cinnamomum* cfr. *lanceolatum* and *Metasequoia* cf. *occidentalis* and three exotic species, which are not known to live in Japan, such as *Sequoia* ? sp. *Fagus hayatae* and *Liquidambar formosana*. Among them, *Cinnamomum* cfr. *lanceolata* is known to occur only from the A–1 Formation, and *Fagus hayatae* is from the B Formation. The other three species of the genera *Cunninghamia*, *Metasequoia* and *Liquidambar* occur from the A–1 and the A–2 Formations. The two species, *Metasequoia* cf. *occidentalis* and *Liquidambar formosana* are assumed to be the survivors in the humid region of the warm forest zone.

1) 提水流
2) 塩杣

V. Vegetation Analysis

Most of the species treated in the present article are known to live in the northern hemisphere at present. It may be reasonable, therefore, to assume the paleoecology of them based on the knowledge concerning the growth habit, the abscission habit, the habitat, the marginal nature of leaves, the vertical distribution and the geographic distribution of them.

Table 3. Data on the vegetation analysis. Number of species and percentage (parenthesized) in each formation.

Formation	Growth Habit				Abscission Habit				Margin	
	t	s	v	h	e-n	d-n	e-b	d-b	e	s
B	25 (74)	8 (24)	0 (0)	1 (2)	5 (20)	0 (0)	10 (32)	15 (48)	14 (50)	14 (50)
A–2	20 (77)	5 (19)	0 (0)	1 (4)	2 (7)	2 (7)	1 (4)	22 (82)	2 (10)	20 (90)
A–1	14 (74)	3 (21)	1 (5)	0 (0)	2 (13)	2 (13)	1 (6)	11 (68)	2 (15)	11 (85)

Formation	Vertical Distribution			Habitat			Climate	
	l	sl	mo	m	st	c	c	w
B	14 (30)	29 (62)	4 (8)	1	1	8	13 (48)	14 (52)
A–2	4 (11)	24 (68)	7 (21)	3	4	0	16 (70)	8 (30)
A–1	3 (12)	16 (67)	5 (21)	3	4	0	12 (71)	5 (29)

1) Growth habit

According to the ordinary way in plant ecology, growth habits are recognized as the four different types such as "tree", "small tree and shrub", "vine" and "herb". In the table 2 are shown the growth habit of every species.

Statistics of growth habits of all the species treated in the present article (table 3) clearly show the predominance of the species having the growth habit of "tree". This tendency is also recognzied when the fossil assemblage in each formation is treated. It may be noticeable, however, that the slight difference in the ratio of "tree" and "small tree and shrub" is recognized between the assemblages from the A–1 and the B Formations, and that of the A–2 Formation shows an intermediate character. Namely, the A–1 Formation is characterized by the species having the growth habit of "tree" outnumbering the "small trees and shrub", while the B Formation is by the considerable number of species regarded as the "small tree and shrub".

2) Abscission Habit

The abscission habits (evergreen needle-leaf, deciduous needle-leaf, evergreen broad-leaf and deciduous broad-leaf) of the species identified are shown in the table 2.

The present fossil assemblage, as a whole, clearly indicates that the "evergreen" species predominate the "deciduous" ones among the "needle-leaves", and that the "deciduous" species predominate the "evergreen" ones among the "broad-leaves" (table 3). From the abscission habits of the species from each formation, it is reasonable to state that the three formations are characterized by the three tendencies different from each other. Observing the "needle-leaf" species, at first, no deciduous species are found from the B Formation while the A–1 is characterized by the occurrence of two deciduous species, and the number of evergreen species is five in the B Formation and only two in the A–1. Secondly, concerning the broad-leaf species, the percentage in the number of evergreen species is considerably high in the B Formation compared with those of the other two formations.

As the conclusion on the abscission habit, it may be reasonable to say that the B Formation is characterized by the fifty-fifty occurrence of the evergreen and deciduous species, and on the contrary, the A–2 and the A–1 Formations are by the abundant occurrence of the deciduous broad-leaved species and the occurrence of the deciduous needle-leaves even though it is quite a few in number of species.

3) Marginal Nature of the Broad-leaved Species

One of the most important characters of broad-leaves relating to the climatic environments is their marginal nature (Endo, 1934; Tanai and Onoe, 1961; Tanai, 1961). From the table 2, in which the marginal natures ("serrate" or "entire") of the broad-leaved species identified are given, the following statistics were obtained.

When all the species found from the present area are treated, the number of species with the serrated margin amount to 35 (65%) and that with the entire margin is 19 (35%). This tendency is represented more strongly in the assemblages of the A–1 Formation and of the A–2 (table 3). On the other hand, the assemblage of the B Formation shows a same ratio between "serrate" and "entire". This is suggestive of the climatic environments of the present plant assemblages in relation to the Tanai's generalization on the marginal nature as one of the climatic indications (Tanai, 1961)[1].

4) Habitat

As one of the clues for the consideration on the physiographic conditions of the areas where the present fossil plants grew, the habitats of the modern equivalent species are adopted. The habitats of some species identified are shown in the table 2

1) The detailed historical review on the studies of leaf-characters is given by Tanai (1961, p. 195–197).

in terms of "marsh", "stream side" and "coastal plain". Although the species treated here are rather small in number, it is recognzied that the numbers of species of each habitat of the A–1 and the A–2 Formations show striking contrast to that of the B Formation. Namely, the former two have no species of "coastal plain" habit, while the latter has those in high percentage (84%). This relation can be more reliable through the consideration on the number of individuals occurred from each Formation; the predominant species of the A–1 Formation is *Metasequoia occidentalis* which is regarded as a typical "marsh" species, while those of the B Formation are of the family Lauraceae and *Quercus glauca* which are all regarded as the "coastal plain" species.

5) Vertical Distribution

The vertical distribution of each species identified, which is treated here refering to the following three types of topography, is described in the table 2. From the statistics of the vertical distribution of the plant assemblages from the three formations (table 3), it is clearly recognized that the percentage of the "slope" elements is extremely high in every formation (62–68%), and of the other two ("lowland" and "montane") are recognized to show slight differences between the formations. The lowland element is quite a few in number of species from the A–1 and the A–2 Formations and is as many as one-thirds in the B Formation. In every formation, the percentage of the number of species regarded as the montane elements is rather low. It is noticeable that the plant assemblages of the A–1 and the A–2 Formations are composed mainly of the "slope" and the "montane" elements (88 and 89% respectively) and on the other hand that of the B Formation is mainly of the "slope" and the "lowland" elements (92%).

6) Horizontal Distribution

Based on the forest zone[1)] data of each species identified (table 2), the following figures were obtained (table 3). It seems to be rather difficult to say definitely the climatic conditions under which the plants lived in the three different ages. Comparing the statistics on the plant assemblages of the B and the A–1 Formations, however, a considerable difference is recognzied. That is, the species referable to the warm forest zone in the B Formation indicate the highest percentage (52%) while in the A–1 Formation the highest percentage is represented by the cool-temperate species. This may suggest, to some extent, a cooler climate at the time of deposition of the A–1 Formation than that of the B Formation which is assumed to be nearly the same as the

1) The following forest zones are generally accepted in and around the Japanese Islands (Iwanami Dictionary of Biology, 1960):
Subarctic forest zone: annual mean temperature is below 6°C.
Cool temperate forest zone: between 6°C and 13°C.
Warm forest zone: between 13°C and 21°C.
Tropical forest zone: above 21°C.

climatic condition at present in the present area. For the consideration on the climatic condition, however, it seems to be important that the plant assemblages of the A–1 and the A–2 Formations indicating cooler climate comprises a few extinct and exotic species regarded to be of the warm forest zone, such as *Cunninghamia protokonishii*, *Metasequoia* cf. *occidentalis* and *Liquidambar formosana*. Another noticeable fact is that the B Formation representing a warmer climate comprises a few cool elements, such as *Thujopsis dolabrata* and *Fagus hayatae*.

VI. Paleoecological Consideration

On the basis of the results of observation on the mode of occurrence and the floral composition and of the vegetation analysis given in the foregoing pages, it is possible to understand, to some extent, the respective features of the fossil assemblages from the three consecutive Formations, and to assume the paleoecological conditions under which those fossil plants lived. Here the writers intend to describe them on each Formation.

1) The Lower Formation of the Older Sedimentary Group (A–1)

The flora from the present Formation consists of 19 species of 15 genera belonging to 11 families and is characterized by the occurrence of two exotic and three extinct species, such as, *Liquidambar formosana*, *Sequoia* ? sp., *Metasequoia* cf. *occidentalis*, *Cunninghamia protokonishii* and *Cinnamomum* cf. *lanceolatum*. Comparing with the flora from the B Formation, several differences are poientd out as follows. In the flora from the A–1 Formation, *Cinnamomum* cf. *lanceolatum* is the only species belonging to the family Lauraceae which is represented by the commonly occurring five species in the B Formation. *Fagus crenata* Blume, which is the only one species common to the B Formation, is represented in the A–1 Formation by the specimens much larger than those from the B Formation. *Fagus hayatae* commonly occurring in the B Formation is scarecely found from the A–1 Formation. The species belonging to the families Betulaceae and the Aceraceae are common in occurrence in the A–1 Formation while those are rather rarely found from the B Formation. Judging from the foregoing features of the floral composition, it is reasonable to say that the flora from the A–1 formation represents the mixed assemblage of the cool-temperate (such as the species of the families Betulaceae, Fagaceae and Aceraceae) and the warm forest zone elements (including two exotic species such as of the genera *Metasequoia* and *Liquidambar* and an extinct species of *Cunninghamia*).

Based on the data given in the preceding chapter, the environmental conditions which affected the flora from the A–1 Formation can be summarized as follows. The feature of the present flora is assumed to be of the slope association mainly of trees with a small amount of vines and shrubs in marshy or river-side area close to highland. The climatic condition under which the flora existed may be of the cool-temperate forest zone judging from the high percentage of the species living in the cool-temperate zone at present and of deciduous broad leaves mostly of serrate margin and subordinate needle leaves. It is also probable that the temperature at that time was not so lowered as it freezes because of the coexistence of several exotic species indicating the warm-temperate climate.

2) The Upper Formation of the Lower Sedimentary Group (A–2)

From the present Formation are discriminated 26 species of 21 genera refered to 14 families. Among them, seven species of three genera, which mean the largest number of species belonging to a single family treated here, are of the family Fagaceae. The genus *Quercus* of this family is represented solely by the deciduous oak without the evergreen one which is commonly found from the B Formation. It is also noticeable that the species of the families Betulaceae and Aceraceae found scarcely from the B Formation occur commonly from the present formation. The present flora comprises the species of the genera *Cunninghamia, Metasequoia* and *Liquidambar* which are common to that of the A–1 Formation. On the other hand, the species suggesting of a little older age such as *Cinnamomum* cf. *lanceolatum* and *Sequoia* ? sp. are not known from the present Formation. Judging from the above-stated features it can be pointed out that the floral composition of the present formation is nearly the same as that of the A–1 Formation indicating the cool-temperate forest zone flora accompanied with a few warm-temperate exotic elements. Such being the case, the similarity of the floral character of the present Formation is considered to be much closer to the A–1 Formation than to the B Formation. This seems to correspond quite well with the stratigraphic relations between the three formations.

The data given in the preceding chapter suggest that the feature of the present flora is almost the same as that of the A–1 Formation except for the following points. The numbers of species considered to had lived in the lowland area and of the broad-leaved species with serrated margin are both intermediate between those of the A–1 and the B Formations respectively. Further, the present flora is characterized by the species having the growth habit of tree amounting to nearly two-thirds of the total number of species, of shrub amount to one-third and of herb of quite a few species. This feature of the growth habits composition is quite similar to that of the B Formation.

3) The Younger Sedimentary Formation (B)

The fossil flora from the present formation consists of 33 species of 27 genera of 20 families. Among them, the families represented by rather many species are Fagaceae (five species of two genera) and Lauraceae (five species of four genera). These are followed in number of species by the families Magnoliaceae, Anacardiaceae, Ericaceae and Theaceae. The species occurred most frequently is of the families Lauraceae and Pinaceae and of the genus *Quercus*. The last one is exclusively represented by the evergreen oak. Following these, the species of *Fagus* and *Zelcova* are common in occurrence. All the families in the present flora are represented by the species living at present in the northern hemisphere and most of which distributes geographically in the cool-temperate and the warm forest zones. The exotic species *Liquidambar formosana* and *Sequoia* sp. and also the extinct species *Metasequoia* cf. *occidentalis*, *Cunninghamia protokonishii* and *Cinnamomum* cf. *lanceolatum* are not known from the present formation. The absence of these species, which commonly occur in the A–1 and the A–2 Formations, may have a deep concern with the consideration on the geological ages of them. On the contrary, frequent occurrence of *Fagus hayatae*, an exotic species, is known only from the B Formation.

The living distribution of the most species from the present formation is restricted to the southwest Honshu, Shikoku and Kyushu, and majority of them are known to live at present in and around the present area. From the data given in the preceding chapter, the flora is assumed to be a slope and lowland association mainly of trees and shrubs mixed in the coastal plain environment. That the climatic condition under which the flora lived is of the warm-temperate forest zone as already stated is also endorsed by the highest percentage of the evergreen broad-leaved species and the absence of the deciduous needle-leaved ones and by the nearly fifty-fifty occurrence of the species with leaves of entire or serrated margins. As the result of observation, it is concluded that the present flora indicates an environmental condition quite similar to that of the coastal plain district surrounding the present day Kagoshima Bay. It is noticeable that the floral character of the present formation shows a striking contrast with those of the A–2 and the A–1 Formations in habitat, abscission habit and leaf character of the constitutent species.

Concluding Remarks

There have been no evidences to determine the geological ages of the A–1 and A–2 Formations. On the contary, several data and opinions concerning the geological ages of the B Formation and the overlying marine beds (the Yoshidamura Shell Beds) have been given (ENDO, 1939; YABE, 1941, 1946, 1955; YABE and HATAI, 1941; SHIKAMA, 1967[1]; ONOE, 1972).

Although there are still room for further study concerning the geological ages of these formations, it is noticeable that the fossil flora of these three consecutive formations clearly shows the characteristic features respectively as already stated in the preceding chapters and summarized in the following table.

This may serve as one of the criteria to ascertain the stratigraphic relation of the plant-bearing formations to those in the neighbouring area, on which the writers' study will be undertaken hereafter.

1) According to SHIKAMA (1967), who had described *Rhinoceros* aff. *sinensis* OWEN from the formation correlative to the writers' B Formation, the *Rhinoceros*-bearing bed can be regarded to be the Choukuotienian (=Lower Kuzuuan).

Formation	Predominant elements	Subordinate elements	Climatic condition	Habitat
B	Lauraceae *Quercus* (evergreen) *Zelcova serrata* *Fagus crenata* (small-sized) *Fagus hayatae*	Pinaceae	Warm forest zone	Coastal plain and lowland forest of broad-leaved trees in the warm forest zone, neighbouring the mountainous hinterland with a cool-temperate forest of the needle-leaved trees.
A–2	*Quercus* (deciduous) *Fagus crenata*	*Metasequoia* *Cunninghamia* *Liquidambar* *Camelia* *Rhus*	Cool-temperate forest zone	Lowland forest of cool-temperate deciduous trees in a humid inland area mixed with a few warm forest elements (mainly of exotic).
A–1	*Metasequoia* *Fagus crenata* (large-sized) Betulaceae *Acer pictum*	*Cunninghamia* *Liquidambar*		

Description of Some Species

Family Taxaceae

Taxus cuspidata SIEBOLD et ZUCCARINI

(Pl. 1, fig. 1)

Taxus cuspidata SIEBOLD et ZUCCARINI, MATSUO, 1968, Ann. Sci. Kanazawa Univ., vol. 5, p. 42, pl. I, figs. 2, 3.

Leaves linear lanceolate in outline, 1.0 to 1.5 cm long and about 0.2 cm wide; tapering toward the acuminate apex; midrib straight. Leaves in two rows arranged spirally on both sides of spray.

Remarks: The present specimens are identifyable as the Recent species *Taxus cuspidata*, which lives in the mountains of the Central and Northern Honshu, Japan. MATSUO (1968) has reported the present species from the Pliocene Minoshirotori Formation.

Occurrence: A–1 and A–2 Formations.

Family Pinaceae

Pinus cf. *thunbergii* PARLATORE

(Pl. 1, fig. 2).

Remarks: Leaves linear in shape, about 10 cm long and 0.2 cm wide, acutely pointe at apex. The present materials are closely similar to the living two-leaved pine, *Pinus thunbergii*, which is at present widely distributed near the coastal plain and in the slope area in Honshu, Shikoku and Kyushu.

Occurrence: Locality Nos. 12 and 13. B Formation.

Family Taxodiaceae

Cunninghamia protokonishii TANAI et ONOE
(Pl. 1, fig. 3)

Cunninghamia konishii HAYATA, TANAI, 1955, Geol. Surv. Jap. Rep. No. 163, pl. 1, fig. 6.
Cunninghamia protokonishii TANAI et ONOE, 1961, Geol. Surv. Jap. Rep. 187, p. 18–19, pl. 1, fig. 1.
Cunninghamia protokonishii TANAI et ONOE, MURAI, Rep. Tech. Iwate Univ., vol. 15, no. 2, p. 6–7, pl. 1, figs. 7–9.
Cunninghamia protokonishii TANAI et ONOE, MATSUO, 1963, Geol. Surv. Jap. 80th Aniv., pl. 40, fig. 3; pl. 45, figs. 1, 2.

Leaves arranged spirally from shoot-axis, but often distichously arranged. Each leaves lanceolate or linear in shape, about 1.5–2.0 cm long and 0.2–0.3 cm wide, but rather variable in shape and length; broadest near the middle portion, gradually narrowed towards both apex and base; apex acute; shoot often slightly curve upwards; margin coarsely serrate; stem thick, 0.3 to 0.4 cm wide, surface scaled.

Remarks: The present specimens are quite identical with *Cunninghamia protokonishii* originally described from the Mio-Pliocene Onbara Formation in the borderland of the Tottori and Okayama Prefectures. There are two species known to live, namely *Cunninghamia konishii* HAYATA in Formosa and *C. lanceolata* HOOK in the central and southern China. *C. lanceolata* is longer in outline than *C. konishii* and shows linear lanceolate sickleshape. The present species also resembles some species of *Torreya*, but is distinguishable from the latter by having finely serrulate margins. This species has been known to occur in Japan commonly from the formations ranging from the Middle Miocene to the Late Pliocene in age. It is noticeable that the present species occurs only from the Older Sedimentary Group (A–1 and A–2 Formations).

Occurrence: Locality Nos. 1 and 3 (A–1 Formation) and No. 11 (A–2 Formation).

Metasequoia cf. *occidentalis* (NEWBERRY) CHANEY
(Pl. 1, figs. 4, 5)

Compared with:

Metasequoia japonica (ENDO), TANAI, 1952, Jap. Jour. Geol. Geogr., no. 22, p. 122–123, pl. IV, figs. 2, 3.
Sequoia (=*Metasequoia*) *japonica* ? ENDO, 1954, Kumamoto Jour. Sci, Ser. B, pl. II, figs. 4, 6.
Metasequoia occidentalis (NEWBERRY) CHANEY, TANAI & ONOE, 1959, Bull. Geol. Surv. Jap. vol. 10, no. 4, pl. 1, fig. 2.
Metasequoia occidentalis (NEWBERRY) CHANEY, TANAI, Jour. Fac. Sci., Hokkaido Univ., Ser. IV, vol. XI, no. 2, p. 263–264, pl. 3, figs. 1–3, 5–8, 14.
Metasequoia occidentalis (NEWBERRY) CHANEY, HUZIOKA, 1963, Jour. Min. Coll. Akita Univ., Ser. A, vol. III, no. 4, p. 63–64, pl. II, figs. 9–12.
Metasequoia occidentalis (NEWBERRY) CHANEY, TANAI, 1964, Geol. Surv. Jap. 80th Aniv., p. 104, pl. 2, figs. 5–7.
Metasequoia occidentalis (NEWBERRY) CHANEY, HUZIOKA and TAKAHASHI, 1970, Jour. Min. Coll. Akita Univ., Ser. A, vol. IV, no. 5, p. 48, pl. II, figs. 9, 9a, 10.

Remarks: The specimens compared with the named species occur abundantly from the A–1 and the A–2 Formations. The specimens from the latter formation have foliated shoots longer than the ones from the former. This may suggest a subspecific difference between them.

Occurrence: Locality Nos. 1 (A–1 Formation) and 8 (A–2 Formation).

Cryptomeria japonica D. DON
(Pl. 1, fig. 7)

Cryptomeria ? cf. *japonica* D. DON, MURAI, Tech. Rep. Iwate Univ., vol. 3, no. 3, pl. 4, fig. 8.
Cfr. *Cryptomeria japonica* D. DON, MATSUO, Ann. Sci. Kanazawa Univ., vol. 5, p. 43, pl. I, figs. 8, 9, 11.

Leaves small in size and linear-lanceolate in shape, 0.7 to 0.8 cm long. Leaves arranged innumerably on both sides of spray.

Remarks: The present specimens are identical with *Cryptomeria japonica* D. DON ("Sugi" in Japanese), living in Honshu and Shikoku as one of the elements characteristic of the Japanese vegetation.

Family Fagaceae

Fagus hayatae PALIB
(Pl. 1, fig. 12)

Fagus hayatae PALIB, OISHI, 1950, Illus. Cat. East-Asiatic Fossil Plants, pl. 42, fig. 4.
Fagus hayatae PALIB, TANAI, 1955, Rep. Geol. Surv. Jap., no. 163, pl. VII, fig. 7.
Fagus hayatae PALIB, SUZUKI, 1959, Assoc. Geol. Coll. Jap., p. 36, pl. 1, fig. 6.
Cfr. *Fagus hayatae*, PALIB, HUZIOKA, 1972, Jour. Min. Coll. Akita Univ., Ser. A, vol. V, no. 1, p. 51.

Leaves small in size, 4 to 5 cm long and 2.5 to 3 cm wide, ovate or elliptically ovate in outline, generally narrowing upwards, apex acute, base round or cuneately round. Midrib (primary nerve) generally stout and undulating, narrowing toward apical part; secondaries generally slender but distinct, 8 to 12 paris, alternate, diverging from primary nerve at angles of about 3–40° in the lower part and about 60° in the upper part, ending as the marginal teeth; margin with fine serrate teeth.

Remarks: The present specimens are safely referable to the named species, which lives at the altitudes of about 1500 m in Formosa.

Occurrence: Loc. No. 14 (B Formation).

Quercus glauca THUNBERG
(Pl. 2, fig. 1)

Quercus glauca THUNBERG, Onoe, 1971, Geol. Surv. Jap. Rep. 241, p. 26, pl. V, fig. 1.

Leaves large, oblong-ovate in outline, 7 to 8.5 cm long and 2.5 to 3 cm wide; base cuneiform; apex acuminate; midrib nearly straight, stout; secondaries rather slender, 11 to 12 pairs, opposite to subalternate, almost parallel and regularly spaced (5 to 6 mm), diverging from the midrib at angles of about 50° (at the base and of about 40° at the top, gently curving up and ending in the marginal teeth; margin denticulate on the upper two thirds of blade, and entire on the basal part; petiole stout, about 2.5 cm long.

Remarks: The present species abundantly occurs from the locality no. 12 and is one of the representative species of the B Formation. The specimens treated here are quite identical with the leaves of the living *Quercus glauca*, which is widely distributed in the warm forest zone ranging from the central Honshu to Shikoku and Kyushu, Japan and southward to Formosa, China and the Himalayas. No materials have been found from the A–1 and the A–2 Formations.

Occurrence: Locality Nos. 12 and 13 (B Formation).

Family Lauraceae

Cinnamomum cfr. *lanceolatum* HEER

(Pl. 2, fig. 4)

Compared with:

Cinnamomum lanceolatum HEER, ENDO, 1955, Icones Foss. Plants Jap. Isl., pl. 26, figs. 3, 5.
Cinnamomum lanceolatum HEER, MURAI, 1963, Tech. Rep. Iwate Univ., vol. 16, no. 1, p. 84, pl. 14, fig. 1.

Leaf elliptical in outline, about 8 cm long, 2.5 cm wide at the middle; margin entire, base cuneiform, broadest at the middle and gradually narrowing to acuminate apex; midrib straight and thinning upwards, lateral primaries more slender, ascending from the base to the middle portion of leaf margin with slight curves nearly parallel with leaf margin.; petiole about 1 to 1.5 cm long.

Remarks: The present species has been reported to occur from the Miocene Oguni plant bed in Yamagata Prefecture and from the Miocene-Pliocene Kobe Formation in Hyogo Prefecture.

Occurrence: Locality No. 1 (A–1 Formation).

Family Hamamelidaceae

Liquidambar formosana HANCE

(Pl. 2, fig. 5)

Liquidambar formosana HANCE, Oishi, 1950, Illust. Cat. East-Asiatic Fossil Plants, p. 154, pl. 45, fig. 4.
Liquidambar formosana HANCE, ENDO, 1954, KUMAMOTO Jour. Sci., Ser. B, no. 4, pl. III, pl. IV, figs. 10, 11.
Liquidambar formosana HANCE, OKUTSU, 1955, Sci. Rept. Tohoku Univ., Ser. 2, vol. 26, p. 98–100, pl. 2, figs. 1–3.
Liquidambar formosana HANCE, TANAI, 1955, Rep. Geol. Surv. Jap. no. 163, pl. XII, figs. 8–10.
Liquidambar formosana HANCE, SUZUKI, 1961, Sci. Rep. Fukushima Univ., no. 10, p. 70–72, pl. 15, fig. 5; pl. 16, figs. 1–7.
Liquidambar formosana HANCE, MURAI, 1963, Tech. Rep. Iwate Univ., vol. 16, no. 1, p. 89–90, pl. 15, fig. 2.
Liquidambar formosana HANCE, MURAI, 1968, Tech. Rep. Iwate Univ., vol. 3, no. 3, p. 5–6, pl. 2, fig. 7.

Leaves palmately three lobed, midlobe large and triangular or ovate-lanceolate, acute at apex; lateral lobes generally small, triangular or ovate, acuminate tips; margin coarsely serrulate throughout, teeth short; base round, truncately round or cordate. Leaves of medium size, 5 to 6 cm long and 6 cm wide in maximum, orbiculate or semi-orbiculate in general outline. Palmately three-nerved, mid-primary nerve stout, lateral primary nerve diverging from mid-primary at angle of about 50 degrees, spreading in a gentle upward curve to the pointed tip of lateral lobes. Secondaries numerous, alternate or opposite, arching upwards near margin; basal pair of secondaries running somewhat parallel to upper border of respective lateral lobe. Petiole more than 1 cm long.

Remarks: The present species is one of the species characteristic of the A–1 Formation.

The specimens in the collection are quite identical with the Recent *Liquidambar formosana*, living in the southern China and Formosa. In Japan, fossil remains of this species have been reported from many localities of the Tertiary formations ranging from Eocene to Pliocene in age and its most common occurrence is known from the Middle Miocene.

Occurrence: Locality Nos. 3 (A–1 Formation) and 8 (B Formation).

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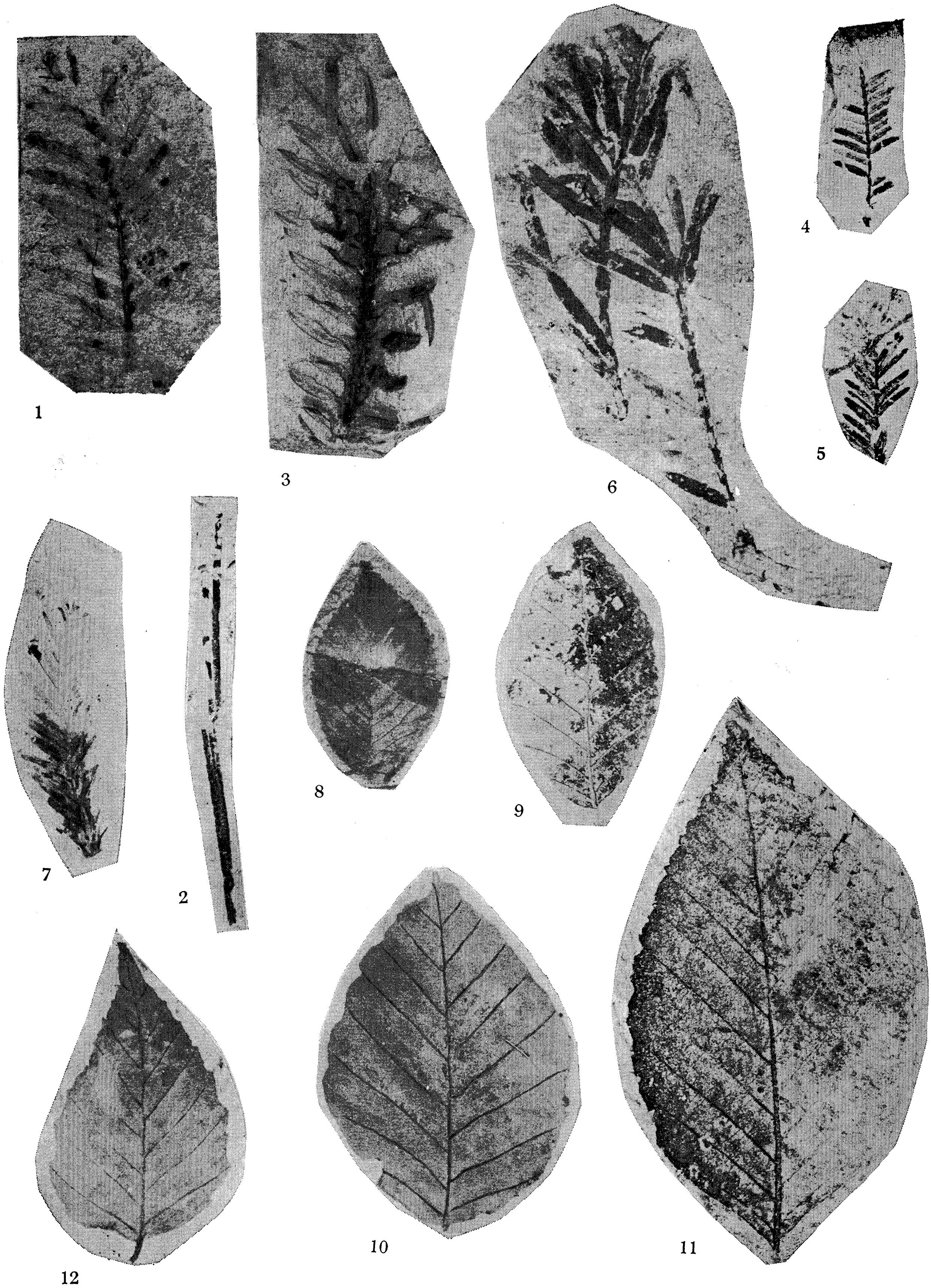
Explanation of Plate 1

(All figures are in natural size)

Fig. 1. *Taxus cuspidata* SIEBOLD et ZUCCARINI.
Loc. Nos. 1 (A–1 Formation), 9 (A–2 Formation) 12 (B Formation).
Fig. 2. *Pinus* cf. *thunbergii* PARLATORE.
Loc. No. 13 (B Formation).
Fig. 3. *Cunninghamia protokonishii* TANAI et ONOE.
Loc. Nos. 1, 3 (A–1 Formation), 11 (A–2 Formation).
Figs. 4, 5. *Metasequoia* cf. *occidentalis* (NEWBERRY) CHANEY
Loc. Nos. 1 (A–1 Formation), 8 (A–2 Formation).
Fig. 6. *Sequoia* sp.
Loc. Nos. 3, 4 (A–1 Formation).
Fig. 7. *Cryptomeria japonica* D. DON
Loc. No. 11 (A–2 Formation).
Fig. 8. *Ostrya japonica* SARGENT
Loc. No. 8 (A–2 Formation).
Figs. 9–11. *Fagus crenata* BLUME
Loc. Nos. 1, 3 (A–1 Formation), 7, 9, 10, 11 (A–2 Formation).
Fig. 12. *Fagus hayatae* PALIB
Loc. 14 (B Formation).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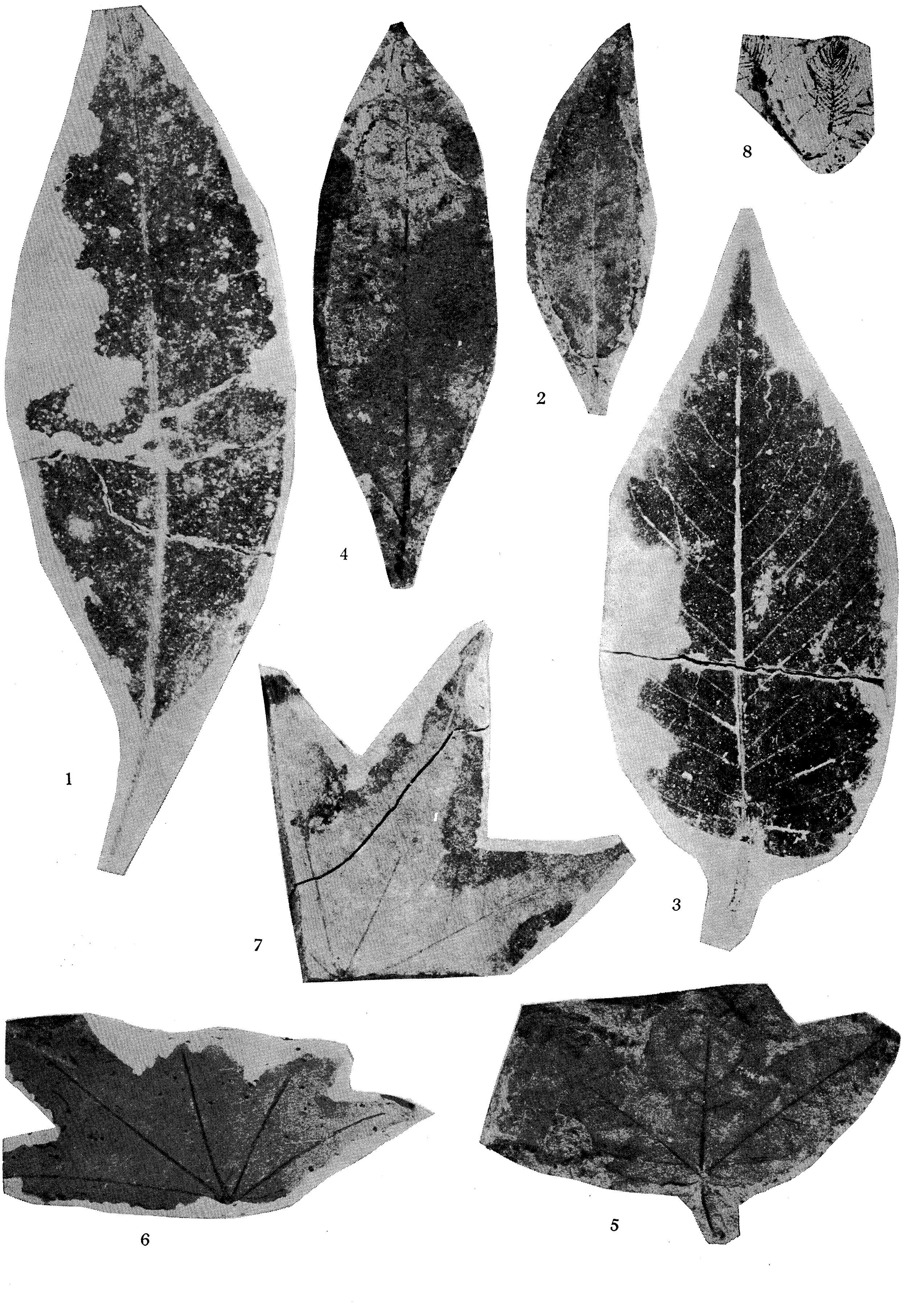
Explanation of Plate 2

(All figures are in natural size unless otherwise stated)

Fig. 1. *Quercus glauca* THUNBERG, ×1.5
Loc. Nos. 12, 13 (B Formation).
Fig. 2. *Zelcova serrata* MAKINO
Loc. Nos. 3 (A–1 Formation), 12, 13 (B Formation).
Fig. 3. *Zelcova serrata* MAKINO, ×1.5
Loc. Nos. 3 (A–1 Formation), 12, 13 (B Formation).
Fig. 4. *Cinnamomum* cf. *lanceolatum* HEER
Loc. No. 1 (A–1 Formation).
Fig. 5. *Liquidambar formosana* HANCE
Loc. Nos. 3 (A–1 Formation), 8 (A–2 Formation)
Fig. 6. *Acer pictum* THUNBERG
Loc. Nos. 3, 6 (A–1 Formation), 11 (A–2 Formation).
Fig. 7. *Acer palmatum* THUNBERG
Loc. Nos. 1, 2 (A–1 Formation), 13 (B Formation).
Fig. 8. *Myriophyllum spicatum* LINNE
Loc. No. 12 (B Formation).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