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Vegetation and Climate of the New Siberian Islands for the Past 15,000 Years

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Abstract

This article presents paleobotanical and paleoclimatic reconstructions of the New Siberian Islands for the past 15,000 years based on data from Quaternary geology and archaeology collected in the late 1980s and early 1990s as part of research conducted by the Arctic and Antarctic Research Institute, St. Petersburg, Russia. The data were obtained from 18 reference sites from Holocene and upper Pleistocene deposits on Kotelny Island, the largest island of the New Siberian Archipelago, and from the smaller and more northerly Zhokhov Island. Conclusions are also drawn from the composition of the avian fauna recovered during the excavations of the Zhokhov archaeological site on that island. The composition of bird species is an important source of information which helps interpret the results of palynological analysis because the birds are very sensitive indicators of changes in temperature and vegetation. The palynological analysis has revealed a sequence of 13 spore-pollen complexes that have been generalized as a scheme showing a broad sequence of events in the area of survey. The complexes belonging to the early Holocene time are markedly different from the others. The most favorable conditions occurred in the time span from 10,000 to 9000 BP. After 8000 yr ago the fluctuations were of lesser amplitude, and both their sequence and timing were close to those of Northern Europe, though there appear to be differences between the two areas in the range of variation.

Introduction

The area of the New Siberian Islands is one of the most remote and difficult-to-access parts of the Northern Hemisphere. The island chain is the natural border between Laptev and East Siberian Seas, and consists of three groups: Lyakhovskiye, Anju, and DeLong Islands (Fig. 1). Although some 10 to 15 expeditions worked in this area in the second half of the last century, it could be said that almost none of them produced results which contributed to understanding of the late Quaternary history of this part of the world. In this article we present the most important results of the field survey in Kotelny and Zhokhov Islands carried out in the late 1980s and early 1990s (Fig. 2). Although these expeditions took place more than 10 yr ago, the information collected remains relevant because of the lack of research activity in this area in the intervening years. These results have been reported previously in summary form, primarily in Russian (e.g., Makeyev et al., 1989, 1992).

Areas Studied

KOTELNY ISLAND

The late Quaternary geology and geochronology of Kotelny Island (Figs. 1, 2) have been described in detail by Makeyev et al. (1989); the most important features are shown in Figure 3. We have observed that the late Pleistocene and Holocene deposits of Kotelny Island are quite widespread and are dominant in the relief depressions of the pre-Holocene age such as river and lake valleys, coastal lowlands, etc. The visible thickness of the deposits normally does not exceed 10 m. They are represented mostly by the continental deposits of alluvial, lake-alluvial, lacustrian, swamped-lake, and eluvial-taluvial origin. Marine deposits are found only in the locations of modern shorelines. The first four genetic types of deposits were studied mainly because they are most informative in terms of paleogeography. The lithology of these deposits is characterized as strongly iced sand and aleurites, which sometimes contain various organic interlayers or lenses of moss and moss-herb peat. These vary in size, and sometimes contain stems and twigs of dwarf-shrub plants and shrubs. In many cases peat accumulations of up to 3 m thickness that are associated with different forms of the relief can be observed directly on the surface. The radiocarbon dating of the peat bogs shows that during the entire Holocene there were some areas where the natural conditions remained good for the formation of peat bogs. The surface of deposits usually have clear polygonal structures, and in the profiles they often have veins of the ice, ice interbeds, and wedges of polygonal ice, which are up to 3 m high and up to 1.5 m wide.

In total 18 sections of the Holocene deposits on Kotelny Island have been investigated. Unfortunately none of them covers the whole Holocene. A number of the most complete sections are located in the eastern part of Kotelny Island, mainly in the valleys of Balyktakh and Dragotsennaya rivers and in their tributaries (Fig. 2A). They are typically located on floodplain terraces. Four of them partly overlap, allowing us to create a general stratochronological scheme (Table 1) that shows a sequence of local environmental changes in the Holocene data from 10 profiles that produce a good sequence of pollen complexes.

POLLEN RECORD FOR KOTELNY ISLAND

Pollen compositions of the samples allow us to identify 13 spore-pollen complexes (Table 1) that represent seven periods of

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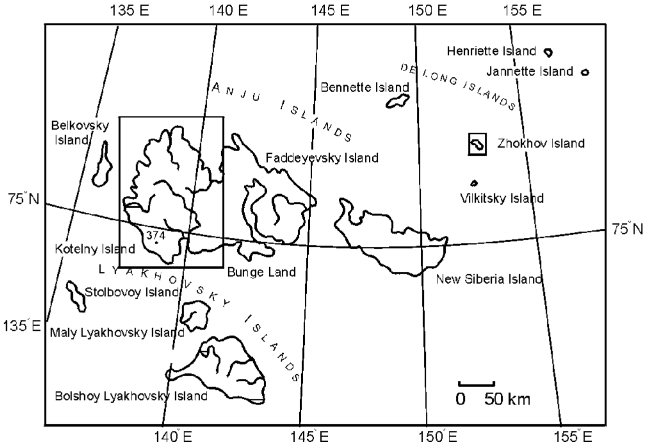


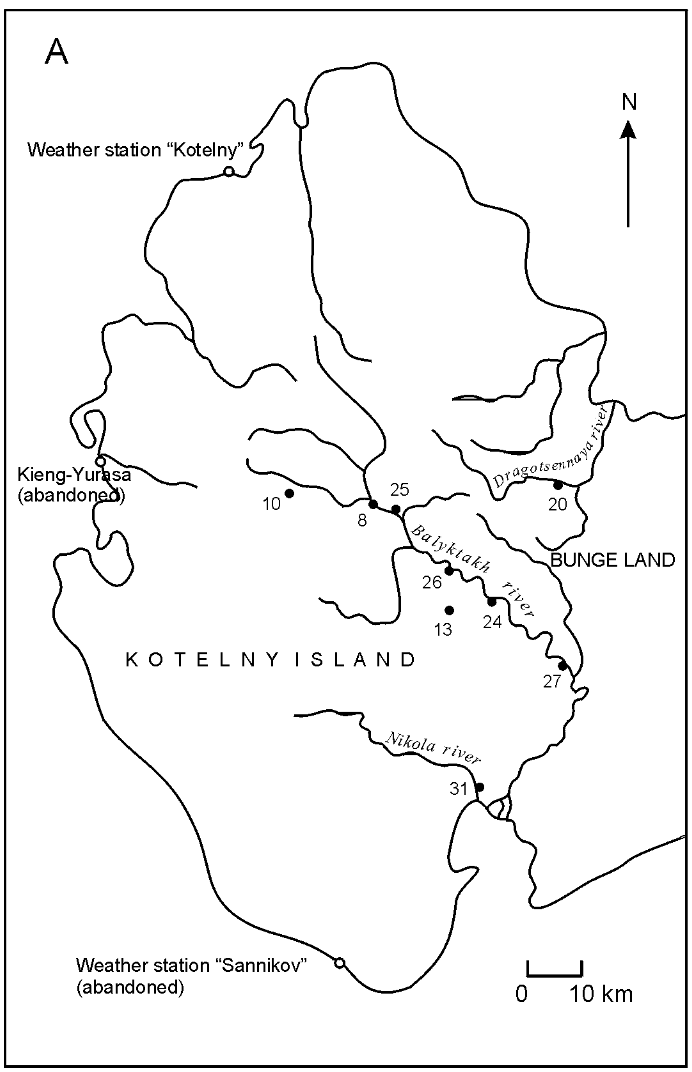
FIGURE 1. General area of survey. Boxes indicate islands shown in Figure 2.

the development of vegetation. The highest variation observed within the complexes is that of the Arboreal Pollen (AP) species, while the Nonarboreal Pollen (NAP) content itself varies slightly.

A comparison of these complexes with subrecent pollen compositions, as well as analysis of macroremains, and studies in geology, geomorphology, and cryology of the area give us an opportunity to identify a sequence of some major periods of the development of vegetation and environmental trends for the terminal Pleistocene and Holocene on Kotelny Island. While we believe these trends can be said to characterize the New Siberian Islands generally, we also believe that the changes taking place in the northernmost portion of the island chain (i.e., DeLong Islands) must be of smaller range and differ from the ''big islands area'' in some important details. Seven major periods based on pollen dyagrams are identified from the 13 complexes shown in Table 1: (1) 15,400–12,500 BP; (2) 12.5,000–12.200 BP; (3) 12,200–10,000 BP; (4) 10,000–9000 BP; (5) 9000–8000 BP; (6) 8000–5000 BP; (7) 5000 BP–present time.

The first period (Sartan, 15,400–12,500 BP) is characterized by conditions of a sharp continental climate and the xerophyte herb vegetation, and the development of so-called tundra-steppe landscapes populated by the mammals of the late Pleistocene (mammoth) fauna complex. Pollen complexes that are characteristic for these deposits are revealed from core 27 (Fig. 4) (samples 7–11 taken at 3–6-m depth, 19,990 ± 130 BP, LU-1780) and profile 8 (Fig. 5) (sample 15 taken at a 7-m depth). No evidence of surface glaciation was found for this time except in the DeLong Islands region. For most of the area development of permafrost is typical.

The second period (late glacial) (12,500–12,200 BP) is characterized by increased humidity and moderated continental characteristics. Winter air temperatures were warmer than previously, creating favorable conditions for the spread of associa-



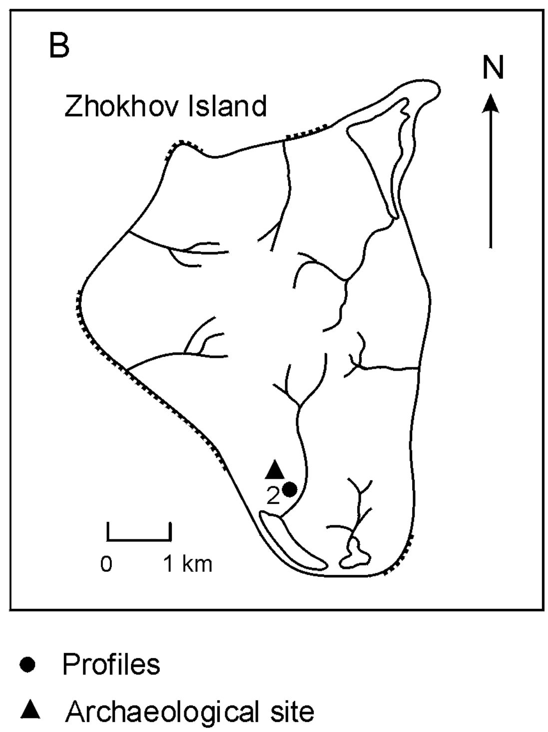


FIGURE 2. Location of profiles surveyed in Kotelny Island and in Zhokhov Island.

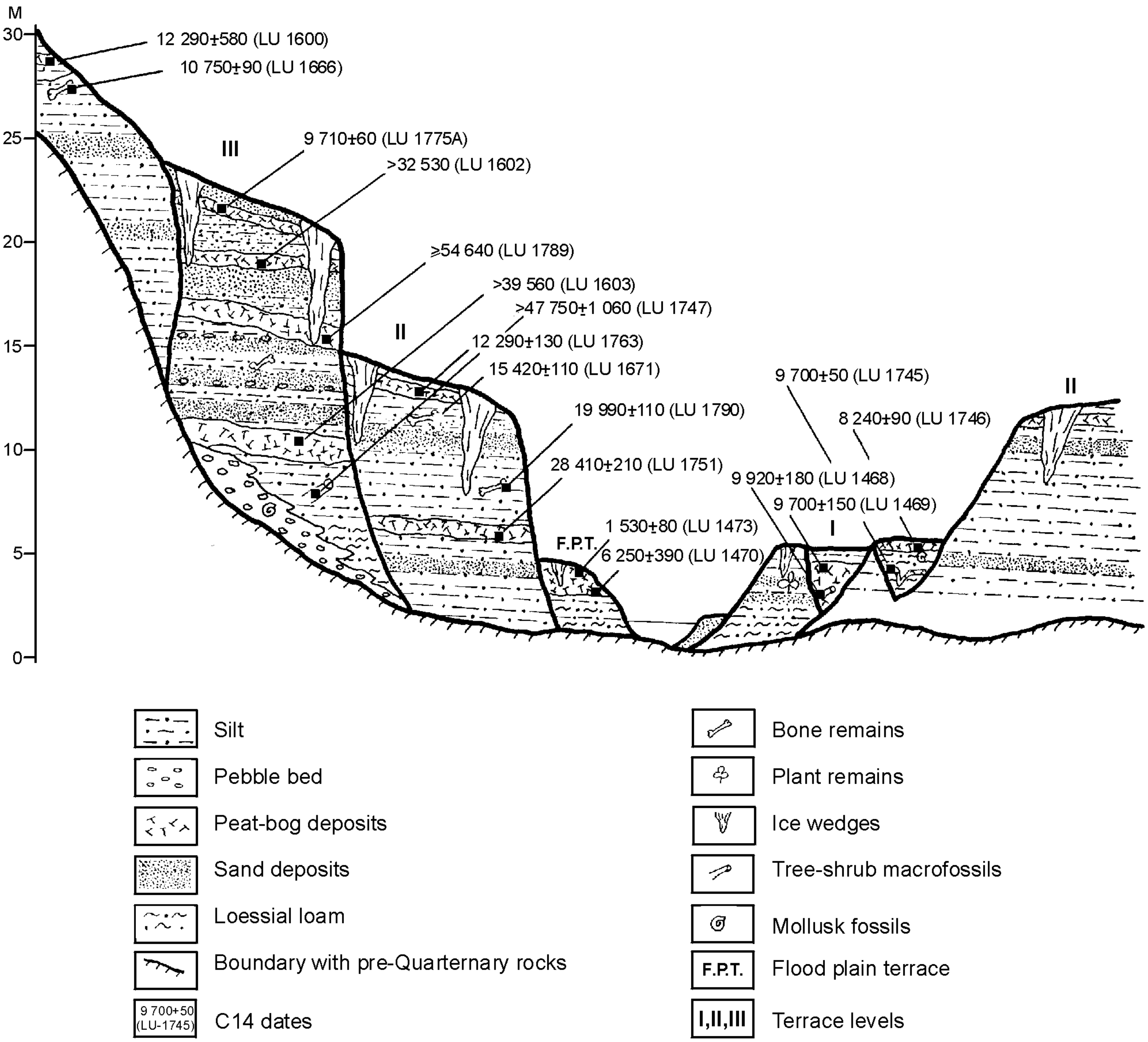


FIGURE 3. Generalized scheme of the geological position of the late Pleistocene and Holocene deposits in Kotelny Island for Balyktakh and Dragotsennaya River valleys (modified from Makeyev et al., 1989).

tions with shrub and dwarf-shrub birch species (*Betula* cf. *Tortuosa, B. exilis*), as well as willow (*Salix* spp.) and alder shrubs (*Alnus frutocosa*). During this time (Bølling Interstadial, 12,800–12,300 BP) the landscapes of Kotelny were dominated by underbrush birch tundras (*Betula exilis*, *B.* cf. *tortuosa*), alder (*Alnus fruticosa*), and willow (*Salix* spp.). A typical pattern is seen in profile 27 (samples 2 and 3 from the depth of 1.2–1.0 m, 12,290 ± 130 BP, LU-1763) (Fig. 4) and profile 8 (sample 11 from the depth 4.6 m) (Fig. 5). Thermokarst erosion and formation of lakes and swamps became more active during this time, and peat accumulations began to appear.

The third period (12,200–10,000 BP) follows after this short-term warming and rise of humidity. A strong continental trend affects the climate of that time, resulting in the almost complete disappearance of shrub and dwarf-shrub vegetation and the flourishing of xerophyte plants. The colder periods following Bølling Interstadial witnessed the spread of sedge-*Artemisia*-grass associations close in their specific composition to ‘‘tundra-steppes’’ (Fig. 6, samples 8–13 taken at a depth from 4.5 to 7.9 m). At the same time, the presence of shrubs and dwarf shrubs shows that the late-glacial climatic conditions were somewhat milder than those of the Sartan Glaciation. The mammals of the mammoth complex still populated at the islands, but numbers of them as well as a number of species probably became considerably reduced. This period is not homogeneous, with two subperiods that are clearly identifiable in changes of vegetation: the climate of the first subperiod is more continental, and *Artemisia* dominates it, while the second one is more humid, with grass compositions becoming more important.

The fourth period (10,000–9000 BP) is characterized by several dramatic and significant changes in landscapes, related to climate warming that reaches its Holocene maximum (average value for July is 5–6°C higher than modern). Profile 8 (Fig. 5) enables us to characterize the change of vegetative cover during the Pre-Boreal time (samples 2–8 taken at a 5–7-m depth, 9920 ± 180 BP, LU-1468, and 9700 ± 150 BP, LU-1469). The diagram reveals three phases: 1—underbrush tundras with birch and heather shrubs; 2—birch tundras; 3—underbrush-birch tundras. The data also correlate well with pollen compositions from profile 20 (Fig. 7, samples 3–7 taken at 1.5–4-m depths, 9700 ± 50 BP, LU-1749). The tree-shrub and dwarf-shrub vegetation became common in the valleys and also occupied flat interfluves.

TABLE 1

Spore-pollen complexes found in Kotelny island for Late Pleistocene and Holocene deposits

Complex 1, Period 1 15.4–12.5 kyr BP	AP—up to 18%, NAP—up to 80%. Spores reach 18%, the pollen of the xerophyte herbs dominates (*Artemisia*—up to 40% and other similar herbs—up to 30%).
Complex 2, Period 2 12.5–12.2 kyr BP	AP—about 45%, NAP—up to 50%, spores—2–20%; the presence of shrubs (*Betula* sect. *Fruticosae*) and dwarf shrubs (*Betula* sect. *Nanae*) with single grains of *Betula* sect. *Albae.* Two species are found to play the most important role in that composition. These are alder (*Alnus* cf. *Fruticosus*), with a pollen content from 15 to 30%, and willow (*Salix* sp.). The content of the latter is 38%, and this is the absolute maximum of it for the terminal Pleistocene and Holocene in the New Siberian Islands. NAP is represented by grass, sedges, and ericaceous dwarf-shrub species (*Ericaceae*), with a content up to 15%.
Complex 3, Period 2 12.2–10.0 kyr BP	AP—up to 20%, NAP—up to 70%, spores within 10%; pollen of herb plants prevails with a large portion of pollen grains of cryoxerophyte plants.
Complex 4, Period 4 10.0–9.0 kyr BP	AP—up to 80%, NAP is about 15%. Spores—5%; maximum of the shrub and a dwarf-shrub birch pollen. Tree pollen grains appear. The NAP is represented by pollen grains of herbs and ericaceous dwarf shrubs. Peat deposits of that time contain twigs, stems, and branches of the shrubs; some of them reach 10 cm in diameter.
Complex 5, Period 5 9.0–8.0 kyr BP	AP—45%; NAP—up to 50%. Spores are about 10%. A gradual decrease of pollen contents of shrubs and dwarf shrubs is observed. The sedge and grass dominate among NAP. Content of alder shrubs increases up to 30% around 8000 BP, while the AP content drops dramatically (to 23%).
Complex 6, Period 6 8.0–7.0 kyr BP	AP—up to 40%, NAP—up to 60%, spores—3–5%. Content of shrubs and dwarf shrubs are found to be equal in AP. Pollen grains of tree vegetation are also found. They belong to birch (*Betula* sect. *Albae*), pine (*Pinus sylvestris*), and spruce trees (*Picea* sect. *Eupicea*). NAP is composed by grass and sedge. The peat deposits are characterized by rare occurrences of shrub branches.
Complex 7, Period 6 7.0–6.0 kyr BP	AP is increasing up to 30%, NAP—up to 70%, the presence of spores is still low (2–5%). The AP content has some changes: the pollen grains of spruce trees disappear while the content of the pine pollen remains the same as it was found to be at the previous complex 6. Sharp increase of the role of *Artemisia* is found in NAP.
Complex 8, Period 6 6.0–5.0 kyr BP	AP—up to 50%, NAP—45%, spores—5%. The pollen of shrub and dwarf-shrub birch species (*Betula* sect. *Nanae, B.* sect. *Fruticosae,* and *B.* sect. *Albae*) prevails and pine tree pollen grains are present. The birch and spruce tree pollen appear again, the percentage of alder shrubs rises up to 30% and that of willow reaches 25%. In NAP, sedges and grass dominate. The role of *Artemisia* becomes more important close to 5000 BP.
Complex 9, Period 7 5.0–3.7 kyr BP	AP—20–30%, NAP—25–70%, spores reach 45%. Content of pine pollen sharply increases in AP. Birch pollen belongs to *Betula* sect. *Nanae* and *B.* sect. *Fruticosae.* Sedge and grass dominate NAP. Tree and shrub pollen disappear almost completely ca. 3800 yr ago.
Complex 10, Period 7 3.7–3.0 kyr BP	AP—40–43%, NAP—50–55%, spores—about 10%. Birch pollen represented by *Betula* sect. *Nanae, B.* sect. *Fruticosae* dominates among AP. The composition of shrub vegetation is dominated by willow. The second willow maximum occurs when its pollen content reaches 30%. No grains of pine, spruce, and birch tree pollen have been found. Grass dominates within NAP.
Complex 11, Period 7 3.0–2.7 kyr BP	This interval still needs to be studied. The composition remains unclear.
Complex 12, Period 7 2.7–1.7 kyr BP	AP—45%, NAP—up to 50%, spores—up to 70%. The pollen of shrub and dwarf-shrub birch species prevails, dominated by a number of pine pollen grains (35–40%). Pollen grains of spruce and birch trees have also been identified. Grass, sedge, and *Artemisia* are found among the AP.
Complex 13, Period 7 after 1.7 kyr BP	AP and NAP—spores of green moss prevail (*Bryatea*—up to 100%). About 1000 BP AP—up to 20%, NAP—up to 70%; with the domination of the grass pollen.

Birch, willow, and strong alder shrubs (the stems of which could be 15 cm thick) were widespread during this time. Many of surfaces became eroded by intensive thermokarst processes, leading to the formation of a large number of lakes inhabited by mollusk fauna species. The rate of peat accumulation increased, with growth rates in some locations found to be 0.5 cm yr^{-1}.

The fifth period (9000–8000 BP) is marked by a gradual cooling with contemporary rise of humidity. The Boreal deposits from Kotelny Island have no absolute dates, and the history of vegetative cover is described here according to their relative position in the profiles. Thus we can interpret BO-1 from profile 8, sample 1 with sedge-*Artemisia*-grass associations with shrubs and dwarf shrubs growing in the most favorable locations (Fig. 5), and BO-2 by profile 31, sample 1 (Fig. 7), as well as from profile 13, samples 15–17 (Fig. 8). They represent underbrush tundras (*Alnaster fruticosa, Betula* cf. *Tortuosa, B. exilis, Salix* spp., Ericaceae). The tree-shrub group of vegetation became considerably reduced not only at flat interfluves but also in the river valleys. Slow accumulation of peat and domination of sedges between the herbs also characterize this time span. The coldest part of that cooling period is between 8300 and 8000 BP.

The sixth period (8000–5000 BP) (complex 6–8) is of a complex structure characterizing the Atlantic (AT) period. Changes of pollen compositions observed from that dated from 8070 ± 90 BP (LU-1915) to 5120 ± 90 BP (LU-1806) for profile 31 (Fig. 7) and/or to 4980 ± 70 BP (LU-1819) for profile 13 (Fig. 8), making it possible to define three subperiods, i.e., AT-1, AT-2, and AT-3. They correspond to complexes 6, 7, and 8 described above. It could be divided in three subperiods that correspond to 6, 7, and 8 pollen complexes (see above). The subperiod 1 (corresponding to AT-1) is characterized by the relative rise of summer temperatures. Favorable climatic conditions produced a widespread development of shrub vegetation in river

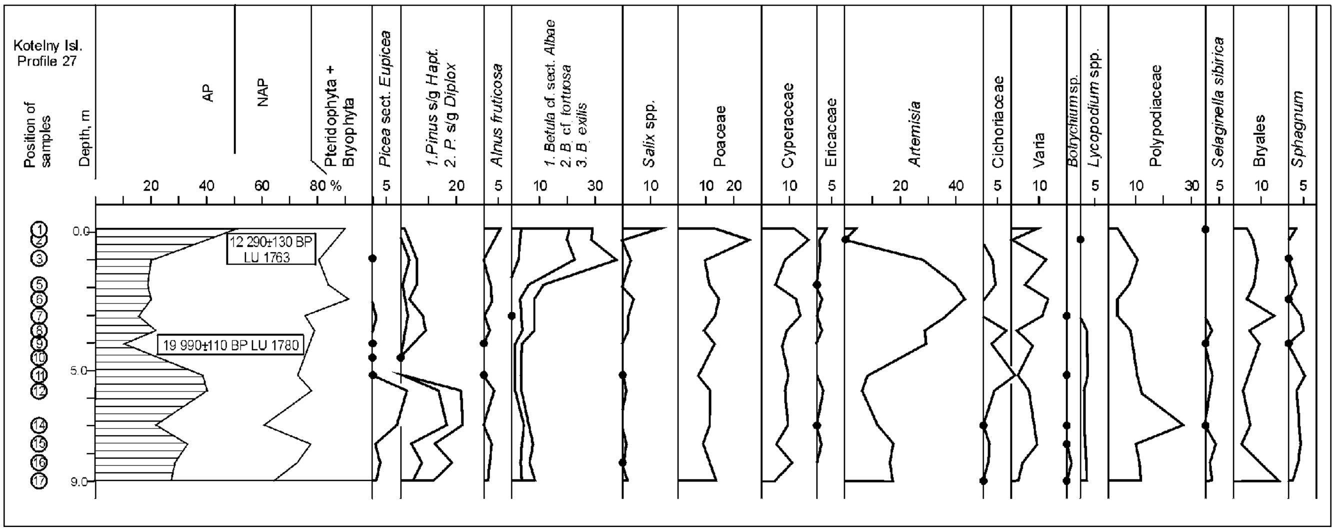


FIGURE 4. Kotelny Island. Pollen record found from the core 27 (by D. P. Ponomareva).

valleys, as indicated by the presence of large branches and stems in the peat accumulations and appearance of pollen of birch, spruce, and pine trees. Plant associations of that time were represented by *Artemisia*, sedge, and grass compositions accompanied by shrubs and birch (Fig. 7, profile 31, samples 2, 4; Fig. 8, profile 13, samples 15–17). The grass plants were rather diverse and were presented by Caryophyllaceae, Ranunculaceae, Asteraceae, and *Valeriana* sp. In general, on the basis of the analysis of the pollen spectrum, it is possible to define a tendency of development of the associations from the arctic tundra of the sedge-*Artemisia*-grass type with shrubs and birch, common in the beginning of that period, to shrub and dwarf-shrub tundra associations.

The second subperiod (AT-2) (Fig. 7, profile 31, sample 5; Fig. 8, profile 13, sample 14) was apparently cooler, which produced a reduction of shrub vegetation in river valleys. Herb plants became relatively more numerous. In AT-2 typical dwarf-shrub and sedge-grass tundra associations became more developed because of cooling in that time. During the third subperiod (AT-3) (Fig. 7, profile 31, samples 6–11; Fig. 8, profile 13, samples 9–13) new warming started and the vegetation was most likely of the same type as during the first subperiod. According to pollen data this period is characterized the development of grass-sedge and shrub and dwarf-shrub tundra with some elements of southern tundra. However, no macroremains of tree-shrubs were found from the deposits dated to that time.

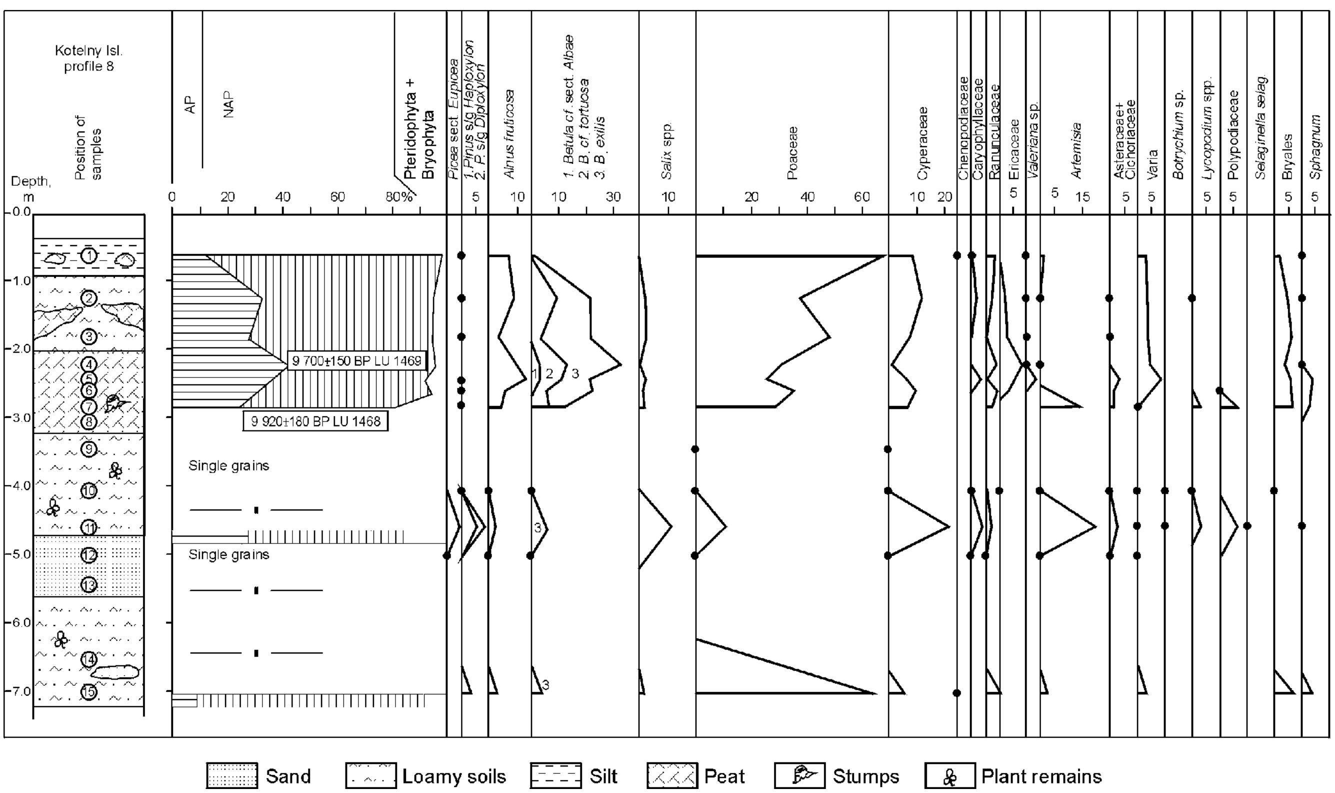


FIGURE 5. Kotelny Island. Pollen record found from profile 8 (by D. P. Ponomareva).

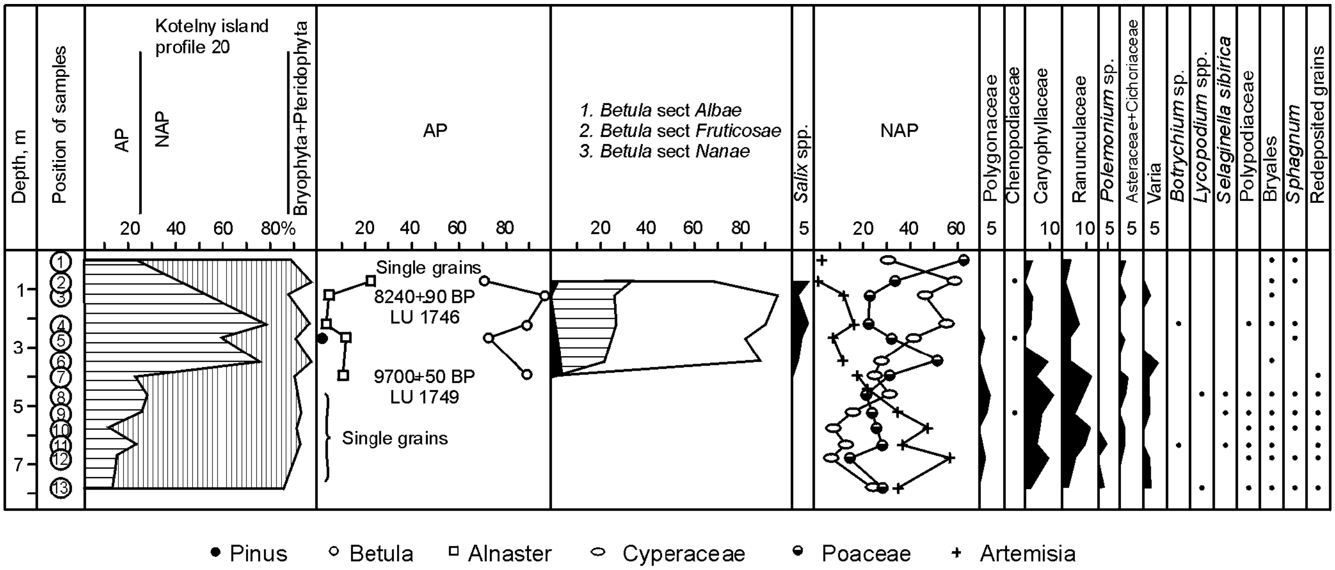


FIGURE 6. Kotelny Island. Pollen record found from the profile 20 (by D. P. Ponomareva).

The seventh period covers a time span from 5000 BP to the present, and it has a more complex structure than the previous one. It is possible to identify five subperiods that correspond to pollen complexes 9–13 (discussed above). Subperiods 1, 3, and 5 are represented by cold compositions (complexes 9, 11, and 13, respectively). Samples 4, 5, 6, and 8 from the pollen record of the profile 13 (Fig. 9) characterize a cold temperature trend; thus, plant association of SB-1 degrades from the birch tundra type to sedge-grass tundra. Subperiod 1 corresponds to complex 9 (see the description above). The effects of that cooling were probably complicated by the rise of humidity. The speed of ice-wedge polygon formation increased during that time. During the cold period in SA-2, the plant associations were represented by sedge-grass tundra, corresponding to subperiod 5 (i.e., complex 13, Table 1). The vegetation and landscapes of that time were rather close to the present. During the second and the fourth subperiods the climate was warmer. That corresponds to SB-2 and it is well represented by samples 1 and 2 from profile 13 (Fig. 8). The river valleys were probably occupied by shrub and dwarf-shrub plants (birch, willow, and alder shrubs). Accumulation of peat deposits goes faster and thermokarst erosion becomes more intensive during these two time spans.

ZHOKHOV ISLAND

Although Zhokhov Island remained unsurveyed for years (perhaps because of its small size and remoteness), it became an important source of paleoenvironmental and paleogeographic information once the first field survey was conducted in 1989. In addition to the research program in these areas, the Zhokhov phase of the project included archaeological survey and excavations of the site discovered in 1967 but previously untested. Efforts to locate additional archaeological sites on the island were unsuccessful. However, excavation of the Zhokhov site produced clear evidence of early Holocene human occupation of the High Arctic. Cultural remains from the site have been dated by ^{14}C to approximately 8000 BP (Pitulko, 1993, 1998). Multiple dates on a variety of organic substances including bone, charcoal, and wood provide confirmation. Human habitation in the northernmost portion of the island chain during the early Holocene raises a number of important questions including the nature of the physical environment at the time of occupation and the effects of changes in that environment on the people who lived there. Other paleogeographic questions include whether Zhokhov was an island at that time, and if so, how far it was from the larger landmasses to the south. The presence of humans on Zhokhov Island may be taken as indirect evidence for a relatively favorable environment 8000 yr ago.

ZHOKHOV PALEOENVIRONMENTAL RECORD

Samples taken from the archaeological excavation and four test pits were subjected to palynological analysis. The detailed description of the site itself and the history of its study are given by one of the authors elsewhere (Pitulko, 1998). Because the archaeological site had to thaw, generally at a rate of 2 to 3 cm d^{-1}, before excavation could take place, samples were collected from thawed and drying layers. An additional complicating factor is cryoturbation, as much of the site has clearly been altered by thermokarst and the formation of ice bodies. Unfortunately, this could have caused some loss of palynological information: the samples differ sharply from each other by their saturation in pollen and spores. The depth of the modern active horizon does not exceed 20 cm, and subjacent deposits are characterized by permafrost conditions.

Elsewhere on the island, test pits 1, 1a, and 1b are situated on the left bank of the Lagernaya stream facing west and characterize the western and eastern parts of the excavated area of the Zhokhov site. Test pit 2 is situated in the southern part of Zhokhov Island on the watershed of the Lagernaya and Ozernaya rivers (Fig. 2B).

In this paper we would like to dwell at length on the characteristics of those aspects of the paleogeographic situation on Zhokhov Island that can be elucidated with the help of our palynological data and radiocarbon dates. We concur with Serebryaniy et al. (1984) that for the arctic regions the analysis of botanical composition of peat is of primary importance for paleobotanical reconstructions. The botanical composition of our peat samples was determined under the guidance of Dr. V. P. Denisenkov (St. Petersburg State University, Department of Geobotany).

The bottom part of the deposits discovered in test pit 2 is represented by loamy soils with the lenses of brown peat which is dated to 10,070 ± 100 BP (LU-2501). The pollen complex

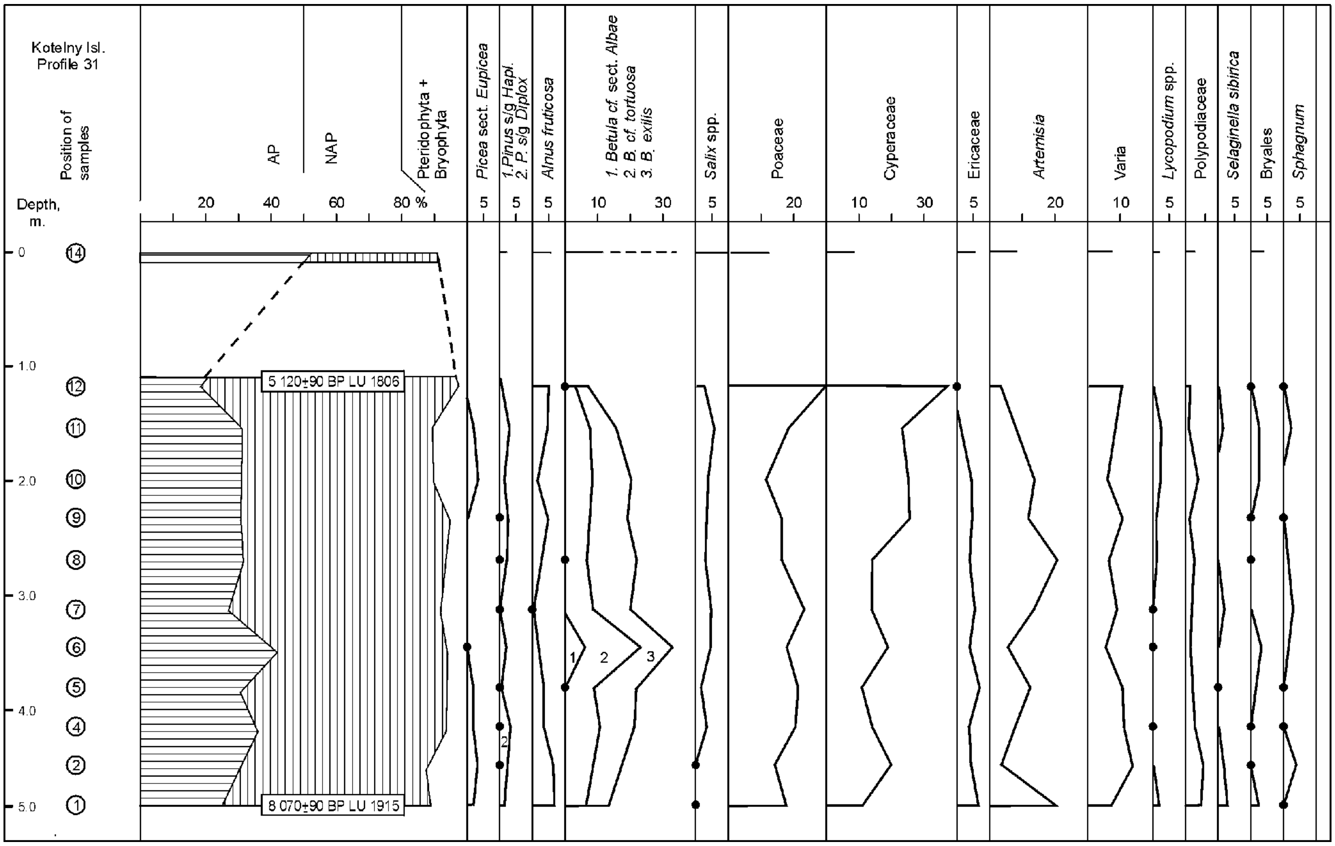


FIGURE 7. Kotelny Island. Pollen record from profile 31 (by D. P. Ponomareva).

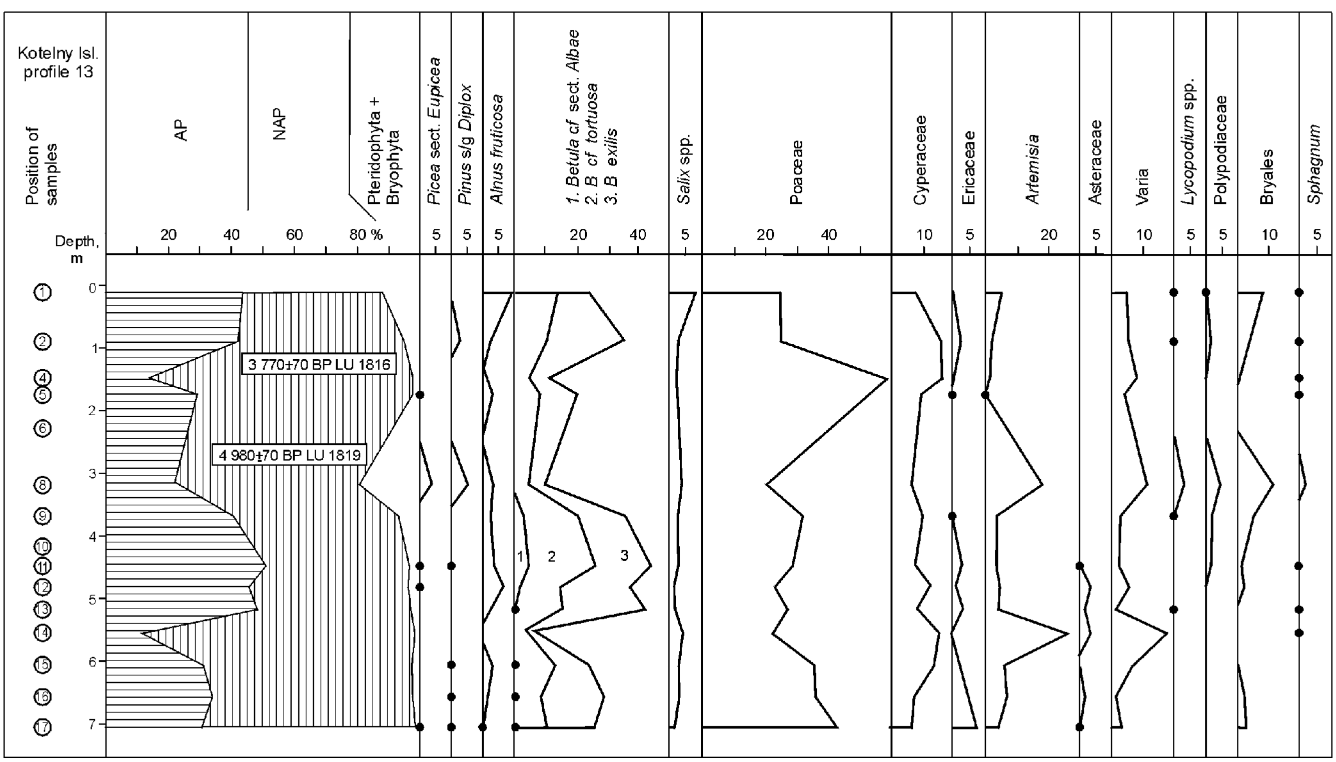


FIGURE 8. Kotelny Island. Pollen record from profile 13 (by D. P. Ponomareva).

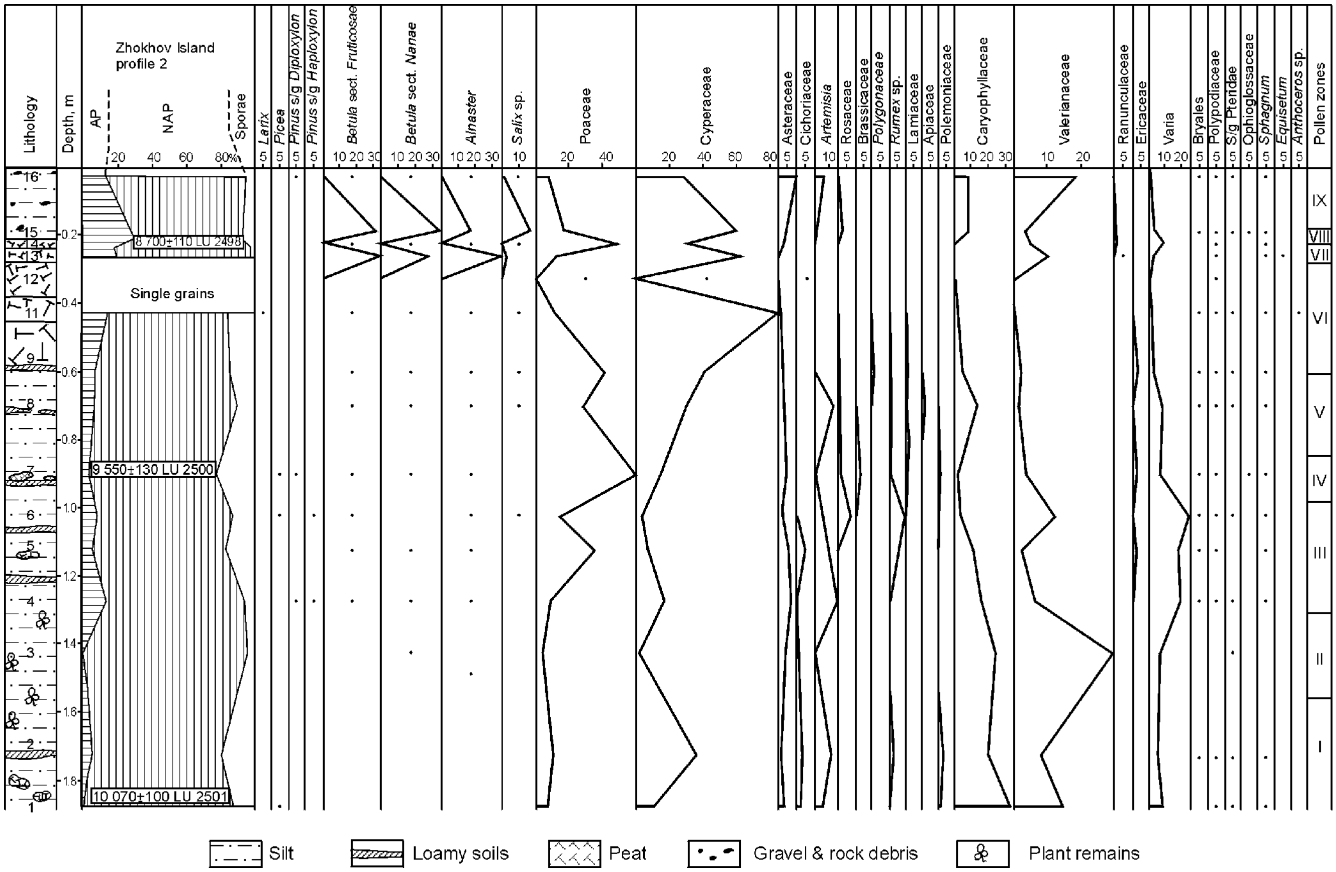


FIGURE 9. Zhokhov Island. Pollen record found from the reference profile in the southwest part of the island (by G. M. Chernova).

has a high content of grass and dwarf-shrub pollen grains (NAP) that reaches up to 90% of the total (Fig. 9). Pollen grains of Valerianaceae, Caryophyllaceae, and Cyperaceae are rather numerous between grass species, though Poaceae and *Artemisia* play an important role also. Trees, shrubs, and dwarf-shrub plants (AP) are found to be represented by single pollen grains as well as spores. Unfortunately the botanical composition for this peat could not be identified. The results indicate that herbaceous associations of tundra-steppe type dominated in the area of Zhokhov Island around the Pleistocene-Holocene boundary (10,000 yr ago). Their formation was obviously influenced by late Dryas cooling. After that, during the post-Dryas warming, the tundra-steppe formations were gradually replaced by sedge-grass tundra associations with plant elements of tundra-steppe type, and then by grass tundra compositions.

In a depth of 0.9–1.0 m from the surface, a lens of the brown peat had been found. A ^{14}C date for that accumulation is 9950 ± 130 BP (LU-2500). Brown peat is formed by low-moor peat with a high content (to 65%) of *Sphagnum* spp., *Drepanocladus* sp., *D. exannulatus,* and *D. fluitans.* In addition it contains some remains of *Tomenthypnum nitens* (10%), *Calliergon cordifolium, Aulacomnium turgidum, Eriophorum* sp. (5% each), as well as *Carex* sp., *C. rotundata,* and *C. meirera* (15% altogether). It should be noted that whereas *D. exannulatus* is a highly polymorphous species widespread from plains to high mountains and usual for the arctic regions, *D. fluitans,* though also cosmopolitan, is less frequently found in the arctic zone than in temperate latitudes. The pollen composition is represented by NAP—73.3% (composed almost entirely of grasses, with a content of Ericaceae less than 5%), spores—21.4%, and AP—5.3%. Thus, it is possible to reconstruct the type of vegetation for 9500 BP as open landscapes of sedge-grass tundra. Swamping of that area started during this time as well as the formation of Hypnum bogs in topographic depressions.

The layer of dark brown peat (8700 ± 110 yr ago, LU-2498) is characterized by a high content of pollen from arboreal species—29.6%, NAP take 68.5%, and spores 1.9%. This is a *Carex-Sphagnum* low-moor peat with numerous (55%) remains of mosses (*Sphagnum aongstroemii* and *S. lindbergii*). It contains also remains of *Carex* sp. (about 35%), *Tomenthypnum nitens* (5%), and single residues of *Aulacomnium* sp., *Calliergon cordifolium, Equisetum* sp., *Picea,* and *Salix.* Plant associations of this time were represented by compositions of sedge-shrub tundra type (with the participation of *Betula* sect. *Frucosae, Betula* sect. *Nanae, Alnaster* sp., *Salix* sp.) and the formation sedge-moss (*Sphagnum*) bogs in depressions with submineral groundwater feed.

A sample taken from the uppermost part of the peat stratum that underlies the cultural layer produced a date of 8790 ± 90 yr ago (LU-2502). Unfortunately, we have no data regarding the botanical composition of the peat. However, both pollen and spores are well preserved, and 561 grains were obtained from two slides measuring 24 by 24 mm. Grasses and dwarf shrubs (63.5%), followed by sporophytes (23.2%) dominate the pollen spectrum. The arboreal species are dominated by *Betula* sect. *Nanae* (29,4%), *Alnaster* sp. (20%), and *Salix* sp. (18,6%). *Cyperaceae* predominates among grasses (50.4%), while undetermined tricolpate forms make up 16.3%, and Valerianaceae accounts for 10.7% of the herbs. In addition there is some pollen of Polygonaceae, Caryophyllaceae, and Ranunculaceae as well as isolated grains of Chenopodiaceae and Saxifragaceae. Sporophytes are mainly represented by the spores of green mosses (76.9%) which is a characteristic feature of the tundra spectra.

The presence of pollen and twig fragments of *Alnaster* sp., *Betula* sect. *Frucosae*, *Betula* sect. *Nanae*, and *Salix* sp., as well as spores and leaf fragments of *Sphagnum* sp., is indicative of some warming of the climate in that time. The role of Cyperaceae becomes more important in the plant associations. A replacement of Hypnum bogs by sedge-moss (*Sphagnum*) ones is observed in this time span, indicating the increase of humidity between 9500 and 8500 yr ago. Therefore, our data testify to the existence of sedge-Sphagnum bogs and underbrush tundra phytocoenoses on Zhokhov Island at the period of initial peopling of the High Arctic regions. According to the data of other researchers (e.g., Kaplina and Lozhkin, 1982), a substantial warming took place 8500 yr ago, when large alders and birches reached Kotelny Island. At that time the northern boundary of the birch area was situated 600 km farther to the north than it is at present.

A characteristic sample, sample 8 from the excavation pit, contained mineral and carbonaceous particles, plant remains, and a pollen grain of *Artemisia* sp. At the same time the moss peat from which the sample was taken contains *Calliergonella cuspidata, Sphagnum* sp., *Bryum* sp., *Drepanocladus* sp., *D. sendtneri, Aulacomnium turgidum, Tomenthypnum nitens, Philonotis* sp., *Campylium* sp., *Paludells squarrosa, Equisetum* sp., *Carex* sp., and some unidentified grassy remains. The moss *Calliergonella cuspidata* is widespread in the forest zone of the Northern Hemisphere and occasionally is found in the arctic regions. It grows on bogs, along rivers and brooks (sometimes on decayed wood), and in tundras with *Salix. Drepanocladus sendtneri* is usual for the tundra zone, and is a calcareophyte (Savich-Lyubitskaya, 1961). Although we do not have a ^{14}C date for it, we can assume from the stratigraphy of the site that its age should be the same as for the cultural layer at this site, or shortly after that.

Two additional samples were taken from the peat layer discovered during the excavations of the site. This layer disturbs the very top of the cultural deposits (Pitulko, 1993). Evidently, the genesis of this peat accumulation is related to the last of the Holocene warmings. The age of it is 2200 $\pm$ 30 years ago (LU-2435), and most probably it is a small peat deposit filling some old thermokarst depression. Its thickness is 20 cm. The sample 5/1 (top) represents moss low-moor peat mainly formed by *Aulacomnium turgidum* (80%)—an Arcto-Alpine species preferring moist habitats. There are also remains of *Drepanocladus* sp.—highly variable mosses that are very sensitive to any environmental changes (particularly to changes in humidity) and produce numerous ecological forms and transitions between them (Savich-Lyubitskaya, 1961). In addition there are some remains of *Calliergon* sp., *Tomenthypnum nitens,* and *Carex* sp. sample 5/2 (bottom) is very close in its composition to sample 5/1. It is moss peat with remains of *Aulacomnium palustre.* The pollen spectrum is dominated by arboreal species, particularly birch: *Betula* sect. *Albae* (2.8%), *Betula* sect. *Fruticosae* (21.1%), and *Betula* sect. *Nanae* (15.5%). Well represented is foreign pollen of *Pinus* s/g *Diploxylon* (35.5%) and *Pinus* s/g *Haploxylon* (14.1%). Single grains represent *Picea, Alnus,* and *Alnaster.* Grasses and dwarf shrubs are dominated by Cyperaceae (42%) and Caryophyllaceae (22.6%). Some pollen of Valerianaceae and Asteraceae is also found. No percentage ratios have been calculated for Sporophyta. There are spores of *Sphagnum,* Polypodiaceae, Bryales, *Dicranum,* and *Lycopodium.* This period was probably one of recovery for underbrush tundras. The similarity of the compositions found from these samples indicates that the accumulation of peat was comparatively rapid, but not long in duration, and this raises new questions about late Holocene environmental changes on Zhokhov Island.

ZHOKHOV ARCHAEOLOGICAL EVIDENCE

According to Olga Potapova, who has provided identification for bird species from bones collected from the archaeological site, remains of three waterfowl species were excavated from the Zhokhov site (Pitulko, 1998). They belong to the Bewick swan (*Cygnus bewickii*), bean goose (*Anser fabalis*), and greater white-fronted goose (*Anser albifrons*). Recent northern limits of breeding and molting distribution of those species do not include Zhokhov Island (Fig. 10). The distribution of Bewick swan is now restricted to mainland tundra in East Siberia. These birds rarely penetrate to the New Siberian Islands except as an irregular vagrant. Remains of bean geese are the most abundant on site (the collection indicates at least six individuals), which apparently means that these geese were widespread about the Northern New Siberian Islands 8000 yr ago. However, the northern subspecies of bean goose (*A. fabalis serrirostris*) currently inhabits the southern bush tundra and forest-tundra area in the mainland, with a small remnant population in Kotelny Island reported by Rutilevsky (1967). The greater white-fronted goose (*Anser albifrons*) inhabits the moss-lichen arctic tundra on the mainland and rarely penetrates even to Lyakhovsky Islands for molting. Therefore, all three waterfowl species belong to the recent southern Arctic complex and do not inhabit the high Arctic areas.

There are two possible scenarios for hunting of the waterfowl species discovered during the excavations on Zhokhov Island: (1) The people might hunt molting geese and swans, which arrived on Zhokhov for a short period of the flight-feather molt, or (2) they might hunt nesting and brood-rearing pairs. Either is plausible, and the presence of these species in the island indicates important peculiarities of natural conditions that differ from those found at present. Given what we know of waterfowl behavior, their presence on the island suggests that numerous lakes with abundant aquatic vegetation and grassy sides covered the island or the area adjacent to the land that constitutes the island today. Chains of lakes with an area about 1 ha, linked by small streams, are used by bean and white-fronted geese and Bewick swans during flight-feather molt. The flightless period of nonbreeding geese and swans lasts from early July till early August in recent populations.

Breeding in Bewick swan requires approximately 100–110 d of above-freezing temperatures from nest initiation to fledging (Syroechkovsky, 1998). In the Lena delta area, swans start to nest in the first days of June and fledge young in early to mid-September. Freezing of tundra lakes pushes late broods into delta channels, where the water remains relatively warm until late September. Breeding of Bewick swan on Zhokhov Island was possible only under either the presence of a large, relatively warm river (northwest Indigirka riverbed?) or warm climate with freshwater freezing not earlier than mid-September. For breeding, Bewick swan favors open maritime tundra, primarily moss-lichen and sedge tundras, and low-lying marshes with numerous pools and lakes (Rees et al., 1997). On breeding grounds, swans feed in marshes and lakes and favor the tundra sedges *Carex aquatilis* and *C. lachenalii*; the grasses *Dupontia fisherii, Arctophila fulva,* and *Calamagrostis neglecta*; and some herbaceous plants (Rees et al., 1997).

The breeding season is shorter for both goose species than

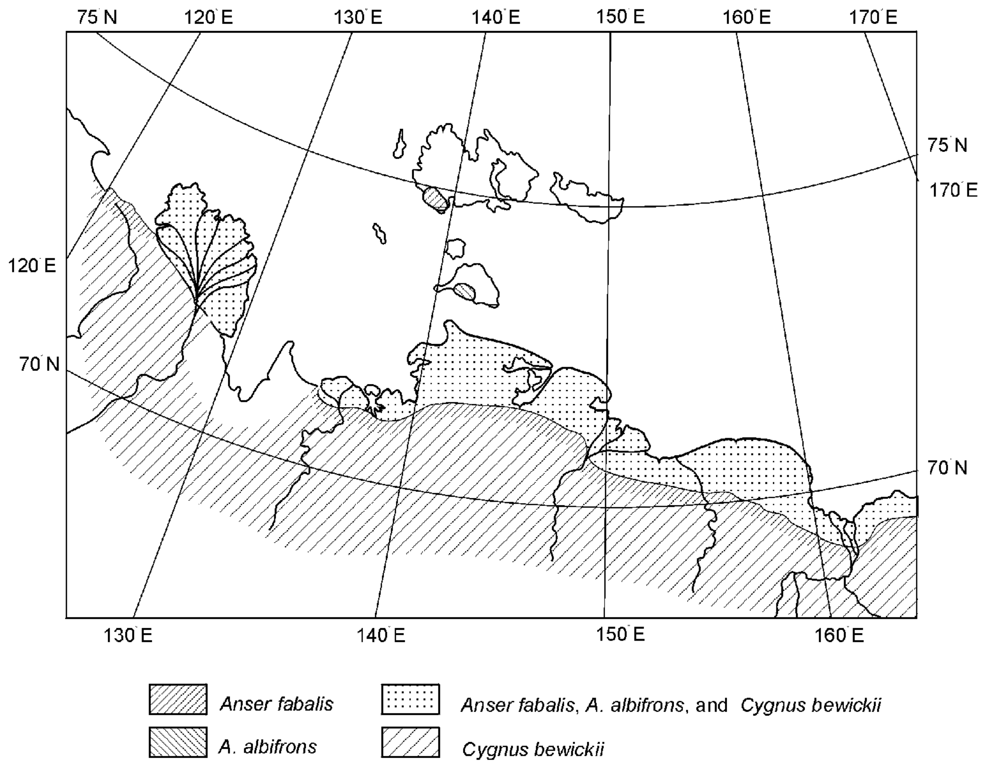


FIGURE 10. Distribution of waterfowl species in the area of New Siberian Islands (by D. V. Solovyeva).

for the Bewick swan. It lasts for 90–100 days, but nests are initiated only after 90 to 95% of upland areas become snow free (Ely and Raveling, 1984). The white-fronted goose feeds on near-root starch-containing parts of different sedges and berries. Its principal food is *Carex aquatilis* and *C. stans, Arctophila fulva,* and berries of *Arctostaphylos uva-ursi, Empetrum nigrum,* and *Vaccinium myrtillus*. The bean goose's principal food is tundra species of *Gramineae* and *Cyperaceae.* These geese prefer blooming heads and underground stems of *Eriophorum* spp., shoots of *Arctophila fulva,* and water sedge (Tertitsky and Kondratiev, 1998).

The species that are the food source for these waterfowl species are consistent with flora associations found to be flourishing ca. 8000 yr ago on Zhokhov Island as deduced from pollen and macrofossil data. According to interpretation of the pollen spectra from Kotelny Island (see above), the warmest period for the Holocene should be dated 10,000–9000 yr ago, with mid-July temperatures much higher than in recent times. We estimate that temperatures must be 5 to 6°C higher in Kotelny. Zhokhov Island is located far northeast of this island, but even in Zhokhov, July temperatures for that time were significantly warmer than now.

All these waterfowl species require a period of above-freezing temperatures which must be, with some variations, approximately 100 d long for successful breeding. The climatic record for at least 50 yr of the twentieth century shows that even in Kotelny this period is shorter than is needed for breeding (82 d), and Kotelny is one of the warmest islands of the whole chain. Farther north on Zhokhov the above-freezing period is restricted to approximately 60 d, and the temperature normally does not exceed 1–2°C above freezing. However, even in the period of cooling (after 9000 BP) that follows the early Holocene warming in the New Siberian Islands, the summer temperatures were still higher than at present, and the islands provided breeding habitat for waterfowl species. The presence of waterfowl in the diet of Zhokhov's human occupants also raises, and helps answer, questions of paleogeography. If Zhokhov was an island similar to its current size at the time of human occupation, it probably could not have provided the sort of landscape which would have sustained waterfowl. We believe Zhokhov was probably part of a much larger island 8000 yr ago.

Conclusions

1. After the cryoarid epoch (25,000–12,500 yr ago, Sartan Glaciation) ended, significant changes of natural conditions and landscapes began in Kotelny and in New Siberian Islands ca. 12,500 yr ago. These changes are contemporary with those in the Severnaya Zemlya island chain and in the East Siberian Arctic region generally.

2. The presence of tree-shrub and dwarf-shrub pollen, as well as the pollen of the arid flora complex, which was characteristic of the earlier epoch, is typical for most of the Holocene pollen complexes discovered in New Siberian Islands so far. This indicates that the climate of the islands was comparatively warmer and less humid during most of the Holocene than it is at present. Such conditions were favorable for the existence here of the plant compositions of typical tundra flora and even that of southern tundra over long intervals. The elements of forest tundra vegetation appear in the southern tundra compositions in the interval from 10,000 to 9000 BP. The fact that macroremains of shrubs and trees are confined to the layers that are not younger than 8000 yr shows that shrub vegetation was widespread in the early Holocene only, whereas in the middle and late Holocene it grew only in some particularly favorable areas in river valleys.

3. If compared, the results of paleobotanical studies of the Holocene deposits found in Kotelny and Zhokhov Islands allow us to conclude the following: The general tendency of climate warming that started in the late glacial/early Holocene occurred both in Kotelny and Zhokhov Islands. However, the climate change in each of them had clear and distinct features. Thus, the vegetation in Zhokhov Island was effected by the post-Dryas

cooling much more strongly than that of Kotelny. The grass tundra-steppe type of vegetation was typical for this time on Zhokhov Island, while sedge-*Artemisia*-grass associations with shrubs and dwarf-shrub plants flourished on Kotelny Island. The Holocene optimum is found to take place 10,000–9000 yr ago on Kotelny, but is hard to recognize from data collected in Zhokhov. The character of environmental changes in Kotelny was sharp and rapid while that of Zhokhov was comparatively slow and gradual. The difference can be easily seen from the pollen data from 10,000–9000 BP showing the existence of shrub and dwarf-shrub tundra associations with some features of southern tundra, and even forest tundra type in Kotelny, and contemporaneous development of vegetation from sedge-grass tundra with tundra-steppe elements to herbaceous and sedge-grass tundra in Zhokhov. However, the latest portion of the Holocene has the same trend in humidity which is increasing because of sea-level rise.

4. The structure of climatic and environmental variation in the Holocene of both Kotelny Island and Severnaya Zemlya (Makeyev et al., 1979; Makeyev, 1983) has a number of differences from that of the western Russian Arctic regions (Surova et al., 1982) and northern Eurasia as a whole (Khotinsky, 1987). The differences are especially well pronounced in the early Holocene. In the region we have studied, we consider no significant changes are observed for the interval from 12,000 to 10,000 yr ago, and the Holocene climatic optimum falls within the period of 10,000–9000 yr ago. In the last 8000 yr the structure of climatic and environmental fluctuations was in general very close to that described by Khotinsky (1987) for the north of Eurasia, but these fluctuations, including those occurring during the Atlantic period, were of small range.

5. The structure of environmental variability reported for the Holocene of Severnaya Zemlya (Makeyev et al., 1979; Makeyev, 1983) is also characteristic of the New Siberian Islands; that is, it was spread over vast areas of the Asian high Arctic. This structure testifies once again to the regional character of environmental variability both in the Upper Pleistocene and Holocene. In our view it was connected (particularly in the Holocene) with different scales and types of glaciation in the European Arctic and the Asian Arctic in the preceding glacial period, and with greater climatic stability of the latter region.

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References Cited

Ely, C. R., and Raveling, D. G., 1984: Breeding biology of Pacific white-fronted geese. *Journal of Wildlife Management,* 48(3): 823–837.

Kaplina, T. V., and Lozhkin, A. V., 1982: The Holocene history of development of vegetation of the coastal lowlands in Yakutia. *In* Velichko, A. A. (ed.), *Development of the Environment of the USSR in the Late Pleistocene and Holocene.* Moscow: Nauka, 207–220. (In Russian.)

Khotinsky, N. A., 1987: Radiocarbon chronology and the correlation of natural and anthropogenic boundaries of the Holocene. *In* Velichko, A. A. (ed.), *New Data on Quarternary Geochronology.* Moscow: Nauka, 39–45. (In Russian.)

Makeyev, V. M., 1983: History of periglacial lakes in Severnaya Zemlya. *In* Punning, Ya. M.-K. (ed.). *History of the Lakes in USSR. Abstracts of the conference.* Tallinn, 122–123. (In Russian.)

Makeyev, V. M., Arslanov, Kh. A., and Garutt, V. E., 1979: The age of mammoths in Severnaya Zemlya and some questions of the Late Pleistocene paleogeography. *Doklady Akademii Nauk SSSR,* 245 (2): 421–424. (In Russian.)

Makeyev, V. M., Arslanov, Kh. A., Baranovskaya, O. F., Ponomareva, D. P., Kosmodamiansky, A. V., and Tertychnaya, T. V., 1989: Stratigraphy, geochronology and paleogeography of Kotelny Island in the Late Pleistocene and Holocene. *Bulletin of the Commission for Study of the Quaternary,* 58: 58–69. (In Russian.)

Makeyev V. M., Pitulko, V. V., and Kasparov, A. K., 1992: Ostrova De-Longa: an analysis of paleoenvironmental data. *Polar Record,* 28(167): 301–306.

Pitulko, V. V., 1993: An Early Holocene site in the Siberian high Arctic. *Arctic Anthropology,* 30: 13–21.

Pitulko, V. V., 1998: *The Zhokhov Site.* St. Petersburg: Dm. Bulanin Publishers. 186 pp. (In Russian.)

Rees, E. C., Bowler, J. M., and Beekman, J. H., 1997: *Cygnus columbianus*: Bewick's swan and Whistling swan. *BWP Update,* 1: 63–74.

Rutilevsky, G. L., 1967: *Birds. In* Gakkel, Ya. Ya. (ed.), *New-Siberian Islands.* Leningrad: Gidrometeoizdat, 67–79. (In Russian.)

Savich-Lyubitskaya, L. I. (ed.), 1961: *A Handbook for the Cormophytic Mosses of the Soviet Arctic.* Moscow and Leningrad: Nauka. 714 pp. (In Russian.)

Serebryany, L. R., Tishkov, A. A., Solomina, O. N., Malyasova, E. S., and Ilves, E. O., 1984: A reconstruction of the development of vegetation in the High Arctic. *Izvestiya Akademii Nauk USSR, Geographic Series,* 6: 75–84. (In Russian.)

Serebryany, L. R., Tishkov, A. A., Malyasova, E. S., Solomina, O. N., and Ilves, E. O., 1993: Paleoecology of the Arctic-Atlantic area in the Holocene. *Izvestiya Akademii Nauk USSR, Geographic Series,* 2: 39–52. (In Russian.)

Surova, T. G., Troitsky, L. S., and Punning, Ya. M.-K., 1982: The history of the glaciation in Svalbard during the Holocene from the pollen record. *Materials for Glaciological Studies,* 42: 100–106. (In Russian.)

Syroechkovsky, E. V., 1998: Ways of adaptation of Anseriformes tribe Anserini to the arctic environment. Full degree thesis. Petrozavodsk University. (In Russian.)

Tertitsky, G. M., and Kondratiev, A. V., 1998: Bean goose. *In* Brude, O. W., et al. (eds.), *Northern Sea Route Dynamic Environmental Atlas.* Oslo: Norsk Polarinstitutt, 32.

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