Diatom dispersal phenomena: diatoms in rime frost samples from Cape Herschel, central Ellesmere Island, Northwest Territories

Project 720078

Sigrid Lichti-Federovich
Terrain Sciences Division

Lichti-Federovich, S., Diatom dispersal phenomena: diatoms in rime frost samples from Cape Herschel, central Ellesmere Island, Northwest Territories; in Current Research, Part B, Geological Survey of Canada, Paper 85-1B, p. 391-399, 1985.

Abstract

The presence of marine and freshwater diatoms in rime frost samples collected in two successive years, clearly shows the significance of atmospheric diatom dispersal. Floristic similarity between all samples, based mainly on the abundance of the principal element, **Nitzschia cylindrus** (Grunow) Hasle, overrides any spatial or temporal differences as well as dissimilarities due to variation in substrate. A positive causal relationship exists with two meteorological variables, fog and southwesterly wind.

Résumé

La présence de diatomées d'eau salée et d'eau douce dans des échantillons de givre prélevés au cours de deux années successives fait clairement ressortir l'importance de la dispersion des diatomées dans l'atmosphère. Les similitudes observées au point de vue de la flore entre tous les échantillons, qui tiennent surtout à l'abondance de l'élément principal, **Nistzschia cylindrus** (Grunow) Hasle, l'emportent sur toute différence spatiale ou temporelle, de même que sur toute différence attribuable à la variation du substrat. Une relation de cause à effet est établie avec deux variables météorologiques, soit le brouillard et le vent du sud-ouest.

Introduction

The aim of this paper is to aid our understanding of the complexities involved in the study of diatom dispersal and to attain a clearer insight into the role of wind transport as one of its mechanisms.

Atmospheric transport of diatoms in polar regions has been convincingly demonstrated by the discovery of marine-derived diatoms and diatom fragments in the surface snow from arctic ice caps (Lichti-Federovich, 1984; and unpublished data). Since, however, the resultant data were based on a time span of several months, this investigation was subject to interpretative limitations.

Therefore it was hoped that a more tightly controlled investigation with regard to meteorological variables would resolve some of the ambiguities and uncertainties posed by the process of diatom dispersal. The following study is based on rime frost samples and thus is concerned with certain aspects of short term diatom dispersal phenomena.

This report is Contribution No. 24 from the Cape Herschel project.

Material and methods

The diatoms, which form the basis of this report, were recovered from rime frost samples collected by W. Blake, Jr. in east-central Ellesmere Island during June 1983 and 1984. The collection sites include two granite boulders located south and southeast of the base camp on the Cape Herschel peninsula; other samples were collected from radio antenna and various support structures at the Cape Herschel base (Fig. 47.1 and 47.2).

Table 47.1 lists the dates on which the collections were made and the prevailing meteorological conditions. It should be noted that all 1983 meteorological data were compiled from instantaneous readings taken at specific times (0630 and 1830 hours) within the approximated rime frost formation time interval. The 1984 wind data were extrapolated from a continuous chart (anemograph). All other 1984 meteorological information is given as instantaneous readings at 12 hour intervals within the rime frost formation time span.

In each case field procedures included removal of the ice into a plastic bag (1983 samples) or a low stainless steel pan covered with aluminum foil (1984 samples). Subsequent melting at room temperature and removal of meltwater into precleaned, tightly capped, plastic bottles was followed by storage under dark conditions at or near outdoor temperatures.

After initial treatment with hydrogen peroxide and potassium dichromate, followed by repeated washings with distilled water, the meltwater residue was concentrated on a 25 mm diameter, 0.8 µm nuclepore filter. The filter then was either mounted with Hyrax for light microscopy at 250x and 400x magnification using a Leitz Ortholux or prepared for SEM examination with a Cambridge Instruments Stereoscan 180 at 20 kv.

Limitations

As with most scientific enquiries, certain limitations must be acknowledged. In general, the greatest restrictive aspect in aerobiological investigations arises in the evaluation of diatom analytical data on a highly detailed comparative basis, since the results of such assays are based on a system in flux, nonstationary, ever changing.

More specifically, for this study, since the time of initial onset of rime frost formation was unknown, meteorological conditions such as wind velocity and direction had to be abstracted for a 24 hour period.

Another methodological limitation affecting the quantitative evaluation of the results is that the diatom valves and frustules were fragmented. Nevertheless, quantitative determination, on a comparative basis, with each fragment counted as one unit regardless of size, retains some measure of validity.

In addition to this numerical ambiguity, underestimation of the minute **Nitzschia cylindrus**, resulting in somewhat lower sum totals as well as lower percentage values, is imposed by optical difficulties, especially with samples examined under 250x magnification. One must also take into account the lack of transparency and the textural irregularity of a 0.8 µm nuclepore filter when examined using transmitted light. Such implied underrepresentation of **N. cylindrus** is also supported by visual examination of 0.8 µm nuclepore filters utilizing scanning electron microscopic techniques. Without any doubt, investigation by scanning electron microscopy convincingly established the marked predominance of this diatom. Essentially, however, it is a matter of balance or reasonable trade off, which an investigator dealing with time consuming scientific techniques attempts to reach between time expended (person hours) and the scientific value of the results obtained.

Notwithstanding these restrictions, this study clearly indicates that on a broad delineatory basis, uniform comparable results can be obtained.

Results and discussion

Approaching atmospheric dispersal studies on an evaluatory basis, the immediate perception is one involving a system of immense lability, a system influenced by incessant change. Considering the many variables operative – meteorological factors such as wind direction and velocity, precipitation duration and intensity, as well as dispersal distance, sources of origin, and diatom content of the atmosphere modified by seasonal changes – it is deemed rather unlikely to obtain valid spatio-temporal correlates.

The present investigation, however, was able to eliminate a few uncertainties and to introduce some measure of scientific control and environmental uniformity.

Experimental consistency relates to the following (Table 47.1):

1. All rime frost samples (excluding those from rock) were collected from a diatom-free surface above ground. Such above-surface sampling ensures that all diatoms originate from the aerial plankton. In particular the smooth metal surface of the antenna, devoid of adhering diatoms, represents a convincing means of demonstrating the impact of atmospheric transport as a diatom dispersal mechanism.
2. Although the rime frost samples were derived from two successive years, they were collected within the same week, thus eliminating floristic differences due to seasonal variation.
3. In addition, the formation of rime frost represents a short term phenomenon, in this example representing meteorological conditions operative within a 36 hour maximum time span.

Diatom analytical results of these rime frost samples were therefore awaited with a great deal of anticipation to see whether these methodological and meteorological uniformities translated into semblances expressed as diatom floristic correlates. Since, however, as mentioned previously, scientific assays with regard to aerobiological investigations are subjugated to such immense flux, detailed systematic evaluation of the various samples was omitted in favour of emphasizing the most immediate observable floristic similarity or difference.

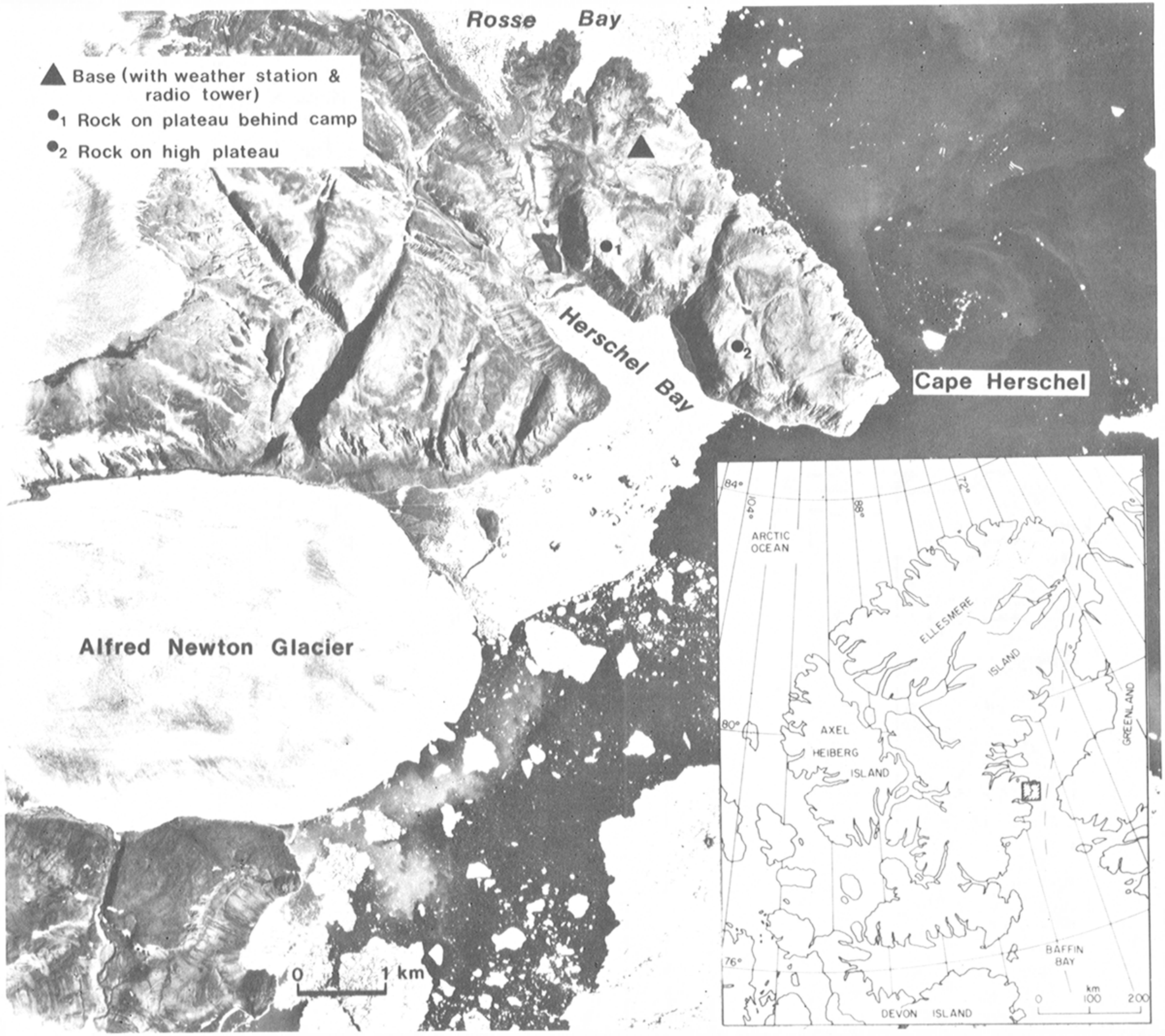

Figure 47.1. *Aerial view of Cape Herschel, Ellesmere Island showing rime frost collection sites.*

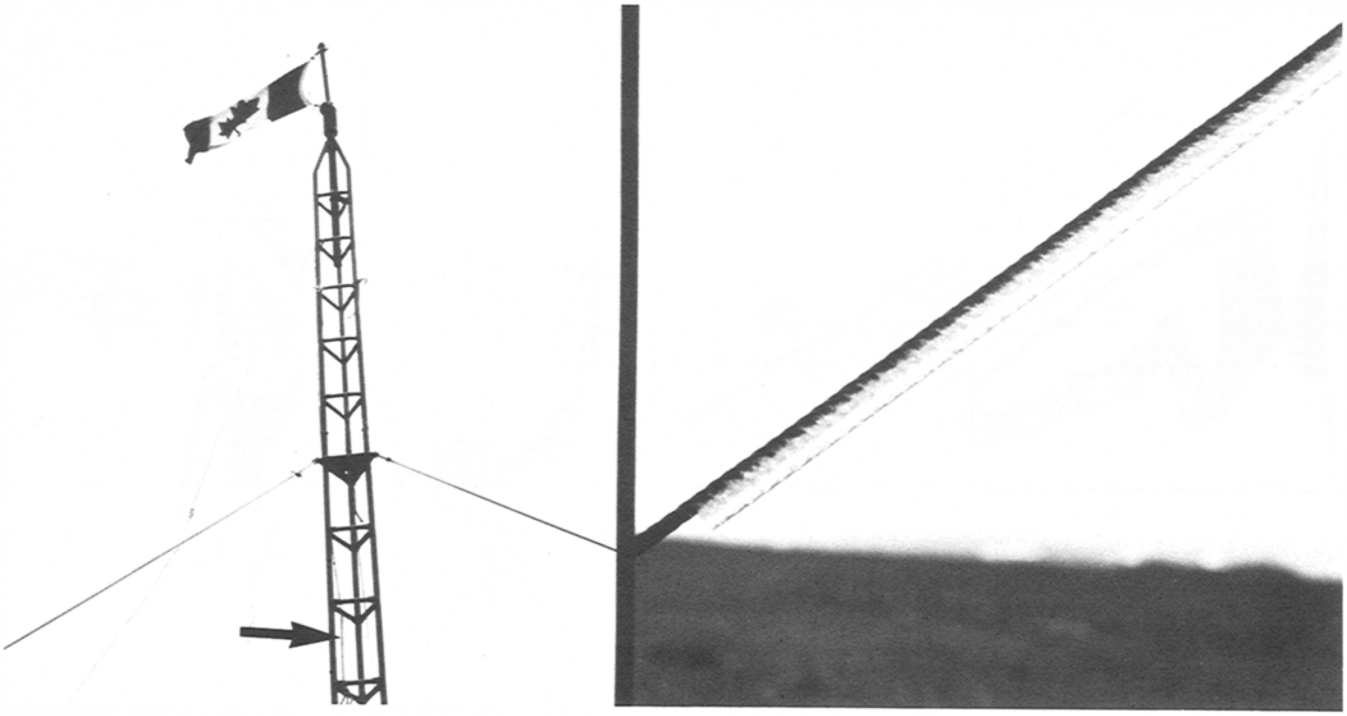

Figure 47.2. *Radio tower, Cape Herschel Base, with string attached to the antenna (arrow) and support steel cables from which rime frost was collected. (Photograph by W. Blake, Jr.)*

Diatom floristic similarities and/or differences between 1) 1983 rime frost samples collected from rock and antenna; 2) 1984 rime frost samples; and 3) 1983 and 1984 rime frost samples rests upon floristic composition, diatom frequency, and key species.

Although diatom analysis of these rime frost samples on a comparative basis indicates some heterogeneity, the most immediate, most important factor, which holds for all rime frost samples, is that diatom floristic similarity overrides any quantitative/qualititative variance due to spatio-temporal differences.

Floristic similarity, with some reservation, also holds for the diatom associations characterizing the two rime frost samples collected from granite boulders. In both cases there is a high relative abundance of **N. cylindrus;** however diatom diversity and frequency increase in the samples from rock. These discrepencies between rime frost samples from antenna and those from rock can be explained in terms of autochthonous epilithic diatoms within encrustations or attached to the outer surfaces of rock.

Floristic composition

The diatom complex of each rime frost sample represents an admixture of fresh water and marine elements, thus reflecting different origins or biotopes and varying dispersal distances. The freshwater diatoms, predominantly aerophilous taxa, may have derived from short distance semi-aquatic, nival, or terrestrial sources such as ephemeral meltwater pools or as algal detrital matter from marginal areas of lakes and ponds. Several such ponds, both temporary and permanent, are close to the sampling sites.

This general view is also supported by Blake's description of the low-lying area or pass west and southwest from the base as a veritable "quagmire" in the spring (W. Blake, Jr., personal communication, 1985). This pass, which connects Herschel and Rosse bays, not only contains a large shallow lake, but may be considered as a major source area for these diatoms with its numerous aero-aquatic habitats such as meltwater pools and puddles, standing water in depressions on rock outcrops, and shallow streams.

The marine component, on the other hand, taking into consideration the prevailing wind direction, must have been transported at least 0.8 km.

Diatom frequency

All rime frost samples are characterized by a relative abundance of diatoms. For example, the sum total of diatoms, including diatom fragments, of sample 11-1983 (DT-84-13) comprises 614/50 mL (x25 objective) and of sample 20-1984 (DT-84-17) is 868/50 mL (x40 objective), thus in each case exceeding 1000 diatom units/100 mL meltwater. The lower numerical value for sample 11-1983 may in part be due to microscopic examination under lower magnification (see limitations). These numerical values, as reflections of the diatom load of the atmosphere, gain added significance when considering the short time interval (not exceeding 36 hours) representing the period from initial rime frost formation to sample collection.

Key species

Nitzschia cylindrus (Grunow) Hasle (Plate 47.1, fig. 1-12) is the most abundant species in the rime frost diatom assemblages. This predominance necessitates its ecological and distributional characterization.

Antarctic distribution. As a member of the antarctic sea ice community, **N. cylindrus** is reported by Krebs (1977) from fast ice, intermittent and grounded pack ice, shore ice, drifting sea ice, and from brown ice slush at Arthur Harbor. Clarke and Ackley (1983) listed this taxon's abundant occurrence in Weddell Sea pack ice at 44-58 cm depth. Furthermore, **N. cylindrus** represents one of the major

Table 47.1. Characterization of rime frost samples from Cape Herschel, Ellesmere Island.

Location	Elevation (m/a.s.l.)	Field/Lab Numbers	Sample material	Volume of meltwater (mL)	Temperature (°C)	Wind direction	Wind speed (m/s)	Other meteorological data	Time interval from frost formation to time of collection	Date/Time of collection
1983 Rime frost collection										
Plateau behind base 78°36.3'N, 74°43.5'W	200	#4-1983 DT-84-11	Rime frost from south-facing rock	100	min. -2.2	11th 1900 h SW	10.9	clear some	12 h minimum	13.6.83
						12th 0700 h SW	2.2	fog; trace of precipitation		
						12th 1900 h SW	13.5	fog; blowing snow (48 mm)		
					max. 0.1	13th 0700 h SW	1.0	sun dimly visible; precipitation (10 mm)		
						13th 1900 h SW	5.2	trace of precipitation		
Base 78°37.0'N, 74°41.4'W	70	#11-1983 DT-84-13	Rime Ice from support string of radio antenna	100	min. -1.6	25th 1900 h SW	13.5	trace of precipitation	at least 12 h, more likely 24-36 h	27.6.83 0900-1000 h
						26th 0700 h SW	12.0	fog; new snow (0.85 mm)		
					max. 0.5	26th 1900 h SW	6.2	fog; new snow (0.51 mm)		
						27th 0700 h SW	0.52	fog; new snow (1.0 mm)		
High plateau 78°35.5'N, 74°40.0'W	260	#12-1983 DT-84-12	Rime frost (melting) from rock	100	min. -1.6	27th 1900 h SW	5.2	some fog	12 h minimum	29.6.83
						28th 0700 h S	7.8	trace of precipitation		
						28th 1900 h N	0.52	trace of precipitation		
					max. 2.6	29th 0700 h N	3.6	precipitation (1.5 mm)		
						29th 1900 h N	2.6	rain since 1100 hrs; snow above 200 m (2.0 mm)		
1984 Rime frost collection										
Base 78°37.0'N, 74°41.4'W	70	#20-1984 DT-84-17	Rime frost from steel cable	265	min. -2.5	27th 0700 h SW	10.4	light snow (0.5 mm); changed to S wind during day	approximately 36 h	28.6.84 1200 h
Base 78°37.0'N, 74°41.4'W	70	#21-1984 DT-84-18	Rime frost from metal struts of radio tower	280	max. 2.0	27th 1900 h SW	5.7	fog; precipitation (0.8 mm)		
						28th 0700 h SW	9.9	fog; trace of precipitation		
Base 78°37.0'N, 74°41.4'W	70	#22-1984 DT-84-19	Rime frost from support string of radio antenna	530		28th 1200 h SW	10.4			

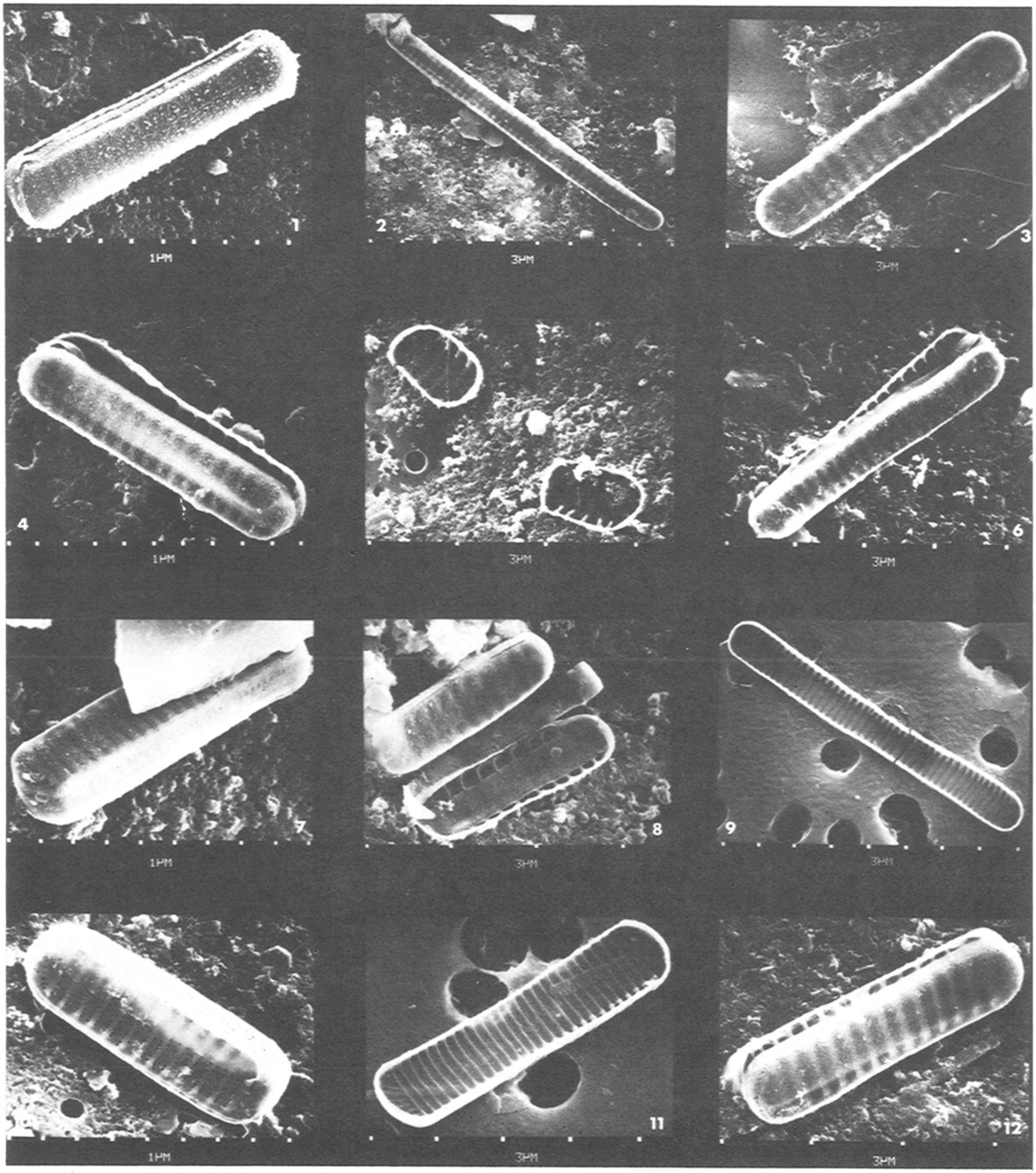

PLATE 47.1

Nitzschia cylindrus (Grunow) Hasle.

figures 1, 2, 3, 7, 8, 10. Scanning electron micrographs of external view of frustule.

figures 4, 6, 12. Scanning electron micrographs of oblique view of partially separated frustule.

figures 5, 8, 9, 11. Scanning electron micrographs of inside view of valve.

constitutents of the ice-algal population of Weddell Sea ice floes, frazil ice, and congelation ice (Garrison et al., 1983; Clarke et al., 1984). These recent findings substantiate Fukushima and Meguro's (1966) observation that **N. cylindrus** represents the dominant species in surface type as well as bottom type plankton ice around the Antarctic peninsula.

South polar distribution of **N. cylindrus** as numerically important cryoplanktonic species includes the following oceanic regions: Antarctic and Southern oceans (Guillard and Kilham, 1977), Southwestern Atlantic and Indian oceans (El-Sayed and Hampton, 1981; El-Sayed et al., 1983; Fryxell et al., 1983). Krebs (1977, 1983) based the importance of **N. cylindrus** as a cryoplanktonic species on its abundant occurrence in intertidal and shallow subtidal areas of Arthur Harbor, where it also characterizes the clayey ooze of offshore sediments.

Arctic distribution. Relevant north polar distribution of **N. cylindrus** listed by Hasle (1965), using various source references, include the following areas: Arctic Ocean, Barents Sea, Franz Josef Land, North Norwegian fiords, Denmark Strait, Greenland, Canadian Arctic, Baffin Bay, Davis Strait, Hudson Bay, Hudson Strait, Cape Wankerema, and the northern waters of the U.S.S.R. as well as the North Pacific and Sub-Antarctic basins as cited by Guillard and Kilham (1977).

Considering the distributional aspects of **N. cylindrus** as a sea ice diatom and phytoplankton element in Arctic Canada, foremost mention need be made of the useful compilation of its occurrences by Hsiao (1983) who enumerated the following localities: Arctic Ocean and Robeson Channel at the northern tip of Ellesmere Island; coastal and oceanic areas surrounding the central arctic islands such as Lancaster Sound, Barrow Strait, Wellington Channel, Resolute Passage, and Austin Channel; the waters surrounding Baffin Island, specifically Eclipse Sound, Baffin Bay, Cape Eglinton, Davis Strait, Brevoort Harbour and vicinity, Frobisher Bay, Igloolik, and Creswell Bay, as well as the Beaufort Sea and Eskimo Lakes in the southwestern part of the Canadian Arctic.

Similar to antarctic habitat associations, high concentrations of **N. cylindrus** are reported also from various arctic sea ice and plankton communities. Usachev (1946), for example, described the quantitative dominance of this taxon in ice floes from coastal sections of the U.S.S.R. and the Kara Sea. Its ice-linked occurrence is further documented by Grainger and Hsiao (1982), who recorded optimal occurrence of **N. cylindrus** in the bottom 5 cm of sea ice during May at Frobisher Bay. According to Cross (1982), **N. cylindrus** ranked as the third most abundant species in diver-collected ice cores from Pond Inlet during the period of May 12th to July 2nd, 1979. This rating was based on 41 samples from 12 ice edge and fast ice stations.

Its abundant occurrence is also reported as a member of the ice plankton community; it grows extensively in brines among ice crystals during winter and early spring in the seasonally ice-covered areas of the Bering and Chukchi seas (Saito and Taniguchi, 1978).

Other numerically significant planktonic occurrences of **N. cylindrus** have been observed by Cleve (1896) in Davis Strait and Baffin Bay, who described it as characteristic species of polar sea plankton most abundant during May, and by Polunin (1934), who noted its abundant representation in the spring plankton of Hudson Bay.

Detailed observations by Bursa (1961) of seasonal phytoplankton successions at Igloolik, north of Melville Peninsula, Northwest Territories, denote a more than threefold increase of the initial ice-linked populations of **Achnanthes taeniata** and **Nitzschia cylindrus** between April 26th and May 5th, with the first increase for **N. cylindrus** recorded as 17 200 cells/L. This under-ice spring growth occurred despite minimal light conditions. By June 19th surface diatom populations had reached a maximum and by July 2nd optimal growth conditions had descended to the 10 m level.

One can hypothesize that the **N. cylindrus** dominance (31% in sample 20-1984) relates to seasonal bloom and is further aided by its dispersive and floating abilities optimized by the small size and lightness of its frustule. Furthermore, its colonial, ribbon-like growth habit suggests the possibility of multitudinous dissemination. In either case, incorporation of **N. cylindrus** into the atmosphere, by either splash droplets from sea spray, bursting sea foam and white cap bubbles, or uptake as sloughed off minute ice algal particulates, must have occurred through turbulent wave and wind action.

This marked influx of **N. cylindrus** raises a number of perplexing questions. For example, it is rather intriguing to speculate on the postdepositional fate of these diatoms. Aside from an occasional occurrence in surface snow from two arctic ice caps, never to my knowledge has **N. cylindrus** been found in samples collected from arctic lakes and ponds. In the light of its abundance in the rime frost samples, the apparent absence of this taxon in water samples and in surface lake and pond upper sediments from Cape Herschel (Table 47.2) is difficult to understand. This is especially true as **N. cylindrus**, although numerically insignificant, has been documented by Fukushima (1967) from three antarctic inland lakes.

There are two possible explanations for the apparent lack of **N. cylindrus**, in particular, and the scarcity of marine diatoms in general: 1) rapid dissolution of the exceedingly small **N. cylindrus** frustules under hostile environmental conditions and 2) the dilution effect manifested by the influx of marine diatoms and their fragments into a freshwater biotope inhabited by an unprecidented number of authochthonous freshwater diatoms

Table 47.2. Surficial lake and pond samples from Cape Herschel examined for the presence of **Nitzschia cylindrus**

Location	Field No.	Lab. No.	Sample material
'Camp Lake' 78°37.1'N, 74°41.5'W	Diat. coll. #4-1977 Diat. coll. #12-1977	DT-77-136 DT-78-8	water and surface sediment
'Beach ridge pond' 78°37.2'N, 74°42'W	Diat. coll. #41-1979	DT-80-36	pond water and bottom sediment
'Col Lake' 78°36.2'N, 74°40'W	Diat. coll. #1-1979	DT-80-27	black lake sediment and water
	Diat. coll. #2-1979	DT-80-28	brownish sediment and water
'Willow pond' 78°37.2'N, 74°42'W	BS-80-2 (1: 0 cm and up into ice)	DT-80-91	frozen core, top of sediment and up into ice

with active growth potential. Furthermore, the comparatively lower diversity and frequency of diatoms characterizing the antarctic lakes may have helped facilitate immediate observation and ready recognition of this minute diatom during routine light microscopic examination.

In summary, it can be stated that these rime frost samples are characterized not only by a high relative abundance of diatoms, but also by compositional similarities and most noticeably by the marked predominance of **N. cylindrus.**

This diatom floristic semblance of the 1983 and 1984 rime frost samples suggests a causal interrelation with physical parameters. Table 47.1 shows an identifiable correlation with wind direction and the occurrence of fog (except for June 29th, 1983). The occurrence of sea fog, usually associated with some precipitation and southwesterly wind, is the most significant meteorological factor prevailing during the 1983 and 1984 collection periods.

However, as yet, there are no means of ascertaining whether these diatoms acted as a nucleating agent for the supercooled mist and fog droplets, whether they were removed from the atmosphere by precipitation, or whether direct impaction of wind dispersed diatoms onto the freezing surface took place during the process of rime frost build up.

In this context, it is of interest to mention the various electron microscope studies of fog nuclei documenting combustion particles, soil particles, and sea salt as nucleating agents (Kuroiwa, 1951, 1953, 1956; Yamamoto and Ohtake, 1955).

Concluding remarks

The most important result of this study is the demonstration of aerial transport as an effective mechanism of diatom dispersal, shown by the presence of these algae in rime frost collected from above-ground diatom free surfaces.

These discoveries not only verify the significance of atmospheric dispersal, but they also illuminate the fundamental issue concerning the nature of the colonization process with regard to diatoms, i.e. active versus passive dispersal. Rime frost analyses and assays conducted on precipitation samples (study in progress) indicate that the passive mode of diatom dissemination carries unprecedented impact. Thus, it is reasonable to challenge Hustedt's (1943) concept of active diatom dispersal which ascribes to the passive mode a rather insignificant function. Wind dispersed diatoms serve as massive inoculum, the significance of this process being evidenced by the cosmopolitan distribution of most diatoms within certain limitations, i.e., restrictions imposed by microenvironmental factors characterizing specific biotopes.

Although this study elucidates some aspects of diatom dispersal phenomena, these findings do not allow a firm conclusion to be drawn with regard to point source of origin or dispersal distance of diatoms. Nor does this study indicate the actual mechanism involved in the removal of these diatoms from the atmosphere. Furthermore, resolving the question of the fate of **N. cylindrus**, present in such significant numbers, and that of other marine diatoms, poses a challenge for future investigations.

Acknowledgments

I wish to express my indebtedness and appreciation to W. Blake, Jr. for placing his 1983 samples at my disposal and for the 1984 collection of additional rime frost material. I would also like to thank him for providing detailed information regarding the meteorological conditions prevailing during rime frost formation. To D. Walker, as always, I gratefully express my indebtedness for providing me with such excellent scanning electron micrographs.

References

Bursa, A.S.
1961: The annual oceanographic cycle at Igloolik in the Canadian Arctic. II. The phytoplankton, "Calanus" Series, No. 17; Journal of the Fisheries Research Board of Canada, v. 18, no. 4, p. 563-615.

Clarke, D.B. and Ackley, S.F.
1983: Relative abundance of diatoms in Weddell Sea pack ice; Antarctic Journal of the United States, v. 18, no. 5, p. 181-182.

Clarke, D.B., Ackley, S.F., and Kumai, M.
1984: Morphology and ecology of diatoms in sea ice from the Weddell Sea; Cold Regions Research and Engineering Laboratory, Report 84-5, 41 p.

Cleve, P.T.
1896: Diatoms from Baffins Bay and Davis Strait; collected by M.E. Nilsson; Bihang till kungliga Svenska Vetenskaps-Akademiens Handlingar, v. 22, no. 4, p. 3-22.

Cross, W.E.
1982: Under-ice biota at the Pond Inlet ice edge and in adjacent fast ice areas during spring; Arctic, v. 35, no. 1, p. 13-27.

El-Sayed, S.Z. and Hampton, I.
1981: Phytoplankton ecology and krill distribution in the southern ocean; Antarctic Journal of the United States, v. 16, no. 5, p. 138-139.

El-Sayed, S.Z., Weber, L.H., and Kopczynska, E.E.
1983: Phytoplankton studies in the sector between Africa and Antarctica; Antarctic Journal of the United States, v. 18, no. 5, p. 188-190.

Fryxell, G.S., Buck, K.R., and Theriot, E.C.
1983: Phytoplankton from the southwestern Atlantic and Indian Oceans; Antarctic Journal of the United States, v. 18, no. 5, p. 186-188.

Fukushima, H.
1967: A brief note on diatom flora of Antarctic inland waters; Proceedings of the Symposium on Pacific-Antarctic Sciences, Japanese Antarctic Research Expedition, Scientific Reports, Special Issue No. 1, p. 253-264.

Fukushima, H. and Meguro, H.
1966: The plankton ice as basic factor of the primary production in the Antarctic Ocean; Antarctic Record, v. 27, p. 99-101.

Garrison, D.L., Buck, K.R., and Silver, M.W.
1983: Studies of ice-algal communities in the Weddell Sea; Antarctic Journal, v. 18,no. 5, p. 179-181.

Grainger, E.H. and Hsiao, I.C.
1982: A study of the ice biota of Frobisher Bay, Baffin Island 1979-1981; Canadian Manuscript Report of Fisheries and Aquatic Sciences, No. 1647, 128 p.

Guillard, R.R.L. and Kilham
1977: The ecology of marine planktonic diatoms; in The Biology of Diatoms, ed. D. Werner; Botanical Monographs, v. 13, University of California Press, Berkeley and Los Angeles, 498 p.

Hasle, G.R.
1965: **Nitzschia** and **Fragilariopsis** species studied in the light and electron microscopes. III. The Genus **Fragilariopsis**; Skrifter Utgitt av Det Norske Videnskaps-Akademi i Oslo I. Matematisk-Naturvidenskapelig Klasse, Ny Serie No. 21, 49 p., 17 pl.

Hsiao, S.I.C.
1983: A checklist of marine phytoplankton and sea ice microalgae recorded from Arctic Canada; Nova Hedwigia, v. 8, p. 225-313.

Hustedt, F.
1943: Die Diatomeen einiger Hochgebirgsseen der Landschaft Davos in den Schweizer Alpen; Internationale Revue der gesamten Hydrobiologie und Hydrographie, v. 43, p. 124-197, 225-280.

Krebs, W.N.
1977: Ecology and presentation of neritic marine diatoms, Arthur Harbor, Antarctica; unpublished Ph.D. thesis, University of California, Davis, California, 216 p.

1983: Ecology of neritic marine diatoms, Arthur Harbor, Antarctica; Micropaleontology, v. 29, no. 3, p. 267-297.

Kuroiwa, D.
1951: Electronmicroscope study of fog nuclei, Journal of Meteorology, v. 8, p. 157-160.

1953: Electron microscope study of fog nuclei (on the condensation nuclei of cloud particles); Low Temperature Science, v. 10, p. 39-52.

1956: The composition of sea-fog nuclei as identified by electron microscope; Journal of Meteorology, v. 13, p. 408-410.

Lichti-Federovich, S.
1984: Investigation of diatoms found in surface snow from the Sydkap Ice Cap, Ellesmere Island, Northwest Territories; in Current Research, Part A, Geological Survey of Canada, Paper 84-1A, p. 287-301.

Polunin, N.
1934: The flora of Akpatok Island, Hudson Strait; Journal of Botany, v. 72, p. 197-204.

Saito, K. and Taniguchi, A.
1978: Phytoplankton communities in the Bering Sea and adjacent seas. II. Spring and summer communities in seasonally ice-covered areas; Astarte, v. 11, no. 1, p. 27-35.

Usachev, P.I.
1946: Biological indicators of the origin of the ice-floes in the Kara Sea and of Brothers Laptev and the Straits of the Franz-Josef-Land Archipelago; Akademiya Nauk SSSR, Institut Okeanologii, Trudy, v. 1, p. 113-150.

Yamamoto, G. and Ohtake, T.
1955: Electron microscope study of cloud and fog nuclei. II. Science Reports; Tôhoku University, Fifth Series, v. 7, p. 10-16.