Journal of Foraminiferal Research, v. 23, no. 1, p. 1–18, January 1993

LATE QUATERNARY BENTHIC FORAMINIFERAL BIOFACIES AND PALEOCEANOGRAPHY OF QUEEN CHARLOTTE SOUND AND SOUTHERN HECATE STRAIT, BRITISH COLUMBIA

R. TIMOTHY PATTERSON

Ottawa-Carleton Geoscience Center and Department of Earth Sciences, Carleton University, Ottawa, Ontario, Canada, K1S 5B6

ABSTRACT

Analysis of Late Quaternary benthic foraminifera in cores from Queen Charlotte Sound and Hecate Strait yields new information on the paleoceanographic history of the region. Q-mode cluster analysis grouped samples into seven associations reflecting benthic foraminiferal biofacies: the *Gyroidina-Bolivina* Biofacies and *Gyroidina-Seabrookia* Biofacies are relict lower to middle bathyal faunas introduced to shallower depths when cooler water masses influenced the area; the *Cribroelphidium* Biofacies, *Islandiella* Biofacies, *Epistominella* Biofacies, and *Bucella* Biofacies are similar to each other in faunal makeup and characterize varying depositional conditions at neritic depths; the *Lobatula-Gavelinopsis* Biofacies characterizes shallow, high energy, shelly banks. Repetition of many of these biofacies in the cores indicates an overall instability, or cyclic nature, of the water masses affecting the region through the Late Quaternary.

A gradual increase in the proportion of *Buliminella elegantissima,* a foraminifer associated with terriginous plant debris suggests a gradual decrease in sea level during deposition of the B_1 lithologic unit ($\leq\approx$12,000 years BP in the cores presented here) deposited at most sites. A population maximum of *Buliminella elegantissima* in diachronous lag deposits of the B_2 lithologic unit ($\approx$11,600–10,000 years BP) indicates a maximum lowstand. The almost complete absence of this species in superjacent B_3 lithologic unit sediments indicates subsequent rapid subsidence and termination of terrestrial organic input, probably due to the collapse of the Fraser Glaciation forebulge. Deposition of the B_3 unit had terminated everywhere in the region by $\approx$9,000 years BP. A *Cassidulina reniforme* population maximum occurs in sediments dated between about 10,100 and 11,300 years B.P. The presence of high proportions of this species, associated with very cold water (glacial or near-glacial) regimes, indicates a brief interval of cooler conditions during deglaciation, isochronous with the Younger Dryas event of Europe and eastern North America. This suggests that this event is not restricted to the North Atlantic but represents a much more widespread phenomenon.

INTRODUCTION

The purpose of the present research is to analyze foraminiferal faunas found in Quaternary core samples from Queen Charlotte Sound (Fig. 1). Foraminiferal assemblages have been shown to be very useful in recognizing temperature and salinity changes of water masses during glaciation and interglacial intervals (Smith, 1970; Sejrup and Guilbault, 1980; Patterson and Cameron, 1991). In this study foraminiferal distributions are coupled with sedimentological and geochronological data (Luternauer et al., 1989a, 1989b) to determine depositional paleoenvironments. Qualitative and quantitative analysis of benthic foraminifera at closely spaced sampling intervals should provide corroborative evidence for suspected rapid water-depth changes indicated by sedimentological results. Finally, as there has never been a thorough examination of Quaternary foraminifera from this area, this research will provide a valuable baseline on foraminiferal distribution and ecology for future studies.

PREVIOUS WORK

Very few published studies on Holocene shelf foraminifera (see Patterson and Cameron, 1991, for summary), and only four studies of Pleistocene foraminifera (Smith, 1970; 1978; Conway and Luternauer, 1984; Patterson and Cameron, 1991) have been carried out along the coast of British Columbia. Smith (1970, 1978) interpreted the depositional history of Late Quaternary land-exposed marine sections in southern British Columbia based on the foraminiferal fauna observed. Conway and Luternauer (1984) listed a few species found at three horizons in a core from Goose Island Trough. Patterson and Cameron (1991) interpreted the paleoenvironmental history of the Fraser Delta based on the foraminiferal and ostracode content of two Quaternary cores.

GEOLOGIC HISTORY

Queen Charlotte Basin is part of a 50,000 km^2 Eocene to Recent basin that underlies the Queen Charlotte Islands and the adjacent shelf areas to the east of Hecate Strait and Queen Charlotte Sound. Quaternary sediments vary in thickness but locally exceed 100 m (Shouldice, 1973). Most of Hecate Strait above the 200 m isobath is covered by up to 50 m of Quaternary sands and gravels, and minor

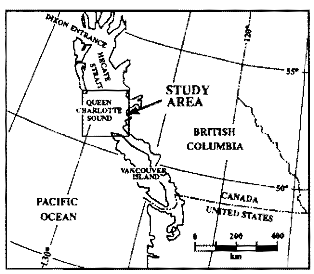

FIGURE 1. Continental shelf of western Canada showing location of Queen Charlotte Sound and Hecate Strait.

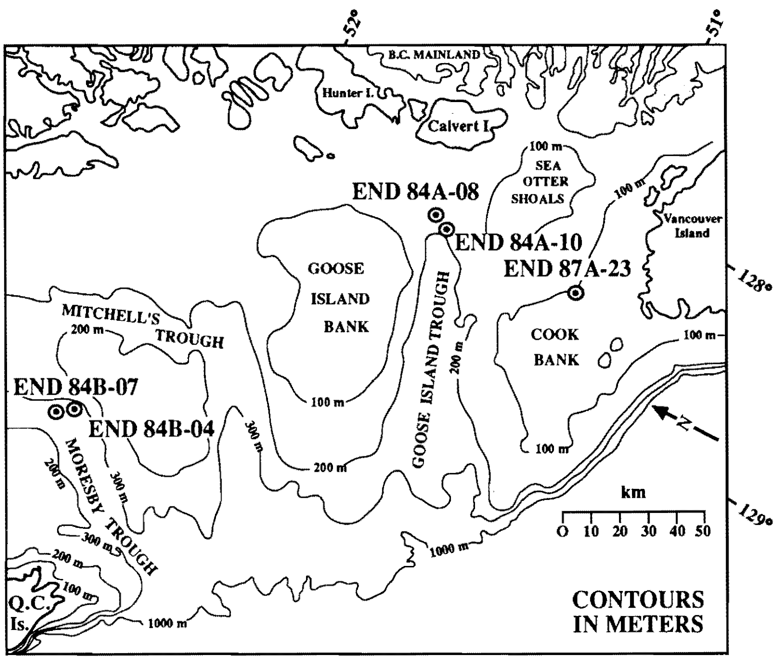

FIGURE 2. Bathymetric map of Queen Charlotte Sound-southern Hecate Strait showing location of cores from which Late Quaternary benthic foraminifera were examined.

amounts of silt (Barrie and Bornhold, 1989). Beneath the 200 m isobath within the strait and extending into Moresby Trough, the surface is covered with stratified sediments of silt and minor amounts of clay and sand.

Glaciation in the late Wisconsin was brief and of limited extent in Queen Charlotte Sound and Hecate Strait (Luternauer and Murray, 1983; Conway and Luternauer, 1984; Luternauer et al., 1985; Barrie and Bornhold, 1989). Clague and others (1982a) and Warner and others (1982) inferred from data on the coastal lowlands of eastern Graham Island that late Wisconsinian glaciation was weak and of short duration, and part of northeastern Graham Island was ice-free. Deglaciation probably commenced about 15,000 years B.P., and parts of northern Vancouver Island were ice-free by 13,600 years B.P. (Hebda, 1983). After deglaciation the mainland coast was submerged, with sea level 200 m higher than at present (Clague et al., 1982b). In contrast many shelf banks probably were emergent at this time. Luternauer and others (1989a) report a minimum emergence of 95 m on Cook Bank about 11,000 to 10,000 years B.P. This great eustatic variation across a relatively narrow geographic range is probably the result of glacial unloading and perhaps local tectonic events. Sea level stabilized in the region about 9,000 to 10,000 years B.P. (Luternauer et al., 1989a).

LITHOLOGIC SUMMARY

Core END 87A-23 (Fig. 2.) was collected from Cook Bank at a water depth of 95 m. This core, described fully in Luternauer and others (1989a), is divided into three units (Fig. 3). The lower unit (88 to 183 cm) is comprised of many fine- to coarse sand and gravel beds, which tend to fine upwards towards the top of the unit. The upper part (above 110 cm) is characterized by oxidized sediments invaded by rootlets extending down from an overlying silt bed in the middle unit. This gymnosperm root material indicates a stable subaerial paleosol (Luternauer and others, 1989a). The middle unit (54 to 88 cm) is comprised of well-sorted fine to medium sands and interbeds of silt, and high concentrations of organic plant debris. *Pinus contorta* (lodgepole pine) pollen were found in this material. Higher in this unit, pollen, various fern spores, and debris of other marsh inhabiting flora, indicate the presence of local wetlands. The upper part of the core is characterized by fine to medium sands and silts, and a macrofauna of marine gastropods and bivalves.

Cores END 84B-07 and END 84B-04 (Figs. 4, 5) collected on the margins of Moresby trough at water depths of 474 m and 327 m respectively, and cores END 84B-08 and END 84B-10 (Figs. 6, 7) collected from Goose Island Trough at water depths of 173 m and 184 m respectively (Fig. 2), are described in detail by Luternauer and others (1989b). A brief summary of their lithologic characteristics are provided here. The various lithologic units in these cores are designated by letters. Unit B_1 at the base of cores END 84B-07 (514 to 564 cm), END 84B-08 (549 to 1125 cm) and END 84B-10 (696 to 1008 cm) is a dark gray laminated to massive mud with a minor shell component. This unit overlies a glaciomarine till (unit A, not observed in the cores used in this study). Unit B_1 is very similar to unit A but lacks gravel and ice-rafted debris.

Unit B_2 was found in cores END 84B-04 (350 to 450 cm), END 84B-07 (471 to 514 cm), END 84B-08 (483 to 549 cm) and END 84B-10 (600 to 696 cm). Unit B_2 is a dark-gray, weakly bedded, shelly, sandy mud. Although it contains abundant gravel in some areas of Goose Island Trough, little was logged in cores END 84B-08 and END 84B-10. In general, sediments from unit B_2 are the coarsest found in these cores. The included macrofauna consists of articulated and disarticulated bivalves, gastropods, barnacles, calcareous worm tubes, and bryozoans. Some of this debris dates older than material lower in the core(s), indi-

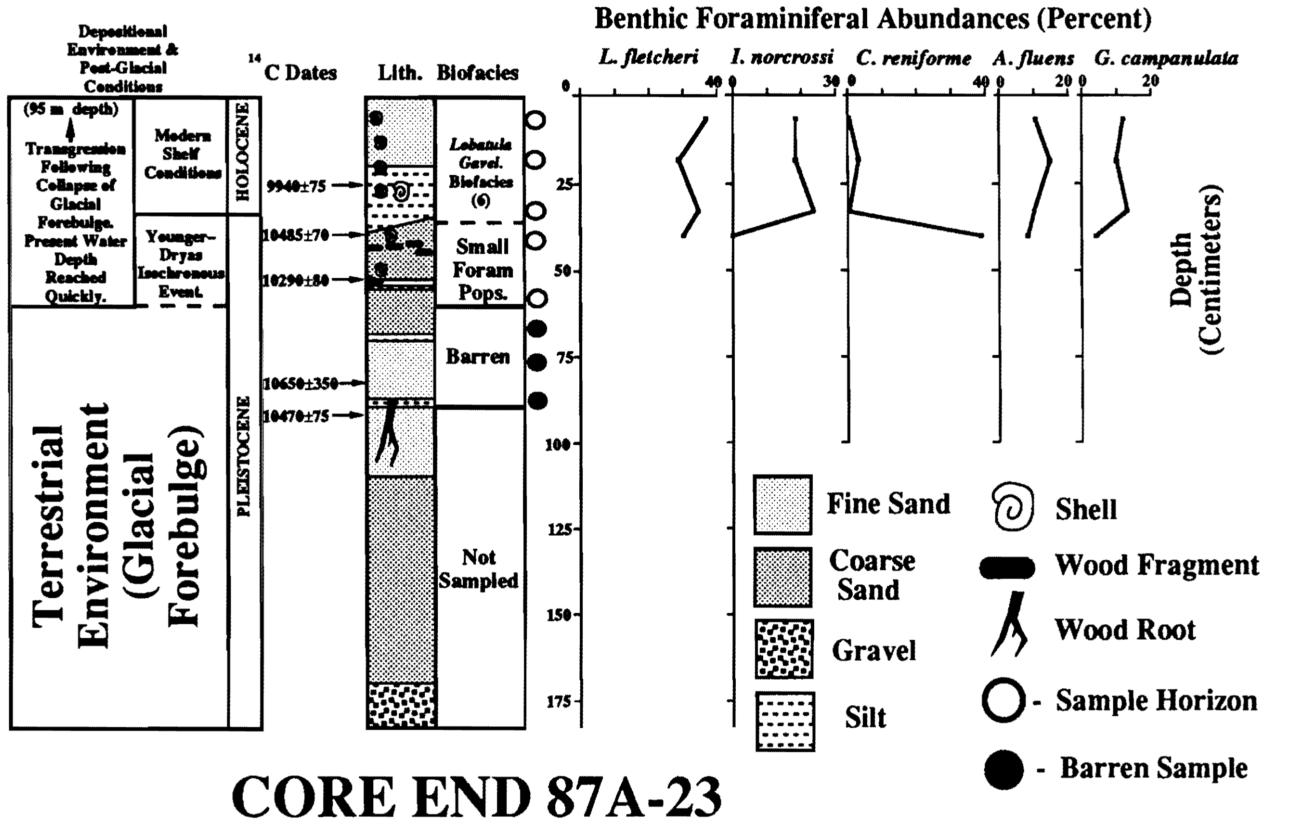

FIGURE 3. Stratigraphic section of Core END87A-23 showing lithology, ^{14}C radiocarbon dates, foraminiferal biofacies, and distribution of key indicator species through the cored interval.

cating that it was reworked. However, the presence of fragile yet articulated bivalves in these sediments indicate incomplete reworking. The lower contact of unit B_2 tends to be gradational with unit B_1, whereas the upper contact with unit B_3 is usually sharp.

Unit B_3 is found in cores END 84B-04 (14 to 350 cm), END 84B-07 (421 to 471 cm), END 84B-08 (216 to 483 cm) and END 84B-10 (199 to 600 cm). This dark-gray to olive-gray unit varies from massive to laminated. Lithologically similar to unit B_1, radiocarbon dates confirm that unit B_3 is younger.

Unit C is found in cores END 84B-04 (0 to 14 cm), END 84B-07 (0 to 421 cm), END 84B-08 (0 to 216 cm) and END 84B-10 (0 to 199 cm). Highly variable in thickness, this olive-colored mud is the surface unit over much of Goose Island Trough, where it is up to 20 m thick, and at the western margin of Moresby Trough, where it is up to 7 m thick. However, as seen in core END 84B-04, this lithology is almost absent from parts of the eastern margin of Moresby Trough.

Based on an analysis of radiocarbon dates, Luternauer and others (1989b) determined that sedimentation rates were highly variable during the Late Pleistocene and Holocene in Goose Island Trough. The average rate of accumulation was about 4 mm a^{-1} for unit A, 0.1 mm a^{-1} in unit B, and 0.2 mm a^{-1} in unit C. At site END 84B-10, the sedimentation rate for unit B_3 was about 5 mm a^{-1}.

METHODS AND MATERIALS

Forty-six samples were obtained from five Geological Survey of Canada vibrocores collected in Queen Charlotte Sound (Fig. 1). Core END 87A-23 was collected from Cook Bank off the northwestern tip of Vancouver Island, and Cores END 84B-04, END 84B-07, END 84B-08, and END 84B-10 were collected from the margin of Moresby Trough and Goose Island Trough between the southeastern tip of Queen Charlotte Island and Vancouver Island (Fig. 2). Locations of cores are presented in Table 1. Sampled intervals are shown in Appendices 1–5.

All samples were processed by the method described by Patterson and Cameron (1991) and rinsed using 63 μm screens. Forty-three of the 46 samples were found to contain foraminifera, and 40 of these samples (Appendices 1 to 5) contained populations large enough for statistical analysis (see Patterson and Fishbein, 1989).

Seventy-five species of benthic foraminifera are identified in this study. Planktic foraminifera were not considered during the quantitative examination as they were almost entirely absent from these shelf samples. The percent abundances given for species characterizing the various biofacies differentiated herein have had the standard error correction integrated into the given ranges. For this reason, the percentages will not exactly match the fractional abundance values recorded in the data tables (Appendices 1 to 5; Table 4). Patterson and Fishbein (1989) suggest that the percent error abundances be included with estimated abundances to provide an indication of their accuracy. The percent error was calculated using the standard error equation ($^{s}x_i$):

$$s_{x_i} = 1.96\sqrt{\left[\frac{X_i[1 - X_i]}{N}\right]}$$

where (N) is the total number of counts, and (X) is the

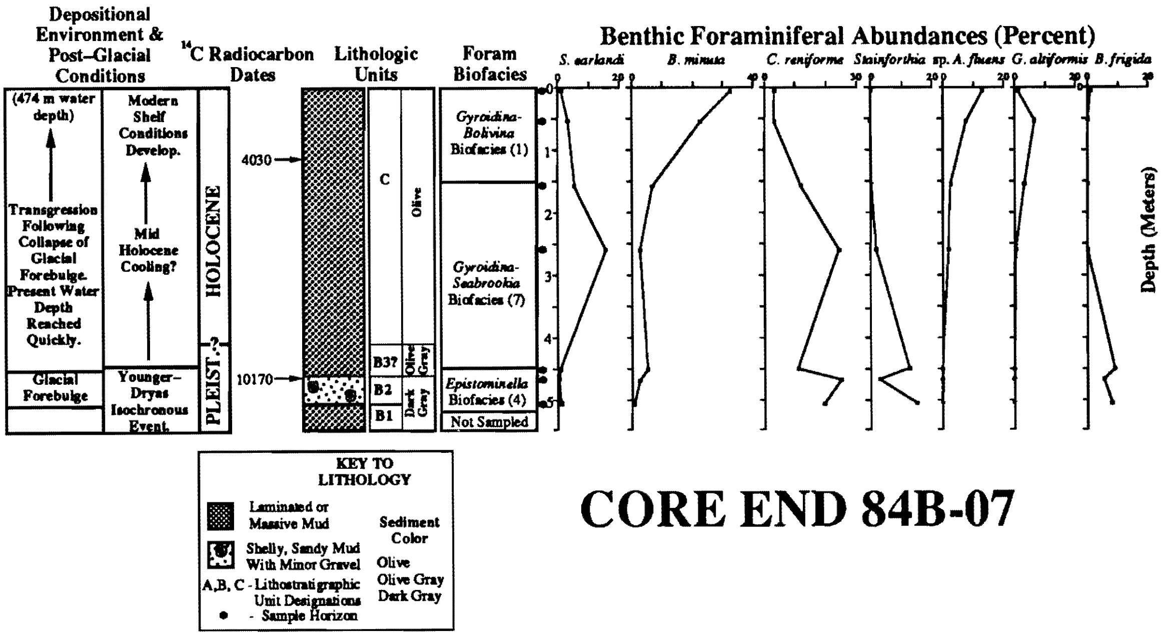

FIGURE 4. Stratigraphic section of Core END84B-07 showing lithology, ^{14}C radiocarbon dates, foraminiferal biofacies, and distribution of key indicator species through the cored interval.

fractional abundance of a species (Patterson and Fishbein, 1989).

A Q-mode cluster analysis was carried out on the data using a technique shown to closely emulate the results of a statistically significant "error weighted maximum likelihood" clustering method presently under development (Fishbein and Patterson, in press). This method requires that only species present in statistically significant populations be analyzed. Nineteen species were found to have a statistically significant population in at least one sample. These include: *Seabrookia earlandi* Wright, 1891, *Bolivina minuta* Natland, 1938, *Islandiella islandica* Nørvang, 1945, *Islandiella norcrossi* Cushman, 1933, *Cassidulina reniforme* Nørvang, 1945, *Stainforthia exilis* (Brady, 1884), *Buliminella elegantissima* (d'Orbigny, 1839), *Angulogerina fluens* Todd, 1948, *Gavelinopsis campanulata* (Galloway and Wissler, 1927), *Epistominella pacifica* (Cushman, 1927), *Epistominella vitrea* Parker, 1953, *Lobatula fletcheri* (Galloway and Wissler, 1927), *Nonionella stella* Cushman and Moyer, 1930, *Nonionellina labradorica* (Dawson, 1970), *Gyroidina altiformis* Stewart and Stewart, 1930, *Buccella frigida* (Cushman, 1922), *Cribroelphidium excavatum* (Terquem, 1876), *Cribroelphidium foraminosum* (Cushman), 1939, and *Cribroelphidium subarcticum* (Cushman, 1944).

Prior to clustering, a principal components analysis (PCA) was performed on the reduced species dataset utilizing a covariance matrix of the 19 species and a varimax rotation (Table 2). The first six principal components accounted for 89.45% of the data variance. The purpose of the

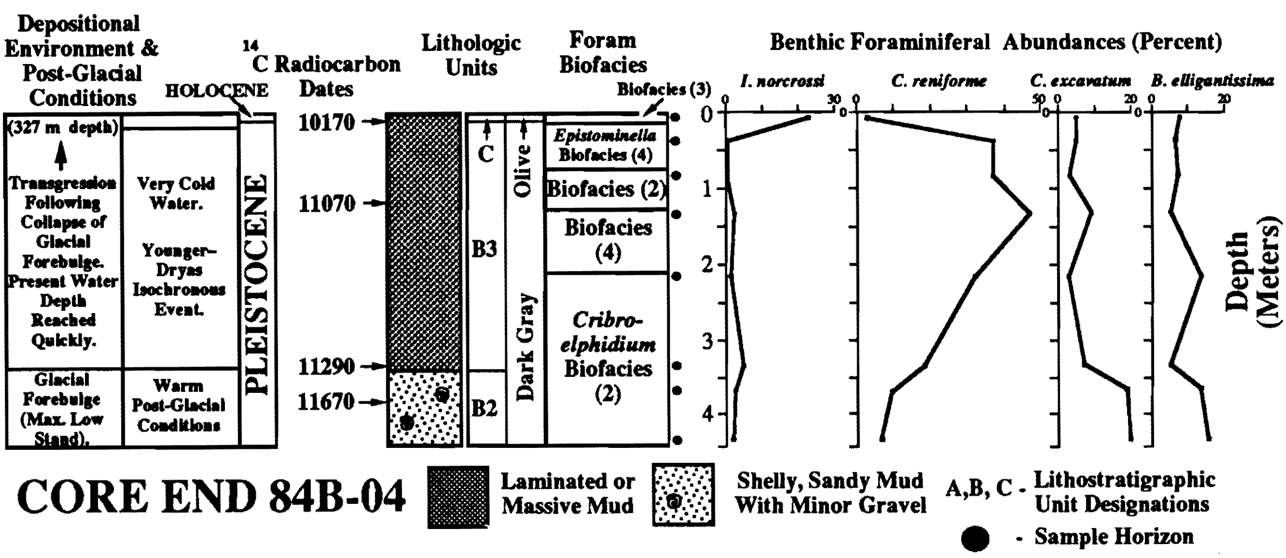

FIGURE 5. Stratigraphic section of Core END84B-04 showing lithology, ^{14}C radiocarbon dates, foraminiferal biofacies, and distribution of key indicator species through the cored interval.

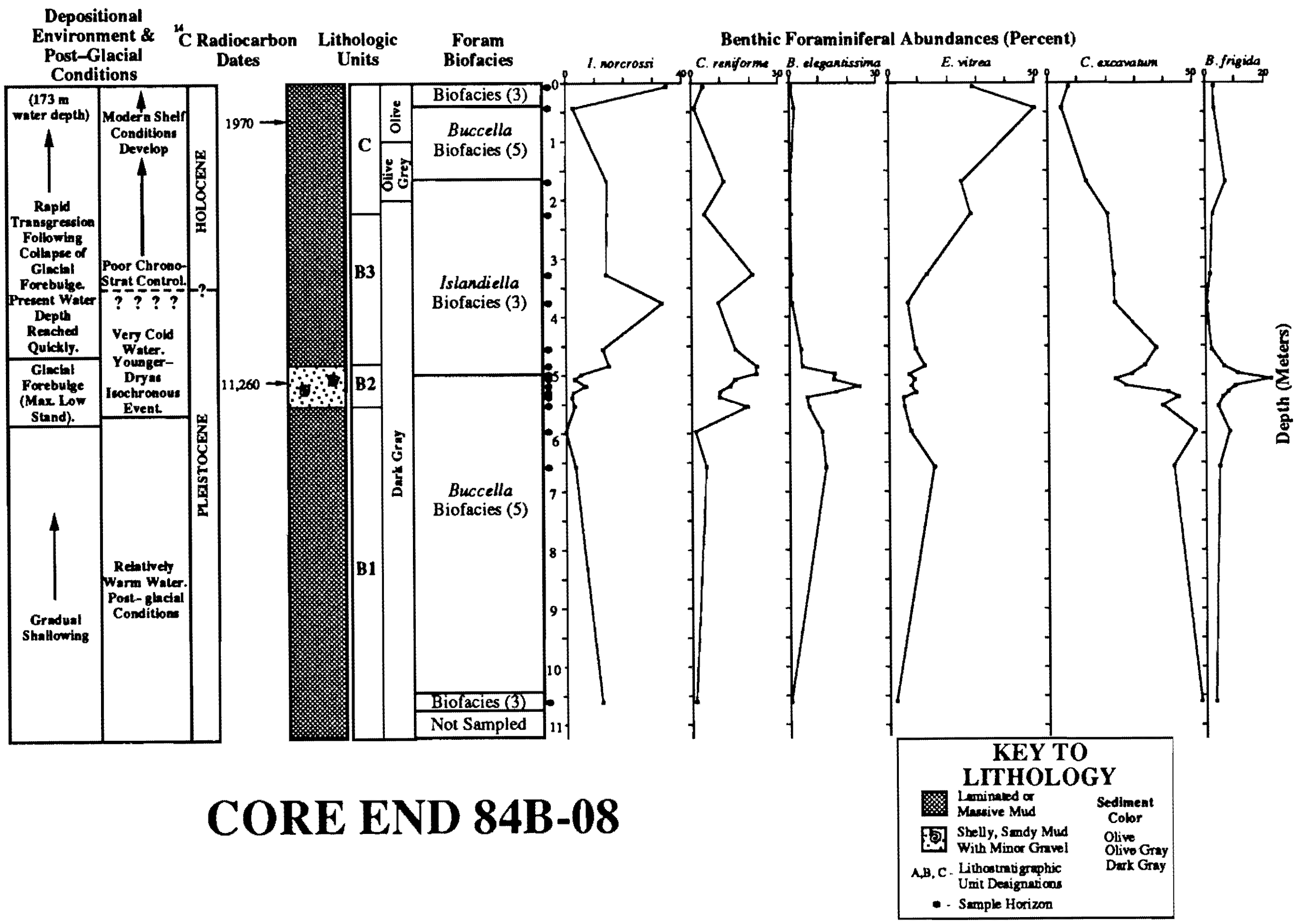

FIGURE 6. Stratigraphic section of Core END84B-08 showing lithology, ^{14}C radiocarbon dates, foraminiferal biofacies, and distribution of key indicator species through the cored interval.

PCA here was to further condense the data set. For small data sets this step is optional and often unnecessary as similar results can be obtained by simply clustering a covariance matrix comprised of statistically significant species (Fishbein and Patterson, in press).

Following examination of the PCA results, a Q-mode cluster analysis was carried out using the first six principal components. This Q-mode cluster analysis was performed using the Data, Factor and Cluster Modules of Systat 2 (Wilkinson, 1987). Simple correlation coefficients were used to measure similarity between pairs of species, and the complete linkage method was utilized to arrange sample pairs and sample groups into a hierarchic dendrogram (Fig. 8).

Conventional radiocarbon (^{14}C) dating was performed on mollusc shells and plant material at the Radiocarbon Laboratory of the Geological Survey of Canada. Accelerator mass spectrometry radiocarbon dating was conducted at the IsoTrace Laboratory of the University of Toronto and by the Radio-Isotope Direct Detection Laboratory of McMaster University (Table 3). Marine AMS ^{14}C dates were corrected for reservoir effects before comparison with dates on terrestrial carbon. Southon and others (1990) estimated the reservoir difference between late-glacial and early Holocene ocean and atmosphere based on data from fossil wood-marine shell pairs from the Queen Charlotte Island and core END 87A-23. The mean age difference of 13 comparisons about 9,000 years old was reported as 726 ± 48 years with a range of 550–898 years. The rounded value of 730 years was subtracted from the reported ages in Table 3. Corrected values are given throughout the text and in Figures 4–7.

TABLE 1. Latitude, Longitude and water depth of cores examined for this study.

Core	Bathymetric depth of core (m)	Latitude	Longitude
87A-23	95 m	50°59.94′	128°26.55′
END 84B-04	327 m	52°14.72′	130°09.05′
END 84B-07	474 m	52°16.70′	130°12.27′
END 84B-08	173 m	51°31.07′	128°23.11′
END 84B-10	184 m	51°28.14′	128°25.14′

RESULTS

BIOFACIES AND INDICATOR SPECIES DISTRIBUTION

Biofacies 1 (GYROIDINA-BOLIVINA Biofacies; Appendix 2; Table 4).

This biofacies is dominated by *Epistominella vitrea* (20.2 to 31.3%) and *Bolivina minuta* (20.6 to 35.0%). The presence of *Gyroidina altiformis* (<1–7.6%) also characterizes this biofacies, although this species is also found in Biofacies 5 where it occurs in similar abundances.

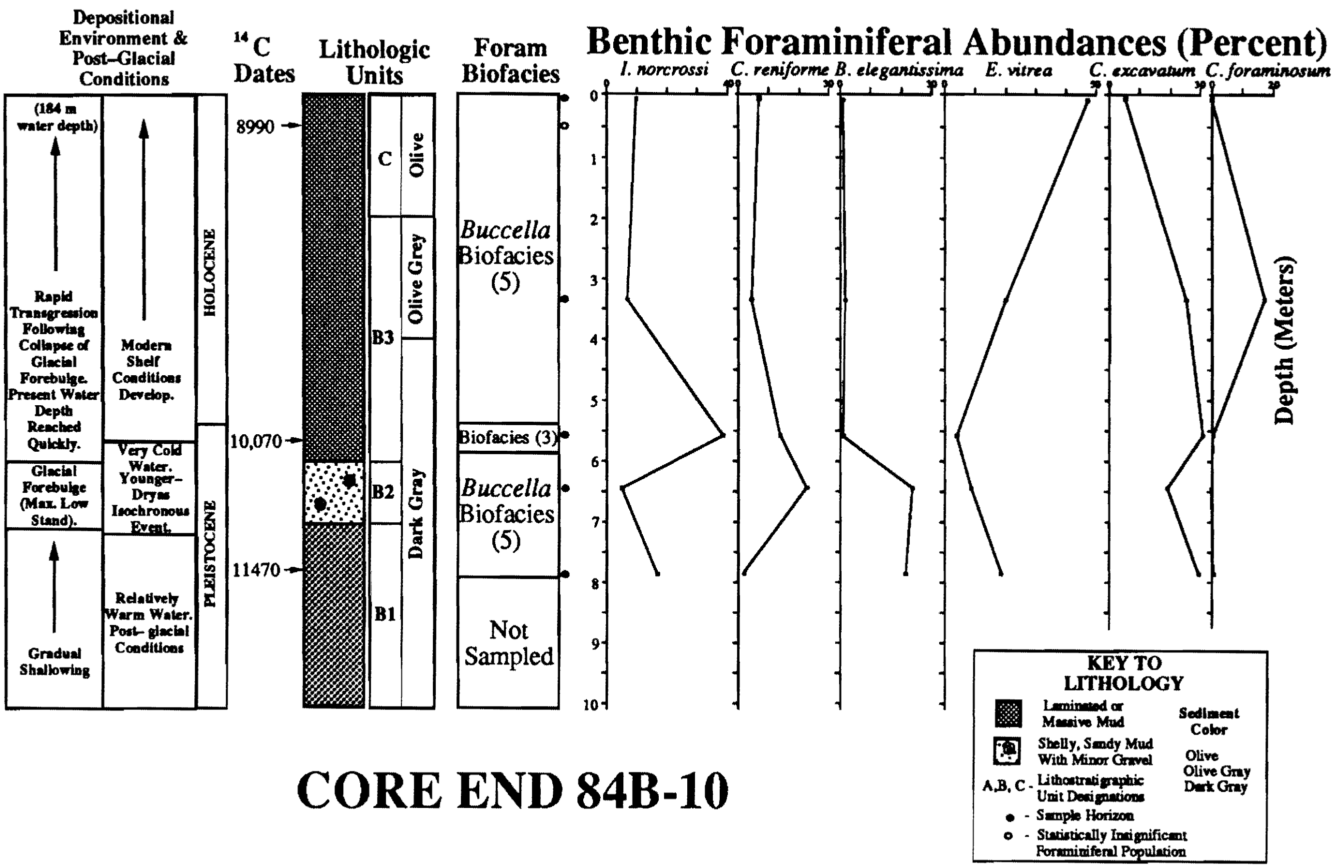

FIGURE 7. Stratigraphic section of Core END84B-10 showing lithology, ^{14}C radiocarbon dates, foraminiferal biofacies, and distribution of key indicator species through the cored interval.

Biofacies 2 (CRIBROELPHIDIUM Biofacies; Appendix 1; Tables 4).

This biofacies is distinguished by higher abundances of *Cribroelphidium subarcticum* (7.1 to 15.4%) than in most of the other biofacies, although this species reaches 8.4% of some *Islandiella* Biofacies (Biofacies 3) assemblages. *Islandiella* Biofacies assemblages also have more *Islandiella norcrossi* (10.2 to 41.6%) than found in *Cribroelphidium* Biofacies (<1 to 6.1%). Biofacies 2 to 5 are quite similar in overall faunal makeup. In addition, the relative abundances of some of the dominant species fluctuate within individual assemblages of this group. Nevertheless, each biofacies can be readily differentiated on the fractional abundances of one or more key species.

Biofacies 3 (ISLANDIELLA Biofacies; Appendix 1,3,4; Table 4).

The *Islandiella* Biofacies is best characterized by the relatively high proportions of *Islandiella norcrossi* (10.2 to 41.6%). Up to 18.4% *Islandiella norcrossi* may also be found in Biofacies 5. However Biofacies 5 is characterized by a generally higher proportion of *Bucella frigida* (2.5 to 23.7%) as opposed to <1 to 8.5% of *Buccella frigida* in the *Islandiella* Biofacies. A high proportion of *Islandiella norcrossi* (16.9 to 25.4%) is also found in Biofacies 6. However, the two biofacies are readily separated by the much lower abundances of *Angulogerina fluens, Gavelinopsis campanulata*, and *Lobatula fletcheri* in the *Islandiella* Biofacies.

Biofacies 4 (EPISTOMINELLA Biofacies; Appendix 1,2; Table 4).

This biofacies is characterized by a relatively higher proportion of *Epistominella pacifica* (6.1 to 26.4%) than found in most samples of other biofacies. Although *Epistominella pacifica* reaches up to 11.4% in Biofacies 2, that biofacies can be readily differentiated by its higher proportion of *Cribroelphidium subarcticum*. Similarly, the abundance of *Epistominella pacifica* may reach as high as 9.4% of assemblages in Biofacies 5. However, samples characterizing the two biofacies can be separated by the generally lower proportions of *Bucella frigida* (<1 to 10.6% as opposed to 2.6 to 23.7% in the *Buccella* Biofacies), *Cribroelphidium excavatum* (<1 to 10.8% as opposed to 3.5 to 53.3% in the *Buccella* Biofacies) and the higher proportions of *Lobatula fletcheri* (2.7 to 15.1% as opposed to to 0 to 4.0% in the *Buccella* Biofacies).

Biofacies 5 (the BUCCELLA Biofacies; Appendix 3,4; Table 4).

The generally high proportion of *Buccella frigida* best characterizes this biofacies. Despite an overlap in the proportions of *Buccella frigida* in some samples referable to the *Islandiella, Buccella* and *Epistominella* Biofacies these biofacies are readily distinguishable as described above. The

TABLE 2. Varimax rotated scores of the first six principal components of raw data using covariance matrix of the 19 most definitive species (variables) and 40 most populous samples (cases) from the Queen Charlotte Strait/Hecate Strait area. Horizontal axis is made up of Principal Components while Vertical axis is a list of samples examined. The resulting data was used in the multivariate analysis to generate a cluster dendrogram.

Principal components/ sample numbers	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
425	0.984	0.037	0.062	0.084	0.119	−0.001
428	0.953	−0.032	−0.099	0.119	0.107	0.170
429	0.951	0.159	−0.016	0.077	0.167	0.126
426	0.914	−0.103	0.079	0.137	0.201	0.188
424	0.907	0.054	0.197	−0.012	0.057	−0.265
427	0.875	−0.084	0.261	0.153	0.281	0.040
422	0.854	0.024	0.380	0.067	0.185	−0.259
433	0.833	0.318	−0.099	−0.113	0.266	−0.071
420	0.825	0.048	0.194	0.015	0.487	0.038
423	0.819	0.088	0.254	0.083	0.032	−0.203
430	0.805	−0.145	−0.124	0.031	0.406	0.284
409	0.766	0.042	0.236	−0.451	−0.231	0.150
421	0.761	0.140	0.323	0.003	0.498	−0.114
435	0.745	0.087	0.462	0.040	0.041	−0.392
408	0.724	−0.153	0.414	−0.108	−0.083	0.241
434	0.604	0.365	−0.051	0.136	0.415	0.352
418	0.526	0.200	0.449	0.055	0.656	0.015
425	0.146	0.937	0.127	−0.028	0.154	0.098
397	−0.103	0.914	−0.059	0.015	−0.027	−0.109
415	0.117	0.892	0.090	0.105	0.062	0.272
398	−0.029	0.889	0.244	−0.043	0.294	−0.080
895	−0.065	0.727	−0.077	0.019	−0.205	−0.163
896	0.097	0.655	−0.030	−0.323	0.624	−0.021
399	−0.039	0.647	0.553	0.142	0.158	−0.192
416	0.293	0.624	0.192	0.089	0.605	0.136
417	0.398	0.573	−0.079	0.097	0.571	0.254
400	0.031	0.550	0.661	−0.007	−0.110	0.337
404	0.126	0.023	0.960	0.056	0.053	−0.158
403	0.161	0.060	0.959	0.055	0.079	−0.153
406	0.173	−0.017	0.916	−0.123	−0.053	−0.213
405	0.199	0.027	0.910	0.102	0.197	−0.231
402	0.120	0.058	0.885	−0.124	−0.094	0.263
401	0.044	0.120	0.787	0.020	−0.022	0.112
407	0.164	0.027	0.741	0.009	0.131	0.291
412	−0.133	−0.044	−0.056	−0.962	0.109	−0.019
410	−0.086	−0.050	−0.010	−0.948	0.032	0.038
411	−0.106	−0.060	−0.020	−0.936	0.074	−0.058
894	0.121	0.418	0.110	−0.516	0.417	0.072
419	0.377	0.039	−0.054	−0.207	0.878	−0.036
432	0.495	0.006	0.044	−0.270	0.774	−0.118
Percent of Variance Explained	31.026	15.776	18.771	9.049	11.277	3.550

Buccella Biofacies is differentiated from the *Lobatula-Gavelinopsis* Biofacies by the much lower abundances of *Angulogerina fluens*, *Gavelinopsis campanulata*, and *Lobatula fletcheri* in the *Islandiella* Biofacies.

Biofacies 6 (LOBATULA-GAVELINOPSIS *Biofacies; Appendix 5; Table 4).*

The most common species found in samples characterizing this biofacies are *Islandiella norcrossi* (16.9 to 25.4%), *Angulogerina fluens* (8.9 to 15.8%), *Gavelinopsis campanulata* (9.1 to 14.5%) and *Lobatula fletcheri* (27.2 to 36.6%). The species best characterizing this biofacies are *Gavelinopsis campanulata* and *Lobatula fletcheri*. These species are more abundant in this biofacies than in any other biofacies recognized in these cores.

Biofacies 7 (GYROIDINA-SEABROOKIA *Biofacies; Appendix 2; Table 4).*

This biofacies is readily recognized by higher proportions of *Seabrookia earlandi*—4.9 to 16.8% as opposed to 0 to 4.0% in the *Gyroidina-Bolivina* Biofacies. The presence of *Gyroidina altiformis* and *Seabrookia earlandi* in this biofacies separates it from all others except those placed in the *Gyroidina-Bolivina* Biofacies (Biofacies 1).

The abundance of individual species in Pleistocene and Holocene samples can also be useful in interpreting paleoenvironmental conditions. The percent abundances of key indicator taxa were therefore plotted against the stratigraphic horizon in the cores where each sample was collected (Figures 3–7). The distribution of these key indicator species in relation to the various biofacies is apparent in Table 4 and is discussed in the next section.

DISCUSSION

The general paleoceanographic changes that have occurred in this region from the Late Pleistocene to Holocene are recognizable in all of the cores samples in this study. Differences in foraminiferal biofacies makeup of these cores are primarily related to depositional water depth, water temperature, and substrate. For these reasons, the dep-

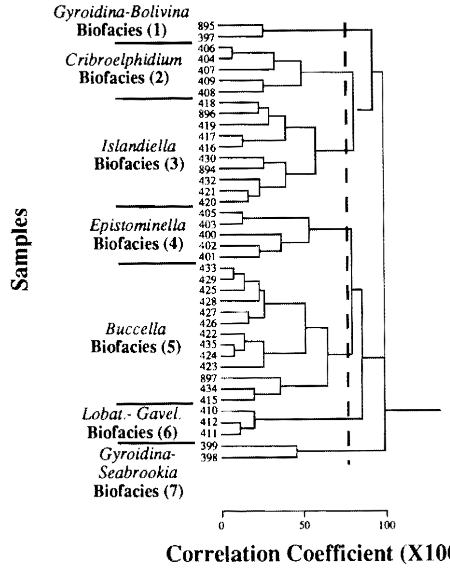

FIGURE 8. Q-Mode dendrogram showing 40 most populous samples (listed vertically by number) from the late Quaternary cores of Queen Charlotte Sound and Hecate Strait, divided into seven distinct biofacies as indicated by the dashed line. Distinct clusters of samples with correlation coefficients greater than a selected level were considered biofacies.

ositional scenarios for Cook Bank, Goose Bank, and Moresby Trough, are discussed separately below.

COOK BANK

Core END 87A-23, the most southerly core examined (Figs. 2, 3), preserves a lithologic and palynologic record of the transition from terrestrial to marine conditions. The presence of a 10,500 year old paleosol containing gymnosperm rootlets at 88 cm indicates that relative sea level was at least 95 m lower than it is today. Luternauer and others (1989a) concluded that shortly after soil formation terminated, deposition of an eolian or fluvial unit began in a shallow lagoon or pond. Foraminiferal data indicate that between 10,400 and 10,000 years BP, the area was first transgressed by marine incursions and eventually submerged permanently. The stratigraphically lowest foraminifera were recovered from the 59 to 61 cm interval. It is likely that the few specimens recovered there were transported onshore to a coastal lowland area during storms. The first relatively large foraminiferal assemblage was recovered from the 40 to 50 cm interval of the core. This assemblage is characterized by a high proportion of *Cassidulina reniforme* providing evidence of very cold water conditions in the area shortly after submersion. Sejrup and Guilbault (1980) determined that this species is restricted almost exclusively to biofacies strongly influenced by glacial or near glacial conditions. Abundance peaks of this species are also found at coeval intervals in the other cores examined.

Luternauer and others (1989a) present evidence that present day sea level at Cook Bank had been attained between 9,500 and 9,000 years BP. They conclude that present conditions resulted from a rapid transgression involving a sea level rise of more than 95 m as a result of migration and collapse of the late Pleistocene glacial forebulge. This would account for the sudden appearance of the *Lobatula-Gavelinopsis* Biofacies in most of the marine sediments of this core. This occurrence reflects a rapid shift to a relatively high-energy middle neritic environment. The *Lobatula-Gavelinopsis* Biofacies resembles the *Cassidulina-Hanzawaia* Assemblage (biofacies) reported by Douglas (1981) from modern offshore ridges and deep banks in the California Borderland at depths averaging 50 m but ranging from 20 to 400 m.

GOOSE ISLAND TROUGH

The foraminiferal assemblages recovered from cores END 84B-08 and END 84B-10, collected in 173 m and 184 m of water respectively, in Goose Island Trough are correlatable from the Late Pleistocene through the Holocene (Figs. 2, 6, 7). However, the stratigraphic record of END 84B-08 appears to be more complete partly due to higher sampling resolution and greater core length.

The Goose Island Trough cores are characterized exclusively by the *Islandiella* and *Buccella* Biofacies. Although these two biofacies are very similar in faunal composition, their alternation throughout the faunal succession indicates a period of poorly understood, oscillating, oceanographic conditions since deglaciation. Similar cycles have been reported from a variety of other studies on the Holocene, including cyclic eolian activity recorded in tropical Australian cores (De Deckker and Corrège, 1991), glacial advances in the northern hemisphere (Denton and Karlen, 1973; Nesje and Kvamme, 1991), oxygen isotope records from Greenland ice cores (Dansgaard and others, 1984), and deep sea benthic faunal compositions and isotopic records (Pisias, 1983; Pestiaux and others, 1988). More detailed analysis of cores is required to ascertain the significance of the cycles in this region.

Varying proportions of certain indicator species in the Goose Island Trough cores record changing paleoclimatic conditions. The proportion of *Cribroelphidium excavatum* declines gradually from the basal B_1 unit toward the surface through both cores. The age of the lowermost part of the B_1 unit is extrapolated to be around 12,000 years B.P. because: 1) the overlying B_2 lithologic unit has a precise ^{14}C date of 11,260 years BP, and; 2) the underlying A lithologic unit is 12,180 years B.P. determined by correcting a date of 12,910 $\pm$ 90 (Luternauer et al., 1989b) for reservoir difference (Southon and others, 1990). In Pleistocene sediments *Cribroelphidium excavatum* is associated with glacial conditions, particularly in Wisconsin-aged occurrences where it often constitutes 60–80% of the foraminiferal fauna (Feyling-Hanssen, 1976; Knudsen, 1976; Osterman, 1984; Hald and Vorren; 1987; Rodriguez and Richard, 1986). *Cribroelphidium excavatum* also comprises more than 30% of modern foraminiferal faunas on higher latitude shelves surrounding North America and Europe (Cockbain, 1963; Vilks et al., 1979; and Miller et al., 1982). However, this species also occurs in reduced numbers at lower latitudes of the modern North Atlantic in areas of depressed salinity (Hald and Vorren, 1987). The low abundance of the cold-water indicator *Cassidulina reniforme* in B_1 sediments further indicates that depressed salinities rather than very cold water conditions explain the high proportion of *Cribroelphidium excavatum*. Therefore, the large abundance of

TABLE 3. Radiocarbon dates obtained from shell and wood material from the cores examined for this study. RIDDL (Radio-Isotope Direct Detection Laboratory (McMaster University); TO-(IsoTrace Laboratory, University of Toronto); GSC (Geological Survey of Canada). Radiocarbon date corrections based on Southon and others (1990). Radiocarbon date corrections not required for terrestrial based wood samples from core END 87A-23 (N/A = not applicable).

Core	Depth in core (cm)	Lithologic unit	Radiocarbon date (yrs B.P.)	Corrected radiocarbon date (yrs B.P.)	Laboratory number	Location: Latitude	Location: Longitude	Bathymetric depth of core (m)	Dated material
END 84B-04	5–9	B3	10,900 ± 360	10,170	GSC-4210	52°14.72′	130°09.05′	327	*Macoma brotta*
END 84B-04	121	B3	11,800 ± 120	11,070	GSC-4115	52°14.72′	130°09.05′	327	Buccinidae
END 84B-04	343	B3	12,020 ± 90	11,290	TO-167	52°14.72′	130°09.05′	327	*Macoma liparia*
END 84B-04	390	B2	12,400 ± 290	11,670	GSC-4120	52°14.72′	130°09.05′	327	*Macoma calcarea*
END 84B-07	118	C	4760 ± 70	4030	TO-249	52°16.70′	130°12.27′	474	Gastropod shell
END 84B-07	470–472	B2	10,900 ± 280	10,170	GSC-4108	52°16.70′	130°12.27′	474	*Macoma liparia*
END 84B-08	66	C	2700 ± 60	1970	TO-250	51°31.07′	128°23.11′	173	*Yoldia thraciaformis*
END 84B-08	509–511	B2	11,990 ± 90	11,260	TO-79	51°31.07′	128°23.11′	173	*Macoma* sp.
END 84B-10	50–52	C	9720 ± 70	8990	TO-169	51°28.14′	128°25.14′	184	*Yoldia* sp.
END 84B-10	563–565	B3	10,800 ± 80	10,070	TO-170	51°28.14′	128°25.14′	184	*Macoma* sp.
END 84B-10	773–775	B1	12,200 ± 80	11,470	TO-171	51°28.14′	128°25.14′	184	Gastropod
END 87A-23	25	—	9940 ± 75	N/A	RIDDL-979	50°59.94′	128°26.55′	95	Plant material
END 87A-23	41	—	10,485 ± 70	N/A	RIDDL-981	50°59.94′	128°26.55′	95	Wood
END 87A-23	54–55	—	10,290 ± 80	N/A	RIDDL-983	50°59.94′	128°26.55′	95	Wood
END 87A-23	83–86	—	10,650 ± 350	N/A	RIDDL-984	50°59.94′	128°26.55′	95	Wood
END 87A-23	83–86	—	10,470 ± 75	N/A	RIDDL-985	50°59.94′	128°26.55′	95	Root

Cribroelphidium excavatum in B_1 sediments is probably related to transient low-salinity oceanic conditions during and shortly after deglaciation (i.e. approximately 12,000 years B.P.). The subsequent decline of this species up-core may indicate a gradual loss of ecospace as a modern oceanographic regime developed (Osterman, 1984).

The upper part of the B_1 unit and the entire B_2 unit of both cores are characterized by a relatively high proportion of *Buliminella elegantissima,* indicating an environment enriched in nutrients (Snyder, 1989). In a study centered around the mouth of the Columbia River, Harmon (1972) correlated maximum abundances of vascular plant debris, diatoms and *Buliminella elegantissima*. The terrestrial plant debris may have been flushed into Goose Island Trough from subaerial exposures of Goose Island Bank or Sea Otter Shoals and/or from an area adjacent to a much larger ancestral Calvert Island. Several land and sea based studies in the area present evidence that sea-level in this area was at least 95 m lower than at present (Clague et al., 1982b; Howes, 1981, Luternauer et al, 1989a; Barrie and Bornhold, 1989). Changes in the proportion of *Buliminella elegantissima* throughout both cores provide evidence of relative sea level changes in the area through the sampled time period. The increase in the proportion of *Buliminella elegantissima* in the core through the B_1 and B_2 lithologic units suggests an increasing supply of terrigenous debris accompanying marine regression. The gradational nature of the lower contact of the B_2 unit provides sedimentological evidence of such a gradual regressive event (Luternauer, et al., 1989b). The maximum abundance spike of *Buliminella elegantissima* occurs in the B_2 lithologic unit. Luternauer and others (1989b) suggested that the winnowed and lagged sediments of this unit, which were deposited between 11,500 and 10,000 years BP, were deposited during the period of lowest sea level. The B_2 horizon also had relatively high proportions of *Buccella frigida*. This association suggests deposition in a cool, shallow near shore environment (Barrick et al, 1989). Immediately following deposition of the B_2 unit, the proportion of *Buliminella elegantissima* inhabiting the area dropped precipitously. A very rapid

TABLE 4. Ranges of observed percent occurrence, including calculated percent uncertainty, of principal species within each biofacies. "X" refers to <1%.

Species/Biofacies	1 *Gyroidina-Bolivina* Biofacies	2 *Cribroelphidium* Biofacies	3 *Islandiella* Biofacies	4 *Epistominella* Biofacies	5 *Buccella* Biofacies	6 *Lobatula-Gavelinopsis* Biofacies	7 *Gyroidina-Seabrookia* Biofacies
Seabrookia earlandi	X-4.0	0–X	0–X	0–X	0	0	4.9–16.8
Bolivina minuta	20.6–35.0	X-2.5	0–9.8	X-6.3	0–1.6	0–X	1.6–7.5
Islandiella norcrossi	1.4–4.3	X-6.1	10.2–41.6	0–2.7	0–18.4	16.9–25.4	1.6–13.7
Cassidulina reniforme	2.8–4.7	5.3–38.0	X-25.0	1.7–49.2	X-25.3	X-3.9	X
Stainforthia exilis	0	2.2–28.9	0–14.7	2.2–17.8	0–9.3	0–X	X-2.5
Buliminella elegantissima	0–X	3.9–16.3	X-8.6	X-6.9	X-25.9	0–X	0–X
Angulogerina fluens	7.0–15.5	0–X	0–3.0	0	0–X	8.9–15.8	1.3–3.3
Gavelinopsis campanulata	0	0	0–X	0–1.7	0–X	9.1–14.5	0
Epistominella pacifica	X	1.8–11.4	0–3.7	6.1–26.4	X-9.4	0–X	0–3.8
Epistominella vitrea	20.2–31.3	3.8–11.7	1.3–30.9	6.7–19.1	3.7–50.4	0–X	24.5–32.5
Lobatula fletcheri	3.0–4.6	2.5–21.4	0–8.8	2.7–15.1	0–4.0	27.2–36.6	2.4–4.3
Gyroidina altiformis	X-7.6	0	0	0	0	0	X-4.3
Buccella frigida	0–X	X-4.4	X-8.5	X-10.6	2.6–23.7	1.9–5.7	0
Cribroelphidium excavatum	0–2.2	2.0–22.0	4.6–55.7	X-10.8	3.5–53.3	0–2.1	X-2.2
Cribroelphidium foraminosum	0	0	0–18.9	0–2.0	0–19.9	0	0
Cribroelphidium subarcticum	0	7.1–15.4	0–8.4	X-5.6	0–5.6	2.4–6.4	0

transgression over the terrestrial source of this debris best explains the sudden dramatic reduction of this population. The sharp contact of the upper margin of the B_2 unit with B_3 sediments also supports the hypothesis of rapid subsidence (Luternauer et al, 1989b). Clague (1983) and Luternauer and others (1989a) suggest that rapid migration and collapse of the forebulge during deglaciation would result in this scenario.

The high proportions of *Cassidulina reniforme* characterizing the upper part of the B_1 unit to the lower part of the B_3 lithologic unit indicates that water temperatures were generally quite cool during deposition of this interval. The presence of high proportions of this species in these cores (and also in cores END 84B-04, END 84B-07, END 87A-23) indicates a major cooling of marine waters off the coast of British Columbia between 11,300 and 10,100 years B. P. Brunner and Ledbetter (1989) have also identified a cooling event about 11,000 years B.P. in turbidites from the central California continental margin. Heusser (1960) and Mathewes (1973) reported an increase in the proportion of *Tsuga mertensiana* between 11,000 and 10,000 years B.P. on Vancouver Island and in the Fraser River Valley. Heusser (1973) suggests that this species became more abundant because of a climatic cooling, although Hebda (1983) suggests that an increase in moisture levels would have had a similar effect. Most recently, Mathewes (written pers. comm., unpublished data, 1991) has constructed a curve of mean July temperatures using fourier transform functions, based on a proxy pollen record spanning the last 15,000 years showing a late glacial warming trend that is abruptly reversed between 11,100 years and 10,000 years B.P. This interval correlates very well with the Younger Dryas cooling event recorded from marine and terrestrial sediments from Europe (Mörner, 1970, 1976) and eastern North America (Mott, et al., 1986; Broecker, et al., 1988).

For the most part the succession recorded by the foraminiferal populations through the remainder of units B_3 and C indicate a transition to modern day conditions characterized by abundant *Epistominella vitrea;* the steady increase in the proportion of *Epistominella vitrea* accompanies a steady decline in *Cribroelphidium excavatum*. Bergen and O'Neil (1979) observed high proportions of *Epistominella vitrea* in surficial sediments at water depths between 100 and 200 meters in the Gulf of Alaska. In a more recent study Snyder and others (1990) observed this species comprising 28% of a sample collected in 143 m of water off the coast of northern Oregon. Therefore, it can be inferred that this species is an important component of modern foraminiferal biofacies in outer neritic zones all along the coast of the Pacific Northwest. Based on an extrapolation of ^{14}C dates from Core END 84B-08 and END 84B-10 fully modern foraminiferal faunas did not develop at these sites until between 8,500 and 10,000 years BP.

Moresby Trough

The two cores recovered from Moresby Trough were from significantly different depths and environments and not surprisingly are characterized by significantly different faunas (Figs. 2, 4, 5). Core END 84B-04, taken at a depth of 327 m, only penetrated as far as the B_2 lithologic unit. Although Luternauer and others (1989b) suggests a similar depositional scenario for these lag deposits as at the other sample localities, the sediments are older (≈11,600 years B.P.) than observed elsewhere. The foraminiferal fauna alternates between the similar *Cribroelphidium* and *Epistominella* Biofacies throughout deposition of units B_2 and B_3. As in cores END 84B-08 and END 84B-10 these alternating biofacies indicate fluctuations in environmental conditions during the succession of foraminiferal faunas from the Late Pleistocene to Recent. As in the cores from Goose Island Trough there was a relatively high proportion of *Buliminella elegantissima* present in samples obtained from the B_2 lithologic unit and from the 215 to 219 cm interval of the B_3 lithologic unit (Appendices 1,2). This species is not nearly as abundant here as in the Goose Island Trough cores due to a greater depositional depth. However, the presence of significant populations of this species does indicate that plant detritus was being flushed to this site from nearby land areas. The earliest stages of deposition were marked by relatively low proportions of *Cassidulina reniforme*. Abundances of this species increase dramatically in the section of the core dated between 10,170 and 11,290 years BP. However, the lithologies do not match a similarly aged *Cassidulina reniforme* abundance spike (>10,170 years B.P.) observed in core END 84B-07 from the western margin of Moresby Trough. This good faunal and radiocarbon correlation indicates that the B_2 units of these cores are diachronous, perhaps reflecting migration of the collapsing glacial forebulge.

Core END 84B-07 from the western margin of Moresby Trough was recovered at the greatest depth of any sample (474 m), which probably explains the distinct fauna observed. However, a depositional scenario similar to the other samples can be applied. The age of the lag deposits of the B_2 lithologic unit here (10,000 to 10,500 years BP) is similar to the age of the B_2 unit of cores examined from the Goose Island trough, but is somewhat younger than the B_2 unit of core END 84B-04 across the trough. The fauna in the upper B_1 unit, B_2 unit and lower B_3? unit is characterized by the *Epistominella* Biofacies and is correlated with similarly aged B_3 sediments of core END 84B-04 from the eastern side of the Moresby Trough.

The foraminiferal fauna characterizing the *Gyroidina-Seabrookia* (Biofacies 7) and *Gyroidina-Bolivina* Biofacies (Biofacies 1) are difficult to explain. This is because *Gyroidina altiformis* and to a lesser extent *Seabrookia earlandi* and *Bolivina minuta* and normally all deep dwelling and the core was obtained at only 474 m water depth. *Gyroidina altiformis* occurs in water depths between 1662 and 2205 meters in the Gulf of Alaska (Bergen and O'Neil, 1979), between 2375 and 2700 m off the west coast of Vancouver Island (Enbysk, 1960), and approximately 1000 m in basins along the California Borderland (Uchio, 1960). *Bolivina minuta* has a preferred habitat between 365 and 900 m in areas such as the San Diego Trough off the coast of Southern California (Uchio, 1960). *Seabrookia earlandi* has not been previously reported from Moresby Trough, although the *Seabrookia* sp. of Conway and Luternauer (1984) from nearby Goose Island Trough may be referable to this species. Uchio (1960) reported the species from a wide variety of water depths (60 to 1170 meters) off southern California, although never in excess of 1%. Douglas and others (1980) found all these species to be components of fossil assemblages found in near shore California Borderland basins with a basin floor of greater than 700 m. The fossil assemblages inhabited the area earlier in the Holocene and Pleistocene, and differ considerably from the faunas characterizing these environments at present (Douglas et al., 1979; Douglas, 1981). Probably some elements of the present fauna (such as *Gyroidina altiformis*) are relict in nature. It is well known that some foraminiferal species have migrated to different water depths in response to changing water masses—e.g. *Melonis pompilioides* (Fichtel and Moll), 1798—(Blake and Douglas, 1980). In the present case these species probably migrated from deep to shallow levels when much colder water masses influenced the region, as indicated by the high proportion of *Cassidulina reniforme* in the *Gyroidina-Seabrookia* Biofacies. The evolution of this fauna to a more modern one in response to Holocene warming is indicated by the increasing proportion of such species as *Bolivina minuta* and *Angulogerina fluens* toward the top of the core.

SUMMARY

1. Deglaciation at the end of the late Wisconsinian substage was marked by the presence of ice-rafted debris (unit A, not sampled in this study) terminating at least 12,180 years B.P. (reinterpretation of the 12,910 ± 90 years B.P. date provided by Luternauer and others, 1989b, based on the data of Southon and others, 1990).

2. Water temperatures increased rapidly after deglaciation as indicated by the very low proportions of *Cassidulina reniforme* in the basal units of most cores. There was a gradual decrease in water depth throughout the region during the latter stages of deposition of the B_1 lithologic unit. This decrease in water depth is evidenced by a gradual increase in the proportion of *Buliminella elegantissima,* often associated with high proportions of terriginous debris.

3. Relative sea level was lowest during deposition of the B_2 unit as indicated by lag deposits (Luternauer and others, 1989b) and the acme of *Buliminella elegantissima* population maximum. This population maximum was not observed in core END 84B-04 because this area was still too deep. The timing of the maximum lowstand varies between 11,700 years B.P. at core END 84B-04 to about 10,000 years B.P. The diachroneity may be related to a difference in timing of glacial forebulge collapse after deglaciation across the region.

4. A *Cassidulina reniforme* maximum in these cores is approximately dated between about 10,100 and 11,300 years B.P., and reflects maximum cooling. An isochronous cooling event has been noted in pollen studies based on terrestrial deposits in coastal British Columbia. Because this horizon correlates well with the Younger Dryas Event of Europe and eastern North America (11,000 to 10,000 years B.P.) the brief interruption of deglaciation determined from the northeast Pacific appears to be the same event recorded from the Atlantic margin (Mörner, 1970, 1976; Broecker et al., 1988).

ACKNOWLEDGMENTS

This research was partially supported by Natural Sciences and Engineering Research Council of Canada Operating Grant OGPO041665 and Department of Supply and Services Contract 23254-9-05-2/01-XSB. I would like to thank J. Luternauer of the Geological Survey of Canada, Vancouver, British Columbia, for providing the core samples examined for this report. I also wish to thank John Luternauer for providing use of the scanning electron microscope at the Geological Survey of Canada, Vancouver, and to Peter Krause for assistance in its operation. I also thank A. R. Loeblich Jr., H. Tappan Loeblich, J. L. Luternauer, H. Elizabeth Anderson, S. A. Revets and K. L. Finger for critically reviewing the manuscript.

REFERENCES

BARRICK, R. E., BEVERAGE, A. E., PATTERSON, R. T., and SCHUBERT, J. K., 1989, Reexamination of the benthic foraminiferal fauna from a Late Pleistocene marine terrace deposit near Goleta, California: Journal of Paleontology, v. 63, p. 261–267.

BARRIE, J. V., and BORNHOLD, B. D., 1989, Surficial geology of Hecate Strait, British Columbia continental shelf: Canadian Journal of Earth Sciences, v. 26, p. 1241–1254.

BERGEN, F. W., and O'NEIL, P., 1979, Distribution of Holocene foraminifera in the Gulf of Alaska: Journal of Paleontology, v. 53, 1267–1292.

BLAKE, G. H., and DOUGLAS, R. G., 1980, Pleistocene occurrence of *Melonis pompilioides* in the California borderland and its implications for foraminiferal paleoecology: Cushman Foundation for Foraminiferal Research Special Publication 19, 59–67.

BROECKER, W. S., ANDREE, M., WOLFLI, W., OESCHGER, H. BONANI, G., KENNETT, J. P. and PETEET, D., 1988, The chronology of the last deglaciation: implications to the cause of the Younger Dryas Event. Paleoceanography, v. 3, p. 1–19.

BRUNNER, C. A. and LEDBETTER, M. T. 1989, Late Quaternary quantitative planktonic foraminiferal biostratigraphy in turbidite sequences of the central California continental margin. Micropaleontology, v. 35, p. 321–336.

CLAGUE, J. J., 1983, Glacio-isostatic effects of the Cordilleran Ice Sheet, British Columbia, Canada: *In* Smith, D. E. and Dawson, A. G., (eds.), Shorelines and Isostasy, Academic Press, London, p. 321–343.

CLAGUE, J. J., MATHEWES, R. W., and WARNER, B. G., 1982a, Late Quaternary geology of eastern Graham Island, Queen Charlotte Islands, British Columbia: Canadian Journal of Earth Sciences, v. 19, p. 1786–1795.

CLAGUE, J. J., HARPER, J. R., HEBDA, R. J., and HOWES, D. E., 1982b, Late Quaternary sea levels and crustal movements, coastal British Columbia: Canadian Journal of Earth Sciences, v. 19, p. 597–618.

COCKBAIN, A. E., 1963, Distribution of foraminifera in Juan de Fuca and Georgia Straits, British Columbia, Canada: Contributions from the Cushman Foundation for Foraminiferal Research, v. 14, p. 37–57.

CONWAY, K. W. and LUTERNAUER, J. L., 1984, Longest core of Quaternary sediments from Queen Charlotte Sound: preliminary description and interpretation: In Current Research Pt. A, Geological Survey of Canada, Paper 84-1A, p. 647–649.

DANSGAARD, W., JOHNSEN, S. J., CLAUSEN, H. B., DAHL-JENSEN, D., GUNDERSTRUP, N., HAMMER, C. H., and OESCHGER, H., 1984, North Atlantic climatic oscillations revealed by deep Greenland ice cores. *in* Hansen, J. E., and Takahashi, T., eds., Climate processes and climate sensitivity: American Geophysical Union Monograph 29, p. 288–298.

DE DECKKER, P., and CORRÈGE, T., 1991, Late Pleistocene record of cyclic eolian activity from tropical Australia suggesting the Younger Dryas is not an unusual climatic event: Geology, v. 19, p. 602–605.

DENTON, G., and KARLEN, W., 1973, Holocene climatic variations—their pattern and possible cause: Quaternary Research, v. 3, p. 155–205.

DOUGLAS, R. G., 1981, Paleoecology of continental margin basins: a modern case history from the borderland of southern California. *in* Douglas, R. G., Colburn, I. P., and Gorsline, D. S., (eds.), Depositional Systems of Active Continental Margin Basins: Short Course Notes, Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 121–156.

DOUGLAS, R. G., COTTON, M. L. and WALL, L., 1979, Distributional and variability analysis of benthic foraminifera in the southern California Bight: Bureau of Land Management, Dept. Interior Contract AA550-CT6-40, 219 p.

DOUGLAS, R. G., LIESTMAN, J., WALCH, C., BLAKE, G. H., and COTTON, M. L., 1980, The transition from live to sediment assemblages in benthic foraminifera from the southern California Borderland. *In* Field, M., Bouma, A., Colburn, I., Douglas, R. G., and Ingle, J. C. (eds.), Quaternary depositional environments of the Pacific Coast, Pacific Coast Paleogeography Symposium, Pacific Section Society of Economic Mineralogists and Paleontologists, v. 4, p. 257–280.

ENBYSK, B. J., 1960, Distribution of foraminifera in the northeast Pacific: Unpub. Ph.D. Dissertation, University of Washington, 150 p.

FEYLING-HANSSEN, R. W., 1976, A mid-Wisconsinian Interstadial on Broughton Island, Arctic Canada, and its foraminifera: Arctic and Alpine Research, v. 8, p. 161–182.

FISHBEIN, E., and PATTERSON, R. T., (in press), Re-examination of the statistical methods used to cluster micropaleontological quantitative data. Journal of Paleontology.

HALD, M. and VORREN, T. O., 1987, Foraminifera stratigraphy and environment of Late Weichselian deposits on the continental shelf off Troms, Northern Norway: Marine Micropaleontology, v. 12, p. 129–160.

HARMON, R. A., 1972, The distribution of microbiogenic sediment near the mouth of the Columbia River. *In* Pruter, A. T., and Alverson, D. L., (eds), The Columbia River Estuary and Adjacent Ocean Waters: University of Washington Press, Seattle, Washington, p. 265–277.

HEBDA, R. J., 1983, Late-glacial and postglacial vegetation history at Bear Cove Bog, northeast Vancouver Island, British Columbia: Canadian Journal of Botany, v. 61, p. 3172–3192.

HEUSSER, C. J., 1960, Late-Pleistocene environments of North Pacific North America: American Geographical Society Special Publication v. 35.

HEUSSER, C. J., 1973, Environmental sequence following the Fraser advance of the Juan de Fuca Lobe, Washington: Quaternary Research, v. 3, p. 284–306.

HOWES, D. E., 1981, Terrain inventory and geological hazards: northern Vancouver Island: Assessment and Planning Division, Terrestrial Studies Branch, British Columbia Ministry of Environment, Bulletin 5.

KNUDSEN, K. L., 1976, Foraminifera faunas in Weichselian stadial and interstadial deposits of the Skaerumhede boring, Jutland Denmark: *in* Schafer, C., and Pelletier, B. R., (eds.) First International Symposium on Benthonic Foraminifera of Continental Margins, Halifax, 1975, Part B; Paleoecology and Biostratigraphy: Maritime Sediments Special Publication 1, p. 131–151.

LUTERNAUER, J. L., CLAGUE, J. J., CONWAY, K. W., BARRIE, J. V., BLAISE, B., and MATHEWES, R. W., 1989a, Late Pleistocene terrestrial deposits on the continental shelf of western Canada: Evidence for rapid sea-level change at the end of the last glaciation: Geology, v. 17, p. 357–360.

LUTERNAUER, J. J., CONWAY, K. W., CLAGUE, J. L., and BLAISE, B., 1985, Timing and extent of Late Wisconsinan glaciation on the central continental shelf off western Canada: Canadian Quaternary Association, Symposium on the Paleo-environmental construction of the Late Wisconsinan Deglaciation and the Holocene, Lethridge, Alta, Program with Abstracts, p. 41.

LUTERNAUER, J. J., CONWAY, K. W., CLAGUE, J. L., and BLAISE, B., 1989b, Late Quaternary geology and geochronology of the central continental shelf of western Canada: Marine Geology, v. 89, p. 57–68.

LUTERNAUER, J. J. and MURRAY, J. W., 1983, Late Quaternary morphologic development and sedimentation, central British Columbia continental shelf: Geological Survey of Canada Paper 83–21, 38 p.

MATHEWES, R. W., 1973, A palynological study of postglacial vegetation changes in the University Research Forest, southwestern British Columbia: Canadian Journal of Botany, v. 51, p. 2085–2103.

MILLER, A. A. L., SCOTT, D. B. and MEDIOLI, F. S., 1982, *Elphidium excavatum* (Terquem); Ecophenotypic versus subspecific variation: Journal of Foraminiferal Research, v. 12, p. 116–144.

MÖRNER, N.-A., 1970, The Younger Dryas Stadial: Förhandlingar, v. 92, p. 5–20.

———, 1976, The Pleistocene/Holocene boundary in southern Sweden *in* Mörner, N.-A., (ed.), The Pleistocene/Holocene boundary: a proposed boundary-stratotype in Gothenburg, Sweden, Boreas, v. 5, p. 197–204.

MOTT, R. J., GRANT, D. R., STEA, R., and OCCHIETTI, S., 1986: Late-Glacial climatic oscillation in Atlantic Canada equivalent to the Allerød/Younger Dryas event: Nature, v. 323, p. 247–250.

NESJE, A., and KVAMME, M., 1991, Holocene glacier and climate variations in western Norway: evidence fro early Holocene glacier demise and multiple neoglacial events: Geology, v. 19, p. 610–612.

OSTERMAN, L., 1984, Benthic foraminifera zonation of a glacial/interglacial transition from Frobisher Bay, Baffin Island, North West Territories, Canada. *in* Oertli, H. J., (ed.), Benthos '83: Second International Symposium on Benthic Foraminifera (Pau, 1983), Elf Aquitane, Esso REP, TOTAL, CFP, Bordeaux, France, p. 471–476.

PATTERSON, R. T. and CAMERON, B. E. B., 1991, Paleoenvironmental significance of the foraminiferal biofacies succession in the Late Quaternary sediments of the Fraser River Delta, British Columbia. Journal of Foraminiferal Research, v. 21, p. 228–243.

PATTERSON, R. T., and FISHBEIN, E., 1989, Re-examination of the statistical methods used to determine the number of point counts needed for micropaleontological quantitative research: Journal of Paleontology, v. 63, p. 245–248.

PESTIAUX, P., VAN DER MERSCH, I., BERGER, A. E., and DUPLESSY, J. C., 1988, Paleoclimate variability at frequencies ranging from 1 cycle per 10,000 years to 1 cycle per 1000 years: evidence from nonlinear behavior of the climate system. Climatic Change, v. 123, p. 9–37.

PISIAS, N. G., 1983, Geologic time series from deep-sea sediments: Time scales and distortion by bioturbation. Marine Geology, v. 51, p. 99–113.

RODRIGUEZ, C. G., and RICHARD, S. H., 1986, An ecostratigraphic study of Late Pleistocene sediments of the western Champlain Sea Basin, Ontario and Quebec: Geological Survey of Canada Paper 85–22, 33 p.

SEJRUP, H. P. and GUILBAULT, J.-P., 1980. *Cassidulina reniforme* and *C. obtusa* (foraminifera), taxonomy, distribution and ecology: SARSIA, v. 65, p. 79–85.

SHOULDICE, D. H., 1973, Western Canadian continental shelf. *in* McCrossan, R. D., (ed.). Future petroleum provinces of Canada: their geology and potential: Canadian Society of Petroleum Geologists, Memoir 1, p. 7–35.

SMITH, R. K., 1970, Late glacial foraminifera from southeast Alaska and British Columbia and a world-wide high northern latitude shallow-water faunal province: Archives des Sciences, v. 23, p. 675–702.

SMITH, R. K., 1978, Systematics of the North American high latitude very shallow cold water foraminiferal fauna: Archives des Sciences, v. 31, p. 133–162.

SNYDER, S. W., 1989, Relationship between benthic foraminiferal assemblages and Neogene phosphatic sediments, North Carolina coastal plain and continental shelf, *in* Riggs, S. R. and Burnett, W. (eds.), Phosphates of the World, III: Cambridge U.K., Cambridge University Press, 445–465.

SNYDER, S. W., HALE, W. R., KONTROVITZ, M., 1990, Distributional patterns of modern benthic foraminifera on the Washington continental shelf: Micropaleontology, v. 36, p. 259–282.

SOUTHON, J. R., NELSON, D. E. and VOGEL, J. S., 1990, A record of past ocean-atmosphere radiocarbon differences from the northeast Pacific: Paleoceanography, v. 5, p. 197–206.

UCHIO, T., 1960, Ecology of living benthonic foraminifera from the San Diego, California, area: Cushman Foundation for Foraminiferal Research, Special Publication no. 5, 72 p.

VILKS, G., WAGNER, F. J. E., PELLTIER, B. R., 1979, The Holocene marine environment of the Beaufort Shelf: Geological Survey of Canada Bulletin 303, 43 p.

WARNER, B. G., MATHEWES, R. W. and CLAGUE, J. J., 1982, Ice-free conditions on the Queen Charlotte Islands, British Columbia, at the height of Late Wisconsin glaciation: Science (Washington, D.C.) v. 218, p. 675–677.

WILKINSON, L., 1987, SYSTAT: the system for statistics: Evanston, IL: SYSTAT, Inc.

Received July 5 1991
Accepted September 27 1992

APPENDIX 1. Foraminiferal occurrences in samples from Core END 84B-04. Samples were quantitatively analyzed and are recorded as fractional abundances. * designates those species containing a statistically significant population in at least one sample, which were then used in the multivariate analysis. "Percent of sample quantified" refers to the proportion of sample where the foraminiferal population was counted. "Species/Sample" refers to the sample numbers along the horizontal axis and the list of species on the vertical axis.

Species/Sample	894	403	404	405	406	407	408	409
Depth in Core (cm)	0–1	32–36	71–75	137–141	215–219	342–345	377–381	443–447
Percent of Sample Quantified	25.0	100	25.0	18.9	9.3	6.2	12.6	12.6
Shannon-Weiner Diversity	2.38	2.19	2.17	1.93	2.13	2.16	2.39	2.38
Biofacies	3	4	2	4	2	2	2	2
Total Number of Specimens	535	821	1067	317	343	419	506	347
Trochammina nana	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Spirosigmoilina tenuis	0.002	0.006	0.004	0.003	0.000	0.005	0.006	0.006
Favulina melo	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Homalohedra quasilineata	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
Fissurina eburnea	0.000	0.000	0.001	0.000	0.006	0.000	0.000	0.000
Fissurina lucida	0.000	0.000	0.001	0.000	0.000	0.000	0.002	0.000
Fissurina subquadrata	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Fissurina vitreola	0.000	0.000	0.001	0.000	0.006	0.000	0.002	0.000
Palliolatella immemora	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Parafissurina semicarinata	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Pytine petaloskelis	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
**Seabrookia earlandi*	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
**Bolivina minuta*	0.086	0.018	0.010	0.009	0.017	0.005	0.012	0.014
Bolivinellina pacifica	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Islandiella islandica	0.002	0.000	0.000	0.000	0.000	0.000	0.002	0.000
**Islandiella norcrossi*	0.239	0.006	0.003	0.025	0.017	0.050	0.028	0.020
**Cassidulina reniforme*	0.032	0.373	0.370	0.464	0.321	0.184	0.097	0.066
**Stainforthia sp.*	0.133	0.105	0.136	0.098	0.122	0.267	0.089	0.032
Euloxostomum alata	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Protoglobobulimina pupoides	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
**Buliminella elegantissima*	0.075	0.061	0.071	0.050	0.131	0.050	0.130	0.144
Euuvigerina aculeata	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Euuvigerina juncea	0.000	0.004	0.007	0.006	0.003	0.005	0.002	0.003
Angulogerina angulosa	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006
**Angulogerina fluens*	0.024	0.000	0.004	0.000	0.000	0.000	0.000	0.003
**Gavelinopsis campanulata*	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Rosalina columbiensis	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
**Epistominella pacifica*	0.024	0.089	0.042	0.076	0.026	0.033	0.101	0.052
**Epistominella vitrea*	0.140	0.091	0.083	0.082	0.061	0.103	0.047	0.078
**Lobatula fletcheri*	0.077	0.066	0.061	0.038	0.114	0.033	0.071	0.193
Nonionella digitata	0.004	0.006	0.001	0.003	0.000	0.000	0.000	0.000
**Nonionella stella*	0.009	0.018	0.052	0.013	0.038	0.048	0.063	0.040
Nonionella turgida	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
**Nonionellina labradorica*	0.004	0.006	0.001	0.003	0.000	0.000	0.008	0.000
Pseudononion basispinata	0.002	0.001	0.001	0.003	0.000	0.000	0.000	0.003
Astrononion gallowayi	0.000	0.002	0.005	0.003	0.000	0.000	0.000	0.003
Pullenia salisburyi	0.002	0.010	0.001	0.000	0.000	0.000	0.000	0.003
Chilostomella oolina	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Buccella depressa	0.000	0.001	0.000	0.003	0.000	0.000	0.000	0.003
**Buccella frigida*	0.019	0.024	0.024	0.013	0.015	0.012	0.014	0.035
**Cribroelphidium excavatum*	0.056	0.055	0.036	0.091	0.029	0.074	0.184	0.199
**Cribroelphidium foraminosum*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
**Cribroelphidium subarcticum*	0.064	0.049	0.079	0.016	0.093	0.131	0.138	0.089
Elphidiella nitida	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
Patellina corrugata	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.003

APPENDIX 2. Foraminiferal occurrences in samples from Core END 84B-07. Samples were quantitatively analyzed and are recorded as fractional abundances. * designates those species containing a statistically significant population in at least one sample, which were then used in the multivariate analysis. "Percent of sample quantified" refers to the proportion of sample where the foraminiferal population was counted. "Species/Sample" refers to the sample numbers along the horizontal axis and the list of species on the vertical axis.

Species/Sample	895	397	398	399	400	401	402
Depth in Core (cm)	0–1	56–59	152–156	260–264	456–460	470–474	516–520
Percent of Sample Quantified	9.3	3.1	3.1	3.1	9.3	12.6	12.6
Shannon-Weiner Diversity	2.17	2.33	2.48	2.35	2.67	2.28	2.37
Biofacies	1	1	7	7	4	4	4
Total Number of Specimens	324	647	874	331	352	356	318
Spirosigmoilina tenuis	0.003	0.008	0.006	0.006	0.000	0.000	0.000
Botuloides pauciloculus	0.000	0.000	0.000	0.003	0.000	0.000	0.000
Lenticulina nikobarensis	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Hyalinonetrion clavata	0.000	0.000	0.000	0.003	0.000	0.000	0.000
Lagena semilineata	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Favulina melo	0.000	0.005	0.000	0.000	0.000	0.000	0.000
Homalohedra borealis	0.003	0.002	0.001	0.000	0.000	0.000	0.000
Fissurina vitreola	0.000	0.005	0.002	0.000	0.000	0.000	0.003
Palliolatella frangens	0.000	0.000	0.003	0.006	0.003	0.000	0.000
Palliolatella immemora	0.000	0.000	0.001	0.006	0.003	0.000	0.000
Pytine petaloskelis	0.000	0.000	0.000	0.006	0.003	0.000	0.000
**Seabrookia earlandi*	0.009	0.032	0.057	0.148	0.006	0.000	0.009
**Bolivina minuta*	0.324	0.223	0.066	0.024	0.051	0.020	0.006
Bolivinellina pacifica	0.003	0.017	0.019	0.036	0.006	0.003	0.000
Brizalina fragilis	0.028	0.017	0.016	0.009	0.000	0.000	0.000
Brizalina subaenariensis	0.000	0.002	0.003	0.000	0.000	0.000	0.000
Islandiella islandica	0.022	0.036	0.042	0.021	0.006	0.003	0.000
**Islandiella norcrossi*	0.003	0.059	0.126	0.024	0.020	0.003	0.000
**Cassidulina reniforme*	0.037	0.036	0.120	0.242	0.111	0.250	0.198
**Stainforthia sp.*	0.000	0.000	0.002	0.018	0.125	0.031	0.157
Euloxostomum alata	0.022	0.005	0.014	0.012	0.000	0.000	0.000
Bulimina inflata	0.006	0.006	0.002	0.000	0.000	0.000	0.000
Praeglobobulimina spinescens	0.000	0.000	0.000	0.003	0.000	0.000	0.000
Protoglobobulimina elongata	0.000	0.005	0.007	0.009	0.000	0.000	0.000
Protoglobobulimina pupoides	0.012	0.000	0.000	0.000	0.000	0.000	0.000
**Buliminella elegantissima*	0.003	0.000	0.002	0.000	0.023	0.011	0.031
Euuvigerina aculeata	0.037	0.006	0.014	0.009	0.003	0.000	0.000
Euuvigerina juncea	0.009	0.000	0.009	0.006	0.028	0.042	0.009
Angulogerina angulosa	0.000	0.002	0.000	0.000	0.000	0.000	0.000
**Angulogerina fluens*	0.136	0.080	0.027	0.021	0.000	0.000	0.000
Pleurostomella delicatula	0.000	0.005	0.003	0.018	0.000	0.003	0.000
**Gavelinopsis campanulata*	0.000	0.000	0.000	0.000	0.011	0.000	0.000
**Epistominella pacifica*	0.003	0.002	0.032	0.000	0.085	0.242	0.132
**Epistominella vitrea*	0.225	0.295	0.309	0.269	0.170	0.101	0.085
**Lobatula fletcheri*	0.046	0.037	0.033	0.033	0.071	0.096	0.132
Nonionella digitata	0.000	0.000	0.000	0.012	0.014	0.003	0.000
**Nonionella stella*	0.009	0.006	0.006	0.000	0.068	0.037	0.019
**Nonionellina labradorica*	0.000	0.008	0.006	0.015	0.034	0.031	0.035
Pseudononion basispinata	0.000	0.000	0.000	0.000	0.006	0.000	0.000
Astrononion gallowayi	0.000	0.008	0.001	0.000	0.017	0.011	0.025
Pullenia salisburyi	0.009	0.003	0.008	0.000	0.000	0.000	0.016
Chilostomella oolina	0.003	0.009	0.005	0.033	0.000	0.000	0.000
**Gyroidina altiformis*	0.012	0.066	0.034	0.003	0.000	0.000	0.000
Buccella depressa	0.000	0.000	0.000	0.000	0.000	0.003	0.006
**Buccella frigida*	0.006	0.000	0.000	0.000	0.091	0.056	0.079
**Cribroelphidium excavatum*	0.015	0.003	0.016	0.003	0.017	0.034	0.047
**Cribroelphidium foraminosum*	0.000	0.000	0.000	0.000	0.000	0.014	0.000
**Cribroelphidium subarcticum*	0.000	0.000	0.000	0.000	0.020	0.006	0.006
Lagena weisneri	0.000	0.000	0.001	0.000	0.003	0.000	0.003
Patellina corrugata	0.000	0.000	0.000	0.000	0.000	0.003	0.000

APPENDIX 3. Foraminiferal occurrences in samples from Core END 84B-08. Samples were quantitatively analyzed and are recorded as fractional abundances. * designates those species containing a statistically significant population in at least one sample, which were then used in the multivariate analysis. "Percent of sample quantified" refers to the proportion of sample where the foraminiferal population was counted. "Species/Sample" refers to the sample numbers along the horizontal axis and the list of species on the vertical axis.

Species/Sample	896	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430
Depth in Core (cm)	0–1	41–	165–	228–	329–	375–	455–	480–	499–	504–	517–	528–	535–	552–	595–	658–	1063–
		44	167	232	332	377	457	482	501	506	520	530	539	555	598	661	1066
Percent of Sample Quantified	18.3	12.6	25	6.3	6.3	6.3	6.3	6.3	6.3	3.2	3.2	1.6	1.6	6.3	6.3	9.5	6.3
Shannon-Weiner Diversity	2.08	2.09	2.18	1.93	2.14	1.89	2.10	1.84	1.99	2.05	2.04	1.93	2.03	1.93	1.78	1.97	1.66
Biofacies	3	5	3	3	3	3	3	3	5	5	5	5	5	5	5	5	3
Total Number of Specimens	425	296	274	304	678	309	339	280	888	834	560	513	306	297	449	338	279
Spirosigmoilina tenuis	0.000	0.003	0.000	0.000	0.004	0.000	0.003	0.000	0.000	0.005	0.000	0.004	0.000	0.000	0.000	0.000	0.000
Lagena semilineata	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006	0.000
Lagena striaticollis	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000
Procerolagena amphoriniformis	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000
Procerolagena complurecosta	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Procerolagena gracilis	0.000	0.000	0.000	0.003	0.001	0.003	0.003	0.000	0.001	0.000	0.000	0.000	0.003	0.000	0.002	0.000	0.000
Procerolagena meridionalis	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Procerolagena simulampulla	0.000	0.003	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.002	0.000	0.003	0.000	0.000	0.000
Procerolagena wiesneri	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pygmaeoseistron hispidum	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Homalohedra quasilineata	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fissurina eburnea	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fissurina lucida	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fissurina vitreola	0.002	0.007	0.000	0.000	0.001	0.000	0.003	0.000	0.000	0.001	0.000	0.000	0.003	0.000	0.000	0.000	0.000
**Seabrookia earlandi*	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
**Bolivina minuta*	0.045	0.007	0.007	0.000	0.000	0.000	0.003	0.000	0.002	0.000	0.005	0.006	0.007	0.003	0.011	0.000	0.000
Bolivinellina pacifica	0.009	0.003	0.000	0.000	0.003	0.000	0.006	0.004	0.003	0.000	0.000	0.004	0.000	0.000	0.002	0.000	0.000
Islandiella islandica	0.002	0.000	0.000	0.000	0.000	0.000	0.003	0.004	0.001	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000
**Islandiella norcrossi*	0.344	0.024	0.142	0.141	0.140	0.333	0.127	0.146	0.056	0.036	0.070	0.025	0.020	0.030	0.000	0.033	0.122
**Cassidulina reniforme*	0.040	0.014	0.117	0.043	0.215	0.097	0.159	0.225	0.221	0.150	0.136	0.099	0.095	0.195	0.013	0.050	0.007
**Stainforthia sp.*	0.009	0.034	0.022	0.000	0.081	0.003	0.044	0.025	0.020	0.014	0.016	0.021	0.052	0.077	0.058	0.033	0.122
Euloxostomum alata	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Protoglobobulimina pupoides	0.007	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
**Buliminella elegantissima*	0.002	0.020	0.004	0.003	0.007	0.010	0.044	0.046	0.159	0.157	0.241	0.160	0.062	0.071	0.116	0.124	0.004
Euuvigerina aculeata	0.007	0.030	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Euuvigerina juncea	0.016	0.010	0.004	0.007	0.003	0.000	0.003	0.000	0.002	0.001	0.005	0.000	0.000	0.003	0.009	0.006	0.000
Angulogerina angulosa	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
**Angulogerina fluens*	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000
Pleurostomella delicatula	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
**Gavelinopsis campanulata*	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000
Rosalina columbiensis	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
**Epistominella pacifica*	0.005	0.010	0.018	0.010	0.001	0.000	0.018	0.004	0.002	0.014	0.011	0.012	0.078	0.000	0.007	0.021	0.007
**Epistominella vitrea*	0.287	0.490	0.248	0.280	0.133	0.065	0.094	0.121	0.073	0.089	0.079	0.096	0.049	0.054	0.076	0.154	0.022
**Lobatula fletcheri*	0.026	0.010	0.000	0.003	0.006	0.000	0.009	0.004	0.015	0.012	0.023	0.014	0.003	0.000	0.002	0.012	0.000
Nonionella digitata	0.002	0.044	0.000	0.000	0.015	0.000	0.003	0.000	0.001	0.002	0.002	0.000	0.007	0.003	0.007	0.000	0.004
**Nonionella stella*	0.012	0.047	0.007	0.007	0.007	0.016	0.015	0.021	0.019	0.025	0.036	0.033	0.052	0.054	0.060	0.015	0.025
Nonionella turgida	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
**Nonionellina labradorica*	0.026	0.088	0.106	0.095	0.083	0.071	0.029	0.000	0.011	0.008	0.000	0.004	0.010	0.007	0.002	0.009	0.007
Pseudononion basispinata	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.004
Astrononion gallowayi	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.002	0.000	0.000	0.002	0.000	0.000
Pullenia salisburyi	0.005	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Buccella depressa	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
**Buccella frigida*	0.033	0.037	0.069	0.026	0.019	0.006	0.021	0.064	0.116	0.223	0.102	0.080	0.062	0.044	0.082	0.050	0.036
**Cribroelphidium excavatum*	0.073	0.047	0.128	0.204	0.223	0.227	0.372	0.332	0.282	0.236	0.263	0.415	0.444	0.397	0.510	0.435	0.527
**Cribroelphidium foraminsoum*	0.000	0.000	0.095	0.168	0.041	0.113	0.015	0.000	0.000	0.0000	0.000	0.004	0.016	0.030	0.013	0.003	0.079
**Cribroelphidium subarcticum*	0.012	0.044	0.029	0.007	0.010	0.052	0.024	0.000	0.012	0.020	0.009	0.019	0.033	0.020	0.016	0.006	0.029
Elphidiella nitida	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.003	0.000	0.030	0.000
Patellina corrugata	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000

APPENDIX 4. Foraminiferal occurrences in samples from Core END 84B-10. Samples were quantitatively analyzed and are recorded as fractional abundances. Biofacies designations followed by a "?" indicate an indeterminate biofacies assignment, as the population of a sample was not statistically significant and thus not well known. * designates those species containing a statistically significant population in at least one sample, which were then used in the multivariate analysis. "Percent of sample quantified" refers to the proportion of sample where the foraminiferal population was counted. "Species/Sample" refers to the sample numbers along the horizontal axis and the list of species on the vertical axis.

Species/Sample	897	431	434	432	435	433
Depth in Core (cm)	0–1	52–54	334–337	555–557	640–643	783–785
Percent of Sample Quantified	6.3	100	18.9	18.9	6.3	12.6
Shannon-Weiner Diversity	1.98	1.87	2.10	1.65	1.99	1.89
Biofacies	5	?	5	3	5	5
Total Number of Specimens	293	36	294	294	381	542
Lagena semilineata	0.000	0.000	0.000	0.003	0.000	0.000
Procerolagena amphoriniformis	0.003	0.000	0.000	0.000	0.000	0.000
Procerolagena gracilis	0.000	0.000	0.000	0.003	0.000	0.000
Procerolagena meridionalis	0.003	0.000	0.000	0.000	0.000	0.000
Pygmaeoseistron hispidum	0.003	0.000	0.000	0.000	0.000	0.000
Pygmaeoseistron hispidulum	0.000	0.000	0.000	0.000	0.000	0.000
Favulina melo	0.000	0.028	0.000	0.000	0.000	0.000
Homalohedra borealis	0.003	0.000	0.000	0.000	0.000	0.000
Fissurina lucida	0.000	0.000	0.000	0.000	0.000	0.002
**Bolivina minuta*	0.041	0.000	0.000	0.003	0.005	0.004
**Islandiella norcrossi*	0.099	0.028	0.071	0.388	0.052	0.168
**Cassidulina reniforme*	0.068	0.028	0.044	0.139	0.231	0.020
**Stainforthia sp.*	0.003	0.000	0.000	0.014	0.021	0.013
Euloxostomum alata	0.007	0.000	0.000	0.000	0.000	0.000
**Buliminella elegantissima*	0.007	0.000	0.017	0.010	0.239	0.214
Euuvigerina aculeata	0.003	0.000	0.000	0.000	0.000	0.000
Euuvigerina juncea	0.007	0.472	0.010	0.003	0.003	0.006
Angulogerina angulosa	0.020	0.028	0.000	0.000	0.000	0.000
**Angulogerina fluens*	0.034	0.056	0.000	0.000	0.000	0.006
**Gavelinopsis campanulata*	0.003	0.000	0.000	0.000	0.000	0.000
**Epistominella pacifica*	0.003	0.111	0.071	0.027	0.008	0.011
**Epistominella vitrea*	0.474	0.111	0.201	0.041	0.089	0.181
**Lobatula fletcheri*	0.034	0.000	0.031	0.003	0.021	0.006
**Nonionella stella*	0.007	0.028	0.037	0.014	0.039	0.022
**Nonionellina labradorica*	0.010	0.028	0.044	0.007	0.000	0.000
Pseudononion basispinata	0.000	0.000	0.000	0.000	0.000	0.002
Pullenia salisburyi	0.007	0.028	0.000	0.000	0.000	0.000
**Buccella frigida*	0.096	0.056	0.041	0.034	0.092	0.044
**Cribroelphidium excavatum*	0.055	0.000	0.255	0.306	0.194	0.293
**Cribroelphidium foraminosum*	0.000	0.000	0.177	0.003	0.000	0.002
**Cribroelphidium subarcticum*	0.007	0.000	0.000	0.000	0.005	0.007

APPENDIX 5. Foraminiferal occurrences in samples from Core END 87A-23. Samples were quantitatively analyzed and are recorded as fractional abundances. Biofacies designations followed by a "?" indicate an indeterminate biofacies assignment, as the population of a sample was not statistically significant and thus not well known. * designates those species containing a statistically significant population in at least one sample, which were then used in the multivariate analysis. "Percent of sample quantified" refers to the proportion of sample where the foraminiferal population was counted. "Species/Sample" refers to the sample numbers along the horizontal axis and the list of species on the vertical axis.

Species/Sample	410	411	412	413	414	891	892	893
Depth in Core (cm)	6–8	18–20	33–38	40–50	59–61	65	75	90
Percent of Sample Quantified	12.5	6.3	6.3	100	100	100	100	100
Shannon-Weiner Diversity	2.19	2.31	2.00	1.56	0.69	0.00	0.00	0.00
Biofacies	6	6	6	?	?	void	void	void
Total Number of Specimens	966	790	653	23	2	0	0	0
Gaudryina arenaria	0.004	0.004	0.006	0.000	0.000	0.000	0.000	0.000
Gaudryina subglabrata	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Karreriella bradyi	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Spirosigmoilina tenuis	0.001	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Frondicularia gigas	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Marginulina pauciloculata	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Metapolymorphina charlottensis	0.002	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Lagena semilineata	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Favulina melo	0.010	0.009	0.009	0.000	0.000	0.000	0.000	0.000
Homalohedra borealis	0.007	0.005	0.008	0.000	0.000	0.000	0.000	0.000
Homalohedra quasilineata	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fissurina artolabiata	0.000	0.005	0.003	0.000	0.000	0.000	0.000	0.000
Fissurina lucida	0.001	0.003	0.002	0.000	0.000	0.000	0.000	0.000
Fissurina vitreola	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Palliolatella frangens	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
Palliolatella immemora	0.005	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Parafissurina semicarinata	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Laryngosigma trilocularis	0.005	0.004	0.006	0.000	0.000	0.000	0.000	0.000
**Bolivina minuta*	0.001	0.006	0.000	0.000	0.000	0.000	0.000	0.000
Bolivinellina pacifica	0.002	0.009	0.002	0.000	0.000	0.000	0.000	0.000
Islandiella islandica	0.013	0.006	0.012	0.043	0.000	0.000	0.000	0.000
**Islandiella norcrossi*	0.184	0.182	0.237	0.000	0.000	0.000	0.000	0.000
**Cassidulina reniforme*	0.005	0.033	0.008	0.391	0.000	0.000	0.000	0.000
**Stainforthia sp.*	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Protoglobobulimina pupoides	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
**Buliminella elegantissima*	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Euuvigerina juncea	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Angulogerina angulosa	0.012	0.001	0.000	0.000	0.000	0.000	0.000	0.000
**Angulogerina fluens*	0.107	0.146	0.101	0.087	0.000	0.000	0.000	0.000
**Gavelinopsis campanulata*	0.120	0.101	0.132	0.043	0.000	0.000	0.000	0.000
Rosalina columbiensis	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
**Epistominella pacifica*	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
**Epistominella vitrea*	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000
**Lobatula fletcheri*	0.347	0.289	0.348	0.304	0.000	0.000	0.000	0.000
Lobatula mckannai	0.013	0.011	0.000	0.000	0.000	0.000	0.000	0.000
Montfortella bramlettei	0.004	0.005	0.017	0.000	0.000	0.000	0.000	0.000
Dyocibicides biserialis	0.011	0.001	0.003	0.000	0.000	0.000	0.000	0.000
**Nonionella stella*	0.003	0.011	0.003	0.000	0.000	0.000	0.000	0.000
Pseudononion basispinata	0.002	0.022	0.000	0.000	0.000	0.000	0.000	0.000
Astrononion gallowayi	0.025	0.022	0.017	0.000	0.000	0.000	0.000	0.000
Pullenia salisburyi	0.003	0.011	0.003	0.000	0.000	0.000	0.000	0.000
**Buccella frigida*	0.050	0.029	0.025	0.000	0.000	0.000	0.000	0.000
**Cribroelphidium excavatum*	0.003	0.016	0.000	0.043	0.500	0.000	0.000	0.000
**Cribroelphidium subarcticum*	0.029	0.056	0.049	0.087	0.500	0.000	0.000	0.000
Elphidiella nitida	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Robertina charlottensis	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000

APPENDIX 6. Faunal List.

Due to space considerations species observed are listed in alphabetical order and only the author and year of description is indicated. In cases where the present generic designation differs from the original, the original genus name is provided in square brackets at the end.

Angulogerina angulosa (Williamson), 1858, [*Uvigerina*].
Angulogerina fluens Todd, 1948.
Astrononion gallowayi Loeblich and Tappan, 1953.
Bolivina minuta Natland, 1938.
Bolivinellina pacifica (Cushman and McCulloch), 1942, [*Bolivina acerosa* Cushman var.].
Botuloides pauciloculus Zheng, 1979.
Brizalina fragilis (Phleger and Parker), 1951, [*Bolivina*].
Brizalina subaenariensis (Cushman), 1922.
Buccella depressa Andersen, 1952.
Buccella frigida (Cushman), 1922, [*Pulvinulina*].
Bulimina inflata Seguenza, 1862.
Buliminella elegantissima (d'Orbigny), 1839, [*Bulimina*].
Cassidulina reniforme Nørvang, 1945, [*Cassidulina crassa* d'Orbigny var.].
Chilostomella oolina Schwager, 1878.
Cribroelphidium excavatum (Terquem), 1876, [*Polystomella*].
Cribroelphidium foraminosum (Cushman), 1939, [*Elphidium hughesi* var.].
Cribroelphidium subarcticum (Cushman), 1944, [*Elphidium*].
Dyocibicides biserialis Cushman and Valentine, 1930.
Elphidiella nitida Cushman, 1941.
Epistominella pacifica (Cushman), 1927, [*Pulvinulina*].
Epistominella vitrea Parker, 1953.
Euloxostomum alatum (Seguenza), 1862, [*Vulvulina*].
Euuvigerina aculeata (d'Orbigny), 1846, [*Uvigerina*].
Euuvigerina juncea (Cushman and Todd), 1941, [*Uvigerina*].
Favulina melo (d'Orbigny), 1839, [*Oolina*].
Fissurina eburnea (Buchner), 1940, [*Lagena*].
Fissurina lucida (Williamson), 1848, [*Entosolenia marginata* (Montagu) var.].
Fissurina subquadrata Parr, 1945.
Fissurina vitreola (Buchner), 1940, [*Lagena*].
Frondicularia gigas Church, 1929.
Gaudryina arenaria Galloway and Wissler, 1927.
Gavelinopsis campanulata (Galloway and Wissler), 1927, [*Globorotalia*].
Gyroidina altiformis Stewart and Stewart, 1930, [*Gyroidina soldanii* d'Orbigny var.].
Homalohedra borealis (Loeblich and Tappan), 1954, [*Oolina*].
Homalohedra cf. *H. quasilineata* Patterson, 1990.
Hyalinonetrion clavatum (d'Orbigny), 1846, [*Oolina*].
Islandiella islandica (Nørvang), 1945, [*Cassidulina*].
Islandiella norcrossi Cushman, 1933, [*Cassidulina*].
Karreriella bradyi (Cushman), 1911, [*Gaudryina*].
Lagena semilineata Wright, 1886, [*Oolina*].
Laryngosigma trilocularis (Bagg), 1912, [*Polymorphina*].
Lenticulina nikobarensis (Schwager), 1866, [*Cristellaria*].
Lobatula fletcheri (Galloway and Wissler), 1927, [*Cibicides*].
Lobatula mckannai (Galloway and Wissler), 1927, [*Cibicides*].
Marginulina pauciloculata (Cushman and Gray), 1946, [*Vaginulina advena* Cushman var.].
Metapolymorphina charlottensis (Cushman), 1925, [*Polymorphina*].
Montfortella bramlettei Loeblich and Tappan, 1963.
Nonionella digitata Nørvang, 1945, [*Nonionella turgida* (Williamson) var.].
Nonionella stella Cushman and Moyer, 1930, [*Nonionella miocenica* Cushman var.].
Nonionella cf. *N. turgida* (Williamson), 1858, [*Rotalina*].
Nonionellina labradorica (Dawson), 1870, [*Nonionina scapha* var.].
Palliolatella frangens Buchner, 1940, [*Lagena*].
Palliolatella immemora Patterson, 1990.
Parafissurina semicarinata (Buchner), 1940, [*Parafissurina lateralis* (Cushman) forma].
Patellina corrugata Williamson, 1858.
Pleurostomella delicatula Patterson, 1991.
Praeglobobulimina spinescens (Brady), 1884, [*Bulimina pyrula* d'Orbigny subsp.].
Procerolagena amphoriniformis (McCulloch), 1977, [*Lagena*].
Procerolagena complurecosta (Patterson), 1990, [*Lagena*].
Procerolagena gracilis (Williamson), 1848, [*Lagena*].
Procerolagena meridionalis Wiesner, 1865, [*Lagena gracilis* Williamson, var.].
Procerolagena simulampulla Patterson, 1991.
Procerolagena wiesneri Parr, 1950, [*Lagena striata* (Montagu) var.].
Protoglobobulimina elongata (d'Orbigny), 1826, [*Bulimina*].
Protoglobobulimina pupoides (d'Orbigny), 1846, [*Bulimina*].
Pseudononion basispinata (Cushman and Moyer), 1930, [*Nonion pizarrensis* Berry var.].
Pullenia salisburyi R. E. and K. C. Stewart, 1930.
Pygmaeoseistron hispidum (Reuss), 1863, [*Lagena*].
Pytine petaloskelis Patterson and Richardson, 1988.
Robertina charlottensis (Cushman), 1925, [*Cassidulina*].
Rosalina columbiensis (Cushman), 1925, [*Discorbis*].
Seabrookia earlandi Wright, 1891.
Spirosigmoilina tenuis (Czjzek), 1848, [*Quinqueloculina*].
Stainforthia sp.
Trochammina nana (Brady), 1881, [Haplophragmium].