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GEOMORPHOLOGY

Reconstruction of Late Glacial Conditions of Exogenic Landscape Formation of Central Kamchatka: Data on Spore–Pollen Analysis

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Abstract—Spore–pollen analysis of lacustrine and subaerial sediments of the KamPlen reference section in the Central Kamchatka Depression (CKD) is conducted. The results of the analysis allowed the reconstruction of the CKD landscape formation conditions in the Late Peni-Glacial, Late Glacial, and the transition to the Holocene, which significantly expands the paleogeographical record elaborated for the Holocene of Kamchatka into the past. It is established that, after 18 ka (under relatively cold climate), the watershed of the paleolake that filled the CKD during the last glaciation was characterized by open landscapes with dominant herbaceous–grass communities. The presence of pollen of trees and warm water plants indicates the limited scales of mountainous–valley glaciation. The identified cooling period of 15–13 ka characterized by scarcer vegetation did not lead to a significant expansion of glaciers. After 13 ka, warming of the climate with a gradual degradation of glaciers resulted in regeneration of coniferous forests on the paleolake watershed. The drainage of the lake at ~11.5 ka BP and the beginning of sedimentation of subaerial deposits in the area of the studied section approximately correspond to the lower boundary of the Holocene, which confirms the key role of the climate at stages of the CKD landscape formation during the period considered.

Keywords: Kamchatka, Pleistocene, Holocene, pollen analysis, reconstruction of vegetation

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INTRODUCTION

The strongest climatic and environmental changes in the entire Northern Hemisphere including northeastern Asia occurred at the Late Pleistocene–Holocene boundary. Although these climatic changes are most striking in the ice core of Polar regions and marine sedimentary columns, the continental sediments of that period for Western Beringia including Kamchatka are poorly studied. The last large studies of the Late Pleistocene glaciation epoch in Kamchatka were conducted ~50 years ago [1–3], when the possibilities of dating of sediments were imperfect. In 2014–2019, the sediments of a giant Pleistocene lake within the Central Kamchatka Depression (CDK) were found and described by us and our colleagues [4]. The current study presents the first data on the spore–pollen analysis of sediments of this lake at the Late Pleistocene–Holocene boundary. Our materials allow the recognition and dating of the main stages of exogenic landscape-forming processes, which are recorded in previously unstudied paleoarchives of the Pleistocene environment of Kamchatka.

REGION OF STUDY

The region studied is part of the active continental margin at the junction of the Asian Continent and Pacific Ocean. The CKD is the largest element of the present-day morphostructure of Kamchatka. It is rimmed by the Vostochnyi and Sredinnyi ranges to the east and west, respectively (Fig. 1). Its total length reaches 450 km, and the maximum width is 80–90 km. The depression has an asymmetric structure with flat western and steep eastern walls. The Kamchatka River is the largest in the CKD and Kamchatka in general; it extends along the CKD turning to the east in the lower reaches and crossing the Kumroch Range.

The latitudinal position of the peninsula, as well as the influence of cold seas and cold currents, is responsible for its harsh climate; however, these factors were also favorable for the formation of the typical marine climate. Because of the isolation from marine air masses, the CKD has a more continental climate in comparison with the rest part of the peninsula. Winter is severe (the average January temperature is –28°C), whereas summer is warm with an average July temperature of +16°C [5]. Due to protection from moisture-saturated air masses from the east, the amount of

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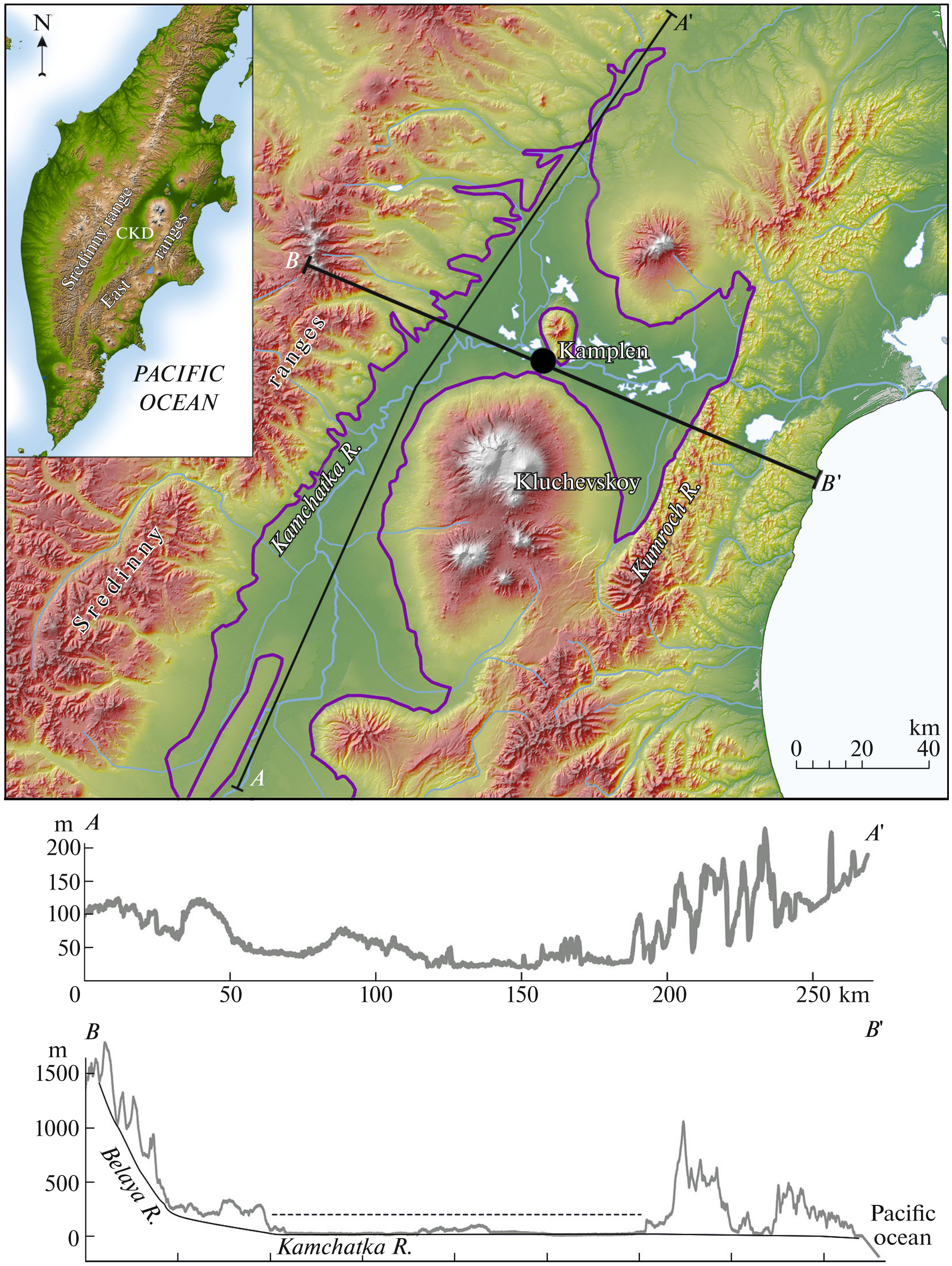

Fig. 1. Position of the KamPlen section relative to the current landscape and erosion network. The violet line shows the contour of the Late Pleistocene lake [4]. The hypsometric profiles along lines *A*–*A*' and *B*–*B*' with thalweg lines composed from SRTM data are shown in the lower part of the figure.

precipitation is also lower (~400 mm/year). The dry spring–summer and rainy summer–autumn periods are characterized by a wet regime within the depression.

The wet marine climate, active volcanic activity, and predominance of mountains caused the high diversity of flora and plants of Kamchatka. Woodlands composed of larch (*Larix cajanderi*) and small areas of spruce (*Picea ajaensis*) are abundant in the CKD. The larch woods occupy the largest areas in the CKD bottom and rise along the slopes up to 500–600 m [6]. The mountainous slopes are covered with forests of

Erman's birch (*Betula ermanii*). The upper boundary of the forests (in the bush belt) is dominated by the Japanese stone pine (*Pinus pumila*), alder (*Alnus fruticosa* or *Duschekia fruticosa*), and dwarf birch (*Betula exilis*). The meadow, low bush, stony lichen, and moss kinds of tundra are dominant in the Alpine belt. The floodplain territories are occupied by willows, poplar (*Populus suaveolens*), chosenia (*Chosenia arbutifolia*), alder (*Alnus hirsuta*), and bird cherry (*Padus avium*). Typical meadow bushes of large grass up to 3 m high are observed along the river and creek valleys [6].

Large and detailed studies of the region dedicated to the paleogeography and stratigraphy of loose deposits were mainly conducted in the 20th century. Kushev and Liverovskii [7] suggested the presence of large preglacial and interglacial Pleistocene lakes within the CKD [7]. Later, Braitseva et al. [2] continued these works and noted a link between the interglacial conditions with expanded areas of dark-coniferous forests and alien flora. The cooling periods were characterized by a reduction of areas of forest cenoses and expansion of marsh, meadow, and tundra communities [2]. Kuprina [1] emphasized that even the interglacial palyniflora is "cold"; thus, the earlier works suggested a unity of two phases of the Late Pleistocene glaciation.

The deposits of the second stage of the Late Pleistocene glaciation are described in works of Kuprina [1], Braitseva et al. [2], Skiba [3], and other authors. Their analysis showed that the deposits accumulated in cold tundra conditions. Skiba [3] reports on dominant open spaces occupied by meadows and sedge swamps with *Betula exilis* [3]. The tundra species *Selaginella sibirica, Lycopodium alpinum*, and *Armeria sibirica* were present. Unfortunately, most works provide only lists of the taxa found and a general description of pollen complexes, because the Late Peni-Glacial and Late Glacial deposits contain insufficient pollen for spore–pollen diagrams. Skiba [3] also notes that spruce remained in refugia during the glacial stage and after it propagated again for the entire CKD territory occupying a wider aureole during the last interglacial period.

At present, the study of changes in the vegetation and climate of Kamchatka Peninsula and Western Beringia is continued [8–10], although most works consider Holocene events. A few tens of sections of the CKD lacustrine deposits were found and described for the first time in 2014–2019 by us and our colleagues [4]. All deposits occur directly below the Holocene soil-pyroclastic cover and contain more interlayers of volcanic ash (tefra); thus, they can be correlated among each other. The study of these sections allowed us to substantiate the presence of a vast glacial-dam lake in the CKD.

OBJECT OF STUDY AND ANALYTICAL METHODS

We studied the deposits exposed in a coastal cliff of Klyuchevskoe Lake, which is located in a floodplain of the Kamchatka River near the northern foot of the Klyuchevskoi volcanic group (Fig. 1), 9 km east of the settlement of Klyuchi. The section was described for the first time and published by our group [4] as KamPlen.

The section exposes a weakly inclined surface near the northeastern foot of the Klyuchevskoi volcanic group at a height of 21 m above sea level. This territory and the genesis of its deposits have controversial interpretations in the literature: deluvial–proluvial [11], lacustrine [11], or cover [7]. Ponomareva et al. [1] suggested that these deposits are lacustrine and could have accumulated in a large near-glacial basin, which probably occurred in the CKD during the last glaciation (MIS 2) up to the beginning of the Holocene. This age is supported by radiocarbon and tefrochronological dating [4].

The section is composed of light creamy loams with frequent interlayers of volcanic ash 0.5–4.0 cm thick (Fig. 2), which emphasizes the fine horizontal layering of deposits. In the upper part of the section (from the depth of 95 cm), they are overlapped by a soil-pyroclastic cover. The lavas of the Klyuchevskaya volcanic group are exposed at the bottom of the section.

The total thickness of deposits exposed by the KamPlen section exceeds 10 m from the borehole face to a tefra layer of eruption of the Khangar volcano (KHG), the ash of which is widely abundant and is dated at 7872 ± 50 years according to the study of the Greenland ice core (GICC05) [12]. This is one of the striking CKD marking horizons [13], and its foot is accepted as the upper count point of the depth in the KamPlen section. Ten radiocarbon measurements were conducted for the section by accelerating mass spectrometry (AMS) at Beta Analytic (Miami, United States), which, together with ice date for the KHG ash, allowed the calculation of the age model of the KamPlen section in the Bacon package [4]. For the aims of our study, the age model of the entire section was previously published [4], however, the age–depth correlation was calculated again and detailed for depths of 71–289 m corresponding to 17.9–10.5 ka (hereinafter, the age is given as a point value of the average age in calibrated radiocarbon years) (Fig. 3). In our opinion, this is an especially interesting and poorly studied interval of Central Kamchatka.

The analysis of a plot of the sedimentation rate minus visible pyroclastic falls (Fig. 3) showed that the rates remained approximately the same during the entire period considered. The lowermost part of the deposits with the age of >17 ka has slightly higher values (0.38 mm/year) in comparison with later accumulated deposits. It can be suggested that this is related to

Fig. 2. Frontal photograph and main elements of the KamPlen section. (*1*) Soil-pyroclastic cover; (*2*) fine-layered lacustrine loams with ash interlayers. The double line shows the bottom of the Khangar ash (KHG).

the active contribution of loose material to the near-glacial basin during glacial thaw, as well as slightly higher volcanic activity between 27 and 17 ka [4]. Later, the rates of the accumulation of clastic material were almost unchanged up to the Holocene (~0.25 mm/year).

Samples for spore–pollen analysis were taken with a step of 5 cm. The preparation of samples was conducted in a laboratory of Lakehead University (Orillia, Canada) following the standard procedure using HCl, KOH, HF, and acetolysis. The mineral part of the deposit was separated using sieves with the cell sizes of 150 and 100 μm. Samples 1.5–2.0 mL in volume were treated in the following manner: each sample was doped with one tablet of specially processed *Lycopodium* spores for further calculation of the concentration of pollen grains on a Motic BA-310 microscope with magnifications of 200 for searching for pollen and 400 for detailed analysis. No fewer than 120–150 pollen grains for the Late Pleni-Glacial and 300–500 grains for the Holocene were calculated for each sample.

RESULTS OF SPORE–POLLEN ANALYSIS

The pollen diagram shows the main results of the analysis of lacustrine loams and subaerial deposits from the KamPlen section at a depth of 71–289 cm corresponding to 17.9–10.5 ka. The pollen content (%) from each taxon is calculated from the total spore and pollen amount and is shown in Fig. 4.

Two types of the *Alnus* pollen were identified in spore–pollen samples (Alnus 1 and Alnus 2 in the diagram). In morphology, they are similar to the pollen of wooden forms of alder and shrubs, respectively. At present, only two alder species occur in the Kamchatka Peninsula: downy alder (*Alnus hirsuta*) and shrubby alder (*Alnus fruticosa*) [15]. In the foreign literature, the corresponding pollen taxa are known as *Alnus/Alnus incana* (Alnus 1) and *Duschekia kamchatical/Alnus viridis* (Alnus 2) [8, 9] in contrast to *Alnus* (Alnus 1) and *Alnaster* (Alnus 2) in the domestic literature [1, 3, 16]. Similarly to the present-day Kamchatka flora, we suggest that Alnus 1 corresponds to downy alder (further, alder), whereas Alnus 2 is shrubby alder; however, no detailed morphological works were conducted on this problem.

By the changes of in the pollen spectra and the composition of the fossil palynoflora, four local palynozones (LPZ) can be distinguished on the spore–pollen diagram (Fig. 4). The temporal limits corresponding to each LPZ are determined by the depth–age curve (Fig. 3).

LPZ KR-1 (289–205 cm) characterizes a period of 17.9–15.1 ka. The general composition of spectra is dominated by the pollen of grass plants (Non-Arboreal Pollen, NAP) (53–87%) at a significantly lower amount of pollen of trees and bushes (Arboreal Pollen, AP) (4–31%), as well as spores (5–25%). The pollen of *Populus* (up to 8%), alder (Alnus 2 1.5–8.0%), and *Salix* (up to 8%) is dominant. There is also pollen of *Pinus pumila* (3.0–5.5%), *Betula sect. Nanae* (up to 5.5%), and *Juniperus* (up to 3%). Other tree taxa include single pollen grains (*Picea, Larix, Betula ermanii, Betula, pendula, Chosenia*, etc.). The NAP group is dominated by pollen of grasses (from 6 to 58% of the spectrum). The pollen of Cyperaceae and Ranunculaceae is also abundant (up to 9%). In general, the pollen of grass plants is characterized by high diversity and the presence of cold taxa like cloudberry (*Rubus chamaemorus*) (a plant of moss swamps), koenigia (*Koenigia*) (an inhabitant of wet tundra), and sunrose (*Helianthemum*) (a typical heliophite). The amount of the Saxifrage family (Saxifragaceae) reaches 4%. The spores are dominated by *Sphagnum*, *Equisetum*, and green mosses (Bryidae) (up to 6% of the spectra); other spores are single. The pollen of some water plants is also single. About 800 pollen grains (on average) correspond to 1 cm^3 of samples of this palynozone (450–2100 grains/1 cm^3).

LPZ KR-2 corresponds to a depth of 205–135 m (15.1–12.8 ka). It is characterized by totally dominant

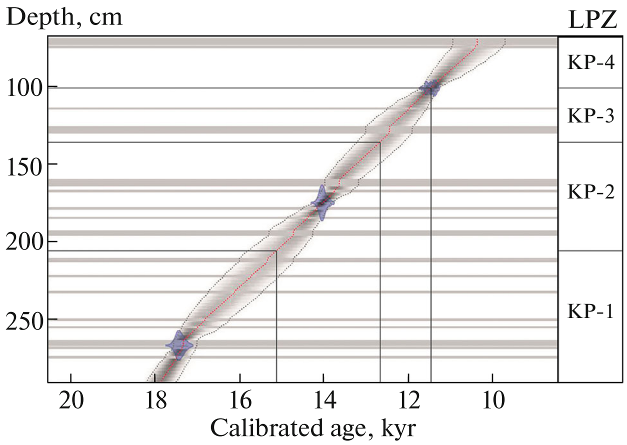

Fig. 3. Age model of part of the KamPlen section for the depth of 71–289 m calculated in the Bacon package [14] by ages from [4]. Central dotted line, average age values; gray tints, decreasing probability with the distance from the average value; gray dotted lines limit the range of the 95% probability. Gray horizontal bands show the depths and thicknesses of tefra horizons. LPZ, local pollen zones.

pollen of grass plants (85–93%), mainly, Poaceae (67–85%). The amount of pollen of other tree taxa is only 3–6% and the content of spores is 3–11%. It is important that this palynozone is characterized by the lowest concentration of pollen relatively to the rest interval (400 pollen grains per 1 cm^3). Among the AP group, this LPZ contains only few percent of pollen of shrubby alder (*Alnus* 2) and poplar (*Populus*), whereas other findings are single. The NAP group is dominated by pollen of Cyperaceae (5–17%) with a minor amount of Chenopodiaceae, *Thalictrum*, and Saxifragaceae (up to 3%). The spore plants include abundant *Equisetum* (1.5–4.2%) and Bryidae (2.5–3.2%).

The spore–pollen spectra at a depth of 135–100 cm belong to LPZ KR-3 (12.8–11.5 ka). This zone is also characterized by dominant pollen of grass plants (47–75%), and the AP amount increases from 5 to 40% in its upper part, whereas the spore amount is 4–12%. The AP group includes mostly shrubby alder (18–35%) and, to a lesser extent, an arboreal form of alder (no more than 5% of the spectra). There is also coniferous pollen: *Larix* and *Picea*. The content of pollen of these Boreal types also increases in comparison with LPZ KR-2. The group of grass plants is still dominated by Poaceae pollen (5–10%). Amid spores, the largest content corresponds to Polypodiaceae, *Licopodium clavatum*, and *Equisetum* (by 2–3%). One sample contains fir clubmoss (*Huperzia selago*), the amount of spore of which reaches 7%. There are single grains of pollen of cattail (*Typha*) and spores of quillwort (*Isoetes*). The concentration of pollen grains in comparison with LPZ KR-1 and LPZ KR-2 increases from 450 grains/1 cm^3 in the lower part of the LPZ KR-3 to 8000–9000 in the upper part.

LPZ KR-4 mostly characterizes subaerial deposits at depths of 100–71 cm, which include light brown to dark gray loamy sand with a high content of volcanic ash. The temporal interval of accumulation of this layer, according to our estimations, is 11.5–10.5 ka. The spectra in LPZ KR-4 contain a high amount of pollen of arboreal species (46–81%), the NAP amount is 17–49%, and the spore content is 1–3%. The AP group is dominated by alder and shrubby alder pollen (in total, up to 77% of the spectrum). The grass plants mostly include Poaceae (9–43%) with a minor amount of pollen of Caryophyllaceae and Cyperaceae (up to 2%). In the spore group, 1% corresponds to *Lycopodium clavatum*, whereas other findings are single. The pollen concentration in this interval continues to increase and reaches 300 000 pollen grains per 1 cm^3 at the upper margin of the studied part of the KamPlen section.

DISCUSSION: CONDITIONS OF THE CKD LANDSCAPE FORMATION FROM THE LATE PENI-GLACIAL TO THE EARLY HOLOCENE

The palynological data indicate the presence of several stages of changes in vegetation and climate of Central Kamchatka from 17.9 to 10.4 ka. These changes unambiguously affected the spectrum and the intensity of landscape formation processes of the period studied. In accordance with the LPZ distinguished, the results can be interpreted as follows.

LPZ KR-1. Up to 15 ka, the valley of the Kamchatka River was a host for a vast lacustrine basin, which was surrounded by open grass-herbaceous communities with small areas of shrubs. The very low concentration of wood pollen indicates the limited role of woody plants. The present-day spore–pollen spectra [17] indicate a higher amount of pollen of Japanese stone pine and shrubby alder relative to their amount in the vegetation cover. All this indicates the restricted role of shrubby alder in the vegetation of this interval. The presence of single grains of spruce and larch pollen is important, however, in this period. The analysis of recent spore–pollen samples of soil from the above-floodplain terrace of the Kabeku River (the left tributary of the Kamchatka River near the KamPlen section) showed that, even in the larch forest, where *Larix* is dominant among the trees, the larch pollen covers only 5% of the spectrum. This inconsistency of the proportion between the amount of larch amid the trees and the content of its pollen in pollen spectra is also noted by other authors [10, 18]; thus, even the minor presence of larch pollen can indicate that the larch massifs with gooseberries, rose, and spirea in the understory occurred within the lake drainage area. Thus, during the maximum phase of the last glaciation, larch and spruce remained in the small CKD refugia, which allowed their fast propagation, when natural conditions become more favorable. Single findings of the pollen of conifers indicate their limited

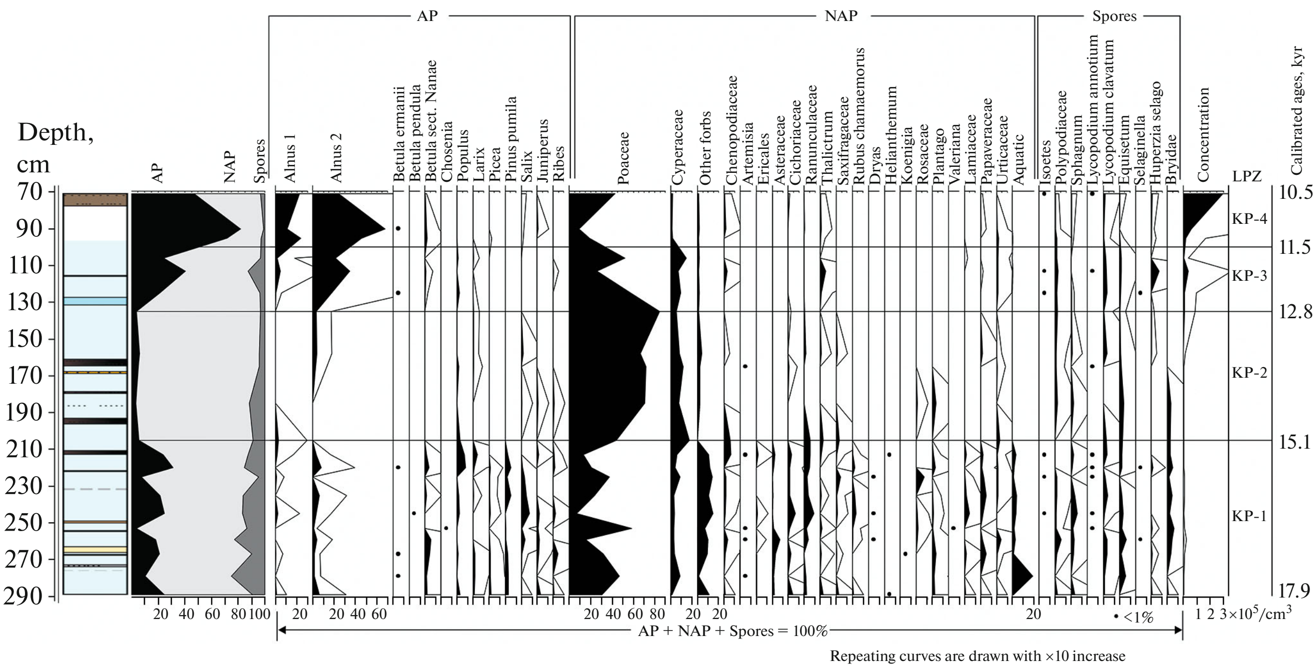

Fig. 4. Spore–pollen diagram for the KamPlen lacustrine loams at a depth of 71–289 cm. White color, subaerial deposits; light blue, lacustrine deposits; interlayers, tefra.

role in the vegetation of the studied territory after the maximum of the last glaciation. In addition, the presence of cold taxa (*Koenigia, Dryas, Ranunculus nivalis*-t.) typical of high-mountainous landscapes also indicates that the climate of that period was rather cold and wet (relatively to the next stage).

This layer also contains pollen of warm water plants (*Nymphaea, Nuphar*, etc.), which do not occur now to the north of Kamchatka. At present, the pigmy water-lily (*Nymphae tetragona*) in Kamchatka is observed mainly in the southeastern part of the peninsula in lakes, river meanders, and swamp hollows, although it is known in Central Kamchatka, whereas the least water-lily (*Nuphar pumila*) grows mostly in central and southern Kamchatka in lakes, meanders, and river blackwater areas. The pollen of cryophyte taxa (*Koenigia, Dryas, Ranunculus nivalis*-t.) apparently corresponds to high-mountainous landscapes within the drainage area of the lake.

Thus, the pollen spectra of the reviewed period contradict the scenarios of extensive glaciation of Kamchatka in the Peni-Glacial. The mountainous-valley glaciers were sufficiently large to block the present-day CKD runoff; however, the forest communities remained in the depression. The principle scheme of this stage is shown in Fig. 5a in comparison with further stages. The reconstruction is conducted by intervals, which correspond to the pollen zones recognized. At this stage, the activity of warm glaciers resulted in active upheaval and accumulation of the material and the large lake was favorable for the coastal processes and relative fast bottom sedimentation.

LPZ KR-2. At the early stage of the Late Glacial (15.1–12.8 ka), the climate became drier and possibly more continental. The wooden taxa almost completely disappeared from palynoflora and the amount of spores decreased to 3–6% of the spectrum. The dominant role in the vegetation was played by herbaceous communities, and the diversity of pollen of herbaceous plants decreased in comparison with the previous period. The pollen concentration at this stage is the lowest for the entire section. All these data indicate the sparse vegetation of this period. It is possible that the coasts of the water reservoir still contained small "islands" of poplar and larch forests and shrubs in the most protected areas. In the rest, the entire coastal zone and the slopes of adjacent mountains were covered with herbaceous plants with dominant grass and, to a lesser extent, the species of the family Cyperaceae. No pollen of the relatively thermophile water plants mentioned above was found in this layer. Possibly, the changes observed during transition from LPZ KR-1 to LPZ KR-2 at about 15 ka indicate the decrease in the upper boundary of the forest and the area of propagation of the forest (with spruce, larch, and Erman's birch) and shrub (with rose, spirea, and juniper) belts up to their complete disappearance with a simultaneous increase in the area of grass–herbaceous meadows.

Our data confirm the results of study of the Krutoberegovo coastal section in eastern Kamchatka [10], where spectra of 16.0–12.3 ka are dominated by pollen of herbaceous plants. Amid trees, similarly to the KamPlen section, this period is dominated by shrubby alder, dwarf birch, and willow. In contrast to our data, the pollen of Cyperaceae (rather than Poaceae) predominates among herbaceous plants of the Krutoberegovo section, but this fact is most likely related to the coastal position of the studied territory. In addition, the authors also noted a high taxonomic diversity of the pollen of herbaceous plants typical of this palynozone at a significantly lower concentration of pollen in the deposit in general, which was interpreted as a signature of a relatively dry and continental climate. Analyzing the sections of the eastern and western coasts of the Bering Sea, Edward et al. [9] noted the predominance of steppe and shrub tundra landscapes in Western Beringia up to 11.5 ka, which is also in agreement with our results. According to [9], the shrub forms of plants (shrubby alder, willow, birch) were typical of Western Beringia from 13 to 6 ka.

Thus, this stage was significantly drier and, probably, colder than previously, which resulted in almost complete disappearance of woody communities (Fig. 5b). The absence of a solid plant cover intensified the fluvial and slope processes, which, however, did not affect the sedimentation rate (Fig. 3). The movement of glaciers could be expected from general suggestions on the absence of data on the position of glaciers and the coastal line of the lake. The scales of glaciation, however, were comparable with the previous stage, because the normal lacustrine sedimentation remained in the studied section near the foot of the largest ice-reservoirs of Shiveluch and Ploskie sopki [4].

LPZs KR-3 and 4 (12.8–10.4 ka) correspond to a final stage of the Late Glacial and the transition to the Holocene. At a depth of 95 cm (11.5 ka), the lacustrine deposits in the section are replaced by subaerial, deposits which marks the period of emptying of the CKD lake, and the beginning of the formation of the present-day valley of the Kamchatka River. According to the available geochronological data (Fig. 3), the time of this change approximately corresponds to the lower boundary of the Holocene.

A strong increase in the amount of shrubby alder in the pollen spectra is a typical feature of KP-3 and, especially, KP-4, which probably can be an indicator of glacial recession (Fig. 5c) leading to the expansion of the area of sub-Alpine cenoses. In addition, there was an increase in the amount of pollen of downy alder, which, in turn, can indicate the decrease in the level of the lake.

It is possible that free areas became covered by a moisture-loving floodplain forest of fragrant poplar and downy alder. As in LPZ KR-1, the amount of alder pollen can be excessive in comparison with its real amount in communities; however, we cannot deny the increasing role of alder in the vegetation of the studied territory. This period is also characterized by the presence of pollen and spores of coastal and water plants (cattail, quillwort), but the species diversity of water and coastal plants in comparison with LPZ KR-1 is significantly reduced. A strong increase in the pollen content indicates a significant increase in the productivity of plants, which was probably a result of warming of the climate.

Similar strong changes in the composition of the pollen spectra ~11.5 ka are registered by many researchers of Western Beringia. The increase in the amount of shrub forms of alder and birch is also noted in the Krutoberegovo section [10], as well as in other sections of the western coast of the Bering Sea [9].

The largest change in the spore–pollen spectra at the boundaries of the KP-3 and KP-4 zones corresponds to the emptying of the lake and the change in the lacustrine deposits of the KamPlen section by subaerial ones (Fig. 5d). The amount of local spectra components increases [19]. Because of the temporal proximity, it is impossible to divide the results of the climate change at the Pleistocene–Holocene boundary and a sharp emptying of the lake. Both LPZs reflect a gradual warming, degradation of glaciation, and expansion of areas of more thermophylic plant communities. A strong increase in the pollen concentration in samples from KR-4 reflects the primary succession in the basin of the emptied lake.

CONCLUSIONS

(1) Our materials allowed the first reconstruction of some conditions of the CKD landscape formation in the Late Peni-Glacial, Late Glacial, and transitional period to the Holocene, which significantly expands to the past the detailed paleogeographical record elaborated for the Holocene of Kamchatka.

(2) Under a relatively cold and wet climate (15–18 ka), the drainage area of the paleolake was characterized by open landscapes with dominant herbaceous-grass communities and Boreal flora in some refugia, which does not support the extensive glaciation of Central Kamchatka in this period.

(3) In the period of 15–13 ka, the plant cover became sparser because of the increase in the continental character of the climate. The CKD territory was dominated by herbaceous communities with low species diversity, and woody vegetation almost completely vanished. The reduction of the plant cover, however, was accompanied by an insignificant movement of glaciers, which did not affect the change of the sedimentation type and its rate.

(4) After 13 ka, warming of climate led to degradation of glaciation and expansion of larch forests in the drainage area of the paleolake. The emptying of the lake at about 11.5 ka and the beginning of accumulation of subaerial deposits in the area of the studied section correspond approximately to the lower boundary of the Holocene, which is an argument in favor of the glacial hypothesis of the damming of the paleolake.

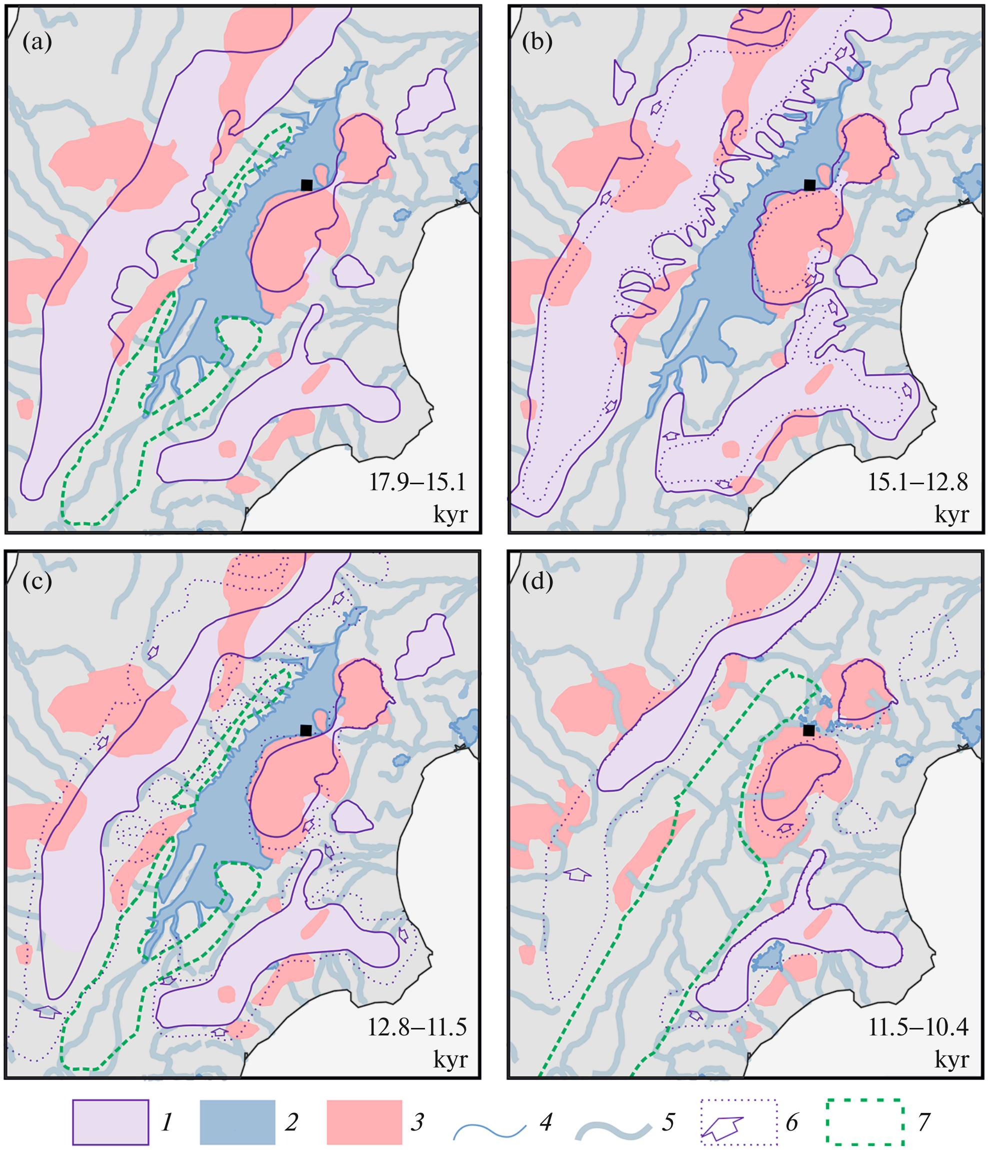

Fig. 5. Principal scheme of dynamic vegetation and landscape-forming processes of the Central Kamchatka Depression in the studied period. (*1–5*) areas of glacial processes of mountainous–valley glaciation (*1*), lacustrine accumulation (*2*), volcanic accumulation (during the entire Late Quaternary period after [20]) (*3*), lacustrine coastal (*4*), and fluvial processes in the largest river valleys (*5*); (*6*) dynamic of glaciation; (*7*) contours of possible propagation of woody vegetation. The contours reflect the scale and temporal dynamic of considered phenomena rather than their precise geographic position.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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