Late Quaternary climate variations recorded in North Atlantic deep-sea benthic ostracodes

Spätquartäre Klimaschwankungen aufgezeichnet in benthischen Tiefsee-Ostracoden des Nordatlantiks

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»There are many things in the deep water; and seas and lands may change. And it is not our part here to take thought only for a season, or for a few lives of Men, or for a passing age of the world.«
'Gandalf', first volume of 'The Lord of the Rings'
by J.R.R. Tolkien, 1966.

Es gibt viele Dinge in tiefen Wassern; und Meere und Länder können sich ändern. Und es ist nicht unsere Aufgabe hier, nur Überlegungen für ein Jahr oder ein paar Menschenleben oder für ein vorübergehendes Zeitalter der Welt anzustellen.«
'Gandalf' im ersten Band 'Der Herr der Ringe'
von J.R.R. Tolkien, 1966.

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Abstract

The presented study investigates the response of the North Atlantic ostracode fauna to the glacial/interglacial climate changes of the past 200,000 years (marine isotope stages 7-1). Two sediment cores, one from the Iceland Plateau in the Nordic Seas and one from the Rockall Plateau, NE Atlantic, were selected.

By means of Q-mode factor analyses three clearly climate-related ostracode assemblages were identified in each core. On the Iceland Plateau *Henryhowella* dominates the interglacial periods MIS 5e and 1 (interglacial assemblage), whereas *Eucythere* shows increased abundances during the interstadial phases MIS 5a-d and 3 (transitional assemblage). The globally distributed taxa *Krithe* and *Cytheropteron* are abundant throughout the core and reach highest relative abundances during the glacial and stadial periods (background assemblage).

On the Rockall Plateau, a group of ostracode taxa consisting of *Pelecocythere, Eucytherura, Cytherella, Nannocythere, Aversovalva, Echinocythereis,* and *Henryhowella* is clearly linked to the interglacial and interstadial periods (interglacial assemblage). A second group consisting of the genera *Polycope, Propontocypris, Paracytherois, Bairdoppilata, Bythocythere, Bosquetina, Swainocythere, Bythoceratina, Pseudocythere,* and *Ambocythere* is related to the glacial periods (glacial assemblage). The third assemblage consists mainly of the common deep-sea genera *Krithe*, *Cytheropteron*, and *Argilloecia* and is abundant throughout the core (background assemblage).

The climate-dependent abundance of the assemblages is mainly related to glacial/interglacial changes in the food flux as well as to changes in the flow of well-ventilated NADW. The glacial ostracode taxa are interpreted as opportunistic, taking advantage of the absence of other taxa. The background assemblage shows no obvious relation to the environmental changes.

In both cores high ostracode diversities are observed during the glacial periods and, particularly, during meltwater events that are characterized by increased input of ice rafted detritus (IRD). Low carbonate content in these IRD-rich samples points to decreased phytoplankton production in the surface waters during the meltwater events. The observed relation of decreased food flux and increased benthic diversity has been found before for benthic foraminiferal faunas.

Aside from faunal analyses, stable carbon and oxygen isotope analyses were performed on the two ostracode genera *Krithe* and *Henryhowella* from the Iceland Plateau. Ostracodes from several surface sediment samples from the same area were analyzed as well. The results were compared to the isotope values of the epibenthic foraminifer *Cibicidoides wuellerstorfi* and the endobenthic foraminifer *Oridorsalis umbonatus*.

In contrast to the foraminifers that show well-known negative offsets from the oxygen isotope value of the equilibrium calcite, both ostracode taxa display positve offsets. *Krithe* reveals an offset of about +1.4 ‰ and *Henryhowella* shows an offset of approximately +0.4 ‰.

The downcore oxygen isotope records of *Krithe* paralles the record of *O. umbonatus*, whereas the record of *Henryhowella* displays a similar trend to the record *of C. wuellerstorfi*. The isotopic results and faunal analyses point to an endofaunal mode of life for *Krithe*, whereas *Henryhowella* is thought to live epibenthic.

In comparison to the carbon isotope values of *C. wuellerstorfi* that well-represent the isotope value of the dissolved inorganic carbon (DIC) the other taxa are depleted with respect to $\delta^{13}C_{DIC}$. The $\delta^{13}C$ values of *Henryhowella* are extremely negative (down to -7 ‰) and its isotope record displays large amplitudes possibly due to strong vital effects. However, the carbon isotopic record of *Henryhowella* shows the globally observed trend of low values during the glacial and high values during the interglacial periods, whereas the $\delta^{13}C$ record of *Krithe* reveals no obvious climate-related trend.

Kurzfassung

Im Rahmen der vorliegenden Arbeit wurde die benthische Ostracodenfauna zweier Sedimentkerne aus dem nördlichen Nordatlantik (M23352 vom Island Plateau, Europäisches Nordmeer und M23414 vom Rockall Plateau, Nordostatlantik) untersucht. Im Mittelpunkt standen dabei die Auswirkungen der glazial/interglazialen Klimawechsel der letzten ca. 200.000 Jahre (Sauerstoffisotopenstadien 7-1) auf die Ostracodenfauna des Nordatlantiks.

Mittels Q-modus Faktorenanalyse konnten in beiden Sedimentkernen je drei Ostracodenvergesellschaftungen identifiziert werden, deren Auftreten und Häufigkeit mit bestimmten klimaabhängigen Umweltbedingungen in Zusammenhang steht. Auf dem <u>Island Plateau</u> ist *Henryhowella* die dominante Gattung während der Interglaziale MIS 5e und 1 (Interglaziale Vergesellschaftung), während *Eucythere* hohe Häufigkeiten in den Stadien 5a-d und 3 aufweist (Übergangsvergesellschaftung). *Krithe* und *Cytheropteron*, beides global verbreitete Gattungen, weisen generell hohe relative Häufigkeiten in diesem Sedimentkern auf und erreichen höchste relative Häufigkeiten während der Glaziale und Stadiale (Hintergrundgesellschaft).

Die Ostracodenfauna auf dem <u>Rockall Plateau</u> ist gekennzeichnet durch eine Vergesellschaftung, die deutlich an interglaziale und interstadiale Bedingungen gebunden ist. Hierzu gehören Ostracoden der Gattungen *Pelecocythere, Eucytherura, Cytherella, Nannocythere, Aversovalva, Echinocythereis* und *Henryhowella* (Interglaziale Vergesellschaftung). Eine zweite charakteristische Gruppe ist an glaziale Bedingungen angepasst und umfasst die Gattungen *Polycope, Propontocypris, Paracytherois, Bairdoppilata, Bythocythere, Bosquetina, Swainocythere, Bythoceratina, Pseudocythere* und *Ambocythere* (Glaziale Vergesellschaftung). Eine dritte Gruppe erreicht durchgehend hohe Häufigkeiten und umfasst die weitverbreiteten und generell häufigen Gattungen *Krithe, Cytheropteron* und *Argilloecia* (Hintergrundgesellschaft).

Das offensichtlich klimaabhängige Auftreten der beschriebenen Ostracodenvergesellschaftungen hängt vermutlich hauptsächlich mit dem während der wärmeren Klimaphasen höheren Nahrungsangebot sowie dem Fluß von gut durchlüftetem Nordatlantischem Tiefenwasser in diesen Phasen zusammen. Die besonders in den Glazialzeiten häufigen Ostracodentaxa werden als opportunistisch interpretiert. Die 'Hintergrundgesellschaft' scheint nicht auf die glazial/interglazialen Änderungen der Umweltbedingungen zu reagieren.

In beiden Sedimentkernen wurden hohe Ostracodendiversitäten bei niedrigen Ostracodenkonzentrationen in den Glazialen und insbesondere in den Perioden erhöhten terrigenen Anteils (Schmelzwasserereignisse) beobachtet. Der gleichzeitig niedrige Karbonatanteil in solchen Abschnitten geht u.a. auf die erniedrigte Phytoplanktonproduktion während der Schmelzwasserereignisse zurück. Wie bereits für benthische Foraminiferenfaunen gezeigt werden konnte, scheint ein Zusammenhang zwischen niedrigem Nahrungsangebot und hoher Diversität des Benthos zu bestehen.

Neben den faunistischen Untersuchungen bildeten Analysen der stabilen Sauerstoff- und Kohlenstoffisotope an den beiden benthischen Ostracodengattungen *Krithe* und *Henryhowella* einen zweiten Schwerpunkt dieser Arbeit. In Ergänzung zu dem Sedimentkern vom Island Plateau wurden auch Ostracoden aus einigen Oberflächensedimentproben der selben Gegend analysiert. Die Ergebnisse wurden mit den Isotopenwerten zweier benthischer Foraminiferenarten, der epibenthischen *Cibicidoides wuellerstorfi* und der endobenthischen *Oridorsalis umbonatus*, verglichen.

Die Sauerstoffisotopenwerte beider Ostracodentaxa zeigen im Gegensatz zu denen benthischer Foraminiferen positive Abweichungen vom errechneten Gleichgewichtskalzit. *Krithe* zeigt um ca. 1,4 ‰ und *Henryhowella* etwa 0,4 ‰ erhöhte Werte.

Die in Kern M23352 an *Krithe* gemessene Sauerstoffisotopenkurve verläuft parallel zu der an *O. umbonatus* gemessenen, während die Isotopenkurven von *Henryhowella* und *C. wuellerstorfi* ebenfalls parallel zueinander verlaufen sich aber von den ersten beiden unterscheiden. Anhand der Isotopenwerte und faunistischen Analysen können

Rückschlüsse auf das Habitat der Ostracoden gezogen werden, welche frühere Beobachtungen bestätigen: *Krithe* lebt wie *O. umbonatus* endobenthisch, während *Henryhowella* wie *C. wuellerstorfi* epibenthisch lebt.

Im Vergleich zum Kohlenstoffisotopenwert von *C. wuellerstorfi*, der dem des im Wasser gelösten anorganischen Materials (DIC) entspricht, weisen die anderen Taxa niedrigere Werte auf. Die δ^{13}C-Werte von *Henryhowella* weisen über die letzten 200.000 Jahre eine Schwankungsbreite von über 6 ‰ auf und erreichen extrem negative Werte von bis zu -7 ‰. Vermutlich sind starke Vitaleffekte dafür verantwortlich. Dennoch zeigt die Kohlenstoffisotopenkurve von *Henryhowella* den global beobachteten Verlauf von niedrigen Werten im Glazial und hohen Werten im Interglazial, während die δ^{13}C-Kurve von *Krithe* keinen klimaabhängigen Trend erkennen läßt.

1. Introduction

The Quaternary climate periodically underwent massive changes from glacial periods with large ice sheets to interglacial periods similar to the present climate mode. These climate changes are linked to variations in the Earth's orbital parameters that cause fluctuations in solar energy received by the Earth (see Berger et al., 1984). Since the oceans store and transport heat, they play a crucial role in the Earth's heat balance. Changes in ocean circulation are of major importance with respect to climate change. During the past 25 years a global ocean circulation pattern has been discovered that plays a major role for the development of glacial and interglacial climate periods: Warm low-latitude Atlantic water masses are transported north by the Gulf Stream. On their way north these high-saline water masses cool down, gain density, and eventually begin to sink and flow southward across the Greenland-Scotland Ridge. There they form the major part of North Atlantic Deep Water (NADW), which travels around the globe through the Atlantic and Indian Oceans until it upwells in the North Pacific Ocean and returns as surface water to the Atlantic (this cycle is known as Global Ocean Conveyor Belt, see Broecker [1991]). The northern North Atlantic is considered the pace-maker of this sensitively balanced circulation system that provides heat and moisture to the northern Hemisphere and ventilates the deep ocean (e.g., Broecker and Denton, 1990). Even minor changes in surface-water salinity or temperature may cause disruptions in the formation of deep waters and, thus, influence the warm water flow that is responsible for the present-day mild climate of Europe (e.g., Rahmstorf, 1994).

Since the North Atlantic plays a crucial role in the global thermohaline ocean circulation, the complex interrelations between surface- and deep-water circulation, in particular in the northern North Atlantic, have become the focus of many scientific investigations (e.g., CLIMAP, 1976, 1981). To achieve an assessment of fluctuations in the flow of deep-water masses that would mirror thermohaline overturn through glacial-interglacial cycles is thus one of the major goals in paleoclimatic and paleoceanographic research. In this respect, various proxies, such as distribution and abundance of planktic and benthic microfossils, have been investigated in order to reconstruct past ocean temperatures, productivity, and circulation modes (e.g., Imbrie and Kipp, 1971, Pflaumann et al., 1996; Streeter et al., 1982; Herguera and Berger, 1991).

Aside from many micropaleontological proxies, geochemical proxies such as stable oxygen and carbon isotopes are instrumental for the reconstruction of paleocirculation modes (e.g., Duplessy et al., 1980; Oppo and Fairbanks, 1987; Labeyrie et al., 1987; Sarnthein et al., 1994). So far, information of past deep-water circulation modes has been gained almost exclusively from benthic foraminiferal isotope records since these bear signals on deep-water temperatures and rates in deep-water formation. Although benthic foraminifers are usually abundant in most deep-sea sediments, it has been shown that, e.g., in glacial sediment sections from the Nordic Seas benthic foraminifers are extremely rare (see Schnitker, 1979; Streeter et al., 1982; Duplessy et al., 1988).

Deep-sea benthic ostracodes are globally distributed microcrustaceans that live in the same environment as foraminifers. They build a calcitic, fossilizable carapace that can be used for stable isotope analyses (e.g. von Grafenstein et al., 1992). In contrast to benthic foraminifers, however, many of the modern deep-sea ostracode taxa occur continuously during interglacial as well as glacial periods, which makes them most valuable for the reconstruction of past ocean environmental conditions.

The use of all microfossil-based proxies requires a detailed knowledge of the complex relationships between environmental parameters and the biotic response. This is particularly important for those conditions that influence the stable isotope ratios incorporated in the microfossil tests. Numerous studies on habitat and habits of benthic foraminifers together with isotope analyses of the ambient pore- and bottom waters have been carried out to shed light on these complex interactions, (Woodruff et al., 1980; Belanger et al., 1981; McCorkle and Keigwin, 1994; McCorkle et al., 1997). Yet, no investigation has been carried out that would have examined systematically these parameters with respect to deep sea ostracodes. In the present study, a combination of faunal and stable isotope analyses will be used to extend the knowledge of the environmental demands of deep-sea benthic ostracodes, and finally, to evaluate ostracodes as another principal paleoceanographic proxy.

1.1 Main objectives

In order to investigate the potential of deep-sea benthic ostracodes, detailed faunal and stable isotopes analyses were carried out for paleoceanographical reconstructions. For this purpose, two sediment cores from the climate-sensitive region of the North Atlantic were selected, both covering the past 200,000 years, i.e. the last two climate cycles. Both cores yielded substantial numbers of ostracodes throughout the investigated intervals. The massive environmental changes that occurred in the course of late Quaternary climate change, such as changes in deep-water circulation and food supply, should have affected the ostracode fauna in a similar way as benthic foraminifers. A number of previous studies on both cores include investigations of the benthic foraminiferal fauna as well as of the abundance of various planktic microfossils (Struck, 1992, 1997; Nees 1993; studies by the SYNPAL working group [see Hass et al., in press for summary]). The valuable paleoenvironmental information provided by these studies and other sources will be used to contribute to the yet insufficiently known ecology and environmental demands of deep-sea ostracodes and their relation to climate change. Although much has been published on ostracode taxonomy, stratigraphical range, and relation to water masses, relatively little is known about the ecology of deep-sea ostracodes. Not much has been published so far about the food preferences of distinct ostracode species and their relation to food flux, a factor known to be most important for the distribution and abundance of benthic life in an open ocean environment (e.g., Gooday and Lambshead, 1989). Comparison with productivity proxy data from the research area will be used to gain more information of the ecology of some deep-sea ostracode taxa.

A second focus of the study is the paleoceanographical use of stable carbon and oxygen isotope records of two globally distributed deep-sea ostracode genera. So far, stable isotope analyses have been sucessfully applied to non-marine ostracodes and some shallow-marine taxa, also suggesting promising results for the paleoceanographical use of stable isotope records derived from deep-marine ostracodes. In contrast to many freshwater ostracode taxa not much is known yet about possible species dependant offsets of the isotope values derived from marine ostracodes from the isotope value of the ambient water. The use of ostracode stable isotope data similar to those of benthic foraminifers requires the examination and quantification of these possible offsets. To determine specific 'vital effects', ostracode isotope records are compared to those of benthic foraminifers, for which constant offsets from the isotope value of the equilibrium calcite have been well manifested (Shackleton and Opdyke, 1973; Streeter and Shackleton, 1979). The isotope analyses on benthic foraminifers and ostracodes from surface sediments will be supported by isotope analyses of the ambient bottom water. The comparison of foraminiferal and ostracodal downcore isotope records will be used to determine possible offsets during the time of the last two climate cycles.

1.2 Physiography and hydrography of the research area

1.2.1 Physiography

The modern physiography of the working area reflects the plate-tectonic evolution of the North Atlantic Ocean. The <u>Rockall Plateau</u> is a relatively shallow area (in some areas < 500 m water depth) situated NW of Ireland (Fig. 1.1). It consists of the shallow Rockall Bank in the east and Hatton Bank in the west, separated by the Rockall-Hatton Basin, bordered by the Rockall Trough in the east and the Iceland Basin in the west.

The <u>Iceland Plateau</u> (up to < 1000 m water depth) is situated north of Iceland, bordered by the active Kolbeinsey Ridge in the west, the Jan Mayen Fracture Zone in the north and the Jan Mayen Ridge in the east (Fig. 1.1).

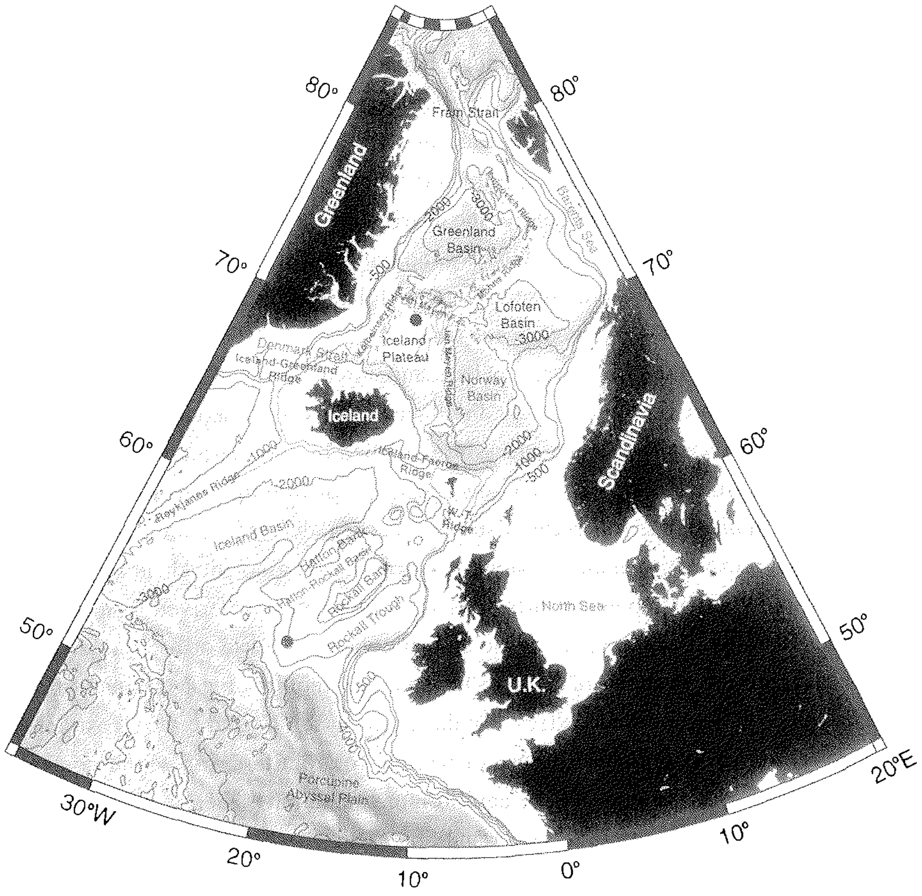

Fig. 1.1. Bathymetric map of the research area. Black dots indicate core sites.

1.2.2 Modern North Atlantic deep-water circulation

The modern circulation system of the Atlantic is directly linked to the tectonic development in the North Atlantic region. After the subsidence of the Greenland-Scotland Ridge the flow of cold bottom waters from the Nordic Seas to the south established during the middle Miocene and has since remained relatively strong (Wright and Miller, 1996). This deep-water flow to the south was finally intensified after the closure of the Panama Isthmus around 1.8 my ago, which is considered as the onset of the modern North Atlantic deep water circulation (e.g., Burton et al., 1997).

The circulation in the modern North Atlantic is of major importance for the global ocean circulation. The Gulf Stream that originates in the Caribbean, and its continuation, the North Atlantic Drift (NAD) and the Norwegian Current (NC), transports warm, saline waters into the Nordic Seas along the coasts of northwestern Europe (Fig. 1.2). It is this current that is responsible for the present mild climate in northwestern Europe. The counterpart of this northward-flowing, temperate current is the East Greenland Current (EGC) that transports cold, low-saline waters from the Arctic Ocean southward along the east coast of Greenland. In the Nordic Seas these two surface water masses mix, developing two major convective gyres in the Greenland Basin and over the Iceland Plateau (see e.g., Aagaard et al, 1985). Low temperature and relatively high salinity lead to an increase in the density of the surface water. Additional cooling by cold katabatic winds from Greenland, forces these waters to sink, forming well-ventilated intermediate and deep-water masses (e.g., Broecker, 1987, 1991).

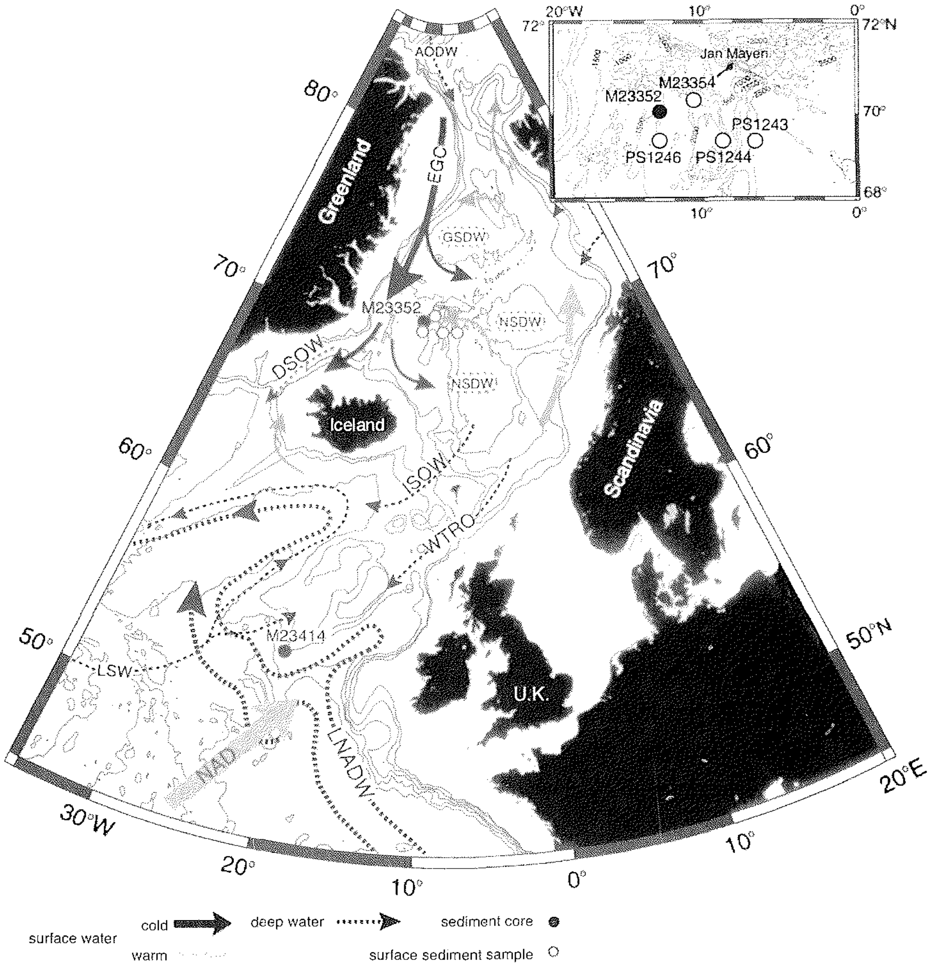

Fig. 1.2. Overview of modern surface and deep-water circulation in the northern North Atlantic with core locations (hydrography after Koltermann, 1987; McCave and Tucholke, 1986; Manighetti and McCave, 1995). Enlargement shows core locations on the Iceland Plateau.

The two dominant water masses found in the deep Nordic Seas are: in the Greenland Basin the Greenland Sea Deep Water (GSDW) that forms by stepwise convection and entrainment of southward-flowing Arctic Ocean Deep Water (AODW); and the Norwegian Sea Deep Water (NSDW) in the Norway and Lofoten Basins that forms by fast, deep-convection processes and the entrainment of GSDW (Koltermann, 1987). The major part of these dense deep waters flow across the Greenland-Scotland Ridge via the Denmark Strait (as Denmark Strait Overflow Water, DSOW), the Iceland Scotland Ridge (as Iceland-Scotland Overflow Water, ISOW), and further east as Wyville-Thomson Ridge Overflow Water (WTRO) (see Fig. 1.2). These overflow waters are the principal sources of NADW that eventually forms south of the Greenland-Scotland Ridge as a mixture of several water masses (see McCave and Tucholke, 1986). Labrador Sea Water (LSW) together with Mediterranean Outflow Water (MOW) and parts of the overflow waters from the Norwegian Sea form the upper portion of the NADW (UNADW), found in depths shallower than 2000 m (Kawase and Sarmiento, 1986).

The lower NADW (LNADW), found below 2000 m, is mainly composed of overflow waters from the Nordic Seas and an integral part of LSW. Below 3500 m a water mass of southern origin is located. This Southern Source Water (SSW) is modified Antarctic Bottom Water (AABW) that entrained parts of LNADW and other water masses (see Manighetti and McCave, 1995).

1.2.3 Glacial circulation modes

When compared to an interglacial circulation mode, major differences characterized the circulation pattern during the Pleistocene glaciations. According to numerous studies, deep water was still produced during the glacial periods but not to the same extent as during interglacial times (e.g., Boyle and Keigwin, 1987; Oppo and Fairbanks, 1987; Rahmstorf, 1994; Sarnthein et al., 1994; Venz et al., 1999). Sea ice and low density meltwater that covered the Nordic Seas prevented deep convection and supported instead the production of intermediate deep water during summer (e.g., Boyle and Keigwin, 1987; Sarnthein et al., 1994; Weinelt et al., 1996). It is believed that the major part of this intermediate deep-water mass, the so-called Glacial North Atlantic Intermediate Water (GNAIW), was produced south of the glacial polar front, probably somewhere southwest of Iceland (e.g., Weinelt et al., 1996; Venz et al., 1999; Flower et al., 2000). The weaker production of northern source deep water resulted in increasing influence of southern source water, which extended further north and to shallower water depths during the glacial periods (e.g., Venz et al., 1999). Since the amount of southward-flowing deep water is proportional to the northward-flowing warm surface water, the weak production of GNAIW instead of NADW results in less heat release in the northern North Atlantic which in turn added to the cooling of the northern Hemisphere climate (Lynch-Stieglitz et al., 1999; Flower et al., 2000).

Oxygen isotope records derived from ice cores drilled in the Greenland ice (GRIP and GISP2) revealed several short-term climate fluctuations that occurred particularly between 100,000 and 10,000 years BP (e.g., Dansgaard et al., 1993; GRIP Members, 1993; Grootes et al., 1993). Warm so-called Dansgaard-Oeschger events alternate with cold events, the latter being characterized, for example, by increased abundances of the polar planktic foraminifer *Neogloboquadrina pachyderma* sin. in the North Atlantic (e.g., Bond et al., 1993). Each of these climate cycles culminated in a massive iceberg discharge into the North Atlantic affecting the area from the Labrador Sea to the British Islands (Bond et al., 1992, 1993). Traces of these ice-rafting events are the so-called Heinrich layers (after Heinrich, 1988); layers consisting of ice-rafted debris (IRD) that occurred every 7,000-9,000 years in the area of the North Atlantic (Bond et al., 1992; Grousset et al., 1993). These Heinrich events are considered to be linked to changes in surface- and deep-water circulation and to cold climate periods in the northern high latitudes (Broecker, 1994; Maslin et al., 1995). Low-density meltwater that covered the North Atlantic during these events prevented the formation of NADW and promoted a change in circulation (e.g., Maslin et al., 1995; Seidov et al., 1996). Circulation models run by Seidov et al. (1996), suggested a circulation pattern during meltwater events that differs significantly from the interglacial but also from the glacial circulation modes.

1.3 Ostracodes as proxies in paleoclimatology and paleoceanography – state of the art

Studies investigating the ostracode faunas of the northern North Atlantic, mainly of descriptive nature, began in the middle of the 19th century (e.g., Brady, 1868, 1878; Norman, 1877; Brady and Norman, 1889; Stephensen, 1939; Elofson, 1941). More recently further studies have been carried out that were still mainly taxonomic. These include examinations of the ostracode fauna off the coasts of Greenland (Penney, 1989; Whatley et al., 1996), North America (Hazel, 1967, 1970; Cronin, 1989), Iceland (Cronin, 1991), Spitsbergen (Hartmann, 1993) and Novaya Zemlya (Neale and Howe, 1975). The taxonomy of many North Atlantic shallow-water and shelf taxa that occur in the two sediment cores of the present investigation has been provided by these studies.

The evolution and taxonomy of the North Atlantic Cenozoic deep-sea ostracode fauna has been studied in detail by several authors using samples from various DSDP and ODP legs: Cenozoic ostracodes from the Rockall Plateau area were studied by Benson (1972) and Ducasse and Peypouquet (1979). The latter authors used ostracode faunal assemblages for paleobathymetric reconstructions. They also suggested that food supply in combination with circulation modes controls ostracode abundance and faunal composition. They attributed the sudden decrease in diversity from the lower to the upper Pliocene to the arrival of cold deep waters (< 3° C) from the Nordic Seas, which forced a new ostracode fauna to evolve. Another investigation used the deep-sea ostracode fauna off New Jersey for Eocene paleodepth and paleoceanographical reconstructions (Cronin and Compton-Gooding, 1987). An impoverished Pleistocene ostracode fauna found on the Vøring Plateau has been related to the influence of a food-limiting ice cover, whereas the low species diversity in Miocene and Pliocene samples from the same location is probably caused by the existence of the Iceland-Faeroe Ridge that may have prevented the migration of taxa from the south (Malz, 1989). Two studies on ostracodes from several DSDP and ODP legs provided a detailed taxonomic framework for North Atlantic ostracodes from the late Miocene to the Quaternary, on which much of the taxonomy used in the present investigation is based (Whatley and Coles, 1987, Coles and Whatley, 1989).

In the past decade, a growing number of authors has related ostracode faunal assemblages to the physico-chemical properties of water masses and used ostracode faunal investigations for paleoceanographical and paleoclimatological reconstructions. For instance, the water-mass distribution associated with the Benguela upwelling system together with surface-water productivity and oxygen content of the bottom water has been considered responsible for the development of specific ostracode faunas (Dingle et al., 1989, 1990; Dingle and Giraudeau, 1993 and Dingle, 1995). Variations in Pliocene North Atlantic ostracode assemblages have been correlated with glacial-to-interglacial circulation changes in that a strong influence of either relatively warm NADW or cold AABW results in the development of different faunal assemblages (Cronin et al., 1996). Investigations in the Southern Ocean found the depth distribution of ostracodes closely related to water-mass boundaries (Ayress et al., 1997). Studies on late Quaternary paleoceanography of the Arctic Ocean considered the inflow of warm Atlantic water masses and increased surface water productivity responsible for the development of highly abundant and diverse ostracode assemblages (Cronin et al., 1994, 1995; Jones et al., 1999).

Nowadays more attention is paid to the shell chemistry of ostracodes, which can be used as a powerful tool in paleoclimatology and paleoceanography since the trace-element content of the valves provides information concerning paleosalinity and paleotemperature (Chivas et al., 1986; De Deckker et al. 1988; Corrège, 1993; Dwyer et al., 1995; Hu et al., 1998). The Mg/Ca ratio in ostracode shells has been used to reconstruct the temperature of Pliocene and late Quaternary deep waters (Dwyer et al., 1995; Cronin et al., 1996, 1999, 2000). These studies showed that high ostracode Mg/Ca ratios reflect increased bottom-water temperatures. These are linked to the enhanced flow of relatively warm NADW, which clearly correlates to orbitally and suborbitally forced climate changes.

In particular, stable carbon and oxygen isotopes derived from non-marine ostracode shells gained attention, since ostracodes are often the only available calcareous microfossils in fresh-water sediments and their stable isotope records provide valuable paleoclimatic information (von Grafenstein et al., 1992, 1996, 1998, 1999a; Heaton et al., 1995). High-resolution oxygen isotope records derived from ostracodes from German lakes revealed decadal variations in European climate during the past 15,000 years that were clearly linked to changes in the North Atlantic thermohaline circulation (von Grafenstein et al., 1998, 1999a). Since ostracodes are such valuable proxies in the non-marine environment, systematic investigations have been carried out to elucidate the complex interactions between environmental factors and shell-chemistry of non-marine ostracodes (Xia et al., 1997; von Grafenstein et al., 1999b).

1.4 Methods and Material

1.4.1 Samples

The investigated sediment cores and the related boxcores M23352-3/2 from the Iceland Plateau and M23414-6/9 from the Rockall Plateau were taken during 'METEOR' cruises M7/5 in 1988 and M17/2 in 1991 (Hirschleber et al., 1988; Suess and Altenbach, 1992) Additional surface sediment samples that were selected for isotope analyses on distinct benthic foraminifer and ostracode taxa were taken during 'METEOR ' cruise M7/5, in 1988 and 'POLARSTERN' cruise ARK II/5 in 1984 (Augstein et al., 1984). All samples are listed in Table 1.1, core locations are shown in Fig. 1.2.

Table 1.1 Geographical positions of all used samples

Site	Device	Longitude	Latitude	Water depth	Reference; Cruise
M23352-3	kasten core	70° 00.4' N	12° 25.8' W	1819 m	1; M7/5
M23352-2	boxcore	70° 00.5' N	12° 25.5' W	1822 m	1; M7/5
M23414-9	kasten core	53° 32.2' N	20° 17.3' W	2196 m	2; M17/2
M23414-6	boxcore	53° 32.2' N	20° 17.4' W	2201 m	2; M17/2
PS1243-2	boxcore	69° 22.5' N	06° 31.3' W	2716 m	3; ARK II/5
PS1244-1	boxcore	69° 22.0' N	08° 40.0' W	2122 m	3; ARK II/5
PS1246-2	boxcore	69° 23.0' N	12° 55.0' W	1902 m	3; ARK II/5

References: 1. Hirschleber et al. (1988); 2. Suess and Altenbach (1992); 3. Augstein et al. (1984).

Since the abundance of ostracodes is known to be low in some sediments, new, relatively large samples (1 cm thick slices) of approximately 50 g dry sediment were taken from the archive liners of both kasten cores and the box core of site M23352. From the boxcore of site M23414 large sieved samples were already available, provided by S. Nees.

1.4.2 Sample treatment

The sample treatment followed standard methods; the flow chart in Fig. 1.4 shows the general treatment of the samples. After washing (63 µm) and sieving, using standard sieves, the ostracodes were picked separately from the subfractions 125-250 µm, 250-500 µm and >500 µm. SEM photographs were taken from most taxa for taxonomic identification. After extracting the ostracodes from each subfraction these were identified and counted (see Chapter 2 for details). All results are listed in the appendix (Tables A16 and A17) and all samples as well as the extracted ostracodes are housed at GEOMAR, Kiel. The ostracode fauna is documented by SEM photographs shown in the appendix.

As dissolution may obscure trends in faunal composition and diversity, the Ostracode Dissolution Index (ODI) according to Passlow (1997) was applied to the valves of *Krithe* (see Chapters 2 and 4).

For the identification of ice-rafting events, such as Heinrich events, the amount of IRD (expressed as grains/g dry sediment) was determined by counting the lithic grains in split samples of the subfractions 250-500 and >500µm (see tables A5 and A11).

For stratigraphical purposes approximately 30 specimens of the planktic foraminiferal species *Neogloboquadrina pachyderma* sin. from the 125-250 µm fraction of each sample of core M23352 and approximately 15 specimens of *Globigerina bulloides* from the 250-500 µm fraction of core M23414 were selected for stable isotope analyses. Additionally, several AMS ^{14}C analyses were carried out on *N. pachyderma* sin. All AMS analyses were carried out at Leibniz Laboratory at Kiel University (AMS ages are listed in Table A2). Numerous benthic and planktic isotope data of core M23414 were taken from Jung (1996) and several isotope data of core M23352 were provided by H.A. Bauch. On the basis of the partly new data the stratigraphy was established that slightly differs from the one used in earlier publications (e.g., Jung, 1996). The stratigraphy is described in detail in Chapter 4.

Benthic isotope records were performed using approximately 7 specimens of *Cibicidoides wuellerstorfi* from the 250-500 µm fraction and approximately 20 specimens of *Oridorsalis umbonatus* (the latter from core M23352 only). Most stable isotope analyses were carried out at the Leibniz Laboratory of Kiel University using a Finnigan MAT 251 mass spectrometer with a fully automated carbonate preparation device (analytical accuracy is ±0.08 ‰ for δ^{18}O and ±0.05 ‰ for δ^{13}C); some analyses were carried out at the GEOMAR isotope laboratory using a Finnigan MAT 252 mass spectrometer with Kiel-Carbo II device (analytical accuracy is ±0.03 ‰ for $\delta^{18}O$ and ±0.015 ‰ for $\delta^{13}C$). All isotope values are given in the conventional δ-notation relative to the NBS 20 standard, which is equal to the Pee Dee Belemnite (PDB).

For each ostracode stable isotope analysis, approximately 4 valves of *Henryhowella* and approximately 7 valves of *Krithe* were selected from the >250 µm fraction (see Chapter 3 for details).

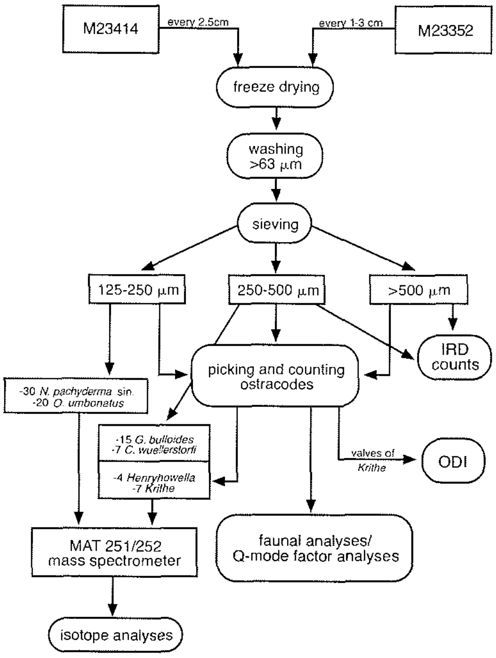

Fig. 1.4. Flow chart of general sample treatment.

1.4.3 Data treatment

For paleoceanographical interpretations, the relative abundances of ostracode taxa or groups were used. Since relative abundances do not take the total number of specimens into account, the absolute abundances of ostracodes (expressed as valves/g dry sediment) were also calculated (see Chapters 3 and 5).

The multivariate statistic technique of factor analysis is commonly used to reduce large numbers of variables (taxa) to interpretable small numbers (assemblages) (e.g., Reyment and Jöreskog, 1996). A Q-mode factor analysis was carried out using the software package CABFAC based on relative abundance data (see Imbrie and Kipp, 1971; Klovan and Imbrie, 1971). Because both cores were too different in their ostracode assemblages, separate factor analyses were run for each core (see Chapter 4 for details).

Diversity data may provide additional information about environmental conditions that influence a community. Among many available indices to express diversity, the number of ostracode species (S) and the commonly used Shannon-Wiener index (H') were calculated in the present study (see Chapter 4). In contrast to S, H' takes the proportion of each species within the community into account, thus, avoiding over-representation of rare species.

1.5 Individual studies

The following chapters address the above-mentioned subjects. Each chapter represents a paper submitted to a peer-reviewed scientific journal. In the following section a short overview of each study is given. For convenience, the references of each chapter are combined into a complete list that can be found in Chapter 6.

Chapter 2

Species composition and glacial-interglacial variations in the ostracode fauna of the northeast Atlantic during the past 200,000 years

C. Didié and H.A. Bauch, published in Marine Micropaleontology, Vol. 40, 105-129, 2000.

Long- and short-term climate changes of the past 200,000 years are reflected in the temporal distribution and faunal composition of deep-sea ostracodes on the Rockall Plateau. Two specialized ostracode assemblages were identified, an interglacial and a glacial assemblage. The manuscript contains detailed illustrations of the highly diverse and well preserved ostracode fauna including roughly 100 species, some of them so far not described from the research area.

Chapter 3

Implications of upper Quaternary stable isotope records of marine ostracodes and benthic foraminifers for paleoecological and paleoceanographical investigations

C. Didié and H.A. Bauch, accepted for publication *in*: 'The Ostracoda: Applications in Quaternary Research', edited by J.A. Holmes and A.R. Chivas. American Geophysical Union Monograph Series.

For the first time stable carbon and oxygen isotope records covering the past 200,000 years derived from deep-sea benthic ostracodes are presented. For the analyses the two globally distributed and abundant deep-sea ostracode genera *Krithe* and *Henryhowella* were selected and the results are compared to the isotope records of the well known benthic foraminifers *Cibicidoides wuellerstorfi* and *Oridorsalis umbonatus*. The ostracode oxygen isotope records confirmed earlier observations of a decoupling of endo- and epibenthic oxygen isotope data during glacial terminations I and II. The carbon isotope record of *Krithe* revealed no obvious climate-related systematic variations, whereas the carbon isotope record of *Henryhowella* displayed a clear glacial-interglacial pattern including low values during glacial and high values during interglacial periods.

Chapter 4

Faunal and diversity changes of North Atlantic deep-sea benthic ostracodes of the past 200,000 years

Didié, C., Bauch, H.A., and Helmke, J.P.

In this study Q-mode factor analyses were carried out for both investigated sediment cores. The resulting factor-assemblages are related to specific environmental conditions as inferred from IRD and isotope data, productivity indices, and literature data. Both cores reveal ostracode faunas characterized by three distinct assemblages, that are related to surface water productivity and the production of NADW. Diversity calculations revealed higher diversities during the glacial than during the interglacial periods and particularly high diversities during Heinrich events, possibly caused by decreased food supply and enhanced environmental heterogeneity.

Chapter 2 published in Marine Micropaleontology 40 (2000) 105-129

Species composition and glacial-interglacial variations in the ostracode fauna of the northeast Atlantic during the past 200,000 years

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Abstract

Sediment core M23414 from the Rockall Plateau (North Atlantic) covering the last two climatic cycles, marine isotope stages (MIS) 7 to 1, was investigated for glacial-interglacial variations in the deep-sea benthic ostracode fauna. A highly diversified ostracode fauna including 98 species was found. Two climate-related assemblages were identified, associated with interglacial and peak glacial periods, respectively. The 'interglacial' group occurs during the end of MIS 7, MIS 5 and 1 and is composed of the genera *Henryhowella, Pelecocythere, Echinocythereis, Cytherella, Bradleya, Aversovalva* and *Eucytherura.* The 'glacial' group consists of the genera *Acetabulastoma* (which is known as sea ice indicator in the modern Arctic Ocean), *Polycope, Bythoceratina, ?Rhombobythere,* and some species possibly belonging to the genus *Pseudocythere* and is found during MIS 6, 4 and 2. These longer-term variations within the ostracode fauna seem related to the particular glacial and interglacial climate conditions which affected both deep-water production as well as primary production in the surface waters. However, a detailed comparison of ostracode abundances with the occurrence of events marked by increased ice-rafted debris reveals also much shorter-term climate related changes in the ostracode fauna. Thus, the temporal fluctuations within ostracode assemblages reflect long- and short-term alterations of the deep-sea environment that are clearly linked to climate changes.

Keywords: ostracodes; paleoceanography; late Quaternary; North Atlantic

2.1 Introduction

Large changes in the North Atlantic ocean circulation have occurred during the late Pleistocene glacial to interglacial cycles (e.g., CLIMAP, 1976, 1981). These climate-induced changes have altered the environmental conditions at the ocean surface as well as in the deep sea and, thus, had major impact on the benthic communities (e.g., Schnitker, 1979). In a number of studies during the past decade ostracode distribution patterns have been successfully applied to paleoceanography (Dingle et al., 1989; Dingle and Lord, 1990; Corrège, 1993; Cronin, 1993; Cronin et al., 1994; Cronin et al., 1995; Ayress et al., 1997; Passlow, 1997; Whatley et al., 1998, and Jones et al., 1998). All these studies suggest that the physicochemical characteristics of water masses are the major factor for the distribution of deep-sea ostracodes. Thus, the North Atlantic with its well known glacial-to-interglacial changes in surface and deep-water mass properties should be a good research area to validate the relation between ostracode fauna and long- and short-termed climatic changes. During the glacial-to-interglacial transitions (called 'terminations') the source area for deep convection moved northward to the Nordic seas while thermohaline overturn switched from an intermediate to a deep mode leading to a poorly ventilated water mass in the intermediate depth North Atlantic (e.g., Venz et al., 1999). The circulation pattern changed significantly especially during Heinrich events (Heinrich, 1988; Broecker et al., 1992) when icebergs were discharged into the northern North Atlantic and the sea surface was covered by meltwater (e.g., Bond et al., 1992, 1993; Beveridge et al., 1995; Vidal et al., 1997). In addition to circulation changes, primary production in the surface layers decreased during glacial periods as well as during Heinrich events (Thomas et al., 1995). Since food supply to the deep sea is one of the major factors controlling benthic life (e.g., Gooday,1988, 1993; Graf, 1989; Loubere, 1991; Smart et al., 1994), it is assumed that climate-induced changes in surface productivity also had a significant influence on the ostracode fauna. The importance of surface production to benthic organisms has been shown before for the distribution and composition of benthic foraminiferal assemblages (e.g., Linke and Lutze, 1993; Corliss et al., 1986; Thomas, et al. 1995; Struck, 1997; Nees, 1997). The goal of our study is to investigate the response of the ostracode fauna to such climate-induced changes of the ocean circulation.

2.2 Material and Methods

For the present study we selected kasten core M23414-9 from the southern Rockall Plateau (2196 m water depth) (Fig. 2.1).

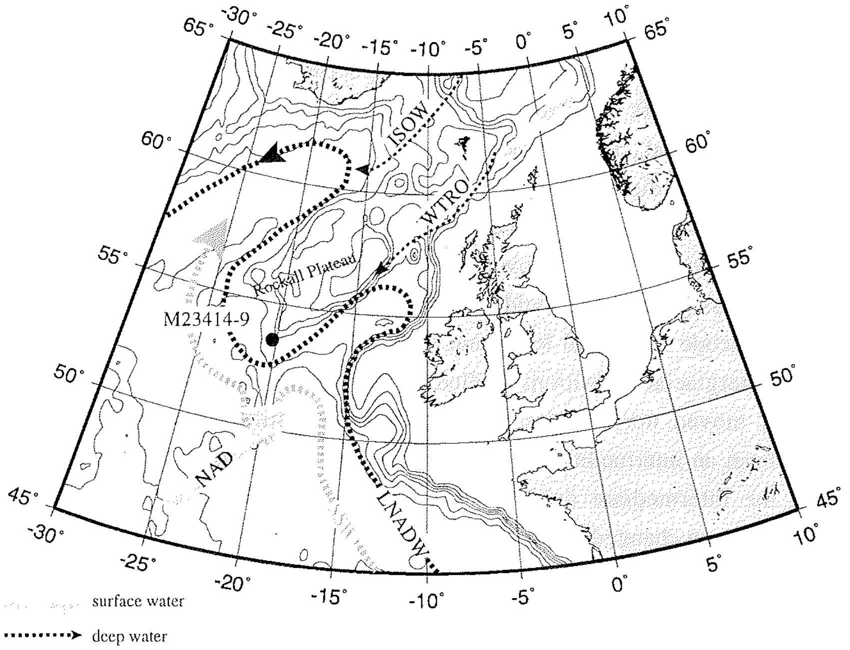

Fig. 2.1. Core location and general circulation pattern in the Rockall area (after McCave and Tucholke, 1986; Manighetti and McCave, 1995). NAD = North Atlantic Drift, LNADW = Lower North Atlantic Deep Water, SSW = Southern Source Water, ISOW = Iceland Scotland Overflow Water, WTRO = Wyville-Thompson-Ridge Overflow Water. ISOW and WTRO represent the overflow waters from the Nordic seas. Dashed lines indicate deep-water masses, full-grey arrows indicate surface-water masses.

A total of 128 samples (1 cm thick slices) were taken at 5 cm intervals. The relatively large samples (about 40 g dry weight) were freeze-dried and washed over a 63µm sieve. After sieving the samples into subfractions

of 125-250 µm, 250-500 µm and >500 µm, ostracodes were picked from these fractions, identified, and counted. Subfractions with too much material (mostly in the 125-250µm-fraction) were divided by means of a microsplitter prior to picking and counting. To prevent errors through overemphasizing single valves of rare species, subfractions were not split more than two times, meaning that at least a quarter of the entire fraction was picked. Statistical control was maintained by double-checking a number of samples (Fig. 2.2). From these samples two splits from the same fraction were picked and counted separately. Figure 2.2 shows the results for 10 selected taxa. Some of them like *Cytheropteron*, *Polycope*, and *Krithe* are abundant taxa and show a small error compared to their high relative abundances. As expected, the results of generally low abundant taxa e.g., *Aversovalva* sp., *E. echinata*, and *A. arcticum* reveal larger error bars. However, the general distribution pattern still remains the same. As shown in the lower part of Figure 2.2 there is no obvious connection between sample size, the number of ostracodes counted and the size of the error bars.

In addition to calculating total (valves/g) and relative (%) ostracode abundances, the ostracode dissolution index (ODI) was determined. For this study we used the ODI after Passlow (1997) (Table 1), which is a simplification of the ODI first described by Swanson and van der Lingen (1994). For determining the ODI only specimens of the genus *Krithe* were used because this genus is generally abundant in deep-sea sediments and relatively resistant to dissolution. Moreover, using only one genus avoids comparison between different taxa with possibly different dissolution characteristics (Passlow, 1997). Besides the ostracode faunal investigations, the amount of ice rafted debris (IRD) in the size fraction 250-2000 μm was counted at 2.5 cm intervals and expressed as grains per g dry sediment. In comparison to recently published data from this core (Bauch et al., 2000), all IRD countings in the present study were executed on the newly taken set of large samples also used for the ostracode faunal investigations.

Table 2.1

Ostracode dissolution stages (after Passlow, 1997)

Scale	Carapace preservation
1	transparent
2	translucent, shiny
3	translucent, dull
4	opaque, edges abraded, pores enlarged
5	white, chalky, with delamination

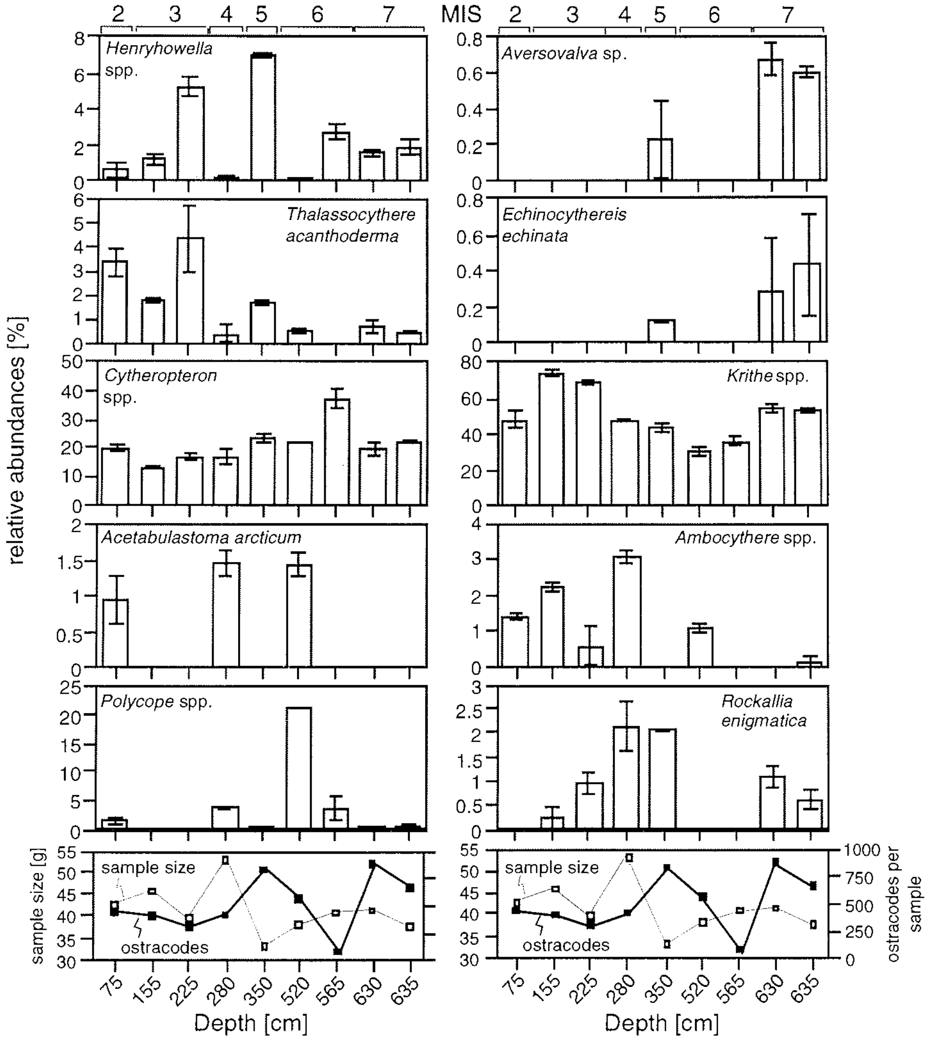

Fig. 2.2. Relative abundances of some ostracode taxa calculated on the basis of two separate splits from the 125-250 µm-size fraction. For statistical control this method was applied to 9 samples from core M23414-9. Numbers at the top indicate marine isotope stages (MIS). The difference between the two counted splits is represented by the error bars. Taxa of low abundance reveal larger errors than taxa which reach high abundances. In general, the differences between both splits are negligible. The lower part of the figure shows sample size and total number of counted ostracodes.

2.3 Stratigraphy

The stratigraphy of core M23414-9 was established on the basis of oxygen isotopes measured on tests of the planktic foraminifer *Globigerina bulloides* as well as the epibenthic foraminifer *Cibicidoides wuellerstorfi* (Jung, 1996) (Fig. 2.3). The studied core interval covers the time span from the end of MIS 7 to MIS 1; it covers the past 200,000 years years with an average resolution of about 300 years per sample and a sample interval of about 1500 years. The isotope stages, marked on top of Fig. 2.3, were classified according to significant changes within the oxygen isotope records. Peak glacial periods (MIS 6, 4, and 2) are marked by heavy oxygen isotope values and highest amounts of IRD whereas peak interglacial phases (MIS 5e and 1) can be clearly identified by lightest isotope values and very low IRD contents. The remaining substages within MIS5 (d-a) are marked by variable but small amounts of IRD and intermediate oxygen isotope values, indicating that the entire part may be considered relatively warm, interglacial-like interval.

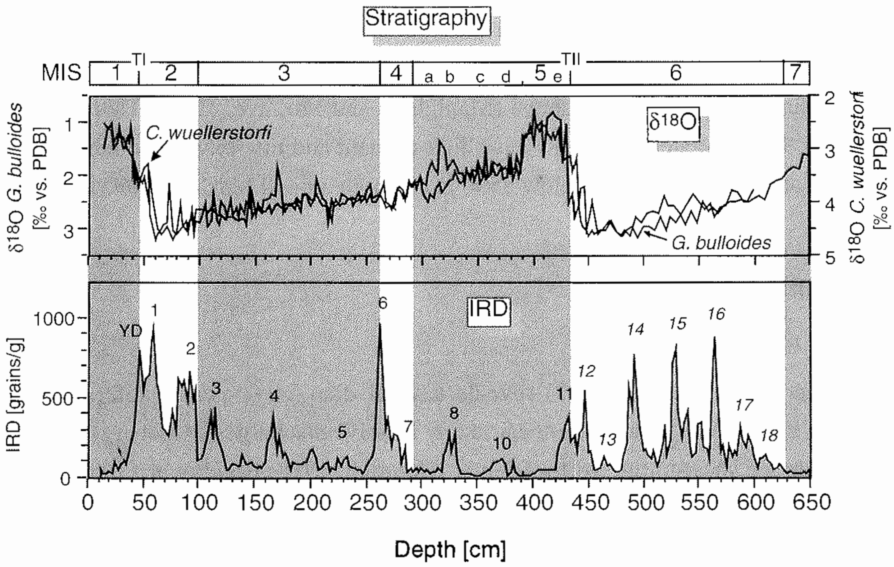

Fig. 2.3. Combination of the stable oxygen isotope records of the benthic foraminifer *Cibicidoides wuellerstorfi* and the planktic foraminifer *Globigerina bulloides*, respectively, plotted versus core depth (from Jung, 1996) and the amount of ice-rafted debris (IRD) >250 µm, expressed as grains per g dry sediment. Numbers on the IRD record indicate IRD events 1-11 as defined by Heinrich (1988). Numbers *12-18* represent Heinrich-like IRD events established exclusively on the basis of IRD peaks. To better distinguish between different isotope stages (indicated by numbers at the top) those with odd numbers were shaded. Stage 5 has been further subdivided with stage 5e separated by the broken line. YD = Younger Dryas; TI and TII = Terminations.

2.4 Oceanography of the Rockall area

Today, the surface circulation in the Rockall area is characterized by warm, highly saline water of the North Atlantic Drift (NAD) which forms the continuation of the Gulf Stream heading to the Nordic Seas (Fig. 2.1). In the Iceland and Greenland seas, the Norwegian Current mixes with water from the cold East Greenland Current coming from the Arctic Ocean. In winter, these surface water masses are cooled by cold, westerly winds and eventually commence sinking, forming deep water that flows to the south (e.g., Worthington, 1970; Broecker and Denton, 1990). The overflow waters that originate in the Norwegian Sea form the main deep-water components in the study area (e.g., McCave and Tucholke, 1986). Together with Labrador Sea Water (LSW), and parts of Mediterranean Overflow Water (MOW), they form the North Atlantic Deep Water (NADW) (McCave and Tucholke, 1986), which is well oxygenated and eventually ventilates the world ocean (Broecker, 1987, 1991).

At present, the location of M23414-9 is under the influence of the lower portion of the NADW (LNADW), which is located between 2000 and 3500 m water depth (e.g., Venz et al., 1999). The deepest water mass in the Rockall area consists of modified Antarctic Bottom Water (AABW) which is characterized by lower temperatures and lower salinity than the waters above (Manighetti and McCave, 1995). This so-called Southern Source Water (SSW) displays high-nutrient and low-oxygen contents and is today located in water depths below 3500 m (Manighetti and McCave, 1995).

2.5 Results

2.5.1 *Ice rafted debris (IRD)*

The record of IRD (Fig. 2.3) reveals several distinctive peaks, referred to as Heinrich Events (HE). These were caused by massive discharges of icebergs from the Laurentide ice sheet to the North Atlantic (Heinrich, 1988; Bond et al., 1992, 1993). Our detailed IRD record reveals HE 1-11 described first by Heinrich (1988). The numbering of the IRD-layers found in core M23414-9 follows Heinrich (1988) and was exclusively established on the amount of IRD in contrast to Heinrich's study, where in addition the relative abundances of planktic foraminifers were used to determine the cold events. Although the total number of HEs found in different cores from the North Atlantic varies, there are distinctive IRD-peaks occuring in most cores such as HE 11 at the stage boundary MIS 6/5, HE6 in late MIS 4, HE 4 in MIS 3, HE 2 in MIS 2 and HE 1 in late MIS 2 (Bond et al., 1993; Grousset et al., 1993; Broecker, 1994; McManus et al., 1994; Cortijo et al., 1995; Vidal et al., 1997; Chapman and Shackleton,1999). As mentioned before by Jung (1996) HE 5 in core M23414-9 is questionable because there is no significant drop within the benthic $d^{13}C$-record.

However, exceeding the record of Heinrich (1988), we further found the interval of the glacial MIS 6 punctuated by a series of at least seven additional Heinrich-like IRD events, referred to as IRD events *12-18* (Fig. 2.3).

2.5.2 *The ostracode fauna*

A number of studies on deep-sea ostracodes from the North Atlantic has been carried out (Ducasse and Peypouquet, 1979; Cronin, 1983; Whatley and Coles, 1987; Coles and Whatley, 1989; van Harten, 1990; Whatley et al., 1996). In this study, we followed mainly the taxonomy provided by Whatley and Coles (1987). The determined taxa and corresponding references are listed in Table 2. The taxa were identified to generic level with most of the genera further identified to species level. Because of its smooth carapace and the missing characteristic features of juvenile valves, the taxonomy of the genus *Krithe* remains problematic. To identify adult valves the taxonomical classification after Coles et al. (1994), van Harten (1996) and Rodriguez-Lazaro and Cronin (1999) was used which resulted in a total of 10 *Krithe* species.

The entire set of 128 investigated samples yielded up to 98 species belonging to 46 genera (see Table 2). Most of the observed genera are present with more than one species, although these species are closely related. For displaying trends in faunal composition, congeneric species were grouped together.

Table 2.2

List of species determined in core 23414-9. The species marked by an asterisk are supposed ice-rafted, shallow-water taxa (after Coles et al., 1996; Reimnitz et al., 1992, 1993). See Appendix for Plates.

Species	Reference	Figs. this paper
Acetabulastoma arcticum (Schornikov), not benthic, commensal ice-amphipods	(1), Pl. 2, Figs. 7-9	Pl. 1, Figs. 13-15
Ambocythere sp. cf. *A. ramosa* Van den Bold	(2), Pl. 6, Figs. 4-5	Pl. 3, Figs. 25
Ambocythere sp.		Pl. 3, Fig. 26
Argilloecia spp.	(2), Pl. 1, Figs. 11-22	Pl. 3, Figs. 1-6
Aversovalva sp. cf. *A. hydrodynamica* Whatley and Coles	(2), Pl. 3, Figs. 10-11	Pl. 1, Fig. 12
Bairdoppilata sp. cf. *B. victrix* (Brady)	(2), Pl. 1, Figs. 1-2	Pl. 4, Figs. 27-28
Bosquetina mucronalatum (Brady)	(2), Pl. 5, Figs. 1-2	Pl. 4, Figs. 23-24
Bradleya dictyon (Brady)	(2), Pl. 6, Figs. 8-9	Pl. 1, Fig. 4
Bythoceratina scaberrima (Brady)	(3), Pl. 1, Figs. 6-7	Pl. 1, Fig. 29
Bythocypris sp.	(4), Pl. 2, Figs. E-H	Pl. 3, Figs. 7-8
Bythocythere bathytatos Whatley and Coles	(2), Pl. 1, Figs. 26-31	Pl. 3, Figs. 27-28
Cythere lutea Müller*	(5), Pl. 1, Fig. 1	Pl. 4, Fig. 30
Cytherella serratula (Brady)	(2), Pl. 6, Figs. 30-31	Pl. 1, Fig. 5
Cytherella sp. 1		Pl. 1, Fig. 6
Cytherella sp. 2		Pl. 1, Fig. 7

Table 2.2 continued

Species	Reference	Figs. this paper
Cytheropteron alatum (Sars)	(**1**), Pl. 2, Figs. 4-6	Pl. 2, Fig. 6
Cytheropteron arcuatum Brady, Crosskey and Robertson*	(**6**), Pl. 1, Fig. 4	Pl. 2, Figs. 7-8
Cytheropteron branchium (Whatley and Ayress)	(**7**), Pl. 2, Figs. 2a, 2b	Pl. 2, Figs. 4a, b
Cytheropteron sp. cf. *C. carolinae* Whatley and Coles	(**2**), Pl. 2, Figs. 6,7,9	Pl. 2, Fig. 23
Cytheropteron C. champlainum Cronin*	(**8**), Pl. 8, Figs. 7-8	Pl. 2, Fig. 18
Cytheropteron hamatum (Sars)	(**3**), Pl. 1, Figs. 17-19	Pl. 2, Fig. 22
Cytheropteron inflatum Brady, Crosskey and Robertson	(**8**), Pl. 7, Figs. 3-4	
Cytheropteron sp. cf. *C. latissimum* (Norman)	(**6**), Pl. 6, Figs. 7, 9, 12	Pl. 2, Fig. 17
Cytheropteron lineoporosa Whatley and Coles	(**2**), Pl. 2, Figs. 11-14	Pl. 2, Fig. 14
Cytheropteron massoni Whatley and Coles	(**2**), Pl. 2, Figs. 15-17	Pl. 2, Fig. 11
Cytheropteron nealei Cronin*	(**3**), Pl. 1, Figs. 22-23	Pl. 2, Fig. 24
Cytheropteron sp. cf. *C. nodosum* Brady	(**3**), Pl. 1, Fig. 24	Pl. 2, Fig. 10
Cytheropteron pherozigzag Whatley and Ayress	(**2**), Pl. 2, Fig. 24	Pl. 2, Fig. 5
Cytheropteron porterae Whatley and Coles	(**2**), Pl. 2, Figs. 21-23	Pl. 2, Fig. 19-21
Cytheropteron syntomoalatum Whatley and Coles	(**2**), Pl. 2, Figs. 25-29	Pl. 2. Fig. 13
Cytheropteron tenuialatum Whatley and Coles	(**2**), Pl. 2, Figs. 30-32	Pl. 2, Fig. 9
Cytheropteron testudo Sars	(**2**), Pl. 3, Fig.	Pl. 2, Fig. 12
Cytheropteron tressleri Whatley and Coles	(**2**), Pl. 3, Figs. 2-3	Pl. 2, Fig. 15-16
Cytheropteron sp. 1		Pl. 2, Fig. 25
Cytheropteron sp. 2		Pl. 2, Fig. 26
Echinocythereis echinata (Sars)	(**2**), Pl. 5, Figs. 7-8	Pl. 1, Fig. 3
Elofsonella concinna (Jones)*	(**5**), Pl. 5, Fig. 3	Pl. 4, Fig. 5
Eucythere multipunctata Whatley and Coles	(**2**), Pl. 4, Figs. 12-14	Pl. 3, Fig. 22
Eucythere sp. cf. *E. pubera* Bonaduce et al.	(**2**), Pl. 4, Fig. 15	Pl. 3, Fig. 23
Eucythere triangula Whatley and Coles	(**2**), Pl. 4. Figs. 16-18	Pl. 3, Fig. 21
Eucythere sp.		Pl. 3, Fig. 24
Eucytherura calabra (Colalongo and Passini)	(**2**), Pl. 3, Figs. 14-16	Pl. 1, Figs. 9-10
Eucytherura sp.	(**2**), Pl. 3, Fig. 19	Pl. 1, Fig. 11
Finmarchinella finmarchica (Sars)	(**9**), Pl. 14, Figs. 9,12	Pl. 4, Fig. 1
Hemicythere villosa (Sars)*	(**5**), Pl. 4, Fig. 8	Pl. 4, Fig. 3
Hemicythere sp. cf. *H. rubida* (Brady)	(**5**), Pl. 4, Fig. 9	Pl. 4, Fig. 4
Henryhowella sp. cf. *H. asperrima* (Reuss)	(**2**), Pl. 5, Figs. 9-11	
Henryhowella sp. cf. *H. dasyderma* (Brady)	(**2**), Pl. 5, Figs. 12-13	Pl. 1, Figs. 1-2
Krithe aequabilis Ciampo	(**10**), Fig. 3, i	
Krithe ayressi Coles, Whatley and Moguilevsky	(**10**), Fig. 3, c	
Krithe dolichodeira Van den Bold	(**10**), Fig. 3, l	
Krithe minima Coles, Whatley and Moguilevsky	(**10**), Fig. 3, f	Pl. 2, Fig. 3
Krithe morkhoveni Van den Bold	(**10**), Fig. 3, b	
Krithe pernoides (Bornemann)	(**10**), Fig. 3, g	
Krithe trinidadensis Van den Bold	(**10**), Fig. 3, a	Pl. 2, Figs. 1-2
Krithe sp. X van Harten	(**10**), Fig. 3, k	
Krithe sp. Y van Harten	(**10**), Fig. 3, e	
Krithe sp. Z van Harten	(**10**), Fig. 3, h	
Macrocypris sp.	(**2**), Pl. 1, Fig. 7	Pl. 4, Fig. 16

Table 2.2 continued

Species	Reference	Figs. this paper
?Monoceratina sp.	**(7)**, Pl. 1, Fig. 1	Pl. 4, Fig. 22
Nannocythere sp.	**(3)**, Pl. 3, Figs. 9-10	Pl. 4, Fig. 25
Oxycythereis dorsoserrata (Brady)	**(2)**, Pl. 5, Figs. 14-17	Pl. 3, Figs. 9-11
Oxycythereis horridus Whatley and Coles	**(2)**, Pl. 5, Figs. 18-22	Pl. 3, Fig. 12
Oxycythereis sp.	**(2)**, Pl. 5, Figs. 23-25	
Paracythereois flexuosum (Brady)	**(3)**, Pl. 3, Fig. 15	Pl. 4, Fig. 13
Paracytherois sp.	**(11)**, Pl. 71, Fig. 4	Pl. 4, Fig. 14
Paradoxostoma sp. cf. *P. simile* (Müller)*	**(11)**, Pl. 71, Figs. 10-11	Pl. 4, Fig. 12
Pedicythere polita Colalongo and Passini	**(2)**, Pl. 4, Fig. 3	Pl. 3, Fig. 18
Pedicythere sp.	**(2)**, Pl. 4, Figs. 4-5	Pl. 3, Fig. 19
Pelecocythere sylvesterbradleyi Athersuch	**(2)**, Pl. 3, Fig. 20	Pl. 1, Fig. 8
Pelecocythere sp.		
Polycope sp. cf. *P. arcys* Joy and Clark	**(1)**, Pl. 2, Figs. 18-21	Pl. 1, Fig. 28
Polycope sp. cf. *P. horrida* Joy and Clark	**(1)**, Pl. 3, Figs. 5-8	Pl. 1, Fig. 26
Polycope sp. cf. *P. punctata* Sars	**(1)**, Pl. 3, Figs. 14-16	Pl. 1, Fig. 22
Polycope sp.		Pl. 1, Fig. 27
?Pontocypris sp.	**(11)**, Pl. 9, Figs. 1-2	Pl. 4, Fig. 17
Poseidonamicus sp. cf. *P. major* Benson	**(2)**, Pl. 6, Fig. 11	Pl. 4, Figs. 6-7
Propontocypris trigonella (Sars)	**(3)**, Pl. 1, Figs. 4-5	Pl. 3, Fig. 17
Pseudocythere caudata Sars	**(3)**, Pl. 1, Figs. 8-9	Pl. 1, Fig. 20
?Pseudocythere sp. 1		Pl. 1, Figs. 16-18
?Pseudocythere sp. 2		Pl. 1, Figs. 19a, b
Rabilimis mirabilis (Brady)*	**(3)**, Pl. 3, Fig. 17	Pl. 4, Fig. 8
Rimacytheropteron longipunctata (Breman)	**(2)**, Pl. 3, Figs. 12-13	Pl. 4, Fig. 26
Robertsonites tuberculatus (Sars)*	**(12)**, Pl. 2, Figs. 1-3	Pl. 4, Fig. 2
Rockallia enigmatica Whatley, Frame and Whittaker	**(2)**, Pl. 2, Figs. 3-4	Pl. 3, Figs. 13-14
?Rhombobythere sp. 1		Pl. 1, Fig. 21
?Rhombobythere sp. 2	**(13)**, Pl. 1, Figs. 3-4	Pl. 1, Figs. 23-24
?Rhombobythere sp. 3		Pl. 1, Figs. 25
Roundstonia globulifera (Brady)*	**(2)**, Pl. 4, Fig. 27	Pl. 4, Fig. 29
Sarsicytheridea bradii (Norman)	**(5)**, Pl. 3, Fig. 3	Pl. 4, Fig. 18
Sclerochilus contortus (Norman)	**(14)** Pl. 2, Figs. 5-6	Pl. 4, Fig. 15
Semicytherura complanata (Brady, Crosskey and Robertson)*	**(15)**, Pl. 3, Fig. 3	Pl. 4, Fig. 10
Semicytherura pulchra (Coles and Whatley)	**(16)**, Pl. 19, Figs. 1a, b	Pl. 4, Fig. 9
Semicytherura sp. *		Pl. 4, Fig. 11
Swainocythere nanseni (Joy and Clark)	**(17)**, Pl. 19, Figs. 2a, b	Pl. 4, Fig. 21
Swainocythere sp. 1		Pl. 4, Fig. 19
Swainocythere sp. 2		Pl. 4, Fig. 20
Thaerocythere sp.	**(9)**, Pl.10. Fig.13	Pl. 3, Fig. 20
Thalassocythere acanthoderma (Brady)	**(2)**, Pl. 6, 1-2	Pl. 3, Figs. 15-16

Note: Numbers in parentheses indicate references: **(1)** Joy and Clark (1977); **(2)** Whatley and Coles (1987); **(3)** Whatley et al. (1998); **(4)** Cronin (1983); **(5)** Athersuch et al. (1989); **(6)** Whatley and Masson (1979); **(7)** Whatley and Ayress (1988); **(8)** Cronin (1981); **(9)** Cronin (1991); **(10)** van Harten (1996); **(11)** Bonaduce et al. (1975); **(12)** Neale and Howe (1975); **(13)** Corrège (1993); **(14)** Coles et al. (1996); **(15)** Brouwers et al. (1991); **(16)** Ayress and Corrège (1992); **(17)** Corrège et al. (1992).

The ostracodes extracted from the samples were generally well preserved. In most samples valves of *Krithe* were translucent which corresponds to category 2 to 3 of the ODI (Fig. 2.4). In only a few samples, valves of *Krithe* were opaque. Even the very delicate spines of juvenile *Thalassocythere acanthoderma* were usually well preserved (see Plate 3, Fig. 16). This implies that most of the samples were not severely affected by corrosion.

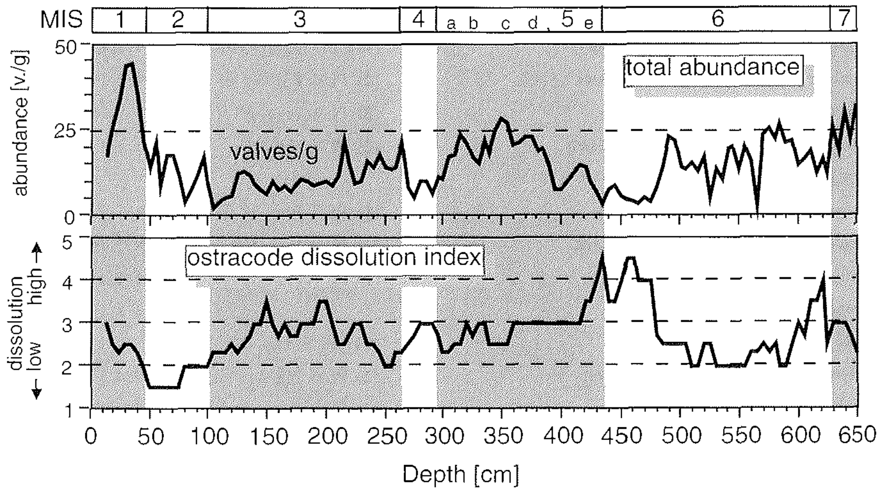

Fig. 2.4. The total abundance of ostracodes given in valves per g dry sediment and the ostracode dissolution index (ODI) established on the valves of *Krithe*. High numbers indicate enhanced dissolution. Categories of ODI are listed in Table 1.

The total abundance (valves per g dry sediment) reached values of up to 43 specimens/g (Fig. 2.4). Low abundances were observed in single samples of MIS 6, at the end of MIS 6, during MIS 4, at the end of MIS 3 and in MIS 2. Most of these periods reveal slightly increased dissolution, as suggested by the ODI results (Fig. 2.4). A second reason for low total abundances is dilution caused by high contents of IRD, which can be recognized e.g., at 565 cm (Figs. 2.2, 2.3, and 2.4). However, the number of ostracodes found in these samples is still relatively high in terms of marine ostracode studies (see e.g., Cronin et al., 1999 or Whatley and Coles, 1987). In average, 27 ostracode species were found per sample. Altogether, the large sample size used allows further interpretations on the temporal variations in ostracode abundance and its paleoceanographic implication.

2.5.3 *Relative abundances*

A broad range of further taxa was found throughout core M23414-9 (Fig. 2.5). The genus *Krithe,* generally the most abundant as well as the most diverse genus in deep-sea environments (see Coles et al., 1994; Cronin et al., 1996), dominates the fauna with up to 80 % of the assemblage. Species of the genus *Cytheropteron* make up to 40 % and species belonging to the genus *Argilloecia* account for up to 17 % of the total ostracode fauna. The other ostracode genera show lower relative abundances; none of these genera exceeds 10 % (Fig. 2.5). Beside this main assemblage the relative abundance data reveal two groups of ostracode genera that are constrained to distinct time periods: a group composed of the genera *Henryhowella, Pelecocythere, Echinocythereis, Cytherella, Bradleya, Aversovalva* and *Eucytherura* mainly corresponds to the warmer time periods (MIS 7, 5, 3, and 1) (Fig. 2.6). The most abundant genera of this assemblage are *Henryhowella* and *Bradleya*, with up to 15 % of the total ostracode fauna during MIS 1 and MIS 5, respectively. The other genera commonly remain below 4 %. Some of these taxa do not exceed 0.5 % but occur almost exclusively within the interglacial periods (see Table A17 in the appendix). The second group forms an assemblage that appears to be restricted to the peak glacial periods (Fig. 2.7). It consists of the genera *Acetabulastoma, ?Rhombobythere, Bythoceratina, Polycope,* and some (probably new) species of the genus *Pseudocythere* (Whatley pers. com., 1999). The most abundant genus of this assemblage is *Polycope*, which accounts for up to 50 % of the total ostracode fauna, followed by *Bythoceratina scaberrima* and *Acetabulastoma arcticum,* each less than 6 %. The occurrence of *A. arcticum* is particularly noteworthy since this species has been reported to live as a parasite on sea-ice amphipods and its valves can be found in surface sediments of the modern Arctic Ocean (Schornikov, 1970; Joy and Clark, 1977; Cronin et al. 1995). *Acetabulastoma arcticum* occurs exclusively in samples from the peak glacial stages 6, 4, and 2, coeval with increased IRD deposition, thus suggesting icebergs or sea ice at these times over the core location.

Some of the species found in core 23414-9 are known as shallow-water species (e.g., Jones et al., 1998). Many of these taxa have been found in sediments extracted from ice samples from the Beaufort Sea, northern Alaska (Reimnitz et al., 1992, 1993). Their occurrence in core M23414-9 suggests that they have been incorporated into the ice on the shelf and were ice rafted (Reimnitz et al., 1992, 1993; Jones et al., 1998). Generally, these shallow-water specimens are very rare in the investigated core. They usually occur as single specimens in some of the samples. The shallow water taxa are marked with an asteriks in Table 2.2.

For comparison, the total abundances of the 'glacial' and the 'interglacial' assemblages are shown in Figure 2.8. Both the relative and the total abundance records are very similar. The 'glacial' assemblage reaches highest relative abundances during MIS 6, 4 and 2 with up to 55 % of the total ostracode fauna and up to 8 valves/g, respectively. The 'interglacial' assemblage is most abundant during the end of MIS 7, MIS 5 and 1 with up to 25 % of the total ostracode fauna and up to 8 valves /g.

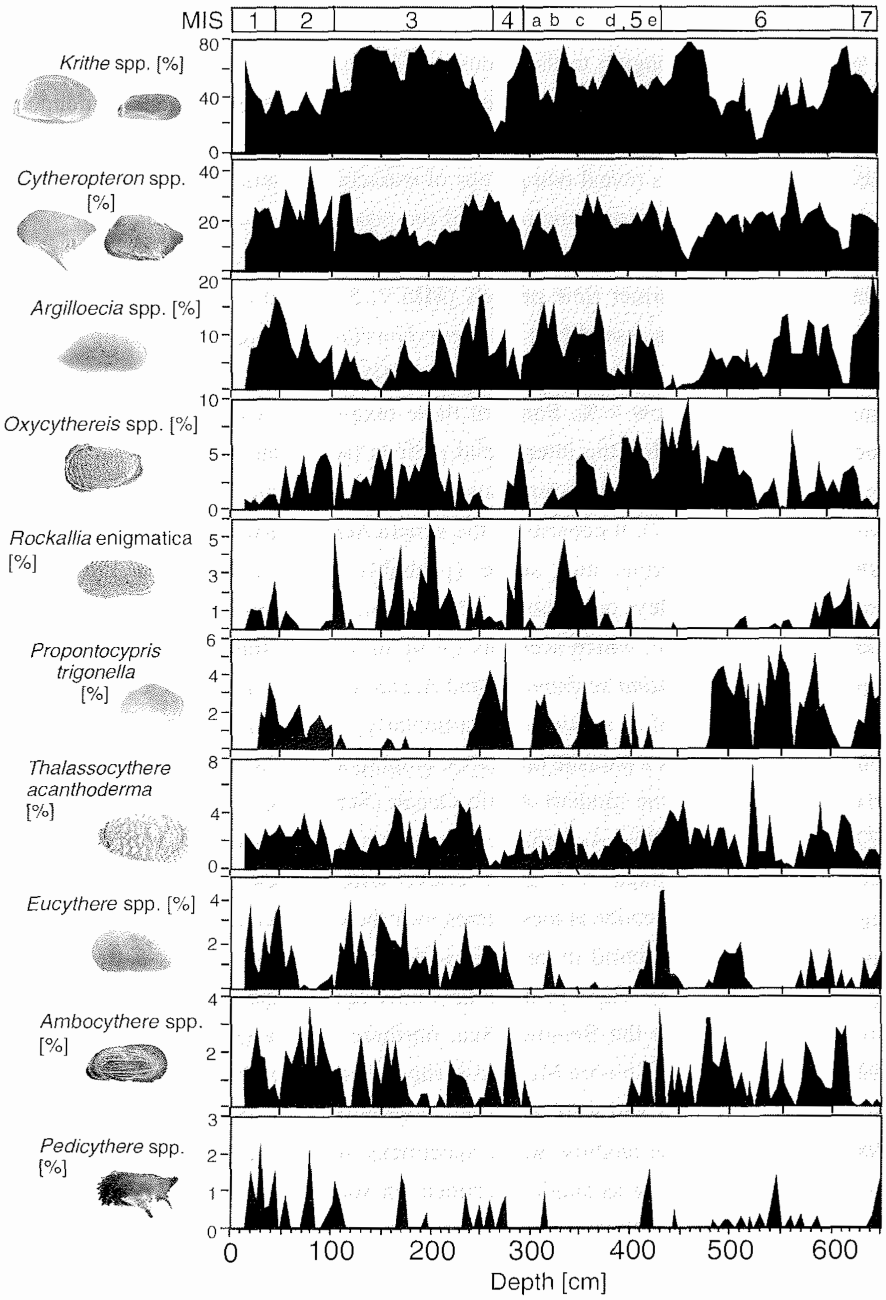

Fig. 2.5. Down core overview of the most abundant taxa, given in percent of the total ostracode fauna.

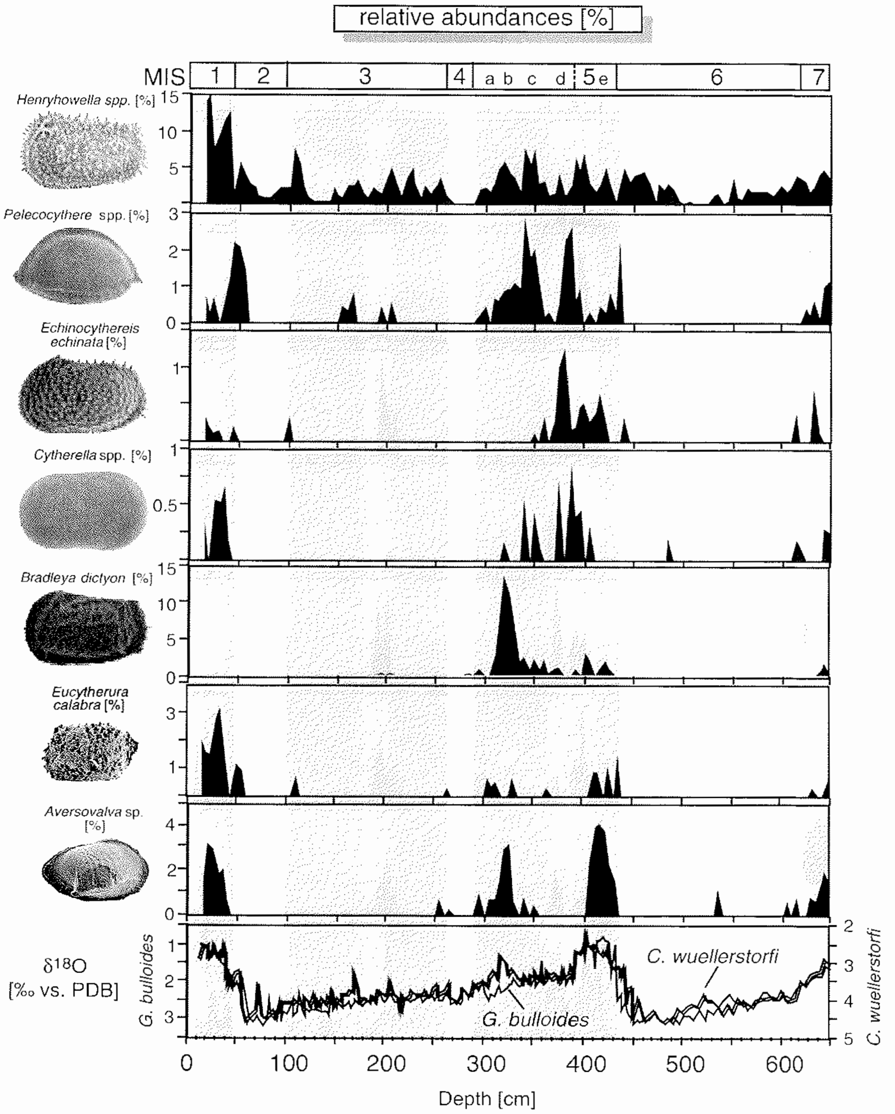

Fig. 2.6. The relative abundances of taxa belonging to the 'interglacial' assemblage, given in percent of the total ostracode fauna.

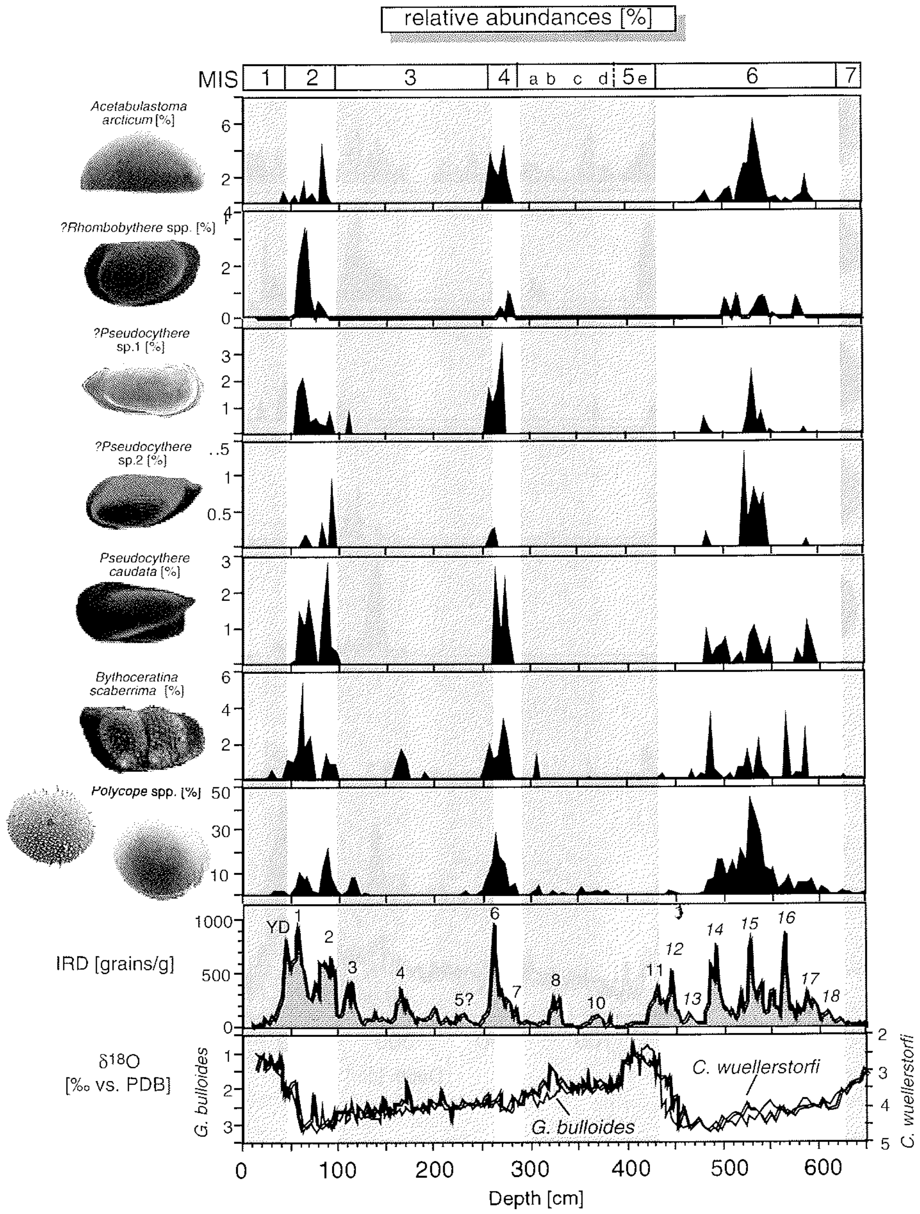

Fig. 2.7. The relative abundances of taxa belonging to the 'glacial' assemblage given in percent of the total ostracode fauna. Numbers on the IRD-record indicate Heinrich events (1-11) and Heinrich-like IRD events (*12-18*), respectively.

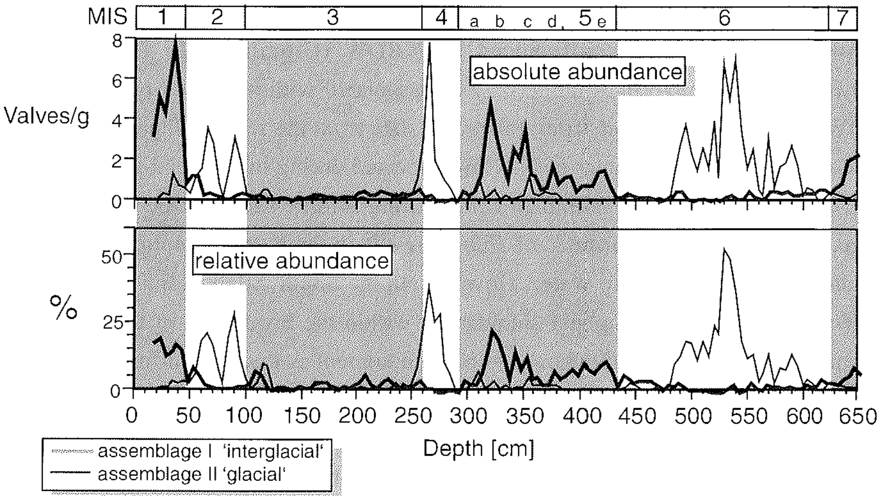

Fig. 2.8. Comparison of total abundances and relative abundances of the 'interglacial' (dashed line) and the 'glacial' ostracode assemblages (full line).

2.6 Discussion

2.6.1 *Ostracode abundance and ocean circulation*

Many authors have described the relationship of ostracode species to deep-water mass characteristics such as temperature, oxygen content and nutrients (Dingle and Lord, 1990; Dingle et al., 1989; van Harten, 1990; Cronin et al., 1994; Cronin et al., 1995; Cronin et al., 1996; Ayress et al., 1997; Jones et al., 1998, Jones et al., 1999). Following this concept, the observed faunal changes in core M23414-9 may be related to climate-forced changes in the deep-water circulation. A number of studies have already shown that the mode of deep-water convection in the North Atlantic switched from a deep mode producing NADW during the interglacials to an intermediate mode producing Glacial North Atlantic Intermediate Water (GNAIW) during the glacials (Boyle and Keigwin, 1987; Oppo and Fairbanks, 1987; Duplessy et al., 1988, 1991; Venz et al., 1999), while the source area for the deep water moved from the Nordic seas further south. The GNAIW was located at a depth of 1000 to about 2200 m, whereas Southern Source Water (SSW) was conveyed northward below 2200 m water depth (Venz et al., 1999 and references therein). According to Jung (1996), core M23414-9 was influenced by GNAIW during the glacials whereas today this site is under influence of lower NADW. These glacial/interglacial changes in deep-water circulation may have been one reason for the observed changes in the ostracode fauna. *Henryhowella*, for example, is thought to prefer well oxygenated deep water (Cronin et al., 1994). This genus occurs on the Rockall Plateau with increased abundances during MIS 5 and with highest abundances during the present interglacial (Fig. 2.5), an observation which was also made at a location further southwest, which today is influenced by NADW (Cronin et al., 1999). Thus, *Henryhowella* in the North Atlantic may be associated with increased production of NADW, which gains support from down core data from the Iceland Plateau, a region where one of the source waters of NADW is located during interglacial times. There, *Henryhowella* is clearly the dominant genus during MIS 5e and 1 (Didié et al., 1999). Hence, the interglacial occurrence of *Henryhowella* in the North Atlantic may indeed indicate well-ventilated deep water. However, in the South Atlantic and in the Coral Sea *Henryhowella* shows highest abundances within the lower part of the Antarctic Intermediate Water (AAIW) where the oxygen content is lower than in the NADW (Dingle et al., 1989; Corrège, 1993). According to Bonaduce et al. (1998) who investigated the distribution of *Henryhowella* in the Gulf of Naples, there was no obvious relationship found between the abundance of *Henryhowella* and the oxygen content. One possible explanation for this inconsistency may be the fact that in most of these studies different species of *Henryhowella* are found, although there is some discussion about the taxonomy of this genus (e.g., Dingle and Lord, 1990; Bonaduce et al., 1998).

On the Rockall Plateau, the genus *Krithe* tends to be more abundant during the interglacial stages and within some intervals of MIS 6 where the total abundance of ostracodes is low (Figs. 2.4 and 2.7). This interglacial dominance is in contrast to data from the Iceland Plateau (Didié et al., 1999) and from west of Mid-Atlantic Ridge (Cronin et al. 1999), where *Krithe* dominates the 'glacial' assemblages. This may be due to different species of *Krithe* present in these North Atlantic cores.

2.6.2 *Ostracodes and ice-rafted debris*

Massive iceberg discharge to the North Atlantic, marked by a sudden increase in the coarse lithic fraction and known as Heinrich events (Heinrich, 1988; Broecker et al., 1992), led to decreased surface-water salinities and to a reduction of deep-water production (Bond et al., 1992, 1993; Maslin et al., 1995). If ostracodes are reliable recorders of significant changes in deep circulation, changes in abundance and faunal compositon during times of enhanced ice rafting should be observed on the sea floor.

The relative abundances of ostracodes belonging to the 'glacial' assemblage reveal a reasonably good correlation to IRD-events (Fig. 2.7). Especially the distinctive IRD layers observed during MIS 6 are also clearly reflected in the ostracode abundances. The first significant peak in IRD (*17*) corresponds to the first occurrence of most of the glacial taxa, which occur very distinctively during short intervals. Most of the glacial taxa correspond to each of the HEs during MIS 6, MIS 4 and MIS 2. However, the IRD-peak related to Termination II is not reflected in any of these taxa, which is most likely due to dissolution. As shown in Figure 2.4, the total number of ostracodes decreases during Termination II and the ODI shows highest values. Among all glacial taxa *Bythoceratina scaberrima* shows the closest relation to the IRD-record. Beside IRD events *17-14*, even minor events like HE 10 and HE 4, are reflected in the relative abundance record of this species (Fig. 2.7). This pattern can also be recognized at 565 cm core depth (Figs. 2.2, 2.4, and 2.7), although the total abundance of ostracodes is low in this sample, which is probably caused by dilution related to IRD event *16*.

Altogether, the ostracode genera of the 'glacial' assemblage may be considered as opportunistic, taking advantage of the glacial conditions which other taxa cannot. Especially, the environmental conditions during periods of enhanced ice rafting seem to be favourable for these ostracodes. *Polycope,* the most abundant genus of the 'glacial' assemblage, has been described as a good swimmer preferring fine-grained, organic-rich sediments. This genus reveals highest abundances and diversity in cold waters (Kornicker, 1959; Neale, 1983) and it dominates the ostracode assemblages in most Arctic Ocean sediments with up to 80 % of the total ostracode fauna (Jones et al., 1998). High abundances of *Polycope* during the glacial periods in the North Atlantic, therefore, may mirror these environmental conditions, which are found in the deep Arctic Ocean today, where an assemblage of *Pseudocythere caudata, Polycope* spp. and *Acetabulastoma arcticum* is representative of cold, saline Arctic Ocean Deep Water (Cronin et al., 1995). Benson et al. (1983) found *Polycope* on the Newfoundland slope in water depths of 1500 to 1600 m where the sediments are fine-grained due to low current velocities. They interpret *Polycope* as associated with diminished vertical circulation because of its tolerance for oxygen deficient conditions (Benson et al., 1983 and references therein), conditions which may have existed in the Rockall area during the glacial periods.

2.6.3 *Ostracode abundances and surface productivity*

A number of investigators have proposed food supply to the deep sea as the main factor controlling the distribution of benthic life (e.g., Gooday ,1988, 1993; Loubere, 1991; Smart et al., 1994). This suggests that the observed faunal changes reflect primarily productivity changes in the surface waters rather than circulation changes in the deep-water masses. High abundances of phytodetritus-consuming benthic foraminifers together with increased abundances of certain planktic foraminferal species are indicators for high primary production in the surface water (Thomas et al., 1995). Results of a sediment core covering the past 45 ka in the Rockall area revealed that productivity during the last glacial period was lower than it is today (Thomas et al., 1995). This has been confirmed e.g., by Andruleit (1995), who found increased abundances of coccolithophores during the present interglacial compared to the last glacial period. With regard to the ostracode abundance pattern this inference implies that genera belonging to the 'interglacial' assemblage may be dependent on a certain amount of phytodetritus exported to the sea bottom. Faunal analyses on *Henryhowella* from the Iceland Plateau suggest a habitat similar to that of the epibenthic foraminifer *Cibicidoides wuellerstorfi* (Didié et al., 1999). On the Rockall Plateau *Cibicidoides wuellerstorfi* shows low abundances during the glacials and increased abundances during interglacial periods (Nees, 1997). This may indicate increased primary production in the surface waters and increasing bottom current activity during the interglacials, both providing favourable conditions for epibenthic foraminifers (Struck, 1997; Bauch et al., in press). The same may be true for the ostracodes of the 'interglacial' assemblage. However, the glacial abundance of *Polycope* is in contrast to this as *Polycope* has been described as indicative for increased surface production (Cronin et al. 1995). According to this, one would expect increased abundances of *Polycope* during interglacial periods. As assumed by Jones et al. (1998) *Polycope* may take advantage of the absence of many competitors and, thus, may have found more suitable conditions on the Rockall Plateau during glacial periods.

2.7 Summary and conclusion

We have investigated a sediment core from the Rockall Plateau covering the past two climatic cycles in order to determine the reaction of the deep-sea benthic ostracode fauna to climate-induced environmental changes. On the basis of relatively large samples, a highly diverse ostracode fauna was found to consist of up to 98 species belonging to 46 genera. Calculating both the relative and the total abundances of ostracodes, two faunal assemblages are observed that are related to interglacial and peak glacial periods respectively. The 'interglacial' assemblage includes the taxa *Henryhowella, Pelecocythere, Echinocythereis, Cytherella, Bradleya, Aversovalva* and *Eucytherura*, whereas the 'glacial' assemblage is composed of the taxa *Acetabulastoma arcticum* (which is known as sea-ice indicator in the modern Arctic Ocean), *?Rhombobythere, ?Pseudocythere, P. caudata, Bythoceratina scaberrima*, and *Polycope.*

The temporal variations within the ostracode assemblages are most likely related to climate-driven changes in the North Atlantic ocean circulation. During the glacial periods, the NADW production ceased and GNAIW was produced while the source area for these watermasses moved to the south. Additionally, the primary production in the surface waters decreased during glacial conditions. These significant environmental changes are thus reflected in the ostracode fauna.

A detailed record of IRD revealed several distinct peaks referred to as Heinrich events. During these periods of enhanced iceberg discharge to the North Atlantic the production of NADW ceased due to freshened surface waters. In addition to the eleven events originally described by Heinrich (1988) seven more Heinrich-like IRD events were observed in the Rockall core during MIS 6 that are clearly accompanied by short-term increased relative abundances of the glacial ostracodes. Hence, we conclude that the deep-sea benthic ostracode fauna not only records climate variations on glacial-interglacial time scales, but also appears sensitive to much shorter-term environmental changes such as those conditions that lead to massive iceberg discharges to the North Atlantic.

Since ostracode ecology is not yet well known, it is difficult to clearly identify which of the various conditions that characterize the deep-sea environment are responsible for the temporal variability within the ostracode assemblages. So far, we conclude that it is most likely that specific water-mass characteristics as well as food supply to the deep sea are the main factors controlling the ostracode community on the Rockall Plateau. However, the glacial-interglacial changes in the ostracode fauna reflect deep-sea environmental variations, which can be clearly linked to past climate changes.

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The ostracodes are documented by SEM photographs shown in the appendix (plates 1-4).

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Implications of upper Quaternary stable isotope records of marine ostracodes and benthic foraminifers for paleoecological and paleoceanographical investigations

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Abstract

A sediment core, covering marine isotope stages (MIS) 7 to 1, and several surface sediment samples, all from the Iceland Plateau, were investigated for deep-sea ostracode carbon and oxygen isotopes. In contrast to the benthic foraminiferal species *Cibicidoides wuellerstorfi* and *Oridorsalis umbonatus*, which both display well-known negative offsets from the oxygen isotope value of the equilibrium calcite, the investigated ostracode genera *Krithe* and *Henryhowella* reveal positive offsets. We calculated an offset of about +1.4 ‰ for *Krithe* and about +0.4 ‰ for *Henryhowella* with respect to the equilibrium calcite. Downcore isotope analyses revealed differences between the oxygen isotope records of the infaunal-living foraminiferal species *O. umbonatus* and the epifaunal-living species *C. wuellerstorfi* during periods of increased deposition of IRD (iceberg rafted debris). These differences between infaunal and epifaunal oxygen isotope signals have been recognized before within the area of the Nordic Seas and were likely caused by environmental conditions during late MIS 6 and MIS 2, affecting mainly the epifaunal-living taxa. The oxygen isotope record of *Henryhowella* reveals the same trend as the record of *C. wuellerstorfi*, whereas the oxygen isotope records of *Krithe* and *O. umbonatus* are parallel to each other. This suggests an epifaunal habitat for *Henryhowella* and an infaunal habitat for *Krithe*, which is in agreement with the faunal abundance data as well as with other ostracode studies. The carbon isotope records of *Henryhowella* and *O. umbonatus* display a globally observed trend of low $\delta^{13}C$ values during the glacial and high values during the interglacial periods, whereas the $\delta^{13}C$ record of *Krithe* shows no such climate-related trend, probably due to strong vital effects.

3.1 Introduction

On the basis of their geographical distribution, abundance, and composition of assemblages, benthic foraminifers are being widely used for studying past and present environmental conditions in the deep ocean (e.g., Streeter et al., 1982; Herguera and Berger, 1991; Mackensen et al., 1985). Moreover, the carbon and oxygen isotopic composition of their tests is an important tool to determine changes in global ice volume, deep-ocean circulation, and the marine carbon cycle (e.g., Shackleton, 1977; Duplessy et al., 1980; Savin et al., 1981; Woodruff et al., 1981; Labeyrie et al., 1987; Mackensen et al. 1993; Keigwin et al., 1994).

Because deep-water formation in the northern North Atlantic is considered to be the engine that drives the global thermohaline circulation, a number of studies have been carried out to interpret glacial-to-interglacial changes in deep-water production (e.g., Veum et al., 1992; Sarnthein et al., 1994; Oppo and Lehman, 1995; Raymo et al., 1998). Surface ocean changes, particularly in the Nordic Seas, are regarded as crucial for the global ocean circulation at present and over glacial-interglacial timescales. (e.g., Aagaard et al., 1985; Labeyrie et al., 1987).

In the Nordic Seas the abundance and diversity of benthic foraminifers is generally low in glacial sediments and epifaunal species usually taken for stable isotope analyses are often lacking from these records (Streeter et al., 1982; Struck, 1995, 1997). In contrast, ostracodes (microcrustaceans with a bivalved calcitic carapace) are comparatively abundant in both glacial and interglacial intervals (Didié et al., 1999). However, in deep-sea sediments of late Pleistocene age ostracodes are usually less abundant than benthic foraminifers. This may be the reason why their use as a paleoceanographic proxy has been limited mainly to faunal analyses (e.g., Dingle and Lord, 1990; Cronin et al., 1994, 1995). There are no published data that show the relationship between environmental parameters and stable oxygen and carbon isotopes in marine ostracodes, although such investigations are applied commonly to non-marine ostracodes (e.g., Chivas et al., 1993; von Grafenstein et al., 1992, 1999; Xia et al. 1997a, b; Hammarlund, 1999).

The aim of this study is to investigate whether stable isotope signals derived from marine ostracode valves are reliable recorders of major glacial-interglacial climate changes. For the first time a systematic comparison with isotope data of some common benthic foraminifers from the same sequence will be used to reveal the relationship of marine ostracode isotope signals to a variable environment and to make assumptions also on their ecology. In addition to the downcore records, isotope analyses were also carried out on ostracodes and benthic foraminifers from surface sediment samples to determine their modern departure from isotopic equilibrium.

3.2 Oceanography of the investigated area

The surface circulation in the Nordic Seas is dominated by the northward-flowing warm, saline waters of the Norwegian Current in the eastern part and by the southward-flowing cold, low saline waters of the East Greenland Current in the western part (Fig. 3.1). Due to cooling processes by cold catabatic winds over Greenland during winter, the surface waters eventually start to sink as they gain density. Two main convective gyres therefore exist in the Greenland Basin and on the Iceland Plateau (Aagaard et al., 1985). By overflowing the Greenland-Scotland Ridge, the deep-water masses return into the Atlantic Ocean as part of the North Atlantic Deep Water (NADW), which ventilates the World Ocean (e.g., Broecker, 1991; Aagaard and Carmack, 1994). It is believed that deep convection in the North Atlantic was less effective during glacial times due to reduced deep-water formation in the Nordic Seas (e.g., Duplessy et al., 1988; Sarnthein et al., 1994).

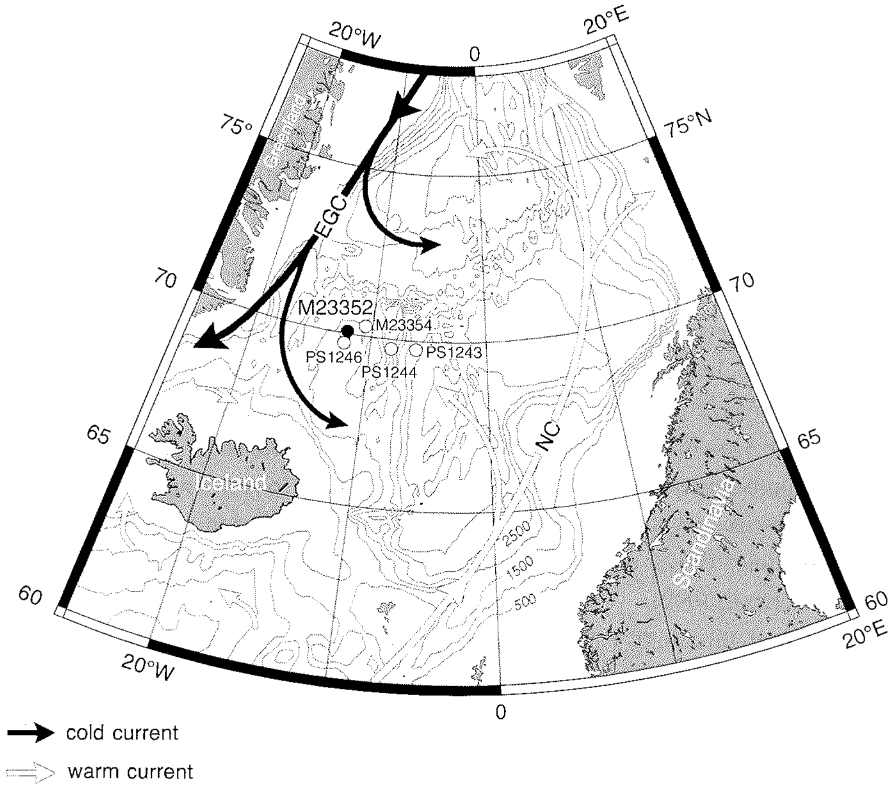

Fig. 3.1. Overview of the modern ocean surface circulation in the Nordic Seas after Swift (1986) with core locations. EGC = East Greenland Current, NC = Norwegian Current. White arrows indicate warm currents, black arrows cold currents. Open circles indicate surface sediment samples, filled circle indicates position of sediment core.

3.3 Materials and Methods

3.3.1 *Sediment samples and treatment*

The selected kasten core M23352 and its corresponding boxcore from the same site were recovered from the northern Iceland Plateau at 1819 m water depth. The boxcore, containing the upper most 35 cm of undisturbed sediment, and the kasten core were combined on the basis of planktic and benthic foraminiferal isotope records as well as on the basis of previously published gray-level records (Bauch and Helmke, 1999).

The core was sampled in 1-3 cm intervals down to 3.5 m core depth. Each 1 cm thick sediment slab (yielding between 10 and 74 g of dry sediment) was freeze-dried and then washed over a 63 µm sieve. After drying, the samples were separated into the subfractions 125-250 µm, 250-500 µm and >500 µm. A detailed record of iceberg rafted debris (IRD) was established by counting lithic grains in the >250 µm size fractions (Fig. 3.2). The study of ostracode faunal assemblages was carried out separately using the fractions >125 µm (Didié et al., 1999). Additionally, surface sediment samples of four boxcores from the Iceland Plateau (M23354, PS1243, PS1244, and PS1246) were analysed for their benthic foraminiferal and ostracodal isotope signals (see Figure 3.1 and Table 3.1 for core locations).

Table 3.1 Geographical position and water depth of the used sediment samples and cores.

Site	Longitude	Latitude	Water Depth, m
M23352	12.92 °W	70.06 °N	1819
M23354	10.63 °W	70.33 °N	1747
PS1243	6.54 °W	69.37 °N	2710
PS1244	8.67 °W	69.37 °N	2162
PS1246	12.92 °W	69.38 °N	1902
V29-202	21 °W	60 °N	2658
M23414	20.29 °W	53.54 °N	2196
V19-30	83.35 °W	3.38 °S	3091

3.3.2 *Stable isotope analyses*

For each oxygen and carbon isotope analysis about 28 specimens of the polar planktic foraminifer *Neogloboquadrina pachyderma* sinistral were taken from the 125-250 µm fraction of core M23352. Benthic isotope records were established using the two foraminiferal species *Cibicidoides wuellerstorfi* (= *Planulina wuellerstorfi*, *Fontbotia wuellerstorfi*) and *Oridorsalis umbonatus* cf. *O. tener*. About 25 specimens of *O. umbonatus* from the 125-250 µm fraction and usually about 5-7 specimens of *C. wuellerstorfi* from the 250-500 µm fraction were analyzed. Only few specimens of

C. wuellerstorfi were found in the intervals from 38-44 cm (MIS 2), around 250 cm (T II), from 265-270 cm, and from 304-314 cm (cold phases of MIS 6). In these cases analyses on 1 or 2 specimens were performed (intervals, where *C. wuellerstorfi* was very rare are indicated by the black bars in Fig. 3.4).

For isotope analyses on ostracodes we selected the genera *Krithe* and *Henryhowella* because these two were found, with few exceptions, continuously throughout the investigated core interval as well as in the surface sediment samples of sites M23354, PS1243, PS1244, and PS1246. Both genera are common deep-sea ostracodes that display a global distribution. In particular, *Krithe* is found in substantial numbers in nearly all sediments, ranging from shallow waters down to the deep sea (Coles et al., 1994). For the ostracode isotope analyses about 2-5 (mostly 5) specimens of *Henryhowella* and about 5-10 specimens of *Krithe* from the 250-500 µm fraction were used. If possible, we avoided analyses of single valves to minimize possible errors caused by bioturbational effects. In only few samples the number of *Henryhowella* was low, e.g., in some samples of MIS 5e and around 290 cm (MIS 6). In these cases only 1 or 2 valves were analyzed.

For stable isotopic measurements we used a Finnigan MAT 251 mass spectrometer combined with an automated carbonate preparation device (at the Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research at Kiel University) and a Finnigan MAT 252 with Kiel-Carbo II device (at the stable isotope laboratory at GEOMAR), respectively. The analytical precision of the MAT 251 system is ±0.08 ‰ for $\delta^{18}O$ and ±0.05 ‰ for $\delta^{13}C$. For the MAT 252 system the analytical precision is ±0.03 ‰ for $\delta^{18}O$ and 0.015 ‰ for $\delta^{13}C$. The results are given in the conventional δ-notation relative to the NBS 20 standard, which is equal to the Pee Dee Belemnite standard (PDB).

3.3.3 *Notes on ostracode taxonomy*

Little morphological variation makes the classification of ostracodes belonging to the genus *Krithe* to species level somewhat problematic. Kempf (1988) listed at least 115 described species belonging to the *Krithe* group (several species are described in Coles et al. (1994), van Harten (1996), and Rodriguez-Lazaro and Cronin (1999)). *Krithe* has a smooth carapace that lacks ornamentation, which explains some of these classification difficulties. Besides shape and size of the carapace, proper identification is only possible if the ostracode valve is well preserved so that its anterior vestibulum of the inner lamella can be observed, a feature that is only developed in adult specimens (for the principal morphological characteristics of *Krithe* refer to Coles et al. (1994)). Because some samples yielded only few specimens of *Krithe*, adult and juvenile specimens were combined for the analyses. Since most of the adult *Krithe* found in the samples were identified as *K. glacialis* (Brady, Crosskey and Robertson) 1874, we assume that the juveniles recovered belong to the same species. Although the number of adult and juvenile specimens of *Krithe* is very different (the number of juveniles is usually about 10 times higher than the number of adults), both show parallel trends in their abundance throughout the core. For the analyses we usually selected large specimens, which includes adult specimens and prior molt stages.

The taxonomy of *Henryhowella* at the species level is also insufficiently known and the conspecificy of some species has still to be confirmed (Dingle and Lord, 1990). In core M23352, most of the *Henryhowella* are what Whatley and Coles (1987) referred to as *H.* sp. cf. *H. dasyderma* (Brady) 1880. Only large specimens from the size fraction 250-500 µm were selected for isotope analyses. Hence, most of the analyzed valves represent adult specimens or at least penultimate juvenile instars (A-1).

3.3.4 *Stratigraphy*

The stratigraphy of core M23352 is well established on the basis of the stable oxygen isotope record of the polar planktic foraminifer *Neogloboquadrina pachyderma* sin. reaching back to MIS 12 (Bauch and Helmke, 1999). Using the oxygen isotope stratigraphy of Martinson et al. (1987) and faunal data MIS 1 to 7 could be identified between 0 and 350 cm core depth (Didié et al., 1999; Bauch et al., 2000) (Fig. 3.2).

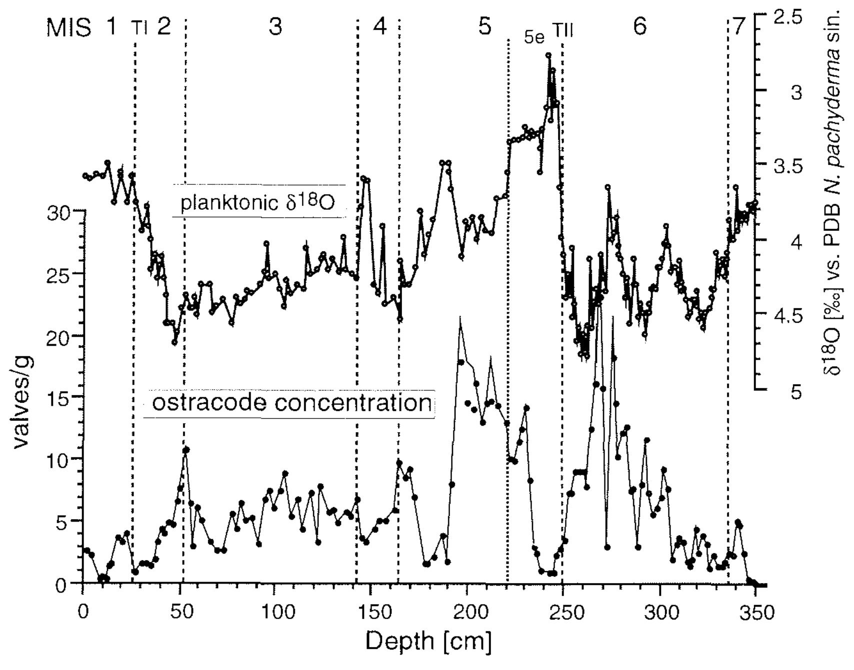

Fig. 3.2. Planktic oxygen isotope record and ostracode concentration of core M23352. Numbers on top indicate marine isotope stages (MIS), TI and TII indicate Terminations I and II.

As usually observed in cores from the Nordic Seas, substages b-d of MIS 5 are not well resolved (see e.g., Bauch, 1997). However, the interval of MIS 5e is recognized between 220 and 250 cm core depth, which is confirmed by foraminiferal proxy data (see Bauch et al., 1999, 2000). The average sample resolution is about 500-1000 years per sample.

3.4. Results

3.4.1 *Downcore ostracode concentration and faunal composition*

Average ostracode concentration was about 6 valves per g (v./g) dry sediment (Fig. 3.2). The downcore faunal record reveals that ostracode concentration increases from MIS 7 to MIS 6. After a strong decrease during Termination (T) II, MIS 5 shows relatively high ostracode concentrations. Highest ostracode concentrations occur in MIS 6 and 5 (>20 v./g) whereas lowest concentrations (<1 v./g) were found in MIS 7, early MIS 5e (T II) and the Holocene. Investigations on carbonate preservation patterns in the Nordic Seas show both, high carbonate contents and signs of increased corrosion on foraminiferal tests during the interglacial stages 5e and 1 (Helmke and Bauch, in press). The few ostracodes found in the interval of early MIS 5e show signs of corrosion, thus suggesting dissolution as possible cause for the low ostracode abundance during this period. As noted in the downcore Holocene samples, the investigated surface sediment samples from the Iceland Plateau are also marked by very low ostracode abundances. Although corrosion is also apparent in the Holocene samples (see Helmke and Bauch, in press) we can exclude dissolution as sole cause for the lack of ostracodes during the peak interglacial periods. Extremely high amounts of *C. wuellerstorfi* in these samples contradict increased dissolution. Strong bottom currents during MIS 1, as inferred from grain size analyses (Michels, 1995), may provide better environmental conditions for *C. wuellerstorfi*, which is attached to objects at the sea floor in contrast to ostracodes.

Detailed faunal analyses revealed a relatively low diversity ostracode fauna dominated by the genera *Henryhowella*, *Krithe* and *Cytheropteron* (Didié et al., 1999). The surface sediment samples contained only a few specimens of *Krithe* and *Henryhowella*, some of them still with a complete carapace, and very few specimens belonging to the genus *Cytheropteron*.

3.4.2 *Surface sediment isotope analyses*

In order to investigate the deviation of ostracode oxygen isotope values from the equilibrium calcite and deviation of carbon isotope values from bottom water DIC, analyses on the selected benthic taxa *C. wuellerstorfi*, *O. umbonatus*, *Henryhowella*, and *Krithe* were carried out using several surface sediment samples from the Iceland Plateau. Figure 3 shows that the measured isotope values of each taxon plot in clearly defined areas. In general, the oxygen isotope analyses of all taxa reveal only little deviation from the taxon specific average values (Fig. 3.3, Tab. 3.2). The same applies for the $\delta^{13}C$ values of *Krithe* and *O. umbonatus*, whereas the $\delta^{13}C$ values of *Henryhowella* and *C. wuellerstorfi* exhibit a significantly larger scatter.

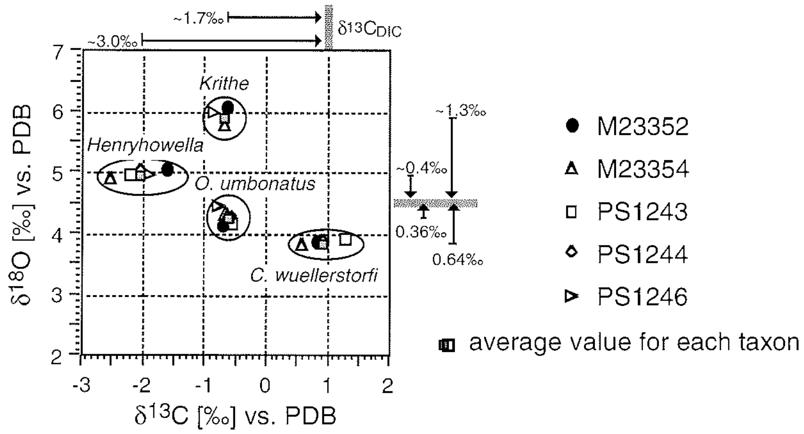

Fig. 3.3. Results of the oxygen and carbon isotopic analyses on the ostracodes *Krithe* and *Henryhowella* and on the benthic foraminifers *C. wuellerstorfi* and *O. umbonatus* from Iceland Plateau surface sediment samples. The values for *C. wuellerstorfi* represent average values calculated from 15 to 29 single and bulk analyses per sample. The right bar represents the average $\delta^{18}O$ value of the equilibrium calcite calculated after the $\delta^{18}O$ value of the deep water measured at all core sites. Bar on top represents the $\delta^{13}C_{DIC}$ value (Erlenkeuser unpubl. data).

Oxygen isotope values of *C. wuellerstorfi* and *O. umbonatus* are considered to display a constant species-specific offset from equilibrium calcite oxygen isotope values of -0.64 ‰ and -0.36 ‰, respectively (Shackleton and Opdyke, 1973; Streeter and Shackleton, 1979; Labeyrie et al., 1987). Adding these offsets to the average $\delta^{18}O$ values of *O. umbonatus* and *C. wuellerstorfi*, we calculate an oxygen isotope value of 4.56 ‰ ±0.07 ‰ for the equilibrium calcite at the core locations (Fig. 3.3). To verify this result we also calculated the $\delta^{18}O$ value of the equilibrium calcite by using $\delta^{18}O$ values and temperatures of the bottom water sampled at the core sites ($\delta^{18}O_{water, SMOW} = 0.22$ ‰ and $T = -0.9$ °C; Tab. 3.2).

$$\delta^{18}O_{water, PDB} = 0.9998 * \delta^{18}O_{water, SMOW} - 0.2 \qquad (1)$$

$$\delta^{18}O_{calcite} = (21.9 - 3.16 * (31.061 + T)^{0.5}) + \delta_{w, PDB} \qquad (2)$$

Equation (1) after Bemis and Spero (1998) is used for converting $\delta^{18}O$ values of water relative to SMOW ($\delta^{18}O_{water, SMOW}$) into $\delta^{18}O$ values in the standard δ notation relative to PDB ($\delta^{18}O_{water, PDB}$). Using equation (2), after O'Neil et al. (1969), the $\delta^{18}O$ value of the equilibrium calcite is 4.57 ‰, which is consistent with the value derived from the foraminiferal oxygen isotope values (4.56 ‰, see above).

Comparison of the equilibrium calcite $\delta^{18}O$ value to the isotopic values of both investigated ostracode species reveals that the ostracode valves are not built in equilibrium with the host water. In contrast to the foraminiferal tests, the two ostracode taxa show positive offsets from the equilibrium calcite. The same has been found in non-marine ostracodes, which also revealed positive offsets from equilibrium calcite (von Grafenstein et al., 1999a). On the basis of surface sediment specimens we calculated an average offset of +1.25 ‰ (±0.26) for *Krithe* and about +0.48 ‰ (±0.04) for *Henryhowella.*

The $\delta^{13}C$ value of the dissolved inorganic carbon (DIC) in the bottom water of the Iceland Sea is about 1 ‰ (H. Erlenkeuser, unpublished data). *Cibicidoides wuellerstorfi* represents the $\delta^{13}C_{DIC}$ value rather well (Fig. 3.3), whereas other analyzed taxa are depleted with respect to $\delta^{13}C_{DIC}$. *Krithe* and *O. umbonatus* both show a similar depletion of about -1.7 ‰. In contrast, values of *Henryhowella* are about 3 ‰ lighter than $\delta^{13}C_{DIC}$, indicating significant vital effects.

Table 3.2 Results of the benthic isotope values from Iceland Plateau surface sediment samples given in ‰ relative to PDB, and the water $\delta^{18}O$ values and temperatures [from *Hirschleber et al.*, 1988]. $\delta^{18}O$ values of the bottom water are given in ‰ relative to Standard Mean Ocean Water (SMOW). The abbreviations are: *Henry.* for *Henryhowella*; *O. u.* for *O. umbonatus*, and *C. w.* for *C. wuellerstorfi*, St. dev. for standard deviation.

Site	*C. w.*	*C. w.*	*O u.*	*O. u.*	*Henry.*	*Henry.*	*Krithe*	*Krithe*	water	water
	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$	$\delta^{18}O$	temp.°C
M23352	0.85	3.85	-0.66	4.13	-1.6	5.02	-0.62	6.04	0.26	-0.9
M23354	0.59	3.78	-0.64	4.33	-2.51	4.88	-0.65	5.74	0.18	
PS1243	1.31	3.88	-0.53	4.18	-2.19	4.94				
PS1244	0.94	3.9	-0.53	4.26	-2.03	5.01				
PS1246	0.98	3.79	-0.75	4.44	-1.88	4.93	-0.83	5.95		
average	0.93	3.84	-0.62	4.27	-2.04	4.96	-0.7	5.91	0.22	-0.9
st. dev.	0.259	0.054	0.095	0.122	0.34	0.059	0.114	0.154		

3.4.3 *Downcore oxygen isotope records*

With respect to the oxygen isotope records, the analyzed taxa can be separated into two groups: The isotope records of *O. umbonatus*, *Krithe* and *N. pachyderma* sin. display the same trends while the records of *C. wuellerstorfi* and *Henryhowella* are also similar to each other but differ significantly from the records of the first group (Fig. 3.4).

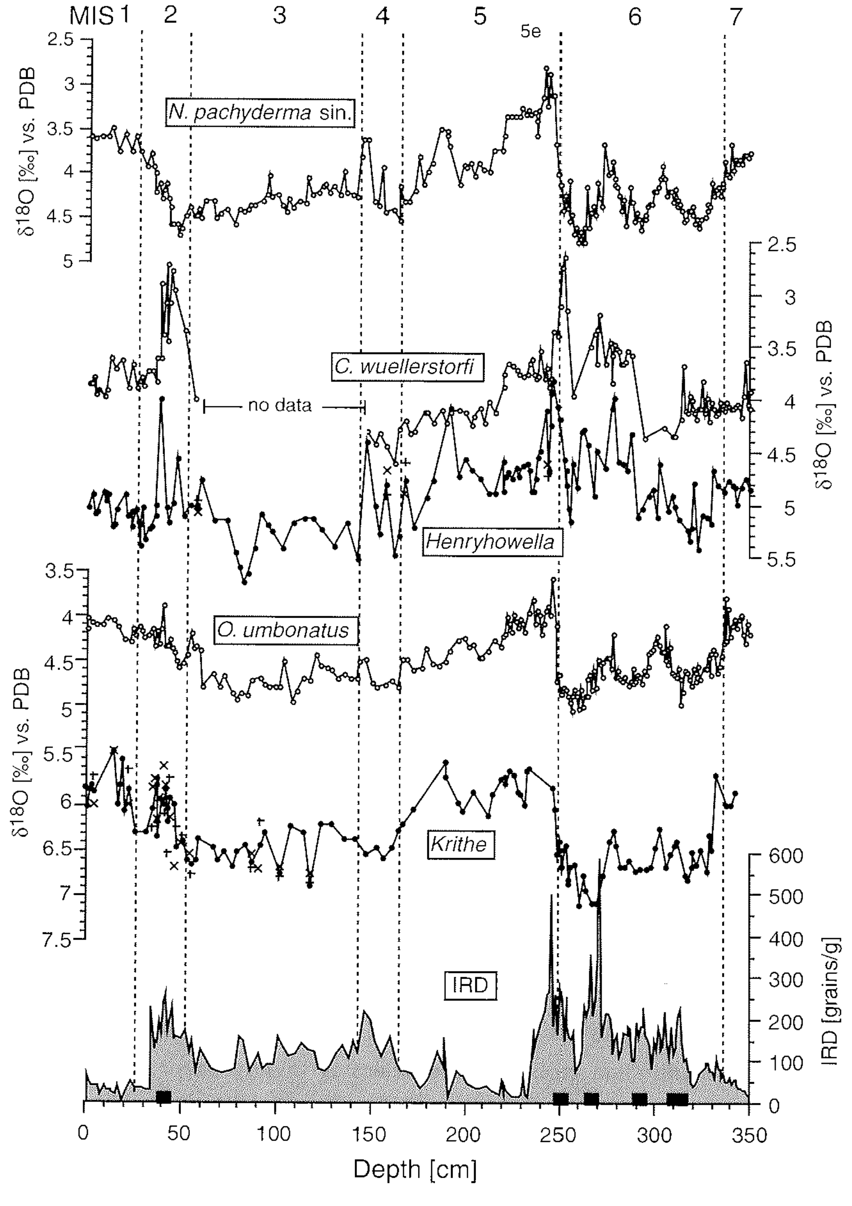

Fig. 3.4. Benthic foraminiferal and ostracodal oxygen isotope records of core M23352 compared to the planktic oxygen isotope record and the content of IRD. Crosses at the ostracode isotope records indicate duplicate analyses, revealing a relatively good correspondence for the $\delta^{18}O$ values (in average ±0.34 ‰ for *Krithe*, n=13 and ± 0.19 ‰ for *Henryhowella*, n=4). Black bars on X-axis indicate intervals, where *C. wuellerstorfi* was rare and analyses on 1-2 specimens were performed.

Oridorsalis umbonatus, *Krithe* and *N. pachyderma* sin. display a general trend of low $\delta^{18}O$ values during the interglacial stages 7, 5e and 1 and high values during the glacial stages 6, 4, and 3. The second group (*C. wuellerstorfi* and *Henryhowella*) reveals also high values during early MIS 6, 4 and 3 but, in contrast to the first group, low values in late MIS 6 and during MIS 2. Each of these negative excursions is accompanied by increased IRD contents. Similarly, during late MIS 6 two negative excursions in $\delta^{18}O$ values are observed in *C. wuellerstorfi* and *Henryhowella* together with two peaks in the IRD record. Slight differences are recognized in both $\delta^{18}O$ records during T II. Whereas *C. wuellerstorfi* displays a strong negative excursion during early T II, *Henryhowella* shows two $\delta^{18}O$ minima in early MIS 5e. The records of all taxa except from *Krithe* display relatively constant values for the short period of MIS 5e, when the amount of IRD is lowest (at about 220-230 cm). Another marked $\delta^{18}O$ depletion is observed in the records of *N. pachyderma*, *Henryhowella* and *Krithe* around 180-190 cm, accompanied by an IRD peak. The next negative excursion is observed in the oxygen isotopes of *Henryhowella*, N. pachyderma and not the same extend of *O. umbonatus* at the MIS 4/3 transition, again accompanied by increased amounts of IRD. During MIS 2, the $\delta^{18}O$ records of all benthic taxa display low values. *Krithe* and *O. umbonatus* show negative excursions in their oxygen isotope records but not to the same extent as observed in the oxygen isotope records of *C. wuellerstorfi* and *Henryhowella.* Although the IRD content is higher in late MIS 6 than in MIS 2, no negative excursions are found in the $\delta^{18}O$ records of *O. umbonatus* and *Krithe* during late MIS 6 (between 276 and 260 cm core depth).

Using the species-specific offsets of *C. wuellerstorfi* and *O. umbonatus* from the $\delta^{18}O$ value of the equilibrium calcite we calculated the downcore values of the equilibrium calcite and the deviation of ostracode $\delta^{18}O$ values from equilibrium calcite. As result we found an average offset of about +1.52 ‰ for *Krithe* and +0.34 ‰ for *Henryhowella* (Tab. A4 of the appendix). The offset calculated for *Henryhowella* is slightly smaller than the value calculated from the surface sediment isotope analyses. This is caused by some marked negative excursions within the downcore oxygen isotopes of *Henryhowella* that are not found in the $\delta^{18}O$ record of *C. wuellerstorfi*, e.g., in MIS 5 (at 180-190 cm) and at the MIS 4/3 transition (Fig. 3.4, Tab. A4). The downcore deviation of *Krithe* from equilibrium calcite isotope values is slightly larger as found in the surface sediment samples. Downcore isotope data from a North Atlantic core suggest an offset of about 1.35 ‰ for *Krithe,* which is in agreement with the surface sample data from the Iceland Plateau (Didié, unpublished data). In general, the calculated downcore offsets of the ostracode $\delta^{18}O$ from the equilibrium calcite are confirmed by the results of the surface sample isotope analyses.

3.4.4 *Downcore carbon isotope records*

The general trends observed in the carbon isotope records differ from the results of the oxygen isotope records. The $\delta^{13}C$ record of *Henryhowella* parallels the record of *O. umbonatus* showing heaviest values within MIS 7, 5 and 1, including some positive excursions during MIS 4 (Fig. 3.5).

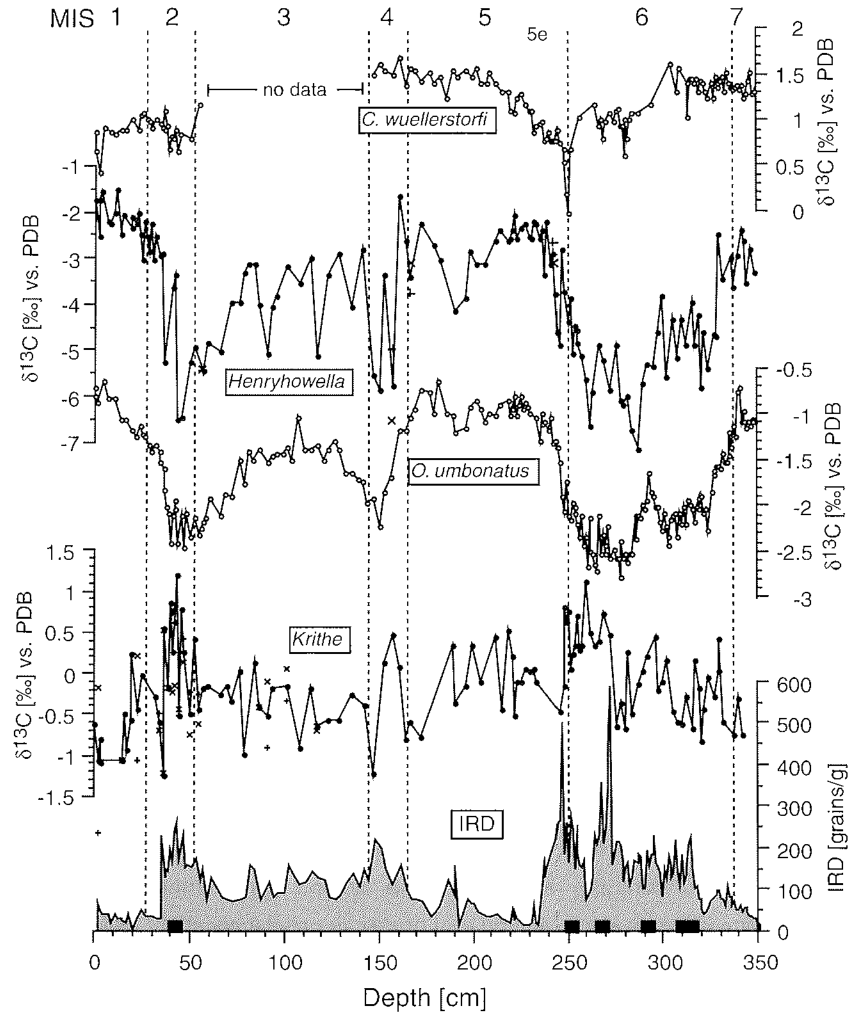

Fig. 3.5. Benthic foraminiferal and ostracodal carbon isotope records of core M23352 and IRD content. Duplicate analyses, indicated by the crosses on the ostracode isotope records reveal a relatively low reproducibility of $\delta^{13}C$ analyses on *Krithe* (in average ±0.49 ‰, n=13). The few duplicate analyses carried out on *Henryhowella* reveal a reproducibility of ±0.67 ‰ (n=4) on average (especially the analyses carried out on the 157 cm sample show a large scatter of ±0.79 ‰). Black bars see Fig. 3.4.

Lightest values are found during the glacial stages 6, 4, and 2, periods of increased IRD contents. Both taxa reveal increasing $\delta^{13}C$ values from MIS 6 to 5 as well as from MIS 2 to 1. In contrast to this, the $\delta^{13}C$ record of *C. wuellerstorfi* shows significant differences with lightest $\delta^{13}C$ values during T II, slightly increasing through MIS 5 and 4. A small depletion is noticed in the $\delta^{13}C$ records of *C. wuellerstorfi* and *O. umbonatus*, and even stronger in the record of *Henryhowella* at 180-190 cm, when a small peak in IRD is noted. Otherwise, only minor changes within the *C. wuellerstorfi* $\delta^{13}C$ record are observed from MIS 2 to 1.

The $\delta^{13}C$ record of *Krithe* with heavy values during MIS 6, 4, and 2 rather seems to anticorrelate with the other records. The *Krithe* carbon isotope record shows maximum amplitudes of about 2 ‰ throughout the investigated interval with obviously no glacial-to-interglacial dependencies. Compared to the other taxa, *Henryhowella* exhibits extremely light $\delta^{13}C$ values down to -6.5 ‰ and a maximum amplitudinal range of about 5 ‰. *Oridorsalis umbonatus* displays lightest $\delta^{13}C$ values of about -2.5 ‰, whereas *C. wuellerstorfi* displays generally positive $\delta^{13}C$ values, both species revealing maximum amplitudes of up to 1.5 ‰.

3.5 Discussion

3.5.1 *Oxygen isotope values and species habitats*

Cibicidoides wuellerstorfi is known to live on the sediment surface, attached to objects, in a slightly elevated position (Lutze and Thiel, 1989). According to Altenbach (1992) *C. wuellerstorfi*, being a suspension feeder, requires a certain amount of organic detritus as well as bottom currents and is considered a reliable recorder of the bottom water isotopic signals (Belanger et al., 1981; Graham et al., 1981; Curry et al., 1988; McCorkle and Keigwin, 1994). This is confirmed by our findings (see Fig. 3.3). In contrast, *O. umbonatus*, which is a detritus feeder, has a facultative behaviour. Although living mainly within the uppermost centimeter of the sediment, it can also dwell on the sediment surface (Corliss, 1985; Rathburn and Corliss 1994). This species is thought to be adapted to a low flux of organic carbon (Mackensen et al., 1985; Altenbach, 1992).

The differences in ecological preferences of the two foraminifers are probably responsible for the contrasts observed in both isotopic test chemistry (Bauch et al., 2000) and abundance on glacial-interglacial time scales (Belanger et al., 1981; Streeter et al., 1982; Struck, 1997). Because *C. wuellerstorfi* is clearly linked to environmental conditions, characterized by relatively high phytoplankton production, deep-water production and bottom currents, it shows increased abundances only during warmer climatic periods (Struck, 1997; Bauch et al., in press a). On the other hand, *O. umbonatus* is continuously found in core M23352 throughout the investigated interval, including the glacial periods. Therefore, its isotopic signal may reflect better the average environmental conditions that occurred during the time interval represented by the thickness of each sample (~500-1000 years). In contrast to this, the few specimens of *C. wuellerstorfi* found in the glacial core sections might represent only episodic events with enhanced phytoplankton productivity which do not necessarily represent the average, longer-term environmental conditions (Bauch et al., in press a). In addition, in those few samples where the number of *C. wuellerstorfi* was so low, that only 1 or 2 specimens could be analyzed, bioturbation has to be taken into account as well.

Another aspect that needs consideration when comparing foraminiferal and ostracodal isotopes is the fact that ostracodes are arthropods and have to moult up to 9 times before they reach adulthood. During moulting they build their calcitic carapaces within hours to days (Turpen and Angell, 1971). Thus, ostracode valves contain environmental information that represents a very short time period.

In terms of habitat and diet preferences of deep-sea ostracodes, only limited information is available. Coles et al. (1994) interpreted *Krithe* as an infaunal-living genus because of its smooth carapace and the lack of eyes. In laboratory experiments Majoran and Agrenius (1995) found *Krithe* burrowing down to more than 10 cm deep into the sediment. In contrast, *Henryhowella* is thought to 'plough' through the upper few millimeters of the sediment (Kempf and Nink, 1993, these suggestions were made on fossil material). These differences in the habitats of both taxa are mirrored in their temporal distribution.

Our comparison of the relative abundances of benthic foraminifers and ostracodes reveals that *O. umbonatus* and *Krithe* reach highest percentages during the glacial MIS 6 and 3-2, whereas *C. wuellerstorfi* is most abundant during MIS 7, 5e and 1 together with *Henryhowella* (Fig. 3.6).

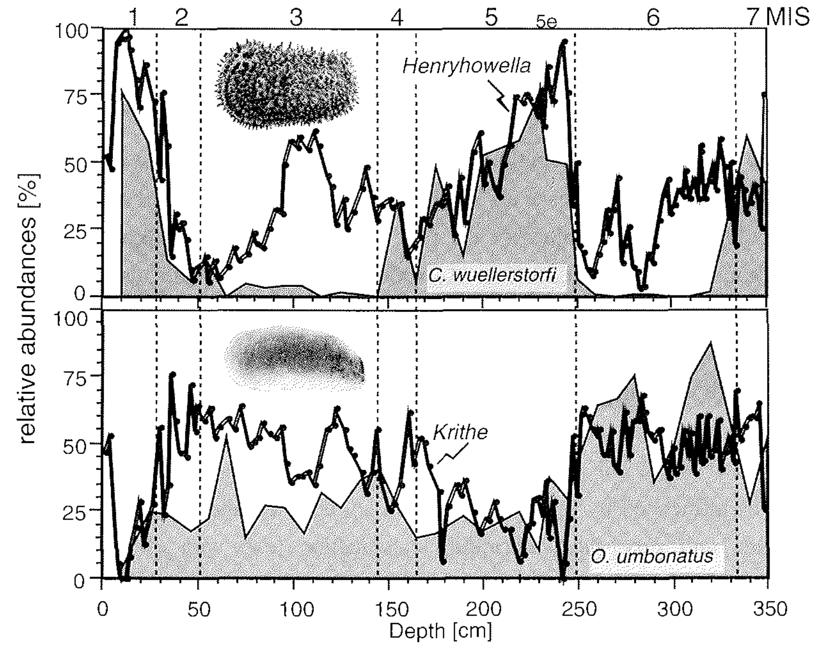

Fig. 3.6. Comparison temporal distribution of the selected benthic foraminifers and ostracodes within core M23352 given in percent of the total benthic foraminiferal and ostracodal fauna, respectively. SEM photographs show typical examples of *Henryhowella* and *Krithe*, both are about 1 mm in length (*Henryhowella* from 337 cm core depth; *Krithe* from 215 cm core depth).

Although, *Henryhowella* shows again high abundances during MIS 3, when *C. wuellerstorfi* is nearly absent. Because of their covariant records it can be concluded that

Henryhowella and *C. wuellerstorfi* may be related to the same environmental conditions such as food supply and well ventilated bottom waters due to deep convection, whereas *Krithe*, like the infaunal-living *O. umbonatus*, is better adapted to lower flux of organic matter and less ventilated bottom water.

The similarities between the oxygen isotope records of *C. wuellerstorfi* and *Henryhowella* on one hand and *O. umbonatus* and *Krithe* on the other hand are most likely caused by the species-specific micro-environmental settings (epifaunal or infaunal habitat, respectively). The unusual, light $\delta^{18}O$ values of epifaunal benthic taxa observed in late MIS 6 have been recognized before in glacial sediments of the Nordic Seas (Duplessy et al., 1988; Vogelsang, 1990; Costello and Bauch, 1997; Bauch et al., 2000). Their origin, however, has been controversely discussed, being either the product of brine formation (Fronval and Jansen, 1997; Vidal et al., 1998; Dokken and Jansen, 1999) or the influence of inflowing relatively warm Atlantic water masses at the subsurface (Bauch et al., 2000; Bauch et al., in press a). Whatever, the actual cause, the environmental conditions during these specific time intervals apparently did not affect the isotope signals of taxa living within the sediment to the same degree as epifaunal-living taxa (Bauch et al., 2000).

3.5.2 *Carbon isotope values and microhabitats*

It has been shown that the deeper in the sediment foraminiferal species live, the lighter is their $\delta^{13}C$ signature (Belanger et al., 1981; Corliss, 1985; McCorkle et al., 1997). This mirrors the decreasing ^{13}C values of the pore water caused by the oxidation of ^{12}C-enriched organic matter (Woodruff et al., 1980; Corliss, 1985) and also explains the relatively heavy $\delta^{13}C$ values of the epifaunal-living *C. wuellerstorfi* compared to the lighter values of the infaunal-living *O. umbonatus* (Figs. 3.3 and 3.5). According to this observation, the presumably infaunal-living ostracode *Krithe* should also show lighter $\delta^{13}C$ values than the possibly epifaunal-living *Henryhowella*. However, the opposite is observed in our records. This could be explained by specific 'vital effects', which may be influenced by many factors, such as the microhabitat, the specific diet of the ostracode, and processes controlling calcification (e.g., von Grafenstein et al., 1999a). But particularly for deep-sea ostracodes, these processes are not well understood because of lack of investigations.

Detailed studies that elucidate some of the complex connections concerning the $\delta^{13}C$ valve chemistry in ostracodes are mainly based on non-marine taxa (Heaton et al., 1995; Xia et al., 1997a, b; von Grafenstein et al., 1998, 1999a). According to these studies, $\delta^{13}C$ values of the ostracode valves are mainly influenced by the $\delta^{13}C$ value of the dissolved inorganic carbon of the host water (von Grafenstein et al., 1999). However, it has been found that specific micro-habitats, e.g., the sediment depth in which the ostracodes live, also affect the $\delta^{13}C$-values of ostracodes (Heaton et al., 1995; Xia et al., 1997b; von

Grafenstein et al., 1999). It has been further suggested that juvenile specimens of some non-marine ostracode species may live on the sediment surface whereas the adult specimens may live within the soft sediment where the pore water is enriched in ^{12}C due to degradation of organic matter (Xia et al., 1997b; von Grafenstein et al., 1999a). Assuming that deep-sea ostracodes show a comparable behaviour as non-marine ostracodes, these observations may help explaining the scatter within the $\delta^{13}C$ record of *Krithe* in core M23352. Preliminary results of *Krithe* isotope analyses in a North Atlantic sediment core point to lighter $\delta^{13}C$ values in juvenile specimens, whereas the $\delta^{18}O$ signature seems not dependant on the molt stage (C. Didié, unpublished data).

3.5.3 *Carbon isotope records and circulation changes*

On climatically relevant timescales such as glacial-interglacial cycles, benthic carbon isotopes may contain important information about changes in ocean circulation patterns. Due to photosynthetic removal of ^{12}C from the surface water, the surface water $\sum CO_2$ remains enriched in ^{13}C, whereas the deep-water masses are more depleted in ^{13}C due to the oxidation of the sinking organic matter which releases isotopically light CO_2 (e.g., Kroopnick, 1985; Curry et al., 1988). Benthic organisms that incorporate the $\delta^{13}C$ signature of the deep water into their calcitic tests are therefore used as proxies for reconstructing past ocean circulation patterns (e.g., Boyle and Keigwin, 1982, 1985). Generally, high $\delta^{13}C$ values in North Atlantic benthic foraminifers are interpreted as a consequence of intense vertical convection in the Nordic Seas (interglacial circulation mode), whereas low $\delta^{13}C$ values indicate diminished deep-water formation and an increased influence of characteristically ^{12}C enriched water of a southern source (glacial circulation mode) (e.g., Boyle and Keigwin, 1982, 1985; Duplessy and Shackleton, 1985; Oppo and Lehman, 1995). This trend of low glacial $\delta^{13}C$ values is observed in the carbon isotope records of *O. umbonatus* and *Henryhowella* in core M23352 (Fig. 3.5). Synchroneity of increased IRD input and low $\delta^{13}C$ values, e.g., in late MIS 6, during a short period in MIS 5, at the MIS 3/4 transition, and during MIS 2 suggests that deep convection was diminished due to meltwater-coverage of the area.

The $\delta^{13}C$ records of *O. umbonatus* and *Henryhowella* differ particularly during late MIS 6 from the $\delta^{13}C$ record of *C. wuellerstorfi*, the latter known to display $\delta^{13}C$ values close to $\delta^{13}C$ of the ambient water (e.g., Belanger et al., 1981; McCorkle and Keigwin, 1994) (Fig. 3.5) One reason for the differences within the isotope records of *O. umbonatus* and *C. wuellerstorfi* may be the different environmental demands of each species. The generally low abundance of *C. wuellerstorfi* during these intervals (see Fig. 3.5) indicates that the conditions were not suitable for *C. wuellerstorfi*. As discussed above, the few specimens of *C. wuellerstorfi* found in the glacial sediments may represent short events of enhanced phytoplankton productivity and vertical overturn but not necessarily the overall, long-term conditions that characterize these periods (Bauch et al., 2000). We thus assume *O. umbonatus* in core M23352 to better represent the average climate-related environmental conditions than *C. wuellerstorfi*, although *C. wuellerstorfi* more likely records the actual $\delta^{13}C$ value of the bottom water DIC.

Compared to *C. wuellerstorfi*, the $\delta^{13}C$ records of *O. umbonatus* and particularly *Henryhowella* seem to be biased by a significant fractionation to light carbon isotopes, leading to extremely light $\delta^{13}C$ values and large amplitudes. The offset of the $\delta^{13}C$ records of both species with respect to the $\delta^{13}C$ of the ambient water seems variable through time, revealing larger offsets during the glacial than during the interglacial periods. Interglacial-to-glacial changes in food supply as inferred from the temporal distribution of epi- and infaunal foraminiferal taxa (see Fig. 3.6; Struck, 1997; Nees and Struck, 1999) and/or changes in the open ocean convection mode (see Dokken and Jansen, 1999; Bauch et al., in press b) may be reasons for this. The actual cause for the variable offsets between *C. wuellerstorfi* on one hand and *O. umbonatus* and *Henryhowella* on the other hand remains unsolved.

As discussed above, we consider an epifaunal mode of life for *Henryhowella*. This is additionally stressed by the spiny surface of *Henryhowella* (see Fig. 3.6). It is unlikely that an animal with such a shape is able to burrow deep into the sediment (see the smooth surface of *Krithe* for comparison). We therefore exclude the possibility that the extremely negative $\delta^{13}C$ values of *Henryhowella* are caused by ^{13}C depleted pore water. Strong species specific vital effects seem to bias the $\delta^{13}C$ values of *Henryhowella*, although differences in the diet of ostracodes compared to foraminifers and/or different mechanisms involved in precipitating the tests or valves, respectively, have to be considered.

However, the downcore comparison of the $\delta^{13}C$ records of *Henryhowella* and *O. umbonatus* suggests the specific $\delta^{13}C$ fractionation to record and amplify a globally observed signal. We compared these two benthic carbon isotope records to benthic foraminiferal $\delta^{13}C$ records from two North Atlantic sites and the tropical East Pacific (Fig. 3.7). All records display a similar pattern of high $\delta^{13}C$ values during the warmer, and low values during the colder periods. Although the records reveal a different resolution, they all have in common low $\delta^{13}C$ values during the peak glacial MIS 6 and 2 and a very marked depletion during late MIS 4, while characteristically high values are observed during interglacial and interstadial stages. It is intriguing that even though the *Henryhowella* $\delta^{13}C$ record seems to be biased towards light $\delta^{13}C$ values by fractionation particularly during the glacial periods, it clearly shows a trend in accordance with the other isotope records, implicating a strong global imprint probably due to changes in the carbon cycle.

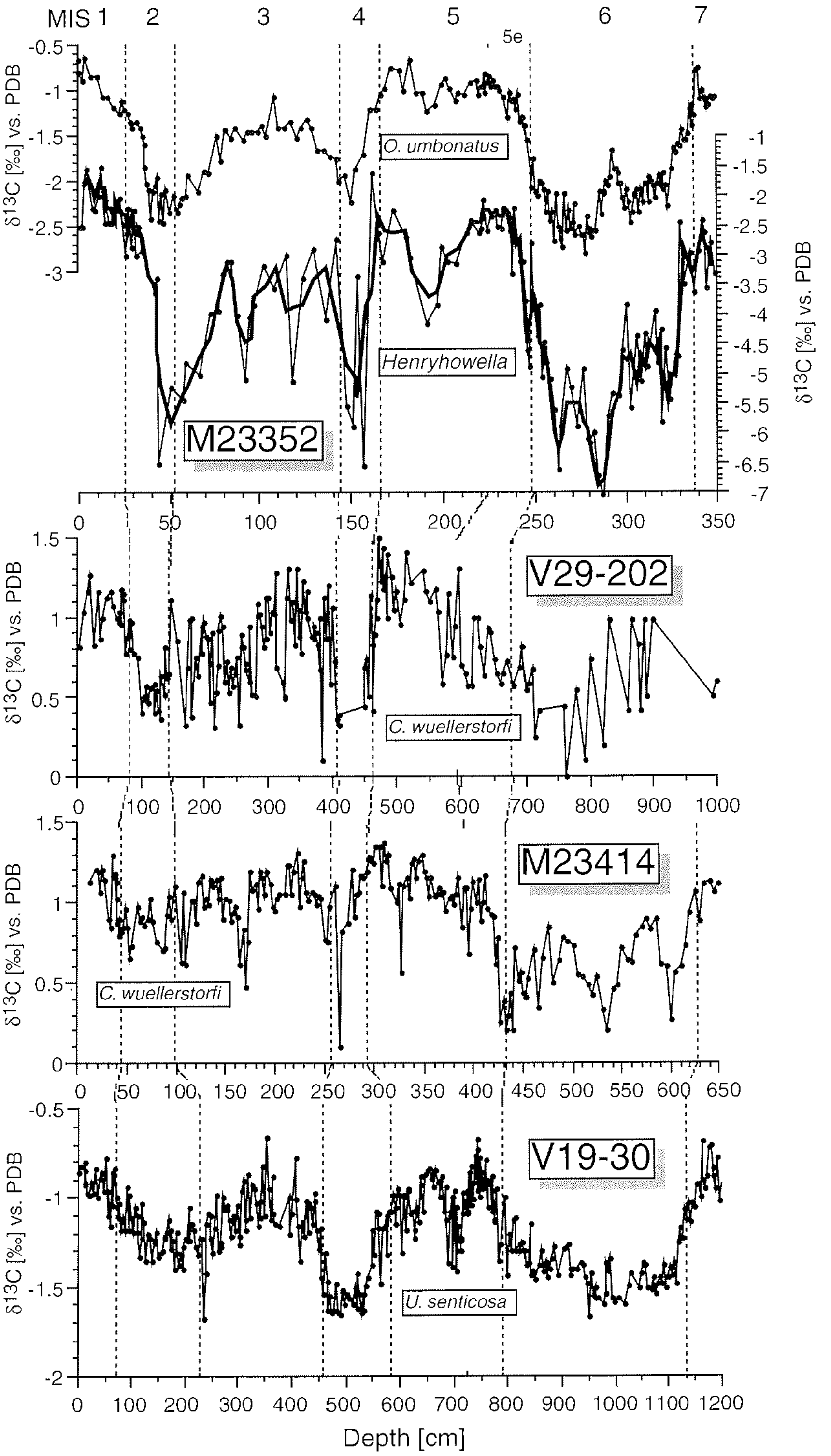
MIS 1
2
3
4
5
5e
6
7
δ13C [‰] vs. PDB
-0.5
-1
-1.5
-2
-2.5
-3
O. umbonatus
Henryhowella
M23352
δ13C [‰] vs. PDB
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
-5.5
-6
-6.5
-7
0
50
100
150
200
250
300
350
V29-202
δ13C [‰] vs. PDB
1.5
1
0.5
0
C. wuellerstorfi
0
100
200
300
400
500
600
700
800
900
1000
M23414
δ13C [‰] vs. PDB
1.5
1
0.5
0
C. wuellerstorfi
0
50
100
150
200
250
300
350
400
450
500
550
600
650
V19-30
δ13C [‰] vs. PDB
-0.5
-1
-1.5
-2
U. senticosa
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Depth [cm]

Fig. 3.7. previous page. The carbon isotope records of *O. umbonatus* and *Henryhowella* (bold line = 3pt moving average) from core M23352 compared to benthic foraminiferal isotope records of two North Atlantic cores (M23414 and V29-202) and core V19-30 from the East Pacific.
Data sources: M23414 from *Jung* [1996]; V29-202 from *Oppo and Lehmann* [1995]; V19-30 from *Shackleton and Pisias* [1985].

3.6 Summary and conclusions

In order to examine the potential of stable isotope records of deep-sea benthic ostracodes as paleoenvironmental proxies we studied a core from the Iceland Plateau covering the past two climatic cycles, i.e. late MIS 7 to MIS 1. For the first time systematic investigations on stable carbon and oxygen isotopes derived from deep-sea benthic ostracodes were carried out. For these analyses the ostracode genera *Krithe* and *Henryhowella* were used because both show a relatively abundant and consistent occurrence throughout the investigated interval, in contrast to benthic foraminifers which are rare during glacial periods (e.g., MIS 2-3). To investigate ostracode isotopic offsets from equilibrium calcite, foraminifers and ostracodes from several surface sediment samples from the Iceland Plateau were analyzed. Compared to the calculated isotopic signal of the equilibrium calcite, the ostracode stable isotope analyses lead to the following results:

- The valves of both investigated ostracode genera are not built in equilibrium with the ambient water. In contrast to the investigated benthic foraminifers *C. wuellerstorfi* and *O. umbonatus*, both ostracode genera reveal positive $\delta^{18}O$ values with respect to the equilibrium calcite, which is confirmed by studies on fresh-water ostracodes. The calculated offset for *Krithe* is about +1.4 ‰, whereas *Henryhowella* displays an offset of about +0.4 ‰.
- The oxygen isotope record of *Krithe* parallels the record of the infaunal-living foraminiferal species *O. umbonatus*. This observation together with faunal abundance data suggests an infaunal habitat for *Krithe* as proposed before by several authors. The oxygen isotope record of *Henryhowella* displays a trend parallel to the record of the epibenthic foraminifer *C. wuellerstorfi*. This is in agreement with faunal abundance data and implies an epifaunal habitat for *Henryhowella*, which has been suggested before.
- The ostracode $\delta^{18}O$ results confirm the observations made earlier by others who found differences of infaunal and epifaunal foraminiferal oxygen isotope signals during glacial periods in the area of the Nordic Seas. These differences are likely caused by specific environmental conditions during late MIS 6 and MIS 2, characterized by increased IRD deposition, that obviously affected infaunal-living taxa not to same extent as epifaunal-living taxa.
- The $\delta^{13}C$ values of *Henryhowella* are significantly lower than the values of all other investigated taxa. This is in contrast to the faunal and oxygen isotopic results, that

would imply an epifaunal habitat for *Henryhowella.* As known from benthic foraminifers the carbon isotope values of infaunal-living species are influenced by the ^{12}C enriched pore water and are, therefore, depleted in ^{13}C, in contrast to epifaunal-living species which display heavier $\delta^{13}C$ values.

- Although obviously biased by a specific fractionation towards light values, the carbon isotope record of *Henryhowella* follows a globally observed trend of light values during glacial periods and heavy values during interglacial periods. This trend is also discovered in the carbon isotopic record of *O. umbonatus* in the investigated core but not to same extent in the record of *C. wuellerstorfi.* In contrast, the downcore carbon isotope record of *Krithe* does not correspond to the climatic cycles.

Altogether, our analyses reveal that stable isotope records of deep-sea ostracodes display similar trends to isotope records of benthic foraminifers. Although still more knowledge on the environmental demands, such as food- and habitat preferences of deep-sea ostracodes is needed, their stable isotopic compositions may be used for the reconstruction of past environmental conditions.

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Chapter 4

Faunal and diversity changes of North Atlantic deep-sea benthic ostracodes related to climate-induced changes of the past 200,000 years

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Abstract

Two sediment cores from the northern North Atlantic were investigated in order to examine the response of deep-sea benthic ostracodes to climate-related environmental changes. The two selected cores both cover the past two climate cycles, i.e. marine isotope stages (MIS) 7 to 1. Ostracode assemblages were defined by using Q-mode factor analyses and diversity was calculated by using the Shannon-Wiener index. In both cores three factor assemblages could be identified.

Core M23352 from the Iceland Plateau revealed an interglacial assemblage dominated by *Henryhowella*, a transitional assemblage dominated by *Eucythere*, and a background assemblage that consists of the common taxa *Krithe* and *Cytheropteron*. The presence of *Henryhowella* is clearly linked to conditions such as increased food supply, well oxygenated bottom water, and lateral advection that prevailed during the peak interglacial periods (MIS 5e and 1). The presence of *Eucythere* mainly during the interstadial periods appears to be related to slightly increased food supply as inferred from benthic foraminiferal data. The background assemblage is considered to be opportunistic, able to cope with glacial conditions such as decreased food supply, as inferred from the carbonate content.

Core M23414 from the Rockall Plateau is dominated by the background assemblage (consisting mainly of *Krithe* and *Cytheropteron*) that shows no obvious relation to climate change. The interglacial assemblage consists of several taxa, dominated by *Pelecocythere* and also containing *Henryhowella*. The third assemblage is the glacial assemblage, consisting of a variety of taxa, several of them known from the modern Arctic Ocean and the Greenland Sea shelf. Thus, this assemblage indicates glacial conditions on the Rockall Plateau that are comparable to conditions found in the present-day polar oceans.

Diversity calculations revealed higher glacial than interglacial ostracode diversities in both cores and particularly high diversities during periods of increased IRD input in the Rockall Plateau core. Concomitantly, both cores reveal lower surface-water productivity during the glacial than during the interglacial periods and particularly low productivity during the IRD events, as inferred from carbonate contents. We therefore assume benthic diversity in the research areas to be negatively correlated with food flux.

Keywords: ostracodes; biodiversity; Late Quaternary; North Atlantic

4.1 Introduction

Benthic and planktic microfossils are widely used for paleoceanographic and paleoclimatic reconstructions. Besides a variety of proxies, such as stable isotopes and trace elements in planktic and benthic foraminifers (Boyle and Keigwin, 1982; Schneider et al., 1994; Sarnthein et al., 1995; Oppo and Lehman, 1995), the abundance and composition of planktic and benthic foraminiferal assemblages have been used to reconstruct past ocean circulation modes and surface water productivity (e.g., Pflaumann et al., 1996; Schnitker, 1980, 1984; Schmiedl et al., 1997).

Benthic foraminifers are widely distributed in most pelagic sediments. They were the subject of numerous studies focusing on past climate change and deep-ocean circulation, particularly in the climate-sensitive region of the North Atlantic (Streeter et al., 1982; Schnitker, 1984; Thomas et al., 1995; Struck, 1997). Early investigations suggested mainly the physico-chemical character of water masses to determine the faunal composition and distribution of benthic foraminifers (Lohmann, 1978; Schnitker, 1980). Later, numerous studies suggested food supply to the ocean floor as the major controlling factor for benthic life in an open ocean environment (e.g., Gooday, 1988; Loubere, 1991). Since phytoplankton production in the surface water controls food supply to the ocean floor, a process known as 'benthic-pelagic coupling' (Graf, 1989), benthic foraminiferal assemblages were used to reconstruct past ocean productivity (Herguera and Berger, 1991). Meanwhile it has been widely accepted that a combination of several factors such as quality, quantity and seasonality of food supply, and also the oxygen content of bottom and interstitial waters mainly influence the deep-sea benthic community (see Jorissen et al., 1995; Kurbjeweit et al., 2000). On the other hand, factors controlling biodiversity are still controversely discussed and not fully understood. However, it seems as if food supply again plays a crucial role (see Rex et al., 1993).

In the past decades, an increasing number of investigations also found deep-sea benthic ostracodes clearly linked to water-mass distribution and circulation patterns (Dingle and Lord, 1990; Cronin et al., 1994, 1995; Ayress et al., 1997; Passlow, 1997; Jones et al., 1998). Aside from glacial-to-interglacial climate changes, even millennial-scale climate variability was reconstructed on the basis of deep-sea ostracode faunal and diversity changes (Cronin et al., 1994, 1995, 1999). Thus, ostracodes may be useful paleoceanographic indicators where the usually investigated benthic foraminifers are rare, such as, for example, in glacial sediments from the Nordic Seas (see Schnitker, 1979; Duplessy et al., 1988).

In the present investigation, we examined ostracode faunal composition and diversity in the northern North Atlantic over the past 200,000 years with regard to long- and short-term climate change. Two sediment cores were selected, core M23352 from the Iceland Plateau in the Nordic Seas, and core M23414 from the Rockall Plateau in the northeast Atlantic. In the area of the Iceland Plateau deep-water formation takes place today, whereas the Rockall Plateau is presently influenced by the southward flowing deep waters from the Nordic Seas. Significant circulation and productivity changes that occurred in the North Atlantic during the past two climatic cycles characterize the sediments of both sites. In contrast to the interglacial periods decreased primary production predominated during the glacial periods. However, circulation changes influenced the core sites in a different way. Since deep-water formation was reduced during the glacial periods, deep water on the Iceland Plateau is considered to have been less well ventilated (Duplessy et al., 1988) and possibly even warmer than during the interglacial periods (Bauch et al., 2000). At the same time, the Rockall Plateau is thought to have been influenced by a well ventilated water mass, colder than the interglacial deep water (Bertram et al., 1995).

Goal of this study is to determine the interglacial-glacial changes in the ostracode assemblages of both cores. Comparison with available productivity and circulation proxies from both areas shall reveal whether the effect of climate-induced circulation and/or productivity changes and local differences in these proxies can be traced in the ostracode fauna of both sites.

4.2 Late Quaternary oceanography of the research area

The present-day ocean circulation in the North Atlantic is characterized by the warm, saline surface waters of the North Atlantic Drift (NAD) and the Norwegian Current (NC) that form the continuation of the Gulf Stream heading north (Fig. 4.1). In the Nordic Seas these temperate waters mix with the cold, southward flowing waters of the East Greenland Current (EGC). In the Greenland Basin and on the Iceland Plateau the surface waters eventually start to sink due to their increasing density (Aagaard et al, 1985). The resulting cold, dense bottom waters flow to the south across the Greenland-Scotland Ridge, entrain other deep-water masses and finally form North Atlantic Deep Water (NADW) (e.g., Broecker, 1991). In the northeast Atlantic NADW forms the principal water mass that surrounds the Rockall Plateau, where the core site of core M23414 is presently bathed by the lower portion of NADW (LNADW) (Fig. 4.1).

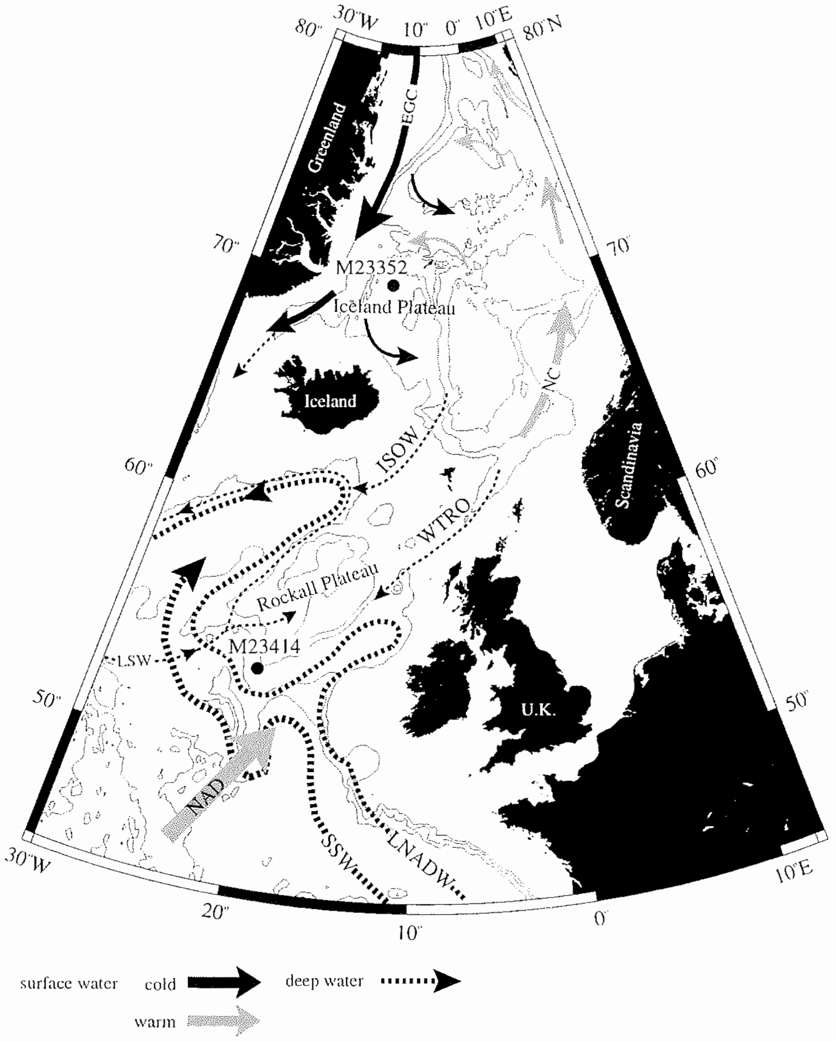

Fig. 4.1. Core locations and general circulationpattern in the working area (after McCave and Tucholke, 1986; Manighetti and McCave, 1995; Koltermann, 1987). NAD = North Atlantic Drift, NC = Norwegian Current, EGC = East Greenland Current, LNADW = Lower North Atlantic Deep Water, SSW = Labrador Sea Water, SSW = Southern Source Water, ISOW = Iceland-Scotland Overflow Water, WTRO = Wyville-Thompson Ridge Overflow Water. ISOW and WTRO represent the the overflow waters from the Nordic Seas. Dashed lines indicate deep-water masses; full black arrows indicate cold, full grey arrows warm surface currents.

During late Quaternary glacial periods the formation of deep water was significantly reduced due to low density meltwater and sea ice that covered the Nordic Seas (e.g., Duplessy et al., 1988; Sarnthein et al., 1994; Seidov et al., 1996). It is believed that during these times the mode of deep water formation switched to an intermediate mode hence producing Glacial North Atlantic Intermediate Water (GNAIW) instead of NADW (Oppo and Fairbanks, 1987; Duplessy et al., 1991; Venz et al., 1999). GNAIW may have originated mainly somewhere in the north western Atlantic (Sarnthein et al., 1995; Weinelt et al., 1996). Due to the decreased strength of northern source deep water during the glacials, deep water of southern origin (SSW = Southern Source Water) extended further north, reaching the area of the Rockall Plateau, where the water-mass boundary between GNAIW and SSW was probably situated somewhere around 2200 m (Bertram et al., 1995; Venz et al., 1999).

4.3 Methods and materials

4.3.1 *Core locations and sample treatment*

Kasten core M23352 was obtained from the Iceland Plateau (12.92°W, 70.06°N) at 1819 m water depth and kasten core M23414 was taken from the southern Rockall Plateau (20.29°W, 53.54°N) at 2196 m water depth (Fig 4.1). To obtain the upper most centimeters of undisturbed sediment, corresponding trigger box cores have been taken at both locations. Core M23352 was sampled every 1-3 cm down to 350 cm, core M23414 every 2.5 cm down to 650 cm. The standard sample processing of the relatively large samples is described in detail by Didié and Bauch (in press) and Didié and Bauch (2000).

In addition to the ostracode census data and the amount of IRD, we determined the ostracode dissolution index (ODI) according to Passlow (1997) on valves of the genus *Krithe*, a common and abundant genus in most deep-sea sediments (Table 4.1). Despite the corrosion ratings, it should be noted that in most samples complete and well-preserved ostracode valves were found - only few samples contained opaque and/or white valves; broken specimens were extremely rare and possibly resulted from sample treatment.

As a measure for paleoproductivity the amount of total organic carbon (TOC) and calcium carbonate was analyzed using a LECO C200 carbon determinator.

Table 4.1
Ostracode corrosion stages (after Passlow, 1997)

Scale	Carapace preservation
1	transparent
2	transparent, shiny
3	translucent, dull
4	opaque, edges abraded
5	white, chalky

4.3.2 *Diversity indicators*

Among many indices available to measure diversity we determined the number of species (S) and the Shannon-Wiener-Index (H'). The advantage of H' is that, in addition to the number of species, this index takes into account the proportion of each species within the community. H' was calculated after equation 1:

$$H' = -\sum [Pi*\ln (Pi)] \qquad (1)$$

where Pi is the number of a given category (species or genus) divided by the total number of ostracodes found in a given sample. The maximum value for H', meaning that all categories are represented equally, can be calculated for each system by the equation: ln (1/number of categories). The minimum value is 0 when all specimens fall into the same category. For diversity calculations, we omitted all shallow-water supposedly ice-rafted taxa, including *Acetabulastoma arcticum*, which is believed to live as a parasite on amphipods that live near the sea surface (Schornikov, 1970). Because it was not possible to identify the numerous juvenile moult stages of *Krithe* down to the species level, all *Krithe* specimens were combined under the genus name. Hence, the calculated total diversity may be underestimated.

4.3.3 *Statistics*

Factor analyses is a common technique to reduce large numbers of variables (i.e. taxa) to an interpretable number of factors (assemblages) (e.g., Reyment and Jöreskog, 1996). Q-mode factor analysis was carried out with the software package CABFAC, using the relative abundance data of the various taxon groups (Imbrie and Kipp, 1971; Klovan and Imbrie, 1971). Because both cores were rather different in their ostracode assemblages, separate factor analyses for each core were run.

4.4 Results

4.4.1 *Stratigraphy*

The stratigraphy of both cores was established on the basis of planktic and benthic oxygen isotope records (Fig. 4.2). In core M23352 the planktic foraminifer *Neogloboquadrina pachyderma* sin. and the endobenthic foraminifer *Oridorsalis umbonatus* were analysed. On the basis of the oxygen isotope records and sediment reflectance data, the kasten core and the corresponding box core were spliced together (Bauch and Helmke, 1999; Didié and Bauch, in press). In addition, for core M23352 seven and for core M23414 four AMS ^{14}C dates were obtained based on planktic foraminifers (Fig. 4.2).

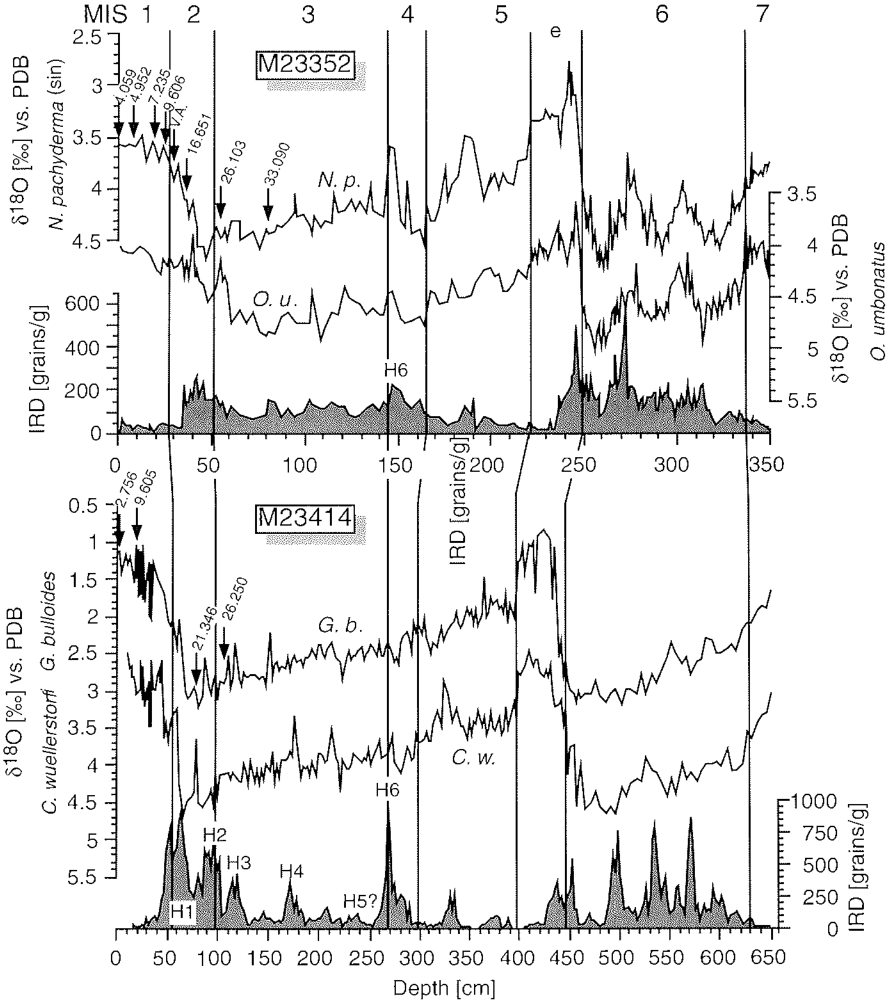

Fig. 4.2. Stratigraphy of the investigated cores M23352 and M23414 based on planktic (N. *pachyderma* sin. and *G. bulloides*) foraminiferal isotope records, AMS ^{14}C ages (indicated ages are calibrated calender years), and distinct Heinrich layers (see numbers at IRD records). Marine Isotope Stages (MIS) are indicated at top. Isotope data of kasten core M23414 are from Jung (1996).

The ^{14}C ages were converted into calender years using the CALIB 4.1.2 software, whereas the ages older than 25 ky were converted according to Voelker et al. (1999). For core M23352 additional age points were available based on the well-dated Vedde Ash and Heinrich layer 6 that marks the stage boundary MIS 4/3 (see Voelker, 1999). For core M23414 additional age points were set on the basis of the distinguished Heinrich layers 1-6 following the age model of Sarnthein et al. (in press.). The planktic isotope records of both cores were further adjusted to the SPECMAP chronology of Martinson et al. (1987).

The studied core sections span the time from about 190 ka to the Holocene, i.e. they cover the time period from end of MIS 7 to 1. According to the age-/depth relation linear sedimentation rates (LSR, given in cm/ky) were calculated (Fig. 4.3). The average glacial sedimentation rates are < 2 cm/ky on the Iceland Plateau and 2-3 cm/ky on the Rockall Plateau, whereas the average interglacial sedimentation rates are 3-5 cm/ky on the Iceland Plateau and around 5 cm/ky on the Rockall Plateau. Particularly the sedimentation rates on the Rockall Plateau are influenced by a number of IRD events, that occurred at the glacial/interglacial transitions (=Terminations), TI and TII, during MIS 6, and MIS 3-2.

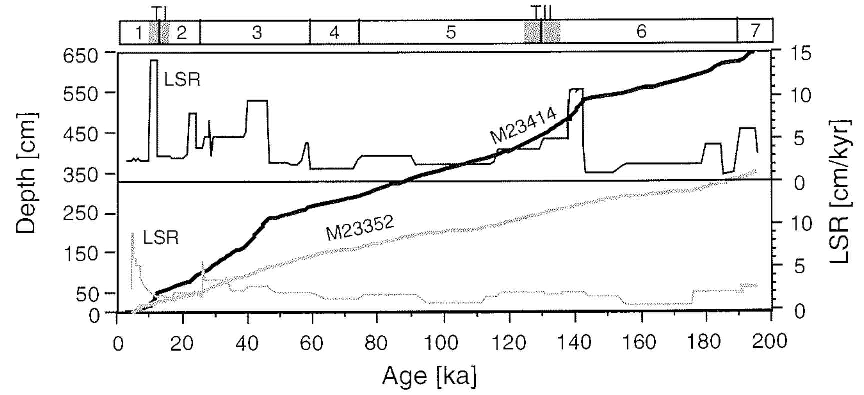

Fig. 4.3. Age/depth relation of both investigated cores and linear sedimentation rates (LSR). TI and TII = Terminations I and II.

4.4.2 *The ostracode fauna*

Core M23352 is dominated by the genera *Henryhowella* (mainly *H.* cf. *H. dasyderma*), *Krithe* (mainly *K. glacialis*), *Cytheropteron,* and *Eucythere,* the latter two genera represented by a number of species. The genera *Bythocypris*, *Swainocythere* and *Polycope* show increased percentages in only few samples (Fig. 4.4).

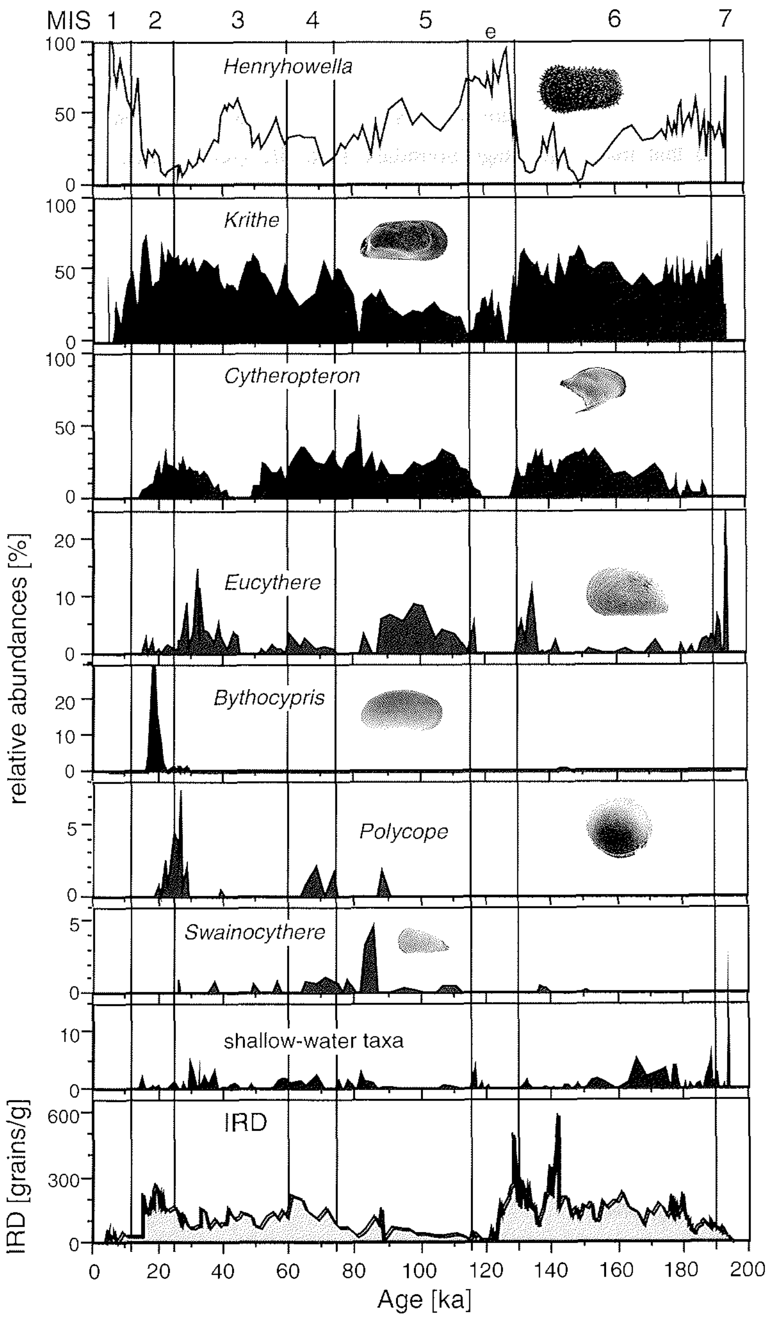

Fig. 4.4. The ostracode relative abundance data of core M23352 (Iceland Plateau), over the last 200 ky.

Numerous other taxa were found in rather low numbers, some of them were only present in one or two samples. These mainly belong to shallow-water taxa that are considered to have been ice-rafted (see Reimnitz et al., 1992; Jones et al., 1998). Figure 4.4 shows the relative abundances of the main taxa found in core M23352. *Henryhowella* reveals highest abundances (up to 100 %) during the interglacial periods MIS 5e, and 1, and the interstadial MIS 3, whereas *Krithe* displays highest abundances (up to 70 %) during the peak glacial phases MIS 6 and 2. *Cytheropteron* seems also related to the colder phases, when relatively high abundances were reached (>30% during MIS 6, 5d-a, 4, and MIS 3/2). *Bythocypris* occurs only twice in this core: during MIS 2 (30 %) and with very few specimens around 145 ka in MIS 6. *Eucythere* shows highest abundances (10-25 %) during MIS 5 and 3. *Swainocythere* and *Polycope* reveal variable but relatively low abundances < 5% and no obvious preferences for distinct climate periods. Single ostracodes belonging to other taxa are found in some samples usually not reaching more than 1% of the total ostracode fauna (see Table A16 of the appendix).

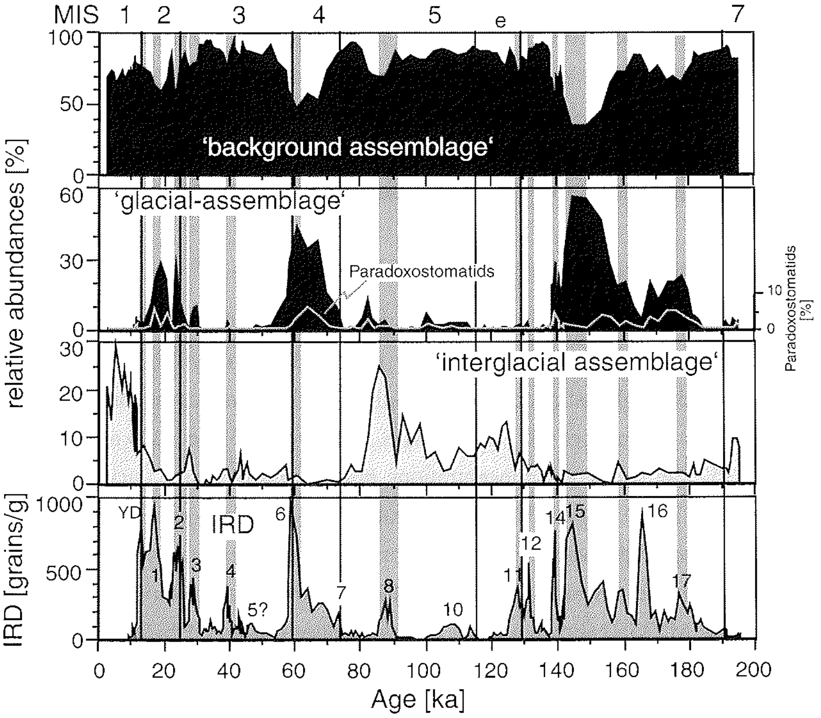

Fig. 4.5. Relative abundances of the ostracode assemblages of core M23414 (Rockall Plateau) versus age in ka BP. Numbers on the IRD record indicate Heinrich layers and other Heinrich-like IRD layers (from Didié and Bauch, 2000).

Figure 4.5 shows the temporal distribution of the relevant assemblages (the highly diverse ostracode fauna of core M23414 is shown in detail by Didié and Bauch, 2000). The generally most abundant taxa *Krithe*, *Argilloecia*, *Cytheropteron* and *Oxycythereis* reveal no obvious relation to the climate periods. This assemblage comprises between 40 and >90 % of the total ostracode fauna. In contrast to this group, two other assemblages were identified that are clearly linked to distinct climate modes. A 'glacial' group consisting mainly of *Acetabulastoma arcticum*, *Rhombobythere*, *Pseudocythere*, *Bythoceratina scaberrima*, and *Polycope* displays its highest abundances during MIS 6, 4 and 2, and an 'interglacial' group that is dominated by *Pelecocythere*, *Echinocythereis*, *Eucytherura*, *Cytherella*, *Aversovalva* and *Henryhowella*, showing peak abundances during MIS 7, 5 and 1.

4.4.3 *Ostracode faunal diversity*

In general, the ostracode fauna from the Rockall Plateau reveals a higher diversity than the fauna from the Iceland Plateau. There, between 1 and 13 taxa occurred per sample, which represents a Shannon-Wiener diversity (H') between 0 and 1.8. On the Rockall Plateau, between 8 and 39 taxa were found per sample, which equals H'-values between 1 and 2.8 (Fig. 4.6). Altogether, both cores yield relatively high numbers of ostracodes, when compared to other ostracode studies (see Whatley and Coles, 1987; Cronin et al., 1999). Therefore, the common flaw that rare taxa are underrepresented because of a too small sample size is here considered to be negligible (see Cronin et al., 1999).

4.4.4 *Ostracode concentration, diversity, and IRD content*

High diversity is usually observed during the glacial periods MIS 6, 4 and 2, although the ostracode concentration remains low, probably due to dilution by IRD (Fig. 4.6). Both cores show relatively high ostracode concentrations and diversities accompanied by low ODI values and low amounts of IRD during MIS 5 (between 95 and 120 ka).

In core M23352 the ostracode concentrations reach highest values during MIS 6 (>20 v./g) and in MIS 5 (15-20 v./g). After about 90 ka BP the ostracode concentration decreased and remained low (around 5 valves/g). Lowest ostracode concentrations are observed at the end of MIS 7, in MIS 5e, towards the end of MIS 5 and during the Holocene.

The ODI in core M23352 shows a trend of high values during MIS 5e, 3 and 1 and low values (meaning good preservation) during MIS 6, most of MIS 5 and from MIS 3 to 2. Highest diversity values are found at about 85 ka BP, during MIS 4, around the MIS 3/2 transition and in MIS 2. Here low ostracode concentrations correlate with good preservation and relatively high amounts of IRD.

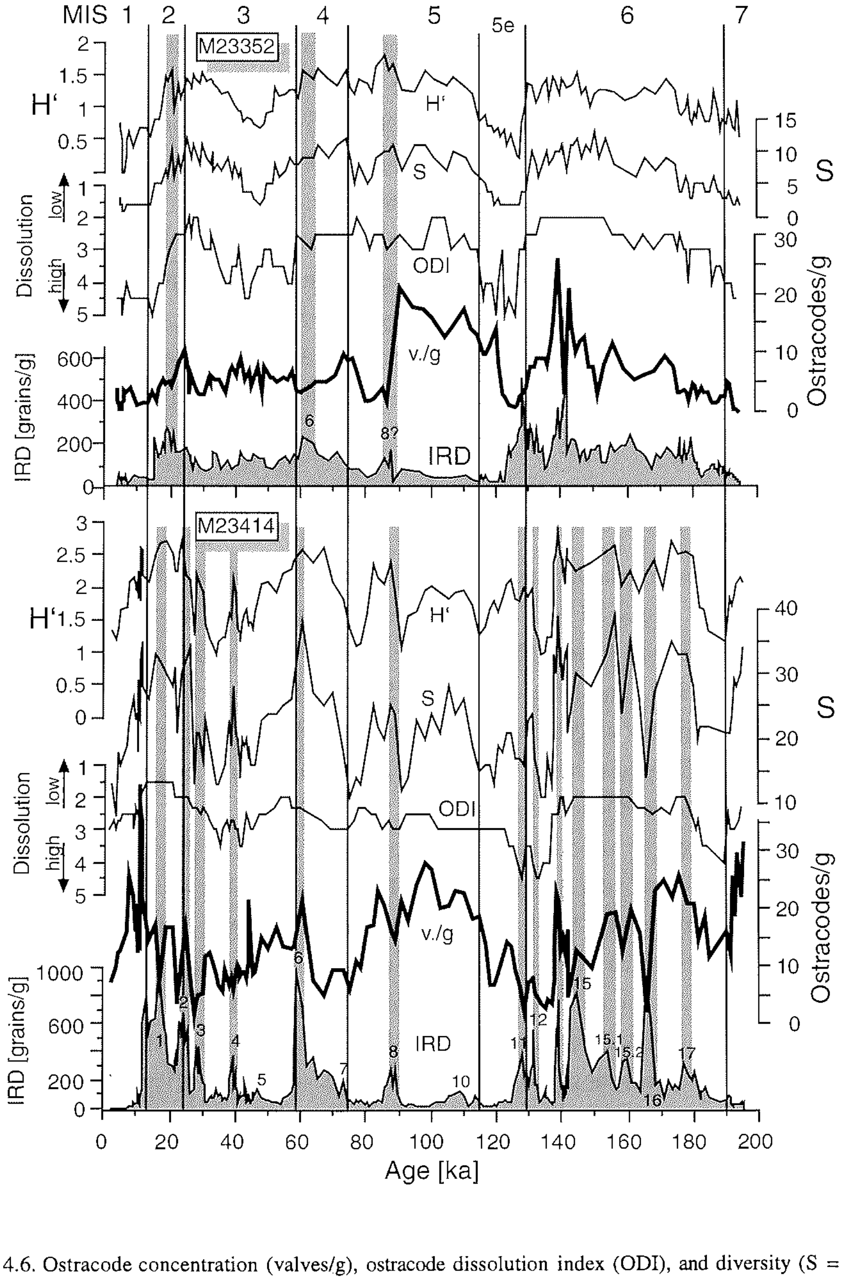

Fig. 4.6. Ostracode concentration (valves/g), ostracode dissolution index (ODI), and diversity (S = number of species; H' = Shannon-Wiener index) versus age in ka BP. Shaded bars indicate distinct IRD layers referred to in the text.

Core M23414 from the Rockall Plateau shows strong variations in all these parameters. Ostracode concentrations are generally higher than in core M23352. Highest ostracode concentrations (>25 v./g) are observed during the end of MIS 7, MIS 5 (85-110 ka), and after TI, but best preservation appears during MIS 6 and 2. As in core M23352, highest diversity is reached during parts of MIS 6, during MIS 4 and 2. Almost all distinct IRD peaks (indicated by the numbers in Fig. 4.6) are accompanied by low ostracode concentrations but high diversity values. Exceptions form IRD peaks 16 and 11. At IRD peak 16, a massive decrease in ostracode concentration and the number of species is observed, which is most likely related to dilution by IRD. At IRD peak 11, which is related to TII, low ostracode concentrations lead to a decreased diversity. Aside from dilution by IRD, this significant decrease in ostracode concentration may have been caused additionally by corrosion, as indicated by high ODI values.

4.4.5 *Carbonate - and TOC contents*

The carbonate content on the Iceland Plateau is relatively low (about 10%), except during the peak interglacial stages 5e and 1, when maximum values of 40-50 % are reached (Fig. 4.7). On the Rockall Plateau the carbonate content is generally higher. Maximum values are found during almost the entire MIS 5 and MIS 1, whereas lowest values are observed during the glacial stages 6 and 4. Decreased carbonate values are also found in relation to several IRD peaks, such as H 3, 4, 6, 8, and 11, indicating either dilution by IRD or decreased carbonate production as cause.

The TOC values are low in both cores (commonly < 0.5 %). In the Iceland core small peaks in the TOC content occur in MIS 4 and 2. These are most likely caused by the input of fossil organic matter in the form of IRD (Henrich et al., 1995). The increasing TOC values during MIS 1 are caused by decreasing diagenetic degradation of organic matter (Henrich et al., 1995). In the core from the Rockall Plateau, highest TOC values (> 0.4 %) are found around 135-140 ka, possibly due to fossil organic matter related to IRD layer 14. In general, the TOC content shows no systematic interglacial-glacial variations (Fig. 4.7).

4.4.6 *Results of the Q-mode factor analyses*

A 3-factor model was found to represent the ostracode faunal data of both cores best. The data set of core M23352 from the Iceland Plateau is composed of 10 taxa or groups, respectively. The composition of the 3 factors that characterize core M23352 is shown in Fig. 4.8. The importance of a taxon within a factor is expressed by the factor score, i.e., the length of the bars in Fig 4.8. Factor 1 is dominated by *Krithe*, *Cytheropteron* and the shallow-water group. Factor 2 is clearly dominated by *Henryhowella* and contains accessory *Krithe*. Factor 3 is composed of several taxa clearly dominated by *Eucythere*. The factor analysis calculated with the data set of core M23352 resulted in a relatively low cummulative variance of 85 %, distributed as follows: factor 1 has a variance of 34 %, the variance of factor 2 is 28.8 %, and factor 3 has a variance of 22.1 %.

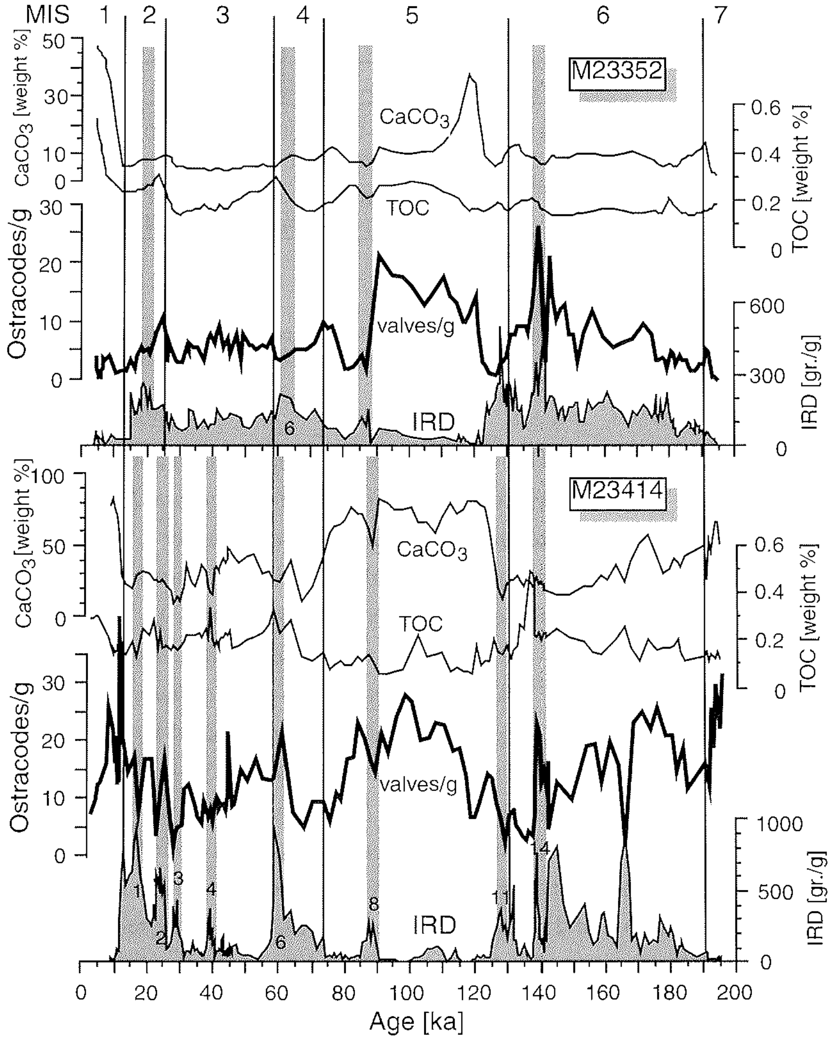

Fig. 4.7. Content of TOC and $CaCO_3$ (given in weight %) and the ostracode concentration (valves/g) versus age in ka BP. Shaded bars indicate distinct IRD layers, see text.

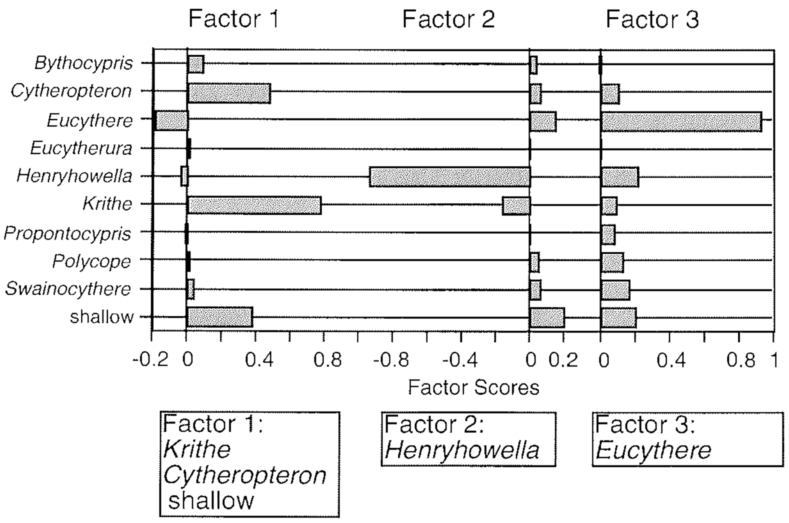

Fig. 4.8. Factor score matrix for the dataset of core M23352 (Iceland Plateau), indicating the composition of each factor. The factor score (= length of the bar) indicates the importance of each taxon in the relevant assemblage.

The large data set of core M23414 from the Rockall Plateau yielded a total of 36 taxa and groups, respectively (Fig. 4.9). Factor 1 is composed of the genera *Krithe*, *Argilloecia*, *Oxycythereis*, and accessory *Cytheropteron* and *Henryhowella*. Factor 2 contains a mixture of several taxa, none of them is dominant. Although the variables in factor 2 reveal generally low factor scores, we considered those taxa that reach factor scores > 0.2 to characterize this factor. Accordingly, factor 2 is composed of *P. trigonella, Polycope, B. victrix, B. bathytatos, Paracytherois, B. mucronalatum, Swainocythere, B. scaberrima, Pseudocythere, Ambocythere,* and *Argilloecia*. Factor 3 is dominated by *Pelecocythere* and contains several accessory taxa such as *Eucytherura, Cytherella, Nannocythere, Aversovalva, Echinocythereis, Henryhowella* and *Polycope*.

The cummulative variances of the model for core M23414 are even lower than for core M23352. The 3-factor model accounted for 58 % of the total variance. Factor 1 reveals a variance of 21.7 %, factor 2 of 21.2 %, and factor 3 of 15.5 %. These relatively low values may be caused by the large number of taxa, which are represented by only few individuals. To overcome the problem of low cummulative variance, which means that a number of samples is not explained by the model, the number of factors can be increased. However, in the case of both cores, this did not lead to significantly higher cummulative variances.

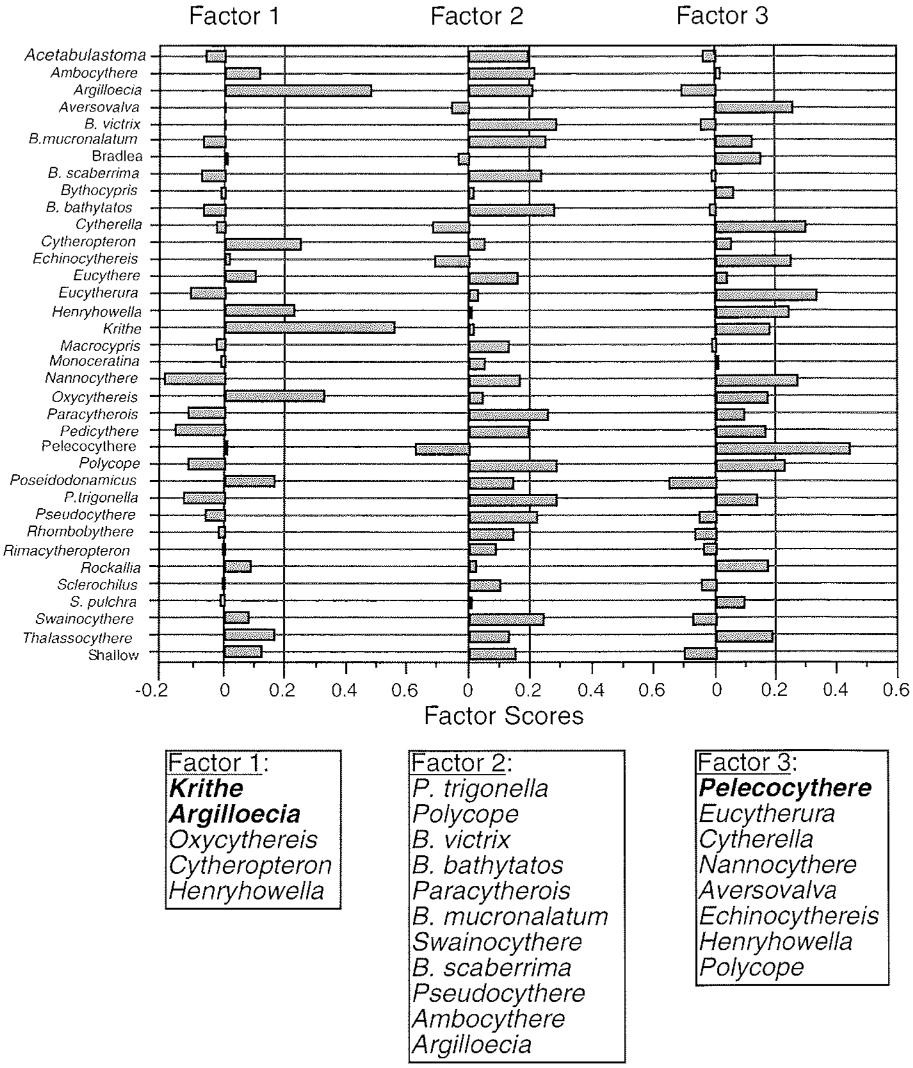

Fig. 4.9. Factor score matrix for the dataset of core M23414 (Rockall Plateau). Explanation see Fig. 8.

Figure 4.10 shows the results of the factor analyses for core M23352 versus time. Factor 1 (composed of *Krithe*, *Cytheropteron*, and the shallow-water group) reaches highest factor loadings during MIS 6, in late MIS 5, in MIS 3 and 2, whereas factor 2 (dominated by *Henryhowella*) reveals its highest factor loading during MIS 5e and the Holocene. Factor 3 (dominated by *Eucythere*) displays several peaks in MIS 6, high factor loadings during MIS 5 (between 90 and 115 ka), in MIS 4, and partly in MIS 3.

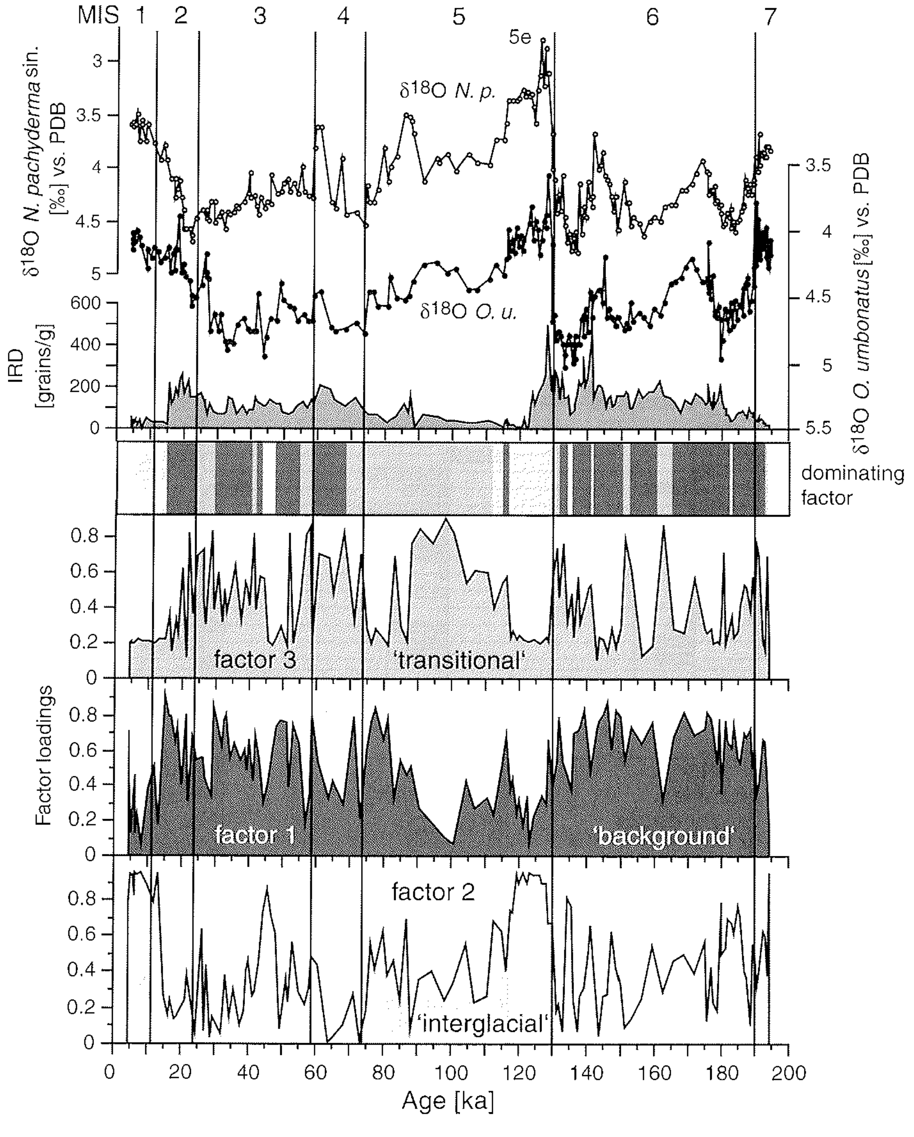

Fig. 4.10. The importance of the three factors of core M23352 (Iceland Plateau) versus time together with the benthic and planktic oxygen isotope records and the amount of IRD. The middle section summarizes the distribution of the three factors throughout the past 200 ky.

The results of the factor analysis calculated with the data set of core M23414 are shown in Figure 4.11. A clear climate-related distribution of the three factors is observed. Factor 2 (composed of a variety of taxa) displays highest factor loadings during the glacial MIS 6, 4, and 2. Factor 3 (dominated by *Pelecocythere*) clearly reveals highest factor loadings during MIS 7, 5 and 1, whereas factor 1 (dominated by *Krithe* and *Argilloecia*) is dominant when the others are of minor importance, such as during distinct periods of MIS 6 (around 170 ka), at TII, and during short periods of MIS 5 (at 100 ka, 90-95 ka, and 85-75 ka), MIS 3 (50-30 ka), and in MIS 1 (10-5 ka).

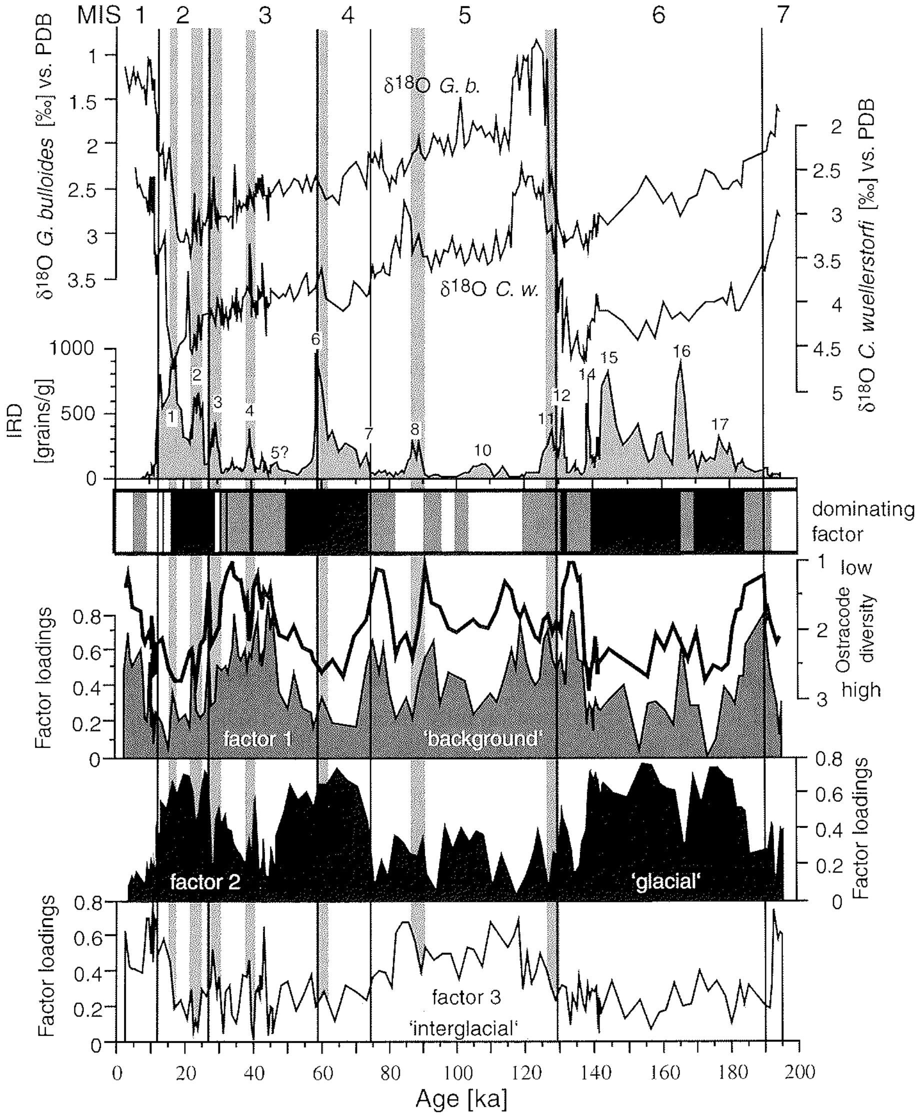

Fig. 4.11. The importance of the three factors of core M23414 (Rockall Plateau) versus time together with the foraminiferal benthic and planktic oxygen isotope records and the amount of IRD. Additionally the diversity (H') is plotted. Low diversity correlates with high factor loadings of factor 1, the 'background assemblage'. Shaded bars indicate distinct IRD layers, see text. The middle section summarizes the distribution of the three factors throughout the past 200 ky.

4.5 Discussion

4.5.1 *Ostracode faunal variations through time*

The ostracode faunas on the Rockall and on the Iceland Plateau can be subdivided into three groups according to the result of the Q-mode factor analysis, corroborating earlier observations (see Didié et al., 1999 and Didié and Bauch, 2000). According to the interglacial and interstadial dominance of the factor 3 assemblage in the Rockall core, this is referred to as 'interglacial assemblage' (Figs. 4.5 and 4.11; for details see Didié and Bauch, 2000). The most pronounced factor in the Rockall core is factor 2 that comprises the 'glacial assemblage'. This assemblage consists of a large variety of taxa, none of them dominating (Fig. 4.9). Besides the taxa belonging to the 'glacial assemblage' that were already described by Didié and Bauch (2000), the factor analysis revealed some more taxa associated with this assemblage (Fig. 4.9). Factor 1 contains several taxa (e.g., *Krithe*, *Argilloecia*, and various species belonging to the genus *Cytheropteron* that are common in most deep-sea sediments (e.g., Coles et al., 1994) (Fig. 4.9). These taxa occur on the Rockall Plateau continuously throughout the past 200 ka (Figs. 4.5 and 4.11). We therefore interpret this assemblage as 'background assemblage' that shows no obvious response to climate-induced environmental changes.

On the Iceland Plateau, the three assemblages are also related to climate change. The 'interglacial assemblage', clearly dominated by *Henryhowella*, is confined to the relatively short periods of peak interglacial times, such as MIS 5e and the Holocene. Factor 3 dominates during the main parts of MIS 5, 4 and 3, and short periods of MIS 6. Because it seems not related to either fully glacial or fully interglacial periods, it is considered as 'transitional assemblage'. The assemblage that forms factor 1, seems to be related to the glacial periods, mainly MIS 6 and 3. Because this assemblage consists of the genera *Krithe* and *Cytheropteron*, and therefore resembles the factor 1-assemblage of the Rockall core, we interpret this assemblage as well as 'background assemblage'.

4.5.2 *What controls the ostracode faunal variations?*

In both investigated cores *Henryhowella* is part of the interglacial assemblage. It also belongs to the interglacial assemblage of a core further south in the NW Atlantic (Chain 82-24, 41°43'N, 32°51'W, see Cronin et al., 1999). In that core, similar to the Rockall Plateau, also *Echinocythereis* belongs to the interglacial assemblage. Cronin et al. (1999) related these taxa to the influence of NADW during the interglacial periods, which is confirmed by our data. A study on the Iceland Plateau examined the stable oxygen isotope records of *Henryhowella* and the benthic foraminifer *Cibicidoides wuellerstorfi* and additionally the temporal distribution of both taxa (Didié and Bauch, in press). According to the similarities both taxa display in these parameters, it has been suggested that these two taxa may be related to the same environmental conditions, such as food supply, lateral advection, and bottom water oxygen content, the latter linked to the formation of deep water.

It has been shown that in the North Atlantic surface water productivity and therefore food supply to the ocean floor was higher during the interglacial than during the glacial periods (e.g., Thomas et al., 1995; van Krefeld et al., 1996; Struck, 1997, Hass et al., in press). This is confirmed by increased interglacial carbonate contents of both cores, taking the carbonate contents of deep-sea sediments as one reliable proxy for paleoproductivity (Brummer and van Eijden, 1992). We therefore conclude that the interglacial ostracode assemblages of both cores are related to a combination of environmental factors, such as food supply and the presence of NADW (affecting bottom current velocities and oxygen content). In this respect, *Henryhowella* proved to represent a valuable indicator for these conditions in the North Atlantic. *Echinocythereis* may indicate the same conditions, but its abundance is quite low and seems restricted to the low- and mid-latitude Atlantic.

The transitional assemblage found in the Iceland core appears to indicate moderate climate conditions. The dominant genus of this assemblage, *Eucythere*, shows highest abundances in late MIS 7, at the beginning of TII, during MIS 5 and 3 (Fig. 4.4). During these periods, slightly increased abundances of distinct benthic foraminiferal taxa were observed (Struck, 1997). For example *C. wuellerstorfi* shows relatively high abundances during late MIS 7 and during entire MIS 5, which indicates reasonably high food fluxes and bottom current activity. During MIS 3 when benthic foraminifers are generally rare, slightly increased abundances of taxa, that indicate moderate productivity are observed, and during MIS 4 *C. wuellerstorfi* and few specimens of *Epistominella exigua* indicate reasonably high, most likely strongly seasonal productivity (Struck, 1997). Thus, we conclude that *Eucythere,* at least in the area of the Nordic Seas, seems to be adapted to conditions of moderate, possibly seasonal phytoplankton production and food supply.

In the Rockall core, *Eucythere* never reaches more than 4 % of the total ostracode fauna (Didié and Bauch, 2000) and according to the factor analysis, it is not relevant for any of the factors (Fig. 4.9). Its occurrence mainly during the Terminations and MIS 4-3 on the Rockall Plateau may be linked to the relative low ostracode concentrations during these periods. In some Arctic Ocean cores, *Eucythere* was found in low numbers in late glacial intervals that revealed an impoverished ostracode fauna consisting mainly of *Henryhowella* and *Krithe* (Cronin et al., 1995). There, *Eucythere* is possibly related to weak surface water productivity. However, more studies are needed to fully determine the relation of *Eucythere* to the amount of food supply.

Many of the taxa belonging to the glacial assemblage of the Rockall core are also observed in the modern Arctic Ocean and on the Greenland Sea shelf (Cronin et al., 1995; Whatley et al., 1998). Particularly the Greenland Sea shelf is influenced by the high oxygen, low temperature Greenland Sea Deep Water (see Aagaard et al., 1985). These polar areas are also characterized by low surface water productivity and limited food supply due to an almost year round ice cover (e.g., Whatley et al., 1998; Andersen, 1989). We conclude that during the glacial periods on the Rockall Plateau, the influence of cold, oxygen-rich GNAIW together with decreased phytoplankton production and therefore decreased food flux caused conditions at sea floor that were comparable to the present-day conditions on the Greenland Sea shelf or the Arctic Ocean. These environmental conditions are mirrored in the glacial ostracode assemblage in core M23414.

Besides the glacial occurrence of the sea-ice indicating *Acetabulastoma arcticum* (Schornikov, 1970), the occurrence of several other paradoxostomatid taxa is noteworthy. They clearly belong to the glacial assemblage (Fig. 4.4). Many of these taxa are globally distributed and known from a variety of environments. For instance, they are found living on algae, linked to vents at the mid-Atlantic ridge or related to artificial 'wood parcels' deposited on the ocean floor (Cronin, 1981; Coles et al., 1996; van Harten, 1990; Maddocks and Steineck, 1987). Because of this variety of habitats they are considered to indicate increased nutrient availability, probably through bacteria on which they feed (Maddocks and Steineck, 1987). The glacial abundance of these taxa may point to the availability of this special kind of food during these periods. The reasons for the almost complete absence of these and most of the other glacial taxa in the entire Iceland core remain uncertain.

The abundance and temporal distribution of *Krithe* in both cores seem somewhat contradicting, since *Krithe* is more abundant during the glacial periods on the Iceland Plateau but shows higher abundances during the interglacial periods on the Rockall Plateau (see Didié and Bauch, 2000 and Fig. 4.4). Also Cronin et al. (1999) found *Krithe* more abundant during the glacial periods and considered it to be related to cold Antarctic Bottom Water and low food supply. These differences in interpretations may be explained by the relative abundance data used in these studies. Since *Krithe* is often the most abundant ostracode genus in most deep-sea sediments, high glacial relative abundances of *Krithe* simply may reflect an impoverished ostracode fauna during these periods. In the Chain core only few ostracodes were found e.g., during MIS 4, most of them *Krithe*. But taking the total numbers of *Krithe* found in this core, it is obvious that more specimens of *Krithe* occur during the interglacial sections (see Cronin et al., 1999). The same is found in the Iceland core, where *Krithe* is generally abundant, when the number of other taxa is clearly decreased during glacial periods, thus increasing the relative abundance of *Krithe*.

The endobenthic, detritus-feeding foraminifers dominating during glacial periods in the Nordic Seas were interpreted as opportunistic species that are able to survive long periods of low C_{org} flux (Altenbach, 1992) because they can feed on older organic matter, which is more difficult to digest (Graf et al., 1995; see also Jorissen et al., 1995). The endobenthic taxa present during interglacial and glacial periods are thus considered to take advantage of the absence of competitors (Altenbach, 1992; Struck, 1997). The same may be true for the ostracodes of the background assemblage, particularly *Krithe* and also *Argilloecia,* which are known as endofaunal-living taxa (Coles et al., 1994; Majoran and Agrenius, 1995; Maddocks, 1969).

As on the Iceland Plateau, *Krithe* is also the most abundant genus on the Rockall Plateau and occurs throughout the core. But here the glacial periods are characterized by conditions that were obviously still suitable for a variety of other ostracode taxa too, possibly due to the presence of well-oxygenated GNAIW. The presence of a diverse ostracode fauna decreases the relative abundance of *Krithe,* particularly, during the glacial periods. The same seems true for many taxa belonging to the common genera *Cytheropteron* and *Argilloecia,* at least in the two investigated areas. However, *Argilloecia* and *Cytheropteron* are considered to be characteristic for deglacial periods in the Chain core further south where they indicate increasing influence of NADW (Cronin et al., 1999). Despite the large data set used by us, we cannot confirm a special deglacial affinity of these two genera for the two areas studied.

4.5.3 *Ostracode faunal diversity and environmental changes*

In the past decades much progress has been made to assess biodiversity in the deep sea, but the exact processes and interactions that influence biodiversity are still under debate (see Rex et al., 1997). Diversity-controlling factors may include a number of biotic and abiotic factors such as competition, predation, food supply, disturbance of the environment, sediment diversity, and oxygen content (Rex et al., 1997; Gage, 1997; Kurbjeweit et al., 2000; Wollenburg and Kuhnt, 2000).

The two investigated cores reveal the well-known pattern of decreasing diversity from low latitudes to high latitudes that is particularly pronounced in the North Atlantic (e.g., Williamson, 1997; Rex et al., 1997). In particular, the Norwegian Sea is known for its low biodiversity, which has been related to the Quaternary glaciations (Rex et al., 1997). Investigations of the NE Atlantic shelf ostracode faunas from the Tropics to the Arctic Ocean revealed also lower diversities for the high-latitudinal fauna (Wood and Whatley, 1994). Therefore, it is not surprising that the diversity in the core from the Iceland Plateau is generally lower than in the Rockall core (Fig. 4.6). However, both cores show high diversities during most parts of the glacial periods and relatively low diversities during the interglacial and interstadial periods (Fig. 4.6). This is unexpected since in both cores the concentration of ostracodes is low during most of the glacial intervals in contrast to the interglacial intervals.

On the Rockall Plateau, the diversity of the ostracode fauna is directly linked to the presence of the three factor assemblages (Fig. 4.11). As shown in Fig. 4.9, the 'interglacial assemblage' and, particularly, the 'glacial assemblage' are composed of a variety of taxa. Therefore, high diversity is observed when one of the two specialized assemblages occurs in addition to the 'background assemblage'. Because the 'glacial assemblage' contains more taxa than the 'interglacial assemblage', diversity shows highest values when the 'glacial assemblage' reaches highest abundances.

Diversity in the Iceland core appears to be at least biased by corrosion, as indicated by the parallel trends of ODI and diversity (Fig. 4.6). Corrosion is strongest during the peak interglacial stages 5e and the Holocene. During these periods diversity reveals lowest values. According to the high carbonate contents during these periods, we may conclude that high surface water productivity led to high food fluxes to the sea floor. Decomposition of organic matter can reduce the oxygen content in the pore water while the content of CO_2 increases. This scenario may explain enhanced dissolution during peak interglacial periods.

In the Rockall core, the valves are mostly better preserved than in the Iceland core. However, some signs for corrosion can be observed during TII (Fig. 4.6). The carbonate content during this interval is low while the IRD content is high as shown in Fig. 4.7. This short period of increased corrosion may be related to a short-term influence of SSW due to the cessation of GNAIW prior to the re-initiation of NADW (see Venz et al., 1999). Since the ostracode valves are well preserved almost throughout the entire Rockall core, we suggest the diversity trends to mirror environmental conditions that directly influenced the living ostracode community.

Cronin et al. (1999) considered increased bottom water temperature to be partly responsible for increased ostracode diversity observed in the NW Atlantic. This might be also one reason for the higher glacial than interglacial diversity on the Iceland Plateau, since bottom water temperatures there could have been higher during the peak glacial and the deglacial phases when open-ocean convection was inhibited due to sea-ice cover and low-density meltwater lid (Bauch and Bauch, subm.). But for the area of the Rockall Plateau the opposite was found: the glacial bottom water temperatures (GNAIW) were about 2°C colder than the interglacial (NADW) bottom water temperatures (Bertram et al., 1995). Since ostracode diversity is significantly high during the glacial periods on the Rockall Plateau changes in bottom water temperature can be precluded as main controlling factor for ostracode diversity.

Today, the Rockall area is characterized by a high, strongly seasonal flux of phytodetritus to the sea floor (Smart et al., 1994; Smart and Gooday, 1997). Despite such high food flux a low-diverse foraminiferal fauna is observed, dominated by few fast-developing 'phytodetritus species' (Smart and Gooday, 1997). Consequently, the benthic foraminiferal diversity was higher during the last glacial than during the Holocene because the decrease in food supply prevented the development of these 'phytodetritus species', which in turn supported the development of other taxa (Thomas et al., 1995). This illustrates that high food flux does not inevitably lead to a highly diverse community. In contrast, high diversity and relatively low numbers of benthic foraminifers are described to indicate a typical open-ocean environment with a low flux of food (e.g., Sanders et al, 1965; Kaminski, 1985). A study that investigated numerous surface sediment samples from the Arctic Ocean revealed a positive correlation between C_{org} flux and diversity of benthic foraminifers in areas of relatively low C_{org} fluxes (Wollenburg and Kuhnt, 2000). In contrast, negative correlation of diversity and C_{org} flux was found by these authors in areas of higher C_{org} fluxes. Since in the two investigated areas present-day primary production is higher than in the Arctic Ocean (compare Smart and Gooday, 1997), our observation of increased diversity during times of decreased food flux is in accordance with the observation of Wollenburg and Kuhnt (2000).

4.5.4 *Ostracode diversity during IRD events*

Particularly in the Rockall core, high diversities are observed when the IRD content is increased, although the ostracode concentration is often low during these periods (marked by grey bars in Fig. 4.6). When interpreted in terms of food supply as discussed above, this would mean that food supply decreased during these IRD events. In this respect, the influence of icebergs on phytoplankton production in the surface waters has been controversely discussed. Icebergs, which were present during the Heinrich events, may have created a special environment in the surface waters characterized, e.g., by vertical mixing, upwelling in the vicinity of the icebergs and possibly enrichment of nutrients released from the melting icebergs (Sancetta, 1992 and references therein). On the other hand, a number of authors suggested that the periods of enhanced IRD input were associated with low-productivity (e.g., Broecker et al., 1992; Bond et al., 1992; Broecker, 1994; van Krefeld et al., 1996). Investigations of the benthic foraminiferal fauna in the Rockall area also point to strongly reduced productivity during the Heinrich events (Thomas et al., 1995).

The decreased carbonate content during the IRD events in the Rockall core indicates decreased productivity, which is confirmed by the results of an adjacent core (van Krefeld et al., 1996), although dilution by IRD should be kept in mind (Fig. 4.7). Whatever the exact environmental factors may be that control ostracode diversity, it seems as if during the IRD events conditions prevailed that were suitable for a number of ostracode taxa.

It has been shown that several taxa of the glacial assemblage are linked to distinct IRD events (Didié and Bauch, 2000). However, no distinct IRD-related ostracode assemblage was found (see Fig. 4.4). During the IRD events not only taxa of the glacial assemblage were observed. In many of the IRD-rich samples taxa of the glacial and the interglacial assemblages in addition to the 'background assemblage' were observed, which is reflected in the diversity peaks during these periods.

Aside from decrased food flux, the sediment heterogeneity may be one reason for increased diversity values (Etter and Grassle, 1992). However, as mentioned above, the lack of corrosion due to decreased amounts of decomposing organic matter may positively influence the Shannon-Wiener diversity (see Wollenburg and Kuhnt, 2000).

4.6 Summary and conclusion

Two sediment cores from the northern North Atlantic (Iceland Plateau and Rockall Plateau) both covering the past two climate cycles were investigated for their ostracode faunas. Q-mode factor analyses and diversity calculations were carried out in order to decipher the response of deep-sea benthic ostracodes to distinct climate modes that are characterized by certain circulation and productivity patterns. The principal results are summarized as follows:

In both cores three factor assemblages could be distinguished. On the Iceland Plateau the 'interglacial assemblage' dominated by *Henryhowella* reveals highest abundances during periods of higher surface water temperatures, high phytoplankton production, and formation of NADW. During these times, the benthic foraminifer *C. wuellerstorfi* is most abundant and some productivity-indicating benthic foraminifers occur, too. During periods of lower phytoplankton production, the 'transitional assemblage' dominated by *Eucythere* appears. During the glacial periods the 'background assemblage' is dominant, composed of the globally distributed taxa *Krithe* and *Cytheropteron*. These taxa are considered to be opportunistic, able to cope with environmental conditions that are not suitable for most other taxa.

On the Rockall Plateau the 'background assemblage' is abundant throughout the investigated interval, showing no obvious relation to climate change. In contrast, two other assemblages are clearly linked to distinct climate periods. The 'interglacial assemblage' consists of a variety of taxa; it is dominated by *Pelecocythere*. The presence of *Henryhowella* in this assemblage is noteworthy since *Henryhowella* is also present in the interglacial assemblage of a core in the NW Atlantic and clearly dominates the peak interglacial intervals also on the Iceland Plateau. Thus, *Henryhowella* appears to be a useful indicator of interglacial conditions in North Atlantic sediments. The third assemblage on the Rockall Plateau is the 'glacial assemblage' that consists of a variety of taxa including several possibly bacteria-feeding paradoxostomatid ostracodes and one sea-ice indicating species. Many of the taxa of the glacial assemblage are found in the modern Arctic Ocean and on the Greenland Sea shelf. We thus conclude that during the glacial periods the influence of cold, oxygen-rich GNAIW together with decreased phytoplankton production and decreased food flux caused conditions at the Rockall Plateau sea floor that were similar to the present-day conditions in the Greenland Sea and the Arctic Ocean.

The two cores yielded higher glacial than interglacial ostracode diversities. In both areas surface water productivity was higher during interglacial than during glacial periods, as inferred from the carbonate contents. These findings are in agreement with other studies that found decreasing diversities in benthic foraminiferal assemblages with increasing food flux. Particularly high ostracode diversities are observed during times of IRD events on the Rockall Plateau. Low carbonate values indicate low primary production during these periods, which is confirmed by other studies in the same area. On the basis of our data we conclude that increased diversity reflects decreased primary production, at least in the investigated areas. Although the exact cause for high ostracode diversity remains unclear, it appears that during the glacial periods, and particularly during the short-termed IRD events, conditions prevailed that were suitable for a variety of taxa.

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5. Summary and outlook

The ostracode fauna in two northern North Atlantic sediment cores (from the Iceland and the Rockall plateaus) was investigated in order to determine the response of ostracodes to climate-induced environmental changes. Goal of this study is to emphasize the potential of deep-sea benthic ostracode faunal and isotopic data as paleoceanographic proxies.

The two investigated cores are well dated, spanning the past two climatic cycles (MIS 7-1). In contrast to most other ostracode studies, the relatively large samples yielded large numbers of well-preserved ostracodes; roughly 100 taxa were identified. Results of faunal and isotopic investigations are summarized as follows:

- As a result of the faunal analyses, including Q-mode factor analyses, three distinct ostracode assemblages were identified in each core, that are linked to distinct climate-related environmental conditions:
  On the **Iceland Plateau**, *Henryhowella* is dominant during the peak interglacial periods (MIS 5e and 1), whereas *Eucythere* reveals increased abundances during the interstadials (MIS 5 and 3). The globally distributed taxa *Krithe* and *Cytheropteron* are generally abundant in this core and reach highest relative abundances during the glacial and stadial periods.
  On the **Rockall Plateau**, a group of ostracode taxa comprising of *Pelecocythere, Eucytherura, Cytherella, Nannocythere, Aversovalva, Echinocythereis, and Henryhowella* is clearly linked to interglacial and interstadial periods. A second group of taxa is related to the glacial climate periods. This group consists of *Polycope, P. trigonella, B. victrix, B. bathytatos, Paracytherois, B. mucronalatum, Swainocythere, B. scaberrima, Pseudocythere,* and *Ambocythere*. The third group consists mainly of the common deep-sea taxa *Krithe*, *Cytheropteron,* and *Argilloecia* and is abundant throughout the core.
- According to the preferences of these assemblages for distinct climate modes, the assemblages are labelled 'interglacial', 'transitional', 'glacial', and 'background' assemblage.
- The interglacial assemblage seems related to enhanced food supply (as inferred from increased carbonate contents during the interglacial periods) and the formation of NADW. In this respect, the abundance of *Henryhowella* is noteworthy, since this genus was already found to correlate to the flow of NADW in a core further south in the NW Atlantic (Chain 82-24 core) and is also part of the interglacial assemblages on the Rockall and the Iceland plateaus. In the Iceland core, *Henryhowella* often co-occurs with the epibenthic foraminifer *C. wuellerstorfi* and is therefore considered to be linked to similar environmental conditions, such as food supply and bottom current activity. Some other

taxa of the interglacial assemblage of the Rockall core also occur in the interglacial assemblage of the Chain-core, which supports their use as indicator taxa.

- The transitional assemblage observed in the Iceland core is dominated by *Eucythere* and seems related to interstadial periods that were characterized by slightly increased food supply as inferred from benthic foraminiferal data from the same core.

- The most pronounced assemblage is the glacial assemblage of the Rockall core. Many of the taxa that form this assemblage - several of them so far not described from this area - are clearly limited to the peak glacial periods (MIS 6, 4, and 2). The glacial assemblage consists of several taxa that are known from the modern Arctic Ocean, including a sea-ice indicating species. The occurrence of this assemblage is considered to mirror mainly the decrease in food supply during the glacial periods and the changes in deep-water circulation from an interglacial mode while NADW formation takes place to a glacial mode characterized by the formation of colder GNAIW.

- The 'background' assemblage, observed in both cores, contains mainly *Krithe* and *Cytheropteron*, taxa that are globally distributed and abundant in most deep-sea sediments. On the Rockall Plateau this assemblage shows no obvious relation to climate change, whereas it displays high relative abundances during the glacial periods on the Iceland Plateau. The taxa of this assemblage are considered opportunistic, able to survive periods of low food supply.

- Several taxa of the glacial assemblage on the Rockall Plateau also seem related to distinct short-termed events of diminished deep-water formation (= Heinrich events), characterized by increased amounts of IRD and decreased carbonate contents, the latter pointing to decreased food supply. Altogether, the glacial North Atlantic assemblage indicates environmental conditions that resemble the conditions of the modern Arctic Ocean, which is mainly characterized by strongly limited food supply.

- The ostracode fauna of the glacial periods and, particularly, of the short-termed Heinrich-events, revealed high diversities in both cores, although the ostracode concentration during these intervals was relatively low. This trend has been observed earlier in glacial-to-interglacial benthic foraminiferal assemblages in the Rockall area. The highly diverse ostracode assemblages during the glacial periods may have been related to decreased food supply and possibly also to an increase in environmental heterogeneity.

- For the first time systematic investigations on stable oxygen and carbon isotopes of deep-sea benthic ostracodes were carried out. For isotope analyses the common deep-sea taxa *Henryhowella* and *Krithe* were selected. Both taxa occurred throughout the Iceland Plateau core as well as in several surface sediment samples from the same area. For comparison, the two benthic foraminiferal species, the epifaunal-living *Cibicidoides wuellerstorfi* and the infaunal-living *Oridorsalis umbonatus,* were analyzed as well. The analyses on ostracodes and foraminifers lead to the following results:

- As observed in freshwater ostracodes, the **oxygen isotope** values of both marine ostracode taxa reveal positive offsets from equilibrium calcite. This is in contrast to the benthic foraminiferal species, that display well-known negative offsets. The calculated offset for *Krithe* is about +1.4 ‰; for *Henryhowella* an offset of about +0.4 ‰ was found.

- The downcore oxygen isotope records of *Krithe* and the infaunal-living *O. umbonatus* are parallel to each other. The similarities in isotope records and temporal distribution of both taxa suggest an infaunal habitat for *Krithe*, which is confirmed by other studies.

- The oxygen isotope record of *Henryhowella* displays a similar trend as the epifaunal-living *C. wuellerstorfi.* This is also in agreement with the faunal data and suggests an epifaunal habitat for *Henryhowella.*

- The ostracode oxygen isotopic results confirm earlier observations that revealed differences between the isotope records of epi- and infaunal-living benthic foraminiferal species from Nordic Seas glacial sediments. The process that caused these differences is controversely discussed, however, it obviously affected the infaunal taxa not to the same extent than the epifaunal taxa.

- The **carbon isotope** values of *Hernyhowella* are extremely negative, which would contradict an epifaunal habitat of *Henryhowella.* The negative isotope values and large amplitudes in the $\delta^{13}C$ record are most likely due to strong vital effects that bias the carbon isotope values of *Henryhowella.* However, the $\delta^{13}C$ record of *Henryhowella* shows a globally observed trend of low values during glacial and high values during interglacial periods. The same trend was observed in the $\delta^{13}C$ record of *O. umbonatus.* Both taxa reveal larger offsets from the isotope value of the ambient water (inferred from the $\delta^{13}C$ values of *C. wuellerstorfi*) during the glacial than during the interglacial periods. The cause remains unclear, however, both taxa record and amplify the global signal.

- The carbon isotope record of *Krithe* reveals no obvious climate-related signal. Preliminary results of isotope analyses on *Krithe* suggest that juvenile specimens tend to show lower values than adult specimens. The same was found for certain fresh-water ostracodes. This observation was related to the habitat of juvenile specimens, which are thought to live deeper in the sediment than adult specimens. The same may be true for *Krithe*.

The illustrated results clearly reveal the impact of climate-induced environmental changes on the deep-sea ostracode fauna. However, not much is known yet about the exact environmental demands of deep-sea benthic ostracodes. Studies like the one presented here contribute valuable information on habitat and behaviour of ostracodes, but for a detailed knowledge more investigations are needed. Systematic studies should involve the documantation of as many environmental parameters as possible of surface sediment samples. Particularly, the detailed comparison of benthic foraminiferal and ostracode faunal assemblages could provide important information on the factors that control deep-sea communities. To learn more about ostracodes and the processes that influence stable isotope incorporation into the valves, systematic investigations on bottom- and pore water isotope values and marine ostracodes are needed. In this respect, laboratory expriments are considered particularly valuable.

The results of the presented study clearly reveal the potential of deep-sea benthic ostracodes as paleoceanographical proxies. This is particularly stressed by the first stable isotope records derived from upper Quaternary deep-sea benthic ostracodes.

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7. Appendix

7.1 Basic information on ostracodes

7.2 Taxonomy of the observed ostracode taxa including key references and available information on distribution and ecological preferences.

7.3 Plates 1-5 show SEM photographs of the observed ostracode taxa.

7.1 Basic information on ostracodes

The Ostracoda are a subclass of small (< 2 mm) crustaceans known from the Cambrian period onwards (Moore, 1961). Ostracodes occur in all aquatic environments from the deep sea over high-saline and brackish water to freshwater lakes and streams, and even wet moss. Most of the ostracodes are benthic (approximately 95%), burrowing in or crawling on the sediment. Many are able to swim at least for some time (Athersuch et al., 1989). Ostracodes include a variety of feeding habits: there are filter-feeders, detritivores, herbivores, predacious carnivores, scavengers, and commensals. They usually bear four pairs of different appendages and up to three pairs of legs (Fig. 7.1), completely enclosed in a distinctive bivalve calcitic carapace built of low-magnesium calcite. The two valves are connected dorsally by a hinge. The valves are closed by adductor muscles attached to the valves, leaving a distinct pattern on the inner side of the valves. Hinge and muscle scars are of great taxonomic significance.

Like all crustaceans, an ostracode has to moult as many as eight times before it reaches adulthood. The carapace therefore lacks growthlines. Ostracodes have juveniles, not larvae that hatch from eggs. The juveniles usually resemble the adults but are much smaller with a reduced number of appendages, some are showing reduced ornamentation, too. Not much is known about reproduction and life cycle of deep-sea ostracodes. Some shallow-living taxa complete their life cycles in about one year, others need as long as two years. It has been shown that development of eggs and instars takes longer at low temperatures (Athersuch et al., 1989 and references herein). Roughly 8,000 living species have been described until now and there are perhaps as many as 25,000 including extant and yet undescribed species (Cohen et al., subm).

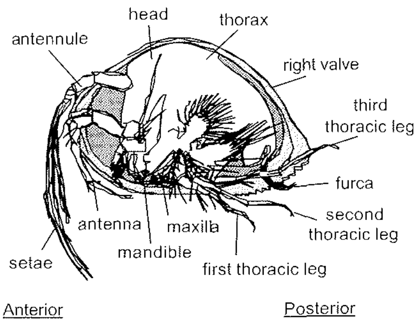

Fig. 7.1. General arrangement of appendages in a podocopid ostracode with left valve removed (from Moore, 1961).

7.2 Taxonomy

The ostracodes found in the two sediment cores from the North Atlantic were exclusively classified by the morphology of the valves in using descriptions and SEMs published in various papers. Since some confusion occurred in the published systematic classifications, the most recent references have been used. The following list contains the systematics of each genus and species found and a key reference used for the identification. Under 'remarks' notes on distribution and/or ecology when available from literature and the distribution in the two investigated cores are given.

Phylum **ARTHROPODA** Siebold and Stannius 1845
Class **CRUSTACEA** Pennant 1777
Subclass **OSTRACODA** Latreille 1806

Order **MYODOCOPIDA** Sars 1866
Suborder **CLADOCOPINA** Sars 1866
Family **POLYCOPIDAE** Sars 1866
Genus Polycope Sars 1866

Polycope arcys Joy and Clark 1977
Ref.: Joy and Clark (1977), Pl. 2, Figs. 18-21

Polycope horrida Joy and Clark 1977
Ref.: Joy and Clark (1977), Pl. 3, Figs. 5-8

Polycope punctata Sars 1870
Ref.: Joy and Clark (1977), Pl. 3, figs. 14-16
Remarks: *Polycope* is a globally found genus, occurring in the Arctic Ocean as well as in the Mediterranean and the Bahama region. It is described as good swimmer, preferring fine-grained, organic rich sediments. It reveals highest abundances and diversity in cold waters (Kornicker, 1959; Neale, 1983) and it dominates the ostracode assemblages in most Arctic Ocean sediments (Jones et al., 1998). *Polycope* has also been observed associated with diminished circulation because of its tolerance for oxygen deficient conditions (Benson et al., 1983).
In core M23352 *Polycope* sp. occurs in only few samples with not more than 8 %. In core M23414 *Polycope* (dominated by *P.* sp. cf. *P. arcys* and *P.* sp. cf. *P. punctata*) belongs to the 'glacial assemblage' showing highest abundances during the glacial stages. Maximum relative abundance of 46 % in MIS 6.

Order **PODOCOPIDA** Müller 1894
Suborder **PODOCOPINA** Sars 1866
Superfamily **CYTHERACEA** Baird 1850

Family **BYTHOCYTHERIDAE** Sars 1926
Genus Bythocythere Sars 1866

Bythocythere bathytatos Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 1, Figs. 26-31
Remarks: Found in deep-sea sediments of Late Quaternary age in the North Atlantic (Whatley and Coles, 1987).
Occurs in core M23414 with up to 3 % in MIS 6 and belongs to the 'glacial assemblage'.

Genus Bythoceratina Hornibrook 1952

Bythoceratina scaberrima (Brady) 1886
Ref.: Whatley et al. (1998), Pl. 1, Figs. 6, 7
Remarks: Found in the deep eastern Arctic Ocean (Cronin et al., 1994).
Occurs in core M23414 during the glacial stages with up to 3.8 % in MIS 6.

Genus Monoceratina Roth 1928

Monoceratina? sp.
Ref.: Whatley and Ayress (1988), Pl. 1, Fig. 1
Remarks: Occurs in some samples of core M23414 with usually <1 %.

Genus Pseudocythere Sars 1866

Pseudocythere caudata Sars 1866
Ref.: Whatley et al (1998), Pl. 1, Figs. 8, 9
Remarks: This species has been found worldwide e.g. in the Antarctic and in the deep North Atlantic. It is common in the Arctic Ocean, but also found in the Mediterranean (Joy and Clark, 1977).
Aside *P. caudata* two more, probably new, species have been found in core M23414. *Pseudocythere* belongs to the 'glacial assemblage' and occurs with up to 4 % in MIS 4 and 6.

Genus Rhombobythere Schornikov 1982

Rhombobythere sp.
Ref.: Corrège (1993), Pl. 1, Figs. 3, 4
Remarks: The specimens found in the present study resemble those found in the western Coral Sea down to 2215 m water depth (Corrège, 1993).
They occur in core M23414 during the glacial stages and reach up to 3 % in MIS 2.

Family **CYTHERIDAE** Baird 1850
Genus Cythere Müller 1785

Cythere lutea Müller 1785
Ref.: Athersuch et al. (1989), Pl. 1, Fig. 1
Remarks: Amphiatlanitc, mild temperate to subfrigid, shallow-water species, living on seaweed in the tidal zone (Cronin, 1981; Cronin et al., 1993).

This species occurs in both cores and belongs to the shallow-water taxa. It is either ice-rafted or transported with plants, on which it feeds. In usually remains <1 %.

Genus *Nannocythere* Schäfer 1953

Nannocythere sp.
Ref.: Whatley et al. (1998), Pl. 3, Figs. 9, 10
Remarks: Found in the deep North and South Atlantic (Whatley and Coles, 1987 and references herein).
In core M23414 *Nannocythere* shows affinities to the factor 3 assemblage, although seldom reaching more than 1 %. It is extremely rare in core M23352.

Family **CYTHERIDEIDAE** Sars 1925

Genus *Sarsicytheridea* Athersuch 1982

Sarsicytheridea bradii (Norman) 1865
Ref.: Athersuch et al. (1989), Pl. 3, Fig. 3
Remarks: Amphiatlantic, mild temperate-frigid (Cronin, 1981).
In core M23414 found in few samples, commonly remaining <1 %. In core M23352 found in few samples, reaching up to 1.6 % in MIS 6. Most likely ice-rafted.

Genus *Pelecocythere* Athersuch 1979

Pelecocythere sylvesterbradleyi Athersuch 1979
Ref.: Whatley and Coles (1987), Pl. 3, Fig. 2
Remarks: Common deep-water species in the eastern North Atlantic (Neale, 1988).
Pelecocythere is the major component of the 'interglacial assemblage' in core M23414; it reaches up to 3 % in MIS 5.

Genus *Heterocyprideis* Elofson 1941

Heterocyprideis sorbyana (Jones) 1857
Ref.: Cronin (1981), Pl. 2, Figs. 1-4
Remarks: Occupies a broad temperature and salinity range. Living in cold regions of the Atlantic and the Arctic Oceans (Cronin, 1981). Shallow-water species. *Heterocyprideis* belongs to the ice-rafted taxa and only few single specimens occur in both cores.

Family **CYTHERURIDAE** Müller 1894

Genus *Aversovalva* Hornibrook 1952

Aversovalva hydrodynamica Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 3, Figs. 10, 11
Remarks: Found in the Quaternary sediments of DSDP leg 94 in the North Atlantic and in sediments of the Indo-Pacific.
In core M23414 *Aversovalva* belongs to the 'interglacial assemblage' reaching highest abundances during MIS 5e and 1 (up to 4 %).

Genus *Cytheropteron* Sars 1866

Cytheropteron alatum Sars 1866
Ref.: Joy and Clark (1977), Pl. 2, Figs. 4-6
Remarks: Present in moderate to deep waters, common in the North Atlantic region (Whatley and Masson, 1979).
This species occurs in both cores. In core M23352 it belongs to factor 1, which is more abundant during the glacial stages and reaches up to 3.6 % in MIS 2. In core M23414 *C. alatum* accounts for up to 8 % in MIS 5. The *Cytheropteron* species belong to factor 1, the 'background assemblage'.

Cytheropteron arcuatum Brady, Crosskey and Robertson 1874
Ref.: Whatley and Masson (1979), Pl. 1, Fig. 4
Remarks: Common in Arctic sediments, shallow living species (Whatley and Masson, 1979).
This species is very rare in both cores and is most likely ice-rafted. In core M23352 it remains usually below 1% (maximum 1.5 % in MIS 5); in core M23414 it reaches up to 0.8 % in MIS 3.

Cytheropteron biconvexa Whatley and Masson 1979
Ref.: Whatley and Masson (1979), Pl. 3, Figs. 9, 10, 14, 15
Remarks: Probably a cold water, marine species, living at moderate depth (Whatley and Masson, 1979).
This species is very rare in both cores and may be ice-rafted. In core M23352 it has been found in 4 samples from MIS 6, not reaching more than 0.6 %. In core M23414 it was found in one sample from MIS 3 (0.8 %).

Cytheropteron branchium (Whatley and Ayress) 1988
Ref.: Whatley and Ayress (1988), Pl. 2, Figs. 2a, 2b
Remarks: Deep-water species, known from the Atlantic and Pacific oceans (Whatley and Ayress, 1988).
This species is found frequently in core M23414 reaching up to 3.4 % in MIS 6, it belongs to the 'background assemblage'.

Cytheropteron bronwynae Joy and Clark 1977
Ref.: Joy and Clark (1977), Pl. 2, Figs. 1-3
Remarks: Occurs in the central Arctic Ocean (Joy and Clark, 1977).
Few specimens of this species are found in some samples of MIS 6 in core M23352

Cytheropteron carolinae Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 2, Figs. 6, 7, 9
Remarks: Widespread in the Quaternary North Atlantic (Whatley and Coles, 1987).
This species is the most abundant *Cytheropteron* of core M23352, accounting for up to 29 % of the total ostracode fauna in MIS 2, 4 and 6.

Cytheropteron champlainum Cronin 1981
Ref.: Cronin (1981), Pl. 8, Figs. 7-8
Remarks: Amphiatlantic, frigid (Cronin, 1981).
Occurs very seldom in core M23414 (up to 1.2 % in MIS 3) and is most likely ice-rafted. Very few specimens are observed in core M23352.

Cytheropteron hamatum Sars 1869
Ref.: Whatley et al. (1998), Pl. 1, Figs. 17-19
Remarks: Deep-water species, found off the NW-coast of Europe.
This species is common in both cores (up to 9 % in MIS 3 and 5 of core M23352 and up to 6 % in MIS 5 of core M23414).

Cytheropteron inflatum Brady, Crosskey and Robertson 1874
Ref.: Cronin (1981), Pl. 7, Figs. 3, 4
Remarks: Occurs in relatively deep waters of the North Atlantic and the Arctic Ocean (Whatley and Masson, 1979).
C. inflatum occurs in some samples of both cores. In core M23352 it reaches up to 1.8 % in MIS 4 and 6; in core M23414 it accounts for up to 2.1 % in MIS 2.

Cytheropteron latissimum (Norman) 1864
Ref.: Whatley and Masson (1979), Pl. 6, Figs. 7, 9, 12
Remarks: Boreal shallow-water species, occurring off the NW coast of Europe (Whatley and Masson, 1979).
This species is very rare in core M23414 not reaching more than 0.5 %, most likely ice-rafted.

Cytheropteron lineoporosa Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 2, Figs. 11-14
Remarks: Widespread in the Late Quaternary of the North Atlantic, north of 42°N and around the Mediterranean entrance (Whatley and Coles, 1987).
C. lineoporosa is found in core M23414 not exceeding 1 %.

Cytheropteron massoni Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 2, Figs. 15-17
Remarks: Found in various DSDP sites of the North Atlantic (Whatley and Coles, 1987).
This species is found frequently in core M23414, where it accounts for up to 3 % in MIS 3.

Cytheropteron nealei Joy and Clark 1977
Ref.: Whatley et al. (1998), Pl. 1, Figs. 22, 23
Remarks: Occurs in the central Arcic Ocean (Joy and Clark, 1977).
This species is found very seldom in core M23414 not exceeding 0.7 %.

Cytheropteron nodosum Brady 1868
Ref.: Cronin and Compton-Gooding 1987, Pl. 5, Fig. 7
Remarks: Abundant in shallow and moderatly deep waters of the North Atlantic. Found also in the Greenland Sea and in the Scoresby Sund (Whatley et al., 1998).
C. nodosum occurs in some samples of both cores and accounts only for up to 1.7 % in MIS 5 in core M23352 and up to 1.3 in MIS 3 in core M23414.

Cytheropteron pherozigzag Whatley and Ayress 1988
Ref.: Whatley and Coles (1987), Pl. 2, Fig. 24
Remarks: Found in the sediments of the deep North Atlantic (Whatley and Coles, 1987).
This species is found regularly in core M23414, where it accounts for up to 4.7 % in MIS 5.

Cytheropteron porterae Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 2, Figs. 21-23
Remarks: Widespread in Late Quaternary North Atlantic deep-sea sediments (Whatley and Coles, 1987).
This species occurs in core M23414 with up to 13 % in MIS 2. In core M23352 this species is extremely rare.

Cytheropteron pseudoinflatum Whatley and Eynon 1996
Ref.: Whatley et al. (1998), Pl. 2, Figs. 7-9
Remarks: Found in the Greenland Sea between 650 and 2600 m (Whatley et al., 1998).
This species is found in core M23352, where it occurs frequently in MIS 6.

Cytheropteron pseudomontrosiense Whatley and Masson 1979
Ref.: Cronin, 1981, Pl. 6, Fig. 5
Remarks: High latitude, cold water species (Whatley and Masson, 1979).
This species is found very seldom in core M23352, and is also very rare in core M23414 (<1 %).

Cytheropteron scoresbyi Whatley and Eynon 1996
Ref.: Whatley et al. (1998), Pl. 2, Figs. 6, 10
Remarks: Cold water, deep-living marine species. Common on the Greenland Sea slope (Whatley et al., 1998).
C. scoresbyi is found in core M23352 with up to 7.6 % in MIS 6.

Cytheropteron syntomoalatum Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 2, Figs. 25-29
Remarks. Widespread and abundant in late Quaternary North Atlantic sediments (Whatley and Coles, 1987).
One of the most abundant *Cytheropteron* species in core M23414, with up to 21 % in MIS 4.

Cytheropteron tenuialatum Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 2, Figs. 30-32
Remarks: Abundant throughout the North Atlantic (Whatley and Coles, 1987).
Relatively abundant in core M23414, where it accounts for up to 11.3 % in MIS 5.

Cytheropteron testudo Sars 1869
Ref.: Whatley and Coles (1987), Pl. 3, Fig. 1
Remarks: Globally distributed, common in the deep North Atlanic and on the Greenland Sea shelf (Whatley et al., 1998).
This species occurs in both cores (up to 8.7 % in MIS 6 of core M23352 and up to 21 % in MIS 6 of core M23414).

Cytheropteron tressleri Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 3, Figs. 2, 3
Remarks: Found in North Atlantic, western Pacific and eastern Indian Ocean deep-sea sediments (Whatley and Coles, 1987).
This species is found in some samples of core M23414 and reaches up to 6.8 % in MIS 2.

Genus Eucytherura Müller 1894

Eucytherura calabra (Colalongo and Pasini) 1980
Ref.: Whatley and Coles (1987), Pl. 3, Figs. 14-16
Remarks: Widespread in deep-sea sediments of the world's oceans.

Eucytherura sp.
Whatley and Coles (1987), Pl. 3, Fig. 19
Remarks: Found in the sediments of the North Atlantic (Whatley and Coles, 1987). Some confusion about taxonomy occurs in literature. However, similar specimens found at the Florida-Hattaras Slope (Cronin, 1983; Pl. VI, Fig. A, named ?*Tuberculocythere* sp.), and in the Mediterranean (Malz and Jellinek, 1994; Pl. 7, Figs. 37-40, named *Parahemmingwayella tetrapteron*). The genus has recently renamed by Aiello et al. (2000).
The *Eucytherura* species belong to the 'interglacial assemblage' of core M23414 and account for up to 1.4 % in MIS 5. In core M23352 in only one sample a specimen was found.

Genus *Hemicytherura* Elofson, 1941
Hemicytherura clathrata (Sars) 1866
Ref.: Coles et al. (1996), Pl.2, Fig. 9
Remarks: A common shallow-water ostracode, found off the coasts of Europe and North America (e.g. Cronin, 1981; Coles et al., 1996).
Single specimens are found in core M23352.

Genus Pedicythere Eagar 1965
Pedicythere polita Colalongo and Pasini 1980
Ref.: Whatley and Coles (1987), Pl. 4, Fig. 3
Remarks: Recorded from the deep sea sediments of the SW Pacific and the Indian Ocean, also present in the Mediterranean and the North Atlantic (Whatley and Coles, 1987).
Pedicythere was found in core M23414 to account up to 2.3 % in MIS 1.

Genus *Rimacytheropteron* Whatley and Coles 1987
Rimacytheropteron longipunctata (Breman) 1976
Ref.: Whatley and Coles (1987), Pl. 3, Figs. 12, 13.
Remarks: Found in the deep North Atlantic (Whatley and Coles, 1987).
This species was found in several samples of core M23414, not exceeding 1.5 %.

Genus *Semicytherura* Wagner 1957
Semicytherura complanata (Brady, Crosskey and Robertson) 1874

Ref.: Brouwers et al. (1991), Pl. 3, Fig. 3
Remarks: Found off the eastern Canadian coast as part of a cold water, Arctic ostracode fauna (Cronin, 1989).
Several *Semicytherura* species were found in some samples of both cores and are most likely ice-rafted. In core M23352 they reach up to 2.6 % in MIS 2; in core M23414 they account for up to 1.4 % in MIS 5.

Semicytherura pulchra (Coles and Whatley) 1989
Ref.: Ayress and Corrège (1992), Pl. 19. Figs. 1a, b
Remarks: Found in late Miocene sediments of Sicily as well as in late Oligocene to Recent of the North Atlantic, and the Quaternary of the E Indian Ocean and SW Pacific (Ayress and Corrège, 1992).
This species was found only in core M23414 and accounts for up to 2.3 % in MIS 5.

Genus *Swainocythere* Ishizaki 1981
Swainocythere nanseni (Joy and Clark) 1981
Ref.: Corrège et al. (1992), Pl. 19, Figs. 2a, b
Remarks: Found in the deep Arctic Ocean (Joy and Clark, 1981) as well as around Australia (Corrège et al., 1992).
Some *Swainocythere* species were found in core M23414 with up to 5% in MIS 6. *Swainocythere* belongs to the 'glacial assemblage' in this core. In core M23352 *Swainocythere* was found in several samples of MIS 5 and 4 (with up to 4.7 %).

Family **EUCYTHERIDAE** Puri 1954
Genus Eucythere Brady 1868
Eucythere argus (Sars) 1866
Ref.: Cronin (1981), Pl. 4, Figs. 3, 4
Remarks: Amphiatlantic, warm temperate-subfrigid (Cronin, 1981). Common in core M23352, where it is the dominant species of the 'transitional assemblage'.

Eucythere multipunctata Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 4, Figs. 12-14
Remarks: Global distribution (e.g. found in DSDP leg 94 in the North Atlantic and on the Queensland Plateau, S.W. Pacific).

Eucythere pubera Bonaduce, Ciampo and Masoli, 1976
Ref.: Whatley and Coles (1987), Pl. 4, Fig. 15
Remarks: Known from the North Atlantic, the Mediterranean and the Indian Ocean (see Whatley and Ayress, 1988).

Eucythere triangula Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 4, Figs. 16-18
Remarks: Found in Late Quaternary and Pliocene sediments from the (boreal) North Atlantic (Whatley and Coles, 1987).
Eucythere species were found frequently in core M23414 (with up to 4.3 % in MIS 5). In core M23352 this genus is the main component of factor 3, the 'transitional assemblage'. In this core this genus accounts for up to 15 % in MIS 3.

Family **HEMICYTHERIDAE** Puri 1953

According to (Reimnitz et al., 1992, 1993; Jones et al., 1998) the following genera of the Hemicytheridae are shallow-water taxa. They occur in very low numbers in some of the investigated samples of both cores (mostly in the glacial core sections) and are considered ice-rafted.

Genus *Elofsonella* Pokorny 1955
Elofsonella concinna (Jones) 1856
Ref.: Athersuch et al. (1989), Pl. 5, Fig. 3
Remarks: Amphiatlantic, cold temperate to frigid (Cronin, 1981).

Genus *Finmarchinella* Swain 1963
Finmarchinella finmarchica (Sars) 1865
Ref.: Cronin (1991), Pl. 14, Figs. 9, 12
Remarks: Widely distributed in the northern seas (Neale and Howe, 1975).

Genus *Hemicythere* Sars 1925
Hemicythere villosa (Sars) 1866
Ref.: Athersuch et al. (1989), Pl. 4, Fig. 8
Remarks: Amphiatlantic species, found around the Arctic coasts (Alaska as well as Sibiria) (Cronin et al., 1993).

Hemicythere rubida (Brady) 1868
Ref.: Athersuch et al. (1989), Pl. 4, Fig. 9
Remarks: Similar distribution as *H. villosa*.

Genus *Normanicythere* Neale 1957
Normanicythere leioderma (Norman) 1869
Ref.: Neale and Howe, 1975, Pl. 3, Figs. 9, 10
Remarks: Amphiatlantic, cold temperate to frigid (Cronin, 1981).
Only few specimen are found in core M23352 in MIS 6.

Genus *Rabilimis* Hazel 1967
Rabilimis mirabilis Brady 1968
Ref.: Whatley et al. (1998), Pl. 3, Fig. 17

Remarks: Widespread in the Arctic Ocean (Hartmann, 1993) and found in the Greenland Sea only in 274 m waterdepth (Whatley et al., 1998).

Family **KRITHIDAE** Mandelstam 1960
Genus Krithe Brady, Crosskey and Robertson 1874
Krithe aequabilis Ciampo 1986
Ref.: van Harten (1996), Fig. 3 i

Krithe ayressi Coles, Whatley and Moguilevsky 1994
Ref.: van Harten (1996), Fig.3 c

Krithe dolichodeira van den Bold 1946
Ref.: van Harten (1996), Fig. 3 l

Krithe glacialis Brady, Crosskey and Robertson 1874
Ref.: Whatley et al. (1998), Fig. 7, figs. 1-4

Krithe minima Coles, Whatley and Moguilevsky 1994
Ref.: van Harten (1996), Fig. 3 f

Krithe morkhoveni van den Bold 1960
Ref.: van Harten (1996), Fig. 3 b

Krithe pernoides (Bornemann) 1855
Ref.: van Harten (1996), Fig. 3 g

Krithe trinidadensis van den Bold 1958
Ref.: van Harten (1996), Fig. 3 a
Remarks: The genus *Krithe* is generally an abundant, cosmopolitan taxon. It is adapted to an infaunal mode of life and supposed to be confined to fully marine waters with salinities >35 ‰. *Krithe* occupies a wide depth range and is the most abundant genus in deep-sea ostracode assemblages >1000 m water depth (Coles et al., 1994).
Because of the lacking internal features (vestibulum) it is not possible to identify the juvenile specimens of *Krithe* to the species level.
Among the adult valves of core M23352 mainly *K. glacialis* is found, whereas the most adult valves found in core M23414 belong to *K. trinidadensis*. In both cores *Krithe* is very abundant throughout the investigated core sections. In core M23352 it reaches up to 75 %; in core M23414 it accounts for up to 80 % of the total fauna.

Family **LOXOCONCHIDAE** Sars 1925
Genus Roundstonia Neale 1973
Roundstonia globulifera (Brady) 1868
Ref.: Whatley and Coles (1987), Pl. 4, Fig. 27
Remarks: Common in many high-latitude Pleistocene deposits (Cronin 1981).
This species is found in very few samples of both cores and belongs to the ice-rafted taxa, remaining <1 %.

Genus Cytheromorpha Hirschmann 1909
Cytheromorpha macchesneyi (Brady and Crosskey) 1871
Ref.: Neale and Howe (1975), Pl. 3, Figs. 5, 6
Remarks: Common shallow-water ostracode of the coasts of northern Europe and Alska (Cronin, 1981; Brouwers et al., 2000). Very few specimens are found in core M23352.

Family **PARADOXOSTOMATIDAE** Brady and Norman 1889
Genus Acetabulastoma Schornikov 1970
Acetabulastoma arcticum (Schornikov) 1970
Ref.: Joy and Clark (1977), Pl. 2, Figs. 7-9
Remarks: Living as parasite on amphipods that live under sea-ice. It is described from Arctic Ocean sediments (Joy and Clark, 1977; Cronin et al., 1994).
This species is found in several samples exclusively from the glacial stages of core M23414. It therefore belongs to the 'glacial assemblage' in this core. In core M23352 this species is not observed.

Genus Paracytherois Müller 1894
Paracytherois flexuosum (Brady) 1867 sensu Sars 1928
Ref.: Whatley et al (1998), Pl. 3, Fig. 15
Remarks: Found e.g. in the Adriatic Sea (Bonaduce et al., 1975) and on the Greenland Sea shelf (Whatley et al., 1998).

Genus Paradoxostoma Fischer 1855
Paradoxostoma simile Müller 1894
Ref.: Bonaduce et al. (1975), Pl. 71, Figs. 10, 11
Remarks: Found in the Adriac Sea, where it shows no relationship to water depth or substrate (Bonaduce et al., 1975).

Genus Sclerochilus Sars 1866
Sclerochilus contortus (Norman) 1862
Ref.: Coles et al. (1996), Pl. 2, Figs. 5, 6
Remarks: Amphiatlanic, cold temperate to frigid (Cronin 1981). This species has been widely reported from North Atlantic and Arctic waters at depth of 5-80 m on algae.

Coles et al. (1996) found specimens belonging to the genera *Paracytherois*, *Paradoxostoma*, and *Sclerochilus*, that are typically shallow-water species, at moderate depth in the

Procupine Basin connected with carbonate mounds and van Harten (1993) recorded them in connection with vents at the Mid-Atlentic ridge in depths >2200 m. Maddocks and Steineck (1987) found them attached to "wood parcels" brought to the deep sea. Accordingly these genera may indicate increased nutrient availability, probably through bacteria they feed on.

In core M23414 these species belong to the 'glacial assemblage'. In core M23352 only 2 specimens of these taxa are observed.

Family **ROCKALLIIDAE** Whatley et al. 1982

Genus *Rockallia* Whatley, Frame and Whittaker 1978

Rockallia enigmatica Whatley, Frame and Whittaker 1978

Ref.: Whatley and Coles (1987), Pl. 2, Figs. 3, 4

Remarks: An bathyal and abyssal species found in the North Atlantic (Whatley et al., 1982).

This species occurs regularly in core M23414 (with up to 5.7 % in MIS 4).

Family **SCHIZOCYTHERIDAE** Howe 1961

Genus *Palmenella* Hirscbmann 1916

Palmenella limicola (Norman) 1965

Ref.: Cronin (1981), Pl. 11, Figs. 1, 2, 4

Remarks: Amphiatlanic, cold temperate to frigid, also known from Alaska (Cronin, 1981).

This species is extremely rare in core M23352 and most likely ice-rafted.

Family **THAEROCYTHERIDAE** Hazel 1967

Genus *Bradleya* Hornibrook 1952

Bradleya dictyon (Brady)1880

Ref.: Whatley and Coles (1987), Pl. 6, Figs. 8, 9

Remarks: This species is known from the deep waters of the entire Atlantic Ocean (Guernet and Fourcade, 1988).

Bradleya is found almost exclusively in MIS 5 of core M23414 (with up to 13.4 %).

Genus *Thaerocythere* Hazel 1967

Thaerocythere sp.

Ref.: Cronin (1991), Pl. 10, Fig. 13

Remarks: This genus is found at the North Atlantic coasts (Cronin et al., 1993).

This species is extremely rare in core M23414, one specimen was found in a sample of MIS 2. This is most likely ice-rafted.

Family **TRACHYLEBERIDIDAE** Sylvester-Bradley 1948

Genus *Ambocythere* van den Bold 1957

Ambocythere ramosa van den Bold 1965

Ref.: Whatley and Coles (1987), Pl. 6, Figs. 4, 5

Remarks: Found in North Atlantic deep waters (e.g. Whatley and Coles, 1987).

Ambocythere is frequently found in core M23414 and accounts for up to 3.5 % in MIS 5.

Genus *Bosquetina* Keij 1957

Bosquetina mucronalatum (Brady) 1880

Ref.: Whatley and Coles (1987), Pl. 5, Figs. 1, 2

Remarks: Found in the entire Atlanic within the depth of the NADW (Dingle and Lord, 1990).

Belongs to the 'glacial assemblage' of core M23414 and reaches up to 3.5 % in MIS 3.

Genus *Echinocythereis* Puri 1954

Echinocythereis echinata (Sars)1866

Ref.: Whatley and Coles (1987), Pl. 5, Figs. 7, 8

Remarks: This species lives in the cold, deep Atlantic Ocean (Guernet and Fourcade, 1988).

Although not abundant, one of the clearly interglacial taxa of core M23414., only reaching up to 1. 3 % in MIS 5.

Genus *Henryhowella* Puri 1957

Remarks: *Henryhowella* is a widespread globally distributed genus, that seems not correlated with water depth, salinity, temperature, and dissolved oxygen (Bonaduce et al., 1998). There is some confusion about species level taxonomy (see Bonaduce et al., 1998 and Dingle and Lord, 1990). In the presented study the taxonomy of Whatley and Coles (1987) is used.

Henryhowella asperrima (Reuss)1850

Ref.: Whatley and Coles (1987), Pl. 5, 9-11

Henryhowella dasyderma (Brady) 1880

Ref.: Whatley and Coles (1987), Pl. 5, Figs. 12, 13

H. dasyderma is the dominant *Henryhowella* species in both cores. *Henryhowella* shows highest abundances during the interglacial stages. In core M23352 it accounts up to 100% in some ostracode barren samples of MIS 5e and 1. In core M23414 *Henryhowella* is most abundant in MIS 1 with up to 15 %.

Genus "Oxycythereis" Benson 1974
= Pennyella Neale 1974
"Oxycythereis" dorsoserrata (Brady) 1880
Ref.: Whatley and Coles (1987) Pl. 5, Figs. 14-17

"Oxycythereis" horridus Whatley and Coles 1987
Ref.: Whatley and Coles (1987), Pl. 5, Figs. 18-22
Remarks: Common deep-water genus, globally distributed (Whatley and Coles, 1987; Coles and Whatley, 1989).
Oxycythereis occurs in many samples of core M23414 with up to 10 % in MIS 3 and 6. It belongs to the 'background assemblage'.

Genus Poseidonamicus Benson 1972
Poseidonamicus major Benson 1972
Ref.: Whatley and Coles (1987), Pl. 6, Fig. 11
Remarks: A widely distributed and abundant deep-sea ostracod (e.g. Whatley and Coles, 1987; Dingle and Lord, 1990).
This species accounts for up to 9 % in MIS 5 of core M23414 and is found frequently throughout the core.

Genus Robertsonites Swain 1963
Robertsonites tuberculatus (Sars) 1865
Ref.: Neale and Howe (1975) Pl. 2, Figs. 1-3
Remarks: Abundant in Arctic Ocean sediments, amphiatlantic, mild temperate-frigid (Cronin 1981). Well-known component of shallow water boreal and Arctic faunas (Neale and Howe, 1975).
Belongs to the ice-rafted taxa, that are found in both cores in some samples.

Genus "Thalassocythere" Benson 1977
= Legimocythere Coles and Whatley 1989
"Thalassocythere" acanthoderma (Brady) 1880
Ref.: Whatley and Coles (1987), Pl. 6, Figs. 1, 2
Remarks: A characteristic component of deep water ostracod faunas throughout the world's oceans, but has never been recovered further north than 61°N (Coles and Whatley, 1989).
This species is frequently found in core M23414 with up to 7.5 % in MIS 6.

Superfamily BAIRDIACEA

Family **BAIRDIIDAE** Sars 1866
Genus Bairdoppilata Coryell, Sample and Fields 1935
Bairdoppilata victrix (Brady) 1954
Ref.: Whatley and Coles (1987), Pl. 1, Figs. 1, 2
Remarks: Found in the deep waters of the North Atlantic (Whatley and Coles, 1987).
B. victrix belongs to the 'glacial assemblage' of core M23414 and reaches up to 2.5 % in MIS 6.

Family **BYTHOCYPRIDIDAE** Maddocks 1969
Genus Bythocypris Brady 1880
Bythocypris sp.
Ref.: Cronin (1983), Pl. 2, Figs. E-H
Remarks: Widely distributed deep-sea ostracod, found e.g. in the eastern North Atlantic, and the Florida-Hattaras Slope (Whatley and Coles, 1987; Cronin, 1983).
Specimens of this genus are found in some samples of both cores. In core M23352 it is abundant during a short period from late MIS 3 to MIS 2, where it accounts for up to 30 %. In core M23414 it is rare, not exceeding 1 %.

Superfamily CYPRIDACEA

Family **MACROCYPRIDIDAE** Müller 1912
Genus Macrocypris Brady 1868
Ref.: Whatley and Coles (1987), Pl. 1, Fig. 7
Remarks: Widespread in bathyal and abyssal depths of the world's oceans (Maddocks, 1977).
Specimens of *Macrocypris* are found in some samples of core M23414, where it accounts for up to 3.4 % in MIS 6.

Family **PONTOCYPRIDIDAE** Müller 1894
Genus Argilloecia Sars 1866
Ref.: Whatley and Coles (1987), Pl. 1, Figs. 11-22
Remarks: Often abundant and highly diverse in the deep-sea sediments of the world's oceans (e.g. Whatley and Coles, 1987). *Argilloecia* is supposed to burrow in the sediment (Maddocks, 1969). Because particularly juveniles are difficult to identify to the species level, these specimens were grouped under the genus name.
Argilloecia is one of the most abundant taxa of core M23414, where it belongs to the 'background assemblage' and reaches up to 20 % in MIS 7.

Genus Pontocypris Sars 1866
Ref.: Bonaduce et al. (1975), Pl. 9, Figs. 1, 2
Remarks: Pontocypris is described as quick swimmer and e.g. found in the shallow-water environments of the Indian Ocean (Maddocks, 1969).
This taxon is extremely rare in core M23414.

Genus Propontocypris Sylvester-Bradley 1947

Propontocypris trigonella (Sars)

Ref.: Whatley et al. (1998), Pl. 1, Figs. 4, 5

Remarks: Almost all species are quick swimmers. *Propontocypris* is e.g. characteristic of shallow-water environments in the Indian Ocean (Maddocks, 1969). It is supposed to feed on decaying plant and animal tissue, external mucus secretions, bacterial slime or fecal pellets (Maddocks and Steineck, 1987).

This species belongs to the 'glacial assemblage' of core M23414 and reaches up to 5.8 % in MIS 4.

Suborder **PLATYCOPINA** Sars 1866
Superfamily **CYTHERELLACEA**
Family **CYTHERELLIDAE** Sars 1866
Genus Cytherella Jones 1849

Cytherella serratula (Brady) 1880

Ref.: Whatley and Coles (1987), Pl. 6, Figs. 30, 31

Remarks: An Atlantic genus, not described from the northern North Atlantic (e.g. the Nordic Seas). This genus is common in Caribbean sediments from the Eocene and Oligocene (van den Bold, 1960). *Cytherella* is a filter-feeder (Whatley, 1992).

In core M23414 *Cytherella* clearly belongs to the 'interglacial assemblage', although it shows very low abundances not exceeding 0.9 % of the total ostracode fauna. In core M23352 only one specimen of *Cytherella* is found in MIS 5.

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7.3 Plates

PLATE 1

All figures are external lateral views except where stated, the white bar scale equals 100 μm. LV= left valve, RV= right valve; all specimens are from core M23414.

Figs. 1, 2: *Henryhowella* sp. cf. *H. dasyderma* (Brady)
  1. LV, male, 225 cm, MIS 3
  2. LV, female, 320 cm, MIS 3
Fig. 3: *Echinocythereis echinata* (Sars), LV, 100 cm, MIS 3
Fig. 4: *Bradleya dictyon* (Brady), RV, 320 cm, MIS 5
Fig. 5: *Cytherella serratula* (Brady), RV, 320 cm, MIS 5
Fig. 6: *Cytherella* sp. 1, LV, 650 cm, MIS 7
Fig. 7: *Cytherella* sp. 2, RV, 20 cm, MIS 1
Fig. 8: *Pelecocythere sylvesterbradleyi* Athersuch, LV, 165 cm, MIS 3
Figs. 9,10: *Eucytherura calabra* (Colalongo and Passini)
  9. LV, 650 cm, MIS 7
  10. LV, 15 cm, MIS 1
Fig. 11: Eucytherura sp. LV, 20 cm, MIS 1
Fig. 12: *Aversovalva* sp. cf. *A. hydrodynamica* Whatley and Coles, RV, 650 cm, MIS 7
Figs. 13-15: *Acetabulastoma arcticum* (Schornikov)
  13. LV, 260 cm, MIS 4
  14. internal view, LV, 530 cm, MIS 6
  14.b muscle scars, LV; "
  15. ventral view, RV, 590 cm, MIS 6, arrow indicates anterior direction
Figs. 16-18: *?Pseudocythere* sp.1
  16. RV, 65 cm, MIS 2
  17. RV, 260 cm, MIS 4
  18. internal view, LV, 545 cm, MIS 6
  18.b muscle scars, LV, "
Fig. 19: *?Pseudocythere* sp.2
  19. LV, 265 cm, MIS 4
  19.b muscle scars, internal view, LV, 70 cm, MIS 2
Fig. 20: *Pseudocythere caudata* Sars, LV, 70 cm, MIS 1
Figs. 21, 23-25: *?Rhombobythere* (Schornikov)
  21. *?Rhombobythere* sp.1, LV, 55 cm, MIS 2
  23. *?Rhombobythere* sp.2, RV, 70 cm, MIS 2
  24. *?Rhombobythere* sp.2, LV, 60 cm, MIS 2
  25. *?Rhombobythere* sp.3, LV, 545 cm, MIS 6
Fig. 22: *Polycope* sp. cf. *P. punctata* Sars, 270 cm, MIS 4
Fig. 26: *Polycope* sp. cf. *P. horrida* Joy and Clark, RV, 265 cm, MIS 4
Fig. 27: *Polycope* sp., 90 cm, MIS 2
Fig. 28: *Polycope* sp. cf. *P. arcys* Joy and Clark, 265 cm, MIS 4
Fig. 29: *Bythoceratina scaberrima* (Brady), RV, 90 cm, MIS 2

PLATE 1

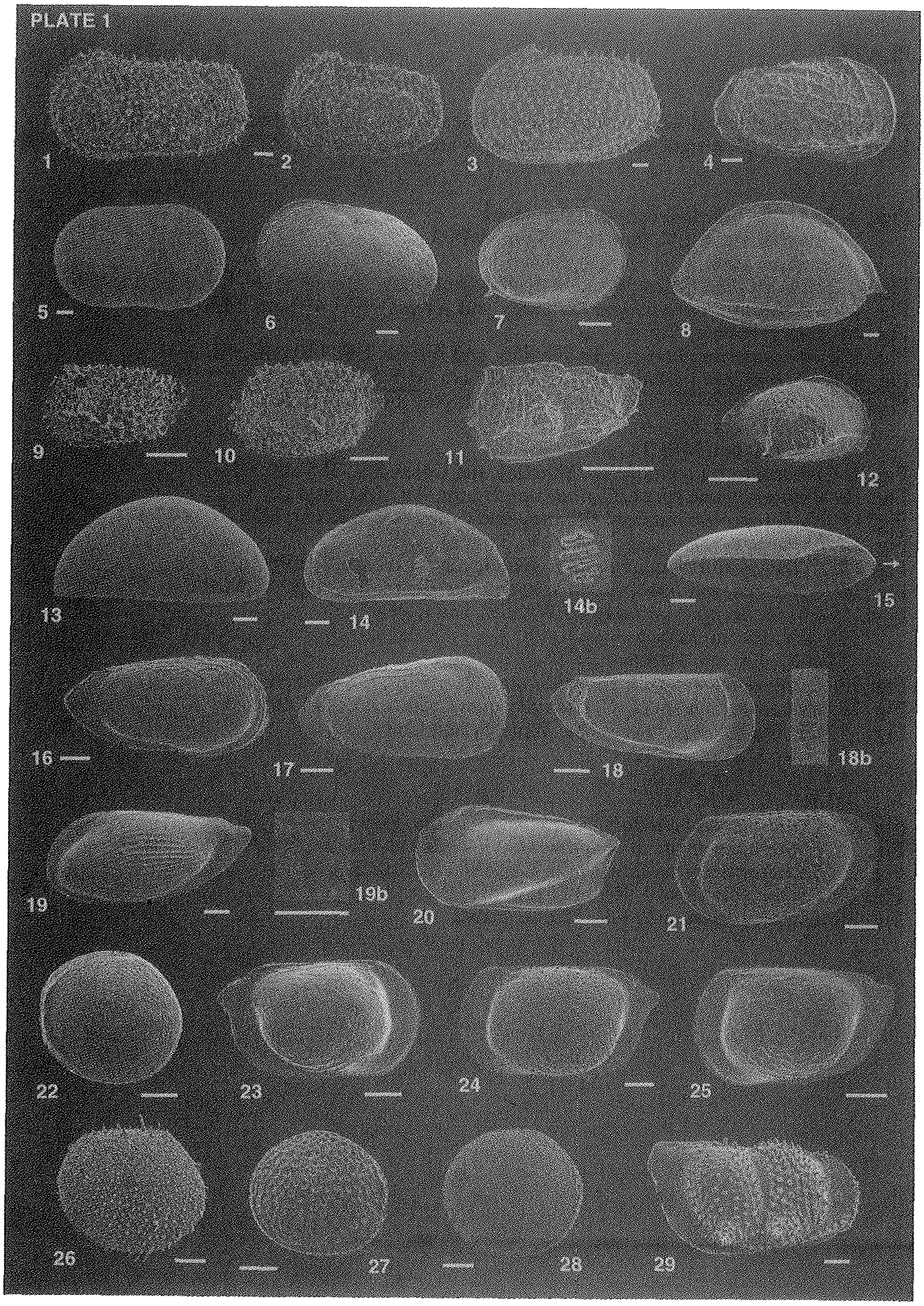
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PLATE 2

All figures are external lateral views except where stated, the white bar scale equals 100 μm. LV= left valve, RV= right valve; all specimens are from core M23414.

Figs. 1-2: *Krithe trinidadensis* Van den Bold
  1. internal view, LV, female, 335 cm, MIS 5
  2. internal view, RV, 335 cm, MIS 5
Fig. 3: *Krithe minima* Coles, Whatley and Moguilevsky, internal view, LV, 345 cm, MIS 5
Fig. 4: *Cytheropteron branchium* (Whatley and Ayress), RV, 495 cm, MIS 6
Fig. 4b: enlargement of Fig. 4
Fig. 5: *Cytheropteron pherozigzag* Whatley and Ayress, LV, 140 cm, MIS 3
Fig. 6: *Cytheropteron alatum* (Sars), RV, 315 cm, MIS 5
Figs. 7-8: *Cytheropteron arcuatum* Brady, Crosskey and Robertson
  7. RV, 515 cm, MIS 6
  8. LV, 120 cm, MIS 3
Fig. 9: *Cytheropteron tenuialatum* Whatley and Coles, LV, 355 cm, MIS 5
Fig. 10: *Cytheropteron* sp. cf. *C. nodosum* Brady, RV, 100 cm, MIS 3
Fig. 11: *Cytheropteron massoni* Whatley and Coles, RV, 620 cm, MIS 6
Fig. 12: *Cytheropteron testudo* Sars, LV, 315 cm, MIS 5
Fig. 13: *Cytheroteron syntomoalatum* Whatley and Coles, LV, 130 cm, MIS 3
Fig. 14: *Cytheropteron lineoporosa* Whatley and Coles, RV, 495 cm, MIS 6
Figs. 15-16: *Cytheropteron tressleri* Whatley and Coles
  15. RV, 60 cm, MIS 2
  16. LV, 490 cm, MIS 6
Fig. 17: *Cytheropteron* sp. cf. *C. latissimum* (Norman), LV, 440 cm, MIS 6
Fig. 18: *Cytheropteron* sp. cf. *C. champlainum* Cronin, LV, 115 cm, MIS 3
Figs. 19-21: *Cytheropteron porterae* Whatley and Coles
  19. LV, 325 cm, MIS 5
  20. LV, 235 cm, MIS 3
  21.RV, 650 CM, MIS 7
Fig. 22: *Cytherpteron hamatum* (Sars), RV, 410 cm, MIS 5
Fig. 23: *Cytheropteron* sp. cf. *C. carolinae* Whatley and Coles, RV, 275 cm, MIS 4
Fig. 24: *Cytheropteron nealei* Cronin, LV, 180 cm, MIS 3
Fig. 25: *Cytheropteron* sp.1, RV, 111 cm, MIS 3
Fig. 26: *Cytheropteron* sp.2, RV, 70 cm, MIS 2

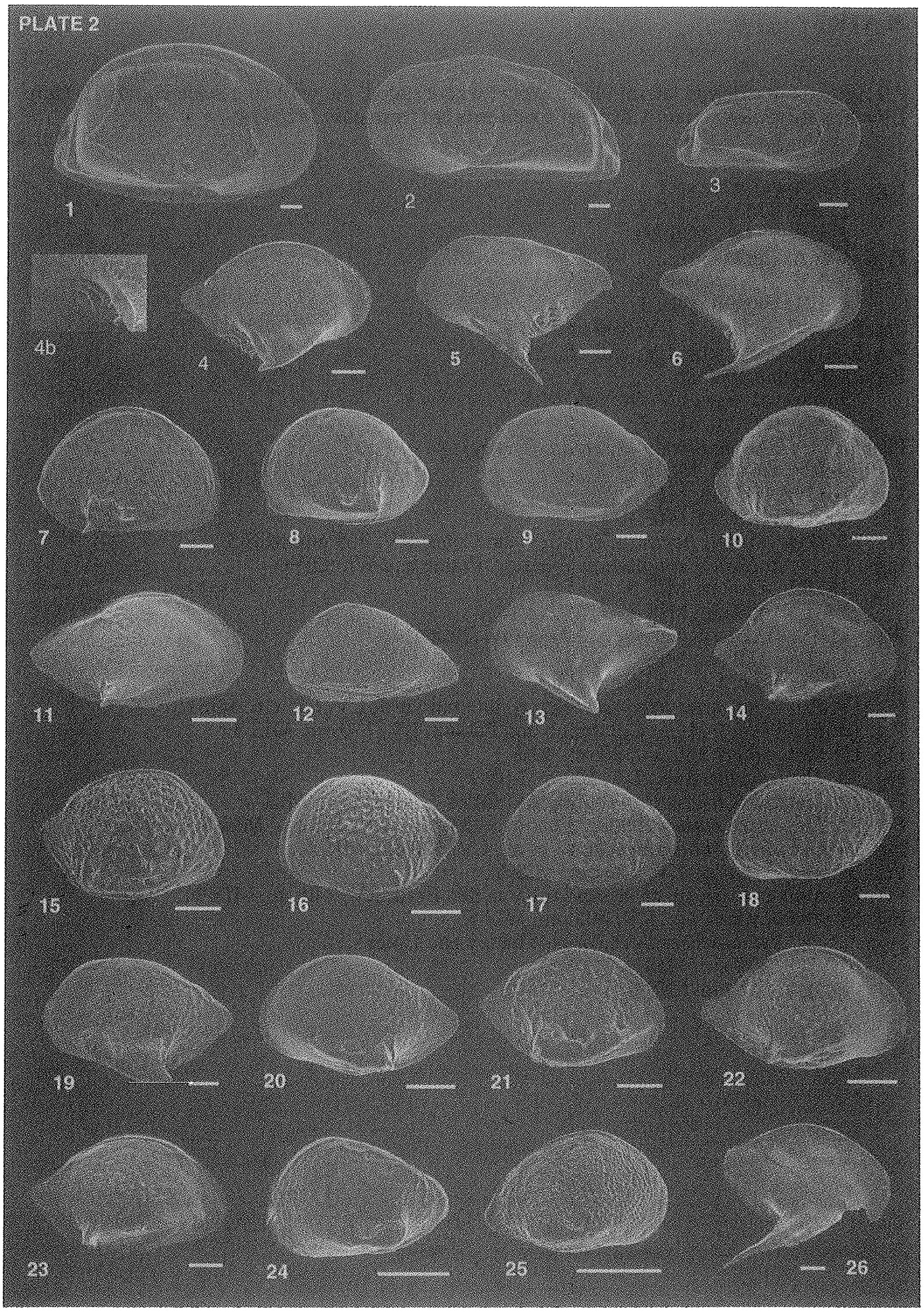

PLATE 2

PLATE 3

All figures are external lateral views except where stated, the white bar scale equals 100 µm. LV= left valve, RV= right valve; all specimens are from core M23414.

Figs. 1-2: *Argilloecia* sp.1
  1. RV, 235 cm, MIS 3
  2. LV, 45 cm, MIS 2/1
Figs. 3-4: Argilloecia sp.2
  3. RV, 235 cm, MIS 3
  4. LV, 190 cm, MIS 3
Fig. 5. *Argilloecia* sp.3, LV, 190 cm, MIS 3
Fig. 6. *Argilloecia* sp.4, LV, 650 cm, MIS 7
Figs. 7-8 *Bythocypris* sp.
  7. internal view, LV, 645 cm, MIS 7
  8. LV, 650 cm, MIS 7
Figs. 9-11: *Oxycythereis dorsoserrata* (Brady)
  9. RV, 130 cm, MIS 3
  10. LV, 390 cm, MIS 5
  11. LV, 130 cm, MIS 3
Fig. 12: *Oxycythereis horridus* Whatley and Coles, RV, 365 cm, MIS 5
Figs. 13-14: *Rockallia enigmatica* Whatley, Frame and Whittaker
  13. RV, 120 cm, MIS 3
  14. LV, 650 cm, MIS 7
Figs. 15-16: *Thalassocythere acanthoderma* (Brady)
  15. RV, 180 cm, MIS 3
  16. juvenile, LV, 250 cm, MIS 3
Fig. 17: *Propontocypris trigonella* (Sars), internal view, LV, 645 cm, MIS 7
Fig. 18: *Pedicythere polita* Colalongo and Passini, LV, 170 cm, MIS 3
Fig. 19: *Pedicythere* sp., LV, 30 cm, MIS 1
Fig. 20: *Thaerocythere* sp., LV, 80 cm, MIS 2
Fig. 21: *Eucythere triangula* Whatley and Coles, RV, 635 cm, MIS 7
Fig. 22: *Eucythere multipunctata* Whatley and Coles, LV, 585 cm, MIS 6
Fig. 23: *Eucythere pubera* Bonaduce et al., LV, 620 cm, MIS 6
Fig. 24: *Eucythere* sp., LV, 610 cm, MIS 6
Fig. 25: *Ambocythere* sp. cf. *A. ramosa* Van den Bold, RV, 240 cm, MIS 3
Fig. 26: *Ambocythere* sp., RV, 405 cm, MIS 5
Figs. 27-28: *Bythocythere bathytatos* Whatley and Coles
  27. RV, 170 cm, MIS 3
  28. LV, 555 cm, MIS 6

PLATE 3

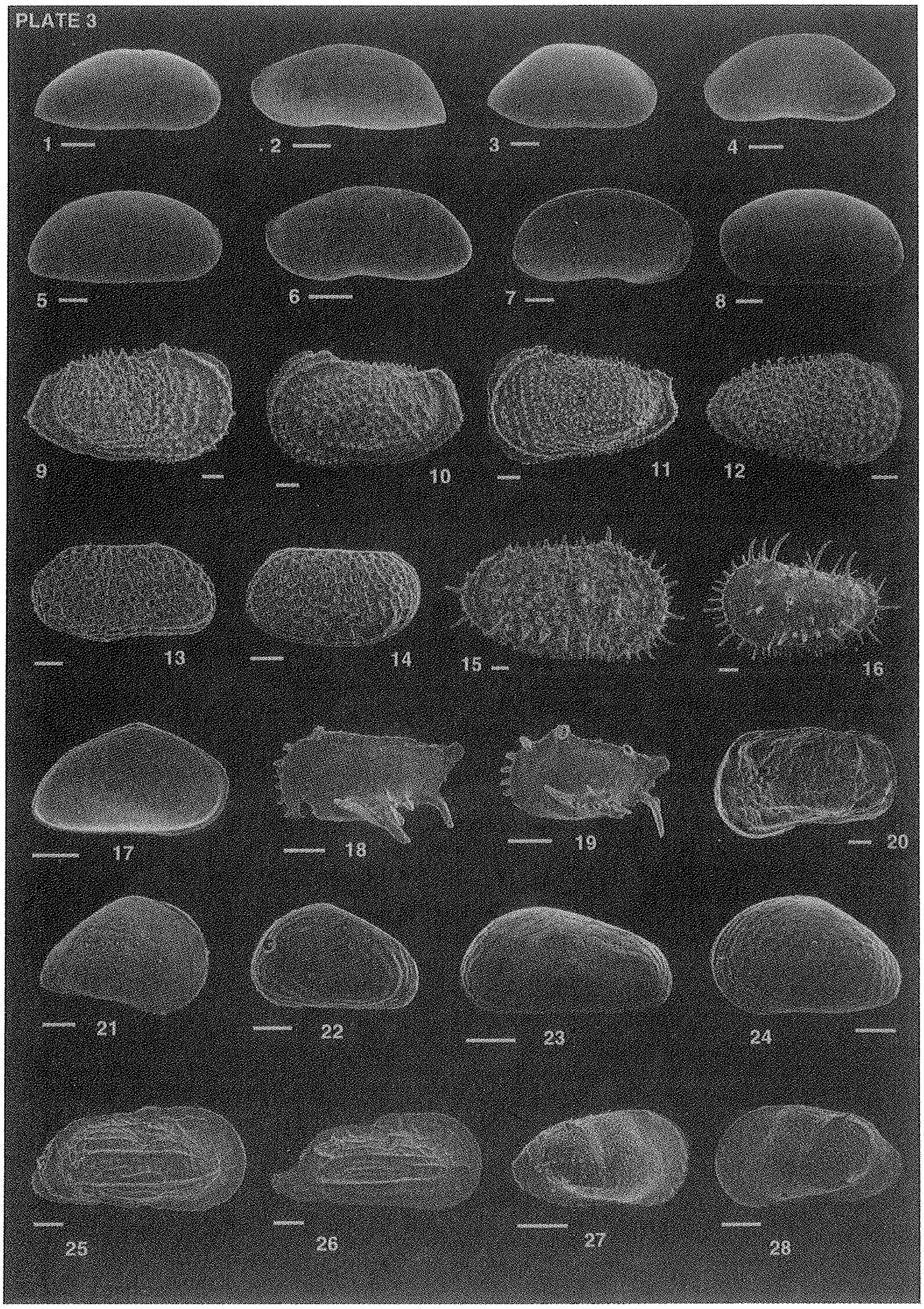

PLATE 4

All figures are external lateral views except where stated, the white bar scale equals 100 μm. LV= left valve, RV= right valve; all specimens are from core M23414.

Fig. 1: *Finmarchinella finmarchica* (Sars), RV, 590 cm, MIS 6
Fig. 2: *Robertsonites tuberculatus* (Sars), juvenile, RV, 80 cm, MIS 2
Fig. 3: *Hemicythere villosa* (Sars), female, RV, 240 cm, MIS 3
Fig. 4: *Hemicythere* sp. cf. *H. rubida* (Brady), RV, 585 cm, MIS 6
Fig. 5: *Elofsonella concinna* (Jones), LV, 590 cm, MIS 6
Fig. 6-7: *Poseidonamicus* sp. cf. *P. major* Benson
    6. LV, 260 cm, MIS 4
    7. RV, 435 cm, MIS 5
Fig. 8: *Rabilimis mirabilis* (Brady), RV, 270 cm, MIS 4
Fig. 9: *Semicytherura pulchra* Coles and Whatley, LV, 410 cm, MIS 5
Fig. 10: *Semicytherura complanata* Brady, Crosskey and Robertson, LV, 590 cm, MIS 6
Fig. 11: *Semicytherura* sp., RV, 155 cm, MIS 3
Fig. 12: *Paradoxostoma* sp. cf. *P. simile* (Müller), LV, 515 cm, MIS 6
Fig. 13: *Paracytherois flexuosum* (Brady), 70 cm, MIS 2
Fig. 14: *Paracytherois* sp., internal view, RV, 545 cm, MIS 6
Fig. 15: *Sclerochilus contortus* (Norman), internal view, LV, 645 cm, MIS 7
Fig. 16: *Macrocypris* sp., LV, 255 cm, MIS 3
Fig. 17: *Pontocypris* sp., RV, 100 cm, MIS 3
Fig. 18: *Sarsicytheridea bradii* (Norman), LV, 185 cm, MIS 3
Fig. 19: *Swainocythere* sp.1, LV, 35 cm, MIS 1
Fig. 20: *Swainocythere* sp.2, LV, 315 cm, MIS 5
Fig. 21: *Swainocythere* nanseni (Joy and Clark), LV, 575 cm, MIS 6
Fig. 22: *?Monoceratina* sp., RV, 20 cm, MIS 1
Figs. 23-24: *Bosquetina mucronalatum* (Brady)
    23. LV, 375 cm, MIS 5
    24. LV, 165 cm, MIS 3
Fig. 25: *Nannocythere* sp., LV, 35 cm, MIS 1
Fig. 26: *Rimacytheropteron longipunctata* (Breman), LV, 75 cm, MIS 2
Figs. 27-28: *Bairdoppilata* sp. cf. *B. victrix* (Brady)
    27. RV, 490 cm, MIS 6
    28. LV, 95 cm, MIS 2
Fig. 29: *Roundstonia globulifera* (Brady), LV, 605 cm, MIS 6
Fig. 30: *Cythere lutea* Müller, RV, 180 cm, MIS 3

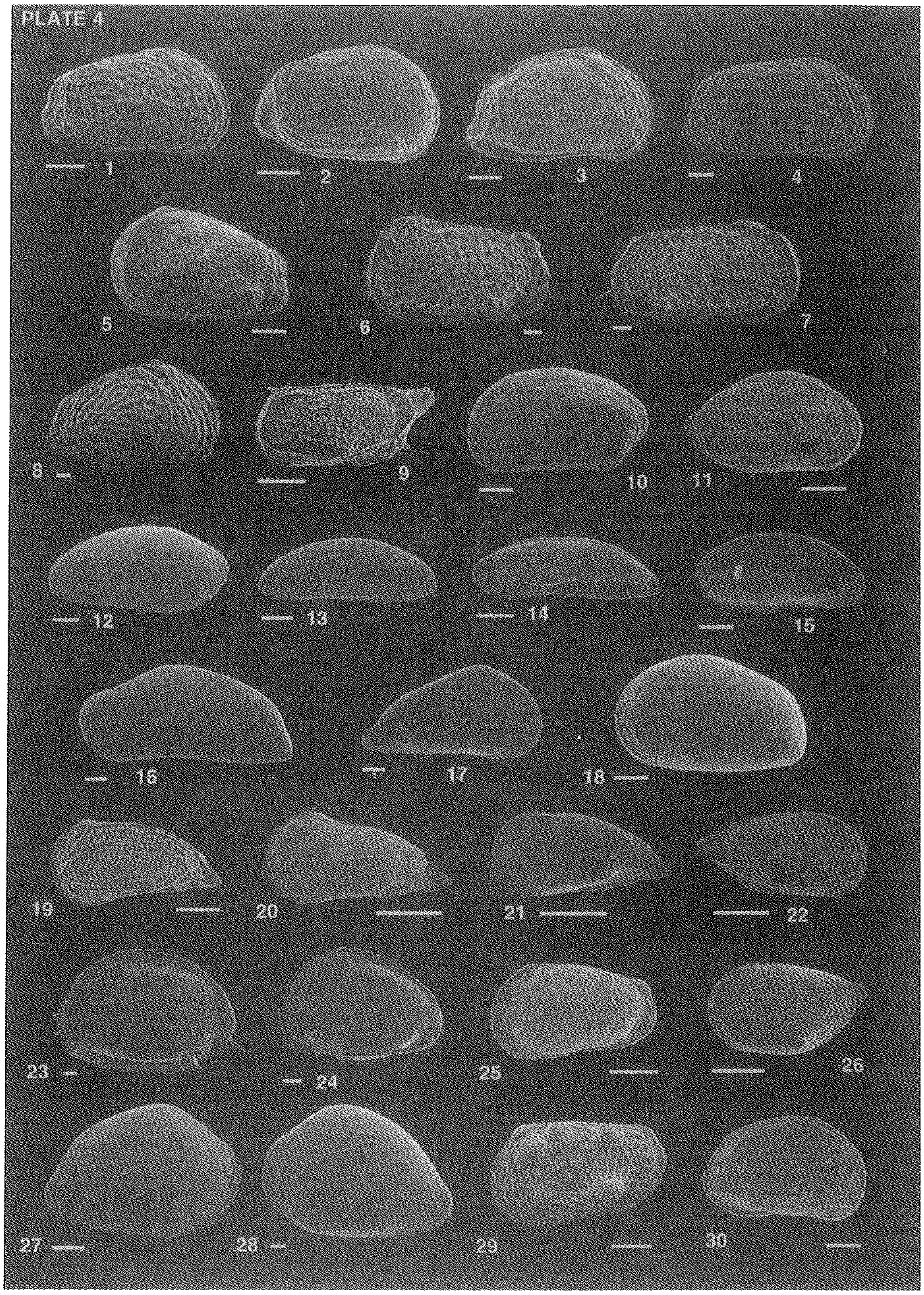
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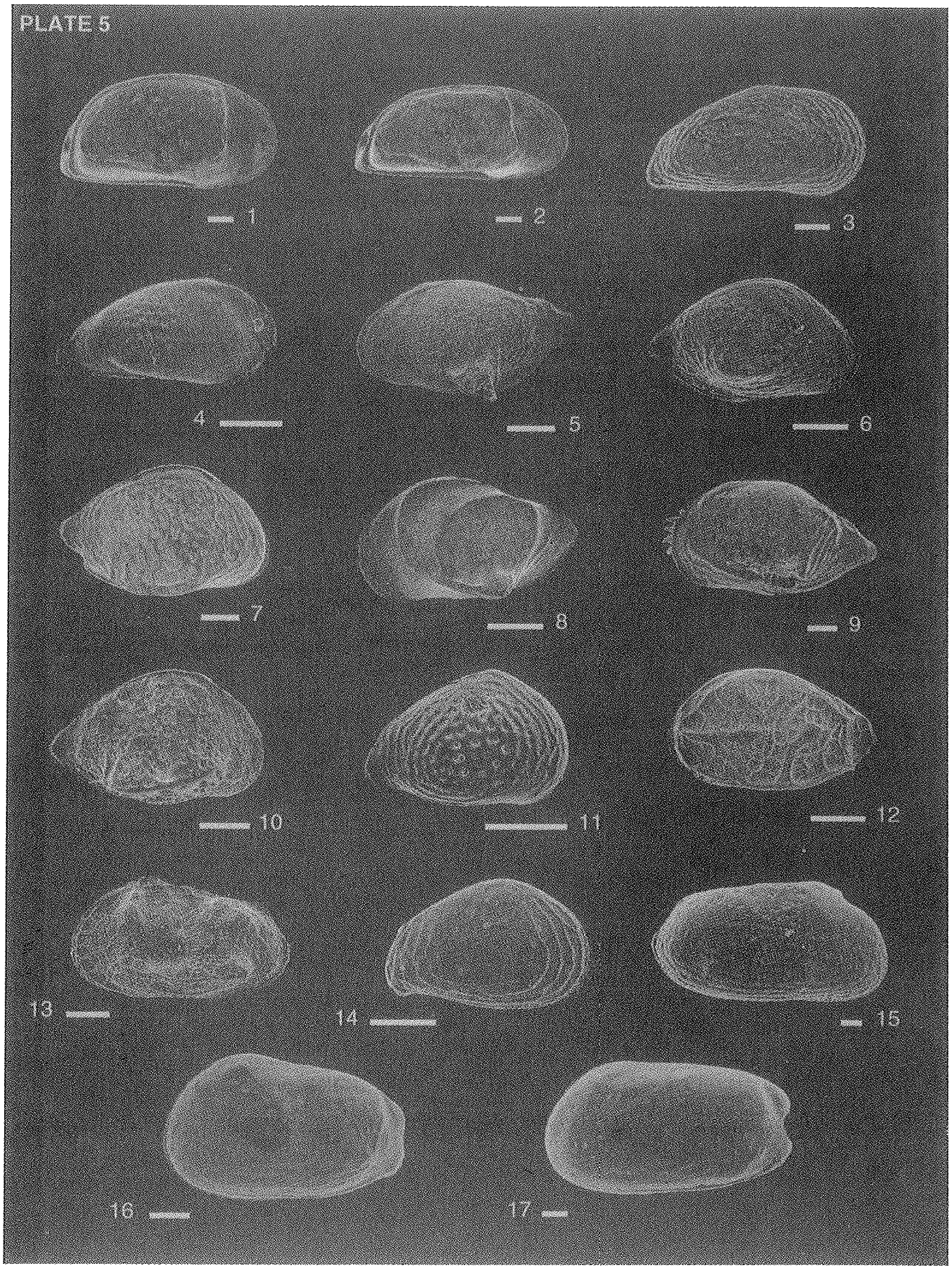
PLATE 5

All figures are external lateral views except where stated, the white bar scale equals 100 µm. LV= left valve, RV= right valve; all specimens are from core M23352, Iceland Plateau.

Fig. 1-2: *Krithe glacialis* Brady, Crosskey and Robertson
    1. internal view, LV, female, 102 cm, MIS 3
    2. internal view, LV, male, 102 cm, MIS 3
Fig. 3: *Eucythere* sp. cf. *E. argus* (Sars), RV, 254 cm, MIS 6
Fig. 4: *Swainocythere nanseni* (Joy and Clark), RV, 286 cm, MIS 6
Fig. 5: *Cytheropteron scoresbyi* Whatley and Eynon, LV, 204 cm, MIS 5
Fig. 6: *Cytheropteron pseudoinflatum* Whatley and Eynon, RV, 264 cm, MIS 6
Fig. 7: *Cytheropteron champlainum* Cronin, RV, 309 cm, MIS 6
Fig. 8: *Cytheropteron biconvexa* Whatley and Masson, LV, 290 cm, MIS 6
Fig. 9: *Cytheropteron bronwynae* Joy and Clark, LV, 275 cm, MIS 6
Fig. 10: *Cytheropteron nodosum* Brady, RV, 284 cm, MIS 6
Fig. 11: *Cytheropteron pseudomontrosiense* Whatley and Masson, RV, 179 cm, MIS 5
Fig. 12: *Hemicytherura clathrata* (Sars), LV, 286 cm, MIS 6
Fig. 13: *Palmenella limicola* (Norman), LV, 191,5 cm, MIS 5
Fig. 14: *Heterocyprideis sorbyana* (Jones), RV, juvenile, 72 cm, MIS 3
Fig. 15: ?*Cytheromorpha macchesneyi* Brady and Crosskey, RV, 300 cm, MIS 6
Figs. 16-17: *Normanicythere leioderma* (Norman)
    16. LV, female, 308 cm, MIS 6
    17. LV, male, 300 cm, MIS 6

PLATE 5



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* **Heft Nr. 5/1982** – "Joint Biological Expedition on RRS 'John Biscoe', February 1982" by G. Hempel and R. B. Heywood

* **Heft Nr. 6/1982** – „Antarktis-Expedition 1981/82 (Unternehmen ‚Eiswarte‘)“
zusammengestellt von Gode Gravenhorst

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Heft Nr. 8/1983 – "The Post-Fibex Data Interpretation Workshop" by D. L. Cram and J.-C. Freytag with the collaboration of J. W. Schmidt, M. Mall, R. Kresse, T. Schwinghammer

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Heft Nr. 11/1983 – "Joint Biological Expedition on RRS 'John Biscoe', February 1982 (II)"
Data of micronecton and zooplankton hauls, by Uwe Piatkowski

Heft Nr. 12/1983 – „Das biologische Programm der ANTARKTIS-I-Expedition 1983 mit FS ‚Polarstern‘“ Stationslisten der Plankton-, Benthos- und Grundschleppnetzfänge und Liste der Probennahme an Robben und Vögeln, von H. E. Drescher, G. Hubold, U. Piatkowski, J. Plötz und J. Voß

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Heft Nr. 15/1983 – "German Antarctic Expedition 1980/81 with FRV 'Walther Herwig' and RV 'Meteor'" – First International BIOMASS Experiment (FIBEX) – Data of micronekton and zooplankton hauls by Uwe Piatkowski and Norbert Klages

Sonderheft Nr. 5/1984 – "The observatories of the Georg von Neumayer Station", by Ernst Augstein

Heft Nr. 16/1984 – "FIBEX cruise zooplankton data" by U. Piatkowski, I. Hempel and S. Rakusa-Suszczewski

* **Heft Nr. 17/1984** – „Fahrtbericht (cruise report) der ‚Polarstern‘-Reise ARKTIS I, 1983“
von E. Augstein, G. Hempel und J. Thiede

Heft Nr. 18/1984 – „Die Expedition ANTARKTIS II mit FS ‚Polarstern‘ 1983/84“,
Bericht von den Fahrtabschnitten 1, 2 und 3, herausgegeben von D. Fütterer

Heft Nr. 19/1984 – „Die Expedition ANTARKTIS II mit FS ‚Polarstern‘ 1983/84“,
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Heft Nr. 28/1986 – „Die Expedition ARKTIS III mit ‚Polarstern' 1985" mit Beiträgen der Fahrtteilnehmer",
herausgegeben von Rainer Gersonde

• **Heft Nr. 29/1986** – „5 Jahre Schwerpunktprogramm ‚Antarktisforschung' der Deutschen Forschungsgemeinschaft."
Rückblick und Ausblick. Zusammengestellt von Gotthilf Hempel, Sprecher des Schwerpunktprogramms

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by Marianne Gube and Friedrich Obleitner

* **Heft Nr. 31/1986** – „Zur Biologie der Jugendstadien der Notothenioidei (Pisces) an der Antarktischen Halbinsel"
von A. Kellermann

* **Heft Nr. 32/1986** – „Die Expedition ANTARKTIS IV mit FS ‚Polarstern' 1985/86" mit Beiträgen der Fahrtteilnehmer,
herausgegeben von Dieter Fütterer

Heft Nr. 33/1987 – „Die Expedition ANTARKTIS-IV mit FS ‚Polarstern' 1985/86 –
Bericht zu den Fahrtabschnitten ANT-IV/3-4" von Dieter Karl Fütterer

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