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LATE QUATERNARY PALEOCEANOGRAPHIC CHANGES IN DIXON ENTRANCE, NORTHWEST BRITISH COLUMBIA, CANADA: EVIDENCE FROM THE FORAMINIFERAL FAUNAL SUCCESSION

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ABSTRACT

Late glacial and Holocene foraminiferal stratigraphy of 7 piston cores from Dixon Entrance on the Pacific coast of Canada yielded 11 biofacies defined in part by cluster analysis and in part by the percentage of temperate species. Temperate species are defined as those that are not reported to be living north of the southern Bering Sea. It is possible to define three phases in the latest Wisconsinan deglaciation based on the percentage of temperate species: the glacial phase with 0 to 5% temperate species, the transitional phase with 5 to 20%, and the temperate phase with more than 20%. Assemblages dominated by *Epistominella vitrea* and *Cassidulina reniforme* characterize the oldest, "glacial" deposits (14,000–12,900 BP). Younger sediments have substrate-influenced assemblages. Muddy "transitional" deposits (12,900–10,500 BP) are dominated by the same species as the glacial material, but the coarser sediments are dominated by the attached form *Lobatula fletcheri.* The most abundant species in muddy "temperate" deposits (<10,500 BP) is either *Epistominella pacifica* or *Nonionella stella.* Coarse sediments of the same age are numerically dominated *L. fletcheri,* and also contain temperate species of the genus *Islandiella.* Compared to Queen Charlotte Sound further south, Dixon Entrance had generally more open marine conditions due in part to the greater depth that facilitated shoreward advection of warmer and more saline deep waters as part of an intense estuarine circulation driven by glacial melt.

INTRODUCTION

Several paleoceanographic studies of late Quaternary cores carried out on the British Columbia continental shelf in recent years (Mathewes and others, 1993; Patterson, 1993; Patterson and others, 1995) have improved understanding of the paleoceanographic history of that region. An important outcome of those studies was recognition that the Pacific coast of Canada had undergone drastic cooling between ~11,000 and 10,000 years BP, coeval with the Younger Dryas cold episode in the North Atlantic region. Hence, the Younger Dryas episode may have been a hemispheric or global phenomenon, rather than a regional North Atlantic one as previously supposed.

Located north of the Queen Charlotte Islands on the British Columbia Shelf (Fig. 1), Dixon Entrance is an east–west trending bathymetric trough up to 450 m deep (Conway and Barrie, 1994). Dixon Entrance is floored by Quaternary sediments underlain by Tertiary marine and non-marine sedimentary rocks of the Skonun Formation (Sutherland Brown, 1968). Surficial geologic mapping of the coastal and nearshore areas began in 1984 and examination of deeper water portions of the Entrance began in 1988 (Conway and Barrie, 1994). This paper is based on foraminiferal analysis of several piston cores taken during those studies with the purpose of: 1) increasing our general knowledge of the late Quaternary paleoceanographic history of the west coast of Canada, 2) determining whether Younger Dryas cooling is recognizable further north on the British Columbia shelf, and 3) providing data to assist in determination of the depositional history of the area.

LITHOSTRATIGRAPHIC FRAMEWORK

Based on analysis of a large number of cores and 2,130 km of acoustic data collected on four cruises between 1988 and 1994, Barrie and Conway (1993) have developed a late Quaternary lithostratigraphic or "lithoacoustic" framework that allows correlation despite the limited number of ^{14}C dates; this framework is a northward extension of the lithostratigraphic scheme set up by Luternauer and others (1989) for Queen Charlotte Sound and employs the same unit nomenclature (Table 1). Lithoacoustic Unit A of Barrie and Conway (1993), a glacial marine clay with ice-rafted stones, was deposited between 14,000 and 12,900 BP when the ice front was in the waters of Dixon Entrance. Lithoacoustic Unit B_2 (Units B_1 and B_3 of Luternauer and others [1989] are not found in Dixon Entrance) consists of sand, gravel, and sandy gravelly muds deposited between 12,900 and 10,500 BP. Deposition took place during a period of reduced water depths in the area caused by the combined effects of eustacy and landward movement of the glacial forebulge following early retreat of the main glacial ice from the coastal area. However, glaciers probably were still in contact with the sea at the heads of fjords. According to the results of Barrie and Conway (1993), water depths at the sites where Unit B_2 was sampled probably were never less than 100 m; despite this, redeposition of marine sediments was common during that interval, as suggested by the abundance of B_2 sands and gravels in the region. Lithoacoustic Unit C, overlying B_2, is of variable composition and consists of laminated or bioturbated massive mud and sandy mud and sandy and gravelly sediments (possibly lags). Unit C was deposited during the Holocene, under temperate conditions after water depths had increased to near modern values.

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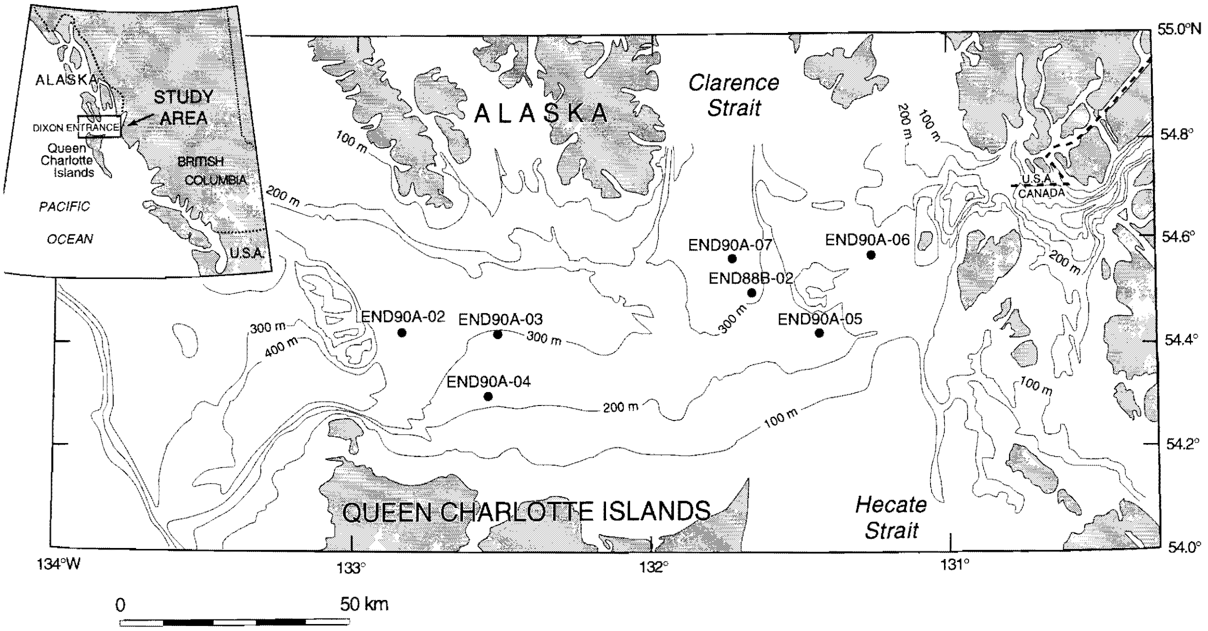

FIGURE 1. Map of Dixon Entrance showing core locations and depth contours (reproduced from Conway and Barrie, 1994).

WEST COAST PALEOCEANOGRAPHIC REGIME

Paleoceanographic data have been much more difficult to interpret on the Pacific coast than on the Atlantic coast of Canada. On the Atlantic coast, widespread, sudden changes in the stratigraphic distribution of foraminiferal faunas accompany climatic shifts. On the Pacific coast, climatic changes are accompanied by more subtle, locally gradual changes in foraminiferal faunas delineated most clearly by the use of cluster analysis and of the proportion of species of temperate origin (Patterson and others, 1995). At the present time on the Atlantic coast, areas and depth intervals under the influence of West Atlantic Water (WAW), whether in the Gulf of St. Lawrence or on the Scotian Shelf, primarily host species of temperate origin (e.g., *Bulimina aculeata* and *Bolivina subaenariensis*). On the other hand, areas influenced by the Labrador Shelf Water (LSW), of more northerly origin, are inhabited by more arctic-tolerant forms (e.g., *Islandiella islandica, I. helenae, Eggerella advena* and *Adercotryma glomerata*) (Vilks, 1968; Rodrigues and Hooper, 1982; Williamson and others, 1984). Atlantic coast shelf waters are stratified with the less dense LSW overlying the WAW with a transitional zone in-between. This stratification has led to rather sharp faunal changes in the postglacial record, in particular the passage to the *Bulimina-Bolivina* assemblage (PGS zone of Rodrigues and others, 1993; unpublished data of Guilbault concerning the shelf south of Newfoundland) marking the establishment of the WAW over the deeper parts of the Gulf of St. Lawrence.

TABLE 1. Summary of Late-Glacial and Postglacial lithofacies in Dixon Entrance and Queen Charlotte Sound.

Litho-acoustic unit	Dixon Entrance (Barrie and Conway, 1993)	Queen Charlotte Sound (Luternauer and others, 1989)
C	Bioturbated and laminated mud. Also, sands and gravels (lag deposits)	Olive colored clay-rich mud
B_3	Absent	Dark grey to olive grey, laminated to massive mud without dropstones
B_2	Gravelly and muddy sand	Shelly, sandy muds; some muddy sand
B_1	Absent	Dark grey to olive grey, laminated to massive mud without dropstones
A	Glaciomarine mud with ice-rafted gravel	Dark grey laminated to massive sandy mud with dropstones

By contrast, oceanographic conditions on the Pacific coast are characterized by upwelling events that modify the coastal stratification (Thomson, 1981). Examination of the late Glacial to Recent faunal succession from the Pacific shelf of Canada indicates that a certain number of temperate foraminiferal species were present through the entire sampled interval (up to 14,000 BP), although their numbers were low during the coldest phases. This continuous occurrence results from the upwelling of deep (200–500 m), warmer and more saline water of the northward-flowing California Undercurrent (cf. Hickey, 1979; Huyer, 1983) onto the shelf that partially offsets any atmospheric climatological effects (Patterson and others, 1995). Thus, no interpretation of the paleoceanographic history of that region is possible without taking into consideration the effects of deep onshore water transport.

The impact of onshore transport of deep upwelled water can be seen clearly in the distribution of neritic foraminifera along the entire Pacific coast of North America. Despite considerable geographic distances, only three major faunal provincial boundaries have been recognized between Panama and the Aleutian Islands: at Juan de Fuca Strait, at Point Conception, and at the southern tip of Baja California (Culver and Buzas, 1985, 1986; Buzas and Culver, 1990). Furthermore, in contrast to what Culver and Buzas (1980) observed on the Atlantic shelf of North America, none of the

Pacific coast provincial boundaries are sharp and considerable faunal overlap exists. We believe that this overlap is caused in part by summertime upwelling that pumps deep warm water carried northward by the California Undercurrent onto the continental shelf (Thomson, 1981; Patterson and others, 1995). Warmer water is also carried northward at depth in winter by the wind-driven Davidson Current, but downwelling conditions then prevail along the coast. The ameliorating effect of summertime upwelling is probably the reason why changes in water temperature during deglaciation are more gradual here than along the Atlantic coast.

The distribution of water masses, and particularly the impact of upwelling on the shelf, is strongly influenced by the positioning of atmospheric high- and low-pressure systems. At present, the climate in the northeastern Pacific is dominated by the North Pacific High (clockwise flowing winds) in summer and the Aleutian Low (counterclockwise winds) in winter (Kendrew and Kerr, 1955; Thomson, 1981). The dynamics of these winds result in Ekman transport that produces upwelling in summer and downwelling in winter. At the present time, the Pacific High is dominant in summer (COHMAP, 1988), resulting in an overall annual upwelling effect that brings more warm California Undercurrent flow onto the shelf. However, during colder intervals (the Younger Dryas and the glacial phase corresponding to Lithoacoustic Unit A), the climate of the region was dominated by the Aleutian Low (COHMAP, 1988), resulting in a net annual downwelling that blocked much of the warming influence of the California Undercurrent. This alternating upwelling-downwelling situation must have been established long before the last glaciation, resulting in the formation of extensive laminated diatomites as far back as the Miocene in California (Douglas, 1981).

At present, the California Undercurrent does not appear to extend north of Queen Charlotte Sound and neither does summertime upwelling. At the latitude of Dixon Entrance, onshore Ekman transport is dominant. However, onshore transport of deep shelf-upper slope water (upwelling) exists as a consequence of estuarine circulation. This estuarine circulation results from the shape of the sounds and inlets in combination with strong vertical tidal mixing; this is true in Dixon Entrance as it is also further south in Juan de Fuca Strait (Thomson, 1994).

MATERIAL AND METHODS

One-hundred eleven samples were examined from seven piston cores (END 88B-02, END 90A-02, END 90A-03, END 90A-04, END 90A-05, END 90A-06, END 90A-07; Fig. 1, Table 2 and Appendix 1). These cores were collected in water depths ranging from 130 to 394 m, and they vary in length from 80 cm to 670 cm. In addition, it was possible to examine undisturbed surface sediments in gravity pilot cores recovered at four sites: END 90A-04, END 90A-05, END 90A-06, and END 90A-07. The ca. 20 cm^3 samples, each representing 2 to 3 cm of core length, were sieved using a 63 μm screen (No. 230 Tyler mesh). Foraminifers were concentrated using heavy liquids, either dibromoethane+methanol (density: 1.9) or a solution of sodium polytungstate (density: 2.31). As foraminiferal recovery was complete using both methods, the difference in heavy liquid density did not cause sample biasing. The concentrated fossil residue was then split into aliquots with a microsplitter until a fraction manageable for counting was obtained. Fractions bearing 500 or more specimens were considered large enough to provide a reliable estimate of the frequency of important species (Patterson and Fishbein, 1989). For samples from which counts of ca. 300 or less were obtained (see Appendix 1), all specimens were counted. All samples were found to have statistically significant populations, although some (e.g., the 358–360 horizon of core END 90A-07 with 63 counts) were of marginal statistical quality.

TABLE 2. Latitude, longitude and water depth of cores examined for this study.

Core	Bathymetric depth of core (m)	Latitude (N)	Longitude (W)
END88B-02	319	54°30.16′	131°39.70′
END90A-02	389	54°25.24′	132°50.10′
END90A-03	277	54°25.02′	132°30.71′
END90A-04	254	54°18.89′	132°32.96′
END90A-05	282	54°25.25′	131°29.16′
END90A-06	130	54°35.02′	131°16.43′
END90A-07	394	54°34.92′	131°43.07′

A total of 204 taxa of benthic foraminifera were identified (Appendix 2). The percent error for each species in each sample was calculated using the standard error equation (S_{x_i}):

$$S_{X_i} = 1.96\,[X_i(1 - X_i)/N]^{1/2}$$

where N is the total number of specimens in a sample, and X is the fractional abundance of a given species (formula developed by Patterson and Fishbein, 1989). Only 46 species occurred in statistically significant populations[5] in at least one sample.

Q-mode cluster analysis of the data utilized a technique documented to closely emulate the results of a statistically significant "error-weighed maximum likelihood" clustering method developed by Fishbein and Patterson (1993). This method requires that only species present in statistically significant populations be analyzed. Cluster analysis was applied to the 46 statistically significant species using SYSTAT (SYSTAT, 1992). Euclidean distance correlation coefficients were used to measure similarity between pairs of species, and Ward's linkage method was utilized to arrange sample pairs and sample groups into a hierarchic dendrogram.

In this paper, reference is made to 8 accelerator mass spectrometry (AMS) radiocarbon ages (Table 3) originally published by Barrie and Conway (1993). The ages were corrected for reservoir effect (−730 yr.) using the wood/shell pair data of Southon and others (1990). The corrected values are used throughout the paper.

TEMPERATE SPECIES AS PALEOCEANOGRAPHIC INDICATORS

Patterson and others (1995) demonstrated that oceanographic conditions along the Pacific coast of North America require that the proportion of temperate species be used to estimate paleoceanographic temperature regimes under

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[5] A population is considered statistically significant if species percentage is greater than standard error plus 1%.

TABLE 3. Radiocarbon dates on shell and wood material extracted from Dixon Entrance cores.

Core	Depth in core (cm)	Lithologic unit	Radiocarbon age (14C yr BP)[1]	Corrected radiocarbon age (yr BP)[2]	Laboratory number[3]	Dated material
END88B-02	77	B_2	11,200 ± 90	10,470	TO-2251	Serpulid tube[4]
END90A-02	108	B_2	12,830 ± 110	12,100	TO-2252	*Chlamys rubida*
END90A-02	309	B_2	13,270 ± 100	12,540	TO-2253	*Nuculana fossa*
END90A-04	253	C	10,490 ± 80	9760	TO-4361	*Yoldia thraciaeformis*
END90A-04	543	C	10,450 ± 90	9720	TO-2254	*Yoldia thraciaeformis*
END90A-06	130	C	2170 ± 60	1440	TO-2255	*Compsomyax subdiaphana*
END90A-07	411	C	3770 ± 70	3020	TO-2256	Shell fragments
END90A-07	534	B_2	10,580 ± 90	10,580[5]	TO-2257	Twig

[1] Laboratory-reported error terms are 1 σ. Age corrected to $\delta^{13}C = -25.0‰$ PDB.

[2] Date correction of −730 years applied to marine material based on Southon and others (1990).

[3] TO: IsoTrace (University of Toronto).

[4] Probably displaced.

[5] No correction on wood material.

which a given sample has been deposited. Much of our paleoenvironmental evaluation rests on the reliability of our temperate species determinations (Appendix 2). To assist with this aim, we prepared an inventory of "arctic" species, i.e., those species that have been reported in the literature to be living from the middle of the Bering Sea northward (Patterson and others, 1995); a species is considered "temperate" if it is absent from that inventory. Species occurring in very small numbers are not taken into consideration; this includes all unilocular species. For this paper, we have moved the "arctic"/temperate boundary from the Aleutian Islands (as proposed by Patterson and others, 1995) to the middle of the Bering Sea, because we now know that *Nonionella stella,* a common temperate species, occurs as far north as the Pribilof Islands (Brouwers and McDougall, 1984). The southern Bering Sea around the Pribilofs is too warm to be considered "arctic", or even "subfrigid" (Fig. 2), with temperatures at 25 m depth of 0–1°C in winter and 7–8°C in summer. Furthermore, winter ice cover does not reach the Pribilofs even in April, when it is the most extensive (Anonymous, 1974; less detailed but corroborative data [depth: 10 m] can be found in Barkley, 1968). In contrast, temperatures at 25 m in the northern Bering Sea around St. Lawrence Island are below −1°C in February and about 2°C in August. Therefore, the northern Bering Sea qualifies as "arctic" water, and the southern Bering Sea is better described as cold temperate.

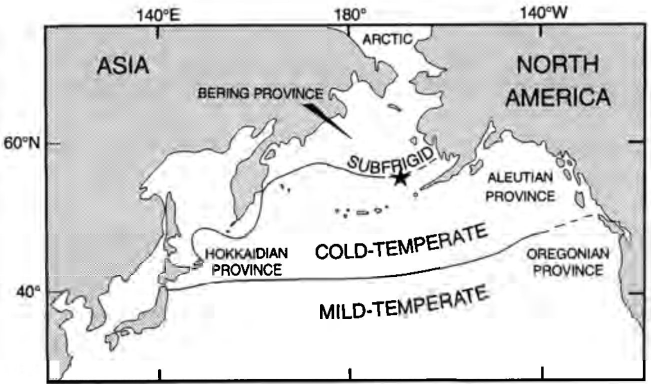

FIGURE 2. Map of the Bering Sea showing the limit between cold temperate and subfrigid marine climates, according to the U.S. Navy, Chief of Naval Operations (1977). Star indicates position of Pribilof Islands. Redrawn from Brouwers and McDougall (1984).

For the rest of this paper, we shall consider samples containing 20% or more temperate species as "temperate", that is indicative of deposition under temperate conditions similar to those prevailing today in the study area, if not warmer. This arbitrary cut-off was chosen following analyses of foraminiferal samples from the Holocene Lithoacoustic Unit C, which was deposited under the same oceanographic regime as that prevailing in the region today (Luternauer and others, 1989). Temperate species represent no less than approximately 20% of the counted specimens in any sample from Unit C. Modern bottom temperatures in western Dixon Entrance, reported by Thomson and others (1988) at 200 m depth, are slightly above 6°C in summer and somewhat below 7°C in winter. At the other extreme, samples from Lithoacoustic Unit A contain no more than 5% temperate species and correspond to temperatures that are between −2.5 and 3°C year-round, similar to those in the modern northern Bering Sea or further north. Thus, we regard as "arctic" or "glacial marine" any sample containing less than 5% temperate species. Samples containing between 5 and 20% temperate species, which belong neither to the "glacial marine" nor to the "temperate" categories, are considered representative of "transitional" water temperatures. "Transitional" faunas typically occur in Lithoacoustic Unit B_2 in Dixon Entrance, and are comparable to the B_1 samples from Queen Charlotte Sound (Patterson and others, 1995).

RESULTS

CLUSTER ANALYSIS

Q-Mode Cluster analysis subdivided the samples into five groups that we term the Green, Orange, Blue, Red and Yellow Clusters, respectively (Fig. 3). The content of the clusters are briefly described, followed by more detailed descriptions of the contained biofacies.

The Green Cluster (27 samples) is dominated by *Epistominella vitrea,* which accounts for 13 to 63% of the population. The other common species are *Stainforthia feylingi, Cassidulina reniforme, Cribroelphidium excavatum, Nonionellina labradorica* and, locally, *Siphonaperta stalkeri, Islandiella helenae, Angulogerina fluens, Buccella frigida* and *Lobatula fletcheri.*

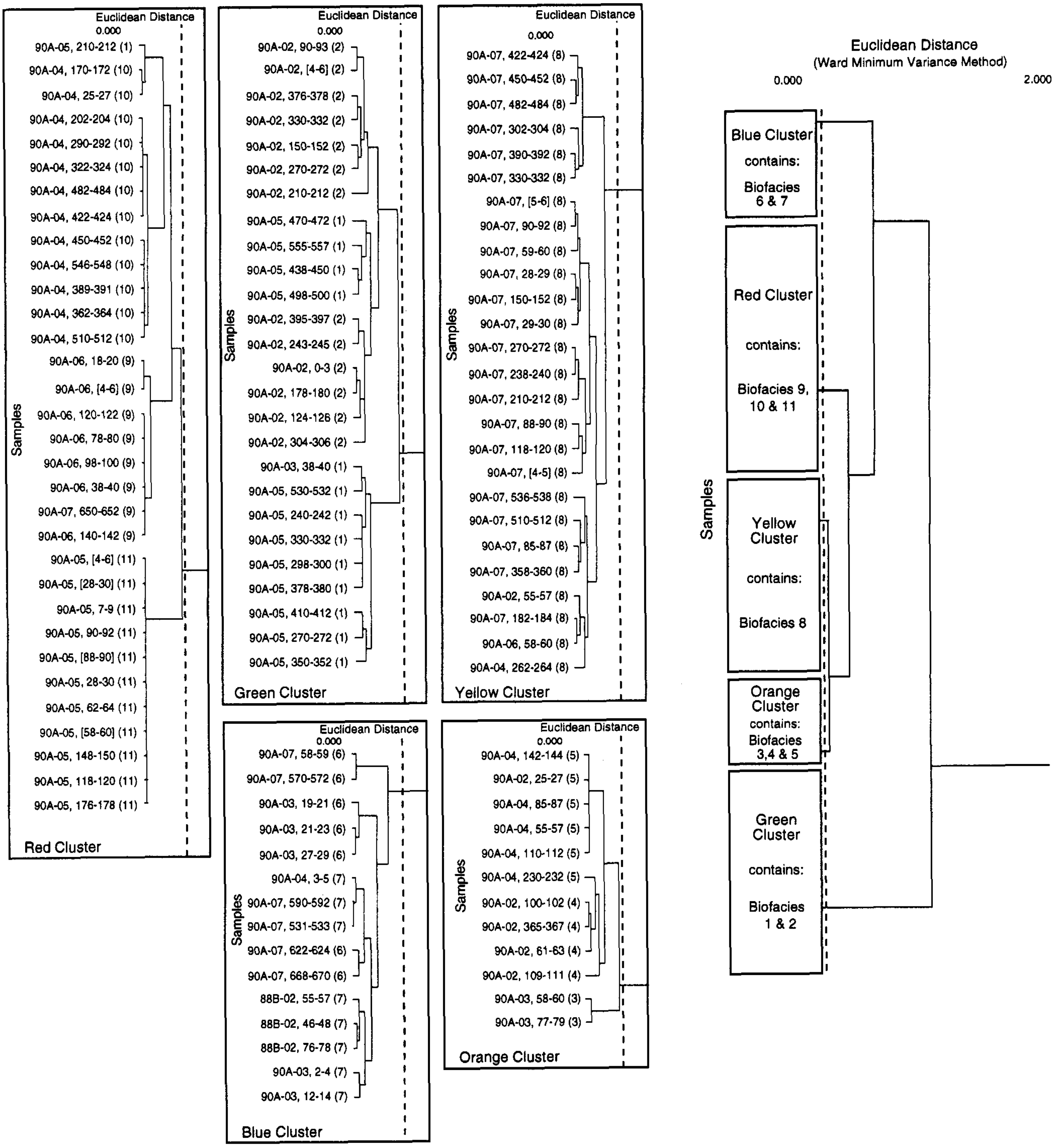

FIGURE 3. Q-Mode dendrogram showing the 111 samples containing statistically significant numbers of specimens from the Dixon Entrance cores. Clusters of samples with correlation coefficients greater than the level indicated by the dashed line were given conventional color names and were subsequently subdivided into biofacies on the basis of their temperate species content. Due to scaling problems associated with the large number of samples involved, an enlargement of each cluster is illustrated. Each sample is indicated by the core and sample depth in cm, and the biofacies is indicated within parentheses. Sample horizons collected from pilot cores are indicated by square brackets.

The Orange Cluster (12 samples) is controlled by *Cassidulina reniforme* (12 to 73% of the assemblage). Other frequently occurring species include *Cribroelphidium excavatum, E. vitrea, A. fluens, L. fletcheri* and a variable number of *Epistominella pacifica.*

All 15 samples of the Blue Cluster are numerically dominated by *L. fletcheri* (20 to 76%). Less abundant species found in this cluster include *C. excavatum, Cribroelphidium hallandense, E. vitrea, Bolivina decussata, C. reniforme* and *Lobatula mckannai.*

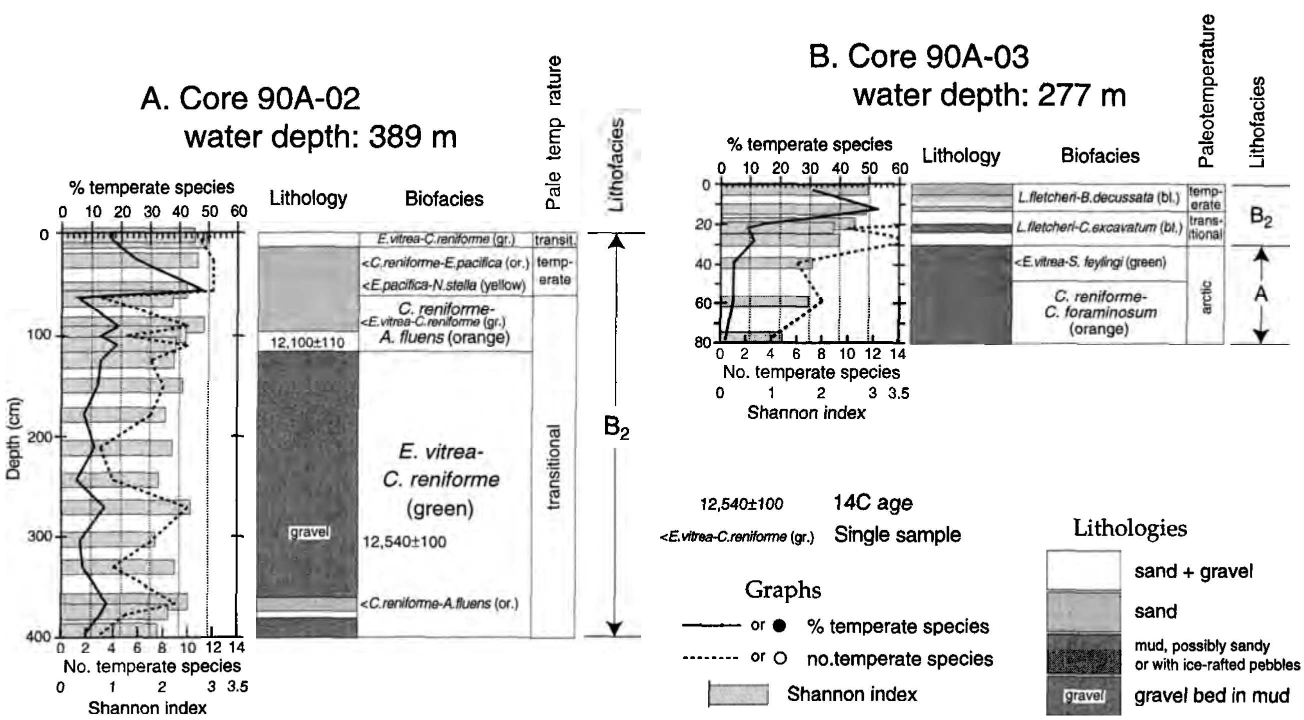

FIGURE 4. Stratigraphic section showing lithostratigraphy, biofacies distribution, ^{14}C dates, Shannon Index, and percent and number of temperate species in: A. core 90A-02 and B. core 90A-03. Biofacies names preceded by a "<" refer to single sample occurrences, whereas biofacies names placed in the middle of the Biofacies column mean that more than one sample of the given biofacies were observed in succession. The "<" indicates the exact level of the single sample occurrence.

The most abundant species contained within the Yellow Cluster (26 samples) are *E. pacifica* (4–40%), *Nonionella stella* (2–34%) and, to a lesser degree, *C. reniforme* (1–26%). The sum of *E. pacifica* and *N. stella* makes up from 16 to 51% of the assemblage. Less frequent species include *Euuvigerina juncea, B. decussata* and *B. frigida.* Locally, *L. fletcheri, C. excavatum, Euloxostomum alatum* and *Laevidentalina pauperata* are important.

The Red Cluster (31 samples) includes assemblages of various composition whose more common species are (not in order of abundance) *C. excavatum, L. fletcheri, B. decussata, B. frigida, Buliminella elegantissima, E. vitrea, S. feylingi, E. pacifica, C. hallandense and C. reniforme.* Faunal dominance is low: less than 27% in all but one sample and in most instances, less than 20%. The frequency of *L. fletcheri* is never as high as in the Blue Cluster and that of *E. pacifica* and *N. stella,* always less than the Yellow Cluster.

Three of the above clusters owe their existence to the numerical dominance of a single abundant species: the Orange Cluster (*C. reniforme*), the Blue Cluster (*L. fletcheri*) and the Green Cluster (*E. vitrea*). In contrast, the Red Cluster comprises many low-frequency species occurrences while the Yellow Cluster is made up of an assemblage of relatively uniform composition including two co-dominant species.

BIOFACIES DESCRIPTION

Visual inspection of the data reveals that within a given cluster the temperate species content of some samples may be less than 5% ("arctic"), 5 to 20% ("transitional"), or more than 20% ("temperate"). For that reason, the biofacies described below are defined by splitting the above clusters on the basis of the temperate species content. Biofacies distribution within each core, percentage of temperate species, Shannon Index variations, and radiocarbon ages are summarized on Figures 4–6.

Examination of the Green Cluster reveals the existence of two contained biofacies: the cold water "glacial marine" *E. vitrea-S. feylingi* Biofacies (1), and the "transitional" water temperature *E. vitrea-C. reniforme* Biofacies (2).

E. vitrea-S. feylingi Biofacies (1)

The eleven samples of this "glacial marine" biofacies occur in stony muds and clays from core END 90A-05 below 200 cm and core END 90A-03 at 39 cm. The faunal makeup of the sample from the 210–212 cm level in core 90A-05 indicates that it should be included in this biofacies even though it belongs to the Red Cluster. *Epistominella vitrea* makes up 37 to 61% of the Biofacies (1) assemblage except in two samples where its abundances are 23 and 26%. Other important species include *S. feylingi, C. reniforme,* and *N. labradorica.* The proportion of temperate species never exceeds 4.6%, and in most cases remains below 1%. The Shannon Index[6] is also low, even for an arctic environment (see Discussion), varying from 1.32 to 2.03. This biofacies is similar to Biofacies 5 of Patterson and others (1995) from core 84B-10 in Queen Charlotte Sound

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[6] The Shannon Index H(S) is defined as: $H(S) = -\Sigma p_i \cdot \ln p_i$ where p_i is the proportion of the ith species in the assemblage.

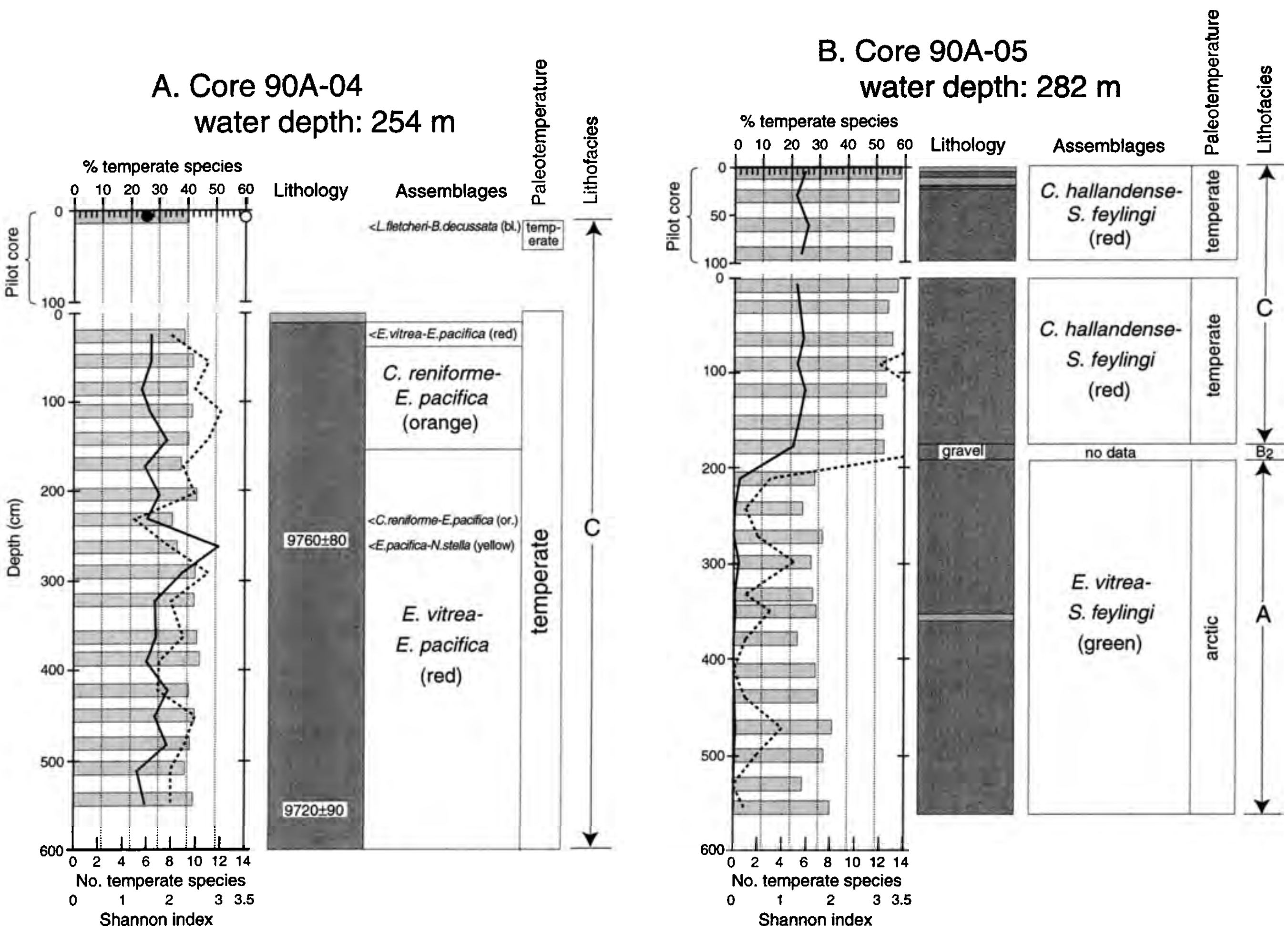

FIGURE 5. Stratigraphic section showing lithostratigraphy, biofacies distribution, ^{14}C dates, Shannon Index, and percent and number of temperate species in: A. core 90A-04, and B. core 90A-05.

based on the dominance of *E. vitrea.* However, it differs by its lower temperate species content.

E. vitrea-C. reniforme Biofacies (2)

The 13 samples of sandy muds containing this "transitional" temperature biofacies occur through most of core END 90A-02, except the uppermost part. *Epistominella vitrea* varies from 13 to 47% of the assemblage and other common species (*C. reniforme, C. excavatum* and *N. labradorica*) do not differ much from proportions observed in the *E. vitrea-S. feylingi* Biofacies (1). The significant difference between the two biofacies in the Green Cluster is the higher proportion of temperate species in the *E. vitrea-C. reniforme* Biofacies (2) (5.1 to 19%). The Shannon Index (1.86 to 2.87) is also higher in this biofacies.

The Orange Cluster can be subdivided into three biofacies that grade into each other: the "glacial-marine" *C. reniforme-Cribroelphidium foraminosum* Biofacies (3), the "transitional" *C. reniforme-A. fluens* Biofacies (4), and the "temperate" *C. reniforme-E. pacifica* Biofacies (5).

C. reniforme-C. foraminosum Biofacies (3)

This "glacial marine" biofacies, which occurs in sandy muds and sands in only two samples at the bottom of core END 90A-03, consists of 57 to 73% *C. reniforme,* accompanied by lesser proportions of the secondary species *C. foraminosum* (ca. 9%), *E. vitrea* (1 to 9%) and *C. excavatum* (6 to 7%). Values of the Shannon Index are 1.73 and 1.22, and the percentages of temperate species are 4.2 and 2.0, respectively.

C. reniforme-A. fluens Biofacies (4)

The four sandy mud samples of this "transitional" biofacies, present in core END 90A-02 below 60 cm, contain 19 to 34% *C. reniforme.* Faunal composition is irregular with secondary species including variable proportions of *L. fletcheri, A. fluens, C. excavatum, C. foraminosum, E. vitrea, E. pacifica* and *B. frigida.* The Shannon Index varies from 2.2 to 2.5 and the proportion of temperate species, from 6 to 18%.

C. reniforme-E. pacifica Biofacies (5)

This "temperate" biofacies is found in five samples in the upper part of core END 90A-04 and in one sample near the top of core END 90A-02. This biofacies is dominated by *C. reniforme* (16–28%) with the second most important species being *E. pacifica.* Other species present in order of decreasing abundance are: *C. excavatum, E. vitrea, A.*

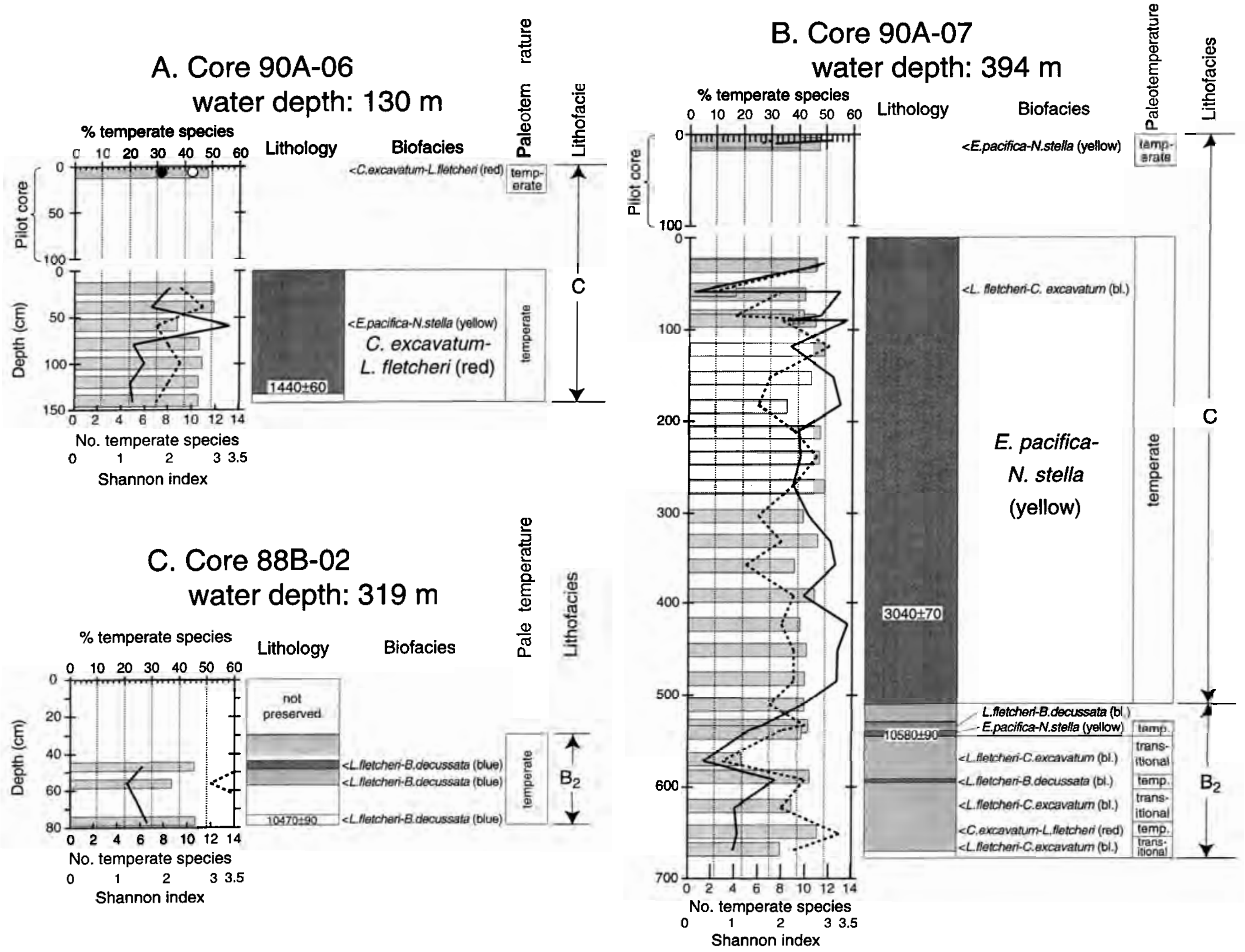

FIGURE 6. Stratigraphic section showing lithostratigraphy, biofacies distribution, ^{14}C dates, Shannon Index, and percent and number of temperate species in: A. core 90A-06, B. core 90A-07, and C. core 88B-02.

fluens, S. feylingi, L. fletcheri and *N. stella.* The Shannon Index varies from 2.32 to 2.79 and proportions of temperate species range from 24 to 33%.

The Blue Cluster groups samples of transitional and temperate origin having the cosmopolitan attached form *L. fletcheri* as their main component. This cluster is found in sand, gravelly sands, and muds rich in sand and gravel. We have split the blue cluster into two biofacies: the transitional *L. fletcheri-C. excavatum* Biofacies (6) and the temperate *L. fletcheri-B. decussata* Biofacies (7).

L. fletcheri-C. excavatum Biofacies (6)

In the seven samples of mostly coarse sediment containing the "transitional" *L. fletcheri-C. excavatum* Biofacies (6), the most important species after *L. fletcheri* (25–76%) are *C. excavatum* and *C. hallandense.* The proportion of temperate islandiellids (*Islandiella californica, I. limbata, I. tortuosa*) is low, making up less than 2% of the total fauna (Appendix 1). Temperate islandiellids are large and constitute an important fraction of the foraminiferal biomass on many parts of the Pacific North American continental shelf (Bergen and O'Neil, 1979; Douglas, 1981; Culver and Buzas, 1985, 1986; Patterson and others, 1990). Therefore, they deserve attention even when their numbers are small. The abundance of temperate forms varies from 6 to 18% and the Shannon Index from 1.13 to 2.65. A single sample (at 58–59 cm depth in core 90A-07) containing only 2% temperate species yielded only 98 specimens and so has marginal statistical significance. In addition, it lies inside a succession of late Holocene muds with a faunal content typical of the Yellow Cluster. This anomalous sample does not justify the designation of a cold *L. fletcheri* biofacies.

L. fletcheri-B. decussata Biofacies (7)

The second Blue Cluster biofacies, the *L. fletcheri-B. decussata* Biofacies (7), occurs in eight samples with coarse sediments. After *L. fletcheri* (28–47%), the most abundant taxon of this biofacies is *B. decussata.* The proportion of temperate species (21 to 53%) is much higher than in the "transitional" *L. fletcheri-C. excavatum* Biofacies, and temperate islandiellids make up 7 to 13% of the assemblage. The Shannon Index is also higher than in the other *L. fletch-*

eri-dominated biofacies, ranging from 2.17 to 2.90. The distinction between biofacies 6 and 7 is minor and of a gradational nature because both are numerically dominated by the same attached species, *L. fletcheri.* For example, in core END 90A-03 the "transitional" *L. fletcheri-C. excavatum* Biofacies (6) is overlain by the "temperate" *L. fletcheri-B. decussata* Biofacies (7) with no accompanying change in sedimentary regime. Unfortunately, some assemblages referable to both of the *Lobatula*-dominated biofacies, namely those found in clean sands, are of limited value for paleoenvironmental reconstruction because they may have been reworked and modified, sorted, or contaminated by sedimentary transport. The overwhelming dominance of the cosmopolitan species *L. fletcheri* (over 70% in some samples) also limits the paleoecological utility of these biofacies as little space is left for temperate species.

E. pacifica-N. stella Biofacies (8)

The Yellow Cluster consists of only the *E. pacifica-N. stella* Biofacies (8) and includes 26 samples. As outlined in the Yellow Cluster description, this biofacies inhabits muddy substrates and is dominated by *E. pacifica, N. stella,* and occasionally *C. reniforme.* This biofacies is entirely "temperate" as temperate species make up 38 to 58% of the assemblages (except for 23% in one sample). The Shannon Index varies from 2.09 to 2.89. Twenty-three of the samples constituting this biofacies come from massive muds in the upper part of core END 90A-07, the deepest core in terms of modern water depth (394 m). Because of its greater depth, this site was least exposed to surface climatic variations and most exposed to upwelling of warmer upper slope water. The three remaining samples attributable to this biofacies are scattered over three cores. One of these samples comes from Unit B_2 (upper core END 90A-02) but, because it is a sand, it may have been redeposited; the other two samples come from sandy muds.

The Red Cluster may be subdivided into three "temperate" biofacies: the *C. excavatum-L. fletcheri* Biofacies (9), the *E. vitrea-E. pacifica* Biofacies (10), and the *C. hallandense-S. feylingi* Biofacies (11). Biofacies 9 and 11 occur primarily in sandy muds whereas Biofacies 10 is observed in massive mud. These three biofacies are intermediate in composition between the Blue Cluster *L. fletcheri-B. decussata* Biofacies (7) and the Yellow Cluster *E. pacifica-N. stella* Biofacies (8). One of the "red" biofacies is richer in *L. fletcheri* whereas another is richer in *E. pacifica.* All three are characterized by approximately the same set of species in varying proportions and all three are temperate. Each occurs in only one core and it is likely that additional coring would have shown intergradation between them.

C. excavatum-L. fletcheri Biofacies (9)

In addition to high proportions of *C. excavatum* and *L. fletcheri,* the eight samples making up this biofacies contain significant percentages (on the average, more than 4%) of *B. elegantissima, B. frigida* and *C. hallandense.* The most common temperate species is *N. stella* (averaging 3.3%) and overall temperate species make up 18 to 35% of the fauna. The Shannon Index varies from 2.21 to 2.96. All samples but one come from the sandy muds and muddy sands of core END 90A-06, which represent the late Holocene part of Lithoacoustic Unit C. The exception is a sample from the 650–652 cm level of core 90A-07. This sample contains 18% temperate species, less than the 20% required for temperate conditions; we don't think it justifies the designation of an additional biofacies. Furthermore, it comes from sands of Lithoacoustic Unit B_2 which may have been modified by reworking.

E. vitrea-E. pacifica Biofacies (10)

This biofacies consists of 12 samples characterized by an assemblage of several species of comparable abundance, most notably *E. vitrea, B. elegantissima, L. fletcheri, E. pacifica, S. feylingi* and *B. decussata.* The temperate species content varies from 22 to 38%, and the Shannon Index from 2.52 to 2.95. This biofacies occurs only in core END 90A-04, in one sample at 25–27 cm and the rest found below 170 cm. The lithology is slightly sandy massive mud.

C. hallandense-S. feylingi Biofacies (11)

The third biofacies of this grouping coincides with the lower arm of the Red Cluster in the dendrogram (Fig. 3). It is found only in the 11 samples that compose the upper 177 cm of core 90A-05, and in the associated pilot core. The faunal composition varies little from sample to sample and the main species are, in decreasing order of abundance, *C. hallandense, S. feylingi, B. frigida* and *C. reniforme.* Temperate species make up 21 to 26% of the assemblages with a Shannon Index varying from 3.1 to 3.4, the highest value for any biofacies.

DISCUSSION

RECOGNITION OF BIOFACIES USEFUL IN PALEOENVIRONMENTAL INTERPRETATION

The Green Cluster *E. vitrea-S. feylingi* Biofacies (1) and the Orange Cluster *C. reniforme-C. foraminosum* Biofacies (3), as indicated by their low proportion of temperate species, represent cold, glacially influenced water. These biofacies constitute the first documentation of foraminifera from the glacial marine Lithoacoustic Unit A. Both biofacies are characterized by the complete absence of arenaceous specimens, which is typical of modern as well as fossil glacial marine (≠ modern arctic shelf) deposits and may be due to postmortem disintegration or dissolution (Elverhøi and others, 1980).

The faunal makeup of the *E. vitrea-S. feylingi* Biofacies (1) is unusual in that an *E. vitrea*-dominated assemblage has not been reported from glacial marine deposits elsewhere. We attribute this to the deep shelf setting of Lithoacoustic Unit A and its contained fauna. To date, foraminiferal assemblages from deep (>200 m) glacial marine open seas have been poorly sampled. Previously described glacial marine sediments exposed above sea-level were typically deposited in hyposaline settings frequently dominated by elphidiids or cassidulinids. Glacial marine sediments deposited on continental shelves off eastern Canada may also contain a large proportion of *Nonionellina labradorica* (Vilks, 1980), but *E. vitrea* remains a minor faunal element.

The reason for the deep shelf distribution of *E. vitrea* during deglaciation is unknown. The low Shannon Index values for some samples are difficult to reconcile with the relatively great depths under which these sediments were deposited. In the Arctic, values of ca. 1.8 are usual for depths between 100 and 1,000 m; values below 1.5 are exceptional (Lagoe, 1980). Hyposalinity in Dixon Entrance was probably not a factor because salinities would have to have been significantly reduced (less than 30‰) to explain the low Shannon Index; such salinities are difficult to imagine at 200 m on an open shelf. High sedimentation rates could have contributed to reduced diversity but the solution to the problem will have to wait until more is known about the autecology of *E. vitrea*.

The *C. reniforme-C. foraminosum* Biofacies (3) is closer to glacial-marine assemblages reported in the literature because the dominant species, *C. reniforme,* is one of the most common in such environments. However, as there are only two samples in this biofacies, its paleoenvironmental significance is uncertain. Because of the stratigraphic relations within core END 90A-03, it is probable that this biofacies represents deep shelf conditions not unlike those found in the *E. vitrea-S. feylingi* Biofacies (1).

The *E. vitrea-C. reniforme* Biofacies (2) resembles the *E. vitrea-S. feylingi* Biofacies (1) except for the relatively high Shannon Index values and the greater amount of temperate species present, which is consistent with its occurrence in Lithoacoustic Unit B_2. Biofacies 2 represents bottom temperatures intermediate between full glacial and modern conditions. The increase in temperate species content could be the result of two factors operating individually or together: increased wind-induced upwelling and intense melt-driven estuarine circulation drawing in deep water from the outer shelf and slope. Enhanced upwelling is unlikely because the importance of the Aleutian Low pressure system would have been greater than today and so, downwelling conditions would have prevailed (as explained by Patterson and others, 1995, for Queen Charlotte Sound for the same period, ca. 12,000 BP). At present, upwelling conditions are infrequent off northern British Columbia so that it is highly unlikely that the California Undercurrent would extend to such high latitudes. Even today, the California Undercurrent is not recorded north of the northern tip of Vancouver Island (Thomson, 1994). This undercurrent intensifies during conditions favorable to upwelling, rather than the downwelling conditions present at the time Biofacies 3 was deposited. This leaves deep-water intrusion caused by enhanced estuarine circulation as the principal cause for the increase in temperate species. This mechanism was already in place at the time of Biofacies 1 and 3 (Lithoacoustic Unit A), and explains the minor occurrence of temperate species even when the ice front was standing on the shelf. During development of Biofacies 2 (Lithoacoustic Unit B_2), increased meltwater flow resulting from warmer climate would have increased onshore deep water transport. Even if relative sea level during stage B_2 had been as much as 123 m lower than at present, as suggested by side-scan sonar data of Josenhans and others (1995), the water depth at the site of core END 90A-02 (the only occurrence of the *E. vitrea-C. reniforme* Biofacies) would still have been 267 m, more than sufficient for onshore deep water transport to take place unhampered.

The *C. reniforme-A. fluens* Biofacies (4) is associated with the *E. vitrea-C. reniforme* Biofacies (2) in core END 90A-02. Biofacies 4 occurs in sands of Lithoacoustic Unit B_2 instead of muds but contains a comparable percentage of temperate species. The difference between Biofacies 4 and 2 may result from differences in substrate or from different water depths during deposition. Although there is no indication of reduced water depth from the composition of the *C. reniforme-A. fluens* Biofacies (4), post-mortem transport from shallower depths has to be considered because the sands of Unit B_2 suggest a phase of redeposition.

The *L. fletcheri-C. excavatum* Biofacies (6) occurs in cores END 90A-03 and END 90A-07. Like the temperate *L. fletcheri-B. decussata* Biofacies (7), it is found in coarse sediment and the composition of some of its samples may have been altered by postmortem transport. The overall composition of this biofacies may be explained in terms of coarse sediment microhabitats (see later section, "Substrate Control on Biofacies Distribution"). Biofacies 6 has been tentatively categorized as representing transitional water temperatures but the percentage of temperate species may be of limited paleoenvironmental significance in this case. For example, in the lower part of core END 90A-07, three samples with *L. fletcheri-C. excavatum* Biofacies (6), which indicates transitional temperatures, occur in sand and are interspersed with three samples containing temperate biofacies. Two of these three temperate samples (including one *L. fletcheri-B. decussata* Biofacies [7] sample) occur in muds and are probably undisturbed. From this evidence, and despite the presence of the transitional *L. fletcheri-C. excavatum* Biofacies (6), bottom temperatures at the site of core END 90A-07 are reflected by the samples containing temperate assemblages. Thus, paleotemperatures were comparable with those of today by 10,580 BP. The sands and gravels at the top of core END 90A-03 and in core 88B-02, where Biofacies 7 is also found, may be interpreted in terms of modern microhabitats, as will be discussed in the section on "Substrate Control on Facies Distribution".

SIGNIFICANCE OF TEMPERATE SPECIES

Patterson and others (1995) assigned greater significance to the number of temperate species than to the proportion of temperate individuals in their analysis of Queen Charlotte Sound/Hecate Strait foraminifera because, in many instances, there were only a few temperate species present that represented a significant percentage of a given population. In these cases, use of absolute abundance of temperate specimens would have given a false impression of increased temperature. In Dixon Entrance, the range of variation of the percent of temperate taxa is much larger and so is the number of species, making the caveats used by Patterson and others (1995) less important. Still, the number and the percentage of temperate species at times exhibit slightly diverging trends, most notably at the top of core END 90A-02, in the upper half of core END 90A-04, and in the lower third of core END 90A-07 (Figs. 4, 5 and 6, respectively). However, the good correlation between both curves in cores END 90A-03 and END 90A-05 shows that when a sharp contrast in water temperature occurs, the number of temperate species and the percentage of temperate species give comparable results.

Because sediments of Unit B_2 from Dixon Entrance were deposited diachronously, their temperate foraminiferal species percentages vary considerably. "Transitional" biofacies are found when Unit B_2 is dated at ca. 12,500 years BP (core END 90A-02), but assemblages are "temperate" when Unit B_2 is dated at around 10,600 years BP (core END 90A-07). This is consistent with other biological indicators of warming from the region, particularly pollen records (Mathewes, 1993). The anomalous fully "temperate" date of 10,790 years BP obtained from Unit B_2 material in core END 88B-02 is probably from displaced material and thus is discounted.

In the Fraser delta, Patterson and Cameron (1991) reported an assemblage of *C. excavatum, B. frigida, Elphidiella hannai* and *N. stella* in sediments as old as 9950 years BP, identical to that found at present in the Strait of Georgia (Cockbain, 1963). Thus, evidence from Dixon Entrance, Queen Charlotte Sound and the Strait of Georgia indicates that oceanographic conditions did not change markedly after 10,000 BP, though water depth may have changed locally from the effects of isostasy/eustacy.

SUBSTRATE CONTROL ON BIOFACIES DISTRIBUTION

The six "temperate" biofacies are found in a variety of substrates. The defining characters of these biofacies, in addition to the percentage of temperate species, are the relative dominance of attached forms on one hand and of nonionellids, plus *Epistominella pacifica,* on the other. At one extreme, the *L. fletcheri-B. decussata* Biofacies (7), found in coarse substrates, contains a high proportion of attached forms, primarily *L. fletcheri.* This species is accompanied by *Cribroelphidium* spp., *Astrononion gallowayi* and another attached form, *Lobatula mckannai.* This is also the only biofacies characterized by *I. californica* and *I. limbata,* making it the only assemblage in the present study to contain an appreciable amount of the "gold assemblage" reported by Bergen and O'Neil (1979), i.e., *I. californica, I. limbata* and *I. tortuosa* in addition to *L. fletcheri* and *L. lobatula.* The *L. fletcheri-B. decussata* Biofacies (7) is also similar to various carbonate bank biofacies described from Bathhouse Beach and elsewhere on the California Borderland (Patterson and others, 1990; Douglas and others, 1976, 1979; Douglas, 1981). At the other extreme, the *E. pacifica-N. stella* Biofacies (8) occurs in massive muds. In this biofacies, attached forms are few and so are cribroelphidiids.

The variability in fauna found in temperate biofacies has been experimentally linked to microhabitats within the sediment (Kitazato, 1984; 1994). Kitazato collected live foraminifers with their associated substrate in various environments around Japan and kept them alive in the laboratory under controlled conditions of temperature, oxygenation and illumination. In coarse sands in shallow seas (5–100 m), attached forms adhered to sand grains (*Hanzawaia nipponica* and *Elphidium subarcticum* [=*Cribroelphidium hallandense*]), whereas cassidulinids moved around sand grains where they seemed to feed on bacterial and algal films covering the grains. Rocky bottoms were similar to rocky shores with attached forms (e.g., *Cibicides lobatulus, Glabratella* sp., *Rosalina* spp., *Elphidium crispum* and various species of Miliolidae) found clinging to rocks and seaweeds. A characteristic of muddy bottoms was the existence of a reduced-anoxic layer below a few centimeters in the sediment. Kitazato (1994) reported *N. stella* living in shallow (5 to 100 m) muddy areas around Japan, in deep infaunal "position", apparently tolerant of this anaerobic setting. Above the reduced-anoxic sediment was an oxygenated, flocculent layer inhabited by species such as *Bolivina pacifica* and *Textularia kattegatensis,* which moved in and out of the layer. Attached forms were found only clinging to polychaete tubes in this setting.

In our material, the types of fauna found in the *L. fletcheri-B. decussata* Biofacies (7) are similar in overall makeup to assemblages from rocky bottoms or coarse sands reported by Kitazato (1994), even though the species are not the same. *Hanzawaia nipponica* is absent from the British Columbia shelf, but *L. fletcheri* can be compared to it because it lives firmly attached to hard surfaces. The presence of cassidulinids as major components in both our assemblages and Kitazato's material reinforces the analogy. Even though the sediment texture in some cases suggests a lag deposit, the fact that the Japanese faunas have been observed alive and *in situ* on a coarse sandy substrate is strong indication that the tests in even the coarsest samples of Biofacies 7 can be considered *in situ.* The *E. pacifica-N. stella* Biofacies (8) is comparable to the fauna described by Kitazato (1994) as living deep in a muddy substrate (e.g., the abundance of *N. stella* and the low numbers of attached forms). However, better knowledge of the life habit of *E. pacifica* (not reported by Kitazato) would considerably improve our interpretation of this material, as this species characterizes several biofacies. Although some information exists concerning the distribution of *E. pacifica* off the Pacific coast of North America (Echols and Armentrout, 1980), nothing has been published about its relationship to the substrate. The four temperate biofacies of intermediate composition that occur in sandy muds and muds (Biofacies 5, 9, 10, and 11; Table 4) can at this time only be described in terms of varying intermediates between the substrate extremes.

The transitional temperature biofacies show the same segregation between attached and non-attached species, in both coarse and muddy substrates. However, the fauna in glacial assemblages consists of undifferentiated mixtures of attached, epifaunal and infaunal species. The *C. reniforme-C. foraminosum* Biofacies occurs on sandier substrates but it does not contain a noticeably larger proportion of attached forms. It seems that during glacial times, the less-differentiated, poorly sorted, clay-rich glacial sediment provided comparable substrate or habitat everywhere; then, as the ice receded, sediment types on the sea floor became more differentiated, and foraminiferal assemblages adapted to these various new habitats. Also, it is possible that the high rate of sedimentation in glacial times hampered the formation of segregated habitats.

TABLE 4. Biofacies in Dixon Entrance cores in function of sediment type and temperate foraminifer content.

	Sand and gravel	Sandy mud	Massive mud	Clay and stony clay
Temperate	7–*L. fletcheri–B. decussata* (blue cluster)	5–*C. reniforme–E. pacifica* (orange) 9–*C. excavatum–L. fletcheri* (red) 10–*E. vitrea–E. pacifica* (red)	8–*E. pacifica–N. stella* (yellow) 11–*C. hallandense–S. feylingi* (red)	
Transitional	6–*L. fletcheri–C. excavatum* (blue)	4–*C. reniforme–A. fluens* (orange)	2–*E. vitrea–C. reniforme* (green)	
Glacial		3–*C. reniforme–C. foraminosum* (orange)		1–*E. vitrea–S. feylingi* (green)

INFLUENCE OF CIRCULATION PATTERNS AND WATER TEMPERATURE ON BIOFACIES DISTRIBUTION

All of the temperate biofacies described here were deposited below 100 m water depth (that is, below the top of the regional North Pacific pycnocline) and all were exposed to upwelling conditions. Shoreward transport of deep water resulted in fairly consistent salinity conditions at all sites in Dixon Entrance, despite highly variable water depths during deposition. Thus, cluster analysis of these data detected habitats controlled primarily by variation in substrate. Another major environmental factor controlling glacial and transitional biofacies distribution was temperature, which increased through time. As expected, colder water assemblages have lower Shannon Index values. A few individual samples had a very low Shannon Index (ca. 1.2), but these isolated occurrences cannot be interpreted to indicate further reduction in salinity or temperature. Although salinity may have been somewhat reduced, we believe, on the basis of faunal composition, that the glacial samples were deposited in an environment where salinities were not less than 30‰, and were probably closer to 32–33‰. We apply a similar paleosalinity interpretation to the transitional and temperate samples. As salinities above the seasonal pycnocline (situated between 10 and 40 m) are often quite low, our results imply that shallowing associated with Unit B_2 never approached this limit at any of the sites we sampled.

Unit B_2 in Dixon Entrance differs from its equivalent in Queen Charlotte Sound. It is coarser, not framed by B_1 and B_3 muds, and up to 20 m thick according to seismic data—in contrast to between <1 m and 4 m in Queen Charlotte Sound (Luternauer and others, 1989). The difference may arise from the east–west orientation of Dixon Entrance, and from the position of the glacial forebulge. As deglaciation proceeded from west to east, there was more time for Unit B_2 sediments to accumulate at the oceanic end of the Entrance, and lowering of relative sea level caused by forebulge effect was probably maximum in the west. This hypothesis is supported by radiocarbon dating: Unit B_2 sediments cored in the eastern part of Dixon Entrance just south of Clarence Strait (Table 5, Fig. 1) are relatively young, from 11,000 to 10,000 ^{14}C years old, whereas those from the western part, sampled in core 90A-02, fall into the 13,000-to-12,000 BP range.

The paleotemperatures changed from glacial to transition-

TABLE 5. Lithoacoustic facies, lithology, and paleoclimatic interpretation in function of age. Cores are positioned from left to right following their west-to-east position in Dixon Entrance. Cores 84B-08 and 10 from Queen Charlotte Sound are added for comparison.

Age (yr B.P.)	90A-02 depth: 389 m	90A-04 254 m	90A-03 277 m	90A-07 394 m	88B-02 319 m	90A-05 282 m	90A-06 130 m	84B-08 & 10, Queen Charlotte Sound 184 m
0–10,000		C mud temperate		C massive mud temperate		C* sandy mud temperate	C sandy mud temperate	B_3 + C massive mud transit + temper
10,000–11,000				B_2 sand temper + transit	B_2† sand temperate			B_2 + B_3 mud + sandy mud transit + glacial
11,000–12,000								B_1 + B_2 mud + sandy mud transitional
12,000–13,000	B_2 mud + sand transitional							B_1 massive mud transitional
13,000–14,000			A* sandy clay glacial			A* stony clay glacial		

* Age conjectured.

† Possibly resedimented material. Unit may be younger.

al at or shortly after 13,000 BP, and then to temperate sometime between 11,000 and 10,000 BP. We do not have enough data at the moment to demonstrate the synchroneity of the change over the whole of Dixon Entrance. However, there is a sharp difference compared with Queen Charlotte Sound, where transitional biofacies prevail until after 10,000 BP and where there is a short quasi-glacial interval just after 11,000 BP (Patterson and others, 1995). The colder bottom conditions in Queen Charlotte Sound can be explained by more intense "downwelling", resulting from the fact that between 11,500 and 10,000 BP it was shallow and had its northern end (Hecate Strait) blocked, thus forming a restricted basin tentatively called the "Hecate Sea" by Patterson and others (1995). In contrast, the greater depths in Dixon Entrance, the east-west shape of the basin, and its deep connection with Clarence Strait favored advection of warmer outer shelf-upper slope water, so that temperatures rose more rapidly. The more open marine conditions in Dixon Entrance, as compared to "Hecate Sea", are also clearly indicated by the number of species in both regions: 204 species in Dixon Entrance as compared with 75 reported by Patterson (1993) and 88 by Patterson and others (1995) in Queen Charlotte Sound. This evidence of more open marine conditions suggests more vigorous circulation in Dixon Entrance, resulting in coarser substrates.

The above remarks do not alter our opinion (Patterson and others, 1995) that, during deposition of Unit B_1 and upper Unit B_3 in Queen Charlotte Sound, warmer ocean water was advected in Goose Island Trough by summertime upwelling induced by Ekman transport. This is favored by the depth of the trough and its east-west orientation, but mostly by the fact it is (and was) situated far enough to the south to be within the reach of California Undercurrent water and summertime upwelling. During the Younger Dryas-like cold interval (upper B_2 and lower B_3), the northern limit of summertime upwelling was pushed southward so that warm offshore water did not extend to the site of core END 84B-10.

MEANING OF *C. RENIFORME* REGARDING WATER TEMPERATURE

The data presented here may limit the value of *Cassidulina reniforme* as a definitive cold-water indicator. Sejrup and Guilbault (1980) presented convincing evidence that this species is limited to glacial marine areas. This has been generally accepted since, and it has been assumed that significant populations of *C. reniforme* can only develop at temperatures of less than 3 or 4°C. For example, Patterson (1993) and Patterson and others (1995) observed an increase in *C. reniforme* in late glacial units from cores in Queen Charlotte Sound at a time when pollen data from the coastal areas indicate colder temperatures. In core 84B-10, the increase in *C. reniforme* is concomitant with an increase in the cold water indicator *I. helenae* (Patterson and others, 1995).

Although *C. reniforme* undoubtedly has a preference for "arctic" conditions (Sejrup and Guilbault, 1980), its presence in large numbers in core END 90A-07 as late as 3000 BP in an otherwise cool temperate setting requires some alternate explanation. Reworking from glacial-marine deposits must be discounted here because *C. reniforme* is disproportionately abundant compared to other glacial-marine species (e.g., *B. frigida, C. excavatum, I. helenae*) found at this horizon. There is also no corroborative evidence of an extremely cold interval that young.

SUMMARY AND CONCLUSIONS

The distributions of foraminiferal biofacies in late Pleistocene-Holocene sediments from Dixon Entrance are controlled by water temperature and by substrate (Table 4). Two glacial biofacies can be identified: the *E. vitrea-S. feylingi* Biofacies (1) in stony muds and clays, and the *C. reniforme-C. foraminosum* Biofacies (3) in more sandy sediments (sandy muds and sands). There are also three biofacies indicative of transitional temperatures, listed here in order of increasing substrate coarseness: the *E. vitrea-C. reniforme* Biofacies (2), the *C. reniforme-A. fluens* Biofacies (4), and the *L. fletcheri-C. excavatum* Biofacies (6).

There are five temperate biofacies found in a variety of substrates. At one extreme is the *E. pacifica-N. stella* Biofacies (8), which occurs in muds. At the other extreme is the *L. fletcheri-B. decussata* Biofacies (7), which occurs in coarse sediments. The three temperate biofacies in intermediate substrates include the *C. excavatum-L. fletcheri* Biofacies (9) in sandy mud and muddy sand, the *C. hallandense-S. feylingi* Biofacies (11) from sandy mud, and the *E. pacifica-E. vitrea* Biofacies (10) in mud virtually as fine as that harboring the *E. pacifica-N. stella* Biofacies (8).

The more open circulation and deeper water in Dixon Entrance prevented the intense downwelling of lower salinity, colder surface waters and the associated blocking of deep-water intrusions that prevailed during the "Hecate Sea" phase of Queen Charlotte Sound (≈11,100–10,000 years BP). As with the modern flow pattern in this area, buoyancy-driven estuarine circulation, with freshwater export in an upper layer and saltwater import in a deeper return layer, resulted in a more rapid and uninterrupted warming of this area than occurred in Queen Charlotte Sound. This flow may have been enhanced during the glacial forebulge stage by more vigorous tidal mixing in the shallower water and by greater freshwater discharge from glaciers. The situation is not unlike the modern Juan de Fuca Strait, where vigorous tidal mixing and a deep canyon at the entrance to the strait allows shoreward intrusion of deep continental slope water in the bottom layer of the channel (Thomson, 1994). Our evidence suggests that modern circulation and temperatures had developed along the entire length of the British Columbia shelf shortly after 10,000 years BP.

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APPENDIX 1. Fractional abundance of species present in statistically significant numbers in all examined samples from Dixon Entrance.

Core	88B-02	88B-02	88B-02	90A-02	90A-02	90A-02	90A-02	90A-02	90A-02	90A-02	90A-02	90A-02	90A-02	90A-02
Depth in core (cm)†	76–78	46–48	55–57	0–3	4–6	25–27	55–57	61–63	90–93	100–102	109–111	124–126	150–152	178–180
Biofacies	7	7	7	2	2	5	8	4	2	4	4	2	2	2
Total number of specimens	725	563	607	460	447	1983	1153	120	210	211	479	700	1043	402
Angulogerina angulosa	0.014	0.011	0.008	0.007	0.009	0.002	0.001	0.008	0.005	0.005	0.013	0.007	0.007	—
Angulogerina fluens	0.007	0.004	0.012	0.024	0.116	0.025	0.021	0.033	0.110	0.152	0.225	0.044	0.056	0.017
Astrononion gallowayi	0.021	0.023	0.020	0.015	0.007	0.019	0.001	0.008	0.014	0.005	0.002	0.001	0.005	0.002
Bolivina decussata	0.110	0.085	0.097	0.046	0.007	0.047	0.042	—	0.014	0.005	0.040	0.001	0.004	0.010
Bolivinellina pacifica	0.001	0.002	—	0.007	0.002	0.020	0.001	—	—	—	—	—	0.005	0.007
Bucella depressa	0.001	—	—	0.002	0.009	0.013	0.001	—	0.005	—	0.004	0.004	0.003	—
Buccella frigida	0.033	0.041	0.061	0.024	0.018	0.030	0.087	0.067	0.033	0.071	0.015	0.067	0.035	0.012
Buliminella elegantissima	0.003	—	0.002	0.011	0.011	0.019	0.011	—	0.029	0.005	0.002	—	—	0.002
Cassidulina reniforme	0.068	0.071	0.031	0.067	0.105	0.164	0.114	0.342	0.086	0.194	0.299	0.146	0.147	0.149
Cribroelphidium excavatum	0.025	0.028	0.064	0.020	0.051	0.073	0.029	0.100	0.138	0.100	0.008	0.080	0.153	0.077
Cribroelphidium foraminosum	0.008	0.009	0.007	0.009	0.020	—	0.001	—	—	0.005	0.006	0.007	0.017	0.010
Cribroelphidium hallandense	0.023	0.027	0.035	0.011	0.074	0.007	0.002	—	0.005	0.005	—	0.001	0.012	0.002
Eggerella advena	0.001	—	—	—	—	—	—	—	—	—	—	—	—	—
Eilohedra laevicula	0.011	0.023	0.015	—	—	—	—	—	—	—	—	—	—	—
Elphidiella hannai	—	0.002	—	—	0.002	—	—	—	—	—	—	—	—	—
Epistominella pacifica	0.021	0.044	0.002	0.033	0.076	0.141	0.260	0.042	0.052	0.104	0.004	0.070	0.085	0.042
Epistominella vitrea	0.048	0.050	0.053	0.389	0.181	0.139	0.011	0.050	0.129	0.109	0.006	0.371	0.244	0.440
Euloxostomum alatum	0.006	0.009	—	—	—	—	0.023	—	—	—	—	—	—	—
Euuvigerina juncea	0.010	0.016	0.002	—	0.013	0.013	0.083	0.008	0.014	0.019	0.008	0.007	0.005	0.007
Favulina melo	—	0.004	—	0.002	0.004	0.001	—	—	0.005	—	0.006	—	—	—
Gaudryina arenaria	—	—	—	0.011	—	0.001	—	—	—	—	—	—	—	—
Gavelinopsis campanulata	0.006	—	—	0.002	—	0.001	—	—	—	—	0.002	—	0.003	0.002
Globubulimina auriculata	—	0.011	—	—	0.002	—	—	—	—	—	—	—	—	—
Globocassidulina bradshawi	0.006	0.004	—	—	—	—	—	—	—	—	—	—	—	—
Globocassidulina subglobosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Homalohedra borealis	—	—	—	0.002	0.007	—	—	—	—	—	0.029	—	—	—
Islandiella californica	0.032	0.021	0.028	—	—	—	—	—	—	—	—	—	—	—
Islandiella helenae	0.001	—	0.002	—	0.009	—	—	0.033	0.024	0.009	0.002	0.001	0.011	0.005
Islandiella limbata	0.046	0.021	0.026	—	—	—	—	—	—	—	—	—	—	—
Islandiella norcrossi	0.004	0.021	0.005	0.009	0.031	0.009	0.001	0.050	0.043	0.038	0.008	0.034	0.083	0.040
Islandiella tortuosa	—	0.007	0.018	—	—	—	—	—	—	—	—	—	—	—
Karreriella bradyi	0.004	0.009	0.005	—	0.011	0.002	—	—	0.005	0.005	0.019	0.001	0.002	0.002
Laevidentalina pauperata	—	—	—	—	0.004	—	—	—	—	—	—	0.007	0.001	—
Lobatula fletcheri	0.373	0.371	0.466	0.063	0.083	0.116	0.047	0.183	0.100	0.095	0.146	0.033	0.034	0.042
Lobatula lobatula	0.006	—	0.007	0.002	0.002	—	—	0.008	0.005	0.005	0.008	—	—	—
Lobatula mckannai	0.004	0.007	0.002	0.015	0.011	0.009	0.002	0.008	0.005	—	0.019	—	—	—
Nonionella stella	0.004	0.012	—	0.013	0.013	0.021	0.129	—	0.048	0.014	—	0.023	0.005	0.007
Nonionella turgida digitata	0.003	0.002	—	0.017	—	0.008	0.002	—	—	—	—	—	—	0.002
Nonionellina labradorica	0.015	0.011	—	0.072	0.045	0.022	0.075	—	0.038	0.019	—	0.043	0.053	0.075
Pseudononion basispinatum	0.003	0.005	0.003	0.022	0.034	0.003	0.003	—	0.010	0.005	—	0.030	0.019	0.012
Rosalina columbiensis	—	—	—	0.015	0.004	—	0.007	0.008	0.029	—	0.004	—	—	—
Siphonaperta stalkeri	0.003	0.005	—	—	—	—	—	—	—	—	—	—	—	—
Spirosigmoilina tenuis	—	—	—	0.004	0.002	0.018	0.001	—	0.014	—	—	—	—	—
Stainforthia feylingi	0.011	0.005	0.002	0.026	0.004	0.058	0.013	0.008	—	0.005	—	0.004	0.003	0.017
Trochammina ex. gr. *squamata*	0.011	—	—	—	—	—	—	—	—	—	—	—	—	—
Trochammina nana	0.003	—	—	0.007	—	0.001	—	0.008	—	—	—	—	—	—

† Depths between parentheses: pilot core depths.

APPENDIX 1. Extended.

Core	90A-02	90A-02	90A-02	90A-02	90A-02	90A-02	90A-02	90A-02	90A-03	90A-03	90A-03	90A-03	90A-03	90A-03
Depth in core (cm)†	210–212	243–245	270–272	304–306	330–332	365–367	376–378	395–397	2–4	12–14	19–21	21–23	27–29	38–40
Biofacies	2	2	2	2	2	4	2	2	7	7	6	6	6	1
Total number of specimens	991	453	1447	821	446	371	501	483	1149	527	467	413	500	696
Angulogerina angulosa	—	—	0.015	—	0.002	0.032	0.010	—	0.005	0.017	—	0.002	—	—
Angulogerina fluens	0.034	0.015	0.056	0.021	0.025	0.070	0.042	0.017	0.021	0.011	0.009	0.002	0.004	0.009
Astrononion gallowayi	—	0.009	0.003	—	—	—	0.002	0.004	0.023	0.025	0.056	0.032	0.028	0.004
Bolivina decussata	—	0.011	0.002	—	—	0.011	0.010	—	0.098	0.177	0.058	0.032	0.042	0.004
Bolivinellina pacifica	—	0.007	0.001	—	—	0.003	—	0.002	0.001	0.002	—	—	—	0.004
Bucella depressa	—	—	0.008	0.004	0.004	0.003	—	0.002	0.006	0.002	0.002	0.002	—	—
Buccella frigida	0.014	0.020	0.024	0.023	0.052	0.016	0.014	0.012	0.022	0.019	0.049	0.044	0.048	0.009
Buliminella elegantissima	—	—	—	0.001	—	—	0.004	—	—	—	0.004	0.002	—	—
Cassidulina reniforme	0.189	0.238	0.163	0.076	0.135	0.240	0.144	0.259	0.028	0.029	0.024	0.041	0.044	0.076
Cribroelphidium excavatum	0.083	0.073	0.109	0.096	0.166	0.089	0.096	0.072	0.056	0.013	0.052	0.058	0.088	0.057
Cribroelphidium foraminosum	0.032	0.011	0.011	0.004	0.009	0.022	0.006	0.002	0.009	0.002	0.013	0.019	0.010	0.075
Cribroelphidium hallandense	0.009	0.007	0.022	0.001	0.011	0.022	—	0.002	0.063	0.021	0.234	0.241	0.184	0.013
Eggerella advena	—	—	—	—	—	—	—	—	0.001	0.002	—	—	—	—
Eilohedra laevicula	—	—	—	—	—	—	—	—	0.011	0.042	0.006	—	—	—
Elphidiella hannai	—	—	—	—	—	—	—	—	0.001	—	—	—	—	—
Epistominella pacifica	—	0.022	0.101	0.049	0.054	0.092	0.110	0.052	0.006	0.002	0.002	0.007	0.014	0.001
Epistominella vitrea	0.262	0.415	0.225	0.474	0.305	0.092	0.331	0.393	0.064	0.053	0.056	0.083	0.118	0.565
Euloxostomum alatum	—	0.002	0.001	—	—	—	—	—	—	—	—	—	—	—
Euuvigerina juncea	0.002	0.007	0.035	—	0.011	0.005	—	0.006	0.001	0.002	—	—	—	—
Favulina melo	—	—	—	0.001	—	—	—	—	—	0.002	0.002	—	—	0.001
Gaudryina arenaria	—	—	—	—	—	—	—	—	0.004	—	—	—	0.002	—
Gavelinopsis campanulata	0.101	—	0.003	—	—	0.003	—	—	—	0.002	0.002	0.007	—	—
Globubulimina auriculata	0.001	—	—	—	—	—	—	—	—	—	—	—	—	—
Globocassidulina bradshawi	—	—	—	—	—	—	—	—	0.002	0.010	0.009	0.005	0.002	—
Globocassidulina subglobosa	0.112	—	—	—	—	—	—	—	0.022	0.015	0.002	—	—	—
Homalohedra borealis	—	—	0.001	—	—	0.003	—	0.002	0.001	0.002	—	0.002	—	—
Islandiella californica	—	—	—	—	—	—	—	—	0.055	0.091	0.002	—	0.010	0.010
Islandiella helenae	—	0.002	0.008	0.132	0.056	0.043	0.066	0.037	0.003	0.002	—	—	0.002	0.006
Islandiella limbata	—	—	—	—	—	—	—	—	0.047	0.042	0.004	0.012	—	0.001
Islandiella norcrossi	0.080	0.042	0.039	0.026	0.047	0.032	0.034	0.035	0.007	0.006	—	0.015	0.006	0.042
Islandiella tortuosa	—	—	—	—	—	—	—	—	0.015	0.069	—	—	0.002	—
Karreriella bradyi	—	—	0.003	—	0.004	0.008	—	—	0.024	0.029	0.013	0.007	0.014	0.006
Laevidentalina pauperata	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lobatula fletcheri	0.011	0.051	0.040	0.052	0.036	0.154	0.100	0.035	0.279	0.204	0.256	0.331	0.312	0.045
Lobatula lobatula	—	—	—	—	0.002	0.003	—	—	0.043	0.019	0.011	0.002	0.014	—
Lobatula mckannai	—	—	0.001	—	—	0.008	0.002	—	0.007	0.023	—	0.002	0.002	—
Nonionella stella	0.004	—	0.003	0.002	—	—	—	—	0.002	0.002	0.006	0.005	0.002	—
Nonionella turgida digitata	0.002	—	0.001	—	—	—	—	—	—	—	—	—	—	0.003
Nonionellina labradorica	0.046	0.044	0.072	0.024	0.061	0.016	0.018	0.039	0.003	—	0.011	0.015	0.004	0.024
Pseudononion basispinatum	0.009	0.015	0.026	0.002	0.011	0.011	0.010	0.019	0.003	—	0.009	—	0.006	0.023
Rosalina columbiensis	—	—	0.001	0.001	—	—	—	—	0.003	0.002	0.002	—	0.002	—
Siphonaperta stalkeri	—	—	—	—	—	—	—	—	0.001	—	0.002	—	0.006	0.003
Spirosigmoilina tenuis	—	—	—	0.002	—	0.003	—	—	—	—	—	—	—	—
Stainforthia feylingi	0.006	0.004	0.005	0.002	—	0.003	—	0.004	0.007	0.004	0.011	—	0.006	0.009
Trochammina ex. gr. *squamata*	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Trochammina nana	—	—	—	—	—	—	—	—	—	0.002	—	—	—	0.001

APPENDIX 1. Extended.

Core	90A-03	90A-03	90A-04	90A-04	90A-04	90A-04	90A-04	90A-04	90A-04	90A-04	90A-04	90A-04	90A-04	90A-04
Depth in core (cm)†	58–60	77–79	(3–5)	25–27	55–57	85–87	110–112	142–144	170–172	202–204	230–232	262–264	290–292	322–324
Biofacies	3	3	7	10	5	5	5	5	10	10	5	8	10	10
Total number of specimens	754	552	1248	337	1013	472	982	805	774	480	437	779	620	424
Angulogerina angulosa	0.001	—	0.021	—	0.004	0.023	0.011	0.010	0.005	0.004	0.007	0.036	0.003	0.005
Angulogerina fluens	0.015	0.007	0.073	0.006	0.043	0.049	0.064	0.045	0.012	0.023	0.078	0.053	0.035	0.045
Astrononion gallowayi	0.007	0.002	0.022	—	0.024	0.015	0.044	0.012	0.013	0.031	0.005	0.001	0.005	0.002
Bolivina decussata	0.023	0.009	0.079	0.050	0.023	0.015	0.009	0.052	0.053	0.079	—	0.060	0.100	0.097
Bolivinellina pacifica	0.005	0.002	0.008	0.030	0.047	0.040	0.049	—	0.026	0.023	—	0.004	0.052	0.033
Bucella depressa	—	—	0.023	—	—	0.002	0.007	0.016	0.040	0.038	—	0.014	0.039	0.009
Buccella frigida	0.020	0.018	0.041	—	0.013	0.032	0.018	0.027	0.016	0.029	0.009	0.051	0.018	0.021
Buliminella elegantissima	0.003	—	0.009	0.033	0.043	0.036	0.036	0.051	0.037	0.069	—	0.037	0.119	0.113
Cassidulina reniforme	0.574	0.728	0.067	0.101	0.155	0.227	0.163	0.123	0.048	0.071	0.279	0.010	0.034	0.033
Cribroelphidium excavatum	0.074	0.056	0.026	0.077	0.125	0.083	0.126	0.060	0.027	0.081	0.053	0.058	0.071	0.071
Cribroelphidium foraminosum	0.088	0.091	—	—	0.001	—	—	—	—	—	0.064	—	—	—
Cribroelphidium hallandense	0.016	0.009	0.013	0.003	0.002	0.002	—	0.001	0.001	0.013	—	—	—	0.045
Eggerella advena	—	—	0.013	—	—	—	0.002	—	—	—	—	0.006	0.002	—
Eilohedra laevicula	—	0.002	—	—	—	—	—	—	—	—	—	—	—	—
Elphidiella hannai	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Epistominella pacifica	0.003	0.007	0.067	0.068	0.146	0.123	0.137	0.171	0.075	0.102	0.149	0.383	0.126	0.106
Epistominella vitrea	0.090	0.011	0.058	0.214	0.115	0.083	0.024	0.161	0.176	0.077	0.037	0.042	0.111	0.120
Euloxostomum alatum	—	—	0.001	—	—	—	0.004	—	—	—	—	—	—	—
Euuvigerina juncea	—	—	0.003	0.012	0.014	0.002	0.015	0.029	0.013	0.035	0.016	0.032	0.011	—
Favulina melo	—	—	0.003	—	0.004	—	0.002	—	—	—	—	0.003	—	—
Gaudryina arenaria	—	—	0.003	—	—	—	—	—	—	—	—	—	0.002	—
Gavelinopsis campanulata	—	—	0.003	—	0.003	—	—	0.002	0.003	0.002	—	—	0.006	0.007
Globobulimina auriculata	—	—	0.006	—	0.001	—	—	0.001	0.004	—	—	—	—	—
Globocassidulina bradshawi	0.001	—	—	—	—	—	—	—	—	—	—	—	—	—
Globocassidulina subglobosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Homalohedra borealis	—	—	0.002	—	—	0.002	—	—	—	—	—	—	—	—
Islandiella californica	0.005	0.002	—	—	—	—	—	—	—	—	—	—	—	—
Islandiella helenae	0.003	—	—	—	—	—	—	—	—	—	—	—	—	—
Islandiella limbata	0.001	—	—	—	—	—	—	—	—	—	—	—	—	—
Islandiella norcrossi	0.019	0.007	0.035	—	—	—	—	—	—	—	0.101	—	—	0.007
Islandiella tortuosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Karreriella bradyi	—	—	0.008	—	0.007	0.004	0.001	0.024	0.013	0.006	0.080	—	0.005	0.002
Laevidentalina pauperata	—	—	—	—	0.003	—	—	—	—	—	0.007	0.012	0.008	0.002
Lobatula fletcheri	0.023	0.009	0.317	0.059	0.021	0.047	0.087	0.075	0.074	0.148	0.071	0.095	0.084	0.064
Lobatula lobatula	—	—	—	—	—	—	—	0.002	—	0.002	0.002	0.006	—	—
Lobatula mckannai	—	—	0.041	0.009	0.002	0.004	0.012	0.002	—	0.008	0.005	0.014	0.003	—
Nonionella stella	—	—	0.007	0.050	0.051	0.055	0.057	0.047	0.058	0.044	0.025	0.022	0.060	0.059
Nonionella turgida digitata	0.001	0.005	—	0.012	0.020	0.019	0.040	0.026	0.023	0.021	—	0.024	0.018	0.035
Nonionellina labradorica	0.008	0.011	0.011	0.009	—	—	—	—	—	—	—	0.001	—	—
Pseudononion basispinatum	0.001	—	0.002	0.047	0.005	0.008	0.009	0.007	0.001	0.010	—	—	—	—
Rosalina columbiensis	—	—	—	0.027	0.008	0.004	0.006	0.002	0.003	—	—	0.006	0.015	—
Siphonaperta stalkeri	0.003	—	—	—	—	—	—	—	—	—	—	—	—	—
Spirosigmoilina tenuis	—	—	0.002	0.006	0.018	0.011	0.019	0.002	0.005	—	—	0.008	0.026	0.005
Stainforthia feylingi	—	0.002	—	0.145	0.056	0.083	0.031	0.032	0.265	0.050	0.007	0.006	0.019	0.078
Trochammina ex. gr. *squamata*	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Trochammina nana	—	—	0.002	—	0.001	—	0.001	0.002	0.001	—	—	—	—	—

APPENDIX 1. Extended.

Core	09A-04	90A-04	90A-04	90A-04	90A-04	90A-04	90A-04	90A-05	90A-05	90A-05	90A-05	90A-05	90A-05	90A-05
Depth in core (cm)†	362–364	389–391	422–424	450–452	482–484	510–512	546–548	(4–6)	(28–30)	(58–60)	(88–90)	7–9	28–30	62–64
Biofacies	10	10	10	10	10	10	10	11	11	11	11	11	11	11
Total number of specimens	405	493	418	422	681	755	438	689	737	762	1442	1285	1025	676
Angulogerina angulosa	0.030	0.018	0.010	—	0.001	0.015	—	0.012	0.004	0.003	0.002	0.002	—	0.001
Angulogerina fluens	0.020	0.020	0.017	0.019	0.021	0.023	0.034	0.003	0.005	0.005	0.007	0.010	0.009	0.013
Astrononion gallowayi	0.025	0.026	0.017	0.021	0.012	0.026	0.021	0.033	0.033	0.033	0.012	0.014	0.018	0.015
Bolivina decussata	0.126	0.097	0.062	0.090	0.072	0.105	0.071	0.022	0.050	0.055	0.040	0.043	0.052	0.070
Bolivinellina pacifica	0.015	0.049	0.031	0.036	0.023	0.020	0.041	0.006	0.008	0.004	0.009	0.010	0.008	0.012
Bucella depressa	0.022	0.016	0.014	0.007	0.006	0.004	0.011	—	0.001	0.003	0.004	0.001	—	0.006
Buccella frigida	0.022	0.028	0.036	0.026	0.016	0.013	0.037	0.104	0.095	0.085	0.060	0.082	0.080	0.074
Buliminella elegantissima	0.136	0.101	0.120	0.114	0.090	0.138	0.164	0.036	0.031	0.020	0.010	0.019	0.017	0.018
Cassidulina reniforme	0.010	0.037	0.010	—	0.018	0.007	0.009	0.061	0.080	0.073	0.055	0.064	0.071	0.043
Cribroelphidium excavatum	0.049	0.051	0.041	0.036	0.054	0.083	0.039	0.026	0.023	0.012	0.024	0.037	0.021	0.033
Cribroelphidium foraminosum	—	—	—	0.009	—	—	—	0.032	0.020	0.016	0.010	0.011	0.002	0.004
Cribroelphidium hallandense	0.059	0.065	0.057	0.145	0.040	0.102	0.078	0.087	0.100	0.163	0.135	0.118	0.120	0.126
Eggerella advena	—	—	—	—	—	—	—	0.015	0.030	0.024	0.033	0.030	0.042	0.034
Eilohedra laevicula	—	—	—	—	—	—	—	0.004	—	—	0.001	0.005	0.004	0.003
Elphidiella hannai	0.002	—	—	—	—	—	—	—	—	0.003	0.003	0.002	0.002	—
Epistominella pacifica	0.047	0.063	0.177	0.071	0.123	0.041	0.068	0.065	0.024	0.034	0.045	0.052	0.031	0.030
Epistominella vitrea	0.067	0.075	0.110	0.088	0.104	0.128	0.066	0.019	0.033	0.041	0.032	0.034	0.047	0.043
Euloxostomum alatum	—	—	—	0.002	—	—	—	—	0.005	0.007	0.007	0.005	0.005	0.001
Euuvigerina juncea	0.005	0.004	0.005	0.014	0.009	0.005	0.002	0.009	0.015	0.008	0.001	0.007	0.004	0.004
Favulina melo	—	0.002	—	—	—	0.001	—	0.001	—	—	0.001	0.002	—	—
Gaudryina arenaria	0.002	—	—	—	—	—	—	0.001	0.003	0.004	0.001	0.002	—	—
Gavelinopsis campanulata	0.002	0.002	—	0.002	0.001	0.001	0.007	0.020	0.038	0.030	0.018	0.020	0.036	0.021
Globubulimina auriculata	0.002	—	—	—	—	—	—	0.013	0.015	0.008	0.015	0.019	0.003	0.004
Globocassidulina bradshawi	—	—	—	—	—	—	—	0.030	0.014	0.029	0.021	0.019	0.033	0.034
Globocassidulina subglobosa	—	—	—	—	—	—	—	0.003	—	—	—	0.005	0.002	0.001
Homalohedra borealis	—	—	0.002	—	0.001	—	0.005	—	—	—	—	—	—	—
Islandiella californica	—	—	—	—	—	—	—	—	—	0.003	0.002	—	—	—
Islandiella helenae	—	—	—	—	—	—	—	—	—	—	—	—	0.001	—
Islandiella limbata	—	—	—	—	—	—	—	0.001	—	0.001	—	—	—	—
Islandiella norcrossi	0.005	—	—	—	—	—	—	0.003	0.004	0.014	0.010	0.019	0.002	0.004
Islandiella tortuosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Karreriella bradyi	—	—	0.005	—	—	—	—	—	0.003	—	0.001	—	0.001	0.001
Laevidentalina pauperata	0.017	0.012	0.010	0.012	0.003	0.005	0.005	—	—	—	—	—	—	—
Lobatula fletcheri	0.133	0.103	0.093	0.069	0.101	0.170	0.130	0.067	0.069	0.035	0.035	0.058	0.024	0.050
Lobatula lobatula	0.007	0.002	—	0.002	—	—	—	—	0.003	—	—	0.003	—	—
Lobatula mckannai	—	—	—	0.005	0.010	0.017	0.018	0.006	0.005	—	—	0.002	—	—
Nonionella stella	0.067	0.045	0.062	0.045	0.090	0.046	0.041	0.035	0.023	0.045	0.058	0.044	0.031	0.028
Nonionella turgida digitata	0.017	0.041	0.010	0.014	0.044	0.009	0.032	0.003	0.005	0.004	0.010	0.005	0.006	0.003
Nonionellina labradorica	—	—	0.002	—	—	—	—	0.022	0.020	0.010	0.012	0.016	0.004	0.004
Pseudononion basispinatum	—	—	—	—	—	—	—	0.016	0.012	0.012	0.012	0.008	0.009	0.006
Rosalina columbiensis	0.007	0.008	—	0.002	0.001	0.003	0.005	0.020	0.014	0.010	0.011	0.001	0.006	0.006
Siphonaperta stalkeri	—	—	—	—	—	—	—	0.006	0.007	0.003	0.012	0.005	0.004	0.010
Spirosigmoilina tenuis	0.015	0.026	0.010	0.057	0.023	0.007	0.032	—	—	—	—	—	—	—
Stainforthia feylingi	0.057	0.079	0.084	0.083	0.122	0.017	0.066	0.060	0.069	0.074	0.166	0.095	0.139	0.096
Trochammina ex. gr. *squamata*	—	—	—	—	—	—	—	0.033	0.057	0.042	0.049	0.051	0.083	0.095
Trochammina nana	—	—	—	—	—	—	—	0.036	0.015	0.013	0.015	0.015	0.017	0.010

APPENDIX 1. Extended.

Core	90A-05	90A-05	90A-05	90A-05	90A-05	90A-05	90A-05	90A-05	90A-05	90A-05	90A-05	90A-05	90A-05	90A-05
Depth in core (cm)†	90–92	118–120	148–150	176–178	210–212	240–242	270–272	298–300	330–332	350–352	378–380	410–412	438–440	470–472
Biofacies	11	11	11	11	1	1	1	1	1	1	1	1	1	1
Total number of specimens	297	416	667	802	416	397	805	729	711	478	1224	719	834	632
Angulogerina angulosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Angulogerina fluens	0.003	0.014	0.007	0.007	—	—	—	—	—	—	—	—	—	—
Astrononion gallowayi	0.010	0.010	0.016	0.014	—	—	0.001	0.004	—	—	—	—	—	—
Bolivina decussata	0.027	0.034	0.036	0.029	—	—	—	0.003	—	0.002	—	—	—	—
Bolivinellina pacifica	0.010	0.005	0.007	0.006	—	—	0.006	0.001	—	0.002	0.002	0.007	0.013	0.005
Bucella depressa	0.007	0.002	—	0.004	—	—	—	—	—	—	—	—	—	—
Buccella frigida	0.061	0.060	0.078	0.054	—	—	—	0.005	0.003	—	0.001	—	—	—
Buliminella elegantissima	0.007	0.019	0.016	0.014	—	—	—	—	—	—	—	—	—	—
Cassidulina reniforme	0.040	0.115	0.063	0.072	0.007	0.028	0.061	0.082	0.110	0.071	0.083	0.121	0.146	0.122
Cribroelphidium excavatum	0.034	0.022	0.039	0.029	0.031	0.038	0.050	0.047	0.041	0.023	0.035	0.056	0.084	0.136
Cribroelphidium foraminosum	0.010	0.007	0.010	—	0.019	0.028	0.012	0.018	0.042	0.059	0.002	0.014	0.004	0.027
Cribroelphidium hallandense	0.111	0.149	0.165	0.204	—	—	—	0.007	0.003	0.004	0.002	0.001	—	—
Eggerella advena	0.027	0.017	0.025	0.017	—	—	—	0.001	—	—	—	—	—	—
Eilohedra laevicula	—	—	0.001	0.004	—	—	—	—	—	—	—	—	—	—
Elphidiella hannai	—	0.002	—	0.001	—	—	—	—	—	—	—	—	—	—
Epistominella pacifica	0.054	0.070	0.082	0.037	0.007	—	—	0.008	0.004	—	—	—	—	0.002
Epistominella vitrea	0.024	0.043	0.066	0.049	0.257	0.549	0.453	0.572	0.525	0.400	0.634	0.503	0.409	0.228
Euloxostomum alatum	—	—	0.003	0.002	—	—	—	—	—	—	—	—	—	—
Euuvigerina juncea	0.010	0.005	0.004	—	0.002	—	—	—	—	—	—	0.001	—	0.002
Favulina melo	0.003	—	—	0.001	—	—	—	—	—	—	—	—	—	—
Gaudryina arenaria	—	—	0.003	0.002	—	—	—	—	—	—	—	—	—	—
Gavelinopsis campanulata	0.010	0.017	0.004	0.016	—	—	—	—	—	—	—	—	—	—
Globobulimina auriculata	0.010	0.005	0.004	0.001	—	—	—	—	—	—	—	—	—	—
Globocassidulina bradshawi	0.024	0.024	0.028	0.025	—	—	—	0.001	—	—	—	—	—	—
Globocassidulina subglobosa	—	0.002	—	—	—	—	—	—	—	—	—	—	—	—
Homalohedra borealis	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Islandiella californica	—	—	—	—	—	0.003	—	—	—	—	—	—	—	—
Islandiella helenae	—	—	—	—	0.002	0.013	0.007	0.022	0.007	0.004	0.002	—	0.001	—
Islandiella limbata	—	0.005	—	0.002	—	—	—	—	—	—	0.002	—	—	—
Islandiella norcrossi	0.017	0.007	0.012	0.005	—	0.005	0.009	0.001	—	—	0.004	0.011	—	0.013
Islandiella tortuosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Karreriella bradyi	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Laevidentalina pauperata	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lobatula fletcheri	0.027	0.041	0.033	0.034	—	0.003	—	0.010	0.001	—	0.001	—	—	—
Lobatula lobatula	—	—	—	0.002	—	—	—	—	—	—	—	—	—	—
Lobatula mckannai	0.007	0.002	0.001	—	—	—	0.001	—	—	—	—	—	—	—
Nonionella stella	0.054	0.050	0.034	0.034	0.012	—	—	0.003	—	0.004	—	—	—	—
Nonionella turgida digitata	0.010	0.010	0.003	0.005	0.043	0.010	0.047	—	0.003	0.048	0.029	0.039	0.068	0.066
Nonionellina labradorica	0.010	0.014	0.019	0.012	0.038	0.013	0.084	0.004	0.018	0.096	0.047	0.063	0.158	0.248
Pseudononion basispinatum	0.017	0.007	0.004	—	—	—	—	—	—	0.002	—	—	—	0.002
Rosalina columbiensis	0.003	0.010	0.004	0.014	—	—	—	—	—	—	—	—	—	—
Siphonaperta stalkeri	—	0.007	0.001	0.005	0.096	0.071	0.093	0.067	0.108	0.015	0.010	0.019	0.001	0.035
Spirosigmoilina tenuis	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Stainforthia feylingi	0.172	0.113	0.105	0.135	0.459	0.237	0.158	0.132	0.117	0.270	0.140	0.145	0.101	0.103
Trochammina ex. gr. *squamata*	0.098	0.026	0.037	0.065	0.002	—	—	—	—	—	—	—	—	—
Trochammina nana	0.034	0.012	0.021	0.007	—	—	—	—	—	—	—	—	—	—

APPENDIX 1. Extended.

Core	90A-05	90A-05	90A-05	90A-06	90A-06	90A-06	90A-06	90A-06	90A-06	90A-06	90A-06	90A-07	90A-07	90A-07
Depth in core (cm)†	498–500	530–532	555–557	(4–6)	18–20	38–40	58–60	78–80	98–100	120–122	140–142	(4–5)	(5–6)	28–29
Biofacies	1	1	1	9	9	9	8	9	9	9	9	8	8	8
Total number of specimens	737	1076	667	529	316	502	504	532	430	414	466	384	480	437
Angulogerina angulosa	—	—	—	—	0.003	—	0.002	—	0.002	—	0.002	—	—	0.005
Angulogerina fluens	—	0.001	—	0.023	0.022	0.014	0.032	0.026	0.016	—	0.019	0.055	—	0.039
Astrononion gallowayi	—	—	—	0.021	0.060	0.020	0.004	0.024	0.012	0.041	0.013	—	0.004	0.007
Bolivina decussata	—	—	—	0.036	0.108	0.060	0.030	0.024	0.037	0.019	0.041	0.094	0.056	0.092
Bolivinellina pacifica	0.008	—	0.004	—	0.006	0.002	0.002	0.004	0.002	0.007	—	0.005	0.004	0.005
Bucella depressa	—	—	—	0.053	0.041	0.048	0.002	0.043	0.058	0.027	0.062	0.018	—	0.009
Buccella frigida	—	0.001	—	0.115	0.082	0.066	0.028	0.086	0.072	0.065	0.058	0.052	0.017	0.039
Buliminella elegantissima	—	—	—	0.059	0.082	0.086	0.014	0.090	0.112	0.065	0.142	0.008	0.021	0.007
Cassidulina reniforme	0.188	0.147	0.087	0.043	0.032	0.024	0.159	0.011	0.014	0.024	0.032	0.065	0.210	0.146
Cribroelphidium excavatum	0.137	0.059	0.118	0.117	0.111	0.181	0.014	0.227	0.219	0.200	0.206	0.031	0.010	0.009
Cribroelphidium foraminosum	0.016	0.046	0.060	0.002	—	—	0.002	—	—	0.034	0.006	0.018	0.008	0.021
Cribroelphidium hallandense	—	0.005	—	0.045	0.025	0.066	—	0.081	0.072	0.123	0.026	0.013	0.015	0.021
Eggerella advena	—	—	—	—	—	0.004	—	0.002	—	0.002	—	—	—	—
Eilohedra laevicula	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Elphidiella hannai	—	—	—	0.002	—	—	—	0.004	—	—	0.004	—	—	—
Epistominella pacifica	—	—	—	0.034	0.054	0.030	0.367	0.009	0.026	0.007	0.049	0.089	0.233	0.190
Epistominella vitrea	0.378	0.614	0.366	0.049	0.013	0.044	0.038	0.011	0.009	—	0.026	0.023	0.010	0.011
Euloxostomum alatum	—	—	—	—	—	—	0.036	—	—	—	—	0.042	0.050	0.023
Euuvigerina juncea	0.003	0.003	0.001	—	—	0.008	0.048	0.006	0.005	0.010	0.004	0.086	0.063	0.053
Favulina melo	—	—	—	—	0.003	0.004	—	0.006	0.002	—	0.002	—	—	—
Gaudryina arenaria	—	—	—	—	0.016	0.030	—	0.024	0.007	—	—	—	—	0.007
Gavelinopsis campanulata	—	—	—	0.047	0.041	0.010	—	0.024	0.040	0.051	0.026	—	—	0.005
Globubulimina auriculata	—	—	—	—	0.028	0.006	0.004	—	0.005	0.017	—	0.013	0.040	0.023
Globocassidulina bradshawi	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Globocassidulina subglobosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Homalohedra borealis	—	—	—	—	—	0.002	—	—	—	—	0.002	—	—	—
Islandiella californica	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Islandiella helenae	—	0.002	—	—	—	—	—	—	—	—	—	—	—	—
Islandiella limbata	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Islandiella norcrossi	0.005	0.014	0.027	—	0.003	0.008	0.006	0.006	0.002	0.007	0.017	—	0.015	—
Islandiella tortuosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Karreriella bradyi	—	—	—	—	—	0.004	—	—	—	—	—	—	—	—
Laevidentalina pauperata	—	—	—	0.008	0.013	0.020	0.022	0.015	0.012	0.019	0.002	0.185	—	0.007
Lobatula fletcheri	—	0.001	—	0.159	0.092	0.100	0.040	0.145	0.123	0.157	0.167	0.081	0.038	0.021
Lobatula lobatula	—	—	—	0.011	—	—	—	—	—	—	—	—	0.002	—
Lobatula mckannai	—	—	—	0.074	0.025	0.030	—	0.023	0.014	0.031	0.006	—	0.004	0.005
Nonionella stella	—	—	—	0.047	0.047	0.060	0.129	0.062	0.067	0.056	0.026	0.068	0.171	0.158
Nonionella turgida digitata	0.044	0.017	0.067	0.002	0.003	0.004	0.002	—	0.005	—	—	—	0.004	—
Nonionellina labradorica	0.107	0.043	0.120	—	—	—	—	—	—	—	0.015	—	—	0.066
Pseudononion basispinatum	0.002	—	0.001	—	—	—	—	—	—	—	—	—	—	—
Rosalina columbiensis	—	—	—	0.006	0.003	0.004	0.002	—	—	0.007	—	—	0.002	—
Siphonaperta stalkeri	0.009	0.007	0.006	—	—	—	—	—	—	—	—	—	—	—
Spirosigmoilina tenuis	—	—	—	0.015	0.013	—	0.002	0.006	0.005	0.005	—	0.003	0.002	0.002
Stainforthia feylingi	0.082	0.039	0.124	0.002	0.003	0.002	0.012	—	0.012	0.002	0.004	0.013	0.017	—
Trochammina ex. gr. *squamata*	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Trochammina nana	—	—	—	0.011	0.047	0.024	—	0.024	0.028	0.014	0.019	0.021	—	0.005

APPENDIX 1. Extended.

Core	90A-07	97A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07
Depth in core (cm)†	29–30	58–59	59–60	85–87	88–90	90–92	118–120	150–152	182–184	210–212	238–240	270–272	302–304	330–332
Biofacies	8	6	8	8	8	8	8	8	8	8	8	8	8	8
Total number of specimens	543	98	448	242	726	566	428	440	451	553	527	434	328	548
Angulogerina angulosa	—	—	0.002	0.004	0.007	—	—	0.002	—	0.002	0.006	0.002	—	—
Angulogerina fluens	0.006	0.010	0.007	0.033	0.021	0.002	0.040	0.018	0.027	0.022	0.021	0.030	0.015	0.013
Astrononion gallowayi	0.009	—	0.009	—	0.010	0.004	0.012	0.016	—	0.004	0.006	0.007	0.009	0.011
Bolivina decussata	0.039	—	0.074	0.025	0.084	0.044	0.114	0.093	0.029	0.094	0.140	0.083	0.024	0.088
Bolivinellina pacifica	—	—	0.004	—	0.003	0.002	0.009	0.002	—	0.005	0.006	0.007	0.003	0.018
Bucella depressa	0.007	—	0.002	0.008	0.001	0.004	0.002	0.002	—	0.014	0.002	0.007	—	—
Buccella frigida	0.026	—	0.063	0.070	0.039	0.035	0.040	0.043	0.051	0.047	0.057	0.094	0.088	0.018
Buliminella elegantissima	0.009	—	0.016	—	0.011	0.007	0.016	0.014	—	0.007	0.008	0.005	—	0.005
Cassidulina reniforme	0.142	0.020	0.158	0.029	0.260	0.200	0.154	0.123	0.100	0.116	0.148	0.076	0.067	0.093
Cribroelphidium excavatum	0.006	0.102	0.013	0.062	0.014	0.014	0.042	0.007	0.027	0.034	0.046	0.025	0.021	0.029
Cribroelphidium foraminosum	0.011	—	0.002	—	0.003	—	0.009	0.005	—	0.016	0.006	—	—	—
Cribroelphidium hallandense	0.009	—	0.018	0.017	0.019	0.007	0.019	0.023	0.016	0.013	0.015	0.032	0.006	0.031
Eggerella advena	—	—	—	—	—	—	—	—	—	0.002	—	—	—	—
Eilohedra laevicula	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Elphidiella hannai	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Epistominella pacifica	0.131	—	0.263	0.293	0.136	0.281	0.063	0.195	0.397	0.188	0.139	0.115	0.125	0.040
Epistominella vitrea	0.009	—	0.013	0.021	0.011	0.004	0.012	0.014	0.024	0.024	0.065	0.076	0.012	0.036
Euloxostomum alatum	0.092	—	0.036	—	0.022	0.030	0.035	0.050	0.018	0.027	0.036	0.069	0.012	0.102
Euuvigerina juncea	0.099	—	0.036	0.087	0.052	0.058	0.070	0.048	0.047	0.092	0.042	0.067	0.143	0.047
Favulina melo	0.002	—	—	—	—	—	—	—	—	0.002	—	—	—	—
Gaudryina arenaria	0.002	—	0.007	—	0.010	—	0.005	—	—	0.007	0.006	—	—	—
Gavelinopsis campanulata	—	—	—	—	0.003	—	0.002	0.005	0.002	—	—	—	—	—
Globubulimina auriculata	0.074	—	0.011	—	0.012	0.032	0.016	0.020	—	0.005	0.004	0.037	—	0.029
Globocassidulina bradshawi	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Globocassidulina subglobosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Homalohedra borealis	—	—	—	0.004	0.001	—	—	0.005	—	0.004	0.004	0.002	0.003	—
Islandiella californica	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Islandiella helenae	—	—	—	0.004	—	—	—	—	—	0.002	—	—	0.006	—
Islandiella limbata	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Islandiella norcrossi	—	0.031	0.002	0.062	0.003	0.004	0.005	0.005	—	0.016	0.017	0.002	0.058	0.009
Islandiella tortuosa	—	—	—		—	—	—	—	—	—	—	—	—	—
Karreriella bradyi	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Laevidentalina pauperata	0.044	—	0.022	0.025	0.059	0.004	0.075	0.064	—	—	—	—	0.003	—
Lobatula fletcheri	0.033	0.765	0.018	0.050	0.059	0.021	0.058	0.036	0.031	0.058	0.065	0.046	0.034	0.029
Lobatula lobatula	—	0.020	—	—	—	—	—	—	—	—	0.002	—	—	—
Lobatula mckannai	0.002	0.010	0.004	—	0.003	—	0.009	—	0.002	0.009	0.002	—	—	—
Nonionella stella	0.168	—	0.165	0.157	0.091	0.207	0.126	0.182	0.109	0.056	0.074	0.094	0.253	0.246
Nonionella turgida digitata	0.006	—	—	—	0.008	0.005	0.005	0.002	—	0.002	0.002	0.007	—	0.018
Nonionellina labradorica	0.011	—	0.022	0.017	0.018	—	0.016	0.005	0.111	0.094	0.053	0.058	0.082	0.046
Pseudononion basispinatum	—	—	—	—	—	—	—	—	—	—	—	0.002	0.018	—
Rosalina columbiensis	—	—	—	—	—	—	0.002	—	—	0.007	0.002	0.005	—	0.011
Siphonaperta stalkeri	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Spirosigmoilina tenuis	0.002	—	—	—	0.007	0.002	0.009	0.002	—	0.002	0.002	0.002	—	0.024
Stainforthia feylingi	0.013	—	0.016	0.012	0.010	0.014	0.007	0.005	—	—	0.004	0.016	0.003	0.029
Trochammina ex. gr. *squamata*	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Trochammina nana	0.006	—	0.004	—	—	—	0.002	0.002	—	—	—	0.005	—	0.005

APPENDIX 1. Extended.

Core	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07	90A-07
Depth in core (cm)†	358–360	390–392	422–424	450–452	482–484	510–512	531–533	536–538	570–572	590–592	622–624	650–652	668–670
Biofacies	8	8	8	8	8	8	7	8	6	7	6	9	6
Total number of specimens	63	419	503	774	634	458	558	429	234	435	476	945	372
Angulogerina angulosa	—	—	0.004	0.008	—	0.015	—	0.007	—	0.007	0.002	0.003	0.003
Angulogerina fluens	0.016	0.017	0.020	0.030	0.027	0.055	0.023	0.047	—	0.018	0.015	0.012	0.011
Astrononion gallowayi	—	0.005	0.004	0.001	0.003	0.007	0.013	—	—	0.002	0.025	0.033	0.011
Bolivina decussata	0.063	0.026	0.026	0.052	0.058	0.017	0.036	0.021	0.034	0.053	0.017	0.066	0.030
Bolivinellina pacifica	—	0.007	0.008	0.001	0.005	—	—	—	—	—	—	0.003	—
Bucella depressa	—	0.002	—	—	—	0.002	0.005	0.002	—	0.005	0.004	0.004	0.003
Buccella frigida	0.095	0.072	0.048	0.044	0.044	0.070	0.034	0.142	—	0.037	0.027	0.052	0.032
Buliminella elegantissima	—	0.010	—	0.003	0.002	—	0.002	0.002	—	0.002	0.008	0.163	0.005
Cassidulina reniforme	0.063	0.057	0.042	0.049	0.030	0.015	0.032	0.044	0.038	0.037	0.023	0.051	0.024
Cribroelphidium excavatum	0.079	0.031	0.064	0.032	0.036	0.035	0.134	0.054	0.073	0.080	0.149	0.163	0.148
Cribroelphidium foraminosum	—	0.010	0.004	—	0.006	0.007	0.004	—	—	0.002	0.002	0.002	0.003
Cribroelphidium hallandense	—	0.012	0.006	0.019	0.009	—	0.041	0.007	0.030	0.023	0.036	0.080	0.019
Eggerella advena	—	—	—	—	—	—	—	—	—	—	—	—	—
Eilohedra laevicula	—	—	—	—	—	—	—	—	—	—	—	—	—
Elphidiella hannai	—	—	—	—	—	—	—	—	—	—	—	—	—
Epistominella pacifica	0.270	0.041	0.187	0.177	0.218	0.234	0.034	0.145	—	0.067	0.011	0.024	0.008
Epistominella vitrea	—	0.031	0.018	0.037	0.047	0.015	0.013	0.019	—	0.009	0.013	0.052	0.011
Euloxostomum alatum	—	0.038	0.020	0.021	0.008	0.009	0.002	—	—	0.009	—	—	—
Euuvigerina juncea	0.095	0.119	0.064	0.097	0.084	0.070	0.027	0.207	—	0.034	0.011	0.004	0.005
Favulina melo	—	—	0.004	—	—	0.002	0.004	—	—	—	—	0.001	—
Gaudryina arenaria	—	0.005	—	—	—	—	—	—	—	—	—	0.002	—
Gavelinopsis campanulata	—	—	—	0.008	—	—	—	—	—	—	—	0.024	0.003
Globubulimina auriculata	—	0.033	0.026	0.003	—	0.007	0.002	0.002	—	—	0.002	0.003	—
Globocassidulina bradshawi	—	—	—	—	—	—	—	—	—	—	—	—	—
Globocassidulina subglobosa	—	—	—	—	—	—	—	—	—	—	—	—	—
Homalohedra borealis	—	—	0.002	—	0.002	0.004	0.013	0.012	—	0.007	0.015	0.003	0.011
Islandiella californica	—	—	—	—	—	—	—	—	—	—	—	—	—
Islandiella helenae	—	—	—	0.003	0.006	0.011	0.002	0.012	0.009	0.002	0.004	—	0.005
Islandiella limbata	—	—	—	—	—	—	—	—	—	—	—	—	—
Islandiella norcrossi	0.079	0.012	0.028	0.040	0.054	0.124	0.022	0.093	0.068	0.016	0.023	0.002	0.022
Islandiella tortuosa	—	—	—	—	—	—	—	—	—	—	—	—	—
Karreriella bradyi	—	—	—	—	—	—	0.016	—	—	0.009	0.015	0.001	0.013
Laevidentalina pauperata	—	—	—	—	—	—	—	—	—	—	—	—	—
Lobatula fletcheri	0.016	0.021	0.016	0.026	0.038	0.081	0.328	0.126	0.718	0.331	0.443	0.138	0.505
Lobatula lobatula	—	—	0.002	0.001	—	—	0.011	—	—	0.021	0.004	0.002	0.013
Lobatula mckannai	0.032	0.002	—	0.004	0.006	—	0.090	0.023	0.021	0.085	0.074	0.007	0.075
Nonionella stella	0.159	0.296	0.340	0.279	0.244	0.155	0.038	0.026	—	0.078	0.006	0.031	0.005
Nonionella turgida digitata	—	0.005	—	0.001	0.002	—	—	—	—	—	—	—	—
Nonionellina labradorica	—	0.079	0.042	0.040	0.052	0.055	0.002	—	—	0.018	—	—	—
Pseudononion basispinatum	0.016	0.007	0.004	—	0.005	—	—	—	—	0.002	—	0.010	—
Rosalina columbiensis	—	—	—	0.003	0.002	—	0.002	—	—	—	—	0.006	—
Siphonaperta stalkeri	—	—	—	—	—	—	—	—	—	0.002	—	—	—
Spirosigmoilina tenuis	—	0.005	—	0.001	0.002	0.002	—	—	—	—	—	0.006	—
Stainforthia feylingi	—	0.033	0.004	0.004	—	—	—	—	—	—	0.002	0.010	—
Trochammina ex. gr. *squamata*	—	—	—	—	—	—	—	—	—	—	—	—	—
Trochammina nana	—	0.002	—	—	—	—	—	—	—	—	0.002	0.022	—

APPENDIX 2. List of all species encountered. Due to space considerations, species are listed with author name and year of publication only. In cases where the present generic designation differs from the original, the original name is provided in square brackets. Species preceded by † are "temperate" species, that is, not found living in the northern Bering Sea and further north.

†?*Acervulina*
Adercotryma glomerata (Brady), 1878, [*Lituola*]
Ammodiscus cf. *A. catinus* Höglund, 1947
?*Ammotium salsum* (Cushman and Brönniman), 1948, [*Ammobaculites*]
Angulodiscorbis quadrangulata Uchio, 1953
Angulogerina angulosa (Williamson), 1858, [*Uvigerina*]
Angulogerina fluens Todd, 1948
Astacolus planatus Galloway and Wissler, 1927
Astacolus sp.
Astrononion gallowayi Loeblich and Tappan (1953)
†*Bolivina decussata* Brady, 1881 (=*Bolivina minuta* Natland of Patterson and others, 1995)
Bolivina fragilis Phleger and Parker, 1951
Bolivina pseudoplicata Heron-Allen and Earland, 1932
†*Bolivina subaenariensis* Cushman, 1922
Bolivinellina pacifica (Cushman and McCulloch), 1942, [*Bolivina acerosa* Cushman var.]
Botuloides pauciloculus Zheng, 1979
Brizalina cf. *B. quadrata* (Cushman and McCulloch), 1942, [*Bolivina*]
Brizalina spinata (Cushman), 1936, [*Bolivina striatula* Cushman var.]
†*Buccella depressa* Andersen, 1952
Buccella frigida (Cushman), 1922, [*Pulvinulina*]
Bulimina aculeata d'Orbigny, 1826
†*Bulimina inflata* Seguenza, 1862
Buliminella elegatissima (d'Orbigny), 1839, [*Bulimina*]
†*Buliminella subfusiformis* Cushman, 1925
Cassidulina reniforme Nørvang, 1945, [*Cassidulina crassa* d'Orbigny var.]
Chilostomella oolina Schwager, 1878
†*Cribroelphidium advenum* (Cushman), 1922, [*Polystomella*]
Cribroelphidium aff. *C. discoidale* (d'Orbigny), 1839, [*Polystomella*]
Criboelphidium excavatum (Terquem), 1876, [*Polystomella*]
Criboelphidium foraminosum (Cushman), 1939, [*Elphidium hughesi* Cushman and Grant var.]
†*Criboelphidium gerthi* (van Voorthuysen), 1957, [*Elphidium*]
Criboelphidium hallandense (Brotzen), 1943, [*Elphidium*]
Criboelphidium incertum (Williamson), 1858, [*Polystomella*]
†*Criboelphidium microgranulosum* (Galloway and Wissler *in* Thalmann), 1951, [*Elphidium*]
Cribostomoides jeffreysii (Williamson), 1858, [*Nonionina*]
Cyclogyra involvens (Reuss), 1850, [*Operculina*]
Dentalina ittai Loeblich and Tappan, 1953
†*Dorothia bradyana* Cushman, 1937
†*Dyocibicides biserialis* Cushman and Valentine, 1930
Eggerella advena (Cushman), 1922, [*Verneuilina*]
†*Ehrenbergina compressa* Cushman, 1927
†*Eilohedra laevicula* (Resig), 1958, [*Epistominella*]
Elphidiella arctica Parker and Jones, 1864
Elphidiella hannai (Cushman and Grant), 1927, [*Elphidium*]
Eoeponidella pulchella (Parker), 1952, [*Pninaella*]
†*Epistominella pacifica* (Cushman), 1927, [*Pulvinulina*]
Epistominella vitrea Parker, 1953
Epistominella sp.
†*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 artolabiata Patterson, 1990
Fissurina copiosa McCulloch, 1977
Fissurina cucurbitasema Loeblich and Tappan, 1953
Fissurina eburnea (Buchner), 1940, [*Lagena*]
Fissurina fasciata (Egger), 1857, [*Oolina*]
Fissurina laevigata Reuss, 1850
Fissurina lucida (Williamson), 1848, [*Entosolenia marginata* (Montagu) var.]
Fissurina marginata (Walker and Boys), 1784, [*Serpula*]
Fissurina marmoraria (Buchner), 1940, [*Lagena*]
Fissurina cf. *F. pseudoglobosa* (Buchner), 1940, [*Lagena*]
Fissurina serrata (Schlumberger), 1894, [*Lagena*]
Fissurina subquadrata Parr, 1945
Fissurina vitreola (Buchner), 1940, [*Lagena*]
Fissurina sp. 1
Fissurina sp. 2
Fissurina sp. 3
Fissurina sp. 4
Fissurina sp. 5
Fredsmithia sanclementensis McCulloch, 1977
†*Frondicularia gigas* Church, 1929
Galwayella sp.
†*Gaudryina arenaria* Galloway and Wissler, 1927
†*Gaudryina subglabrata* Cushman and McCulloch, 1939
†*Gavelinopsis campanulata* (Galloway and Wissler), 1927, [*Globorotalia*]
Glabratella arctica Scott and Vilks, 1991
Glabratella californiana Lankford *in* Lankford and Phleger, 1973
Glabratella ornatissima (Cushman), 1925, [*Discorbis*]
Glabratella wrightii (Brady), 1881, [*Discorbina*]
Glabratella sp.
Globobulimina auriculata (Bailey), 1851, [*Bulimina*]
†*Globocassidulina bradshawi* (Uchio), 1960, [*Cassidulina*]
†*Globocassidulina* cf. *G. obtusa* (Williamson), 1858, [*Cassidulina*]
Globocassidulina subglobosa (Brady), 1881, [*Cassidulina*]
Glomospira sp.
?*Goesella flintii* Cushman, 1933
?*Gyroidina*
Gyroidinoides altiformis Stewart and Stewart, 1930
Haplophragmoides bradyi (Robertson), 1891, [*Trochammina*]
Haplophragmoides cf. *H. quadratus* Uchio, 1960
Haynesina cf. *H. incilis* (Lankford & Phleger), 1973, [?*Astrononion*]
Haynesina aff. *H. nivea* (Lafrenz), 1963, [*Nonion*?]
Haynesina orbiculare (Brady), 1881, [*Nonionina*]
Heronallenia sp.
Homalohedra apiopleura (Loeblich and Tappan), 1953, [*Lagena*]
Homalohedra borealis (Loeblich and Tappan), 1954, [*Oolina*]
Homalohedra gunteri (Earland), 1934, [*Lagena*]
Homalohedra quasilineata Patterson, 1990
Hyalinonetrion dentaliforme (Bagg), 1912, [*Lagena*]
Hyalinonetrion sahulense Patterson and Richardson, 1988
Irenita cf. *I. cornigera* (Buchner), 1940, [*Lagena*]
†*Islandiella californica* (Cushman and Hughes), 1925, [*Cassidulina*]
Islandiella helenae Feyling-Hanssen and Buzas, 1976
†*Islandiella limbata* (Cushman and Hughes), 1925, [*Cassidulina*]
Islandiella norcrossi (Cushman), 1933, [*Cassidulina*]
†*Islandiella tortuosa* (Cushman and Hughes), 1925, [*Cassidulina*]
†*Karreriella bradyi* (Cushman), 1911, [*Gaudryina*]
Laevidentalina californica (Cushman and Gray), 1946, [*Dentalina*]
Laevidentalina pauperata (d'Orbigny), 1846, [*Dentalina*]
Lagena dorseyae McLean, 1956
Lagena fidicularia Patterson, 1993
Lagena flatulenta Loeblich and Tappan, 1953
Lagena cf. *L. laevis* Wright, 1886
Lagena semilineata Wright, 1886

APPENDIX 2. Continued.

Lagena aff. *L. semilineata*
Lagena spicata Cushman and McCulloch, 1950
Lagena striata (d'Orbigny), 1839, [*Oolina*]
Lagena striaticollis (d'Orbigny), 1839, [*Oolina*]
Lagena sp.
Lagenosolenia aff. *L. soulei* McCulloch, 1977
Lagenosolenia sp.
Lamarckina haliotidea (Heron-Allen and Earland), 1911, [*Pulvinulina*]
Laryngosigma trilocularis (Bagg), 1912, [*Polymorphina*]
Laryngosigma spp.
†*Lenticulina nikobarensis* (Schwager), 1866, [*Cristellaria*]
Lenticulina spp.
Lobatula fletcheri (Galloway and Wissler), 1927, [*Cibicides*]
Lobatula lobatula (Walker and Jacob), 1798, [*Nautilus*]
†*Lobatula mckannai* (Galloway and Wissler), 1927, [*Cibicides*]
†*Lobatula pseudoungeriana* (Cushman), 1922, [*Truncatulina*]
Marginulina pauciloculata (Cushman and Gray), 1946, [*Vaginulina advena* Cushman var.]
†*Metapolymorphina charlottensis* (Cushman), 1977, [*Polymorphina*]
†*Montfortella bramlettei* Loeblich and Tappan, 1963
†*Neoconorbina parkerae* (Natland), 1950, [*Discorbis*]
†*Nonionella stella* Cushman and Moyer, 1930, [*Nonionella miocenica* Cushman var.]
Nonionella turgida (Williamson), 1858, [*Rotalina*]
Nonionella turgida digitata Nørvang, 1945
Nonionellina labradorica (Dawson), 1860, [*Nonionina*]
Oolina caudigera (Wiesner), 1931, [*Lagena* (*Entosolenia*) *globosa* (Montagu) var.]
Oolina lineata (Williamson), 1848, [*Entosolenia*]
Oolina squamoso-sulcata (Heron-Allen and Earland), 1922, [*Lagena*]
Oolina williamsoni (Alcock), 1865, [*Entosolenia*]
Palliolatella frangens (Buchner), 1940, [*Lagena*]
Palliolatella immemora Patterson, 1990
Parafissurina semicarinata (Buchner), 1940, [*Parafissurina lateralis* (Cushman) forma]
Parafissurina tectulostoma Loeblich and Tappan, 1953
Parafissurina sp.
Patellina corrugata Williamson, 1858
Undifferentiated polymorphinids
Praeglobobulimina spinescens (Brady), 1884, [*Bulimina pyrula* d'Orbigny var.]
Procerolagena amphoriniformis (McCulloch), 1977, [*Lagena*]
Procerolagena complurecosta (Patterson), 1990, [*Lagena*]
Procerolagena gracilis (Williamson), 1848, [*Lagena*]
Procerolagena meridionalis Wiesner, 1931, [*Lagena gracilis* Williamson var.]
Procerolagena simulampulla Patterson, 1991
Procerolagena wiesneri Parr, 1950, [*Lagena striata* (Montagu) var.]
†*Pseudononion basispinatum* (Cushman and Stewart), 1930, [*Nonion pizarrensis* Berry var.]
?*Pullenia osloensis* Feyling-Hanssen, 1964
†*Pullenia salisburyi* Stewart and Stewart, 1930
Pygmaeoseistron hispidulum (Cushman), 1913, [*Lagena*]
Pygmaeoseistron hispidum (Reuss), 1863, [*Lagena*]
Pyrgo lucernula (Schwager), 1866, [*Biloculina*]
Pyrgo vespertilio (Schlumberger), 1891, [*Biloculina*]
Quinqueloculina akneriana d'Orbigny, 1846
Quinqueloculina arctica Cushman, 1948
Quinqueloculina seminulum (Linné), 1758, [*Serpula*]
Recurvoides sp.
†*Remaneica helgolandica* Rhumbler, 1938
Reophax cf. *R. subfusiformis* Earland, 1933
Rhizammina sp.
Robertinoides charlottensis (Cushman), 1925, [*Cassidulina*]
Robertinoides cf. *R. suecicum* Höglund, 1947
†*Rosalina columbiensis* (Cushman), 1925, [*Discorbis*]
Rosalina sp.
†*Rutherfordoides* cf. *R. rotundiformis* (McCulloch), 1977, [*Rutherfordia*]
Saccammina atlantica (Cushman), 1944, [*Proteonina*]
Scutuloris tegminis Loeblich and Tappan, 1953
†*Seabrookia earlandi* Wright, 1889
Siphonaperta stalkeri (Leoblich and Tappan), 1953, [*Quinqueloculina*]
†*Siphonaperta* n. sp. (to be described in a forthcoming paper)
Solenina sp.
Spiroplectammina biformis (Parker and Jones), 1865, [*Textularia agglutinans* d'Orbigny var.]
†*Spirosigmoilina tenuis* (Czjzek), 1848, [*Quinqueloculina*]
Stainforthia feylingi Knudsen and Seidenkrantz, 1993
†*Stainforthia sandiegoensis* (Uchio), 1960, [*Virgulina*]
Stetsonia arctica (Green), 1960, [*Epistominella*]
Suggrunda eckisi Natland, 1950
?*Textularia earlandi* Parker, 1952
Tortaguttus timmsensis (Cushman and Gray), 1946, [*Entosolenia*]
Triloculina cf. *T. tricarinata* d'Orbigny, 1826
Triloculina oblonga (Montagu), 1803, [*Vermiculum*]
Triloculina sp.
Trochammina cf. *T. advena* Cushman, 1922
Trochammina cf. *T. globigeriniformis* (Parker and Jones)
Trochammina nana (Brady), 1881, [*Haplophragmium*]
Trochammina cf. *T. rotaliformis* Heron-Allen and Earland, 1911
Trochammina ex gr. *T. squamata* Parker and Jones, 1865
Ventrostoma depressa (Chaster), 1892, [*Lagena*]
Ventrostoma cf. *V. fovigera* (Buchner), 1940, [*Lagena*]
Waldoschmittia sp.
Wiesnerina cf. *unguis* (Heron-Allen and Earland), 1913, [*Lagena*]
Wiesnerina sp.