FEATURES OF THE FORMATION OF LAKES IN THE CRYOGENIC REGIONS OF THE UPPER KOLYMA, NORTHEAST SIBERIA

A. V. Lozhkin¹, P. M. Anderson²

¹*North-East Interdisciplinary Scientific Research Institute n. a. N. A. Shilo, FEB RAS, Magadan*

²*Earth & Space Sciences and Quaternary Research Center, University of Washington, Seattle WA, USA*

E-mail: lozhkin@neisri.ru, pata@uw.edu

Long-term observations of the evolution of the Elikchan lakes (Kolyma Upland, Maimandzha Mountains), which form a “chain” that stretches across the flat watershed separating the Upper Kolyma and the Sea of Okhotsk drainages, make it possible to determine how slope, thermokarst processes, and ecology affected landscape changes within this area. Clastic material coming from the slopes of the Maimandzha Mountains formed dams, which created large lakes within the Okhotsk basin (Elikchan-4 Lake, Elikchan-3 Lake). The origin of the lakes belonging to the Kolyma basin is the result of active thermokarst processes associated with the thawing of ice wedges, the development of bogs, the confluence of small lakes and the formation of new larger reservoirs. Such thermokarst processes were some of the main factors in the origin of Elikchan-1 Lake. The continuous palynological record and radiocarbon dating of the Elikchan-1 Lake sediments reflect the successive changes of biocenoses, which correspond to the general pattern of the evolution of the vegetation cover in the Upper Kolyma basin and in Northern Priokhotye. This record shows a change in plant communities over at least the past 9 000 years with a climatic optimum at ca. 8 000–6 100 years ago. Comprehensive analysis of Elikchan-1 Lake also emphasizes the significant discrepancies between the boundaries of Holocene subdivisions in the Far Eastern region and the European chrono-stratigraphy for the Holocene. Attempts to resolve the problems of Far East stratigraphy by comparison to the traditional divisions for Europe are a serious mistake. Moreover, a complete analogy of the Far Eastern subdivisions of the Holocene with the European chronological standard should not be expected, just as it is inappropriate to use the “European” terminology in the Far Eastern reconstructions. The influences of the primary factors that determine the Holocene events in the Far East sharply differ from those of Europe, including the specific features of the regional climates as they respond to global forcing factors, diversity of the vegetation cover, and variations in the timing of changes in the biocenoses. Given such differences, it is quite natural that equating the Holocene divisions between the two regions is unacceptable. Radiocarbon dating at the base of the Elikchan-1 Lake sedimentary column indicates that the site was originally a peat bog in the Early Holocene with subsequent lake formation. Comparison of radiocarbon dates from the Elikchan-1 peat with other peat deposits in the region suggests that the Early Holocene was a time of active formation and fairly widespread development of peat bogs in the mountainous regions of the Kolyma and Northern Priokhotye.

Keywords: Holocene, thermokarst, lake, peat bog, pollen analysis, radiocarbon, tephra.

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An examination of paleoenvironmental data from the area of the Elikchan lakes, which form a “chain” of four lakes that transects the drainage divide between the Upper Kolyma basin and the Sea of Okhotsk (Fig. 1), reveals the complex interactions of slope and thermokarst processes with other environmental changes that shaped the origin and history of these lakes. The climate history recorded in the Elikchan sediments also has implications for chrono-stratigraphic terminology commonly used in the Russian Far East.

The Elikchan lakes are located in a wide, northwest-southeast trending, intermontane valley, which lies in the middle part of the Kolyma Uplands with-

in the foothills of the Maimandzha Mountains. The “chain” consists of one small and three large lakes. The biggest lakes, Elikchan-4 (elevation 798.9 m above sea level (a. s. l.), length ca. 4 300 m, maximum width 1 750 m) and Elikchan-3 (length 1 450 m, width 500 m) are part of the Okhotsk drainage basin (Fig. 1). The Maimandzha River (Yama River), which flows into Shelikhov Bay, originates as the outflow of Elikchan-4 Lake. A small stream connects Elikchan-4 and Elikchan-3 lakes. Two other lakes – Elikchan-1 and Elikchan-2 – have outflows to the Maltan River, which is a right tributary of the Bakhapcha River (Upper Kolyma basin). The drainage divide, with an elevation of 815 m a. s. l., is formed by a narrow (250 m wide) rise that separates the second and third Elikchan lakes. The length

Fig. 1. Map showing the location of the Elikchan Lakes in the Okhotsk-Kolyma drainage divide: 1 – drainage divide between the Sea of Okhotsk and the Upper Kolyma basins; 2 – valley of the Elikchan Lakes

Рис. 1. Географическая схема расположения Эликчанских озер на Охотско-Колымском водоразделе: 1 – водораздел бассейнов Охотского моря и Верхней Колымы; 2 – район долины Эликчанских озер

of the valley, which includes all the lakes, is 12 km with a maximum width between 2.5 and 3 km.

The peaks of the mountains surrounding the Elikchan valley reach 1 200–1 500 m a. s. l., whereas the greatest heights of the Maimandzha Mountains are 1 600–1 800 m a. s. l. The slopes bordering the lakes are covered by a sparse larch (*Larix cajanderi*) forest that extends from the lakes to an elevation of 1 100–1 300 m a. s. l. The forest understory consists of high shrubs of *Pinus pumila*, *Duschekia fruticosa*, and *Betula middendorffii* with a well-developed ground cover of moss (Bryales) and low shrubs. Additionally, the vegetation in the Elikchan valley includes *Rhododendron parvifolium*. Shallow areas within the lakes are overgrown with *Potamogeton perfoliatus*, *P. berchtoldii*, *Sparganium hyper-boreum*, *S. emersum*, *Menyanthes trifoliata*, *Cicuta virosa*, and *Hippuris vulgaris*; sedges (Cyperaceae) are abundant along the lakeshores. The composition of the vegetation of the Elikchan valley is determined by the region's harsh continental climate. Mean annual temperature

is -12°C . Mean January temperature is -32°C , and in December-February the minimum temperatures drop to -55°C . Mean July temperature is $+10.6^{\circ}\text{C}$; on especially warm days, summer temperatures can rise to $+25^{\circ}\text{C}$. Mean annual rainfall is 293 mm. Precipitation, groundwater, and overland runoff are the sources of water input into the lakes.

Geomorphological and geological data from the Malan and Maimandzha catchments suggest that the restructuring of the river network in the Elikchan lakes area was caused by Late Pleistocene glaciation originating in the Maimandzha Mountains (Pakhomov, 2004). The thickness of the glacier in the Elikchan valley exceeded 150 m. Morphological traces of glaciers representing at least two cool periods (oxygen isotopic stages 4 and 2 equivalents) were preserved in the valleys of the Malan River, Maimandzha River, Basandra River and their tributaries. On the northern shore of Elikchan-3 Lake and in the stream valley between Elikchan-3 and Elikchan-4 lakes, these deposits are observed in the

form of poorly sorted glaciofluvial sediments, accumulating to 20–30 m thicknesses on the gently sloping hills (Lozhkin and Fedorova, 1989). From the steep slopes of the Maimandzha Mountains, a mass of clastic colluvial and proluvial material has entered the Elikchan valley. These sediments partially, and in some places completely, cover the valley bottom, forming dams that separate one lake from another (Lozhkin et al., 1995). The presence of such dams and the altering of the valley topography resulted in the formation of the large lakes belonging to the Okhotsk basin (Elikchan-4, Elikchan-3). The origin of the lakes belonging to the Kolyma drainage is related to active thermokarst processes associated with the melting of ice veins, the subsequent development of boggy terrain, the merging of small lakes within polygons formed by the intersection of the ice veins, and ultimately the development of a larger lake basin as ice melt continued. Such thermokarst processes were the main factors in the emergence of Elikchan-1 Lake.

Elikchan-1 Lake is located in a relatively wide, flat, swampy valley, which borders the Elikchan Valley of the Maimandzha Mountains. It is the third largest in the Elikchan Lakes group and is connected to the headwaters of the Maltan River by a small stream. The length of the lake reaches 900 m with a width of 700 m. The depth in the central portion of the basin does not exceed 4 m. The almost oval shape of the lake is altered by a small cape (elevation of 792.5 m a. s. l. at the water's edge), which protrudes into the northwestern part of the lake.

Cores were raised from the center of the lake in several different years (in early spring from the ice surface and in summer from a platform attached to rafts, which formed a catamaran). The coring recovered sediments with a thickness of 162 cm. They are from top to bottom:

- 0–55 cm – gray silt, saturated with water;
- 55–61 cm – silt with an abundance of plant debris;
- 61–91 cm – silt, gray, horizontally layered;
- 91–98 cm – silt with a large number of remains of aquatic plants;
- 98–140 cm – silt, gray, horizontally layered; plant remains, including small fragments of shrub branches, occur at the base of the layers;
- 140–142 cm – whitish-gray volcanic ash;
- 142–150 cm – silt, gray, horizontally layered, with plant debris;
- 150–162 cm – brown *Sphagnum* peat, fibrous.

From the peaty material at the base of the sediment column, radiocarbon dates of $8\,500 \pm 100$ years ago (MAG-876; $9\,490$ cal yr BP) at a depth of 155–157 cm and $8\,800 \pm 100$ years ago (MAG-875; $9\,860$ cal yr BP) at a depth of 160–162 cm were obtained. Thus, the continuous palynological record of lake sediments shows a change in plant communities during approximately the past 9 000 radiocarbon years ($10\,200$ cal yr BP).

Peat dates from the base of the Elikchan-1 core and similar radiocarbon dates from other sites in Northeast Siberia fall within the Holocene climatic optimum (Lozhkin, Vazhenina, 1987). For example, *Betula* trees and large shrubs of *Duschekia fruticosa* expanded into the zone of modern herb and shrub-herb tundra (low-growth shrubs include *Salix* sp., and *Betula exilis*) of the Kolyma lowland during this period. Today this region supports low shrub and herb-dominated tundra.

To present the results of the palynological analysis, computer programs *Tilia* and *Tilia-graph* (<http://www.tiliat.com>) were used to calculate percentages and to construct the pollen diagrams, respectively. The spore-pollen diagram shown in Fig. 2 illustrates the ratios of vegetation groups (the left side of the diagram illustrates total pollen from the group of trees and shrubs; pollen from the group of subshrubs and herbaceous plants; and from the group of spores) and the percentages of the major individual pollen and spore taxa. Minor pollen and spores are shown in Fig. 3. Each pollen taxon is shown as a percentage of the sum of all pollen grains, excluding aquatics. Percentages of individual spore taxon are determined separately based on the pollen sum. Calibration of radiocarbon dates was done with CALIB 7.1 (Stuiver et al., 2020).

In the spore-pollen diagram of Elikchan-1 Lake sediments, five pollen zones have been identified. The spectra of the lower pollen zone EL1 are dominated exclusively by *Betula* and *Alnus* pollen. The pollen of one of the most characteristic and beautiful plants of the modern Kolyma flora, *Pinus pumila*, is found only as single grains. Such extremely low percentages or the complete absence of pollen of *Pinus pumila* is very typical of spore-pollen assemblages associated with the vegetation of the transitional period between the Late Pleistocene and Early Holocene (Lozhkin, 1997; Late..., 2002). The constant occurrence of *Larix* pollen in zone EL1 is of particular interest. Because *Larix* is an under-represented taxon, even trace amounts of its pollen are good indicators of the presence of larch in Northeast Siberia (Vaskovsky, 1956, 1957). The altitudinal forest boundary in the mountains perhaps rose to elevations above the modern limits of 1 100–1 300 m a. s. l. during the Early Holocene due to climate warming and an increase in precipitation. In the central mountainous regions of the Kolyma River basin (e. g., Jack London Lake), open larch forests occupied significant areas by 11 600 radiocarbon years ago ($13\,440$ cal yr BP). The post-glacial spread of this tree indicates that the average summer temperatures increased to 12°C (Lozhkin, 1997).

The very high percentages of *Betula* pollen in zone EL1 can indicate both the wide distribution of dense thickets of birch (ernik) and the establishment of scattered stands of tree birch (*Betula platyphylla*, *B. cajanderi*). These birch communities also grew

Fig. 2. Ratio of vegetation groups and the main pollen and spore taxa in the palynological spectra from sediments of Lake Elikchan-1
Рис. 2. Соотношение групп растительности, основных пыльцевых и спорных таксонов в спектрах осадков оз. Эликчан-1

Fig. 3. Minor pollen and spore taxa in the spectra from sediments of Lake Elikchan-1

Рис. 3. Второстепенные пыльцевые и спорные таксоны в спектрах осадков оз. Эликчан-1

within the larch forest. The first post-glacial peak of *Betula* pollen in continuous lake pollen records of Northeast Siberia dates to 12 500 years ago (14 760 cal yr BP), when the herb and herb-subshrub tundra that dominated most of the region was rapidly replaced by tall shrub birch, then by birch-shrub alder tundra and finally by *Larix cajanderi* forest (Lozhkin, 1997; Late..., 2002).

A significant change in the regional biocenosis is reflected in pollen zone EL2. Firstly, this zone is characterized by a sharp increase in the percentage of *Pinus pumila* pollen, which, like *Betula* and *Alnus* pollen, becomes dominant in the spore-pollen spectra. *Pinus pumila* (i. e., *Pinus* subgen. Haploxylon, whose source is the species *Pinus pumila*; Vaskovsky, 1956) undoubtedly began to play a significant role in the undergrowth of the larch forests at this time. The first post-glacial peak of *Pinus pumila* pollen in the records of lakes of Northeast Siberia has been dated in Northern Priokhotye to 8 300–8 000 years ago (9 340–8 880 cal yr BP; Anderson et al., 1998; Late..., 2002). This change in vegetation approximately corresponds to the boundary of the Early and Middle Holocene at ~ 8 000 years ago (8 880 cal yr BP) in the standard chronology proposed by Khotinsky (1977) for subepochs within the Holocene (note: recent changes in timing of these subepochs are shown in Table 1). The dates obtained from the peat at the base of the Elikchan-1 Lake core are consistent with such reconstructions.

A second significant increase in pollen of *Pinus pumila* is observed at the boundary of zones EL2 and EL3. Such peaks of *Pinus pumila* pollen are common in continuous Holocene pollen records from lakes in Northeast Siberia (Late..., 2002). Interestingly the maximum percentages of *Pinus pumila* pollen recorded in zone EL3 approximately correspond in time with the deposition of a volcanic ash layer in the lake sediments. This volcanic ash, first discovered in the sediments of the Elikchan lakes, was named the Elikchan tephra (Lozhkin et al., 2016). Sediments recovered using a Livingstone piston sampler (Wright et al., 1984) clearly show the horizontal layers of tephra within sediments from all four of the Elikchan lakes. The thickness of the tephra varies depending on the local conditions of accumulation and/or the amount of material redeposited from the shores of the lakes. For example, in Elikchan-4 Lake, the thickness of the volcanic ash varies from 1–2 to 5.5–6 cm. In terms of granulometric composition, the Elikchan tephra is silty and pelitic with an admixture of fine-grained sand. The ash is composed mostly of volcanic glass (< 95% >). In terms of its chemical composition, the tephra corresponds to liparites with a SiO₂ content of 74–76% (Melekestsev et al., 1991).

Volcanic ash, which is similar to the Elikchan tephra, has been found in the sediments of glacial lakes in the Upper Kolyma region, the Upper Indigirka ba-

sin, and in the northern Okhotsk region (Lozhkin et al., 2016). The age of the ash horizons in the lake sediments was determined by radiocarbon dating the plant remains in the underlying and/or overlying sediments. The radiocarbon results suggest that the age of the Elikchan tephra is between 7 600–7 700 years ago (8 400–8 480 cal yr BP). These dates correspond to the timing of the largest explosive eruption in southern Kamchatka during the last 10 000 years (11 700 cal yr BP), which resulted in the formation of the Kuril Lake – Ilinskaya caldera (Melekestsev et al., 1991). The small size of the ash particles in the Elikchan sediments and their well-sorted structure are indicative of distant wind transport from the eruption site. Lacustrine cores from Northeast Siberia show that this volcanic ash spread up to 1 800 km north of the Kamchatka caldera, spanning a ~ 500-km-wide region encompassing northern Priokhotye and the mountainous areas of the Kolyma and Indigirka drainages. Numerous radiocarbon analyses from deposits in Kamchatka and from the lake cores has dated the tephra more precisely to $7\,650 \pm 50$ years ago (8 400 cal yr BP). Thus, the Elikchan tephra is a key chronostratigraphic marker that is particularly important for reconstructing the timing of changes in Holocene climate and vegetation in Northeast Siberia.

The maximum percentages of *Pinus pumila* pollen in the spectra of zone EL3 (Fig. 2) clearly distinguish this assemblage from others in the continuous record of the Elikchan-1 sediments. Dwarf pine (*Pinus pumila*), which we believe migrated into the Elikchan region from an area near the Sea of Okhotsk, played a significant role both in the understorey of the larch forest, and also formed a belt of shrub pine tundra in the Maimandzha Mountains above the forest border. *Pinus pumila* survived the glacial stages of the Late Pleistocene in refugia near the coast of the Sea of Okhotsk, most probably in deep valleys filled with snow from early autumn to late spring (Shilo et al., 2007; Anderson et al., 2010). The EL3–EL4 zone boundary is marked by a change in biocenoses with zone EL4 characterized primarily by a noticeable reduction in the pollen of dwarf pine (*Pinus pumila*) and by the greater occurrence of pollen from shrub birch and meadow communities, the later dominated by Poaceae. To determine the age of the boundary between pollen zones EL3 and EL4, we calculated the rate of sediment accumulation in the lake, which showed an almost constant value of 0.18 mm / year throughout the record. Given these data, the age of the upper EL3 boundary is 6 100 years ago (6 970 cal yr BP). Following the chronological standard for the division of the Holocene suggested by Khotinsky (1977) and IUGS (Head, 2019), pollen zone EL3 can be assigned to the Middle Holocene (Table 1).

Comprehensive paleobotanical studies, including palynological and carpological analyzes, as well

as radiocarbon dating carried out in the neighboring Ola River basin (Lozhkin et al., 2018), suggest that zone EL3 represents the Middle Holocene climatic optimum. At this time, this part of northern Priokhotye was dominated by *Larix cajanderi* – *Betula platyphylla* forests with a *Sphagnum* ground cover. Computer climate models show that the average August temperatures in northern Priokhotye were 2–4°C higher than modern (Lozhkin et al., 2019). The models also show greater winter precipitation and a longer growing season than at present.

An analysis of the continuous pollen record from Elgygytgyn Lake (northern Chukotka), which spans the entire Quaternary, indicates that coniferous forest was characteristic of the warm intervals of the Quaternary period (Lozhkin, Anderson, 2020). This light coniferous forest was dominated by *Larix*, and possibly included tree or tree-sized shrubs of *Betula* and *Alnus*. In contrast, herbaceous and subshrub tundra predominate in this region today. Comparison of the Elgygytgyn, Elikchan-1 and other pollen records from Northeast Siberia indicate that isotope stages 5 and 1 represent the two most recent thermal maxima within the Quaternary. Thus, while zone EL2 and EL1 show the effects of postglacial climatic amelioration, zone EL3 is the last interval that reflects the influence of a thermal optimum on the regional vegetation.

If zone EL3 encompasses all of the Middle Holocene thermal optimum, the age assignment (~ 7 600–6 100 ¹⁴C; ~ 8 400 – 6 970 cal yr BP) suggests that the boundary between the Middle and Late Holocene is not ~ 4 600 years ago (~ 5 300 cal yr BP; Atlantic/Subboreal boundary) as proposed by Khotinsky. The Elikchan data suggest the interval of maximum warmth may be up to ~ 1 500 ¹⁴C yr shorter in this region of the Far East as compared to other

areas of northern Eurasia. This discrepancy perhaps is the result of an error in the Elikchan-1 age model. However, the general uniformity of the spectra in zone EL4 (i. e., the pollen data show no fluctuations equivalent to those described in the Blytt-Sernander scheme) and the differences in timing more likely reflect the strong regional responses to global climate forcings, such as changes in insolation, sea-surface temperatures, and atmospheric composition, rather than a dating error.

All the spectra in zone EL4 are characterized by an abundance of *Betula* and *Alnus* pollen, an almost constant presence of *Larix* pollen, and relatively high percentages of Poaceae pollen. As mentioned above, the composition of the biocenoses are relatively stable throughout the zone. However, modest variations in the pollen percentages of *Pinus pumila*, *Betula*, and *Alnus* allow us to define three sub-zones (zone EL4a – 6 100–3 300 years ago [6 970–3 520 cal yr BP]; zone EL4b – 3 300–2 200 years ago [3 520–2 240 cal yr BP]; zone EL4c – 2 200 years ago –550 years [2 240–550 cal yr BP]). Relatively high pollen percentages of *Pinus pumila* are observed only in subzone EL4b, which may indicate an expansion of the shrub pine zone in the mountains. The general characteristics of the palynological results for zone EL4 also indicate that the vegetation cover on the mountain slopes of the Elikchan Valley consisted of *Larix cajanderi* forests with an understory of shrub birch (probably dominated by *Betula middendorffii*), *Salix* sp., *Duschekia fruticosa*, and *Pinus pumila*. Ground cover was formed by dwarf shrubs, moss (*Sphagnum*), and heather (Ericales). *Duschekia fruticosa* probably formed dense thickets on the valley slopes and along the banks of rivers and lakes.

Table 1. Divisions of the Holocene

Таблица 1. Разделы голоцена

System	Epoch	Subepoch	Age ¹⁴ C	Age cal yr
Quaternary	Holocene	Late (Meghalayan)	~ 3 800–0	~ 4 200 to present
		Middle (Northgrippian)	~ 7 500–3 800	~ 8 200 – 4 200
		Early (Greenlandian)	~ 10 000 to 7 500	~ 11 700 – 8 200

After the International Union of Geological Sciences (Head, 2019).

Blytt-Sernander System for the Holocene

Epoch	Climatic Event	Age ¹⁴ C (Age cal yr) Russia	Age ¹⁴ C (Age cal yr) Europe
Holocene	Subatlantic	~ 2 500 – 0 (~ 2 600 – 0)	~ 2 500 – 0 (~ 2 600 – 0)
	Subboreal	~ 4 600 – 2 500 (~ 5 300 – 2 600)	~ 5 000 – 2 500 (~ 5 700 – 2 600)
	Atlantic	~ 8 000 – 4 600 (~ 9 000 – 5 300)	~ 8 000 – 5 000 (~ 9 000 – 5 700)
	Boreal	~ 9 200 – 8 000 (~ 10 340 – 9 000)	~ 9 000 – 8000 (~ 10 000 – 9 000)
	Preboreal	~ 10 300 – 9 200 (~ 12 000 – 10 340)	~ 10 100 – 9 000 (~ 11 640 – 10 000)

Blytt (1876) and Sernander (1908) divisions of the Holocene developed for Northwest Europe with ages proposed for Russia (Khotinsky, 1977) and for Europe (Schroder et al., 2004).

The pollen spectra of zone EL5 show an even wider presence of shrub birch thickets (dwarf birch; *ernik*), as well as a local reduction in *Pinus pumila*. The constant presence of *Larix* pollen in the spore-pollen spectra of zones EL4 and EL5 indicates the long-term development of larch forests, although the composition of the understory communities varied slightly between zones.

The sequential changes in biocenoses, represented in the continuous palynological record from Elikchan-1 Lake, allow us to consider the temporal variations in vegetation communities in terms of the broader paleoenvironmental trends within the Holocene. The Holocene traditionally has been divided according to differences in paleoclimates into three subepochs: Early, Middle, and Late (Table 1). Note that recently, the International Union of Geological Sciences renamed these subepochs as the Greenlandian, Northgrippian, and Meghalayan, respectively (Head, 2019). In the Elikchan-1 record, pollen zones EL1 and EL2 can be assigned to the Early Holocene. As mentioned previously, this is a time, centered around 8 500 years ago (9 500 cal yr BP or late Early Holocene), when tree or tree-sized *Betula*, *Duschekia fruticosa*, and *Salix* shrubs expanded into the zone of modern herb tundra along the East Siberian Sea coast. This expansion coupled with the high growth form of the woody species indicates significant climatic amelioration during the Early Holocene in Northeast Siberia (Lozhkin, Vazhenina, 1987). Undoubtedly, these paleovegetation changes reflect the influence of post-glacial warming, the beginning of which is evident as early as 12 500 ¹⁴C years ago (14 760 cal yr BP) in Northeast Siberia (Lozhkin, 1997; Late..., 2002). The Early Holocene also includes the formation of large deposits of *Sphagnum* peat in the Kolyma Lowland, further indicating warming conditions.

Peat bogs are common today in the Elikchan valley, along the steep banks of the Maltan River, as well as across the Kolyma Lowland. These deposits often include the remains of large shrubs and trunks of tree birch. The occurrence of such organic-rich materials allowed the development of multiple radiocarbon-based site chronologies, which in the pioneering studies typically were based on the scintillation version of the radiocarbon method. As dating methods developed, chronologies are now more standardly presented in calibrated rather than in radiocarbon years. Thus, Table 1 provides an updated, calibrated version of the Blytt-Sernander scheme, the divisions of which have been the basis for describing Holocene paleoenvironmental events throughout Russia (Khotinsky, 1977). Because both types of dates occur in the Late Quaternary literature, it is recommended that in addition to calibrated ages, the original radiocarbon dates be given in all publications. The latter provide a more reliable comparison to results from investigations that were done prior to

the development and/or widespread use of chronologies based on calibrated years.

The spore-pollen spectra of zone EL3 not only indicate further climate warming, which had begun in the Early Holocene, but also exhibit the warmest and wettest conditions in the Elikchan-1 pollen record. The upper boundary of zone EL3, which clearly is emphasized by the change of biocenoses at the boundary with zone EL4 (Fig. 2), can be dated to 6 100 years ago (6 970 cal yr BP). More favorable climatic conditions, possibly with average July temperatures slightly exceeding +16°C (North..., 1970), favored the development of closed larch forests with a rich understory of *Duschekia fruticosa*, *Betula middendorffii*, and *Pinus pumila*. Widespread, dense thickets of *Pinus pumila* indicate the response of the vegetation to greater winter precipitation. Furthermore, tree birch spread over the Kolyma Lowland either establishing as individual trees or in small groups; this change has been radiocarbon dated regionally to ~ 7 500 years ago (8 340 cal yr BP; Lozhkin, Vazhenina, 1987). Thus, the paleobotanical features of zone EL3 as well as the Elikchan-1 age model support a general age assignment of the zone to the Middle Holocene. Cooler and drier conditions, indicated by the shift in biocenoses between pollen zones EL3 and EL4, is characteristic of climatic trends associated with the Late Holocene (represented by zones EL4 and EL5), perhaps with a slight warming and/or increase in depth or duration of snow cover in zone EL4b as indicated by a minor rise in *Pinus pumila* pollen percentages.

The comprehensive analysis of Elikchan-1 Lake provides an ideal example that illustrates the successive changes of biocenoses during the Holocene, which in turn correspond to the general pattern of the evolution of vegetation communities in the Upper Kolyma Basin and Northern Priokhotye (for example, the absence of *Pinus pumila* in the Early Holocene and the appearance of this pine species, which is very characteristic of modern plant communities, at the boundary of the Early and Middle Holocene). The analysis of the Elikchan-1 core also emphasizes the significant discrepancies between the boundaries of the Holocene subdivisions in the Far East as compared to boundaries defined in the standard Holocene chrono-stratigraphy defined for Europe (Table 1). For example, the Elikchan-1 record shows relatively warm conditions during zones EL1, EL2, and EL3, the latter representing the Holocene climatic optimum. Zone EL4 suggests little variation in climate or vegetation, except for a small amelioration in zone EL4b, and zone EL5 marks the recent establishment of modern conditions. Neither the paleovegetational nor the paleoclimatic pattern parallels the European (i. e., Blytt-Sernander) sequence. Thus, when trying to resolve the problems of the Holocene stratigraphy in the Russian Far East, it is a serious mistake to compare the subdivisions

of the Far East with the traditional Holocene divisions used in Europe. Moreover, one should not look for a complete analogy of the Far Eastern subdivisions of the Holocene with the European chronological standard; equally it is inappropriate to use the "European" terminology in the Far Eastern paleoenvironmental reconstructions as specific climatic conditions are associated with each of the European intervals. Such paleoenvironmental variations should not be surprising, because the primary natural factors determining the Holocene events in the Far East differ sharply from those in Europe. These factors include the specific features that control the regional climates (e. g., influences of the North Atlantic vs. the North Pacific), a diverse vegetation cover that varies in composition and in the nature of the response to climate change between Europe and the Far East, and the dissimilarity in the timing of vegetation change during the Holocene as documented on each side of the vast Eurasian continent. Given these factors, it is quite natural to conclude that it is unacceptable to apply the traditional chronological boundaries developed for the Holocene in Europe to describe the Holocene chrono-stratigraphy of the Far East.

Elikchan-1 Lake is also an excellent example for the long-term study of thermokarst processes, both in the area of the Elikchan lakes and in the Malan River valley. The initiation of thermokarst processes was associated with the thawing of ice veins and ice wedges, which began, as noted previously, during a significant and rapid climate warming about 12 500 years ago (14 760 cal yr BP). As a result of such thaw processes, ice wedge polygons were common features of the landscape. Small, shallow lakes and wetlands were formed in the center (i.e., in the cores) of the polygons, the convergence of which led to the formation of larger bodies of water. These processes probably were one of the main factors in the emergence of Elikchan-1 Lake. Radiocarbon dating of the peat at the base of the Elikchan-1 core shows that lake formation occurred in the Early Holocene. In addition, the peat found at the bottom of Elikchan-1 Lake allows a direct comparison with the timing of peat initiation in the Malan River Valley (Lozhkin, Glushkova, 1997) to those in the Elikchan Valley (Lozhkin et al., 2004). Do such materials give reason to believe that the Early Holocene was a time of active peat formation and relatively widespread development of bogs in the mountainous regions of the Kolyma and Northern Priokhotye?

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ОСОБЕННОСТИ ФОРМИРОВАНИЯ ОЗЕР В КРИОГЕННЫХ РАЙОНАХ ВЕРХНЕЙ КОЛЫМЫ, СЕВЕРО-ВОСТОК СИБИРИ

Лошкин А. В.¹, Андерсон П. М.²

¹ФГБУН Северо-Восточный комплексный научно-исследовательский институт
им. Н. А. Шило ДВО РАН, г. Магадан

²Вашигтонский университет, факультет наук о Земле и Космосе,
Центр четвертичных исследований, г. Сиэтл, США

Многолетние наблюдения за эволюцией Эликчанских озер (Колымское нагорье, Майманджинские горы), протянувшихся в виде «цепочки» через плоский водораздел между реками бассейна Верхней Колымы и Охотского моря, позволили определить специфику склоновых, термокарстовых процессов, экологических изменений, происходящих в этом районе. Обломочный материал, поступающий со склонов Майманджинских гор, образует плотины, создающие крупные озера, принадлежащие Охотскому бассейну (оз. Эликчан-4, оз. Эликчан-3). Происхождение озер, относящихся к Колымскому бассейну, обусловлено активными термокарстовыми процессами, связанными с вытаяванием жил повторно-жильных льдов, развитием болот, слиянием мелких озер и формированием нового обширного водоема. Такие термокарстовые процессы явились одним из главных факторов возникновения оз. Эликчан-1. Непрерывная палинологическая летопись и радиоуглеродные датировки осадков оз. Эликчан-1 отражают последовательную смену биоценозов, отвечающую общей закономерности эволюции растительного покрова Верхней Колымы и Северного Приохотья. Они показывают смену растительных сообществ за последние не менее 9000 лет с климатическим оптимумом около 8000–6100 лет назад. Комплексный анализ оз. Эликчан-1 также подчеркивает значительные несовпадения границ подразделений голоцена в Дальневосточном регионе с границами хронологического эталона периодизации голоцена Европы. Серьезной ошибкой при решении вопросов стратиграфических построений голоцена на Дальнем Востоке являются попытки сопоставить подразделения дальневосточного голоцена с традиционным делением голоцена общей шкалы европейского региона. Тем более не следует искать полной аналогии дальневосточных подразделений голоцена с европейским хронологическим эталоном, так же как нецелесообразно использовать в дальневосточных построениях «европейскую» терминологию. Основными природными факторами, определяющими события голоцена Дальнего Востока, резко отличными от голоцена Европы, являются, несомненно, специфические особенности климата, весьма разнообразный растительный покров, иная смена во времени биоценозов. Вполне естественно, что в Дальневосточном регионе деление голоцена в соответствии с традиционными границами хронологического эталона периодизации голоцена Европы неприемлемо. Радиоуглеродные датировки торфяника в основании колонки осадков оз. Эликчан-1 показывают, что образование озера следует отнести к ранне-

му голоцену. Сопоставление этого торфяника с другими торфяными залежами дает основание полагать, что ранний голоцен был временем достаточно широкого развития болот и активного формирования торфяников в горных районах Колымы и Северного Приохотья.

Ключевые слова: голоцен, термокарст, озеро, торфяник, палинологический анализ, радиоуглерод, вулканический пепел.

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