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Late Pliocene Pollen Assemblages from Ocean Drilling Project Hole 646B: Census Data and Paleoclimatic Estimates

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INTRODUCTION

This report provides summary data from palynological analyses of Pliocene samples from ODP Site 646B, which currently is being studied as part of the PRISM Projects (Pliocene Research, Interpretation, and Synoptic Mapping) aimed at reconstructing Pliocene paleoclimate throughout the Northern Hemisphere. Both faunal and floral evidence from Pliocene deposits throughout the world indicate that climates were significantly warmer and that the North Atlantic lacked substantial ice sheets during Pliocene time (Dowsett and Poore, 1990; Dowsett and Poore, 1991). Using microfaunal data and transfer functions, estimates for Pliocene sea-surface temperatures at about 3.0 Ma have been calculated; this study is aimed at augmenting such estimates of oceanographic variability with estimates of air temperature and precipitation for the surrounding landmasses.

Foraminifers and dinoflagellates from Hole 646B samples, dated at approximately 3.0 Ma, have been analyzed (Dowsett and Poore, 1991; Edwards, et al, 1991), and transfer functions for each group have yielded conflicting estimates of paleotemperature for the time around 3.0 Ma. Planktic foraminifers suggest that conditions were similar to those existing today near the polar front (Dowsett and Poore, 1991), whereas dinoflagellate data indicate much warmer conditions, more similar to those at DSDP Hole 410 at about 45°N (Edwards, et al., 1991). Because pollen previously had been reported as abundant in some samples from Hole 646B (deVernal and Mudie, 1989), more intensive sampling between 3.165-3.226 Ma was undertaken to analyze the pollen assemblage, estimate paleotemperature and precipitation from pollen data, and use pollen data to try to resolve the differences in climatic estimates from the foraminifer and dinoflagellate records.

MATERIALS AND METHODS

Eleven samples were collected from core 29 of Hole 646B in the southeastern Labrador Sea, about 200 km southwest of the southern tip of the Greenland continental shelf. Latitude, longitude, and water depth are provided in Table 1.

TABLE 1. Latitude, longitude, and water depth for ODP Hole 646B, illustrated in Figure 1.

Latitude	Longitude	Water Depth
58°12.559' N	48°22.147'W	3458 m

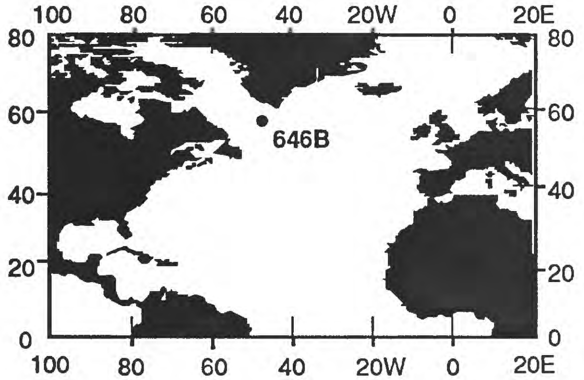

Figure 1. Location of ODP Hole 646B, Labrador Sea.

Eleven samples were collected at intervals ranging from about 0.5-1.0 m, covering an age range from approximately 3.165 Ma - 3.226 Ma (Dowsett and Poore, 1991). For each sample, a 10 cc plug was removed from the core. To remove carbonates, samples were treated with 10% HCl until the reaction ceased and then were neutralized with repeated deionized water washes. Samples were treated with concentrated HF to dissolve silicates; typically, the samples remained in HF for 2-3 days before being neutralized with repeated water washes. Clay-sized particles were removed by suspending the sediment in a dilute detergent solution, centrifuging for 1 minute at 500 rpm, decanting the supernatant, and repeating the process until the supernatant was clear. The supernatant then was sieved through an 8 μm mesh, the > 8 μm fraction recombined with residue remaining in the centrifuge tube, and the entire residue acidified using 2% HCl. After centrifuging the residue and decanting the HCl, a $ZnCl_2$ solution (S.G. ~2.0) was added, and the organic material was separated from the mineral matter by centrifuging at 500 rpm for 20 minutes and at 1500 rpm for 10 minutes. The organics were pipetted from atop the supernatant and treated with 2% HCl and distilled water washes to remove the $ZnCl_2$. The residue then was washed with ethanol and stained with Bismarck Brown before being mixed with warm glycerin jelly and mounted on microscope slides.

Every slide made from each sample was scanned to identify the pollen and spore genera present, and 300 pollen grains from each sample were identified and counted. In several cases, the sample sizes were small enough that fewer than 300 pollen grains were present. In cases where there were approximately 100 grains, the data were included in the analysis; otherwise, the samples were omitted from the analysis.

QUANTITATIVE DATA ANALYSIS

Abundance data from Hole 646B were compared with a modern data set composed of pollen abundance data collected from shallow-marine bottom samples forming a transect along the northeast coast of North America from the Bay of Fundy to Baffin Bay (Mudie, 1980). The samples were compared using squared chord distance (SCD) dissimilarity coefficients; the modern sample with the lowest SCD is the closest modern analogue (see Overpeck, et al., 1985). Because the data being compared are from two very different depositional settings and because an important component of the fossil assemblages no longer occurs near the study region, SCD values were not expected to fit within the critical range defined by Overpeck, et al. (1985); rather, the comparison was intended to determine the most similar extant pollen assemblage.

RESULTS

Pollen Abundance

Pollen was abundant enough in 9 samples to count and estimate abundance of the different pollen taxa; this includes counts ranging from 80-300 grains (Figure 2). Raw data from pollen counts are provided in Table 2. Pinus pollen dominated every assemblage (50-82.5%), and Picea pollen ranked second in abundance (12.5-22.5%). Other common taxa throughout the section include Abies, Betula, Alnus, and Quercus and various herbs, including grasses, sedges, and heaths. Sciadopitys and Tsuga are present in most samples but are most abundant (up to 12% and 6% respectively) in the lower samples.

Modern Analogues for Hole 646B

Squared chord distances for the five most similar sites for each sample are provided in Table 3. In seven of nine samples, site 67-134, located off the east coast of Newfoundland, is the most similar modern analogue (Figure 3). In most of the samples, the SCD for site 67-134 is significantly lower than those for the other samples (Table 3). In sample P 10 I, site 67-134 does not have the lowest SCD but has the same SCD value as sample KC323, located near the east coast of Nova Scotia (Figure 3). For another sample (P 10 J), the lowest SCD values are from KC336, located in the Labrador Sea and from 75-118 in the St. Lawrence River (Figure 3). Other sites represented by the lowest five SCDs are located off the eastern coast of Nova Scotia (Figure 3).

DISCUSSION

Modern Distribution of Genera Preserved in Hole 646B

The modern distribution of genera identified in samples from Hole 646B and their pollen provides qualitative evidence of Pliocene paleoclimates, and the most valuable data are provided not by the most abundant genera but, rather, by the less common components of the pollen record. The pollen of the two most abundant taxa, Pinus and Picea, is ubiquitous in terrestrial pollen assemblages of southeastern Canada, even though the actual distribution of plants is geographically limited (Elliott-Fisk, et al, 1982). In marine sediments, taphonomic factors such as air and wind transport govern the distribution of the two pollen types, with most pollen deposited in deep-sea sediments thought to be transported to the depositional site by wind currents (Mudie, 1982). Pinus pollen increases in abundance with greater distances offshore, but Picea pollen decreases in abundances with increasing distance from shore; its highest abundances are found offshore from Newfoundland (Mudie, 1982; Heusser, 1983).

The most climatically informative taxa from these samples are Quercus, Sciadopitys, and Tsuga. All three genera have a limited geographic distribution of both trees and pollen. The northern limit for Quercus trees lies at approximately 48° N (Delcourt, et al., 1984), and, in continental sediments, its pollen is present only in sediments south of 50° N (Webb and Bernabo, 1977). In marine samples, Quercus pollen is most commonly found in samples collected south of 48° N, with

FIGURE 2. Percent abundance of pollen taxa, ODP Hole 646B

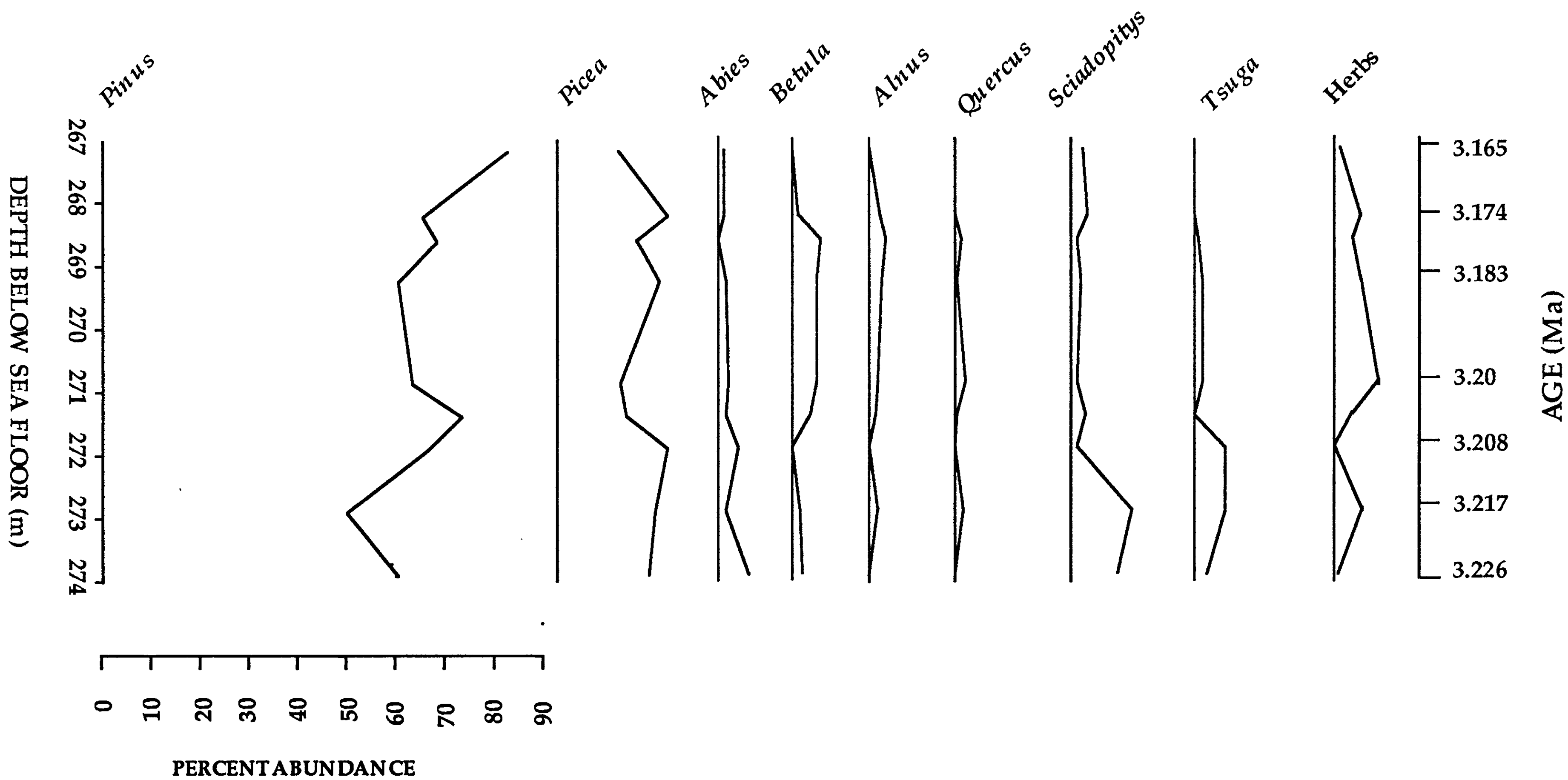

TABLE 2. Pollen abundance in samples from ODP Hole 646B, Labrador Sea. Plus (+) signs indicate that the taxon was present in the sample but was not encountered in the count of 300 grains.

ODP SITE	646 B	646 B	646 B	646 B	646 B	646 B	646B	646 B	646 B	646 B	646 B
CORE	29	29	29	29	29	29	29	29	29	29	29
SECTION	2	2	2	3	3	4	4	5	5	6	6
TOP INTERVAL (cm)	36	88	142	30	96	36	106	10	62	12	110
BOTTOM INTERVAL (cm)	38	90	144	32	98	38	108	12	64	14	112
DEPTH (M)	267.16	267.68	268.22	268.6	269.26	270.16	270.86	271.40	271.92	272.92	273.92
APPROXIMATE AGE (Ma)	3.165		3.174		3.183	3.192	3.20		3.208	3.217	3.226
SAMPLE NUMBER	P 10 A	P 10 B	P 10 C	P 10 D	P 10 E	P 10 F	P 10 G	P 10 H	P 10 I	P 10 J	P 10 K
Pinus	66	+	64	107	181	+	193	220	66	149	97
Picea	10		22	25	62	+	39	42	22	60	30
Abies	1		1		4	+	6	4	4	4	10
Betula			1	9	14	+	15	11		5	3
Alnus			2	5	7	+	4	3		4	
Fraxinus											
Quercus				2	1		6	1		4	
Corylus					2	+	3				
Ostrya/Carpinus											
Castanea							+				
Salix					2		2				
Acer							2				
Tsuga				1	4		4		6	18	4
Juglans										2	1
Larix											
Carya											
Sciadopitys	2		3	2	6		3	8	1	37	15
Pterocarya					1		1				
Poaceae				1	+			1		2	
Umbelliferae	1			1	2						
Artemesia											
Cyperaceae			4	1	7	+	14	2		14	
Ericaceae			1	2	6		12	5			
Ranunculaceae							1	1		1	
Liguliflorae					1		1				
Polygonum viviparum				1	+						
Galium					+						
Ambrosia											1
Aster								2			
Labiatae											
Total pollen counted	80	BARREN	98	157	300	BARREN	306	300	99	300	161
Trilete spores	5		4	31	52	2	66	11	1	7	7
Monolete spores			1			1	3			2	
Lycopodium complanatum	6		4	5	12	1	32	28		15	6
Lycopodium lucidulum								2		2	
Lycopodium selago											
Sphagnum	1		1	2	10	1	6	4		5	
cf. Cheilanthes											
Nuphar										1	
Osmunda	2							3		13	
Polypodium virginianum							+	1			

TABLE 3. Five most similar SCDs for samples from Hole 646B.

HOLE 646 SAMPLE	MODERN SITE	SCD VALUE	LATITUDE DEGREES (N)	LATITUDE MINUTES (N)	LONGITUDE DEGREES (W)	LONGITUDE MINUTES (W)
10A	67 - 134	0.28	49	0	50	5
10A	75 -118	0.49	48	22	70	36.5
10A	75 - 117	0.52	43	45.26	62	48.55
10A	KC335	0.53	44	41.5	63	39.5
10A	KC336	0.54	56	32	61	55
10C	67 - 134	0.30	47	15	59	30
10C	75 -118	0.34	48	22	70	36.5
10C	23 - 30	0.35	50	33.55	53	32.31
10C	23 - 21	0.38	50	22.4	55	0.8
10C	KC336	0.39	56	32	61	55
10D	67 - 134	0.18	49	0	50	5
10D	75 -118	0.25	48	22	70	36.5
10D	KC335	0.31	44	41.5	63	39.5
10D	KC336	0.31	56	32	61	55
10D	NS2	0.35	47	15	59	30
10E	67 - 134	0.21	49	0	50	5
10E	75 -118	0.25	48	22	70	36.5
10E	KC335	0.27	44	41.5	63	39.5
10E	KC336	0.28	56	32	61	55
10E	73 - 34	0.29	43	46	62	56.5
10G	67 - 134	0.18	49	0	50	5
10G	KC335	0.30	44	41.5	63	39.5
10G	75 -118	0.33	48	22	70	36.5
10G	73 - 34	0.34	43	46	62	56.5
10G	PQ1	0.36	49	30	49	18
10H	67 - 134	0.19	49	0	50	5
10H	75 -118	0.33	48	22	70	36.5
10H	KC335	0.36	44	41.5	63	39.5
10H	73 - 34	0.37	43	46	62	56.5
10H	KC336	0.38	56	32	61	55
10I	KC323	0.34	44	34.95	64	0.5
10I	67 - 134	0.34	49	0	50	5
10I	BP6	0.38	44	44	63	15.05
10I	75 -118	0.39	48	22	70	36.5
10I	KC336	0.39	56	32	61	55
P 10J	KC336	0.26	56	32	61	55
P 10J	75 -118	0.26	48	22	70	36.5
P 10J	KC323	0.26	44	34.95	64	0.5
P 10J	KC335	0.27	44	41.5	63	39.5
P 10J	PQ1	0.28	49	30	49	18
10K	67 - 134	0.25	49	0	50	5
10K	KC335	0.30	44	41.5	63	39.5
10K	KC323	0.32	44	34.95	64	0.5
10K	KC336	0.32	56	32	61	55
10K	75 -118	0.33	48	22	70	36.5

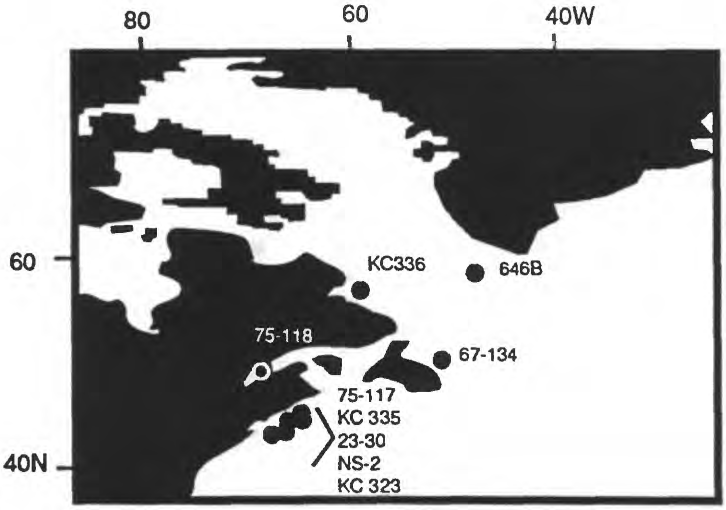

FIGURE 3. Location of site 646B and most similar modern analogues.

greatest abundances occurring off of the western Scotian shelf (Mudie, 1982). Tsuga also is found only south of about 48° N (Mudie, 1982; Delcourt, et al., 1984), and, onshore, its pollen is restricted to sediments between 35-50° N (Webb and Bernabo, 1977). Offshore, the highest recorded abundances for Tsuga are from sediments off western Nova Scotia (Mudie, 1982). Sciadopitys presently is native only to Japan (Sporne, 1965), but it has been recorded from Pliocene sites as far south as central Europe and central France (Gaussen, 1967).

Probable Source Area for Pollen in Hole 646 B

In estimation of likely source areas for pollen recovered from samples taken from Hole 646B, both the phenology of the plants and the likely patterns of atmospheric circulation must be considered. Most of the trees represented in the pollen assemblage flower in May and June, and the herbs flower from May to September (Table 4). Therefore, circulation patterns in the spring and summer are of primary interest.

TABLE 4. Summary of flowering times for genera recovered from Hole 646 B (from Bassett, et al., 1978)

Pinus	May
Picea	late May - June
Abies	May - early June
Betula	April - May
Alnus	May - July
Quercus	May - June
Tsuga	April - May
Herbs	May - September

Maps of air circulation patterns for the spring and summer (see Hare and Hay, 1974) suggest that the most likely North American source area for pollen deposited in Hole 646B at present would be the Labrador/Quebec region. Although it is possible that air-circulation patterns may have changed somewhat since Pliocene time, present circulation patterns will be used to infer the likely source area until evidence indicating Pliocene differences is produced. Additionally, pollen from plants growing on Greenland may have been deposited at the site of Hole 646B, but present circulation patterns suggest that most pollen produced in Greenland would be deposited east of the island.

Present Vegetation and Pollen Rain in Labrador and Quebec

Vegetation in southern Labrador and eastern Quebec is classified as part of the circumpolar boreal forest, grading from spruce-fir forests in the south to the forest-tundra in central Labrador (Hare and Ritchie, 1972; Lamb, 1984). The vegetation typically is dominated by Picea, and Abies, Larix, Betula, Populus, Pinus, and Thuja also are common (Elliott-Fisk, 1988). Terrestrial pollen assemblages from this region are characterized by abundant Picea, Pinus, Betula, and Alnus pollen, with lesser representation of Salix, Gramineae, Cyperaceae, and Ericaceae (Morrisson, 1970; Elliott-Fisk, et al., 1982; Lamb, 1984). Assemblages of pollen from marine sediments off the coast of Labrador are dominated by Picea pollen, with abundant Pinus, Betula, and Alnus pollen; pollen of Abies, Cyperaceae, and Rosaceae also are present. Tsuga and Quercus are found only rarely in marine sediments this far north (Davis and Webb, 1975; Mudie, 1982).

Present Vegetation and Pollen Rain in Greenland

The present vegetation in southern Greenland consists primarily of Empetrum heaths and dwarf shrubs such as Betula glandulosa, Vaccinium, and Salix. The dominance of heath vegetation is not maintained in the pollen record, however, partly because some of the herbs do not produce pollen. Rather, about 3/4 of the pollen is produced by dwarf shrubs compared to only about 1/4 by the heath vegetation (Fredskild, 1972). These taxa also are represented in the pollen rain offshore. During daily monitoring of the pollen rain on a cruise around the southern tip of Greenland, Dyakowska (1948) noted the presence of Pinus, Abies, Picea, Betula, Alnus, Juglans, and Salix pollen as well as herbaceous pollen. Of these, the bisaccate conifer pollen was transported from either North America or Europe; Pinus, Picea, and Abies do not grow on Greenland at the present time (Dyakowska, 1948).

Modern Analogues for Pollen Assemblages from Hole 646 B

Both quantitative and qualitative examination of pollen assemblages from Hole 646 B suggest that the most similar modern assemblages are those presently found on Nova Scotia or Newoundland. Squared-chord distances calculated for samples from Hole 646B indicate that the most similar modern analogue (see Table 3) is from a site located at 49°0'N 50°5'W (Site 67-134), off the east coast of Newfoundland (Figure 3). Other, sites with slightly higher SCD values also are shown in Figure 3 and are located off the east coast of Nova Scotia and in the Gulf of St. Lawrence.

The present vegetation in the Nova Scotia-Newfoundland region is part of the hemlock-northern hardwood forest, grading into the boreal forest zone at the northern end of Newfoundland (Braun, 1950). The northern hardwood forests are composed of Tsuga, Fagus, Acer, Betula, Pinus, Quercus, Castanea, and Fraxinus (Braun, 1950). Terrestrial pollen assemblages from this region typically are dominated by Pinus and Betula pollen, with abundant Quercus and Picea pollen. Alnus, Tsuga, Abies, Ulmus, Fagus, and Acer also are common in assemblages from the northern hardwood forest zone (Davis and Webb, 1975). Offshore from this region, Pinus and Picea are very abundant; Abies, Betula, Quercus, Tsuga, and Alnus also are important components of the offshore pollen assemblages (Mudie, 1982). These pollen spectra closely resemble those from Hole 646B; the primary differences are in the higher abundances of Pinus pollen and the presence of Sciadopitys in Hole 646B.

Estimates of Pliocene Temperature and Precipitation

Based on modern values for temperature and precipitation for the site off the coast of Newfoundland, I estimate that the source area for pollen preserved in Hole 646B had a mean annual temperature about 3.5° C warmer than present and mean annual precipitation at least 20 cm greater. Presently, Newfoundland has a mean annual temperature of 2-4.5° C, with mean January temperatures of -7° to -12° C and mean July temperatures of 15° C. Labrador, the proposed source area for the Pliocene pollen under study, has a mean annual temperature ranging from -1° to -4° C, mean January temperatures of -12° to -18° C, and mean July temperatures of 10-13° C (NAVAIR, 1981; Thomas, 1953; Hare and Hay, 1974).

Comparison with Other Pliocene Floras

Other Pliocene sites located at similar to higher latitudes uniformly show evidence of a warmer Pliocene climate than present. In Reuverian strata of the Netherlands and the Red Crag of East Anglia, the pollen of Pinus and taxodiaceous plants are abundant along with Sciadopitys, Tsuga, Carya, and other taxa characteristic of the "hemlock-northern hardwoods" zone (Zagwijn, 1974; West, 1977; Zalasiewicz, et al., 1988). Similarly, in Mactra Zone strata of the Tjörnes Sequence in Iceland, the pollen of Pinus, Picea, Castanea, Quercus, and dwarf shrubs are common (Akhmetiev, et al, 1978; Schwarzbach and Pflug, 1957; Willard, unpub. data). Pollen assemblages from ODP Hole 642 in the Norwegian Sea collected around the 3.0 Ma time interval are very similar to those of Hole 646B; Pinus pollen is dominant, Picea is subdominant, and Quercus, Sciadopitys, and Tsuga are common components of the flora (Willard and Dowsett, in prep.). Samples from the Gubik Formation in northern Alaska also provide evidence of a Picea-Betula-dominated boreal forest during Late Pliocene time; these samples were collected at least 300 km north of the present northern limit of Picea (Nelson and Carter, 1985). On the northern tip of Greenland itself, the Kap Kobenhavn Formation has preserved macro- and microfloral evidence of a boreal forest in what presently is arctic tundra (Funder, et al., 1985). Although these units are somewhat younger than samples from Hole 646B, they provide evidence of a significantly warmer Greenland during Plio-Pleistocene time, with dominance of Betula pollen and abundant Picea, Larix, and Pinus pollen (Bennike, 1990). The presence of such a flora in Plio-Pleistocene time is consistent with southern Greenland as at least a partial source of pollen preserved in Hole 646B.

CONCLUSIONS

Pollen abundance data from Late Pliocene samples in ODP Hole 646B are representative of vegetation found in the hemlock-northern hardwoods vegetation zone. Probable source areas for the pollen are Labrador or eastern Quebec, which presently are part of the circumpolar boreal forest. Squared chord distances calculated for samples from Hole 646B indicate that the most similar modern sample was collected off the east coast of Newfoundland, and other sites with low SCDs are located east of Nova Scotia. The source area for the pollen in Hole 646B clearly was warmer during Pliocene time with higher levels of precipitation. It is estimated that mean annual temperature was at least 3.5° C warmer and that mean annual precipitation was at least 20 cm greater than present. These estimates are consistent with those based on dinoflagellates (Edwards, et al., 1991) that warmer conditions prevailed at Hole 646B during the Pliocene.

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