U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

DIATOMS FROM ICE-RAFTED SEDIMENT COLLECTED FROM THE BEAUFORT SEA, ARCTIC ALASKA

by

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Open-File Report 92-439

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INTRODUCTION

Deposition on the sea floor of the central Arctic Ocean has been dominated by ice transport of lithogenous sediment, or ice rafting, during the last 5 m.y. according to Clark and Hanson (1983). Reimnitz and others (in press a) have shown that ice cover in the Arctic Ocean carries several times more sediment than what accumulates on the sea floor in one year. Reimnitz and others (in press b) estimate this sediment load at over 1400 tons/km^2 in regions of dense pack ice, seaward of the shelf. The present study is part of an effort by Erk Reimnitz and Peter Barnes of the U.S. Geological Survey to determine the sources, amount, and character of sediment transported in ice cover,

Reimnitz participated in a sediment coring operation aboard the U.S. Coast Guard ice breaker *Polar Star* between August 15 and 26, 1989, during which he observed and sampled the ice at all opportunities provided (stations #4-19 in Figure 1.) Continuous ship-board observations were made along 275 km of trackline, and helicopter observations along an additional 150 km of lines were also made (Figure 1). Ice samples were also collected in coastal waters (stations #20-23, Figure 1) by Barnes using the U.S. Geological Survey ship R/V *Karluk* during the same period. The details of this sampling are outlined in Reimnitz and others (in press b).

Mollusks and benthic microfossils found in these ice-cover sediment samples indicate that much of the sediment was removed from inner neritic depths seaward to 50 m and transported seaward by the ice (Reimnitz and others, in press a and b). It was concluded that ice entrainment and transport causes significant shelf erosion in the Beaufort Sea region. Although nothing is known of the ultimate settling of this sediment over the Arctic Ocean Basin, it appears likely that such ice-entrained neritic sediment constitutes a significant portion of sea-floor sediments in the Arctic Ocean. Consequently, any paleoclimatic or paleoceanographic signal contained in Arctic Ocean sea-floor sediment is likely to be strongly influenced by such ice-transported material.

Extensive literature exists on Arctic marine diatoms including those which are found in association with sea ice (see references in Arctic Bibliography, 1953 and Horner, 1985). The purpose of this report is to document the diatoms present in the ice-entrained sediment collected by Reimnitz and Barnes (Reimnitz and others, in press b). in order to determine whether the diatoms present in this sediment were entrained from shelfal sediments (like the benthic

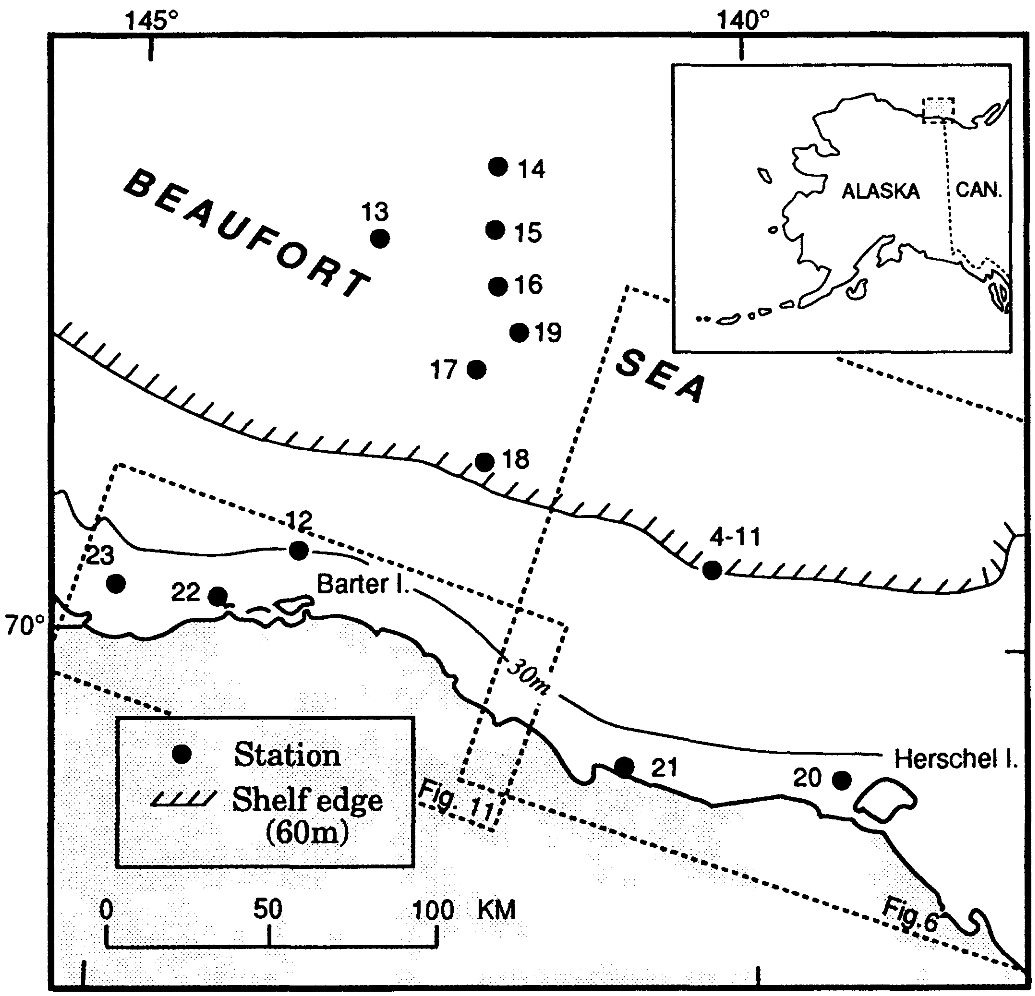

Figure 1. Location of ice-rafted sediment samples studied from the Beaufort Sea coast of northeast Alaska. Sample stations are after Reimnitz et al. (in press b).

foraminifers and ostracods) or are local (ice-related forms) in origin.

MATERIALS

Figure 1 shows the localities of stations PS-89-4 through -23 in the Beaufort Sea. Localities 89-PS-4 to -11 are all within 1 to 2 km of each other. At the time that these samples were taken, the ice cover at these sites was 6 to 7/10th's and 30-40% of this ice was turbid.

Sample 89-PS-4 was taken from sediment present in a local depression on a turbid floe of granular ice.

Samples 89-PS-5 through -10 were taken from sediment in local depressions present on slightly turbid ice floes.

Sample 89-PS-11 was taken from the surface of a floe of turbid ice.

Sample 89-PS-12 was taken from a 3 cm-thick surface mud layer present on ice floes of granular ice. Ice cover was about 5/10, and slabs of ice were incorporated into abundant ridges and hummocks that were 20-40 cm thick.

Sample 89-PS-13 was taken from a 5 x 4 m turbid ice flow. The sediment chips were not strongly concentrated.

Samples 89-PS-14 and -15 were taken from the surface of turbid ice floes.

Sample 89-PS-16 was taken from mud concentrations on the surface of first-year, granular ice.

Samples 89-PS-17 and -18 were taken from surface scapings of mud from turbid ice floes. No evidence of anchor ice was seen at these localities.

Sample 89-PS-19 was taken from a 3 cm-thick surface mud layer present on a small, turbid ice floe.

Sample 89-PS-20 was taken from small broken pieces of ice which floated into a plastic bag (69°27'N, 139°20'W, 20 m water depth).

Sample 89-PS-21 was taken from turbid ice on the bottom of a half-tilted ice block (69°40'N, 141°00'W, 6 m water depth).

Sample 89-PS-22 was taken from a grounded, pock-marked ice mass. (70°08'N, 144°11' W, water depth 15 m).

Sample 89-PS-23 was taken from a heavily sediment-laden ice mass. Surface deposits were 1 mm to 1 cm in thickness. (70°09'N, 144°59'W, water depth 22 m).

METHODS

Strewn slides (cover glass size 22 X 30 mm) were prepared for each of the 20 sediment samples by placing a small amount of sediment in an empty vial, adding distilled water, agitating the vial, and removing a small quantity of the suspension with a pipette. This material was then placed onto a cover glass, dried on a hot plate, and mounted onto a glass slide using Hyrax.

An entire slide was examined under the light microscope at X540 and the siliceous microfossils were tabulated. Relative abundances were estimated as follows: abundant, numerous specimens present in each filed of view; common, at least one specimen in a total of two fields of view; few, at least one specimen per each vertical (22 mm-long) traverse); and rare, for sparser occurrences.

RESULTS

The diatoms encountered in the 20 ice-rafted sediment samples are tabulated on Table 1. Undifferentiated chrysophyte cysts, sponge spicules, and the silicoflagellate, *Distephanus speculum*, are also tabulated. In the following section some remarks are made on these taxa and their ecology, and reference to illustrations in plates 1 and 2 is given. The taxa and their ecology are taken from Cleve and Grunow (1880), Grunow (1884), Østrup (1895, 1910, 1918), Gran (1904), Hustedt (1930, 1959, 1961-1966), Hasle (1976), Sancetta (1982), Medlin and Round (1986), and R. Horner (written comm., 1990).

Achnanthes sp. cf. *A. groenlandica* (Cleve) Grunow
pl. 2, fig. 20.
Ecology: A benthic marine coastal form found in northern ice seas.

Amphora sp.
Ecology: A benthic marine taxon.

Chaetoceros sp. cf. *C. mitra* (Bailey) Cleve
pl. 2, fig. 12
Ecology: A widespread planktonic neritic species from polar seas.

Chaetoceros spores
Ecology: These neritic planktonic diatom spores are found in coastal regions of high productivity.

Taxon/Sample (89-PS-)	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4
Reported Associated with Ice:																				
Navicula algida							F			R	R		F	R	R	F		R		R
Navicula kepesii					R	R	F						F	R	R	F		R		F
Navicula transitans							C	R	F	F	F		C	F	A	R	R	F	R	F
Navicula transitans var. erosa							R	R	R	R	R		R		R	R				F
Navicula trigonocephala																R				R
Navicula valida					R		R	R		F	F		R	F		R		R		R
Nitzschia cylindra							F			R			R	R	C	R	F			R
Nitzschia grunowii					R			F	R											
Nitzschia polaris	R						C	F	R	F	R		C	C	F	C	R	F		F
Pinnularia quadratarea bicontracta							R		R	R			R	R	R	R				R
Pinnularia quadratarea constricta	R					R	R			F	R		R	F	R	R		F	R	R
Pinnularia quadratarea leptostauron									R					R		R	R			
Pinnularia quadratarea stuxbergii														R		R				
Porosira glacialis							R								R					
Pseudogomphonema groenlandicum							R			R				F						
Pseudogomphonema septentrionale							C	F		F			C	F	R	F		R		
Thalassiosira gravida	R				R	R	R	R	R		R			R	F	R	R		R	
Thalassiosira hyalina							R	R	R	R										
Thalassiosira kryophilia							R							R			F			R
Thalassiosira lacustris				R			R		R		R		R	R	R	R		R	R	R
Thalassiosira nordenskioldii							R													
CHRYSOPHYTE cysts	R	R			R	F	F	R	F	F	R		R	C	R	R	F	R	R	C
Other Taxa:																				
Achnanthes cf. groenlandicum							R							R	R					
Amphora sp.		R																		
Chaetoceros mitra	R										R	R								
Chaetoceros spores	F	F			R	R	R	R	R	R		R	R	R	R	R	F			
Coscinodiscus? (fragments)		R		R		R			R		R	R								R
Cyclotella sp.?											R		R	R			R			
Diploneis litoralis clathrata							F	R		R	R		R	R	R	R		R		R
Diploneis cf. smithii			R			R		R												
Grammatophora sp.			R																	
Navicula sp. 2	R		R				F	F	C	R	R		F	C	R	F		R		F
Navicula sp. (fragments)	R	R	R	R		R														
Nitzschia socialis	R			R		R	F	R	R	F	F		F	R	R	F		R		R
Paralia sulcata														R						
Pleurosigma fallax							R			R			R	R		R				R
Stenoneis inconspicua						R		R		R			R	R	R	F				R
Stephanopyxis sp.														R						
Thalassionema nitzschioides								R	R	R	R			R	R	R	R			R
Thalassiosira baltica																				R
Thalassiothrix sp.?	R																			R
SPONGE SPICULES						R					R									
Distephanus speculum							R							R	F					

Table 1. Occurrence of diatoms, chrysophyte cysts, sponge spicules, and the silicoflagellate, *Distephanus speculum*, in the samples studied. C = common; F = few; R = rare.

Coscinodiscus ? sp. fragments

Ecology: Marine planktonic taxa.

Cyclotella ? sp.

pl. 2, fig. 5

Ecology: Possibly a freshwater planktonic form .

Diploneis litoralis var. *clathrata* (Østrup) Cleve

pl. 1, fig. 19; pl 2, fig. 8

Ecology: An Arctic benthic marine species.

Diploneis sp. cf. *smithii* (Breb.) Cleve

Ecology: A benthic marine, cosmopolitan taxon.

Grammatophora sp.

Ecology: A benthic marine taxon.

Navicula algida Grunow

pl. 1, fig. 18

Ecology: An Arctic marine benthic diatom that is associated with sea ice.

Navicula kepesii Grunow

pl. 2, fig. 13

Grunow, 1884, pl. A, fig. 37

Ecology: Found on the underside of an ice flow at 74°48'4"N, 54°52'8"E in the Arctic Ocean.

Navicula transitans Cleve

pl. 1, fig. 6

Ecology: An Arctic benthic marine diatom which is found associated with sea ice.

Navicula transitans var. *erosa* (Cleve) Cleve

pl. 1, fig. 17

Ecology: An Arctic benthic marine diatom which is found associated with sea ice.

Navicula trigonocephala Cleve

pl. 2, figs. 17, 19

Ecology: An Arctic benthic marine diatom that is associated with sea ice.

Navicula valida Cleve et Grunow
pl. 1, fig. 4.
Ecology: A benthic Arctic species found associated with ice.

Navicula sp. 2 of Sancetta 1982
pl. 1, fig. 8; pl. 2, fig. 18
Ecology: Found in Bering Sea and Sea of Okhotsk sediments.

Navicula sp. fragments

Navicula valida Cleve et Grunow
pl. 1, fig. 4
Ecology: An Arctic marine, benthic taxon that is associated with sea ice.

Nitzschia cylindra (Grunow) Hasle
pl. 2, fig. 9
Ecology: An Arctic and Antarctic marine, planktonic taxon that is associated with sea ice.

Nitzschia grunowii Hasle
pl. 2, figs. 10?, 11
Ecology: An Arctic marine planktonic taxon, associated with sea ice.

Nitzschia polaris Grunow in Cleve & Möller
pl. 1, fig. 14
Ecology: An Arctic planktonic marine taxon, associated with sea ice.

Nitzschia socialis Gregory
pl. 1, fig. 15
Ecology: An Arctic, coastal planktonic marine taxon.

Paralia sulcata (Ehrenberg) Cleve
pl. 2, fig. 6.
Ecology: A benthic marine taxon that is also common in coastal plankton.

Pinnularia quadratarea var. *bicontracta* Østrup
pl. 1, fig. 11

Ecology: An Arctic benthic marine taxon that is associated with sea ice.

Pinnularia quadratarea var. *constricta* (Østrup) Heiden
pl. 1, fig. 16
Ecology: An Arctic benthic marine taxon that is associated with sea ice.

Pinnularia quadratarea var. *leptostauron* (Cleve) Cleve
pl. 1, fig. 5
Synonym: *Navicula stuxbergii* var. *leptostauron* Grunow, 1884, pl. A., fig. 32.
Ecology: Found on the underside of an ice flow at 74°48'4"N, 54°52'8"E in the Arctic Ocean.

Pinnularia quadratarea var. *stuxbergii* Cleve
pl. 1, fig. 7
Ecology: An Arctic marine benthic taxon that is associated with sea ice.

Pleurosigma fallax Grunow
pl. 1, fig. 10
Ecology: An Arctic coastal, benthic taxon.

Porosira glacialis (Grunow) Jørgensen
Ecology: A coastal planktonic form found associated with sea ice in northern seas as well as the seas around Antarctica.

Pseudogomphonema groenlandicum (Østrup) Medlin
pl. 2, fig. 14
Ecology: Present on pack ice (Østrup, 1910, 1918).

Pseudogomphonema sepentrionale (Østrup) Medlin
pl. 1, fig. 9
Ecology: Present on pack ice (Østrup, 1910, 1918).

Stenoneis inconspicua (Gregory) Cleve
pl. 1, figs. 12, 13
Ecology: A benthic marine taxon found from the middle parts of Europe to northern ice seas.

Stephanopyxis spp.
Ecology: A coastal planktonic taxon.

Thalassionema nitzschioides (Grunow) Peragallo
pl. 2, fig. 16
Ecology: A cosmopolitan planktonic marine form.

Thalassiosira baltica (Grunow in Cleve & Grunow) Östenfeld
Ecology: A planktonic Arctic marine species and Baltic brackish water species.

Thalassiosira gravida Cleve
pl. 1, figs. 2, 3
Remarks: *T. antarctica* Comber and *T. gravida* are included together. Resting spores are not differentiated from vegetative valves.
Ecology: A planktonic, Arctic marine species that is associated with ice. *T. antarctica* is a bipolar form (Hasle, 1976).

Thalassiosira hyalina (Grunow) Gran
Ecology: An Arctic marine planktonic species that is associated with seas ice. Also found in northern seas.

Thalassiosira kryophilia (Gran) Jørgensen
pl. 2, figs. 1?, 2.
Ecology: A coastal planktonic form from northern ice seas.

Thalassiosira lacustris (Grunow) Hasle
pl. 1, fig. 1; pl. 2, fig. 3
Remarks: The two varieties, *T. lacustris* var. *septrionalis* (Grunow) Hasle and *T. lacustris* var. *hyperborea* (Grunow) Hasle, are tabulated together.
Ecology: These two varieties are both Arctic marine planktonic taxa; the latter was found in ice floes by Gran (1904).

Thalassiosira nordenskioeldii Cleve
pl. 2, fig. 4
Ecology: An Arctic coastal planktonic species that is often found associated with ice.

Thalassiothrix ? sp.
Ecology: A cosmopolitan planktonic taxon which may be associated with upwelling regions.

CHRYOSPHYTE cysts

pl. 2, fig. 7

Ecology: Freshwater? and associated with ice.

SILICOFLAGELLATE

Distephanus speculum Ehrenberg

pl. 2, fig. 15

Ecology: Marine planktonic form, common in cooler waters.

DISCUSSION

The siliceous taxa on Table 1 are separated into those which are known to be associated with ice and other taxa which are either not reported to be associated with ice or have an unknown ecology. The table shows than the nearshore samples (#'s 12 and 20-23) contain a sparser and lower diversity diatom assemblage than do the more offshore samples (#'s 4-11, 13-19). Offshore samples are dominated by taxa associated with ice, whereas such taxa are generally rare in the nearshore samples.

Meltwater ponds in Arctic ice can harbor brackish and freshwater communities according to Gran (1904). Such meltwater ponds may be the source for the numerous chrysophyte cysts as well as for *Cyclotella*? sp. and *Thalassiosira baltica*.

Taxa that are reported to be associated with ice are particularly common in offshore sample #'s 17, 11-8, and 4. Many of these ice-related taxa possess relatively finely silicified frustules (plates 1 and 2) that are easily fragmented upon burial. Arctic Ocean sea-floor sediments examined by the author typically contain only the more heavily silicified, ice-related taxa (i.e., *Nitzschia grunowii*, *N. cylindra*, and *Thalassiosira gravida*) that are reported by Sancetta (1982) from Bering Sea and Sea of Okhotsk sediments.

Diatoms are typically sparse and poorly-preserved in nearshore sediments, and sediments scavenged from such areas by anchor ice are likely to be poor in diatoms (sample #'s 12 and 20-23 of Table 1). The best candidates for such scavenging are relatively resistant taxa such as *Chaetoceros* spores, *Coscinodiscus* spp., *Diploneis* spp., *Paralia sulcata*, and *Thalassionema nitzschioides*. *Chaetoceros* spores and *Thalassionema nitzschioides*, however, are relatively common in the water column and may just as likely have been entrained into the sea ice by freezing.

In as much as a large majority of the diatoms encountered in the offshore 1989 Polar Star samples are either ice-related forms or are marine planktonic taxa, it would seem likely that most of the diatom frustules released over the Arctic Ocean basin by melting sea ice had similar origins. Consequently, diatoms are probably a poor means with which to track the origin of Arctic ice-entrained sediment.

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ACKNOWLEDGEMENTS

Erk Reimnitz is thanked for providing the samples. Appreciation is due to Rita Horner of the University of Washington for providing the identification and the ecology of taxa recovered from ice-rafted sediment collected on previous cruise USGS PI-88-AR. These samples were used for comparison.

This manuscript benefitted from the reviews of Scott Starratt and Louie Marincovich, Jr. of the U.S. Geological Survey. Kevin Purcell of the USGS prepared the microscope slides and assisted with the photography.

PLATE 1

1. *Thalassiosira lacustris* var. *hyperborea* (Grunow) Hasle, diameter 32 µm. 2. *Thalassiosira gravida* Cleve (spore), diameter 23 µm. 3. *T. gravida* Cleve, low and high focus, diameter 24 µm. 4. *Navicula valida* Cleve et Grunow, length 42 µm. 5. *Pinnularia quadratarea* var. *leptostauron* (Cleve) Cleve, length 70 µm. 6. *Navicula transitans* Cleve, length 63 µm. 7. *Pinnularia quadratarea* var. *stuxbergii* Cleve, length 39 µm. 8. *Navicula* sp. 2 of Sancetta 1982, length 32 µm. 9. *Pseudogomphonema sepentrionale* (Østrup) Medlin, length 35 µm. 10. *Pleurosigma fallax* Grunow, length 74 µm. 11. *Pinnularia quadratarea* var. *bicontracta* Østrup, length 70 µm. 12., 13. *Stenoneis inconspicua* (Gregory) Cleve), length 76 and 62 µm, respectively. 14. *Nitzschia polaris* Grunow, length 88 µm. 15. *Nitzschia socialis* Gregory, length 172 µm. 16. *Pinnularia quadratarea* var. *constricta* (Østrup) Heiden, length 54 µm. 17. *Navicula transitans* var. *erosa* (Cleve) Cleve, length 59 µm. 18. *Navicula algida* Grunow, length 43 µm. 19. *Diploneis litoralis* var. *clathrata* (Østrup) Cleve, length 48 µm.

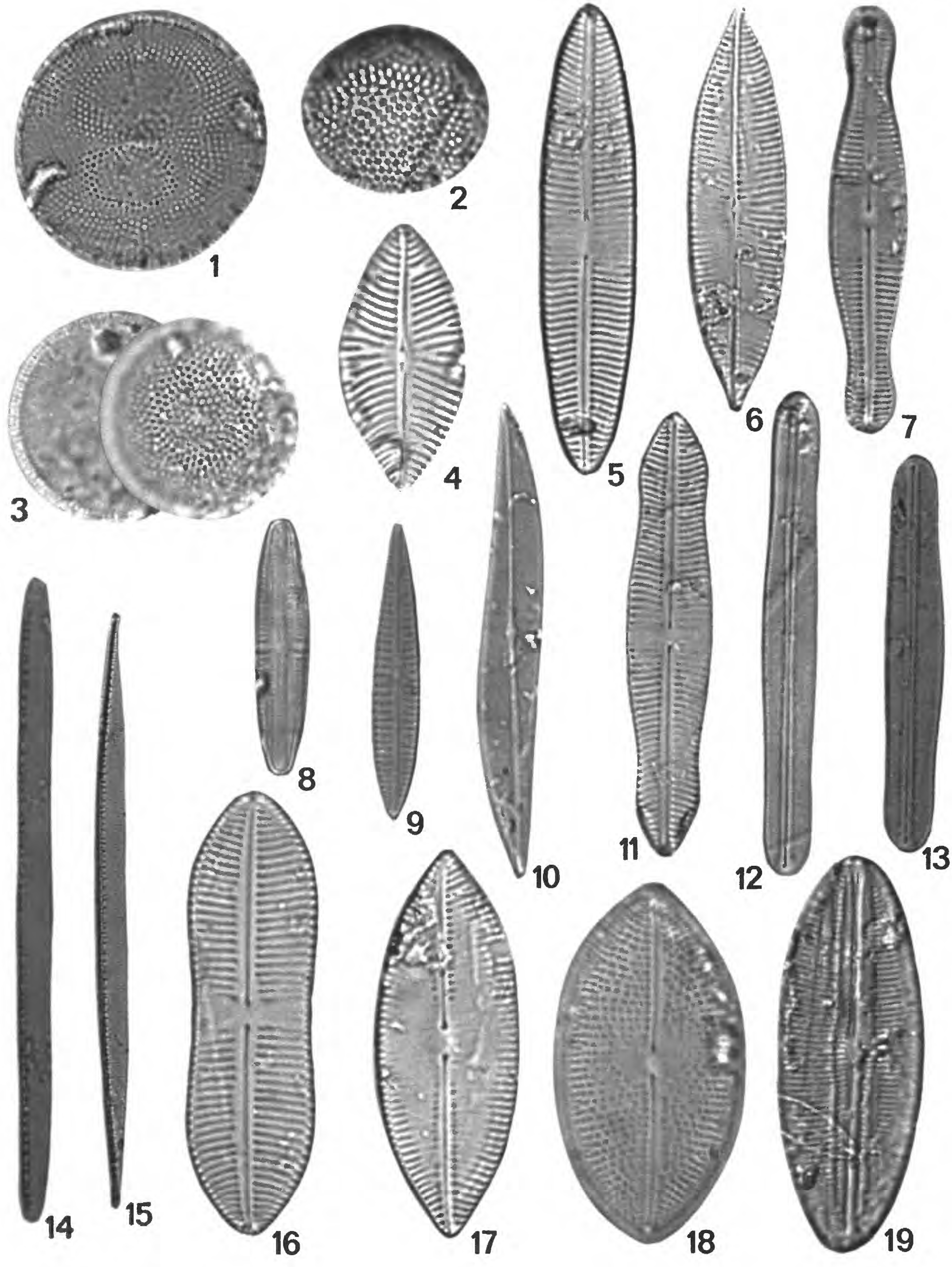
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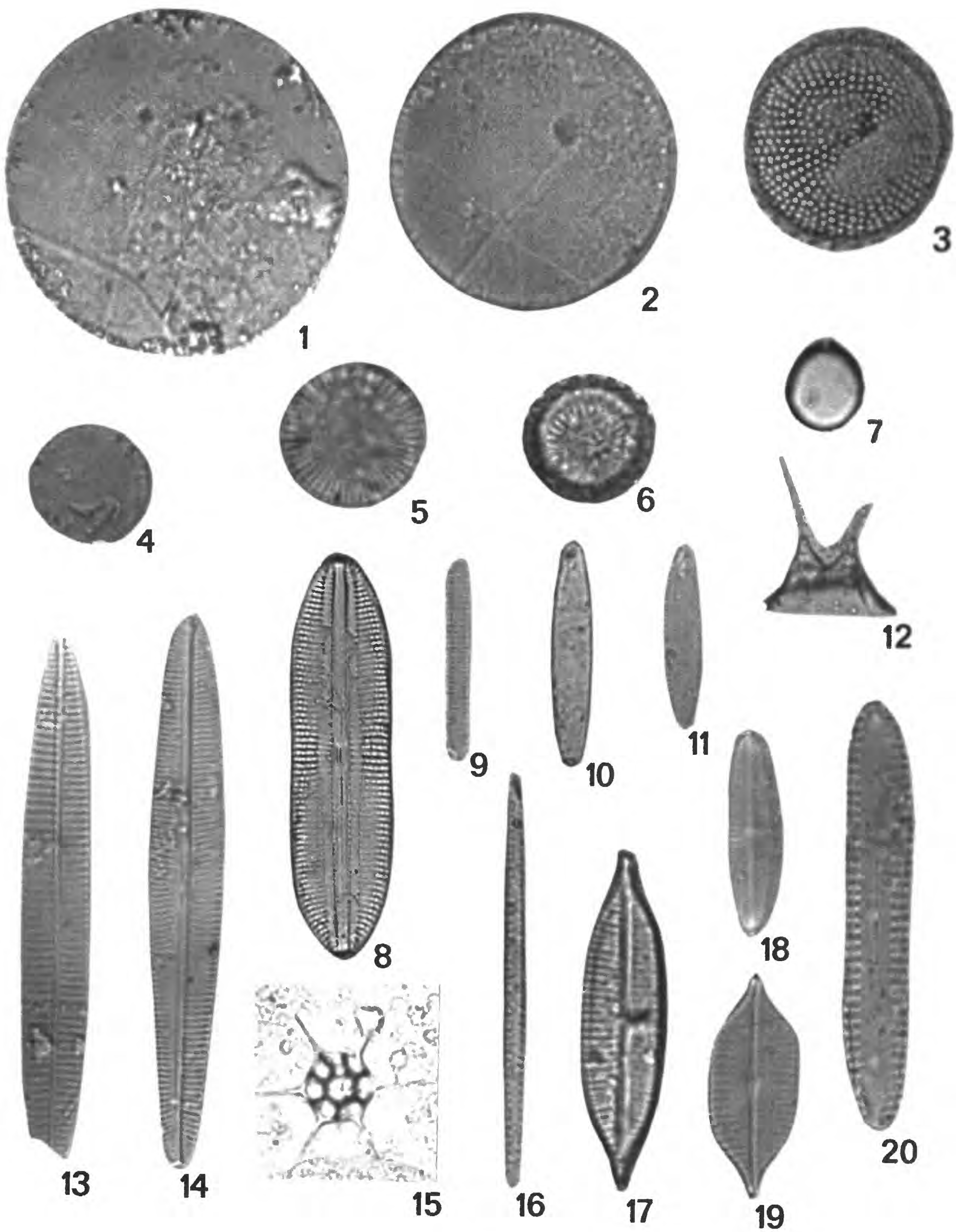
PLATE 2

1. *Thalassiosira kryophilia*? (Gran) Jørgensen, diameter 48 µm. 2. *Thalassiosira kryophilia* (Gran) Jørgensen, diameter 42µm. 3. *Thalassiosira lacustris* var. *septrionalis* (Grunow) Hasle, diameter 38 µm. 4. *Thalassiosira nordenskioeldii* Cleve, diameter 17µm. 5. *Cyclotella* ? sp., diameter 21 µm. 6. *Paralia sulcata* (Ehrenberg) Cleve, diameter 18 µm. 7. Chrysophyte cyst, diameter 7 µm. 8. *Diploneis litoralis* var. *clathrata* (Østrup) Cleve, length 68 µm. 9. *Nitzschia cylindra* (Grun.) Hasle, length 16 µm. 10. *Nitzschia grunowii*? Hasle, length 32 µm. 11. *Nitzschia grunowii* Hasle, length 27 µm. 12. *Chaetoceros* sp. cf. *C. mitra* (Bailey) Cleve, width 48 µm. 13. *Navicula kepesii* Grunow, length 79 µm. 14. *Pseudogomphonema groenlandicum* (Østrup) Medlin, length 112 µm. 15. *Distephanus speculum*, base 23 µm. 16. *Thalassionema nitzschioides* (Grunow) Peragallo, length 59 µm.. 17., 19. *Navicula trigonocephala* Cleve, 17, length 47 µm, 19, length 30 µm. 18. *Navicula* sp. 2 of Sancetta 1982, length 28 µm. 20. *Achnanthes* sp. cf. *A. groenlandica* (Cleve) Grunow, length 60 µm.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