

24. PLIOCENE AND PLEISTOCENE PALYNOSTRATIGRAPHY AT ODP SITES 646 AND 647, EASTERN AND SOUTHERN LABRADOR SEA¹

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ABSTRACT

Pliocene and Pleistocene sediments from ODP Hole 647A in the south central Labrador Sea and Hole 646B off southwest Greenland were sampled at 1.5-m intervals for studies of terrestrial and marine palynomorphs, including pollen, spores, dinocysts, and acritarchs. The dinocyst assemblages suggest that surface-water masses were cool-temperate to subarctic during most of the Pliocene and Pleistocene. The occurrence of a few warm-temperate indicators, notably *Impagidinium* species and *Polyspaeridium zoharyi*, suggests almost continuous northward advection of warm North Atlantic Drift into the Labrador Sea. A major decrease in dinocyst diversity and abundance marks the late Pliocene to early Pleistocene interval. The abundance of acritarchs in Pliocene sediments off southwest Greenland suggests high productivity, which may reflect nutrient flux from the shelf or upwelling; productivity appears to have been much lower at the central Labrador Sea site. Pollen and spore concentrations also decrease from the late Pliocene to early Pleistocene. This diminution probably reflects the impoverishment of vegetation and southward migration of the eastern Canadian tree line at the onset of climatic cooling and glaciation.

INTRODUCTION

During Leg 105, holes were drilled in Cenozoic sediments at two sites in the Labrador Sea (Fig. 1): (1) Site 647, located on the abyssal plain (water depth = 3862 m) at the southern edge of the central Labrador Sea (53°19.87'N, 45°15.72'W); and (2) Site 646, on the continental rise (water depth = 3451 m) off southwest Greenland (58°12.56'N, 48°22.15'W). Drilling at these sites provided a unique opportunity to study the biostratigraphy and climatostratigraphy of the high-latitude northwest Atlantic in a region that has been strongly affected by the late Cenozoic glaciations. The first occurrence of ice-rafted debris, which indicates glacial activity, is dated at about 2.6-2.5 Ma at both Sites 646 and 647 (Srivastava, Arthur, et al., 1987), as recorded elsewhere in the North Atlantic (e.g., Backman, 1979; Shackleton et al., 1984; Eldholm, Thiede, et al., 1987).

Pliocene-Pleistocene sediments from Holes 647A and 646B were sampled at about 1.5-m intervals for palynological analyses to provide a regional dinocyst and acritarch stratigraphy and to reconstruct changes that occurred in surface-water masses (dinocysts and acritarchs) and terrestrial vegetation (pollen and spores) as a result of the late Cenozoic cooling.

METHODS

Samples were prepared for palynological analysis using the following techniques.

1. Measuring the sample volume (usually between 5 and 10 cm³) by immersion in a graduated cylinder.
2. Spiking the sample with an aliquot volume (1.00 mL) of a calibrated suspension of *Eucalyptus globulus* pollen grains.
3. Sieving at 125 and 10 μm with distilled water to eliminate coarse sand and gravel, fine silt, and clay particles;
4. Treating with cold 10% HCl (until visible reaction ceases) to remove carbonates.

5. Treating with repeated hot 52% HF (1 to 12 hr) to dissolve silicate minerals.

6. Treating with hot 10% HCl (15 min) to eliminate fluorosilicates formed during the reaction with HF.

7. Sieving at 10 μm to clean the preparation.

8. Mounting the residual sample in glycerine gel on microscope slides.

This preparation method limits the losses that can result from strong chemical treatments, such as acetolysis (Mudie, 1980) or nitric acid treatment (de Vernal et al., 1983; Mudie, 1986). However, organic and mineral remains are often abundant. Thus, only a few samples were reprocessed to obtain clean specimens for photography. These samples were immersed in an ultrasonic bath for 30 to 60 s and then sieved at 20 μm.

The palynomorph concentrations were calculated on the basis of the marker-grains method (Matthews, 1969). The *Eucalyptus globulus* suspension used for the source of marker grains was calibrated by several counts on a hemacytometer. This method is accurate to approximately 10%-12% for a 0.95 confidence interval (de Vernal et al., 1987).

The index to genera and species of Lentini and Williams (1985) was used as reference for the dinoflagellate cyst nomenclature. New cysts and other microplankton are described in the "Systematic Descriptions" section (this chapter).

HOLE 646B

During drilling at Site 646, an almost complete upper Miocene to Holocene sedimentary sequence was recovered. The Pliocene-Pleistocene interval is represented by approximately 484 m of sediment. This interval is characterized by apparently uniform sedimentation rates of 7.9 to 9.6 cm/k.y., averaging 9.0 cm/k.y. (Srivastava, Arthur, et al., 1987). Two main lithological units were distinguished.

1. Unit I (236.4-0 mbsf; ~2.6-0 Ma) was defined by the presence of gravel and cobble originating from ice rafting. This unit is of late Pliocene to Holocene age. Sediments are predominantly grayish silty clays, clayey silts, and clayey muds. Terrigenous material dominates, with some intervals rich in biogenic carbonates and silicates. Deposits are mainly fine-grained, either homogeneous or bioturbated, and show little evidence of turbidites.

2. Unit II (766.7-236.4 mbsf; ~8.5-2.6 Ma) is uniform and consists mainly of bioturbated gray silty clays and clays of late

¹ Srivastava, S.P., Arthur, M., Clement, B., et al., 1989. *Proc. ODP, Sci. Results*, 105: College Station, TX (Ocean Drilling Program).

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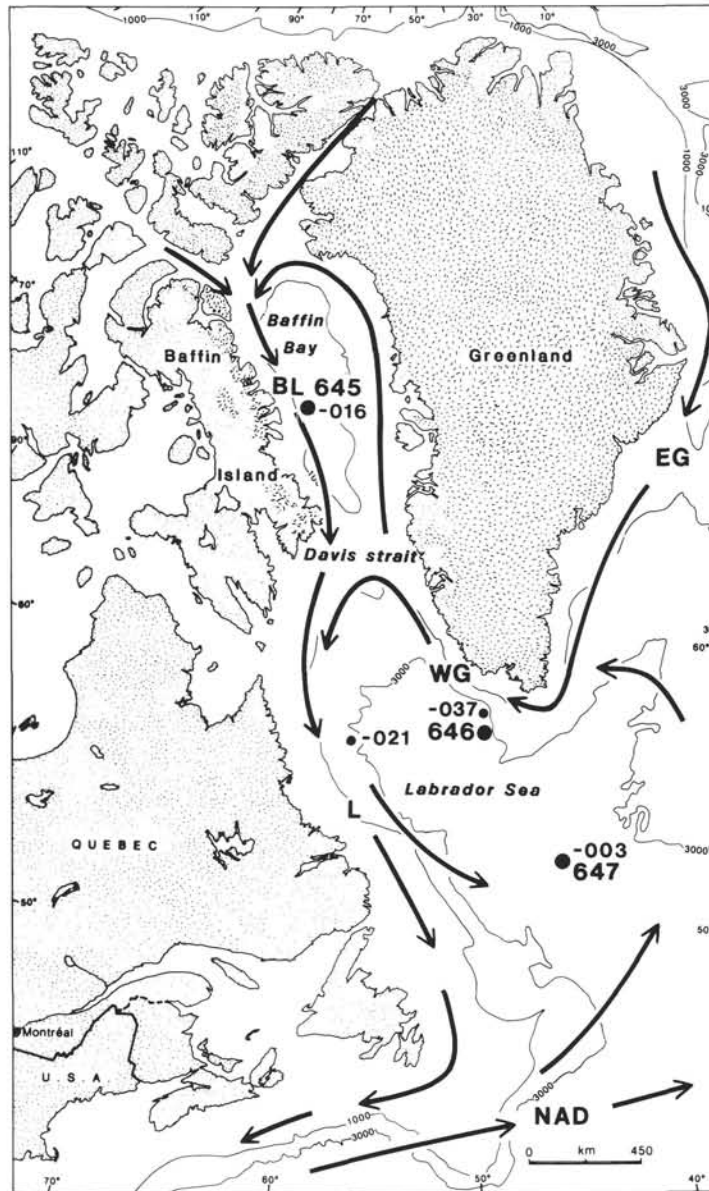


Figure 1. Location map of ODP Sites 645, 646, and 647 and of site survey piston cores. The modern surface-water circulation is indicated by arrows: NAD = North Atlantic Drift; EG = East Greenland Current; WG = West Greenland Current; L = Labrador Current; and BL = Baffin Land Current.

Miocene to late Pliocene age. No evidence of turbidite sedimentation exists.

Recovery of Pliocene-Pleistocene sediments was 61%. Because of this poor core recovery, the magnetostratigraphic data do not provide a continuous time control. Thus, the chronostratigraphic framework depends strongly on biostratigraphic data, notably planktonic foraminifers and calcareous nannofossils. Berggren et al.'s time scale (1985) is used here and is defined mainly by the planktonic foraminifer stratigraphy (Srivastava, Arthur, et al., 1987). However, the early-late Pleistocene boundary corresponds to the Brunhes/Matuyama magnetic reversal recorded at 59 mbsf.

Palynomorphs were analyzed and counted in 155 samples from core-catcher samples and core sections above 484 mbsf (lower Pliocene to Holocene sediments) at Hole 646B. The palynological results are compiled in Table 1 and summarized in Fig-

ure 2. Additional high-resolution (20-cm sampling intervals) palynological studies of upper Pleistocene sediments at Site 646 are reported by Aksu et al. (this volume).

Marine Palynoflora

Dinocyst and Acritarch Stratigraphy

The assemblage composition of the marine palynoflora varies considerably through the Pliocene-Pleistocene sequence drilled at Site 646 (Fig. 3). Note that several taxa characteristic of the Pliocene interval have not been reported previously in the literature. In addition, acritarchs that are rarely included in Neogene palynostratigraphies constitute a large part of the Pliocene marine palynoflora. Based on the acme occurrences of the most common taxa, five assemblage intervals can be defined as follows.

Table 1. Palynomorph concentrations in analyzed samples from Hole 646B.

Lab no.	Core-section interval (cm)	Total dinocysts	Peridiniaceae	Acritarchs	Pollen	Spores	Terrestrial reworked palynomorphs	Marine reworked palynomorphs	<i>Pediastrum</i>	Tasmanideae
UQP-03/6	1H, CC	59	14	—	82	28	73	4	—	—
UQP-03/7	2H, CC	112	4	—	65	4	53	12	—	—
UQP-03/8	3H, CC	98	4	—	31	4	39	—	—	—
UQP-04/1	4H, CC	8,717	672	—	133	108	86	—	—	—
UQP-04/2	5H, CC	94	—	—	26	3	267	—	—	—
UQP-04/3	6H, CC	56	35	—	63	21	278	21	—	—
UQP-04/4	7H, CC	441	166	—	64	6	212	24	6	—
UQP-04/5	9H, CC	136	7	—	30	9	24	—	—	—
UQP-04/6	10H, CC	166	—	—	204	42	57	7	—	—
UQP-04/7	11H, CC	605	3	—	95	58	61	—	—	—
UQP-93/1	12H-1, 75-80	45	—	—	143	36	89	8	—	—
UQP-93/2	12H-2, 75-80	543	270	—	997	220	442	10	—	10
UQP-93/4	12H-4, 75-80	218	—	—	149	43	26	—	—	—
UQP-93/5	12H-5, 75-80	1,133	—	—	667	57	185	—	—	—
UQP-04/8	12H, CC	461	318	—	563	150	406	—	—	—
UQP-93/6	13H-1, 20-25	493	—	—	124	69	29	—	—	—
UQP-94/1	13H-2, 20-25	217	217	—	2,386	1,798	186	—	434	—
UQP-94/2	13H-3, 20-25	176	—	—	156	69	137	—	—	—
UQP-94/3	13H-3, 20-25	61	—	—	79	16	95	8	—	—
UQP-94/4	13H-5, 20-25	2,797	97	—	1,021	433	587	—	—	—
UQP-94/5	13H-6, 20-25	14	—	—	91	28	168	—	—	—
UQP-05/1	13H, CC	407	85	—	43	17	159	—	—	—
UQP-94/6	14H-1, 35-40	169	—	—	381	150	94	6	—	—
UQP-95/1	14H-2, 35-40	194	26	—	283	142	52	—	—	—
UQP-95/2	14H-3, 35-40	809	255	—	783	298	111	—	25	—
UQP-95/3	14H-4, 35-40	395	7	—	322	73	100	—	—	—
UQP-95/4	14H-5, 35-40	905	24	99	459	149	174	—	—	—
UQP-95/5	14H-6, 35-40	291	—	—	436	66	875	93	—	13
UQP-05/2	14H, CC	80	6	—	74	24	264	12	—	—
UQP-05/3	16X, CC	182	9	144	134	9	180	9	—	—
UQP-05/4	17X, CC	—	—	—	76	9	19	—	—	—
UQP-95/6	18X-1, 40-45	45	6	—	269	45	745	45	6	—
UQP-96/1	18X-2, 28-33	80	—	—	199	42	137	32	—	—
UQP-96/2	18X-3, 28-33	1,789	40	350	316	270	139	20	—	—
UQP-05/5	18X, CC	87	—	9	70	35	360	9	—	—
UQP-05/6	19X, CC	302	5	—	65	25	241	—	—	—
UQP-96/3	20X-1, 27-32	11,004	447	6,351	9,393	1,073	894	89	—	—
UQP-96/4	20X-2, 27-32	148	80	34	1,231	578	318	80	22	—
UQP-96/6	20X-4, 27-32	96	19	9	404	127	368	48	—	—
UQP-97/2	20X-6, 27-32	231	50	115	123	33	41	—	—	91
UQP-05/7	20X, CC	78	35	—	364	69	459	9	—	—
UQP-97/3	21X-1, 17-22	139	—	—	153	56	1,248	56	—	—
UQP-97/4	21X-2, 17-22	285	143	109	484	219	54	—	—	12
UQP-97/5	21X-3, 17-22	1,677	121	161	891	179	122	19	—	—
UQP-97/6	21X-4, 17-22	10,455	734	7,315	1,102	601	635	33	—	—
UQP-98/1	21X-5, 17-22	268	—	28	240	139	83	—	—	—
UQP-05/8	21X, CC	943	409	46	613	145	26	7	—	7
UQP-98/2	22X-1, 65-70	1,191	794	122	2,230	855	1,764	244	31	—
UQP-98/3	22X-2, 64-69	438	158	65	764	214	270	9	—	28
UQP-98/4	22X-3, 65-70	468	19	370	195	107	127	—	—	—
UQP-98/5	22X-4, 64-69	1,148	130	521	496	52	52	—	—	—
UQP-98/6	22X-6, 64-69	4,817	—	770	514	128	—	—	—	—
UQP-99/1	22X-7, 5-10	1,864	757	728	1,864	495	233	—	—	29
UQP-06/1	22X, CC	3,000	12	532	551	80	123	6	—	—
UQP-99/2	23X-1, 35-40	3,513	569	1,610	1,530	113	82	16	—	33
UQP-99/3	23X-2, 35-40	3,686	1,814	1,555	2,333	1,295	201	—	—	144
UQP-99/4	23X-3, 35-40	2,302	42	2,055	525	224	75	—	—	—
UQP-99/5	23X-4, 34-39	5,243	228	4,859	603	137	64	—	—	9
UQP-99/6	23X-5, 34-39	2,463	488	1,210	945	148	127	21	—	106
UQP-06/2	23X, CC	1,827	94	1,544	1,132	141	47	—	—	35
UQP-06/3	25X, CC	1,140	161	630	316	96	97	16	—	8
UQP-100/1	26X-1, 39-44	7,762	519	5,934	2,077	225	249	22	—	67
UQP-100/2	26X-2, 39-44	5,052	57	4,884	509	113	209	9	9	—
UQP-100/3	26X-3, 39-44	7,838	581	6,764	1,015	285	84	11	—	36
UQP-100/4	26X-4, 39-44	9,088	1,108	6,412	2,677	198	142	—	—	28
UQP-100/5	26X-5, 39-44	5,807	550	4,965	1,436	240	86	—	—	34
UQP-06/4	26X, CC	3,683	227	3,334	370	360	52	—	—	—
UQP-06/5	28X, CC	10,747	255	3,213	2,052	255	154	50	—	123
UQP-100/6	29X-1, 40-45	2,559	163	2,119	2,669	435	163	—	—	54
UQP-101/1	29X-2, 40-45	1,187	143	1,014	992	338	130	—	—	78
UQP-101/2	29X-3, 40-45	1,285	149	1,088	1,288	853	64	—	—	43
UQP-101/3	29X-4, 40-45	1,670	101	1,393	1,630	1,002	127	25	—	51
UQP-101/4	29X-5, 40-45	2,159	21	1,965	1,489	691	64	—	—	—
UQP-101/5	29X-6, 40-45	2,930	374	1,078	1,932	528	22	—	—	44
UQP-06/6	29X, CC	2,470	113	1,224	2,084	272	68	—	—	—
UQP-101/6	30X-1, 39-44	1,017	261	639	1,005	456	117	—	—	117
UQP-102/2	30X-3, 39-44	4,163	605	985	1,486	345	138	—	—	35
UQP-102/3	30X-4, 39-44	1,972	374	1,278	1,578	354	118	—	—	79

Table 1 (continued).

Lab no.	Core-section interval (cm)	Total dinocysts	Peridiniaceae	Acritarchs	Pollen	Spores	Terrestrial reworked palynomorphs	Marine reworked palynomorphs	<i>Pediastrum</i>	Tasmanideae
UQP-102/4	30X-5, 39-44	1,231	215	873	1,117	501	71	—	—	—
UQP-06/7	30X, CC	2,615	1,383	1,153	1,518	672	376	16	—	16
UQP-108/2	31X-1, 27-32	2,451	480	1,173	2,185	640	80	—	—	53
UQP-108/3	31X-2, 27-32	5,733	800	2,867	2,221	671	232	26	—	129
UQP-108/4	31X-3, 27-32	5,450	406	2,944	3,284	812	177	34	—	203
UQP-108/6	31X-4, 27-32	7,629	494	2,166	3,301	494	190	—	—	152
UQP-108/6	31X-5, 27-32	1,140	209	835	610	225	144	16	—	—
UQP-06/8	31X, CC	3,080	373	1,291	1,412	252	171	—	—	31
UQP-110/2	32X-1, 18-23	4,139	772	2,941	1,447	331	436	36	—	181
UQP-110/4	32X-3, 18-23	6,041	1,326	4,272	3,487	1,572	147	—	—	—
UQP-110/6	32X-5, 18-23	1,703	700	880	1,783	180	60	20	—	—
UQP-111/1	32X-6, 18-23	2,919	321	2,321	1,769	574	138	—	—	22
UQP-07/1	32X, CC	1,535	642	791	1,459	493	224	—	—	—
UQP-111/2	33X-1, 25-30	5,374	432	4,572	2,095	205	477	67	22	—
UQP-111/3	33X-2, 25-30	6,915	234	6,188	1,803	858	260	—	—	26
UQP-111/4	33X-3, 25-30	2,851	106	2,652	635	412	42	—	—	11
UQP-111/5	33X-4, 25-30	17,458	456	16,742	1,401	1,008	24	—	—	—
UQP-111/6	33X-5, 25-30	14,560	593	13,727	2,992	1,928	89	—	—	—
UQP-07/2	33X, CC	3,022	109	2,761	490	77	122	—	—	—
UQP-07/3	34X, CC	7,920	1,241	2,547	2,482	514	300	21	—	86
UQP-112/1	35X-1, 22-28	4,815	485	2,207	2,994	703	97	—	—	24
UQP-112/2	35X-2, 22-28	1,370	279	804	281	234	67	—	—	—
UQP-112/3	36X-1, 82-87	4,822	417	2,169	1,169	626	125	21	—	43
UQP-112/4	36X-2, 71-76	5,064	216	1,458	685	216	198	—	—	18
UQP-112/5	36X-3, 8-13	6,090	1,251	1,467	1,644	645	172	129	—	43
UQP-112/6	36X-4, 53-55	1,156	366	405	1,194	656	115	—	—	—
UQP-113/2	36X-5, 8-13	1,586	579	406	1,487	792	19	—	—	38
UQP-113/4	36X-6, 114-119	1,549	351	198	998	824	61	—	—	—
UQP-07/4	36X, CC	1,746	140	60	160	60	80	—	—	—
UQP-114/1	37X-1, 30-35	3,258	65	1,404	509	359	49	—	—	49
UQP-114/3	37X-3, 30-35	2,940	136	833	734	170	—	17	—	34
UQP-114/4	37X-4, 30-35	3,854	118	3,066	1,217	280	59	—	—	29
UQP-114/5	37X-5, 30-35	10,747	201	10,496	451	100	—	—	—	—
UQP-115/1	37X-7, 30-35	4,888	24	2,856	1,050	288	48	—	—	48
UQP-115/2	38X-1, 58-61	5,684	96	1,290	828	135	77	—	—	96
UQP-115/4	38X-3, 53-56	2,129	294	1,404	883	272	45	—	—	—
UQP-115/5	38X-4, 58-61	1,707	162	675	1,724	513	81	—	—	54
UQP-116/1	38X-6, 55-58	1,961	175	1,229	833	137	39	—	—	39
UQP-07/6	38X, CC	584	47	374	498	259	86	—	—	—
UQP-116/2	39X-1, 19-24	8,968	400	4,108	1,772	396	—	—	—	41
UQP-116/3	39X-2, 19-24	17,637	153	5,956	2,376	333	77	—	—	25
UQP-116/4	39X-3, 19-24	20,384	31	11,067	822	806	62	—	31	—
UQP-116/5	39X-4, 19-24	32,966	651	11,072	1,866	690	51	51	—	77
UQP-116/6	39X-5, 19-24	15,982	150	5,160	2,237	437	72	—	—	—
UQP-117/1	39X-6, 19-24	6,220	167	2,296	1,169	334	84	—	—	42
UQP-07/7	39X, CC	2,812	82	1,078	817	278	16	—	—	—
UQP-117/2	40X-1, 21-26	12,149	123	2,518	1,109	260	260	—	—	26
UQP-117/3	40X-2, 12-16	22,273	200	8,267	1,850	389	266	—	—	82
UQP-117/4	40X-3, 21-26	13,472	50	5,666	1,058	334	167	—	—	56
UQP-117/5	40X-4, 21-26	16,137	58	7,661	2,242	815	29	—	—	29
UQP-118/1	40X-6, 21-26	20,597	92	6,495	3,897	1,206	92	—	—	92
UQP-118/3	41X-2, 26-30	9,626	250	3,865	1,825	286	—	—	—	250
UQP-118/4	41X-3, 27-31	9,805	429	2,683	1,564	268	161	—	—	54
UQP-118/5	41X-4, 27-31	5,111	185	1,549	696	84	101	—	—	17
UQP-118/6	41X-5, 27-31	7,150	276	2,300	863	230	23	—	—	—
UQP-119/1	41X-6, 27-31	7,870	247	2,793	1,432	437	112	—	—	19
UQP-08/1	41X, CC	3,383	85	1,117	423	101	51	—	—	—
UQP-119/2	42X-1, 16-21	10,420	75	6,385	977	275	100	—	—	20
UQP-119/3	42X-2, 9-14	8,805	102	4,572	2,172	1,118	127	—	25	25
UQP-119/4	42X-3, 9-14	3,444	271	1,899	730	355	63	—	—	21
UQP-119/5	42X-4, 9-14	5,979	118	2,295	717	118	134	—	—	34
UQP-119/6	42X-5, 8-14	9,300	266	2,398	1,066	506	53	—	—	106
UQP-120/1	42X-6, 17-22	2,600	119	739	787	429	72	—	—	—
UQP-08/2	42X, CC	3,418	1,386	531	1,006	132	94	19	—	37
UQP-120/2	43X-3, 111-116	9,959	30	4,949	1,131	763	91	—	—	30
UQP-08/3	43X, CC	4,326	473	1,072	491	127	55	18	—	18
UQP-08/4	44X, CC	2,863	553	1,259	582	57	57	—	—	—
UQP-08/5	45X, CC	4,717	80	4,029	704	144	48	—	—	—
UQP-120/3	46X-2, 64-67	6,398	232	4,630	1,328	181	90	—	—	—
UQP-08/6	46X, CC	720	20	300	90	38	9	—	—	—
UQP-08/7	47X, CC	2,631	54	2,509	177	68	81	13	—	—
UQP-08/8	48X, CC	1,701	169	543	241	12	24	—	—	—
UQP-120/4	49X-2, 64-67	6,548	20	2,666	868	197	79	—	—	—
UQP-09/1	49X, CC	3,143	66	2,081	136	44	—	—	—	—
UQP-120/5	50X-1, 72-77	5,559	34	5,352	1,167	720	34	—	—	—
UQP-120/6	50X-3, 0-5	3,177	46	1,832	186	231	232	23	23	23
UQP-09/2	50X, CC	1,061	37	689	223	73	73	37	—	—

Note: Total dinocysts include dinoflagellate cysts and acritarchs.

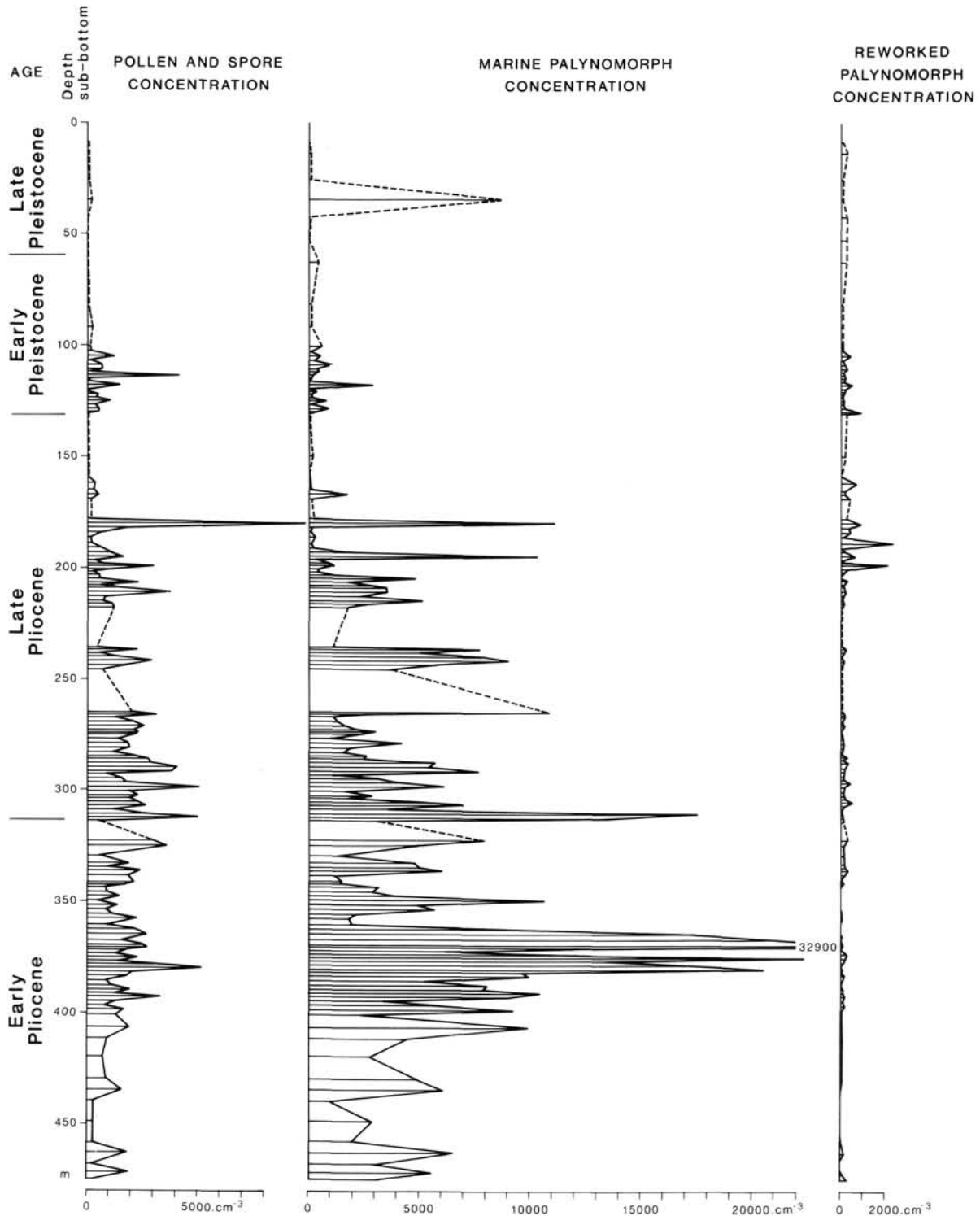


Figure 2. Palynomorph concentrations vs. depth at Hole 646B. Marine palynomorphs include dinocysts and acritarchs. In the text, we frequently refer to common or abundant occurrence of taxa, which correspond to concentrations of 100-1000 cysts/cm³ and >1000 cysts/cm³, respectively.

1. Interval V (484-435 mbsf; ~5.4-4.8 Ma); relatively low taxonomic diversity characterizes this interval, which is of probable earliest Pliocene age. *Brigantedinium* sp., *Nematosphaeropsis labyrinthea*, *Filisphaera filifera*, *Cymatiosphaera* sp. I, and *Batiacasphaera sphaerica* constitute the dominant taxa.
2. Interval IV (435-361 mbsf; ~4.8-4.0 Ma), this early Pliocene interval is defined by the stratigraphic range and abun-

dance of cyst type I. The assemblages are dominated by this unusual cyst-form, along with *Cymatiosphaera* sp. I, *Brigantedinium* sp., *Nematosphaeropsis labyrinthea*, *Filisphaera filifera*, *Corrudinium* sp. I, and *Batiacasphaera sphaerica*, which are all common to abundant in most samples. *Operculodinium crasum* and *Operculodinium longispinigerum* also are present in most samples. This assemblage interval contains the highest tax-

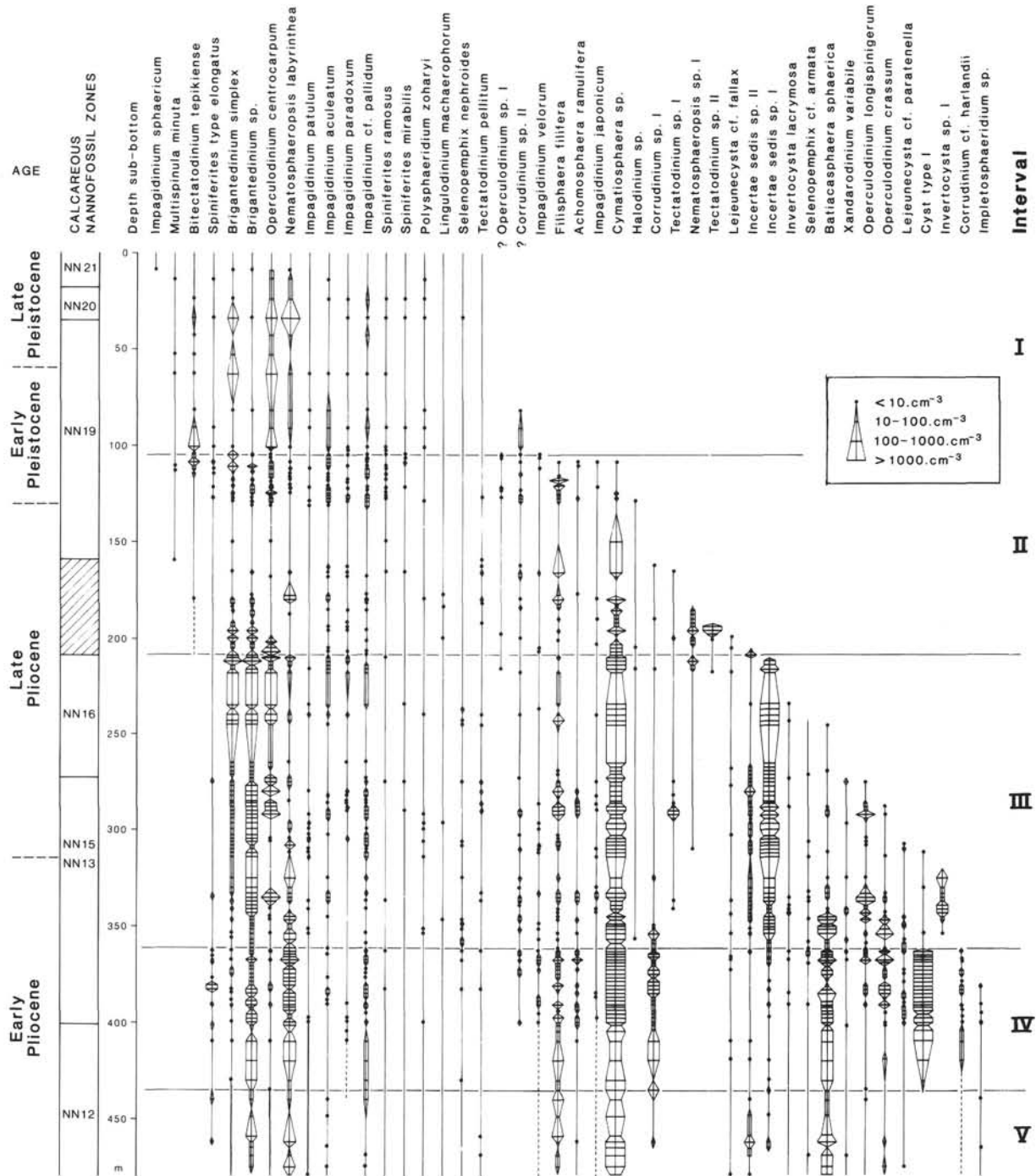


Figure 3. Stratigraphic range of dinoflagellate cysts and acritarchs in Pliocene-Pleistocene sediments of Site 646.

onomic diversity and concentrations observed in the Pliocene-Pleistocene sequence of Site 646.

3. Interval III (361–209 mbsf; ~4.0–2.3 Ma); this interval covers the early-late Pliocene transition, which is distinguished by common-to-abundant acritarchs, referred to here as *Incertae sedis* I, that belong to the Pterospermopsis subgroup of Downie (1973). The acritarchs *Cymatiosphaera* sp. I and *Incertae sedis* I dominate the assemblages, accompanied by the dinocysts *Brigantedinium simplex*, *Filisphaera filifera*, *Nematosphaeropsis labyrinthea*, and *Operculodinium centrocarpum*. The lower part of the interval is characterized by the last common occur-

rences of *Corrudinium* sp. I, *Batiacasphaera sphaerica*, *Operculodinium longispinigerum* and *Operculodinium crassum*. The base of the interval also is marked by the occurrence of *Invertocysta* sp. I, which has a restricted stratigraphic range at Site 646.

4. Interval II (209–105 mbsf; ~236–123 Ma) this interval includes the upper Pliocene and the lowest Pleistocene. The top of interval II is distinguished by the last occurrence of several taxa, notably *Filisphaera filifera* and *Cymatiosphaera* sp. I, which dominate the upper Pliocene assemblages. The common occurrence of *Nematosphaeropsis* sp. I and *Tectatodinium* sp. II marks the base of this zone.

5. Interval I (105–0 mbsf; ~1.2–0 Ma); the top interval includes most of the Pleistocene and it is essentially characterized by dinocyst species that are common in modern marine sediments of the Labrador Sea, e.g., *Operculodinium centrocarpum*, *Nematosphaeropsis labyrinthea*, and *Brigantedinium simplex* (Mudie, 1980; de Vernal, 1986; de Vernal and Hillaire-Marcel, 1987a, 1987b). The last appearance of *Corrudinium* sp. II occurs near the base of this interval (~82 mbsf).

Except for Interval V, the diversity and abundance of dinocysts and acritarchs at Site 646 decreases gradually from the early Pliocene to the early Pleistocene. However, an abrupt disappearance of seven taxa marks the Interval II/I transition, which is early Pleistocene in age.

Paleoenvironmental Interpretation

Large fluctuations in the total abundance of marine palynomorphs occur throughout the Pliocene-Pleistocene interval: concentrations vary from 0 to 32,900 cysts/cm³, with the amplitude generally increasing uphole. Assuming uniform sedimentation rates, these changes in concentrations of up to five orders of magnitude must reflect fluctuations in production of dinocysts and acritarchs influxes that, to some extent, reflect fluctuations in the phytoplankton productivity. Most modern dinocysts correspond to a dormant stage in the life cycle of motile dinoflagellates (e.g., Wall and Dale, 1968). Not all dinoflagellate genera produce fossilizable sporopollenin cysts, and the number of cysts does not always reflect the size of the motile-stage plankton (Dale, 1976, 1983). Thus, the dinocyst assemblages provide only a fragmentary picture of the dinoflagellate populations, but an overall correlation between total annual phytoplankton population size and cyst production does exist. A few prasinophytes also produce sporopollenin phycocysts that are represented by *Pterospermopsis*-group cysts, notably the acritarch *Cymatiosphaera*. Dinocysts and prasinophyte cysts constitute meroplanktonic populations that are approximate indicators of phytoplankton productivity.

The intervals V to III, which include most of the Pliocene (~5.4 to 2.3 Ma), are characterized by high marine palynomorph concentrations (>2000/cm³), which indicates a high primary productivity. However, in these intervals concentrations show fluctuations of two orders of magnitude, which may correspond to productivity cycles, changes in sedimentation rates and processes, or both. In intervals II and I (~2.3 to 0 Ma), the average cyst concentration is less than 1000/cm³, which suggests a trend of decreasing productivity from Pliocene to Pleistocene. The amplitude of cyclical variations in concentrations also increases in parts of this interval (Fig. 2).

High-resolution studies of the upper Pleistocene sediments at Site 646 (Aksu et al., this volume) and other Labrador Sea locations (Cores 84-030-021, 84-030-003, and HU-75-037; de Vernal and Hillaire-Marcel, 1987a, 1987b) reveal important fluctuations in dinocyst concentrations that directly correlate with the $\delta^{18}\text{O}$ stratigraphy: the rich assemblages occur in interglacial stages, while the low concentrations mark glacial episodes. At Site 646, the strong diminution in marine palynomorph concentrations recorded at the base of interval II (~2.3 Ma) occurs slightly above the first ice-rafted deposit (~2.6 Ma). The late Pliocene decrease in dinocyst concentrations, interpreted in terms of reduced productivity, seems related to the initiation of glaciations at high latitudes.

Despite large variations in their taxonomic diversity and composition, the dinocyst assemblages are predominantly boreal in character throughout the Pliocene-Pleistocene. The exact environmental affinities of many dinocyst species are presently unknown. However, the dominant components of Site 646 assemblages are found most commonly in Neogene and modern sediments of high-latitude regions, such as Bering Sea and North

Pacific (Bujak, 1984), western North Pacific (Matsuoka, 1983), central and eastern North Atlantic (Mudie, 1986; Harland, 1979) and Norwegian Sea (Mudie, 1988). In addition, the co-occurrence of *Operculodinium centrocarpum* and *Nematosphaeropsis labyrinthea*, which dominate modern dinocyst assemblages of the Labrador Sea (de Vernal, 1986; de Vernal and Hillaire-Marcel, 1987a), suggests boreal cool-temperate to subarctic conditions in surface waters. The presence of the subarctic *Spiniferites elongatus* species complex (Harland et al., 1980) also indicates boreal to subpolar waters. *Filissphaera filifera*, a species found in Pliocene sediments of the Arctic Ocean (Aksu and Mudie, 1985; Mudie, 1985) and Bering Sea (Bujak, 1984), is another indicator of cool water masses. During most of the Pliocene-Pleistocene, cool-temperate to subarctic conditions probably prevailed in the surface waters of the eastern Labrador Sea. However, notable occurrences of warm-temperate to subtropical taxa (*Impagidinium aculeatum*, *I. patulum*, *Spiniferites mirabilis*; e.g., Harland, 1983; Turon, 1984), indicate a southern influence and suggest an almost continuous penetration of the North Atlantic Drift into the eastern Labrador Sea.

The abundance of acritarchs (*Cymatiosphaera* sp. I and *Incertae sedis* I) in the Pliocene deposits may indicate a high primary productivity. *Cymatiosphaera* and similar morphotypes, e.g., *Incertae sedis* I, are resting cysts of prasinophytes (Boalch and Parke, 1971) which are generally associated with nearshore environments (Tappan, 1980). In the Quaternary fossil record, *Cymatiosphaera* has been reported exclusively from neritic or epicontinental marine environments, such as the Ariake Sea (Takahashi, 1971) and the Black Sea (Wall et al., 1973). In studies of Paleozoic sediments (al-Ameri, 1986), acritarchs with a *Pterospermopsis*-type of wall (as in *Cymatiosphaera* and *Incertae sedis* I and II) are produced in the outer neritic zones where the water depth is about 100–200 m. The abundance of acritarchs in Pliocene sediments from Site 646 therefore may reflect influx of neritic sediments, with subsequently enhanced primary productivity. Similarly, the common presence of peridinioid cysts (*Brigantedinium* spp., *Lejeunecysta* spp., and *Selenopemphix* spp.) and tasmanides, which are often associated with neritic-type environments (e.g., Tappan, 1980), also suggests influxes from the shelf. Alternatively, increased production of peridinioid cysts may be associated with upwelling conditions in oceanic environments (Wall et al., 1977; Matsuoka, 1985; Stein and Duffield, 1985). Abundant *Pterospermopsis*-type acritarchs also are commonly associated with diatom-rich sediments at DSDP Sites 607 and 611 from the North Atlantic (Mudie, 1986) and in the Norwegian Sea (Mudie, 1988), where they appear to reflect nutrient upwelling in a pelagic environment.

Terrestrial Palynoflora

Pollen and spores are common to abundant throughout the lower Pliocene to lower Pleistocene sedimentary sequence of Site 646 (Fig. 2), with concentrations of 500 to 5000/cm³ in most samples. Counts of more than 100 pollen and spores in several samples are reported in the percentage diagram illustrated in Figure 4. The diversity of the pollen and spore assemblages is low, as normally found in oceanic sediments because of aerodynamic or hydrodynamic selection during transportation. *Pinus* pollen grains, which have a saccate morphology favorable to long-distance atmospheric and hydrologic transport, are particularly over-represented in deep-sea sediments off eastern Canada (Mudie, 1980, 1982; Heusser, 1983). *Pinus* is the dominant taxon of the pollen assemblages at Site 646, accompanied mainly by *Picea*, *Betula*, *Tsuga*, *Lycopodium*, *Sphagnum*, and Polyodiaceae.

Despite fluctuations in percentages, the taxonomic composition of the pollen and spore assemblages is relatively uniform

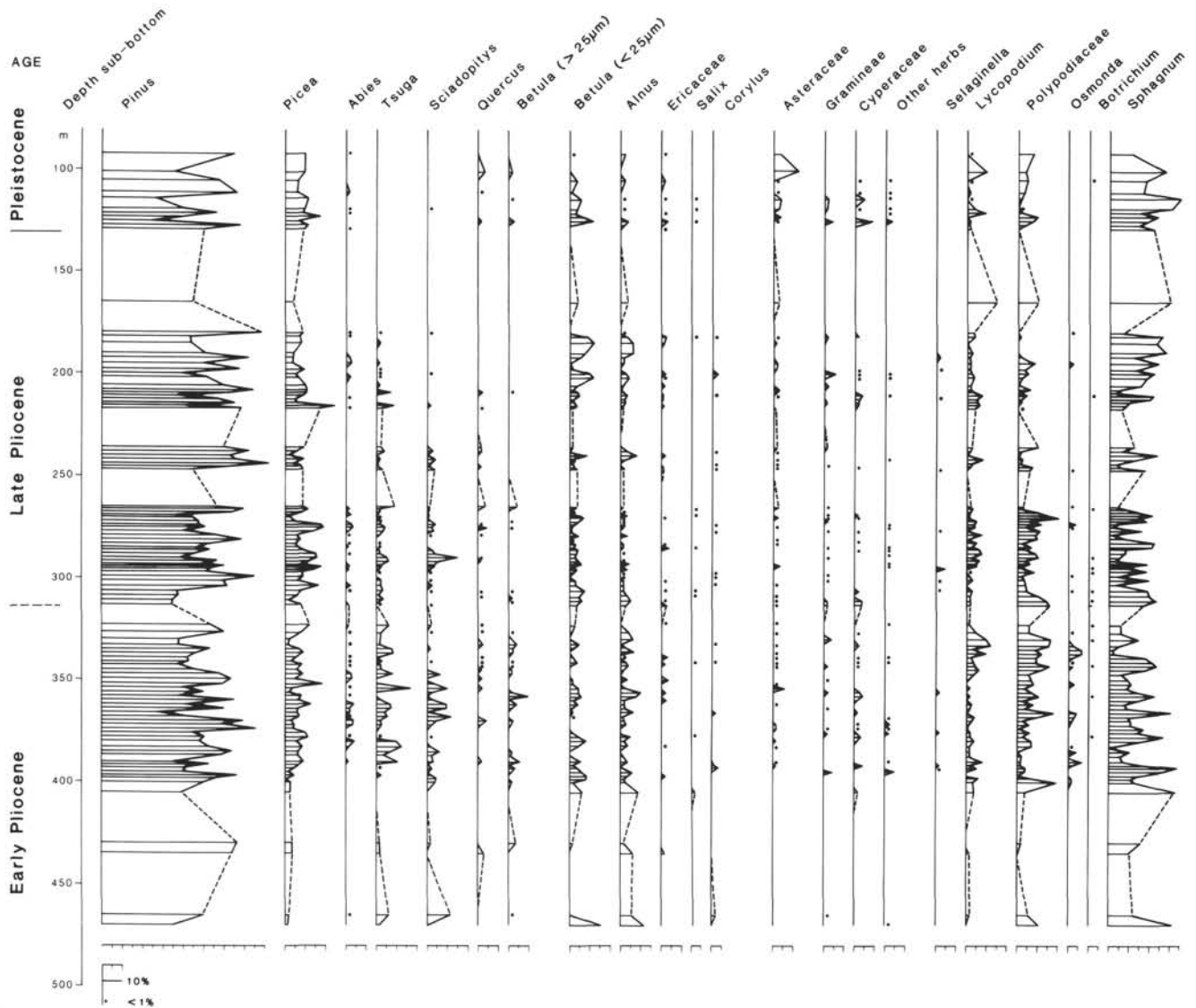


Figure 4. Summary diagram of pollen and spore percentages at Site 646. These percentages are based on sums that include all the pollen grains and spores counted. The spectra reported here consist of sums higher than 100 individuals in most cases; spectra with sums lower than 50 individuals are not reported. Because of the low diversity, 100 individuals may be considered statistically representative (Mudie, 1982). The genus *Betula* is subdivided into two categories on the basis of pollen grain dimension: pollen grains with a diameter of less than 25 μm probably represent shrub species, while larger grains are from tree taxa (Richard, 1970; Usinger, 1975). Several taxa are grouped into genera or families to simplify the results: *Lycopodium* spores include mainly *L. annotinum*, *L. selago*-type, and *L. clavatum*-type; the most common Asteraceae are *Artemisia* and undifferentiated Tubuliflorae; other herbs include mainly Polygonaceae, Cruciferae, Caryophyllaceae, and Chenopodiaceae pollen grains; *Alnus* is mainly represented by *A. crispa*, although *A. rugosa* sometimes was seen. The other taxa are grouped into genera because of the uncertainty of the species identification. Several taxa observed rarely are not reported in the diagram: notably *Ulmus*, *Fraxinus*, *Carya*, *Ostrya*, and *Nemopanthus*.

throughout the Pliocene-Pleistocene sequence. The only taxon with a limited stratigraphic range is *Sciadopitys*, which is restricted to Pliocene sediments. *Tsuga*, which is occasionally observed in Pleistocene sediments (Aksu et al., this volume), is also relatively abundant in the Pliocene sequence.

The pollen and spore assemblages show a boreal character, as indicated by the dominance of *Picea*, *Betula*, *Alnus*, *Sphagnum*, and Lycopodiaceae. By comparison with the modern distribution of pollen and spores in marine sediments off eastern North America, the assemblages at Site 646 suggest influxes ranging from mixed forest with boreal characteristics to open boreal forest or even shrub tundra (Mudie, 1982; Heusser, 1983). Thus, the terrestrial flora indicates the existence of humid cool-

temperate to subarctic climatic conditions in the source areas. Decreasing percentages of temperate trees, notably *Tsuga*, *Sciadopitys*, *Betula*, and *Quercus*, are recorded in the upper Pliocene sediments, which suggests a change in the dominant vegetational source from a cool-temperate mixed forest to a more boreal vegetation. The decreasing pollen concentrations also suggest reduced influxes, probably from an impoverishment of the vegetation cover.

Pollen and spores reach marine sediments by multiple pathways (e.g., Mudie, 1982); therefore, the source area is often difficult to determine with certainty. Influxes of pollen and spores depend strongly upon transportation by atmospheric and/or oceanic circulation. Nevertheless, comparison of the continental

palyostratigraphy with the upper Pleistocene stratigraphy at Site 646 (Aksu et al., this volume) and at nearby core sites (HU 75-37; de Vernal ad Hillaire-Marcel, 1986) reveals pollen influxes from southeastern Canada, mainly controlled by southwest-northeast or west-southwest/east-northeast atmospheric transportation. Assuming pollen influxes dominated by aerial transportation throughout the Pliocene-Pleistocene and atmospheric trajectories similar to those of today, the pollen diagram for Site 646 (Fig. 4) should reflect the vegetational changes over southeastern Canada. Such an interpretation is probably oversimplified because the atmospheric paleocirculation pattern cannot be assumed to have been uniform during the Pliocene-Pleistocene interval. In addition, the possibility of significant influxes from Greenland and through the Greenland current cannot be totally discounted. Despite these difficulties in interpretation, it seems clear that the palyostratigraphy at Site 646 indicates boreal, cool-temperate, and subarctic conditions around the Labrador Sea throughout most of Pliocene and early Pleistocene. A significant impoverishment of the vegetation, probably from global cooling, is evident for the latest Pliocene-earliest Pleistocene interval.

Reworked Palynoflora

Reworked palynomorphs were observed in most of the samples from Site 646. These consist mainly of trilete spores, notably *Cicatricosisporites* and *Appendisporites*, and bisaccate pollen grains. These terrestrial palynomorphs are characterized by a high degree of compression and a brownish color. Reworked acritarchs and dinocysts also are present: *Veryhachium*, *Deflandrea* spp., and *Wetzeliellaceae* are the most common taxa. The recognizable reworked palynomorph assemblages reflect the erosion of Paleogene and older strata, although reworked younger material also may be present. The reworked palynomorphs are most abundant in the upper 210 m of sediments. This may be attributed to increased erosion caused by continental glaciations and fluctuations in relative sea levels. The occurrence of ice-rafted debris in this interval also is indicative of glacial activity.

HOLE 647A

The sediments drilled at Site 647 include large unconformities (Srivastava, Arthur, et al., 1987), with a sharp contact between mottled olive-yellow silty clays and gray silty muds that separates upper Miocene from upper Pliocene sediments at about 116 mbsf. The upper Pliocene to Holocene sediments (110–0 mbsf; ~2.5–0 Ma) constitute lithologic Unit I, which consists of interbedded gray to brownish-gray silty clay, clayey mud, and clayey silts that contain variable amounts of biogenic carbonates and ice-rafted debris. Silts, sands, and detrital carbonates are common in the uppermost 60 m, which corresponds to the Pleistocene according to the planktonic foraminifer stratigraphy. Sedimentation rates at Site 647 are uniform and average 4.5 cm/k.y. for the Pliocene-Pleistocene sequence (Srivastava, Arthur, et al., 1987) and about 4.7 cm/k.y. during the late Pleistocene (site survey Core 84-030-003; de Vernal and Hillaire-Marcel, 1987b).

The recovery of Pliocene-Pleistocene sediments by rotary drilling in Hole 647A was about 64%, providing an almost complete section for the 2.5–0 Ma time interval. The Pliocene/Pleistocene boundary is located at about 58 mbsf, according to the planktonic foraminifer stratigraphy (Srivastava, Arthur, et al., 1987). The early/late Pleistocene boundary corresponds to the Brunhes/Matuyama magnetic reversal recorded at 35 mbsf (Srivastava, Arthur, et al., 1987).

Palynomorphs were studied in 51 samples from core sections and from core-catcher samples of Site 647. Expressed in terms of concentrations, the results are summarized in Figure 5 and Table 2.

Marine Palynoflora

Dinocyst and Acritarch Stratigraphy

The taxonomic composition of the marine palynoflora varies significantly from the late Pliocene to late Pleistocene at Site 647 (Fig. 6). Two main assemblage intervals can be distinguished.

1. Interval II (116–50 mbsf; ~2.5–1.1 Ma); this upper Pliocene to lower Pleistocene interval is marked by the occurrence of several taxa, in addition to the extant taxa that characterize interval I. The most common species in interval II are *Filisphaera filifera*, *Cymatiosphaera* sp. I, and *Corrudinium* sp. I.

2. Interval I (50–0 mbsf; ~1.1–0 Ma); this Pleistocene interval is almost exclusively characterized by dinocysts, which are common in modern marine sediments of the region (Mudie, 1980; Mudie and Short, 1985; de Vernal, 1986). We do not consider the rare occurrence of the extinct species, *Impagidinium velorum* and *I. japonicum*, significant in this interval since only one specimen of each species was observed. The assemblages are dominated by *Nematosphaeropsis labyrinthea*, *Operculodinium centrocarpum*, *Bitectatodinium tepikiense*, *Impagidinium aculeatum*, *I. cf. pallidum*, *I. paradoxum*, and *I. patulum*. The only species that is restricted to this interval is *Impagidinium sphaericum*.

As at Site 646, the interval II/I transition, which marks the beginning of the early Pleistocene, is characterized by a significant decrease in dinocyst species diversity.

Paleoenvironmental Interpretation

The concentrations of marine palynomorphs (dinocysts and acritarchs) in the Pliocene-Pleistocene sediments of Site 647 are relatively low and average 500 cysts/cm³. Extrapolated from sedimentation rates, the corresponding influxes (~2.5 cyst/cm²/yr) suggest a low local dinoflagellate productivity. This may be caused by the offshore location of Site 647, which lies in a mid-ocean gyre and probably receives the limited influx of organic nutrients required for dinoflagellate metabolism (e.g., Margalef, 1978; Harland, 1983). In addition, dinoflagellate reproduction by excystment of dinocysts deposited on the abyssal seafloor is most improbable. Thecate-stage dinoflagellates were recorded from station Bravo near the drill site (Holmes, 1956); however, a large part of the dinocyst flux over the abyssal plain may be due to lateral oceanic transport (de Vernal, 1986; de Vernal and Hillaire-Marcel, 1987a, 1987b). Warm-temperate to subtropical (*Impagidinium aculeatum*, *I. patulum*, *Lingulodinium machaerophorum*, *Spiniferites mirabilis*; e.g., Harland, 1983), low salinity (*Brigantedinium simplex*; Mudie and Short, 1985) and arctic to subarctic (*Multispinula minuta*, *Spiniferites elongatus*; Harland et al., 1980) taxa occur together in most of the dinocyst assemblages at Site 647. Thus, multiple influxes from the Gulf Stream, North Atlantic Drift, and Labrador Current, must be considered. The notable occurrence of warm-water species indicates a penetration of temperate North Atlantic Drift water into the Labrador Sea throughout most of the late Pliocene to Holocene interval. However, the dominance of *Filisphaera filifera* (Bujak, 1984) suggests cool-temperate to subarctic conditions. The occurrence of common *Brigantedinium simplex*, which may be associated with low salinity conditions (<30‰; Mudie and Short, 1985), is noticeable in lower Pleistocene sediments. In the upper Pliocene sediments, particularly between about 85 and 116 mbsf, the dominance of acritarch cysts (*Cymatiosphaera* sp. I) also suggests an influx from neritic areas.

Terrestrial Palynoflora

The terrestrial palynomorph concentrations vary considerably throughout the Pliocene-Pleistocene sequence, which sug-

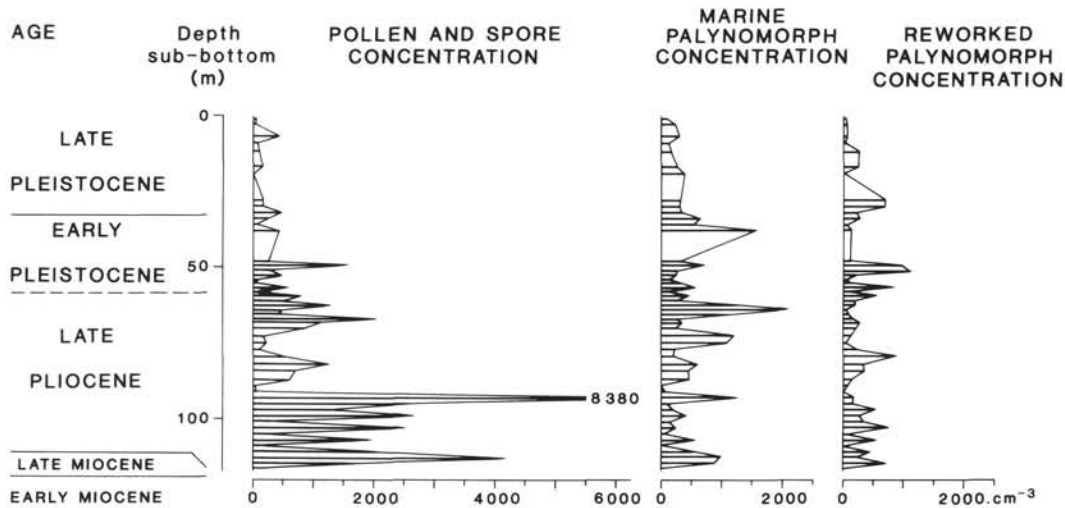


Figure 5. Palynomorph concentrations vs. depth at Hole 647A.

gests changes in the influx volumes and the extent of vegetation sources. Pollen and spore assemblages are similar in composition to those at Site 646, with influxes from boreal coniferous forest vegetation during most of the interval (Fig. 7). In Pliocene sediments, the assemblages are dominated largely by *Pinus*, *Picea*, and *Sphagnum*, suggesting the prevalence of relatively dense coniferous forests and humid cool-temperate to subarctic climatic conditions in the source areas. These source areas would have been primarily in southeastern Canada, if influxes were mainly from southwest-northeast atmospheric circulation similar to that of today. The latest Pliocene and early Pleistocene interval also is marked by relatively high percentages of *Quercus* and *Betula*, which suggests influxes from a temperate mixed forest. Low pollen concentrations in the upper Pleistocene sediments and the limited number of samples prevent detailed interpretation. However, the decrease in pollen concentrations and the diminution of *Quercus* percentages in the upper Pleistocene sediments probably indicate an impoverishment of the vegetation that reflects long-term climatic cooling in eastern Canada.

DISCUSSION OF THE ACRITARCH AND DINOCYST STRATIGRAPHY

Our knowledge of the geographical distribution and stratigraphic range of Neogene dinoflagellate cysts is still fragmentary, especially for the high latitudes of the Northern Hemisphere. Studies conducted during the last decade have significantly increased the data base for high-latitude Neogene palynostratigraphy, notably reports by Manum (1976: Norwegian Sea), Harland (1979: Bay of Biscay; 1984: Goban Spur), Edwards (1984: Rockall Plateau), Bujak (1984: Bering Sea), Matsuoka (1983: central Japan), Mudie (1986: central North Atlantic) Mudie (1988: Norwegian Sea); Aksu and Mudie (1985: Arctic Ocean). Most of these studies led to the description of new dinoflagellate cyst species and erection of dinocyst zonation. Some "regionalism" seems to characterize all the above dinoflagellate stratigraphies. This probably reflects the relationship between fossil dinoflagellate assemblages and paleoenvironmental conditions in different high-latitude ocean basins. The modern distribution of dinocysts on the ocean floor is closely related to environmental parameters such as surface-water temperature and salinity (e.g., Wall, 1971; Wall et al., 1977; Harland, 1983; Turon, 1984), especially in high-latitude regions (Mudie and Short, 1985; Harland et al., 1980). Therefore, it is not surprising to find that the Pliocene-Pleistocene palynoflora in the Lab-

rador Sea differs from those at other North Atlantic sites and that to date it cannot be correlated directly with other zonations.

In the Pliocene-Pleistocene dinocyst assemblages of Sites 646 and 647, several taxa occur throughout most of the sequence, notably *Operculodinium centrocarpum*, *Nematosphaeropsis labryrinthea*, and *Brigantidinium simplex*. These taxa have a wide geographical distribution in the Atlantic Ocean and occur in modern sediments from temperate to circum-Arctic areas. These opportunistic taxa appear to tolerate a wide range of temperature and salinity conditions, which also may explain their long stratigraphic range, especially in high-latitude regions of the Northern Hemisphere, where strong climatic fluctuations took place during the late Cenozoic.

In the Labrador Sea, several taxa have their last appearances in the upper Pliocene and lower Pleistocene sediments. The last appearance of *Filisphaera filifera* in the lowermost Pleistocene deposits at both Sites 646 and 647 is approximately synchronous with that of other boreal areas, such as the central North Atlantic (Mudie, 1986), eastern Norwegian Sea (Mudie, 1988), Bering Sea, and northern North Pacific (Bujak, 1984). *Filisphaera filifera* seems to have been an ubiquitous boreal species until the early Pleistocene and thus constitutes a good stratigraphic marker for northern high latitudes. Several other taxa that range into the early Pleistocene in the North Atlantic and North Pacific have their last appearance in Pliocene sediments of the Labrador Sea. These dinocysts are *Operculodinium crassum*, *Operculodinium longispinigerum*, *Corrudinium harlandii*, and *Xandarodinium variabile*. Their early disappearance in the Labrador Sea may reflect harsher environmental conditions because of the greater influence of arctic overflow water, compared to other boreal regions of the North Atlantic and North Pacific oceans. In contrast, *Impagidinium cf. pallidum* occurs throughout the Pliocene to Holocene interval in the Labrador Sea, while the morphologically similar species *Impagidinium pallidum* occurs only to the earliest Pleistocene in the North Pacific (Bujak, 1984) and Arctic oceans (Aksu and Mudie, 1985). *Impagidinium cf. pallidum* appears to be a form adapted to subpolar conditions: it is abundant in surface sediments on the Barents Shelf slope in the eastern Arctic (Mudie and Matthiessen, 1988).

Several other dinocysts that are abundant in Labrador Sea Pliocene sediments appear to have ranges that may be useful from a biostratigraphic viewpoint: these taxa are *Batiacasphaera sphaerica*, *Invertocysta* sp. I (Fig. 8), cyst type I, and *Corrudinium* sp. I, which have relatively narrow ranges in lower Plio-

Table 2. Palynomorph concentrations in analyzed samples from Hole 647A.

Lab no.	Core-section interval (cm)	Total dinocysts	Peridiniaceae	Acritarchs	Pollen	Spores	Terrestrial reworked palynomorphs	Marine reworked palynomorphs	<i>Pediastrum</i>	Tasmanideae
UQP-33/5	1R-1, 58-64	94	—	—	31	9	47	—	—	—
UQP-33/6	1R-2, 63-69	235	—	—	15	5	61	2	2	—
UQP-33/7	1R-6, 82-88	300	63	—	389	63	90	5	5	—
UQP-12/8	1R, CC	113	—	—	35	39	37	2	—	—
UQP-33/8	2R-1, 7-12	160	—	—	100	8	200	12	—	—
UQP-34/1	2R-6, 33-39	241	20	—	126	47	232	12	—	—
UQP-13/1	2R, CC	296	—	—	10	—	5	—	—	—
UQP-34/2	4R-1, 92-96	467	14	—	252	98	235	11	11	4
UQP-34/3	4R-2, 69-74	162	33	—	138	24	687	24	—	—
UQP-34/4	4R-3, 36-41	337	32	—	332	124	192	24	5	—
UQP-34/5	4R-4, 43-48	634	160	—	194	47	246	33	5	—
UQP-34/7	4R-6, 84-89	575	—	—	40	13	23	8	—	—
UQP-13/2	4R, CC	1,669	1,364	—	375	31	118	16	—	—
UQP-13/3	5R, CC	299	102	—	173	85	105	—	—	—
UQP-35/1	6R-1, 43-48	689	634	—	1,392	717	952	13	55	—
UQP-35/2	6R-2, 43-48	242	37	—	188	82	988	121	—	—
UQP-35/3	6R-3, 43-48	228	—	—	306	118	196	—	—	—
UQP-35/4	6R-4, 43-48	149	—	—	48	5	77	—	—	—
UQP-35/5	6R-5, 43-48	330	—	—	23	10	75	—	—	—
UQP-35/6	6R-6, 43-48	541	11	—	260	55	779	33	—	—
UQP-13/4	6R, CC	104	—	—	19	19	67	9	—	—
UQP-36/1	7R-1, 3-8	426	9	—	725	64	526	55	—	—
UQP-36/2	7R-2, 3-8	282	20	—	393	111	182	30	—	—
UQP-36/3	7R-3, 3-8	1,285	470	—	770	450	211	—	—	—
UQP-36/4	7R-4, 3-8	2,070	98	—	306	108	39	—	—	—
UQP-36/5	7R-5, 3-8	915	58	—	282	117	87	10	—	—
UQP-36/6	7R-6, 3-8	283	85	9	1,502	548	171	9	18	—
UQP-13/5	7R, CC	357	105	7	783	273	273	21	14	—
UQP-37/1	8R-1, 21-26	274	18	—	526	156	187	9	—	—
UQP-37/2	8R-2, 21-26	1,179	—	—	108	36	115	—	—	—
UQP-37/3	8R-3, 21-26	1,088	—	—	168	58	39	—	—	—
UQP-13/6	8R, CC	217	—	—	124	12	221	—	—	—
UQP-37/4	9R-1, 15-20	194	—	—	417	136	680	165	9	—
UQP-37/5	9R-2, 15-20	631	—	305	878	364	336	18	—	—
UQP-37/6	9R-3, 15-20	359	—	39	538	161	341	18	9	—
UQP-13/7	9R, CC	477	5	185	468	148	115	5	5	—
UQP-38/1	10R-1, 9-14	—	—	—	10	—	48	58	—	—
UQP-38/2	10R-2, 9-14	63	—	8	16	—	8	8	—	—
UQP-38/3	10R-3, 9-14	1,266	18	1,081	5,704	2,676	74	74	46	—
UQP-38/4	10R-4, 9-14	88	—	—	2,099	569	119	18	—	—
UQP-13/8	10R, CC	193	51	—	1,135	168	503	26	52	—
UQP-38/5	11R-1, 29-34	392	69	161	1,682	970	161	92	—	—
UQP-38/6	11R-2, 29-34	134	—	50	201	75	310	8	8	—
UQP-39/1	11R-3, 29-34	264	226	13	1,799	818	703	52	39	—
UQP-39/2	11R-4, 29-34	77	—	—	15	—	46	8	—	—
UQP-14/1	11R, CC	560	8	488	1,404	542	249	9	18	—
UQP-39/3	12R-1, 33-38	29	—	—	19	—	—	9	—	—
UQP-39/4	12R-2, 33-38	530	82	40	1,896	550	408	20	—	—
UQP-39/5	12R-3, 33-38	960	80	672	2,306	1,856	128	64	16	—
UQP-39/6	12R-4, 33-39	843	76	383	1,499	342	652	38	38	—
UQP-14/2	12R, CC	7	—	—	7	—	7	—	—	—
UQP-14/3	13R, CC	—	—	—	8	8	—	—	—	—

cene sediments of Site 646. The abundance of the acritarchs *Cymatiosphaera* sp. I and *Incertae sedis* I also seems characteristic of high-latitude Pliocene sediments in the North Atlantic, including Baffin Bay (de Vernal and Mudie, this volume), Norwegian Sea (Mudie, 1988) and Gardar Drift south of Iceland (Mudie, 1986), in addition to the Labrador Sea.

CONCLUSIONS

The dinocyst and acritarch stratigraphy of Labrador Sea Sites 646 and 647 suggests that major changes occurred in surface-water conditions during the Pliocene-Pleistocene, especially off southwest Greenland. During the Pliocene, the eastern Labrador Sea was probably characterized by high primary productivity that may have been related to nutrient influx from the shelf or to upwelling, as suggested by abundant acritarchs, Peridiniaceae cysts, and Tasmanidae. The decreasing dinocyst and

acritarch concentrations throughout the Pliocene-early Pleistocene interval suggest a reduction in primary productivity. This interval also corresponds to a significant decrease in dinocyst diversity that probably reflects a change from cool-temperate to more rigorous subarctic environmental conditions. The dinocyst assemblages are generally boreal in character throughout the Pliocene-Pleistocene interval, but the frequent occurrence of warm-temperate to tropical species, such as *Impagidinium aculeatum* and *Impagidinium patulum*, suggests that a small but significant volume of North Atlantic Drift water continued to flow northward into the Labrador Sea.

The pollen and spore assemblages show variations in influx that are probably related to changes in the vegetation of south-eastern Canada. A cool-temperate forest with *Tsuga* and *Sciadopitys* and some areas of temperate *Quercus* woodland were apparently replaced by widespread coniferous boreal forest vegetation during the late Pliocene.

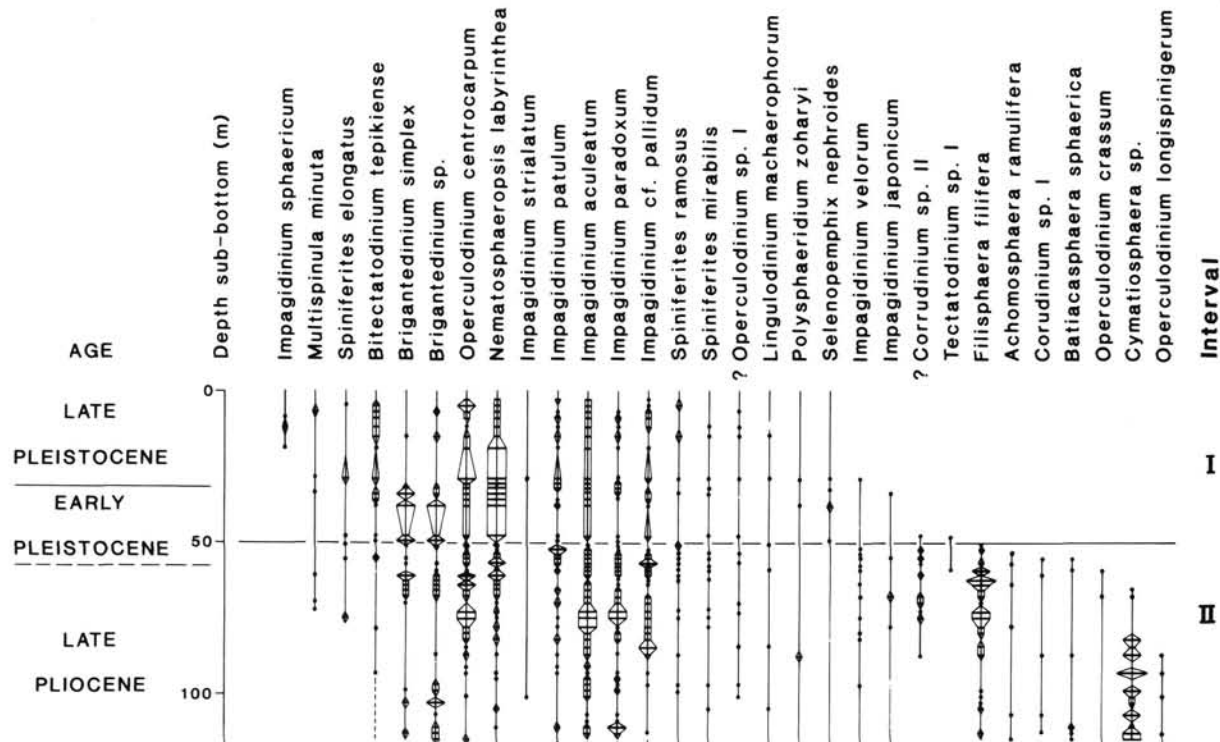


Figure 6. Stratigraphic range of dinoflagellate cysts and acritarchs in Pliocene-Pleistocene sediments of Site 647.

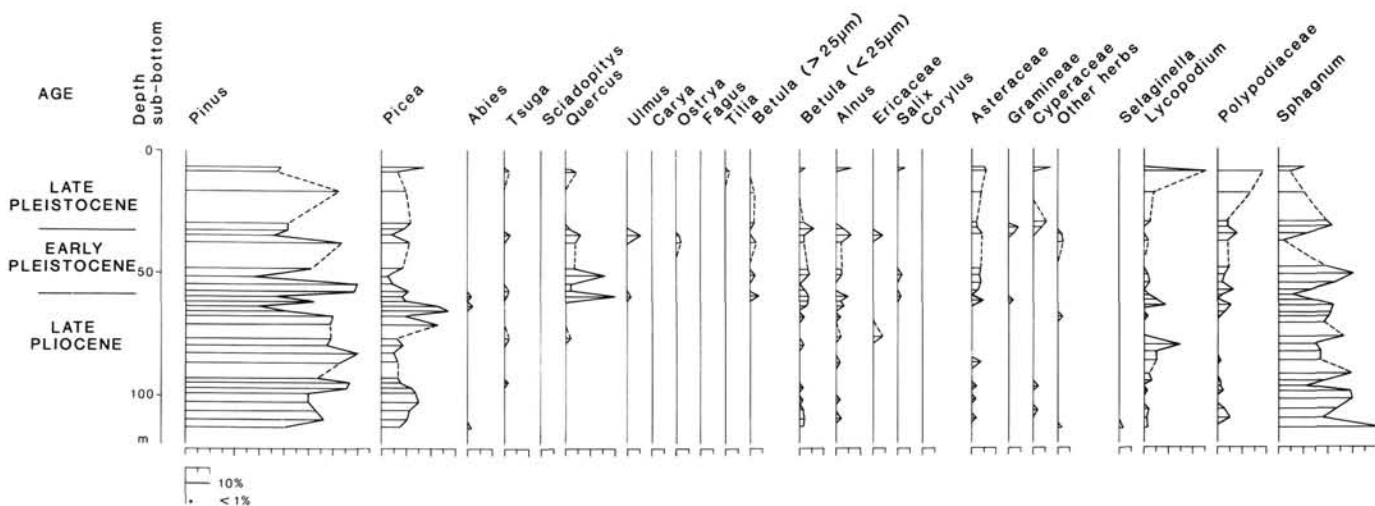


Figure 7. Summarized diagram of pollen and spore percentages at Site 646 (see remarks for Fig. 4).

SYSTEMATIC DESCRIPTIONS

Division PYRRHOPHYTA Pascher 1914
 Class DINOPHYCEAE Fritsch 1929
 Order PERIDINIALES Haeckel 1894
 Genus *ACHOMOSPHAERA* Evitt 1963
Achomosphaera andalouisiensis Jan du Chêne, 1977
 (Pl. 2, Figs. 13-15)

Remarks. The observed specimens show slightly more rigid, larger processes than the holotype. At Site 646, *A. andalouisiensis* is recorded in Pleistocene interglacial sediments of isotopic stage 7 (Aksu et al., this volume). The relatively high concentrations of *A. andalouisiensis* (>100/cm³) in some middle Pleistocene samples suggest local production rather than reworking. The stratigraphic range of *Achomosphaera andalouisiensis* may extend to the Pleistocene in the northeast Labrador Sea.

Achomosphaera ramulifera (Deflandre) Evitt, 1963
 (Pl. 2, Figs. 5 and 6)

Genus *ATAXIODINIUM* Reid 1974
Ataxiodinium choanum Reid, 1974
 (Pl. 5, Fig. 17)

Occurrence. This species is found scattered in upper Pleistocene sediments from Site 646 (Aksu et al., this volume).

Genus *BATIACASPHAERA* Drugg 1970
Batiacasphaera sphaerica Stover, 1977
 (Pl. 3, Figs. 17-19)

Description. Cysts of *Batiacasphaera sphaerica* observed in sediments from Site 646 are spherical to subspherical and relatively small. Diameter varies from 24 to 36 µm and averages 30 µm (N = 11). The

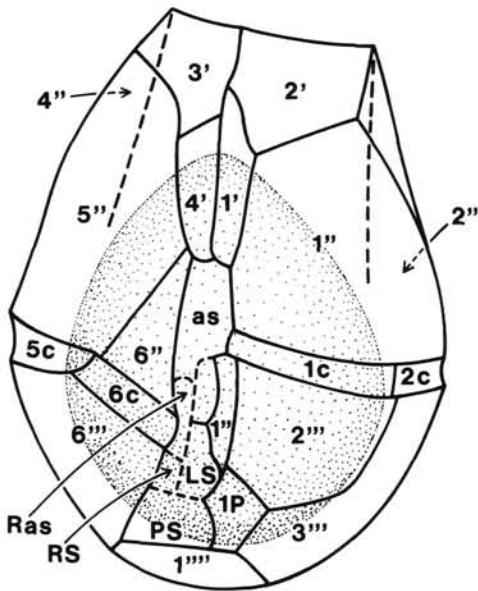


Figure 8. Paratabulation of *Invertocysta* sp. I. Plates are labeled with the conventional Kofoid designations.

autophragm is thin and covered by small granules joined to form a coarse microreticulation. The apical archeopyle, generally free, corresponds to the displacement of paraplates 1' to 3'. The operculum may be *in-situ* (see Pl. 3, Fig. 18).

Occurrence. *Batiacaspheera sphaerica* is abundant in lower Pliocene sediment from the Labrador Sea (Site 646) and can be scattered in upper Pliocene sediments from Labrador Sea Sites 646 and 647.

Genus *BITECTATODINIUM* Wilson 1973
Bitectatodinium tepikiense Wilson, 1973
(Pl. 4, Figs 9-11)

Remarks. The archeopyle formed by the loss of two precingular paraplates (2' and 3'') is usually open (Pl. 4, Fig. 10) although one or both plates can be *in-situ* (Pl. 4, Figs. 11 and 9).

Occurrence. In the Labrador Sea, *B. tepikiense* is found mainly in Pleistocene deposits. It is frequently present but rarely abundant, with the exception of some interglacial episodes (Aksu et al., this volume; de Vernal and Hillaire-Marcel, 1987a).

Genus *BRIGANTEDINIUM* Reid 1977
Brigantedinium simplex (Wall, 1965) Reid, 1977
(Pl. 5, Fig. 11)
Brigantedinium sp.

Remarks. The archeopyle sutures cannot be distinguished on many cysts of *Brigantedinium* because of poor preservation, orientation, or folding; it is often difficult to speciate the genus. *Brigantedinium* sp. includes all round, brown, protoperidinioid cysts except *B. simplex*.

Genus *CORRUDINIUM* Stover and Evitt, 1978
Corrudinium harlandii Matsuoka, 1983
Corrudinium sp. I
(Pl. 3, Figs. 14-16)

Description. These dinocysts are similar to *C. incompositum* (Drugg, 1970) Stover and Evitt, 1978, from which they differ by being distinctly ovoidal, with the hypocyst bigger and rounder than the epicyst. In addition, the parasutural and accessory septa appear equally well developed, thick, straight or slightly curved, and of uniform height. The area between the septa is smooth or scabrate, without any granular ornamentation. The archeopyle is precingular and reduced. The polar and equatorial axes of *Corrudinium* sp. I are 30 and 26 μm long, respectively (N = 5). The height of the parasutural and accessory septa is 3 μm . The septa are almost 1 μm thick.

Occurrence. *Corrudinium* sp. I is common in lower Pliocene sediments from the Labrador Sea (Site 646). It is scattered in upper Pliocene sediments from the Labrador Sea (Sites 646 and 647).

?*Corrudinium* sp. II
(Pl. 3, Figs. 11 and 12)

Description. The cysts are small (22 to 30 μm long; N = 4), subspherical, and are characterized by a dense network of undulating crests that make it impossible to distinguish the paratabulation. The archeopyle is precingular, and the operculum is free. The field areas between crests are smooth. The taxonomic affinity of these cysts with the genus *Corrudinium* is uncertain since the accessory crests cannot be distinguished from the parasutural ones: the only clearly delineated parasutural feature is the paracingulum.

Occurrence. ?*Corrudinium* sp. II is frequently observed in Pliocene and lower Pleistocene sediments of Labrador Sea Sites 646 and 647. It is never abundant.

Genus *FILISPHAERA* Bujak 1984
Filisphaera filifera Bujak, 1984
(Pl. 4, Figs. 1 and 2)

Remarks. Dinocysts from the Labrador Sea assigned to *F. filifera* vary considerably in size. The diameter ranges from about 35 to 55 μm . The thickness of the wall also varies between 2 and 4 μm . In a single sample, the size range is relatively uniform. The larger cysts of *F. filifera* are recorded in a few samples dated from the late Pliocene to the early Pleistocene. In these samples, *F. filifera* may be particularly abundant (>1000 cysts/cm³) and constitutes the dominant taxon. Many specimens of *F. filifera* have a well-developed apical boss (see Pl. 4, Fig. 1). The precingular archeopyle (3') is generally open, although the operculum can be *in-situ*. The radiating fibers that compose the outer wall are usually straight, but can sometimes be slightly curved, which gives a microreticulate appearance to the outer cyst wall (see Pl. 4, Fig. 2). *F. filifera* specimens having slightly curved radiating fibers are difficult to distinguish from *Bitectatodinium tepikiense*, especially when the orientation or folding obscures the archeopyle.

Occurrence. In the Labrador Sea, *F. filifera* is common in Pliocene and lowest Pleistocene sediments.

Genus *IMPAGIDINIUM* Stover and Evitt 1978
Impagidinium aculeatum (Wall, 1967) Lentin and Williams, 1981
(Pl. 1, Figs. 5 and 6)

Remarks. *Impagidinium aculeatum* is recorded in small numbers through the Pliocene-Pleistocene in the Labrador Sea. Specimens are slightly larger in Pliocene and lower Pleistocene sediments than in modern ones. This size gradation also was observed in central North Atlantic at DSDP Sites 611 and 607 (Mudie, 1986).

Impagidinium japonicum Matsuoka, 1983
(Pl. 1, Figs. 17 and 18)
Impagidinium cf. *pallidum* Bujak, 1984
(Pl. 1, Figs. 15 and 16)

Description. Specimens from Labrador Sea sediments are similar to *I. pallidum* Bujak, 1984, with respect to the thinness and transparency of the wall, the smoothness of the parasutural crests, and the frequent folding. The observation of several well-preserved specimens from Holocene Labrador Sea sediments suggests the following paratabulation: 3', 6'', 4c, 4'' or 5'', and 1''. The parasutural region is clearly outlined by parasutural septa, but no sulcal paratabulation is evident. The archeopyle is reduced, precingular, and is formed by the loss of paraplate 3''. The height of the parasutural septa varies: the longest sutures exhibit the widest septa. The length of the polar axis varies from 58 to 78 μm , and the crest height ranges from 3 to 7 μm (N = 14).

Occurrence. In the Labrador Sea, *Impagidinium* cf. *pallidum* is common in Pliocene to Holocene sediments, while *I. pallidum* has a reported age range from Eocene to earliest Pleistocene in the North Pacific and Bering Sea (Bujak, 1984).

Impagidinium paradoxum (Wall, 1967) Stover and Evitt, 1978
(Pl. 1, Figs. 3 and 4)
Impagidinium patulum (Wall, 1967) Stover and Evitt, 1978
(Pl. 1, Figs. 1 and 2)
Impagidinium sphaericum (Wall, 1967) Lentin and Williams, 1981
(Pl. 1, Figs. 7-9)

Occurrence. In the Labrador Sea, *I. sphaericum* occurs exclusively in upper Pleistocene sediments and is common in Holocene sediments (de Vernal, 1986). The modern distribution of *I. sphaericum* ranges

from tropical (e.g., Harland, 1983) to subarctic climatic zones (de Vernal, 1986) and suggests a wide temperature tolerance.

Impagidinium velorum Bujak, 1984
(Pl. 1, Figs. 19 and 20)
Impagidinium sp. I
(Pl. 1, Figs. 10-12)

Remarks. *Impagidinium* cysts with unknown species affinity are recorded in several samples from Labrador Sea sediments. Because these cysts are usually rare and poorly preserved, we made no attempt to differentiate most of them. However, one of these forms (Pl. 1, Figs. 10-12), is common in a few lower Pliocene samples. This form is referred to here as *Impagidinium* sp. I. This morphotype is similar to *Impagidinium sphaericum*, from which it differs by a more oblate shape, absence of apical boss, and less distinct sulcal paratabulation.

Genus *IMPLETOSPHAERIDIUM* Morgenroth 1966
Impletosphaeridium sp. I

Remarks. Specimens of *Impletosphaeridium* sp., scattered in lower Pliocene sediments of Site 646, appear similar to *Impletosphaeridium* sp. I of Manum (1976). According to Matsuoka (1983), *Impletosphaeridium* sp. I Manum could belong to the species *Reticulosphaera stellata*, which is characterized by intratabular processes with trifurcate distal ends, apparently twiglike and connected by trabecula. Specimens of *Impletosphaeridium* sp. I observed in Pliocene sediments from the Labrador Sea and Baffin Bay, however, cannot be referred to *Reticulosphaera stellata* Matsuoka, 1983, because of the lack of trabeculae joining processes.

Genus *INVERTOCYSTA* Edwards 1984
Invertocysta lacrymosa Edwards, 1984
(Pl. 4, Figs. 16 and 17)
Invertocysta sp. I
(Pl. 4, Figs. 12-15; text, Fig. 8)

Description. This cavate cyst is characterized by a ventrally adpressed periphragm and endophragm. The paratabulation, which is clearly outlined on the periphragm, especially in the ventral view (see Pl. 4, Figs. 12 and 13), is 4', 6", 6c, 6'", 1p, 1"', and 5s (text, Fig. 8). The archeopyle is delineated on the periphragm by a large opening that corresponds to the paraplate 3". The endocyst is elongate and 48 to 58 μm long; the maximum length of the periphragm is about 76 to 84 μm . *Invertocysta* sp. I differs from *I. tabulata* Edwards, 1984 in having more distinct ventral paratabulation and a larger endocyst without an apical protrusion.

Occurrence. *Invertocysta* sp. I is common in the uppermost lower Pliocene sediments from Site 646.

Genus *LEJEUNECYSTA* Artzner and Dorhofer 1978
Lejeunecysta cf. *fallax* (Morgenroth, 1966) Artzner and Dorhofer 1978
(Pl. 5, Fig. 12)

Remarks. The dinocysts attributed to *Lejeunecysta* cf. *fallax* show variations in the length of their equatorial (52 to 66 μm) and polar (56 to 78 μm) axes.

Lejeunecysta paratenella (Benedek 1972) Artzner and Dorhofer 1978
(Pl. 5, Fig. 13)

Genus *LINGULODINIUM* Wall 1967
Lingulodinium machaerophorum (Deflandre and Cookson, 1955) Wall, 1967
(Pl. 3, Fig. 10)

Genus *MULTISPINULA* Bradford 1975
Multispinula minuta Harland and Reid in Harland et al., 1980
(Pl. 5, Fig. 6)
Multispinula quanta Bradford, 1975
(Pl. 5, Fig. 10)

Occurrence. *M. quanta* can be scattered in Pleistocene sediments from Site 646 (Aksu et al., this volume).

Genus *NEMATOSPHEROPSIS* Deflandre and Cookson, 1955
Nematosphaeropsis labyrinthea (Ostenfeld, 1903) Reid, 1974
(Pl. 2, Figs. 12 and 16)

Remarks. *N. labyrinthea*, which occurs through the Pliocene-Pleistocene, shows variations in size from about 40 to 70 μm in total diameter. Both robust and fragile forms are illustrated in Figures 16 and 12 of Plate 2. On the whole, small *Nematosphaeropsis labyrinthea* cysts are more frequent in Pleistocene sediments.

Nematosphaeropsis sp. I
(Pl. 2, Figs. 9-11)

Description. Cysts of *Nematosphaeropsis* sp. I are distinguished by their small size (25 to 30 μm) and by processes, which are joined by single trabeculae. The body diameter varies from 15 to 20 μm , while the process length is 4 to 6 μm . *Nematosphaeropsis* sp. I differs from *Nematosphaeropsis aquaeducta* Piasecki, 1980, which is larger and bears massive processes.

Occurrence. *Nematosphaeropsis* sp. I is recorded in a few upper Pliocene samples from Site 646.

Genus *OPERCULODINIUM* Wall 1967
Operculodinium centrocarpum (Deflandre and Cookson, 1955) Wall, 1967
(Pl. 3, Figs. 1-4)

Remarks. In Pliocene-Pleistocene sediments from the Labrador Sea, cysts of *O. centrocarpum* show wide variation in body size and process length. A specimen bearing very short processes (2 μm) is illustrated in Figures 3 and 4 of Plate 3. Such a form was observed in both Pliocene and Pleistocene sediments.

Operculodinium crassum Harland, 1979
(Pl. 3, Figs. 7-9)

Remarks. *Operculodinium crassum* varies widely in body size and in process length. It is common in a few lower Pliocene samples from Site 646 and is scattered in upper Pliocene deposits from the Labrador Sea Sites 646 and 647.

Operculodinium longispinigerum Matsuoka, 1983
(Pl. 3, Figs. 5 and 6)
?Operculodinium sp. I
(Pl. 3, Fig. 13)

Description. Cysts are subspherical, have no processes, and are characterized by microgranular ornamentation. Microgranules form an irregular, nontabular reticulation. Archeopyle is precingular of type P and constitutes the only expression of the paratabulation.

Occurrence. *Operculodinium* sp. I has been recorded in Pliocene and Pleistocene sediments of the Labrador Sea.

Genus *POLYSPHAERIDIUM* Davey and Williams 1966
Polysphaeridium zoharyi (Rossignol, 1962) Bujak et al., 1980

Genus *SELENOPEMPHIX* Benedek 1972
Selenopemphix nephroides Benedek, 1972, emend. Bujak et al., 1980
(Pl. 5, Fig. 8)
Selenopemphix cf. *armata* Bujak et al., 1980
(Pl. 5, Fig. 9).

Remarks. We included in this category the *Selenopemphix* cysts bearing spines, although these spines may have a variable morphology.

Genus *SPINIFERITES* Mantell 1850
Spiniferites elongatus Reid, 1974
(Pl. 2, Figs. 2-4)

Here, this taxon includes both *Spiniferites elongatus* Reid, 1974, *Spiniferites frigidus* (Harland and Reid in Harland et al., 1980), and intergrades between these two taxa.

Spiniferites mirabilis (Rossignol, 1962) Sarjeant, 1970
(Pl. 2, Fig. 1)
Spiniferites ramosus (Ehrenberg, 1838) Loeblich and Loeblich, 1966
(Pl. 2, Figs. 7 and 8)

Genus *TECTATODINIUM* Wall 1967*Tectatodinium pellitum* Wall 1967*Tectatodinium* sp. I

(Pl. 4, Figs. 3-5)

Description. *Tectatodinium* sp. I is a spherical cyst characterized by a thick wall (2.5-3 μm). The thin periphragm is supported by baculae that form a punctuated surface. Diameter varies from 36 to 45 μm (N = 4). *Tectatodinium* sp. I could be a morphotype of *Tectatodinium pellitum*.

Tectatodinium sp. II

(Pl. 4, Figs. 6-8)

Description. Cysts of *Tectatodinium* sp. II are distinguished by the ornamentation of the outer wall, which forms a clear, regular microreticulation. The operculum of the type P archeopyle may be *in-situ*. Cyst diameter varies from 36 to 51 μm and averages 44 μm (N = 40); the wall is 2-2.3 μm thick. *Tectatodinium* sp. II may be a morphotype of *Tectatodinium pellitum*.

Occurrence. *Tectatodinium* sp. II is common in a few upper Pliocene samples from Hole 646B.

Genus *XANDARODINIUM* Reid 1977*Xandarodinium variabile* Bujak, 1984

(Pl. 5, Figs. 7)

Genus Uncertain

Cyst type I

(Pl. 5, Figs. 1-5)

Description. Cyst type I is small, chorate, and subspherical to ellipsoidal. Body bears massive processes with trifurcate or tetrafurcate terminations joined by thick trabeculae. Processes are numerous and uniformly distributed around the body. Consequently, trabeculae are short and give an alveolar appearance to the outer cyst. The latter is characterized by a polygonal opening that corresponds to the archeopyle (Pl. 5, Fig. 1), which appears precingular. The relationship between process distribution and paratabulation is unclear. However, the dense and relatively uniform pattern of processes and their positions around the archeopyle does suggest intratabular distribution. Diameter of the central body varies from 12 to 17 μm ; the polar axis length of the overall cyst ranges from 21 to 35 μm and averages 27 μm (N = 50).

Occurrence. Cyst type I is abundant in lower Pliocene sediments of the Labrador Sea (Site 646). Because it occurs in large numbers and has a narrow stratigraphic range, Cyst type I may be a good stratigraphic marker for the Labrador Sea region.

Division CHLOROPHYTA Pascher 1914

Class CHLOROPHYCEAE Kutzing 1843

Order CHLOROCOCCALES Pascher 1915

Family HYDRODICTYACEAE Dumortier 1829

Genus *PEDIASTRUM* Meyen 1829

Remarks. Colonies of the algae *Pediastrum* were scattered in Pliocene-Pleistocene sediments of Labrador Sea Sites 646 and 647. Most belong to the species *Pediastrum boryanum* (Turpin) Meneghini, 1840, which is an ubiquitous freshwater form (e.g., Prescott, 1953; Prescott and Vinyard, 1965). In deep-sea sediments, the occurrence of *Pediastrum boryanum* probably is related to runoff from the continent.

Division PRASINOPHYTA Round 1971

Order PTEROSPERMALES Schiller 1925

Family TASMANIDACEAE Sommer 1956

Undifferentiated tasmanides frequently were observed in Pliocene sediments from Labrador Sea Site 646 (See Table 1).

INCERTAE SEDIS

Group ACROTARCHA Evitt 1963

Subgroup PTEROSPERMOPSIS Downie 1973

Genus *CYMATIOSPHAERA* (Wetzel) Deflandre 1954*Cymatiosphaera* sp. I

(Pl. 5; Figs. 14-16)

Remarks. In the Pliocene sediments of the Labrador Sea, *Cymatiosphaera* sp. I is abundant and often dominates the marine palynomorph assemblages. Large variations in the size of the overall cysts (12 to 30

μm) and of the height of intersecting crests (2 to 7 μm) were observed. Several species or morphotypes therefore may be represented by the genus *Cymatiosphaera*.

According to phycologists, the fossil *Cymatiosphaera* represents the cyst stage or phycoma of green algae (Boalch and Parke, 1971) that belong to Division Prasinophyta Round 1971, Order Spermatales Schillers 1925, and Family Cymatiosphaeraceae Madler 1963.

Incertae sedis I

(Pl. 5, Figs. 20 and 23)

Description. This taxon designates small cysts (12 to 25 μm) having a *Pterospermopsis*-type of wall, i.e., having a surface divided into fields by a reticulum of intersecting crests (Downie, 1973). *Incertae sedis* I is characterized by large fields and wide (up to 6 μm), thick, massive crests. Crests are more or less striate; in optical section, their margins are straight to undulating or even spiny. The intersections between crests are nodal. A pylome with a subrectangular outline may be observed. According to its morphology, *Incertae sedis* I could be included in the *Cymatiosphaera* genus. As *Cymatiosphaera*, it probably represents the cyst stage of a Prasinophyta.

Occurrence. *Incertae sedis* I is abundant in upper Pliocene sediments of the Labrador Sea.

Incertae sedis II

(Pl. 5; Figs. 18 and 19)

Description. This taxon is probably a *Pterospermopsis*-type of acritarch. It is small (15 to 25 μm) and characterized by a dense network of massive cones and/or spines that are apparently connected along crests. A pylome with a subrectangular outline frequently was observed.

Occurrence. *Incertae sedis* II was observed in small numbers throughout the Pliocene sediments from Site 646.

Palyonoplankton *INCERTAE SEDIS*Genus *HALODINIUM* Bujak 1984

Description. Specimens of *Halodinium* observed in sediments from Site 646 are relatively large (about 50 to 75 μm in total diameter). They have a discoidal, thin, brownish endophragm with a semitransparent, smooth, irregular periphragm. Central pylome (15 to 20 μm in diameter) is always free. The taxonomic affinity of *Halodinium* is unknown.

Occurrence. *Halodinium* microfossils were scattered in Pliocene and Pleistocene sediments from Site 646.

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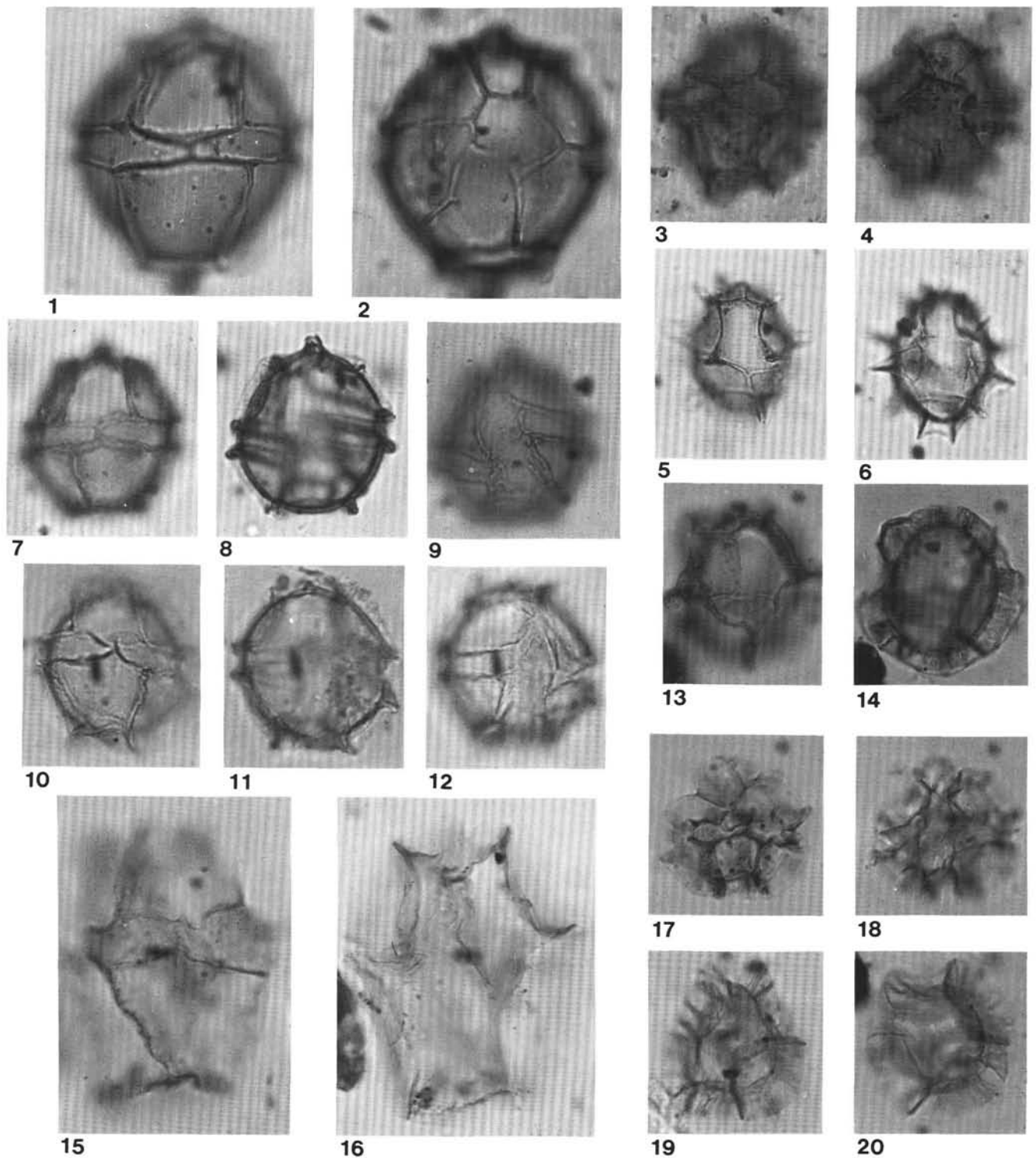


Plate 1. (All magnifications $\times 650$; photographs taken in normal transmitted light). UQP refers to the Université du Québec à Montréal, where all reference slides are curated. The alphanumeric code after the sample interval is the England Finder coordinate. **1,2.** *Impagidinium patulum* in dorsal view; (1) dorsal surface, (2) ventral surface, Sample UQP-84-030-003P, 38–40 cm, J25/4. **3,4.** *Impagidinium paradoxum* in ventral view: (3) dorsal surface, (4) ventral surface, Sample UQP-84-030-003TWC, 0–1 cm, P43/2. **5,6.** *Impagidinium aculeatum* in ventral view: (5) dorsal surface, (6) ventral surface, Sample UQP-84-030-003P, 320–321 cm, M 42/2. **7–9.** *Impagidinium sphaericum* in ventral view: (7) dorsal surface, (8) optical section, (9) ventral surface, Sample UQP-84-030-003P, 19–20 cm, D59/3. **10–12.** *Impagidinium* sp. I in dorsal view: (10) dorsal surface, (11) optical section, (12) ventral surface, Sample UQP-112/4', 646B-36X-2, 71–76 cm, Y70/3. **13,14.** *Impagidinium striatum*: (13) dorso-lateral view, (14) optical section, Sample UQP-84-030-003P, 19–20 cm, G40/2. **15,16.** *Impagidinium* cf. *pallidum* in ventral view: (15) dorsal surface, (16) ventral surface, Sample UQP-84-030-003P, 470–471 cm, S27/0. **17,18.** *Impagidinium japonicum* in dorsal view: (17) dorsal surface, (18) ventral surface, Sample UQP-112/4', 646B-36X-2, 71–76 cm, C65/4. **19.** *Impagidinium velorum*: optical section, orientation unknown, Sample UQP-112/4', 646B-36X, 2, 71–76 cm, J29/3. **20.** *Impagidinium velorum*: optical section, orientation unknown, Sample UQP-115/4, 646B-3BX-3, 53–56 cm, U69/3.

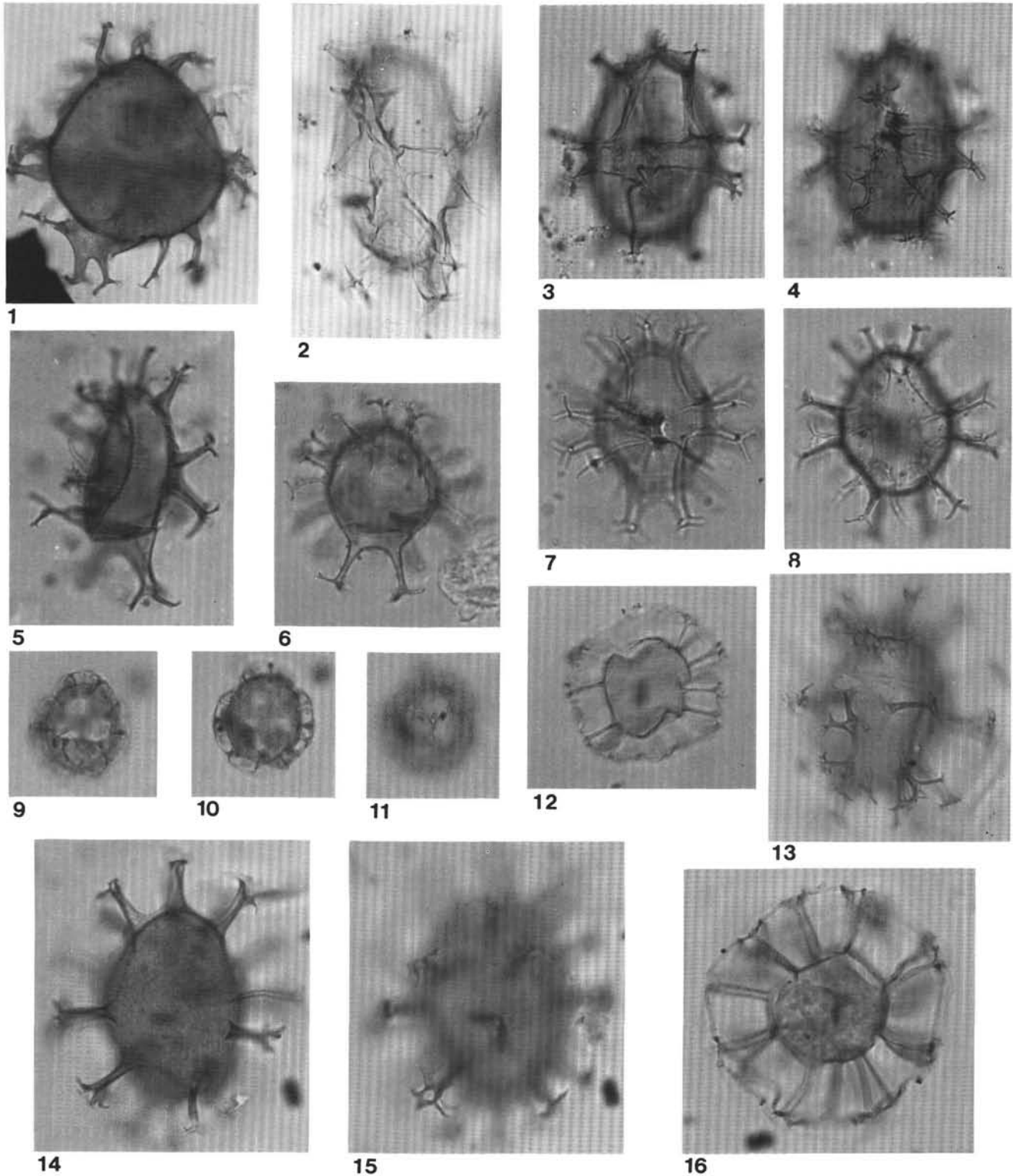


Plate 2. (All magnifications $\times 650$; photographs taken in normal transmitted light). UQP refers to the Université de Québec à Montréal, where all reference slides are curated. The alphanumeric code after the sample interval is the England Finder coordinate. 1. *Spiniferites mirabilis*: optical section, Sample UQP-138/6', 105-646B-2H-4, 18-20 cm, S49/4. 2. *Spiniferites elongatus* in ventral view (*S. frigidus* morphotype): ventral surface, Sample UQP-116/2, 105-646B-39X-1, 19-24 cm, S32/2. 3,4. *Spiniferites elongatus* in ventral view: (3) dorsal surface, (4) ventral surface, Sample UQP-138/6', 105-646B-2H-4, 18-20 cm, S32/2. 5. *Achomospaera ramulifera*: optical section, Sample UQP-117/2, 105-646B-40X-1, 21-26 cm, T60/0. 6. *Achomospaera ramulifera*: oblique antapical view, UQP-108/5, 105-646B-31X-4, 27-32 cm, O69/0. 7,8. *Spiniferites ramosus* in dorsal view: (7) dorsal surface, (8) ventral surface, Sample UQP-84-030-003P, 19-20 cm, U51/0. 9-11. *Nematosphaeropsis* sp. I: (9) dorsal surface, (10) optical section, (11) ventral surface, Sample UQP-97/6', 105-646B-21X-4, 17-22 cm, S55/0. 12. *Nematosphaeropsis labyrinthea* (gracile form): optical section, Sample UQP-142/3', 105-646B-3H-4, 126-128 cm, N38/3. 13. *Achomospaera andalouisiensis*: ventral view, Sample UQP-142/3', 105-646B-3H-4, 126-128 cm. 14,15. *Achomospaera andalouisiensis*: (14) optical section in lateral view, (15) focus on process tips, Sample UQP-142/3', 105-646B-3H-4, 126-128 cm, U69/4. 16. *Nematosphaeropsis labyrinthea* (robust form): optical section, Sample UQP-139/3', 105-646B-2H-4, 77-79 cm, T50/2.

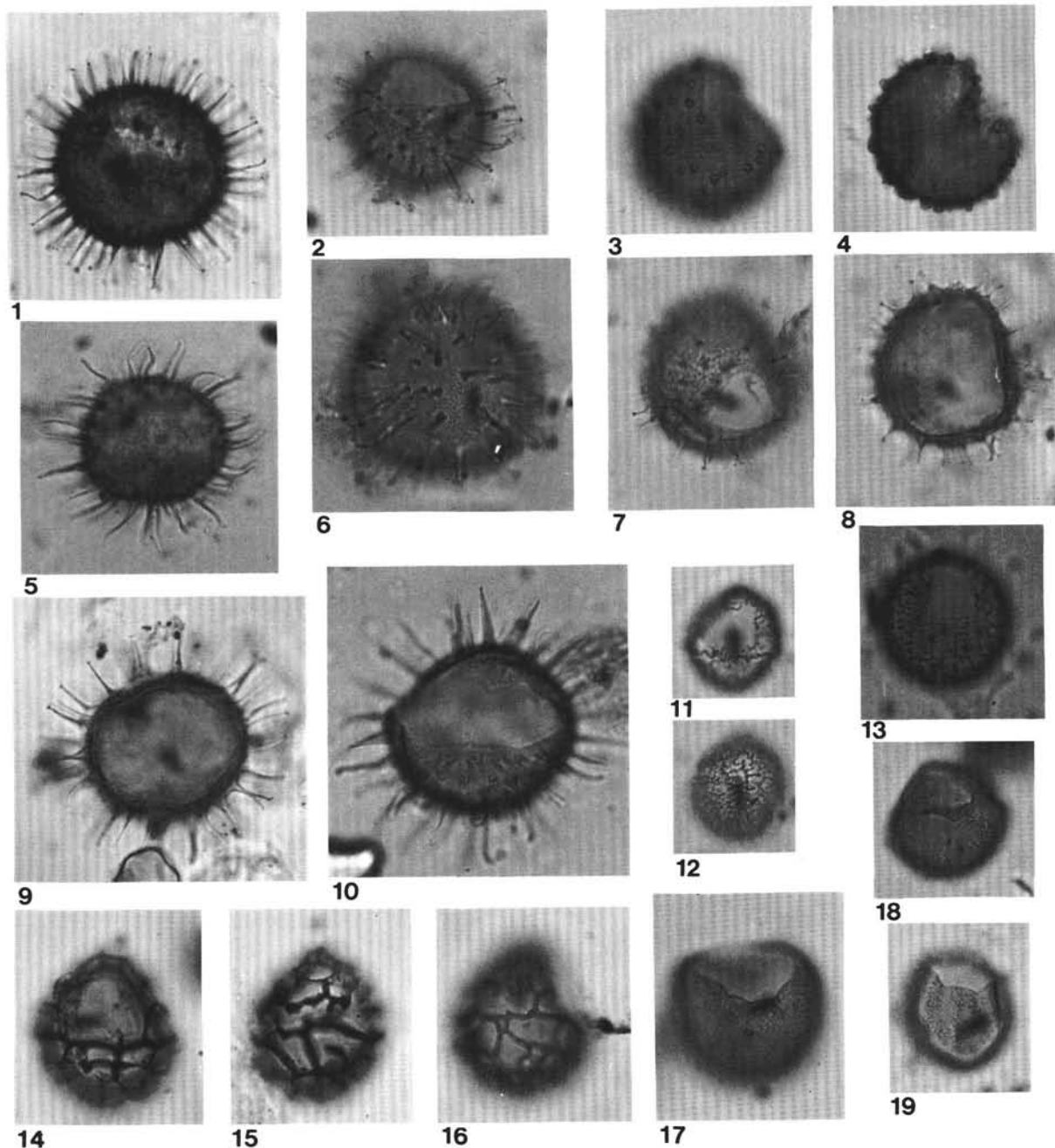


Plate 3. (All magnifications X650; photographs taken in normal transmitted light). UQP refers to the Université du Québec à Montréal, where all reference slides are curated. The alphanumeric code after the sample interval is the England Finder coordinate. 1. *Operculodinium centrocarpum*: optical section, Sample UQP-139/6', 105-646B-2H-4, 18-20 cm, Y27/0. 2. *Operculodinium centrocarpum*: dorsal surface, Sample UQP-139/3', 105-646B-2H-4, 77-79 cm, T70/1. 3,4. *Operculodinium centrocarpum* (form bearing short processes): (3) lateral view, (4) optical section, Sample UQP-139/6', 105-646B-2H-4, 18-20 cm W55/0. 5. *Operculodinium longispinigerum*: optical section, Sample UQP-108/5', 105-646B-31X-4, 39-44 cm, G26/0. 6. *Operculodinium longispinigerum*: focus on the wall ornamentation, Sample UQP-112/4', 105-646B-36X-2, 71-76 cm, V67/3. 7,8. *Operculodinium crassum*: (7) oblique apical surface, (8) optical section, Sample UQP-116/2', 105-646B-39X-1, 19-24 cm, Q27/0. 9. *Operculodinium crassum*: optical section, Sample UQP-115/2', 105-646B-38X-1, 58-61 cm, V29/0. 10. *Lingulodinium machaerophorum*: dorsal surface, Sample UQP-84-030-003P, 526-527 cm, Q24/3. 11,12. *Corrudinium* sp. II: (11) dorsal surface, (12) ventral surface, Sample UQP-05/5, 105-646B, 18X, CC, Y48/2. 13. *Operculodinium* sp. I: dorsal surface, Sample UQP-84-030-003P, 844-846 cm, V45/0. 14. *Corrudinium* sp. I: dorsal surface, Sample UQP-115/2', 105-646B-38X-1, 58-61 cm, S70/1. 15. *Corrudinium* sp. I: lateral view, Sample UQP-115/2', 105-646B-38X-1, 58-61 cm, R65/1. 16. *Corrudinium* sp. I: lateral view, Sample UQP-115/2', 105-646B-38X-1, 58-61 cm, T67/1. 17. *Batiacasphaera sphaerica*: Sample UQP-115/2', 105-646B-38X-1, 58-61 cm, S67/0. 18. *Batiacasphaera sphaerica*: specimen with operculum, Sample UQP-115/2', 105-646B-38X-1, 58-61 cm, U61/2. 19. *Batiacasphaera sphaerica*: Sample UQP-115/2', 105-646B-38X-1, 58-61 cm, Q59/4.

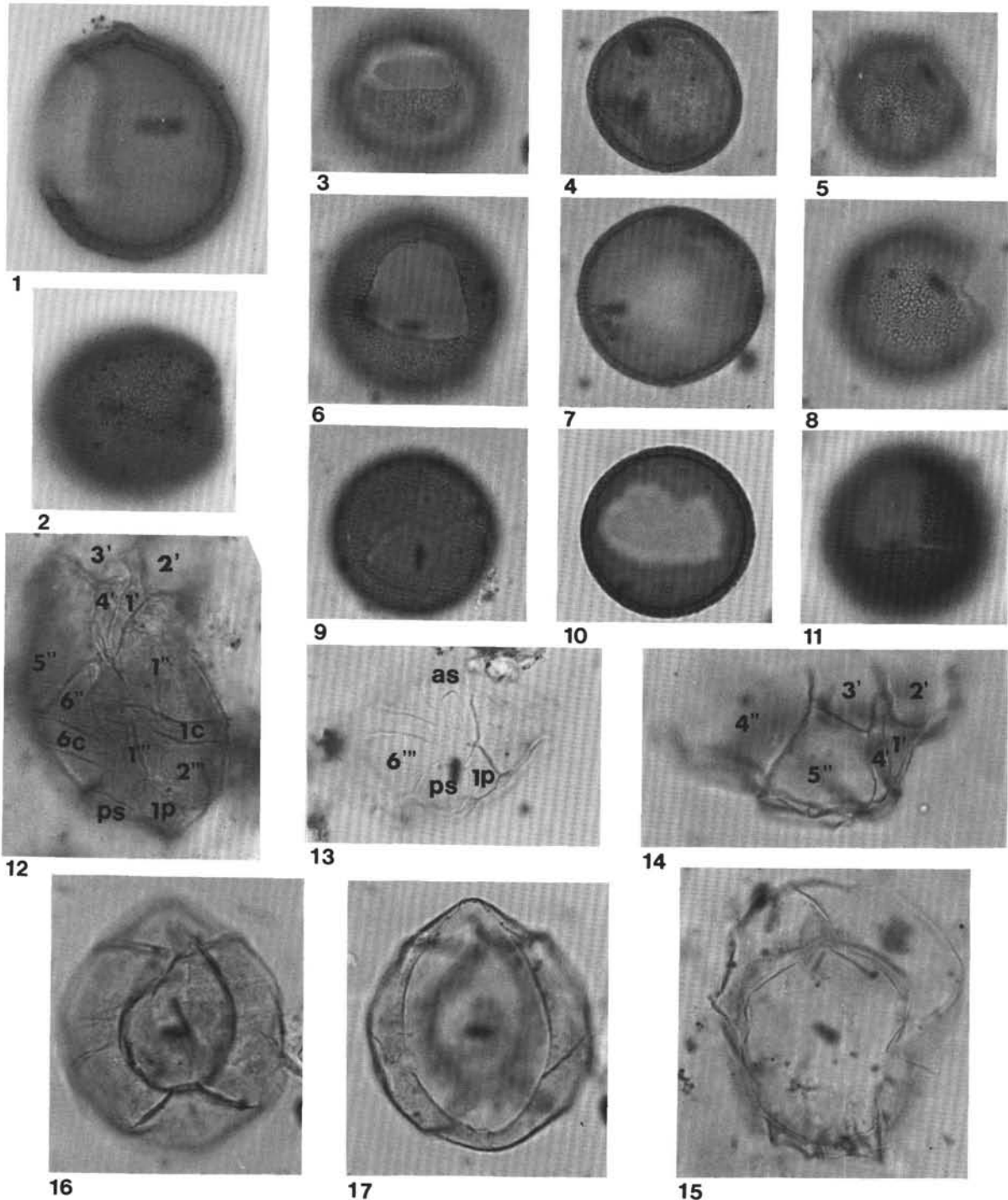


Plate 4. (All magnifications $\times 650$; photographs taken in normal transmitted light). UQP refers to the Universit  du Qu bec   Monr al, where all reference slides are curated. The alphanumeric code after the sample interval is the England Finder coordinate. 1. *Filisphaera filifera*: lateral view of specimen with a well developed apical boss, Sample UQP-94/4, 105-646B-13H-5, 20-25 cm, F52/0. 2. *Filisphaera filifera*: tangential view, Sample UQP-115/2', 105-646B-38X-1, 58-61 cm, L30/0. 3. *Tectatodinium* sp. I: dorsal surface, Sample UQP-108/5', 105-646B-31X-4, 27-32 cm, F53/0. 4. *Tectatodinium* sp. I: optical section, Sample UQP-108/5', 105-646B-31X-4, 27-32 cm, R51/1. 5. *Tectatodinium* sp. I: lateral view, focus on the wall ornamentation, Sample UQP-108/5', 105-646B-31X-4, 27-32 cm, R44/0. 6. *Tectatodinium* sp. II: dorsal surface, Sample UQP-97/6', 105-646B-21X4, 17-22 cm, T59/3. 7. *Tectatodinium* sp. II: optical section, Sample UQP-97/6', 105-646B-21X4, 17-22 cm, X27/2. 8. *Tectatodinium* sp. II: lateral view, focus on the wall ornamentation, Sample UQP-97/6', 105-646B-21X4, 17-22 cm, X27/2. 9. *Bitectatodinium tepikiense*: oblique apical surface, specimen with operculum, Sample UQP-138/6', 105-646B-2H-4, 18-20 cm, V40/1. 10. *Bitectatodinium tepikiense*: optical section, specimen with operculum free, Sample UQP-84-030-003P, 19-20 cm, W63/0. 11. *Bitectatodinium tepikiense*: dorsal surface, specimen with one (over two) archeopyle paraplate attached, Sample UQP-139/3', 105-646B-2H-4, 77-79 cm, Q42/2. 12. *Invertocysta* sp. I: ventral view, Sample UQP-112/3, 105-646B-36X-1, 82-87 cm, U52/0. 13. *Invertocysta* sp. I: focus on the parasulcus in ventral view, Sample UQP-112/2', 105-646B-35X-2, 22-28 cm, U71/3. 14. *Invertocysta* sp. I: apical view, Sample UQP-112/2', 105-646B-35X-2, 22-28 cm, E34/0. 15. *Invertocysta* sp. I: optical section, Sample UQP-113/4, 105-646B-36X-6, 114-119 cm, U49/0. 16,17. *Invertocysta lacrymosa*: (16) ventral surface, (17) dorsal surface, Sample UQP-108/5', 105-646B-31X-4, 27-32 cm, P22/2.

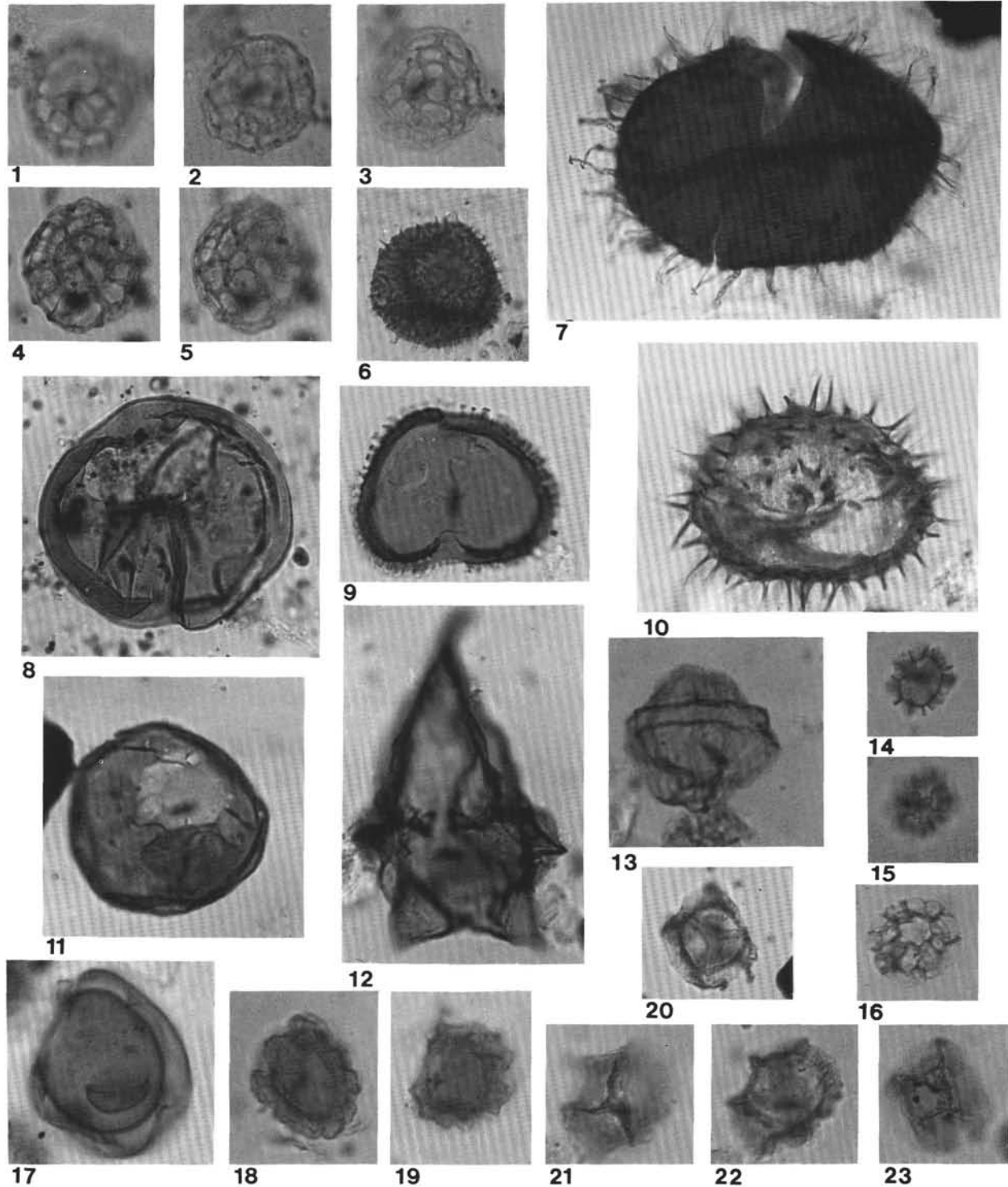


Plate 5. (All magnifications $\times 650$; photographs taken in normal transmitted light). UQP refers to the Université du Québec à Montréal, where all reference slides are curated. The alphanumeric code after the sample interval is the England Finder coordinate. 1-3. Cyst type I: (1) dorsal surface, (2) optical section, (3) ventral surface, Sample UQP-116/4', 105-646B-39X-3, 19-24 cm, U71/0. 4,5. Cyst type I: (4) optical section, (5) lateral view, Sample UQP-07/7, 105-646B-39X,CC, P36/0. 6. *Multispinula minuta*: Sample UQP-84-030-003TWC, 0-1 cm, K63/3. 7. *Xandarodinium variabile*: Sample UQP-108/5', 105-646B-31X-4, 27-32 cm, R46/1. 8. *Selenopemphix nephroides*: Sample UQP-35/1, 105-647A-7R-1, 3-8 cm, X39/0. 9. *Selenopemphix* cf. *armata*: Sample UQP-116/3, 105-646B-39X-2, 19-24 cm U39/4. 10. *Multispinula quanta*: Sample UQP-139/3', 105-646B-2H-4, 77-79 cm, V65/3. 11. *Brigantedinium simplex*: Sample UQP-116/4', 105-646B-39X-3, 19-24 cm, D52/2. 12. *Lejeunecysta* cf. *fallax*: Sample UQP-115/2, 105-646B-38X-1, 58-61 cm. R36/4. 13. *Lejeunecysta paratenella*: Sample UQP-116/4', 105-646B-39X-3, 19-24 cm, G71/3. 14,15. *Cymatiosphaera* sp. I: Sample UQP-112/2', 105-646B-35X-2, 22-28 cm, E37/2. 16. *Cymatiosphaera* sp. I: Sample UQP-116/4', 105-646B-39X-3, 19-24 cm, P45/2. 17. *Ataxidinium choanum*: lateral view, Sample UQP-138-6', 105-646B-2H-4, 18-20 cm, M38/2. 18. *Incertae sedis* II: Sample UQP-108/5', 105-646B-31X-4, 27-32 cm, V56/2. 19. *Incertae sedis* II: Sample UQP-112/4', 105-646B-36X-2, 71-76 cm, F65/3. 20,23. *Incertae sedis* I: Sample UQP-07/3, 105-646B-34X,CC, Y43/1. 21,22. *Incertae sedis* I: Sample UQP-108/5', 105-646B-31X-4, 27-32 cm, W24/1.