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Early Holocene environments on October Revolution Island, Severnaya Zemlya, Arctic Russia

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ABSTRACT

Pollen, palynomorphs, and rhizopods were studied from several <1 m thick, peaty and silty sediment sections on southwestern October Revolution Island, Severnaya Zemlya. Six AMS radiocarbon ages from the sections show that peat accumulation started at ca. 11,500 and stopped after 9500 cal. yr BP, consistent with several previously reported ^{14}C ages. Open steppe-like vegetation existed on the island during the late Glacial, shortly before the Pleistocene/Holocene transition. Environmental conditions on the island were most favourable for local biota during the early Holocene, ca. 11,500–9500 cal. yr BP, when tundra-like sedge-grass communities dominated the vegetation. Low shrub tundra associations with dwarf birch and willow grew in more wind-sheltered localities. The temperatures during the growing season were at least 4 °C higher than today. The Vavilov Ice Cap was at or behind its present margins. Environmental conditions in the region changed significantly ca. 9400 cal. yr BP as a result of colder and drier conditions, when vegetation became similar to the modern, sparse lichen–moss–grass cover.

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1. Introduction

Although recent palaeoenvironmental studies on the Severnaya Zemlya archipelago have revealed a long and complex history of glaciations and associated sea-level changes from the middle to the late Pleistocene (Bolshiyanov and Makeyev, 1995; Andreev et., al., 1997a; Raab et al., 2003; Möller et al., 2007), relatively little is known about environmental changes during and after the Pleistocene/Holocene transition (ca. 11,500 cal. yr to present). The early Holocene is an especially intriguing period based on a brief mention by Arslanov et al. (1980) of a peat deposit containing moss, herbs, and twigs which were radiocarbon dated to 11,477±177 cal. yr BP, indicating the dominance of shrub tundra. Later, this single datum point was supplemented (Makeyev et al., 1992; Bolshiyanov and Makeyev, 1995) with the identification of twig remains of dwarf willow and birch, including dwarf willow found near Changeable Lake dated to 11,692± 243 cal. yr BP (Bolshiyanov and Makeyev, 1995). Pollen of these taxa and Poaceae and Cyperaceae were identified in sediments radiocarbon dated to 10,961±169 and 13,440±455 cal. yr BP. However, pollen count data were not reported, so the full pollen spectra remain unknown. Most of the samples dated thus far were collected within a few km of the present ice-cap margins, some immediately adjacent to the ice. These samples show that the ice caps extent were similar to or smaller than present in the early Holocene (Stiévenard et al., 1996). A number of ice cores drilled on the Archipelago, some up to 725 m long, have the potential to help reconstruct past ice-cap dimension and environmental conditions for the early Holocene to the present. However, these chronologies remain hotly debated, with two estimates for the basal age of the oldest core (Akademii Nauk) diverging enormously: ca. 14,000 and 2500 cal. yr. The latter age is based on the most recently collected core (Fritzsche et al., 2005), and implies that glaciers may have been absent for much of the early and middle Holocene.

These sparse observations present intriguing preliminary evidence suggesting ameliorated environmental conditions during the early Holocene (especially ca. 11,500 cal. yr), similar to other regions of the high Arctic (i.e., Andreev et al., 1997b; Serebryanny et al., 1998; Andreev et al., 2003, 2005). Additional studies on Severnaya Zemlya are needed to reconstruct better past vegetation assemblages and determine the timing and magnitude of environmental changes (i.e. growing season temperature). We present new palaeoenvironmental data based on five disjunct <1 m thick peaty and silty sections, all but one of which were described and sampled on southwestern

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October Revolution Island, close to the present Vavilov Ice-Cap margin, during a joint Swedish-American-Russian expedition in 2002 (see Möller et al., 2007). The fifth section, located on Bolshevik Island, was previously studied by Raab (2003) and we have added new data to this record. Our study focuses on palynological and rhizopod (protozoan) records of the early Holocene and associated inferred palaeoenvironmental changes.

2. Study area

October Revolution Island is situated on the Siberian continental shelf (Fig. 1) and is the largest island of the Severnaya Zemlya archipelago. Cambrian and Devonian bedrock outcrops over large areas, but elsewhere it is covered by a relatively thin blanket of Quaternary deposits and periglacial regolith (Bolshiyanov and

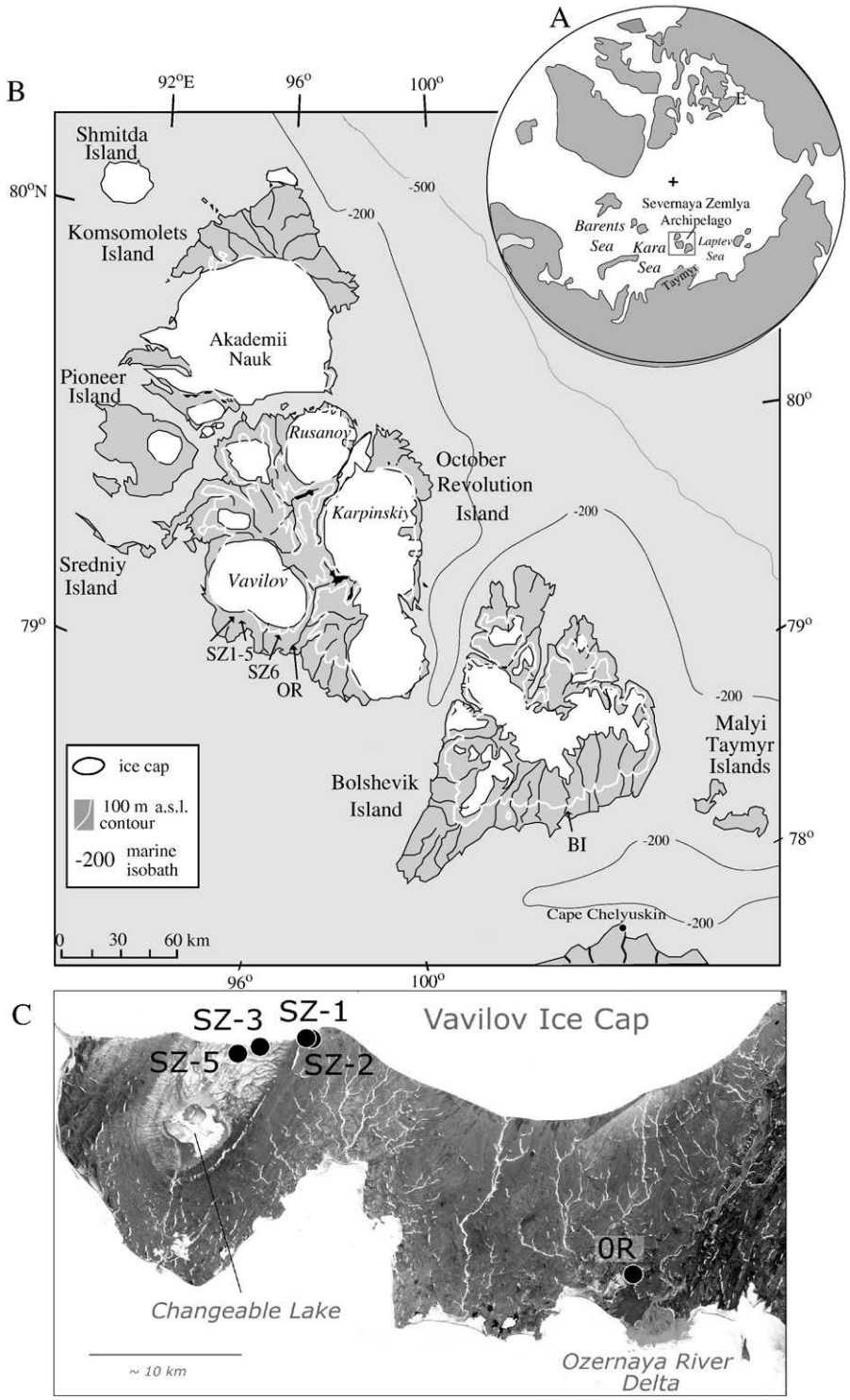


Fig. 1. A. Map of the Arctic. B. Map of the Severnaya Zemlya Archipelago. C. Study area on the October Revolution Island. Locations of the studied profiles and surface samples are in Table 1.

Table 1
Locations of the peaty profiles and surface samples

Region	Site ID	Field ID	Latitude (N)	Longitude (E)	Thickness (cm)
Southwestern October Revolution Island					
Changeable Lake	SZ-2	TH-2	79°10.571′	95°29.716′	30
Changeable Lake	SZ-5	5	79°10.163′	95°16.291′	20
Changeable Lake	SZ-3	3	79°10.298′	95°20.724′	95
Changeable Lake	SZ-1a–b–c	TH-1	79°10.558′	95°30.125′	30, 30, 10
Ozernaya River delta	OR	Lagoon	79°01.051′	96°29.664′	60
Changeable Lake	SZ-20	SZ 1	79°09.36′	95°53′	Surface sample
Changeable Lake	SZ-21	SZ 2	79°08.72′	95°20.724′	Surface sample
Ozernaya River	SZ-24	SZ 5	79°09.34′	96°53.968′	Surface sample
Bolshevik Island					
Solnechnaya Bay	BI		78°14`	103°10′	13

Makeyev, 1995). The geomorphology of the non-glaciated areas is characterized by broad valleys and extensive flat lowlands below 100 m a.s.l., dissected by a number of river valleys and ravines of which the largest are those of the rivers draining the Vavilov and Karpinskiy Ice Caps (Möller et al., 2007). The studied peat and silt profiles were collected from banks of small streams eroded into the flat lowlands along the Vavilov Ice Cap and in the Ozernaya River valley.

The present climate is extremely harsh with a mean annual air temperature of about −13 °C (Bolshiyanov and Makeyev, 1995). Mean monthly temperatures for July and August are near 0 °C, but there is substantial daily variability. Daily temperatures well above freezing occur with warm air masses sourced from northern Siberia (Bassford et al., 2006). Colder temperatures are common with the persistence of cloudy, foggy and windy conditions and summer snowfall is not unusual. Colder conditions prevail with katabatic winds occasionally blow from the ice caps. In some years, particularly in September there are one or more marked warming events lasting several days with associated surface melting of the ice caps (Bassford et al., 2006). The annual precipitation ranges from 240 to 400 mm, with most of the precipitation falling as snow.

The archipelago is in the polar desert zone with patchy, poorly developed polar desert, arctic, and peaty soils (Govorenkov, 1981). Generally, vegetation cover is very scarce (<10%) with the predominance of lichens–moss–grass communities. On south-and-west-facing slopes shielded from prevailing winds (e.g. Ozernaya River basin), plant communities are richer, with the occurrence of dwarf willows, *Salix polaris,* and *S. reptans* (Korotkevich, 1958). Only 71 species of vascular plants have been described from October Revolution Island (Safronova, 1981; Khodachek, 1986).

3. Methods

Six short sediment profiles were described from the Changeable Lake and the Ozernaya River basins (Fig. 1) on October Revolution Island and sampled for ^{14}C dating and palynological and rhizopod analyses. Samples were taken from vertical sections in frozen deposits. Samples from an additional profile on Bolshevik Island (Raab, 2003) were analyzed for rhizopods. The locations of the studied profiles are listed in Table 1.

Samples for ^{14}C dating were wet-sieved, macrofossils were hand picked from the samples, rinsed in deionized water, and dried. The samples received a standard acid-base-acid pretreatment after submission to the NSF Arizona AMS Facility. The results are presented in Table 2. The Calpal program (http://www.calpal-online.de/) was used to calibrate the ^{14}C ages.

A standard HF technique was used for pollen preparation (Berglund and Ralska-Jasiewiczowa, 1986). The samples were investigated under a light microscope at 200–400× magnifications. At least 200 pollen grains were counted for each organic-rich sample. Generally, the number of counted pollen grains was less in pollen-poor silt samples. Pollen concentration was calculated in grains per gram. The relative frequencies of pollen taxa were calculated using sum of the terrestrial pollen taxa. Spore percentages are based on the sum of pollen and spores. The relative abundances of reworked taxa (Tertiary spores and redeposited Quaternary pollen) were based on the sum of pollen and redeposited taxa, and the percentages of algae were based on the sum of pollen and algae. Tilia/TiliaGraph software (Grimm, 1991) was used for the calculation of percentages and for drawing the diagrams. Diagrams were zoned by visual inspection.

The quantitative method known as the best modern analogue (BMA) approach (e.g. Guiot, 1990) was used to reconstruct past climate variables from the early Holocene pollen spectra. The same approach has already been used to infer palaeoclimatic signals from

Table 2
Late Glacial and Holocene radiocarbon dates from October Revolution (SZ), Bolshevik (BI), and Komsomolets (KI) Islands

Sample ID (depth, cm)	Fraction dated	Radiocarbon age (^{14}C yr BP)	Calibrated age (cal yr BP)	$\delta^{13}C$ (‰)	Lab. no	Reference
SZ, site 103	Plant remains*	11,460±410	13,440±455		LU-1127	Bolshiyanov and Makeyev, 1995
SW Universitetskiy Ice Cape	Mammoth tusk	11,500±60	13,403±121		LU-610	Makeyev et al., 1979; Arslanov et al., 1980
E Vavilov Ice Cape	Mammoth tusk	10,450±110	12,254±214		LuA-4820	Möller et al., 2007
SZ, site 31	Dwarf willow	10,100±100	11,692±243		LU-1161	Bolshiyanov and Makeyev, 1995
SZ, site 80, 30–45	Peat*	9950±100	11,477±177		LU-655	Arslanov et al., 1980
SZ-2, 15–20	Plant remains*	9810±45	11,229±20	−27.5	CURL-6932	This study
SZ, site 103	Plant remains*	9620±110	10,961±169		LU-1120	Bolshiyanov and Makeyev, 1995
SZ-5, 40–45	Plant remains*	9440±45	10,670±57	−28.3	CURL-6931	This study
SZ-5, 30–35	Plant remains*	9250±55	10,415±91	−26.3	CURL-6930	This study
SZ-3, 75–80	Plant remains*	9020±50	10,199±31	−27.7	CURL-6935	This study
SZ-1A, 25–30	Plant remains*	8770±40	9811±145	−26.0	CURL-6933	This study
SZ, site 103 site 93	Plant remains*	8800±200	9884±250			Bolshiyanov and Makeyev, 1995
SZ-1B, 45–50	Plant remains*	8580±60	9569±50	−29.1	CURL-6934	This study
SZ, an alluvial terrace, 303	Plant detritus	3400±90	3664±124		LU-1123	Bolshiyanov and Makeyev, 1995
SZ, an alluvial terrace, 420	Plant detritus	3280±130	3534±145		LU-1125	Bolshiyanov and Makeyev, 1995
SZ, site 103 site 93	Plant remains?	3200±100	3434±116			Bolshiyanov and Makeyev, 1995
SZ, site 103 site 93	Plant remains?	910±1000	1270±869			Bolshiyanov and Makeyev, 1995
BI, 0–10	Willow remains	8790±60	9859±149	−30.0	UtC-7429	Raab, 2003
BI, 0–10	Insect remains	8650±60	9628±63	−35.9	UtC-7430	Raab, 2003
BI, 0–10	Decomposed peat	8350±60	9369±72	−31.9	UtC-7431	Raab, 2003
KI, margin of ice cap	Plant remains?	6990±170	7831±148		IGRAN-879	Stiévenard et al., 1996

* plant remains are unidentified in these samples.
All radiocarbon ages are normalized to a $\delta^{13}C$ of −25‰ vs PDB.

Arctic pollen records (Andreev et al. 2003, 2004a,b, 2005, in press). In the present study, we used the reference data set of 1173 modern pollen spectra from Northern Eurasia (for details see Tarasov et al., 2005). The BMA method uses a chord distance to determine the dissimilarity between fossil pollen spectra and spectra in the modern data set. In the present study, eight spectra with the smallest chord distance were considered as the closest modern analogues to the fossil spectrum. An empirical check used the surface data set shown that eight spectra are giving the best result in reconstructing modern climate at the surface pollen sampling sites (Tarasov et al., 2005). Then the reconstructed value (treated as the most probable) was calculated as the weighted average of the climatic variables of the selected best analogues, with the inverse of the chord distance as weights (Tarasov et al., 2005).

The samples prepared for rhizopod analyses were wet-sieved through a 500 µm screen to remove organic and mineral particles that prevented identification of rhizopods. Rhizopod taxa were identified in a water suspension with a drop of glycerol on a slide, within 24 h of preparation. The samples were investigated under a light microscope at 200–400× magnifications. On average, five slides were examined for each sample. Study of a sample was terminated if no rhizopod shells were identified in the first two slides.

4. Results and discussion

4.1. SZ-2 section (late Pleistocene and ca. 11,200 cal. yr BP)

The oldest pollen spectrum occurs in the lowermost part of the SZ-2 profile (Fig. 2). It is dominated by Poaceae, *Artemisia*, and Cyperaceae with a few other pollen and palynomorphs. The pollen concentration is very low. These sediments are older than 11,200 cal. yr, based on the age of macrofossils from the overlying peat horizon (Table 2). Similar Poaceae–*Artemisia* dominated spectra are found in the undated loess-like sediments of the Changeable Lake basin (Makeyev et al., 1992; Bolshiyanov and Makeyev, 1995). The pollen taxa indicate rather warm but relatively dry conditions, characteristic of a late Pleistocene open steppe-like vegetation on northern Taymyr (Andreev et al., 2002b, 2003). The lack of erosional indicators above our Severnaya Zemlya sample combined with similarity in pollen spectra to northern Taymyr suggests a late Pleistocene age, possibly from the Allerød period (ca. 14,000–13,000 cal yr BP).

An Allerød age is consistent with several additional lines of indirect evidence. The SZ-2 samples include spores of dung-inhabiting fungi, *Sordaria* (van Geel and Aptroot, 2006), indicating the presence of grass-eating animals on the island during the time of sediment accumulation. This result fits previous radiocarbon dates of several mammoth bones found on Severnaya Zemlya (Arslanov et al., 1980). The youngest of these bones, a tusk, yielded an Allerød age of 13,403 ± 121 cal. yr BP. A similar tusk age, 12,254 ± 214 cal. yr BP, is also reported by Möller et al. (2007). The remaining mammoth ages of ca. 30,000 and 24,000 cal. yr BP are consistent with the Lake Changeable core data and relative sea-level observations showing the absence of substantial ice over Severnaya Zemlya during the Last Glacial Maximum from ca. 22,000 to 18,000 cal. yr (Raab et al., 2003; Möller et al., 2007). There is also an interesting single radiocarbon age of 13,440 ± 455 cal. yr BP from the "lake-bog" sediments of Bolshiyanov and Makeyev (1995) that suggests possible accumulation of terrestrial organics in Allerød time.

The pollen concentration is much higher in the peaty layers dated to 11,229 ± 20 cal. yr BP. The spectrum is dominated mostly by Poaceae and Cyperaceae, although with a large number of *Betula* sect. *Nanae* and *Salix* pollen indicating significant climate amelioration after the late Glacial/Holocene transition. Single pollen grains of exotic tree and shrub pollen probably originated from long-distance sources. Bolshiyanov and Makeyev (1995) also mentioned similar pollen spectra from their "lake-bog" sediments, radiocarbon dated to 11,477 ± 177 and 10,983 ± 170 cal. yr BP. Typical wetland taxa dominate the rhizopod communities at SZ-2 (Table 3).

Thus, the ca. 11,200 cal. yr period (early Preboreal) at the SZ-2 site was characterized by open tundra and dwarf-shrub tundra associations. The local environment was rather humid. Results of the climate reconstruction by the BMA method suggest warmer-than-present conditions with the mean temperature of the warmest month at least 4 °C higher than modern and accumulated mean daily temperatures above 5 °C (so-called growing-degree-days, GDD5 (Prentice et al., 1992) between 200 and 300 °C. The reconstructed values of annual

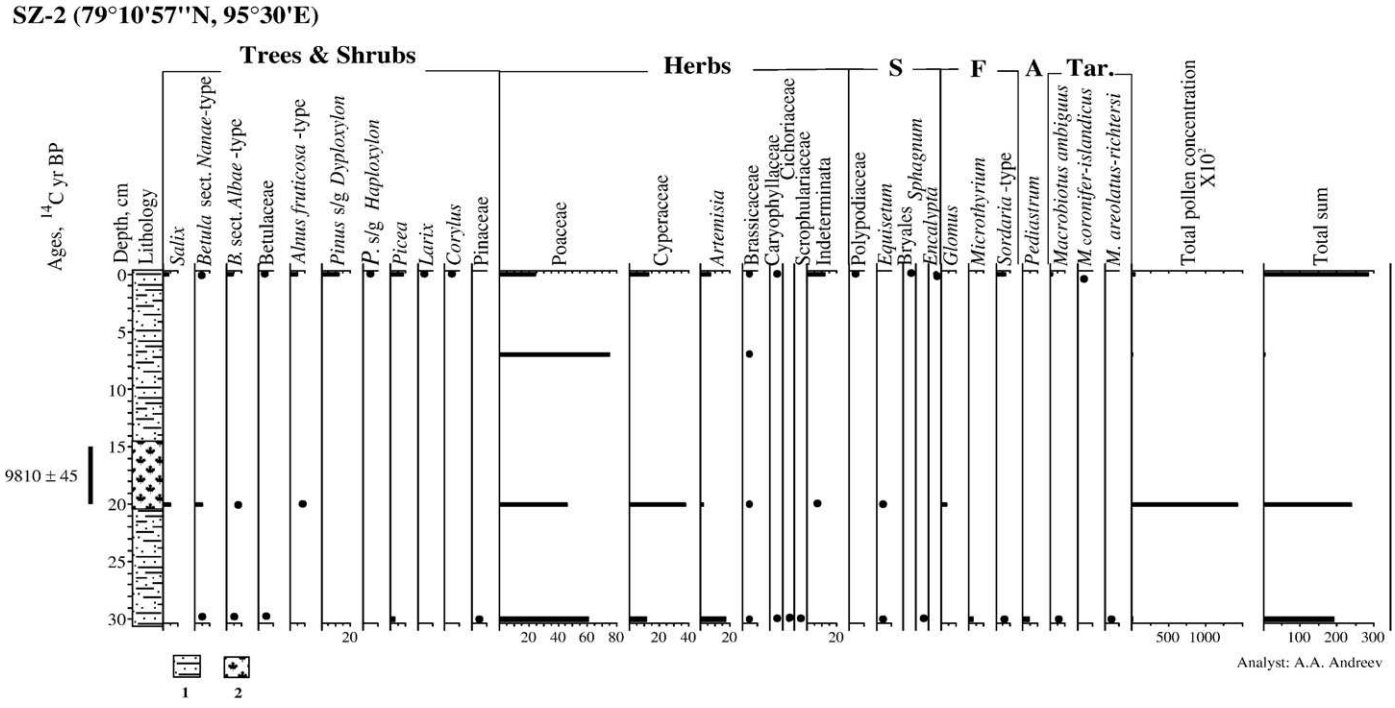


Fig. 2. Pollen and non-pollen palynomorphs percentage diagram of section SZ-2. 1—clayey silt, 2—silty peat, •—presence less than 1%.

Table 3
List of rhizopod species found in the studied deposits from the October Revolution and Bolshevik Islands. Ecological preferences are according Chardez (1965): sh—*Sphagnum*, m—green moss, s—soils, w—water

Taxa	ecology/sample ID, cm	SZ-2, 10	SZ-5, 30-35	SZ-5, 35-40	SZ-5, 40-45	SZ-3, 75-80	SZ-1A, 30	SZ-1B, 50	SZ-1C, 30	SZ-47, 60	SZ-46,, 55	SZ-49, 50	SZ-48, 0	51 SZ-6, 80	90 SZ-3, surface	9 BI, 8	8 BI, 7	7 BI, 5	2BI, 1-2	1m BI, 0.5	1s BI, surface
Eurybiotic and soil species																					
Centropyxis aerophila	m	1	4	5			6	5	6	1		5	3		1	4	1	1	2	2	1
C. aerophila v. grandis	w						5		3						1	1					
C. aerophila v. minuta	wms		13	6																	
C. cassis	shsbm						1								0	3					
C. constricta	ws		1	2			5	10	3			1	2		1						
C. constricta v. minima	w	1	26	13			9	2	8	1		33	21		9	4	8	2			7
C. kahli	wm			3																	
C. sylvatica	wshm		1	1			1	2	1		1	1	6		2	1	2			8	2
C. sylvatica v. minor	shs		5	2						1	1	3	4				10	10		1	
Cyclopyxis sp.								2													
C. eurystoma v. parvula	s		23	15									4			4	6	13			1
Euglypha cuspidata	swbm															2		1			
E. laevis	swbm												27			11		2	2		
E. laevis v. lanceolata	swbm												1								
Plagiopyxis declivis	shs																	1	1		
P. cf. labiata (forma longa)	shm																			1	13
Schoenbornia humicola	s												31						1	2	8
Sch. cf. viscicula	s												8								
Trinema enchelys	wshm															1					
T. lineare	wshms												26			10	3	5			
Calceophilic																					
C. plagiostoma	s		4	5								2	13							1	
C. plagiostoma (forma major)	s		3									1	3								
C. plagiostoma (forma minor)	s		6											1	1			1	1	1	
Sphagnophilic																					
Arcella arenaria v. compressa	m	6			3	1			2												
Assulina muscorum	m																			2	16
Centropyxis aculeata	w	1	7	3	1	2					1					5					
C. aculeata v. minor	w				1																
C. cf capucina	shms																				3
C. discoides	w		1																		
C. ecornis	w							2													
C. ecornis v. megastoma	w							4													
C. orbicularis	wshm			+			1														
C. platystoma	swm											3									
C. sp.																3					
Corythion dubium v. orbicularis	m																				6
Euglypha strigosa (forma glabra)	swbm																				1
Hyalosphenia minuta	sh																				
H. sp.							1														
Heleopera petricola	wsh	2	1		3	2			1	2	2					1					
H. petricola v. amethystea	wsh															3					
H. sp 1			1																		
H. sp 2				1																	
Nebela tincta	shms															6					
N. cf. tincta.	shms	2			2		2	2													
N. minor																1					
Plagiopyxis callida	wshms								1												
P. minuta	ms																			1	
Trigonopyxis arcula	shm							2													
Hydrophilic																					
Difflugia globularis	w								4												
D. globulosa	w							3								1					
D. penardi	w				1												1				
D. lucida	wshm												5								
D. sp.				1																	

precipitation suggest that precipitation was similar or slightly higher than present during the early Holocene. Similar palaeoenvironmental changes with warmer conditions have been recorded in nearby sites in the Eurasian Arctic (e.g. Andreev et al., 1997b; Serebryanny et al., 1998; Andreev et al., 2001, 2002a,b, 2003, 2004a, 2005, in press and references therein).

4.2. SZ-5 section (ca. 10,500 cal. yr)

The vegetation composition reconstructed from the SZ-5 profile (Fig. 3) was similar to the ca. 11,200 cal. yr samples from SZ-2. Its age, however, is probably a few hundred years younger as shown by radiocarbon results of 10,670±57 and 10,415±91 cal. yr BP. High amounts of Cyperaceae in these spectra reflect a local wetland environment. The environmental conditions during this interval were probably the most favourable of the Holocene for vegetation.

The peat also contains rhizopod tests (Table 3). Two sphagnophilic taxa (*Centropyxis aculeata* and *Heleopera petricola*) in the bottom of section SZ-2 suggest oligotrophic peatland conditions. Eurybiotic (*Centropyxis aerophila, C. aerophila* v. *minuta, C. sylvatica, C. sylvatica* v. *minor, Cyclopyxis eurystoma* v. *parvula*), sphagnophilic (*C. aculeata*), and hydrophilic (*Difflugia oblonga, D. pristis*) species found in the upper peat layer point to a significantly wetter habitat. Generally, the high species diversity (13 species and infraspecific forms) reflects a more favourable soil environment than at the beginning of the peat accumulation. Moreover, testate amoebae palaeocommunities reflect richer and less acid environments (presence of calceophilic *Centropyxis plagiostoma)*. Later, around ca. 10,400 cal. yr, the hydrophilic *Difflugia* disappeared from the communities, suggesting drier conditions, while calceophilic *C. plagiostoma* increased. The uppermost peat layer contains no rhizopod shells reflecting environmental conditions unfavourable for rhizopods.

4.3. OR section (undated, ca. 11,000–10,500 cal. yr?)

The undated peaty sediment from an old delta sediments of the Ozernaya River (Fig. 4) may have accumulated contemporaneously with the SZ-2 and SZ-5 sections because its spectra show similar low concentrations of long-distance transported *Alnus fruticosa* (alder) pollen. Later, after 10,200 cal yr, alder pollen was more common, as shown in sections SZ-3 and SZ-1a–c (Figs. 5–6). Thus, sedge-grass communities dominated the vegetation around the OR section shortly before 10,200 cal. yr (probably between 11,000 and 10,500 cal. yr). The relatively high content of dwarf birch and willow pollen in the spectra indicates that these taxa grew in the area.

The Ozernaya River delta samples also contain tests of rhizopods (Table 3). Testate amoebae (mostly eurybiotic species) from the bottom of the profile reflect rather dry soil conditions. Rhizopods from the upper samples indicate a gradual increase of soil moisture as the number of typical bog and hydrophilic taxa (*Difflugia globulus*, *D. penardi*, *Centropyxis platystoma*) increased and reached their maxima at 50 cm depth. The rhizopod community from the uppermost sample records rather high species diversity (14 taxa from all ecological groups). It also reflects a rich mineral nutrition (presence of calceophilic *C. plagiostoma*). The tests of hydrophilic *Difflugia lucida*, inhabitant of peaty soils, point to a high moisture content.

4.4. SZ-3 section (ca. 10.200 cal. yr)

The SZ-3 profile (Fig. 5) is radiocarbon dated to 10,199±31 cal. yr BP. Its pollen spectrum is dominated by Cyperaceae pollen with some *Salix*, *Betula* sect. *Nanae*, *Alnus fruticosa*, and Brassicaceae pollen. The pollen concentration is high. The presence of shrub alder pollen probably does not point to a local source, but rather that pollen was sourced from expanded alder populations on mainland Eurasia (e.g. Andreev et al., 1997b; Macdonald et al., 2000; Andreev et al., 2001, 2002a,b, 2003, 2004a,b, 2005 and references therein). Open tundra and dwarf-shrub tundra associations dominated the vegetation at ca. 10,200 cal. yr. Low species diversity characterizes the rhizopod community from the peat with the dominance of sphagnophilic taxa (Table 3).

4.5. SZ-1 sections (ca. 9700 cal. yr)

The three closely situated peat-silt profiles (SZ-1a–c, Fig. 6) yield similar pollen spectra. In particular, the abundance of long-distance transported pollen (mostly *Alnus fruticosa*) is much higher than in the

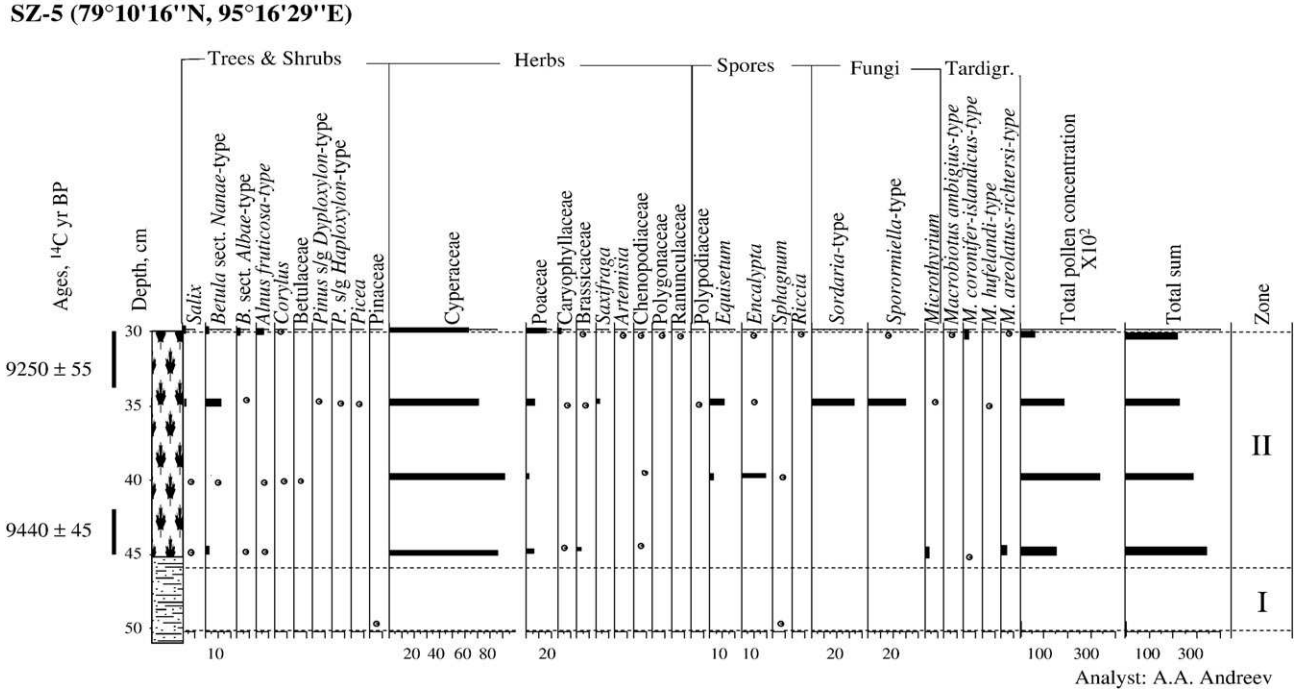


Fig. 3. Pollen and non-pollen palynomorphs percentage diagram of section SZ-5. For legend see Fig. 2.

older pollen spectra for ca. 10,400 cal. yr. The age of the SZ-1 peat is constrained by two radiocarbon dates on plant macrofossils: 9811±145 and 9569±50 cal. yr BP. Plant remains from a nearby location were dated by Bolshiyanov and Makeyev (1995) and yielded a similar age of 9884±250 cal. yr BP, but there is no additional information about the dated sample.

Rhizopod communities from the SZ-1 profiles reflect a rather wet moss habitat. Generally, the number of bog inhabitants is relatively high, although, species diversity (eight species) is rather low in the older sample. The sphagnophilic and hydrophilic (*Difflugia globulosa*) taxa are more numerous (11 taxa) in the younger sample pointing to a wetter local environment compared to other SZ-1 samples (Table 3).

4.6. BI section (ca. 9900–9400 cal. yr)—Bolshevik Island

Peaty sediments from the bottom of a hummock near Solnechnaya Bay on Bolshevik Island (Raab, 2003; BI profile) yielded three ages between 9900 and 9400 cal. yr (Table 2). Two samples from this 13 cm-thick peat monolith have been also studied for pollen (Raab, 2003). The spectra are dominated mostly by Cyperaceae and Poaceae with few other herb pollen taxa like Brassicaceae and Saxifraga reflecting environmental conditions similar to those on October Revolution Island at ca. 9500 cal. yr BP. Long-distance transported *Alnus* and *Betula* are also common in the studied samples.

A total of 17 species, varieties, and forms of rhizopod were found in the bottom of the studied BI monolith (Table 3). The inferred fossil community consists of wetland and eurybiotic taxa. The high species diversity indicates a favourable, wet soil environment. The rhizopods from the upper part of the BI monolith demonstrate the gradual disappearance of typical bog taxa and dominance of eurybiotic and drier soil taxa (Table 3). The presence of calceophilic *C. plagiostoma* (xerophytic forma minor) and the soil taxon, *Plagiopyxis declivis* at a depth of 5 cm in the monolith points to an enhanced mineral supply and rather xerophytic conditions. The litter inhabitant *Schoenbornia humicola,* found at a depth of 2 cm in the monolith indicates dry soil conditions.

The remains of soil ticks found in the BI peaty monolith belong to taxa currently restricted to Arctic tundra on mainland Arctic Eurasia (O. Makarova, Severtsev Institute of Ecology and Evolution Moscow, personal communication). Their presence indicates mean summer temperatures were ca. 4 °C higher than current conditions.

4.7. Peat accumulation

Our results combined with prior research suggest that peat accumulation on Severnaya Zemlya was limited mostly to the early Holocene from ca. 11,500 to 9500 cal. yr (Table 2). We did not find peaty sediment younger than 9569±50 cal. yr BP on October Revolution Island, but prior studies have produced five younger ages: four from October Revolution Island (3664±124, 3534±145, 3434±116, and 1270±869 cal. yr BP; Bolshiyanov and Makeyev, 1995) and one from the margin of the Academy of Science Ice Cap on Komsomolets Island (7831±148 cal. yr BP; Stiévenard et al., 1996). Unfortunately, there is no additional information concerning these younger samples, which could be used to reconstruct palaeoenvironmental conditions.

The overall distribution of published ages suggests a reduction in peat accumulation after ca. 9500 cal. yr. The cause of this apparent deterioration of local environmental conditions remains unknown. Potential factors include decreasing summer insolation and rising sea level, the latter causing cold sea-ice laden water to move across the shallow Kara Sea shelf and closer to the sample sites, especially those on October Revolution Island.

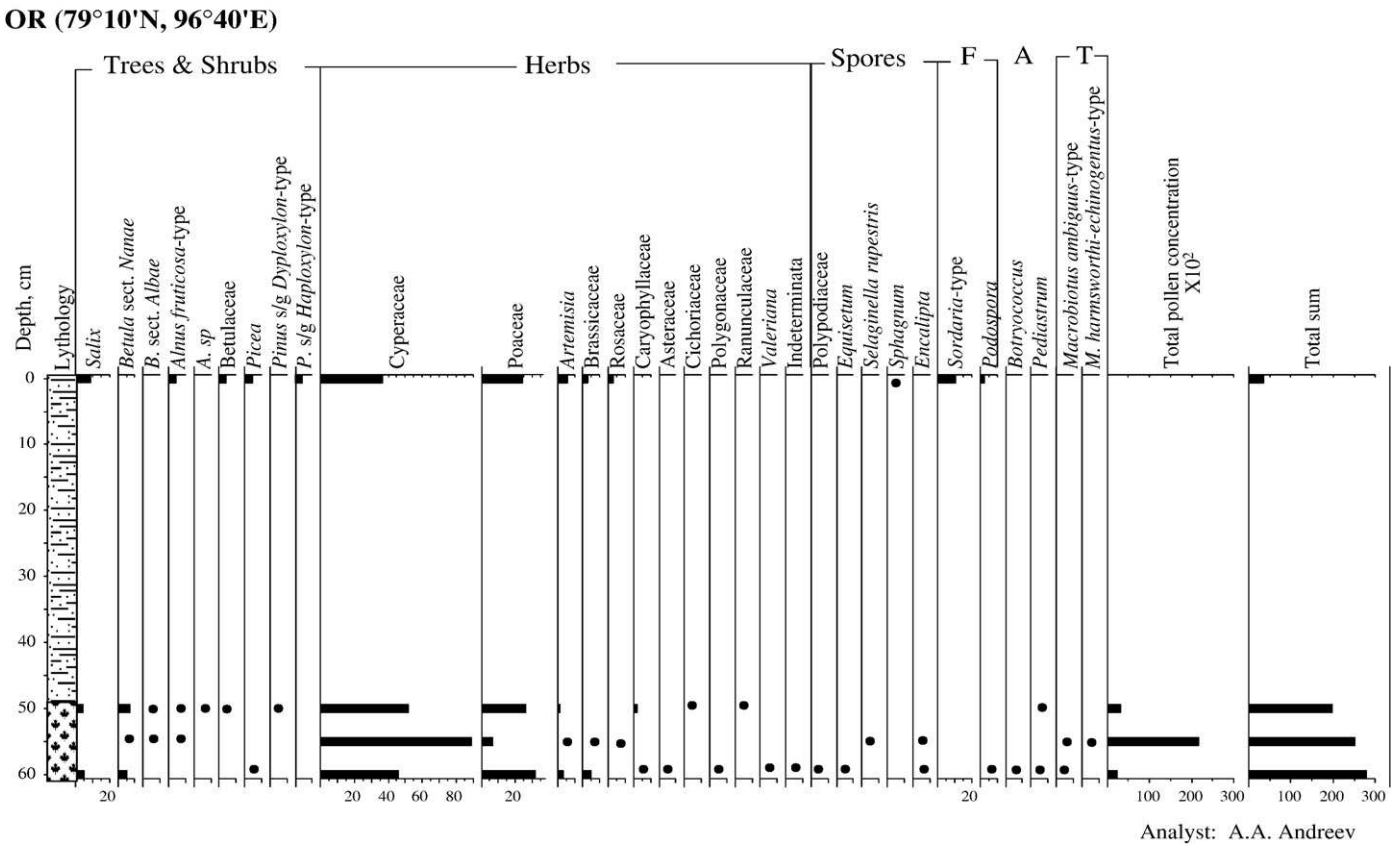


Fig. 4. Pollen and non-pollen palynomorphs percentage diagram of section OR. For legend see Fig. 2.

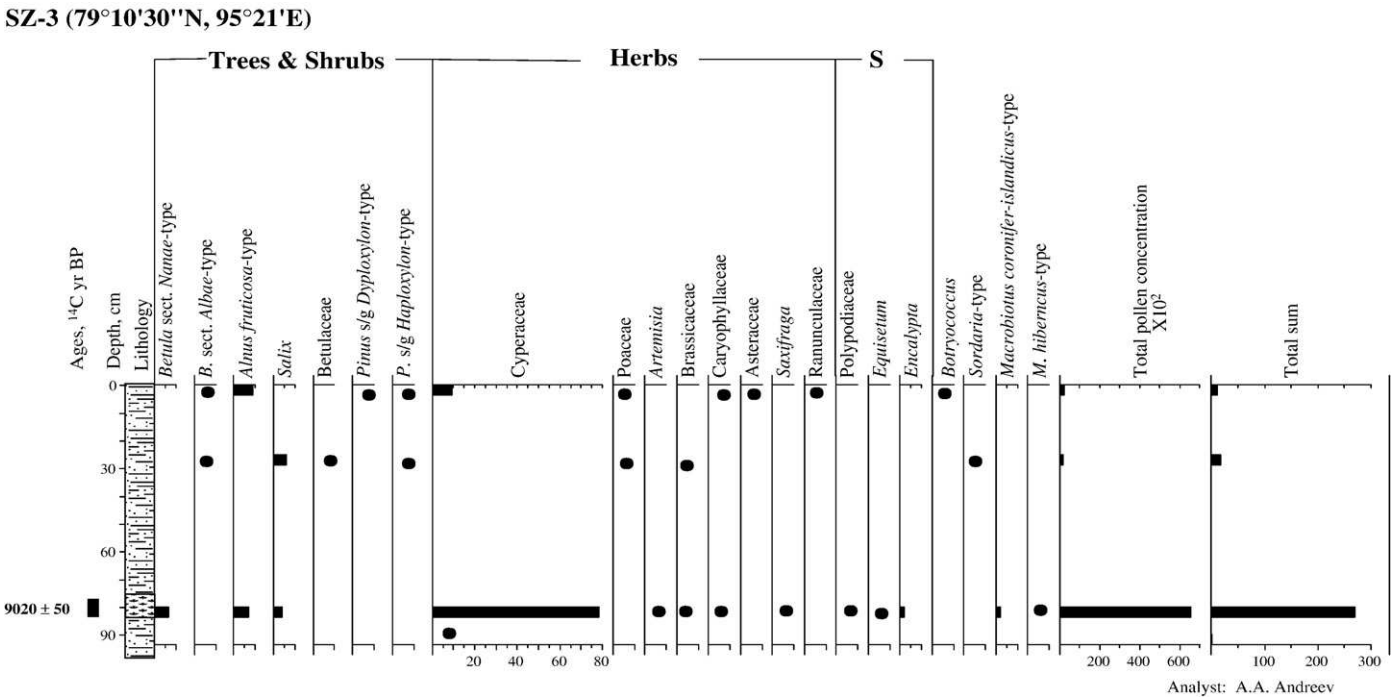


Fig. 5. Pollen and non-pollen palynomorphs percentage diagram of section SZ-3. For legend see Fig. 2.

4.8. Modern samples

Modern surface samples presented in Fig. 7 and subrecent spectra from SZ-2 (Fig. 2) and SZ-3 (Fig. 5) demonstrate high percentages of pollen transported long distances (mostly *Pinus*, *Betula*, and *Alnus*). Other common taxa, Poaceae and Cyperaceae, also may have been partially transported long distances. Previous studies of pollen from the October Revolution Island also indicate high amounts of long-

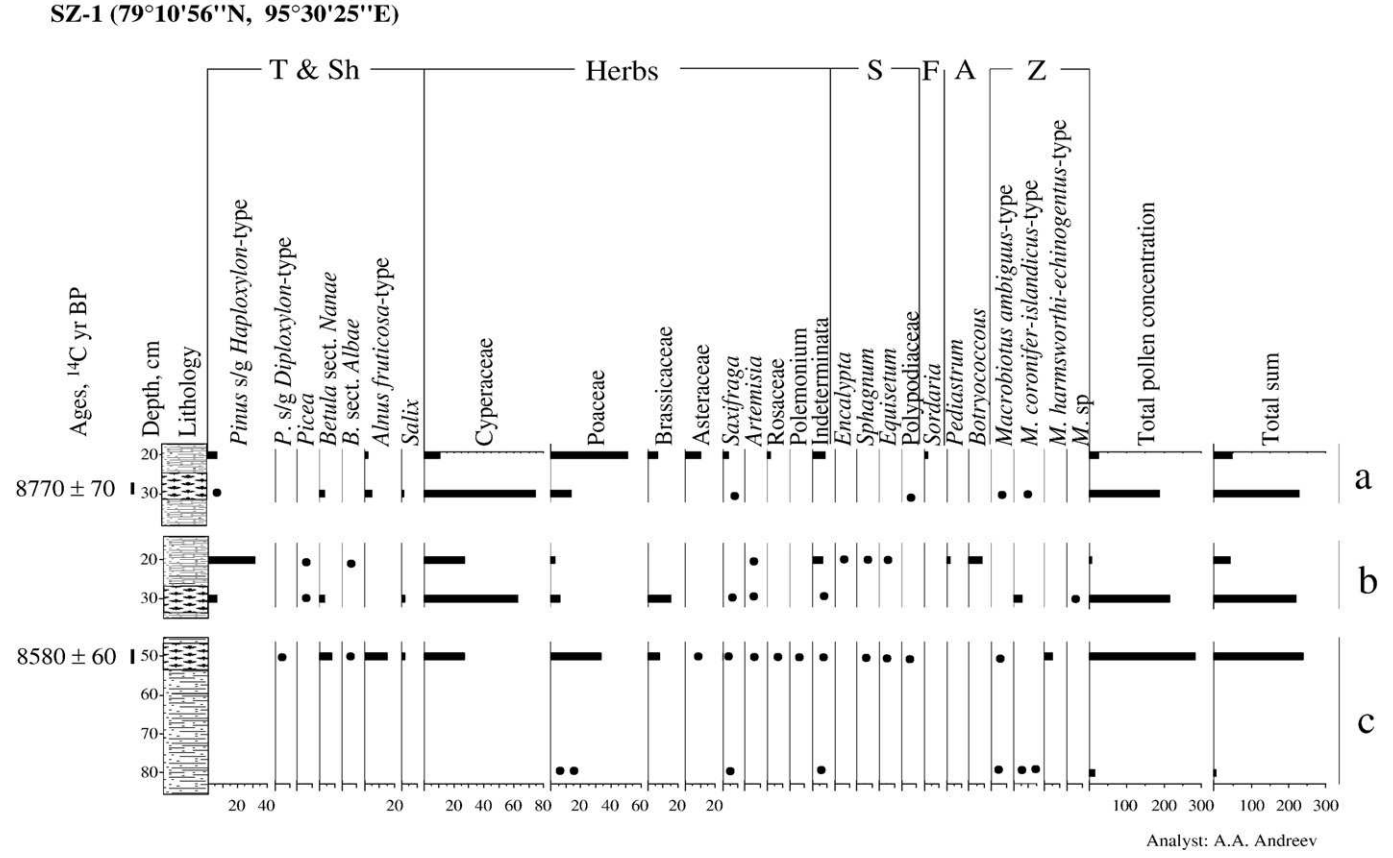


Fig. 6. Pollen and non-pollen palynomorphs percentage diagram of sections SZ-1. a—SZ-1A, b—SZ-1C, c—SZ-1B. For legend see Fig. 2.

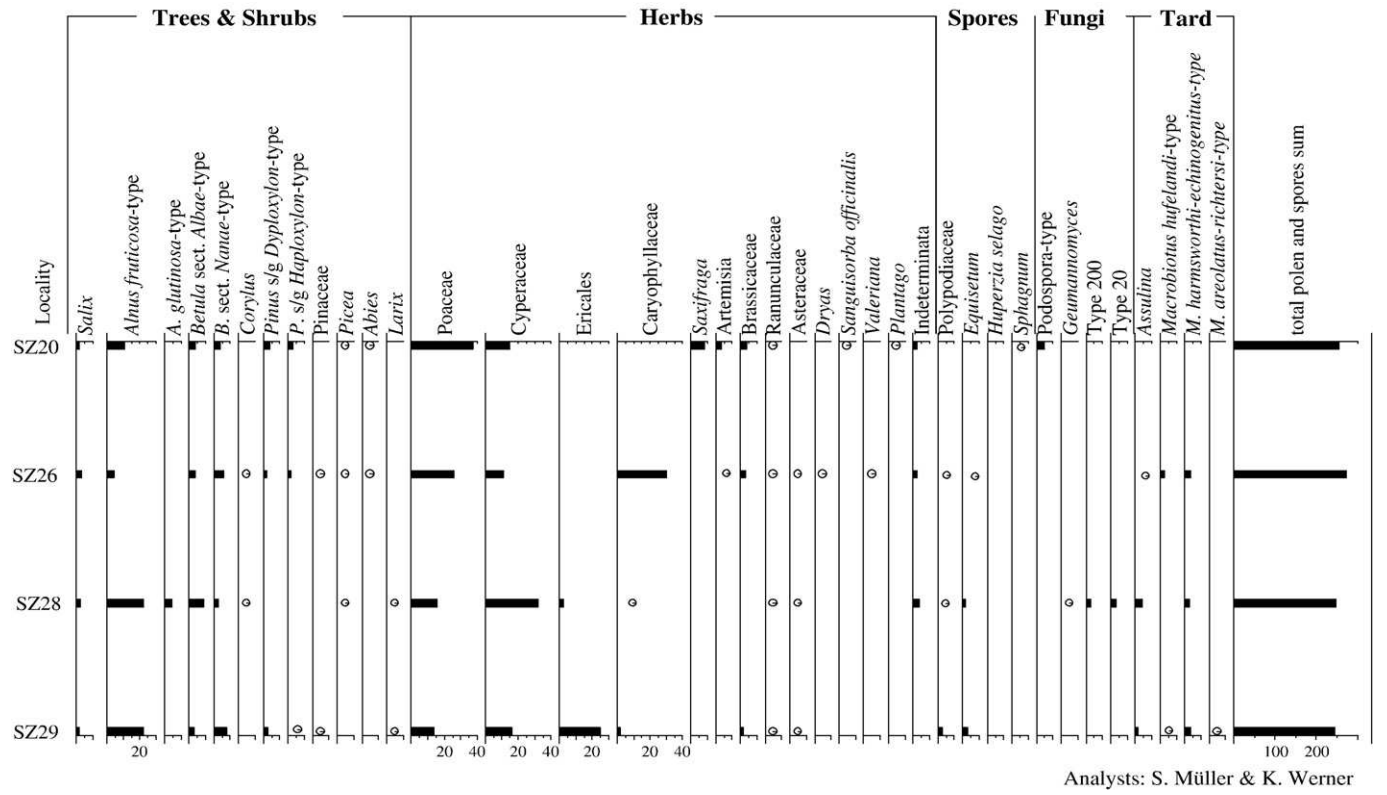


Fig. 7. Surface pollen spectra. For legend see Fig. 2.

distance transported pollen in late Holocene and recent spectra (Kalugina et al., 1981; Andreev et al., 1997b).

Rhizopods were found in only one surface sample from October Revolution Island (the top of the SZ-3 profile), where the community consists of few eurybiotic and soil taxa. The subrecent and recent samples from Bolshevik Island contain mostly soil and sphagnophilic taxa. Rare species, *Centropyxis capucina* and *Plagiopyxis labiata* (f. longa, not previously mentioned as an infraspecific form), were identified also in the recent sample (moss poster). Generally, species diversity is higher in the past and in modern communities from south Bolshevik Island.

5. Conclusions

Open Poaceae–*Artemisia*–Cyperaceae, steppe-like vegetation existed on October Revolution Island shortly before the late Glacial/Holocene transition. Environmental conditions on the island were most favourable for local biota during the early Holocene ca. 11,500–9500 cal. yr BP. Tundra-like sedge-grass communities dominated the vegetation. Low shrub tundra associations with dwarf birch and willow grew in more sheltered localities. The temperatures were at least 4 °C higher than today ca. 11,500–9500 cal. yr BP. Environmental conditions changed significantly around 9500 cal. yr, probably due to a combination of colder and drier conditions, with the vegetation similar to modern. Little is known about the vegetation and climate changes on October Revolution Island after ca. 9500 cal. yr.

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