

Palaeoenvironment of Maastrichtian ostracods from ODP Holes 1049B, 1050C and 1052E in the Western North Atlantic

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ABSTRACT – The Maastrichtian ostracods recovered from ODP Holes 1049B, 1050C and 1052E on the Blake Nose, Western North Atlantic, are investigated. The three sites are located on a depth transect encompassing middle to lower bathyal, Late Cretaceous palaeodepths. Fourteen samples ranging in age from early to late Maastrichtian are investigated from Hole 1052E, which is the shallowest site. The early Maastrichtian *G. falsostuarti*–*G. gansseri* Zone of Hole 1052E yields rare ostracods. The species richness, abundance and faunal density are on average considerably higher in the late Maastrichtian *R. fructicosa* and *A. mayaroensis* Zones of Hole 1052E, possibly, at least partly, as a result of palaeoceanographical changes that were also responsible for the disappearance of the inoceramid bivalves at this location. A palaeobathymetrical comparison among the late Maastrichtian ostracod assemblages recorded from Holes 1049B, 1050C and 1052E shows that the faunal density and mean number of taxa are inversely correlated with palaeodepth; however, the dominance of the platycopid genus *Cytherella* increases with palaeodepth. A dominance of platycopids may signify environmental stress related to low oxygen content. The dominance of the benthic foraminifer *Nuttalides trumpeyi* in the Late Cretaceous of Holes 1049B and 1050C provides additional evidence of oxygen deficiency. From a total of 28 genera recorded from Holes 1049B, 1050C and 1052E, 14 were previously recorded from Hole 689B, a high latitude hole in the Southern Ocean, and show that many ostracod genera display a wide latitudinal distribution in the Late Cretaceous deep sea, although more geographically restricted genera are also present, analogous with modern and Tertiary oceans. *J. Micropalaeontol.* 18(2): 125–136 December 1999.

INTRODUCTION

During the Maastrichtian, world-wide biotic changes occurred which included the global extinction of the inoceramid bivalves (MacLeod, 1994; MacLeod *et al.*, 1996) and the tropical rudist reef faunas (Johnson & Kauffman, 1990). There were also major latitudinal shifts in the distribution of planktonic foraminifers and calcareous nannoplankton (Huber & Watkins, 1992).

According to Saltzman & Barron (1982), the formation of Late Cretaceous deep water occurred both in low latitude marginal seas by evaporation forming warm, saline bottom waters and at high latitudes by the subsidence of cool surface water. For the Maastrichtian, Barrera & Huber (1990) and Barrera *et al.* (1997) showed that planktonic and benthic foraminiferal $\delta^{18}\text{O}$ isotopes provide evidence of a trend of cooling of surface and intermediate waters between 74 and 68 Ma at high southern latitudes. Superimposed on this trend, there is isotopic evidence of a temporarily short event in the early Maastrichtian (between 71 and 70 Ma) during which the oceanic circulation may have become more typical of the Recent thermohaline pattern with an intensified production of cool, well-oxygenated bottom and intermediate waters at high latitudes (MacLeod & Huber, 1996; Barrera *et al.*, 1997). Before and after this event, the oceanic circulation was probably more typical of the Late Cretaceous pattern with a stronger influence of warm saline plumes formed at low latitudes (Barrera *et al.*, 1997). According to MacLeod (1994), the last inoceramids were adapted to warm, oxygen-deficient conditions. Their extinction was possibly, at least partly, a consequence of such changes in oceanic circulation as occurred between 71 and 70 Ma (MacLeod, 1994). In addition, an increase in the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of sea water at 71 Ma indicates intensified continental weathering, and may be an expected result of a global regression

(Barrera *et al.*, 1997). Such a regression may have drained the low- and mid-latitude epicontinental seas and temporarily reduced the formation of warm, saline bottom waters. The extinction of rudist reefs has been related to the disappearance of hypersaline surface water produced in shallow epicontinental seas (Johnson & Kauffman, 1990).

Little is known about how the Maastrichtian palaeoceanographic perturbations that occurred between 74 and 68 Ma affected nannofossils, benthic foraminifers and ostracods at lower latitudes. Low latitude sites with good recovery and preservation through this time interval are rare. One of the objectives of Leg 171B, which included five sites drilled along a depth transect on the Blake Nose in the Western North Atlantic, was to study patterns of turnover in middle Maastrichtian microbiota. Benson *et al.* (1984, 1985) have previously shown the usefulness of ostracod studies in detecting major palaeoceanographic changes in the Cenozoic world ocean. The objective of the present preliminary study is partly to describe faunal changes in middle bathyal ostracod assemblages throughout the Maastrichtian at Site 1052. The intention is also to describe late Maastrichtian palaeobathymetrical changes in the composition of bathyal ostracod assemblages along a depth transect on the Blake Nose encompassing ODP Sites 1049, 1050 and 1052 (Fig. 1).

Swain (1978) and Guernet (1982) have previously described Cretaceous and Palaeogene ostracods, respectively, from Site 390 (DSDP Leg 44) on the Blake Nose. Previous studies, partly or completely focused on Late Cretaceous deep-sea ostracods (i.e. from a palaeodepth > 500 m) of the Atlantic and Southern Oceans include Benson (1975, 1977), Benson *et al.* (1984, 1985), Damotte (1979, 1988), Dingle (1981), Swain (1973, 1978, 1983), Majoran *et al.* (1997), Majoran *et al.* (1998) and Majoran & Widmark (1998).

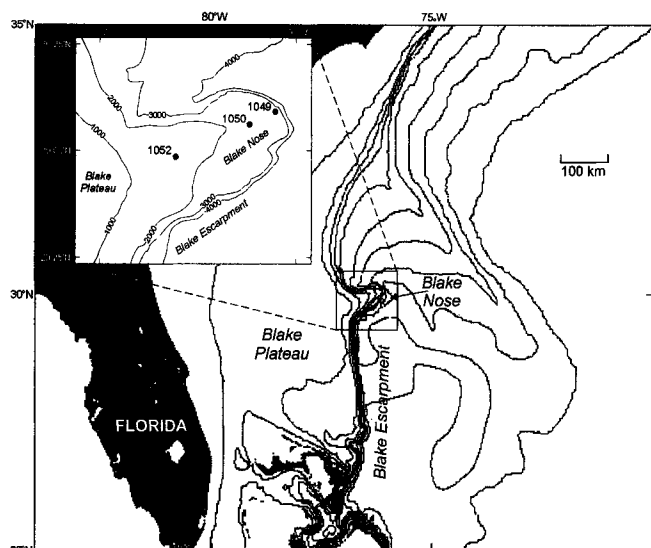


Fig. 1. Location map of Sites 1049, 1050 and 1052 on the Blake Nose, Western North Atlantic.

METHODS

A total of 24 Maastrichtian samples (20 cm³ each) were studied from ODP Holes 1049B, 1050C and 1052E (see Table 1). All samples were dried and subsequently immersed in deionized water and placed on a rotary table for 24 h. They were then washed over a 63 µm sieve and dried. The dried samples were sieved through a 125 µm sieve. All ostracods retained from this sieve fraction were picked under a binocular microscope and arranged on faunal slides. Almost all the specimens picked consisted of single valves or valve fragments. One valve was counted as one specimen, as were identifiable broken specimens that were greater than half the size of a complete valve. Broken specimens less than half the size of a complete valve were counted as fragments. The specimens were mainly identified to the level of the species, although some featureless genera, difficult to separate at specific level, were lumped together into multispecific categories, e.g. *Cytherella* spp., *Krithe* spp. and *Argilloecia* spp. The figured specimens (Plates 1 and 2) were coated with gold and photographed under a Zeiss Digital Scanning Microscope DSM 940 at the Department of Marine Geology, Earth Sciences Centre, Gothenburg University. All

Table 1. Samples of ODP Holes 1052E, 1050C and 1049B investigated for ostracods.

Hole	Section	Interval (cm)	Depth (mbsf)	Weight (g)	N	F
1052E	20-1	100–103	320.30	23.64	93	28
1052E	20-4	111–114	324.91	17.63	108	18
1052E	20-6	93–96	327.73	29.51	123	42
1052E	22-1	112–115	339.72	39.95	175	39
1052E	23-2	117–120	350.97	24.15	17	18
1052E	24-1	109–113	358.99	17.67	1	1
1052E	25-1	113–117	368.63	21.48	24	0
1052E	26-1	138–143	378.48	46.99	7	4
1052E	27-1	98–102	387.68	30.26	46	24
1052E	29-1	121–125	407.11	31.38	1	1
1052E	31-1	116–120	426.26	36.00	4	0
1052E	31-cc	0–3	434.70	32.20	3	1
1052E	34-1	74–77	454.64	23.16	1	0
1052E	35-1	110–113	464.70	27.84	2	1
1050C	11-1	102–105	409.71	42.57	25	15
1050C	11-1	146–149	410.15	44.85	17	8
1050C	11-2	23–27	410.42	43.75	22	5
1050C	11-2	52–55	410.71	54.68	42	11
1050C	11-2	75–78	410.94	51.52	11	7
1049B	8-3	85–87	112.85	29.38	1	2
1049B	8-4	25–27	113.75	28.54	5	6
1049B	8-4	115–117	114.65	27.11	1	0
1049B	8-5	10–12	115.10	25.89	7	1
1049B	8-5	110–115	116.10	39.36	11	0

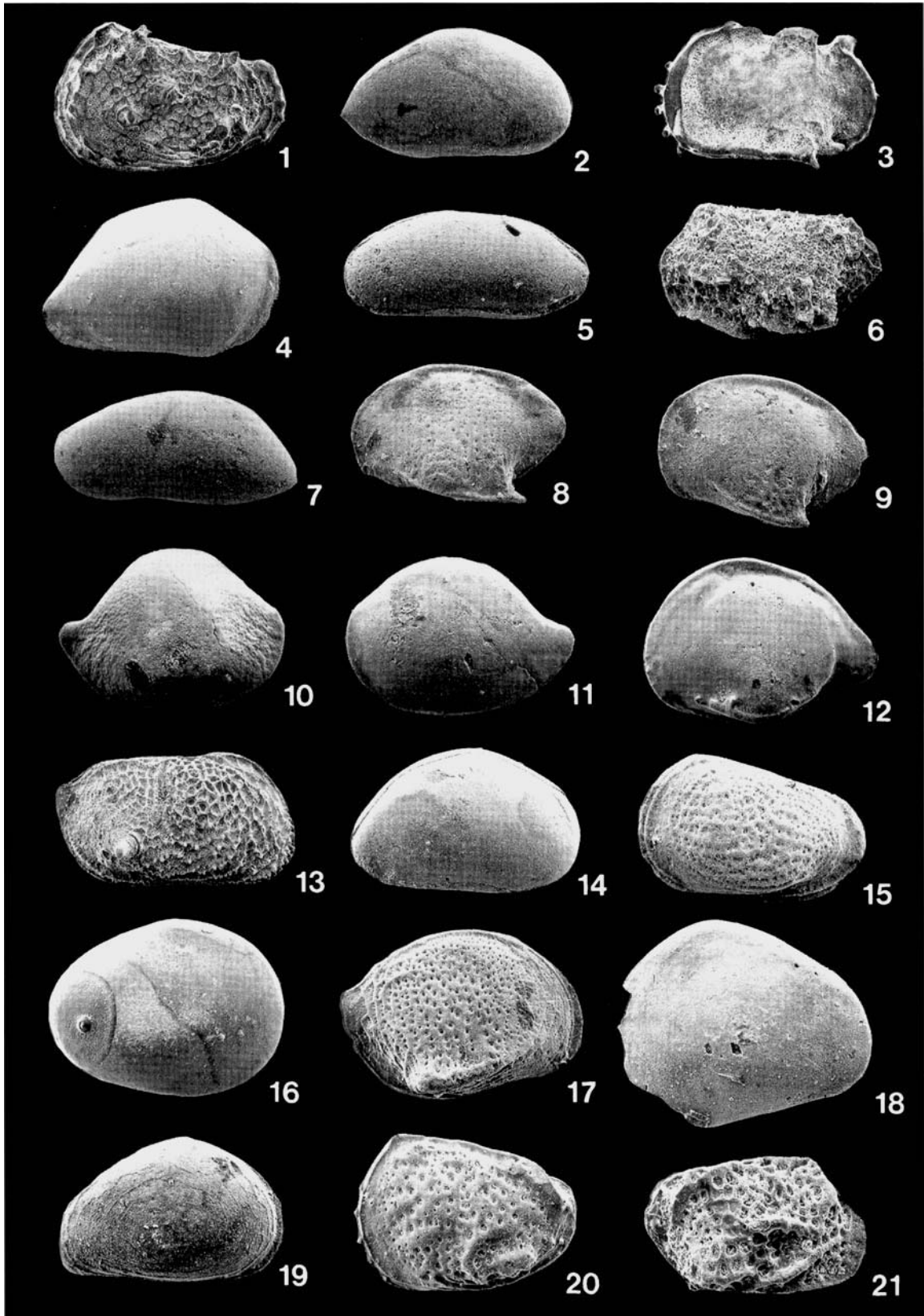
N represents number of identified specimens; *F* represents number of unidentified fragments.

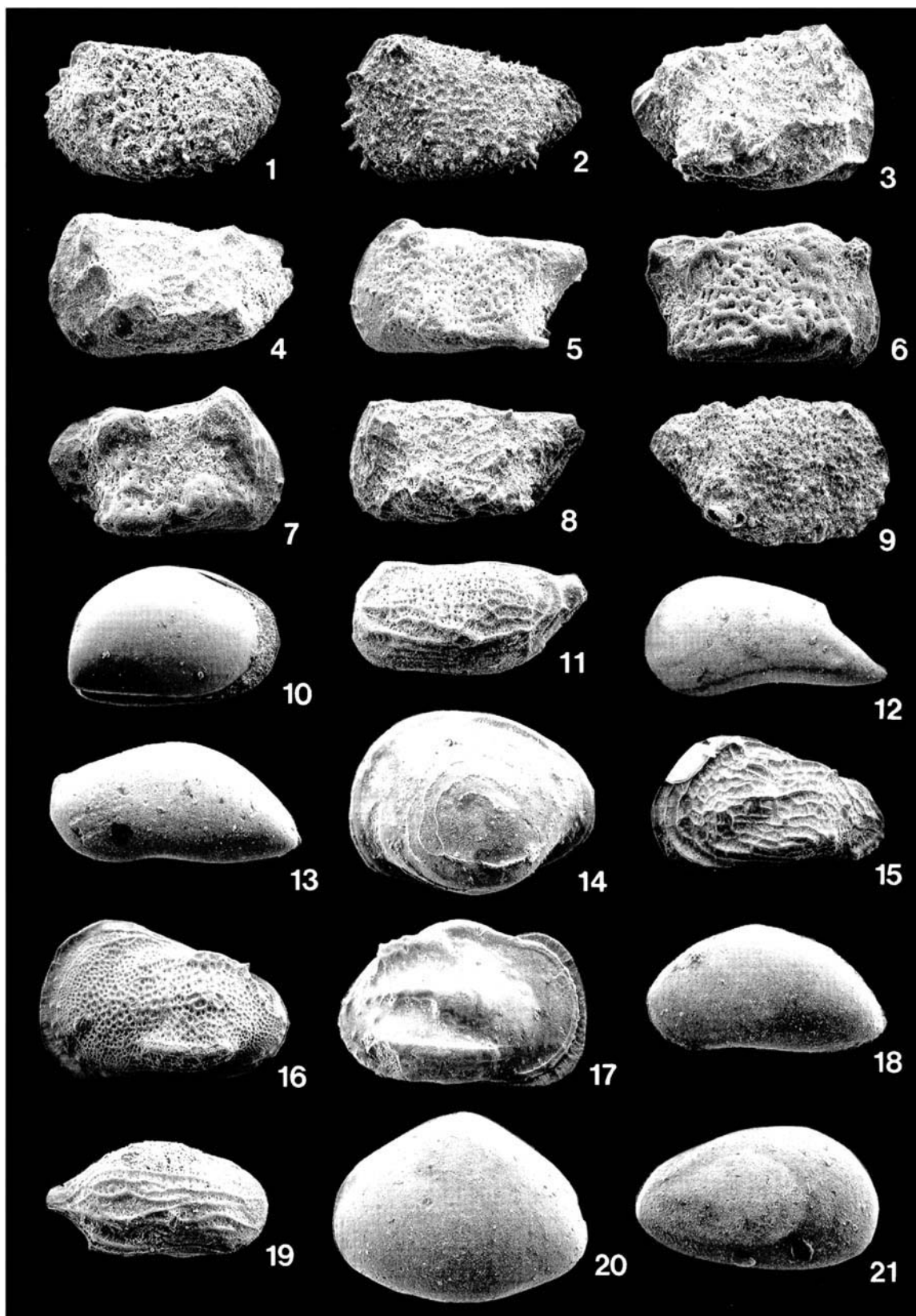
figured specimens and faunal slides are stored at this location. The figured specimens are stored under the designation codes DMGUG.N.Atl.1–42.

The ostracod valve accumulation rate (OVAR) (Majoran *et al.*, 1997) was taken as a measure of the faunal density of ostracods, or more precisely the number of ostracods produced per unit area and unit time. The OVAR (the number of valves and unidentified fragments per cm² and kyr) was calculated as *NDS*, where *N* is the number of valves and unidentified fragments per gram of sediment, *D* is the dry density of the sediment in g/cm³ and *S* is the sedimentation rate in cm/kyr. The OVAR corresponds to the benthic foraminifer accumulation rate (BFAR) of Herguera & Berger (1991), which has been suggested as a proxy for palaeoproductivity. The BFAR

Explanation of Plate 1

fig. 1. *Dutoitella?* sp., sample 171B-1049B-8H-5, 110–115 cm, LV, Juv., ×66, DMGUG.N.Atl.1. fig. 2. *Cardobairdia* sp., sample 171B-1049B-8H-4, 25–27 cm, RV, ×66, DMGUG.N.Atl.2. fig. 3. *Pterygocythereis* sp., sample 171B-1050C-11R-1, 146–149 cm, LV, ×38, DMGUG.N.Atl.3. fig. 4. *Bairdia* sp., sample 171B-1052E-22R-1, 112–115 cm, RV, Juv., ×62, DMGUG.N.Atl.4. fig. 5. *Abyssoocypris?* sp., sample 171B-1052E-27R-1, 98–102 cm, LV, Juv., ×86, DMGUG.N.Atl.5. fig. 6. *Apateloschizocythere?* sp., sample 171B-1052E-20R-6, 93–96 cm, LV, Juv., ×108, DMGUG.N.Atl.6. fig. 7. *Argilloecia* sp., sample 171B-1052E-20R-6, 93–96 cm, LV, ×76, DMGUG.N.Atl.7. fig. 8. *Aversovalva* sp. 1, sample 171B-1052E-20R-6, 93–96 cm, LV, ×113, DMGUG.N.Atl.8. fig. 9. *Aversovalva* sp. 2, sample 171B-1052E-25R-1, 113–117 cm, LV, ×113, DMGUG.N.Atl.9. fig. 10. *Bairdia* sp. 1, sample 171B-1052E-20R-6, 93–96 cm, RV, ×24, DMGUG.N.Atl.10. fig. 11. *Bairdia* sp. 2, sample 171B-1052E-22R-4, 111–114 cm, LV, Juv., ×52, DMGUG.N.Atl.11. fig. 12. *Brachyocythere?* sp., sample 171B-1052E-20R-6, 93–96 cm, LV, ×47, DMGUG.N.Atl.12. fig. 13. *Bythoceratina* sp., Sample 171B-1052E-22R-1, 112–115 cm, RV, ×43, DMGUG.N.Atl.13. fig. 14. *Bythocypris* sp., sample 171B-1052E-20R-6, 93–96 cm, RV, Juv., ×54, DMGUG.N.Atl.14. fig. 15. *Palmoconcha* sp., sample 171B-1052E-27R-1, 98–102 cm, LV, Juv., ×119, DMGUG.N.Atl.15. fig. 16. *Cytherella* sp., sample 171B-1052E-22R-1, 112–115 cm, RV, ×38, DMGUG.N.Atl.16. fig. 17. *Cytheropteron* sp., sample 171B-1052E-22R-1, 112–115 cm, RV, Juv., ×94, DMGUG.N.Atl.17. fig. 18. *Eucythere* sp. 2, sample 171B-1052E-22R-1, 112–115 cm, LV, Juv., ×94, DMGUG.N.Atl.18. fig. 19. *Eucythere* cf. *circumcostata* Whatley and Coles, 1987, sample 171B-1052E-22R-1, 112–115 cm, RV, Juv., ×113, DMGUG.N.Atl.19. fig. 20. *Eucytherura* sp. 1, sample 171B-1052E-22R-1, 112–115 cm, LV, ×109, DMGUG.N.Atl.20. fig. 21. *Eucytherea* sp. 2, Sample 171B-1052E-22R-1, 112–115 cm, RV, ×119, DMGUG.N.Atl.21.





hypothesis is based on the assumption that the number of benthic foraminifera produced per cm² and kyr is related to the supply of organic material to the seafloor which in turn is positively correlated with the productivity in the photic zone (Herguera & Berger, 1991). An exception is in areas with a pronounced oxygen minimum zone such as the Oman Margin where Naidu & Malmgren (1995) showed that the BFAR values were negatively correlated with the productivity of surface waters during the Holocene. They suggested that this may be due to the influence of low dissolved oxygen concentrations on benthic foraminiferal assemblages. According to Naidu & Malmgren (1995), BFAR may not be generally taken as a measure of productivity.

OSTRACOD DISTRIBUTION

Most specimens recorded are juveniles, which makes precise taxonomic determinations difficult. Most species are represented by only a few individuals. All ostracod species recorded were blind and therefore indicative of palaeodepths exceeding 700–800 m (Benson, 1975).

Site 1052

Hole 1052E (29°57.08'N, 76°37.61'W) was drilled on the upper part of the Blake Nose at a water depth of 1343.5 m, being one of a suite of holes associated with the shallowest site of Leg 171B. It penetrated 175.8 m of Maastrichtian sediments, which, on the basis of lithology, can be divided into two subunits: (1) a late Maastrichtian interval of 87.0 m (1052E-18R-3, 0 cm, to 1052E-27R-2, 38 cm), consisting of greenish grey to light greenish grey nannofossil chalk with clay to clayey nannofossil chalk with metre-scale alternations between lighter and darker intervals; and (2) an early Maastrichtian interval of 88.8 m (1052E-27R-2, 38 cm, to 1052E-36R-3, 122 cm), consisting dominantly of light greenish grey to very light greenish grey nannofossil chalk to nannofossil chalk. The older subunit differs from the younger by generally being lighter and more carbonate-rich, by a higher frequency of bioturbated intervals and apparent slump deposits, and by the presence of inoceramid shell remains (Norris *et al.*, 1998).

The benthic foraminifera are represented by oligotaxic faunas in the Upper Cretaceous of Site 1052. *Eouvirgerina subsculptura* constitutes the dominant element in the benthic foraminiferal community. This species is common in high trophic levels in the

Maastrichtian of the Tethyan realm and is thus indicative of high productivity over the Blake Nose (Norris *et al.*, 1998).

A total of 14 samples was investigated for ostracods from the Maastrichtian of Hole 1052E. Five of the samples were taken from the *G. falsostuarti*–*G. gansseri* Zone, two from the *R. fructicosa* Zone and seven from the *A. mayaroensis* Zone (Table 2). The five samples of the *G. falsostuarti*–*G. gansseri* Zone (all within the lower Maastrichtian lithological subunit) are impoverished with respect to ostracods and contain mainly rare specimens of *Cytherella* spp. The species richness and abundance of ostracods are on average considerably higher in the nine samples of the *R. fructicosa* and *A. mayaroensis* Zones (all within the upper Maastrichtian lithological subunit) (Table 2). From these nine samples a total of 594 specimens (not fragments) were recorded and a total of 47 species identified. Many species are represented by only a few or single specimens. The most dominant taxa are *Cytherella* spp. (total relative abundance of 30.3%), *Kriithe* spp. (total relative abundance of 20.2%) and *Argilloecia* sp. 1 and spp. (total relative abundance of 9.6%). Other relatively common species are '*Brachycythere*' sp., *Bairdia* spp., *Cytheropteron* spp. and *Platyleberis* sp. Rarer species with a total relative abundance >1% include *Aversovalva* spp., *Bythoceratina* sp., *Eucythere* cf. *circumcostata*, *Eucytherura* sp. 2, *Paraphysocythere* sp., *Imhotepia* sp. and *Profundobythere?* sp. Of additional interest is the relatively high diversity of cytherurid species (six species of *Eucytherura* and four species of *Hemiparacytheridea*), although most of these species are represented by single or very few specimens.

Figure 2A shows the variation in OVAR among the samples studied from Hole 1052E. In each calculation of the OVAR, the sedimentation rate was set to 2.2 cm/kyr, which is the mean sedimentation rate for the Maastrichtian and Danian (Norris *et al.*, 1998). In all the calculations, the dry density was set to 1.566 g/cm³, which is the mean density in the interval from core section 1052E-20R-1 to 1052E-35R-1 (Norris *et al.*, 1998). In the *G. falsostuarti*–*G. gansseri* Zone, the OVAR is very low and ranges between 0.15 and 0.43. The OVAR increases across the zonal boundary between the *G. falsostuarti*–*G. gansseri* and *R. fructicosa* zones and reaches a value of 7.97 in the oldest sample of the *R. fructicosa* Zone (1052E-27-1: 98–102) before it decreases to 0.81 in the subsequent sample of this zone (1052E-26R-1: 138–143 cm). The OVAR increases across the zonal boundary between the *R. fructicosa* and *A. mayaroensis*

Explanation of Plate 2.

fig. 1. *Eucytherura* sp. 3, sample 171B-1052E-22R-1, 112–115 cm, LV, ×124, DMGUG.N.Atl.22. fig. 2. *Eucytherura* sp. 4, sample 171B-1052E-22R-1, 112–115 cm, LV, ×110, DMGUG.N.Atl.23. fig. 3. *Eucytherura* sp. 5, sample 171B-1052E-25R-1, 113–117 cm, RV, ×134, DMGUG.N.Atl.24. fig. 4. *Eucytherura* sp. 6, sample 171B-1052E-26R-1, 138–143 cm, LV, ×134, DMGUG.N.Atl.25. fig. 5. *Hemiparacytheridea* sp. 1, sample 171B-1052E-20R-4, 111–114 cm, LV, ×120, DMGUG.N.Atl.26. fig. 6. *Hemiparacytheridea* sp. 2, sample 171B-1052E-20R-4, 111–114 cm, RV, ×96, DMGUG.N.Atl.27. fig. 7. *Hemiparacytheridea* sp. 3, sample 171B-1052E-20R-6, 93–96 cm, RV, ×124, DMGUG.N.Atl.28. fig. 8. *Hemiparacytheridea* sp. 4, sample 171B-1052E-22R-1, 112–115 cm, LV, ×96, DMGUG.N.Atl.29. fig. 9. *Hemiparacytheridea* sp. 5, sample 171B-1052E-31R-CC, RV, ×110, DMGUG.N.Atl.30. fig. 10. *Kriithe* sp., sample 171B-1052E-22R-1, 112–115 cm, RV (of carapace), Juv., ×96, DMGUG.N.Atl.31. fig. 11. *Mayburya pulchra* Coles & Whatley, 1989, sample 171B-1052E-27R-1, 98–102 cm, LV, ×110, DMGUG.N.Atl.32. fig. 12. *Paracypris* sp., sample 171B-1052E-22R-1, 112–115 cm, LV, ×82, DMGUG.N.Atl.33. fig. 13. *Argilloecia* sp. 1, sample 171B-1052E-22R-1, 112–115 cm, LV, ×89, DMGUG.N.Atl.34. fig. 14. *Paraphysocythere* sp., sample 171B-1052E-22R-1, 112–115 cm, LV, ×129, DMGUG.N.Atl.35. fig. 15. *Imhotepia* sp., sample 171B-1052E-22R-1, 112–115 cm, LV, ×62, DMGUG.N.Atl.36. fig. 16. *Profundobythere?* sp., sample 171B-1052E-20R-6, 93–96 cm, LV, ×62, DMGUG.N.Atl.37. fig. 17. *Phacorhabdotus* sp. 3, sample 171B-1052E-20R-4, 111–114 cm, RV, ×62, DMGUG.N.Atl.38. fig. 18. *Propontocypris* sp., sample 171B-1052E-22R-1, 112–115 cm, LV, Juv., ×96, DMGUG.N.Atl.39. fig. 19. *Semicytherura* sp., sample 171B-1052E-22R-1, 112–115 cm, RV, ×96, DMGUG.N.Atl.40. fig. 20. *Platyleberis* sp., sample 171B-1052E-22R-1, 112–115 cm, LV, Juv., ×122, DMGUG.N.Atl.41. fig. 21. Unidentified sp. 1, sample 171B-1052E-22R-1, 112–115 cm, RV, ×120, DMGUG.N.Atl.42.

Table 2. Maastrichtian ostracods from Hole 1052E.

Stage	MAASTRICHTIAN													
	early							late						
Zone	<i>G. falsostuarti</i> - <i>G. gansseri</i>				<i>R. fructicosa</i>			<i>A. mayaroensis</i>						
Polarity interval	C31R				C31N				C30N					
Site-Hole	1 0 5 2 E													
Core-section	35R-1	34R-1	31R-cc	31R-1	29R-1	27R-1	26R-1	25R-1	24R-1	23R-2	22R-1	20R-6	20R-4	20R-1
Taxon\Interval (cm)	110-113	74-77		116-120	121-125	98-102	138-143	113-117	109-113	117-120	112-115	93-96	111-114	100-103
<i>Cytherella</i> spp.	2	1	1	4	1	8	2	8		4	41	40	40	37
" <i>Brachycythere</i> " sp.			1			9				5	5	14	9	11
<i>Hemiparacytheridea</i> sp. 5			1											
<i>Argilloecia</i> sp. 1						4		1			6	4	2	4
<i>Krithe</i> spp.						3	2	2			53	25	23	12
<i>Bairdia</i> spp. (juvs.)						2					10	3	9	2
<i>Eucytherura</i> sp. 1						1					2			1
<i>Eucytherura</i> sp. 2						3		1			1		1	4
<i>Imhotepia</i> sp.						2	1	1			5	4	4	
<i>Profundocythere?</i> sp.						1	1	3			3	4	3	
<i>Bythocypris</i> sp.						1						3		
<i>Aversovalva</i> sp. 2						1		2						
<i>Aversovalva</i> spp.						6								
<i>Abyssocypris?</i> sp.						1								
<i>Mayburya pulchra</i>						1								
<i>Palmoconcha</i> sp.						1								
Unidentified sp. 7						1								
Unidentified sp. 8						1								
<i>Eucytherura</i> sp. 6							1							
<i>Cytheropteron</i> spp.								2	1	1	3	3	4	3
<i>Platyleberis</i> sp.								2		2	4	2	2	4
<i>Eucytherura</i> sp. 5								1						
Unidentified sp. 6								1						
<i>Argilloecia</i> spp.										4	11	11	2	8
Unidentified sp. 5										1				
<i>Paraphysocythere</i> sp.											3	1	2	1
<i>Eucythere</i> cf. <i>circumcostata</i>											3	1	1	1
<i>Eucythere</i> sp. 2											3			1
<i>Macrocypris</i> sp.											3			1
<i>Bythoceratina</i> sp.											2	2	2	
Unidentified sp. 1											3			
<i>Hemiparacytheridea</i> sp. 4											3			
<i>Propontocypris</i> sp.											2			
<i>Semicytherura</i> sp.											2			
<i>Eucytherura</i> sp. 4											2			
<i>Eucytherura</i> sp. 3											1			
<i>Paracypris</i> sp.											1			
Unidentified sp. 2											1			
Unidentified sp. 3											1			
Unidentified sp. 4											1			
<i>Bairdia</i> sp.1												2		3
<i>Hemiparacytheridea</i> sp. 3												2		
<i>Apateloschizocythere?</i> sp.												1		
<i>Aversovalva</i> sp. 1												1		
<i>Bairdia</i> sp. 2													1	
<i>Hemiparacytheridea</i> sp. 1													1	
<i>Hemiparacytheridea</i> sp. 2													1	
<i>Phacorhabdotus</i> sp. 3													1	
Unidentified fragments	1		1		1	24	4		1	18	39	42	18	28
Number of specimens (not fragments)	2	1	3	4	1	46	7	24	1	17	175	123	108	93
Ostracod valve accumulation rate (OVAR)	0.37	0.15	0.43	0.38	0.22	7.97	0.81	3.85	0.39	5.0	18.46	19.26	24.62	17.63
Number of taxa	1	1	3	1	1	17	5	11	1	6	27	18	18	15

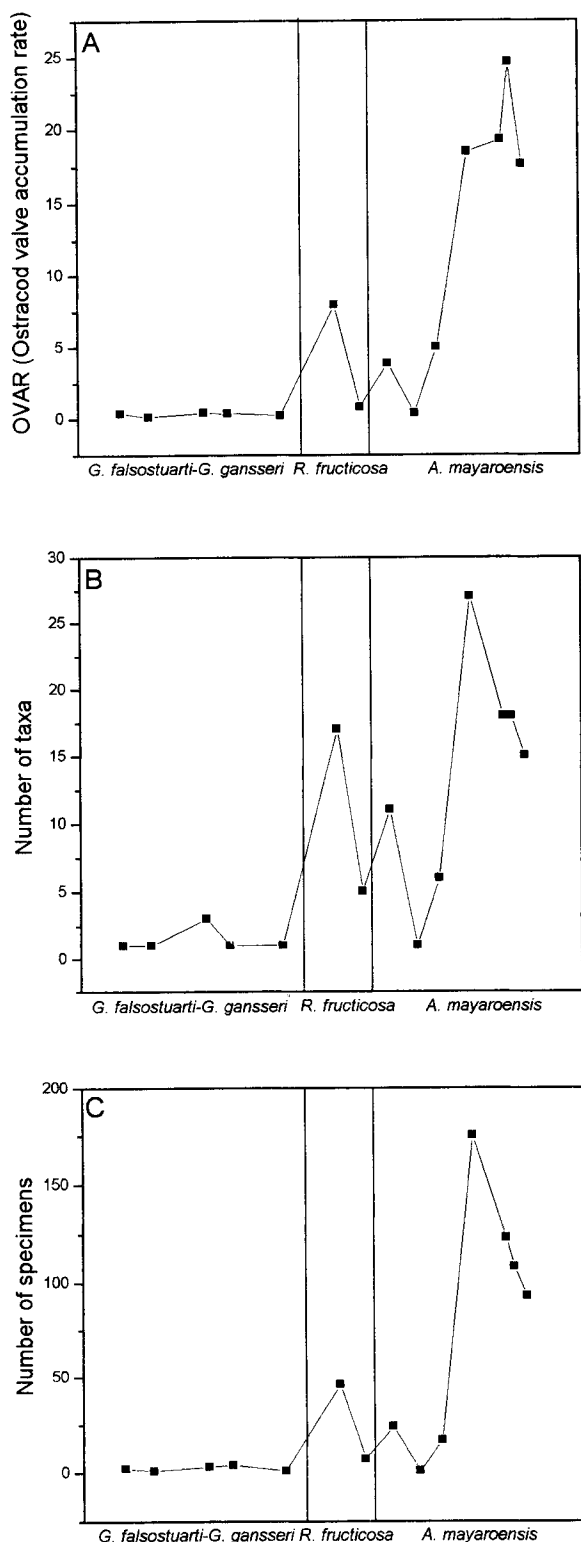


Fig. 2. Faunal analysis of the 14 samples studied from the Maastrichtian of Hole 1052E. (A) Ostracod valve accumulation rate (OVAR in number of specimens/cm²/ka) in each sample. (B) Number of species/taxa in each sample. (C) Number of specimens in each sample.

zones and attains a value of 3.85 in the oldest sample of the *A. mayaroensis* Zone (1052E-25R-1: 113–117 cm). The OVAR drops in the second oldest sample of this zone (1052E-24R-1: 109–113 cm) to a value of 0.39, before it gradually increases to 24.62 in the subsequent four samples of this zone. The OVAR of the youngest sample of the *A. mayaroensis* Zone is 17.63 (see Table 2; Fig. 2A).

The variation in the number of species and specimens among the samples studied in Hole 1052E follows an almost identical pattern to the variation in OVAR (Fig. 2A–C). It can possibly be inferred that the variation in OVAR is related to the variation in productivity, with relatively higher productivity in the late Maastrichtian than the early Maastrichtian of Hole 1052E. Alternatively, the differences in OVAR between the early and late Maastrichtian are due to significantly lower oxygen concentrations at the sediment–water interface in the early Maastrichtian. It cannot be ruled out, however, that part of the differences observed between the early and late Maastrichtian ostracods are due to the effects of dilution from variations in the sedimentation rate. It is also possible that the more impoverished ostracod fauna of the early Maastrichtian (compared with the late Maastrichtian fauna) is a result of selective removal of taxa by winnowing or dissolution.

Site 1050

Hole 1050C (30°6.00'N, 76°14.10'W) was drilled at a water depth of 2296.5 m and represents an addendum to Holes 1050A and 1050B. It was obtained to recover an equivalent sequence of the Cretaceous that was sampled at the shallower Site 1052. Five late Maastrichtian samples from the *A. mayaroensis* Zone were studied for ostracods from a lithological subunit consisting of nannofossil claystone, calcareous nannofossil claystone and nannofossil foraminiferal chalk. A total of 117 specimens (not fragments) were recorded and 14 different species identified (Table 3). The most abundant species are *Cytherella* sp(p). (total relative abundance 47.8%), *Krithe* spp. (total relative abundance 23.1%) and *Argilloecia* sp. 1 and spp. (total relative abundance 12.0%). Other species are represented by only a few or single specimens. *Cardobairdia* sp. and *Pterygocythereis* sp. are two species recorded in Hole 1050C that were not recorded in Hole 1052E. *Cardobairdia* is a deep-water genus common in the Caribbean Tertiary (Van den Bold, 1974) and also elsewhere in the deep sea.

Site 1049

Site 1049 represents a reoccupation of DSDP Site 390, which was drilled on the eastern margin of the Blake Nose 10 km downslope from Site 1050. It represents the deepest site of Leg 171B. Hole 1049B (30°08.54'N, 76°06.73'W) was drilled at a water depth of 2670.8 m. Five samples were studied for ostracods from the *R. fructicosa* and *A. mayaroensis* zones of the late Maastrichtian of this core. They were obtained from a lithological subunit characterized by greenish grey light grey, and pale green clayey nannofossil ooze and clayey nannofossil chalk which is laminated to slightly bioturbated. Ostracods were rare in these samples, with a total of 25 specimens recorded and eight species identified (Table 4). Nine unidentified fragments of ostracods were also recorded. *Cytherella* sp(p). is the dominant species with a total abundance of 52.0%. *Cardobairdia*, with a

Table 3. Maastrichtian ostracods from Hole 1050C.

Stage	MAASTRICHTIAN				
Zone	<i>A. mayaroensis</i>				
Polarity interval	C 3 0 N				
Site-Hole	1 0 5 0 C				
Core-section	11R-2	11R-2	11R-2	11R-1	11R-1
Taxon\Interval (cm)	75-78	52-55	23-27	146-149	102-105
<i>Krithe</i> spp.	7	7	8	1	4
<i>Argilloecia</i> sp. 1	1	1	1	2	2
<i>Argilloecia</i> spp.	1	1		1	4
<i>Cardobairdia</i> sp.	1			1	
<i>Platyleberis</i> sp.	1		1	1	
<i>Cytherella</i> sp(p).		26	11	7	12
" <i>Brachycythere</i> " sp		4		1	
<i>Bairdia</i> sp. 1		1		1	
<i>Paraphysocythere</i> sp.		1			
<i>Eucythere</i> sp. 2		1	1		
<i>Pterygocythereis</i> sp.				1	1
<i>Cytheropteron</i> spp.				1	
<i>Profundocythere</i> sp.					1
<i>Eucytherura</i> sp. 7					1
Unidentified fragments	7	11	5	8	15
Number of specimens (not fragments)	11	42	22	17	25
Ostracod valve accumulation rate (OVAR)	0.95	2.64	1.68	1.52	2.56
Number of taxa	5	8	5	10	7

Table 4. Maastrichtian ostracods from Hole 1049B.

Stage	MAASTRICHTIAN				
Zones	<i>R. fructicosa</i> - <i>A. mayaroensis</i>				
Polarity interval	C 3 0 N ?				
Site-Hole	1 0 4 9 B				
Core-section	8R-5	8R-5	8R-4	8R-4	8R-3
Genus\Interval (cm)	110-115	10-12	115-117	25-27	85-87
<i>Cardobairdia</i> sp.	1			2	1
<i>Cytherella</i> sp(p).	6	3	1	3	
<i>Bairdia</i> sp. juv.	1	1			
<i>Dutoitella?</i> sp. juv.	1				
<i>Phacorbabdotus</i> sp.4	1				
<i>Platyleberis</i> sp.	1				
<i>Pterygocythereis</i> sp.		2			
<i>Krithe</i> spp.		1			
Unidentified fragments		1		6	2
Number of specimens (not fragments)	11	7	1	5	1
Ostracod valve accumulation rate (OVAR)	0.63	0.16	0.02	0.21	0.05
Number of taxa	6	4	1	2	1

total of four specimens and a total relative abundance of 16%, is the second most abundant species. Other species are represented by one or two specimens only.

A PALAEOBATHYMETRIC COMPARISON OF THE LATE MAASTRICHTIAN OSTRACOD FAUNAS OF SITES 1049, 1050 AND 1052

On the basis of benthic foraminifers, Norris *et al.* (1998) estimated the Late Cretaceous palaeodepth of Sites 1052, 1050 and 1049 as middle bathyal (600–1000 m), lower bathyal (1000–2000 m) and lower bathyal (1000–2000 m), respectively. Site 1049 is deepest and is situated approximately 10 km downslope from Site 1050 on the Blake Nose. The following samples were included in the faunal palaeobathymetrical comparison: the five samples of Hole 1050B from the *A. mayaroensis* Zone; the five samples of Hole 1049B that derive from the *R. fructicosa*-*A. mayaroensis* zones; and the nine samples of Hole 1052E that belong to the *R. fructicosa* and *A. mayaroensis* zones. It is interesting to note that cytherurids (*Eucytherura*, *Hemiparacytheridea*) are relatively diverse in Hole 1052E, but are either very rare (*Eucytherura* sp. 7 in Hole 1050C) or not recorded in the deeper Holes 1050C and 1049B (Tables 2–4). The deep-water genus *Cardobairdia* and the genus *Pterygocythere* were recorded in Holes 1050C and 1049B, but not in Hole 1052E.

The mean OVAR, the mean number of taxa and the mean number of specimens were calculated for the late Maastrichtian of each of Holes 1049B, 1050C and 1052E. Each of these parameters is highest in Hole 1052E and lowest in Hole 1049B, and are thus negatively correlated with palaeodepth (Figs 3A–C). The palaeobathymetrical differences in OVAR and abundance (number of specimens) are probably not explained in terms of the effect of dilution of the ostracods by a higher sedimentation rate at greater depths. Norris *et al.* (1998) estimated the mean sedimentation rate for the Maastrichtian of Sites 1052, 1050 and 1049 to be 2.2, 1.7 and 0.36 cm/kyr, respectively. Thus there is also a negative correlation between the sedimentation rate and the palaeodepth. Alternatively, it may be suggested that the winnowing action of bottom currents may be responsible for the lower abundance of ostracods at the deeper sites. There is, however, no evidence of differential assemblage sorting among the various sites as the ontogenetic distribution of the various ostracod species are similar at all sites.

Hole 1052E and 1050C are both dominated by the genera *Cytherella*, *Krithe* and *Argilloecia* (Tables 2 and 3). The most dominant species of Hole 1049B are *Cytherella* spp. (Table 4). Figure 3D shows the variation in the relative abundance of the most dominant species among the three holes. There is a greater dominance from the sum of the three dominant genera *Cytherella*, *Krithe* and *Argilloecia* in the late Maastrichtian of Hole 1050C than in Hole 1052E. The observed increase in dominance with an increase in palaeodepth is further noted for the genus *Cytherella*. The relative abundance of *Cytherella* is approximately 30% in Hole 1052E and approximately 50% in Holes 1050C and 1049B (Fig. 3D). An increase in dominance and a decrease in diversity generally imply increased stress levels. The higher dominance, particularly by *Cytherella* at the deeper sites, may possibly be explained in terms of environmental stress related to low oxygen content. According to Whatley (1991), Boomer & Whatley (1992) and Whatley *et al.* (1994), cytherellids may flourish under low oxygen conditions (contrary to many other ostracod taxa) due to their filter-feeding habit in that they manage to obtain a greater volume of water which they circulate

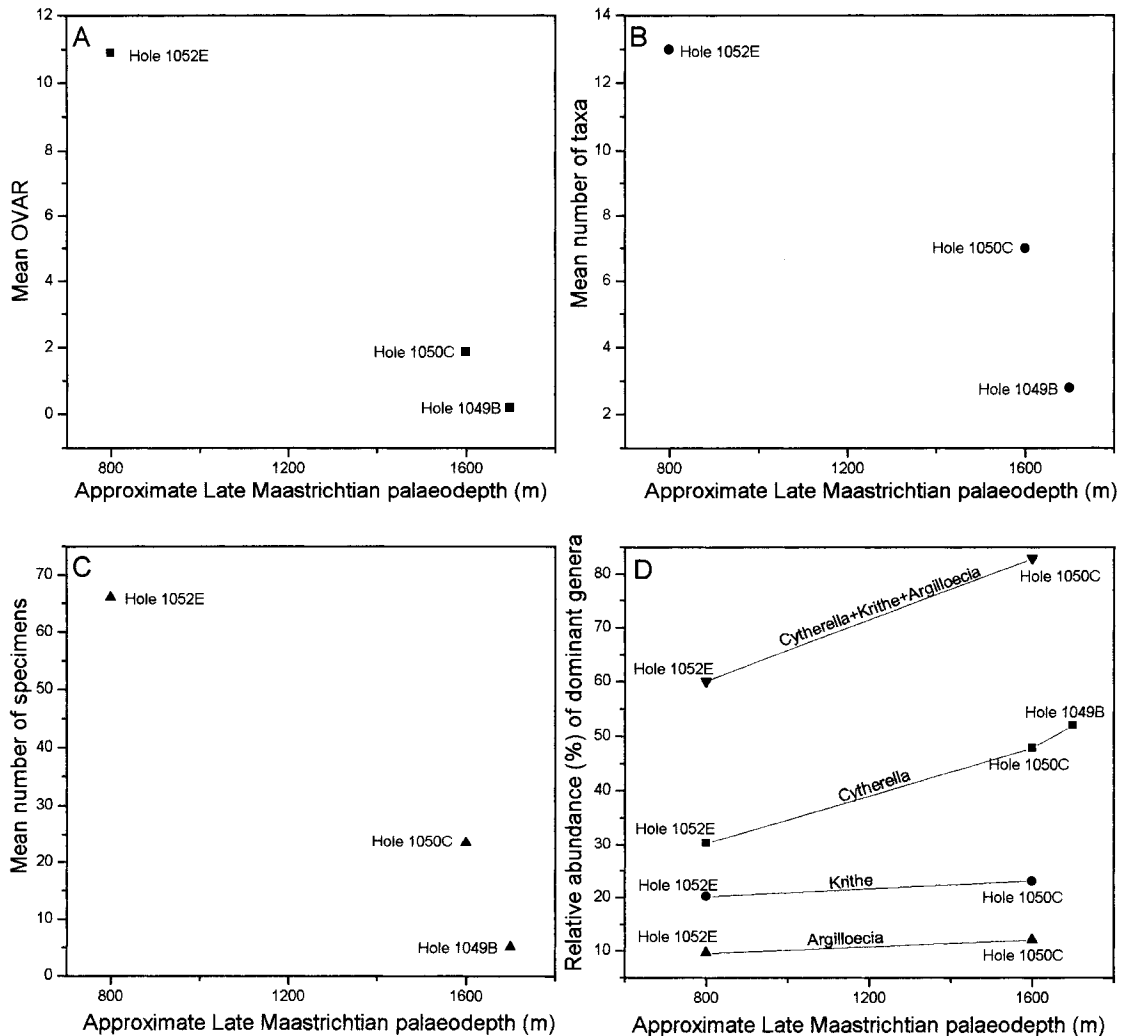


Fig. 3. Palaeobathymetric analysis for the Late Maastrichtian of the nine samples from the *R. fructicosa* and *A. mayaroensis* Zones of Hole 1052E, the five samples from the *A. mayaroensis* Zone of Hole 1050C and the five samples from the *R. fructicosa*–*A. mayaroensis* zones of Hole 1049B. (A) Mean ostracod valve accumulation rate (OVAR in number of specimens/cm²/ka) (for each hole) plotted against palaeodepth. (B) Mean number of species/taxa (for each hole) plotted against palaeodepth. (C) Mean number of specimens for each hole plotted against palaeodepth. (D) Mean relative abundance of the dominant genera *Cytherella*, *Krithe* and *Argilloecia* (for the three holes) plotted against palaeodepth.

across their respiratory surface. That the oxygen content was relatively low during the Maastrichtian of Sites 1049 and 1050 is consistent with the observations from benthic foraminifers, where the dominance of *Nuttalides truempyi* and the low numbers of *Gavelinella beccariformis* may indicate that the benthic community was indeed influenced by low oxygen, warm, saline, deep water circulation (Norris *et al.*, 1998). Thus it is possible that the differences in OVAR among the three holes are largely related to oxygen concentrations at the sediment–water interface.

There may be other explanations that possibly tie together the observed palaeobathymetric differences in species composition, OVAR, number of species and number of specimens among the various sites investigated, related to, for example, palaeoproductivity and palaeobathymetric differences in food supply and sediment characteristics.

PALAEOBIOGEOGRAPHY OF LATE CRETACEOUS DEEP-SEA OSTRACODS IN THE ATLANTIC AND SOUTHERN OCEANS

Table 5 lists previous records of the various ostracod genera identified from the Maastrichtian of the present sites studied. The previous records relate to studies of Campanian–Maastrichtian deep-sea ostracods from the North and South Atlantic and from the Southern Ocean and off southeast Africa (see Benson, 1975, 1977; Damotte, 1979, 1988; Dingle, 1981; Swain, 1973, 1978, 1983; Majoran *et al.*, 1997, 1998; Majoran & Widmark, 1998). The comparison with Dingle (1981) relates only to those species from his assemblages recovered from samples with an estimated palaeodepth > 500 m. The following taxonomic interpretations are presently made: *Neocythere* sp. 19 in Damotte, 1988 belongs to *Paraphysocythere* Dingle, (1969); *Bythocypris* of Sites 689 and 698 in Majoran *et al.* (1997) and

Table 5. Palaeobiogeographical distribution of ostracod genera recorded/identified from the Maastrichtian of ODP Sites 1049, 1050 and 1052 compared with previous records of Campanian–Maastrichtian deep-sea ostracods from the Atlantic, Southern Oceans and off southeast Africa.

Ocean: Genus/location: site and/or reference	North Atlantic Ocean			South Atlantic Ocean				Southern Ocean	SE Africa	
	(1)	(2)	(3)	(4)	Sites 525–29 ⁽⁵⁾	Site 327 ⁽⁵⁾	Site 356 ⁽⁵⁾	Site 698 ⁽⁵⁾	Site 689 ^(5, 6)	(7)
<i>Abyssobairdia?</i>									X	
<i>Abyssocypris</i>								X	X	X
<i>Apateloschizocythere</i>									X	
<i>Argilloecia</i>				X	X	X	X	X	X	
<i>Aversovalva</i>		X			X	X	X	X	X	
<i>Bairdia</i>				X	X		X	X	X	
' <i>Brachycythere</i> '		X	X							X
<i>Bythoceratina</i>	X		X							
<i>Bythocypris</i>				X	X	X	X			
<i>Cardobairdia</i>										
<i>Cytherella</i>	X	X	X	X	X		X	X	X	X
<i>Cytheropteron</i>				X	X			X	X	X
<i>Dutoitella?</i>						X	X	X	X	X
<i>Eucythere</i>					X			X	X	
<i>Eucytherura</i>					X					X?
<i>Hemiparacytheridea</i>							X			
<i>Imhotepia</i>			X							
<i>Krithe</i>				X	X		X		X	X
<i>Macrocypis</i>				X			X		X	
<i>Mayburya</i>					X					
<i>Palmoconcha</i>										
<i>Paracypris</i>		X							X	X
<i>Paraphysocythere</i>		X?			X	X				
<i>Phacorhabdotus</i>		X	X	X	X	X	X	X	X	
<i>Platyleberis</i>										
<i>Profundocythere</i>					X					
<i>Propontocypris?</i>										
<i>Pterygocythereis</i>										
<i>Semicytherura</i>										

(1) Damotte (1979), (2) Damotte (1988), (3) Swain (1978, 1983), (4) Benson (1975, 1977), (5) Majoran *et al.* (1997, 1998), (6) Majoran & Widmark (1998) and (7) Dingle (1981).

Majoran *et al.* (1998) belongs to *Abyssocypris* van den Bold, 1974; *Phacorhabdotus* aff. *marssoni* (Bonnema) in Swain (1978) belongs to *Imhotepia* Gründel, 1969, and *Bythocypris richards-bayensis* Dingle, 1981 belongs to *Abyssocypris* van den Bold, 1974.

Of the 28 genera listed in Table 5, eight have been previously reported from the Campanian–Maastrichtian of the North Atlantic, 17 from the South Atlantic, 14 from the Southern Ocean and 8 from off Southeast Africa. The relatively few ostracod genera, in common with previous studies of the Late Cretaceous North Atlantic, is most certainly due to the limited material published from this region (Damotte, 1979, 1988; Swain, 1978, 1983). It is, however, interesting to note and focus on the relatively large number of genera in common with a single site from a high southern latitude, i.e. Site 689 on the Maud Rise (palaeolatitude *c.* 70°S; palaeodepth *c.* 1200 m, see Zachos & Arthur, 1986; Thomas, 1990) in the Southern Ocean (Majoran *et al.*, 1997; Majoran & Widmark, 1998). Of the 14 genera in common between Site 689 and the present sites, particularly *Argilloecia*, *Cytherella*, *Krithe* and *Eucythere* appear to be relatively abundant at both locations. *Abyssocypris* and *Dutoitella* are more common at Site 689 (Majoran *et al.*, 1997;

Majoran & Widmark, 1998). In the present study of the palaeobiogeography of Late Cretaceous deep-sea ostracods of the Atlantic and Southern Oceans, it must be emphasized that this is a comparison of the data from the present Blake Nose sites and existing information extracted from the references given in Table 5. In this comparison, the genera *Cardobairdia*, *Imhotepia*, *Palmoconcha*, *Platyleberis*, *Propontocypris?*, *Pterygocythereis* and *Semicytherura* were found only in the present Blake Nose sites (*Imhotepia* also from Hole 392A in the Western North Atlantic; see Swain, 1978) and may tentatively be suspected to have a rather restricted low latitudinal distribution in the Late Cretaceous deep sea, as far as can be judged from the present restricted comparison. This concerns also *Bythoceratina*, which is restricted to the North Atlantic (Table 5). *Agulhasina*, *Ginginella* and *Pennyella* seem to be confined to high latitudes in the South Atlantic (see Majoran *et al.*, 1998; Majoran & Widmark, 1998). Remarkable is the presence of the thermophilic genus *Cytherelloidea* at Site 689 (Majoran *et al.*, 1997), in contrast with its absence at mid-latitude sites in the South Atlantic (Majoran *et al.*, 1997, 1998) and from the present sites. This may be one example of ostracod taxa that have largely changed their geographical distribution in the deep sea since the

Late Cretaceous. It is, however, important to point out that the faunal differences and similarities among the various sites compared may not only be due to palaeogeography. Palaeoceanographical aspects such as the oxygen content of various water masses have not been analysed in this section, but are also most certainly important as the results of the study of the present sites seem to show.

DISCUSSION

The replacement of the depleted ostracod assemblage of the *G. falsostuarti*–*G. gansseri* zones by the generally richer and more diversified ostracod assemblage of the *R. fructicosa* and *A. mayaroensis* zones in Hole 1052E occurs near the top of magnetostratigraphic subchron C31R (see Table 2). The replacement seems to post-date the short-lived global palaeoceanographic episode observed in southern high latitudes in the early Maastrichtian between about 71 and 70 Ma (see MacLeod, 1994). The boundary between subchrons C31R and C31N is dated to 68.657 Ma (Gradstein *et al.*, 1994).

It is important to note that the replacement of the ostracod assemblages seems to coincide with the disappearance of inoceramids. Inoceramid prisms occur in samples 1052E-35-1R, 110–113 cm to 1052E-29R-1, 121–125 cm, but were not found in samples 1052E-27R-1, 98–102 cm to 1052E-20R-1, 100–103 cm (Norris *et al.*, 1998). According to MacLeod (1994), inoceramids were adapted to life in warm, oxygen-deficient conditions on a substrate which had a low population of burrowing organisms and few or no shell-crushing predators. Their extinction was possibly a consequence of the global change in oceanic circulation during which warm, oxygen-poor bottom water was replaced by more vigorously circulating, cool, oxygenated Antarctic bottom water (MacLeod, 1994). That extinction was also accompanied by an increase in the populations of burrowing organisms. MacLeod (1994) proposed three changes that may have contributed to the paleoceanographical reorganization: (1) the subsidence of topographic barriers in the deeper parts of the Atlantic during the Late Cretaceous that could have created pathways for deep water circulation; (2) a general cooling trend of surface and intermediate waters between 74 and 68 Ma that could have created a source of cold, Antarctic bottom water; and (3) a mid-Maastrichtian regression that restricted the geographical extent of shallow, low and mid-latitude epicontinental seas that could serve as source regions for the formation of warm, saline bottom waters. A sea-level drop within chron C31R corresponding to the second-order cycle of Haq *et al.* (1987) is estimated to be 50 m in sections in Alabama (see Barrera, 1994 and references cited therein).

It is possible that the observed changes in the composition of ostracod assemblages across subchrons C31R to C31N are, in part, due to the global palaeoceanographic changes responsible for the extinction of the inoceramids. A lowering of the sea level across the early and late Maastrichtian boundary may, for example, have resulted in an increase in ventilation and the disappearance of the oxygen minimum zone from the location of Site 1052 and may also explain the increase in OVAR.

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