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EVOLUTION OF LANDSCAPES IN KHASANSKY DISTRICT (SOUTHWEST PRIMORYE) IN LATE PLEISTOCENE – HOLOCENE

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Khasansky District is located in southwest of Primorye, Russia and occupies approx. 4000 km^2 of land on the coast Peter the Great Bay (Fig. 1).

The **relief** of Khasansky District is represented by spurs of Cherniye Mountains getting lower toward the sea coast from 900–800 m to 400–200 m and passing into low (30–100 m) gently rugged massifs. The seacoast terrace zone is normally not wide and grows up to 3–5 km in river valleys. It increases to 20–40 km in active drift accumulation zones of large rivers – Tumannaya (Tumen R.) and Razdolnaya (Suifun R.) (Fig.1). The height of accumulative terraces gradually grows from 1–2 m near the seacoast to 7–8 m and, less frequently, more near backland areas.

Climate in this region is temperately monsoonal, with dry winter seasons and warm humid summer seasons. Mean air temperature in January varies from minus 10.2°C on the coast to minus 16.7°C at a distance from the sea; in August – 19.9°C and 21.0°C respectively. Mean yearly temperature varies in the range of 5.2–5.7°C on the coast to 3.1°C in inland areas. Mean yearly precipitation is 670 to 1,050 mm (Applied Scientific…, 1988).

Vegetation cover consists of low oak growths, shrub growths, grass meadows and bogs. Accumulative terraces are occupied by reed-grass/ sedge meadows, mixed herb/ grass meadows and, less frequently, bogs. Terrain undulations and low-hill terrain are covered with thin oak forests with low growths of hazel, lespedeza and well developed grass cover. There are multi-species broad-leaved forests, dominated by maple and linden varieties and including oak, birch, lilac, in Cherniye Mountains. Coniferous tree species such as fir, spruce, Korean pine (*Pinus koraiensis*) grow in small numbers here. Pine (*Pinus densiflora*) is met very seldom: on steep-faced banks and rocky mountain slopes. The highest (600–900 m) mountain watershed areas are occupied by pine/broad-leaved forests with fir and spruce. Forest vegetation, dominant in this region, occupies 65 % of territory (Valova, 1967).

Subfossil spore-pollen spectra of this region are of a forest type with tree and shrub pollen dominating in their composition, varying from 54 % to 70 % on average depending on genesis of deposits (Mikishin et al., 2002 a). Broad-leaved trees dominate in pollen, accounting for 34–40 % of its spectrum. Oak (*Quercus*) pollen dominance is observed everywhere, accounting for 23–33 % on average and going down up to 16 % in river deposits, and, in general, truly reflects its contribution to the region's vegetation cover. Other often observed pollens of bro-

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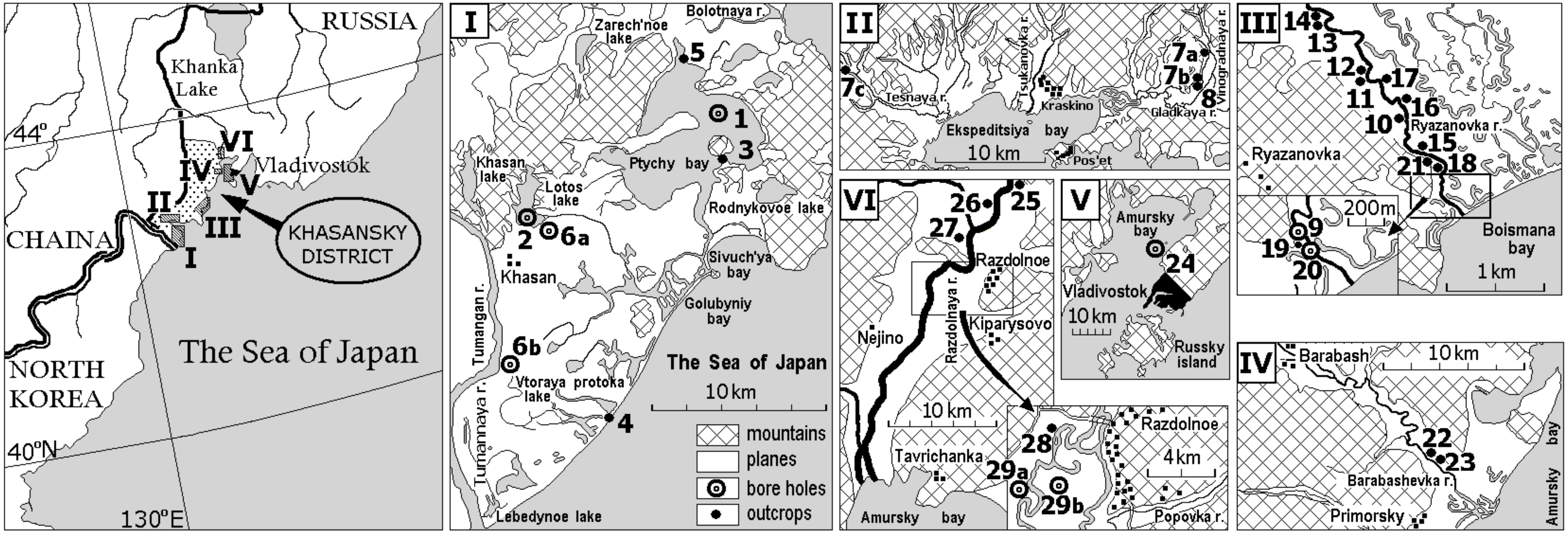

Fig. 1. Locations of Sections in Pleistocene and Holocene Deposits of Khasansky District

I. Khasanskaya Plain: 1 – Skv. Talmi, 2 – Skv. Doritsine, 3 – Lagernyi, 4 – Primetnyi Kholm, 5 – 5-meter terrace of Talmi Lake (Alexeyev, 1978; Golubeva, Karaulova, 1983), 6 a – Skv. 25, 6 b – Skv. 31 (Pavlutkin, Belyanina, 2002). *II. Coast of Expeditsiya Bay:* 7 a – 10-meter terrace of Vinogradnaya R. near Deer Farm (a), 7 b – 7-meter terrace in lower reaches of Vinogradnaya R., 7 c – 10-meter terrace of Tesnaya R. (Alexeyev, 1978; Golubeva, Karaulova, 1983), 8 – Vinogradnaya-272, 4-meter terrace of Vinogradnaya R. *III. – Coast of Boismana Bay:* 9 – Skv. 3, 10 – Pb-3, 11 – Pravyi Bereg, 12 – Pravyi Bereg-99, 13 – Pb-036, 14 – Doroga-98, D-2, 15 – Levyi Bereg-028, 16 – Levyi Bereg, 17 – Lb-4, 18 – Oyster Bed-2, 19 – Site-2, 20 – Skv. 4, 21 – Moika-2. *IV. Barabashevka R. Valley:* 22 – Mangugai, 23 – Barabashevka R., 4-meter terrace of Barabashevka R. (Korotkiy et al., 1980; Karaulova, Golubeva, 1983). *V. Amur Bay:* 24 – Skv. 2 (Karaulova et al., 1973; Troyitskaya et al., 1978, Kuzmin et al., 2004). *VI. Razdolnaya R. Valley:* 25 – R-11-Baranovsky, 26 – R-13, 27– R-14, 28 – R-19, 29 a – Skv. 5-4H», 29 b – Skv. 33 (Pavlutkin, Belyanina, 2002).

ad-leaved species are walnut (*Juglans*) – 3–9 % on average, elm (*Ulmus*) – 1–3 %, linden (*Tilia*) – up to 2 %, and hornbeam (*Carpinus*) – 1 % at most. The content of birch pollen (16–30 %) is higher than its role in vegetation cover. The content of coniferous tree pollens is also higher than their role in vegetation – this applies to Korean pine (*Pinus s/g Haploxylon*) – 18–26 % and, particularly, to pine (*Pinus s/g Diploxylon*) – 16–32 %.

Late Pleistocene and Holocene landscapes were reconstructed through integrated studies of deposits, opened by clearing out their exposed patches on river banks in Khasansky District and by drilling boreholes (Fig. 1), and by data of literature sources.

LATE PLEISTOCENE

Little is known about development of late Pleistocene landscapes in Khasansky District.

The oldest Upper Pleistocene deposits found in this area belong to the Last Interglacial Epoch. They are represented by river pebble with sand and estuary clay-aleurite deposits, which compose Khasansky Plain (Fig. 1-I, sections 6 a, b) and the near-estuary part of Razdolnaya R. valley (Fig. 1-VI, 29 a, b). Based on mollusk shells in the deposits, out-of-limit radiocarbon dates (>38000 and >45400 BP) and uranium/ionium date (80600±2900 yr BP) (K-171) were determined. Spore-pollen spectra in the deposits (Fig. 2 a) contain much pollen of oak (32–61 %), elm (5–23 %) and, in a lesser degree, of other broad-leaved trees: walnut (2–7 %), hornbeam (up to 8 %), hazel, linden, ash, lilac, viburnum (up to 2 %). Narrow-leaved trees are represented by pollens of birch (4–20 %) and, in a lesser degree, alder and willow (1–5 %). Coniferous tree pollens consist of Korean pine *Pinus s/g Haploxylon* (6–30 %) and, much less frequently, spruce (3–4 %) and pine *Pinus s/g Diploxylon* (Pavlutkin, Belyanina, 2002). The spectra reflect multi-species broad-leaved forest landscapes dominated by oak and with more elm than now, occupying hills and low-hill terrain along the coast. There were Korean pine/broad-leaved forests developing on the watershed crests of mountain ranges. Climate was warmer than now.

Upper Pleistocene deposits of the Last Glacial Epoch were studied in the river terrace deposits on the coast of Expeditsiya Bay. In the valley of Vinogradnaya R., on an exposed patch of the 10-meter terrace near a deer breeding farm (Fig. 1-II, 7 a), they are represented by river sands with clay interlayers, peat streaks and wood fragments in the range of 7.1–9.1 m (Alexeyev, 1978; Golubeva, Karaulova, 1983). On these, two radiocarbon dates were obtained: 35000±130 yr BP (ГИН-744) and >50000 yr BP (ГИН-1610). Spore-pollen spectra (Fig. 2 b, complex Vf-1) are dominated by dark-needle tree pollens: spruce – 40–65 % and, in a lesser degree, fir – 5–20 %. Other coniferous trees are represented by pollens of larch (7–15 %) and *Pinus s/g Haploxylon* (2–10 %). Among small-leaved trees, there is quite much pollen of birch (25–42%) and, in a lesser degree, alder. Frigid shrubs are represented by alder (up to 18 %) and shrub-like birch species (up to 25 %). There is no broad-leaved tree pollen. These spore-pollen spectra indicate at distribution of the medium

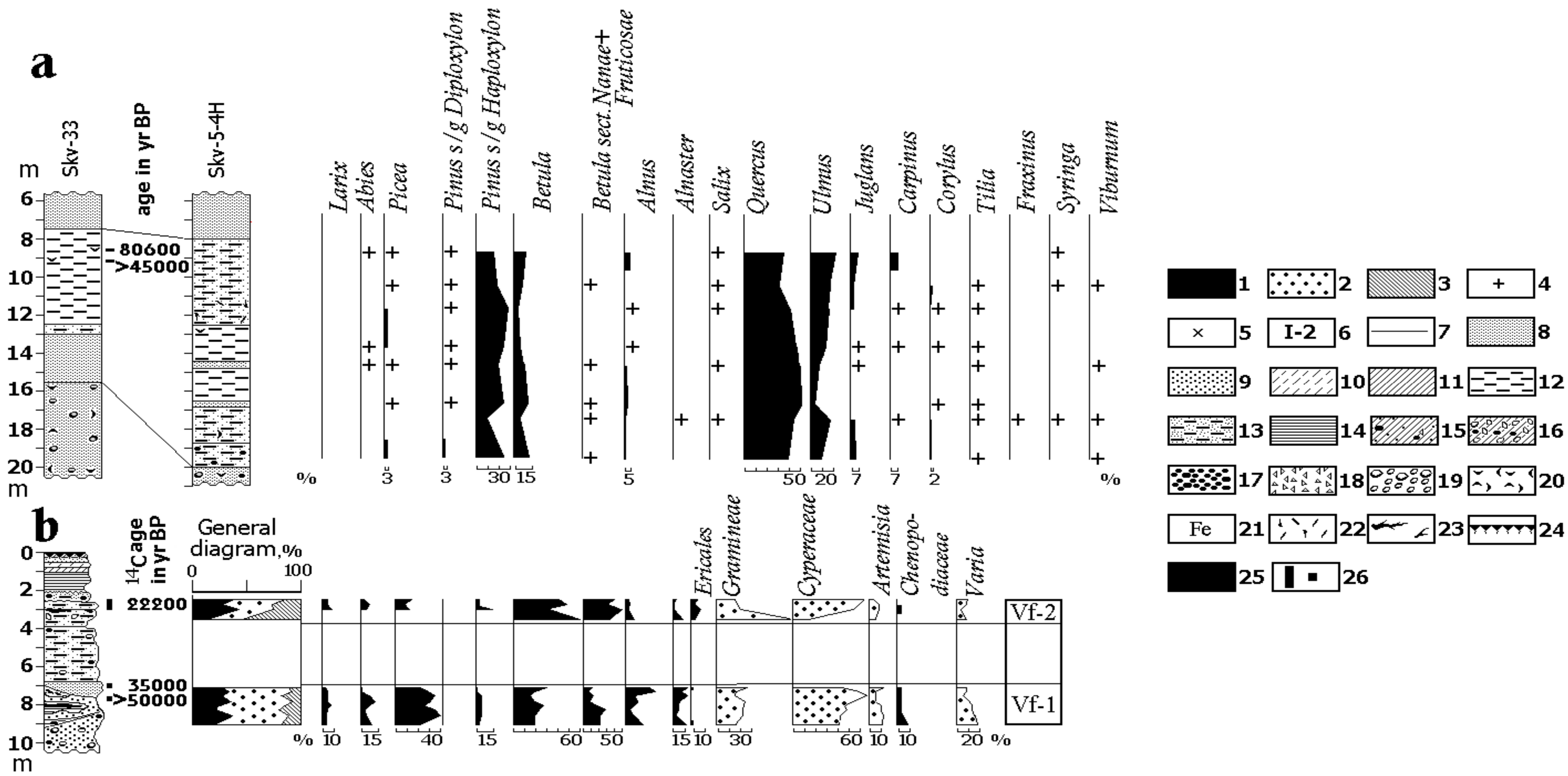

Fig. 2. Pollen Diagram of Upper Pleistocene Deposits: a – Razdolnaya R. Valley (Pavlutkin, Belyanina, 2002), b – 10-meter terrace of Vinogradnaya R. near Deer Farm (Alexeyev, 1978; Golubeva, Karaulova, 1983)

Pollen and spores*:* 1 – pollen of trees and shrubs, 2 – pollen of grasses and sub-shrubs, 3 – spores, 4 – pollen content less than 1 %, 5 – percentage content of pollen and spores was not counted, 6 – spore-pollen complex and its number, 7 – boundaries of spore-pollen complexes. Lithology: 8 – fine and medium sands, 9 – coarse sands, 10 – loamy sand, 11 – loamy clay, 12 – aleurite-pelitic silts, 13 – aleurite sands, 14 – clays, 15 – sandy loamy clays with gravel and broken rock, 16– broken rock and gravel with loamy clay joining material, 17 – gravel beds; 18 – gruss and crushed rock of roadbed, 19 – broken aleurolite rock, eluvium, 20 – sea shells and their fragments, 21 – ferruginous material; 22 – remainders of grass, seaweeds, small wood pieces; 23 – tree branches and trunks; 24 – turf layer of modern soil, 25 – peat and black-colored loamy clays with a high content of organic matter, 26 – sampling interval for radiocarbon dating.

taiga landscapes of spruce/fir and birch/larch forests, which developed in a colder climate than Riss-Wurm era and the present time.

Spore-pollen complexes, similar in composition but featuring a higher content of shrub-like birch (up to 40 %) and alder (up to 25 %) pollen, were registered in the bottom parts of other exposed deposits: 7-meter terrace in the lower reaches of Vinogradnaya R. (Fig. 1-II, 7 b) and in the middle reaches of Tesnaya R. (Fig. 1-II, 7 c). On these deposits, "middle Wurm" radiocarbon dates of 41400±1000 yr BP (ГИН-383) and >36000 yr BP (ГИН-747) were obtained. Some authors (Golubeva, Karaulova, 1983) believe that the first date from the section on the 7-meter terrace of Vinogradnaya R. should be older and these deposits had formed in the first half of the early Wurm glaciation, same as deposits in the bottom parts of other above mentioned terraces. Other researchers (Alexeyev, 1978) refer the time of their formation to the end of the first glacial stage – beginning of the middle Wurm (Karganian) interstadial. The new radiocarbon date of 35095±380 yr BP (СОАН-7180), obtained on the same deposits of the 4-meter terrace in Vinogradnaya-272 exposed area in the range of 2.93–3.04 m (Fig. 1-II – 8), is another evidence that the event dates back to Middle Wurm era.

Deposits of the Last Glacial Maximum were studied in the middle parts of sections in Vinogradnaya R. terraces (Alexeyev, 1978; Golubeva, Karaulova, 1983). In the exposed area of the 10-meter terrace near the deer breeding farm, they are represented by sandy silts with peat streaks and interlayers deposited in the interval of 2.4–3.0 m, on which the radiocarbon date of 22200±500 yr BP (ГИН-745) was obtained. In spore-pollen spectra (Fig. 2 a – complex Vf-2), the content of dark-needle tree pollen decreases: spruce (up to 17–22 %), fir (5–15 %). At the same time, there is more pollen of pine *Pinus s/g Haploxylon* (up to 15 %), which most likely belongs to Japanese stone pine (*Pinus pumila*). Of other coniferous trees, there is still much larch pollen (up to 10 %). Birch pollen dominates among small-leaved tree pollens, with that of shrub-like birches growing almost twice (up to 54 %). A very similar spore-pollen complex was registered in the section on the 7-meter terrace of Vinogradnaya R. in the interval of 2.38–5.35 m, in which spruce and fir pollen content was pronouncedly reducing versus growth and then full dominance of shrub-like birches (Alexeyev, 1978; Golubeva, Karaulova, 1983). Pollen spectra correspond to the distribution of northern taiga landscapes dominated by birch/larch forests and frigid shrub growths which developed in considerably colder climatic conditions than the present time. Dark-needle trees were of secondary importance.

Very little is known about **landscape development in the Late Glacial Period**. Deposits, characterizing one of its cold climatic phases, were studied on the coast of Boismana Bay at a distance of 1.4–3.2 km from the seashore. They were found in the base of the 3–4-meter terrace of Ryazanovka R. (Fig. 1-II, 11-14). These deposits are composed of dense lake clays with subangular pebble and broken rock inclusions, and of small pebble with a clayey joining material, overlain by gravel with a silty dark-gray joining material containing much vegetative detritus and many fragments of small shrub twigs. According to the radiocarbon date of

12240±160 yr BP (Tka-13007) – 14400±390 Cal. yr BP**, obtained on these deposits, they formed during the glacial stage of the Older Dryas. Spore-pollen spectra (Fig. 3 a – complex Pb-1) are dominated by alder pollen, accounting for nearly 90 % of the entire spectrum; other small-leaved tree species are represented by birch (1.7–4.4 %). Of coniferous trees, only pine pollen was found: *Pinus s/g Haploxylon* – 2–4 % and *P. s/g Diploxylon* – less than 1 %. As for broad-leaved tree species, there was not much pollen (no more than 5 % in aggregate): linden– 2–4 %, oak, elm – up to 1 % and hazel – less than 0.5 %. Grass pollen were dominated by wormwood (43–57 %) or, less frequently, by mixed herbs (Varia – 28–36 %) and sedges (Cyperaceae – 7–27 %). Spores were represented by ferns Polypodiaceae (up to 96 %) and, much less frequently, by *Osmunda*. The spore-pollen complex reflects alder forest and wormwood/mixed herb meadow landscapes, which developed in a much colder and drier climate than the present time.

HOLOCENE

The Early Holocene stage of landscape development in Khasansky District is better reflected in marine deposits of the coast than in continental deposits. The deposits of this time compose the base of the marine Holocene bottom section of Amursky Bay at a depth of 30–42 m below the present-day sea level (Fig. 1-V – 24). They are represented by lagoon silts with some broken rock, peat, seaweed fragments and overlaying sea sands and pelitic silts.

Spore-pollen spectra in the base of the section (–40.5–42 m), referred to the Preboreal period of Holocene (hereinafter, Holocene periods are indicated on the Blytt-Sernander scale adapted for North Eurasia (Khotinsky, 1977; 1989; Khotinsky et al, 1991), are characterized by birch pollen dominance (40–60 %), moderate content of broad-leaved tree pollen and low presence of dark-needle trees (Karaulova et al., 1973; Troyitskaya et al., 1978). Broad-leaved tree pollen content is 28–36 % below –41.5 m and, above that depth, its percentage sharply declines with a growing role of shrub-like birch (up to 33 %) and alder (up to 16 %). The spectra reflect distribution of birch and broad-leaved forest landscapes dominated by oak and elm, developed at the beginning of Preboreal period in cooler climatic conditions than the present time (Fig. 3 b – complex Az_2-1; Holocene phase PB-1). During the final cold phase of the period, they were replaced by birch forest and shrub landscapes (Fig. 3 b – complex Az_2-2; phase PB-2).

In spore-pollen spectra of the section's upper part (–30.2–40.5 m), the content of broad-leaved tree pollen grows (up to 50–80 %), with oak and elm dominating. There is a medium content of small-leaved tree pollen, mainly birch, with insignificant presence of coniferous tree pollen (up to 5 %), mainly pine *Pinus s/g Haploxylon* (Karaulova et al., 1973; Troyitskaya et al., 1978). The bottom of this part of the section (deeper than –32.2 m) contains 20–40 % of birch pollen, 34–45 % of oak pollen and a maximum of elm pollen (8–20 %). In the above laying interval of the section (-30.2–32.2 m) oak pollen content grows to maximum values (62–70 %)

** Radiocarbon dates were calibrated using *quickcal2007 ver.1.5* software (http://www.calpal-online.de)

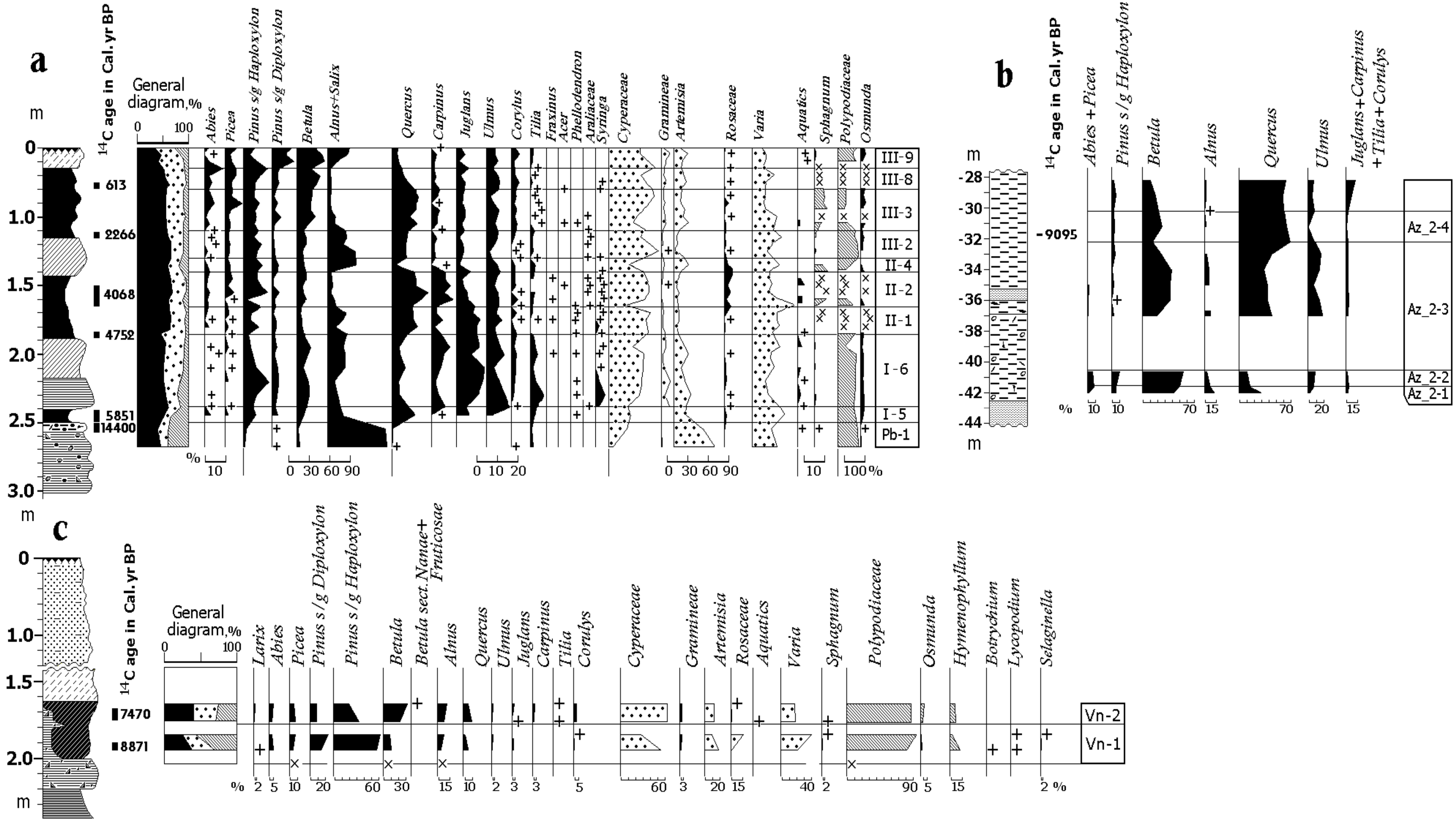

Fig. 3. Pollen Diagram of Late Glacial and Holocene Deposits, Pravyi Bereg (a), Skv. 2 (b) and Vinogradnaya-272 (c). See legend in Fig. 2.

and that of elm (1–10 %) and birches (14–27 %) decreases. The former pollen complex reflects development of birch/oak forest landscapes with wide elm presence, which developed at the beginning of the Boreal period in cooler climatic conditions than the present time (Fig. 3 b – complex Az_2-3; phase BO-1). The latter complex came into existence during the Boreal optimum of the Holocene, occurring 8300–8900 years ago (Khotinsky, 1977; 1989). This is confirmed by the radiocarbon date of 8530±160 yr BP, AA-36617 (9095±207 Cal. yr BP), obtained at the depth of 31.7 m (Kuzmin et al., 2004). The complex corresponds to multi-species broad-leaved forest landscapes dominated by oak, which existed in a drier climate with temperature conditions close to the present time or slightly higher (Fig. 3 b – complex Az_2-4; phase BO-2).

Paleolandscapes of the end of the Boreal period were registered in the deposits on the 4-meter terrace of Vinogradnaya R. on the coast of Expeditsiya Bay, represented by buried soil (Fig. 1-II – 8). Its bottom part in the interval of 1.85–2.0 m contains much coniferous tree pollen dominated by pines (*Pinus s/g Haploxylon* – 59–64 %, *P. s/g Diploxylon* – 15–25 %). The content of other coniferous tree pollens is less significant: spruce – 4–6 %, fir – 5–8 % and larch – less than 1 %. There is little pollen of small-leaved and broad-leaved trees: birch – 9–11 %, alder – 5–9 %, oak – 2–8 %, walnut, elm and hazel – 5 %. Grass plants are represented mainly by pollen of sedges (28–54 %), mixed herbs (23–42 %) and wormwood (10–19 %). Spores almost in full consist of ferns Polypodiaceae (81–95 %), less frequently *Hymenophyllum* (3–13 %) and *Osmunda* (1–2 %). Pollen of spike moss *Selaginella* was found in small numbers (Fig. 3 c – complex Vn-1). The spore-pollen spectra reflected distribution of Korean pine forest landscapes with low presence of broad-leaved trees, which were developing in a colder and drier climate than the present time. The radiocarbon date of 7995±45 yr BP, COAH-7179 – 8871±93 Cal. yr BP, obtained for the depth of 1.90–1.95 m, indicates that they had formed in the end of the Boreal period (phase BO-3).

The **Middle Holocene stage of landscape development**, which featured optimal climatic conditions, is well reflected in the area's deposits opened by boreholes and numerous exposures.

The oldest Middle Holocene deposits have been found in a section on the 4-meter terrace of Vinogradnaya R. in the coast of Expeditsiya Bay (Fig. 1-II, 8). In the upper layer of buried soil, at a depth of 1.63–1.75 m, the content of various broad-leaved (19–21 %) and small-leaved tree pollens rises versus a sharp drop (two-three times) of the coniferous tree role, as compared with the upper boreal layer (Fig. 3 c – complex Vn-2). Pollen spectra reflect birch/alder and Korean pine forest landscapes with some broad-leaved tree contribution, which existed in a cooler climate than the present time. The radiocarbon date of 6555±40 yr BP, COAH-7181 – 7470±28 Cal. yr BP, obtained on the deposits (1.68–1.75 m), dates this event back to the middle of the Atlantic period of Holocene (subphase AT-2 a).

Lagoon-marine deposits, formed during an intensive rise of the Sea of Japan level and widely distributed over the area's cost, have been studied on the coast of Boismana Bay and Khasanskaya Plain (Mikishin et al., 2001; 2002 b). They are represented by thin-bedded aleurites, sands and aleurite/pelitic silts, transgressive on underlying deposits. In Skv. Doritsine section, they lie at a depth of 4–7 m overlying upper Pleistocene sands (Fig. 1-I, 2); in Skv. 4 section – be eluvial-deluvial deposits at a depth of –6.5–6.7 m (Fig. 1-III, 20). The absolute age of these deposits, obtained on a series of samples, is 7100–7350 Cal. yr BP (Mikishin et al., 2008). Pollen spectra are dominated by broad-leaved tree species: oak (36–40 %), elm (7–8 %), walnut (5–7 %), hornbeam (2–4 %). Coniferous tree species consist mainly of Korean pine (*Pinus s/g Haploxylon*) – 19–21 % (Fig. 4 b – complex I-1). The spectra correspond to broad-leaved forest landscapes dominated by oak and to coniferous/broad-leaved forests in the mountains. The climatic conditions of that episode were close to the present time. The time of lagoon-marine deposit accumulation corresponds to the middle of the Atlantic period of Holocene (subphase AT-2 b).

A further rise of the sea level approximately by 1 m above the modern level resulted in formation of numerous lagoons in near-estuary river segments. Lagoon-marine deposits of this transgressive phase, represented by aleurite-pelitic silts with shell fragments, remainders of seaweeds, bark, twigs, tree nuts, have been studied on the coast of Boismana Bay (Mikishin et al., 2001; 2002 b). They lie at depths varying from –0.9–2.4 m in Skv. 3 section to –6.7 m in Skv. 4 (Fig. 1-III, 9, 20). Estuary deposits induced by transgression, represented by clays with tree trunk pieces, have been found in Razdolnaya R. valley. They lie in the terrace section at a depth of 5.7–6.5 m (absolute height +0.3 – –0.5 m), R-13 section in 30.8 km from the estuary (Fig. 1-VI, 26). The absolute age of these deposits is 6600–7100 Cal. yr BP (Mikishin et al., 2008). Pollen spectra are dominated by broad-leaved tree pollens with oak prevailing (30–52 %) and a high content of walnut – 2–9 %, elm and thermophilic hornbeam – 5–14 %. The content of Korean pine pollen declines to 3–13 % (Fig. 4 a, b – complex I-2). The spectra correspond to broad-leaved forest landscapes with oak dominance and greater contribution of hornbeam, walnut and elm than the present time. The climatic conditions of that episode, taking place in the end of the middle Atlantic, were much warmer and more humid than the present time (subphase AT-2 c).

A short-time climate cooling was fixed in the upper layer of lagoon-marine silts and overlying alluvial-lagoon loamy clays with broken rock and gravel in Skv. 3 section on the coast of Boismana Bay (Fig. 1-III, 9, depth 1.7–2.1 m). According to the dates, obtained for the preceding and the succeeding warming, the age of this event is 6450–6600 Cal. yr BP (Mikishin et al., 2008). In these deposits, pollen content declines for many broad-leaved trees and rises for small-leaved and coniferous trees (Fig. 4 a – complex I-3). The role of broad-leaved forest landscapes began to diminish and that of alder/birch and coniferous/broad-leaved forests began to grow. The timing of this relative climate cooling may be attributed to the Late Atlantic (subphase AT-3 a).

The climatic optimum of Holocene (Atlantic period) is reflected in the deposits of a number of sections cut in the area of study (Korotkiy et al., 1980; Golubeva, Karaulova, 1983; Mikishin et al., 2001, 2008). The optimum's deposits correspond to

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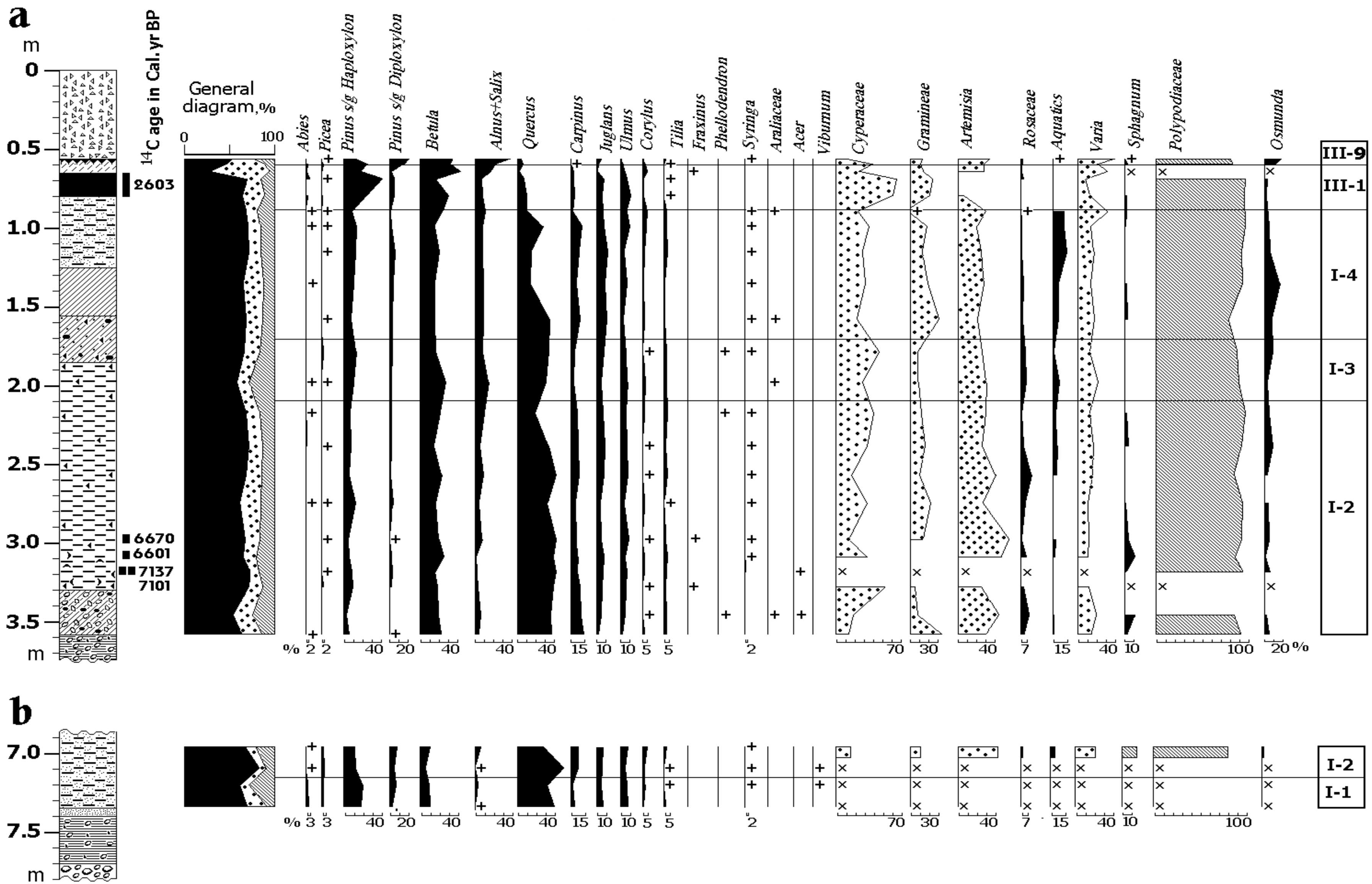

Fig. 4. Pollen Diagram of Holocene Deposits, Skv. 3 (a) and 4 (b). See legend in Fig. 2.

the maximum phase of the postglacial transgression of the Sea of Japan, which exceeded the modern level by several meters. On the coast of Boismana Bay they are represented by alluvial-lagoon loamy clays with broken rock and clayey gravely sands lying at a depth of 0.9–1.7 m (Fig. 1-III, 9) in Skv. 3 section, by lowland peat in Pravyi Bereg-99 section – 2.2–2.5 m (Fig. 1-III, 12) and by oyster beds buried in clayey deposits of a low sea terrace. In the valley of Barabashevka R., they are represented by lagoon aleurites and aleurite sands with walnut and ash-tree trunk pieces in Mangugai section at a depth of 3.2–4.6 m (Fig. 1-IV, 22). Radiocarbon dates on these deposits fit into the interval of 6000–6450 Cal. yr BP, which attributes the timing of their accumulation to the Late Atlantic period (Mikishin et al., 2008). Pollen spectra show a growing role of oak (from 23–35 % to 42–48 %), walnut (3–12 %) and, particularly, thermophilic and hydrophilic hornbeam (6–16 %). The content of small-leaved tree pollens reduced and that of coniferous tree pollens did not show any significant change (Fig. 4 a, 5 a – complex I-4). The spectra reflect broad-leaved forest landscapes with oak dominance and great contribution of other tree species, mainly hornbeam, walnut, ash, and in the mountains – coniferous/broad-leaved forests. In the most optimal time, circa 6450 Cal. yr BP, oak/hornbeam forests were growing here. Climatic conditions became warmer and more humid than both modern and preceding conditions (subphase AT-3 b).

A climate cooling down to a level, close to the present time, was registered in bog deposits on the coast of Boismana Bay (Fig. 1-III, 10 – 2.2–2.3 m; 11 – 1.90–2.0 m; 12 – 2.15–2.20 m) and in lagoon-marine deposits of Razdolnaya R. valley (Fig. 1-VI, 28, depth 3.4–3.7 m). Pollen spectra show an increasing content of alder pollen, nearly three times on average (15–21 %), Korean pine pollen (16–24 %), a sharp, nearly five times on average, drop in the role of thermophilic hornbeam (down to 0–2 %) and, in a lesser degree, elm and walnut (Fig. 3 a, 5 a – complex I-5). The spectra correspond to developing oak and alder forest landscapes, and in the mountains – coniferous/broad-leaved forests. Radiocarbon dates on these deposits fit in the interval of 5500–6000 Cal. yr BP, which places this event into the late Atlantic (subphase AT-3 c). The date of 5198 Cal. yr BP, COAH-4144 – 2.15–2.20 m from Pravyi Bereg-99 section (Fig. 5 a), is obviously too late and contradicts to the composition of spore-pollen spectra.

A warmer and more humid climate at the very end of the Atlantic period of Holocene reflected in lagoon-marine deposits (Fig. 1-III, 12 – 1.26–2.15 m) and lake-lagoon deposits (Fig. 1-III, 13 – 3.25–4.50 m; 14 – 2.0–2.4 m; 16 –3.0–3.3 m). Radiocarbon dates on these deposits fit in the interval of 5000–5500 Cal. yr BP (Mikishin et al., 2008). Tree pollens, dominating in the deposits (33–54 %), show a growing contribution of walnut (3–14 %), elm (4–16 %), hornbeam (2–9 %), lilac (up to 10 %) and linden (up to 7 %), versus a declining role of oak (4–28 %). The content of coniferous tree pollen grows, which applies, first of all, to Korean pine – up to – complex I-6). Spore-pollen spectra reflected polydominant broad-leaved forest landscapes on the coast and on wavy massifs. In the mountains, the role of coniferous/broad-leaved forests grew. The climate was cooler than during the most optimal time intervals at the End of the Middle Atlantic period and of the

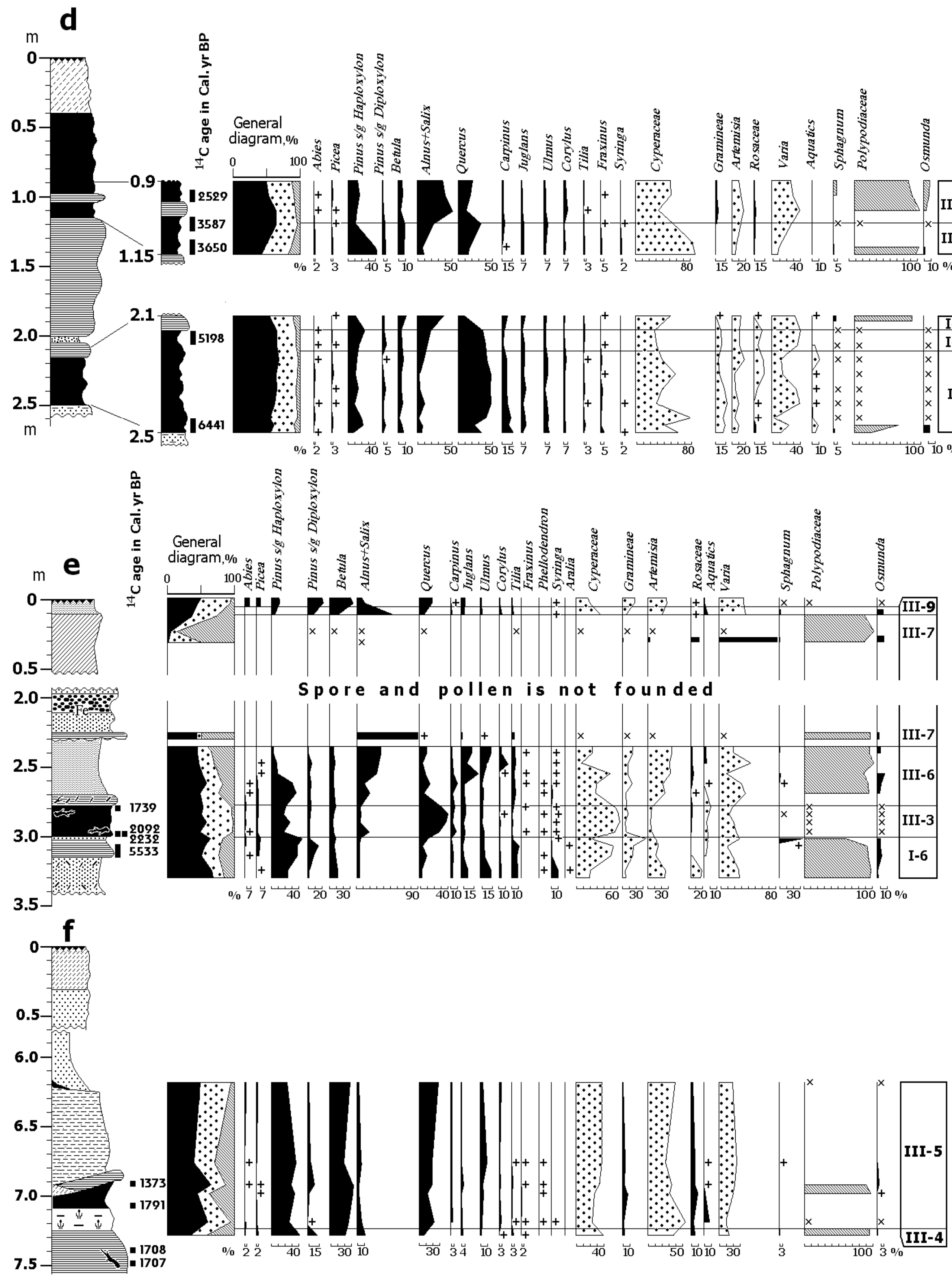

Fig. 5. Pollen Diagram of Holocene Deposits, Pravyi Bereg-99 (a), Levyi Bereg (b) and R-11-Baranovsky. See legend in Fig. 2.

Late Atlantic period, but warmer and more humid than the present time. This event occurred during the final phase of the Late Atlantic (subphase AT-3 d).

The Early Subboreal period was characterized by a global climate cooling (Khotinsky, 1977, 1989; Development of Natural…, 1988; Far East…, 1999). On the coast, it reflected as a hiatus in deposit accumulation in terrace sections, which was caused by a fall of the Sea of Japan level. No deposits corresponding to this event have been identified in the area. North of it, in the adjacent territory of the middle part of Razdolnaya R. catchments area, they were identified as deposits on which a radiocarbon date of 4472±75 yr BP, ДВГУ-ТИГ-29 – 5120 Cal. yr BP was obtained (Pavlutkin et al., 1984). They contain much pollen of birches (up to 50 % in total), alder shrubs (*Alnaster*) (up to 12 %), in a lesser degree – *Pinus s/g Haploxylon* and spruce. Landscapes with birch forests, Japanese stone pine (*Pinus pumila*) growths (?) and alder shrubs (*Alnaster*) were spreading, with coniferous trees occurring very rarely (subphase SB-1).

The Early Subboreal warming, which succeeded the climatic minimum, reflected in bog deposits on the coast of Boismana Bay (Fig. 1-III, 11 – 1.15–1.40 m). They contain much oak pollen (23–30 %) and less pollen of walnut (8–11 %), elm (4–8 %), hornbeam (2–5 %). Small-leaved trees are represented mainly by alder pollen (8–29 %), conifer tree pollen – Korean pine (9–40 %) and common pine (Fig. 3 a – complex II-1). This complex indicates at re-establishment of broad-leaved forest landscapes with oak dominance and in the mountains – of coniferous/broad-leaved forests. Climatic conditions were nearing the present-time conditions but were somewhat warmer. Judging by the date of 4752 Cal. yr BP, this event occurred in the beginning of the Middle Subboreal period (SB-2 a).

The middle Subboreal climatic optimum of Holocene was registered in lagoon silty sands of Khasansky Plain (Fig. 1-I, 1 – 1–2.3 m), in bog and alluvial deposits on the coast of Boismana Bay (Fig. 1-III, 11 – 0.9–1.15 m). Only two radiocarbon dates were obtained on these deposits – 4035 and 4068 Cal. yr BP (Mikishin et al., 2008). The upper chronological limit of this warming is no older than 3700 Cal. yr BP, which is seen from dating results on the succeeding cooler climatic phase. The content of oak pollen (32–53 %) and particularly of thermophilic hornbeam pollen (6–10 %) grows more than twice on average in the pollen spectra of the deposits. This complex corresponds to broad-leaved forest landscapes with oak dominance, broad hornbeam contribution and smaller role of other tree species, in the mountains – to coniferous/broad-leaved forest landscapes (Fig. 3 a, 5 a – II-2). Climate was noticeably warmer than the present time and nearing to the optimal conditions of the middle-late Atlantic period (subphase SB-2 b).

A decline of temperatures approaching to their modern parameters is reflected in bog deposits on the coast of Boismana Bay (Fig. 1-III, 12 – 1.02–1.15 m; 14 – 1.45–1.48 m). The content of oak (17–33 %), hornbeam (1–4 %), walnut (up to 1–4 %), elm (2–6 %) decreases in pollen spectra. The content of Korean pine grows – 11–40 % (Fig. 5 a – complex II-3). Radiocarbon dating data limit the age of this event by 3600–3700 Cal. yr BP, which places it into the final stage of the Middle Subboreal period (subphase SB-2 c).

A more significant climate cooling was registered in thin layers of floodplain loamy clays and peats on the coast of Boismana Bay (Fig. 1-III, 12 – 0.85–0.90 m; 14 – 1.39–1.42 m). In pollen spectra, there is little pollen of broad-leaved trees (oak – up to 5–11 %, walnut – up to 1–2 %, hornbeam – from < 1 to 3 %), but much pollen of small-leaved trees (alder up to 34–41 %) and coniferous trees (*Pinus s/g Haploxylon* – 25–28 %, pine – 4–10 %). The spectra reflect distribution of alder forest landscapes and, in the mountains, – Korean pine forests with a small contribution of broad-leaved trees, which developed in a cooler climate than the present time (Fig. 3 a – complex II-4). Radiocarbon dating of this event shows that it occurred in the Late Subboreal period – 3200–3400 Cal. yr BP (subphase SB-3 a).

Re-establishment of landscapes, similar to the present time, occurred in the latter half of the late Subboreal period. Broad-leaved forests with oak dominance and small contribution of other tree species became distributed again, and coniferous/broad-leaved forest, similar to modern forests, reappeared in the mountains. (Korotkiy et al., 1980; Golubeva, Karaulova, 1983). The radiocarbon date of this event (2653 Cal. yr BP) places it into the end of the Late Subboreal (subphase SB-3 c).

The Late Holocene period of landscape development was characterized by rapid change of warm and cool episodes which is well reflected in the area's deposits.

The early Subatlantic climate cooling is reflected in thin lagoon-bog deposits on the coast of Boismana Bay (Fig. 1-III, 9 – 0.6–0.9 m). Pollen spectra contain much pollen of small-leaved (birch – 17–44 %, alder – 7–18 %) and coniferous (Korean pine – 19–43 %) tree species, with a smaller contribution of broad-leaved trees (elm – 5–11 %, oak – 2–10 %, walnut – 1–8 %). Distributed on the coast were birch-alder forest landscapes which yielded dominance to sedge and mixed herb/grass meadows during the cooling maximum. Mountains were occupied by Korean pine forests with a smaller contribution of broad-leaved trees than at the present time (Fig. 4 a – complex III-1). Climate was cooler than at the present time. The radiocarbon date of 2603 Cal. yr BP places this event into the beginning of the Subatlantic period (subphase SA-1 a).

Younger alluvial and bog deposits on the coast of Boismana Bay were accumulating during a climate warming (Fig. 1-III, 11 – 0.60–0.85 m, 12 – 0.92–1.01 m). They feature high contents of small-leaved tree pollen (alder – 23–52 %, birch – 4–14 %) and broad-leaved tree pollen dominated by oak (12–24 %), with the latter's occurrence rate growing 1.5–2 times (up to 30–40 %) on spectra of the preceding cold episode. Coniferous tree pollens continued to be dominated by Korean pine (13–26 %). The spectra reflected distribution on the seacoast of alder forests and, in a lesser degree, broad-leaved forests with oak dominance, in the mountains – of coniferous/broad-leaved forests (Fig. 3 a, 5 a – complex III-2). Climate was warmer than in the preceding subphase, but cooler than at the present time. The radiocarbon dates of 2266 and 2529 Cal. yr BP confirm the Early Subatlantic age of this event (subphase SA-1 b).

Further improvement of climatic conditions was registered in pollen spectra of bog deposits on the coast of Boismana Bay (Fig. 1-III, 11 – 0.3–0.6 m; 16 – 2.78–

3.0 m). These spectra are dominated by broad-leaved tree pollens (41–61 %) containing much pollen of oak (29–42 %), walnut (3–7 %), hornbeam (up to 8 %), elm (2–6 %), linden and hazel (up to 3 %), lilac, ash, cork tree (*Phellodendron*), aralia (no more than 1 %). The content of small-leaved tree pollen decreased (alder – 5–18 %, birch – 5–9 %) and that of coniferous tree pollen showed almost no change (Fig. 3 a, 5 b – complex III-3). The spectra correspond to distribution of broad-leaved forest landscapes, in the mountains – of coniferous/broad-leaved forests, which developed in a warmer climate than the present time. The series of radiocarbon dates places this event to the end of Early Subatlantic period – 1750–2200 Cal. yr BP (subphase SA-1 c).

The climate warming was succeeded by an intensive cooling, identified in clays from the base of Razdolnaya R. terrace (Fig. 1-VI, 25 – 7.24–8.40 m). In this spectrum, the content of broad-leaved tree pollen sharply, 4 to 5 times, drops (12 %) compared with the preceding subphase: oak (7 %), walnut, elm, linden (2–3 %), and the role of coniferous trees grows with Korean pine dominating – 42 %. The contribution of birch (23 %) and, less frequently, alder pollen rises (Fig. 5 c – spectrum III-4). These spectra correspond to birch/alder forest landscapes, in the mountains – stone pine forests with a small contribution of broad-leaved trees, which developed in a cooler climate than the present time. The radiocarbon dates of 1707 and 1708 Cal. yr BP place this event into the beginning of the Middle Subatlantic period (subphase SA-2 a).

Climatic conditions, nearing to modern conditions, were reflected in the spectra of bog and alluvial deposits in Razdolnaya R. valley (Fig. 1-VI, 25 – 6.20–7.24 m). They fix recovery of multi-species broad-leaved forest landscapes dominated by oak and in the mountains – coniferous/broad-leaved forests (Fig. 5 c – spectrum III-5). The radiocarbon dates of 1791 and 1373 Cal. yr BP limit their development by the first half of the Middle Subatlantic period (subphase SA-2 b).

A warmer and more humid climatic phase than the preceding one was registered in lake-lagoon deposits on the coast of Boismana Bay (Fig. 1-III, 16 – 2.35–2.78 m). They feature dominance of broad-leaved tree pollens, of which oak content decreased (5–16 %) and contribution of other species grew: walnut (5–26 %), elm (3–16 %), hornbeam (2–10 %), linden (4–6 %), lilac (up to 2 %). Alder and Korean pine pollens occur quite frequently – 10–35 % and 36 % respectively (Fig. 5 b – complex III-6). These spectra reflect landscapes of polydominant broad-leaved and alder forests, in the mountains – of coniferous/broad-leaved forests. Climate was warmer and more humid than the present time. The absolute age of these deposits was not identified. This event was likely to occur in the latter half of the middle Subatlantic (subphase SA-2 c). It may be correlated to the major climate warming known as the "VIII–X Century Warming," "Viking Epoch" (Monin, Shishkov, 1979; Zubakov, 1986) or "Nara-Heian-Kamakura" observed in Japan between VIII–IX and XIII centuries (Sakaguchi, 1983).

The following climate cooling is reflected by poor pollen spectra of alluvium on the coast of Boismana Bay (Fig. 1-III, 16 – 0.15–2.35 m). They show dominance of grass pollens and spores in their general composition and an insignificant role of trees (up to 5 %) with alder dominating (89 %). They reflect development of steppe-like landscapes of mixed herb meadows and minor role of alder forests (Fig. 5 b – complex III-7). Climate was much drier and cooler than the present time. The absolute age of this event was not identified. It may be correlated to the severe cooling at one of the stages of the "Little Ice Period" which occurred in XII–XIV centuries of the past millennium (Monin, Shishkov, 1979) and placed into the first half of the Late Subatlantic (subphase SA-3 a).

Distribution of broad-leaved, birch and coniferous/broad-leaved forest landscapes was fixed by pollen spectra of alluvial and bog deposits in Khasanskaya Plain (Fig. 1-I, 4 – 1.2–2.61 m) and on the coast of Boismana Bay (Fig. 1-III, 11 – 0.15–0.30 m). They consist of roughly equal portions of coniferous tree pollens (Korean pine – 18–36 %, less frequently pine, fir, spruce), broad-leaved tree pollens (oak – 14–23 %, walnut – 2–6 %, elm – 3–6 %, hornbeam (up to 2 %) and small-leaved tree pollens represented mainly by birches – 18–34 % (Fig. 3 a – complex III-8). Climatic conditions were slightly cooler and more humid than the present time. The radiocarbon dates of 523–627 Cal. yr BP place this event into the middle of the Subatlantic period (subphase SA-3 b).

Turf layers of meadow soils, thin beds of bog and alluvial deposits of Boismana Bay (Fig. 1-III, 9 – 0.55–0.60 m; 11 – 0.0–0.15 m; 16 – 0,05–0.15 m) contain pollen spectra reflecting the latest historical climate cooling of the "Little Ice Period" in the latter half of XVI century – first half of XIX century (Arakawa, 1975; Monin, Shishkov, 1979; Zubakov, 1986; Sakaguchi, 1983). They feature a decreasing content of tree pollens (34–52 %), of which the role of broad-leaved trees goes down nearly twice (oak – 4–10 %, walnut – 2–5 %, elm – 1–5 %) and small-leaved tree pollen content rises (alder – 14–53 %, birch – 11–40 %). Among coniferous trees, a sharp rise was observed for pollen of pine *Pinus s/g Diploxylon* (7–32 %), which reached the content of Korean pine pollen (Fig. 3 a, 4 a, 5 b – complex III-9). The spectra reflect landscapes of alder/birch forests, sedge and mixed-herb/grass meadows spreading over the coast. In the mountains, the role of coniferous/broad-leaved forests was declining with a small contribution of broad-leaved trees and growing pine contribution. Climate was cooler and drier than the present time (subphase SA-3 c).

In general, landscape development in Khasansky District in the late Pleistocene-Holocene was being determined by the Earth's global climate changes. A more intensive cooling in the Past Glacial Epoch resulted in change of broad-leaved forest landscapes in the temperate zone first to medium-taiga landscapes of spruce/fir and birch/larch forests and later on, during the maximum stage, to north-taiga landscapes dominated by birch/larch forests and frigid shrub growths. On the whole, the warm Holocene epoch was characterized by often repeated short-time changes of broad-leaved forest landscapes prevailing during climate warming periods to landscapes of small-leaved forests – alder and alder/birch forests which were developing during climate cooling period. Open landscapes of steppe-like meadows were emerging mainly during climate cooling periods in the Late Holocene and not spreading widely.

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