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Botanical Garden-Institute FEB RAS
Makovskii Str. 142
Vladivostok 690024 RUSSIA

http://www.geobotanica.ru/bp

botanica.pacifica@icloud.com
krestov@biosoil.ru
v_bak@list.ru

RESEARCH PAPER

Mid-Holocene Vegetation and Environments on the Northeastern Coast of the Korean Peninsula

Tatiana A. Evstigneeva *, Natalia N. Naryshkina

Tatiana A. Evstigneeva *
melnikova@ibss.dvo.ru

Natalia N. Naryshkina
naryshkina@ibss.dvo.ru

Institute of Biology and Soil Science
Vladivostok 690022 Russia

* corresponding author

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ABSTRACT

The pollen and spores from sediments of the core recovered from the shelf zone of the East Korea Bay, Eastern Sea (Sea of Japan) were studied. The vegetation of the northeastern coast of the Korean Peninsula was reconstructed based on pollen records. The most favorable conditions existed in mid-Holocene for the development of oak broadleaved forests. Fossil pollen grains of *Quercus* L. were studied with application of scanning electron microscope. Six types of fossil pollen grains were revealed: four types of them were assigned to deciduous oaks and two types to evergreen oaks. The deciduous oaks *Q. dentata*, *Q. mongolica*, and *Q. serrata* took significant part in vegetative associations of coast in mid-Holocene time.

Keywords

pollen, vegetation history, Holocene, East Asia, marine bottom sediments, *Quercus*

РЕЗЮМЕ

Евстигнеева Т.А., Нарышкина Н.Н.
Растительность и климатические условия северо-восточного побережья Корейского полуострова в среднем голоцене

Изучены пыльца и споры из отложений колонки, отобранной в шельфовой зоне Восточно-Корейского залива (Японское море). Реконструирована растительность северо-восточного побережья Корейского полуострова. В среднем голоцене существовали самые благоприятные условия для развития дубовых широколиственных лесов. С помощью сканирующего электронного микроскопа изучены ископаемые пыльцевые зерна *Quercus*. Выделены шесть типов ископаемых пыльцевых зерен: из них четыре типа относятся к листопадным дубам и два типа – к вечнозеленым. Листопадные дубы *Q. mongolica*, *Q. dentata* и *Q. serrata* принимали значительное участие в растительных ассоциациях побережья в среднеголоценовое время.

Ключевые слова

пыльца, история растительности, голоцен, Восточная Азия, морские донные отложения, *Quercus*

INTRODUCTION

Although the Holocene postglacial period was characterized by global climatic warming, the warmest conditions existed in the mid-Holocene (8000–4500 yr. BP). A study of fossil pollen and spores during this period is very important for understanding the modern vegetation history.

The Holocene vegetation history of the Korean Peninsula based on pollen analysis was previously described by Jo (1979, 1980, 1987), Yasuda et al. (1980), Chang & Kim (1982), Yoon & Jo (1996), Choi (1998), Lee & Yim (2002), Yi et al. (2004, 2008), Fujiki & Yasuda (2004), Chung (2006), Jun et al. (2010), and Chung et al. (2010). However, most investigations have been conducted in the southern part of peninsula, whereas our researches focused on the northeastern coast of the Korean Peninsula (Evstigneeva & Naryshkina 2012). In this study we reconstruct the mid-Holocene vegetation on the northeast peninsula using pollen records. Additionally, we have identified species of *Quercus* L. fossil pollen grains using a scanning electron microscope (SEM) and clarified more detailed vegetation associations.

The northeastern coast of the Korean Peninsula is a temperate vegetation zone (Box & Fujiwara 2012), where the climate of area is controlled by East Asian monsoon (Drozdov et al. 1989). During winter, high pressure air masses develop over inland Siberia, from which strong northwestern winds bring dry, cold air. The summer monsoon brings warm and abundant moisture from the ocean, and produces heavy rainfalls (average annual precipitation about 1500 mm). The mean temperatures in July and in January are +22 °C and −21 °C, respectively. The peninsula is mountainous, with heights of up to 2000 m. Flat sites lie in the coastal zone. The modern vegetation of the area is warm-temperate deciduous broad-leaved forest consisting of *Quercus mongolica*, *Q. aleina*, *Q. serrata*, *Q. dentata*, *Q. variabilis* and *Q. acutissima* (Okumura 1974). Above 1400–1600 m,

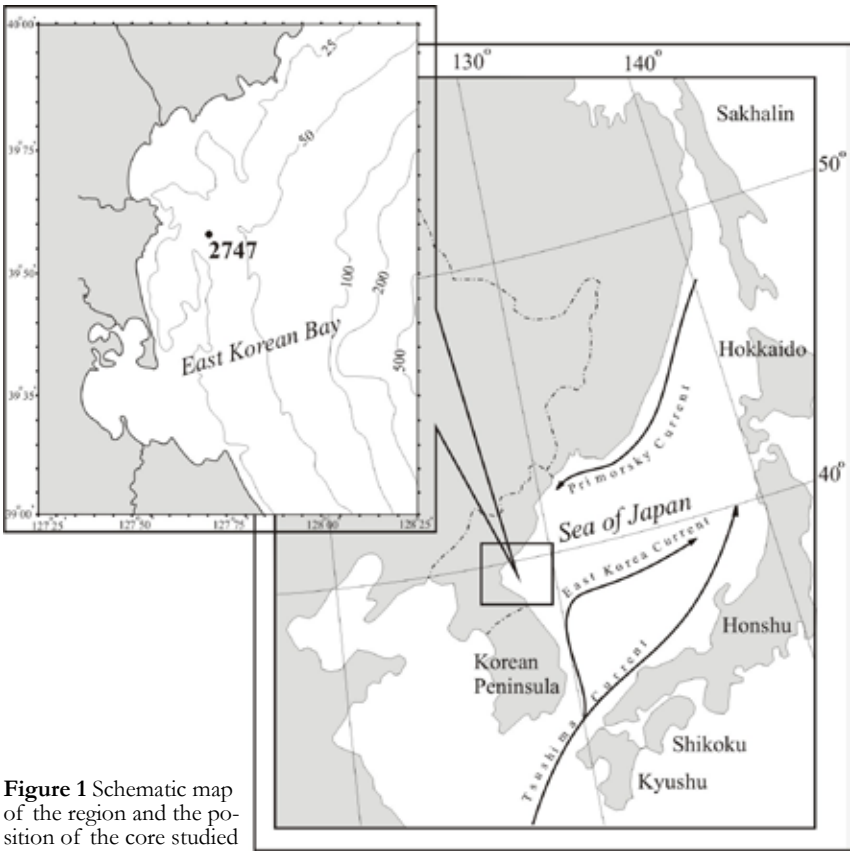

Figure 1 Schematic map of the region and the position of the core studied

the forest is coniferous, composed of *Pinus koraiensis*, *P. densiflora*, *Picea koraiensis*, *Abies holophylla* and *Taxus cuspidata*.

MATERIALS AND METHODS

Core 2747 (280 cm in length) was recovered during a 1989 cruise of the RV "Professor Bogorov", from the shelf zone of the East Korean Bay (Fig. 1). The sediments are clays and siltstones admixed with organic debris and coquina (Fig. 2). The radiocarbon dating of samples from the core was carried out in the Laboratory of geochemistry of isotopes and geochronology of Geological Institute RAS, Moscow with results shown in Table 1. According to Markov et al. (2008), micropaleontological analyses and radiocarbon dating restrict the sediments to the Holocene.

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 a light microscope in glycerine jelly. From 300 to 650 pollen grains and spores were counted for most samples. The percentage ratios for each taxon of pollen and spores were calculated from the total palynomorph sum.

Samples for observation were mounted for SEM (ZEISS EVO-40). The material was dehydrated in series of ethanol solutions (50, 70, 90 %), 15–20 min in each (Gapochka & Chamara 1988). The samples were then set on sample stands and covered with gold under vacuum. Fifty fossil pollen grains of *Quercus* were identified at species level in a sample given at 60 cm depth. The percentage ratios for each type of *Quercus* fossil pollen were then calculated from the total sum of pollen grains *Quercus*.

RESULTS

A variety of fossil pollen and spores were detected in seven samples from depths of 10 to 135 cm. According to radiocarbon dating this interval corresponds to mid-Holocene. Palynomorphs were divided into arboreal pollen, non-arboreal pollen and spores.

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

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

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

Arboreal pollen (Fig. 2) is dominated (55.2–82.5 %); the abundance of non-arboreal pollen (11.9–27.3 %) is slightly higher than that of spores (5.6–17.5 %). Pollen grains of deciduous trees make up 29.5–57.0 %, mostly at the expense of *Quercus* (21.8–44.2 %), *Betula* (0.9–6.7 %), *Corylus* (0.6–4.7 %), *Alnus* (1.7–4.9 %), and *Juglans* (0.3–3.1 %). The amount of conifer pollen varies from 10.2 to 47.0 % constituted by *Pinus* subgenus *Diploxylon* (3.9–35.9 %), *P.* subgenus *Haploxylon* (2.2–10.1 %), *Picea* (1.8–3.9 %), and *Abies* (1.3–3.8 %). *Ephedra*, *Ulmus*, *Castanea*, *Carpinus*, *Carya*, *Tilia*, *Acer*, *Syringa*, *Cornus*, and *Salix* pollen comprised less than 1 %. Non-arboreal pollens are dominated by the Asteraceae (3.0–9.5 %), mostly by *Artemisia* (2.7–7.8 %). Pollen grains of the Poaceae (0.3–4.7 %) and Chenopodiaceae (0.8–1.7 %) are less numerous. Pollen grains of the Caryophyllaceae, *Polygonum* subgenus *Persicaria*, *Sanguisorba*, Fabaceae, Apiaceae, *Ambrosia*, *Typha*, *Polygala*, and Urticaceae comprised less than 1 %. Spores were prevalent in members of the Filicales monolete (5.1–16.4 %), whereas *Sphagnum*, *Lycopodium*, and *Osmunda* spores comprised less than 1 %.

Using a SEM, six types of fossil pollen grains of *Quercus* are identified in Holocene sediments of the southern part of the Japan Sea (Naryshkina & Evstigneeva 2009). The electron microscopic study has shown that the *Quercus* pollen grain studied differ from each other by sculptural ele-

Table 1 Radiocarbon dates of samples from core

Depth (cm)	Laboratory No.	Age (yr. BP)
35–42	GIN-13286	4440 ± 110
120–130	GIN-13287	7750 ± 90

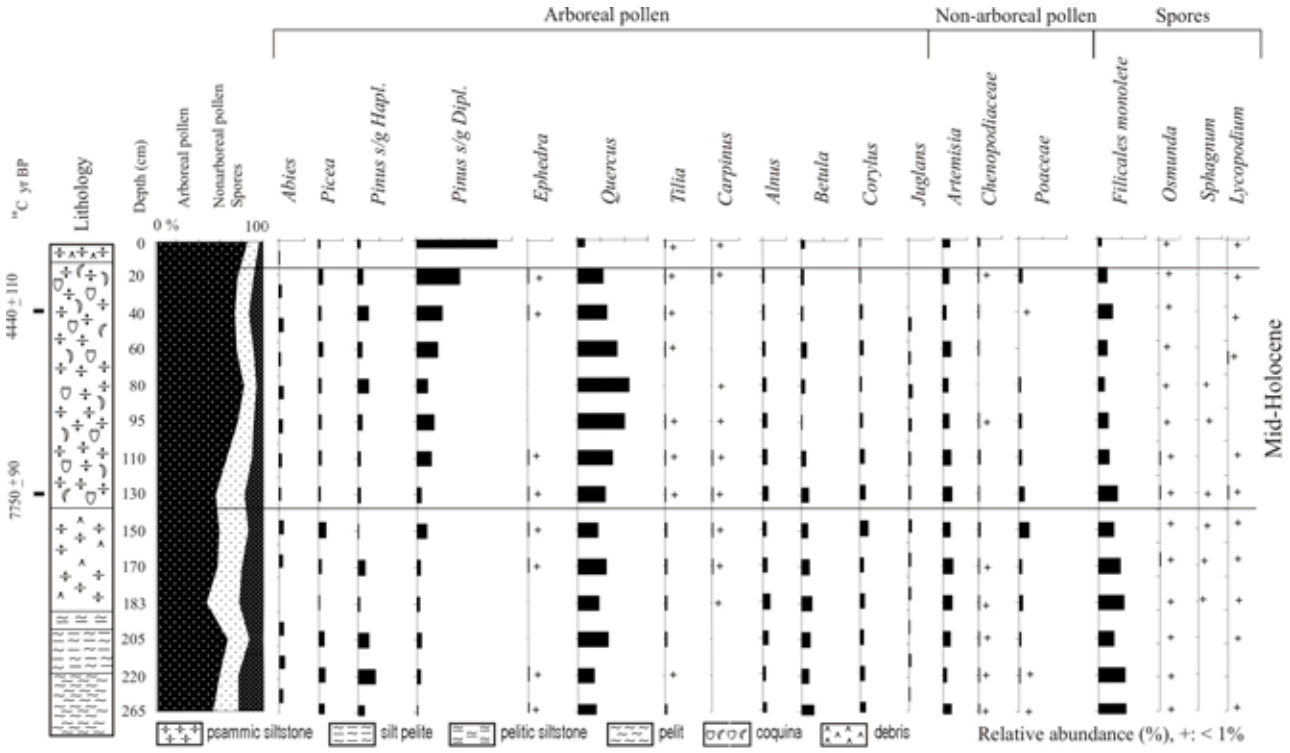

Figure 2 Palynological diagram of the main pollen types of core 2747

ments. All elements differ in size, form and their distribution on the grain surface. These elements may be combined in two groups: basal and secondary. The basal group consists of verrucae, scabrae, rugulae and rod-like elements, which form the sculptural type. Granules, rugules, spinula and perforation form the secondary group. These elements cover the basal ones or tectum.

Q. mongolica type – the sculpture is verrucate, formed by larger and smaller 0.5–07 μm rounded and ellipsoidal verrucae, evenly 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. 1 a, b).

Q. variabilis type – the surface sculpture is verrucate, formed by large rounded verrucae 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. 2 a, b).

Q. serrata type – the sculpture is verrucate, formed by small 0.5–1.00 μm in diameter and ultrafine rounded and ellipsoical 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. 3 a, b).

Q. 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. 4 a, b).

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

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

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

The results of SEM pollen analysis are shown in Fig. 3. Most pollen grains belonged to the *Q. dentata* type (36 %) and *Q. mongolica* type (32 %). The ratio of *Q. serrata* type was 26 %; that of *Q. variabilis* type was 4 %, that of *Q. sessillifolia* type was 1 % and that of *Q. glauca* type was 1 %. Pollen of evergreen oaks *Q. glauca* and *Q. sessillifolia* were recognized in this sample. However, today evergreen *Q. glauca* grows only at the southernmost Korean Peninsula, while *Q. sessillifolia* occurs in evergreen forests of the Japanese Islands and China (Menitskii 1984). Most likely, pollen of these evergreen *Quercus* species was transported into sediments by wind or water streams from long-distance.

To south of the core 2747, pollen grains of *Quercus* were identified in mid-Holocene sediments of Lake Hyangho located in the northeastern coast area of the Korean Peninsula (Fujiki & Yasuda 2004). Most pollen grains of *Quercus* belonged to the *Q. variabilis* type (36.2 %) and *Q. dentata* type (32.6 %). The percentage ratio of *Q. serrata* type was 13.8 %, that of *Q. aliena* type was 8.7 %, that of *Q. crispula* type was 1 %, and that of *Q. acutissima* type was 1 % (Fig. 3). All these *Quercus* types are assigned to deciduous oaks.

To north of the core 2747, fossil pollen grains of *Quercus* were identified in mid-Holocene sediments of the

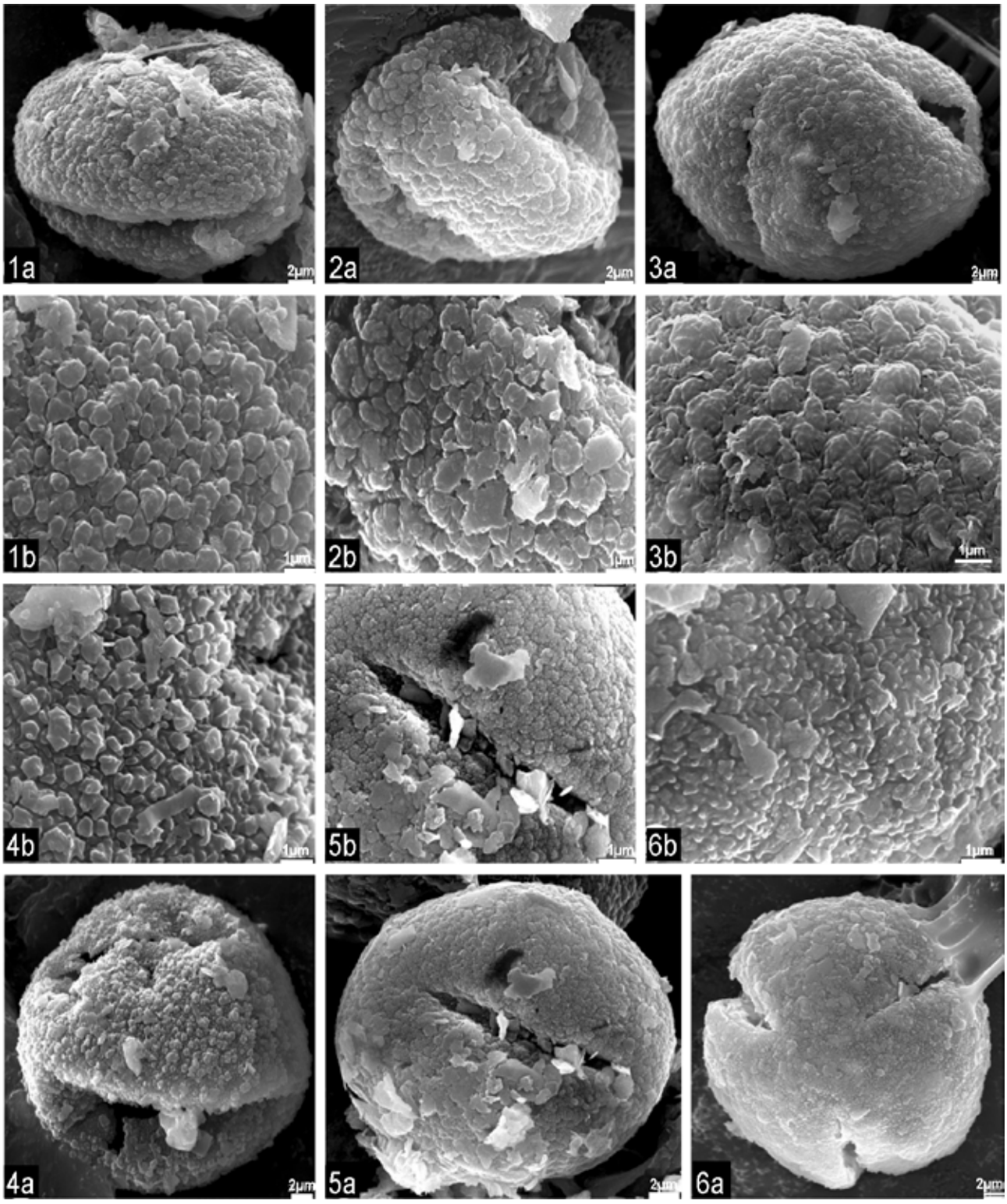

Plate 1 Fossil *Quercus* pollen types from Holocene sediments of East Korean Bay.

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

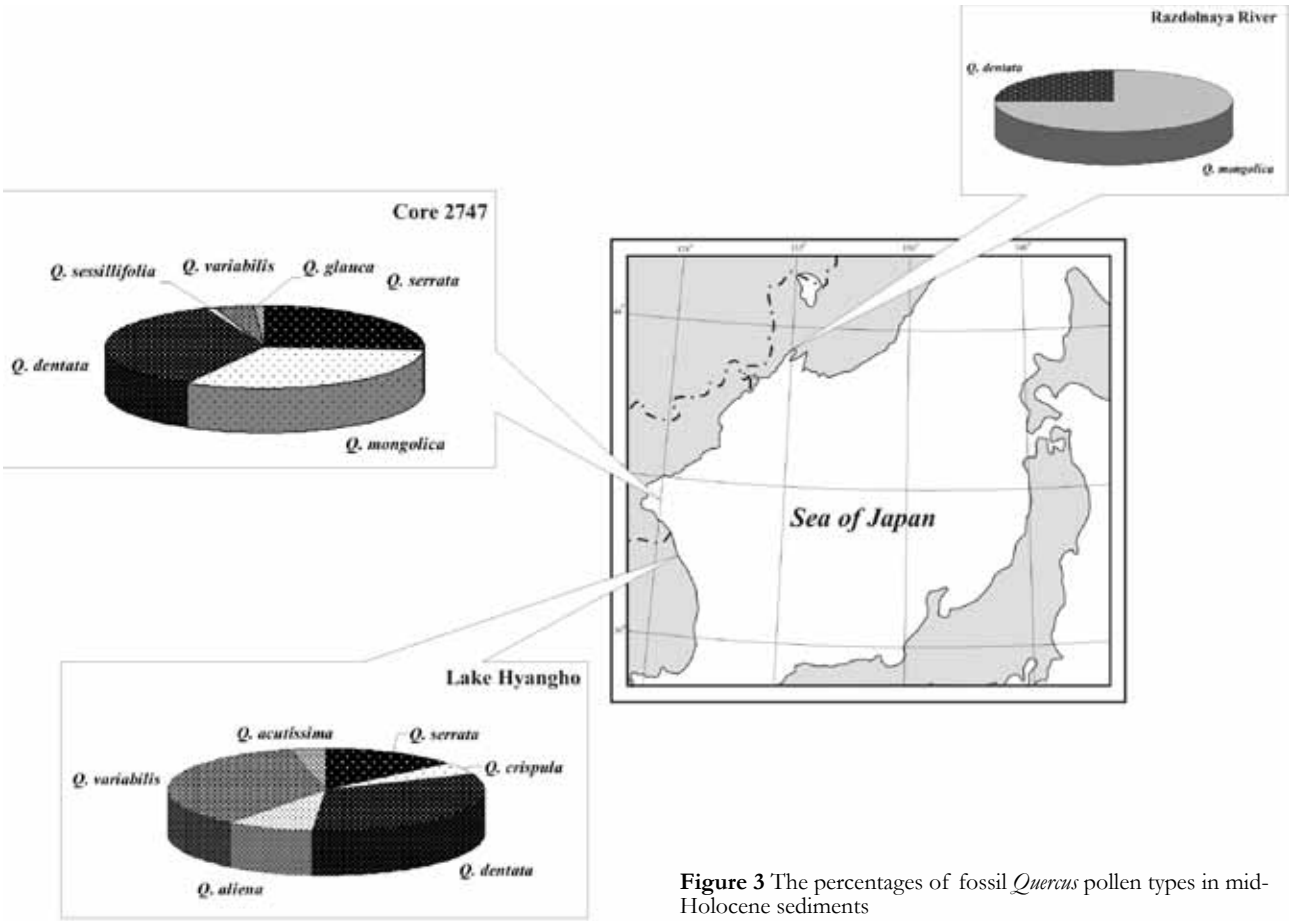

Figure 3 The percentages of fossil *Quercus* pollen types in mid-Holocene sediments

Razdolnaya River valley (Southern Primory'e, Far East of Russia) (Naryshkina 2005). Two types of deciduous oaks (*Q. mongolica* and *Q. dentata* types) were recognized. The appearance ratio of the *Q. mongolica* type was 75 %, and *Q. dentata* type was 25 % (Fig. 3).

DISCUSSION

The palynological records reveal vegetation on northeast of the Korean Peninsula during the Holocene. This paper focuses mainly on the vegetation and environments of mid-Holocene (8000–4500 yr BP). The high proportion of arboreal pollen (about 82.5 %) and negligible amounts of non-arboreal pollen and spores (Fig. 2) indicate a closed forest. During this period, *Quercus*-dominated deciduous broadleaved forests with ferns flourished on the neighboring hills and mountainous area. The deciduous oaks *Quercus mongolica*, *Q. dentate*, and *Q. serrata* occupied a significant part of vegetation associations of the coast. Other deciduous tree species, such as *Corylus*, *Alnus*, *Juglans*, *Castanea*, *Carpinus*, *Carya*, *Tilia*, *Acer*, *Syringa*, *Cornus*, *Ulmus*, and *Salix*, are also represented. The conifer forests consisted of *Abies*, *Picea*, *Pinus* subgenera *Diploxylon* and *Haploxylon* with cold-tolerant *Betula* on mountain tops. Herbaceous steppe and meadow vegetation consisted of Asteraceae, Chenopodiaceae, Urticaceae, *Ephedra*, Caryophyllaceae, *Polygonum* subgenus *Persicaria*, *Sanguisorba*, Fabaceae, Apiaceae, *Polygala*, and Poaceae.

The deciduous *Quercus* forests prevailed over a wide range of the east coast of the Korean peninsula during this time (Yasuda et al. 1980, Jo 1987, Fujiki & Yasuda 2004, Yi et al. 2008). A high concentration of *Q. dentata type* (Fig. 3) allows to assume that this species of oak, probably, was more widespread along the west coast of the Sea of Japan than it is today.

Whereas, in southeastern and central regions of the Korean Peninsula, evergreen broad-leaved trees, such as *Quercus* subgenus *Cyclobalanopsis* and *Castanopsis* appeared. *Alnus*-dominated deciduous forests covered extensive lowlands of the west coast of the Korean peninsula (Yasuda et al. 1980, Jo 1987, Fujiki & Yasuda 2004, Yi et al. 2008).

In China, in mid-Holocene time, the northern limit of broad-leaved evergreen forests was 200 km further north than present (Winkler & Wang 1993, Yafeng et al. 1993, Yu et al. 1998, 2000, Xiaoqiang et al. 2004, Jiang et al. 2006, Tarasov et al. 2006). Temperate deciduous forests occurred 800 km north of its present limit, in the zone occupied today by cool mixed forest and taiga. In northwestern China, the area of desert and steppe vegetation was reduced compared to present.

In mid-Holocene, broad-leaved deciduous forests also have been extensively developed in southern part of the Russian Far East (Karaulova et al. 1978, Golubeva & Karaulova 1983, Kuz'mina et al. 1987, Verkhovskaya & Kundyshev 1995, Korotkii et al. 1996). Oak forests reached the latitudes 50–52° N along the coast of the Sea of Japan and the Ussuri River valley. Vegetation zones were 600-700 km north of today, and the mountains up to 700 m higher.

Deciduous broad-leaved forests dominated by *Quer-*

cus, *Ulmus* and *Juglans* were spread in the south-east of the Sakhalin Island (Mikishin & Gvozdeva 1996). Small groves of broadleaf trees grew near the coast in northern Sakhalin (Mikishin & Gvozdeva 2007).

Quercus subgenus *Lepidobalanus* and *Fagus* were co-dominant taxa in northeastern Japan, and *Quercus* subgenus *Cyclobalanopsis* and *Castanopsis*, in southwestern Japan (Tsukada 1988). Temperate deciduous forests were predicted at elevations up to 500 m higher than today (Takahara et al. 2000). Another characteristic feature is that, in mid-Holocene time, the subalpine and temperate coniferous forests were completely separated into three distinct regions: southwestern Japan, the central mountains, and Hokkaido.

Additionally, the difference between two regions along the Sea of Japan in this time should be mentioned. *Fagus* pollen grains do not appear in Korea but appear in high percentages in Japan (Tsukada 1982). Hence, the climate of the Japan aspect was more humid. Most likely it has been influenced by the warm Tsushima Current, which, on southern part of the Sea of Japan 8000 yr BP, became similar to the modern situation (Ujiie & Ujiie 1999, Oba 1983).

Thus, shifts of vegetation zones reflect a significant difference between the warmest climatic conditions existed in the mid-Holocene and recent climates of southern part of East Asia.

In the Northern hemisphere, the summer solar radiation peaked at about 9000 yr BP. It was 7 % higher than at present (Kutzbach 1981, Neftel et al. 1982, Lorius et al. 1985). As a result, the seasonal range of temperatures increased considerably. The summers were very warm, and winters cold (Krassilov et al. 1985, Kutzbach & Street-Perrott 1985, An et al. 2000). Therefore a majority of thermophilic plants was unable to be sustained.

In the mid-Holocene, the climate became milder with warmer winters. More proportional solar radiation per season led to a decreased annual range of temperatures: July temperatures slightly decreased, and January temperatures increased (Prell & Kutzbach 1987). Mean annual temperature in East Asian was 2–5 ºC higher than nowadays (Yasuda 1982, Golubeva & Karaulova 1983, Sohn 1984, Tsukada 1986, Winkler & Wang 1993, Verkhovskaya & Kundyshev 1995, Kuzmin 1995, Korotkii et al. 1996, Mikishin & Gvozdeva 1996, Yi et al. 2003). However, the climate of this time was cooler than that of warm epochs of the Pleistocene (Golubeva & Karaulova 1983). Mid-Holocene warming has also been observed in pollen analyses in the East Asian region (Yasuda 1982, Golubeva & Karaulova 1983, Tsukada 1986, Winkler & Wang 1993, Verkhovskaya & Kundyshev 1995, Kuzmin 1995, Korotkii et al. 1996, Yi et al. 2003). This climatic event correlates with the Atlantic phase of the scheme Blytt-Sernander modified by Khotinskii (1977).

Mid-Holocene hypsithermal conditions had a profound influence on the whole environment. The temperature of the Sea of Japan water surface was 1–2 ºC higher in that time than at present (Pletnev 1985). Warm waters of the Tsushima Current reached the northern coast of Hokkaido Island and penetrated into the Sea of Okhotsk through the La Perouse Strait (Taira 1992, Taira & Lutaenko 1993). The East Korean Current influenced the coast of the Primorkii Region of Russia up to 40ºN pushing off cold waters of the Primorskii Current (Korotkii et al. 1996). The sea level in the area of the Japanese Islands was 2–6 m higher than the modern level (Fujii & Fuji 1967, Sakaguchi 1983, Umitsu 1991; Mikishin & Gvozdeva 1996, Hwang 1998, Korotkii et al. 1996, Markov et al. 2008). Therefore, large areas of coastal lowlands were submerged by sea water.

Thus, palynological and paleogeographical data studied here indicate that in mid-Holocene the conditions in southern part of East Asia were wetter and warmer than those of present in most areas of East Asian region.

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