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ГЕОЛОГИЧЕСКИЕ НАУКИ

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PHYTOCENOSES OF NORTHERN CHUKOTKA AT THE BOUNDARY OF THE EARLY AND MIDDLE PLEISTOCENE

***A. V. Lozhkin*[1]*, P. M. Anderson*[2]**

[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

The interval that spans marine isotope stages (MIS) 18–21 is one of the coolest recorded in the continuous paleoclimatic record from Lake El'gygytgyn, Polar Chukotka. The pollen zones characterizing these isotope stages reflect plant communities that are only associated with glaciations and interstadials. Cooling maxima are noted for MIS20 in the Early Pleistocene and in MIS18 of the Middle Pleistocene. Maximum warmth is established in MIS21 of the Early Pleistocene. *Larix*, the only coniferous tree found in modern forests in North-East Siberia, is not present in the glacial vegetation. Larch forest-tundra communities are established during interstadials.

***Keywords*: isotope stage, pollen zone, interstadial, forest-tundra, tundra.**

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INTRODUCTION

In 2011, the Executive Committee of the International Union of Geological Sciences approved the proposal of the International Commission on Stratigraphy (ICS) for establishing a global stratotype for the Calabrian-Gelazian boundary (Fig. 1): the Vrica section in southern Italy (Cita et al., 2012). The ICS Quaternary Subcommission defined this boundary as occurring 1.806 million years ago. The upper limit of the Calabrian was placed at 781 ka BP at the boundary of the Brunhes-Matuyama paleomagnetic zones, which also marks the boundary of the Calabrian and the Ionian Stages/Ages of the Middle Pleistocene (0.781–0.126 ka BP). This interval corresponds to marine isotope stages (MIS) 6–19 (Lisiecki, Raymo, 2005).

The first palynological data from the boundary of the Early and Middle Pleistocene in the far north of Chukotka were obtained during a study of the sediments from Lake El'gygytgyn (67°30′ N, 172°05′ E; Fig. 2). The lake, 12–14 km in size, lies within a crater with an 18 km diameter, which was formed by the fall of a meteorite 3.58 million years ago (Layer, 2000).

LAKE EL'GYGYTGYN. RESEARCH METHODS

The comparison of the magnetic characteristics of lake sediments with the Global chronostratigraphic correlation table (Fig. 3) was key in establishing a chronology for the El'gygytgyn record (Wennrich et al., 2016). A comparison of the magnetic characteristics of the Lake El'gygytgyn sediments (vertical column on the left side of the figure) is given with the paleomagnetic scale of normal and reverse magnetization (horizontal scale at the top of the figure). The initial measurements showing the boundaries of magnetic events are marked with black dots. The line connecting them provides information on the age of all sampling levels within the core, including samples for palynological analysis. Thus, all levels have an age reference. The time of the meteorite fall was dated to 3.58 million years ago ($^{40}Ar/^{39}Ar$) and is marked with an asterisk in the lower right corner of the diagram.

In 2009, the Lake El'gygytgyn Drilling Project International Expedition recovered a core (site 5011-1) in the central part of the lake at a water depth of 176 m. The core includes the full 317 m sediment thickness and is dominated by silt with an admixture of fine-grained sand (Fig. 2). Thus, the Lake El'gygytgyn palynological data represent a continuous record of Arctic vegetation changes, covering the Late Neogene and Quaternary periods (Melles et al., 2012; Wennrich et al., 2016).

An idea of the succession of plant communities near the Calabrian-Ionian boundary is represented by MIS21–MIS20 and MIS19–MIS18. MIS21 is

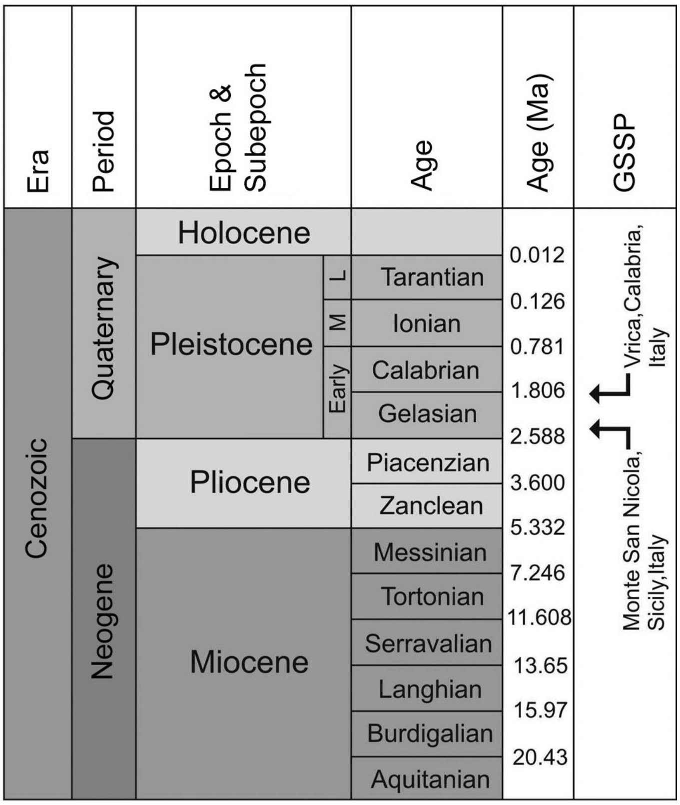

Fig. 1. Late Cenozoic stratigraphic scheme according to the International Union of Geological Sciences. Arrows indicate the ages of key areas used to define the boundaries of the Pliocene and Pleistoceneepochs and the Gelasian and Calabrian ages.

Рис. 1. Позднекайнозойская стратиграфическая схема по данным Международного союза геологических наук. Стрелками отмечен возраст ключевых участков, использованных при определении границ плиоцена и плейстоцена, гелазия и калабрия.

characterized by pollen zones 1, 2 and 3, MIS20 by pollen zone 4, MIS19 by pollen zone 5, MIS18 by the spectra in the upper part of zone 5 and in pollen zones 6, 7 and 8.

The Calabrian-Ionian boundary approximates the boundary of MIS20 (Early Pleistocene) and MIS19 (Middle Pleistocene), which is dated to c. 790 thousand years ago (Lisiecki, Raymo, 2005). The difference of 9 thousand years was not an “obstacle” to the analysis of the features of the spore-pollen spectra of the isotope stages.

The palynological analysis of Lake El’gygytgyn sediments followed the methodology proposed for the study of arctic lakes and estuaries (PALE 1994). These protocols stipulated that a minimum of 300 pollen grains from terrestrial plants should be counted in each sample. The sum of all terrestrial pollen grains is taken as 100 %. The spore-pollen diagram contains data on the ratio of three vegetation groups: trees and shrubs, herbs and spores. The individual pollen taxa are given as a percentage of the sum of all terrestrial pollen grains. The percentage of spores is considered as a relative value, which is determined separately for each spore taxon from the total amount of pollen. The construction of the spore-pollen diagram was done using the TILIA computer program.

The reconstruction of the paleovegetation based on the spore-pollen spectra from Lake El’gygytgyn necessitated a palynological analysis of the modern pollen rain preserved in the lake’s bottom sediments. This analysis showed (Lozhkin et al., 2002) that the spectra from the water-sediment interface is dominated by shrub pollen: *Alnus* (*Duschekia fruticosa*) (up to 35 %), *Betula* (20 %), and *Pinus pumila* (15 %). The total amount of shrub pollen can be up to 45 %. The high proportion of shrub pollen in the bottom sediments can only be explained by long-distance wind transport as the vegetation in the immediate vicinity of the lake is primarily lichens and herbs. The Anadyr Plateau, which surrounds the lake, is characterized by a mosaic of shrub and graminoid tundra with small populations of *Pinus pumila* (Pall.) Regel and *Duschekia fruticose* (Rupr.) Pouzar (Kozhevnikov, 1993) Thus, the modern spectra from Lake El’gygytgyn reflect the regional vegetation of northern Chukotka, and not the discontinuous

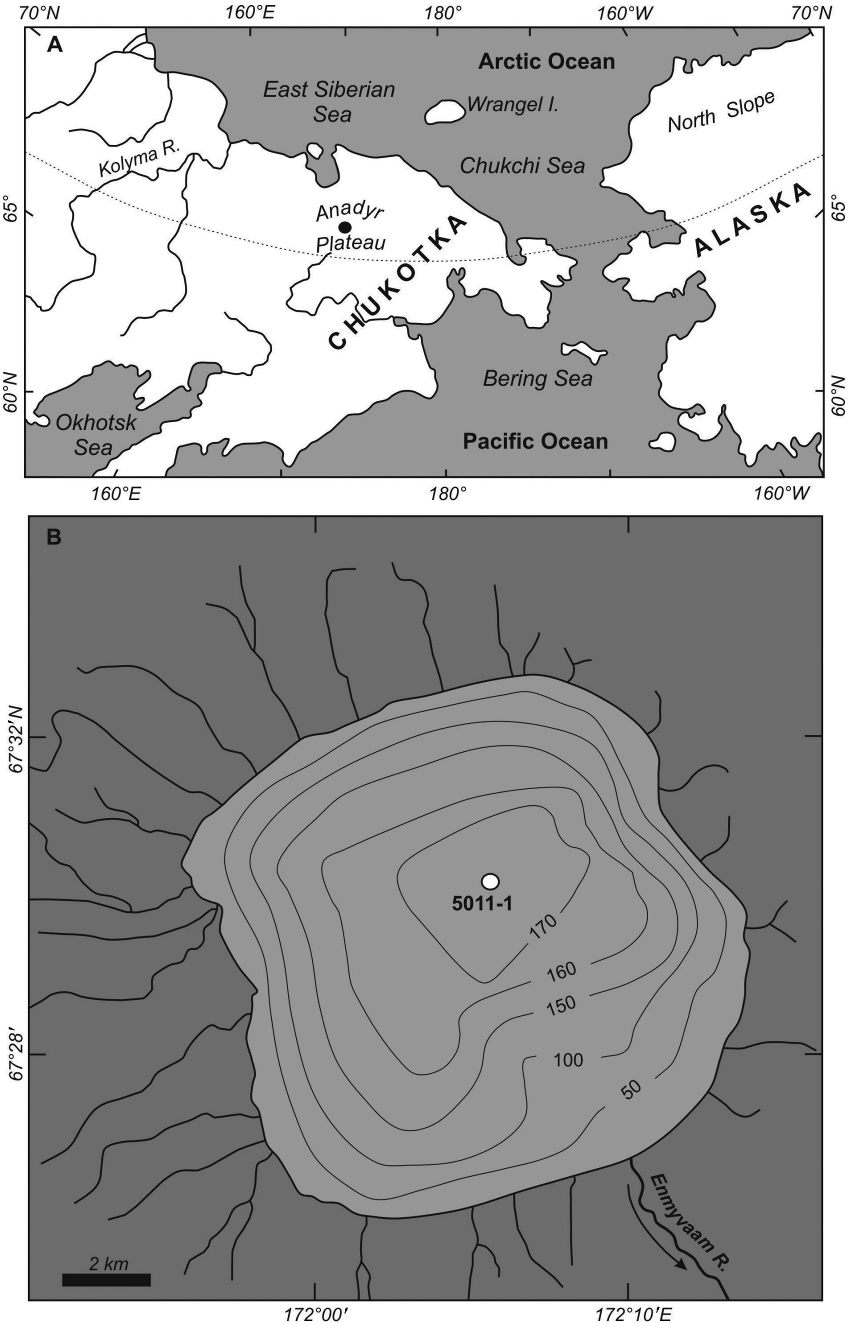

Fig. 2. A – Map of Western Beringia showing the location of Lake El'gygytgyn; B – bathymetry of Lake El'gygytgyn (water depth is given in meters). The position of coring site 5011-1 is indicated by the light circle. Inflowing streams and the Enmyvaam River outlet are also shown.

Рис. 2. А – Географическое положение оз. Эльгыгытгын на карте Западной Берингии; В – батиметрия оз. Эльгыгытгын (глубины озера даны в метрах). Положение скважины 5011-1 (светлый кружок). Ручьи, впадающие в озеро, и вытекающая из озера р. Энмываам.

vegetation cover with low pollen productivity in the vicinity of the lake.

ISOTOPE STAGES AND POLLEN ZONES

Pollen zone 1 is characterized by variability in the spore-pollen spectra, a characteristic usually associated with interstadial pollen records from lakes in North-East Siberia (Late Quaternary…, 2002). The dominants of pollen zone 1 (Figs. 4, 5) include *Betula* (up to 40 %) and Poaceae (up to 53 %). Pollen of *Alnus* (up to 25 %), *Artemisia* (up to 20 %), and Cyperaceae (19 %) are also abundant. Pollen of Caryophyllaceae (5 %), Ericales (4 %), Saxifragaceae (4 %), and Asteraceae (3 %) and *Sphagnum* and *Selaginella rupestris* spores are consistently present. The appearance of *Larix* pollen in the spectra of zone 1 indicates the establishment of larch forest-tundra and of open larch forests with an under-

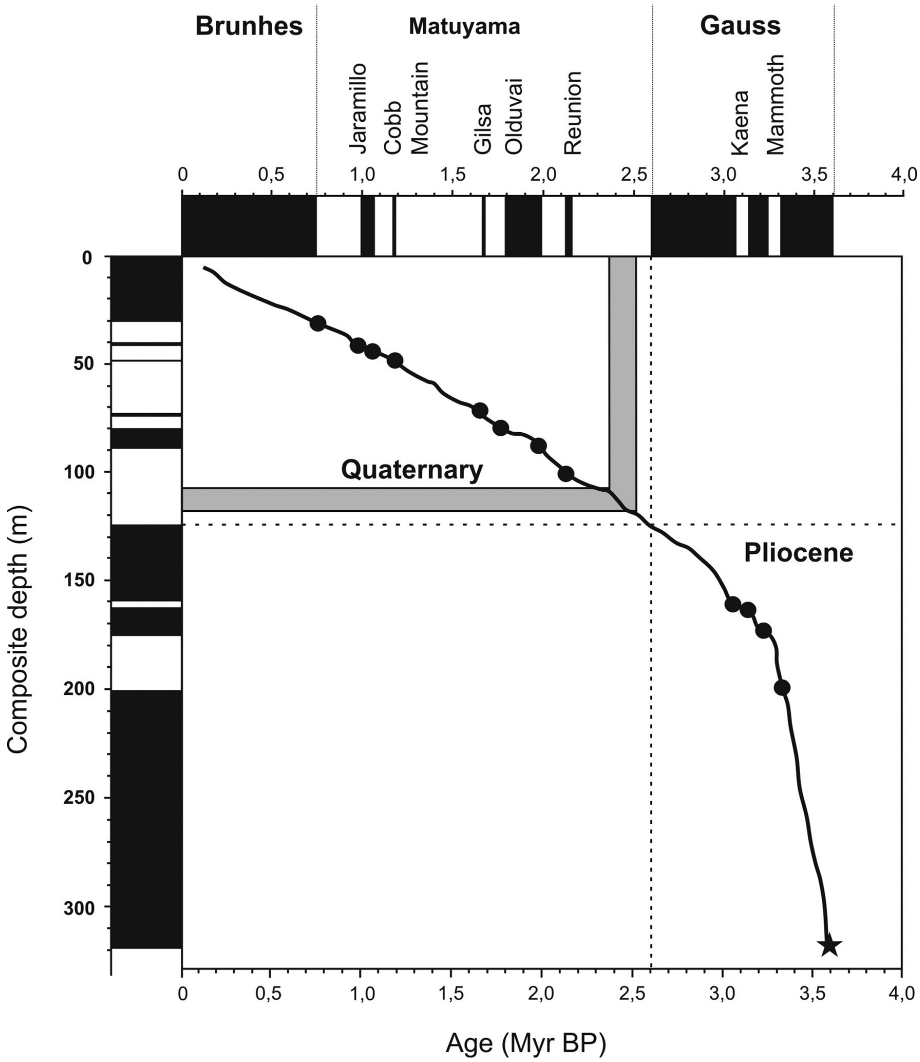

Fig. 3. Paleomagnetic events and age model for the Lake El'gygytgyn core (see text for further explanation) Nowaczyk et al. (2013).

Рис. 3. Палеомагнитные события и возрастная модель оз. Эльгыгытгын (пояснение в тексте) Nowaczyk et al. (2013).

story of shrub birch, alder, willow, and dwarf pine. The forest probably included tree birch. Shrub birch formed dense thickets on the slopes of the stream valleys. Near Lake El'gygytgyn, large areas were occupied by sedge-grass meadows, which were often water logged. These meadows were replaced on better drained slopes by *Artemisia* and *Selaginella rupestris* communities.

In the spectra of pollen zone 2, the amount of pollen from trees and shrubs is sharply reduced (no more than 17 %). *Betula* and *Alnus* pollen do not exceed 15 % and 4 %, respectively. Single pollen grains of *Larix* are rare. The extremely high content of *Artemisia* pollen (peak 65 %) is noteworthy. Another dominant of the assemblage is Poaceae (up to 40 %). Such spectra reflect the importance of graminoid and shrub-graminoid tundra in the vegetation cover, possibly replaced in limited areas by larch forest-tundra. These plant communities developed in a cold, and as the abundance of wormwood pollen shows, in a dry climate with average temperatures during the growing season no higher than +10 °C.

Pollen zone 3, like zone 1, is characterized by an unstable composition of the spore-pollen spectra. In the pollen record for MIS18–MIS21, *Betula* pollen varies from a minimum of 1 % to a maximum of 50 %. *Alnus* pollen is not comparable with the percentages seen in zone 1, and the taxon does not exceed 4 %. Poaceae pollen continues to be an important contributor to the assemblage (up to 45 %). Cyperaceae pollen doubles (up to 24 %). As in the previous pollen zones, *Artemisia* pollen (20–30%, peak 55 %) is among the dominants. The spectra of zone 3 reflect the vegetation that developed under interstadial conditions. The

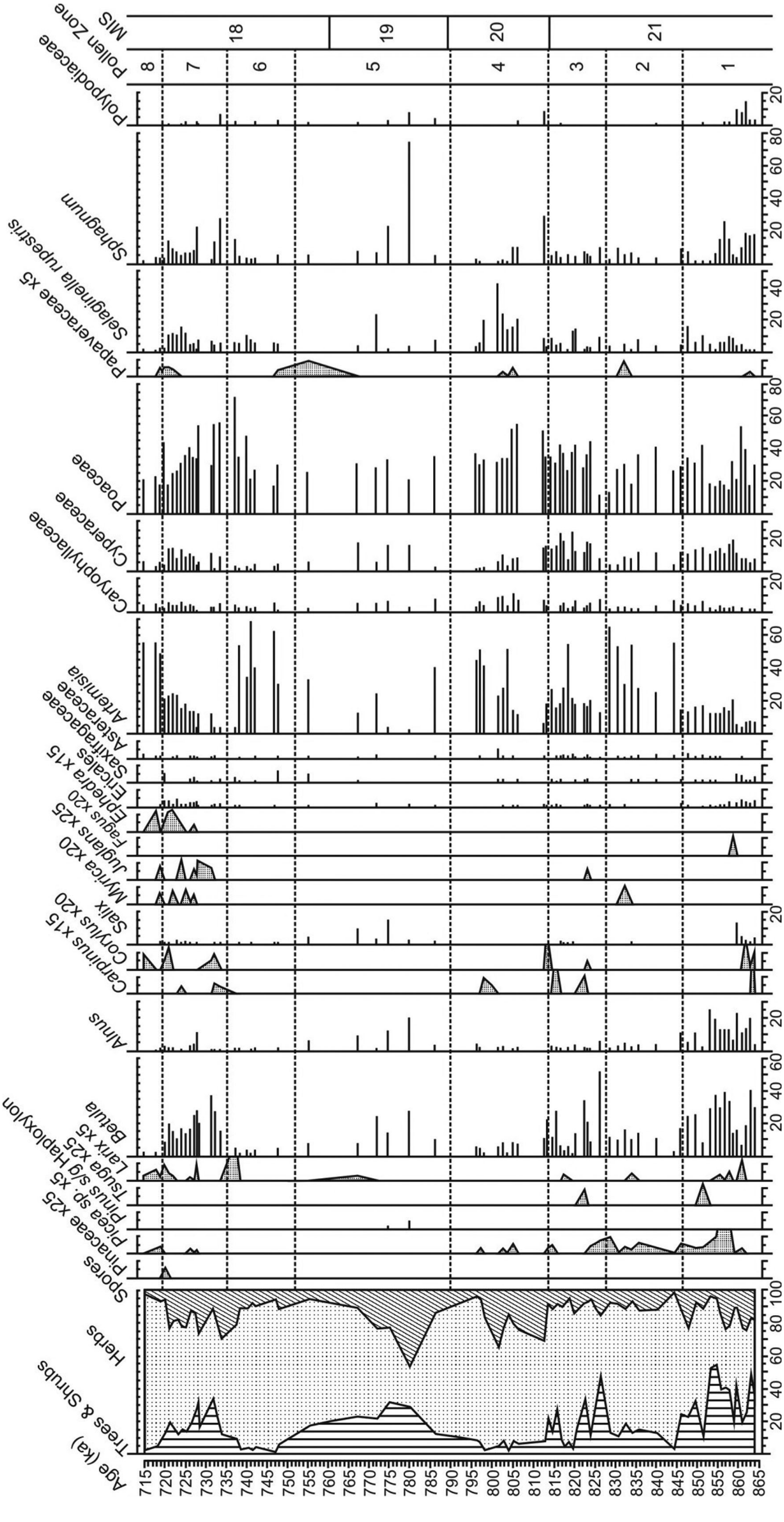

Fig. 4. The ratio of vegetation groups and the main pollen and spore taxa in the spectra of MIS18–MIS21 from Lake El'gygytgyn sediments.

Рис. 4. Соотношение групп растительности, основных пыльцевых и споровых таксонов в спектрах осадков МИС18–МИС21 оз. Эльгыгытгын.

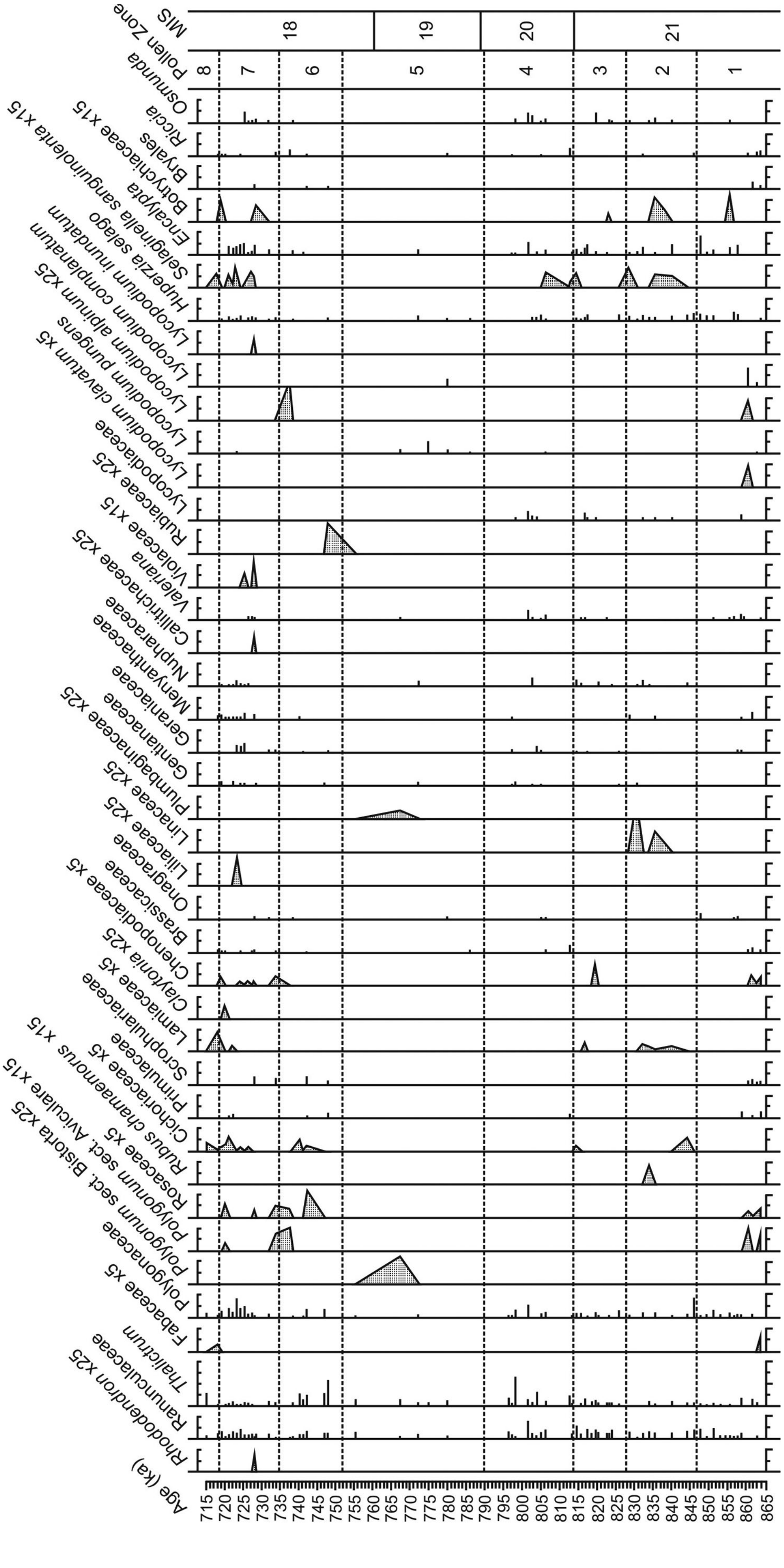

Fig. 5. Minor pollen and spore taxa in the spectra of sediments from Lake El'gygytgyn during MIS18–MIS21.

Рис. 5. Второстепенные пыльцевые и споровые таксоны в спектрах осадков МИС18–МИС21 оз. Эльгыгытгын.

assemblage shows the expansion of sedge-grass meadows that included a variety of herbs. *Artemisia* and *Selaginella rupestris* communities established on the slopes of stream valleys and along the Enmyvaam River. Thickets of shrub birch were also common and, as a single *Larix* pollen grain shows, islands of larch forest-tundra possibly had a minor presence.

The spectra of pollen zone 4 reflect vegetation that developed under conditions of deep climatic cooling. *Larix* pollen is not found in these spectra, and the amount of shrub pollen (mainly *Betula*) varies from single grains to 10 %. The most common taxa in this zone are Poaceae, *Artemisia* and *Selaginella rupestris*. The occurrence of Cyperaceae pollen (up to 10 %) and of taxa typical of the glacial spectra of North-East Siberia (e.g., up to 5 % Asteraceae, up to 12 % Caryophyllaceae) is evident. The spectra of pollen zone 4 undoubtedly indicate the spread of shrub-herb tundra and herb tundra. The vegetation possibly was discontinuous at higher elevations. The assemblage suggests conditions of not only a cold, but a dry climate.

In pollen zone 5, which characterizes the Middle Pleistocene MIS19, variation in the spore-pollen spectra is less marked as compared to interstadial pollen zones 1 and 3. In zone 5, pollen of woody plants does not exceed 30 % (Figs. 4, 5), which includes shrub *Betula* (up to 29 %), *Alnus* (up to 20 %), and *Salix* (up to 15 %). In principle, these taxa can be attributed to one of the dominants of the spectra, as well as *Artemisia* (up to 40 %), Cyperaceae (up to 18 %), and Poaceae (up to 34 %). In the lower part of pollen zone 5, a peak in *Sphagnum* spores is observed (70 %), and in the middle part of the zone, *Selaginella rupestris* spores are 20 %. Even a rare finding of *Larix* in the spectra suggests a limited distribution of larch forest-tundra, possibly with the inclusion of tree birch. During MIS19, the largest areas in the landscape were occupied by shrub tundra. However, sedge-grass meadows were abundant in the vicinity of the lake. Valley slopes were occupied by communities of *Artemisia* and *Selaginellarupestris* with Caryophyllaceae (up to 9 %), Asteraceae, and Saxifragaceae, and thickets of shrub *Betula*. The ratio of vegetation groups, combined with the main pollen and spore taxa indicate that interstadial conditions characterized MIS19.

MIS19 includes three pollen zones in the interval of 715–752 thousand years ago (as already shown, the interval of 752–761 thousand years ago is characterized by pollen zone 5). Pollen zone 6 reflects a cooling period that limited the development of woody vegetation. The shrub pollen in this zone can decrease to 5 %, and this pollen belongs mainly to *Betula* (5 %). *Alnus* and *Salix* pollen do not exceed 1 %. The occurrence of *Larix* pollen at the boundary of pollen zones 6 and 7 probably reflects a change from a glacial to an interstadial environment. The spectra of zone 6 are characterized by peaks of *Artemisia* (68 %) and Poaceae (70 %) pollen, reflecting an extremely wide distribution of herb dominated tundra with prostrate forms of *Betula exilis* Sucacz.

As compared with the glacial conditions of zone 6, pollen zone 7 indicates the occurrence of significant, interstadial warming. Larch forest-tundra with a ground cover of heather and thickets of shrub birch on the valley slopes established both on the Anadyr Plateau and across the region. This vegetation was replaced on well drained, gravelly sites by communities of *Artemisia* and *Selaginella rupestris* with Caryophyllaceae, Asteraceae, and Papaveraceae. Around Lake El'gygytgyn, large areas were occupied by sedge-grass meadows with shrub *Salix*, and areas of waterlogged soils.

The spore-pollen spectra of pollen zone 8 reflect the vegetation of a cold, dry climate as indicated by the spread of sedge-grass communities. However, in some areas in protected valleys larch forest-tundra was established.

CONCLUSION

The pollen zones characterizing MIS18–MIS21 reflect plant communities that developed during both cold (glacial) stages and warmer interstadials. No pollen zone in this portion of Lake El'gygytgyn core has revealed spectra that could indicate interglacial conditions. These data allow us to consider the MIS18–MIS21 interval as one of the "coldest" in the continuous paleoclimatic record from Lake El'gygytgyn.

Larch, as the only coniferous tree that formed forests in the extreme North-East of Siberia during the Quaternary, "disappears" from the vegetation cover during the cold stages of the MIS18–MIS21 interval.

Pollen zone 6 in the middle part of MIS18 shows extremely cold climatic conditions. The lower part of MIS21, characterized by pollen zone 1, experienced the warmest climate during the MIS18-MIS21 interval.

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ФИТОЦЕНОЗЫ СЕВЕРНОЙ ЧУКОТКИ НА ГРАНИЦЕ РАННЕГО И СРЕДНЕГО ПЛЕЙСТОЦЕНА

Ложкин А. В.[1], Андерсон П. М.[2]

[1]ФГБУН Северо-Восточный комплексный научно-исследовательский институт им. Н. А. Шило ДВО РАН, Магадан
[2]Вашингтонский университет, факультет наук о Земле и Космосе, Центр четвертичных исследований, Сиэтл, США
E-mail: lozhkin@neisri.ru, pata@uw.edu

Интервал, охватывающий изотопные стадии 18–21 (МИС), является одним из наиболее холодных в непрерывной палеоклиматической летописи оз. Эльгыгытгын (полярная Чукотка). Характеризующие изотопные стадии пыльцевые зоны отражают растительные сообщества только ледниковых событий и интерстадиалов. Максимумы похолодания отмечаются в раннеплейстоценовой МИС20 и среднеплейстоценовой МИС18. Максимум тепла установлен в раннеплейстоценовой МИС21. *Larix* как единственное хвойное дерево, образующее леса на Северо-Востоке Сибири, не участвует в растительном покрове холодных стадий, формируя лиственничные лесотундровые сообщества в интерстадиалы.

***Ключевые слова*: изотопная стадия, пыльцевая зона, интерстадиал, лесотундра, тундра.**

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