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Late Quaternary paleoenvironments and modern pollen data from Wrangel Island (Northern Chukotka)

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Abstract

New lacustrine records from central and southern Wrangel Island are analyzed for their pollen content in an attempt to clarify possible linkages between paleoenvironmental shifts and the dwarfing and/or extinction of the island's mammoth population. A Younger Dryas-aged peat is also examined to provide better understanding of the regional climatic history. Samples of surficial lake sediments from Wrangel Island and Chukotka aid in interpreting the lacustrine records. The modern spectra differentiate the herb-dominated tundra of Wrangel Island from the shrub tundras of the mainland and are unique when compared to other arctic assemblages. Analysis of the fossil data indicates that a herb-dominated tundra has been present on southern and central Wrangel Island since at least 11 ka BP. Comparison to modern palynological data implies little change in vegetation during the Holocene. The lacustrine interpretations contrast to those based on paleobotanical study of peats and alluvium, which suggest modern vegetation was not present until ca 4–3 ka BP. Pre-Holocene assemblages have high percentages of Cyperaceae pollen, perhaps indicating more moderate conditions. Summer climate is inferred to be warmer and moister than present during the latest Pleistocene and early Holocene. The pattern of postglacial warming on Wrangel Island is more like that from eastern Beringia than from other areas of western Beringia. Modern synoptic anomaly maps indicate that such a climatic pattern is reasonable and related to the presence of negative anomalies over western Beringia and a region of weaker positive 500 mb pressure centered over the Beaufort Sea. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Wrangel Island captured the world's attention with the discovery of the remains of dwarf mammoths dating from ca 7.6–3.7 ka BP (Vartanyan et al., 1993). Vartanyan et al. (1993) attributed the survival of these "mini-mammoths" to the persistence on Wrangel Island of full-glacial environments similar to those of late Pleistocene Beringia. They base this conclusion on the modern occurrence of xerophytic and cryoxerophytic herbs that are thought to represent a depauperate version of a full-glacial tundra-steppe (Yurtsev, 1982). Paleontological data document the presence of large-sized mammoths on Wrangel Island as early as 20 ka BP and as late as ca 13 ka BP. By ca 12.5 ka BP, approximately the time when the island was severed from the mainland, most of northeastern Siberia experienced a rapid shift from herb- to shrub-dominated tundra, followed by the widespread establishment of *Larix* forests at ca 11 ka BP (Lozhkin, 1993). These vegetational and climatic changes had a great impact on the mainland mammoths, resulting in extinction throughout most of their range and reduction in body size of some populations (Sher, 1992, 1995). Northward extensions beyond modern limits of *Larix*, tree *Betula*, and high shrub *Alnus* occurred between ca 9.5 and 8 ka BP and mark the regional post-glacial thermal maximum. No mammoth fossils on Wrangel Island date to this period, but the population had assumed its dwarf form by 7.6 ka BP.

Mid- to late Holocene vegetational changes documented on the mainland are less dramatic than during the late Pleistocene–Holocene transition (Lozhkin, 1993). Vartanyan (1997) suggested that vegetation changes also occurred on Wrangel Island with modern vegetation communities appearing between 4 and 3 ka BP. This interpretation would imply that the

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ultimate demise of the dwarf mammoths may be related to a shift in vegetation and possibly climate. However, the use of records with potentially local signals and the absence of continuous records of Holocene vegetational change on both the island and the mainland make it difficult to assess the regional nature of any vegetational variations and, in some cases, their exact timing. Consequently, a lake-coring expedition to Wrangel Island and northern Chukotka was formed in summer, 1994. Its purpose was the retrieval of continuous records of vegetational change as a means to improve understanding of late Quaternary paleoenvironments of western Beringia, in general, and to document whether the post-glacial history of the Wrangel mammoths was related to paleoenvironmental changes, in particular. The collection of modern lacustrine pollen samples was done to aid interpretations of the fossil records. A peat exposure, previously analyzed by Vartanyan, was also re-sampled to examine the late Pleistocene–Holocene transition. The combination of this work with previous investigations by Vartanyan (1997, unpublished data) provides a stronger understanding of paleoenvironmental change but leaves many unanswered questions concerning the history of the Wrangel Island mammoths.

2. Study area

Wrangel Island currently occupies the northernmost portion of western Beringia, lying 140 km northeast of the Chukotka Peninsula at the joining of the Chukchi and East Siberian Seas (Fig. 1b). The island encompasses an area of ca 7600 km^2 and represents one of the most extreme environments found in modern Beringia. The climate is characterized by mean July temperature of 2.4°C, mean January temperature of -24.0°C, mean annual temperature of -11.4°C, and mean annual precipitation of 275 mm (Klyukina, 1960). Coastal plains of ca 15 and 25 km width fringe the southern and northern portions of the island, respectively, and are underlain by a thick alluvium (Kos'ko et al., 1993). The island's center is dominated by east–west trending mountains of relatively low elevation (generally ca 500 m high) with the highest peak at 1096 m (Mt. Sovetskaya). This mountainous region is ca 40 km wide and stretches ca 145 km from the eastern to western coast. The oldest geologic unit on the island outcrops in the central mountain region and consists of a complex of Upper Proterozoic volcanic and clastic sedimentary rocks with minor granitic and mafic intrusions (Kos'ko et al., 1993). This complex is overlain by a series of clastic and carbonate strata of Upper Silurian to Triassic age. The units of Proterozoic to Triassic age have all been metamorphosed into a greenschist facies during the middle Jurassic to early Cretaceous. Undeformed deposits tens of meters thick comprise the Tertiary and Quaternary units. The latter are late Pleistocene or younger in age (Vartanyan, unpublished data) and are dominated by alluvial and colluvial materials.

The coastal plains, low elevation foothills, and mountain valleys of Wrangel Island support herb-dominated tundra, but this quickly gives way, even at moderate elevations, to unvegetated slopes or sparsely vegetated fell fields (Yurtsev, 1974, 1981, 1982; Veisman et al., 1986; Petrovskii, 1988). Thirty-four steppe and meadow-steppe species that occur on the island are thought to be remnants of the full-glacial Beringian vegetation. Coastal areas support the most continuous vegetation with *Carex* tundra being typical of the southern coastal plain and *Carex–Eriophorum* tundra associations dominating the northern Academy Tundra. Cryogenic processes often disrupt the coastal vegetation cover. In such areas, disturbed ground communities (e.g., *Artemisia borealis*, *A. richardsoniana*, *Oxytropis wrangelii*, *O. uschakovii*, *Lagostis*, and Compositae) predominate. Members of the Ericaceae and Pyrolaceae families (*Cassiope tetragona*, *Vaccinium uliginosum* subsp. *microphyllum*, *V. vitis-idaea* subsp. *minus*, *Ledum decumbens*, *Pyrola grandiflora*, *Orthilia obtusata*) are limited to only the most favorable micro-sites on the coastal plain and the interior, but they generally are not a common component of the vegetation. Sandy riverbeds of the coast and interior support *Artemisia* and other Compositae, *Valeriana capitata*, *Lagotis*, *Claytonia arctica*, *Papaver radicatum*, *Radiola*, *Potentilla*, Primulaceae (e.g., *Primula borealis*), Boraginaceae, and Brassicaceae (e.g., *Draba subcapitata*).

A graminoid-*Dryas*–*Salix*–Bryales tundra occupies the mountain valleys. *Salix* shrubs occur in protected sites and can achieve heights of 0.75–1 m. *Dryas* (e.g., *D. punctata*, *D. integrifolia* var. *canescens*, the latter limited to areas of limestone) is abundant on the low rolling hills, which border the larger mountain valleys, but Poaceae (e.g., *Festuca* spp., *Poa glauca*, *Bromus pumpellianus*), Cyperaceae (e.g., *Carex obtusata*, *C. rupestris*), and *Oxytropis wrangelii* are also common. Bryales often populate areas on small hilltops. Ranunculaceae and *Rumex acetosa* are typical on more mesic to wet sites. The sparse fell field vegetation, which is most common in the interior, includes Poaceae (e.g., *Agrostis vinealis*, *Calamagrostis purpurascens*, *Festuca lenensis*), *Dryas*, Saxifragaceae (e.g., *Saxifrage monticola*, *S. nivalis*), Ranunculaceae, Bryales, and lichens. *Salix arctica* is present but is rare.

3. Site and sediment descriptions

3.1. Modern pollen sites

Samples of the mud–water interface from nine basins were collected in the central mountains and the southern coastal plain of Wrangel Island (Fig. 1 and Table 1).

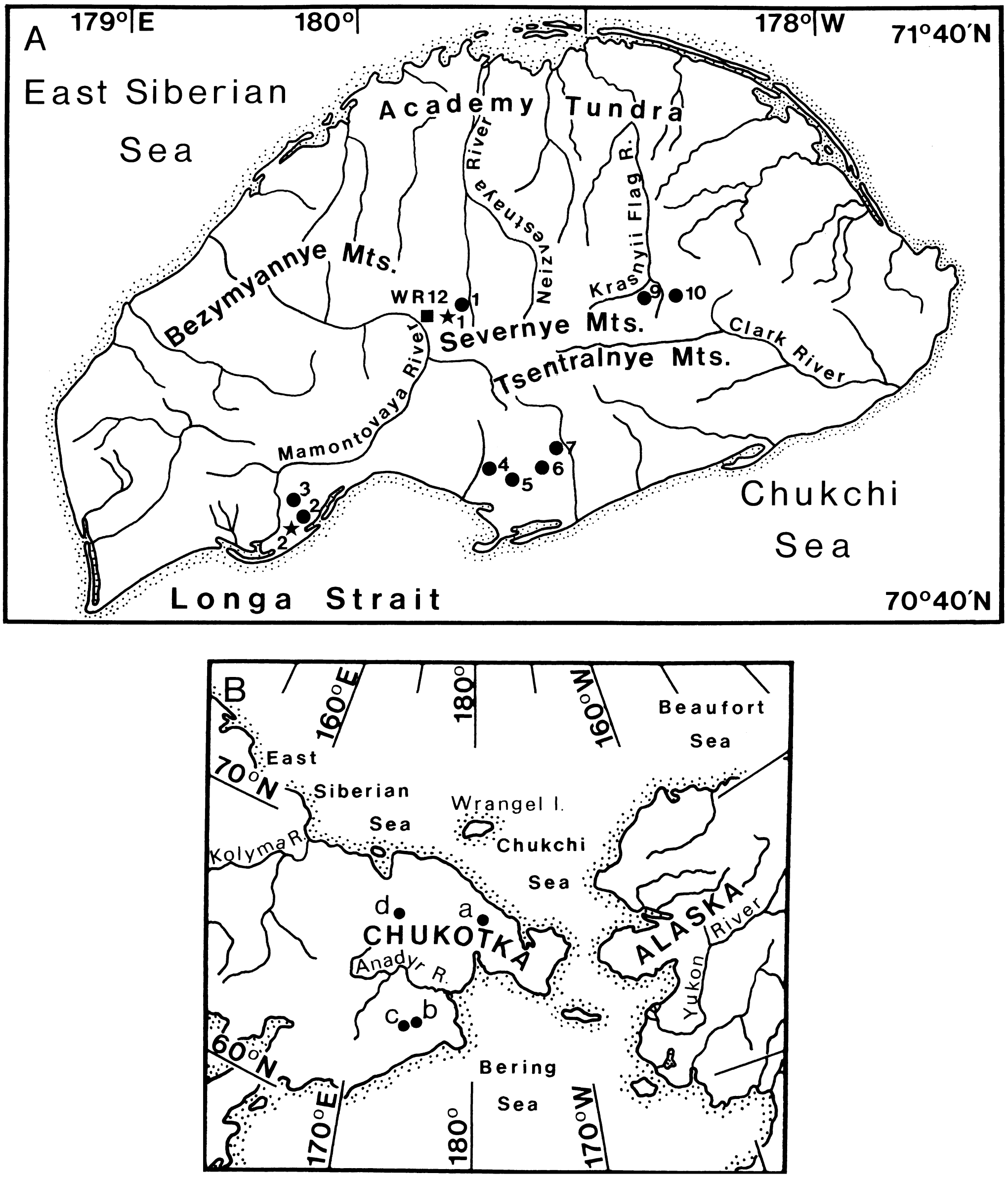

Fig. 1. (A) Map of Wrangel Island showing approximate location of fossil and modern sampling sites. The WR-12 Exposure is indicated by a square. Lake sites are indicated by stars (fossil samples; 1 = Veseloye Lake, 2 = Jack London Lake) and circles (modern samples). Note: Modern samples 1 and 2 are from Veseloye and Jack London Lakes and are offset slightly from the fossil localities. (B) Regional map showing the location of Wrangel Island and Chukotka. Chukotkan surface samples are marked by circles: (a) RS-101; (b) RS-107; (c) RS-108; and (d) RS-140 through RS-142.

These samples include plexiglass core tops from the two fossil sites (Veseloye Lake (RS-1) and Jack London Lake (RS-2)). The other seven sites are lakes or ponds that have been affected by cryogenic activity. Although sediments from thermokarst lakes are not optimal for fossil analysis, Anderson and Brubaker (1986) demonstrated that these samples are representative of the modern vegetation. Silts or sandy silts characterize the Wrangel Island basins. Of the nine lakes, six are coastal plain sites (RS-2 through RS-7) with tundra vegetation similar to that described for Jack London Lake (see below). Three sites are located in the interior (RS-1, RS-9, and RS-10). Fell field or polar stone tundra dominates the areas near RS-9 and RS-10. The vegetation cover at RS-1 is a *Dryas*–Poaceae–Bryales tundra with patches of *Salix* (see Veseloye Lake below).

We also include surficial lake samples of four sites from mainland Chukotka (RS-101, RS-107, RS-108, RS-140 through RS-142; Fig. 1 and Table 1). These samples fall within a broad north–south transect and represent the main vegetation types of eastern Chukotka (Yurtsev, 1974). RS-101 lies in the northern mountains bordering the narrow coastal plain. The vegetation is a Cyperaceae–*Salix*–Ericales low shrub tundra. *Betula exilis*

Table 1
Modern pollen sites from Wrangel Island and Northern Chukotka

Site number	Latitude	Longitude	Elev. (m)	Vegetation
RS-1	71°10′N	179°39′W	204	*Salix*-*Dryas*–Bryales–Poaceae tundra
RS-2	70°50′N	179°45′W	7	Cyperaceae–Poaceae tundra
RS-3	70°50′N	179°45′W	7	Cyperaceae–Poaceae tundra
RS-4	70°55′N	179°25′W	8	Cyperaceae–Poaceae tundra
RS-5	70°55′N	179°25′W	7	Cyperaceae–Poaceae tundra
RS-6	70°55′N	179°25′W	7	Cyperaceae–Poaceae tundra
RS-7	70°57′N	179°10′W	55	Cyperaceae–Poaceae tundra
RS-9	71°12′N	178°45′W	120	Fell field
RS-10	71°12′N	178°42′W	215	Fell field
RS-101	67°45′N	178°50′W	280	*Salix*–Ericales–graminoid tundra; occasional shrub *Betula*
RS-107	63°25′N	176°33′E	103	*Pinus*–*Alnus* high shrub tundra
RS-108	63°10′N	176°45′E	121	*Pinus*–*Alnus* high shrub tundra
RS-140	67°30′N	172°05′E	490	*Betula* shrub tundra
RS-141	67°30′ N	172°05′E	490	*Betula* shrub tundra
RS-142	67°30′ N	172°05′E	490	*Betula* shrub tundra

and *Alnus fruticosa* are present, but these shrubs are minor components restricted to sheltered sites. Elgygytgyn Lake (RS-140 through RS-142) is a large meteor impact crater in central Chukotka. Soils, formed on bedrock altered by the meteor's impact, differ from those typical of the interior mainland. Consequently, the vegetation in the vicinity of the lake is depauperate compared to the regional tundra (e.g., *Pinus pumila* and *Alnus fruticosa* are both absent near the crater). A *Pinus pumila–Alnus fruticosa* high shrub tundra in southern Chukotka (RS-107 and RS-108) gradually replaces the low deciduous shrub tundra of the north. The former vegetation type includes 2–3-m-high *Pinus pumila* and *Alnus fruticosa* shrubs. *Betula*, *Salix*, and Ericales are also present but are not as prevalent as the taller shrubs. Ground cover consists mainly of Cyperaceae and lichen species.

3.2. Exposure WR-12, Mamontovaya River

Exposure WR-12 (71°10′N 179°45′W; 200 m; Fig. 1), first discovered in 1989 by Vartanyan, is located on the left bank of the Mamontovaya River in the mountainous central region of Wrangel Island. The vegetation near the exposure is a *Dryas* tundra with *Oxytropis wrangelii*, Poaceae, Bryales, and lichens. *Salix* typically occurs in prostrate form but can achieve heights of up to 75 cm in occasional small thickets occupying favorable valley sites. Solifluction along the gentle hillslopes leading to the river has resulted in the sloughing of upper soils and unconsolidated sediments into the river floodplain. However, it was possible to clean away this overburden to reveal an undisturbed section.

The 417-cm-high exposure comprises 80 cm of bedrock and 337 cm of unconsolidated sediments of which the upper 307 cm were sampled for pollen, macrofossil, and radiocarbon analyses. The basal 30 cm (Unit 1) of the unconsolidated sediments consist of coarse materials that include water-worn pebbles and cobbles deposited by a pre-Holocene Mamontovaya River. Fine layers of sand and silt interspersed with organic-rich sediments composed primarily of unidentifiable floral remains characterize the overlying 87 cm (Unit 2). This unit probably represents overbank deposits associated with seasonal or longer interval floods. The upper 62 cm of Unit 2 contain greater numbers and frequencies of plant fragments, perhaps indicating a decreasing contribution of river-born sediments and greater input from an increasingly stable shoreline vegetation.

A 110-cm-thick brown Cyperaceae peat (Unit 3) caps the sand-silt deposits. The upper 10 cm of the peat is compressed and blackish in color. The peat includes woody materials (e.g., branch fragments) and occasional sand layers of ca 1 cm thickness. The initiation of peat growth at ca 11 ka BP marks the removal of this area from fluvial influences. Perhaps tectonic activity or re-equilibration of the drainage to the continued rising sea levels resulted in down-cutting of the river channel, thereby forming a stable surface for peat formation. Radiocarbon dates indicate an average growth rate of ca 1 mm yr^{-1}. This rate is very approximate but, interestingly, it is consistent with rates calculated from other areas of northeastern Siberia (Khotinskii, 1977) and for late Holocene Cyperaceae peats of Canada (Ovenden, 1988, 1990; Garneau, 1992). At ca 10 ka BP, peat growth slowed and eventually stopped.

Silty clay (Unit 4) overlies the peat, both the lower 8 cm and upper 14 cm of the unit being gray, whereas the middle 12 cm is blue-gray. Interspersed in the silty clay deposits are well-sorted layers of sand and silt and numerous angular pebbles. A 30-cm-thick light brown sand and silty sand (Unit 5) also includes pebbles. The layers in these upper deposits (Units 4 and 5) are not highly disturbed, having essentially horizontal contacts between the different units, and indicate that sediments creeping down the slight slope towards the river subsequently covered the peat. The upper 40 cm (Unit 6) is a colluvial sand topped by a 1–5-cm thick duff layer (Unit 7).

3.3. Veseloye Lake

Veseloye Lake (71°10′N 179°39′W; 204 m; Fig. 1) lies in the mountainous interior of Wrangel Island and is ca

6 km to the east of WR-12. The lake is a closed, flat-bottomed basin of ca 70 cm depth with gentle slopes from the shore to the lake bottom. The origin of Veseloye Lake is uncertain, but it occupies a natural depression in a broad upland between two creeks that drain into the Mamontovaya River. The basin appears stable with no evidence of slumping or shoreline erosion typical of thermokarst lakes, although frost polygons and sorted circles indicate active freeze–thaw processes in the area. All cores taken in the lake ended at a depth of 40 cm in silty sediments, suggesting that the underlying sediments probably were frozen. A *Salix–Dryas*–Bryales–Poaceae tundra characterizes the upland vegetation. Although vegetation cover is sparse in bordering areas at mid- to high elevations, it is nearly continuous in the vicinity of the lake. Herb taxa are diverse in the general region but are less so near the lake with Cyperacea and Ranunculaceae dominating in seasonally wet areas and *Oxytropis* on better drained sites.

The upper 2 cm of the core are water-rich gray silt. The remaining sediments are gray-brown to dark gray clayey silt. Clay content and plasticity of the sediment increase with depth. Although some thin, horizontal sediment layers are evident in the Veseloye core, they are not as striking as those in Jack London Lake.

3.4. Jack London Lake

Jack London Lake (70°50′N 179°45′W; 7 m; Fig. 1) is located on the southern coastal plain near the mouth of the Mamontovaya River. The lake lies on slightly elevated terrain (+ 200 cm) that probably represents a bank of a former river channel. It has a single flat-bottomed basin with water depths of ca 70 cm. The outlet drains to Longa Strait. Banks of ca 150 cm height border the southern edge of the lake, and here the shoreline is unstable. Unlike migrating thermokarst lakes (e.g., northern coastal plain of Alaska), this basin appears to be expanding from a central point without subsequent drainage of the original basin. The limited amount of sediment slumping and the low water-energy within the lake suggest that contamination has been minimal at the coring site.

A Cyperaceae–Poaceae tundra that is a mosaic of tussocks, wet meadows, and frost-disturbed habitats dominates the coastal plain. In contrast to the interior, Cyperaceae is the dominant herb with limited areas of well-developed tussocks in stable portions of the landscape. *Salix* is less abundant than in the mountains and does not occur in high growth forms. *Dryas* and Bryales also are present, but these taxa are much less abundant than near the interior sites. Mesic to wet microhabitats are common near the coast, especially at intersections of frost cracks.

The upper 2 cm of the Jack London core are watery, brown silt. Below this horizon is 21 cm of gray silt that at times includes fine-grained sand and unidentifiable plant fragments. Gray silt with a small clay component predominates between 23 and 38 cm. The remainder of the core is gray to dark gray silt with fragments of twigs and aquatic plants. Horizontal layers indicate that sediments were not frost-churned, even though the lake is shallow. The lack of dating reversals (Table 2) provides further evidence of an undisturbed sediment record. The radiocarbon dates also indicate variations in sedimentation rates and/or possible hiatuses in the record, although causes for lack of sediment input to the basin are not clear from the available data.

Table 2
Radiocarbon dates[a] for exposure WR-12, Jack London Lake, and Veseloye Lake

Depth (cm)	Sample material	^{14}C date (BP)	Lab number
WR-12			
125	Twig fragments	10,020 ± 60	CAMS18010
130–140	Bulk peat	10,080 ± 50	MAG1498
140	Twig fragments	9980 ± 60	CAMS18009
180	Twig fragments	10,560 ± 60	CAMS18008
190–195	Bulk peat	10,580 ± 80	MAG1496
210–215	Bulk peat	9890 ± 450	MAG1495
217	Twig fragments	10,950 ± 60	CAMS18007
232	Twig fragments	11,150 ± 60	CAMS25903
242	Twig fragments	11,300 ± 50	CAMS25904
247	Twig fragments	11,060 ± 30[b]	CAMS16913 CAMS16914 CAMS16915
Jack London Lake			
5–6	Unidentifiable plant fragments	2050 ± 60	CAMS32937
15–17	Unidentifiable plant fragments	3650 ± 70	CAMS32938
23.6–24.7	Unidentifiable plant fragments	5910 ± 50	CAMS35106
30.2–31.3	Unidentifiable plant fragments	6340 ± 80	CAMS32939
34–37	Humic acid	9190 ± 60	CAMS19050
46–48.5	Terrestrial plant macrofossil	29,890 ± 190	CAMS19033
Veseloye Lake			
29–32	Humic acid	3960 ± 60	CAMS19049

[a] Dates calculated following conventions of Stuiver and Polach (1977).
[b] Average of 3 dates.

4. Methods

Bulk samples for paleobotanical and radiocarbon analyses were taken from the cleaned face of the WR-12 exposure and stored in whirl pac bags. Lakes were sampled using a modified Livingstone piston corer (Wright et al., 1984) for fossil material and a plexiglass tube for surficial sediments. Palynological samples were prepared following standard procedures for arctic sediments (PALE Members, 1994). Summary curves for trees and shrubs, herbs, and spores (Figs. 2a, 3a, 4a, and 5a) are based on a sum of all pollen and spores, following methods of Grichuk and Zalinskaya (1948). Percentages of individual taxa were calculated using a sum of identified and unknown terrestrial pollen. The sum for all levels

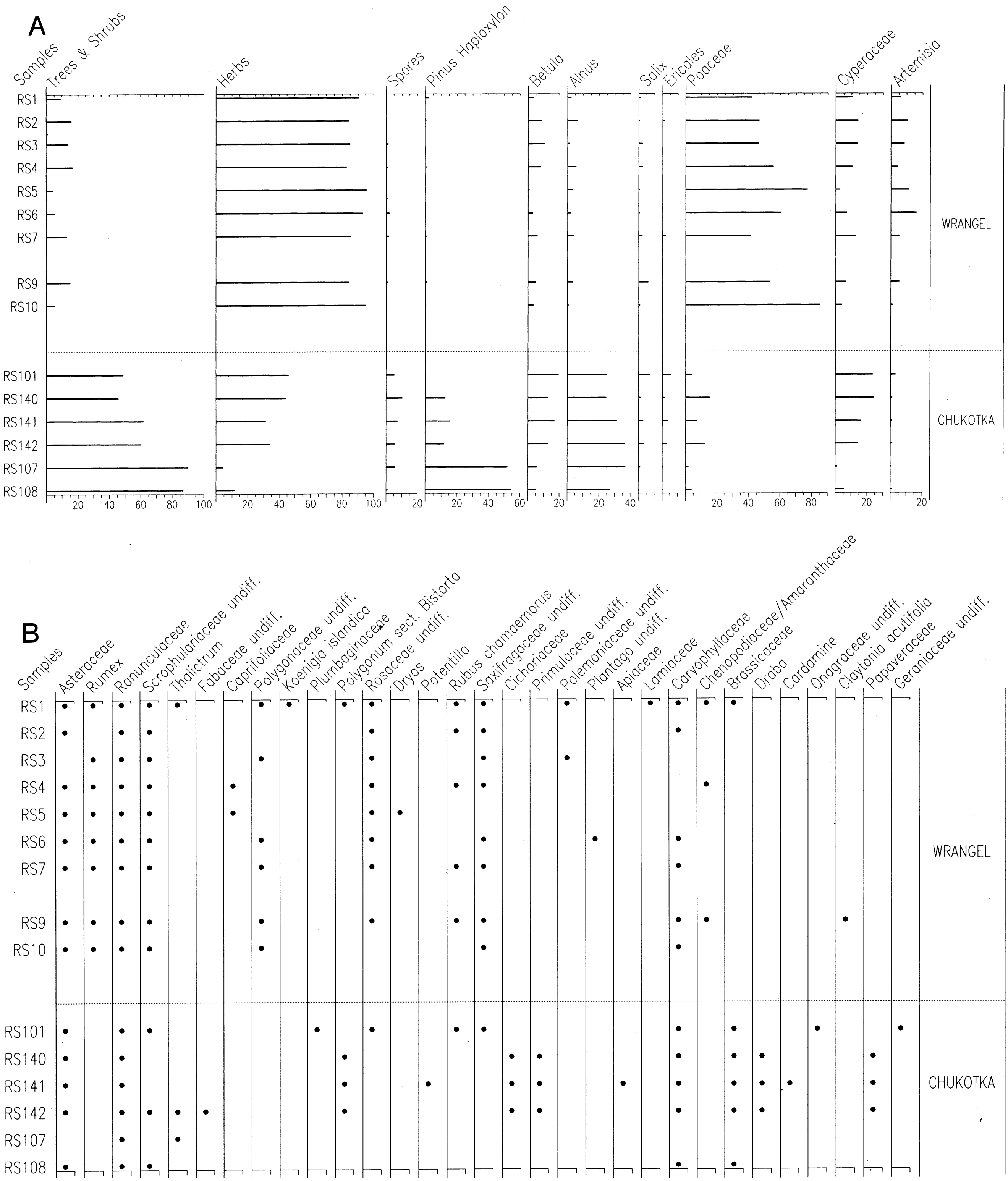

Fig. 2. Percentage diagrams for modern samples: (A) major taxa; (B) presence-absence of minor herb taxa (circle indicates less than 5%); (C) spores and aquatic taxa. Asteraceae pollen is 10% in Fig. 2b but is indicated by a circle on the diagram.

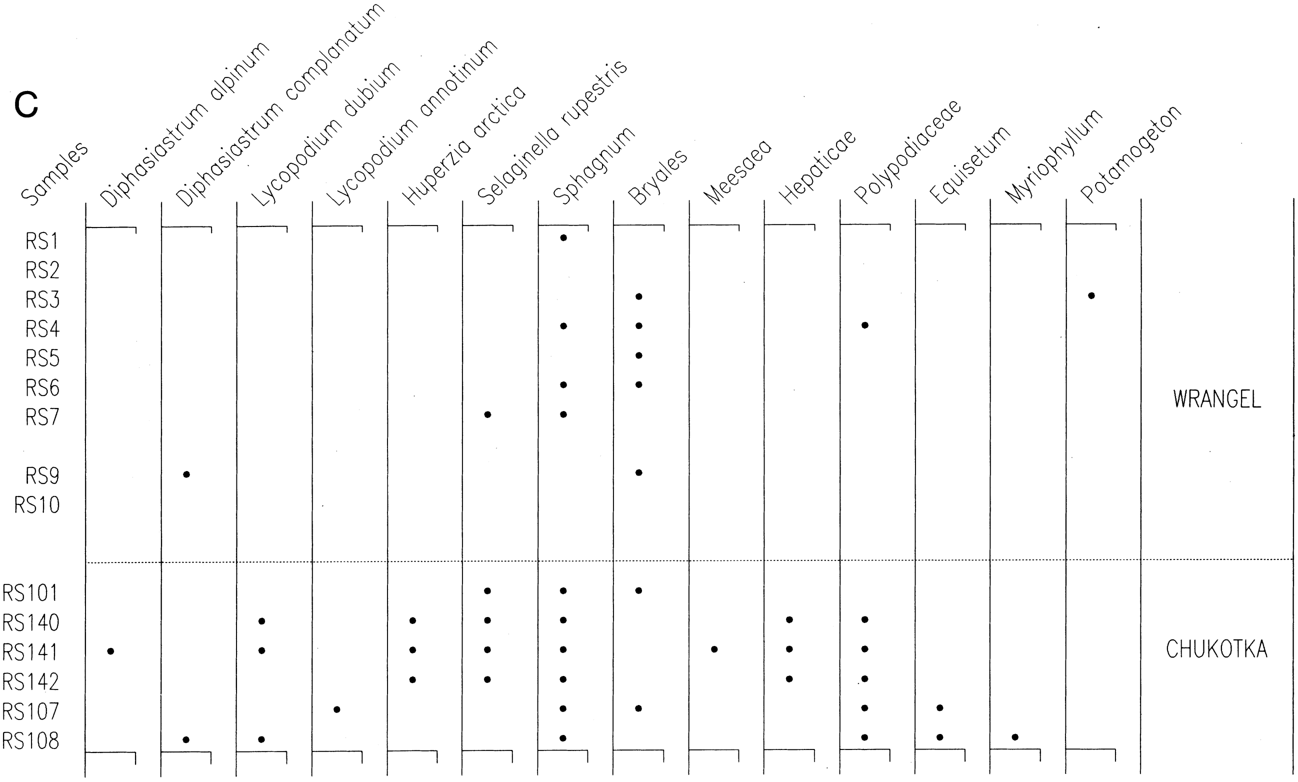

Fig. 2. continued

in zones WR1 through WR4 exceeds 300 grains, whereas pollen sums for zone WR5 are low (generally less than 100 grains except at 70 cm where the sum equals 134 grains). Therefore, interpretations of this zone must be viewed cautiously. Pollen sums for the Jack London core range from 645 to 992 grains identified per level with most samples exceeding 800 grains. The Veseloye samples have sums that generally are between 900 and 1100 grains per level, although the 15 cm sample has a sum of 763 grains. Sums for the modern samples are minimally 300 grains. Pollen zones have been defined qualitatively based on changes in the percentages of major taxa.

Bulk sediment samples (Table 2) were analyzed for radiocarbon content at the Quaternary Geology Lab in Magadan using the benzol scintillation method (Lozhkin and Parii, 1985). The 3 bulk samples yielded: 12 g carbon and 1.5 g benzol (MAG1495); 27 g carbon and 9.5 g benzol (MAG1496); and 33 g carbon and 15 g benzol (MAG1498). Macrofossil samples were prepared for AMS dating at the Quaternary Research Center and the Center for Accelerator Mass Spectrometry (CAMS) following standard methods. Humic materials and possible carbonate contaminants were removed from plant macrofossils used for AMS dating through repeated soakings in 1 N HCl, 1 N NaOH, and 1 N HCl, followed by deionized water rinses and drying. The pretreated macrofossils were combusted at 900°C in sealed, evacuated quartz tubes containing an excess of CuO. This procedure resulted in the quantitative conversion of the carbon in the macrofossils to CO_2. The CO_2 was catalytically reduced to graphite powder on a cobalt catalyst (Vogel et al., 1987), and the graphite/cobalt mixtures were mounted in individual holders for AMS measurement.

5. Palynological results

5.1. Modern pollen samples

The major pollen taxa from coastal and mountain sites of Wrangel Island are similar (Fig. 2a). Poaceae pollen dominates all spectra, although the percentages vary (40–85%). Cyperaceae and *Artemisia* pollen (both $< 15\%$) occur in moderate percentages. Pollen from the only shrub species (*Salix*) on the island occurs in minor amounts ($< 5\%$). Long distance transport of *Betula* ($< 10\%$), *Alnus* ($< 10\%$), and *Pinus* ($< 5\%$) pollen is sufficiently low to have little effect on the percentages of the native species. Twenty minor herb taxa are recorded in the Wrangel samples (Fig. 2b). Asteraceae pollen is most abundant, achieving a high of 10% in RS-1, although other samples vary between 1 and 5%. Ranunculaceae and Scrophulariaceae pollen range from 2 to 5%; other minor herb taxa are $< 2\%$. *Thalictrum*, *Koenigia islandica*, *Polygonum* sect. Bistorta, Lamiaceae,

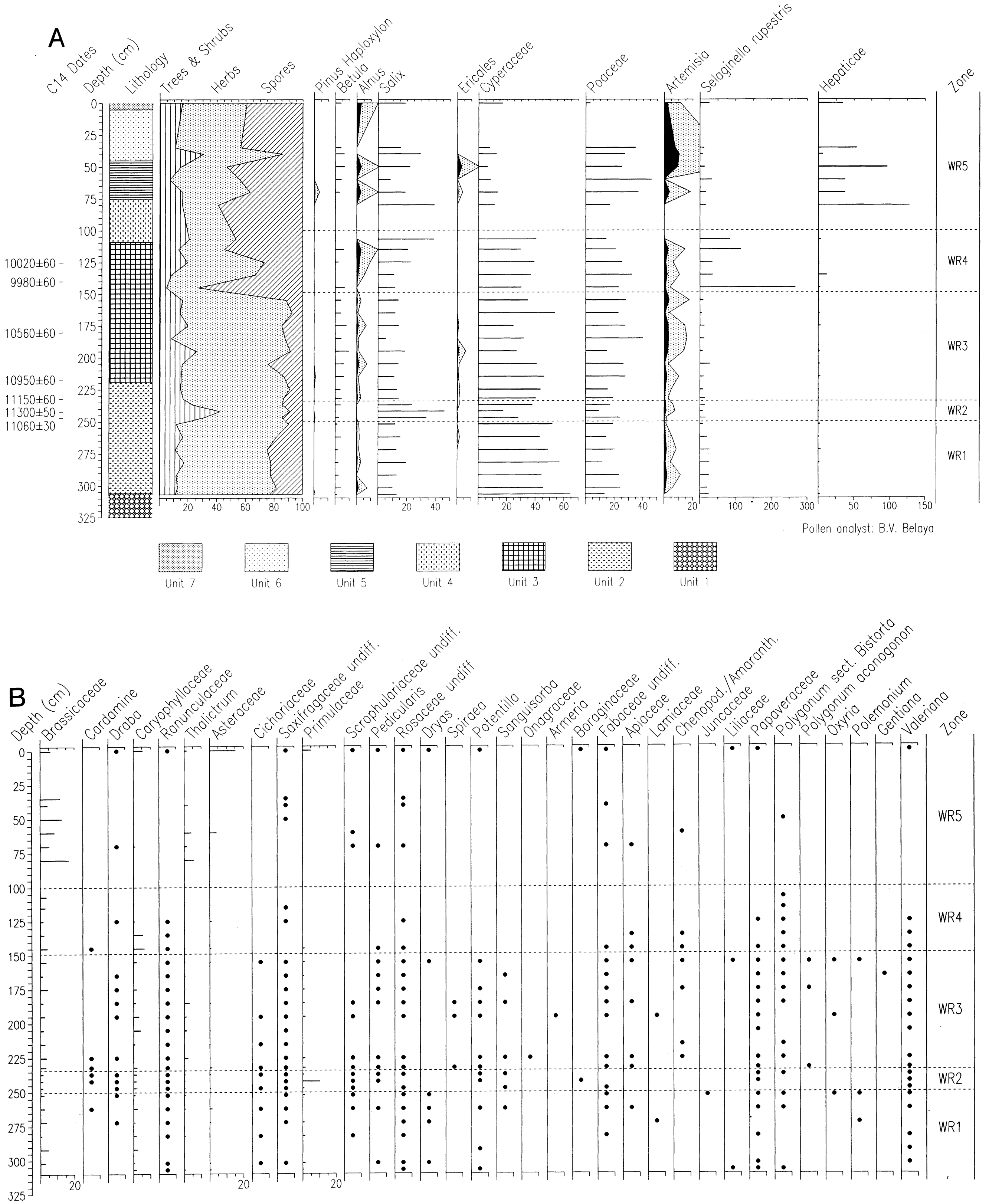

Fig. 3. Percentage diagrams from Exposure WR12: (A) major taxa (exaggeration factor × 10); and (B) minor taxa (circles indicate less than 2%). See text for description of sediment units.

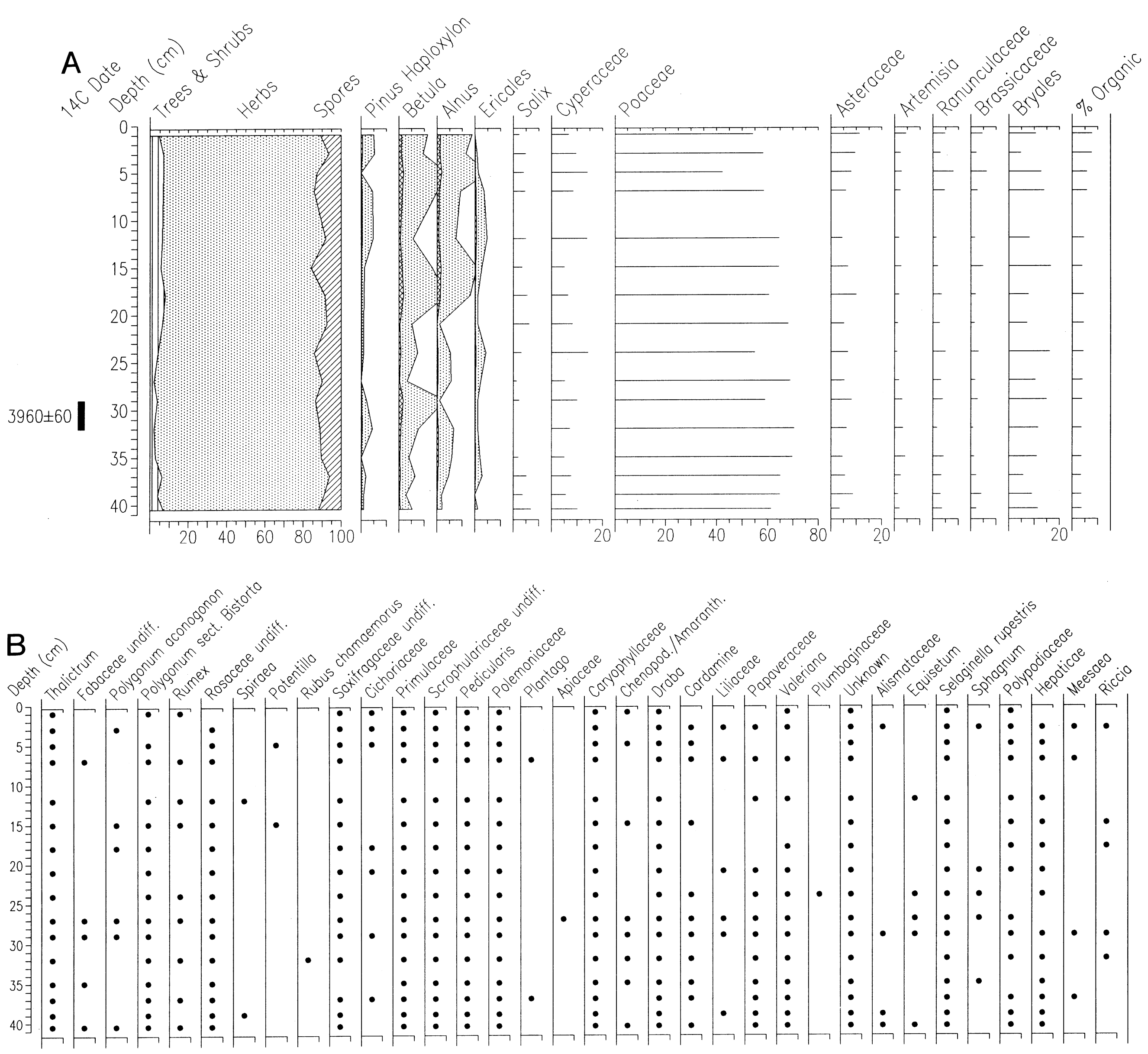

Fig. 4. Percentage diagrams from Veseloye Lake: (A) major taxa (exaggeration factor × 10); and (B) minor taxa (circles indicate less than 2%).

and Brassicaceae pollen are recorded only in RS-1. *Dryas*, *Plantago*, and *Claytonia acutifolia* pollen are unique to RS-5, RS-6, and RS-9, respectively. Types found in the Wrangel spectra but absent in the Chukotkan samples are Polygonaceae (including *Rumex*, *Koenigia islandica*, and Polygonaceae undifferentiated), Caprifoliaceae, Polemoniaceae, Lamiaceae, Chenopodiaceae–Amaranthaceae, *Plantago*, *Dryas*, and *Claytonia acutifolia*. Total percentages of spores are low and never exceed 5% of the pollen + spore sum (Fig. 2c). Bryales and *Sphagnum* are present in most samples. Individual spore taxa occur only in trace (< 2%) amounts.

Samples from mainland Chukotka are characterized by higher percentages of shrub pollen and spores and lower contributions by herb taxa as compared to the Wrangel assemblage (Fig. 2a). *Pinus* pollen is less than 2% in RS-101 and increases to ca 55% in the most southerly samples. *Betula* and Cyperaceae pollen show the inverse pattern with highest percentages (ca 20 and 25%, respectively) to the north and lowest percentages (ca 5 and 2%, respectively) to the south. *Alnus* pollen is an important component of all spectra with percentages ranging from ca 25 to 40%. Poaceae pollen varies from a maximum of ca 17% to trace amounts. Pollen of Ericales, *Salix*, and *Artemisia* typically are < 5%. Twenty-one minor herb taxa occur in trace amounts in one or more of the modern Chukotkan spectra (Fig. 2b). Of these types Fabaceae, Plumbaginaceae, Cichoriaceae, Primulaceae, Apiaceae, Onagraceae, Papaveraceae, Geraniaceae, *Potentilla*, *Draba*, and *Cardamine* pollen are

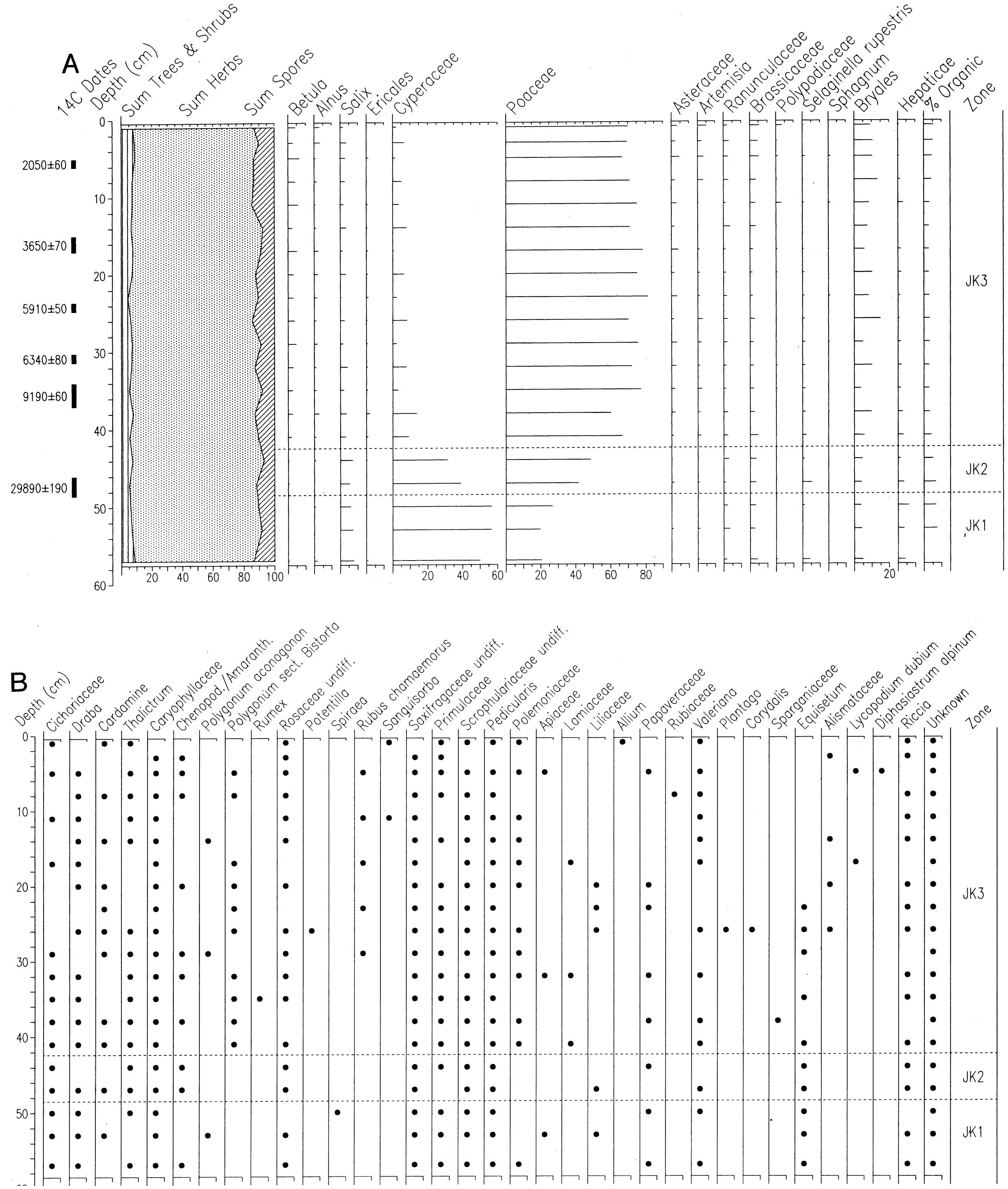

Fig. 5. Percentage diagrams from Jack London Lake: (A) major taxa; and (B) minor taxa (circles indicate less than 2%).

recorded in Chukotka but are absent in the Wrangel samples. Spores of *Selaginella rupestris* reach values of 7% at Elgygytgyn Lake and 5% at RS-101. Other spore types have trace values. *Diphasiastrum alpinum*, *Lycopodium dubium*, *Huperzia arctica*, *Lycopodium annotinum*, *Meesaea*, Hepaticae, and *Equisetum* spores appear in the Chukotkan samples but are absent on Wrangel Island.

5.2. Exposure WR-12, Mamontovaya River

Zone WR1 is dominated by Cyperaceae (ca 45–65%), Poaceae (ca 10–25%), and *Salix* (ca 10–20%) pollen (Fig. 3). All samples contain small amounts of *Betula* pollen (2–5%). Two different samples show trace amounts of Ericales and *Pinus* pollen. Minor ($< 10\%$) types include *Alnus*, *Artemisia*, Cichoriaceae, Asteraceae, Brassicaceae, *Draba*, *Cardamine*, Caryophyllaceae, Ranunculaceae, *Thalictrum*, Saxifragaceae, Primulaceae, Scrophulariaceae, *Pedicularis*, Fabaceae, *Polygonum* sect. Bistorta, *Oxyria*, Rosaceae, *Dryas*, *Potentilla*, *Sanguisorba*, Polemonium, Apiaceae, Lamiaceae, Liliaceae, Papaveraceae, and *Valeriana.* Only Caryophyllaceae occurs in all samples within this zone. *Selaginella rupestris* is the most abundant spore type with minimal percentages of ca 25%.

The main characteristic of zone WR2 is a peak in *Salix* pollen (ca 25–45%). Cyperaceae and Poaceae pollen remain an important component of the spectra (Cyperaceae: 20–35%; Poaceae: 10–20%). *Betula* pollen percentages are similar to those of zone WR1, whereas percentages of *Selaginella rupestris* spores are slightly reduced. Minor taxa are similar to zone WR1 except Boraginaceae pollen is present, but *Oxyria*, *Dryas*, *Polemonium*, Apiaceae, and Lamiaceae are absent in zone WR2.

Cyperaceae (25–55%) pollen continues to dominate in zone WR3. Percentages of Poaceae pollen are higher than in zones WR1 and WR2 (20–40%; most samples near 25%), whereas *Salix* pollen (ca 10%) is less than in zone WR2. The 10% *Betula* pollen represents a maximum for all zones, but values more typically fall between 5 and 8%. Ericales pollen appears in consistent amounts in the lower and middle parts of the zone. Minor taxa unique to zone WR3 include *Polygonum aconogonon*, *Armeria*, *Gentiana*, *Spiraea*, and Onagraceae. Herb taxa shared by zones WR3 and WR1 are *Oxyria*, *Polemonium*, and Lamiaceae. Percentages of *Selaginella rupestris* spores are variable but are generally less than in zone WR1.

Major spectra in zone WR4 are similar to those from zone WR3. Ericales, Cichoriaceae, Scrophulariaceae, *Spiraea*, *Dryas*, *Sanguisorba*, *Potentilla*, Onagraceae, *Armeria*, Lamiaceae, Liliaceae, *Polygonum aconogonon*, *Oxyria*, *Gentiana*, and *Polemonium* pollen are all present in zone WR4 but absent in zone WR3. *Salix* pollen increases to a maximum of 40% at the top of this zone. Percentages of *Selaginella rupestris* spores increase to their maximum values (ca 275% of the pollen sum) in the section.

The low pollen sums that characterize samples in zone WR5 are reflected in the highly variable percentages in the major taxa. Nonetheless, these data indicate a major decrease in Cyperaceae pollen to $< 15\%$ with variable but high percentages of Poaceae pollen (up to 47% although typically 25–35%). Brassicaceae pollen increases to maximum values of ca 15%. No minor taxa are unique to zone WR5. However, types that typically occur in the lower zones (e.g., Cichoriaceae, Lamiaceae, *Cardamine*, *Polygonum aconogonon*, *Oxyria*, *Spiraea*, *Sanguisorba*) are absent here. The absence of these types possibly reflects the small pollen sums. Hepaticae (up to 125% of the pollen sum) replaces *Selaginella rupestris* as the dominant spore type.

5.3. Veseloye Lake

The Veseloye core (Fig. 4) yielded a uniform pollen record dominated by Poaceae (40–70%) pollen. Cyperaceae, Asteraceae, *Salix*, Ranunculaceae, Brassicaceae, and *Artemisia* pollen occur consistently but never exceed 15%. The assemblage also includes trace amounts of *Pinus*, *Betula*, *Alnus*, and Ericales pollen. Twenty-five minor herb taxa were recorded with Rosaceae, Saxifragaceae, Primulaceae, Scrophulariaceae, *Pedicularis*, Polemoniaceae, Caryophyllaceae, *Thalictrum*, *Polygonum* sect. Bistorta, and *Draba* appearing in all levels. Total pollen concentrations vary between ca 500–1500 grains/cm^3. Bryales are the most common spore type at ca 5–15% of the pollen + spore sum.

5.4. Jack London Lake

Three zones have been defined for the Jack London core (Fig. 5). Zone JK1 is dominated by Cyperaceae pollen (50–60%) with moderate amounts of Poaceae (20–30%) and *Salix* (5–8%) pollen. Other minor components include *Artemisia*, Ranunculaceae, Asteraceae, Brassicaceae, Cichoriaceae, Caryophyllaceae, Rosaceae, *Spiraea*, Saxifragaceae, Primulaceae, Scrophulariaceae, *Pedicularis*, Chenopodiaceae–Amaranthaceae, Polemoniaceae, Apiaceae, Liliaceae, Papaveraceae, *Draba*, *Cardamine*, *Thalictrum*, *Polygonum aconogonon*, and *Valeriana*. Spore taxa are never abundant and include Bryales, Hepaticae, *Selaginella rupestris*, Polypodiaceae, *Equisetum*, and *Riccia.*

JK2 is a transitional zone with a co-dominance of Cyperaceae (30–40%) and Poaceae (45–50%) pollen. Minor pollen taxa and spores are similar to zone JK1 except for the absence of *Spiraea*, *Polygonum aconogonum*, and Polemoniaceae.

JK3 is dominated by Poaceae (generally over 70%) pollen with Cyperaceae and *Salix* pollen decreasing to less than 15 and 5%, respectively. *Betula*, *Alnus*, and Ericales pollen occur in consistent amounts of less than 5% throughout the zone. *Artemisia* and Brassicaceae pollen increase slightly at the top of the zone but still remain 5% or less. Minor herb, aquatic, and spore taxa unique to zone JK3 are Rubiaceae, Lamiaceae, *Polygonum aconogonon*, *Polygonum* sect. Bistorta, *Rumex*, *Potentilla*, *Rubus chamaemorus*, *Sanguisorba*, *Allium*, *Plantago*, *Corydalis*, Sparganiaceae, Alismataceae, *Lycopodium dubium*, and *Diphasiastrum alpinum*. Percentages of Bryales spores are generally higher in JK3 as compared to the other zones. Total pollen concentrations are generally less than 100 grains/cm^3, but one sample registered ca 450 grains/cm^3.

6. Radiocarbon dates and chronology

Seven macrofossil samples composed of discrete wood fragments (typically fragments of small twigs) were selected from WR-12 bulk samples for AMS radiocarbon dating. Four samples composed of unidentifiable plant remains and one sample of an unidentified terrestrial macrofossil were obtained from the Jack London core. Humic acids were extracted from bulk sediments for one date each from Jack London and Veseloye Lakes. Contamination by residual tracers used at the College of Forest Resources, University of Washington, prevented additional radiocarbon analyses of the remaining portions of the Veseloye and Jack London cores.

The WR-12 macrofossil samples typically yielded about 1 mg of C for measurement. All of the Jack London wood samples had less than 0.75 mg C, with a minimal carbon content of 0.14 mg C. Calculations based on CO_2 yield during combustion show that all of the pretreated macrofossil samples contained 40–50% carbon (by dry weight), which is consistent with the carbon content expected for typical organic materials such as cellulose. The radiocarbon dates obtained for the WR-12 exposure and the Jack London core (Table 2) show increasing age with increasing depths, and the internal consistency of the dates within each site provides evidence of the reliability of the radiocarbon results.

Most portions of the Jack London and WR-12 diagrams have well-defined chronologies. However, basal or near-basal ages are more poorly defined, making it difficult to assess the exact length of these records. For example, the 29,890 $\pm$ 190 BP date suggests an ancient history from Jack London Lake. The zone JK1 pollen assemblage is unlike those from other well-dated full-glacial lake sites in Beringia which typically have $>$ 10% *Artemisia* pollen (e.g., Lozhkin et al., 1993; Anderson and Brubaker, 1994). If the ca 30 ka BP date is correct, the pollen data suggest that a perennial ice cover existed on the lake, resulting in no sediment input during the Sartan glaciation (marine isotope stage 2 equivalent). An alternative and, we believe, more reasonable hypothesis is that the dated terrestrial macrofossil was redeposited from interstadial materials. Although conditions at times during the last interstade were relatively warm in western Beringia (Vartanyan, 1997; Anderson and Lozhkin, 2001), it seems improbable that the Wrangel Island climate was significantly milder than present at ca 30 ka BP. We postulate that these diagrams are younger than 12.5 ka BP, presuming that high percentages of Cyperaceae pollen are associated with a post-glacial amelioration that occurred across western Beringia at ca 12–12.5 ka BP (Lozhkin, 1993). However, analysis of additional sites is necessary to improve understanding of the timing of late Quaternary vegetational changes.

7. Discussion

7.1. *Modern pollen and spores from Wrangel Island and Chukotka: representation of vegetation and comparison to other arctic assemblages*

The Wrangel Island samples, although modest in number, show a consistency that provides the island with a characteristic modern palynological signature. This signature is one dominated by Poaceae with more moderate amounts of Cyperaceae and *Artemisia* pollen. Percentages of neither major nor minor taxa differentiate fell field from coastal tundra. For example, Caprifoliaceae and *Plantago* occur only in coastal samples, whereas Papaveraceae is unique to fell field. However, none of these taxa appear in all or even most of the samples in their respective vegetation type. The minor taxa seem more a reflection of the herb types growing near the lake's edge that typically include locally disturbed or dry beaches (e.g., Compositae) and/or mesic to wet areas associated with seasonal seepages and snow beds (e.g., *Rumex*, *Rubus chamaemorus*, *Thalictrum*). Taxa important in the regional vegetation (e.g., *Dryas* found on the hills of the mountainous interior) are virtually absent in the pollen record. Perhaps higher pollen counts would increase the visibility of these herbaceous types, but increased pollen sums would not reflect their abundance on the landscape.

Percentages of the major taxa do distinguish the Wrangel Island samples from the shrub tundras of mainland Chukotka. In general, the Chukotkan samples have higher percentages of *Pinus*, *Betula*, and *Alnus* pollen and total spores and lower amounts of Poaceae and *Artemisia* pollen compared to Wrangel Island. Cyperaceae pollen percentages from northern and central Chukotka are higher than those of Wrangel Island, although the southernmost mainland samples are markedly lower (reflecting the high influence of the amounts of *Pinus* pollen on the percentages of nonexotic taxa). Minor types are less helpful in distinguishing tundra types of the mainland from each other or the mainland spectra from those of Wrangel Island. Many pollen taxa that occur only in the Chukotkan samples (e.g., Apiaceae, Fabaceae, and *Potentilla*) also represent plants that grow on Wrangel Island but have not been recorded in the modern samples.

Interpretation of fossil tundra pollen assemblages must consider the possible effects of exotic taxa on the pollen sum. Samples of the modern pollen rain help assess the extent of "noise" introduced to the fossil spectra and can provide useful thresholds for interpreting the presence or absence of over-represented species. For western Beringia, the main types of concern are *Betula*, *Alnus*, and *Pinus*. None of these three taxa are major contributors to the Wrangel Island pollen assemblage, thus suggesting little distortion of the modern pollen percentages by long-distance wind transport. This result differs from other areas of the Arctic where interpretation of the modern pollen rain and choice of pollen sums can become quite complex (e.g., the Canadian islands; Gajewski, 1995). *Pinus* and *Betula* pollen percentages indicate relatively straightforward relationships to the vegetation. That is, the modern samples show a strong south-to-north decrease in *Pinus* pollen percentages that mirror the decline in the shrub on the landscape. The reverse trend is clear for *Betula* pollen. *Alnus* pollen displays little variation among the mainland samples, suggesting that interpreting distributional changes in *Alnus* may be more uncertain than for other shrubs of western Beringia.

The Wrangel Island samples contrast sharply to modern lacustrine samples from other parts of the North American Arctic. The distinction lies mostly with the island's high Poaceae pollen percentages. Modern samples from the high- to mid-Arctic on Banks (Ritchie, 1987) and Somerset (Gajewski, 1995) Islands of the western and central Canadian Arctic, respectively, and from Greenland (Fredskild, 1969, 1983; Pennington, 1980; Ritchie, 1987) have graminoid (i.e., Cyperaceae and Poaceae) dominated assemblages. However, percentages of Cyperaceae pollen are more abundant than Poaceae in both sets of Canadian samples (up to 50% on Banks and 60% on Somerset).[1] Poaceae pollen is generally between ca 15 and 20% for Banks Island. On Somerset Island values are generally less than 20%, although three samples have values near 40%. The Greenland samples, one located in the far north and three in the southwest, are more variable with percentages of Poaceae and Cyperaceae pollen ranging from trace to ca 25% and 5–35%, respectively. Percentages of *Salix* pollen are much greater for the Greenland samples (ca 10–40%) than in the Canadian, Alaskan, or Wrangel spectra. *Artemisia* pollen is a minor component of the Banks Island and Greenland assemblages, but the taxon does vary from trace amounts to ca 30% on Somerset Island. Moderately high percentages of *Oxyria* pollen (up to 35%) characterize many modern samples from Canada and Greenland, making them distinct from the Wrangel or Alaskan spectra.

The percentages of the major pollen taxa from Wrangel Island are the most similar to modern samples from the northwestern Alaskan coast and the Yukon–Kuskokwim deltas of southwestern Alaska (Anderson and Brubaker, 1994). The Alaskan samples are characterized by high percentages of Poaceae pollen, but they also have high percentages of Cyperaceae pollen. Furthermore, the Poaceae species in Alaska are those associated with wet maritime settings in low arctic to subarctic vegetation zones, in contrast to the fell field or xeric high arctic tundras of Wrangel Island. Ritchie (1987, p. 55) noted that modern pollen spectra from grasslands and parklands of western Canada are generally similar to high arctic spectra because of the predominance of herbaceous pollen (total herb pollen of ca 50–70%) in both areas. However, *Artemisia* (ca 5–40%) and Chenopodiaceae–Amaranthaceae (ca 5–30%) pollen are higher in the lower latitudes, and certain minor prairie herbs (e.g., *Amorpha*, *Petalostemum*, and *Sphaeralcea*) help to distinguish the southern from northern herb-dominated vegetation types. Conversely, other minor taxa are restricted to the tundra spectra (e.g., *Saxifraga oppositifolia*, *Oxyria*, Brassicaceae).

7.2. Paleovegetation of Southern and Central Wrangel Island

The variety of depositional environments in the WR-12 exposure, the unstable shorelines and/or shallowness of Jack London and Veseloye Lakes, and the great potential for *in situ* contamination of radiocarbon samples provide less than ideal settings for obtaining accurate data to use in paleovegetational reconstructions. Furthermore, use of records from different sedimentary environments (i.e., peat, alluvium, lakes) can complicate intersite comparisons (Edwards, 1997). Despite these problems, broad similarities exist among the lake and the WR-12 diagrams. The strongest comparison is between the late Holocene lacustrine assemblages, where the interior and coastal sites show a dominance of Poaceae pollen. A slight increase in Poaceae pollen also occurs in the upper portion of WR-12 (zone WR5) and may reflect a vegetation similar to that recorded at Veseloye Lake. However, zone WR5 is undated, and the variation in pollen percentages between this and the lower zones could reflect changes in sediment type. Both the Jack London and WR-12 records have times when Cyperaceae pollen percentages are high. Direct comparisons of these assemblages are limited because of poor dating control and variations in depositional environments. However, changes in pollen percentages in zones WR1 through WR4 (Fig. 3a) are not simply a function of changes in sediment types (e.g., Cyperaceae pollen is dominant in both peat and alluvial sediments; the *Salix* pollen peak occurs within Unit 2; *Selaginella rupestris* spores rise dramatically in zone WR4 which, like zone

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[1] Sums used to calculate percentages of Somerset Island samples did not include exotic taxa. Thus comparison to other spectra is somewhat misleading, but the general observations are valid.

WR3, is peat), allowing some argument for a regional signal in the WR-12 record. Although these observations are intriguing, they are far from conclusive. Thus, the following vegetation history is offered as a working hypothesis and not as a definitive reconstuction.

Before ca 10 ka BP (zones WR1 through WR4), the interior of Wrangel Island supported a Cyperaceae-dominated tundra with *Salix* shrubs. Consistent appearance of moisture-loving taxa not seen or not abundant in the modern spectra (e.g., *Oxyria*, *Sanguisorba*) suggests a more mesic setting than present during the late Pleistocene–Holocene transition. Onset of peat growth and minor occurrence of *Sphagnum* spores lend further support for locally moist environments. The high percentages of graminoid pollen and the lower frequencies of Asteraceae pollen and Hepaticae spores perhaps indicate a more continuous plant cover than seen on the modern interior landscape. Although the presence of *Spiraea* (also at Jack London) may reflect long-distance transport from the mainland, this woody species is insect pollinated, and its appearance implies the plant's presence on the landscape. *Spiraea* does not grow on the island today, suggesting warmer, moister conditions than present. The *Salix* pollen maximum in zone WR2 perhaps indicates the establishment of a local population as areas bordering the river stabilized. Conversely, it may represent a brief time when conditions permitted the flourishing of these shrubs throughout the river valley. High percentages of *Selaginella rupestris* spores, such as seen in zone WR4, are often associated with the dry, cold tundras of the Sartan glaciation (Shilo, 1987). The modern pollen samples suggest an alternative explanation. Palynological spectra from southern Chukotka have slightly higher percentages of *Selaginella rupestris* spores as compared to Wrangel Island (Fig. 2). *Selaginella rupestris* grows on rocky outcrops and is highly indicative of local habitats. However, late-glacial conditions may have ameliorated sufficiently in interior Wrangel Island to allow the plant to establish on the rock-strewn slopes of the mid- to higher elevations.

The coastal pollen assemblages (zones JK1 and JK2) suggest a Cyperaceae-dominated tundra, probably similar to that of the interior, occupied southern portions of Wrangel Island some time prior to ca 9.2 ka BP. The relatively high percentages of Ericales pollen (zones JK1 and JK2) argue for ameliorated conditions and the presence of more mesic settings than found in the area today. Comparison of the fossil pollen spectra to the modern lacustrine pollen data shows similarities to mid- to low arctic tundras. The latter characteristically have high percentages of Cyperaceae and lower percentages of Poaceae pollen (see Fig. 2; Anderson and Brubaker, 1994). Such comparisons suggest that coastal areas may have had a vegetation cover that was more continuous than present with a greater representation of woody species. However, the Lateglacial tundra on southern Wrangel Island was not fully equivalent to the lower latitude modern tundras, because *Betula* shrubs were absent and the organic content of sediments was low, suggestive of a less productive landscape.

The mid- to late Holocene portions of the pollen diagrams from Jack London and Veseloye Lakes indicate that a Poaceae-dominated landscape with a mosaic of mesic to xeric habitats occupied both coastal and interior areas of Wrangel Island. *Salix* is the main woody species represented in these diagrams. The uniformity of zone JK3 and percentages of major taxa that fall within the range of modern spectra suggest a vegetation that has changed little during the Holocene. Low total pollen concentrations and organic content of the sediment imply a relatively unproductive landscape, characteristics that agree with the observed discontinuous nature of much of the present-day vegetation.

In contrast to the above lacustrine-based interpretations, palynological analyses of other peats and alluvium suggest that important changes occurred in the Holocene vegetation of Wrangel Island and modern conditions may not have been achieved until ca 3 ka BP (Vartanyan, 1997). From these data, the maximum expression of subarctic vegetation, including evidence for growth of shrub *Betula* on northern Wrangel Island, occurred between ca 12.5 and 8 ka BP. The mid-Holocene vegetation history of Wrangel Island is not well known, but Vartanyan postulated that the final disappearance of *Betula* shrub tundra occurred ca 4 ka BP. The discrepancies between the lacustrine and non-lacustrine data again raise questions about the influences of depostional/preservational environments on the paleobotanical data. Because lake records provide a more regional integration of palynological data, they may "smooth" some of the more local, landscape-level changes in vegetation that are more clearly evident from the non-lacustrine sites. Clearly, the use of both types of sites for paleovegetational interpretations are necessary, particularly in harsh environments, such as on Wrangel Island, where changes in tundra types can be especially difficult to document.

7.3. Late Pleistocene–early Holocene paleoclimates of Wrangel Island and Beringia

The new paleoenvironmental data discussed in this paper are in general agreement with previous unpublished results of Vartanyan, which suggest more moderate conditions than the present existed on Wrangel Island during the late Pleistocene–early Holocene transition. Of the data presented here, the rapid peat accumulation between ca 11 and 10 ka BP at WR-12 is most striking in that this deposit contrasts sharply to the minimal organic accumulation over the last 6 ka years in southern or central portions of the island (Vartanyan, unpublished data). The initiation of peat growth at

WR-12 could easily represent a response to local hydrological changes and not to shifts in the regional climate. However, Vartanyan reported peat deposits dating between ca 12.5 and 7.7 ka BP in both coastal and intermontane areas of the island. Lozhkin and Postolenko (1989) also have described initiation of peat growth in more southerly areas of western Beringia between ca 12.5 and 11 ka BP. Although the relationship of climate, topography, and hydrology with peat accumulation is complex (e.g., Garneau, 1992), the cause for extensive peat growth in North America has been attributed primarily to climatic factors (Ovenden, 1988). The widespread and essentially synchronous initiation of peat growth in western Beringia argues that, as in North America, a climatic as opposed to an edaphic interpretation of the observed changes is more probable. Palynological data from the mainland indicate that conditions during the late Pleistocene–Holocene transition were warmer than before but still cooler than present (Shilo, 1987), suggesting an increase in effective moisture was possibly responsible for the appearance of these organic-rich landscapes.

Palynological assemblages from other sites on Wrangel Island (Vartanyan, 1997) suggest that the warmest period within the Holocene falls between 10 and 9 ka BP. In contrast, the data from Jack London Lake and WR-12 indicate that the post-glacial thermal maximum likely occurred some time prior to 10–9.2 ka BP. Chemical analysis of a syngenetic ice-wedge in the WR-12 exposure suggests that climate was warmer than present between ca 11 and 9 ka BP (Kotov et al., 1996). Kotov et al. (1996) have suggested that the change in chemical components during this interval is associated with increased marine sources and may indicate a sea-ice cover that was less extensive and/or of shorter seasonal duration than modern.

Paleobotanical data from across Beringia show significant differences in regional climates during the late Pleistocene–Holocene transition. Climate for much of eastern Beringia is inferred to be warmer than present between ca 11 and 9 ka BP (e.g., Ritchie et al., 1983; Cwynar and Spear, 1991; Anderson and Brubaker, 1994), whereas data from western Beringia indicate a continued increase in summer temperature and probably effective moisture during this period, culminating in a post-glacial thermal maximum between ca 9.5 and 8 ka BP (Lozhkin, 1993). Evidence for a Younger Dryas-type climatic event is absent from Wrangel Island, most northern and eastern areas of western Beringia, and much of eastern Beringia. However, records from southwestern Alaska (e.g., Peteet and Mann, 1994; Hu et al., 1995; Brubaker et al., 2001), and possibly some from far western areas of western Beringia (see Velichko et al., 1997) suggest an interval of cooling. Interestingly, the Wrangel Island data indicate a greater affinity to northern and central areas of eastern Beringia, with the warmer than present climate during the Lateglacial to early Holocene, and less similarity to most of western Beringia, which was still cooler than present. However, the onset of peat growth with its implications for increased effective moisture on Wrangel Island is more in accord with the western Beringian data.

Study of modern Beringian synoptic climatology (Mock and Anderson, 1997; Mock et al., 1998) provides a physically viable scenario of atmospheric circulation that could lead to a “warmer than present” Younger Dryas for Wrangel Island but not for other areas of western Beringia. Such an analysis also helps to explain the inferred warm-dry climates of eastern Beringia at a time when western Beringia was experiencing its first post-glacial peat growth. Anomaly maps of the western Beringia Negative type indicate positive July temperature anomalies over eastern Beringia, Wrangel Island, and the north-central coast of Chukotka with negative anomalies over the remainder of western Beringia (Mock et al., 1998). Negative precipitation anomalies characterize eastern Beringia, whereas western Beringia (including Wrangel Island) displays positive anomalies. This pattern is the result of a weaker center of positive 500 mb pressure centered in the Beaufort Sea and a region of negative anomalies over western Beringia. Increased troughing causes an increase in cooler northwesterly flow and storm activity over much of western Beringia. In eastern Beringia and Wrangel Island (located at the edge of the Beaufort Sea anomaly), greater northeasterly flow around the Beaufort Sea anticyclone yields positive temperature and negative precipitation anomalies.

8. Conclusions

New palynological data from Jack London and Veseloye Lakes and the WR-12 exposure indicate that a Cyperaceae–Poaceae tundra established in areas of southern and interior Wrangel Island prior to 10–9.2 ka BP. During a portion of this period, peat accumulated in areas of the mountainous interior that today support discontinuous herb-dominated tundra. The paleovegetational results suggest that climatic conditions were warmer and likely moister than present during the late Pleistocene/Holocene transition. The temperature anomaly inferred from these data is more like that for eastern Beringia than for other areas of western Beringia, although the increase in moisture is more characteristic of western Beringian sites. What may appear as an unlikely paleoclimatic scenario (i.e., that past temperatures were more similar to distant areas of eastern Beringia than to nearby areas of western Beringia) can be observed in modern synoptic patterns, giving added evidence that the paleoclimatic scenario for Wrangel Island is reasonable. The data presented in this paper suggest that modern climate and vegetation were in place in central and southern Wrangel Island between ca 10 and 9 ka BP, with no significant variations during the Holocene. This history contrasts to that drawn from other peat and alluvial deposits, where it appears that the modern vegetation was not established until the mid-Holocene.

Although 34 steppe and meadow-steppe species, thought to be remnants of the full-glacial vegetation, grow today on the island, paleobotanical data indicate a period when the vegetation was a Cyperaceae-dominated tundra rather than a steppe or steppe tundra. The timing of this period is poorly defined with the current data, but it possibly dates to the latest Pleistocene–earliest Holocene. The paleobotanical evidence clearly indicate that Wrangel Island experienced a post-glacial thermal maximum, but the data presented here and those previously analyzed by Vartanyan do not agree on the time of this warm interval. Whenever the time of this climatic amelioration (which may have lasted for ca 4 ka years), the survival of full-glacial vegetation well into the Holocene does not seem likely. The Holocene lacustrine assemblages, which have an abundance of Poaceae pollen, lack the high percentages of *Artemisia* pollen and *Selaginella rupestris* spores that characterize western Beringian sites during glacial times. Thus, the palynological data and inferred paleoclimates suggest that Wrangel Island during the Late Pleistocene and Holocene was not a refugium for full-glacial vegetational communities. Consequently, dwarf mammoths likely adapted to an environment that differed from that of the full-glaciation, and the animals probably did not survive on the island simply because it more closely reproduced glacial conditions. The paleoenvironmental data presented here add no information that clearly defines the ultimate cause of the mammoth's extinction. Perhaps the differences in lacustrine and non-lacustrine based interpretations indicate that relatively subtle alterations at the landscape level, and not broader regional shifts, caused the death of the Wrangel Island population. Clearly, more well-dated records are needed before the complete story of the Wrangel Island mammoths will be known.

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