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Research paper

Linkages between modern benthic foraminiferal assemblages and environmental conditions at continental slope depths: From Baffin Bay to the Labrador Sea

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ABSTRACT

Analysis of benthic foraminiferal assemblages and lipid biomarkers from surface sediments at 10 sites along the Greenland margin in Baffin Bay, in the Davis Strait, and Labrador Sea, spanning both shallow (<1000 m) and deep (>1000 m) water depths, reveals key differences related to environmental gradients. The relative abundance of calcareous and agglutinated foraminifera differentiates sites; deeper Baffin Bay sites are dominated by agglutinated taxa, while shallower Baffin Bay sites and a site in the Labrador Sea are characterised by calcareous taxa. Correlations amongst calcareous species and environmental parameters, specifically bottom water temperature and salinity from CTD casts, sea ice, open water phytoplankton biomarker concentrations and total organic carbon, suggest that carbonate dissolution is associated with seasonal sea-ice formation, cold and less saline bottom waters, and high primary productivity. *Cassidulina neoteretis* and *Cassidulina reniforme* are abundant at almost all sites, reflecting the presence of chilled Atlantic sourced water. In eastern Davis Strait, sea ice is absent for much of the year and the faunal assemblage is dominated by calcareous taxa, specifically *Nonionellina labradorica, Elphidium clavatum, Epistominella arctica* and *Melonis barleeanus*. In the Labrador Sea, which is characterised by warmer bottom waters and less seasonal sea-ice, the fauna differs from Baffin Bay, dominated by *Buccella frigida* and *Nonionella iridea.* Agglutinated taxa, particularly *Portatrochammina bipolaris*, *Hormosinelloides guttifera*, *Lagenammina difflugiformis* and *Recurvoides turbinatus*, dominate Baffin Bay sites, where cold, sea-ice-influenced bottom waters prevail. Linking faunal assemblages, including agglutinated taxa, to environmental datasets is critical for paleoenvironmental reconstructions, especially in regions where calcareous foraminifera are poorly preserved.

1. Introduction

Benthic foraminiferal assemblages have been used extensively for environmental reconstructions in the Arctic, specifically to understand past conditions of ocean circulation, glacial proximity, nutrient availability and sea-ice cover, amongst others (Davies et al., 2022; Hansen et al., 2022; Hansen et al., 2020; Jennings et al., 2011; Kelleher et al., 2022; Pados-Dibattista et al., 2022; Ramsgaard Stoltenberg et al., 2025; Seidenkrantz, 2013). This approach relies on understanding the modern environmental preferences of key foraminiferal species and is

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often complemented by the use of additional sediment-based proxies (e.g. algal lipid biomarkers) for past oceanographic conditions. To provide the most informed paleoenvironmental interpretations, as well as to enable quantification of environmental parameters and associated uncertainties, there is a need to examine the modern distribution of benthic foraminiferal assemblages and algal lipid biomarkers in Arctic surface sediment. During *The Baffin Bay Deglacial Experiment* (BADEX) Expedition (Cruise AR76–01; Hatfield et al., 2023) of RV *Neil Armstrong*, sediment multi-cores were collected along the continental slope of Baffin Bay, Davis Strait, and at one site in the Labrador Sea, to examine benthic foraminiferal assemblage changes along a latitudinal gradient.

Numerous studies have examined the distribution of modern benthic foraminiferal assemblages in the Arctic; in Northeast (e.g. Ahrens et al., 1997; Davies et al., 2023; Limoges et al., 2018; Piepenburg et al., 1997), Eastern (e.g. Jennings and Helgadottir, 1994; Madsen and Knudsen, 1994), Northern (Jennings et al., 2020), and Western (e.g. Lloyd, 2006; Racine et al., 2023; Schafer and Cole, 1986; Schröder-Adams and Van Rooyen, 2011) Greenland, as well as the Arctic Ocean (e.g. Husum et al., 2015; Wollenburg and Mackensen, 1998) and Russian Arctic (e.g. Korsun and Hald, 1998), amongst others. Such studies provide vital information relating to environmental factors controlling the distribution of benthic foraminifera (e.g. water mass temperatures and salinities, sea-ice cover, productivity, amongst others) based on the abundance of specific benthic foraminiferal species as well as percentage of agglutinated vs calcareous taxa.

Environmental reconstructions from marine sediment cores frequently utilise a multi-proxy approach. As such, analysing multiple proxies in modern sediment samples, and comparing the results to known environmental data, improves the reliability of paleoreconstructions. For example, lipid biomarkers (IP_{25}, HBI II and phytoplankton sterols) have been used together with benthic foraminiferal data, to reconstruct sea-ice and productivity conditions (e.g. Jennings

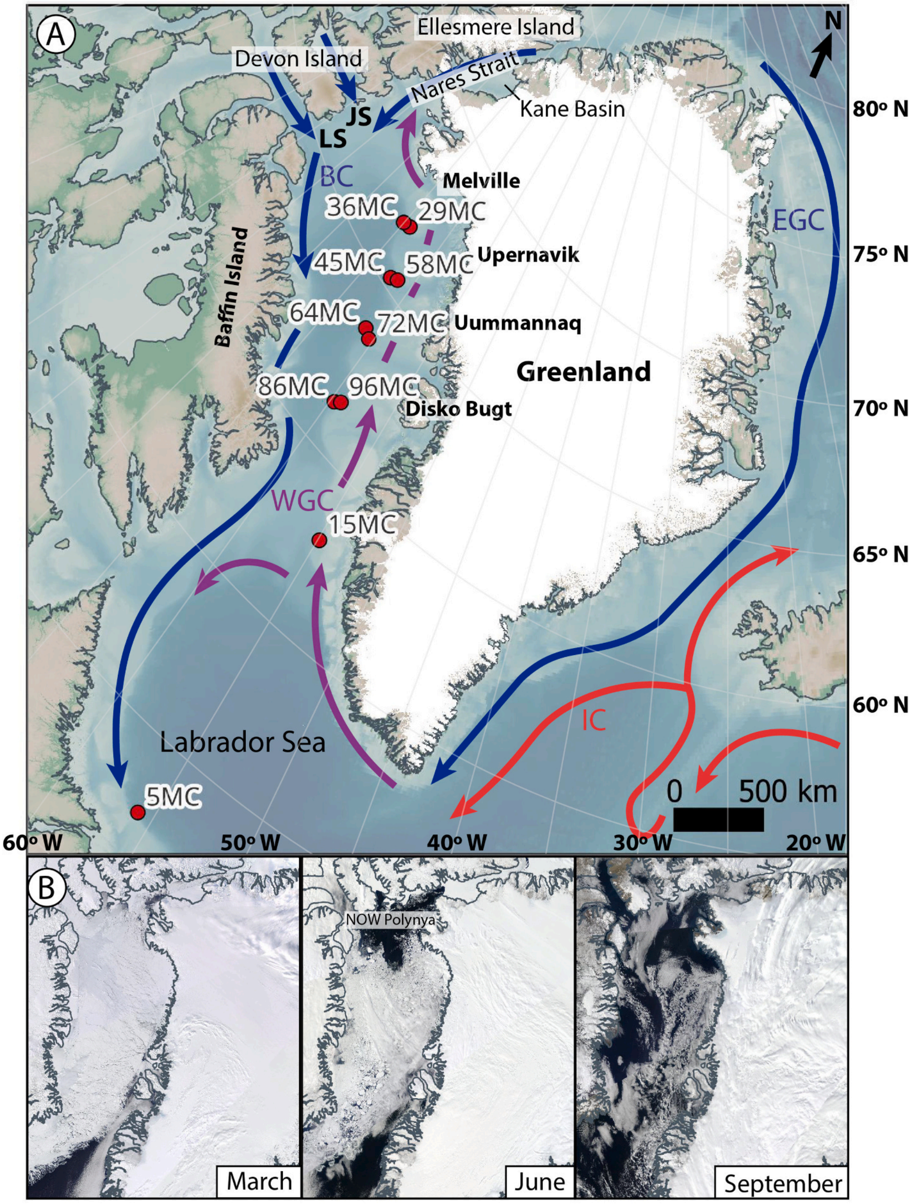

Fig. 1. Overview of study sites: A) Map of Greenland and surrounding oceans showing site locations (red circles), for full sample names see Table 1, and key ocean currents coloured according to the water mass. Polar water masses (blue): East Greenland Current (EGC), Baffin Current (BC), Atlantic sourced waters (red): Irminger Current (IC) and mixed water masses (purple): West Greenland Current (WGC). Lancaster Sound (LS) and Jones Sound (JS) are marked B) Baffin Bay sea-ice conditions in 2023: 23 March (left), 2 June (middle) and 2 September (right). The North Water (NOW) polynya is marked. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

et al., 2018; Lloyd et al., 2023; Syring et al., 2020; Harning et al., 2025). Whilst many studies have utilised benthic foraminiferal assemblages, amongst other proxies, for reconstructions of environmental conditions in Baffin Bay (e.g. Hansen et al., 2020; Jackson et al., 2021; Jennings et al., 2018; Kelleher et al., 2022; Knudsen et al., 2008; Mudie and Aksu, 1984; Perner et al., 2011; Seidenkrantz, 2013), studies of modern foraminiferal assemblages, that link species distributions to environmental characteristics, are fewer and tend to cover smaller geographical areas, shallower water depths, and thus do not encompass large environmental gradients (e.g. Lloyd, 2006; Racine et al., 2023; Schröder-Adams and Van Rooyen, 2011).

Here, we present benthic foraminiferal assemblage and sea-ice biomarker (IP_{25}, HBI II and phytoplankton sterols) data, from sediment samples spanning a north-south transect in Baffin Bay, West Greenland (68°–74.4° N), together with a surface sample from the Davis Strait (65.5° N) and Labrador Sea (55.5° N). These samples span 650 to 1651 m water depth. We use environmental data from these core tops, together with measured oceanic conditions recorded from CTD casts and sea-ice concentration data at the same locations, to explain key drivers of assemblage variance in this region.

2. Study area

Baffin Bay is a 450 km wide, semi-enclosed basin, framed by Greenland, Ellesmere Island, Devon Island and Baffin Island (Fig. 1A); it has an average water depth of 800 m, but exceeds 2300 m in the centre (Tang et al., 2004). The water in Baffin Bay originates from the Atlantic and Arctic oceans (Tang et al., 2004). Baffin Bay is linked to the Labrador Sea by Davis Strait and to the Arctic Ocean by a series of gateways (Lancaster Sound, Jones Sound, and Nares Strait). The West Greenland Current (WGC) transports water masses northwards, consisting of Atlantic-sourced water masses from the Irminger Current (IC) as well as colder polar waters from the East Greenland Current (EGC). These Atlantic-sourced waters occupy the continental slope areas (depths of 200–1000 m) and the lower salinity, polar waters occupy the upper 200 m (Rykova et al., 2015). As the WGC travels northwards it bifurcates with one branch flowing westward in southern Davis Strait, joining the Outer Labrador Current and the other continuing northwards where it meets Arctic waters entering northern Baffin Bay and cools (Tang et al., 2004). The cold Arctic surface layer spreads southwards and extends to depths of about 100 m in northeastern Baffin Bay, occupying surface waters on the Greenland slope (Tang et al., 2004). Arctic surface water travels southwards adjacent to Baffin Island as the Baffin Current (BC). The deepest part of the water column is made up of Baffin Bay Deep Water (BBDW; 1200–1800 m) and Baffin Bay Bottom Water (BBBW; >1800 m), which are formed by local brine production during winter sea ice formation, cooling of surface waters flowing through Kane Basin and movement of cold, saline waters from the North Water (NOW) polynya (Bourke and Paquette, 1991; Tan and Strain, 1980).

Sea ice begins to develop in September in Northern Baffin Bay, as solar radiation and temperatures decline, before expanding southwards and reaching its maximum extent in March when the entire bay, apart from eastern Davis Strait and the NOW Polynya, is covered by sea ice (Fig. 1B; Bi et al., 2019; Tang et al., 2004). Sea ice, including multi-year ice, is also transported to Baffin Bay via Smith Sound and Lancaster Sound (Dey, 1980). More extensive sea-ice cover characterises the western part of Baffin Bay, compared to the east; this is attributed to the flow of relatively warm waters that are carried by the WGC (Tang et al., 2004).

3. Methodology

3.1. Core collection and sampling

Sediment samples were collected as part of the BADEX project, from RV *Neil Armstrong* in July/August 2023. Ten multi-cores (MC) were collected from sites in Baffin Bay, Davis Strait and the Labrador Sea spanning both deep (>1000 m) and shallower (<1000 m) depths along the continental slope (Table 1). Downcore multicore samples were taken at 1 cm increments for all cores, apart from 15MC due to limited recovery. In this study, benthic foraminiferal analysis, together with lipid biomarker and sedimentological analysis were undertaken for the surface sediment samples (0–1 cm) and additional benthic foraminiferal analysis was conducted on subsurface sediment samples (4–5 cm). Biomarker samples were kept frozen in furnaced aluminium foil prior to biomarker analysis. Foraminifera sample volumes were recorded. Bulk density was measured using 1 cm^3 samples; these were weighed wet and after drying in the freeze drier, the concentration of foraminifera/g dry sediment was estimated from the sample volume and bulk density data.

3.2. Benthic foraminiferal analysis

After collection, sediment samples were stored in a buffered solution comprising distilled water (70 %), alcohol (30 %) and baking soda, with Rose Bengal stain added to identify living (stained) and dead (unstained) foraminiferal tests. Whilst staining samples with Rose Bengal is commonly used in foraminiferal research, there are disadvantages linked to overstaining. This specifically relates to the fact that all protein-bearing tests are stained, potentially resulting in species that have recently died being counted as stained leading to an overestimation of living foraminifera (de Nooijer et al., 2006). Samples were stored in this buffered solution at 4 °C until processing. Foraminifera identification and counting was undertaken relatively soon after sample collection (collected in August 2023, counted in Winter/Spring 2024/25), in the Micropaleontology Laboratory at INSTAAR, University of Colorado and at the Lamont-Doherty Earth Observatory (LDEO). Samples were sieved using a 63-μm-mesh size and stored in the buffered solution (minus Rose Bengal stain), keeping the pH close to 8.4. Foraminiferal assemblage analysis was performed for all surface sediment samples (0–1 cm), for comparison with known, modern environmental data, and subsurface (4–5 cm) sediment samples were also examined to quantify the living component of total benthic foraminifera and assess dissolution. A subsurface sample (4–5 cm) was not taken for core 15MC due to limited recovery at this site (Hatfield et al., 2023).

Table 1
Overview of multi-cores (MCs) used in this study. Sites located at >1000 m water depth are marked with *.

Core name	Short name	Lat. (°)	Lon. (°)	Location	Water depth (m)
AR2307-29MC	29MC	74.415	−64.029	Melville Bugt	842
AR2307-36MC	36MC*	74.404	−64.892	Melville Bugt	1651
AR2307-45MC	45MC*	72.836	−62.26	Upernavik	1630
AR2307-58MC	58MC	72.902	−61.546	Upernavik	867
AR2307-64MC	64MC*	71.16	−61.26	Uummannaq	1602
AR2307-72MC	72MC	70.94	−60.437	Uummannaq	781
AR2307-86MC	86MC*	68.7864	−59.736	Disko Bugt	1321
AR2307-96MC	96MC	68.88	−59.26	Disko Bugt	697
AR2307-15MC	15MC	65.039	−55.039	Davis Strait	650
AR2307-5MC	5MC*	55.506	−56.096	Labrador Sea	1247

Analysis of the benthic foraminiferal assemblages was undertaken in the buffered solution in a picking tray using a binocular microscope. Samples with a large number of foraminifera tests were split using a wet splitter to divide samples into eighths. At least 300 benthic foraminifera were counted in each surface (0–1 cm) sample, apart from 15MC where 206 tests were counted (total tests in the sample). There were significantly fewer specimens in subsurface (4–5 cm) samples (< 200 foraminifera) generally, apart from in 45MC and 5MC. Species abundance was calculated as a percentage of the total assemblages (calcareous and agglutinated combined). The concentration of foraminifera (tests/ g dry sed) was calculated, based on the known volume of each sample and the dry weights of a 1 cm^3 sample. Indicator species are plotted, defined as those present in the highest abundances (>4 %), as well as having distinguishable environmental preferences.

3.3. *Lipid biomarkers*

Analysis was undertaken on surface samples (0–1 cm) at all sites. Samples were freeze dried and homogenised prior to analysis. Measurements were made in the LDEO Organic Geochemistry Laboratory.

3.3.1. *HBI and sterol extraction and analysis*

Internal standards were added to homogenised sediment prior to extraction: 9-octylheptadec-8-ene (9-OHD) and 5α-androstan-3β-ol (Androstanol) for the purpose of quantification. Lipids were extracted in a sonication water bath at 70 °C for 1 h using 0.5 N potassium hydroxide (KOH) in methanol (MeOH): organics-free water (*v*/v 95:5). Non-saponifiable lipids were then recovered by liquid-liquid phase separation with hexane three times. Silica gel chromatography was used to separate lipid classes using pre-cleaned 100 % active silica gel: nonpolar lipids (e.g. IP_{25}) were eluted with 4 mL hexane (F_1), and polar alkenones and sterols with 4 mL 3:1 v/v Hexane/ Ethyl acetate (F_2). Sterols were derivitised using 100 μL of BSTFA and 100 μL of pyridine was added as the solvent; this was placed in a heating block at 70 °C for 1.5 h.

Highly branched isoprenoids (HBIs) and sterols were analyzed using an Agilent 7890 A gas chromatograph (GC) equipped with a mass selective detector (MSD) with an Agilent HP-5 ms column (30 m, 0.25 mm ID, 0.25 μm film thickness). The relative response factor was monitored during each run for: IP_{25} (HBI I), HBI II, 9-OHD, all sterols (brassicasterol, choloesterol, dinosterol, campesterol and sitosterol) and androstenol by running a range of concentrations of the known standard and targeted biomarkers for each run on the GC–MS.

Molecular compounds were identified based on their retention times and mass spectra and were quantified with reference to the internal standard, identified with target ions: 9-OHD at *m/z* 350 and 5α-androstan-3β-ol at m/z 257. HBIs were identified in SIM (Selected Ion Monitoring) mode with the following target ions: IP_{25} at m/z 350, HBI II at m/z 348. Sterols were identified in SIM mode with the following target ions: epi-brassicasterol (24-methylcholesta-5,22-dien-3β-ol) at m/z 470, dinosterol (4α,23,24-Trimethyl-5α-cholest-22E-en-3β-ol) at m/z 500, sitosterol (24-ethylcholest-5-en-3β-ol) m/z 486, and campesterol (24-methylcholest-5en-3β-ol) at m/z 472. Biomarkers are reported as ng/g sediment and normalised to total organic carbon (TOC).

3.3.2. *PIP_{25} index*

The PIP_{25} index was calculated using the following Eq. (1) (Müller et al., 2011):

$$PIP_{25} = \frac{IP_{25}}{(IP_{25} + (phytoplankton\ marker^{*}c))} \tag{1}$$

Where c is the balance factor, Eq. (2):

$$c = \frac{mean\ IP_{25}\ concentration}{mean\ phytoplankton\ biomarker\ concentration} \tag{2}$$

Brassicasterol was used as the phytoplankton sterol in this calculation (P_BIP_{25}), and the mean concentration of IP_{25} and brassicasterol across all sites were used to calculate the balance factor (c). Brassicasterol is frequently used as the open water biomarker for calculation of the PIP_{25} index, however research suggests that brassicasterol may also have additional origins: including sea-ice algae, freshwater and terrestrial sources (Belt et al., 2015; Belt et al., 2013; Fahl and Stein, 2012; Huang and Meinschein, 1979; Volkman, 1986). As such, dinosterol is frequently used as an alternative phytoplankton sterol for calculation of the PIP_{25} index (P_DIP_{25}). We present the P_DIP_{25} index in the supplementary material; as results are comparable to the P_BIP_{25} we select the latter for use in this study.

3.4. *Total organic carbon and sedimentology*

At the University of Colorado Boulder's Earth Systems Stable Isotope Laboratory, freeze-dried and decalcified (1 N HCl) samples were analyzed for bulk elemental (%TOC, %TN) geochemistry on a Thermo Delta V elemental analyzer (EA) interfaced to an isotope ratio mass spectrometer (IRMS). Samples were analyzed against a suite of secondary laboratory standards that are extensively calibrated to international standard reference materials to correct for size, blank-mixing, linearity, and drift effects. A Beckman Coulter LS13329 laser diffraction particle size analyzer was used to measure grain size (see supplementary information).

3.5. *CTD data*

Environmental data (temperature, salinity, oxygen and water depth) were measured at each site during the cruise using the RV *Neil Armstrong's* standard Seabird SBE 9+ CTD with dual sets of Temperature and Conductivity sensors and auxiliary sensors (see Hatfield et al., 2023).

3.6. *Sea-ice data*

Sea-ice concentration data (2018–2022) were extracted from the Global Ocean OSTIA Sea Surface Temperature and Sea Ice product, which reprocesses satellite and in-situ observations onto a gap-free grid (Worsfold et al., 2024). Daily data extracted for each core location were downloaded using the Copernicus Data Marine R package" Copernicus Marine" on a 0.05 × 0.05° grid (de Vries, 2025). Data was extracted and averaged using the "tidync" (Sumner, 2025) and "dplyr" (Wickham et al., 2025) R packages. The average annual sea-ice concentration was taken for each site over the five-year period.

3.7. *Data analysis*

Statistical analyses were conducted using the PAST v3 software (Hammer et al., 2001). Two methods are used to plot species diversity in sediment samples: the number of species found at each site as well as the Shannon Diversity index (H′). The Shannon diversity index presents number of species living in a community, together with their relative abundances, with low values representing low diversity, and high values representing higher diversity (Shannon, 1948). It was calculated using the following formula:

$$H' = \sum_{i=1}^{S} p_i \ln(p_i)$$

Where S is the total number of species and p_1 is the proportion of individuals belonging to the *i*th species.

Environmental variables (IP_{25}, brassicasterol, water depth, bottom water temperature, oxygen and salinity, TOC, grainsize data, observational sea-ice concentration data) were normalised using a Box-Cox transformation prior to analysis. Benthic foraminiferal species with at least 2 % abundance in at least one sample were included in the analysis. The link between environmental variables and benthic foraminiferal assemblages was investigated using canonical correspondence analysis

(CCA) for surface samples (0–1 cm) from: 1) Baffin Bay, Labrador Sea and Davis Strait and 2) Baffin Bay samples only. The eigen analysis algorithm follows that in (Legendre and Legendre, 1998), using scaling type 1. Cluster analysis of all species present in at least one sample with >2 % was conducted, using the unweighted pair-group average (UPGMA) and Bray-Curtis similarity index; results of this are presented in the Supplementary Material.

Biplots were made for environmental variables: 1) bottom water temperature, 2) bottom water salinity, 3) IP_{25} concentration, 4) brassicasterol concentration and 5) P_BIP_{25} index, and the percentage calcareous foraminifera. Pearson correlation matrices were used to examine the statistical relationship between these variables.

4. Results

4.1. Environmental data

4.1.1. CTD data: water column salinity and temperature

CTD data show the temperature and salinity profiles for sites in Baffin Bay and the Labrador Sea (Fig. 2). Arctic water masses are present in the surface waters at all sites, with warmer, more saline Atlantic waters that make up West Greenland Intermediate Water (WGIW) carried by the WGC, located beneath (300–800 m water depth). At the deep sites (>1000 m) water depth, the cold waters of the BBDW are present; these are characterised by temperatures around 0 °C and salinity of 34.49 (Lehmann et al., 2019). None of the sites in this study are located deep enough to occupy BBBW (>1800 m water depth). The profiles from World Ocean Atlas 2023 (Locarnini, 2023) show these water masses present in Baffin Bay at different depths, from shallowest to deepest: Arctic Water, WGIW, BBDW (Fig. 3).

4.1.2. Sea-ice biomarkers

IP_{25} concentrations from sediment samples are noticeably low (0.17 ng/ g dry sed) at site 5MC in the Labrador Sea, and absent from site 15MC in Davis Strait (Fig. 4). In contrast, IP_{25} concentrations are higher, yet variable (ranging from 0.23 to 0.90 ng/ g dry sed) in Baffin Bay sites. Concentrations of IP_{25} are generally lower at the shallower sites than at the corresponding nearby deeper sites (e.g. 29MC and 36MC, 58MC and 45MC, 64MC and 72MC, and 86MC and 96MC). In general, concentrations of HBI II follow a similar pattern to IP_{25}, albeit in higher concentrations.

Concentrations of sterols follow a similar pattern in Baffin Bay and the Labrador Sea; they are highest at site 15MC (Davis Strait), and generally decline in concentration in higher latitude sites (Figs. 4 and 5). The P_BIP_{25} index is variable across the region, with highest values found at the shallow, northern and central Baffin Bay sites. In contrast, the P_BIP_{25} index value is zero at site 15MC, and low at site 5MC (0.27).

4.1.3. TOC and TN

The percentage TOC and TN varies from 0.14 to 1.23 % and 0.02 to 0.18 % respectively (Fig. 6). In general, deeper sites in Baffin Bay have a higher percentage of TOC (36MC, 45MC, 64MC, 86MC) in surface sediments (0–1 cm). In contrast shallower sites in Baffin Bay (29MC, 58MC, 72MC, and 96MC) as well as the Labrador Sea site (5MC) and Davis Strait site (15MC) have lower percentages of TOC in surface sediments. A similar pattern is observed in the TN dataset (Fig. 6).

4.2. Modern foraminiferal assemblages

4.2.1. Concentrations of benthic and planktic foraminifera

The concentration of benthic and planktic foraminifera in surface (0–1 cm) and subsurface (4–5 cm) sediment samples for each site are presented as number of foraminifera/g of dry sediment (Fig. 7). The highest concentration of foraminifera is found in the surface sediment sample from the Labrador Sea site (5MC), with 202 benthic foraminifera and 243 planktic foraminifera /g of dry sediment. 96MC, the shallow site in Disko Bugt, has a high concentration of all foraminifera. Lower foraminifera concentrations are generally found in the deeper Baffin Bay sites (36MC, 45MC, 64MC, 86MC). At these sites, the concentration of planktic and calcareous benthic foraminifera are much lower than the shallower sites in the same region in the 0–1 cm samples. The lowest concentration of foraminifera is found in the surface sediments of 15MC,

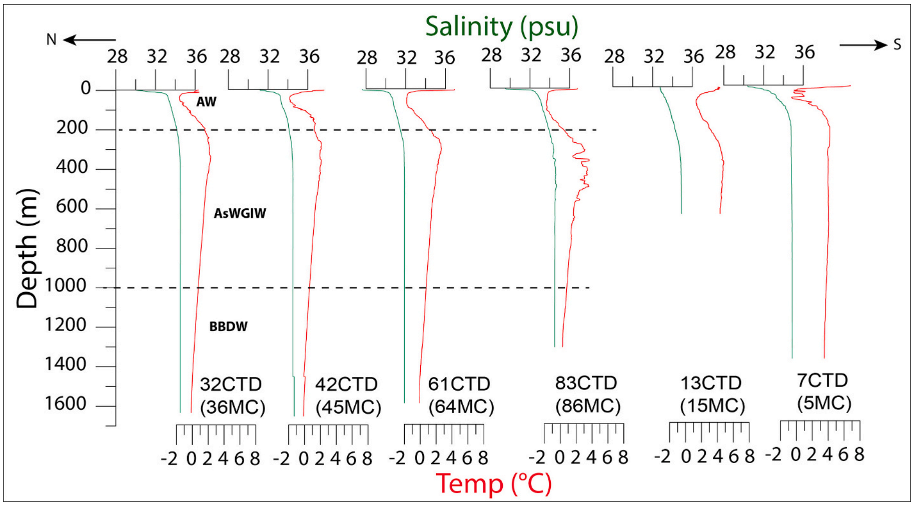

Fig. 2. AR76–01 CTD profiles of temperature and salinity measurements for deep sites used in this study and the Davis Strait site (15MC/13CTD). Each cast was collected near the indicated multicore, with locations plotted in Fig. 1. Sites are plotted from north (left) to south (right) and water masses labelled: Arctic Water (AW), Atlantic-sourced West Greenland Intermediate Water (AsWGIW) and Baffin Bay Deep Water (BBDW).

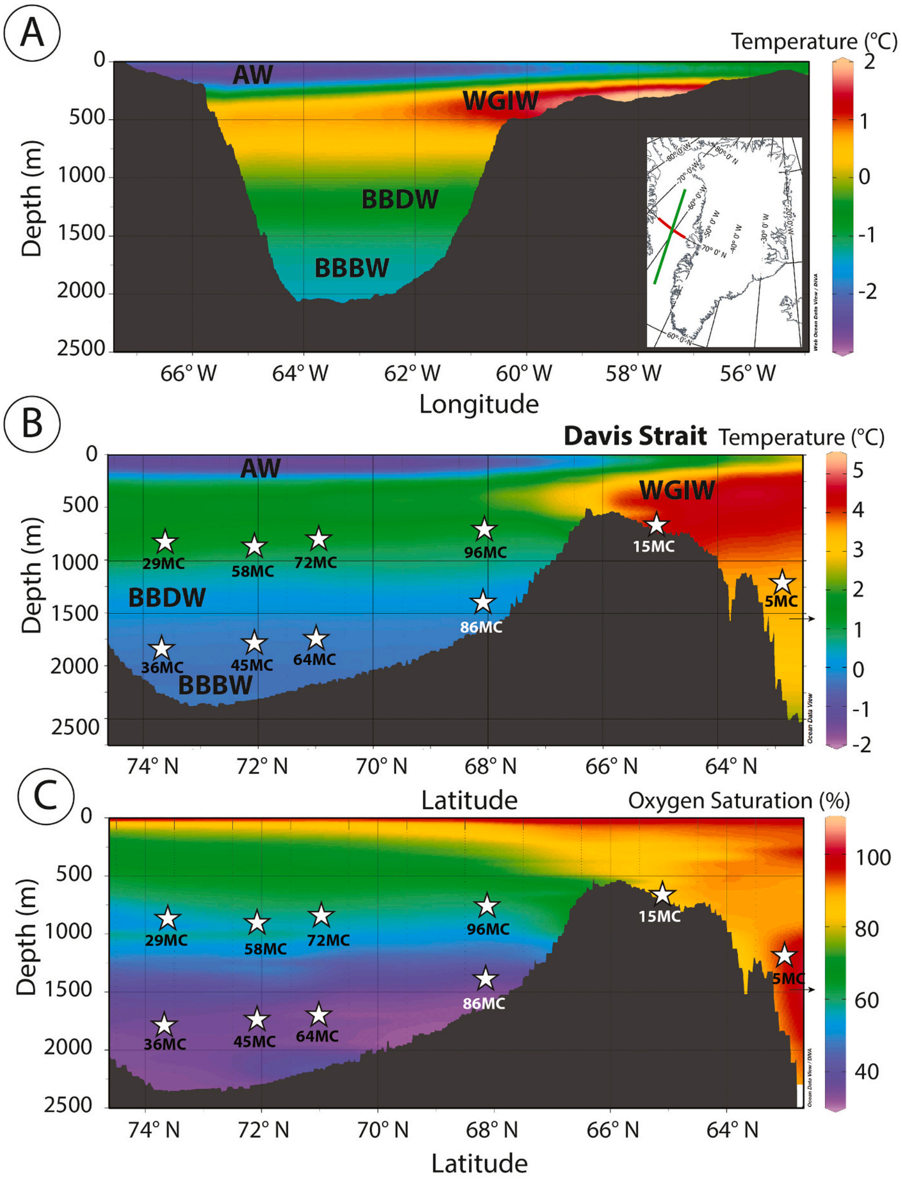

Fig. 3. Water mass characteristics in Baffin Bay and Labrador Sea. A) East-West transect in Baffin Bay at 70°N showing water temperature on depth. B) North-South transect. Water masses are labelled: Arctic Water (AW), West Greenland Intermediate Water (WGIW), Baffin Bay Deep Water (BBDW) and Baffin Bay Bottom Water (BBBW). C) Oxygen saturation (%) on North-South transect. Water mass temperature and oxygen saturation data comes from World Ocean Atlas 2023 (Locarnini et al., 2024). The transect locations are marked on the map insert of panel A (*E*-W transect marked with red line and N-S transect with green line). The latitude and depth of core sites are shown with white stars in panels B and C. Figure created in Ocean Data View. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

which also has lower overall concentrations of agglutinated taxa.

In subsurface samples (4–5 cm) the concentration of foraminifera, both calcareous and agglutinated benthic taxa, as well as planktic foraminifera, are much lower at Baffin Bay and Davis Strait sites than in surface sediment samples. In the Labrador Sea, the concentration of foraminifera in subsurface samples are considerably higher than Baffin Bay samples.

4.2.2. Benthic foraminiferal assemblages: agglutinated vs calcareous tests

The percentage of agglutinated and calcareous benthic foraminifera specimens in samples from Baffin Bay and the Labrador Sea vary spatially (Fig. 8). Broadly, sediment samples from the southernmost sites, 5MC and 15MC, are dominated by calcareous specimens. In contrast, sites in Baffin Bay are dominated by agglutinated tests, with calcareous tests present often poorly preserved. Of these, the deepest sites (>1000 m in water depth) have the highest percentages of agglutinated taxa, an average of 96 % in sites 36MC, 45MC, 64MC, and 86MC. In contrast, the shallower Baffin Bay and Davis Strait sites (29MC, 58MC, 72MC, 96MC, 15MC) have an average of 69 % agglutinated foraminifera in each sample, and better-preserved calcareous taxa. 58MC is anomalous when compared to the other Northern Baffin Bay sites as it has a lower percentage of agglutinated specimens (64 %).

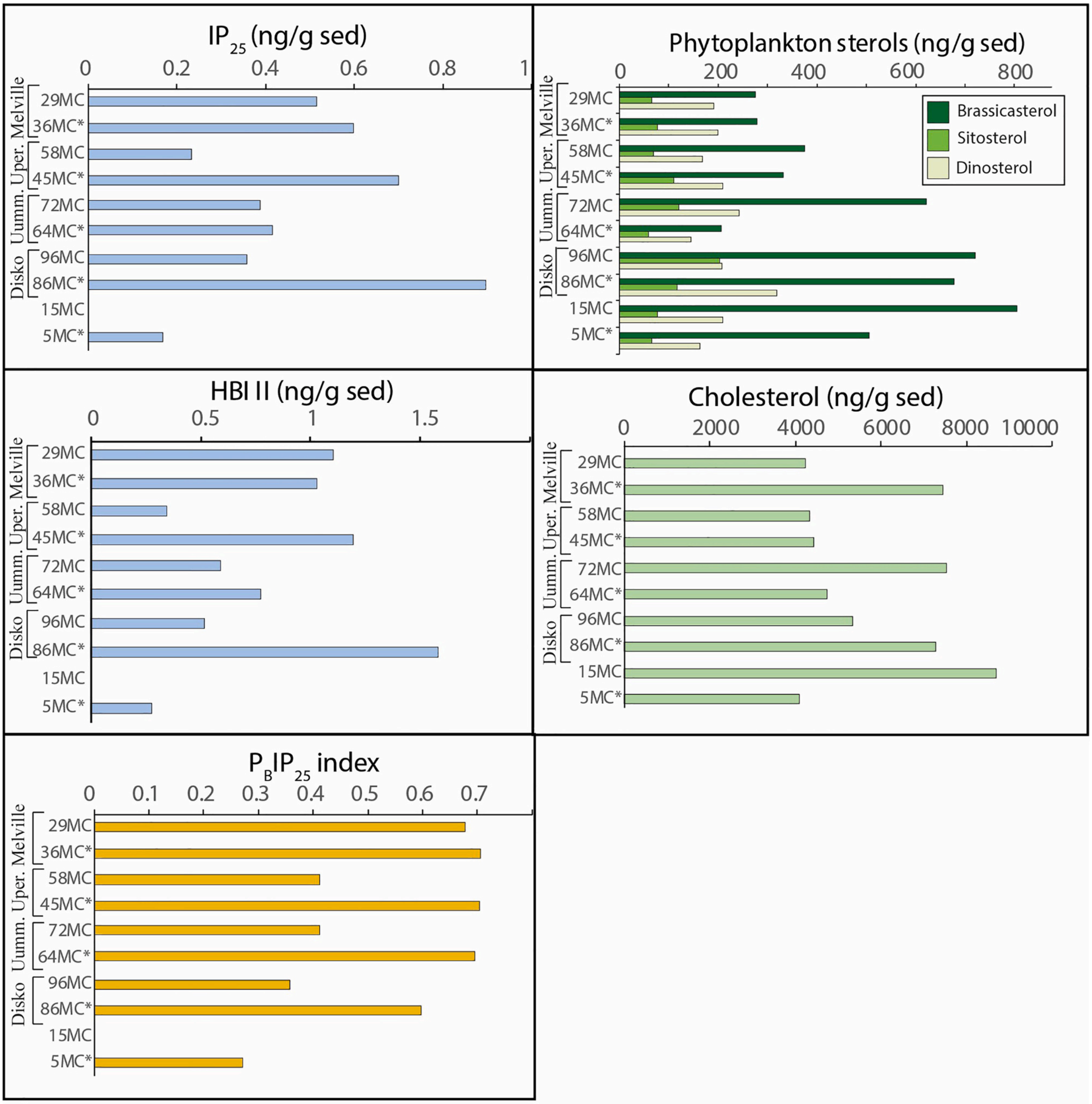

Fig. 4. Concentrations of sea-ice biomarkers (blue; IP_{25} and HBI II), phytoplankton sterols (green; (top right) sitosterol, brassicasterol, dinosterol and cholesterol (middle right)) and the P_BIP_{25} index (yellow) for surface sediment samples (0–1 cm) in Baffin Bay and Labrador Sea: deep sites (>1000 m water depth) are marked with *. Samples are plotted from north (top) to south (bottom). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.2.3. *Living vs dead benthic foraminifera: 0–1 cm and 4–5 cm downcore*

Examining stained vs unstained tests in surface sediment samples allows us to assess the percentage of living vs dead benthic foraminifera, at the time of collection. There are living species of benthic foraminifera (agglutinated and calcareous) in all surface samples (0–1 cm) analyzed (Fig. 9). In general, shallower sites (29MC, 58MC, 72MC, 96MC) have a greater proportion of living calcareous foraminifera (23 % average) compared to deep sites (36MC, 45MC, 64MC, 86MC; average of 3.5 %) in Baffin Bay. In contrast, the percentage living agglutinated taxa is more similar between these sites: 32 % (shallow) and 40 % (deep). The Labrador Sea site has the lowest percentage of living foraminifera of any of the sites (9 %) and site 15MC has the highest percentage.

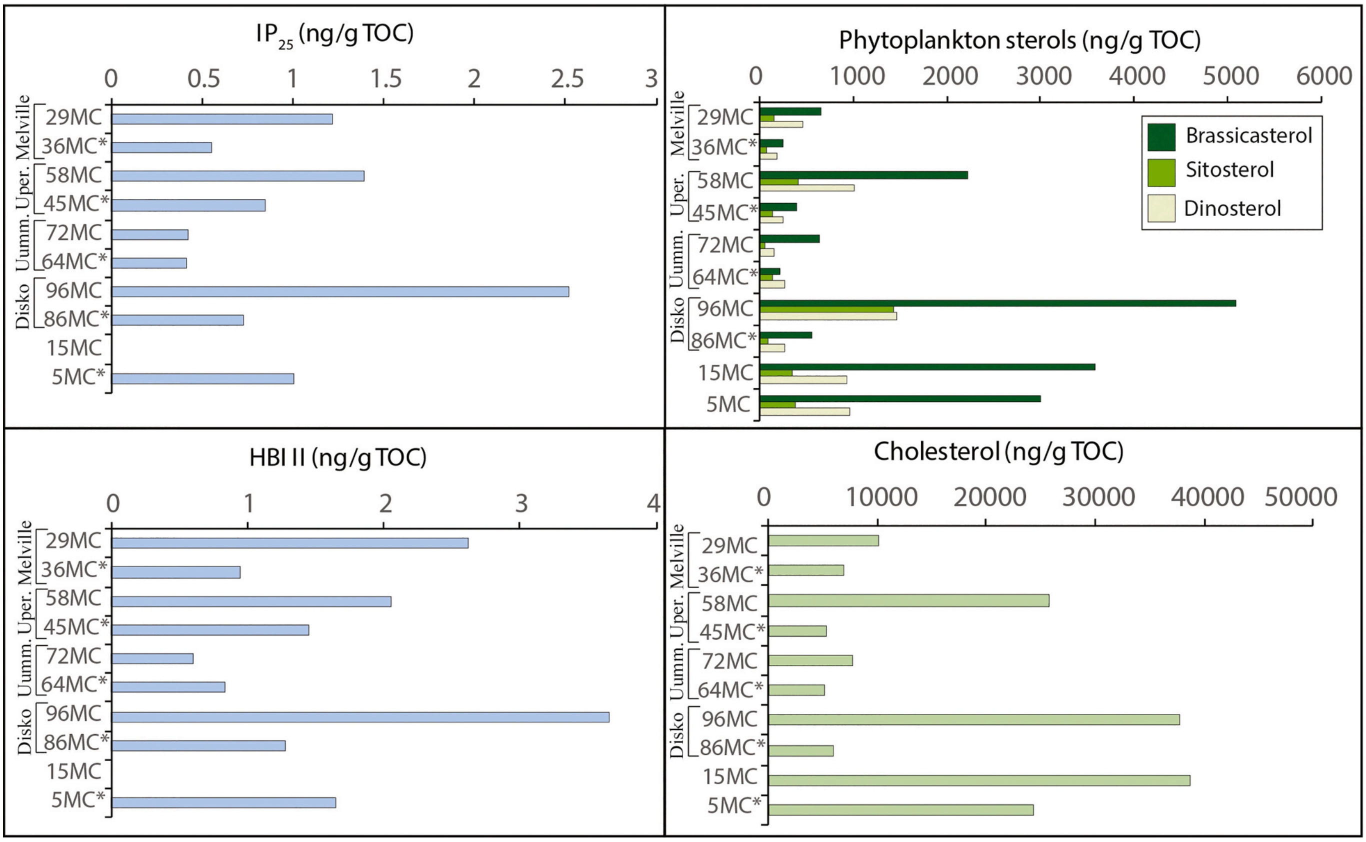

Fig. 5. Concentrations of sea-ice biomarkers normalised to TOC: (blue; IP_{25} and HBI II), phytoplankton sterols (green; (top right) sitosterol, brassicasterol, dinosterol and cholesterol (bottomright) for surface sediment samples (0–1 cm) in Baffin Bay and Labrador Sea: deep sites (>1000 m water depth) are marked with *. Samples are plotted from north (top) to south (bottom). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Sediment samples from 4 to 5 cm have fewer stained foraminifera overall (between 0 and 12 % across all samples) than the surface sediment samples (Fig. 9), yet all samples, apart from 86MC and 5MC have at least one stained foraminiferal test. Overall, few calcareous foraminifera are found in the 4–5 cm Baffin Bay samples (29MC, 58MC and 72MC) and the Labrador Sea sample (5MC) has a higher percentage of calcareous taxa present. Only two sites (29MC and 72MC) have stained calcareous foraminifera present. Eleven stained calcareous benthic foraminifera were found in 29MC, but no unstained specimens were present in this sample, suggesting that calcareous foraminifera were not preserved as empty tests in this instance.

Sites 29MC, 36MC, 58MC, 45MC, 72MC, 64MC, and 96MC have stained agglutinated taxa present (average 5 % of the entire sample) in the 4–5 cm sample. The most common stained agglutinated species present at 4–5 cm are: *Labrospira wiesneri, Adercotryma glomerata, Cribrostomoides crassimargo, Hormosinella guttifera, Lagenammina difflugiformis, Portatrochammina antarctica wiesneri, Reophax subfusiformis* and *Recurvoides turbinatus.* These species were found stained in low numbers at 4–5 cm depth, indicating that they can live in fairly deep infaunal habitats. Of note are the agglutinated taxa present in sites 86MC and 58MC, which showed signs of bleaching and loss of red colour in the cement. The concentration data indicates low preservation potential of both agglutinated and calcareous taxa with sediment depth (Fig. 7).

4.2.4. *Calcareous taxa*

Cassidulina reniforme is present at all sites, apart from 36MC and 45MC, in general percentages are higher at shallow sites, and highest at site 58MC (4 %) (Figs. 10, 11 and 12). *Cassidulina neoteretis* is present at all sites, aside from 36MC. It is also more abundant in shallow sites, and is also abundant at the deep Labrador Sea site (5MC). In general, a high percentage of these species are living at sites where their tests are found, aside from 5MC, where the majority are dead. Site 58MC is characterised by higher percentages of *Cibicides lobatulus* (8 %), compared to other sites in northern and central Baffin Bay. This site also has the highest percentage of *C. reniforme, C. neoteretis* and *B. elegantissima* of all sites in this study.

Site 15MC, in Davis Strait, is characterised by high concentrations of *Nonionellina labradorica, Elphidium clavatum, Epistominella arctica* and *Melonis barleeanus;* these species are notably absent or present in very low abundances at the other sites from this study (Figs. 10, 11 and 12). Almost all the *E. arctica* taxa found in surface sediment samples were living at the time of collection. The calcareous foraminiferal assemblage for site 5MC differs markedly from other sites; it is dominated by *Nonionella iridea, E. clavatum* and *B. frigida* which are all absent or present in low abundances in Baffin Bay sites. Whilst *N. iridea* is present in surface samples from all shallow sites in northern and central Baffin Bay (and of those found, most were living), it is more abundant at site 15MC.

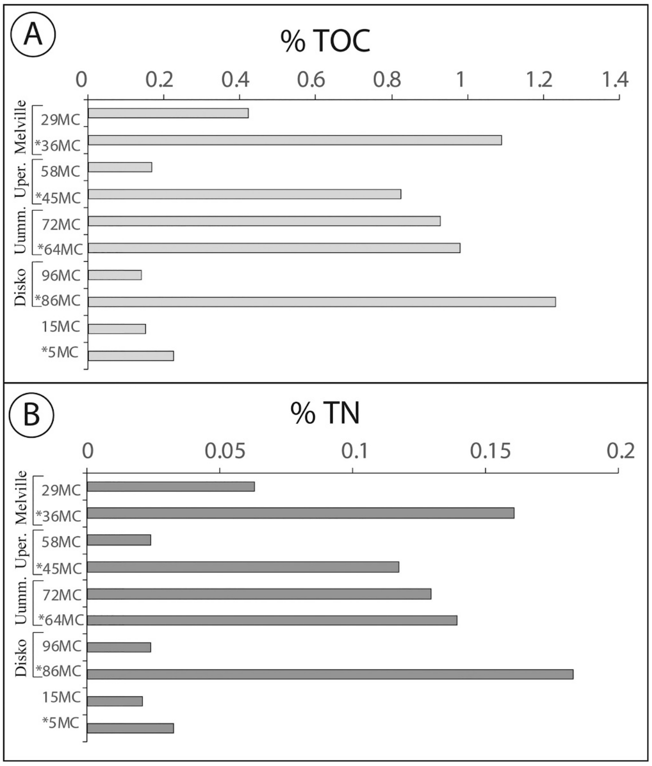

Fig. 6. Total organic carbon (TOC; panel A) and total nitrogen (TN; panel B) in surface sediments (0–1 cm) from sites in Baffin Bay, Davis Strait and the Labrador Sea. Deep sites (>1000 m water depth) are marked with *. Samples are plotted from north (top) to south (bottom).

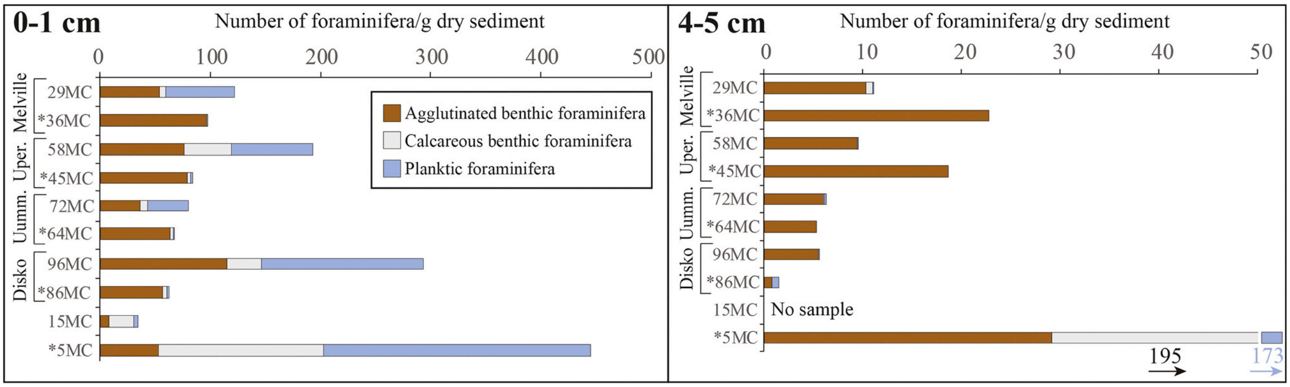

Fig. 7. Concentration of foraminifera (number of foraminifera/g of dried sediment) in surface sediment samples (0–1 cm; left) and subsurface sediment samples (4–5 cm; right). Foraminifera are split into: agglutinated benthic foraminifera (brown), calcareous benthic foraminifera (grey) and planktic foraminifera (blue). Deep sites (>1000 m water depth) are marked with *. Samples are plotted from north (top) to south (bottom). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

4.2.5. *Agglutinated taxa*

The agglutinated taxon, *Recurvoides turbinatus,* is common (7–14 %) at both the shallow and deep sites in northern Baffin Bay (29MC, 36MC, 58MC, 45MC), whereas it is present in much lower percentages (<2 %) at sites further south in Baffin Bay and the Labrador Sea (Figs. 13, 14 and 15). The agglutinated taxa *H. guttifera* and L. *difflugiformis* are notably absent or present in low abundances at sites 15MC and 5MC, but they dominate the agglutinated assemblages at the northern Baffin Bay sites. *Portatrocammina bipolaris* also distinguishes the northern sites, aside from site 64MC, whilst being absent at sites 15MC and 5MC. *Textularia earlandi* is present at most sites along the transect, apart from deep-water sites 36MC and 64MC. In general, it is more abundant at shallow sites (29MC, 58MC, 72MC, 96MC, 15MC) which are located at <1000 m water depth.

Trochammina quadriloba is present at all sites, apart from 15MC; in general, it tends to be more abundant at the shallow sites compared to

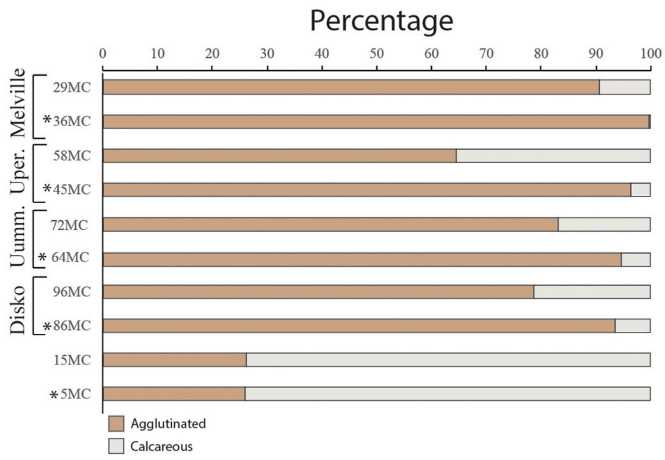

Fig. 8. The percentage of agglutinated (brown) and calcareous (grey) benthic foraminifera species in surface sediment samples (0-1 cm). Samples from >1000 m water depth are marked with *. Samples are plotted from north (top) to south (bottom). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

deeper sites in the same region (Figs. 13 and 14). *Reophax scorpiurus* is notably more abundant at both deep and shallow sites from Uummannaq (72MC and 64MC), as well being found in lower abundances at 29MC, 86MC and 5MC. *Portatrochammina wiesneri antarctica* is present in high abundances at site 96MC (shallow Disko Bugt site), but also, to a lesser extent at shallow sites in Baffin Bay (58MC and 72MC) and in the Labrador Sea (5MC). *Reophax bilocularis* is present in all sites but 58MC and 15MC, with slightly higher percentages in the deeper sites.

4.2.6. *Species diversity*

The diversity of benthic foraminiferal assemblages was calculated for all foraminifera (e.g. living and dead); it varies across the dataset (Fig. 16). The greatest number of species is found at 5MC and, generally, fewer species were found at deeper Baffin Bay sites (36MC, 45MC, 64MC, 86MC). The shallower sites generally have a higher number of species than the nearby deep site at each location (e.g. 29MC and 36MC, 58MC and 45MC, 96MC and 86MC, and 64MC and 72MC). The Shannon diversity index displays a similar pattern with deeper sites generally having lower diversity and the highest diversity found at the Labrador Site, 5MC.

4.3. *Linking benthic foraminiferal assemblages to environmental data*

4.3.1. *Percentage of calcareous foraminifera, sea ice and water masses*

The correlation between bottom water temperature and the percentage of calcareous foraminifera is positive (Figs. 17 and 18); the Pearson correlation coefficient (r) is 0.91. In general, warmer bottom water temperatures, associated with Atlantic sourced waters of the WGIW, are correlated with a higher percentage of calcareous taxa in the benthic foraminiferal assemblage. 58MC is an outlier when the living and dead foraminifera are considered, with relatively high percentages of calcareous taxa compared to the cold bottom water temperatures. This differs from sites with relatively similar bottom water temperatures

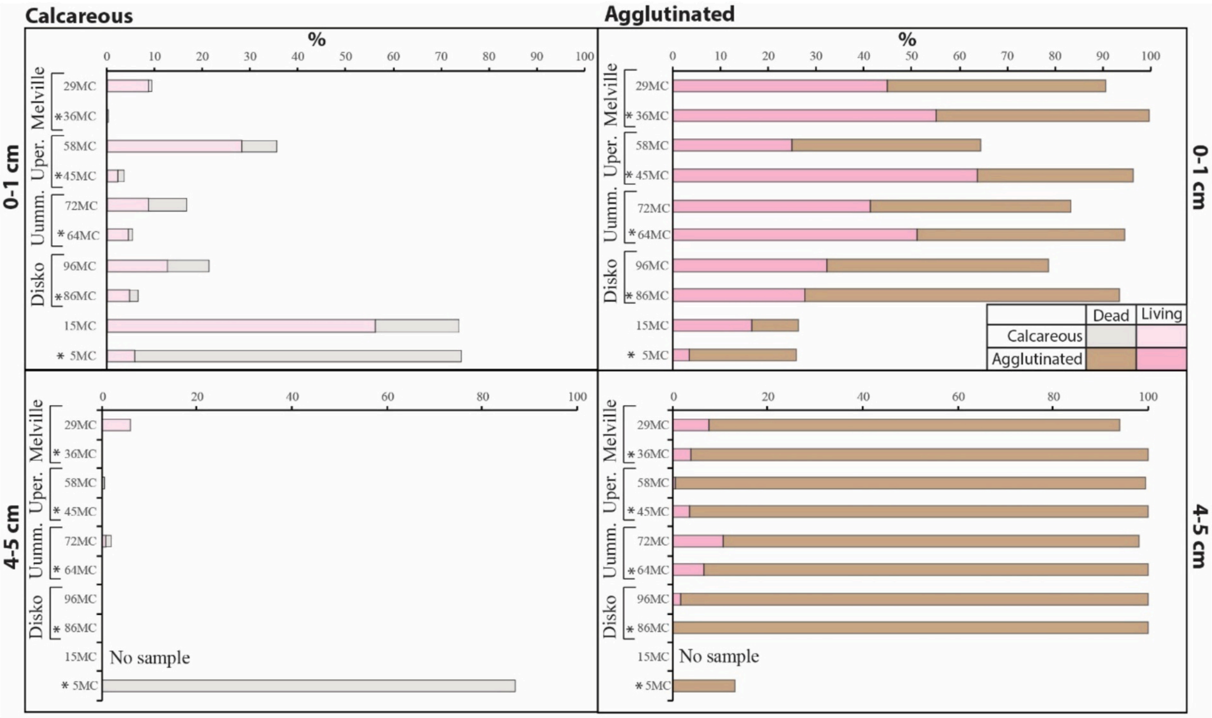

Fig. 9. Living vs dead percentages of benthic foraminifera, both calcareous (left) and agglutinated (right) taxa for surface sediment samples (top; 0–1 cm) and downcore samples (bottom; 4–5 cm) of the same multicores. Deep sites (>1000 m water depth) are marked with *. Samples are plotted from north (top) to south (bottom).

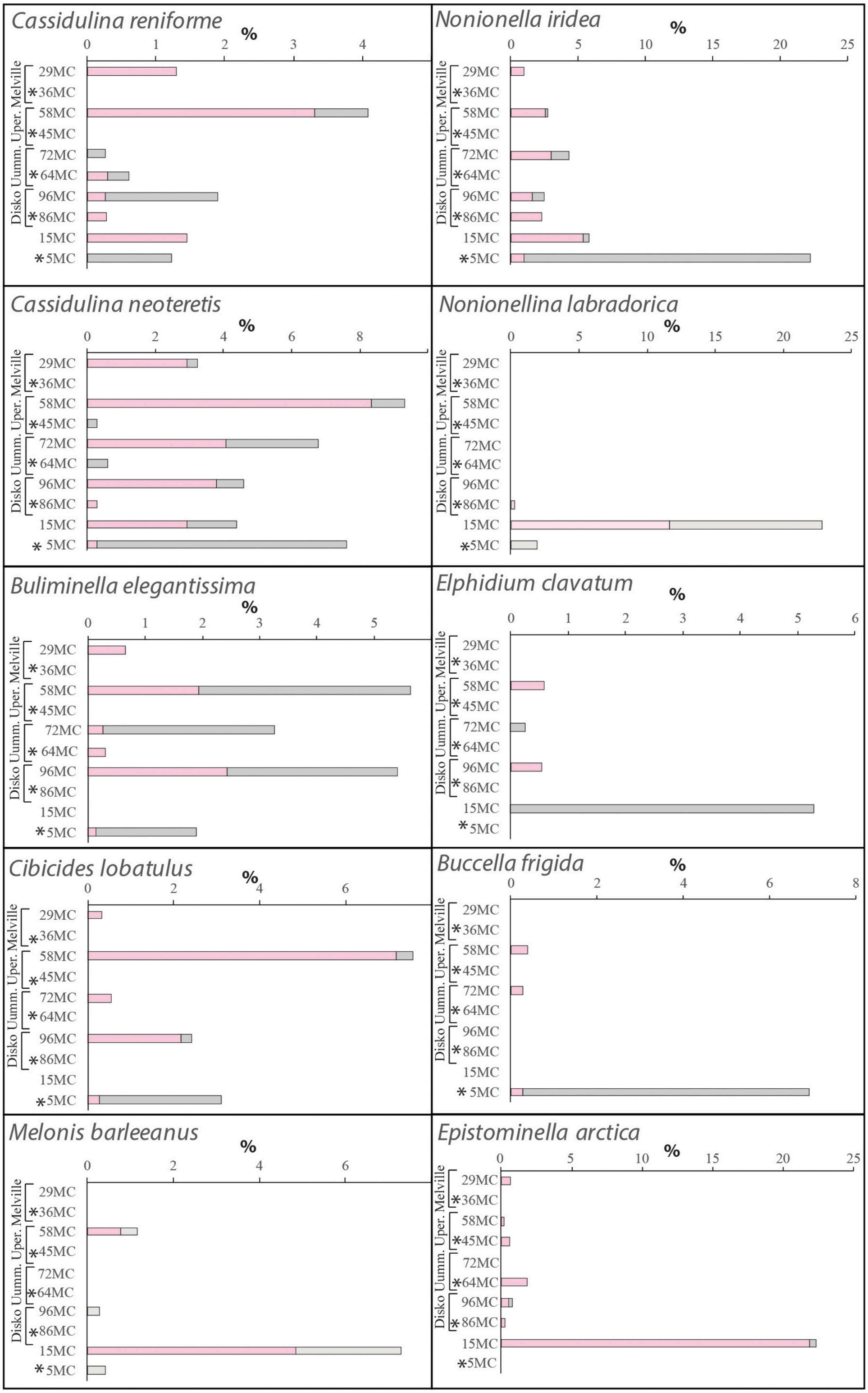

Fig. 10. Indicator calcareous benthic foraminifera species (percentage of total assemblage) for all surface sediment samples (0–1 cm). Living species (pink) are separated from dead (grey). Deep sites are marked with *. Samples are plotted from north (top) to south (bottom). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

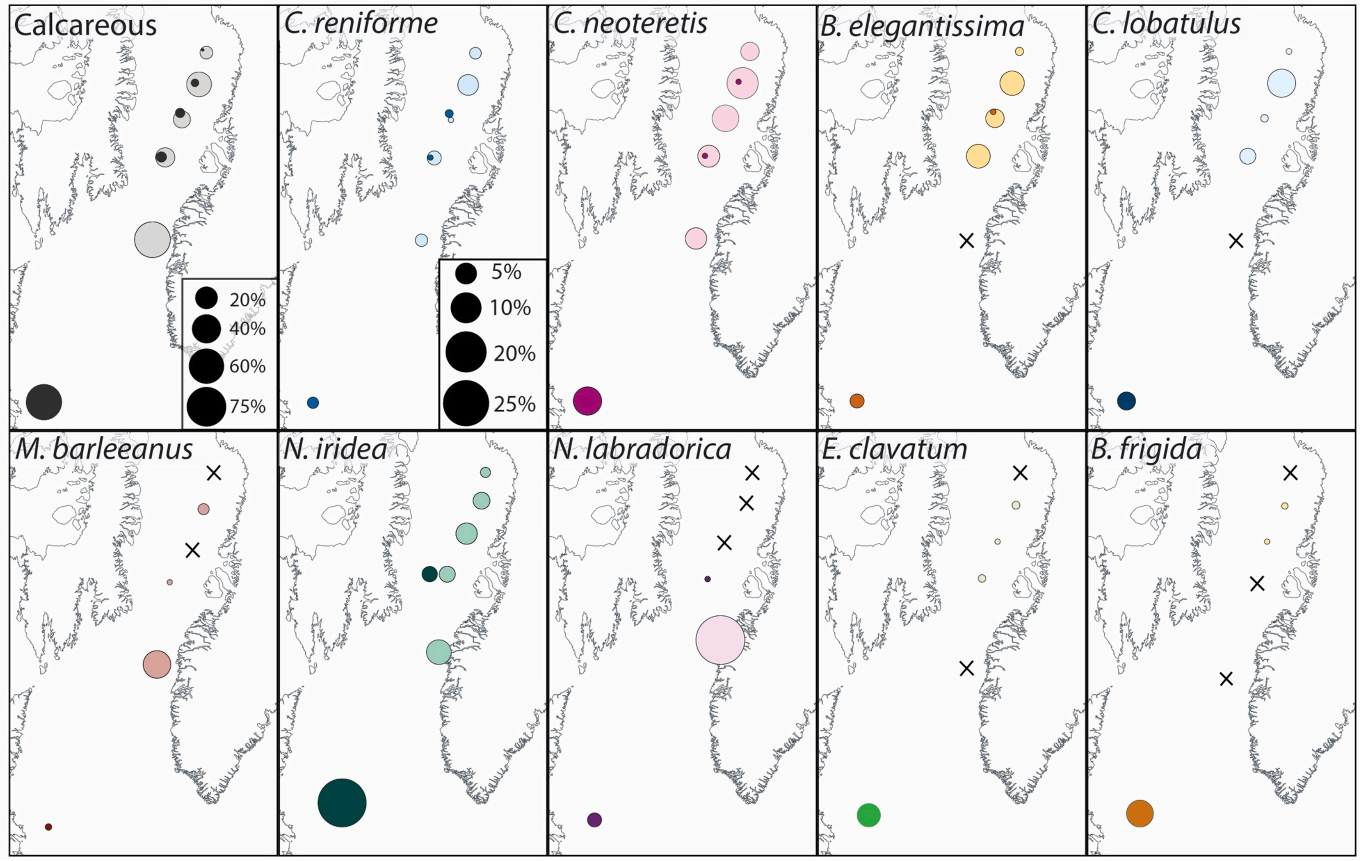

Fig. 11. Map showing the percentages of key calcareous benthic foraminiferal species: *C. reniforme, C. neoteretis, B. elegantissima, C. lobatulus, M. barleeanus, N. iridea, N. labradorica, E. clavatum* and *B. frigida***.** Calcareous species abundance is calculated as a percentage of the total benthic foraminiferal specimens in the assemblage (e.g. calcareous + agglutinated species). Shallow sites (<1000 m water depth) are shown in light shades and deep sites (>1000 m water depth) in dark shades. The size of the circle depicts the percentage abundance. The percent abundance scale in *C. reniforme* is the same for all species. Regions where species are absent are marked with a black cross (e.g. absence from shallow and deep sites).

(29MC and 72MC) that are associated with a lower percentage of calcareous taxa. When only the dead specimens are considered, the percentage of calcareous taxa in 58MC is more similar to 29MC and 72MC. The correlation between bottom water salinity and the percentage of calcareous foraminifera is positive ($r = 0.94$; Fig. 18), with higher salinity values associated with a benthic foraminiferal assemblage with a greater percentage of calcareous taxa (Fig. 17). A plot of bottom water temperature and salinity and the percentage of living calcareous foraminifera is shown in the Supplementary Material.

The percentage calcareous foraminifera are negatively correlated with TOC and TN ($r = -0.71$ and -0.73 respectively); with higher abundances of agglutinated taxa associated with more TOC and TN in the sediment sample. The abundance of calcareous foraminifera is negatively correlated with clay and silt, but positively correlated with sand in surface sediment samples (Fig. 18).

The correlation between the percentage calcareous taxa and the concentration of IP_{25} per g dry sediment is negative ($r = -0.83$) and the correlation between brassicasterol and the percentage of calcareous taxa, is weaker (Figs. 18 and 19). The correlation between the percentage calcareous taxa and the P_BIP_{25} index is strongest ($r = -0.84$); P_BIP_{25} index values correspond to lower percentages of calcareous foraminifera (Fig. 19C).

The CCA performed on the benthic foraminiferal species and the twelve environmental variables for all sites, shows that the majority of variation in benthic foraminiferal data is explained by Axis 1 (54 % Fig. 20A), with Axis 2 explaining <1 %. In general, northern and central Baffin Bay sites are negatively correlated with Axis 1, the exceptions are 58MC and 96MC which are slightly positively correlated with Axis 1 and 2. Sites 15MC and 5MC are positively correlated with Axis 1. CCA Axis 1 is positively correlated with brassicasterol, % sand, temperature, oxygen and salinity; it is negatively correlated with IP_{25}, % silt, % clay, TOC, TN and water depth (Fig. 20A). The CCA indicates that calcareous species generally have a positive loading along Axis 1, and agglutinated taxa have a negative loading. The exceptions are agglutinated species: *P. bipolaris, P. antarctica wiesneri, Rhahbdammina* spp.*, Reophax* spp.*, Textularia torquata and T. earlandi,* which have a positive loading on Axis 1 and 2. *B. elegantissima, C. reniforme, C. lobatulus, Quinqueloculina seminulum* have a positive loading on Axis 2, in contrast to *N. iridea, E. clavatum, B. frigida, Epistominella arctica, Stainforthia feylingi, Cornuspira involvens, Pullenia osloensis, Pseudobolivina antarctica* and *N. labradorica,* that have a negative loading along Axis 2.

The CCA performed with only Baffin Bay sites, excluding 15MC and 5MC, again shows that the majority of variance is explained by Axis I (Fig. 20B). In general, deep Baffin Bay sites are positively correlated

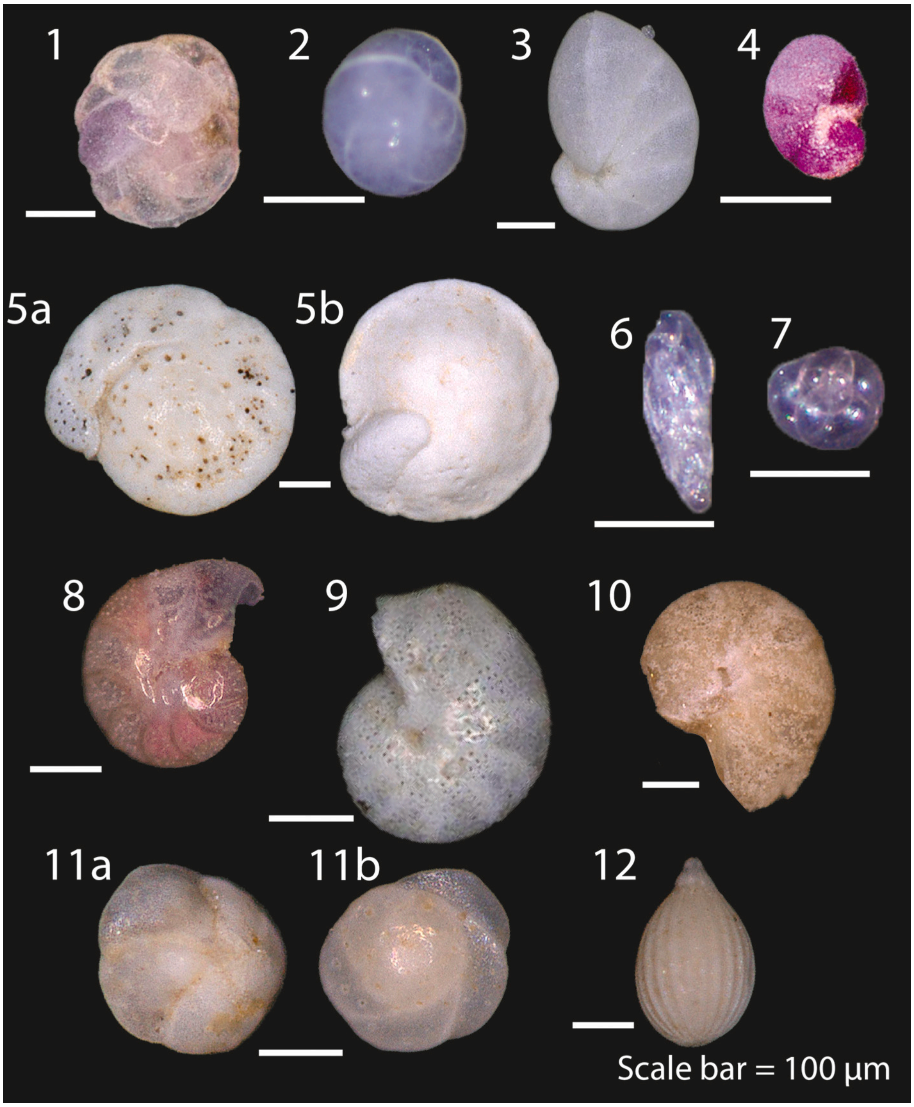

Fig. 12. Examples of calcareous benthic foraminiferal species from surface samples, sites are listed next to each species in parentheses. 1. *Cassidulina neoteretis* (58MC), 2. *Cassidulina reniforme* (96MC), 3. *Nonionellina labradorica* (96MC), 4. Stained *Nonionella iridea* (58MC), 5. *Cibicides lobatulus*, spiral (5a) and umbilical (5b) view (58MC), 6. *Buliminella elegantissima* (96MC), 7. *Epistominella arctica* (96MC), 8. *Melonis barleeanus,* small amount of staining only and thus counted as unstained, (58MC), 9. *Melonis barleeanus* etched test surface (96MC) and 10. poorly preserved test (58MC), 11. *Buccella frigida*, dorsal (11b) umbilical (11a) and view (5MC), 12. *Oolina acuticosta* (5MC).

with annual sea ice concentration, clay, silt, TOC, TN, depth and IP_{25} with the shallower sites 96MC and 58MC positively correlated with temperature, sand, bottom water oxygen, brassicasterol and salinity.

5. Discussion

5.1. Carbonate dissolution impact on faunal assemblages

The concentrations and percentages of calcareous and agglutinated benthic foraminifera, and planktic foraminifera, differentiate sites in Baffin Bay from those in the Davis Strait and Labrador Sea. In general, agglutinated taxa dominate the deep sites in Baffin Bay, with shallower Baffin Bay sites and those in the Labrador Sea and Davis Strait characterised by more abundant calcareous taxa. As such, it is clear that there are environmental factors governing foraminiferal assemblages, but preservation may also be impacting their distribution across this region.

It has long been reported that foraminiferal assemblages dominated by agglutinated taxa are representative of a harsh environment in which agglutinated taxa are better adapted, as they have low trophic requirements (Jernas et al., 2018), or under acidic conditions in which calcareous tests have been dissolved (Murray and Alve, 1999; Steinsund and Hald, 1994). Numerous environmental factors can result in corrosive bottom waters that limit the preservation of calcareous tests, specifically: cold and corrosive bottom water masses (Aksu, 1983; Jennings and Helgadottir, 1994; Seidenkrantz, 2013), the production of sea ice which expels dense brine (Aksu, 1983; Davies et al., 2023; Lloyd, 2006; Seidenkrantz, 2013), and high primary productivity (Walter and Burton, 1990), amongst others.

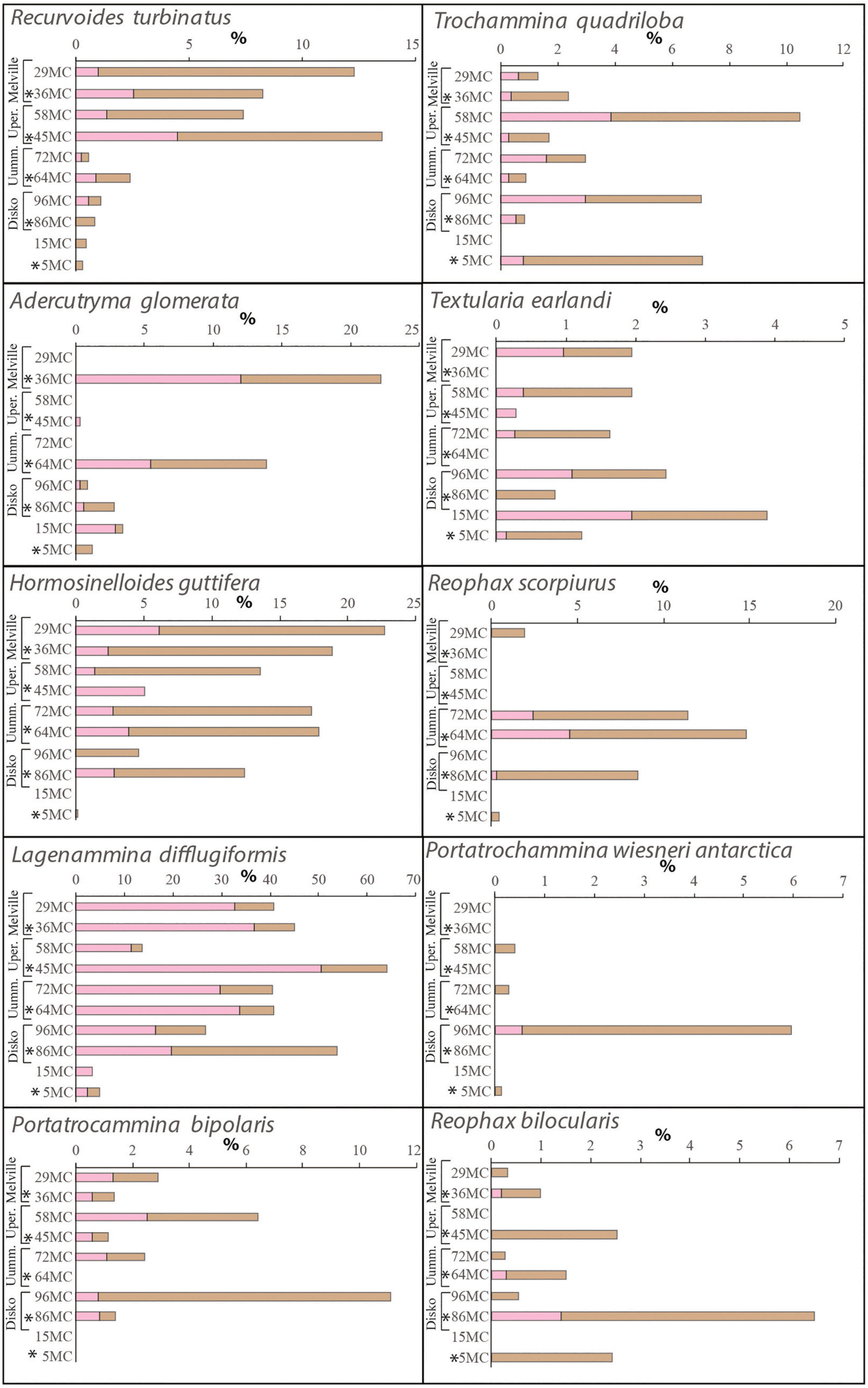

Fig. 13. Indicator agglutinated benthic foraminifera species for all surface sediment samples (0–1 cm) ordered from north (top) to south (bottom) sites. Living percentages (pink) are separated from dead percentages (brown). Deep sites are marked with *. Samples are plotted from north (top) to south (bottom). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

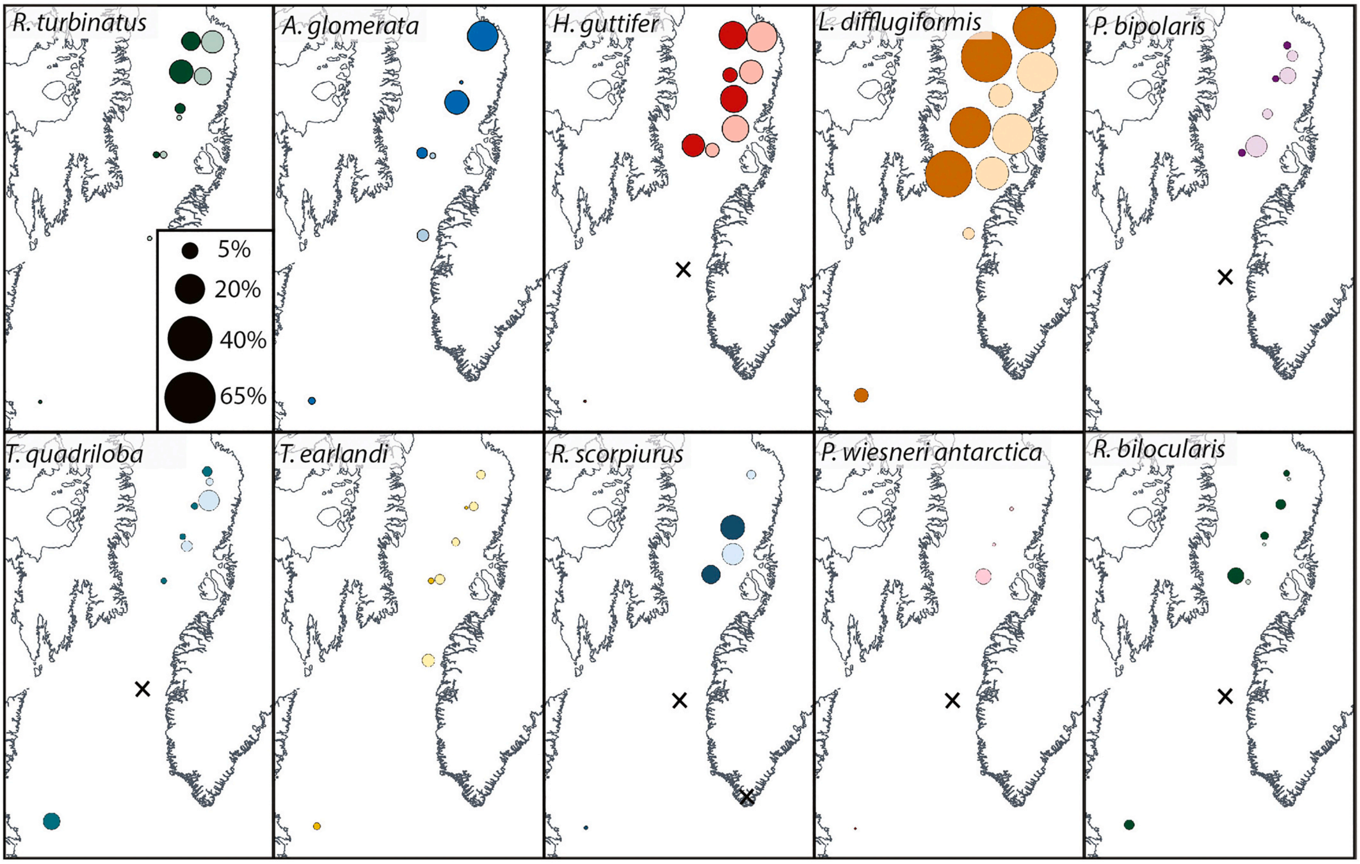

Fig. 14. Map showing the percentages of key agglutinated benthic foraminiferal species: *R. turbinatus, A. glomerata, H. guttifera, L. difflugiformis, P. bipolaris, T. quadriloba, T. earlandi, R. scorpiurus, P. antarctica wiesneri* and *R. bilocularis.* Agglutinated species abundance is calculated as a percentage of the total agglutinated species in the assemblage (e.g. calcareous + agglutinated species). Shallow sites (<1000 m water depth) are shown in light shades and deep sites (>1000 m water depth) in dark shades. Percent abundance scale in *R. turbinatus* is the same for all species. Regions where species are absent are marked with a black cross (e.g. absence from shallow and deep sites).

Importantly, the majority of the calcareous tests counted at deep sites in Baffin Bay are stained, and thus were living at the time of collection. Whilst still a high percentage, lower numbers of living calcareous foraminifera at shallow sites are observed; we postulate that this may be due to the rapid dissolution and disintegration of calcareous tests at deeper sites. This is also supported by small numbers/absence of calcareous taxa in subsurface sediment samples (4–5 cm) in Baffin Bay at the same sites. As sediment accumulation rates are often low on the Greenland Slope during the Holocene (Jackson et al., 2017; Jennings et al., 2017), this may contribute to dissolution of calcareous tests as they are exposed to corrosive waters for longer.

Similar results are reported from the Barents Sea, where high percentages of living foraminifera were used to infer rapid dissolution of calcareous species (Steinsund and Hald, 1994). However, the percentage of living vs dead foraminifera may also be attributed to productivity, as proposed in Petermann Fjord for example (Jennings et al., 2020). In this instance the large living component of opportunistic species (*E. clavatum* and *S. horvathi*) was used to suggest recent blooms in response to the export of labile organic matter (Jennings et al., 2020). This pattern is less clear in Baffin Bay, and whilst it may be a factor, we argue that dissolution is likely driving at least some of this pattern.

5.1.1. *Cold, corrosive bottom waters*

Deeper sites in central and northern Baffin Bay are characterised by colder bottom waters (−0.1 to 0.3 °C) than shallower sites (<1000 m; 0.9–1.8 °C) with lower oxygen saturation (Fig. 3C). In the deeper Baffin Bay sites, the foraminiferal assemblage is dominated by agglutinated taxa, and the calcareous specimens found were living at the time of collection. This pattern may be partly attributed to the fact that Atlantic Water is warmer and has higher alkalinity than the polar water, which is undersaturated with respect to carbonate (Azetsu-Scott et al., 2010). The dissolved oxygen of waters can reflect both the pre-formed oxygen content (source water effect) and remineralisation (cumulative consumption and water mass age). Deep waters in Baffin Bay have a residence time of hundreds of years (Top et al., 1980; Zeidan et al., 2022), allowing more time for remineralization and decreasing pH, resulting in corrosive conditions (Aksu, 1983; Burgers et al., 2024; Zeidan et al., 2022).

Previous studies from Baffin Bay surface sediment samples document benthic foraminiferal assemblages dominated by agglutinated taxa, attributed to carbonate dissolution (Schroder-Adams et al., 1990; Schröder-Adams and Van Rooyen, 2011). Furthermore, studies highlight the presence of abundant planktic foraminifera in the surface waters of

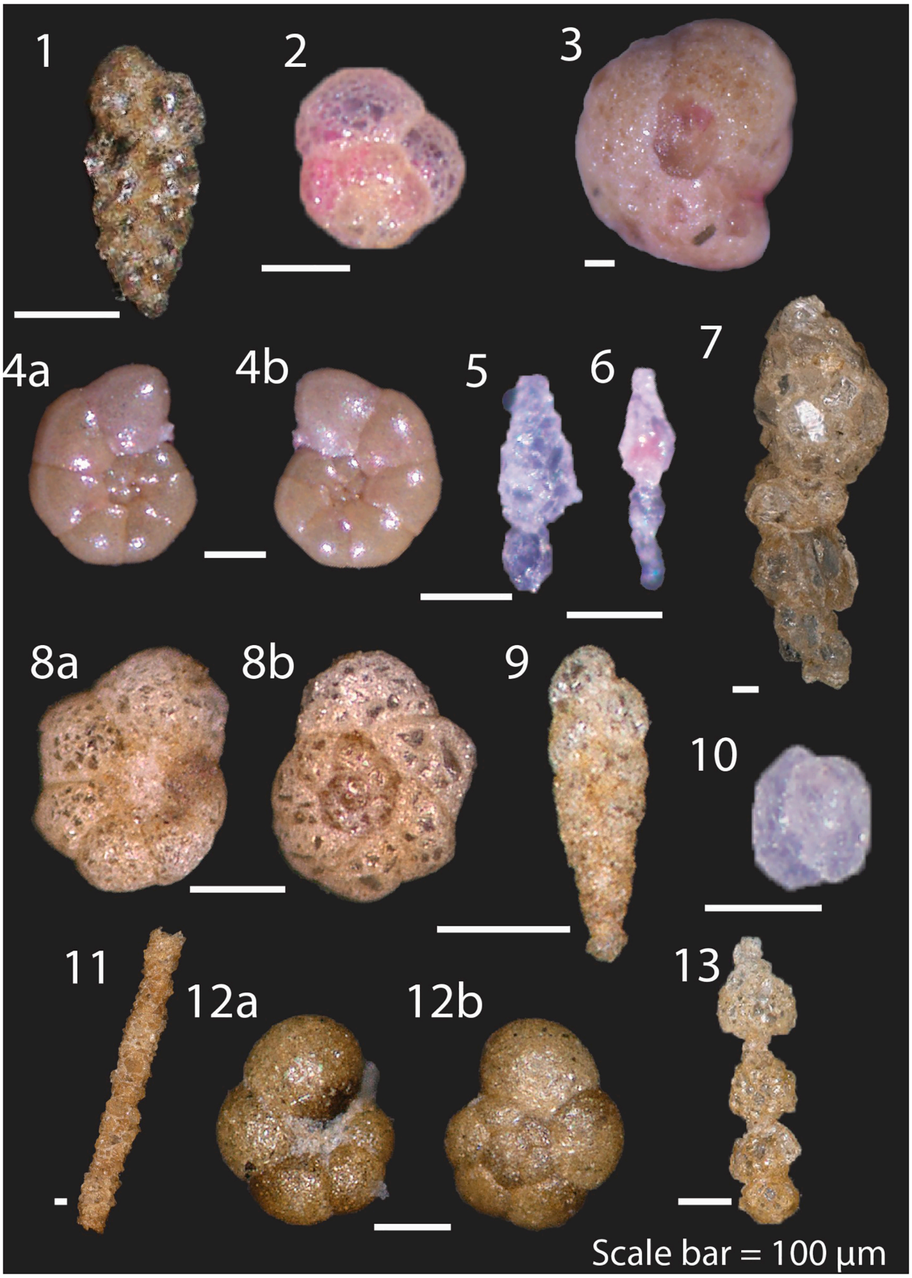

Fig. 15. Examples of agglutinated benthic foraminiferal species from surface samples, sites are listed next to each species in parentheses. 1. *Textularia torquata* (96MC), 2. *Trochammina quadriloba* (58MC), 3. *Recurvoides turbinatus* (96MC), 4. *Labrospira wiesneri* spiral (4a) and other side (4b) view (45MC), 5. *Reophax bilocularis* (64MC), 6. *Reophax scorpiurus* (64MC), 7. *Reophax subfusiformis* (96MC), 8. *Portatrochammina bipolaris,* (58MC), 9. *Textularia earlandi* (58MC), 10. *Adercotryma glomerata* (64MC), 11. *Rhahbdammina* fragment, 12. *Portatrochammina antarctica wiesneri* (96MC), 13. *Hormosinella guttifera* (96MC).

Baffin Bay, suggesting dissolution after deposition, providing further indication of rapid carbonate dissolution across this region (Stehman, 1972; Stehman and Gregory, 1973). Aksu (1983) directly document the intensity of carbonate dissolution of tests in surface sediments below 600–900 m water depth in Baffin Bay, attributed to cold, and saline bottom waters.

Elsewhere in the Arctic, studies report the dissolution of calcareous foraminifera. For example, on the Yermak Plateau in the Arctic Ocean, a lack of calcareous tests is attributed to corrosive bottom waters that dissolve foraminifera and remove calcium carbonate from the water column prior to deposition on the sea floor (Vilks, 1989). Similarly, in Lancaster Sound the dominance of agglutinated species is attributed to the influx of Arctic surface water (Hunt and Corliss, 1993; Kelleher et al., 2022).

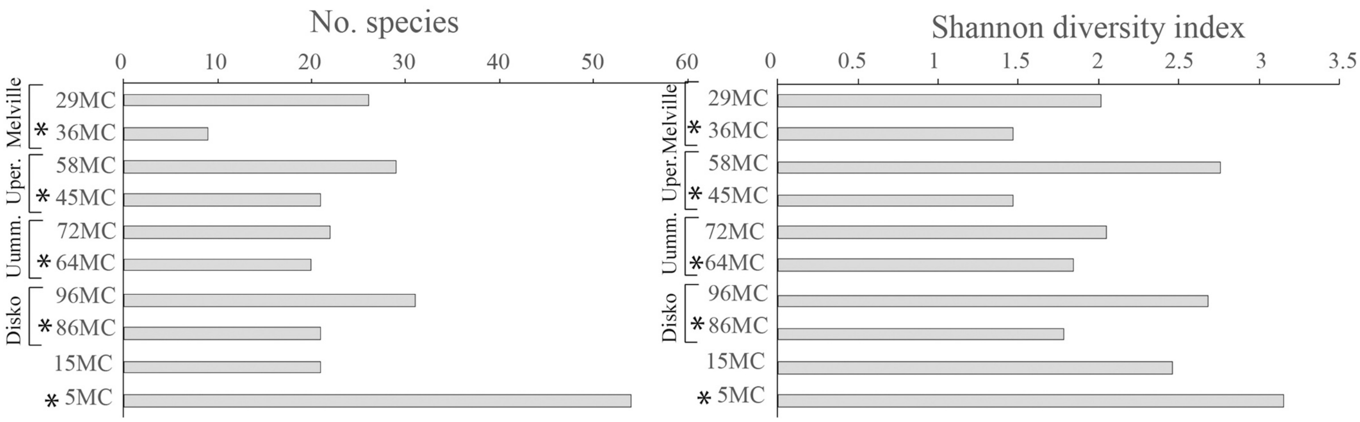

Fig. 16. Measures of diversity across sites: the number of species in each sample (left) and the Shannon diversity index (right). Deep sites (>1000 m water depth) are marked with *. Samples are plotted from north (top) to south (bottom).

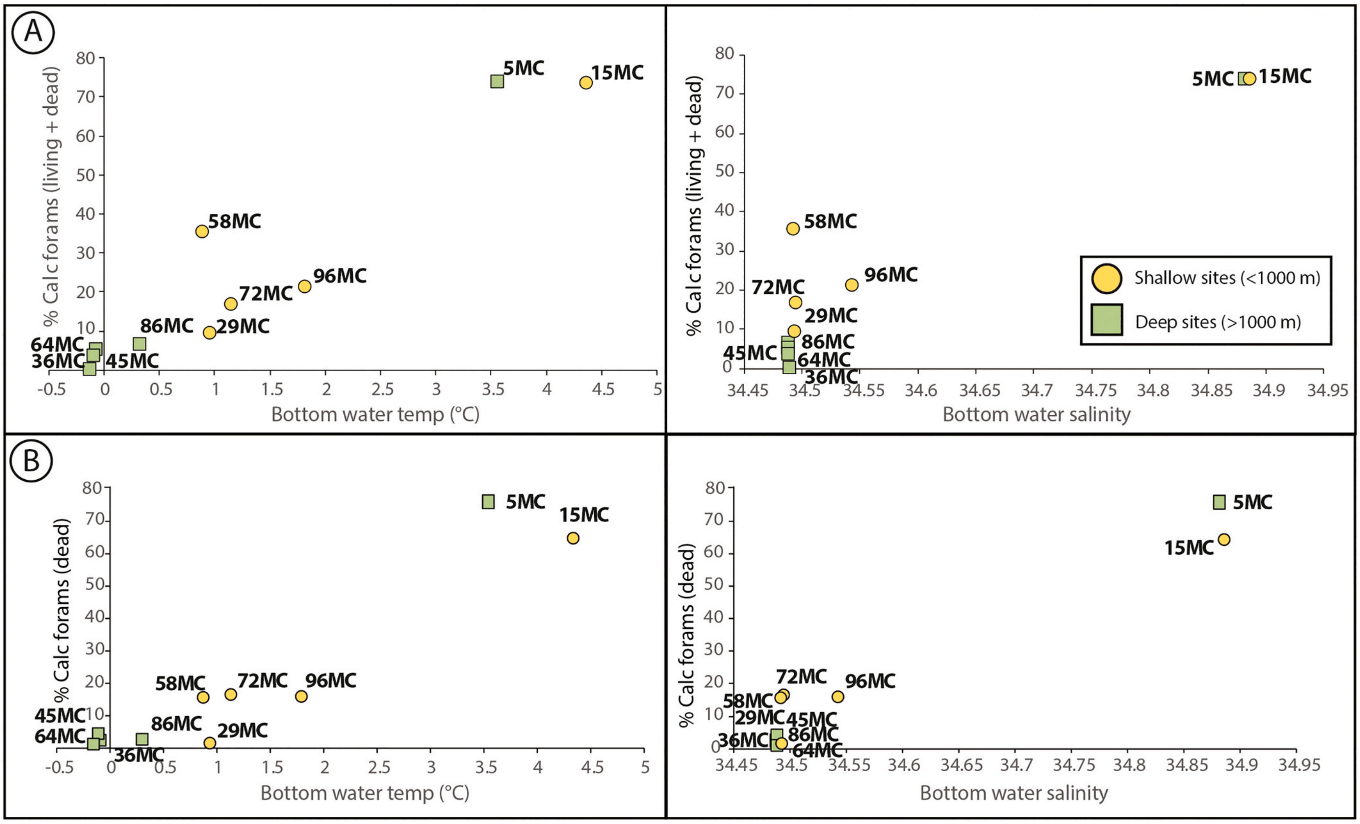

Fig. 17. Bottom water temperature (left) and salinity (right) from CTDs at each site is plotted against the percentage living and dead calcareous foraminifera (top) and dead foraminifera (bottom).

5.1.2. *Sea-ice cover and the dissolution of calcareous foraminifera*

The process of sea-ice formation rejects brine, water which is CO_2 rich, salty and has a low pH (Brown et al., 2015; Miller et al., 2011; Rysgaard et al., 2011). This dense water sinks to a depth in the water column, until it reaches equal density with underlying water, forming stratified bottom water masses that creates a corrosive environment that can dissolve calcium carbonate and affect the composition of foraminiferal assemblages (Haarpaintner et al., 2001; Schauer, 1995; Weeks and Ackley, 1986).

The correlation between the percentage calcareous foraminifera and concentrations of the sea-ice biomarkers IP_{25} and HBI II is negative (Figs. 18 and 19) indicating that the formation of seasonal sea ice may be

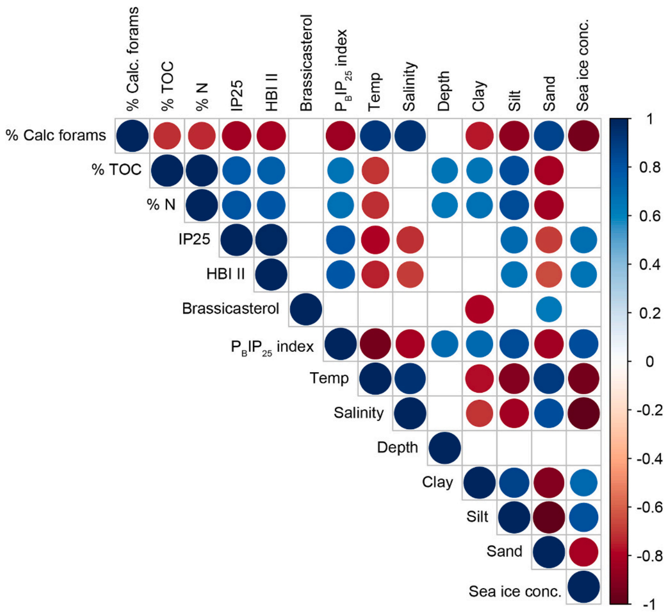

Fig. 18. Pearson correlation coefficients between percentage calcareous foraminifera and environmental variables: total organic carbon (TOC), percentage nitrogen (%N), IP_{25}, HBI II, brassicasterol, sitosterol, cholesterol (all in ng per g sed), P_BIP_{25} index, bottom water temperature and salinity, depth, percentage clay, silt and sand, observational sea-ice concentration data. Positive correlations are shown in blue and negative shown in red. The size and colour of the circle are proportional to the correlation coefficients. Insignificant correlations are left blank (p values >0.05). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

contributing to the dissolution of calcareous tests in this region. IP_{25} is produced by specific Arctic sea-ice dwelling diatoms during the spring bloom, before the lipids are deposited and preserved in marine sediments (Belt, 2019; Belt et al., 2007; Brown et al., 2014). It has been used extensively to reconstruct seasonal sea-ice conditions, extending back millions of years (e.g. Davies et al., 2024; Detlef et al., 2021; Stein et al., 2016; Syring et al., 2020), including in Baffin Bay (e.g. Georgiadis et al., 2020; Jackson et al., 2021; Harning et al., 2025). It is thought that IP_{25} and HBII are biosynthesized together in the base of seasonal sea-ice by the same diatoms (Brown et al., 2014). However, some observations from surface sample studies indicate this relationship is more complex, suggesting regional differences under which these biomarkers are produced (Kolling et al., 2020). Nonetheless, HBI II and IP_{25} follow a similar pattern in our study and we thus use them to infer seasonal sea ice.

The percentage of calcareous foraminifera vs the P_BIP_{25} index shows a negative correlation (Figs. 18 and 19). The P_BIP_{25} index combines open water biomarkers (e.g. brassicasterol) and the seasonal sea-ice indicator IP_{25} in order to estimate semi-quantitative estimates of sea-ice cover (Müller et al., 2011). Sites which lie in the seasonal sea ice range (P_BIP_{25} values between 0.5 and 0.8) have the lowest percentage of calcareous foraminifera, with those in the marginal sea-ice range (P_BIP_{25} values between 0.1 and 0.5), characterised by higher abundances of calcareous taxa. Sea ice is absent at site 15MC (observational data), corresponding with the highest percentage of calcareous foraminifera of all assemblages examined. Similarly, the CCA shows that calcareous species are negatively associated with IP_{25} and positively correlated with brassicasterol. Collectively, this implies that seasonal sea ice may be affecting the distribution of calcareous and agglutinated foraminifera in Baffin Bay and at our site in the Labrador Sea, but other environmental factors likely play a role.

Studies of foraminifera in surface samples from Storfjorden, Svalbard indicate that the agglutinated/calcareous ratio could be used as a proxy for brine formation and thus sea-ice cover, as corrosive, brine-rich bottom waters dissolve calcareous tests (Fossile et al., 2020; Nardelli et al., 2022). Similarly, in Northeast Greenland, foraminiferal assemblages from the outer shelf and in close proximity to the Northeast Water polynya are dominated by agglutinated taxa, and those on the inner shelf under longer lasting sea-ice cover are dominated by calcareous taxa (Davies et al., 2023). In Lancaster Sound, eastern Canadian Arctic, agglutinated taxa also dominate the assemblage and this is attributed to seasonal sea-ice break up (Kelleher et al., 2022; Schroder-Adams et al., 1990).

In contrast, under perennial sea ice, calcareous foraminifera are well preserved due to limited primary productivity and the absence of brine being ejected into surrounding waters, as well as slow sedimentation rates (de Vernal et al., 1992; Schroder-Adams et al., 1990). On the Axel Heiberg Shelf (Canadian Arctic), fauna are characterised by a highly diverse calcareous assemblage, with very few agglutinated taxa present, driven by perennial sea-ice cover (Schroder-Adams et al., 1990). However, the presence of warm Arctic Intermediate Water (Atlantic layer), may also be contributing to a faunal assemblage dominated by calcareous taxa (Aagaard et al., 1985).

5.1.3. *Primary productivity*

The surface samples in deeper sites in Baffin Bay are characterised by a higher TOC percentage than adjacent shallow sites; sediment samples in the Labrador Sea and Davis Strait also have low percentages of TOC. High organic input can result in bottom waters and sediment interstitial waters with a low pH and thus an assemblage dominated by agglutinated fauna. Such patterns are also observed in Drammensfjord, SE Norway (Alve, 1990) and on the Northeast Greenland continental shelf (Davies et al., 2023), where agglutinated dominate samples in areas with high primary productivity. Previously, a high percentage of agglutinated taxa has been used to reconstruct polynya stability, areas characterised by high primary productivity; examples include the Sirius polynya (Jackson et al., 2022) and in Svalbard fjords (Rasmussen and Thomsen, 2014). In our study, the deeper sediment samples have more agglutinated taxa present; the CCA shows positive correlation between TOC and the foraminiferal assemblages of these sites. In contrast, shallower Baffin Bay, the Labrador Sea and Davis Strait sites are negatively correlated with TOC. Furthermore, results from subsurface samples (4–5 cm) in Baffin Bay support the effect of TOC on pore water pH, along with other diagenetic processes, that cause loss of fauna. This suggests that higher primary productivity may be contributing to the dissolution of calcareous tests, to some extent, at these sites and collectively indicates that the low preservation of calcareous and agglutinated taxa in subsurface samples is linked to diagenetic processes.

5.2. *Distribution of key benthic foraminiferal species*

The distribution of many benthic foraminiferal species, as well as the living vs dead component of these assemblages, differentiates deep and shallow sites in Baffin Bay, and the sites in Labrador Sea and Davis Strait. Of particular note is site 58MC, which has a high abundance of calcareous foraminifera compared to other sites in Baffin Bay. It is important to note that the majority of foraminifera found were living, suggesting

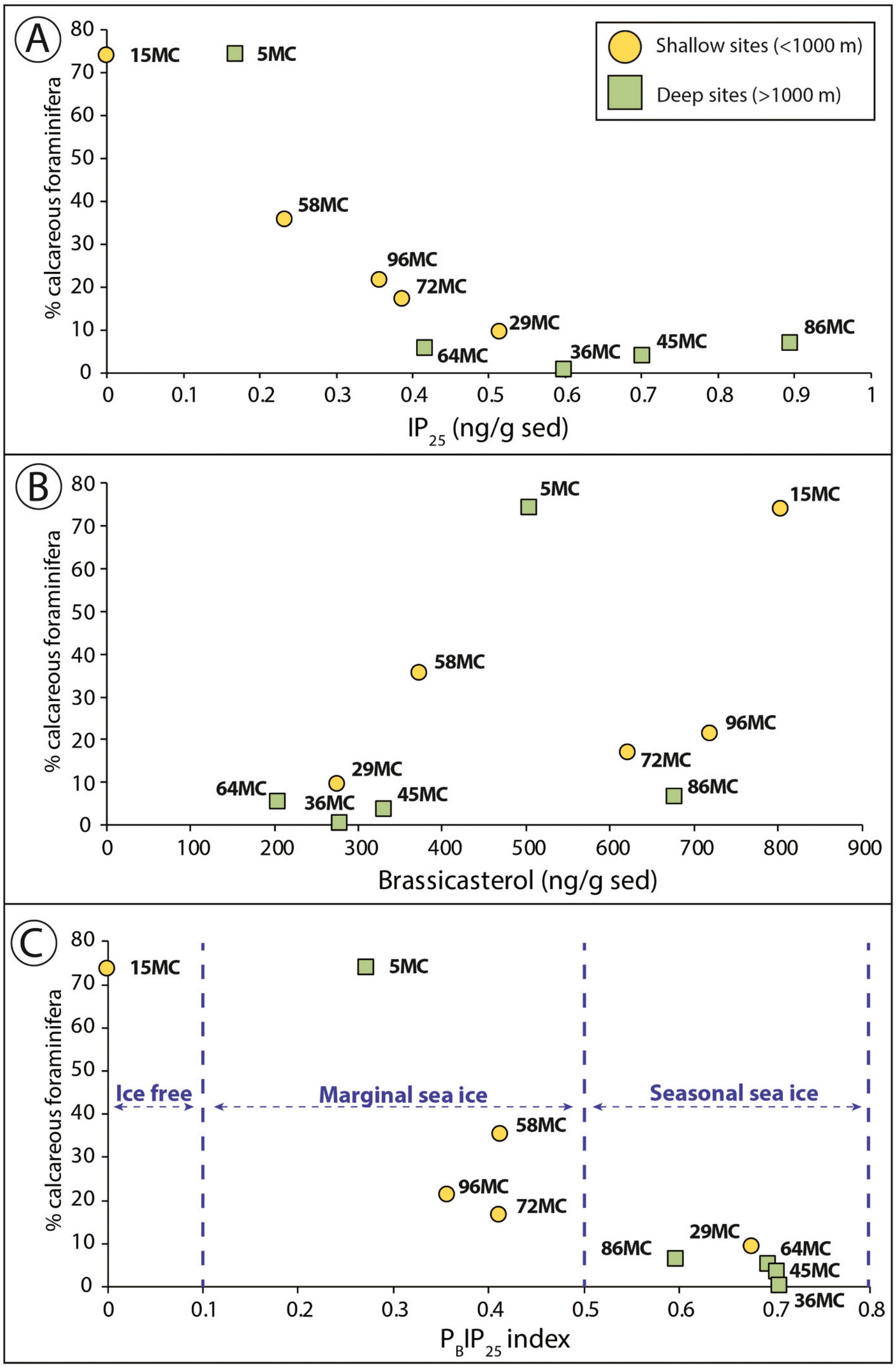

Fig. 19. Sea-ice biomarkers and sterols, specifically: A) IP_{25}, B) brassicasterol C) P_BIP_{25} index plotted against % calcareous foraminifera. Classifications of P_BIP_{25} index: ice free (0–0.1), marginal sea ice (0.1–0.5) and seasonal sea ice (0.5–0.8) come from Müller et al., 2011.

dissolution may be driving this pattern, rather than environmental variables. Whilst the patchy distribution of foraminifera is widely recognised (Fontanier et al., 2003; Hunt and Corliss, 1993; Jorissen et al., 1995), this may be driven by labile food supply, but may also be governed by environmental conditions that are favourable to preservation (e.g. warmer bottom waters). However, our measured environmental dataset provides no clear answer to this outlier (e.g. CCA results), suggesting that other conditions may be governing this distribution.

Here we outline the distribution of key species, link their presence to environmental variables and summarise existing research.

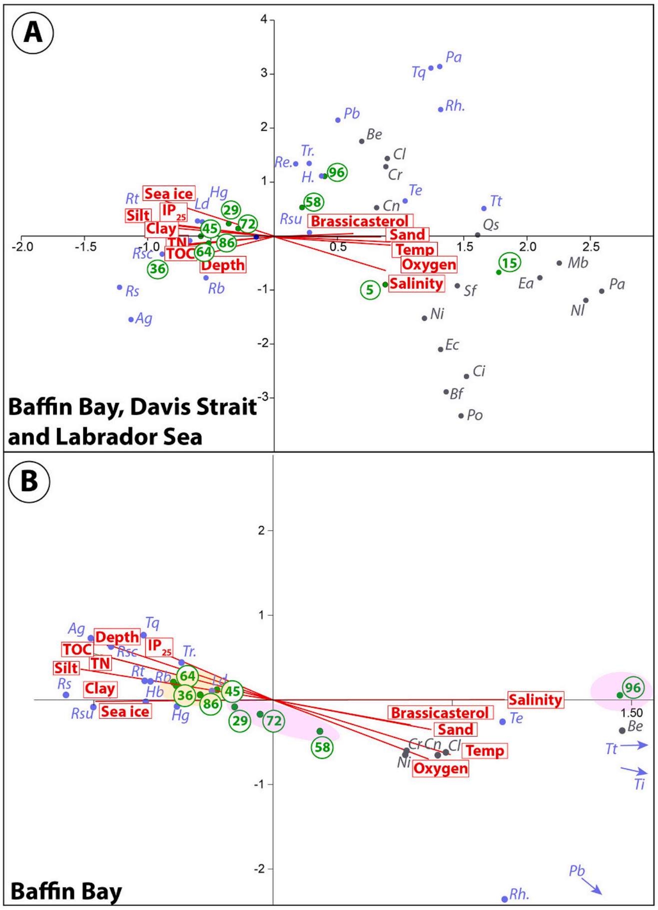

Fig. 20. CCA of benthic foraminiferal species for all sites (A) and Baffin Bay sites only (B). Species with >2 % in at least one sample are included, with calcareous (grey) and agglutinated (blue) shown in surface sediment samples with twelve environmental variables (red). The abbreviations of benthic foraminiferal species are presented in the Supplementary Material. The sites are shown in green circles. In panel B deep sites are shaded with an orange circle and shallow sites with pink circles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Ecology of key foraminiferal species. New data from this study compared to literature information from the Arctic region and elsewhere.

Species	Distribution and environmental preference in Baffin Bay, Davis Strait and Labrador Sea (this study)	Distribution and environmental preference in the Arctic and elsewhere (previous studies)
Cassidulina neoteretis Seidenkrantz, 1995	Dominant at sites in Baffin Bay and the Labrador Sea, apart from 36MC and 45MC. The latter are deep sites with very few calcareous tests in the assemblages suggesting that dissolution of these species may have occurred here.	Linked to Atlantic-sourced water masses stratified beneath cold, fresh waters (Cage et al., 2021; Jennings and Helgadottir, 1994; Seidenkrantz, 1995; Wollenburg et al., 2004).
Cassidulina reniforme Nørvang, 1945	Dominant in surface sediment samples of sites in eastern Baffin Bay and the Labrador Sea, apart from 36MC and 45MC. The latter are deep sites with very few calcareous tests in the assemblages suggesting that dissolution of these species may have occurred here.	This species is linked to cold, polar waters (Hald and Korsun, 1997; Polyak et al., 2002) and chilled Atlantic waters, that are fresher than those where *C. neoteretis* dominates (Ślubowska-Woldengen et al., 2007).
Cibicides lobatulus (Walker and Jacob, 1798)	Found in relatively high abundances at sites 58MC and 96MC and to a lesser extent at other shallow sites in Baffin Bay (29MC, 72MC). It is absent from deeper Baffin Bay sites supporting previous findings that it is found in shallow water and warmer bottom water temperatures.	Commonly found in shallower water and high energy environments (Hald and Steinsund, 1992; Ivanova et al., 2008; Jennings and Helgadottir, 1994). In Disko Bugt, this species dominates sites with relatively warm, low-saline surface waters (Lloyd, 2006).
Epistominella arctica Green, 1959	Abundant in Davis Strait sample, characterised by warmer bottom water temperatures and minimal sea-ice cover. Almost all taxa found were living at the time of collection suggesting it may respond rapidly to input of organic matter.	Linked to the episodic phytodetrital production and abundance in seasonally ice free areas (Gooday and Hughes, 2002; Wollenburg and Mackensen, 1998) and mobile sea ice in Hall Basin (Jennings et al., 2020).
Nonionellina labradorica (Dawson, 1860)	Abundant in Davis Strait but almost completely absent in Baffin Bay suggesting a link to warmer bottom water temperatures sites with less sea ice.	Linked to the availability of fresh organic matter (Hald et al., 1994; Kucharska et al., 2019), and is common in regions with high productivity (Polyak et al., 2002). In shallow sites in Disko Bugt, located close to the seasonal sea ice edge, both species were abundant in surface samples and associated with the highest TOC and TN measurements across all sites in the region (Lloyd, 2006). This was also linked to the distribution of water masses; in Disko Bugt this specifically relates to the strong influx of Atlantic-sourced West Greenland Current waters (Lloyd, 2006). It has also been linked to warmer waters which hug Point Barrow in the Chukchi Sea (Vilks, 1989)
Melonis barleeanum (Williamson, 1858)	Noticeably more abundant in Davis Strait (15MC) than at other sites in Baffin Bay. Absent, or present in low abundances, at Baffin Bay sites that are characterised by colder bottom water temperatures. However, it is more abundant at site 58MC.	Has previously been associated with a high proportion of organic matter (Caralp, 1989; Van Weering and Qvale, 1983),
Elphidium clavatum Cushman, 1930	Abundant in Davis Strait sample and present on at sites 58MC and 96MC in Baffin Bay. Davis Strait is characterised with higher	An opportunistic, glaciomarine species, dominating in environments with low temperatures and

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Species	Distribution and environmental preference in Baffin Bay, Davis Strait and Labrador Sea (this study)	Distribution and environmental preference in the Arctic and elsewhere (previous studies)
	bottom water temperatures and less sea ice than Baffin Bay sites.	salinities, and high turbidity (Hald et al., 1994; Osterman, 1984). In Petermann Fjord, this species was absent from beneath the ice tongue, attributed to its higher trophic requirements than the agglutinated and low-trophic requirement taxa (Jennings et al., 2020). Similarly, on the Northeast Greenland continental shelf, it was absent or present in lower numbers beneath perennial sea ice, close to glacier margins and abundant in areas characterised by high TOC content and low bottom water oxygen content (Davies et al., 2023), and in close proximity to the Northeast Water Polynya (Ahrens et al., 1997). This is also observed by (Vilks, 1989) in the Arctic Island Channels.
Nonionella iridea Heron-Allen & Earland, 1932	Most abundant in the Labrador Sea site. This species is small and fragile (Jennings et al., 2020), suggesting it is more likely to be dissolved. In fact, at all other sites, the majority of *N. iridea* taxa found were living at the time of collection, suggesting rapid dissolution; thus, it's distribution in Baffin Bay is perhaps influenced by corrosive conditions in this instance.	In the NE Atlantic it has been described as an opportunistic species, that is linked to the input of phytodetritus (Gooday and Hughes, 2002) and it has been shown to feed on degrading organic matter in laboratory experiments (Duffield et al., 2015). On the North Iceland Shelf this species is linked to marine frontal productivity (Harning et al., 2021). However, it has also been shown to survive in periods of low food supply, yet still thrives when organic matter input increases (Duchemin et al., 2005). In Northeast Greenland, *N. iridea* is most abundant in a proximal glacial environment, with extensive sea ice and low organic matter (Davies et al., 2023).
Adercotryma glomerata (Brady, 1878)	Absent from northern and central Baffin Bay shallow sites (29MC, 58MC, and 72MC) whilst very abundant at the deeper sites 64MC and 36MC, and, to a lesser extent, 45MC. This indicates different environmental preferences; in Baffin Bay our data suggest that the presence of *A. glomerata* may be linked to less saline, colder bottom water conditions that occupy deeper waters, together with more extensive seasonal sea ice.	Samples from Jones Sound, under the influence of cold, low saline Baffin Bay bottom water, were dominated by *A. glomerata* (Vilks, 1989). Elsewhere, this species has been commonly associated with Atlantic-source waters in high latitude regions (Hald and Korsun, 1997).
Textularia earlandi Parker, 1952	Present at most sites, apart from deep Baffin Bay sites 36MC and 64MC), and is generally more abundant at shallow sites. CCA suggests distribution is driven by high productivity, bottom water temperatures and salinity.	In Petermann Fjord, *T. earlandi* is found under the ice tongue, a low productivity environment (Jennings et al., 2020)
Portatrochammina bipolaris Brönnimann and Whittaker, 1980	Absent/present in low abundances at sites 15MC and 5MC (Davis Strait and Labrador Sea sites) and is present in Baffin Bay, where colder bottom waters dominate.	Has previously been found under polar waters in eastern Greenland fjords, as well as the Canadian Arctic (Jennings and Helgadottir, 1994; Vilks, 1989).
Lagenammina difflugiformis (Brady, 1879)	More abundant in deep and shallow sites across northern and central Baffin Bay, but much less abundant in Davis Strait and the Labrador Sea.	Found to dominate surface samples in Northeast Greenland (Davies et al., 2023), indicating it can thrive in Arctic environments.
Hormosinelloides guttifera Brady, 1881	Absent/present in low abundances at sites 15MC and 5MC (Davis Strait and Labrador Sea sites), it is present in Baffin Bay sites, where colder bottom waters dominate.	Found in surface samples in deep waters from Hecla and Griper Bay, Canadian Arctic. Here, water masses are characterised by low temperatures suggesting a preference for this environment (Vilks, 1989).

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6. Conclusions

Analysis of 10 surface sediment samples spanning Baffin Bay and the Labrador Sea provide the following conclusions, of importance for paleo-reconstructions in the region and elsewhere in the Arctic:

1. The percentage of agglutinated vs calcareous benthic foraminifera in surface sediment samples is a key feature differentiating assemblages in deep northern Baffin Bay sites (36MC, 45MC, 64MC, 86MC), which have fewer calcareous taxa, than shallower sites in the same region (29MC, 58MC, 72MC, 96MC). Our sites in Davis Strait (15MC) and in the Labrador Sea (5MC), are dominated by calcareous species. Importantly, in Baffin Bay sites with fewer calcareous benthic species, the majority of calcareous taxa found were living at the time of collection. This suggests rapid dissolution after deposition.
2. Correlations between the percentage calcareous taxa and bottom water salinities and temperatures, TOC, and the sea-ice biomarker IP_{25} and open water phytoplankton sterols, as well results from the CCA, suggests that the dissolution of calcium carbonate is being driven by cold, low salinity, corrosive bottom waters, high primary productivity and the formation of seasonal sea ice.
3. Whilst calcareous foraminifera are most commonly used in paleo-reconstructions, we show that carbonate dissolution is a problem across many of these sites, particularly deep ones in central and northern Baffin Bay. As such, valuable information can be gained from the agglutinated taxa which are better preserved in surface sediments, but less well preserved downcore (4–5 cm). Key benthic foraminiferal species differentiate surface sediment samples in Baffin

Bay, Davis Strait and the Labrador Sea, providing useful information for paleo-reconstructions.

CRediT authorship contribution statement

Joanna Davies: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Anne Jennings:** Writing – review & editing, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Alice Carter-Champion:** Writing – review & editing, Methodology, Formal analysis. **William J. D'Andrea:** Writing – review & editing, Methodology, Formal analysis. **Cara Fritz:** Writing – review & editing, Formal analysis, Data curation. **Erin E. Gregory:** Writing – review & editing, Investigation, Formal analysis, Data curation, Conceptualization. **David J. Harning:** Writing – review & editing, Formal analysis. **Robert Kelleher:** Writing – review & editing, Data curation. **Alan C. Mix:** Writing – review & editing, Investigation, Funding acquisition, Conceptualization. **Katherine Stelling:** Writing – review & editing, Investigation, Data curation. **Joseph S. Stoner:** Writing – review & editing, Funding acquisition, Data curation. **Maureen H. Walczak:** Writing – review & editing, Funding acquisition. **Shannon Klotsko:** Writing – review & editing, Funding acquisition, Formal analysis, Data curation. **Robert G. Hatfield:** Writing – review & editing, Funding acquisition, Conceptualization. **Brendan Reilly:** Writing – review & editing, Supervision, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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