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16. PLIOCENE–PLEISTOCENE POLLEN ASSEMBLAGES FROM THE YERMAK PLATEAU, ARCTIC OCEAN: SITES 910 AND 911[1]

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ABSTRACT

Palynological and paleobotanical research on upper Pliocene sediments from Meighen Island, Kap København, and deep-sea sites in the North Atlantic Ocean has indicated the presence of forest tundra far north of its present limits and warmer conditions than present. New pollen data from samples obtained on Ocean Drilling Program Leg 151 (Sites 910 and 911) on the Yermak Plateau of the Arctic Ocean provide a record of late Pliocene terrestrial floras characteristic of at least boreal to subarctic climatic conditions in the source areas. Pollen and spores are present in upper Pliocene sediments from both cores, with typical concentrations of 1,000 to 2,000 pollen grains per gram of dry sediment. *Pinus* is the dominant genus in upper Pliocene assemblages, and *Picea* and *Betula* are subdominant. Other taxa typically present include *Alnus, Corylus, Larix, Tsuga, Pterocarya, Sciadopitys* and members of the Poaceae, Cyperaceae, Asteraceae, and Ericaceae. These assemblages are suggestive of open boreal vegetation with relatively temperate deciduous elements and indicate warmer Pliocene conditions than today in the pollen source areas. Pleistocene pollen assemblages from Site 911 consist primarily of *Pinus* and *Picea* pollen with few other taxa present. Such assemblages indicate cold conditions, probably similar to those of today, and palynomorphs are less common in Pleistocene sediments, typically <1,000 pollen grains per gram of dry sediment. In both cores, most reworked palynomorphs, which are two to three times more abundant than nonreworked ones, are Cretaceous in age and include genera characteristic of both the *Aquilapollenites* and Normapolles provinces; this composition suggests that the source of reworked material was the northern Asian coast between the Barents Sea and Laptev Sea, the main region where Cretaceous rocks containing both these assemblages are preserved. These reworked palynomorphs probably were transported either by sea ice or ocean currents via the Transpolar Drift to the Yermak Plateau sites.

INTRODUCTION

The change in the North Atlantic and Arctic area from climates much warmer than today during some periods of middle to late Pliocene time to the oscillations of the glacial-interglacial cycles of the Pleistocene has been documented extensively by vegetational evidence in the forms of pollen and plant macrofossils (Funder et al., 1985; Matthews and Ovendon, 1990; Dowsett et al., 1994; Willard, 1994), by marine microfossils such as planktonic and benthic foraminifers, ostracodes, and diatoms (Dowsett et al., 1992; Cronin, 1991; Barron, 1992), and by the isotopic record (Raymo et al., 1989). Micropaleontological evidence from Pliocene deposits from middle to high latitudes, in particular, has indicated much warmer conditions than today. Pollen records have indicated temperatures up to 5°C warmer than today in areas bordering the North Atlantic Ocean, and the presence of macrofossils from boreal forest elements in North Greenland and the Canadian Archipelago indicates that the boreal forest zone extended much farther north, with tundra and polar deserts extremely reduced during some periods of the Pliocene compared to today (Funder et al., 1985; Matthews and Ovendon, 1990; Dowsett et al, 1994; Willard, 1994). Sea-surface temperature estimates for the North Atlantic are up to 6°C warmer than today (Dowsett et al., 1992), leading to the hypothesis that sea ice in the Arctic Ocean was substantially reduced relative to today and that the ocean was seasonally ice free (Dowsett et al., 1994). However, it has been difficult to test these estimates in the Arctic Ocean and surrounding regions because well-dated, continuous Pliocene sections have not previously been available. An opportunity to test these estimates has been provided by cores drilled on the Yermak Plateau during Leg 151 of the Ocean Drilling Program (ODP). These cores represent the first ODP sediment cores from deep water (>500 m) in the Arctic Ocean and provide a unique opportunity for high-resolution studies of the response of polar ecosystems to climatic changes through the late Neogene and Quaternary. Sites 910 and 911, drilled on the Yermak Plateau (Fig. 1), yielded particularly thick Pliocene and Quaternary

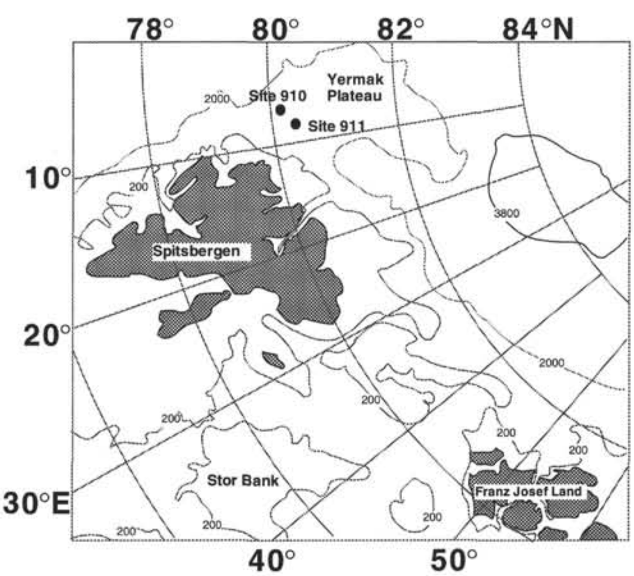

Figure 1. Location of Sites 910 and 911, Leg 151, on the Yermak Plateau, Arctic Ocean. Bathymetry in meters.

[1]Thiede, J., Myhre, A.M., Firth, J.V., Johnson, G.L., and Ruddiman, W.F. (Eds.), 1996. *Proc. ODP, Sci. Results,* 151: College Station, TX (Ocean Drilling Program).
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sequences of homogeneous silty clays and clayey silts. In this study, pollen and spore assemblages were isolated from these sediments to establish preliminary patterns of change in subarctic/arctic vegetation and terrestrial paleoclimate over late Neogene and Quaternary time and to ascertain the sources of reworked material present in the cores.

METHODS

Samples were prepared for palynological analysis using the following techniques.

1. 5-cm^3 sediment samples were dried and weighed with a precision scale.
2. Samples were spiked with one marker tablet of *Lycopodium* spores as described by Stockmarr (1971).
3. Samples were treated with HCl until visible reaction ceased to remove carbonates.
4. Samples were treated with cold 52% HF (2–3 days) to dissolve silicate minerals.
5. Samples were suspended in a dilute detergent solution to disperse clay-sized materials.
6. Samples were sieved through 8-µm nylon mesh to remove clay-sized materials.
7. Residues were centrifuged in a heavy liquid ($ZnCl_2$ at s.g.≈1.8) to separate organics from mineral matter.
8. The organic fraction was removed from the heavy liquid solution and then washed in 20% HCl to remove $ZnCl_2$.
9. Residue was stained with Bismarck Brown before being mixed with warm glycerine jelly and mounted on microscope slides.

Palynomorph concentrations were calculated on the basis of the marker-grain method. The spore concentration of the *Lycopodium* tablets used as the source of marker grains was determined by the manufacturer with a Coulter Counter following the procedures of Stockmarr (1973). When possible, counts of at least 100 pollen grains were made. However, nonreworked palynomorphs were sufficiently sparse in many samples that abundance data from all samples are included in the pollen diagrams; samples in which fewer than 50 grains were counted are indicated by shaded bars (Figs. 2, 4). Although such small abundances are impractical for quantitative analyses of pollen assemblages, they provide a basis for preliminary estimates of the overall composition of assemblages from this region, which has been studied little from a palynological perspective, as well as estimates of broad changes in abundance of plant taxa through time.

HOLE 910C

Drilling of Hole 910C (80°15.894′N, 6°35.430′E at 556.4 m water depth; Fig. 1) yielded 507.4 m of Pliocene and Quaternary sediments (Myhre, Thiede, Firth, et al., 1995). These sediments are mostly very dark gray, nearly homogeneous silts and clays that comprise a single lithostratigraphic unit. Below 19.5 meters below seafloor (mbsf), the sediments are highly compacted; these overconsolidated sediments have been postulated to result from a thick grounded ice sheet resting on the Yermak Plateau during a glacial maximum (Myhre, Thiede, Firth, et al., 1995). Only Pliocene sediments from Hole 910C were sampled for this study, consisting of 21 samples ranging from 93.15 to 481.95 mbsf. Three lithostratigraphic subunits are represented in these samples, and the subunits are summarized below in descending order.

Subunit IA (0–208.7 mbsf) consists of Quaternary and Pliocene silty clays and clayey silts with 20%–30% siliciclastic components. This subunit is characterized by high dropstone abundance, reaching 10–30 dropstones per core.

Subunit IB (208.7–391.5 mbsf) consists of Pliocene silty clays and clayey silts with 10%–20% siliciclastic components. Dropstone abundances are lower throughout the sequence, with <10 dropstones per core.

Subunit IC (391.5–507.4 mbsf) also consists of Pliocene silty clays and clayey silts with siliciclastic components averaging 20%–30%. Dropstones are present in low abundances (<10 per core) throughout the unit.

The silty clays of Hole 910C are primarily terrigenous deposits with only a small hemipelagic component and may represent distal ice-rafted material. Age control is provided primarily by biostratigraphy; paleomagnetic studies could not provide good temporal constraints due to the presence of secondary magnetic minerals in the sediments. Biostratigraphic control, provided primarily by calcareous nannofossils and planktonic foraminifers, indicate that the sediments studied are Pliocene, representing nannofossil Zones NN15–19. Palynological results are illustrated in Figure 2 and compiled in Table 1.

Terrestrial Palynoflora

Pollen is common in samples from Site 910, with typical abundance values of 2,000 pollen grains/gram dry sediment; in one sample, over 11,000 grains/gram sediment were found. Reworked palynomorphs are even more abundant, with 4,000–5,000 reworked grains/gram dry sediment typical values for this core (Fig. 3). The most common components of the assemblages are bisaccate pollen grains, such as *Pinus* and *Picea,* and *Pinus* dominates most samples. In the lower 250 m of core, *Betula* is subdominant, and, in the upper 250 m, *Picea* is subdominant (Fig. 2). Other genera present in low abundances (<10%) are *Abies, Alnus, Corylus, Castanea, Larix, Sciadopitys, Tsuga,* and *Salix.* Families represented by pollen not identifiable to the generic level include the Ericaceae, Cyperaceae, Poaceae, and Cupressaceae (Fig. 2). With only minor fluctuations, the taxonomic composition and percent abundance of the assemblages are fairly uniform throughout the Pliocene sequence. *Sciadopitys* is present in several samples and is the only taxon with a restricted stratigraphic range. *Sciadopitys* is now endemic to Japan (Sporne, 1965), in a relatively temperate climate, but it has been documented from Pliocene sediments in Europe and North America, from middle to high latitude sites (Zagwijn, 1960; Matthews and Ovendon, 1990; Willard, 1994). *Tsuga* presently is found south of 50°N latitude in North America and no longer grows in Europe. However, it has been reported in Pliocene sediments from Iceland, the Norwegian Sea, and the other sites in Europe (Zagwijn, 1960; Godwin, 1975; Willard, 1994). Pollen assemblages from Hole 910C have boreal to subarctic characters; they are similar to those from the Norwegian Sea (Willard, 1994) but probably represent vegetation from slightly cooler conditions, lacking the more temperate elements *Ilex, Pterocarya,* and *Quercus* found at ODP Site 642 in the Norwegian Sea.

Reworked Palynoflora

Reworked palynomorphs are abundant in samples from Site 910, with up to 7,700 grains/gram dry sediment. The reworked grains consist mostly of trilete spores and bisaccate pollen and are distinguishable from nonreworked material by their darker color, highly compressed condition, and, in the case of the bisaccate grains, changes in the texture of the sacci. The most common reworked taxa are Cretaceous in age, including species of *Cicatricosisporites* (*C. australiensis* and *C. subrotundus*), *Appendicisporites potomacensis,* and *Aquilapollenites scabridus. Corollina* (*Classopollis*), and *Gleicheniidites* also were present in one sample (Table 2). The presence of these taxa indicates that source sediments for reworked material were at least Late Cretaceous in age and also may include Early Cretaceous material.

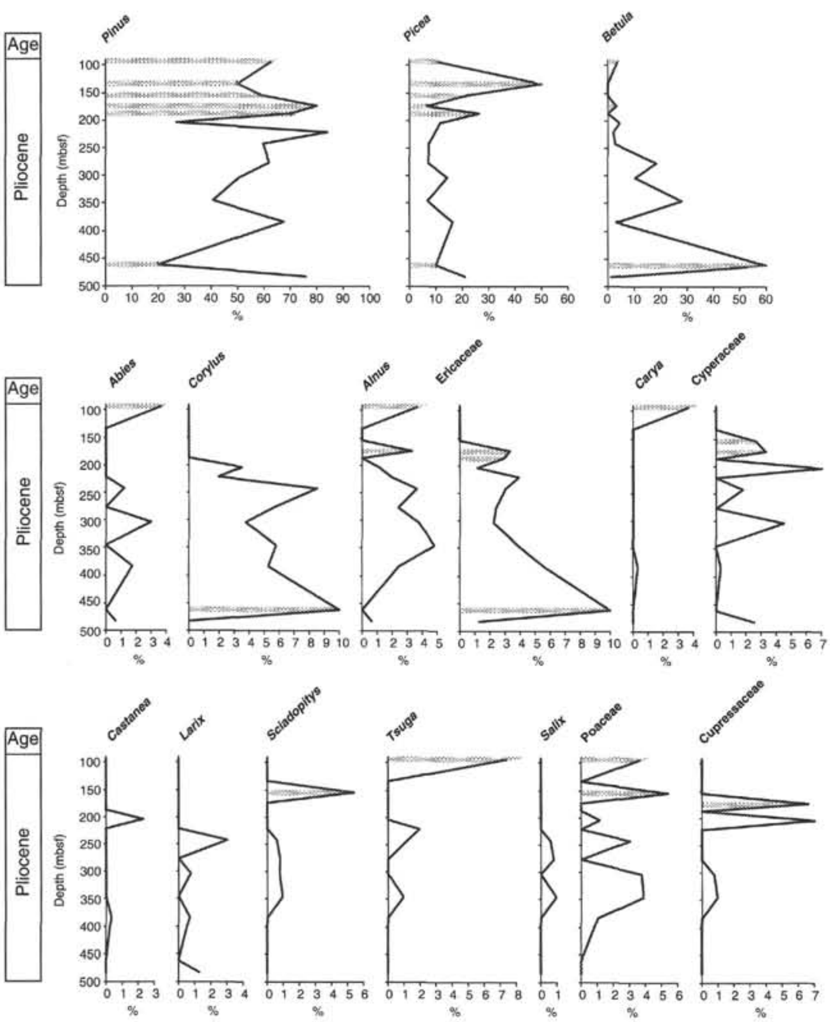

Figure 2. Percent abundance of selected pollen taxa from Leg 151, Hole 910C, Yermak Plateau, Arctic Ocean. Shaded bars indicate samples in which fewer than 50 pollen grains were counted.

HOLE 911A

Hole 911A was drilled about 35 km east/northeast of Hole 910C at 80°28.464′N, 8°13.638′E at 901.6 m water depth (Fig. 1). These sediments also are unlithified, homogeneous, very dark gray clays and silts and are divided into two subunits on the basis of dropstone abundance. Pollen assemblages were analyzed from 26 samples ranging from 0.53 to 501.33 mbsf. Palynological results are illustrated in Figure 4 and compiled in Table 1.

Subunit IA (0–380.4 mbsf) consists predominantly of Pliocene and Quaternary siltstones, sandstones, and shales, with minor representation of coal fragments, plutonic rock, quartzite, and limestone. Dropstones reach a peak abundance of six per core, and the interval is characterized by high amplitude fluctuations of sand, silt, and clay-size fractions. Bioturbation is light to heavy throughout this subunit.

Subunit IB (380.4–505.80 mbsf) has fewer dropstones (0–1 per core) and consists of homogeneous lithologies of gray silty clay and clayey silt of Pliocene age. Bioturbation is moderate to heavy, and there are high-amplitude fluctuations in percentages of clay-, silt-, and sand-size fractions.

The lithologies are interpreted as representing glaciomarine sediments deposited near or under the sea ice cover. No clear contrast of glacial/interglacial sediments is evident at this site, possibly because its position today is ice-free only 2–3 months of the year. Thus, most of the sedimentation at the site probably is controlled by the fluctuation of the ice cover, with significant deposition of siliciclastic particles either by sea ice or icebergs.

Terrestrial Palynoflora

Pollen is less abundant in samples from Site 911 than in those from Site 910, with most Pliocene samples ranging from 500 to 2,500 grains/gram dry sediment and Quaternary samples having <1,000 pollen grains/gram (Fig. 3). As in Site 910, reworked palynomorphs are more abundant than nonreworked grains, ranging from 50 to 11,000 grains/gram. Bisaccate grains, primarily *Pinus* and *Picea*, dominate both Pliocene and Quaternary assemblages (Fig. 4). Other common taxa throughout the core include *Alnus, Corylus,* and members of the Cupressaceae. Taxa most common in Pliocene sediments are *Betula, Salix, Carya, Larix, Tsuga,* Cyperaceae, Ericaceae, and Poaceae. Other taxa present occasionally in Pliocene samples are *Sciadopitys, Tilia, Castanea,* and *Pterocarya.* Pliocene assemblages from Hole 911A have a boreal to subarctic character, similar to those from Hole 910C. Those from Quaternary samples consist almost entirely of bisaccate grains; such assemblages are common at sites far removed from the pollen source, such as Sites 607 and 611 in the central North Atlantic Ocean (Willard, unpubl. data). These Quaternary assemblages are consistent with either tundra vegetation or ice cover in the source area; further research into the composition of modern assemblages from this region is necessary to interpret vegetational distribution from Quaternary pollen assemblages from these sites.

Table 1. Abundance (number of specimens) of taxa present in samples from Leg 151, Holes 910C and 911A, Yermak Plateau, Arctic Ocean.

Core, section, interval (cm)	Depth (mbsf)	*Abies*	*Alnus*	*Betula*	*Carya*	*Castanea*	*Corylus*	Cupressaceae	*Ilex*	*Juglans*	*Larix*	*Liquidambar*	*Ostrya/Carpinus*	*Picea*	*Pinus*	*Pterocarya*	*Quercus*	*Salix*	*Sciadopitys*	*Tilia*	*Tsuga*	*Ulmus*	Asteraceae	Chenopodiaceae	Cyperaceae	Ericaceae	Liguliflorae	Poaceae	Ranunculaceae	*Sagittaria*	Crumpled pollen	Total pollen	Trilete spores	Monolete spores	*Lycopodium complanatum*	*Sphagnum*	Total spores
151-910C																																					
11R-1, 5–6	93.15	1	1	1	1									3	17						2							1				27	3			3	6
13R-1, 60–61	113														4													1			4	5	3		1		4
15R-2, 4–5	133.14													10	10																	20					0
17R-3, 42–43	154.32													8	22	1			2				1		1			2				37	6	3	1	4	14
19R-3, 40–41	173.6		1	1				2						2	24										1	1					2	32	6	1			7
20R-6, 7–8	187.37													9	24							1				1					1	35	1	1	1		3
22R-4, 40–41	203.9		1	4		2	3	6						10	23										6	1		1			5	57	14	2	1		17
24R-3, 55–56	221.85		1	1			1							5	43						1					2				1	4	55	3		2		5
26R-4, 55–56	242.65	2	6	5			14				5		5	12	98			1	1		2				3	5		5				164	10	3	3	15	31
30R-1, 4–5	276.24		3	23			7							9	77			1	1							3					5	63	8	2	1		11
32R-6, 55–56	303.55	4	5	14			5	1			1			19	67				1						6	3		5			12	88	9	1	2		12
37R-1, 55–56	344.35		5	29			6	1						7	42			1	1		1					4		4	1	1		75	13	1	2	1	17
41R-2, 57–58	383.97	5	7	10	1	1	15				2			47	192										1	16	1	3			17	301	25	9	7	3	44
45R-2, 55–56	422.55		1	1			2	1						4	6										1						9	16	14		2		16
49R-3, 42–43	462.52			6			1							1	2											1					1	11	2	1	1		4
51R-3, 55–56	481.95	1	1	2							2			33	119				1						4	2					8	165	4	3	1		8
151-911A																																					
1H-4, 53–54	0.53	1	3	3			4	2		1				28	80		2				1				3			1			11	129	2	1			3
3H-1, 61–62	19.61																1															1					0
5H-2, 55–56	40.05													9	7																	16	1		1		2
7H-3, 61–62	60.61														4																1	5	1			3	4
9H-5, 54–55	80.24													1	2											1						4					0
11H-5, 54–55	100.24		1					1						11	38									1							11	63	15	1			16
13H-6, 56–57	119.47														9																	9	1		1		2
16X-1, 57–58	140.47						2	3						2	10																	17	6				6
20X-2, 61–62	180.41						1							6	15		1														4	28	13	1	1	1	16
22X-2, 65–66	199.65							1						6	27					1											2	37	4			1	5
24X-3, 62–63	220.42						1							11	18						1											31	3				3
26X-3, 60–61	239.7													6	9													1			1	17	1				1
28X-4, 53–54	260.52													14	69													1			5	74	6	1	1	1	9
30X-5, 53–54	281.23		1					1						12	23	1									1	1					7	47	4	1		1	6
32X-4, 62–63	299.05		1											9	14						1					1					1	27		1			1
34X-6, 64–65	321.44	3	1					1						15	28						1				3	2		1			10	65	12	5	2	2	21
37X-6, 62–63	340.72		5	1		2		1						29	63										2	2		1			7	113	14	2		3	19
38X-6, 62–63	360.02			1			1							2	35																2	41	1	1			2
41X-2, 62–63	382.52			2	1		3	1			2			9	54										2			1	1		6	62	15	2	2	1	20
42X-8, 61–62	401.11		1	5		1	4	5	1		1			4	29										1	1		1			9	63	13		4	1	18
44X-3, 61–62	412.91							1						7	30																1	39	1	1			2
47X-2, 55–56	440.25		1	3	1		4							13	26			1	1						3						11	64	13		2		15
49X-2, 62–63	459.62		6	4			1	2						6	73				1	1	2				2	4					12	114	15	1	3		19
51X-3, 57–58	480.37		4	8			1	9			1			7	31			1	1				1		6			3			15	88	25	1	3	1	30
53X-4, 63–64	501.33		9	30			9	3			2	1		13	113	1					3	1	1		4	2		5			19	216	27	3	10	2	42

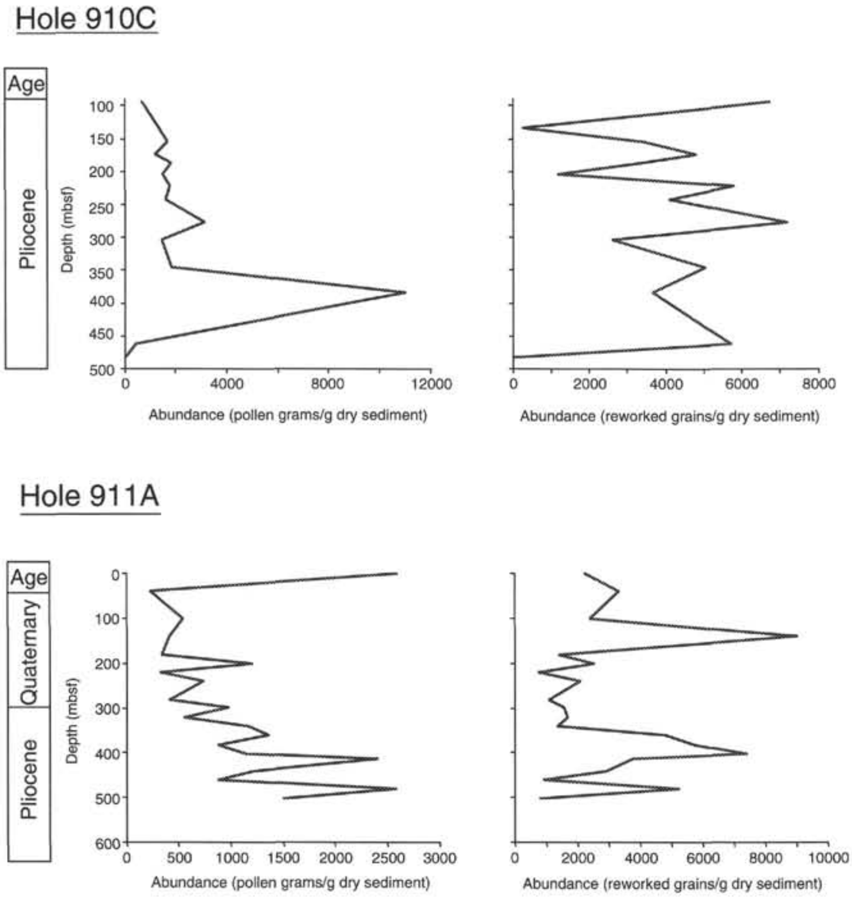

Figure 3. Abundance of pollen and reworked palynomorphs in samples from Leg 151, Holes 910C and 911A, Yermak Plateau, Arctic Ocean. Abundance values are presented as number of palynomorphs per gram of dry sediment.

Reworked Palynoflora

Reworked palynomorphs are abundant in most samples from Site 911 (Fig. 3), with abundances of up to 9,000 grains/gram dry sediment. Reworked grains consist primarily of trilete spores and bisaccate pollen. Upper Cretaceous taxa are common in these samples, including *Cicatricosisporites, Trilobosporites, Appendicisporites, Aquilapollenites, Trudopollis,* and *Oculopollis* (Table 2). Reworked Carboniferous spores also are present in Pliocene and lower Pleistocene samples (150 m and below), with *Thymospora* and *Lycospora* being the most notable.

PALEOENVIRONMENTAL INTERPRETATION

Source Areas and Pollen Transport

The transport of pollen to marine sediments is governed by a number of complex factors, including distance from shore, water depth, depositional environment, and other oceanographic characteristics of the site of deposition. In general, pollen assemblages from continental shelf deposits provide an accurate reflection of the nearby vegetational zones (Heusser and Balsam, 1977; Mudie, 1982), with taphonomic biases becoming greater with increasing distance from shore. Primary transport mechanisms for pollen have been studied in detail for some oceanic regions, such as the western North Atlantic Ocean (Mudie, 1982; Mudie and McCarthy, 1994) and the northeast Pacific Ocean (Heusser and Balsam, 1977). These studies have illustrated that wind, ocean currents, and fluvial discharge from major rivers each play an important role in pollen transport to marine sediments. The relative role of each mechanism, however, varies with oceanographic characteristics. Studies have not been undertaken to determine the relative roles of wind and oceanic current transport for nonreworked pollen grains deposited in the Yermak Plateau region, but it is possible to infer the most likely locations of the source vegetation based on present wind and ocean-current patterns. Modern wind circulation patterns during flowering season flow northward from Scandinavia into the Arctic Ocean region (Tchernia, 1980), so the most likely source areas for pollen deposited by wind at Sites 910 and 911 are nearby Spitsbergen or northern Scandinavia (approximately 800 km south), which are covered by tundra vegetation today. Another possible source for these sites is northeastern Greenland, which now is vegetated by polar desert (Srodón, 1960; Huntley and Birks, 1983). Pollen assemblages from either tundra or polar desert typically are dominated by pollen of herbaceous plants, rather than tree pollen, which is the dominant element in Pliocene sediments from Sites 910 and 911.

Modern ocean surface circulation in the Eurasian Basin of the Arctic Ocean is dominated by the Transpolar Drift (TPD), which carries cold water from the Siberian coast through the Fram Strait to the North Atlantic Ocean (Fig. 5). Warm, saline water is carried into the Arctic Ocean via the West Spitsbergen Current (WSC), which flows north through the Fram Strait along the western side of Spitsbergen (Carmack, 1990). As is the case with wind transport, the most likely vegetational source for pollen transported into the Arctic Ocean via the WSC would be either Spitsbergen itself or coastal Norway, which both presently are vegetated by tundra. If the TPD was a major transporter of pollen, the likely vegetation source is Siberia, which also is covered by tundra at the present time (Koroleva, 1994; Matveyeva, 1994).

Comparison of Fossil and Modern Pollen Assemblages

Modern pollen assemblages from similar latitudes in Spitsbergen, northern Greenland, and Iceland are dominated by nonarboreal pol-

Table 2. Occurrences of reworked palynomorphs in samples from Leg 151, Holes 910C and 911A, Yermak Plateau, Arctic Ocean.

Core, section, interval (cm)	Depth (mbsf)	*Appendicisporites potomacensis*	*Appendicisporites*	*Aquilapollenites scabridus*	*Aquilapollenites*	*Carboniferous spores*	*Cicatricosisporites australiensis*	*Cicatricosisporites* cf. *subrotundus*	*Cicatricosisporites*	*Corollina (Classopollis)*	*Gleicheniidites*	*Lycospora granulata*	*Lycospora pusilla*	*Lycospora*	*Oculopollis*	*Thymospora*	*Trilobosporites*	*Trudopollis*
151-910C-																		
11R-1, 5–6	93.15								P									
13R-1, 60–61	113	P							P									
15R-2, 4–5	133.14																	
17R-3, 42–43	154.32								P									
19R-3, 40–41	173.6								P									
20R-6, 7–8	187.37								P									
22R-4, 40–41	203.9			P														
26R-4, 55–56	242.65																	
30R-1, 4–5	276.24				P		P	P										
32R-6, 55–56	303.55	P							P									
37R-1, 55–56	344.35						P		P									
41R-2, 57–58	383.97						P		P	P	P							
49R-3, 42–43	462.52			P			P		P									
51R-3, 55–56	481.95								P									
151-911A-																		
11H-5, 54–55	100.24								P									
13H-6, 56–57	119.47						P		P									
16X-1, 57–58	140.47								P							P		P
20X-2, 61–62	180.41								P									
22X-2, 65–66	199.65								P									
24X-3, 62–63	220.42																	
26X-3, 60–61	239.7								P									
28X-4, 53–54	260.52								P									
30X-5, 53–54	281.23								P			P	P					
32X-4, 62–63	299.05								P									
34X-6, 64–65	321.44					P			P									
37X-6, 62–63	340.72			P					P						P			
38X-6, 62–63	360.02								P								P	
41X-2, 62–63	382.52				P				P									
42X-8, 61–62	401.11								P									
44X-3, 61–62	412.91								P									
47X-2, 55–56	440.25								P									
49X-2, 62–63	459.62		P						P									
51X-3, 57–58	480.37				P				P									
53X-4, 63–64	501.33								P					P				

Note: P = present.

len such as the Saxifragaceae, Cruciferae, and Poaceae with relatively low percentages of exotic pollen such as *Pinus* (usually <20%), *Picea* (<5%), *Betula* (<10%), and *Corylus* (<1%) (Srodón, 1960; Rymer, 1973; Funder and Abrahamsen, 1988). Vegetation in these areas is classified as tundra or polar desert and consists primarily of algae and lichens with scattered mosses and small angiosperms (Hyvärinen, 1970; Srodón, 1960; Funder and Abrahamsen, 1988). The nearest forests are 800–1000 km away in Lapland and southern Scandinavia (Srodón, 1960; Huntley and Birks, 1983). Boreal forests, with abundant birch and spruce, are present in Lapland today, and mixed conifer-deciduous forests are present in southern Fennoscandinavia (Huntley and Birks, 1983). The dominance of pine, spruce, and birch pollen in samples from Sites 910 and 911 is consistent with the presence of at least a boreal forest or shrub tundra in the source area during Pliocene time, and the presence of several more temperate taxa (*Carya, Tsuga, Larix,* etc.) indicates that deciduous elements also were present and that Pliocene temperatures were warmer than today. Although currently there is no database of modern pollen assemblage composition from marine sediments along the region between northwestern Europe and Spitsbergen to determine modern analogs for fossil assemblages, the presence of temperate taxa in assemblages from Sites 910 and 911 indicates that the boreal to subarctic source vegetation grew farther north than today, in regions presently occupied by tundra or polar desert.

Source of Reworked Palynomorphs

The composition of reworked Cretaceous palynomorph assemblages in sediments from Sites 910 and 911 makes it possible to infer the likely source areas for reworked material because of the provinciality of Late Cretaceous palynofloras. In the Northern Hemisphere, Late Cretaceous assemblages are broadly divisible into the Normapolles Province and the *Aquilapollenites* Province. In Eurasia, the two provinces adjoin at about the longitude of the Ural Mountains, but there is little overlap between the two (Fig. 6B; Herngreen and Chlonova, 1981). Extensive deposits of Cretaceous strata are present along the northern Asian coast from the Barents Sea to the Laptev Sea, and Upper Cretaceous rocks are most widely exposed in the vicinity of the Kara Sea (Okulitch et al., 1989) (Fig. 6A). These Upper Cretaceous rocks correspond to the area where the Normapolles and *Aquilapollenites* Provinces meet (Fig. 6B); if the assemblage represents palynomorphs from a single source area, then this region is the most likely source of reworked Cretaceous palynomorphs deposited at Sites 910 and 911 because it is the only site where pollen characteristic of both provinces would be produced. Carboniferous palynomorphs also are present at Site 911 and also may have originated near this area, where Carboniferous rocks also are exposed (Fig. 6A). However, Carboniferous strata are present on Svalbard (Cutbill et al., 1976), and these also may have been the source. If reworked Creta-

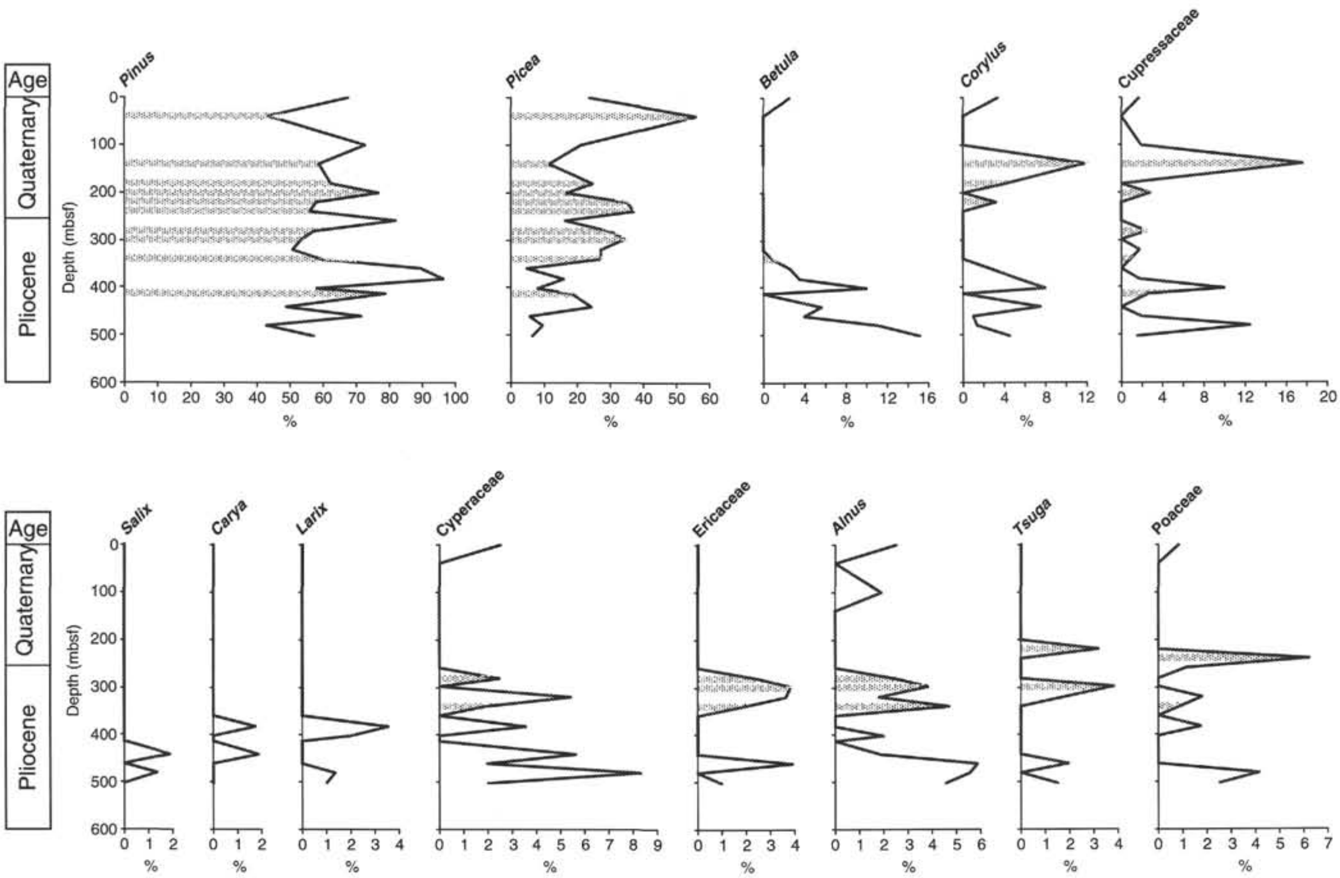

Figure 4. Percent abundance of selected pollen taxa from Leg 151, Hole 911A, Yermak Plateau, Arctic Ocean. Shaded bars indicate samples in which fewer than 50 pollen grains were counted.

ceous palynomorphs represent a mixed assemblage produced from several source areas, possible source areas range from the Barents Sea to the Laptev Sea (Fig. 6A).

The Cretaceous palynomorphs may have been eroded from the Eurasian shelf during highstands of sea level and carried to Sites 910 and 911 via either ocean currents or as sediment entrained in sea ice. Reworked Cretaceous nannofossils have been recovered from Quaternary sediments in cores slightly north of Sites 910 and 911 (Gard and Crux, 1994), and they may have undergone similar transport mechanisms as reworked palynomorphs in the present study. Modern current and sea-ice drift patterns flow from the Siberian shelf, across the Yermak Plateau, and southward through the Fram Strait; the presence of reworked grains from the Eurasian shelf at Sites 910 and 911 on the Yermak Plateau indicates that current patterns may have been similar through Pliocene and Pleistocene time.

CONCLUSIONS

Pollen assemblages from Pliocene and Pleistocene sediments obtained during Leg 151 on the Yermak Plateau in the Arctic Ocean indicate that Pliocene conditions were considerably warmer than those of today and that Pleistocene conditions were substantially cooler than those of the Pliocene. Open boreal forest to mixed conifer-deciduous forest assemblages probably extended as far north as Lapland and northern Greenland during Pliocene time, representing a northward latitudinal shift of vegetation of about 10°, but tundra/polar desert or ice-covered conditions probably prevailed during much of the Pleistocene. Reworked palynomorph assemblages from both cores probably had their source on the Eurasian shelf, where they either were entrained into sea ice and transported via the Transpolar Drift or were transported on surface currents following a similar path. It appears that the Transpolar Drift followed essentially its present path in Pliocene time.

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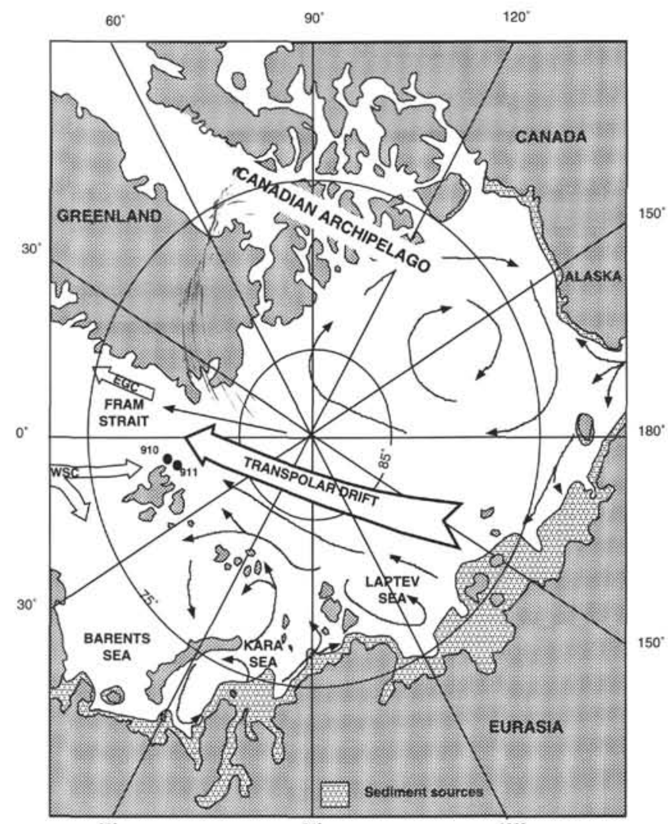

Figure 5. Circumpolar map of Arctic Ocean region, showing major current systems (large labeled arrows) and surface circulation patterns. WSC = West Spitsbergen Current, EGC = East Greenland Current. Modified from Gordienko and Laktionov, 1969.

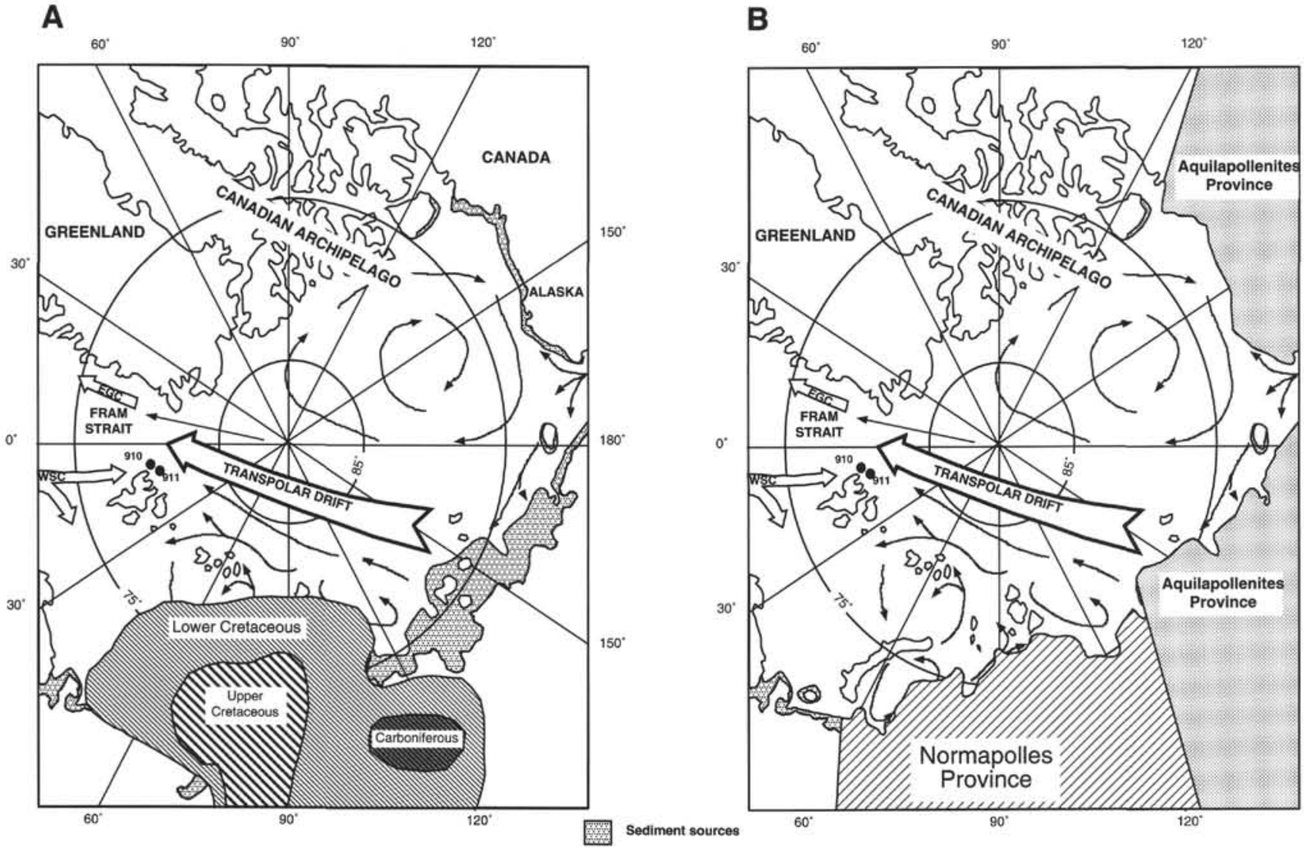

Figure 6. **A.** Circumpolar map of Arctic Ocean region showing major current systems and source areas for reworked palynomorphs (modified from Gordienko and Laktionov, 1969, and Okulitch et al., 1989). **B.** Circumpolar map of Arctic Ocean region showing distribution of Cretaceous floral provinces (modified from Herngreen and Chlonova, 1981, and Okulitch et al., 1989).