U.S. Department of the Interior
U.S. Geological Survey

Distribution of Benthic Foraminifers (>125 µm) in the Surface Sediments of the Arctic Ocean

U.S. GEOLOGICAL SURVEY BULLETIN 2164

science for a changing world

Availability of Publications of the U.S. Geological Survey

Order U.S. Geological Survey (USGS) publications by calling the toll-free telephone number 1–888–ASK–USGS or contacting the offices listed below. Detailed ordering instructions, along with prices of the last offerings, are given in the current-year issues of the catalog "New Publications of the U.S. Geological Survey."

Books, Maps, and Other Publications

By Mail

Books, maps, and other publications are available by mail from—

USGS Information Services
Box 25286, Federal Center
Denver, CO 80225

Publications include Professional Papers, Bulletins, Water-Supply Papers, Techniques of Water-Resources Investigations, Circulars, Fact Sheets, publications of general interest, single copies of permanent USGS catalogs, and topographic and thematic maps.

Over the Counter

Books, maps, and other publications of the U.S. Geological Survey are available over the counter at the following USGS Earth Science Information Centers (ESIC's), all of which are authorized agents of the Superintendent of Documents:

- Anchorage, Alaska–Rm. 101, 4230 University Dr.
- Denver, Colorado–Bldg. 810, Federal Center
- Menlo Park, California–Rm. 3128, Bldg. 3, 345 Middlefield Rd.
- Reston, Virginia–Rm. 1C402, USGS National Center, 12201 Sunrise Valley Dr.
- Salt Lake City, Utah–2222 West, 2300 South (books and maps available for inspection only)
- Spokane, Washington–Rm. 135, U.S. Post Office Building, 904 West Riverside Ave.
- Washington, D.C.–Rm. 2650, Main Interior Bldg., 18th and C Sts., NW.

Maps only may be purchased over the counter at the following USGS office:

- Rolla, Missouri–1400 Independence Rd.

Electronically

Some USGS publications, including the catalog "New Publications of the U.S. Geological Survey," are also available electronically on the USGS's World Wide Web home page at **http://www.usgs.gov**

Preliminary Determination of Epicenters

Subscriptions to the periodical "Preliminary Determination of Epicenters" can be obtained only from the Superintendent of Documents. Check or money order must be payable to the Superintendent of Documents. Order by mail from—

Superintendent of Documents
Government Printing Office
Washington, DC 20402

Information Periodicals

Many Information Periodicals products are available through the systems or formats listed below:

Printed Products

Printed copies of the Minerals Yearbook and the Mineral Commodity Summaries can be ordered from the Superintendent of Documents, Government Printing Office (address above). Printed copies of Metal Industry Indicators and Mineral Industry Surveys can be ordered from the Center for Disease Control and Prevention, National Institute for Occupational Safety and Health, Pittsburgh Research Center, P.O. Box 18070, Pittsburgh, PA 15236–0070.

Mines FaxBack: Return fax service

1. Use the touch-tone handset attached to your fax machine's telephone jack. (ISDN [digital] telephones cannot be used with fax machines.)
2. Dial (703) 648–4999.
3. Listen to the menu options and punch in the number of your selection, using the touch-tone telephone.
4. After completing your selection, press the start button on your fax machine.

CD-ROM

A disc containing chapters of the Minerals Yearbook (1993–95), the Mineral Commodity Summaries (1995–97), a statistical compendium (1970–90), and other publications is updated three times a year and sold by the Superintendent of Documents, Government Printing Office (address above).

World Wide Web

Minerals information is available electronically at **http://minerals.er.usgs.gov/minerals/**

Subscription to the catalog "New Publications of the U.S. Geological Survey"

Those wishing to be placed on a free subscription list for the catalog "New Publications of the U.S. Geological Survey" should write to—

U.S. Geological Survey
903 National Center
Reston, VA 20192

U.S. Department of the Interior
U.S. Geological Survey

Distribution of Benthic Foraminifers (>125 µm) in the Surface Sediments of the Arctic Ocean

By Lisa E. Osterman, Richard Z. Poore, and Kevin M. Foley

U.S. GEOLOGICAL SURVEY BULLETIN 2164

Environmental and oceanographic preferences of
benthic foraminifers are interpreted by using
surface sediment samples from 49 box cores
from the sea floor in the Arctic Ocean

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1999

Published in the Eastern Region, Reston, Va.
Manuscript approved for publication October 9, 1998.

For sale by
U.S. Geological Survey
Information Services
Box 25286, Federal Center
Denver, CO 80225

Library of Congress Cataloging in Publication Data
Osterman, Lisa E.
Distribution of benthic foraminifers (>125 µm) in the surface sediments of the Arctic Ocean / by Lisa E. Osterman, Richard Z. Poore, and Kevin M. Foley.
p. cm.—(U.S. Geological Survey bulletin ; 2164)
Includes bibliographical references.
1. Foraminifera—Arctic Ocean—Vertical distribution. I. Poore, Richard Z. II. Foley, Kevin M. III. Title. IV. Series.
QL368.F6078 1999 98–49720
579.4'417732—dc21 CIP

CONTENTS

FIGURES

TABLES

[Tables 4–7 follow References Cited and precede Appendix]

METRIC CONVERSION FACTORS

Multiply	By	To obtain
micrometer (µm)	0.0000394	inch
meter (m)	3.281	foot
cubic centimeter (cm^3)	0.06102	cubic inch
gram (g)	0.03527	ounce avoirdupois

For temperature conversions from degrees Celsius (°C) to degrees Fahrenheit (°F), use the following:

$$°F = (1.8 \times °C) + 32$$

Distribution of Benthic Foraminifers (>125 µm) in the Surface Sediments of the Arctic Ocean

By Lisa E. Osterman, Richard Z. Poore, and Kevin M. Foley

ABSTRACT

Census data on benthic foraminifers (>125 µm) in surface sediment samples from 49 box cores are used to define four depth-controlled biofacies, which will aid in the paleoceanographic reconstruction of the Arctic Ocean. The shelf biofacies contains a mix of shallow-water calcareous and agglutinated species from the continental shelves of the Beaufort and Chukchi Seas and reflects the variable sedimentologic and oceanic conditions of the Arctic shelves. The intermediate-depth calcareous biofacies, found between 500 and 1,100 meters water depth (mwd), contains abundant *Cassidulina teretis*, presumably indicating the influence of Atlantic-derived water at this depth. In water depths between 1,100 and 3,500 m, a deepwater calcareous biofacies contains abundant *Oridorsalis umbonatus*. Below 3,500 mwd, the deepwater mixed calcareous/agglutinated biofacies of the Canada, Makarov, and Eurasian Basins reflects a combination of low productivity, dissolution, and sediment transport.

Two other benthic foraminiferal species show specific environmental preferences. *Fontbotia wuellerstorfi* has a depth distribution between 900 and 3,500 mwd, but maximum abundance occurs in the region of the Mendeleyev Ridge. The elevated abundance of *F. wuellerstorfi* may be related to increased food supply carried by a branch of Atlantic water that crosses the Lomonosov Ridge near the Russian Continental Shelf. *Triloculina frigida* is recognized to be a species preferring lower slope sediments commonly disturbed by turbidites and bottom currents.

INTRODUCTION

At present, our understanding of the Arctic Ocean lags behind our understanding of other oceans, and fundamental questions still exist about its role in and response to global climate change. The Arctic Ocean is particularly sensitive to climatic fluctuations because small changes in the amounts of sea-ice cover can alter global albedo and thermohaline circulation (Aagaard and Carmack, 1994). Numerous questions still exist regarding the nature and timing of paleoclimatic events in the Arctic Ocean. In order to attempt to answer some of these questions, baseline studies are imperative. This report discusses the distribution of benthic foraminifers in surface sediment samples from 49 box cores (figs. 1 and 2, table 1) collected by the U.S. Geological Survey (USGS) with the assistance of the U.S. Coast Guard (USCG). A modern data set of benthic foraminiferal distribution is necessary for interpreting the paleoclimatic and oceanographic history of the Arctic Ocean.

ACKNOWLEDGMENTS

The work described in this report was funded by the U.S. Geological Survey's Global Change and Climate History Program. We thank the U.S. Coast Guard for assistance in collecting the box cores in the 1992, 1993, and 1994 field seasons. We also thank the Canadian Coast Guard for support with the 1994 sampling program. We thank Ann Rogers (of the USGS) for technical assistance. We thank Martin A. Buzas (Smithsonian Institution), Scott E. Ishman (USGS), Leonid V. Polyak (Ohio State University), and David B. Scott (Dalhousie University) for helpful reviews.

RIDGES AND BASINS OF THE ARCTIC BASIN

The Arctic Ocean occupies the Arctic Basin, which contains several basins and ridges (fig. 2):

- The Lomonosov Ridge, a flat-topped continental fragment believed to have been rifted from the Eurasian margin, lies at an average of 1,600 meters water depth (mwd) and effectively prevents deepwater exchange between the Eurasian Basin to the east and the Amerasian Basin to the west (Aagaard and others, 1985; Aagaard and Carmack, 1994).
- The Eurasian Basin, centered around the actively spreading Gakkel Ridge, lies between 3,000 and 4,000 mwd. The Eurasian Basin contains the Nansen and Amundsen Basins.

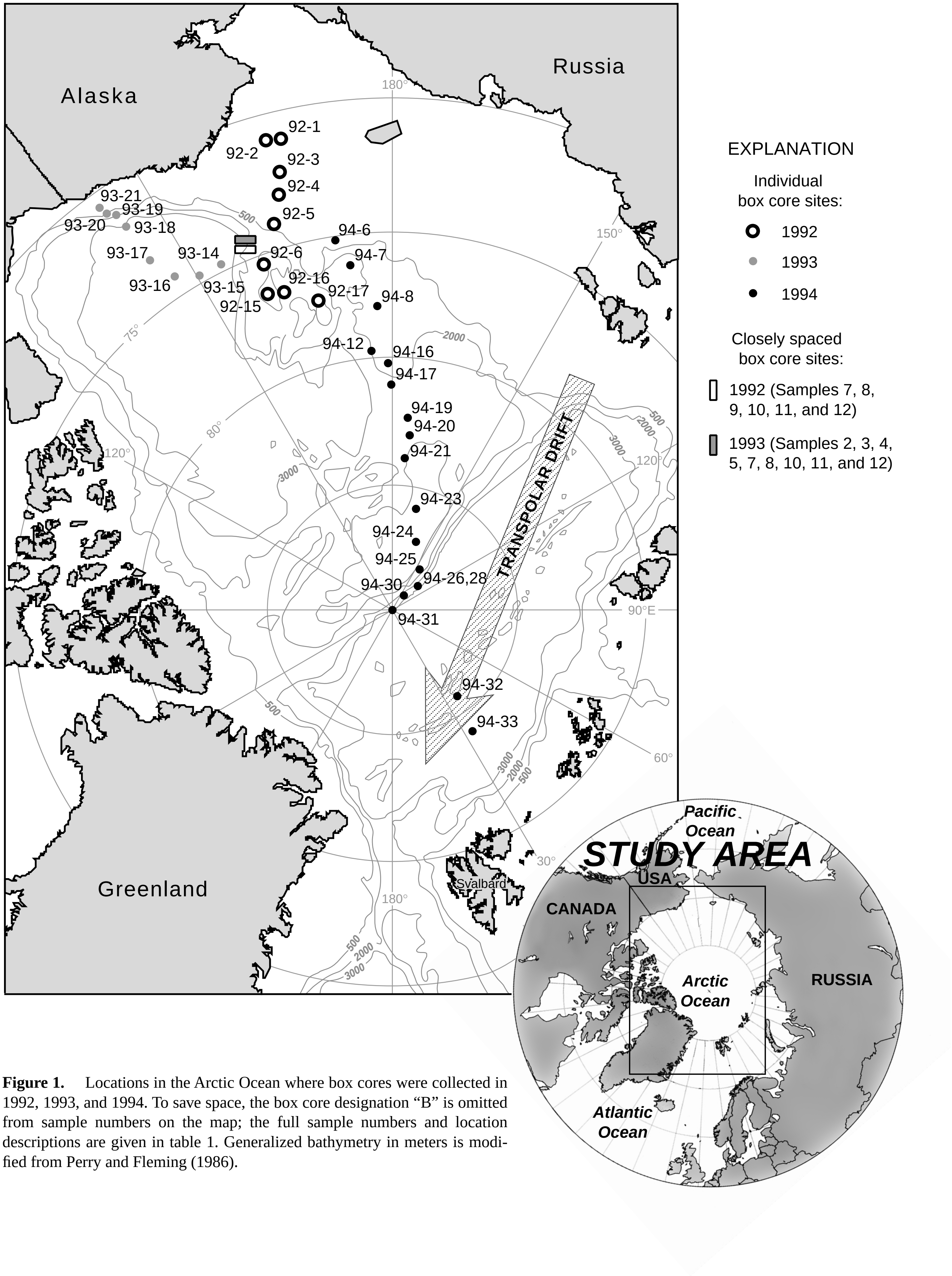

Figure 1. Locations in the Arctic Ocean where box cores were collected in 1992, 1993, and 1994. To save space, the box core designation "B" is omitted from sample numbers on the map; the full sample numbers and location descriptions are given in table 1. Generalized bathymetry in meters is modified from Perry and Fleming (1986).

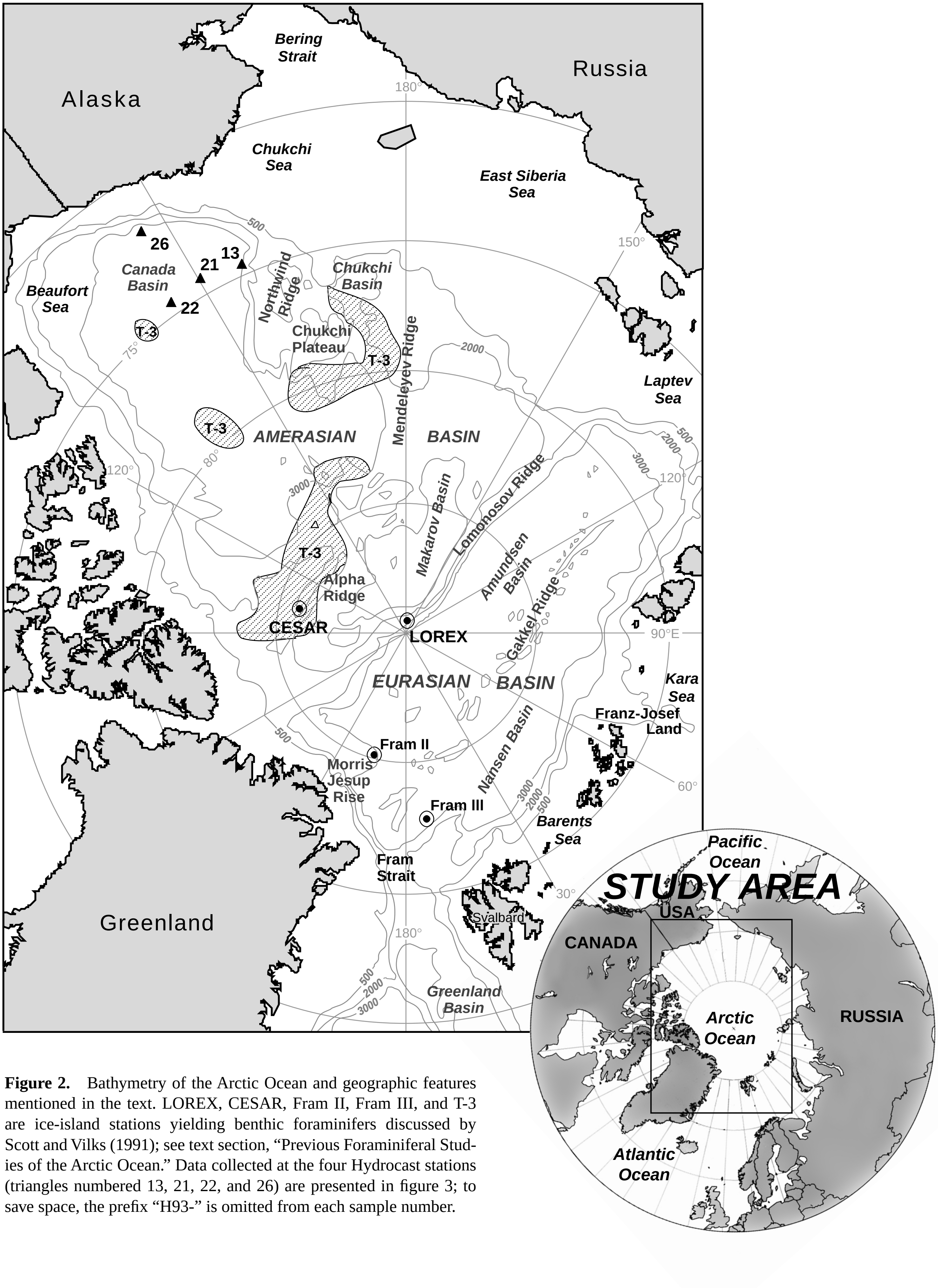

Figure 2. Bathymetry of the Arctic Ocean and geographic features mentioned in the text. LOREX, CESAR, Fram II, Fram III, and T-3 are ice-island stations yielding benthic foraminifers discussed by Scott and Vilks (1991); see text section, "Previous Foraminiferal Studies of the Arctic Ocean." Data collected at the four Hydrocast stations (triangles numbered 13, 21, 22, and 26) are presented in figure 3; to save space, the prefix "H93-" is omitted from each sample number.

Table 1. Latitude, longitude, water depth, and location of sites where box cores were collected in this study of the Arctic Ocean.

[Core sites are plotted in figure 1, and ridges and basins are labeled in figure 2. yr B.P., years before present; carbon-14 ages in the last column are given in years before 1950, the beginning of the present era of widespread human use of radioactivity. The accelerator mass spectrometer (AMS) carbon-14 ages were determined on more than 2,000 specimens of the planktic foraminifer *Neogloboquadrina pachydermal* (sinistral) from the surface sediment samples; the ages were determined at the Lawrence Livermore Laboratory's Center for Accelerator Mass Spectrometry (CAMS) in Livermore, Calif. The carbon-14 ages are corrected for water-mass-reservoir effects by subtracting 440 years (Darby and others, 1997)]

Box core no.	Latitude	Longitude	Water depth (meters)	Location name	C-14 age (yr B.P.)
92-B5	74°30.58' N	159°58.63' W	585	Northwind Ridge	
93-B2	74°45.33' N	157°53.2' W	893	Northwind Ridge	
92-B7	74°49.22' N	157°33.48' W	1,055	Northwind Ridge	3,470 ± 60
92-B8	74°49.42' N	157°25.54' W	1,402	Northwind Ridge	
93-B3	74°44.5' N	157°27.4' W	1,536	Northwind Ridge	
93-B4	74°44.4' N	157°23.5' W	1,779	Northwind Ridge	
93-B5	74°44.4' N	157°21.7' W	1,942	Northwind Ridge	
92-B9	74°49.5' N	157°12.3' W	2,120	Northwind Ridge	3,640 ± 60
93-B7	74°44.4' N	157°18.9' W	2,476	Northwind Ridge	
93-B8	74°44.0' N	157°17.1' W	2,560	Northwind Ridge	
92-B10	74°48.8' N	157°06.2' W	3,145	Northwind Ridge	3,540 ± 60
93-B10	74°44.5' N	157°11.4' W	3,365	Northwind Ridge	
93-B11	74°44.2' N	157°09.5' W	3,482	Northwind Ridge	
93-B17	73°52.4' N	140°36.5' W	3,498	Canada Basin	
93-B16	74°36.2' N	142°05.8' W	3,680	Canada Basin	
93-B15	75°20.3' N	150°00.4' W	3,808	Canada Basin	
92-B12	74°49.46' N	156°52.37' W	3,811	Canada Basin	1,500 ± 60
93-B12	74°43.5' N	156°52.8' W	3,818	Canada Basin	
93-B14	74°49.2' N	155°00.3' W	3,842	Canada Basin	
93-B18	72°08.5' N	141°08.1' W	2,940	Beaufort Sea continental slope	
93-B19	71°17.0' N	147°20.9' W	2,089	Beaufort Sea continental slope	
93-B20	71°03.8' N	147°19.9' W	1,190	Beaufort Sea continental slope	
93-B21	71°00.9' N	147°21.5' W	401	Beaufort Sea continental shelf	
92-B1	72°24.2' N	164°18.2' W	49	Chukchi Sea continental shelf	
92-B2	72°23.8' N	164°16.2' W	48	Chukchi Sea continental shelf	
92-B3	73°41.6' N	162°39.8' W	201	Chukchi Sea continental shelf	
92-B17	76°05.19' N	164°50.15' W	402	Chukchi Plateau	2,110 ± 60
92-B4	74°00.00' N	161°23.7' W	447	Chukchi Sea continental slope	
94-B6	75°21.45' N	170°30.44' W	528	Chukchi Sea continental slope	
92-B16	75°43.75' N	160°05.54' W	1,388	Chukchi Sea continental slope	
92-B6	74°59.74' N	159°18.27' W	1,845	Chukchi Basin	1,240 ± 60
92-B15	75°44.05' N	160°51.63'W	2,135	Chukchi Basin	
94-B7	76°39.99' N	173°23.09' W	2,214	Chukchi Basin	
94-B8	78°07.68' N	176°44.67' W	1,031	Mendeleyev Ridge	
94-B12	79°59.32' N	174°17.32' W	1,609	Mendeleyev Ridge	
94-B16	80°20.33' N	178°42.71' W	1,533	Mendeleyev Ridge	
94-B17	81°15.91' N	178°58.05' E	2,217	Mendeleyev Slope	
94-B19	82°26.80' N	175°45.50' E	2,400	Mendeleyev Slope	
94-B20	83°10.20' N	174°06.36' E	3,110	Makarov Basin	
94-B21	84°05.72' N	174°57.82' E	3,193	Makarov Basin	
94-B23	85°54.40' N	166°41.00' E	3,475	Makarov Basin	
94-B24	87°09.70' N	161°02.20' E	3,890	Makarov Basin	
94-B25	88°03.30' N	147°40.80' E	2,125	Lomonosov Slope	
94-B26	88°48.60' N	142°58.90' E	1,020	Lomonosov Ridge	
94-B28	88°52.40' N	140°10.80' E	1,990	Lomonosov Slope	2,250 ± 60

Table 1. Latitude, longitude, water depth, and location of sites where box cores were collected in this study of the Arctic Ocean—Continued.

Box core no.	Latitude	Longitude	Water depth (meters)	Location name	C-14 age (yr B.P.)
94-B30	88°59.97' N	137°29.70' E	3,930	Eurasian Basin/Amundsen Basin	
94-B31	89°58.85' N	40°30.39' E	4,180	Eurasian Basin/Amundsen Basin	
94-B32	85°43.04' N	37°44.52' E	3,450	Eurasian Basin/Gakkel Ridge	
94-B33	84°16.14' N	34°44.39' E	3,940	Eurasian Basin/Nansen Basin	

- The Amerasian Basin is divided into the Makarov and Canada Basins. The Makarov Basin is a smaller triangular basin, which lies between the Lomonosov Ridge and the Alpha Ridge-Mendeleyev Ridge. The Canada Basin is west of the Makarov Basin and contains several continental fragments and associated basins (Northwind Ridge and Chukchi Plateau and Basin).

The deep basins in the Arctic Basin are surrounded by a narrow Canadian Continental Shelf and a wide Eurasian Continental Shelf. Seas above the Eurasian Shelf are the Chukchi, East Siberia, Laptev, Kara, and Barents Seas (fig. 2).

OCEANOGRAPHY OF THE ARCTIC OCEAN

The modern Arctic Ocean has a Mediterranean-type circulation. Freshwater from rivers combined with low-salinity surface water entering from the Pacific Ocean results in a strongly stratified ocean consisting of three main water masses (fig. 3): Arctic Surface Water (ASW), Arctic Intermediate Water (AIW), and Arctic Deep Water (ADW). ASW contains input from the surface waters of both the Pacific and Atlantic, which may be introduced to the deeper Arctic Ocean through brine formation. In addition, the various forms of ADW and especially the AIW also contain elements of the deeper layers of the Atlantic Ocean. The multiple sources of water complicate the oceanography of the Arctic Ocean.

The Arctic Surface Water usually lies above the upper 0°C isotherm (fig. 3). The depth to the thermocline and the thickness of the ASW are highly variable (75–300 mwd), depending upon the location within the Arctic Ocean (Carmack, 1990; Aagaard and Carmack, 1994) (fig. 3). The ASW includes areas of relatively warm and salty Atlantic water (>3°C, >34.9 ‰) over the Barents Shelf and low-salinity Polar water (<0°C, <34.4 ‰) in areas of melting pack ice. Pacific water, having low salinity (32–33 ‰) and high nutrient contents, enters through the Bering Strait. As some Pacific water freezes on the Chukchi Shelf, the salt content of the ocean water increases to form dense brines, which are injected periodically into the intermediate and deep waters of the Canada Basin (Aagaard and others, 1985; Anderson and others, 1994; Swift and others, 1997). Similarly, it has been suggested by Anderson and others (1994) that Atlantic-derived water freezes on the Barents and Kara Shelves to form brines that are injected into the Eurasian Basin.

The Arctic Intermediate Water, sometimes referred to as “the Atlantic Layer,” lies between the two 0°C isotherms and is identified as the warmest layer of the Arctic Ocean with a relatively high salinity (Aagaard and others, 1985) (fig. 3). The AIW represents the inflow of Atlantic water into the Arctic Ocean through the Fram Strait. The core of the AIW lies between 200 and 900 mwd, but the depth is variable as the AIW is modified by various processes, such as brine injection, that differ across the Arctic Ocean (Carmack, 1990; Swift and others, 1997).

The Arctic Deep Water is mostly deeper than 900 mwd and is cold (<0°C), but its temperature varies slightly by location. The Canada Basin Deep Water (CBDW; –0.5°C, >34.95 ‰) is the warmest and most saline Arctic Deep Water. The coldest and freshest deep water is in the Greenland Basin (–1.2°C, <34.9 ‰), adjacent to the Arctic Ocean. The Eurasian Basin has water of intermediate temperature and salinity (–0.7°C, 34.94 ‰). The exchange of deep water between the North Atlantic and the Arctic Ocean is limited by the sill depth of the Fram Strait at 2,600 mwd.

PRODUCTIVITY OF THE ARCTIC OCEAN

Conventional wisdom would indicate that productivity of the Arctic Ocean is low because of the heavy ice cover. However, ice cover varies throughout the year, and large fringe areas of pack ice melt each summer (Parkinson and others, 1987). On the continental shelves of the Chukchi and Bering Seas, a close relationship exists between surface-water productivity and benthic biomass (Grebmeier and Barry, 1991). On these Arctic shelves, the highest total benthic biomass is found in areas with the largest flux of high-quality nitrogen-rich food (Grebmeier, 1993). The high surface-water productivity in this area is related to the influx of nutrient-rich Pacific water (Springer and McRoy, 1993). Pacific water contains double the nitrogen (N) and phosphorus (P) and seven times the silicon (Si) of North

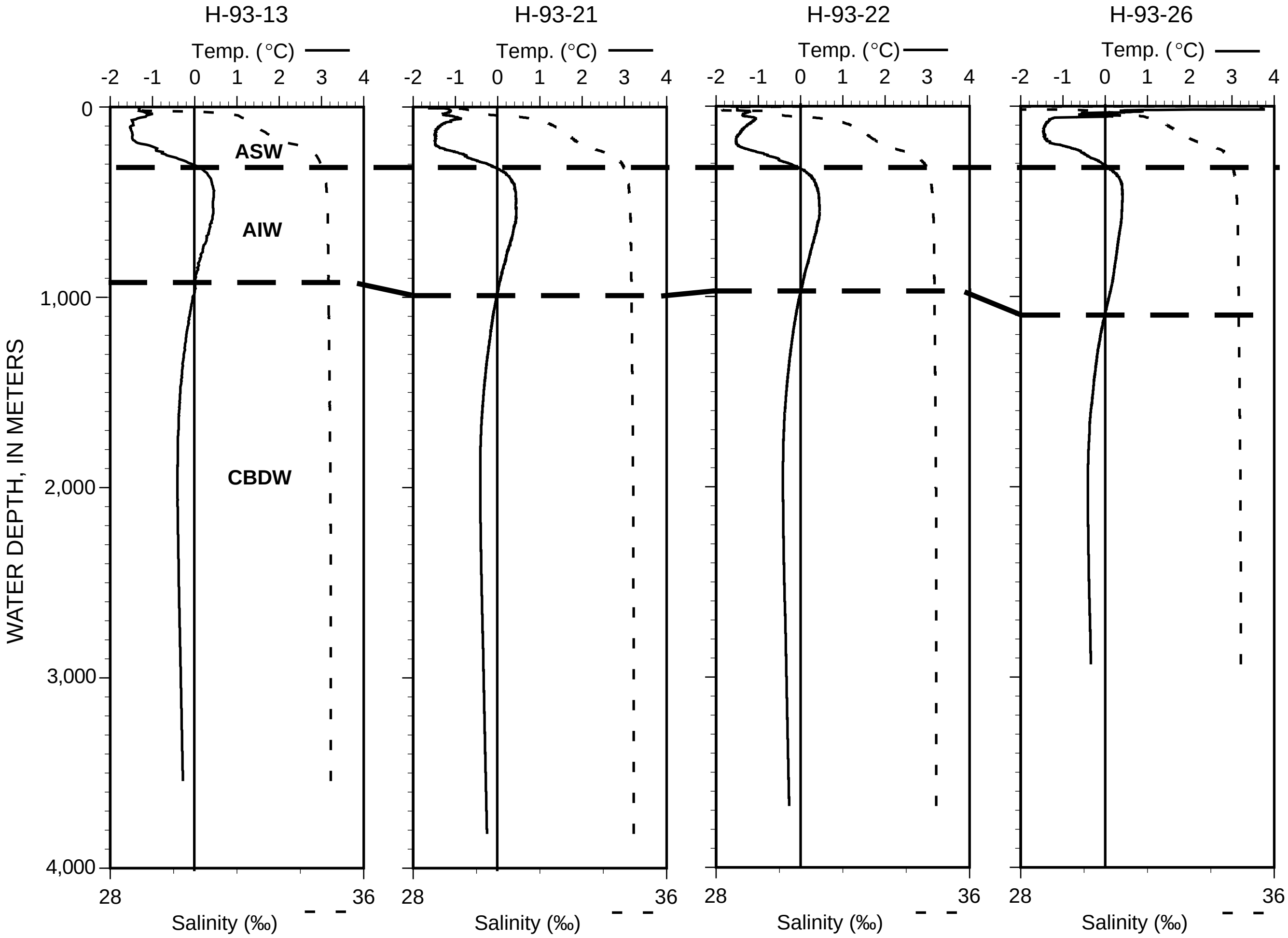

Figure 3. Temperature profiles (solid lines) and salinity profiles (dashed lines) from Hydrocast stations H93-13 (Northwind Ridge), H93-21 and H93-22 (central Canada Basin), and H93-26 (eastern Canada Basin). Station locations are shown in figure 2. Data were collected by the shipboard party as described by Grantz and others (1993). ASW, Arctic Surface Water; AIW, Arctic Intermediate Water; CBDW, Canada Basin Deep Water, a type of Arctic Deep Water.

Atlantic water (Heimdal, 1989); these nutrients result in extremely high primary production of surface plankton, which often sinks directly to the sea floor (Grebmeier, 1993; Springer and McRoy, 1993).

Surface-water productivity in the upper 100 m of the Amerasian Basin indicates an active planktonic community, which would support the cycling of organic carbon to the benthos. The highest productivity occurs in the surface waters above the Northwind Ridge to Makarov Basin (Wheeler and others, 1996). Productivity is lower in the Chukchi Sea and the Eurasian Basin. Plankton productivity depends on ice conditions, as well as nutrients. The higher surface-water productivity of the Amerasian Basin is probably related to the increased nutrient concentration of the inflowing Pacific water (Wheeler and others, 1996, 1997). On the Arctic shelves, increased productivity is reflected in the benthic biomass (Grebmeier, 1993), but it is unclear whether it would be reflected by an increased benthic biomass in deeper water.

Even if Amerasian Basin surface-water productivity is high, the flux of organic matter to the deeper portions of the Arctic Ocean is not well known. It is probable that shallow organic material is transported from the shelf into the basins incorporated in brines. In addition, vertical transport of primary organic material is also increased over oceanographic fronts such as shelf breaks or the one identified between Lomonosov Ridge and Mendeleyev Ridge (Springer and McRoy, 1993; Anderson and others, 1994; Swift and others, 1997). At this time, measurements of benthic biomass in the deep Arctic are in a preliminary stage. Clough and others (1997) indicated that at most stations studied, a significant portion of the biomass consists of foraminifers and values for benthic biomass are highest on the shelves and decrease in the basin. The values for the deep basins are low when compared with values for other ocean basins but are only a first approximation in an area where there is variability of the biomass due to the episodic and seasonal nature of food influx (Clough and others, 1997).

PREVIOUS FORAMINIFERAL STUDIES OF THE ARCTIC OCEAN

Modern deepwater benthic foraminifers have been reported from several studies of the Arctic Ocean. Green (1960) and Lagoe (1977, 1980) reported on the T-3 core tops of the Alpha Ridge and the Canada and Chukchi Basins. Scott and Vilks (1991), Bergsten (1994), Wollenburg (1995), and Wollenburg and Mackensen (1998) described the benthic foraminifers from the Eurasian Basin, and Ishman and Foley (1996) reported on the modern benthic foraminiferal distributions of the Northwind Ridge and Canada Basin. Studies of foraminifers from Arctic continental shelves include those by Loeblich and Tappan (1953), Todd and Low (1967), Vilks (1989), Schröder-Adams and others (1990), Hald and Steinsund (1996), Steinsund and others (in press), and many others.

Green (1960) studied foraminifers (>63 µm) collected between 433 and 2,760 mwd from the continental slope of Ellesmere Island and the Alpha Ridge. He recognized that most species occur at all depths but established four depth zonations where certain species were abundant. The shelf assemblage was characterized by *Cassidulina teretis*, the slope fauna by *Valvulineria arctica*, the apron fauna by *Eponides tumidulus* (=*Ioanella tumidula* of this study), and the abyssal fauna by *Eponides tener* (=*Oridorsalis umbonatus* of this study).

Lagoe (1977) examined the benthic foraminiferal fauna (>63 µm) in 118 samples between 1,069 and 3,812 mwd from the Alpha Ridge and the Chukchi and Canada Basins and correlated foraminiferal assemblages primarily with water masses (Lagoe, 1980). Samples collected beneath Arctic Surface Water contain agglutinated foraminifers or calcareous species. Agglutinated foraminifers are also found in association with the upper portion of the Arctic Intermediate Water, but deeper samples of the AIW are characterized by *C. teretis*. Foraminifers of the Arctic Deep Water include *Stetsonia horvathi, E. tener, E. tumidulus, V. arctica,* and *Planulina wuellerstorfi* (=*Fontbotia wuellerstorfi* of this study).

Scott and Vilks (1991) presented benthic foraminiferal counts (>63 µm) from several ice island stations, including LOREX (fig. 2) (across the Lomonosov Ridge from Amundsen Basin to Makarov Basin), Fram II (Amundsen Basin off the Morris Jesup Rise), Fram III (Svalbard Continental Slope to Nansen Basin), CESAR (Alpha Ridge), and T-3 (Canada Basin). Their study differs from all the other work in that the samples were prepared and counted to ensure high numbers of agglutinated foraminifers. Scott and Vilks (1991) reported that deepwater (>3,600 mwd) samples contained an average of 44 percent *Stetsonia arctica* (which includes *S. horvathi* and *Epistominella arctica* in this study, see taxonomic notes in appendix). In addition, Scott and Vilks (1991) reported a previously unrecognized occurrence of deepwater agglutinated foraminifers.

Bergsten (1994) reported on the recent benthic foraminifers (>63 µm) in 18 samples collected in a transect from the Yermak Plateau to the Lomonosov Ridge and found the deep Eurasian Basin to be dominated by *S. arctica* (average 77 percent). At intermediate depths (500 to 2,000–2,500 mwd), foraminiferal assemblages contain species common in the North Atlantic, including *O. umbonatus* and *P. wuellerstorfi*. The transition from intermediate to deep water is interpreted to occur between 2,000 and 2,500 mwd in the eastern Arctic Ocean (Bergsten, 1994). This transition is below the depth of the core of AIW, which was reported by Swift and others (1997) to be between 200 and 900 mwd. However, Bergsten (1994) believed that it is reasonable to expect Atlantic fauna to the depth of 2,500 m in the eastern Arctic given the sill depth of the Fram Strait at 2,600 m.

Wollenburg (1995) and Wollenburg and Mackensen (1998) reported on two size fractions—those >63 µm and >125 µm—of living and total benthic foraminifers in 50 multicore top samples in the Eurasian and Makarov Basins. In contrast to all other researchers, Wollenburg (1995) believed that the foraminiferal distribution is controlled primarily by productivity in the Arctic Ocean and less by depth, currents, or water masses.

Wollenburg and Mackensen (1998) reported seven factor assemblages based on living assemblages (>125 µm). However, most assemblages occur in only a few widely spaced samples. The assemblages are listed below:

1. The *Lobatula lobatula* assemblage is found associated with strong currents and coarse sediments in <500 mwd along the Svalbard/Barents Sea Shelf.
2. The *C. teretis* assemblage is found between 500 and 1,400 mwd along the Svalbard margin and Morris Jesup Rise and is believed to correspond to increased phytodetritus flux and low current activity.
3. The *F. wuellerstorfi* assemblage occurs between 1,500 and 3,000 mwd along the Amerasian side of the Lomonosov Ridge and is believed to be related to food availability.
4. From 1,500 to 3,000 mwd on the Morris Jesup Rise and the Lomonosov Ridge, the *I. tumidula* assemblage is related to competition and food supply.
5. An assemblage containing *O. tener* (=*O. umbonatus* of this study) and *Triloculina frigida* occurs between 2,000 and 3,600 mwd and relates to food availability and competition. Wollenburg and Mackensen (1998) showed *O. tener* on the Gakkel Ridge and *T. frigida* at the toe of the slope along the Morris Jesup Rise and the Svalbard margin.

6 & 7. The deepest water of the Eurasian Basin has two agglutinated assemblages containing several primitive and attached forms that were not included in our study.

Table 2. Rank and percentage of major benthic foraminifer species in two size fractions (>63 µm and >125 µm) of five samples from a previous study of the Arctic Ocean.

[mwd, meters water depth; N, number of foraminifers counted; dash (—), species not present. Data and species names from Foley and Ishman (1993). Samples are from surface sediments of box cores. Species counts of samples >125 µm differ slightly from data presented in tables 4 and 5 because of taxonomic reassignments indicated in the footnotes]

Foraminifer	92-B17 402 mwd Chukchi Plateau				92-B7 1,055 mwd Northwind Ridge				92-B8 1,402 mwd Northwind Ridge				92-B15 2,135 mwd Chukchi Basin				92-B12 3,811 mwd Canada Basin			
	>63 µm (N=849)		>125 µm (N=312)		>63 µm (N=922)		>125 µm (N=363)		>63 µm (N=1,464)		>125 µm (N=334)		>63 µm (N=1,177)		>125 µm (N=342)		>63 µm (N=261)		>125 µm (N=75)	
	Rank	%	**Rank**	%	**Rank**	%	**Rank**	%	**Rank**	%	**Rank**	%	**Rank**	%	**Rank**	%	**Rank**	%	**Rank**	%
Cassidulina norcrossi[1]	**9**	0.6	**5**	1.6	—		—		—		—		—		—		—		—	
Cassidulina teretis	**1**	66.4	**1**	81.4	**2**	20.5	**2**	29.5	**5**	3.9	**2**	6.9	—		—		—		—	
Cibicides lobatulus[2]	**4**	2.6	**3**	3.2	—		—		—		—		**6**	5.2	—		—		—	
Eponides tumidulus[3]	—		—		**1**	23.8	**6**	3.3	**3**	22.8	**4**	3.6	**2**	21.6	**4**	2.6	**3**	23.8	**2**	10.7
Fontbotia wuellerstorfi	—		—		**8**	1.6	**5**	4.1	**7**	2.5	**3**	6.6	**3**	11.5	**2**	39.5	—		—	
Globocassidulina subglobosa[4]	**2**	15.7	**2**	8.6	—		—		—		—		—		—		—		—	
Nodosariids	**7**	1.2	**3**	3.2	—		—		—		—		**9**	2	**5**	2	**4**	3.1	**2**	10.7
Oridorsalis tener[5]	—		**7**	.6	**3**	17.4	**1**	32.8	**2**	26.2	**1**	72.2	**1**	22.4	**1**	44.2	**1**	33.3	**1**	73.3
Quinqueloculina akneriana[6]	—		**6**	.9	**6**	7.8	**3**	19.8	—		**6**	2.4	**8**	4.1	**3**	8.5	—		—	
Stainforthia concava	**5**	2.4	**8**	.3	—		—		—		—		—		—		—		—	
Stetsonia horvathi	**3**	7.8	—		**4**	10.4	—		**1**	32.5	—		**4**	11.1	—		**2**	28.4	—	
Triloculina frigida	**6**	1.3	—		**7**	5.7	**4**	5.5	**4**	5.2	**4**	3.4	**7**	4.3	**6**	1.8	—		**4**	1.3
Trochammina subglobigeriniformis[7]	**8**	1	—		—		—		—		—		—		—		**5**	1.9	—	
Valvulineria arctica	—		—		**5**	9	**7**	1.9	**6**	3.4	**7**	1.5	**5**	10	—		—		—	
% of total assemblages		99		99		96		97		96		97		92		99		91		96

[1] *Cassidulina norcrossi* = *Islandiella norcrossi* of this report.

[2] *Cibicides lobatulus* = *Lobatula lobatula* of this report.

[3] *Eponides tumidulus* = *Ioanella tumidula* of this report.

[4] Specimens identified as *Globocassidulina subglobosa* have been reidentified as *Cassidulina reniforme*.

[5] *Oridorsalis tener* = *Oridorsalis umbonatus* of this report.

[6] Specimens identified as *Quinqueloculina akneriana* have been reidentified as *Quinqueloculina arctica*, *Miliolinella subrotunda*, and *Triloculinella tegminis*.

[7] *Trochammina subglobigeriniformis* = *Trochammina globigeriniformis* of this report**.**

Ishman and Foley (1996) reported on 22 samples from the Chukchi Shelf and Plateau, Northwind Ridge, Canada Basin, and Beaufort Shelf; they discussed benthic foraminifers in the >125-µm size fraction. Data for the >63-µm fractions of some of the samples are provided in Foley and Ishman (1993). Table 2 shows five samples that were counted at two different sieve sizes (Foley and Ishman, 1993) and gives the most abundant species in rank of abundance as well as percentage occurrence. Cluster analysis of the samples (>125 µm) resulted in the recognition of three biofacies determined by water-mass properties (Ishman and Foley, 1996). The *Textularia* spp. and *Spiroplectammina biformis* biofacies occurred between 48 and 201 mwd. Intermediate-depth samples (401 to 1,190 mwd) are dominated by the *C. teretis* biofacies. The deepest samples (893–3,811 mwd) are composed of the *O. tener* and *E. tumidulus* biofacies.

METHODS

This report describes the modern benthic foraminiferal distribution in surface sediment samples from 49 box cores from 48 to 4,180 mwd in the Arctic Ocean (fig. 1, table 1). The samples were collected during three cruises: the USCGC *Polar Star* in 1992 and 1993 and the USCGC *Polar Sea* in 1994 (Aagaard and others, 1996; Ishman and Foley, 1996; Wheeler, 1997). The 1992 cruise collected box cores from the Chukchi Shelf, Northwind Ridge, and Chukchi Plateau. The 1993 cruise collected box cores from the Northwind Ridge, Canada Basin, and continental shelf and slope of the Beaufort Sea. Twenty-two samples from 1992 and 1993 have been previously reported (Ishman and Foley, 1996). The 1994 cruise collected samples in a transect from the Chukchi Sea to the Nansen Basin (Travis, 1994; Aagaard and others, 1996); they provide data on an area of the Arctic Ocean not previously discussed. This report includes the results from all three cruises.

At most stations, a 50-cubic-centimeter subsample of surface sediments was collected from the top of the boxcore or subcore. Samples were not stained, and no attempt has been made to separate live from dead specimens. In the lab, samples were oven dried (usually overnight at <50°C), weighed, and wet sieved at 63 µm. Samples were dry sieved at 2,000 and 125 µm. Benthic foraminifers in the fraction >125 µm were studied. The entire sample >125 µm was examined, or a representative fraction containing approximately 300 foraminifers was obtained by using a microsplitter; the benthic split ratios are shown in table 3. Benthic foraminiferal counts may differ slightly from previously reported values (Foley and Ishman, 1993; Ishman and Foley, 1996), owing to taxonomic reassignments and additional counts of most samples.

Numbers of sediment grains and of planktic and benthic foraminifers per gram of sediment were calculated from counts of the number of each occurring in a fraction of the sample (table 3). Overall, the highest numbers of planktic and benthic foraminifers per gram in the surface samples are found on the Mendeleyev and Northwind Ridges. The fewest foraminifers per gram occur in the deepest samples of the Canada and Eurasian Basins (table 3).

RESULTS

The percentage of foraminiferal species in each sample is presented in tables 4 and 5. It is most convenient to discuss the benthic foraminifers in two geographic areas. The first includes the Northwind Ridge, Canada Basin, and Beaufort Slope and Shelf; the second is the Arctic transect from the Chukchi Shelf to the Nansen Basin.

NORTHWIND RIDGE, CANADA BASIN, AND BEAUFORT SLOPE AND SHELF (TABLE 4)

Diversity and abundance of foraminifers are high in the Northwind Ridge samples but decrease with depth into the Canada Basin. *Cassidulina teretis* is common to abundant in samples from 585 to 1,055 mwd (>20 percent), and *O. umbonatus* is abundant (33–93 percent) in water depths greater than 893 m (fig. 4). *Fontbotia wuellerstorfi* is 2 to 15 percent in samples from water depths between approximately 1,000 and 3,500 m. *Triloculina frigida* (>10 percent), *I. tumidula*, and selected agglutinated foraminifers are minor components in some samples from intermediate to deep water of the Canada Basin (table 4).

The deepest Beaufort Slope sample (93-B18, 2,940 mwd) resembles samples of comparable depth on the slope of the Northwind Ridge, but the upper three slope and shelf samples (93-B19, 93-B20, and 93-B21) are highly variable, with low-abundance agglutinated assemblages and higher diversity shallow-water calcareous assemblages. The variable nature of the foraminifers near the Canada margin reflects the steepness of the slope and probable downslope transport.

ARCTIC TRANSECT (TABLE 5)

The Arctic transect crosses the Chukchi Shelf and Basin, Mendeleyev Ridge, Makarov Basin, Lomonosov Ridge, and Eurasian Basin; it ends in the Nansen Basin of the Eurasian Basin. Chukchi Shelf samples show considerable variability, including both shallow-water calcareous and low-abundance agglutinated benthic foraminiferal assemblages. *Cassidulina teretis* occurs abundantly (30–80 percent) between 402 and 528 mwd on the Chukchi Plateau and to 1,031 mwd on the Mendeleyev and Lomonosov Ridges (table 5). *Oridorsalis umbonatus* (12–60 percent) occurs in water deeper than 1,020 m. *Fontbotia wuellerstorfi* is more abundant (19–47 percent) in the intermediate-depth waters (1,533–2,400 mwd) of the Chukchi Basin and Mendeleyev Ridge and the northwestern slope of the Lomonosov Ridge (fig. 5) than it is in the intermediate-depth waters of the Northwind Ridge, Canada Basin, and Beaufort Slope and Shelf. *Miliolinella subrotunda* occurs most commonly (13–26 percent) in deep to intermediate samples (1,031–3,198 mwd) on both the Mendeleyev and Lomonosov Ridges and to a lesser extent in the Makarov Basin. *Triloculina frigida* is found throughout the Arctic Ocean but is common to abundant (21–50 percent) in four samples on the lower slope of the Makarov and Eurasian Basins. *Ioanella tumidula* is a consistent component of the samples from intermediate to deep water and is most abundant in the Eurasian Basin.

DISCUSSION

DEPTH ZONATION OF BENTHIC FORAMINIFERS

Because of the stratified oceanography of the Arctic Ocean, it is not surprising that the distribution of benthic foraminifers would be overwhelmingly controlled by depth. We recognize four depth facies: a shelf biofacies, an intermediate-depth calcareous biofacies, a deepwater calcareous biofacies, and a deepwater mixed calcareous/agglutinated biofacies. However, the distribution is far from simple, and some species appear to be responding to other influences, including the melting of pack ice, brine formation, strong bottom contour currents, downslope transport, and inflow of nutrient-rich Pacific water and intermediate-depth Atlantic water.

Table 3. Planktic foraminifers, benthic foraminifers, and sediment grains per gram in surface sediment samples (>125 µm) from this study of the Arctic Ocean.

[The samples are from surface sediments in the box cores (table 1, fig. 1). The benthic split ratio represents the fraction of the sample used to obtain the number of foraminifers presented in tables 4 and 5. ND, no data; planktic foraminifers and sediment grains per gram were not calculated for the 1992 samples]

Box core no.	Water depth (meters)	Sample dry wt. (grams)	No. of planktics >125 µm per gram	Benthic split ratio	No. of benthics >125 µm per gram	No. of sediment grains 125–2,000 µm per gram	Location name
92-B1	49	19.46	ND	1	5	ND	Chukchi Sea continental shelf
92-B2	48	32.06	ND	1	4	ND	Chukchi Sea continental shelf
92-B3	201	23.5	ND	1	17	ND	Chukchi Sea continental shelf
92-B4	447	61.04	ND	0.125	25	ND	Chukchi Sea continental slope
92-B5	585	15.65	ND	1	22	ND	Northwind Ridge
92-B6	1,845	29.17	ND	0.5	85	ND	Chukchi Basin
92-B7	1,055	24.52	ND	0.125	127	ND	Northwind Ridge
92-B8	1,402	76.91	ND	0.0078	515	ND	Northwind Ridge
92-B9	2,120	49.65	ND	0.03125	302	ND	Northwind Ridge
92-B10	3,145	36.99	ND	0.03125	259	ND	Northwind Ridge
92-B12	3,811	76.27	ND	1	1	ND	Canada Basin
92-B15	2,135	26.42	ND	0.125	105	ND	Chukchi Basin
92-B16	1,388	37.07	ND	0.0625	110	ND	Chukchi Sea continental slope
92-B17	402	36.11	ND	0.0078	1,125	ND	Chukchi Plateau
93-B2	893	29.97	3,981	0.125	83	254	Northwind Ridge
93-B3	1,536	14	4,325	0.125	320	706	Northwind Ridge
93-B4	1,779	39.26	12,934	0.0156	502	1,930	Northwind Ridge
93-B5	1,942	35.11	21,466	0.0156	612	4,142	Northwind Ridge
93-B7	2,476	38.69	18,967	0.03125	331	7,250	Northwind Ridge
93-B8	2,560	55.63	12,333	0.0625	241	1,224	Northwind Ridge
93-B10	3,365	35.47	6,990	0.375	25	1,386	Northwind Ridge
93-B11	3,482	27	7,918	0.5	22	6,732	Northwind Ridge
93-B12	3,818	21.12	576	1	2	73	Canada Basin
93-B14	3,842	20.65	1,547	1	4	24	Canada Basin
93-B15	3,808	26.89	1,376	1	7	18	Canada Basin
93-B16	3,680	26.46	2,384	1	7	24	Canada Basin
93-B17	3,498	29.72	2,088	1	10	26	Canada Basin
93-B18	2,940	26.78	363	1	16	461	Beaufort Sea continental slope
93-B19	2,089	21.05	0	1	2	292	Beaufort Sea continental slope
93-B20	1,190	23.34	0	1	4	4,069	Beaufort Sea continental slope
93-B21	401	38.67	0	0.375	20	2,485	Beaufort Sea continental shelf
94-B6	528	39.64	144	0.218	46	364	Chukchi Sea continental slope
94-B7	2,214	50.23	7,309	0.031	182	914	Chukchi Basin
94-B8	1,031	44.29	8,227	0.018	338	1,082	Mendeleyev Ridge
94-B12	1,609	65.9	24,848	0.016	290	3,035	Mendeleyev Ridge
94-B16	1,533	62.18	22,276	0.02	172	1,498	Mendeleyev Ridge
94-B17	2,217	53.34	5,730	0.089	75	212	Mendeleyev Slope
94-B19	2,400	63.73	9,453	0.047	120	691	Mendeleyev Slope
94-B20	3,110	61.97	11,359	0.063	94	1,042	Makarov Basin
94-B21	3,193	49.11	10,682	0.125	103	751	Makarov Basin
94-B23	3,475	78.82	7,306	0.125	32	819	Makarov Basin
94-B24	3,890	75.8	7,434	0.25	16	1,568	Makarov Basin
94-B25	2,125	116.75	5,926	0.033	87	6,729	Lomonosov Slope
94-B26	1,020	60.06	8,666	0.01	563	3,890	Lomonosov Ridge

Table 3. Planktic foraminifers, benthic foraminifers, and sediment grains per gram in surface sediment samples (>125 µm) from this study of the Arctic Ocean—Continued.

Box core no.	Water depth (meters)	Sample dry wt. (grams)	No. of planktics >125 µm per gram	Benthic split ratio	No. of benthics >125 µm per gram	No. of sediment grains 125–2,000 µm per gram	Location name
94-B28.............	1,990	53.14	4,651	0.125	59	405	Lomonosov Slope
94-B30.............	3,930	44.9	2,197	1	3	198	Eurasian Basin/Amundsen Basin
94-B31.............	4,180	46.57	2,301	1	5	154	Eurasian Basin/Amundsen Basin
94-B32.............	3,450	64.09	9,033	0.125	61	4,236	Eurasian Basin/Gakkel Ridge
94-B33.............	3,940	61.14	6,139	0.5	15	885	Eurasian Basin/Nansen Basin

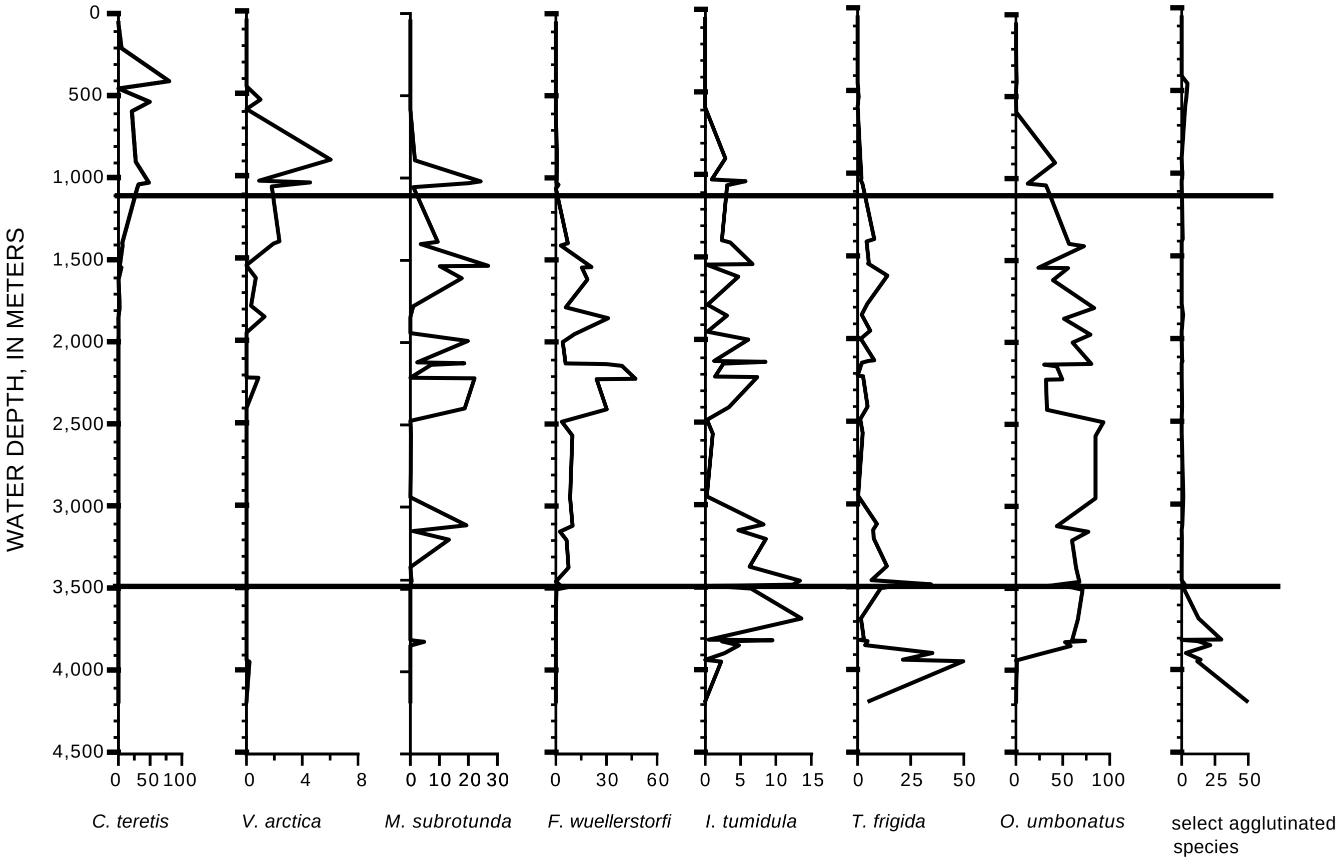

Figure 4. Percentages of selected benthic foraminifer species >125 µm in samples from the Arctic Ocean plotted by water depth. The data are from all samples in tables 4 and 5. The shelf biofacies is not indicated in this figure. Due to the variable nature of this assemblage, many of the species occurring in this biofacies are not included in this figure. The horizontal lines are the boundaries between the intermediate-depth calcareous biofacies (500–1,100 meters water depth, mwd), deepwater calcareous biofacies (1,100–3,500 mwd), and deepwater mixed calcareous/agglutinated biofacies (>3,500 mwd).

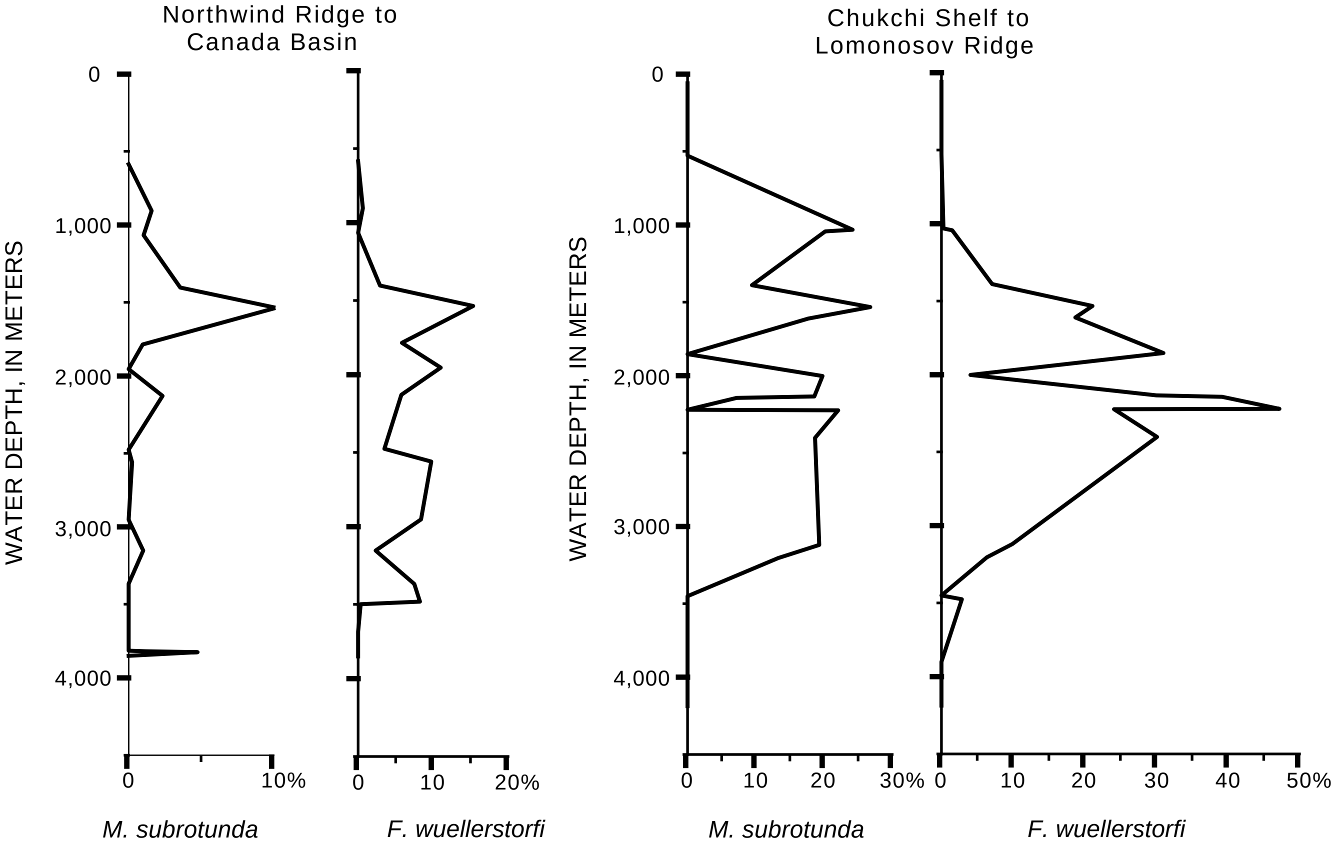

Figure 5. Percentages of two benthic foraminifer species >125 µm in samples from two different geographic areas of the Arctic Ocean—Northwind Ridge to Canada Basin (table 4) and the Chukchi Shelf to the Lomonosov Ridge (table 5)—plotted by water depth. Both *Fontbotia wuellerstorfi* and *Miliolinella subrotunda* are intermediate-depth species that occur more abundantly in the region of the Chukchi Sea to the Lomonosov Ridge than in the region of the Northwind Ridge and Canada Basin. There are no reported occurrences of these species in less than 500 meters water depth, and these species do not occur in the Beaufort Slope region.

SHELF BIOFACIES

The samples collected on the Beaufort and Chukchi Continental Shelves (<500 mwd) have an extremely variable faunal composition (tables 4 and 5). Assemblages are dominated by either calcareous or agglutinated foraminifers and have variable abundance and diversity. The changing compositions of both the shelf sediments and the Arctic Surface Water are affected by seasonal melt of pack ice, brine formation, reworking of sediment by pack ice, and other shelf processes and are responsible for the heterogeneous nature of the foraminifers on the shelf (Lagoe, 1980; Polyak, 1990; Schröder-Adams and others, 1990; Ishman and Foley, 1996).

In spite of the heterogeneity, we combine the shallow-water assemblages into a shelf biofacies, which is clearly distinguishable from intermediate and deeper water biofacies. The shelf biofacies contains shallow-water agglutinated foraminifers including *Trochammina* spp., *Recurvoides scitulus*, *Saccammina difflugiformis*, *Adercotryma glomerata*, and *Saccorhiza ramosa*. Some typical calcareous species of the shelf biofacies include *Islandiella norcrossi*, *Elphidium* spp., and *Cassidulina reniforme*. Shelf species that are found in deeper water are assumed to have been transported either by ice rafting or downslope transport (Reimnitz and others, 1992).

We detect no relationship between ice cover and the occurrence of agglutinated foraminifers on the shelf, as reported by Lagoe (1980). It is probable that ice conditions on the continental shelves fluctuate on decadal scales (Carmack, 1990; Aagaard and Carmack, 1994), whereas the foraminiferal faunas in our samples accumulated during hundreds to thousands of years and therefore represent conditions averaged over longer intervals (see dates in table 1).

INTERMEDIATE-DEPTH CALCAREOUS BIOFACIES

Away from the influence of ASW on the continental shelves, the foraminiferal distribution is strongly correlated with depth. In water depths between 500 and 1,100 m, the intermediate-depth calcareous biofacies contains abundant *C. teretis*, along with common *Valvulineria arctica* (fig. 4). The distribution of *C. teretis* corresponds to the influx of Atlantic water into the Arctic Ocean at intermediate depth.

The "ring" of *C. teretis* between 500 and 1,100 mwd throughout the Arctic has been recognized in earlier studies (Polyak, 1990; Bergsten, 1994; Wollenburg, 1995; Ishman and Foley, 1996) and is evident in the data of Green (1960) and Lagoe (1977). Although the exact controls of Atlantic water on *C. teretis* are not understood, an abundance of this species may be a good long-term indicator of Atlantic water at a particular site.

DEEPWATER CALCAREOUS BIOFACIES

The deepwater calcareous biofacies occurs in water depths from 1,100 to 3,500 m. In this biofacies, *O. umbonatus* is abundant, and it dominates the assemblages in many of our samples (which are >125 µm). Other calcareous species that are common in our deepwater calcareous biofacies include *Miliolinella subrotunda, I. tumidula, T. frigida,* and *F. wuellerstorfi* (tables 4 and 5, fig. 4).

An abundance of *O. umbonatus* in the deep water of the Arctic Ocean has also been recognized in previous studies (for example, those by Green, 1960; Lagoe, 1977, 1980; Ishman and Foley, 1996). In studies that used the >63-µm fraction, *S. horvathi* is reported to dominate in deepwater samples (Scott and Vilks, 1991; Bergsten, 1994). However, a large percentage of *E. tener* (=*O. umbonatus* of this study) was also recorded by Lagoe (1977) in the >63-µm fraction. Figure 6 shows a plot of Lagoe's (1977) data that records up to 33 percent of the foraminifer fauna consisting of *O. umbonatus* between 1,069 and 3,812 mwd in the Canada Basin. It is significant that this species constitutes a significant percentage of the assemblage even at the smaller size fraction. This fact can also be seen in the size-fraction study of Foley and Ishman (1993; see this report, table 2).

DEEPWATER MIXED CALCAREOUS/AGGLUTINATED BIOFACIES

Agglutinated benthic foraminifers occur in two different environments in the Arctic. As discussed above, on the Chukchi and Beaufort Shelves, the shelf biofacies contains a shallow-water agglutinated assemblage including *Trochammina* spp., *R. scitulus, S. difflugiformis, A. glomerata,* and *S. ramosa*. However, in the deepest water samples of the Canada, Makarov, and Eurasian Basins, a different agglutinated assemblage occurs. The deepwater (>3,500 mwd) mixed calcareous/agglutinated biofacies consists of *Reophax nodulosus* and *Hyperammina elongata,* along with assorted calcareous species. A similar deepwater agglutinated assemblage was recognized in the Amundsen Basin by Scott and Vilks (1991) and was correlated with turbidite activity there. These tubular foraminifers either are transported by turbidity currents or are early colonizers in areas of turbidites (Schröder, 1988).

Partial to total loss of the calcareous fauna through dissolution can result in a relative increase in the amount of agglutinated foraminifers (Murray and Alve, 1994). Increased dissolution is consistent with the fact that the deepwater agglutinates occur in Arctic Basin samples having low totals of calcareous benthic foraminifers (tables 4 and 5). Selective dissolution of some calcareous fauna in the Arctic Ocean basins could result from a buildup of carbon dioxide (CO_2) due to low temperatures, great water depths, and slow deepwater overturning. Deepwater residence time is estimated to range from 150 years in the Eurasian Basin to >400 years in the Amerasian Basin (Östlund and others, 1987; Macdonald and others, 1993; Schlosser and others, 1995). Therefore, decreases in calcareous foraminifers and relative increases in agglutinated foraminifers are consistent with increased calcium carbonate dissolution in the deep Arctic basins.

Other possibilities for the low numbers of benthic foraminifers per gram in samples from the Canada, Makarov, and Eurasian Basins could be lower foraminiferal productivity or dilution of the fauna by sediment accumulating at a high rate. Heavy ice cover would limit productivity and result in lower foraminiferal numbers but would result in lower sediment accumulation from melting ice rafts. Neither decreased productivity nor decreased ice rafting would result in increased numbers of agglutinated foraminifers. On the other hand, increased sedimentation in the form of turbidites might result in higher numbers of tubular agglutinated benthic foraminifers and might decrease the total numbers of foraminifers per gram by sediment dilution (Schröder, 1988). However, previous evidence indicates that the sedimentation rates of the Canada Basin are very low (Clark and others, 1980). Most likely a combination of low productivity, turbidite sedimentation, and increased dissolution is responsible for the origin of the deepwater mixed calcareous/agglutinated biofacies.

Furthermore, there is an interesting difference in the calcareous foraminifers in the deep mixed biofacies of the Canada, Makarov, and Eurasian Basins. The Canada Basin contains the deepwater calcareous species *O. umbonatus*. The Eurasian Basin, on the other hand, contains a higher percentage of shallow-water species such as *Haynesina germanica, Buccella* spp., *Cassidulina reniforme,* and various *Elphidium* spp. (tables 6 and 7). In fact, our samples from the Eurasian and Makarov Basins contain the largest percentage of shallow-water calcareous species, whereas the Canada Basin contains the smallest percentage. The processes for the transport of shallow-water species into deep water are ice rafting and downslope transport. The heavy ice cover of the Canada Basin most likely provides the explanation for the decreased percentage of ice-rafted shelf fauna, whereas high percentages of shelf fauna are expected in the Eurasian and Makarov Basins beneath the Transpolar drift of pack ice (Reimnitz and others, 1992).

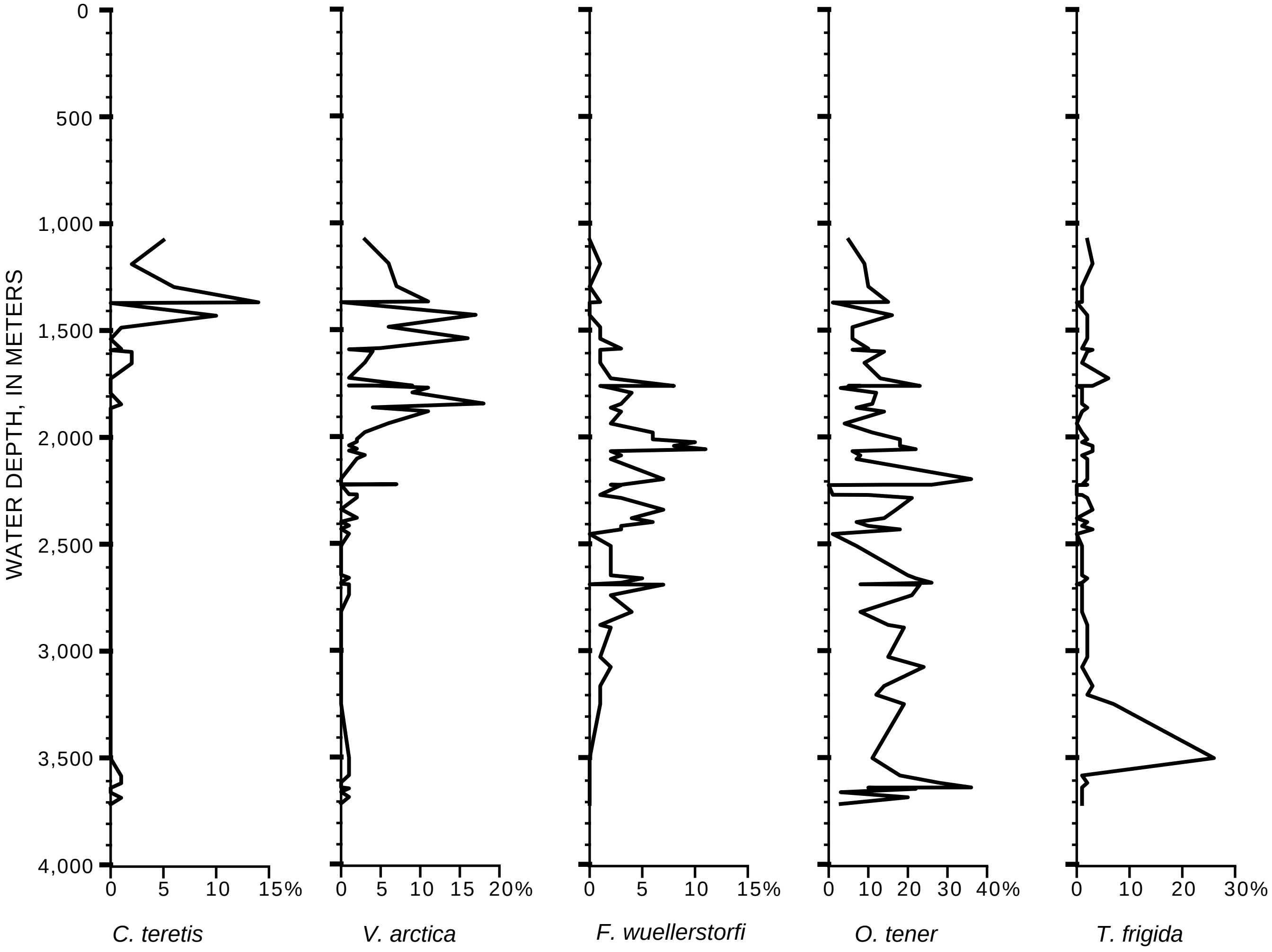

Figure 6. Percentages of selected benthic foraminifer species >63 µm in samples from the Chukchi Basin, Alpha Ridge, and Canada Basin plotted by water depth. Data are from Lagoe (1977), who did not report sample data from less than 1,069 meters water depth. *Oridorsalis tener* of Lagoe (1977) is equivalent to *Oridorsalis umbonatus* of this report.

However, the amount of ice rafting alone cannot fully explain the differences seen in the Arctic. For example, a high percentage of shelf species occurs in the deepest parts of both the Eurasian and Makarov Basins, but lower values occur on the Lomonosov Ridge and Gakkel Ridge (table 7). It is unlikely that the amount of ice rafting would vary significantly over this geographic area, especially considering the position of the Transpolar drift of pack ice over these sites (Reimnitz and others, 1992). We propose that the amounts of ice-rafted foraminifers are fairly uniform over the Arctic, except in the Canada Basin, where they are lower. Higher values of shelf species in the Eurasian and Makarov Basins are probably the result of downslope transport of shelf species via turbidity currents. This interpretation is supported by the increased abundance of tubular foraminifers in both basins (Schröder, 1988). Further discussion of this evidence is in the section below on "Distribution of *Triloculina frigida*."

DISTRIBUTION OF *FONTBOTIA WUELLERSTORFI*

In our study, the highest concentration of *Fontbotia wuellerstorfi* (19–47 percent) occurs in the area from the Northwind Ridge to the western Lomonosov Ridge between 1,533 and 2,400 mwd (fig. 5), and the highest values are on the Mendeleyev Ridge (average 24 percent). Elsewhere in the Amerasian Basin, this species occurs in smaller percentages (0.3–18 percent) between 893 and 3,498 mwd (tables 4 and 5). *Fontbotia wuellerstorfi* does not occur in the Canada Basin below 3,498 mwd and is absent from the Eurasian Basin (3,450–4,180 mwd). Other reports of *F. wuellerstorfi* in the Amerasian Basin include from 740 to 2,760 mwd on the Alpha Ridge (Green, 1960; Lagoe, 1975, 1977; Scott and others, 1989) and from 1,570 to 1,980 mwd on the west side of the Lomonosov Ridge (Scott and Vilks, 1991; Wollenburg, 1995; Wollenburg and Mackensen, 1998).

Fontbotia wuellerstorfi appears to have its distribution partially controlled by depth, and it occurs throughout the Arctic Ocean between 900 and 3,500 mwd. However, the distribution is modified by some other process that causes the species to be most abundant in the Amerasian Basin, specifically in the area of the Mendeleyev Ridge (fig. 5). Bergsten (1994) suggested that *F. wuellerstorfi* is controlled by Atlantic water, whereas Wollenburg (1995) believed that this species responds primarily to food supply. Polyak (1990) reported that *F. wuellerstorfi* is related to relatively mobile water between 1,500 and 2,400 mwd.

The oceanography of the Arctic Ocean is far from completely understood, and the foraminiferal distribution may supply additional information about the oceanography. Evidence of a strong temperature front in the intermediate-depth water over the Lomonosov Ridge indicates that Atlantic water is not exchanged over the central Lomonosov Ridge (Anderson and others, 1994). Instead, Atlantic water travels along the slope to cross the ridge just north of the Russian Continental Slope and enters the Makarov Basin between 500 and 1,500 mwd (Östlund and others, 1987; Swift and others, 1997). In the Amerasian Basin, the Atlantic layer presumably mixes with denser shelf brines to form the relatively warm and saline Canada Basin Deep Water, which is recognized exiting the Amerasian Basin across the Morris Jesup Rise of the Greenland continental margin (Östlund and others, 1987; Anderson and others, 1994). The increased abundance of *F. wuellerstorfi* on the western Lomonosov Ridge and in the Makarov Basin appears to be related to this path of Atlantic water, which is at a deeper bathymetric interval than previously suspected. *Fontbotia wuellerstorfi* is an epibenthic suspension feeder that prefers elevated habitats and is tolerant of sediments having low contents of organic matter (Altenbach and Sarnthein, 1989). Colonization of elevated substrates allows *F. wuellerstorfi* to capture suspended food from passing currents. The geographic distribution of *F. wuellerstorfi* in the Arctic Ocean suggests that this foraminifer may be responding to the organic matter that is transported by an intermediate-depth current.

Wollenburg (1995) reported that productivity and the availability of food are the main controls on the distribution of benthic foraminifers in the Arctic Ocean. However, because of the spatial and temporal variability of food supply to the Arctic benthos, it is unlikely that productivity alone can explain the occurrence of species such as *F. wuellerstorfi*, as proposed by Wollenburg and Mackensen (1998). Although local productivity and food supply are obviously important to the Arctic Ocean benthos, the transport of organic matter by ocean currents, as discussed above, appears to be more important in explaining the observed foraminiferal distributions over the long term.

Our studies also suggest a similar Amerasian Basin occurrence for the species *Miliolinella subrotunda*, with a preference for the intermediate waters of the Northwind Ridge to Makarov Basin (fig. 5). However, the preferences of this common species, given the confused taxonomy (see taxonomic notes in appendix), are unclear. The study of geographic preferences of several Arctic Ocean benthic foraminifers, including *M. subrotunda*, is currently in progress.

DISTRIBUTION OF *TRILOCULINA FRIGIDA*

Another trend observed in our data is the common occurrence (>20 percent) of *Triloculina frigida* in four deepwater samples of both the Makarov and Eurasian Basins (3,475–3,940 mwd). *Triloculina frigida* occurs with significant percentage (>7 percent) in additional samples on the Chukchi Plateau at 1,388 mwd, on the Northwind Ridge and in the Canada Basin from 2,120 to 3,498 mwd, and on the Mendeleyev Ridge/Makarov Basin from 1,606 to 3,198 mwd. Because *T. frigida* occurs in the Eurasian Basin, where *F. wuellerstorfi* is absent, it appears to be related to different environmental conditions. *Triloculina frigida* could be responding strictly as an indicator of intermediate to deep water, ranging from 1,388 to 3,940 mwd with maximum abundance occurring from 3,475 to 3,940 mwd. However, it is the abundance (21–50 percent) in certain samples that is not easily explained. *Triloculina frigida* was first identified by Lagoe (1977) and has been reported in small percentages throughout the Arctic. It appears to be closely related to *Triloculina trihedra* and *Triloculina tricarinata* and has sometimes been misidentified as such, but it is clearly a distinct species (see taxonomic notes in appendix).

Triloculina frigida has been reported in bathyal to abyssal depths of the Norwegian Sea (Sejrup and others, 1981; Mackensen, and others, 1985) and the Gulf of Alaska (Bergen and O'Neil, 1979, as *T. trihedra*). Scott and Vilks (1991, as *T. trihedra*) and Wollenburg (1995) reported up to 18 percent at the base of the Svalbard margin (3,675 mwd), and Lagoe (1977) reported up to 26 percent in the Canada Basin (fig. 6). Examination of our data suggests that the samples where *T. frigida* occurs most commonly are characterized by increased currents or downslope transport. Several lines of evidence suggest this.

First, *T. frigida* is more widespread geographically than *F. wuellerstorfi*, and this difference suggests that the distribution is not related to water masses alone. Most occurrences of *T. frigida* are concentrated along the lower slope and rise, and the maximum abundance is at the base of both sides of the Lomonosov Ridge and along the Svalbard margin. It has been reported that strong bottom contour currents sweep past the Svalbard margin (site 94-B33) and along the base of the Lomonosov Ridge (site 94-B30) in the Eurasian Basin (Aagaard and Carmack, 1994). This strong current activity would likely cause erosion but may transport organic material as well.

Second, most of our samples containing *T. frigida* also contain the tubular agglutinated foraminifer *Hyperammina*.

Large tubular foraminifers have been documented to occur in continental marginal settings in areas of currents or downslope transport (Schröder, 1988; Gooday and others, 1997). Scott and Vilks (1991) reported high occurrences of *Hyperammina* at the base of the Lomonosov Ridge, which is believed to be an area of downslope transport. Most of their samples that contain high abundance of *Hyperammina* also contain small percentages of *T. frigida* (Scott and Vilks, 1991). However, the greatest values of *T. frigida* reported by Scott and Vilks (1991) occur at the base of the Morris Jesup Rise, an area swept by contour currents (Aagaard and Carmack, 1994). In our samples, almost all occurrences of tubular agglutinated foraminifers are marked by an increase in the percentage of *T. frigida.*

Third, our samples with high values of *T. frigida* (94-B23, B24, B30, B31, and B33) also contain numerous shallow-water species, including *C. reniforme*, *H. germanica*, *Elphidium* spp., and *Buccella frigida* (tables 6 and 7). The occurrence of these species suggests transport of shelf sediment, either by ice rafting or by turbidites. Ice rafting of shelf fauna is common in the Arctic Ocean (Wollenburg, 1995), but *T. frigida* has not been reported in any shallow-water samples (Loeblich and Tappan, 1953; Todd and Low, 1967; Vilks, 1989; Steinsund and others, in press), so it is unlikely that ice rafting is responsible for the distribution of both *T. frigida* and the shallow-water species in these samples. As discussed above in the section “Deepwater Mixed Calcareous/Agglutinated Biofacies,” the higher abundance of shallow-water species in the deeper samples of the Eurasian Basin probably relates to downslope transport. Samples that contain the highest abundance of *T. frigida* also contain higher percentages of shelf species. This relationship even holds true in the perennially ice covered Canada Basin, suggesting that the rare occurrences of shelf species in the Canada Basin are also deposited by downslope transport.

These occurrences of *T. frigida* throughout the Arctic Ocean suggest that *T. frigida* is a species that prefers the lower slope and rise and may tolerate the transported sediments that are often found there. Turbidites commonly have high contents of transported shallow-water organic matter, which may make them desirable for food in the ice-covered central Arctic. If *T. frigida* prefers this type of habitat, that preference may explain its occurrence on the slope of both the Canada and Eurasian Basins in areas that are susceptible to both strong contour currents and downslope transport of sediments.

THE QUESTION OF SIEVE SIZE

Concerns have been expressed that, because Arctic foraminifer species are small, the analysis of only the >125-µm fraction will result in the loss of biologic data, as well as valuable oceanographic information (Scott and Vilks, 1991). Data presented on both size fractions—>63 µm and >125 µm—indicate that smaller species are indeed underrepresented in, or even absent from, the >125-µm fraction (Foley and Ishman, 1993; see this report, table 2). However, the goal of our study was to understand the past and present oceanography of the Arctic Ocean through the study of foraminifers and not necessarily to complete a detailed taxonomic assessment.

To determine the effect of sieve size on the data set, we selected five samples that were analyzed at multiple sieve sizes by Foley and Ishman (1993; see this report, table 2). Table 2 includes one sample from each of our biofacies and one sample from the Chukchi Basin in the region where *F. wuellerstorfi* is more abundant. The data presented in table 2 include the most abundant species in rank of abundance, as well as the percentage occurrence for the two sieve fractions (Foley and Ishman, 1993). In all samples, the small species *Stetsonia horvathi* is present (8–33 percent) in the >63-µm fraction and absent from the >125-µm fraction. However, the loss of this species does not significantly alter the interpretation of the data. *Stetsonia horvathi* is the dominant (rank 1) species in only one sample (>63 µm, 92-B8, 33 percent), and, in that sample, it is followed closely by the second ranking species, *O. umbonatus* (26 percent).

In three of the samples (92-B17, 92-B15, and 92-B12), the same species is dominant in both size fractions: *C. teretis* for the shallow sample and *O. umbonatus* for the two deeper samples. Table 2 suggests that significant information is not lost by using only the larger size fraction and that the same depth biofacies (shelf, intermediate-depth calcareous, deepwater calcareous, and deepwater mixed calcareous/agglutinated biofacies) are recognizable regardless of the size fraction used.

Table 2 does indicate some differences in the data sets. The most disparity between the two size fractions occurs with the species *Ioanella tumidula*; however, it still remains in the top six most abundant species even in the larger size fraction (table 2). Therefore, it should be recognized that a small percentage of this species in the >125-µm fraction is more significant than other species. In summary, we feel that the use of the >125-µm fraction in this study does not invalidate the overall conclusions presented in this report. The same depth and environmental biofacies are recognizable, although possibly composed of slightly different species, and regardless of the sieve size used, the same oceanographic trend is discerned.

SUMMARY

Benthic foraminifers (>125 µm) in surface sediment samples of box cores provide information about the oceanography of the Arctic Ocean. Four depth-controlled biofacies are recognized, which are modified by other oceanographic processes. The shelf biofacies is represented by variable foraminiferal faunas found in samples from the Beaufort and Chukchi Continental Shelves. Some shelf samples contain shallow-water calcareous species, whereas others contain low-diversity agglutinated species. This distribution is most likely related to the variable substrate and surface-water processes occurring on the Arctic shelves (Carmack, 1990; Aagaard and Carmack, 1994).

The intermediate-depth calcareous biofacies, found between 500 and 1,100 mwd, contains abundant *Cassidulina teretis* and is apparently associated with Atlantic-water influence in the Arctic Intermediate Water. The exact nature of this relationship is still unclear. A deepwater calcareous biofacies includes an abundance of *Oridorsalis umbonatus* between 1,100 and 3,500 mwd. A deepwater (>3,500 mwd) mixed calcareous/agglutinated biofacies results from low productivity, selective carbonate dissolution in the deepest Arctic basins, the input of shelf foraminifers by downslope transport, and, to a lesser extent, ice rafting.

This study recognizes that the species *Fontbotia wuellerstorfi* has a depth range of 900 to 3,500 mwd throughout the Arctic. Within this depth range, *F. wuellerstorfi* exhibits a geographic preference for the Amerasian Basin, with the highest values of *F. wuellerstorfi* (>24 percent) occurring on the Mendeleyev Ridge from 1,500 to 2,400 mwd. We suggest that the distribution of *F. wuellerstorfi* is related to a branch of Atlantic water that crosses the Lomonosov Ridge near the Russian Continental Shelf. This current may redistribute organic matter to intermediate-depth benthos.

The most abundant and diverse benthic foraminifer assemblages occur in the region from the Northwind to Mendeleyev Ridges and may result from the high surface-water productivity of this area. In contrast, lower foraminiferal diversity and abundance in the Canada and Eurasian Basins are probably related to low productivity, turbidite sedimentation, and increased carbonate dissolution. Turbidite-transported shallow-water foraminifer species compose a significant portion of the assemblage in the samples from the Makarov and Eurasian Basins.

Finally, *Triloculina frigida* is recognized to be a species preferring lower slope sediments affected by downslope transport and strong contour currents in both the Eurasian and Amerasian Basins. Identification of this species in older sediments may indicate areas of downslope transport or episodes of more vigorous bottom circulation.

REFERENCES CITED

Aagaard, K., Barrie, L.A., Carmack, E.C., Garrity, C., Jones, E.P., Lubin, D., Macdonald, R.W., Swift, J.H., Tucker, W.B., Wheeler, P.A., and Whritner, R.H., 1996, U.S., Canadian researchers explore Arctic Ocean: Eos, v. 77, no. 22, p. 209–213.

Aagaard, Knut, and Carmack, E.C., 1994, The Arctic Ocean and climate—A perspective, *in* Johannessen, O.M., Muench, R.D., and Overland, J.E., eds., The polar oceans and their role in shaping the global environment: American Geophysical Union Geophysical Monograph 85, p. 5–20.

Aagaard, Knut, Swift, J.H., and Carmack, E.C., 1985, Thermohaline circulation in the Arctic Mediterranean Seas: Journal of Geophysical Research, v. 90, no. C3, p. 4833–4846.

Altenbach, A.V., and Sarnthein, M., 1989, Productivity record in benthic Foraminifera, *in* Berger, W.H., Smetacek, V.S., and Wefer, G., eds., Productivity of the ocean—Present and past: New York, John Wiley and Sons, p. 255–269.

Anderson, L.G., Björk, G., Holby, O., Jones, E.P., Kattner, G., Koltermann, K.P., Liljeblad, B., Lindegren, R., Rudels, B., and Swift, J., 1994, Water masses and circulation in the Eurasian Basin—Results from the *Oden* 91 expedition: Journal of Geophysical Research, v. 99, no. C2, p. 3273–3283.

Bergen, F.W., and O'Neil, P., 1979, Distribution of Holocene Foraminifera in the Gulf of Alaska: Journal of Paleontology, v. 53, no. 6, p. 1267–1292.

Bergsten, H., 1994, Recent benthic Foraminifera from the North Pole to the Yermak Plateau, eastern central Arctic Ocean: Marine Geology, v. 119, p. 251–267.

Carmack, E.C., 1990, Large scale physical oceanography of polar oceans, *in* Smith, E.O., Jr., ed., Polar oceanography; Part A, Physical science: New York, Academic Press, p. 171–222.

Clark, D.L., Whitman, R.R., Morgan, K.A., and Mackey, S.D., 1980, Stratigraphy and glacial-marine sediments of the Amerasian Basin, central Arctic Ocean: Geological Society of America Special Paper 181, 57 p.

Clough, L.M., Ambrose, W.G., Jr., Cochran, J.K., Barnes, Christina, Renaud, P.E., and Aller, R.C., 1997, Infaunal density, biomass and bioturbation in the sediments of the Arctic Ocean: Deep-Sea Research, Part II, v. 44, no. 8, p. 1683–1704.

Darby, D.A., Bischof, J.F., and Jones, G.A., 1997, Radiocarbon chronology of depositional regimes in the western Arctic Ocean: Deep-Sea Research, Part II, v. 44, no. 8, p. 1745–1757.

Foley, K.M., and Ishman, S.E., 1993, Modern benthic foraminifer census data from box-cores collected on Northwind Ridge, Arctic Ocean during the PI–92–AR cruise of the U.S.C.G.C. *Polar Star*: U.S. Geological Survey Open-File Report 93–515, 9 p.

Gooday, A.J., Shires, R., and Jones, A.R., 1997, Large deep-sea agglutinated Foraminifera—Two differing kinds of organization and their possible ecological significance: Journal of Foraminiferal Research, v. 27, p. 278–291.

Grantz, Arthur, Hart, P.E., Phillips, R.L., McCormick, Michael, Perkin, R.G., Jackson, Ruth, Gagnon, Alan, Li, Shusun, Byers, Carl, and Schwartz, K.R., 1993, Cruise report and preliminary results, U.S. Geological Survey cruise P1–93–AR, Northwind Ridge and Canada Basin, Arctic Ocean, aboard USCGC *Polar Star*, August 16–September 15, 1993: U.S. Geological Survey Open-File Report 93–389, 35 p.

Grebmeier, J.M., 1993, Studies of pelagic-benthic coupling extending onto the Soviet continental shelf in the northern Bering and Chukchi Seas: Continental Shelf Research, v. 13, p. 653–668.

Grebmeier, J.M., and Barry, J.P., 1991, The influence of oceanographic processes on pelagic-benthic coupling in polar regions—A benthic perspective: Journal of Marine Systems, v. 2, p. 495–518.

Green, K.E., 1960, Ecology of some Arctic Foraminifera: Micropaleontology, v. 6, no. 1, p. 57–78.

Hald, Morten, and Steinsund, P.I., 1996, Benthic Foraminifera and carbonate dissolution in the surface sediments of the Barents and Kara Seas: Reports on Polar Research, v. 212, p. 285–307.

Heimdal, B.R., 1989, Arctic Ocean phytoplankton, *in* Herman, Yvonne, ed., The Arctic seas: New York, Van Nostrand Reinhold, p. 193–222.

Ishman, S.E., and Foley, K.M., 1996, Modern benthic foraminifer distribution in the Amerasian Basin, Arctic Ocean: Micropaleontology, v. 42, no. 2, p. 206–220.

Lagoe, M.B., 1975, Recent benthic Foraminifera from the central Arctic Ocean: Madison, Wisc., University of Wisconsin, Masters thesis, 225 p.

_____1977, Recent benthic Foraminifera from the central Arctic Ocean: Journal of Foraminiferal Research, v. 7, no. 2, p. 106–129.

_____1980, Recent Arctic Foraminifera, an overview, *in* Field, M.E., Bouma, A.H., Colburn, I.P., Douglas, R.G., and Ingle, J.C., eds., Proceedings of the Quaternary depositonal environments of the Pacific Coast: Pacific Coast Paleogeography Symposium, 4th, Bakersfield, Calif., 1980, Proceedings, p. 33–42.

Loeblich, A.R., Jr., and Tappan, Helen, 1953, Studies of Arctic Foraminifera: Smithsonian Miscellaneous Collections, v. 121, no. 7, 150 p.

Macdonald, R.W., Carmack, E.C., and Wallace, D.W.R., 1993, Tritium and radiocarbon dating of Canada Basin deep waters: Science, v. 259, no. 5091, p. 103–104.

Mackensen, A., Sejrup, H.-P., and Jansen, E., 1985, The distribution of living benthic Foraminifera on the continental slope and rise off southwest Norway: Marine Micropaleontology, v. 9, no. 4, p. 275–306.

Murray, J.W., and Alve, Elisabeth, 1994, High diversity agglutinated foraminiferal assemblages from the NE Atlantic—Dissolution experiments: Cushman Foundation Special Publication 42, p. 31–55.

Östlund, H.G., Possnert, Göran, and Swift, J.H., 1987, Ventilation rate of the deep Arctic Ocean from carbon 14 data: Journal of Geophysical Research, v. 92, no. C4, p. 3769–3777.

Parkinson, C.L., Comiso, J.C., Zwally, H.J., Cavalieri, D.J., Gloersen, P., and Campbell, W.J., 1987, Arctic sea ice, 1973–1976—Satellite passive-microwave observations: National Aeronautics and Space Administration Special Publication 489, 296 p.

Perry, R.K., and Fleming, H.S., 1986, Bathymetry of the Arctic Ocean: Geological Society of America Map and Chart Series MC–56, scale 1:4,704,075 at 78°N.

Polyak, L.V., 1990, General trends of benthic Foraminifera distribution in the Arctic Ocean, *in* Kotlyakov, V.M., and Sokolov, V.E., eds., Arctic research, advances and prospects, Part 2: Moscow, Nauka, p. 211–212.

Reimnitz, Erk, Marincovich, Louie, Jr., McCormick, Michael, and Briggs, W.M., 1992, Suspension freezing of bottom sediment and biota in the Northwest Passage and implications for Arctic Ocean sedimentation: Canadian Journal of Earth Sciences, v. 29, no. 4, p. 693–703.

Schlosser, Peter, Swift, J.H., Lewis, Diana, and Pfirman, Stephanie, 1995, The role of the large-scale Arctic Ocean circulation in the transport of contaminants: Deep-Sea Research, Part II, v. 42, no. 6, p. 1341–1367.

Schröder, C.J., 1988, Subsurface preservation of agglutinated Foraminifera in the Northwest Atlantic Ocean, *in* Gradstein, F.M., and Rögl, F., eds., Second Workshop on Agglutinated Foraminifera: Abhandlungen der Geologischen Bundesanstalt, v. 41, p. 325–336.

Schröder-Adams, C.J., Cole, F.E., Medioli, P.J., Scott, D.B., and Dobbin, L., 1990, Recent Arctic shelf Foraminifera—Seasonally ice covered vs. perennially ice covered areas: Journal of Foraminiferal Research, v. 20, p. 8–36.

Scott, D.B., Mudie, P.J., Baki, V., MacKinnon, K.D., and Cole, F.E., 1989, Biostratigraphy and late Cenozoic paleoceanography of the Arctic Ocean—Foraminiferal, lithostratigraphic and isotopic evidence: Geological Society of America Bulletin, v. 101, no. 2, p. 260–277.

Scott, D.B., and Vilks, Gustav, 1991, Benthic Foraminifera in the surface sediments of the deep-sea Arctic Ocean: Journal of Foraminiferal Research, v. 21, no.1, p. 20–38.

Sejrup. H.-P., Fjaeran, Tor, Hald, Morten, Beck, Lennart, Hagen, Jens, Miljeteig, Ivor, Morvik, Ivor, and Norvik, Olav, 1981, Benthonic Foraminifera in surface samples from the Norwegian continental margin between 62° N and 65° N: Journal of Foraminiferal Research, v. 11, no. 4, p. 277–295.

Springer, A.M., and McRoy, C.P., 1993, The paradox of pelagic food webs in the northern Bering Sea-III. Patterns of primary production: Continental Shelf Research, v. 13, p. 575–599.

Steinsund, P.I., Polyak, L., Hald, M., Mikhaylov, M., and Karsun, S., in press, Distribution of calcareous benthic Foraminifera in recent sediments of the Barents and Kara Seas: Journal of Foraminiferal Research, v. 27.

Swift, J.H., Jones, E.P., Aagaard, K., Carmack, E.C., Hingston, M., Macdonald, R.W., McLaughlin, F.A., and Perkins, R.G., 1997, Waters of the Makarov and Canada Basins: Deep Sea Research II, v. 44, no. 8, p. 1503–1529.

Todd, Ruth, and Low, Doris, 1967, Recent Foraminifera from the Gulf of Alaska and southeastern Alaska: U.S. Geological Survey Professional Paper 573–A, 46 p.

Travis, John, 1994, Taking a bottom-to-sky "slice" of the Arctic Ocean: Science, v. 266, p. 1947–1948.

Vilks, G., 1989, Ecology of Recent Foraminifera of the Canadian Continental Shelf of the Arctic Ocean, *in* Herman, Yvonne, ed., The Arctic seas: New York, Van Nostrand Reinhold, p. 497–569.

Wheeler, P.A., 1997, Preface—The 1994 Arctic Ocean Section: Deep-Sea Research, Part II, v. 44, no. 8, p. 1483–1485.

Wheeler, P.A., Gosselin, Michel, Sherr, Evelyn, Thibault, Delphine, Kirchman, D.L., Benner, Ronald, and Whitledge, T.E., 1996, Active cycling of organic carbon in the central Arctic Ocean: Nature, v. 380, no. 6576, p. 697–699.

Wheeler, P.A., Watkins, J.M., and Hansing, R.L., 1997, Nutrients, organic carbon and organic nitrogen in the upper water column of the Arctic Ocean—Implications for the sources of dissolved organic carbon: Deep-Sea Research, Part II, v. 44, no. 8, p. 1571–1592.

Wollenburg, Jutta, 1995, Benthic foraminiferal assemblages in the Arctic Ocean—Indicators for water mass distribution, productivity and sea ice drift: Reports on Polar Research, v. 179, 227 p.

Wollenburg, Jutta E., and Mackensen, Andreas, 1998, Living benthic foraminifers from the central Arctic Ocean—Faunal composition, standing stock and diversity: Marine Micropaleontology, v. 34, p. 153–185.

TABLES 4–7 AND APPENDIX

Table 4. Percentages of benthic foraminifers >125 µm in samples from the Northwind Ridge area, Canada Basin, and Beaufort area.

[Only general locations are given here; specific locations are in table 1 and figure 1. The transition between the Northwind Ridge and the Canada Basin is gradual. To save space, dashes following collection year were dropped from sample numbers; for example, sample 92-B5 in table 1 is 92B5 in this table. Asterisks (*) indicate agglutinated foraminifers; all others are calcareous foraminifers]

	Northwind Ridge area									
Water depth (meters)	585	893	1,055	1,402	1,536	1,779	1,942	2,120	2,476	2,560
Box core number	92B5	93B2	92B7	92B8	93B3	93B4	93B5	92B9	93B7	93B8
*Adercotryma glomerata**	0	0	0	0	0	0	0	0	0	0
Ammodiscus catinus *	0	0	0	0	0	0	0	0	0	0
Buccella arctica	0	0	0	0	0	0	0	0	0	0
Buccella frigida	0	0	0	.97	0	.32	0	0	0	.24
Cassidulina reniforme	0	.32	.52	0	.18	.65	.60	.43	.25	0
Cassidulina teretis	21.10	27.30	29.38	6.47	4.64	1.95	.30	0	0	0
Cornuspira involvens	0	0	.26	0	.18	0	0	0	0	0
Dentalina spp.	0	0	.26	.32	0	0	0	0	0	0
Elphidium albiumbilicatum	0	0	0	0	0	0	0	0	0	0
Elphidium excavatum	0	0	.26	.32	0	0	0	0	0	0
Elphidium subarcticum	.29	0	.77	0	0	0	0	0	0	.12
Fontbotia wuellerstorfi	0	.63	0	2.91	15.36	5.84	11.01	5.76	3.49	9.76
Glandulina laevigata	0	0	0	0	0	0	0	0	0	0
Glomospira gordialis *	1.45	0	0	0	0	0	0	.21	0	0
Haynesina germanica	0	0	0	0	0	0	0	0	0	.36
Hyperammina elongata *	0	0	0	0	0	0	0	0	0	0
Ioanella tumidula	0	2.86	3.09	3.56	.18	.32	.30	1.28	.25	1.07
Islandiella norcrossi	0	0	0	0	0	0	0	0	0	0
Laminononion stellatum	0	0	0	0	0	0	0	0	0	0
Lobatula lobatula	0	.95	.77	0	0	0	0	0	0	0
Melonis barleeanus	.58	0	0	0	0	0	0	0	0	0
Miliolinella subrotunda	0	1.59	1.03	3.56	10.18	.97	0	2.35	0	.24
Nodosariids	.87	.32	1.55	.65	1.79	.97	0	.43	.25	.60
Nonionella labradorica	0	0	0	0	0	0	0	0	0	0
Oridorsalis umbonatus	.29	41.59	33.76	72.49	55.54	83.44	79.46	80.38	93.27	85.00
Patellina corrugata	0	0	0	0	.18	0	0	0	0	0
Portatrochammina bipolaris *	2.60	0	0	0	0	0	0	0	0	0
Pyrgo murrhina	0	0	0	0	0	0	0	.21	.75	.12
Pyrgo williamsoni	0	.95	.77	0	.54	0	0	0	0	0
Quinqueloculina arctica	.87	3.17	10.57	.32	6.07	.65	2.38	.85	.50	0
Quinqueloculina sp. B	0	0	.52	0	0	0	0	0	0	0
Recurvoides scitulus *	17.92	4.44	1.55	0	0	0	0	0	0	0
Reophanus oviculus *	0	0	0	0	0	0	0	0	0	.12
Reophax guttifer *	10.40	0	0	.65	0	0	0	0	0	0
Reophax nodulosus *	1.16	0	0	0	0	0	0	0	0	0
Robertinoides charlottensis	0	0	.52	.65	.18	0	0	.21	0	0
Saccammina difflugiformis *	17.34	0	0	0	0	0	0	0	0	0
Saccorhiza ramosa *	10.12	0	0	0	0	0	0	0	0	0
Stainforthia concava	0	0	0	0	0	0	0	0	0	0
Stetsonia horvathi	0	0	0	.32	0	0	0	0	0	0
Triloculina frigida	0	1.27	2.32	4.21	5.00	4.55	5.95	7.89	1.25	2.38
Triloculinella tegminis	0	7.94	10.31	.65	0	0	0	0	0	0
Trochammina globigeriniformis *	10.69	.32	0	0	0	0	0	0	0	0
Trochammina sp. *	2.89	0	0	0	0	0	0	0	0	0
Valvulineria arctica	0	6.03	1.80	1.94	0	.32	0	0	0	0
Verneuilinulla advena *	.58	0	0	0	0	0	0	0	0	0
Other agglutinated *	.87	0	0	0	0	0	0	0	0	0
Other calcareous	0	.32	0	0	0	0	0	0	0	0
Total number of foraminifers	346	315	388	309	560	308	336	469	401	840

Table 4. Percentages of benthic foraminifers >125 µm in samples from the Northwind Ridge area, Canada Basin, and Beaufort area—Continued.

Canada Basin										Beaufort area		
2,940	3,145	3,365	3,482	3,498	3,680	3,808	3,811	3,818	3,842	2,089	1,190	401
93B18	92B10	93B10	93B11	93B17	93B16	93B15	92B12	93B12	93B14	93B19	93B20	93B21
0	0	0	0	0	0	0	0	0	0	10.87	9.68	6.32
.70	0	0	0	.34	0	0	0	0	0	17.39	0	4.56
0	0	0	0	0	.52	.05	0	0	0	0	0	0
0	0	0	.66	0	.52	0	1.19	0	0	0	0	0
0	.67	0	.33	0	0	0	0	2.38	0	0	0	.35
0	0	0	.66	0	0	0	0	0	0	0	2.15	4.56
0	0	0	0	0	0	0	0	0	0	0	0	0
.23	0	.30	.33	.34	0	0	0	0	0	0	0	0
0	1.00	0	0	0	0	0	0	0	0	0	0	0
0	1.00	1.50	.99	0	0	0	1.19	0	0	0	2.15	0
0	.67	.30	.66	0	.52	0	0	2.38	0	0	0	0
8.39	2.34	7.49	8.25	.34	0	0	0	0	0	0	0	0
0	2.01	0	0	0	0	0	0	0	0	0	0	1.40
0	0	0	0	0	0	0	0	0	0	30.43	0	0
0	0	.30	.33	.34	0	0	0	0	0	0	0	.35
0	0	0	0	.34	3.14	4.52	0	4.76	15.48	0	70.97	0
.23	4.68	6.29	.99	6.48	13.61	.50	9.52	2.38	4.76	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	2.11
0	1.00	0	0	0	0	0	1.19	4.76	0	0	0	0
.23	.33	3.29	7.59	7.85	4.19	3.52	10.71	16.67	11.90	0	1.08	1.05
0	0	0	0	0	0	0	0	0	0	0	0	54.74
84.85	77.26	64.07	58.42	70.99	65.97	59.80	73.81	52.38	58.33	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
.23	0	0	0	1.02	.52	3.02	0	0	0	4.35	4.30	4.91
0	1.34	2.69	2.31	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
2.80	0	0	0	0	0	0	0	0	0	21.74	0	0
0	0	0	0	0	0	0	0	2.38	0	0	2.15	4.21
0	0	0	0	0	0	0	0	0	0	8.70	0	0
1.17	0	0	0	1.02	9.42	25.13	0	7.14	5.95	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	5.61
0	0	0	0	0	0	0	0	0	0	0	0	0
.23	7.36	13.77	18.48	10.92	1.57	3.02	1.19	4.76	3.57	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
.93	0	0	0	0	0	0	0	0	0	0	4.30	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	2.17	0	0
0	0	0	0	0	0	0	1.19	0	0	4.35	3.23	8.77
0	.33	0	0	0	0	0	0	0	0	0	0	1.05
429	299	334	303	293	191	199	84	42	84	46	93	285

Table 5. Percentages of benthic foraminifers >125 µm in samples from the Arctic transect from the Chukchi Shelf to the Eurasian Basin.

[Only general locations are given here; specific locations are in table 1 and figure 1. To save space, dashes following collection year were dropped from sample numbers; for example, sample 92-B2 in table 1 is 92B2 in this table. Asterisks (*) indicate agglutinated foraminifers; all others are calcareous foraminifers]

	Chukchi Shelf			Chukchi Slope				Chukchi Basin		
Water depth (meters)	48	49	201	402	447	528	1,388	1,845	2,135	2,214
Box core number	92B2	92B1	92B3	92B17	92B4	94B6	92B16	92B6	92B15	94B7
Adercotryma glomerata *	0	0	8.38	0	1.60	0	0	0	0	0
Ammodiscus catinus *	0	0	.25	0	0	0	0	0	.29	0
Buccella arctica	0	0	0	0	0	0	0	0	0	0
Buccella frigida	1.60	5.21	1.52	0	0	0	0	.08	0	.35
Cassidulina reniforme	.80	3.13	7.87	10.09	0	2.99	.39	.16	0	0
Cassidulina teretis	0	0	4.82	80.13	0	49.25	5.91	.08	0	0
Cornuspira involvens	0	0	0	0	0	0	0	0	0	0
Dentalina spp.	0	0	0	0	0	0	0	.97	0	0
Elphidium albiumbilicatum	0	1.04	1.02	0	0	0	0	0	0	.70
Elphidium excavatum	23.20	57.29	12.69	0	0	1.24	0	0	.29	0
Elphidium subarcticum	0	0	0	0	0	0	0	0	0	0
Fontbotia wuellerstorfi	0	0	0	0	0	0	7.09	31.02	39.19	47.20
Glandulina laevigata	.80	3.13	0	0	0	0	0	0	0	0
Glomospira gordialis *	0	0	0	0	0	.25	.79	.57	0	0
Haynesina germanica	.80	3.13	0	0	0	0	0	.16	0	0
Hyperammina elongata *	0	0	0	0	1.07	0	0	0	0	0
Ioanella tumidula	0	0	0	0	0	0	2.36	3.07	2.59	1.40
Islandiella norcrossi	0	0	47.72	0	0	.25	0	0	0	0
Laminononion stellatum	0	0	.76	0	0	.25	0	0	0	0
Lobatula lobatula	0	0	0	3.15	0	0	0	0	0	0
Melonis barleeanus	0	0	6.85	.32	0	0	0	0	0	0
Miliolinella subrotunda	0	0	0	0	0	0	9.45	0	7.20	0
Nodosariids	0	0	1.52	3.15	0	1.00	2.76	1.86	2.02	.35
Nonionella labradorica	0	1.04	2.03	0	0	0	0	0	0	0
Oridorsalis umbonatus	0	0	0	.63	0	0	56.69	51.29	43.52	49.30
Patellina corrugata	0	0	0	0	0	0	0	0	0	0
Portatrochammina bipolaris *	0	0	0	0	8.56	4.48	0	.73	0	0
Pyrgo murrhina	0	0	0	0	0	0	0	0	0	0
Pyrgo williamsoni	0	0	.76	0	0	0	0	.08	.29	0
Quinqueloculina arctica	0	0	.25	.95	0	0	3.15	.40	.86	0
Quinqueloculina sp. B	0	0	0	0	0	0	0	0	0	0
Recurvoides scitulus *	0	0	0	.95	5.88	7.96	0	3.63	0	0
Reophanus oviculus *	0	0	0	0	0	.25	0	.48	0	0
Reophax guttifer *	0	0	0	0	4.81	2.49	0	0	0	0
Reophax nodulosus *	0	0	0	0	3.21	3.23	0	.48	0	0
Robertinoides charlottensis	0	0	.25	0	0	0	1.18	0	1.44	0
Saccammina difflugiformis *	1.60	1.04	1.02	.32	19.25	2.99	0	0	0	0
Saccorhiza ramosa *	0	0	0	0	42.78	15.42	0	0	0	0
Stainforthia concava	0	0	.51	.32	0	.25	0	0	0	0
Stetsonia horvathi	0	0	0	0	0	0	0	.32	0	0
Triloculina frigida	0	0	0	0	0	.50	7.87	1.94	2.02	0
Triloculinella tegminis	0	0	0	0	0	1.24	0	.65	0	.70
Trochammina globigeriniformis *	0	0	0	0	9.63	4.23	0	.32	0	0
Trochammina sp. *	0	0	.25	0	.53	.75	0	.16	0	0
Valvulineria arctica	0	0	0	0	0	1.00	2.36	1.29	0	0
Verneuilinulla advena *	3 .20	10.42	.25	0	1.60	0	0	.24	0	0
Other agglutinated *	68.00	14.58	.25	0	1.07	0	0	0	0	0
Other calcareous	0	0	1.02	0	0	0	0	0	.29	0
Total number of foraminifers	125	96	394	317	187	402	254	1,238	347	286

Table 5. Percentages of benthic foraminifers >125 µm in samples from the Arctic transect from the Chukchi Shelf to the Eurasian Basin—Continued.

Mendeleyev Ridge					Makarov Basin				Lomonosov Ridge			Eurasian Basin			
1,031	1,609	1,533	2,217	2,400	3,110	3,193	3,475	3,890	2,125	1,020	1,990	3,930	4,180	3,450	3,940
94B8	94B12	94B16	94B17	94B19	94B20	94B21	94B23	94B24	94B25	94B26	94B28	94B30	94B31	94B32	94B33
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
.38	0	0	0	0	.28	0	.32	.68	0	.30	0	1.42	.85	.41	1.35
.38	0	0	.85	0	0	0	.63	1.02	0	0	.51	4.96	2.14	0	2.25
31.56	.33	1.91	0	0	0	0	0	0	0	47.88	0	0	0	0	0
0	0	0	.28	0	0	0	0	0	0	.30	0	0	0	0	0
1.14	1.34	0	0	0	1.10	0	.32	.68	0	.30	0	2.13	2.14	0	.45
0	0	.48	0	2.51	2.20	1.75	4.13	5.46	.32	.30	1.78	13.48	7.26	4.28	9.89
.76	0	.96	2.27	0	.28	1.27	.63	2.39	1.26	.61	0	4.96	2.14	1.22	2.25
0	0	0	.28	.56	.28	.48	.32	1.37	0	0	0	9.93	6.41	0	2.92
1.52	18.73	21.05	24.08	30.08	9.92	6.35	2.86	0	29.97	.30	4.06	0	0	0	0
0	0	0	0	0	0	0	0	.34	0	0	0	0	0	.61	.22
0	0	0	0	.28	0	.16	.32	0	.32	0	0	0	0	0	0
0	0	0	0	1.11	0	0	2.54	5.12	.32	0	1.27	4.26	9.83	2.85	3.37
0	0	0	0	0	.55	0	1.90	2.73	.32	.30	0	14.18	26.50	0	5.39
5.70	4.68	6.70	7.37	3.34	8.26	8.57	12.38	2.73	8.52	.91	6.09	0	0	13.44	2.25
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	.30	0	0	0	0	0
0	0	0	0	0	0	0	0	.34	0	0	0	0	0	0	0
20.15	17.73	26.79	22.10	18.66	19.28	13.33	0	0	18.61	24.24	19.80	0	0	.41	0
.38	2.01	2.87	2.55	1.11	3.58	0	4.13	13.99	2.21	1.21	3.05	20.57	13.25	2.44	8.99
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31.94	39.46	23.92	32.01	33.15	43.53	59.84	34.60	26.28	29.97	12.42	60.41	0	0	67.62	.90
0	0	1.91	0	0	0	0	0	0	.95	.30	0	0	0	.20	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	.85	0	0	0	0	0	0	0	0	0	0	0	0
0	0	7.18	2.27	1.39	0	0	.32	0	.32	5.76	0	0	0	0	0
0	.33	.96	.28	0	0	0	0	0	.63	0	.51	0	.43	0	0
0	0	0	0	0	0	0	0	0	0	1.52	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	.34	0	0	0	0	22.22	0	6.29
0	.67	0	1.13	3.06	1.65	.63	0	0	1.26	0	.25	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	.28	0	0	0	0	0	0	.30	0	0	0	0	0
0	0	0	0	0	0	0	0	1.02	0	0	.25	0	0	0	2.92
1.52	14.05	5.26	2.55	4.74	9.09	7.62	34.60	35.15	5.05	1.82	1.52	21.28	5.56	6.52	49.66
0	0	0	0	0	0	0	0	0	0	0	.51	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	.34	0	0	0	.71	.43	0	0
4.56	.67	0	.85	0	0	0	0	0	0	.91	0	0	0	0	.22
0	0	0	0	0	0	0	0	0	0	0	0	2.13	.85	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.67
263	299	209	353	359	363	630	315	293	317	330	394	141	234	491	445

Table 6. Percentages of selected shallow-water benthic foraminifers >125 µm in samples from the Northwind Ridge area, Canada Basin, and Beaufort area.

[Only general locations are given here; specific locations are in table 1 and figure 1. The transition between the Northwind Ridge and Canada Basin is gradual. To save space, dashes following collection year were dropped from sample numbers; for example, sample 92-B5 in table 1 is 92B5 in this table]

	Northwind Ridge area									
Water depth (meters)	585	893	1,055	1,402	1,536	1,779	1,942	2,120	2,476	2,560
Box core number	92B5	93B2	92B7	92B8	93B3	93B4	93B5	92B9	93B7	93B8
Buccella arctica	0	0	0	0	0	0	0	0	0	0
Buccella frigida	0	0	0	.97	0	.32	0	0	0	.24
Cassidulina reniforme	0	.30	.52	0	.18	.65	.60	.43	.25	0
Elphidium albiumbilicatum	0	0	0	0	0	0	0	0	0	0
Elphidium excavatum	0	0	.26	.32	0	0	0	0	0	0
Elphidium subarcticum	.30	0	.77	0	0	0	0	0	0	.12
Haynesina germanica	0	0	0	0	0	0	0	0	0	.36
Islandiella norcrossi	0	0	0	0	0	0	0	0	0	0
Laminononion stellatum	0	0	0	0	0	0	0	0	0	0
Lobatula lobatula	0	1	.77	0	0	0	0	0	0	0
Total % shallow species	.30	1.30	2.32	1.29	.18	.97	.60	.43	.25	.72
Total number of foraminifers	346	315	388	309	560	308	336	469	401	840

Table 7. Percentages of selected shallow-water benthic foraminifers >125 µm in samples from the Arctic transect from the Chukchi Shelf to the Eurasian Basin.

[Only general locations are given here; specific locations are in table 1 and figure 1. To save space, dashes following collection year were dropped from sample numbers; for example, sample 92-B2 in table 1 is 92B2 in this table]

	Chukchi Shelf			Chukchi Slope				Chukchi Basin			Mendeleyev Ridge	
Water depth (meters)	48	49	201	402	447	528	1,388	1,845	2,135	2,214	1,031	1,609
Box core number	92B2	92B1	92B3	92B17	92B4	94B6	92B16	92B6	92B15	94B7	94B8	94B12
Buccella arctica	0	0	0	0	0	0	0	0	0	0	0	0
Buccella frigida	1.60	5.20	1.52	0	0	0	0	.08	0	.35	.38	0
Cassidulina reniforme	.80	3.10	7.87	10.10	0	2.99	.39	.16	0	0	.38	0
Elphidium albiumbilicatum	0	1.00	1.02	0	0	0	0	0	0	.70	0	0
Elphidium excavatum	23	57.00	12.70	0	0	1.24	0	0	.29	0	.76	0
Elphidium subarcticum	0	0	0	0	0	0	0	0	0	0	0	0
Haynesina germanica	.80	3.10	0	0	0	0	0	.16	0	0	0	0
Islandiella norcrossi	0	0	47.70	0	0	.25	0	0	0	0	0	0
Laminononion stellatum	0	0	.76	0	0	.25	0	0	0	0	0	0
Lobatula lobatula	0	0	0	3.15	0	0	0	0	0	0	0	0
Total % shallow species	26.20	69.40	71.57	13.25	0	4.73	.39	.40	.29	1.05	1.52	0
Total number of foraminifers	125	96	394	317	187	402	254	1,238	347	286	263	299

Table 6. Percentages of selected shallow-water benthic foraminifers >125 µm in samples from the Northwind Ridge area, Canada Basin, and Beaufort area—Continued.

Canada Basin										Beaufort area		
2,940	3,145	3,365	3,482	3,498	3,680	3,808	3,811	3,818	3,842	2,089	1,190	401
93B18	92B10	93B10	93B11	93B17	93B16	93B15	92B12	93B12	93B14	93B19	93B20	93B21
0	0	0	0	0	.52	.50	0	0	0	0	0	0
0	0	0	.66	0	.52	0	1.19	0	0	0	0	0
0	.67	0	.33	0	0	0	0	2.38	0	0	0	.35
0	1.00	0	0	0	0	0	0	0	0	0	0	0
0	1.00	1.50	.99	0	0	0	1.19	0	0	0	2.15	0
0	.67	.30	.66	0	.52	0	0	2.38	0	0	0	0
0	0	.30	.33	.34	0	0	0	0	0	0	0	.35
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	3.34	2.10	2.97	.34	1.56	.50	2.38	4.76	0	0	2.15	.70
429	299	334	303	293	191	199	84	42	84	46	93	285

Table 7. Percentages of selected shallow-water benthic foraminifers >125 µm in samples from the Arctic transect from the Chukchi Shelf to the Eurasian Basin—Continued.

Mendeleyev Ridge—Continued			Makarov Basin				Lomonosov Ridge			Eurasian Basin			
1,533	2,217	2,400	3,110	3,193	3,475	3,890	2,125	1,020	1,990	3,930	4,180	3,450	3,940
94B16	94B17	94B19	94B20	94B21	94B23	94B24	94B25	94B26	94B28	94B30	94B31	94B32	94B33
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	.28	0	.32	.68	0	.30	0	1.42	.85	.41	1.35
0	.85	0	0	0	.63	1.02	0	0	.51	4.96	2.14	0	2.25
.48	0	2.51	2.20	1.75	4.13	5.46	.32	.30	1.78	13.50	7.26	4.28	9.89
.96	2.27	0	.28	1.27	.63	2.39	1.26	.61	0	4.96	2.14	1.22	2.25
0	.28	.56	.28	.48	.32	1.37	0	0	0	9.93	6.41	0	2.92
0	0	1.11	0	0	2.54	5.12	.32	0	1.27	4.26	9.83	2.85	3.37
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	.30	0	0	0	0	0
1.44	3.40	4.18	3.04	3.50	8.57	16.04	1.90	1.51	3.56	39.03	28.63	8.76	22.03
209	353	359	363	630	315	293	317	330	394	141	234	491	445

APPENDIX. SYSTEMATIC LIST AND TAXONOMIC NOTES FOR BENTHIC FORAMINIFERS >125 µm COUNTED IN THIS STUDY OF THE ARCTIC OCEAN

[This appendix provides the names of all species listed in tables 4 and 5, which are the species present in samples counted for this study; it does not list species discussed in the text and table 2 as reported by other authors. Specimens in the National Museum of Natural History (formerly called the United States National Museum), Smithsonian Institution, Washington, D.C., are identified by USNM catalog number]

Adercotryma glomerata (Brady) = *Lituola glomerata* Brady, 1878, Annals and Magazine of Natural History (London), ser. 5, v. 1, p. 433, pl. 20, figs. 1a–c.

Ammodiscus catinus Höglund, 1947, Zoologiska Bidrag Fran Uppsala, v. 26, p. 122, pl. 8, figs. 1 and 7; pl. 28, figs. 19–23; text figs. 82–84, 105–107, 109.

Buccella arctica Voloshinova, 1960, Microfauna of the USSR, Vses. Neft. Nauchno-Issled. Geol.-Razved. Inst. (VNIGRI, Moscow), Trudy, 1960, no. 153, sbornik 11, pl. 8, figs. 2–4.

Buccella frigida (Cushman) = *Pulvinulina frigida* Cushman, 1921, Results of the Hudson Bay Expedition, 1920, 1. The Foraminifera, Contributions to Canadian Biology, no. 9 (1921), p. 135–147.

Cassidulina reniforme (Nørvang) = *Cassidulina crassa* d'Orbigny var. *reniforme* Nørvang, 1945, The Zoology of Iceland, Foraminifera, v. 2, no. 2, p. 1–79.

Cassidulina teretis Tappan, 1951, Northern Alaska Index Foraminifera, Cushman Foundation for Foraminiferal Research Contributions, v. 2, pt. 1, p. 7, pl. 1, fig. 30.

Cornuspira involvens (Reuss) = *Operculina involvens* Reuss, 1850, Denkschriften der Kaiserlichen Akademie der Wissenschaften Wien Mathematisch-naturwissenschaftlichen, Classe 1, p. 370, pl. 46, fig. 30.

Dentalina spp. includes *Dentalina frobisherensis* Loeblich and Tappan, 1953, Studies of Arctic Foraminifera, Smithsonian Miscellaneous Collections, v. 121, no. 7, p. 55, pl. 10, figs. 1–9, and *Dentalina pauperata* d'Orbigny.

Elphidium albiumbilicatum (Weiss) = *Nonion pauciloculum albiumbilicatum* Weiss, 1954, Foraminifera and origin of the Gardiners clay (Pleistocene), eastern Long Island, N.Y., U.S. Geological Survey Professional Paper 254–G, p. 157, pl. 32, figs. 1–2.

Elphidium excavatum (Terquem) = *Polystomella excavata* Terquem, 1876, Société Dunquerquoise, Mémoires, v. 19 (1874–75) p. 429. Note: all forma of *E. excavatum* are included together in these counts.

Elphidium subarcticum Cushman, 1944, Smithsonian Miscellaneous Collections, v. 89, p. 27, pl. 3, figs. 34a, b, 35.

Epistominella arctica Green, 1960, Micropaleontology, v. 6, no. 1, p. 71, pl. 1, fig. 4 (USNM 689643). Note: recorded very rarely in >125-µm fraction of surface samples. See *Stetsonia horvathi* in this list.

Fontbotia wuellerstorfi (Schwager) = *Anomalina wuellerstorfi* Schwager, 1866, Fossile foraminiferen von Kar-Nicobar, Geol. Teil, v. 2, no. 1, Geologische Beobachtungen, no. 2, Paläontologische Mitteilungen, p. 258, pl. 7, figs. 105, 107. Note: *F. wuellerstorfi* includes individuals identified as *Planulina wuellerstorfi* by Lagoe (1977, 1980) and other authors.

Glandulina laevigata (d'Orbigny) = *Nodosaria laevigata* d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, v. 7, p. 252, pl. 10, figs. 1–3.

Glomospira gordialis (Jones and Parker) = *Trochammina squamata* var. *gourdialis* Jones and Parker, 1860, Geological Society of London Quarterly Journal, v. 16, p. 304.

Haynesina germanica (Ehrenberg) = *Nonionina germanica* Ehrenberg, 1840, Koenigliche Akademie Wissenschaften, Berlin, Physik-Math., v. 11, p. 23, pl. 2, figs. 1a–g.

Hyperammina elongata Brady, 1878, Annals and Magazine of Natural History (London), ser. 5, v. 1, p. 433, pl. 20, figs. 2a, b.

Ioanella tumidula (Brady) = *Truncatulina tumidula* Brady, 1884, Rept. Voy. *Challenger*, v. 9 (Zoology), p. 666, pl. 95, figs. 8a–d. Note: *Ioanella tumidula* includes individuals identified as *Eponides tumidulus* by other authors.

Islandiella norcrossi (Cushman) = *Cassidulina norcrossi* Cushman, 1933, Smithsonian Miscellaneous Collections, v. 89, no. 9, p. 7, pl. 2, fig. 7.

Laminononion stellatum (Cushman and Edwards) = *Astrononion stellatum* Cushman and Edwards, 1937, *Astrononion*, a new genus of the Foraminifera, and its species, Contributions from the Cushman Laboratory for Foraminiferal Research, v. 13, p. 29–36. Note: includes *Astrononion gallowayi* Loeblich and Tappan, 1953, in Loeblich and Tappan, 1988, Foraminiferal genera and their classifications, p. 620, pl. 696, figs. 3, 4.

Lobatula lobatula (Walker and Jacob) = *Nautilus lobatulus* Walker and Jacob, 1789, in Kanmacher, Adam's Essays on the Microscope, 2d ed., chap. XI, p. 629–645, pl. XIV.

Melonis barleeanus (Williamson) = *Nonionina barleeana* Williamson, 1858, On the Recent Foraminifera of Great Britain, Royal Society [of London] Publication, p. 32, pl. 3, figs. 68–69.

Miliolinella subrotunda (Montague) = *Vermiculum subrotundum* Montague, 1803. Note: Type species concept was revised with the establishment of neotype for *M. subrotunda* in 1974 by Ponder, The Foramineral Genus *Miliolinella* Wiesner, 1931, and its Synonyms, Micropaleontology, v. 20, p. 197–208. Includes *Pateoris hauerinoides* (Rhumbler) Loeblich and Tappan, 1953, pl. 7, figs. 8–12. Description is quinqueloculine to planispiral chambers with four to five (and as many as seven) chambers visible in last whorl, rounded periphery. Terminal arched aperture is open and rarely may have a small flap or nub, but not a large flap.

Nodosariids. Includes a variety of unilocular calcareous benthic species.

Nonionella labradorica (Dawson) = *Nonionina labradorica* Dawson, 1860, Canadian Naturalist, v. 5, p. 191, fig. 4.

Oridorsalis umbonatus (Reuss) = *Rotalina umbonatus* Reuss, 1851, Zeitschrift der Deutschen Geologischen Gesellschaft, Berlin, v. 3, p. 75, pl. 5, figs. 35a–c. Note: *O. umbonatus* includes individuals identified as *Eponides tener* by other authors.

Patellina corrugata Williamson, 1858, On the Recent Foraminifera of Great Britain, London, Ray Society, p. 46.

Portatrochammina bipolaris (Brady) = *Haplophragmium nanum* Brady, 1881, Notes on Some of the Reticularian Rhizopoda of the *Challenger* Expedition, Part III. 1. Classification. 2. Further Notes on New Species. 3. Note on *Biloculina* Mud, Quarterly Journal of Microscopical Science, new ser., v. 21, p. 50.

Pyrgo murrhina (Schwager) = *Biloculina murrhina* Schwager, 1866, Geologischer Teil, v. 2, no. 1, Geologische Beobachtungen, no. 2, Paläontologische Mitteilungen, p. 187–268.

Pyrgo williamsoni (Silvestri) = *Biloculina williamsoni* Silvestri, 1923, Atti Accad. Pont. Romana Nuovi Lincei, v. 76 (1922–23), p. 73, pl. 6, figs. 169–170.

Quinqueloculina arctica Cushman, 1933, New Arctic Foraminifera Collected by Capt. R.A. Bartlett from Fox Basin and off the Northeast Coast of Greenland, Smithsonian Miscellaneous Collections, v. 89, no. 9, p. 2, pl. 1, figs. 3a–c. Note: illustrated as having an angular periphery with pronounced costae. However, Cushman also reported more rounded specimens (1933, p. 3). Type material shows that small specimens lack costae but have longitudinal striations. Always has a bifid tooth. The holotype is USNM 26152; other examined specimens are in the Cushman Collection, including 59765, 60148.

Quinqueloculina sp. B, Lagoe, 1977, Recent Benthic Foraminifera from the Central Arctic Ocean, Journal of Foraminiferal Research, v. 7, no. 2, p. 119, pl. 2, figs. 19, 20.

Recurvoides scitulus (Brady) = *Haplophragmium scitulum* Brady, 1881, Üeber einige arktische Tiefsee-Foraminiferen gesammelt während der österreichisch-ungarischen Nordpol-Expedition in den Jahren 1872–74, Denkschriften der Kaiserlichen Akademie der Wissenschaften Wien Mathematisch-naturwissenschaftlichen Classe, v. 43, p. 50.

Reophanus oviculus (Brady) = *Reophax ovicula* Brady, 1879, Notes on Some of the Reticularian Rhizopoda of the *Challenger* Expedition, Quarterly Journal of Microscopical Science, new ser., v. 19, p. 20–62.

Reophax guttifer (Brady) = *Lituola (Reophax) guttifera* Brady, 1881, Üeber einige arktische Tiefsee-Foraminiferen gesammelt während der österreichisch-ungarischen Nordpol-Expedition in den Jahren 1872–74, Denkschriften der Kaiserlichen Akademie der Wissenschaften Wien Mathematisch-naturwissenschaftlichen Classe, v. 43, p. 9–110.

Reophax nodulosus Brady, 1881, Üeber einige arktische Tiefsee-Foraminiferen gesammelt während der österreichisch-ungarischen Nordpol-Expedition in den Jahren 1872–74, Denkschriften der Kaiserlichen Akademie der Wissenschaften Wien Mathematisch-naturwissenschaftlichen Classe, v. 43, p. 9–110.

Robertinoides charlottensis (Cushman) = *Cassidulina charlottensis* Cushman, 1925, Contributions from the Cushman Laboratory for Foraminiferal Research, v. 1, pt. 2, p. 41, pl. 6, figs. 6, 7.

Saccammina difflugiformis (Brady) = *Reophax difflugiformis* Brady, 1879, Notes on Some of the Reticularian Rhizopoda of the *Challenger* Expedition, Quarterly Journal of Microscopical Science, new ser., v. 19, p. 20–62.

Saccorhiza ramosa (Brady) = *Hyperammina ramosa* Brady, 1879, Notes on Some of the Reticularian Rhizopoda of the Challenger Expedition, Quarterly Journal of Microscopical Science, new ser., v. 19, p. 20–62.

Stainforthia concava Höglund, 1947, Zoologiska Bidrag Fran Uppsala, v. 26, p. 257, pl. 23, figs. 3, 4; pl. 32, figs. 4–7.

Stetsonia horvathi (Green) 1960, Ecology of Some Arctic Foraminifera, Micropaleontology, v. 6, no. 1, p. 72, pl. 1, figs. 6a,b. Note: In this study, the taxonomic rank of *Stetsonia horvathi* has been retained. Scott and Vilks (1991) showed a gradational series between *S. horvathi* and *Epistominella arctica* but concentrated on the inflated last chamber and did not mention the pronounced differences in coiling that are observed both in the illustrations of Green (1960) and in the type specimens. *Stetsonia horvathi* (USNM 689784) is planispiral to slightly trochospiral, whereas *E. arctica* (USNM 689643) is strongly trochospiral. Until the differences in coiling direction can also be shown to be gradational, we propose to retain the original taxonomic division of Green (1960).

Triloculina frigida Lagoe, 1977, Recent Benthic Foraminifera from the Central Arctic Ocean, Journal of Foraminiferal Research, v. 7, no. 2, p. 120, pl. 1, figs. 12, 17, 18, text figs. 6D, 6E. Note: described by Lagoe as differing from *Triloculina trihedra* (Loeblich and Tappan, 1953) by the presence of an apertural neck. Comparison USNM collection material indicates that *Triloculina trihedra* has no neck and a very distinct tooth, whereas *T. frigida* ranges from having only a small neck with a distinct tooth to having a long neck with an indistinct tooth. Examination of several slides deposited in the USNM and identified by Loeblich and Tappan as *T. trihedra* shows no specimens that could be identified as *T. frigida* (holotype USNM P2110; paratypes USNM 372115 and 372116). It does not appear likely that *T. frigida* is a variety of *T. trihedra*, although it has been misidentified as such. *Triloculina trihedra* was not identified in this study.

Triloculinella tegminis (Loeblich and Tappan) = *Scutuloris tegminus* Loeblich and Tappan, 1953, Studies of Arctic Foraminifera, Smithsonian Miscellaneous Collections, v. 121, no. 7, p. 41, pl. 6, fig. 10; includes *Miliolinella chukchiensis* (Loeblich and Tappan) 1953, pl. 7, fig. 7; *Quinqueloculina subrotunda* (Montague) Todd and Low, 1967; and *Quinqueloculina subrotunda* (Montague?) Cushman, 1948. Note: quinqueloculine or cryptoquinqueloculine with three to five chambers visible. Semicircular aperture at the end of last chamber is nearly filled with a broad low flap, which leaves a slitlike crescentic opening. Found only in shallow-water samples.

Trochammina globigeriniformis (Parker and Jones) = *Lituola nautiloidea* Lamarck var. *globigeriniformis* Parker and Jones, 1865, Royal Society of London Philosophical Transactions, v. 155, p. 407, pl. 17, fig. 96.

Trochammina spp. Includes a variety of unidentified species of *Trochammina*.

Valvulineria arctica Green, 1960, Ecology of Some Arctic Foraminifera, Micropaleontology, v. 6, no. 1, p. 71, pl. 1, figs. 3a–c.

Verneuilinulla advena (Cushman) = *Verneuilina advena* Cushman, 1922, Results of the Hudson Bay Expedition, 1920, 1. The Foraminifera, Contributions to Canadian Biology, no. 9 (1921), p. 141.

Selected Series of U.S. Geological Survey Publications

Books and Other Publications

Professional Papers report scientific data and interpretations of lasting scientific interest that cover all facets of USGS investigations and research.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars are reports of programmatic or scientific information of an ephemeral nature; many present important scientific information of wide popular interest. Circulars are distributed at no cost to the public.

Fact Sheets communicate a wide variety of timely information on USGS programs, projects, and research. They commonly address issues of public interest. Fact Sheets generally are two or four pages long and are distributed at no cost to the public.

Reports in the **Digital Data Series (DDS)** distribute large amounts of data through digital media, including compact disc-read-only memory (CD-ROM). They are high-quality, interpretive publications designed as self-contained packages for viewing and interpreting data and typically contain data sets, software to view the data, and explanatory text.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are produced on request (unlike formal USGS publications) and are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports can consist of basic data, preliminary reports, and a wide range of scientific documents on USGS investigations. Open-File Reports are designed for fast release and are available for public consultation at depositories.

Maps

Geologic Quadrangle Maps (GQ's) are multicolor geologic maps on topographic bases in 7.5- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps (GP's) are on topographic or planimetric bases at various scales. They show results of geophysical investigations using gravity, magnetic, seismic, or radioactivity surveys, which provide data on subsurface structures that are of economic or geologic significance.

Miscellaneous Investigations Series Maps or **Geologic Investigations Series (I's)** are on planimetric or topographic bases at various scales; they present a wide variety of format and subject matter. The series also incudes 7.5-minute quadrangle photogeologic maps on planimetric bases and planetary maps.

Information Periodicals

Metal Industry Indicators (MII's) is a free monthly newsletter that analyzes and forecasts the economic health of five metal industries with composite leading and coincident indexes: primary metals, steel, copper, primary and secondary aluminum, and aluminum mill products.

Mineral Industry Surveys (MIS's) are free periodic statistical and economic reports designed to provide timely statistical data on production, distribution, stocks, and consumption of significant mineral commodities. The surveys are issued monthly, quarterly, annually, or at other regular intervals, depending on the need for current data. The MIS's are published by commodity as well as by State. A series of international MIS's is also available.

Published on an annual basis, **Mineral Commodity Summaries** is the earliest Government publication to furnish estimates covering nonfuel mineral industry data. Data sheets contain information on the domestic industry structure, Government programs, tariffs, and 5-year salient statistics for more than 90 individual minerals and materials.

The Minerals Yearbook discusses the performance of the worldwide minerals and materials industry during a calendar year, and it provides background information to assist in interpreting that performance. The Minerals Yearbook consists of three volumes. Volume I, Metals and Minerals, contains chapters about virtually all metallic and industrial mineral commodities important to the U.S. economy. Volume II, Area Reports: Domestic, contains a chapter on the minerals industry of each of the 50 States and Puerto Rico and the Administered Islands. Volume III, Area Reports: International, is published as four separate reports. These reports collectively contain the latest available mineral data on more than 190 foreign countries and discuss the importance of minerals to the economies of these nations and the United States.

Permanent Catalogs

"Publications of the U.S. Geological Survey, 1879–1961" and **"Publications of the U.S. Geological Survey, 1962–1970"** are available in paperback book form and as a set of microfiche.

"Publications of the U.S. Geological Survey, 1971–1981" is available in paperback book form (two volumes, publications listing and index) and as a set of microfiche.

Annual supplements for 1982, 1983, 1984, 1985, 1986, and subsequent years are available in paperback book form.

Osterman and others—DISTRIBUTION OF BENTHIC FORAMINIFERS (>125 µm), ARCTIC OCEAN—U.S. Geological Survey Bulletin 2164

ISBN 0-607-91660-1

9 780607 915501

Printed on recycled paper

U.S. Department of the Interior

1849•1999

USGS