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PALEOENVIRONMENTAL CHANGES IN ARCTIC CHUKOTKA DURING THE EARLY PLEISTOCENE (Marine Isotope Stages 91–82)

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The continuous palynological record from Lake El'gygytgyn , approximating marine oxygen isotope stages (MIS) 91–82, reflects the response of plant communities in arctic Chukotka to interglacial, glacial, and interstadial climates. According to the current lake age model, the 12 pollen zones described in this paper correspond to the interval 2.350–2.146 Ma BP, the upper limit of which is determined by the Reunion paleomagnetic event (2.140 Ma BP). However, multiple discrepancies between pollen zone and MIS boundaries show the need for a thorough revision of the chronology for the lake sediments. Given the current age scheme, the warmest climatic conditions occurred during MIS 91, whereas the coldest interval corresponds to the second half of MIS84. Interglacial vegetation was *Larix* forest with *Pinus sibirica*, *Abies*, and *Picea*. A mix of *Larix* forest-tundra and shrub tundra characterized cooler climates.

***Keywords*: Gelasian age, isotope stage, spore-pollen spectrum, pollen zone, interstade, interglaciation, glaciation.**

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INTRODUCTION

A continuous palynological record obtained from the study of sediments from Lake El'gygytgyn (Fig. 1) reflects the vegetation response to climate change in arctic Chukotka during the Early Pleistocene. The current El'gygytgyn age model assigns this portion of the record discussed in this paper to marine isotope stages 91–82 (MIS91–MIS82). MIS91–MIS82 corresponds to the period 2.350–2.146 Ma BP (Lisiecki, Raymo, 2005), the upper boundary of which is determined by the Reunion paleomagnetic event (2.140 Ma BP), an important chronological reference point within the core (Fig. 2).

Lake El'gygytgyn is located within a crater that formed 3.59 million years ago (Layer, 2000) following a meteorite impact at 67° 30′ N, 172° 05′ E. The maximum diameter of the crater is 18 km, whereas the diameter of the lake varies between 12 and 14 km. The surface of the lake is 489 m above sea level (a.s.l.). The peaks of the Anadyr Plateau, which surround the lake, rise to 600–1000 m a.s.l. The international expedition "El'gygytgyn Drilling Project," recovered a 317-m-long sediment core from the center of the lake at a water depth of 176 m (well 5011-1). The core is dominated by silt, but in some places the silt is mixed with fine-grained sand (Melles et al., 2012; Nowaczyk et al., 2013; Lozhkin, Anderson, 2020).

RESEARCH METHODS

Palynological analysis of Lake El'gygytgyn sediments followed methods proposed for the study of arctic lakes and estuaries (PALE, 1994). The sum used to calculate the percentages of individual pollen and spore taxa was based on nonaquatic pollen grains. Typically, 300 pollen grains of terrestrial plants were counted in each sample. Percentages were calculated and spore-pollen diagrams were constructed using Tilia and Tiliagraph (http://www.tiliait.com), respectively. The spore-pollen diagrams include both individual taxa and the ratio of three vegetation groups: trees and shrubs, herbs, and spores (Figs. 3, 4). The group percentages, illustrated on the left of the diagram, are based on a sum of all terrestrial and aquatic pollen and spores. In some samples, especially

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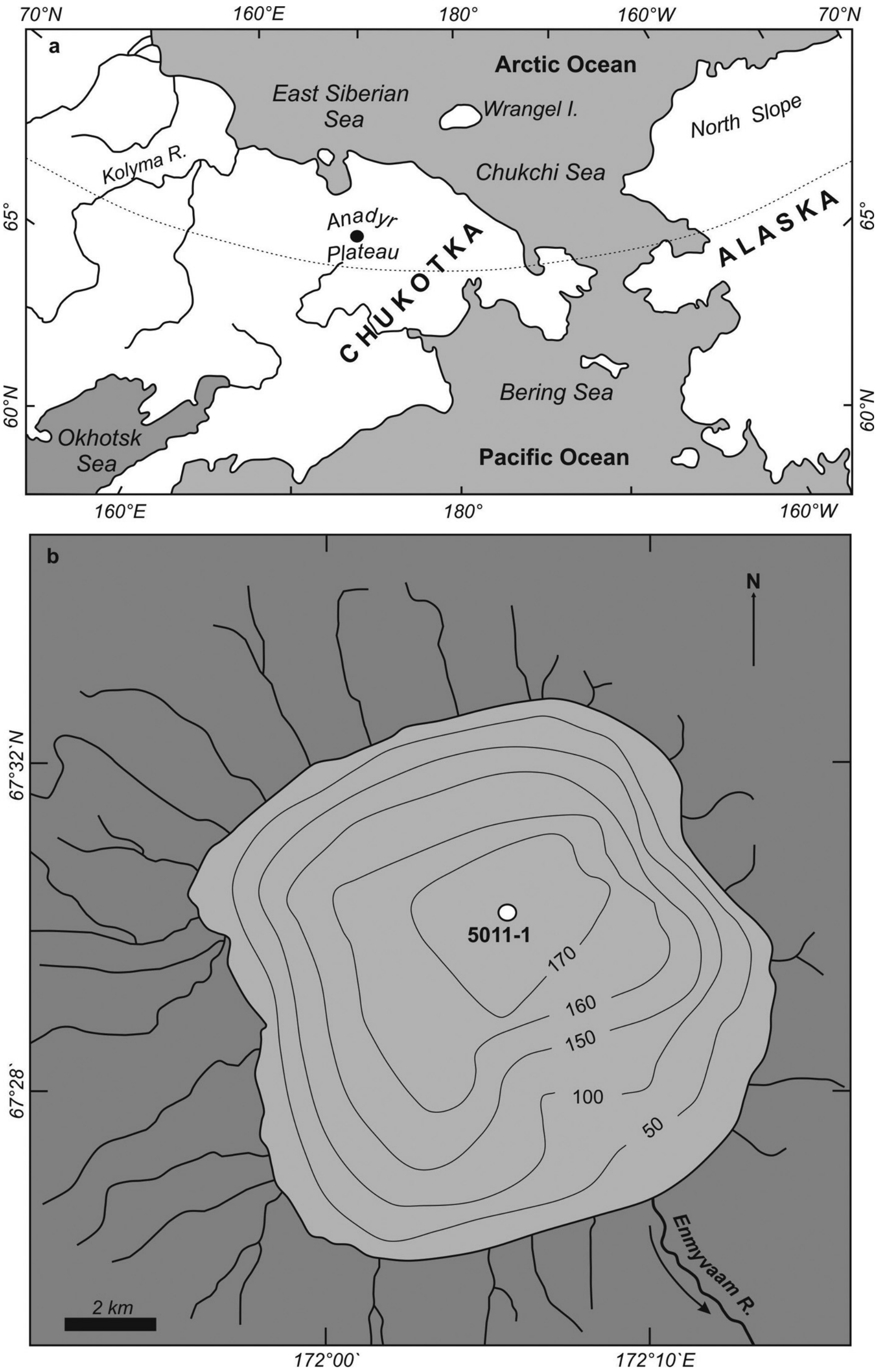

Fig. 1. Maps showing: (*a*) the location of Lake El'gygytgyn (dark circle) within Beringia; the dotted line represents the Arctic Circle; and (*b*) the bathymetry of Lake El'gygytgyn (water depths in meters), the location of the coring site (white circle), and the El'gygytgyn catchment including the Enmyvaam River (lake outlet).

Рис. 1. Карта-схема, показывающая: (*a*) нахождение оз. Эльгыгытгын (темный кружок) в пределах Берингии; пунктирная линия – Полярный круг; (*b*) батиметрию оз. Эльгыгытгын (глубины озера даны в метрах), место отбора керна озерных осадков (белый кружок), ручьи, впадающие в озеро, и вытекающая из озера р. Энмываам.

those formed during the cold stages, obtaining a 300 grain count was difficult. Such samples with low pollen concentrations were supplemented by samples from neighboring levels. Sediments formed during interstades and interglaciations usually had high pollen concentrations.

When interpreting the paleovegetation, modern pollen samples taken from the water-sediment interface were considered. The modern spore-pollen spectra include a significant component of "exotic" taxa carried to the lake by long-distance wind transport, including shrub *Alnus* Mill. (*Duschekia*

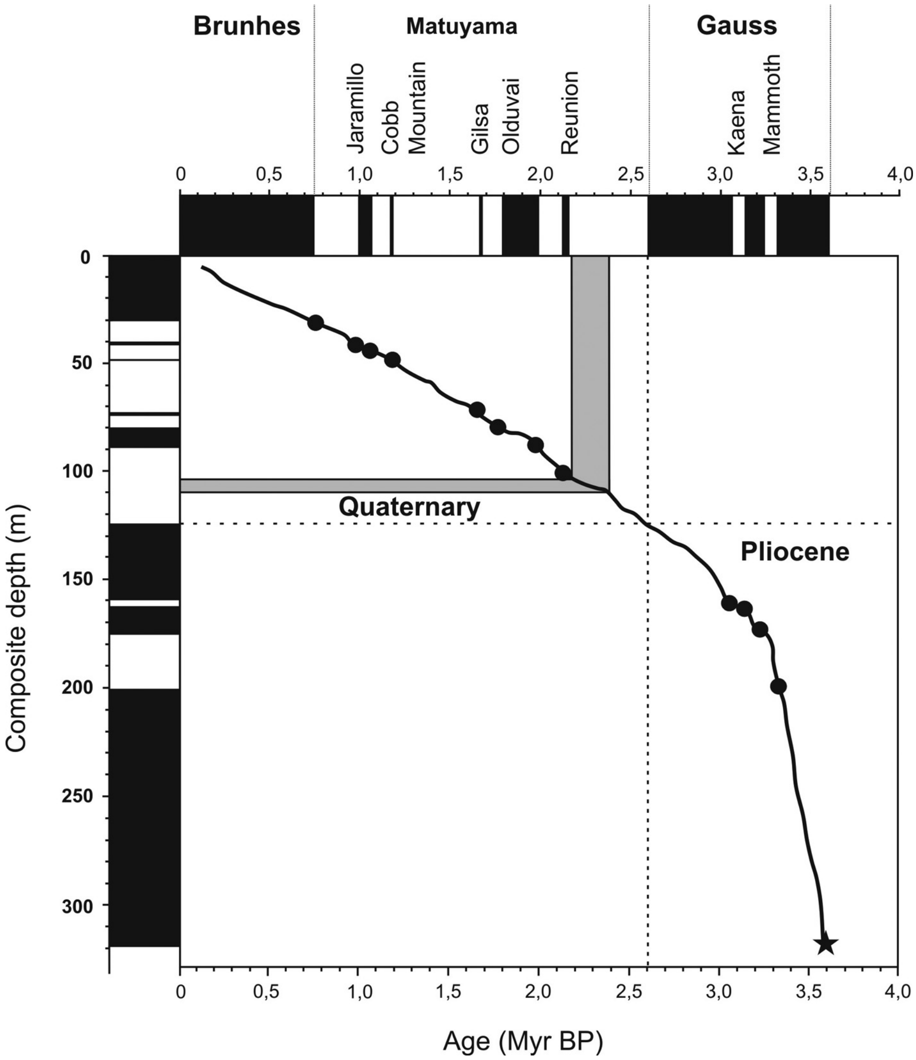

Fig. 2. Paleomagnetic events and the Lake El'gygytgyn age model. The horizontal scale at the top of the figure corresponds to the global paleomagnetic chronology. The vertical column reflects the magnetic characteristics of the El'gygytgyn sediments. The black line indicates the age-depth model used in the El'gygytgyn core. The black dots mark the ages of the magnetic events, and the star denotes the age of the meteorite impact as determined by $^{40}Ar/^{39}Ar$ dating. The gray bar highlights the interval discussed in this paper (2.146–2.350 Ma BP). See Nowaczyk et al. (2013) for more details.

Рис. 2. Палеомагнитные события и возрастная модель оз. Эльгыгытгын. Вертикальный столбец в левой части рисунка отражает магнитные характеристики отложений оз. Эльгыгытгын. Горизонтальная шкала вверху рисунка соответствует глобальной палеомагнитной шкале. Границы магнитных событий отмечены черными точками. Падение метеорита 3.58 млн л. н. ($^{40}Ar/^{39}Ar$) отмечено звездочкой. Изогнутая линия указывает на модель, используемую для определения возраста озерных отложений. Серая полоса – рассматриваемый интервал (2.146–2.350 Ma BP). См. Nowaczyk et al. (2013) для более подробной информации.

fruticosa (Rupr.) Pouzar), *Betula* L., and *Pinus pumila* (Pall.) Regel pollen. These taxa are common in areas of the Anadyr Plateau and can reach 45 % of the pollen sum (Lozhkin et al., 2002). The local vegetation within the crater is dominated by lichens and graminoids (Poaceae and Cyperaceae). At higher elevations the vegetation cover is intermittent. Low shrubs of *Salix krylovii* E. L. Wolf and *S. alaxensis* Coville occupy protected areas within open mountain valleys and in the valley of the Enmynvvam River, the lake's outlet. *Betula exilis* Sukaczev is limited to areas within river valleys where organic matter has accumulated (Kozhevnikov, 1993). Thus, the modern spectra from the bottom sediments of Lake El'gygytgyn reflect the modern regional vegetation of northern Chukotka and not the discontinuous vegetation cover with its low pollen productivity in the vicinity of the lake.

POLLEN ZONES AND THEIR CORRELATION WITH MARINE ISOTOPE STAGES

According to the current age model (Nowaczyk et al., 2013) for the E'lgygytgyn core, the portion of the record discussed in this paper falls within the range of 2.350–2.146 Ma BP (referred to as the study period) and includes 12 pollen zones. Pollen zones 4, 7, 10, and 12 reflect cold intervals during the middle Gelasian age. Pollen zones 2, 6, 9, and 11 indicate the establishment of plant communities that are characteristic of interglaciations. Pollen zones 3, 5, and 8 belong to interstades.

The study period is characterized by discrepancies between pollen zone and marine isotopic stage boundaries (Fig. 3). The only exceptions are the boundaries of pollen zones 6 and 7 coinciding with the boundary of MIS86 and MIS87 and pollen zones 10 and 11 approximating the MIS83–MIS84 boundary. In other cases, the MIS include more than 1 pollen zone: MIS91 – zones 1 and 2; MIS90 – zones 3 lower zone 4; MIS89 – upper zone 4 and lower zone 5; MIS88 – upper zone 5 and lower zone 6; MIS87 – mid to upper zone 6; MIS86 – zone 7 and lower zone 8; MIS85 – zone 8 and lower zone 9; MIS84 – upper zone 9 and zone 10; MIS83 – lower and middle zone 11; MIS82 – upper zone 11 and zone 12. Because the age model for this part of the El'gygytgyn core needs adjustments, we focus on the pollen zones and not the isotope stages in the following interpretations. Reference to the study period is meant as a general time frame to the early to middle Gelasian age.

FEATURES OF THE SPORE-POLLEN SPECTRA

The spore-pollen spectra of Lake El'gygytgyn sediments currently assigned to the study interval (i. e., c. 2.350–2.146 Ma BP) are characterized by the consistent presence of *Larix* pollen in both the spectra of relatively cool and warm stages. *Larix* pollen appears in significant amounts, reaching 12 % in the interstadial pollen zones. Perhaps the Early Pleistocene *Larix* pollen was produced by a species close to the modern *Larix cajanderi* Mayr., the only coniferous tree that now forms forests in northeastern Siberia. For example, an abundance of small cones of *Larix cajanderi* was discovered in the Late Quaternary sediments of yedoma deposits in the Bolshoy Khomus-Yuryakh River valley in the Kolyma Lowland. Alternatively, the larch pollen could indicate the presence of a species close to *Larix sibirica* Ledeb. A large collection of cones and branches of *Larix sibirica* along with cones of *Larix cajanderi* had accumulated in the Late Pleistocene interglacial alluvium of the Nera River in the upper reaches of the Indigirka River. As shown by A. P. Vaskovsky (1957), the basis for the assumption that *Larix sibirica* forest was widespread in northern Chukotka during the study period could be related to the fact that the pollen of *Larix cajanderi*, in contrast to the pollen of *Larix sibirica*, is extremely poorly preserved even in modern spore-pollen spectra. The persistent presence of *Larix* pollen in the spectra characterizing plant communities in the study period indicates that even under harsh climatic conditions, larch forest-tundra was able to survive on the Anadyr Plateau and in the Lake El'gygytgyn region.

Another key taxon in the spore-pollen spectra of the Lake El'gygytgyn sediments during the study period is *Betula*, the values of which can reach 55 % in the warm stages and can remain relatively high (up to 30 %) in the spectra of cool stages. High *Alnus* pollen percentages are observed in pollen zones characterizing interglacial vegetation (e. g., *Alnus* pollen peaks up to 60 % in pollen zone 6). Increases in *Pinus pumila* pollen occur only in the spectra of interglacial stages. Maximum peaks in *Pinus pumila* pollen (up to 75 %) occur in pollen zone 2.

The relatively high percentages of *Artemisia* pollen characterize cold stage assemblages (pollen zones 4, 7, 10, 12; up to 25–35 %). An increase in *Artemisia* pollen is sometimes accompanied by higher percentages of *Selaginella rupestris* (L.) Spring spores (up to 20 %). Poaceae pollen also plays a major role in the pollen record. It is dominant in the spectra of glacial stages (up to 55 %), but its percentages sharply decrease under interglacial conditions (down to 1–5 %). Cyperaceae also plays an important role in interglacial, interstadial and glacial spectra (up to 35 % in samples from interglacial and glacial stages). A noticeable contribution of Ericales pollen is seen in pollen zones that characterize the plant cover during glacial and interstadial climates. The spectra contain single pollen grains of moderately thermophilus taxa such as *Corylus* L., *Carpinus* L., *Fraxinus* L., *Tilia* L., and *Juglans* L. These grains, especially during cool intervals, are clearly redeposited. Interglacial pollen zones 2 and 6, glacial zones 4 and 7, and interstadial zones 1, 3, and 8 include spectra with the highest percentages of *Sphagnum* spores (up to 80 %), indicating the presence of swampy terrain within the crater.

CHARACTERISTICS OF POLLEN ZONES AND PLANT COMMUNITIES

In the spore-pollen spectra of pollen zone 1, *Betula* and *Alnus* pollen are the most dominant taxa (Fig. 3). Shrub *Betula* played an important role both locally and regionally. Tree *Betula* also may have formed independent stands on the slopes of the hills surrounding the lake. Shrub *Alnus* likely occurred as thickets along river banks. Gallery forests composed of *Larix*, *Populus suaveolens* Fisch., and *Chosenia arbutifolia* (Pall.) A. K. Skvortsov perhaps also included alder trees, which possibly were close to the modern species of *Alnus hirsuta* Turcz. The presence in noticeable quantities (10–19 %) of *Pinus* subgen. Haploxylon pollen in the zone 1 assemblage probably reflects the regional distribution of *Pinus pumila*.

In the spectra of zone 1, *Larix* pollen is present consistently, with a maximum of 7 %. The relatively high percentages of *Larix* pollen suggest a regional

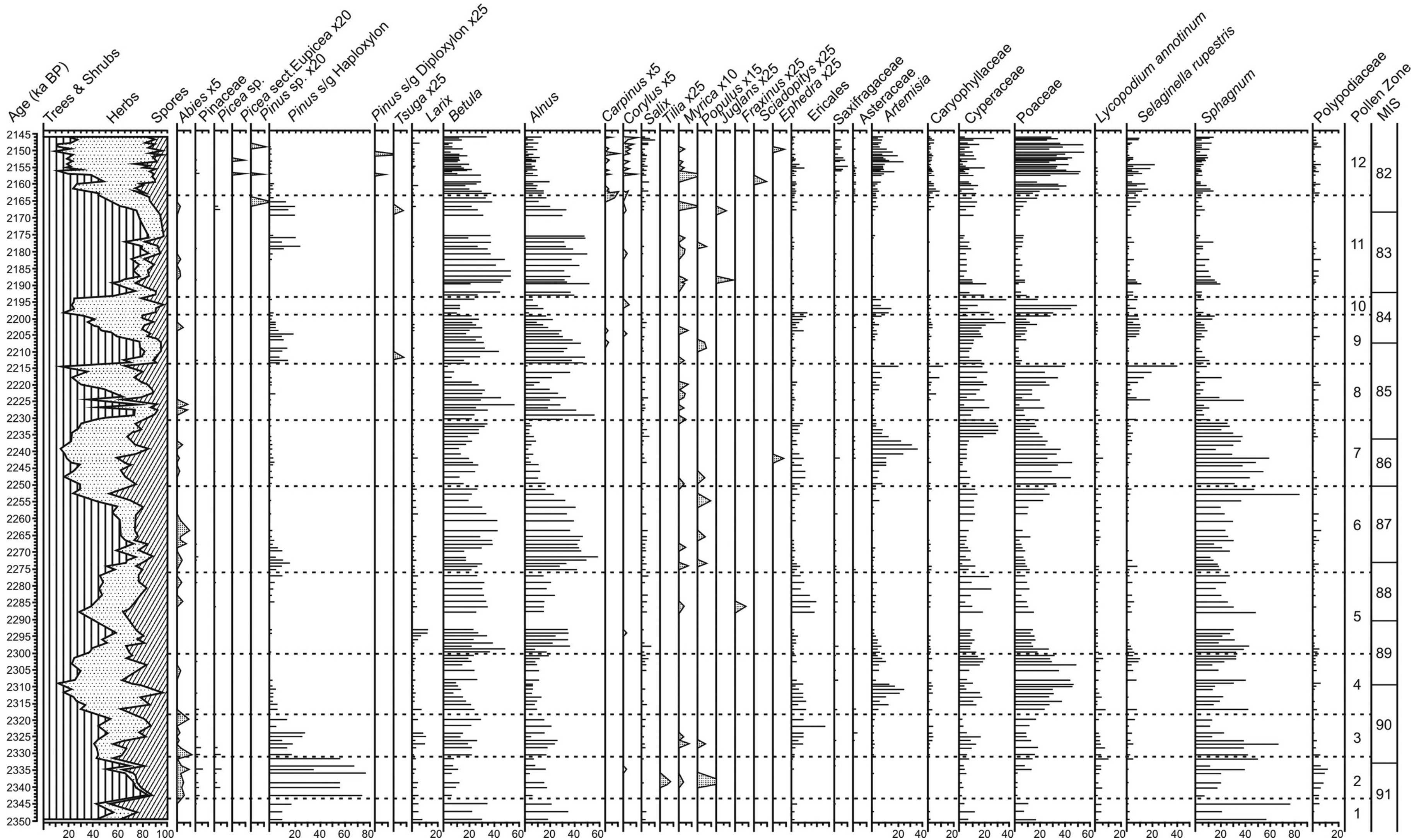

Fig. 3. Percentages of vegetation groups and the main pollen and spore taxa from Lake El'gygytgyn. The current lake age model indicates these spectra approximate MIS82–MIS91.

Рис. 3. Процентные соотношения групп растительности, основных пыльцевых и споровых таксонов оз. Эльгыгытгын. Современная возрастная модель озера указывает на спектры, синхронные MIS82–MIS91.

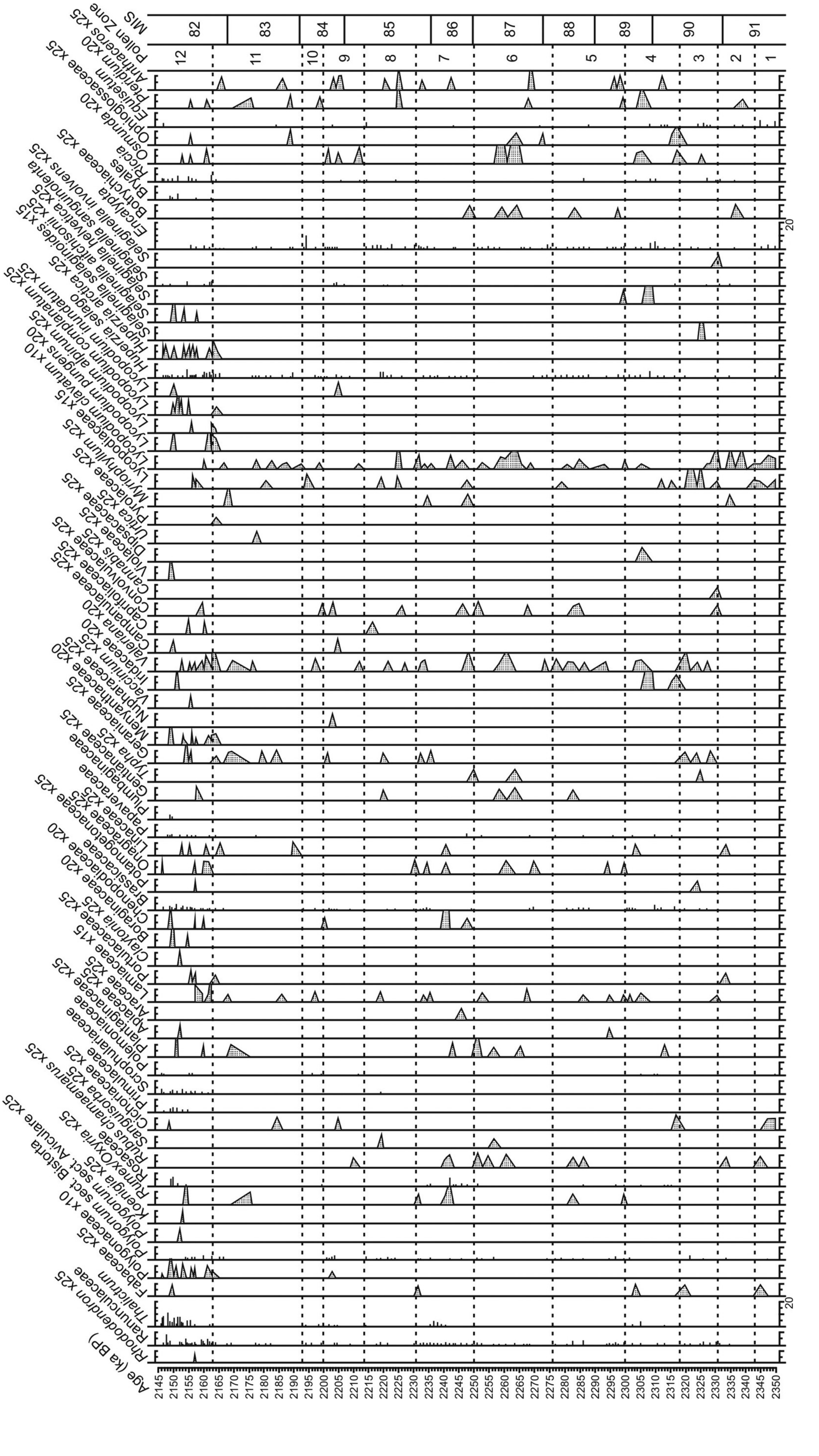

Fig. 4. Minor pollen and spore taxa from Lake El'gygytgyn. The current lake age model indicates these spectra approximate MIS82–MIS 91.

Рис. 4. Второстепенные пыльцевые и споровые таксоны оз. Эльгыгытгын. Современная возрастная модель озера указывает на спектры, синхронные MIS82–MIS91.

establishment of larch forests. The forest understory was composed of shrub *Betula*, *Alnus*, *Salix* L., and *Pinus pumila*. High percentages of *Sphagnum* spores in zone 1 indicate the presence of mesic soils and swampy terrain. The zone 1 vegetation likely developed under interstadial conditions.

A significant restructuring of the vegetation is clearly expressed in the pollen assemblage of zone 2. The spectra of this zone are dominated by pollen of trees and shrubs, but the main feature of pollen zone 2 is the very high percentages of *Pinus* subgen. Haploxylon pollen. The general composition of the zone 2 pollen assemblage, which includes *Picea* sp. (up to 12 %), and *Abies* sp. pollen, suggests that the pine pollen was produced by a species possibly close to the modern Siberian *Pinus sibirica* (Rupr.) Mayr. *Larix* pollen is found in significant quantities in the spectra of zone 2 (up to 11 %), perhaps reflecting the presence of *Larix sibirica* in the forest. Pine-larch and pine-larch-spruce forests, which included tree *Betula,* expanded near El'gygytgyn Lake and spread across the foothills of the Anadyr Plateau. The shrub understory in such forests included *Betula*, *Alnus*, *Salix*, and *Pinus pumila*. Gallery forests consisted of *Larix sibirica*, *Picea* sp. (possibly *Picea obovata* Ledeb.), *Populus suaveolens*, and *Chosenia arbutifolia*, although the most common tree was probably *Alnus hirsuta*. Characteristics of pollen zone 2 suggest the establishment of a vegetation indicative of the warmest conditions during the study period, with a mean July temperature > +16 °C.

The spore-pollen spectra of zone 3 are similar to the interstadial zone 1 assemblage. However, unlike zone 1, the spectra of zone 3 include pollen of *Picea* sp. (up to 5 %) in the lower part of the zone. *Abies* sp. occurs in trace amounts. Percentages of *Larix* pollen are up to 10 %. The high percentages of Ericales pollen (10–28 %) and *Sphagnum* spores (up to 65 %) reflect the significant role of mesic heather communities in the vegetation. Poaceae-Cyperaceae-forb meadows developed near the lake. Larch forests with tree birch and a shrub understory of *Pinus pumila, Betula*, *Alnus*, and *Salix* became widespread across the region. If pollen zone 3 showed the development of plant communities corresponding to an interstadial climate, then the spectra of pollen zone 4 characterize a vegetation indicative of a climatic cooling.

Pollen zone 4 indicates the regional presence of larch forest-tundra and/or the distribution of open larch forests with a shrub understory of *Salix*, *Betula*, *Alnus*, and *Pinus pumila* in the most protected areas, such as along river valleys. The crater also supported a variety of microhabitats (e. g., mesic to wet graminoid-forb meadows with shrub *Salix;* well-drained, gravel slopes with *Artemisia* (peak *Artemisia* pollen 25 %) and *Selaginella rupestris*. The climatic conditions during zone 4 were more favorable than modern ones and were most likely characterized by average July temperatures of at least +11 °C.

Pollen zone 5 has some common features with interstadial zones 1 and 3 but differs from them in having higher percentages of *Betula* and *Alnus* pollen and low percentages of *Pinus* subgen. Haploxylon. In the spectra of zone 5, *Larix* pollen appears consistently, with a maximum value of 10 %. Such features of pollen zone 5 indicate a regional distribution of larch forests with tree *Betula* and a dense shrub understory of *Alnus* (*Duschekia*), *Betula*, *Salix*, and, possibly, *Pinus pumila*. Gallery forests of *Larix*, *Alnus hirsuta*, *Populus suaveolens*, and *Chosenia arbutifolia* developed in river valleys. Important components in the vegetation cover included graminoid and mesic heather communities (up to 20 % Ericales pollen) with areas of well-drained disturbed soils and scree (*Artemisia*, *Selaginella rupestris*). Pollen zone 5, like zones 1 and 3, reflects vegetation that developed under interstadial conditions.

Pollen zone 6 is marked by an increase in *Alnus* (55 % peak) and *Betula* pollen (up to 45 %). *Larix* pollen is found throughout zone 6 (5 %). These data suggest the regional distribution of larch forests, which included tree birch and, probably, some dark coniferous species such as fir and spruce. The dominance in the pollen spectra of *Alnus* and *Betula* may indicate the presence of shrub birch thickets on the slopes, and the establishment of shrub alder and *Alnus hirsuta* in gallery forests in the valleys of streams and rivers. A very small amount of *Pinus* subgen. Haploxylon pollen can be explained by wind transport of *Pinus pumila* or *Pinus sibirica* pollen from the more southern and western regions of northeastern Siberia. The consistently high percentages of *Sphagnum* spores indicate the presence of mesic soils and the local development of swampy landscapes. The noticeable warming of the climate shown by the pollen spectra of zone 6, compared, for example, with the climatic conditions of the interstades, indicates that pollen zone 6 reflects an interglacial vegetation.

Pollen zone 7 indicates a regional distribution of larch forest-tundra, possibly including isolated stands of tree birch. The forest-tundra in some areas of the Anadyr Plateau and in the El'gygytgyn crater was replaced by shrub tundra with *Betula* and *Salix* communities and small thickets of shrub *Alnus* in the valleys of streams and rivers. The dominance of Poaceae pollen in the spectra of zone 7 and high percentages of Cyperaceae pollen clearly reflect the presence of graminoid meadows and wetlands with forbs and shrub *Salix*. Peaks in *Artemisia* pollen (up to 35 %) indicate the development of more xeric communities with wormwood and *Selaginella rupestris* common on well-drained gravel slopes. Heather communities played a major role in the vegetation cover (Ericales pollen 10 %, *Sphagnum* spores 60 %). The palynological characteristics of pollen zone 7 reflect vegetation that developed during a period of climatic cooling associated with glaciations.

Pollen zone 8 is marked by a significant decrease in *Sphagnum* spores as compared to pollen zones 1–7. This decline in *Sphagnum* spores also characterizes the subsequent pollen zones 9, 10, 11, and 12. In comparison with pollen zones 1–7, the percentages of *Selaginella rupestris* spores increase in pollen zones 8–12 (up to 20 % in zone 8), which indicates the presence of well drained substrates. In addition to these changes in spore percentages, the spectra of pollen zone 8 have high percentages of *Betula*, *Alnus*, Cyperaceae, and Poaceae. Of note is the increase in *Artemisia* pollen (up to 10 %), which is consistent with more xeric substrates and the presence of glacial conditions.

Percentages of the major pollen and spore taxa in pollen zone 8 vary markedly, which suggests an unstable climate. Such climatic fluctuations are often observed in pollen records from Northeast Siberia during interstades (Lozhkin, Anderson, 2020). The regional vegetation at this time is dominated by larch forests with tree birch and possibly single individuals or small stands of dark coniferous trees in the gallery forests. Birch trees also formed pure stands on mountain slopes. A small amount of *Pinus* subgen. Haploxylon pollen, found in the spectra of zone 8, most likely indicates that pines, including *Pinus pumila*, were not characteristic of the vegetation. According to the spore-pollen spectra, graminoid-forb meadows played a significant role in the vicinity of Elgygytgyn Lake, replaced by *Artemisia – Selaginella rupestris* forb communities on rocky, well drained slopes. Gallery forests of *Larix*, *Alnus hirsuta*, *Populus suaveolens*, and *Chosenia arbutifolia* occurred in the river valleys. The climate was noticeably warmer than in the previous zone, suggesting the establishment of interstadial conditions.

Further climate warming is reflected in the spectra of pollen zone 9. This zone shows similarities with interglacial pollen zone 6, but differs from zone 6 in the very low percentages of *Sphagnum* spores, indicating a decrease in effective moisture in the younger zone. Regionally and locally, the plant communities that characterize pollen zone 9 include larch forests, which probably included *Pinus sibirica*, tree *Betula*, and along the floodplains *Alnus hirsuta*, *Populus suaveolens* and more rarely dark coniferous trees (*Abies* sp., *Picea* sp.). The dense shrub understory within the forest included *Pinus pumila*, *Betula*, *Alnus*, and *Salix*. It is likely that moderately thermophilus shrubs and trees, such as *Corylus*, *Carpinus*, and *Myrica* L., were found in the forests. The pollen spectra of zone 9 also show that graminoid-forb communities played a noticeable role in the vegetation cover near the lake and on the well-drained slopes where of *Artemisia* and *Selaginella* rupestris were present.

Pollen zone 10 characterizes a short but most intense climate cooling. The pollen zone 10 assemblage reflects the regional distribution of larch forest-tundra, changing to *Betula*-shrub and herb tundra at mid to higher elevations. Probably, small thickets of shrub *Alnus* existed in the valleys of streams and rivers. The pollen of Poaceae and Cyperaceae, which dominates zone 10, underscores the importance of graminoid meadows near the lake and the more common presence of tundra across northern Chukotka. The presence of more xeric communities within the crater is indicated by the moderate percentages of *Artemisia* and *Selaginella rupestris*. The presence of *Larix* suggests that mean July temperatures did not fall significantly below 10 °C.

Pollen zone 11 reflects a marked climate warming from the previous zone. Regionally and locally, the plant communities that formed at that time were represented by larch forests with *Pinus sibirica*, *Abies* sp., *Picea* sp. (*Picea obovata*), tree *Betula*, and a shrub understory of *Pinus pumila*, *Betula*, *Alnus*, and *Salix*. Tree *Betula* also formed scattered stands on the hill slopes surrounding the lake. Tree alder (*Alnus hirsuta*) and *Populus suaveolens* characterized the floodplain forests. Moderately thermophilus species, such as *Carpinus*, *Juglans*, *Corylus*, and *Myrica*, were present in the forest but were not common. The pollen zone 11 assemblage reflects the occurrence of another Gelasian interglaciation.

A climate cooling, as reflected by the palynological spectra of pollen zone 12, is indicated by the greater presence of larch forest-tundra (*Larix* pollen up to 7 %) on the landscape. At the higher elevations of the Anadyr Plateau, forest-tundra gives way to shrub *Betula-Alnus* and graminoid tundra, possibly with a minor presence of *Pinus pumila*. Species such as *Betula middendorffii* Trautv. & C. A. Mey., *Betula exilis* Sukaczev, and *Duschekia fruticosa* probably were important components of both forest-tundra and tundra communities. Increased pollen percentages of Cyperaceae (25 % peak) and Poaceae (50 % peak) indicate open tundra landscapes and meadows in the vicinity of Lake El'gygytgyn. High percentages of *Selaginella rupestris* spores (up to 20 %) and *Artemisia* pollen (up to 25 %) reflect areas of disturbed soils (e. g., on slopes bordering rivers and streams). The consistent presence in zone 12 of Caryophyllaceae pollen (up to 10 %), a taxon typically associated with glacial intervals in the Lake El'gygytgyn record, highlights the increase in herb-dominated communities near the lake. The spore-pollen spectra of pollen zone 12 show a great similarity to the spectra of "glacial" zone 10.

CONCLUSION

The 2.350–2.146 Ma BP interval, as currently defined by the El'gygytgyn age model, is characterized by discrepancies in the boundaries of pollen zones and marine isotopic stages (excepting the boundary between pollen zones 6 and 7 and MIS86–MIS87). These results clearly indicate the need for a thorough revision of the age model for the Lake El'gygytgyn core. Despite the discrepancies between pollen and isotope stage boundaries, the presence of the Reunion paleomagnetic event indicates that this portion of the El'gygytgyn core dates to the middle to early Gelasian age (approximately MIS82–MIS91).

The palynological analysis of sediments from Lake El'gygytgyn presented here completes the study into the response of Eastern Arctic vegetation to climate change during the Early Pleistocene. Twelve pollen zones have been defined. Despite dating concerns, this portion of the continuous palynological record when placed in context with older and younger sections of the core provisionally can be assigned to the following: interglaciations (MIS91, MIS87, MIS84–85, MIS83), glaciations (MIS89–90, MIS85–86, MIS84, MIS82), and interstades (MIS91, MIS90, MIS88–89, MIS85).

Interglacial vegetation (pollen zones 2, 6, 9, 11) is characterized by *Larix* forests with *Pinus sibirica*, *Abies* sp., *Picea obovata*, and tree *Betula* and with a dense shrub understory (*Betula*, shrub *Alnus*, *Salix*, *Pinus pumila*). Possibly, some moderately thermophilus trees and shrubs (e. g., *Juglans, Corylus, Carpinus, Myrica*) were present but were not common. Gallery forests were composed of *Larix sibirica*, *Picea obovata*, *Populus suaveolens*, *Chosenia arbutifolia*, and *Alnus hirsuta*.

During the interstades (pollen zones 1, 3, 5, 8), open larch forests and forest-tundra dominated. Shrub thickets of *Betula*, *Duschekia fruticosa*, and *Pinus pumila* were also important on the northern Chukotka landscape.

During the coolest climates (pollen zones 4, 7, 10, 12) the vegetation consisted of *Larix* forest-tundra and shrub tundra with *Betula*, *Duschekia*, and *Salix*. The high percentages of Poaceae and Cyperaceae pollen highlight the importance of graminoid communities. Minor herb taxa reflect the diversity of microhabitats within the crater. Of note, is the presence of A*rtemisia* and *Selaginella rupestris* indicative of well-drained substrates and gravelly slopes.

The warmest climatic conditions occurred in pollen zone 2. The coldest climate corresponds to zone 10.

The consistent presence of *Larix* pollen in the spectra of all pollen zones indicates that larch was the main forest-forming coniferous tree during the earliest Pleistocene. Larch forests were widespread regionally during interglaciations and interstades. During the coolest periods these forests were replaced by larch forest-tundra, possibly with the inclusion of tree *Betula*.

Palynological analysis of the Lake El'gygytgyn sediments suggests that modern arctic communities may disappear in the future because of global warming.

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ПАЛЕОЭКОЛОГИЧЕСКИЕ ИЗМЕНЕНИЯ В АРКТИЧЕСКОЙ ЧУКОТКЕ В РАННЕМ ПЛЕЙСТОЦЕНЕ (морские изотопные стадии 91–82)

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Непрерывная палинологическая запись оз. Эльгыгытгын, близкая к уровням морских изотопно-кислородных стадий (MIS) 91–82, отражает реакцию растительных сообществ арктической Чукотки на межледниковый, ледниковый и интерстадиальный климаты. Выделенные 12 пыльцевых зон, согласно современной возрастной модели озера, соответствуют интервалу 2.350–2.146 Ma BP, верхняя граница которого определяется палеомагнитным событием Реюньон (2.140 Ma BP). Однако многочисленные несоответствия между границами пыльцевых зон и границами MIS указывают на необходимость тщательного пересмотра хронологии озерных отложений. При современной возрастной схеме наиболее теплые климатические условия наблюдались в течение MIS91, а самый холодный интервал соответствует второй половине MIS84. Межледниковая растительность представлена лиственничным лесом с *Pinus sibirica*, *Abies*, *Picea*, а лиственничная лесотундра и кустарниковая тундра характеризуют более прохладный климат.

***Ключевые слова*: гелазий, изотопная стадия, спорово-пыльцевой спектр, пыльцевая зона, интерстадиал, межледниковье, оледенение.**

ЛИТЕРАТУРА

Васьковский А. П. Спорово-пыльцевые спектры современных растительных сообществ Крайнего Северо-Востока СССР и их значение для восстановления четвертичной растительности // Материалы по геологии и полезным ископаемым Северо-Востока СССР. Магадан: Кн. изд-во, 1957. Вып. 11. С. 130–178.

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