

Abysal ostracods from the South and Equatorial Atlantic Ocean: Biological and paleoceanographic implications

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Abstract

We report the distribution of ostracods from ~5000 m depth from the Southeast and Equatorial Atlantic Ocean recovered from the uppermost 10 cm of minimally disturbed sediments taken by multiple-corer during the R/V *Meteor* DIVA2 expedition M63.2. Five cores yielded the following major deep-sea genera: *Krithe*, *Henryhowella*, *Poseidonamicus*, *Legitimocythere*, *Pseudobosquetina*, and *Pennyella*. All genera are widely distributed in abyssal depths in the world's oceans and common in Cenozoic deep-sea sediments. The total number of ostracod specimens is higher and ostracod shell preservation is better near the sediment–water interface, especially at the 0–1 cm core depths. Core slices from ~5 to 10 cm were barren or yielded a few poorly preserved specimens. The DIVA2 cores show that deep-sea ostracod species inhabit corrosive bottom water near the carbonate compensation depth (CCD) even though their calcareous valves are rarely preserved as fossils in sediment cores due to postmortem dissolution. Their occurrence at great water depths may partially explain the well-known global distributions of major deep-sea taxa in the world's oceans, although further expeditions using minimal-disturbance sampling devices are needed to fill geographic gaps.

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1. Introduction

The distribution and ecology of deep-sea benthic Ostracoda (Crustacea) from <4000 m water depth is relatively well-established, especially in the North Atlantic Ocean, based on numerous bottom sam-

pling programs. Studies include those from the Arctic (e.g., Joy and Clark, 1977; Cronin et al., 1995; Jones et al., 1998), Atlantic (e.g., Cronin, 1983; Dingle and Lord, 1990; Dingle et al., 1990), Pacific (e.g., Corrège, 1993; Ayress et al., 1997; Mazzini, 2004), and Southern oceans (e.g., Ayress et al., 2004; Mazzini, 2005). Together these studies suggest that deep-water and sediment characteristics (e.g., temperature, oxygen, sediment flux) and food supply (i.e., surface primary productivity, almost the only food resource in deep ocean floor, except hydrothermal vents, etc.) are important factors

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controlling deep-sea ostracod distribution and abundance (Cronin et al., 2002; Didié et al., 2002). Fossil ostracods from sediment cores taken from ~1000 to 4000 m have also been investigated to reconstruct the long-term history of deep-sea benthic diversity and community structure (e.g., Benson, 1990; Cronin et al., 1996, 1999; Cronin and Raymo, 1997; Yasuhara et al., 2008).

However, there is relatively sparse information on deep-sea ostracods from abyssal plain environments between 4000 and 5000 m water depth. The few exceptions are from the southeastern Atlantic and yielded sparse and poorly preserved faunas (Peypouquet and Benson, 1980; Dingle and Lord, 1990; Dingle et al., 1990). Except for early 19th century work by Brady (1880) on *Challenger* expedition ostracods, almost nothing is known of abyssal ostracods from >5000 m, a depth that lies below the lysocline and near the carbonate compensation depth (CCD) in parts of the South Atlantic. Consequently, the studied region is under the influence of calcium carbonate dissolution.

Information on >5000-m-depth ostracods is important for understanding the large-scale distribution of deep-sea ostracods because ostracods have no planktonic larvae and corrosive waters below the CCD may serve as a barrier to ostracod migration. Some authors have suggested that ostracods are unable to inhabit regions below the CCD (e.g., Whatley, 1996; Boomer, 1999), because they have calcite shells. Recently, Jellinek et al. (2006) reported living ostracods from ~5500 m depth in the southeastern Atlantic Ocean. This discovery suggests that the thin outer organic epicuticle of the ostracod shell helps to protect the shell from corrosive water when the organism is living, but after death, the outer organic epicuticle decomposes and the calcite shell dissolves. Thus, some ostracod species can inhabit corrosive water found in abyssal plains even below the CCD, but their shells are rarely preserved as fossils. A similar situation is found in acidic lakes where ostracods live but are not preserved as fossils (e.g., Frogley et al., 2002; Boomer et al., 2003; Halse and McRae, 2004).

However, Jellinek et al. (2006) reported only two species belonging to one genus, *Pseudobosquetina*. Here we report the discovery of ostracods from ~5000 m depth of the Southeast and Equatorial Atlantic Ocean recovered from minimally disturbed sediments taken by multiple-corer during research vessel *Meteor* expedition M63.2, the DIVA2 (Latitudinal Gradients

of Deep-Sea BioDiversity in the Atlantic Ocean) cruise. This cruise represents part of the CeDAMar project (Census of the Diversity of Abyssal Marine Life: <http://www.cedamar.org/>), to determine biodiversity and ecology of abyssal benthic communities. Our results contribute to persistent questions about what controls deep-sea biogeography and species diversity gradients (Rex et al., 2000, 2005; Stuart et al., 2003), and new evidence that, at least in some deep-sea regions, there is higher ostracod diversity and endemism than previously believed (Brandão, 2006; Brandt et al., 2007).

2. Materials and methods

Five multiple-corer deployments (sites 37, 38, 62, 78, and 100; ~5030 to 5150 m water depth) were taken from the Cape and Guinea basins in the Southeast and Equatorial Atlantic off Africa, during March 2005 (Fig. 1; Table 1).

The multiple-corer takes 12 cores with one deployment, and one of them was available from each deployment for this study. The core diameter is 9.6 cm. The multiple-corer is a minimal-disturbance sampling device compared to the box-corer, which was formerly the standard sampler for deep-sea sediments especially in the last century (Bett et al., 1994; Shirayama and Fukushima, 1995). Most previous modern deep-sea ostracod studies are based on sampling devices such as box-corers or grab samplers, which often disturb the uppermost few centimeters of sediment. The DIVA2 cores were sliced into 1-cm sections and kept in a freezer at -20°C immediately after sampling without ethanol or formalin that might be corrosive to ostracod calcite valves. Thus, the effects of disturbed sampling (i.e., loss of the sediment–water interface) and post-sampling dissolution should be minimal.

Based on World Ocean Atlas 2001 (WOA01: www.nodc.noaa.gov/OC5/WOA01F/; Conkright et al., 2002), annual mean chlorophyll at the surface, indicating surface primary productivity, is low ($<0.05\ \mu\text{g/L}$) and moderate ($0.1\text{--}0.2\ \mu\text{g/L}$) at the Southeast and Equatorial Atlantic sites, respectively. Cape Basin sites are filled with Antarctic Bottom Water (AABW: strictly speaking, Lower Circumpolar Deep Water, LCDW) and characterized by relatively low temperature, salinity, and dissolved oxygen. On the other hand, Guinea Basin sites are under the influence of North Atlantic Deep Water (NADW) and are characterized by relatively high temperature, salinity, and dissolved

oxygen (Table 2; WOA01: www.nodc.noaa.gov/OC5/WOA01/; Larqué et al., 1997; Boyer et al., 2002; Locarnini et al., 2002; Stephens et al., 2002). In the Cape and Guinea basins, the lysocline is situated at 4400 and 4400–4600 m and the CCD is situated at 5000 and 5400 m depth, respectively

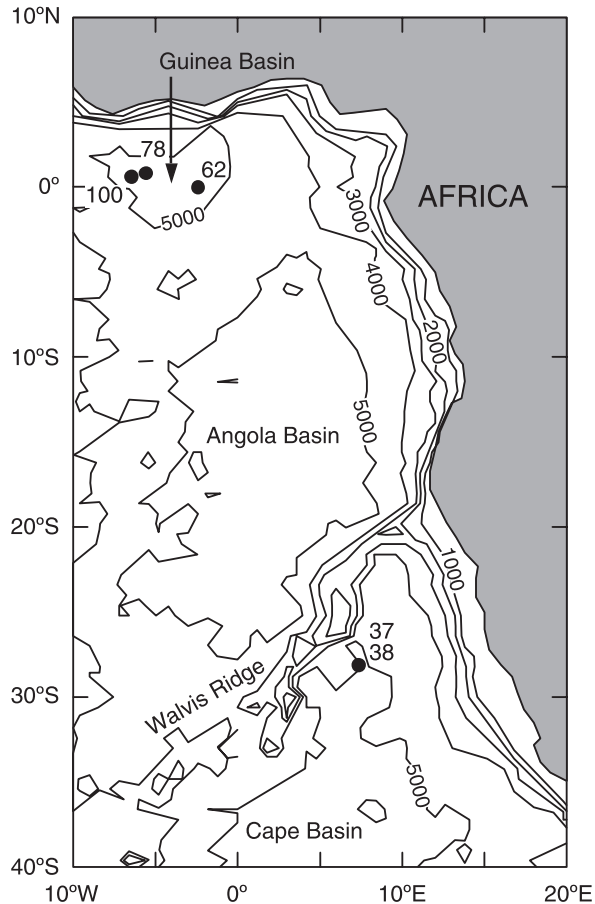


Fig. 1. Locations of multiple-core sites and bathymetry (1000 m contours) of the Southeast and Equatorial Atlantic.

Table 1
Summary of multiple-core sites

Cruise	M63.2 (DIVA2)				
	C	C	G	G	G
Locality Site	37	38	62	78	100
Date (month/day/year)	3/4/05	3/4/05	3/15/05	3/19/05	3/24/05
Water depth (m)	5032	5037	5064	5139	5153
Latitude	28°6.7'S	28°6.8'S	0°0.1'S	0°50.0'N	0°37.2'N
Longitude	7°20.8'E	7°20.8'E	2°25.0'W	5°35.1'W	6°28.1'W

C: Cape Basin; G: Guinea Basin.

(Dittert and Henrich, 2000). Thus, the sampling sites are situated around the CCD.

We examined 25 horizontal slices from the top 10 cm of five cores (0–1, 1–2, 2–3, 4–5, 9–10 cm depth sections) for ostracods. The volume of each horizontal slice was $\sim 290 \text{ cm}^3$. Although most ostracods live in the uppermost 1 cm in sediment, some ostracod taxa are known to be infauna (e.g., *Krithe*) and may live in sediment deeper than 1 cm (Majoran and Agrenius, 1995). Only the $> 150 \mu\text{m}$ size fraction was studied, which allowed us to obtain all adults and most juveniles of late molt stages. All specimens were picked, identified, and mounted from each horizontal slice. The number of specimens refers to valves (i.e., one separated valve = one specimen; one articulated carapace = two specimens). Preservation states of ostracod shells are classified into three categories: white, translucent, and transparent. Translucent and transparent shells indicate good preservation.

3. Results

A total of 136 specimens (four empty articulated carapaces, one articulated carapace with soft parts, 125 empty separated valves, one separated valve with soft parts) was recovered from 25 horizontal slices (Tables 3 and 4). Vertical changes in the total number of specimens and preservation state are shown in Fig. 2.

Krithe spp., which is mainly composed of the species *Krithe lamellalata* Coles et al. and *Krithe morkhoveni* s.l. van den Bold, was dominant throughout the DIVA2 cores. We also found *Henryhowella* spp. (including *Henryhowella asperima* s.l. and a few other species), *Poseidonamicus* sp., *Legitimocythere acanthoderma* (Brady), *Pseudobosquetina semireticulata* Jellinek et al., *Pennyella* sp.,

Table 2
Deep-water characteristics of study sites based on nearby site of WOA01

Sites	WOA01 nearby site location	Temperature (°C)	Salinity	Oxygen (mL/L)
37, 38	7.5°E, 28.5°S; 5000 m water depth	1.17	34.738	4.99
62	2.5°W, 0.5°N; 5000 m water depth	2.17	34.858	5.58
78, 100	5.5°W, 0.5°N; 5000 m water depth	2.14	34.858	5.6

Table 3
List of ostracods from Cape Basin cores

Cruise	M62.3 (DIVA2)									
	37					38				
Site										
Depth (cm)	0–1	1–2	2–3	4–5	9–10	0–1	1–2	2–3	4–5	9–10
<i>Bairdoppilata</i> sp.	5 ^a									
<i>Bythocypris</i> sp. 1	3 ^a									
<i>Bythocythere bathytatos</i>	2									
<i>Henryhowella</i> spp.										1
<i>Krithe</i> spp.			1			4			1	1
<i>Pseudocythere?</i> sp.						1				
Gen. et sp. Indet.										1
Total number of specimens	10	B	1	B	B	5	B	B	1	3

B: barren.

^aIncluding one carapace.

Table 4
List of ostracods from Guinea Basin cores

Cruise	M62.3 (DIVA2)														
	62					78					100				
Site															
Depth (cm)	0–1	1–2	2–3	4–5	9–10	0–1	1–2	2–3	4–5	9–10	0–1	1–2	2–3	4–5	9–10
<i>Bythocypris</i> sp. 2											2				
<i>Henryhowella</i> spp.		3	4	1	3	1	1	1	2	1	2	1	1		1
<i>Krithe</i> spp.	10 ^a	12	10	6 ^b	3	3	6	4	1		6	5	2	2	1
<i>Legitimocythere acanthoderma</i>	1	2					1		1	1				2	1
<i>Pennyella</i> sp.						1									
<i>Poseidonamicus</i> sp.		1					1				2				
<i>Pseudobosquetina semireticulata</i>													1		
<i>Xestoleberis profundis</i>	2 ^c					2 ^c									
Gen. et sp. Indet.										1		1			
Total number of specimens	13	18	14	7	6	7	9	5	4	3	12	8	3	4	3

^aIncluding one carapace with soft parts.

^bIncluding one valve with soft parts.

^cComposed of one carapace.

Bythocythere bathytatos Whatley and Coles, *Xestoleberis profundis* Whatley and Coles, *Bairdoppilata* sp., and *Bythocypris* spp.

At Cape Basin sites 37 and 38, the surface (0–1 cm) layers included 5–10 specimens that are either transparent or translucent, indicating good

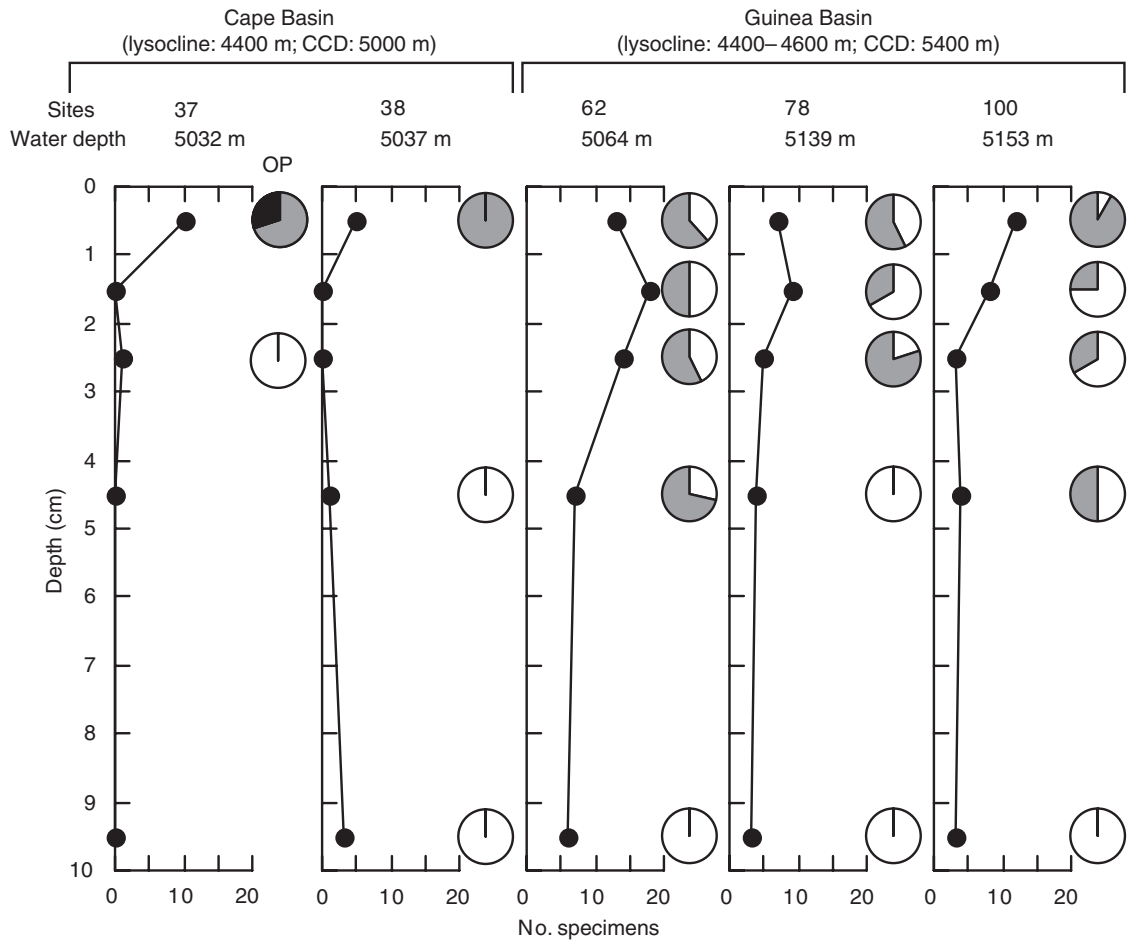


Fig. 2. Vertical changes in total number of specimens and preservation state of ostracods. OP: status of ostracod preservation (black: transparent; gray: translucent; white: opaque white).

preservation. Horizontal slices below 1 cm were barren or included only few, poorly preserved (i.e., opaque white) specimens.

In the Guinea Basin sites 62, 78, 100, the surface (0–1 cm) layers included 7–13 specimens. Number of specimens was higher and ostracod preservation was better (i.e., proportion of translucent specimens is higher) in upper horizontal slices. Juveniles of *K. lamellalata* with soft parts (one carapace and one valve) were found at site 62 of 0–1 and 4–5 cm depth, respectively (Table 4).

4. Discussion

We consider our material as generally *in situ* and the top centimeter of the core as representing the modern faunal assemblage for several reasons.

1. Any effects of disturbance during coring (i.e., loss of the sediment–water interface) should be minimal as described in Section 2.
2. Other cores from each deployment were used for meiofaunal analysis and include numerous rose bengal stained (i.e., living) copepods and nematodes (Martínez Arbizu, P., unpublished data), which are known to inhabit the top few centimeters of sediments (e.g., Shimanaga et al., 2000).
3. The studied sites are far away from the continental slope which is often the source of downslope contamination (Cronin, 1983).
4. The preservation of ostracod shell is generally good in the 0–1 cm layers.

In Cape Basin sites 37 and 38, the patterns of ostracod abundance and preservation apparently

support the hypothesis that ostracods inhabit corrosive environments near the CCD but are rarely preserved as fossils due to postmortem dissolution. In the Guinea Basin sites 62, 78, 100, the vertical pattern is less clear than at the Cape Basin sites. However, higher abundance and better preservation in the upper parts of cores are generally consistent with this hypothesis.

In addition, Cape Basin sites 37 and 38 are in the path of corrosive AABW and have few planktonic foraminifers. In contrast, Guinea Basin sites 62, 78, and 100 are in the path of carbonate ion-saturated NADW and situated above the CCD (Larqué et al., 1997; Dittert and Henrich, 2000) and contain numerous planktonic foraminifers. These differences are generally consistent with the vertical trends of ostracod abundance and preservation in the Guinea Basin sites.

Although low ostracod abundance does not allow us to carry out quantitative analysis of faunas, the results suggest that the abyssal zone around and below CCD is not a limitation for ostracods to inhabit the deepest benthic environments. This also implies that the CCD may not be a barrier for deep-sea ostracods to migrate over large distances over long times. Most genera (e.g., *Pseudobosquetina*, *Krithe*, *Legitimocythere*, *Henryhowella*, and *Pseudonamicus*) and some species (*P. semireticulata* and *L. acanthoderma*) found in this study are also reported from the southeast Atlantic around or below 4500 m water depth under the influence of AABW (Peypouquet and Benson, 1980; Dingle and Lord, 1990; Dingle et al., 1990; Jellinek et al., 2006), suggesting that similar faunas may be present in other areas near the CCD.

The global distribution of many major deep-sea species has been proposed by several authors on the basis of comprehensive sampling of late Quaternary sediments from the world's major deep-sea environments (Whatley and Ayress, 1988; Coles et al., 1990; Whatley, 1996). For example, many *Krithe* species reported from North Atlantic Ocean (Coles et al., 1994) are also found in South Pacific and Southern oceans (Ayress et al., 1999). However, most samples used in these analyses were mostly fossil and subfossil assemblages, and some researchers question the global distribution of some ostracod species due to taxonomic uncertainty and sampling biases (Schornikov, 2005; Jellinek et al., 2006; Brandt et al., 2007). Our results and those from other previous researchers (e.g., Whatley and Coles, 1987; Dingle and Lord, 1990; Dingle et al., 1990; Cronin

et al., 1999; Didié and Bauch, 2000; Jellinek et al., 2006) suggest that at least some deep-sea ostracod species or closely related species groups (e.g., *K. morkhoveni*, *L. acanthoderma*, and *P. semireticulata*) are widely distributed in the Atlantic Ocean and perhaps are conspecific with Pacific species. This suggests that inter-oceanic migration may be achieved under the influence of AABW through abyssal plains below the CCD. Because many deep-sea species have long stratigraphic ranges of millions to tens of millions of years (Whatley, 1985; Whatley and Coles, 1991; Coles et al., 1994; Hunt and Roy, 2006), it is not surprising that they have broad modern geographic distributions.

In contrast to widely distributed abyssal species, our results and those of Dingle and Lord (1990) suggest that species of *Cytheropteron*, *Argilloecia*, *Pedicythere* and *Polycope*, which typically live in depths 1000 to <4000 m, cannot survive in corrosive deep-water, such as the AABW, and may have different biogeographic distributions. Many of these genera appear to be more speciose than abyssal genera and have a higher degree of endemism (e.g., Swanson and Ayress, 1999; Schornikov, 2005), consistent with recent detailed taxonomic analyses of ostracods from the deep Weddell Sea based partly on soft-part anatomy (Brandão, 2006; Brandt et al., 2007).

In conclusion, our results indicate that, like acidic lake ostracods (e.g., Frogley et al., 2002; Boomer et al., 2003; Halse and McRae, 2004), deep-sea ostracods survive in corrosive environments below 5000 m depth but their valves are rarely preserved as fossils in the sediment after their death due to the chemistry of the water. Calcareous foraminiferal species likewise inhabit depths below 5000 m in the Angola and Cape basins (Schmiedl et al., 1997). Since our dataset is small, further research using minimal-disturbance sampling devices, such as the multiple-corer, are absolutely essential to obtain further information about ostracod distributions on abyssal plains below the CCD.

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