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 δ¹⁸O 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 ⁸⁷Sr/⁸⁶Sr 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 palaeocenographic 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 microfauna. Benson et al. (1984, 1985) have previously shown the usefulness of ostracod studies in detecting major palaeocenographic 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).
Multispecific categories, e.g. coated with gold and photographed under a Zeiss Digital Microscope DSM 940 at the Department of Marine Geology, Earth Sciences Centre, Gothenburg University.

**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. One valve was counted as fragments. The specimens were mainly identified to the level of the species, although some featureless genera, counted as fragments. The specimens were mainly identified to the level of the species, although some featureless genera, counted as fragments. 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 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**

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 | 27-1    | 138-143       | 378.48       | 46.99      | 7   | 4  |
| 1052E | 29-1    | 121-125       | 387.68       | 30.26      | 46  | 24 |
| 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       | 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  |

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

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

**Table 1.** Samples of ODP Holes 1052E, 1050C and 1049B investigated for ostracods.
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 inorganic shell remains (Norris et al., 1998).

The benthic foraminifers are represented by oligotaxic faunas in the Upper Cretaceous of Site 1052. *Eouvigerina subsulptura* 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. falsostuartii-G. gansseri* Zone, two from the *R. fructicosa* Zone and seven from the *A. mayaroensis* Zone (Table 2). The five samples of the *G. falsostuartii-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%), *Krithe* spp. (total relative abundance of 20.2%) and *Argilloecia* sp. 1 and sp. (total relative abundance of 9.6%). Other relatively common species are *Brachycythere* spp., *Bairdia* sp., *Cytheropteron* spp. and *Platybleberis* sp. Rarer species with a total relative abundance > 1% include *Aversovalva* spp., *Bythoceratina* sp., *Eucythera* cf. *circumcostata*, *Eucythera* sp. *2*, *Paraphysocythere* sp., *Imhotepia* sp. and *Profundocythere* sp. Of additional interest is the relatively high diversity of *Cytheriduris* species (six species of *Eucythera* 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. falsostuartii-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. falsostuartii-G. gansseri* and *R. fructicosa* zones and reaches a value of 7.97 in the oldest sample of the *R. fructicosa* Zone (1052E-27: 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*
Table 2. Maastrichtian ostracods from Hole 1052E.

| Stage          | MAASTRICTIAN |          | late          |
|               | early |          |              |
| Zone          | G. falsostauri | G. gansseri | R. fructicose | A. mayaroensis |
| Polarity interval | C31R | C31N | C30N |
| Site-Hole     | 1052E |

| Core-section | 36R-1 | 34R-1 | 31R-CC | 31R-1 | 29R-1 | 27R-1 | 26R-1 | 25R-1 | 23R-1 | 22R-1 | 20R-1 | 20R-4 | 20R-1 |
| Core-section | 116-113 | 74-77 | 116-120 | 121-125 | 98-102 | 139-143 | 113-117 | 109-113 | 117-120 | 112-115 | 93-98 | 111-114 | 100-100 |
| Taxon/interval (cm) | 110-113 | 74-77 | 116-120 | 121-125 | 98-102 | 139-143 | 113-117 | 109-113 | 117-120 | 112-115 | 93-98 | 111-114 | 100-100 |

| Cytherella spp. | 2 | 1 | 4 | 1 | 8 | 2 | 8 | 4 | 41 | 40 | 40 | 37 |
| "Brachycythere" spp. | 1 | 9 | 5 | 5 | 14 | 9 | 11 |
| Hemiparacythereidae sp. 5 | 1 |
| Argilloecia sp. 1 | 4 | 1 | 6 | 4 | 2 | 4 |
| Kriithespp. | 3 | 2 | 2 | 53 | 25 | 23 | 12 |
| Bairdia sp. (juvs.) | 2 | 10 | 3 | 9 | 2 |
| Eucytherura sp. 1 | 1 | 2 | 1 |
| Eucytherura sp. 2 | 3 | 1 | 1 | 1 | 4 |
| Imhotepia sp. | 2 | 1 | 1 | 5 | 4 | 4 |
| Profundobitythere? sp. | 1 | 1 | 3 | 3 | 4 | 3 |
| Bythocypris sp. | 1 | 3 |
| Aversovalva sp. 2 | 1 | 2 |
| Aversovalva spp. | 6 |
| Abyssoecypri.s? sp. | 1 |
| Mayburya pulchra | 1 |
| Palmoconcha sp. | 1 |
| Unidentified sp. 7 | 1 |
| Unidentified sp. 8 | 1 |
| Eucytherura sp. 6 | 1 |
| Cytheropteron spp. | 2 | 1 | 1 | 3 | 3 | 4 | 3 |
| Platyleberis sp. | 2 | 2 | 4 | 2 | 2 | 4 |
| Eucytherura sp. 5 | 1 |
| Unidentified sp. 6 | 1 |
| Argilloecia spp. | 4 | 11 | 11 | 2 | 8 |
| Unidentified sp. 5 | 1 |
| Paraphysomythere sp. | 3 | 1 | 2 | 1 |
| Eucytherura cf. circumcostata | 3 | 1 | 1 | 1 |
| Eucytherure sp. 2 | 3 | 1 |
| Macrocypris sp. | 3 | 1 |
| Bythocaritina sp. | 2 | 2 | 2 |
| Unidentified sp. 1 | 3 |
| Hemiparacythereidae sp. 4 | 3 |
| Proproctocypris sp. | 2 |
| Semicytherura sp. | 2 |
| Eucytherura sp. 4 | 2 |
| Eucytherura sp. 3 | 1 |
| Paracypris sp. | 1 |
| Unidentified sp. 2 | 1 |
| Unidentified sp. 3 | 1 |
| Unidentified sp. 4 | 1 |
| Bairdia sp. 1 | 2 | 3 |
| Hemiparacythereidae sp. 3 | 2 |
| Apateloschizocythere? sp. | 1 |
| Aversovalva sp. 1 | 1 |
| Bairdia sp. 2 | 1 |
| Hemiparacythereidae sp. 1 | 1 |
| Hemiparacythereidae sp. 2 | 1 |
| Phacorhabdotus sp. 3 | 1 |
| Unidentified fragments | 1 | 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 |

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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
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.

Table 3. Maastrichtian ostracods from Hole 1050C.

| Stage | MAASTRICHTIAN |
|-------|----------------|
| Zone  | A. mayaroensis |
| 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 |
| Krithe spp. | 7 | 8 | 1 | 4 |
| Argilloecia sp. | 1 | 1 | 1 | 2 | 2 |
| Argilloecia sp. | 1 | 1 | 1 | 4 |
| Cardobairdia sp. | 1 | 1 |
| Platyleberis sp. | 1 | 1 |
| Cytherella sp. | 26 | 11 | 7 | 12 |
| "Brachycythere" sp | 4 | 1 |
| Bairdia sp. | 1 | 1 |
| Paraphysocythere sp. | 1 |
| Eucythere sp. | 1 |
| Pterygocythere sp. | 1 |
| Cytheropteryx sp. | 1 |
| Profundocythere sp | 1 |
| Eucythere sp. | 7 |
| Unidentified fragments | 7 | 11 | 5 | 8 | 15 |
| Number of specimens | 11 | 42 | 22 | 17 | 25 |
| Ostracod valve accumulation rate | 0.95 | 2.64 | 1.68 | 1.52 | 2.56 |
| (OVAR) |
| Number of taxa | 5 | 8 | 5 | 10 | 7 |

Table 4. Maastrichtian ostracods from Hole 1049B.

| Stage | MAASTRICHTIAN |
|-------|----------------|
| Zones | R. fructicosa-A. mayaroensis |
| Polarity interval | C 3 0 N |
| Site-Hole | 1 0 4 9 B |

| Core-section | 8R-5 | 8R-6 | 8R-4 | 8R-4 | 8R-3 |
|--------------|------|------|------|------|------|
| Genus Interval (cm) | 110-115 | 10-12 | 115-117 | 25-27 | 85-87 |
| Cardobairdia sp. | 1 | 2 | 1 |
| Cytherella sp. | 6 | 3 | 1 | 3 |
| Bairdia sp. | 1 |
| Dutoitella sp. | 1 |
| Pteynoma sp. | 1 |
| Platyleberis sp. | 1 |
| Krithe spp. | 2 |
| Unidentified fragments | 1 | 6 | 2 |
| Number of specimens | 11 | 7 | 1 | 5 | 1 |
| Ostracod valve accumulation rate | 0.63 | 0.16 | 0.02 | 0.21 | 0.05 |
| (OVAR) |
| Number of taxa | 6 | 4 | 1 | 2 | 1 |

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, Hemiparacythereidae) 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 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.
Palaeoenvironment of Maastrichtian ostracods

Fig. 3. Palaeobathymetric analysis for the Late Maastrichtian of the nine samples from the R. fructicosa and A. muyaroensis Zones of Hole 1052E, the five samples from the A. muyaroensis Zone of Hole 1050C and the five samples from the R. fructicosa–A. muyaroensis 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 Argilloeca (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: | North Atlantic Ocean | South Atlantic Ocean | Southern Ocean | SE Africa |
|-------|----------------------|----------------------|----------------|-----------|
| Genus/location: site and/or reference | (1) | (2) | (3) | Sites 525-29(5) | Site 327(5) | Site 356(5) | Site 698(5) | Sites 689(5, 6) | (7) |
| Abyssobairdia? | X | X | X | X | X |
| Abyssocypris | | X | X | X | X |
| Apateloschizocythere | | | | | |
| Argilloecia | | X | X | X | X |
| Aversovalva | X | X | X | X |
| Bairdia | X | X | X | X |
| 'Brachycythere' | X | X | | |
| Bythoceratina | X | X | | |
| Bythocypris | | X | X | X | X |
| Cardobairdia | | | | | |
| Cytherellida | X | X | X | X | X |
| Cythereopteron | | | | | |
| Dutoitella? | | | | | |
| Eucythere | X | X | X | X | X |
| Eucytherura | X | X | X | X |
| Henisiparacytheridea | X | | | | |
| Imhotepia | X | | | | |
| Krithe | X | X | X | X |
| Macrocycris | X | X | X | X |
| Maybarya | | X | | |
| Palmoconcha | X | | | | |
| Paracypris | | | X | X | X |
| Paraphysocythere | X? | X | X | X | X |
| Phacorhabdotus | | X | X | X | X |
| Platyleberis | | X | | | |
| Profundobythere | | | | | |
| Propontocypris? | | | | | |
| Pterygocythereis | X | | | | |
| Semicytherura | X | | | | |

(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 southwest 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, Cytherellida, 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. fruticosa* 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 10S2E-35-1R, 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 palaeoceanographical 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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REFERENCES

Barrera, E. 1994. Global environmental changes preceding the Cretaceous-Tertiary boundary: Early-late Maastrichtian transition. *Geology*, 22: 877–880.

Barrera, E. & Huber, B. T. 1990. Evolution of Antarctic waters during the Maastrichtian: foraminifer oxygen and carbon isotope ratios, Leg 113. *Proceedings of the Ocean Drilling Program, Scientific Results*, 113: 813–827.

Barrera, E., Salvini, S. M. & Thomas, S. 1997. Evidence for thermohaline-circulation reversals controlled by sea-level change in the latest Cretaceous. *Lethaia* 8: 69–83.

Benson, R. H. 1975. The origin of the psychrosphere as recorded in changes of deep-sea ostracode assemblages. *Lethaia* 8: 69–83.

Benson, R. H. 1977. The Cenozoic Ostracode faunas of the Sao Paulo Plateau and the Rio Grande Rise (DSDP Leg 39, Sites 356 and 357). *Initial Reports of the Deep Sea Drilling Project, 39*: 869–883.

Benson, R. H., Chapman, R. E. & Deck, L. T. 1984. Palaeoenvironmental changes of deep-sea ostracode assemblages across subchrons C31R to C31N are, in 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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Majoran, S. & Widmark, J. G. V. 1998. Response of deep-sea ostracod assemblages to Late Cretaceous palaeoceanographical changes: ODP Site 689 in the Southern Ocean. Cretaceous Research, 19: 843-872.

Majoran, S., Widmark, J. G. V. & Kucera, M. 1997. Palaeoecological preferences and geographical distribution of late Maastrichtian deep-sea ostracodes in the South Atlantic. Lethaia, 30: 53-64.

Majoran, S., Kucera, M. & Widmark, J. G. V. 1998. Maastrichtian deep-sea ostracods from DSDP/ODP Sites 327, 356, 525, 527, 528, 529, and 698 in the South Atlantic. Revista Española de Micropaleontología, 30: 59-73.

Naidu, P. D. & Malmgren, B. A. 1995. Do benthic foraminifer records represent a productivity index in oxygen minimum zone areas? An evaluation from the Oman Margin, Arabian Sea. Marine Micropaleontology, 26: 49–55.

Norris, D. J., Kroon, D., et al. 1998. Sites 1049-1052. Proceedings of the Ocean Drilling Program, Initial Reports, 171: 47–320.

Saltzman, E. S. & Barron, E. J. 1982. Deep circulation in the Late Cretaceous: oxygen isotope paleotemperatures from Inoceramus remains in D.S.D.P. cores. Palaeogeography, Palaeoclimatology, Palaeoecology, 40: 167–181.

Swain, F. M. 1973. Upper Cretaceous Ostracoda from the northwestern Pacific Ocean. Journal of Paleontology 47: 711–714.

Swain, F. M. 1978. Notes on Cretaceous Ostracoda from DSDP Leg 44, Sites 390 and 392. Initial Reports of the Deep Sea Drilling Project, 44: 921–937.

Swain, F. M. 1983. Cretaceous Ostracoda from DSDP and IPOD Deep-Sea Drilling Sites. In Maddocks, R. F. (Ed.), Applications of Ostracoda. Department of Geosciences, University of Houston: 520–528.

Thomas, E. 1990. Late Cretaceous through Neogene deep-sea benthic foraminifers (Maud Rise, Weddel Sea, Antarctica). Proceedings of the Ocean Drilling Program, Scientific Results, 113: 571–594.

Van den Bold, W. A. 1974. Taxonomic status of Cardobairdia (Van den Bold, 1960) and Abyssocypris n. gen.: two deepwater ostracode genera of the Caribbean Tertiary. Geoscience and Man, 6: 65–79.

Whatley, R. 1991. The platycopid signal: a means of detecting kenoxic events using Ostracoda. Journal of Micropalaeontology, 10: 181–185.

Whatley, R. C., Arias, C. F. & Comas-Rengifo, M. J. 1994. The use of Ostracoda to detect kenoxic events: a case history from the Spanish Toarcian. Geobios, 17: 733–741.

Zachos, J. C. & Arthur, M. A. 1986. Paleoceanography of the Cretaceous/Tertiary event: inferences from stable isotopic and other data. Paleoceanography, 1: 5–26.