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Miocene woods of the Janggi Basin in Korea: Implications for paleofloral changes

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ABSTRACT: Eleven taxa of fossil woods – two gymnosperms and nine dicotyledons – were identified from 59 specimens collected from the Lower Coal-bearing Formation of the Janggi Group at Shinjeong-ri in Donghae-myeon, Pohang City, Gyeongsangbuk-do, Korea. One new taxon, *Fraxinus oligocenica*, was discovered and identified for the first time in the Korean Peninsula. Along with the previous study, 25 Miocene wood taxa, in total, have been described from the Lower and Upper Coal-bearing formations of the Janggi Group. A considerable number of specimens of *Wataria* were collected in this study. *Wataria* is an extinct genus of the Sterculiaceae, and the determination of its true identity is an interesting paleobotanical subject. There may be a possibility that the quantity and diversity of *Wataria* spp. was greater in the Korean Peninsula than in the Japanese Archipelago. Thus, we suggested that the Miocene deposits in Pohang City would be better places for elucidating the real identity of *Wataria* than in Japan. Coal-bearing formations in which fossil woods occur intervene between the Geumgwangdong Formation and the Duho Formation in which abundant fossil leaves occur. In the combined fossil-wood and fossil-leaf data from these formations, we found a transition-type flora situated between the well-known Aniai-type and Daijima-type floras in Japan.

Key words: Miocene, fossil woods, Janggi Basin, Pohang area, Korea

1. INTRODUCTION

The Tertiary period (65 to 2.5 Ma) was the time when modern vegetation was widely distributed across the globe. In particular, Far-East Asia is the premier region for studying plant evolution because quite a few primitive plants have continuously grown in this area (Maekawa, 1974). A recent study on fossil woods from the Upper Cretaceous in Japan identified one of the oldest extant vessel-containing dicotyledonous woods in the world (Takahashi and Suzuki, 2003). Thus, researchers have argued that Tertiary fossil plants in the Far-East Asia could provide information necessary for clarifying the evolution and history of vegetation on Earth.

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The Japanese Archipelago was separated from the eastern margin of the Asian continent during the Tertiary, and presumably from the Eocene to the Miocene (Kim, 1992a). Thus, it is appropriate to suggest that both areas – the Korean Peninsula and the Japanese Archipelago – formed common flora, because of their close proximity prior to this separation. However, they have different types of vegetation in the present (Kim, 1992b). This differentiation resulted from distinct floral evolutionary processes driven by different environments, which themselves are partly due to the formation of the East Sea (Japan Sea).

The Japanese Archipelago is one of the ideal regions for the study of Tertiary plants, because there are many well-developed Tertiary basins containing an abundance of well-preserved fossil plants. Thus, after the pioneering work of Nathorst (1883, 1888), a great deal of paleobotanical studies have been undertaken from the 19th century onward. Several important discoveries have been made on the basis of the abundant paleobotanical data already accumulated. The research to date has identified six stages of floral changes that occurred during the Miocene and Pliocene. Among them, the Miocene floral change from the Aniai- to the Daijima-type was the most conspicuous and representative (Tanai, 1961). The Aniai-type Flora was typified by the cool-temperate vegetation that dominated during the Early Miocene, and the Daijima-type Flora was characterized as warm-temperate and subtropical vegetation, which thrived during the Middle Miocene. Thus the Japanese Miocene fossil-plant data are reference points for studies of the Miocene fossil plants from the Korean Peninsula.

There are several Tertiary basins located along the eastern coast of the Korean Peninsula (Kim, 1970). The fossil plants that had previously been discovered in that area were studied from the beginning of the 20th century, mainly by Japanese researchers (Oishi, 1931, 1935; Endo, 1938a, 1938b, 1939, 1943, 1950a, 1950b, 1951; Huzioka, 1943a, 1943b, 1951, 1954, 1955; Tanai, 1952, 1953). Since Hozioka's synthetic study (1972), only a very limited number of studies have been conducted on Korean fossil plants, including fossil wood (Chun, 1982; Ee, 1982; Kim, 2005, 2008; Kim and Choi, 2008). The Mesozoic fossil woods were, quite a long time ago, studied by several Japanese researchers (Shimakura, 1936, 1937; Ogura et al., 1951), but there has been no study on the Tertiary fossil wood found in Korea. Since the mid-1990s, large amounts of dinosaur remains have been found in several successive positions in the Cretaceous strata in South Korea (Yun and Yang, 1997; Paik, 2000; Paik et al., 2001; Huh and Zelenitsky, 2002; Huh et al., 2003). Thus, much attention was paid to the paleontological sites in the Korean Peninsula. This resulted in the resurgence of interest in the fossil woods of the Mesozoic and the Tertiary periods in Korea (Kim et al., 2002, 2005, 2008; Jeong et al., 2003, 2004, 2009). However, unlike in Japan, the fossil-wood data available in Korea is currently quite limited, despite the abundance of fossil woods on the Peninsula. Due to the lack of resources, it is hard to compare fossil-wood assemblages between Japan and Korea. Thus, increasing attention has been focused on the sample collections and taxonomic treatments of Korean fossil woods. Through these surveys, the researchers expect to obtain much more wood taxonomic data and also hope to fill a gap in the relevant general data.

In this study, we attempted to give a short overview of the Pohang wood assemblage and the recently collected assemblages of the Lower Coal-bearing Formation of the Janggi Group in Pohang City, Korea. The wood assemblages of the Lower and Upper Coal-bearing formations were combined as a dataset for a study investigating the floral changes between the lower Geumgwangdong Formation of the Janggi Group and the upper Duho Formation of the Yeonil Group.

2. GEOLOGICAL SETTING

The Tertiary deposits in South Korea occur in small basins scattered along the eastern coast, and the formation of these basins is deemed to be related to the spreading of East Sea (Kim and Kang, 1996; Chang et al., 2007). The Tertiary basins in the southern part of Pohang City have been interpreted as pull-apart basins (Kim and Kang, 1989; Son et al., 2000, 2007); one of these is the Janggi Basin. The geological age measured for extrusive and intrusive rocks in the Janggi Basin ranges from 18.52 Ma to 24.38 Ma (Jin et al., 1989; Yoon, 1992).

The Janggi Basin is composed of continental deposits consisting of alluvial fan, fluvial, and lacustrine deposits (Kim, 1982), but the detailed sedimentology and depositional environments of these deposits have not yet been studied. In addition, the stratigraphy has not been unified due to the complicated lateral facies changes and the interruption of tuffs and intrusive rocks (Tateiwa, 1924; Kim et al., 1975; Yun et al., 1997).

The Lower Coal-bearing Formation is the lower part of the Janggi Group and was first designated by Tateiwa (1924). It is underlain by the Geumgwandong Formation, which has yielded abundant fossil leaves, and is overlain by basaltic tuff. The Lower Coal-bearing Formation reaches 110 m in thickness, and consists of tuffaceous sandstone, lithic tuff, vitric tuff, shale, mudstone, and lignite (Kim et al., 1975). The coal beds are associated with the shales of the lower and middle parts of the formation. The mudstone is partially bentonitic, and the lithic tuff usually bears pumice fragments.

3. MATERIALS AND METHODS

3.1. Materials

Field studies have been conducted several times around Shinjeong-ri in Donghae-myeon in Pohang City, Korea in the period from 2003 to 2008. All 59 fossil woods were collected from the kaolin mines of the Lower Coal-bearing Formation at Shinjeong-ri (Fig. 1).

3.2. Methods

A diamond lapidary saw was used to cut thick sections (wafers) of cross (transverse), tangential, and radial surfaces of the specimens. After one side of each wafer was polished using a lap to remove saw marks, it was affixed to a glass slide using 24-hour transparent epoxy. The sections were then ground until they were thin enough (~30 μm) that anatomical details could be seen by transmitted-light microscopy. Grinding was done either by hand, using a glass plate and a slurry of carborundum grit, or using a petrographic thin-section grinding machine. Cover slips were mounted

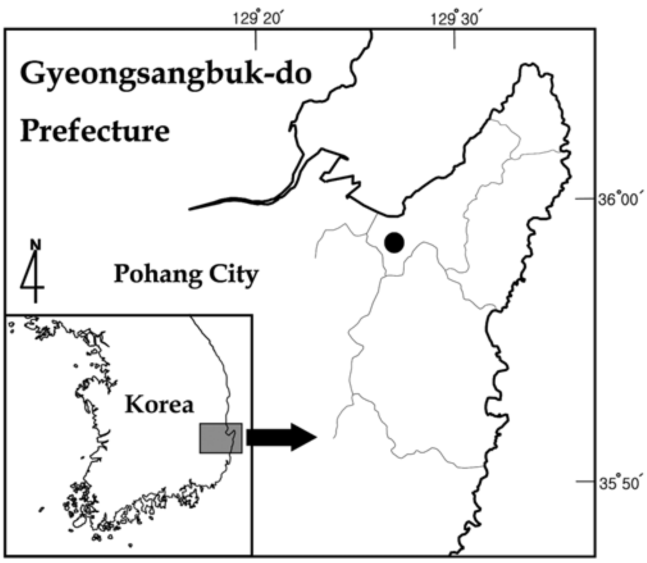

Fig. 1. Map showing collection site (black circle) of the Lower Coal-bearing Formation in Pohang City, Korea.

using Canada Balsam to improve clarity for light microscopy. All samples were deposited in the paleobotanical collections of the Chonbuk National University, Jeonju, Korea.

3.3. Identification of Fossil Woods

The microscope slides of fossil woods under study were examined using an Axiophot light microscope and the wood anatomical features observed and described in order to identify them. Relationships to extant plants were assessed by reference to the collection of wood microscopic slides of the Botanical Garden at Tohoku University, North Carolina State University's InsideWood website (http://insidewood.lib.ncsu.edu/search), the wood database of FFPRI, and many other sources cited in "References".

4. RESULTS

From among the 59 samples, 11 taxa were identified, consisting of two conifers and nine dicotyledons (Table 1). The fossil wood with *Fraxinus* affinity was described here for the first time from the Miocene in Korea. In addition, this data was included in the synthetic data set of the Lower and Upper Coal-bearing formations of the Janggi Group, Pohang, in order to make comparisons between the stratigraphic strata of the Janggi and Pohang Basin (Table 2).

4.1. Brief Description of *Fraxinus* Fossil Wood

Family Oleaceae
Fraxinus oligocenica Suzuki (Fig. 2)
Materials: JNU 21162, 21163, 21164
Locality: Shinjeong-ri, Donghae-myoen, Pohang City, Gyeongsangbuk-do, Korea
Stratigraphic horizon: Lower Coal-bearing Formation
Discussion: These fossil woods have the following six characteristics: 1) ring-porous wood with two to four vessel layers; 2) solitary or radial multiple small vessels with thick walls in latewood; 3) vasicentric axial parenchyma; 4) exclusively simple perforation plates; 5) minute alternate intervessel pits; and 6) two-cell-wide homocellular rays. Based on the above characters, these woods were identified as *Fraxinus* wood.

Table 1. List of fossil wood taxa occurred in the Lower Coal-bearing Formation by this study

Species name	Lower Coal-bearing Formation
1 *Picea* sp.	3
2 *Taxodioxylon* sp.	1
3 *Fagus hondoensis* (Watari) Watari	1
4 *Ulmus* sp.	1
5 *Zelkova* sp.	1
6 *Cercidiphyllum* sp.	1
7 *Acer* sp.	2
8 *Wataria miocenica* (Watari) Terada et Suzuki	5
9 *Wataria parvipora* Terada et Suzuki	9
10 *Wataria* sp.	9
11 *Fraxinus oligocenica* Suzuki	3
Total	36

This is the first description of *Fraxinus* wood in the Miocene of the Korean Peninsula. Almost 11 taxa of *Fraxinus* have been described worldwide and two of these are from Japan (Suzuki, 1982; Suzuki and Watari, 1994). They are usually discriminated from each other by the vessel diameters and layers of earlywood vessels and by seriation of the rays. These fossils have earlywood vessels with a maximum diameter of ~230 μm and almost two cells-wide rays. Thus, this wood is similar *F.* cf. *excelsior* L. (Conwentz, 1882) from the Holocene in Germany and *F. oligocenica* Suzuki (1982) from the Oligocene in Japan. However, in contrast with *F.* cf. *excelsior*, whose layers of earlywood vessels are narrow (one to two layers), our fossil had wider layers, like *F. oligocenica* (two to four layers). Additionally, the age of production was not the Quaternary but Tertiary; thus, it can be identified as *F. oligocenica*.

4.2. Short Notes on Other Fossil Woods which were Described Previously

Most of collected samples could be identified only to the genus level due to their poor preservation, except for two taxa, *Fagus* and *Wataria*.

***Picea* sp.**: Three specimens of kaolin-mine (JNU 21156, 21158, 21166) coniferous woods had vertical and horizontal resin ducts, ray tracheids, and epithelial cells with thick walls. These features indicate that they are woods with *Picea* affinity. However, detailed features for species identification, such as cross-field pits and helical thickenings in the tracheids, could not be seen. Therefore, they could be identified only to genus.

Three taxa of *Picea* woods have been described from the Lower Miocene of Yamagata and Iwate Prefectures in Japan and one from the Upper Coal-bearing Formation of the Janggi Group, Korea (Suzuki, 1982; Suzuki and Terada, 1996; Jeong et al., 2004).

***Taxodioxylon* sp.**: One specimen (JNU 21179) was also coniferous wood with axial parenchyma cells and taxodioid cross-field pits. However, the number and aperture size of the cross-field pits were not clear due to poor sample preservation. This fossil could be also identified only to genus level, as a *Taxodioxylon* sp.

Two taxa, *T. cunninghamioides* (Watari) Watari and *T. sequoianum* (Mercklin) Gothan, have been reported from the Miocene of Japan and the Upper Coal-bearing Formation of the Janggi Group, Korea (Watari, 1948a; Suzuki and

Table 2. Synthetic list of fossil woods from the Miocene of Korea

No.	Families	Species	Lower Coal-bearing Formation	Upper Coal-bearing Formation	Habit[1)]	Habitat[2)]	Living equivalent	Total
1	Pinaceae	*Abies* sp.	1		C	C	*Abies*	1
2		*Picea palaeomaximowiczii*		4	C	C	*Picea maximowiczii*	4
3		*Picea* sp.	3		C	C	*Picea*	3
4	Taxodiaceae	*Taxodioxylon cunninghamioides*		3	C	C–W	*Cunninghamia lanceolata*	3
5		*Taxodioxylon sequoianum*		1	C	C–W	*Metasequoia glyptostroboides*	1
6		*Taxodioxylon* sp.	1		C	C–W	*Metasequoia*	1
7	Juglandaceae	*Carya koreana*	1		D	C–W	*Carya catheyensis*	1
8	Betulaceae	*Betula hanenisiensis*	5		D	C	*Betula schimidtii*	5
9		*Betula janggiensis*	6		D	C	*Betula*	6
10		*Carpinus donghaensis*	1		D	C–W	*Carpinus*	1
11		*Carpinus* sp.	1		D	C–W	*Carpinus*	1
12		*Ostrya geumgwangensis*	1		D	C–W	*Ostrya*	1
13	Fagaceae	*Fagus hondoensis*	2	4	D	C–W	*Fagus crenata*	6
14	Ulmaceae	*Ulmus crystallophora*	1		D	C–W	*Ulmus davidiana*	1
15		*Ulmus* sp.	3		D	C–W	*Ulmus*	3
16		*Zelkova wakimizui*	2		D	C–W	*Zelkova serrata*	2
17		*Zelkova* sp.	1		D	C–W	*Zelkova*	1
18	Cercidiphyllaceae	*Cercidiphyllum* sp.	1	1	D	C–W	*Cercidiphyllum japonicum*	2
19	Theaceae	*Camellia japonoxyla*		1	E	W	*Camellia japonica*	1
20		*Stewartia pseudocamellioxylon*	2		D	C	*Stewartia pseudocamellia*	2
21	Hamamelidaceae	*Distylium chiharu-hirayae*		1	E	W	*Distylium racemosum*	1
22	Rosaceae	*Prunus densiporousum*	1		D	C–W	*Prunus*	1
23	Meliaceae	*Cedreloxylon palaeokoreana*		1	D	W	*Toona sinensis*	1
24	Aceraceae	*Acer minokamoensis*	2		D	C–W	*Acer*	2
25		*Acer momijiyamense*	1		D	C–W	*Acer tschonoskii*	1
26		*Acer pohangensis*	1		D	C–W	*Acer*	1
27		*Acer* sp.	4		D	C–W	*Acer*	4
28	Hippocastanaceae	*Aesculus* sp.		2	D	W	*Aesculus trubinata*	2
29	Sterculiaceae	*Wataria miocenica*	18	2	?	W?	*Triplochiton*	20
30		*Wataria parvipora*	15	3	?	W?	*Triplochiton*	18
31		*Wararia* sp.	9		?	W?	*Triplochiton*	9
32	Oleaceae	*Fraxinus oligocenica*	3		D	C–W	*Fraxinus japonicum*	3
Total			86	23				109

Watari, 1994; Suzuki and Terada, 1996; Jeong et al., 2004). *Taxodioxylon* is one of the most common Miocene woods in Japan. *T. sequoianum*, in particular, is thought to have affinity with extant *Sequoia* or *Metasequoia* species (Suzuki and Watari, 1994).

Fagus hondoensis (Watari) Watari: One specimen (JNU 21159) was a diffuse, porous wood with small vessels, simple and scalariform perforation plates with about ten bars, and heterocellular rays with one- to twenty-seriate width, and crystal-bearing ray cells. We identified it as *Fagus hondoensis* based on the above features.

F. hondoensis was established by Watari (1941, 1952) based on specimens from the Iwate Prefecture in Japan. In addition, this species was reported from the Gifu Prefecture in Japan (Terada, 1998) and the Lower and Upper Coal-bearing formations of the Janggi group in Korea (Jeong et al., 2004, 2009).

***Ulmus* sp.**: One specimen (JNU 21103) was ulmaceous wood which showed ring porosity, clustered latewood vessels, homocellular rays, and helical thickening in small vessels. However, specific identification was impossible due to the poor preservation.

Two taxa, *U. crystallophora* Watari and *U. hachiyaensis* Terada et Suzuki, have been described in the Miocene of Japan and Korea. The former was described in the Lower Coal-bearing Formation of the Janggi Group (Jeong et al., 2009) in Korea and Fukushima, Akita, Ishikawa, Gifu and Hokkaido Prefecture in Japan (Watari, 1952; Terada, 1998), but the latter only in Japan (Terada, 1998).

***Zelkova* sp.**: One specimen (JNU 21178) was wood which

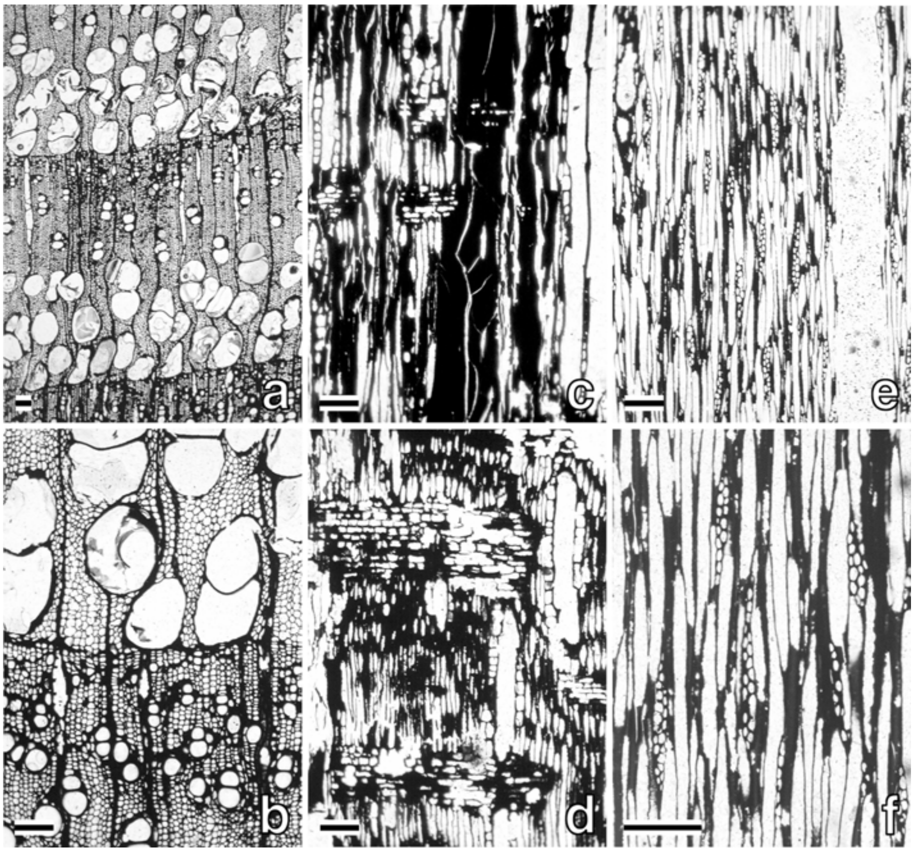

Fig. 2. Photomicrographs of *Fraxinus oligocenica* Suzuki. a–b: Transverse sections showing ring-porous wood and distinct growth rings, radial multiple of two to four small vessels, and vasicentric axial parenchyma; c–d: Radial sections showing simple perforation plates and homocellular rays; e–f: Tangential sections showing one to three cells wide homocellular rays. (scale bars = 100 μm)

showed characteristics of *Zelkova* affinity such as ring porosity, clustered latewood vessels arranged in tangential wavy bands, and helical thickening in small vessels. However, again because of the poor preservation, it was impossible to determine whether gum material was present in the vessel lumens or not, which is a diagnostic character for specific identification.

Two fossil taxa have been previously described in this genus, *Z. wakimizui* (Watari) Watari and *Z. zelkoviformis* (Watari) Watari, the former from the Lower Coal-bearing Formation of the Janggi Group (Jeong et al., 2009) in Korea and Shimane, Iahikawa Prefecture in Japan (Watari, 1948b, 1952; Suzuki and Hiraya, 1989; Suzuki and Terada, 1996), but the latter only from Iwate Prefecture in Japan (Watari, 1952).

***Cercidiphyllum* sp.**: One specimen (JNU 21157) was identified as *Cercidiphyllum* wood based on the diffuse-porous wood with a dense distribution of small vessels, scalariform perforation plates, narrow rays, and scalariform pits between the vessels and rays. However, more detailed features were not preserved, which are essential for specific identification.

Five taxa of fossil woods with *Cercidiphyllum* affinity have been described worldwide; *Cercidiphylloxylon kadanense* Prakash, Brezinova et Buzek, *Cercidiphlloxylon spenceri* (Brett) Pearson, *Cercidiphyllum alalongum* Scott et Wheeler, *Cercidiphyllum spencer* Brett, and *Cercidiphyllum mioxylum* Terada et Suzuki (Brett, 1956; Pearson, 1987; Prakash et al., 1971; Scott and Wheeler, 1982; Terada, 1998). Among these, the same type of *Cercidiphyllum mioxylum* wood was described in the Upper Coal-bearing Formation in Korea (Jeong et al., 2004) and the Gifu Prefecture in Japan (Terada, 1998). Modern *Cercidiphyllum* is an endemic plant in eastern Asia and two species inhabit China and Japan; *C. japonicum* Siebold et Zuccarini is a tree and *C. magnificum* Nakai is a small shrub-like tree.

***Acer* sp.**: Diverse Miocene woods with *Acer* affinity have been described in Korea, North America, Madagascar, Europe, and Japan (Watari, 1952; Prakash and Barghoorn, 1961; Suzuki, 1982; Takahashi and Suzuki, 1988; Terada, 1998; Wheeler and Manchester, 2002; Kim et al., 2008; Jeong et al., 2009). Three taxa, including two new species, have been described in the Lower Coal-bearing Formation of the Janggi Group in Korea (Jeong et al., 2009).

***Wataria miocenica* (Watari) Terada et Suzuki, *W. parvipora* Terada et Suzuki and *Wataria* sp.**: These 23 fossil wood specimens were characterized by 1) distinct ring-porous wood with wide vessels in earlywood, 2) narrow solitary vessels in latewood, 3) exclusively simple perforation plates, 4) uni- and biseriate tangential bands of apotracheal and 1–3-seriate vasicentric paratracheal axial parenchyma, 5) the presence of tile cells in rays, 6) ~10-seriate heterocellular multiseriate rays, and 7) alternate and dense vessel-ray pits. The above characteristics mirror the features of the genus *Wataria*. Nine of them were identified as *W. parvipora* and five of as *W. miocenica*; the other ten were identified only to the genus level (Table 1).

The genus *Wataria* was established by Terada and Suzuki (1998) as an extinct sterculiacean genus. They classified the Miocene genus *Wataria* into two species, *W. miocenica* and *W. parvipora*, based on differences in vessel diameter. *Wataria miocenica* has been reported from Yamagata and Ishikawa Prefectures (Watari, 1952; Suzuki and Watari, 1994; Terada and Suzuki, 1998) in Japan and the Lower and Upper Coal-bearing formations of the Janggi Group in Korea (Jeong et al., 2003, 2004, 2009; Kim et al., 2008). *Wataria parvipora* has been reported from the Gifu Prefecture in Japan (Terada and Suzuki, 1998) and the Lower and Upper Coal-bearing formations of the Janggi Group in Korea (Jeong et al., 2003, 2004, 2009).

As a result, 11 taxa were found in this study from the Lower Coal-bearing Formation of the Janggi Group, Korea. Combining the previous data from the Lower and Upper Coal-bearing formations (Jeong et al., 2003, 2004, 2009; Kim et al., 2008) with this set gives a total of 25 Miocene wood taxa found in these formations of the Janggi Group (Table 2).

5. DISCUSSION

Among the 11 taxa described in this study, four of them were identified to the species level – two gymnosperms and nine dicotyledons – including one taxa, *Fraxinus oligocenica,* which had not been previously reported in Korea (Table 1). Based on the previous studies (Jeong et al., 2009; Kim et al., 2008), 17 wood taxa have been described in the Lower Coal-bearing Formation. As 11 taxa were previously described in a study of the Upper Coal-bearing Formation (Jeong et al., 2004), in total, 25 taxa have been described from the Janggi Group (Table 2).

Only three genera, *Fagus, Cercidiphyllum* and *Wataria*, were found in both of these formations (Table 2). Thus, it can be surmised that the paleovegetation of the formations differed substantially; in other words, the vegetation in this area changed over time. Additionally, *Fagus* is not currently found on the Korean Peninsula except on Ulleungdo Island in East Sea (Japan Sea), and *Wataria* is an extinct sterculian tree. *Cercidiphyllum*, in particular, is a genus native to Japan. However, they clearly flourished in the Korean Peninsula for quite a long time during the Miocene.

A considerable number of specimens of fossil wood of *Wataria* were collected from the kaolin mine at Shinjeong-ri for this study (nine of *W. parvipora*, five of *W. miocenica*, and nine of *Wataria* sp.; see Table 1). The genus *Wataria* was established on basis of the fossil wood of Japan and regarded as an extinct genus of the Sterculiaceae. Its true identity is not yet certain; thus, determining the nature of this problematic taxon is a very interesting subject from the viewpoint of paleobotany. Three taxa of *Wataria* have been described in Korea and Japan. *Wataria oligocenica* (Suzuki) Terada et Suzuki is from the Oligocene of Kyushu, Japan (Suzuki, 1976; Terada and Suzuki, 1998) and other two species, *W. miocenica* and *W. parvipora*, are from the Miocene in Japan (Terada and Suzuki, 1998) and Korea (Jeong et al., 2003, 2004, 2009). The Sterculiaceae are now distributed principally in tropical areas. Among the extant sterculian genera, only some species of *Reevesia, Firmiana*, and *Veeresia* show ring porosity, whereas many other genera distributed throughout tropical and subtropical regions evidence diffuse porosity. Ring porosity is generally considered to be the result of adaptation to a temperate climate with winter dormancy, because species with ring porosity are distributed throughout the warm-temperate regions of East Asia and Mexico (Terada and Suzuki, 1998). The *Wataria* evidence distinct ring porosity, which is regarded as a consequence of adaptation to the cool-temperate climate of the Oligocene, and the *Wataria* appear to have extended their distribution during the Miocene. Based on the similarity of the wood structure to *Firmiana simplex, Wataria* is regarded here as a deciduous tree that is reflective of a warm-temperate climate.

The *Wataria* occurred in both the Lower and Upper Coal-bearing formations and more commonly in the former (a 42:5 ratio) in Korea. The two Miocene taxa, *W. miocenica* and *W. pavipora*, do not occur together in the same strata in Japan (Terada and Suzuki, 1998). However, they do occur together in the same strata of the Lower and Upper Coal-bearing formations (from the kaolin mine). The quantity of *Wataria* in Korea is larger than that in Japan (by over 30%). Thus, it can be suggested that the Miocene deposits in Pohang City would be better places for elucidating the real identity of *Wataria* than in Japan. The climate in East Asia changed from subtropical to warm-temperate, and was then cool-temperate with several oscillations during the Tertiary age (Bloom, 1998). The occurrence of *Wataria* in the Lower and Upper Coal-bearing formations in the Pohang area may be indicative of a basically warm-temperate climate during the Early Miocene with subsequent alteration to a cooler climate with cooler elements in the later stages (late Early Miocene).

The genus *Fagus* is a common fossil in the Tertiary in the Northern Hemisphere. Various fossil *Fagus* types have occurred abundantly and constantly in all the Miocene formations in Korea and Japan. Two species of *Fagus* woods have been described in Japan, in Iwate Prefecture and Gifu Prefecture (Watari, 1952; Terada, 1998). Strangely, *Fagus* wood does not occur in the western Miocene deposits in Japan, such as the western coast of Yamagata Prefecture and the Noto Peninsula. At present, *Fagus* does not inhabit the mainland of the Korean Peninsula, with the exception of Ulleungdo Island in the East Sea (Japan Sea). However,

Table 3. Comparison of fossil leaves and woods from the Janggi and Pohang Basin by stratigraphic orders and their porosity

Families	Species	Janggi Group			Yeonil Group	Porosity[a]
		Geumgwangdong F.	Lower Coal-bearing F.	Upper Coal-bearing F.	Duho F.	
		Fossil leaves	Fossil woods	Fossil woods	Fossil leaves	
Salicaceae	*Salix parasachalinensis*	+				Di
Juglandaceae	*Platycarya miocenica*	+				Ri
	Carya koreana		+			Ri
	Pterocarya asymmetrosa	+			+	Di
Betulaceae	*Betula hommashinichii*	+				Di
	Betula sekiensis	+				Di
	Betula shiragica	+				Di
	Betula hanenishiensis		+			Di
	Betula janggiensis		+			Di
	Carpinus hokoensis				+	Di
	Carpinus donghaensis		+			Di
	Carpinus simplicibracteata	+				Di
	Carpinus stenophylla	+			+	Di
	Carpinus subcordata	+			+	Di
	Carpinus subyedoensis	+				Di
	Carpinus sp.		+			Di
	Ostrya shiragiana	+				Di
	Ostrya geumgwangensis		+			Di
Fagaceae	*Castanea tanaii*				+	Ri
	Fagus antipofi	+				Di
	Fagus hondoensis		+	+		Di
	Fagus cfr.hayatae				+	Di
	Castanopsis pohangensis				+	Ra
	Cyclobalanopsis huziokai				+	Ra
	Cyclobalanopsis mandraliscae				+	Ra
	Cyclobalanopsis yabei				+	Ra
	Pasania miohypophaea				+	Ra
	Psania protokonishii				+	Ra
	Quercus miocrispula	+				Ri
Ulmaceae	*Ulmus shiragica*	+				Ri
	Ulmus crystallophora		+			Ri
	Ulmus sp.		+			Ri
	Zelkova ungeri	+			+	Ri
	Zelkova wakimizui		+			Ri
	Zelkova sp.		+			Ri
Saxifragaceae	*Hydrangea miobretschneideri*	+				Di
Cercidiphyllaceae	*Cercidiphyllum* sp.		+	+		Di
Theaceae	*Camellia japonoxyla*			+		Di
	Stewartia pseudocamellioxylon		+			Di
Hamamelidaceae	*Distylium chiharu-hirayae*			+		Di
	Liquidambar miosinica				+	Di
	Parrotia fagifolia				+	Di
Platanaceae	*Platanus guillelmae*				+	Di
Magnoliaceae	*Magnolia nipponica*	+				Di
	Magnolia miocenica	+				Di
Lauraceae	*Cinnamomum lanceolatum*				+	Di
	Cryptocarya ennichiensis				+	Di
	Lindera gaudini				+	Di
	Phoebe mioformosana				+	Di

[a]Di = diffuse-porous wood, Ri = ring-porous wood, Ra = radial-porous wood.

Table 3. (continued)

Families	Species	Janggi Group			Yeonil Group	Porosity[a]
		Geumgwangdong F.	Lower Coal-bearing F.	Upper Coal-bearing F.	Duho F.	
		Fossil leaves	Fossil woods	Fossil woods	Fossil leaves	
Rosaceae	*Sorbus protoalnifolia*	+				Di
	Sorbus uzenensis	+				Di
	Prunus densiporousum		+			Di
Leguminosae	*Cladrastics aniensis*	+				Ri
	Entada mioformosana				+	Di
Meliaceae	*Cedreloxylon palaeokoreana*			+		Ri
Anacardiaceae	*Rhus inouei*	+				Ri
Aceraceae	*Acer ezoanum*	+				Di
	Acer fatisiaefolium	+				Di
	Acer nordenskioldi	+			+	Di
	Acer rotundatum	+				Di
	Acer subpictum	+			+	Di
	Acer prototrifidium				+	Di
	Acer minokamoensis		+			Di
	Acer momijiyamense		+			Di
	Acer pohangensis		+			Di
	Acer sp.		+			Di
Hippocastanaceae	*Aesculus majus*	+				Di
	Aesculus sp.			+		Di
Sapindaceae	*Sapindus kaneharai*	+				Ri
Rhamnaceae	*Paliurus koreanus*				+	Di
Tiliaceae	*Tilia remotiserrata*	+				Di
Alangiaceae	*Alangium aequalifolium*	+			+	Di
Trapellaceae	*Hemitrapa yokoyamae*				+	-
Ericaceae	*Rhododendron tatewakii*	+			+	Di
Sterculiaceae	*Wataria miocenica*		+	+		Ri
	Wataria parvipora		+	+		Ri
	Wataria sp.		+			Ri
Cornaceae	*Cornus minoensis*	+				Di
Ebenaceae	*Diospyros miokaki*	+				Di
Oleaceae	*Fraxinus tateiwae*	+				Ri
	Fraxinus insularis				+	Ri
	Fraxinus oligocenica		+			Ri
Caprifoliaceae	*Vibrunum uzenensis*	+				Di

[a]Di = diffuse-porous wood, Ri = ring-porous wood, Ra = radial-porous wood.

Fagus is one of the dominant trees in the Japanese Archipelago now. This means that *Fagus* flourished in Korea and Japan during the Miocene, but was later extinct on the Korean Peninsula. Additionally *Fagus* is more common in the Upper than Lower Coal-bearing formations (a 2:4 ratio). As the genus *Fagus* is one of the representative oceanic-type trees (Kim, 1992b, 2006), this may be indicative of a gradual change of Korean flora into the oceanic-type. It can be also suggested that the flora of the Korean Peninsula was of the oceanic-type, similarly to current flora in Japan. It then changed into a kind of continental-type flora, like the current type, owing primarily to the formation of the East Sea (Japan Sea).

As previously mentioned, abundant fossil plants, primarily compressed leaves and seeds, occur in the Miocene deposits of the Japanese Archipelago. They have been studied from the beginning of the 19th century onward (Nathorst, 1883, 1888; Kryshtofovich, 1920) and six stages of floral change during the Miocene have been elucidated thus far (Tanai, 1961). Among them, there are two representative major floral types: the Aniai-type Flora and the Daijima-type Flora (Tanai, 1961). The Aniai-type Flora flourished during the Early Miocene. This flora consisted principally of deciduous trees that inhabited cool-temperate regions. Representative taxa included the Betulaceae, Ulmaceae, and Aceraceae. In particular, Betulaceae such as *Betula*, *Carpinus*, *Corylus*, and *Ostrya* were the most representative taxa. The Daijima-type Flora flourished during the Middle Miocene and consisted principally of evergreen trees that inhabited warm-temperate and subtropical regions. The representative taxa included the Fagaceae, Juglandaceae, Hamamelidaceae, Lauraceae, Leguminosae, and Aceraceae with the Fagaceae the most dominant taxa among them. Their living equivalents are more southern elements (Tanai, 1961). These floral changes have been suggested to reflect climatic changes occurring in northeastern Asia, centered on the Korean Peninsula and the Japanese Archipelago.

The compressed and imprint-fossil plants from the Janggi and Pohang Basins were studied by several Japanese researchers and synthesized into 44 and 35 leaf or seed fossils, respectively, by Huzioka (1972); he compared the Janggi and Yeonil (Pohang) floras with the Aniai-type and Daijima-type floras of Japan, respectively. According to the previous studies of fossil woods, the fossil-wood assemblage of the Lower Coal-bearing Formation could be compared with the Aniai-type Flora (Kim et al., 2008; Jeong et al., 2009). However, the fossil wood assemblage of the Upper Coal-bearing Formation differs from that of the Lower Coal-bearing Formations and features some elements of warm-temperate and subtropical vegetation like *Taxodioxylon cunninghamioides*, including evergreen genera like *Camellia* and *Distylium* (Jeong et al., 2004). Thus, the fossil-wood assemblage of the Upper Coal-bearing Formation appears to be similar to the Daijima-type Flora that flourished in Japan during the Middle Miocene. However, this similarity is complicated by the fact that this fossil-wood assemblage does not harbor the typical Daijiman elements, most notably evergreen Fagaceae and Lauraceae components. Rather, based on the co-occurrence of cool-temperate elements such as *Picea* and *Fagus*, this wood assemblage might more appropriately be regarded as the transition-type flora between the Aniai-type and Daijima-type floras. This transition-type flora was shown more clearly when we compared it with whole fossil plants of basins in Pohang City (Table 3). Thus, we suggest the existence of a transition-type flora between the Aniai- and Daijima-type floras in Pohang, Korea.

It has been known for some time that wood anatomy can reveal environmental factors such as latitude, altitude, temperature, precipitation, seasonality, etc. in the habitat in which the wood grew (Bass, 1986; Carlquist, 1988). Among the anatomical factors relevant to environmental conditions, the porosity of the wood is the most pivotal. Specifically, trees that grow in lowland moist tropic zones tend to have diffuse porous wood with wide vessels (>200 μm). Conversely, wood growing in the seasonal climates of the Northern Hemisphere tends to evidence ring porosity with pore zones characterized by wide earlywood vessels (Bass et al., 2004), but this is not observed in wood extending into high latitudes with short growing seasons and extreme cold (Woodcock and Ignas, 1994). Fossil plants evidencing ring porosity tend to decrease from the Geumgwangdong Formation to the Duho Formation (Table 4). This trend is also considered indica-

Table 4. Comparison of compositional features between fossil bearing formations of Pohang, Korea

	Geumgwangdong Formation	Lower Coal-bearing Formation	Upper Coal-bearing Formation	Duho Formation
	(Fossil leaves)	(Fossil woods)	(Fossil woods)	(Fossil leaves)
Taxa composition	25 families	12 families	9 families	17 families
	44 species	20 species	11 species	35 species
Gymnosperms	11% (5 species)	15% (3 species)	27% (3 species)	9% (3 species)
Dicotyledons	36 species	27 species	8 species	30 species
	Evergreen ------ 0%	Evergreen ------ 0%	Evergreen --- 25%	Evergreen --- 33%
	Deciduous --- 100%	Deciduous --- 100%	Deciduous --- 75%	Deciduous --- 67%
Porosity	Diffuse --- 78%	Diffuse --- 65%	Diffuse --- 62%	Diffuse --- 91%
	Ring ------ 22%	Ring ------ 35%	Ring ------ 38%	Ring -------- 9%
	(8 species)	(6 species)	(3 species)	(3 species)
Diverse group	Betulaceae	Betulaceae	Taxoidaceae	Fagaceae
	(3 genera 8 species)	(3 genera 4 species)	Fagaceae (no evergreen)	(5 genera 8 species)
	Aceraceae	Aceraceae		Lauraceae
	(1 genus 5 species)	(1 genus 3 species)		(4 genera 4 species)
Dominant taxa	*Fagus antipofi*	*Betula, Acer*	*Fagus, Picea*	*Cyclobalanopsis* and Lauraceae
Floral type	Aniai-type Flora	Aniai-type Flora	Transition-type Flora	Daijima-type Flora
Remark	Dicot are all deciduous, and diverse in betulaceous species	Dicots are all deciduous, and diverse in Betulaceae and Aceraceae	Evergreen and deciduous dicots, but no evergeen Fagaceae	Evergeen fagaceous and lauraceous trees are common and diverse

tive of a gradual change from a seasonal cool-temperate climate to a warm subtropical climate in the Pohang area during the Miocene.

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REFERENCES

Bass, P., 1986, Ecological patterns of xylem anatomy. In: Givnish, T.J. (ed.), On the economy of plant form and function. Cambridge University Press, Cambridge, p. 327–352.

Bass, P., Ewers, F.W., Davis, S.D. and Wheeler, E.A., 2004, Evolution of xylem physiology. In: Poole, I. and Hemsley, A.R. (eds.), The Evolution of Plant Physiology: From Whole Plants to Ecosystems (Linnean Society Symposium Series 21). Academic Press, London. p. 273–296.

Bloom, A.L., 1998, Geomorphology: A Systematic Analysis of Late Cenozoic Landforms. Prentice-Hall, New Jersey, 482 p.

Brett, D.W., 1956, Fossil wood of *Cercidiphyllum* Sieb. & Zucc. from the London Clay. Annals and Magazine of Natural History, 9, 657–65.

Carlquist, S., 1988, Comparative wood anatomy. Systematic, ecological, and evolutionary aspects of dicotyledon wood. Springer-Verlag, Berlin, 418 p.

Chang, T.W., Jeong, J.H. and Chang, C.J., 2007, Tectonics of the Tertiary Eoil and Waeup basins in the southeastern part of Korea. The Journal of Engineering Geology, 17, 27–40. (in Korean with English abstract)

Chun, H.Y., 1982, Plant fossils from the Tertiary Pohang sedimentary basin, Korea. Korea Institute of Energy and Resources, Report of Geosciences and Mineral Resources, 14, 7–24. (in Korean with English abstract)

Conwentz, H., 1882, Fossile Hölzer aus des Sammlung der Königlichen geologischen Landesanstalt zu Berlin. Jahrbüch für Königlich Geologie Landesanst, 1881, 144–171. (in Germany)

Ee, I.H., 1982, A study on the Neogene Tertiary Yeonil plant fossils from Pohang formation, Korea. M.S. thesis, Kyungbuk National University, Daegu, Korea, 53 p. (in Korean with English abstract)

Endo, S., 1938a, Cenozoic Plants from Tyosen (Korea) I. Journal of the Geological Society of Japan, 45, 85–90. (in Japanese with English abstract)

Endo, S., 1938b, Cenozoic Plants from Tyosen (Korea) II, Journal of the Geological Society of Japan, 45, 326–328. (in Japanese with English abstract)

Endo, S., 1939, Some new and interesting Miocene plants from Tyosen (Korea). The Jubilee Publication in the Commemoration of Prof. Yabe's 60th Birthday, 1, 339–349, Pl. 23.

Endo, S., 1943, On the fossil *Cedrela* from the Kyusin coal mine, Kankyo-hokudo, Tyosen (Korea). Journal of the Geological Society of Japan, 50, 225–256. (in Japanese with English abstract)

Endo, S., 1950a, On the fossil *Acer* from Japan, Korea and South Manchuria, I. Short Paper, IGPS, 1, 11–17, Pl. 3.

Endo, S., 1950b, On the fossil *Carpinus* from Japan and Korea. Short Paper, IGPS, 2, 51–57, Pl. 6.

Endo, S., 1951, On the fossil *Acer* from Japan, Korea and South Manchuria, II. Short Paper, IGPS, 3, 52–58.

Huh, M. and Zelenitsky, D.K., 2002, Rich Dinosaur nesting site from the Cretaceous of Bosung County, Chullanam-do Province, South Korea. Journal of Vertebrate Paleontology, 22, 716–718.

Huh, M., Hwang, K.G., Paik, I.S., Chung, C.H., and Kim, B.S., 2003, Dinosaur tracks from the Cretaceous of South Korea: distribution, occurrence and paleobiological significance. The Island Arc, 12, 132–144.

Huzioka, K., 1943a, Notes on some Tertiary plants from Tyosen, I. Journal of the Faculty Science, Hokkaido Imperial University, Series 4, 7, 117–141.

Huzioka, K., 1943b, On some fossil involucre of *Ostrya* and *Carpinus* from the Miocene deposits of Hokkaido and Tyosen. Journal of the Geological Society of Japan, 50, 317–325. (in Japanese with English abstract)

Huzioka, K., 1951, Notes on some Tertiary plants from Tyosen, II. Transactions and Proceedings from the Palaeontological Society of Japan, 3, 67–74.

Huzioka, K., 1954, Notes on some Tertiary plants from Tyosen, III. Transactions and Proceedings from the Palaeontological Society of Japan, 13, 117–123.

Huzioka, K., 1955, Notes on some Tertiary plants from Tyosen, IV. Transactions and Proceedings from the Palaeontological Society of Japan, 15, 195–200.

Huzioka, K., 1972, The Tertiary flora of Korea. Journal of Mining College of Akita University Series A, 5, 1–83, pls. 1–14.

Jeong, E.K., Kim, K., Kim, J.H., and Suzuki, M., 2003, Comparison of Korean and Japanese Tertiary fossil wood floras with special references to the genus *Wataria*. Geosciences Journal, 7, 157–161.

Jeong, E.K., Kim, K., Kim, J.H., and Suzuki, M., 2004, Fossil woods from Janggi Group (Early Miocene) in Pohang Basin, Korea. Journal of Plant Research, 117, 183–189.

Jeong, E.K., Kim, K., Suzuki, M., and Kim, J.W., 2009, Fossil woods from the Lower Coal-bearing Formation of the Janggi Group (Early Miocene) in the Pohang Basin, Korea. Review of Paleobotany and Palynology, 153, 124–138.

Jin, M.S., Kim, S.Y., Seo, H.H., and Kim, S.J., 1989, K-Ar whole rock ages of the Rhyolitic rocks at Punggog in the Jangseong sheet, Taebaegsan area. Journal of Korean Institute of Mining and Geology, 22, 17–20.

Kim, B.K., 1970, A study on the Neogene Tertiary deposits in Korea. Journal of the Geological Society of Korea, 6, 77–96. (in Korean with English abstract)

Kim, B.K., Cheong, C.H., and Kim, S.J., 1975, Stratigraphic Studies on the Lignite-bearing Strata Distributed in the Yeongil District, North Gyeongsang-Do, Korea. Journal of the Geological Society of Korea, 11, 187–214.

Kim, I.S., 1992a, Origin and Tectonic Evolution of the East Sea (Sea of Japan) and the Yangsan fault system: A new synthetic interpretation. Journal of the Geological Society of Korea, 28, 84–109. (in Korean with English abstract)

Kim, I.S. and Kang, H.C., 1989, Palaeomagnetism of Tertiary Rocks in the Eoil Basin and its Vicinities, Southeast Korea. Journal of the Geological Society of Korea, 25, 273–293.

Kim, I.S. and Kang, H.C., 1996, Palaeomagnetism of Tertiary Basin in Southern Korea: 1. Changgi Basin. Economic and Environmental Geology, 29, 357–367. (in Korean with English abstract)

Kim, J.H., 2005, Fossil *Albizia* Legume (Mimosacceae) from the Miocene Duho Formation of the Yeonil Group in the Pohang Area, Korea. Journal of the Korean Earth Science Society, 26, 166–171.

Kim, J.H., 2008, A new species of *Acer* samaras from the Miocene Yeonil Group in the Pohang Basin, Korea. Geosciences Journal, 12, 331–336.

Kim, J.H. and Choi, S.I., 2008, Discussion on the *Metasequoia* fossils from the Keumkwandong Formation of the Janggi Group, Korea. Journal of the Korean Earth Science Society, 29, 319–327. (in Korean with English abstract)

Kim, J.W., 1992b, Vegetation of Northeast Asia, on the syntaxonomy and syngeography of the oak and beech forests. Ph.D. thesis, Vienna University, Vienna, 314 p.

Kim, J.W., 2006, Vegetation Ecology. World Science, Seoul, 340 p. (in Korean)

Kim, J.Y., 1982, Sedimentary petrology of the Tertiary sandstones in the Janggi area, Southern part of the Pohang Basin, Gyeongbuk, Korea. Ph.D. thesis, Seoul National University, Seoul, 80 p. (in Korean)

Kim, K., Jeong, E.K., Sun, B.Y., and Lee, J.D., 2008, New record of fossil woods from the Janggi Group in Pohang, Korea. Journal of the Paleontological Society of Korea, 24, 135–147. (in Korean with English abstract)

Kim, K., Jeong, E.K., Suzuki, M., Huh, M., and Paik, I.S., 2002, Some coniferous fossil woods from the Cretaceous of Korea. Geosciences Journal, 6, 131–140.

Kim, K., Jeong, E.K., Kim, J.H., Paek, S.D., Suzuki, M., and Philippe, M., 2005, Coniferous fossil woods from Jogyeri Formation (Upper Triassic) of the Nampo Group, Korea. IAWA Journal, 26, 253–265.

Kryshtofovich, A.N., 1920, A new fossil palm and some other plants of the Tertiary flora of Japan. Journal of the Geological Society of Japan, 27, 120, pls. 13–15.

Maekawa, F., 1974, Origin and characteristics of Japan's flora. In: Numata, M. (ed.), The Flora and Vegetation of Japan. Kodansha, Tokyo, p. 33–85.

Nathorst, A.G., 1883, Contribution à la flore fossile du Japon. Kungliga Svenska Vetenskapsakademiens Handlingar, 20, 3–92, pls. 1–16. (in French)

Nathorst, A.G., 1888, Zur fossilen Flora Japan's. Palaontologische Abhandlungen, 4, 197–250, pls. 17–30. (in Swedish)

Ogura, Y., Kobayashi, T., and Maeda, S., 1951, Discovery of erect stumps of *Xenoxylon latiporosum* in the Jurassic Tetori Series in Japan. Transactions and Proceedings from the Palaeontological Society of Japan, New Series, 4, 113–119.

Oishi, S., 1931, A note on *Pecopteris orientalis* (Schenk) from the *Gigantopteris*-Bed of Chikando, Korea. Science reports of the Tohoku Imperial University, Series 2 (Geology), 14, 97–101, pls. 29–32.

Oishi, S., 1935, A note on *Engelhardia* genus and its occurrence in the Palaeogene of Korea. Journal of the Geological Society of Japan, 43, 56–59.

Paik, I.S., 2000, Bone chip-filled burrows associated with bored dinosaur bone in floodplain paleosols of the Cretaceous Hasandong Formation, Korea. Palaeogeography, Palaeoclimatology, Palaeoecology, 157, 213–225.

Paik, I.S., Kim, H.J., and Lee, Y.I., 2001, Dinosaur track deposits from the Cretaceous Jindong Formation, Korea: occurrence, paleoenvironments and preservation. Cretaceous Research, 22, 79–92.

Pearson, H.L., 1987, Megafossil plants from Suffolk: a review of the pre-Pleistocene records. Transaction of the Suffolk Naturalist's Society, 23, 56–63.

Prakash, U. and Barghoorn, E.S., 1961, Miocene fossil woods from the Columbia basalts of central Washington. Journal of the Arnold Arboretum, 42, 165–195.

Prakash, U., Brezinova, D., and Buzek, C., 1971, Fossil woods from the Doupovske Hory and Ceske Stredohori Mountains in northern Bohemia. Palaeontographica, 133B, 103–128.

Scott, R.A. and Wheeler, E.A., 1982, Fossil woods from the Eocene Clarno Formation of Oregon. IAWA Bulletin, 3, 135–154.

Shimakura, M., 1936, Studies on fossil woods from Japan and adjacent lands, I. Some Jurassic woods from Japan and Manchoukuo. Science Reports of the Tohoku Imperial University, Series 2 (Geology), 18, 267–298.

Shimakura, M., 1937, Studies on fossil woods from Japan and adjacent lands, II. The Cretaceous woods from Japan, Saghalien, and Manchoukuo. Science Reports of the Tohoku Imperial University, Series 2 (Geology), 19, 1–73.

Son, M., Seo, H.J., and Kim, I.S., 2000, Geological Structures and Evolution of the Miocene Eoil Basin, Southeastern Korea. Geosciences Journal, 4, 73–88.

Son, M., Kim, J.S., Chong, H.Y., Lee, Y.H., and Kim, I.S., 2007, Characteristics of the Cenozoic crustal deformation in SE Korea and their tectonic implications. Korean Journal of Petrological Geology, 13, 1–16.

Suzuki, M., 1976, Some fossil woods from the Palaeogene of northern Kyushu. Botanical Magazine, 89, 59–71.

Suzuki, M., 1982, Some fossil woods from the Palaeogene of Northern Kyushu, II. Botanical Magazine, 95, 281–294.

Suzuki, M. and Hiraya, C., 1989, Fossil wood flora from the pumice tuff of Yanagida Formation (Lower Miocene) at Mawaki, Noto Peninsula. The Annals of Science, Kanazawa University, 26, 47–75. (in Japanese with English abstract)

Suzuki, M. and Terada, K., 1996, Fossil wood flora in the Lower Miocene Yanagida Formation of Noto Peninsula, Central Japan. IAWA Journal, 17, 365–392.

Suzuki, M. and Watari, S., 1994, Fossil wood flora of the Early Miocene Nawamata Formation of Monzen, Noto Peninsula, Central Japan. Journal of Plant Research, 107, 63–76.

Takahashi, A. and Suzuki, M., 1988, Two new fossil woods of Acer and a new combination of *Prunus* from the Tertiary of Japan. Botanical Magazine, 101, 473–481.

Takahashi, K. and Suzuki, M., 2003, Dicotyledonous fossil wood flora and early evolution of wood characters in the Cretaceous of Hokkaido, Japan. IAWA Journal, 24, 269–309.

Tanai, T., 1952, Notes a propos de queleques plantes fossiles dans le groupe d'Ennichi (Yongil) de coréé meridionale 1. Transactions and Proceedings from the Palaeontological Society of Japan, New Series, 8, 231–236.

Tanai, T. 1953, Notes on some plant fossils from Ennichi (Yongil) Group in southern Korea. Transactions and Proceedings from the Palaeontological Society of Japan, New Series, 9, 1–7.

Tanai, T., 1961, Neogene floral change in Japan. Journal of the Faculty Science, Hokkaido University, Series IV, 11, 119–398, pls. 1–32.

Tateiwa, I., 1924, Geological Atlas of Chosen. No. 2, Ennichi, Kuryuho and Choyo sheets. Geological Survey of Chosen (in Japanese).

Terada, K., 1998, Fossil wood floras of Early to Middle Miocene in Japan. Ph.D. thesis, Tohoku University, Sendai, 313 p. (in Japanese)

Terada, K. and Suzuki, M., 1998, Revision of the so-called "*Reevesia*" fossil woods from the Tertiary in Japan A proposal of new genus *Wataria* (Sterculiaceae). Review of Paleobotany and Palynology, 103, 235–251.

Watari, S., 1941, Studies on the fossil woods from the Tertiary of Japan, II. Fossil woods from the River Nesori, Namiuti Village, and the River Hiranuka, Kozuya Village, Ninohe District, Iwate Prefecture. Japanese Journal of Botany, 11, 417–438.

Watari, S., 1948a, On a new species of *Glyptostroboxylon*. Botanical

Magazine, 61, 11–14.

Watari, S., 1948b, Studies on the fossil woods from the Tertiary of Japan, V. Fossil woods from the Lower Miocene of Hanenishi, Simane Prefecture. Japanese Journal of Botany, 13, 503–518.

Watari, S., 1952, Dicotyledonous woods from the Miocene along the Japan-Sea side of Honshu. Journal of Faculty of Science University of Tokyo, Section III (Botany), 6, 97–134.

Wheeler, E.A. and Manchester, S.R., 2002, Woods of the Eocene Nut Beds Flora, Clarno Formation, Oregon, USA. IAWA Journal, Supple. 3, 11–88.

Woodcock, D.W. and Ignas, C.M., 1994, Prevalence of wood characters in eastern North America: What characters are most promising for interpreting climates from fossil wood? American Journal of Botany, 81, 1243–1251.

Yun, C.S. and Yang, S.Y., 1997, Dinosaur eggshells from Hasandong Formation, Gyeongsang Supergroup, Koea. Journal of the Paleontological Society of Korea, 13, 21–36. (in Korean with English abstract)

Yoon, S., 1992, Geology of the Tertiary Yangnam and Pohang basins, Korea. Bulletin of Mizunami Fossil Museum, 19, 13–31.

Yun, H., Yi, S., and Byun, H., 1997, Tertiary system of Korea. The Paleontological Society of Korea, Special Publication, 3, 1–30.

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