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Holocene vegetation changes on the north-eastern coast of the Korean Peninsula based on the palynological data

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ABSTRACT. Pollen analysis was made on a piston-core of marine bottom sediments from East Korean Bay (Sea of Japan). Three palynological assemblages were revealed in the sediments. The analyses of palynological records show the changes in surrounding vegetation during Holocene. Fossil pollen grains of *Quercus* L. were studied with application of scanning electron microscope. Six types of fossil pollen grains were revealed: four of them were assigned to deciduous oaks and two to evergreen oaks. The deciduous broad-leaved forests were dominated by *Q. mongolica* and *Q. serrata* in Holocene.

KEYWORDS: *Quercus* pollen, vegetation, Holocene, Korean Peninsula, marine bottom sediments

INTRODUCTION

The Holocene vegetation history of the Korean Peninsula based on pollen analysis was described in: Jo (1979), Chang and Kim (1982), Yoon and Jo (1996), Choi (1998), Chung (2006), Yi et al. (2004), and Fujiki and Yasuda (2004). However, most analyses have focused on the south part of peninsula. In this study, we clarified the Holocene vegetation history of the north-eastern coast of the Korean Peninsula. Additionally, we have identified species of *Quercus* fossil pollen grains using scanning electron microscope (SEM) providing for a more detailed analysis of vegetation history.

ENVIRONMENTAL SETTING

The climate of the north-eastern coast of the Korean Peninsula is mainly under the control of the East Asian monsoon system with seasonal changes in wind (Drozdov et.al. 1989). During the winter season dry and cold winds blows to the south-west from the Asian continent and during the summer season the warm and humid wind comes from the ocean. The mean temperatures in July and in January are +22°C and –21°C, respectively. The average annual precipitation is about 1500 mm, and most part of the annual precipitation falls in the summer.

The relief of the north-eastern part of the Korean Peninsula is mountainous, with average heights of the hills up to 2000 m. Flat sites lie in the coastal zone.

The modern vegetation of the study area belongs to the warm-temperate deciduous broad-leaved forest – woodland zone consisting of *Quercus mongolica*, *Q. aleina*, *Q. serrata*, *Q. dentata*, *Q. variabilis*, *Q. acutissima* (Okumura 1974, Yim 1977).

MATERIAL AND METHODS

Samples of core 2747 were obtained from the shelf zone of the Korean Bay, from the depth of 47 m (Fig. 1). The length of the core samples under study is 280 cm. The sediments are clays and siltstones admixed with organic debris and coquina (Fig. 2). A total of 14 samples

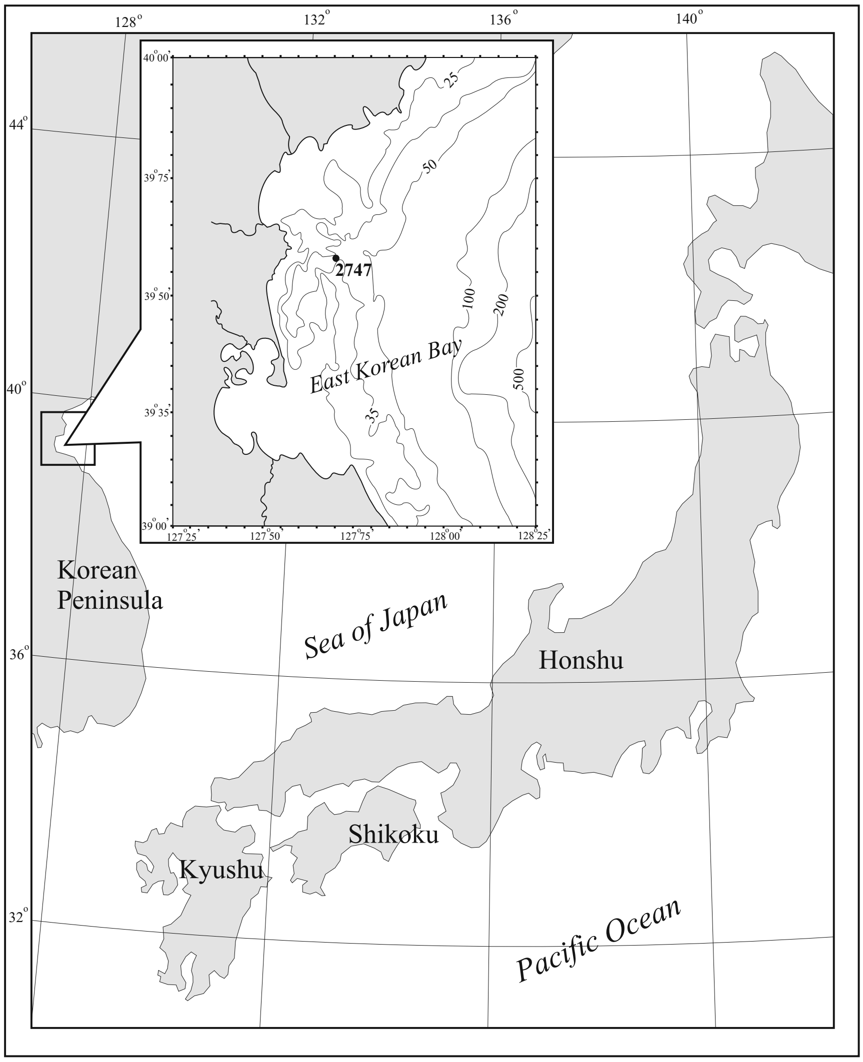

Fig. 1. Schematic map of the region and the position of the core under study

were subjected to palynological examination. Radicarbon datings (the depth of 35–42 cm – 4440 ± 110 yr. BP and 120–130 cm – 7750 ± 90 yr. BP) restrict the sediments to the Holocene (Markov et al. 2008).

Fossil pollen grains were extracted from sediments using standard techniques (Pokrovskaya 1966), which included treatments with 10% KOH, mineral separation with a KJ and CdJ_2 solution (2.2 g/cm^3), acetolysis. Pollen and spores were identified and counted with light microscope in glycerin jelly. At least 250 arboreal pollen grains were counted in each sample. Components of the palynological spectrum were counted in three groups: pollen grains of arboreal elements, pollen grains of herbaceous elements, and spores. Percentage ratios between the groups were counted as well as percentage ratios between components of each group.

Samples were mounted for scanning electron microscopy (ZEISS EVO 40), the material was dehydrated in series of ethanol solutions (50, 70, 90%), 15–20 minutes in each solution (Gapochka & Chamara 1988) and covered with gold in vacuum. A total of 13 samples were studied with SEM. About 50 fossil pollen grains of *Quercus* were identified at species level in each sample. Menitskii's (1984) classification was used to identify species of *Quercus*.

RESULTS

Forty four varieties taxa of fossil pollen grains and spores were detected including:

Arboreal pollen: *Abies*, *Picea*, *Pinus* subgenus *Haploxylon*, *Pinus* subgenus *Diploxylon*, *Ephedra*, *Ulmus*, *Fagus*, *Castanea*, *Quercus*, *Alnus*, *Betula*, *Carpinus*, *Corylus*, *Myrica*, *Juglans*, *Carya*, *Salix*, *Tilia*, *Acer*, *Syringa*, *Cornus*, *Euonymus*, and Ericaceae.

Non-arboreal pollen: Caryophyllaceae, Chenopodiaceae, *Polygonum* subgenus *Persicaria*, *Sanguisorba*, Fabaceae, *Euphorbia*, Apiaceae, *Artemisia*, *Ambrosia*, other Asteraceae, Liliaceae, Poaceae, *Typha*, *Polygala*, Urticaceae, *Iris*, and Ranunculaceae.

Spores: *Sphagnum*, *Lycopodium*, *Osmunda*, and Filicales monolete.

The detailed analysis of the palynological spectra has revealed three assemblages in the

Table 1. Description of pollen assemblages

Pollen assemblages	Depth (cm)	Description
I	275–135	Palynological assemblage is dominated by arboreal pollen (47.0–67.0%); the abundance of herbaceous pollen (18.0–31.0%) is slightly higher than that of spores (12.0–23.0%). In arboreal group, the amount of conifer pollen varies from 11.0 to 47.0% constituted by *Pinus* subgenus *Diploxylon* (2.0–14.8%) and *Pinus* subgenus *Haploxylon* (2.1–26.5%), *Picea* (1.7–9.7%), and *Abies* (0.4–7.4%). Pollen grains of deciduous trees make 28.0–49.6%, mostly at the expense of *Quercus* (24.0–43.0%), *Betula* (10.0–20.8%), *Corylus* (5.0–12.4%), *Alnus* (4.4–12.5%). Pollen grains of the Ericaceae (up to 9.4%), *Juglans* (up to 3.5%), *Tilia* (up to 2.8%), *Ulmus* (up to 1.7%), and *Salix* (up to 2.1%) are less numerous. Pollen grains of the *Ephedra*, *Fagus*, *Castanea*, *Carpinus*, *Myrica*, *Acer*, *Syringa*, *Cornus*, and *Euonymus* are rare. Herbs are dominated by the Asteraceae (26.0–35.0%), mostly by *Artemisia* (14.1–33.6%). The presence of pollen grains of the Poaceaee fluctuates from single pollen grains to 31.6%. Pollen grains of the Urticaceae (up to 5.6%), Apiaceae (up to 4.7%), and Chenopodiaceae (up to 4.4%) are less numerous. Pollen grains of the Caryophyllaceae, *Polygonum* subgenus *Persicaria*, *Polygala*, *Sanguisorba*, Fabaceae, *Euphorbia*, Liliaceae, and *Iris* are rare. Spores are prevailed by members of the Filicales monolete (94.0–99.0%). Spores of *Sphagnum* (up to 2.0%), *Lycopodium* (up to 2.5%), and *Osmunda* (up to 3.0%) are not numerous.
II	135–10	Palynological assemblage is characterized by even higher domination of the arboreal group (55.0–90.0%). The percentage of herbs decreases (11.9–27.0%), but exceeds that of spores (1.3–17.5%). Upwards the section, the abundance of pollen grains of *Abies*, *Picea*, and *Pinus* subgenus *Haploxylon* (up to 13.2%), *Betula* (up to 1.8%), *Corylus* (up to 2.3%), *Alnus* (up to 2.2%) gradually decreases. The participation of *Pinus* subgenus *Diploxylon* sharply increases up to 47.1%. The percentage of *Quercus* pollen reaches the maximal values (59.9%). Pollen grains of the *Ephedra*, *Ulmus*, *Castanea*, *Carpinus*, *Tilia*, *Carya*, *Salix*, *Acer*, *Syringa*, and Ericaceae are rare. Pollen grains of the Asteraceae (up to 65.4%) and Chenopodiaceae (up to 11.5%) dominate among herbs. The participation of Poaceae pollen gradually decreases. Pollen grains of the Caryophyllaceae, *Polygonum* subgenus *Persicaria*, Apiaceae, *Typha*, and *Polygala* are rare. Spores are prevailed by members of the Filicales monolete. The participation of *Sphagnum* (up to 25.0%), *Lycopodium* (up to 6.5%), and *Osmunda* (up to 5.6%) increases.
III	10–0	Palynological assemblage is dominated by arboreal group (76.8–85.5%). Herbs (10.0–15.5%) slightly exceed spores (3.6–8.3%). Among conifer pollen, the participation of *Abies*, *Picea*, and *Pinus* subgenus *Haploxylon* decreases up to 5.7%, while that of *Pinus* subgenus *Diploxylon* increases up to 72.9%. Pollen grains of *Quercus* become less abundant (up to 7.6%). Pollen grains of *Ulmus*, *Castanea*, *Alnus*, *Carpinus*, *Corylus*, *Salix*, *Ace*, *Juglans*, and *Tilia* are rare. Pollen grains of the Asteraceae (up to 61.8%), Chenopodiaceae (up to 15.0%), and *Typha* (up to 15.0%) dominate among herbs. Pollen grains of the *Polygala* are rare. Spores are prevailed by members of the Filicales monolete; the participation of *Lycopodium* and *Osmunda* increases (up to 9.1% each); *Sphagnum* disappears.

sediments of the shelf core (Tab. 1). According to radiocarbon dating, pollen assemblages were correlation with climatic-stratigraphic scheme of Holocene (Khotinskii 1977). The appearance tendencies of the main pollen types are as follows (Fig. 2). The temperate conifer *Pinus* subgenus *Diploxylon* pollen comprised less than 6.0% below 170 cm, but increased gradually to 79.2% at the surface. The percentage of the subarctic conifer *Pinus* subgenus *Haploxylon* pollen was dominant at 10.6–26.5% below 183 cm. However, the percentages of this pollen decreased above 183 cm. Cool-temperate deciduous broad-leaved *Quercus* subgenus *Lepidobalanus* pollen was dominant in the all layers (23.9–53.6%), but decreased at the surface (7.6%). *Alnus*, *Betula*, and *Corylus* pollen comprised less than 20.0% each below 110 cm and decreased at the surface. *Abies*, *Picea* pollen accounted for less than 10.0% each. *Juglans*, *Salix* and *Tilia* pollen comprised less than 5.0% through all layers. Pollen grains of *Ephedra*, *Ulmus*, *Fagus*, *Castanea*, *Carpinus*, *Myrica*, *Carya*, *Acer*, *Syringa*, *Cornus*, and *Euonymus* are rare. Asteraceae pollen was dominant in the all layers (25.9–61.8%). Chenopodiaceae pollen comprised less than 5.0% below 130 cm, but increased slightly above 130 cm. The percentage of Poaceae pollen increased (20.0–31.6%) at 150 cm and 40 cm, but accounted for less than 10.0% at other depths. Filicales monolete spore was dominant in the all layers.

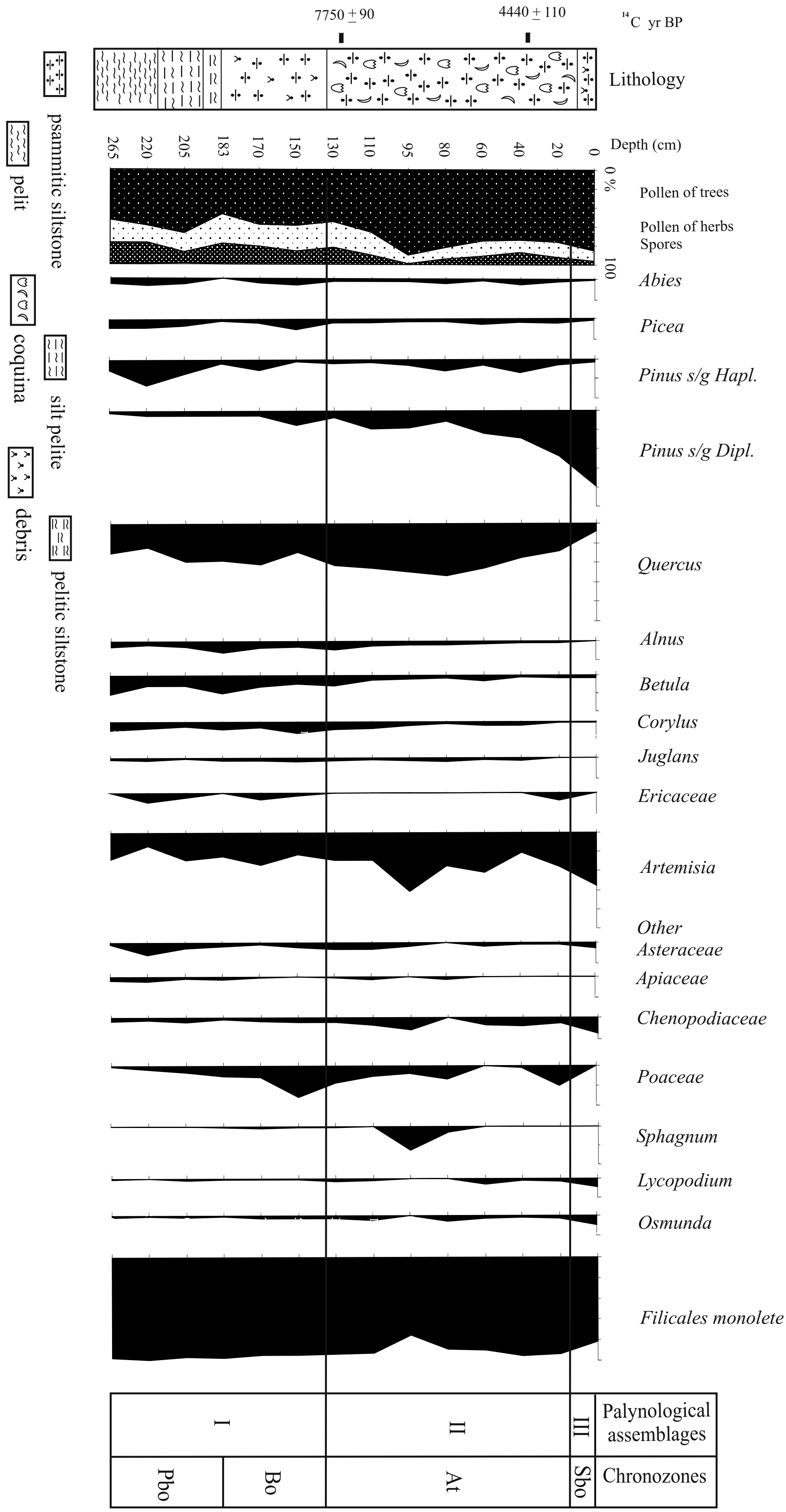

Fig. 2. Palynological diagram of the main pollen type of core 2747

ELECTRON-MICROSCOPICAL STUDY OF FOSSIL POLLEN GRAINS

The modern genus *Quercus* L. (*Fagaceae*) includes more than 500 species of evergreen and deciduous trees and shrubs. Members of the genus have a wide geographical range, occupying vast territories of the north hemisphere in North America, Europe, and Asia (Menitskii 1984). During the Holocene, oak-dominated forests were also common. According to Naryshkina and Evstigneeva (2009), six types of fossil pollen grains of *Quercus* are identified using a SEM in Holocene sediments of south part of Japan Sea. The electron microscopic study has shown that each *Quercus* pollen grain is characterized by the differency of sculptural elements. All elements are in various size, form and their distribution on the grain surface. These elements may be combined in two groups: the basal and secondary ones. The basal group consists of verrucae, scabrae, rugulae and rod-like elements which form the type of a sculpture. Granules, rugules, spinula and perforation form the secondary group. These elements cover the basal ones or tectum.

Quercus mongolica type – the sculpture is verrucate, formed by larger and smaller 0.5–07 µm rounded and ellipsoidal verrucae, regularly distributed on the surface of the pollen grain at a relatively short distance from each other. The surface of large verrucae is covered with small wrinkles and granules (Pl. 1, fig. 1a, b).

Quercus variabilis type – the surface sculpture is verrucate, formed by large rounded verrucae of 0.84–1.24 µm in diameter. The verrucae are situated separately or fused in larger aggregates, forming elevations. Granules are discernable on the surface of the verrucae. The surface pattern does not differ near apertures (Pl. 1, fig. 2a, b).

Quercus serrata type – the sculpture is verrucate, formed by small 0.5–1.0 µm in diameter and ultrafine rounded and ellipsoidal verrucae, which are situated separately from each other and covered with granules and the smallest wrinkles. Perforations and granules are visible on the surface of the tectum (Pl.1, fig. 3a, b).

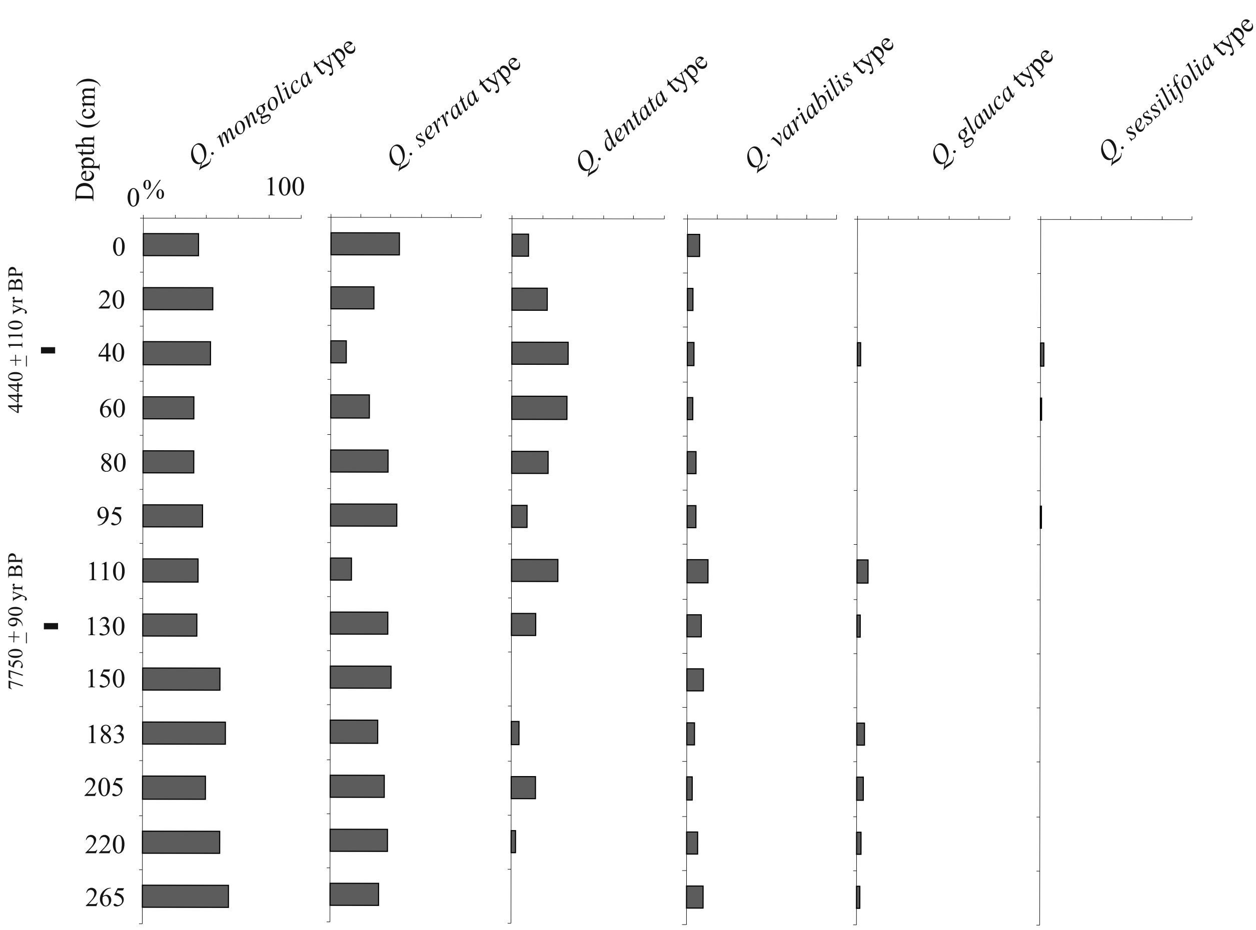

Fig. 3. Occurrence of fossil pollen grains of oaks of different types in deposits

Quercus dentata type – the sculpture is verrucate-granulate, formed by small 0.52–0.94 μm in diameter and ultrafine verrucae, which are spheroidal-angular and nearly rectangular, flat, irregularly distributed over the pollen grain surface, denser on the apocolpium. Main sculptural elements are covered with distinct smallest granules (Pl. 1, fig. 4a, b).

Quercus sessillifolia type – the sculpture is rugulate-echinate, formed by large wrinkles with depression between them. Granules and small wrinkles are visible on the surface of large wrinkles (Pl. 1, fig. 5a, b).

Quercus glauca type – of sculpture is presented by unique partially fused vertical rod-like elements. The sculpture is formed by rhomboidal, oval, and elongated elements, which are covered with numerous fine granules. The texture is with perforations (Pl. 1, fig. 6a, b).

Four of them were assigned to deciduous oaks (*Q. mongolica* type, *Q. variabilis* type, *Q. serrata* type, *Q. dentata* type) and two were assigned to evergreen oaks (*Q. glauca* type, *Q. sessillifolia* type).

The results of SEM pollen analysis are shown in Fig. 3. *Q. mongolica* (32.0–54.4%) and *Q. serrata* (10.2–45.9%) constantly dominate in the sampled core. However, a significant representation of *Q. mongolica* (40.0–54.4%) was found from 275 to 150 cm. The percentages of *Q. dentata* pollen is variable (0.0–36.7%); these pollen grains are numerically prominent from 130 to 20 cm. Pollen grains of *Q. variabilis* comprise less than 14% throughout the sequence. Pollen grains of *Q. sessillifolia* and *Q. glauca* are rare in all the samples.

DISCUSSION

The analysis of palynological records in detail show the changes in surrounding vegetation during Holocene caused by climatic fluctuations. During the Holocene, the northeastern coast of the Korean Peninsula was covered with arboreal vegetation.

In the Preboreal and Boreal phases (10300–8000 yr BP), the coastal vegetation was characterized by the presence of deciduous broadleaved forests comprising ferns. *Quercus mongolica* and *Q. serrata* were dominated in this forest with percentage of *Betula*, *Corylus*, and *Alnus*. Deciduous *Juglans*, *Tilia*, *Ulmus*, and *Salix* were rare. The pinaceous conifer forests of *Abies*, *Picea*, and *Pinus* subgenus *Haploxylon* with *Ephedra* and Ericaceae grew at on higher elevations. The herbaceous assemblages contained *Artemisia*, Poaceae, Chenopodiaceae, Apiaceae, and Urticaceae. The climate was rather cold and dry in this time. About 9000 yr BP, the maximal concentration of CO_2 (up to 380 ppm) was detected in the atmosphere as well as increased solar radiation in the northern hemisphere in summer period (Neftel et al. 1982, Lorius et al. 1985). In June, solar radiation was 7% higher than nowadays. As a result, the seasonal range of temperatures considerably increased. The temperature contrasts warming the continent and ocean increased promoting the monsoons (Kutzbach 1981). The majority of thermophilic plants have been eliminated by cold winters, even though summers were relatively warm.

The Atlantic phase (8000–4500 yr BP) corresponds to a climatic optimum of Holocene. Mean annual temperature in Korea was 2–3°C higher than nowadays (Sohn 1984). The observed changes testify to the reduction of areas occupied by coniferous forests. In deciduous forests, many arboreal elements were replaced by oaks. The deciduous oaks *Quercus mongolica*, *Q. dentata*, *and Q. serrata* took insignificant part in the coastal vegetation. The most favorable conditions existed during that time for the development of these forests. In this time, the deciduous *Quercus* forests prevailed over a wide range in the Korean peninsula (Tsukada 1977, Jo 1979, Yasuda et al. 1980, Chang & Kim 1982, Fujiki & Yasuda 2004). *Fagus* pollen grains was not recorded in Korea but appeared in high percentages in Japan (Yasuda 1982, Tsukada 1986). Hence, the climate Korean Peninsula was considerably drier. Most likely these differences were related to the influence of the warm Tsushima Current, which influence on southern part of the Sea of Japan 8000 yr BP became similar to the modern situation (Ujiie & Ujiie 1999, Oba 1983). Besides, pollen of evergreen oaks *Quercus serrata* and *Q. sessillifolia* were recognized in this zone. It is allowing us to conduct about warming of the climate in that time. However, now evergreen *Q. glauca* grows only at the southernmost of the Korean Peninsula. Hence, boundary of evergreen forests was located to the north from its recent position.

Q. sessillifolia occures in evergreen forests of the Japanese Islands and in Central and Eastern China (Menitskii 1984). Most probably, pollen was transport into sediments by wind or water streams from long-distance regions. Temperature differences between northern and southern parts of the Korea Peninsula remarkably increased to the end of this phase (Sohn 1984).

The Subboreal phase was characterized by the dominance of secondary forest elements, such as *Pinus* subgenus *Diploxylon* (most likely *P. densiflora*), and decline of deciduous broad-leaved trees, accompanied with the rapid increase of herbs. It could mean not only about a minor cooling of a climate but also about human influence on natural vegetation (Fujiki & Yasuda 2004, Chung 2006). In this time, *Quercus mongolica* and *Q. serrata* dominated the warm-temperate deciduous broad-leaved tree zone.

CONCLUSION

The analysis of palynological records reveals changes in vegetation of the northeastern coast of the Korean Peninsula during the Holocene caused by climatic fluctuations. Climate was relatively cool and dry in the Preboreal and Boreal phases. These climatic conditions were suitable for the growth of deciduous broad-leaved forests. The pinaceous conifer forest grew at high elevations. The Atlantic phase is regionally recognized as the Holocene climatic optimum. The observed changes testify to considerable reduction of conifer forests. In deciduous forests, many arboreal elements were replaced by oaks (*Quercus mongolica*, *Q. dentata*, *Q. serrata*). The Subboreal phase was characterized by the dominance of *Pinus* subgenus *Diploxylon* (most likely *P. densiflora*), which suggests a minor cooling of a climate as well as human impact on natural vegetation (Fujiki & Yasuda 2004, Chung 2006).

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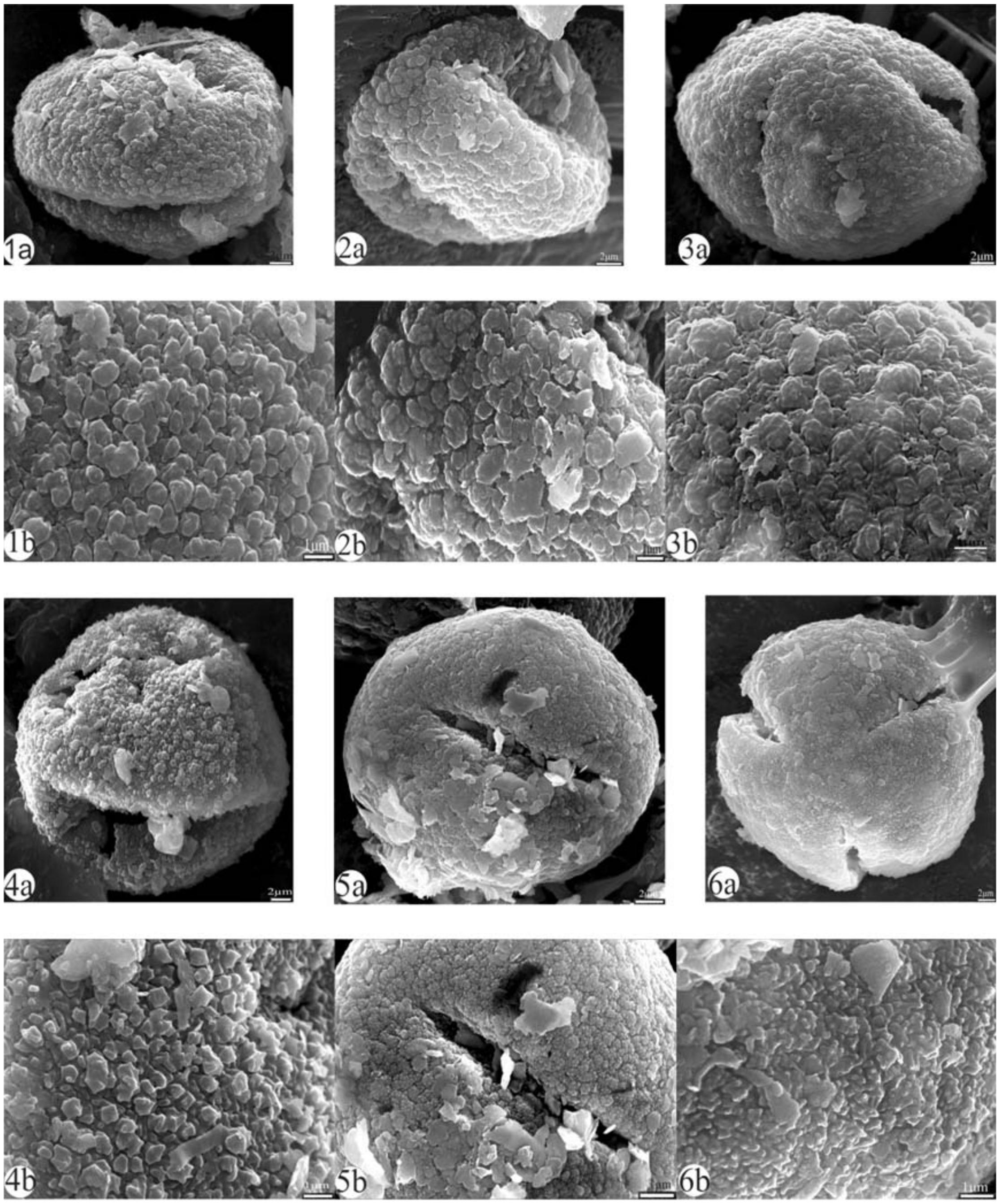
PLATE

Plate 1

Fossil *Quercus* pollen from Holocene sediments of East Korean Bay (Sea of Japan)

1. Fossil pollen grain *Quercus mongolica* – type
   a. general appearance, ×3740, SEM
   b. part of sculpture, ×10 000, SEM
2. Fossil pollen grain *Quercus variabilis* – type
   a. general appearance, ×4340, SEM
   b. part of sculpture, ×10 000, SEM
3. Fossil pollen grain *Quercus serrata* – type
   a. general appearance, ×2300, SEM
   b. part of sculpture, ×10 000, SEM
4. Fossil pollen grain *Quercus dentata* – type
   a. general appearance, ×3740, SEM
   b. part of sculpture, ×10 000, SEM
5. Fossil pollen grain *Quercus sessillifolia* – type
   a. general appearance, ×4340, SEM
   b. part of sculpture, ×10 000, SEM
6. Fossil pollen grain *Quercus glauca* – type
   a. general appearance, ×2300, SEM
   b. part of sculpture, ×10 000, SEM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