

Fossil Plants from the Early Cretaceous Hasandong Formation of Chilgok Area, Korea

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Abstract: Nine species of fossil plants were described based on the new material collected from the Hasandong Formation. They are as follows: *Thallites yabei*, *Onychiopsis elongata*, *Cladophlebis denticulata*, *C. shinshuensis*, *C. (Eboracia ?) lobifolia*, *C. (Klukia ?) koraiensis*, *Brachyphyllum japonicum*, *Elatocladus tennerima*, and *Taeniopteris ?* sp. cf. *T. auriculata*. The floristic composition of the Hasandong flora is very similar to that of the Nakdong flora. This means that both floras might have flourished under subtropical warm arid climate. This flora contains both the Tetori-type and Ryoseki-type floras. It is considered that the Hasandong flora is a member of the Mixed-type floras that existed in eastern Eurasia during the Late Jurassic to Early Cretaceous time.

Keywords: *Taeniopteris*, *Thallites*, ferns, conifers, Hasandong flora, Mixed-type flora

Introduction

The Early Cretaceous Gyeongsang Supergroup of non-marine origin is widely distributed in the south-eastern Korean Peninsula which has been lithostratigraphically divided into the Shindong, Hayang and Yucheon Groups in the ascending orders (Chang, 1975). Of these, both the Shindong and Hayang groups yield abundant vertebrate and invertebrate fossils, while fossil plants are mainly found in the Shindong Group (formerly called Nakdong Series) in the Gyeongsang Basin. The Shindong Group has been yielding abundant fossil plants the so-called ‘Nakdong flora (Tateiwa, 1929)’. Most species have been known from the Nakdong Formation and only a few from the Hasandong and Jinju formations (Tateiwa, 1929; Oishi, 1940).

Since the pioneering study of the Nakdong flora documented by Yabe (1905), some paleobotanical

studies from the Gyeongsang Basin and its equivalent have been carried out by the early workers such as Ogura (1927), Tateiwa (1929), Hatae (1937), Oishi (1939, 1940), and Kobatake (1958). Subsequently additional studies have been made by Chun et al. (1994), Kenrick et al. (2000), Kim (2009), Seo and Kim (2009), Kim et al. (2012), and Kim and Lee (2014). Tateiwa (1976) reviewed the fossil plants described or illustrated by the previous workers as mentioned above. According to him, the Nakdong flora consists of 50 species. Kimura (2000) also made a general review on the Korean Cretaceous floras and reclassified them into 36 species belonging to 20 genera, but he did not give the formal description or illustration of them.

Although the Nakdong flora is varied and abundant in the Gyeongsang Basin and its adjacent regions, it is needs the systematic and critical reexamination for the fossil plants reported from the Shindong Group based on the recent paleobotanical knowledge. Unfortunately all of the specimens of early workers kept in Korea were lost during the Korean War (1950-1953). As already mentioned by Kenrick et al. (2000), the Korean Early Cretaceous flora has been poorly studied despite the widespread distribution of non-marine sedimentary rocks and a long history of paleontological investigation.

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Recently we newly collected a large number of fossil plants from one fossil locality of the Hasandong Formation. The occurrence of fossil plants is very interesting and important in view of the floristic composition and phytogeography. To date the fossil plants from the Hasandong Formation have been scarcely known. Tateiwa (1929) listed only three plant taxa as follows: *Cladophlebis* sp.**, *Taeniopteris* ? sp. cf. *T. auriculata**, and *Cyparissinioum* cf. *japonicum** (*; listed and figured only, **; listed only). Oishi (1940) gave detailed descriptions of *Taeniopteris* ? sp. cf. *T. auriculata* and *Cyparissinioum* cf. *japonicum* based on the Tateiwa's (1929) specimens. The last species was revised by Oishi (1940) as *Brachyphyllum japonicum*.

In this paper we describe 9 species of fossil plants belonging to the fossil liverwort, ferns, conifers, and unclassified plants from the Hasandong Formation, and discussed about implications of these plant fossils for the floristic comparison and phytogeography.

Geological Setting and Geological Age

The Shindong Group is geographically restricted to the western part of the Gyeongsang Basin and divided into the Nakdong, Hasandong, and Jinju formations in the ascending order (Chang, 1975). According to Tateiwa (1929), the Hasandong Formation consists mainly of reddish mudstone, shale, sandstone, and conglomerate. Some beds of mudstone or shale are calcareous and are rich in nodules of marls. The entire thickness of the Hasandong Formation is about 1,300 m. The Hasandong Formation deposited in the floodplain environment (Lee and Hwang, 2012). The fossil locality is located in Seoguri, Gasan-myeon Chilgok-gun Gyeongsangbuk-do, Korea (36°08'54" N, 128°26'30" E). (Fig. 1). Fossil locality is exposed to a small area in the construction site near a road, of which the dip is gradual by 10°. The exposed vertical section has a feature that thinly-split black shale is

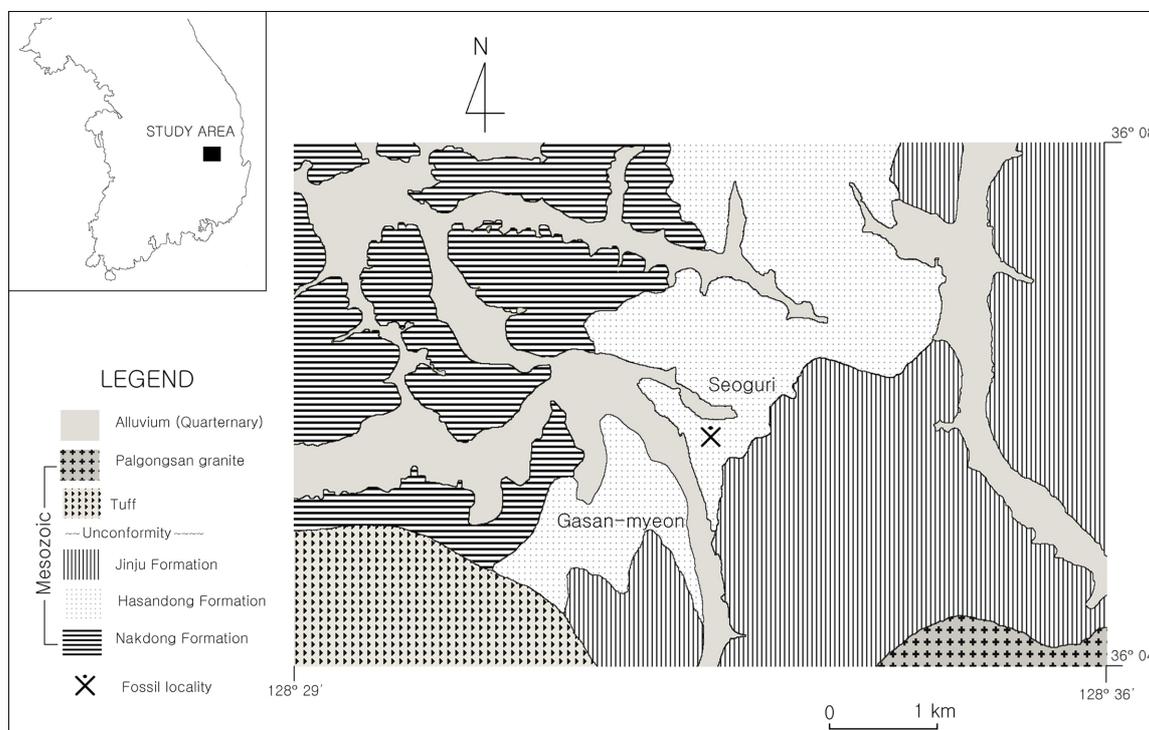


Fig. 1. Geologic map of the Seoguri area of the Gasan-myeon (modified after Kim et al., 1981) and a fossil locality.

alternated with gray mudstone. The fossil plants make thin layers, and are found in high density. In all the exposed areas, a variety of fossil plants are found, and those fossils only fossil plants.

Kang and Paik (2013) briefly reviewed on the geological ages of the formations in the Gyeongsang

Basin. The Hasandong Formation is regarded in age from Aptian to Albian based on the fossil bivalves (Yang, 1982; Yun and Yang, 2001). The numerical age of the Hasandong Formation is the Albian (Sano et al., 2006; Lee et al., 2010). Thus both the fossil and numerical ages are roughly agreed with each other.

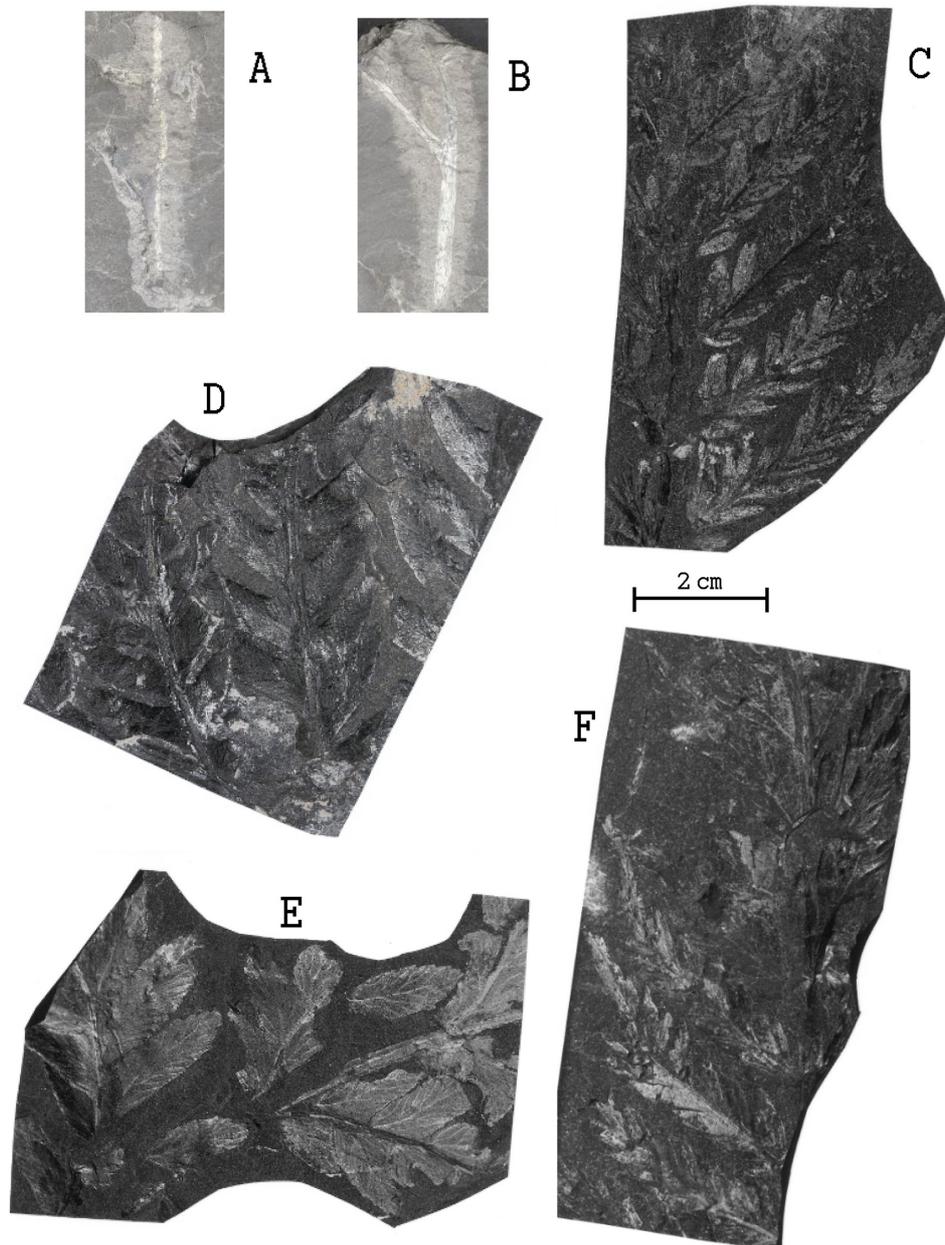


Fig. 2. Fossil plants from the Hasandong Formation. A, B: *Thallites yabei* (Kryshtofovich) Harris (KNC-20131017, 20131018), C, F: *Onychiopsis elongata* (Geyler) Yokoyama (KNU-2013-2041, 2013-1043), D, E: *Cladophlebis denticulata* (Brongniart) Krasser (KNU-2013-1023, 2013-1026).

Material and Method

About 70 fossil plants were obtained from one locality of the Hasandong Formation. Although the fossil plants are abundant in the Hasandong Formation, they are all impressions because of the Bulguksa orogeny with the intrusion of the Bulguksa granite. Consequently, no cuticles are preserved. Accordingly, the specific identification of fossil plants was made mainly based on their external morphology. All the specimens used in this study are deposited in the Department of Earth Science, College of Education, Kongju National University.

Systematic description

Order Marchantiales

Family Marchantiaceae

Genus *Thallites* Walton, 1925

Thallites yabei (Kryshtofovich) Harris

Fig. 2, A, B

1905 *Sagenopteris bilobata* var. *major* Yabe, pl. 3, fig. 16a, (non 16b, c)

1930 *Marchantites yabei* Kryshtofovich, pl. 15, fig. 3

1940 *Marchantites yabei* Kryshtofovich, Oishi, pl. a, fig. 1

1942 *Thallites yabei* (Kryshtofovich) n. comb., Harris, p. 396

1967 *Thallites yabei* (Kryshtofovich) Harris, Jover-Ast, p. 32

2014 *Thallites yabei* (Kryshtofovich) Harris, Kim and Lee, figs. 2A-H.

Material: KNC-20131017, 20131018

Distribution and occurrence: This species has been known from the Hasandong and Nakdong formations and Nieman Series of the Manicaria Border (Yabe, 1905; Oishi, 1940; Harris, 1942). This species is locally rare in the Cretaceous Hasandong Formation.

Description: Two fragments of thallic were obtained. Fig. 2 shows probably lower or middle part of thallic, linear and narrow in shape, do not bifurcates, gradually narrowing to upwards, more than 4cm in

length and 1.5 cm in width in the lower part. Thallic margins are entire and nearly parallel-sided. The midrib is prominent and 1 mm in width. Lateral veins are not preserved. Thallic of the Fig. 2 bifurcates at least two times, 3cm in length and 1cm in width in the lower part. The first branch of thallic is 1cm in length and 5-6 mm in width with branching angle of 30°. The midrib is prominent and 1 mm in width.

Remarks: Recently Kim and Lee (2014) described in detail *Thallites yabei* (Kryshtofovich) Harris based on the newly obtained material from the Nakdong Formation. The present thallic agrees well with those of their *Thallites yabei* (Kryshtofovich) Harris described by Kim and Lee (2014) in all respects.

Order Filicales

Form-genus *Onychiopsis* Yokoyama, 1889

Onychiopsis elongata (Geyler) Yokoyama

Fig. 2, C, F

Korean specimens

1905 *Onychiopsis elongata* (Geyler) Yokoyama: Yabe, p. 22, pl. 1, figs. 9-14; pl. 3, fig. 15.

1929 *Onychiopsis mantelli* ? (Brongniart) Nathorst: Tateiwa, plate, fig. 7

1940 *Onychiopsis elongata* (Geyler) Yokoyama: Oishi, p. 228, pl. 6, figs. 1-6; pl. 7, fig. 7

Material: KNU-20132041, 20131043

Distribution and occurrence: This species has been known in the Early Cretaceous Hasandong and Nakdong formations of Korea and Middle Jurassic and to Lower Cretaceous floras of the Inner and Outer Zone of Central Japan (e.g., Oishi, 1940; Kimura and Hirata, 1975; Kimura and Ohana, 1987). This species is locally rare in the Cretaceous Hasandong Formation.

Description: Obtained specimens are all sterile leaf-fragments and at least bipinnate. Rachis is 1mm in the lower part, sending alternately off pinnae at an angle of about 50°. Pinna is 2.7 cm in length and 0.4 cm in width in the lower part, sending small-sized and elongate-lanceolate pinnules directed forwards of which laminae are basally connected. Pinnule margins

are entire. Venation is simple; each pinnule receives a single vein basally, then repeatedly forking dichotomously near the base; basiscopic one is mostly forking again.

Remarks: The extinct genus *Onychiopsis* Yokoyama is widely distributed in mid-Jurassic to mid-Cretaceous strata and constitutes a conspicuous element in many Lower Cretaceous floras throughout the world (Friis and Pedersen, 1990). The present sterile leaves agree well with those of *Onychiopsis elongata* (Geyler) described from the Middle Jurassic to Lower Cretaceous plant-beds in the Inner Zone of Central Japan by Yokoyama (1889), Oishi (1940), Kimura (1958, 1975), and Kimura and Sekido (1976) and from the Lower Cretaceous of Korea by Yabe (1905) and Tateiwa (1929). *Onychiopsis elongata* (Geyler) is characteristic species of the Late Jurassic to Early Cretaceous floras of The Inner Zone of Japan (Kimura and Aiba, 1986).

Tateiwa (1929) figured sterile leaves belonging to *O. mantelli* ? (Brongniart) from the Jinju Formation. However, according to Oishi (1940), Tateiwa's *O. mantelli* ? (Brongniart) is identical with *O. elongata* (Geyler).

Unclassified ferns

Form-genus *Cladophlebis*, 1849

Cladophlebis denticulata (Brongniart) Krasser

Fig. 2, D, E

Korea specimens

1905 *Cladophlebis* cf. *denticulata* (Brongniart) Krasser: Yabe, p. 32, pl. 3, fig. 11.

1925 *Cladophlebis denticulata* (Brongniart) Krasser: Kawasaki, p. 11, pl. 9, fig. 34; pl. 10, figs. 35-38; pl. 36, fig. 100; pl. 40, figs. 108-109, pl. 46, fig. 123.

1926 *Cladophlebis denticulata* (Brongniart) Krasser: Kawasaki, p. 2, pl. 1, fig. 1.

1939 *Cladophlebis kogendoensis* Kawasaki: Kawasaki, p. 20, pl. 7, figs. 28-29; pl. 8, fig. 36; text-fig. 3b.

1940 *Cladophlebis denticulata* (Brongniart) Krasser: Oishi, p. 256, pl. 48, fig. 1.

Material: KNU-1023, 1026, 1049, 1021

Distribution and occurrence: *Cladophlebis denticulata* has been known from the Hasandong and Nakdong

formations of Korea (Oishi, 1939). This species is locally rare in the Cretaceous Hasandong Formation.

Description: Four fragments of frond were obtained. Frond is bipinnate and complete extent is unknown. Rachis is robust, up to 3 mm in width. Pinnae are subopposite, arising from the rachis at a wide angle, more than 9 cm in length and 3 cm in width. Pinna rachis is slender, up to 1.5 mm in width. Pinnules are long and narrow, 2.0 to 2.5 cm in length and 7-8 mm in width, subopposite to opposite. Pinnule shape is variable; lanceolate, oblong, elongate-oblong, and falcate. Margins are dentate or entire. Apices are abruptly narrowed, acute or obtuse. Midvein is persistent to the pinnule apex. Lateral veins are alternate, parallel to one another, dichotomizing usually once near the pinnule rachis.

Remarks: The foliages hitherto described by Yabe (1905), Kawasaki (1925, 1926, 1939) and Oishi (1940) and the present ones are all steriles. Such a sterile fern leaves have been described from the Mesozoic plant-beds in Korea (Yabe, 1905; Oishi, 1939) and adjacent lands under such comprehensive generic name as *Cladophlebis* (Oishi, 1939). Some *Cladophlebis* from the older Mesozoic plant-beds have been referred to the European species, such as *Cladophlebis denticulata*, *C. haiburnensis* and *C. nebbensis* (Kimura and Ohana, 1980). Foliages of this type can pertain to a number of fern families. This is exemplified in the Yorkshire Jurassic flora in which the families Osmundaceae, Dicksoniaceae and Schizaceae all possess sterile *Cladophlebis*-type foliage (Harris, 1961). It is difficult to assign the *Cladophlebis* fronds found in the Nakdong and Hasandong formations to one of these or any other families due to the lack of reproductive organs. The use of *Cladophlebis* for sterile leaves as suggested by Harris (1961) is followed here.

According to Kimura and Ohana (1980), the Japanese and Korean specimens determined as *Cladophlebis haiburnensis* and *C. nebbensis* differ from the specimens from the type locality. Kimura and Ohana (1980) proposed *Todites fukutomii* Kimura and Ohana and *T. yamanoiensis* Kimura and Ohana instead of *Cladophlebis*

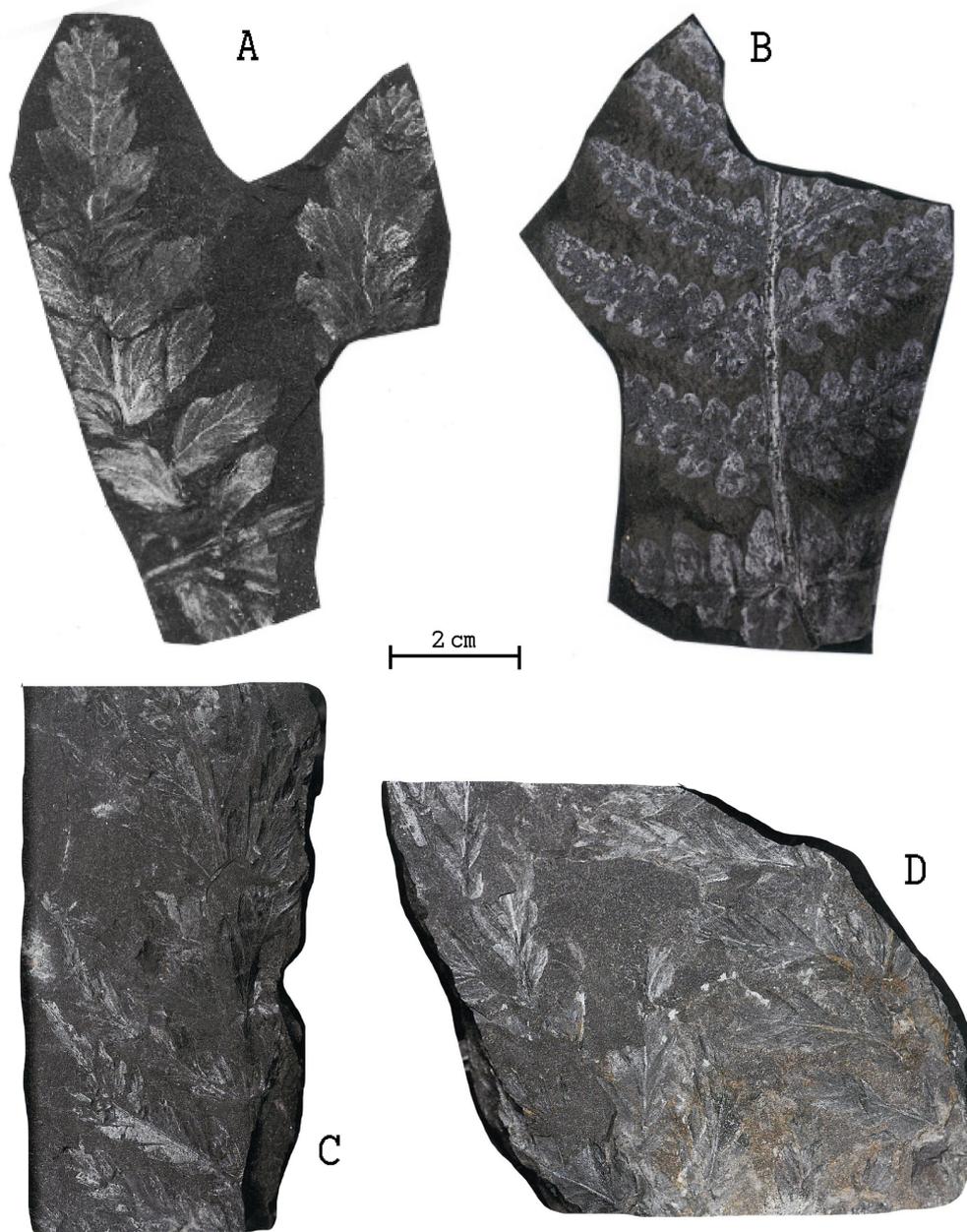


Fig. 3. Fossil plants from the Hasandong Formation. A; *Cladophlebis* (*Eboracia* ?) *lobifolia* (Phillips) Brongniart (KNU-2013-1037), B; *Cladophlebis* (*Klukia* ?) *koraiensis* Yabe (KNU-2013-1030). C, D; *Cladophlebis* *shinshuensis* Tateiwa (KNU-1013-1022, 1013-043).

nebbensis and *C. haiburnensis* respectively on the basis of the fertile and sterile leaves in organic connection obtained from the Carnian Momonoki Formation of Japan. Kimura and Ohana (1980) also changed the Korean fern leaves of *C. denticulata*

described by the previous authors (Yabe, 1905; Oishi, 1939) as cf. *Todites denticulatus*. The present fern leaves probably belong to cf. *Todites denticulatus*. However, due to their lacking any fertile leaves, it is appropriate to describe them as *Cladophlebis denticulata*.

Cladophlebis denticulata (Brongniart) is distinguished from *Todites fukutomii* described by its pinnules with dentate margin and acute or obtuse apex (Kimura and Ohana, 1980).

Cladophlebis shinshuensis Tateiwa

Fig. 3, C, D

1929 *Cladophlebis shinshuensis* Tateiwa: pl 20 , fig. 24

1940 *Cladophlebis shinshuensis* Tateiwa: Oishi, p. 285, pl. 20, figs. 5, 6; pl. 21 figs 5, 5a, b, 6, 7.

Material: KNU-1022, 1043, 1050, and other 15 specimens.

Distribution and occurrence: *Cladophlebis shinshuensis* has been known in the Hasandong and Nakdong formations of Korea (Yabe, 1905; Oishi, 1939). This species is locally very abundant in the Hasandong Formation.

Description: A large number of leaf fragments were obtained. Frond is at least bipinnate. Rachis is slender, up to 1.5 mm in width. Pinnae are opposite or subopposite in order, arising from the rachis at a wide angle, nearly parallel-sided, more than 4 cm in length and 1.5 cm in width. Pinna rachis is slender, up to 1 mm in width. Pinnules are narrow, attached by the whole base to the pinna rachis, tapering to the acuminate apex, 1.2 cm in length and 3 mm in width. Margins are entire. Midvein is persistent to the pinnule apex. Lateral veins are mostly dichotomizing usually once near the margin.

Remarks: *Cladophlebis shinshuensis* was already determined as a new species from the Nakdong Formation (Tateiwa, 1929). Afterwards Oishi (1940) gave full descriptions based on the Tateiwa's specimens. The present sterile fern leaves fully agree with those of *Cladophlebis shinshuensis* described by Oishi (1940).

Cladophlebis (Eboracia ?) lobifolia (Phillips)

Brongniart

Fig. 3, A

1940 *Cladophlebis (Eboracia ?) lobifolia* (Phillips) Brongniart: Oishi, pl. 18, figs. 1-4.

Material: KNU-1037, 1036, 1014, 1033 and other 10 specimens.

Distribution and occurrence: *Cladophlebis (Eboracia ?) lobifolia* has been known in the Jurassic to Cretaceous Tetori and Ryoseki Series of Japan (Oishi, 1940). This species is rare in the Cretaceous Hasandong Formation of Korea.

Description: Four fragments of frond are obtained. Frond is at least bipinnate and more than 13 cm in length. Rachis is thick and grooved, sending oppositely or suboppositely off linear pinnae at a wide angle. Pinna is typically 5 cm in length and 1.5 cm in width in the lower part, bearing semi-orbicular to ovate, sometimes deltoid pinnules. The pinnules are closely set, attached to the axis by the contract base with rounded or obtusely rounded apices. The pinnule margins are entire. Veins are poorly preserved. Midvein is indistinct, giving off many lateral veins of almost equal length and once or twice forked.

Remarks: The present fern leaves closely resemble those of *Cladophlebis (Eboracia ?) lobifolia* (Phillips) Brongniart described from the Jurassic to Cretaceous Tetori and Ryoseki Series of Japan (Oishi, 1940). As mentioned by Oishi (1940), this species is characterized by their forms and venation as mentioned above. The present sterile leaves closely resemble those of *Eboracia lobifolia* (Phillips) described from the Jurassic Yorkshire (Harris, 1961).

Cladophlebis (Klukia ?) koraiensis Yabe

Fig. 3, B, Fig. 4, D

1905 *Cladophlebis koraiensis* Yabe: Yabe, p. 32, pl. 1, fig. 1; pl. 3, fig. 12, 13

1940 *Cladophlebis (Klukia ?) koraiensis* Yabe: Oishi, p. 270, pl. 17, figs. 3, 3a; pl. 19, fig. 3

2000 *Cladophlebis (Klukia ?) koraiensis* Yabe: Kimura, p. 12

Material: KNU-20131030, 20131032

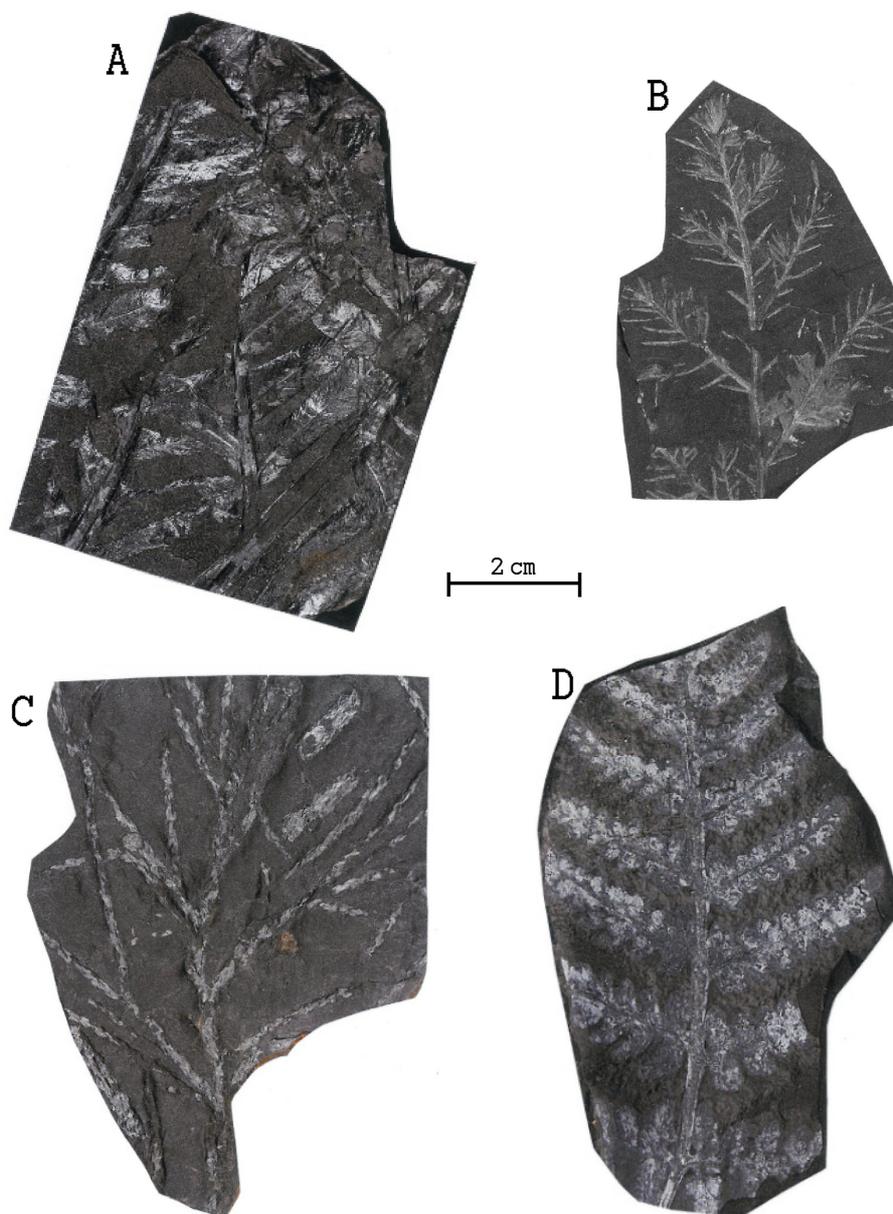


Fig. 4. Fossil plants from the Hasandong Formation. A: *Taeniopteris* ? sp. cf. *T. auriculata* (Fontaine) Berry (KNU-2013-1057). B: *Elatocladus tennerima* (Feistmantel) Shani (KNU-2013-1010), C: *Brachyphyllum japonicum* (Yokoyama) Oishi (KNU-2013-1020), D: *Cladophlebis* (*Klukia* ?) *koraiensis* Yabe (KNU-2013-1032).

Distribution and occurrence: *Cladophlebis koraiensis* has been known in the Cretaceous Hasandong and Nakdong formations of Korea (Yabe, 1905; Oishi, 1939). This species is locally rare in the Hasandong Formation.

Description: Two fragments of frond were obtained.

Frond is at least bipinnate. Pinna is linear, suboppositely attached to the rachis at a wide angle. Pinnules are small and short, opposite to subopposite, varied in size; deltoid, elongate oblong to elongate triangular, 1 mm in width and 2 mm in length with bluntly obtuse apex.

Remarks: Yabe (1905) originally described *Cladophlebis koraiensis* from the Nakdong Formation based on the fertile and sterile fern leaves. As already mentioned by Oishi (1940), Yabe's specimens are poorly preserved. In the Yabe's fig. 12, the fertile frond shows partly rounded soral impressions of 3-4 in number and arranged in a single row on each side of the midrib. However, according to the Oishi's (1940) close examination, sorus-like impressions are not a sorus composed of several sporangia, but a single sporangium. All these features mentioned above closely allies to *Klukia* as mentioned by Oishi (1940) and Seward (1969). Yabe (1905) already pointed out the resemblance of *C. koraiensis* to the well-known species *Klukia exilis* (Philips). Seward (1969) also mentioned that Yabe's *Cladophlebis koraiensis* may be identical with *Klukia exilis* (Philips). However, due to the uncertainty of sorus, Oishi (1940) regarded the Yabe's specimens as *Cladophlebis (Klukia ?) koraiensis*. We also regard the present leaves as *Cladophlebis (Klukia ?) koraiensis* Yabe as suggested by Oishi (1940) because of the shape of the frond and vein.

Coniferales

Form-genus *Brachyphyllum* Lindley et Hutton, 1836
Brachyphyllum japonicum (Yokoyama) Oishi

Fig. 4, A

1894 *Cyparissidium ? japonicum* Yokoyama: p. 229, pl. 20, figs. 3a, 6, 6a, 13; pl. 24, fig. 4.

1929 *Brachyphyllum* cf. *japonicum* (Yokoyama): Tateiwa, p. 23.

1940 *Brachyphyllum japonicum* (Yokoyama): Oishi, p. 391, pl. 42, figs. 2, 3, 3a

Material: KNU-20131020, 20131042, 20131066 and other 20 specimens.

Distribution and occurrence: This species has been known from the Nakdong and Jinju formations of Korea (Yabe, 1905), and from the Ryoseki Series of Japan (Tateiwa, 1929; Oishi, 1940). This species is locally abundant in the Hasandong Formation.

Description: A large number of coniferous shoots were obtained, but they are all fragments and sterile.

In the largest one, the main branch is more than 14 cm in length and 0.3 cm in width, giving alternate off remotely set branches in one plane. The secondary branches are more than 6 cm in length, giving alternately off short third ones. Leaves are spirally arranged and mostly appressed to the stem, triangular in shape, with acute apex.

Remarks: The present specimens agree with those of *Brachyphyllum japonicum* (Yokoyama) described from the Cretaceous plant-beds of Korea and Japan (Oishi, 1940). *Brachyphyllum japonicum* (Yokoyama) closely resembles in external form to *Brachyphyllum expansum* (Sternberg) described from the Nakdong Formation (Oishi, 1940), but the latter is characterized by its broadly triangular leaves with subacute apices.

Genus *Elatocladus* Halle, 1913

Elatocladus tennerima (Feistmantel) Shani

Fig. 4, B

1928 *Elatocladus tennerima* (Feistmantel) Shani: p.14, pl. 1, figs. 10-15.

1932 *Elatocladus tennerima* (Feistmantel) Shani: Oishi, p. 360, p. 51, figs. 8-10.

1940 *Elatocladus tennerima* (Feistmantel) Shani: Oishi, p. 396.

Material: KNU-20131010, 20131031, and other 10 specimens.

Distribution and occurrence: This species has been known in the Cretaceous Tetori Series of Japan (Oishi, 1940). It is locally common.

Description: Obtained specimens are all sterile leaf-fragments. Fronds are at least bipinnate. Rachis is 1mm in the lower part, sending alternately off pinnae at an angle of about 35°. Pinna is 2.5 cm in length and 0.4 cm in width in the lower part. Pinnules are closely attached spirally, 3 mm in length and 0.5 mm in width, linear, slightly curve into the decurrent leaf-base, with a single vein.

Remarks: Though the present leaves are all fragments and impressions, they are close to *Elatocladus tennerima* (Feistmantel) known from the Tetori Series

of Japan by shape of the needles (Oishi, 1932).

Unclassified plant

Form-genus *Taeniopteris* Brongniart, 1828

Taeniopteris ? sp. cf. *T. auriculata* (Fontaine) Berry

Fig. 4, A

Taeniopteris ? sp. cf. *T. auriculata* (Fontaine) Berry, Tateiwa, 1929, fig. 25

Taeniopteris ? sp. cf. *T. auriculata* (Fontaine) Berry, Oishi, 1940, p. 430-431, pl. 47, figs. 1, 2, 2a

Material: KNU-20131057, 20131018, 20131051 and other 30 specimens.

Distribution and occurrence: This species has been known from the Hasandong Formation of the Shindong Group, Korea (Tateiwa, 1929), and Jurassic to Cretaceous Tetori Group of Japan respectively (Oishi, 1940). It is locally very abundant.

Description: Form and size of frond as a whole are unknown. Frond is bipinnate, over 12 cm in length and 10 cm in width. Rachis is comparatively thick, 0.2 cm wide lower and 0.1 cm upper, and its upper surface is longitudinally grooved. Pinnae are alternately attached to the lateral sides of rachis at a wide angle, long and narrow, broad at the base, typically 5-4 cm in length and 1 cm in width at base, gradually narrowing towards acuminate apex. Margins are either entire or sometimes broadly undulated. Base symmetrically contracted and rounded. Midrib is prominent, less than 0.1 cm in width and persisting to the tip. Lateral veins are usually dichotomizing twice or three times at all levels, curving upward, ending at the distal margin.

Remarks: Tateiwa (1929) first determined the present specimens as *Taeniopteris* ? sp. cf. *T. auriculata* (Fontaine) Berry and figured in his Geological Atlas of Tyosen. Afterwards Oishi (1940) gave a detailed description of *Taeniopteris* ? sp. cf. *T. auriculata* (Fontaine) Berry based on the Tateiwa's specimens. The most distinctive character of the present specimens is the pinnate frond, long and narrow pinnae with acuminate apex and rounded base.

Taeniopteris ? sp. cf. *T. auriculata* (Fontaine) Berry

is similar in leaf form to *Angiopteris auriculatum* originally described from the Cretaceous Potomac Formation of North America (Fontaine, 1889). However, the latter species clearly differs from the former by its linear pinna with a distinct cordate base and entire margin. Oishi (1940) already pointed out that the pinna base of American species is distinctly cordate.

Taeniopteris ? sp. cf. *T. auriculata* (Fontaine) Berry is close in base of lamina to *Taeniopteris jourdyi* originally described from the Upper Triassic of North Vietnam (Zeiller, 1903). Whereas in the former species, the lateral veins are nearly perpendicular to the rachis, but those of the latter are curving upward and mostly forking twice to thrice.

Taeniopteris ? sp. cf. *T. auriculata* (Fontaine) Berry also closely resembles pinna form of the sterile leaves of *Marattia asiatica* (Kawasaki) Harris described from the Upper Triassic Amisan Formation of Korea (Kimura and Kim, 1984), but the latter differs from the former by its lateral veins with venuli recurrentes.

Discussion

The Hasandong flora consists of 9 species belonging to 6 genera. It is characterized by the abundant presence of ferns and conifer, *Taeniopteris* of Unclassified plants and the presence of *Thallites* of liverwort.

The ferns are the first dominant group and contain sterile fern-like foliages such as *Onychiopsis* and *Cladophlebis*. The genus *Onychiopsis* is widely distributed in mid-Jurassic to mid-Cretaceous strata and constitutes a conspicuous elements in many Lower Cretaceous floras throughout the world (Friess and Pedersen, 1990). This genus is represented by a single species of *Onychiopsis elongata*. This species is a common element in the Late Jurassic to Early Cretaceous of Japan, China and Korea (e.g., Oishi, 1940; Sze et al., 1963). The genus *Cladophlebis* is the name applied to Mesozoic fern-like leaves of uncertain affinity (Seward, 1969). Foliages of this type are represented by four species (See Table 1). Such sterile foliages of *Cladophlebis* are quite abundant in the Mesozoic plant bearing strata in the world, and also abundant in the

Lower Cretaceous Shindong Group of Korea (e.g., Oishi, 1940; Kimura and Ohana, 1980).

Conifers are represented by *Brachyphyllum* and *Elatocladus*. The former genus belongs to the extinct conifer family Cheirolepidaceae, and is one of the most important Mesozoic conifer together with *Frenelopsis*, *Pseudofrenelopsis*, and *Pagiophyllum*. As already mentioned by Kim et al. (2012), these genera are well represented in the Lower Cretaceous fossil floras of Europe, North America, Africa, and Asia by vegetative and reproductive remains (e.g., Watson, 1977; Zhou, 1995; Saiki, 1999; Yang, 2008). Foliages of *Brachyphyllum* are quite abundant and sometimes thickly massed in the Hasandong Formation. The genus *Elatocladus* is locally common in occurrence. It is rather common in the Jurassic plant-beds in China (Sze et al., 1963).

Fossil liverwort of *Thallites yabei* is rather rare in the Hasandong Formation, but is abundant in the Nakdong Formation. It might have flourished under tall arber trees in the humid environment as well as Nakdong Formation (Kim and Lee, 2014).

Taeniopteris ? sp. cf. *T. auriculata* (Fontaine) is unique and locally abundant. This species has only been known in the Hasandong Formation of the Shindong Group (Tateiwa, 1929).

As shown in Table 1 there are 6 common species between the Hasandong and underlying Nakdong floras. Although the number of species recognized from the Hasandong Formation is 9 species, the Hasandong flora is very similar to the Nakdong flora. This means that both floras might have flourished under similar climate. The Gyeongsang Basin was deposited under subarid to dry warm climate based on the sedimentological evidences (Paik and Chun, 1993; Paik and Lee, 1998, Park et al., 1997) and paleontological evidences (Choi, 1985; Woo et al., 1991). This is partly supported by the presence of the cheirolepidiaceus fossils, Bennettitales, and tree ferns from the Shindong Group. The cheirolepidiaceus fossils such as *Pseudofrenelopsis*, *Frenelopsis* and *Brachyphyllum* are abundant and dominant. These fossil plants have been used as indicator of tropical or

Table 1. Comparison of the Hasandong flora with Nakdong and Jinju floras (Yabe, 1905; Tateiwa, 1929)

Hasandong flora	Nakdong flora	Jinju flora
<i>Thallites yabei</i>	0	x
<i>Onychiopsis elongata</i>	0	0
<i>Cladophlebis denticulatus</i>	0	x
<i>C. shinshuensis</i>	0	x
<i>C. (Eboracia ?) lobifolia</i>	x	x
<i>C. (Klukia ?) koraiensis</i>	0	x
<i>Brachyphyllum japonicum</i>	0	0
<i>Elatocladus tenerima</i>	x	x
<i>Taeniopteris</i> ? sp. cf. <i>T. auriculata</i>	x	x

subtropical arid climate (Alvin, 1982). The fossil Bennettitales is also abundant and varied in the Nakdong flora. It is well known in the Temperature to Subtropical climate (Douglas and Williams, 1982). Especially *Cyathocaulis naktongensis* belonging to tree ferns (Ogura, 1927, 1941) is very interesting. The extant tree ferns is geographically restricted to the Subtropical to Tropic climate (Cheong and Baik, 1992). From the paleobotanical point of view, it is considered that both the Nakdong and Hasandong floras might have flourished under subtropical warm arid climate.

Meanwhile, the number of common species of the Hasandong and Jinju formations is only 2 as shown in the Table 1. Considering their relative stratigraphic relation, the common species is extraordinarily small. It can be explained to be caused by the fossil record of uncertainty. Tateiwa (1929) illustrated 15 plant taxa without descriptions from the Jinju Formation, but his most plant taxa were not precisely identified at specific level. Moreover Tateiwa's specimens were lost during the Korean War (1950-1953) as mentioned before. Therefore, it is impossible to make the critical reexamination for the Tateiwa's specimens. It is needed to find additional material from the Jinju Formation.

Ohana and Kimura (1995) proposed that there existed three floristic provinces in eastern Eurasia during the Late Jurassic to Early Cretaceous time. They are the Ryoseki-type, Tetori-type, and Mixed-type floras. Although the number of species in the

Hasandong flora is small, it includes both the Tetori-type and Ryoseki-type floras. For example, *Onychiopsis elongata* and *Brachyphyllum japonicum* are Ryoseki type and Tetori type floras, respectively (Kimura, 2000). It means that the Hasandong flora is also a member of the Mixed-type floras as well as Nakdong flora. According to Ohana and Kimura (1995), and Kimura (2000), the Nakdong flora, however, belongs to the Mixed-type floras.

Conclusion

The Hasandong flora is characterized by the abundant presence of ferns and conifers, *Taeniopteris* of Unclassified plants and the presence of *Thallites* of liverwort. This flora is similar to the Nakdong flora in floristic composition. It is considered that the Hasandong flora might have flourished under subtropical warm arid climate as well as the Nakdong flora. The Hasandong flora belongs to the Mixed-type floras existing in eastern Eurasia during the Late Jurassic to Early Cretaceous time.

Acknowledgments

This work was supported by the research grant of Kongju National University in 2015. We thank professor Jeong Yul Kim of the Korea National University of Education and professor Kyung Soo Kim of the Chinju National University of Education and anonymous reviewers for the critical reading the manuscript and helpful suggestion.

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Manuscript received: July 11, 2016

Revised manuscript received: September 20, 2016

Manuscript accepted: September 22, 2016