

Global Change and the Biostratigraphy of North Atlantic Cainozoic deep water Ostracoda

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ABSTRACT. The biostratigraphical distribution of deep-sea (>1000m) Palaeocene to Recent benthonic Ostracoda, based on nannofossil NP and NN zones is presented. By excluding very rare species and those represented by juveniles, 184 species are used in constructing range tables from a total fauna for the interval of 230 species. The vertical distribution of these specimens clearly allows of the recognition of all the major stratigraphical units within the Cainozoic and is also sufficiently precise to distinguish most of the nannofossil zones. The principal criteria employed are the first and last appearances of taxa. While eminently possible to create a series of ostracod zones, it is argued that they are best employed in the recognition of particular levels within the existing nannofossil scheme. The interpretation of the range tables is complicated in places by large numbers of Lazarus taxa and also by the fact that many of the 'originations' actually record the arrival of immigrants from the Indo-Pacific.

Graphs of both simple and cumulative species diversity, and of origination and extinction rates, are used to demonstrate major faunal events such as the first arrival in the area, during the Middle Eocene, of cosmopolitan deep-sea species, or the very marked, but stepped, Palaeogene-Neogene faunal turnover. The distribution patterns of the Ostracoda record such global changes as the formation of the psychrosphere and the inception of a marked thermocline but they do not, as other authors have suggested, indicate a dramatic faunal turnover at the Eocene-Oligocene boundary. The more vigorous circulation patterns of the Oligocene, related to the opening of the Drake Passage, are reflected in enhanced ostracod diversity at that time. Elevated late Oligocene extinction rates may be correlated with cooling consequent upon the growth of polar ice. Similarly, Lower Miocene low levels of diversity may be associated with the closure of the Iberian Portal and the effective isolation of the Tethys. The deep-sea ostracods do not, for the most part, record such events as the mid-Pliocene warming nor Quaternary climatic fluctuations.

INTRODUCTION

Although the Cainozoic Ostracoda of the North Atlantic remain imperfectly known, compared with contemporary faunas from other ocean basins, they are relatively well documented. The Recent fauna was first studied by Brady (1880) using material collected by the *Challenger* expedition. This work was followed by that of Brady and Norman (1889). Tressler (1941) studied the ostracods from a transect across the North Atlantic, and Davies (1981) considered the Recent faunas of the Rockall Trough. Van Harten (1990) reports the discovery of many new taxa from the eastern slopes of the mid-Atlantic Ridge.

The principal studies of North Atlantic Tertiary and Quaternary ostracods are by: Ducasse and Peypouquet (1979) on the DSDP Leg 48 sites from the Rockall Plateau and the Bay of Biscay; Guernet (1982) on the Palaeocene and Eocene faunas of DSDP Site 390 in the Bahaama Basin; Cronin and Compton-Gooding (1987) on Eocene, Oligocene and Plio-Pleistocene faunas of DSDP Leg 95, from off the coast of New Jersey; and Whatley and Coles (1987) who studied the late Miocene to

Quaternary ostracoda of DSDP Leg 94 in the central North Atlantic. Other important studies are by Harpur (1985), who studied Quaternary ostracods from cores off the entrance to the Mediterranean, and Porter (1984) who studied Quaternary ostracods from the northern North Atlantic. Coles and Whatley (1989) describe many new taxa from the Palaeogene and Miocene of the area.

Although Whatley and Coles (1987) published range charts illustrating the biostratigraphical distribution of ostracods for the late Miocene to Quaternary (NN 9-21) interval, patchy and incomplete sample coverage has hitherto precluded this being achieved for the entire Cainozoic. However, recent studies of the Palaeogene and Miocene faunas of DSDP Legs 80 (sites 549, 550) and 82 (sites 558, 563) by Coles (1989) and Coles and Whatley (1989) allow the compilation of a comprehensive North Atlantic ostracod range chart for the complete Cainozoic. Using this database, it is also possible to study fluctuating diversity patterns and extinction and origination rates throughout the interval.

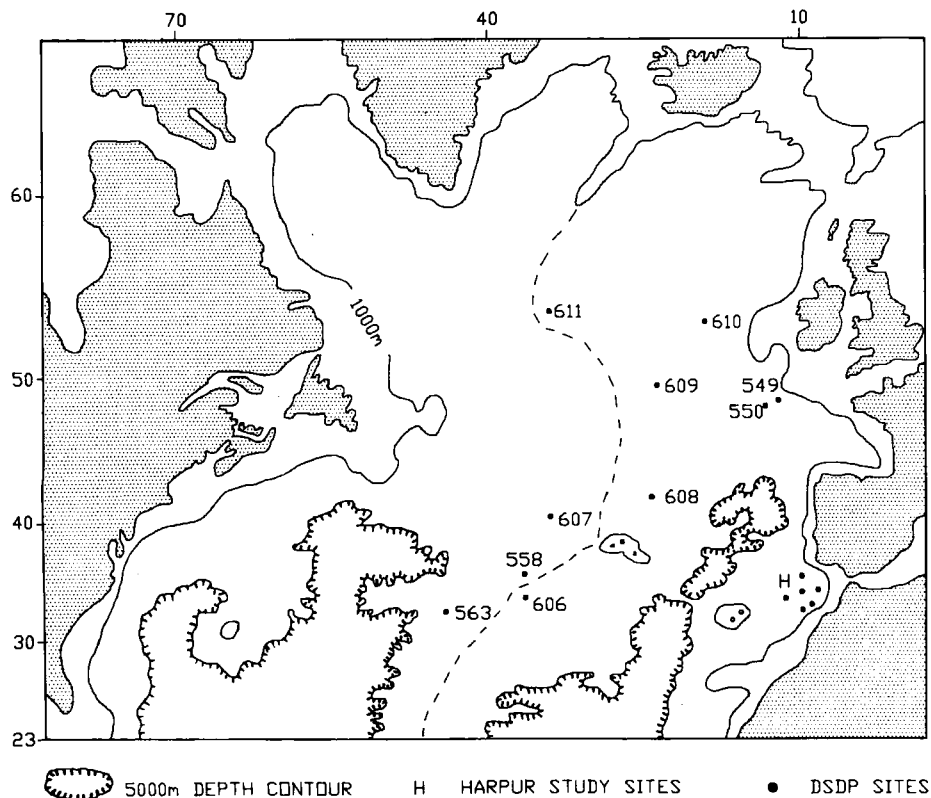


Fig. 1. Location of sites studied in the North Atlantic.

The locations of the DSDP sites we have studied are shown in Fig. 1. More than 300 samples from 10 DSDP sites were analysed and, in addition, data from NATO cores and other samples of Quaternary age were also incorporated. Most of these are detailed by Whatley and Ayress (1988). Data on site locations, water depths and stratigraphy are given in Appendix 1. All the ostracods, Recent and fossil are from water depths greater than 1000m.

BIOSTRATIGRAPHY.

Although a total of 230 species were recorded from the entire Cainozoic of the North Atlantic, in the compilation of the range charts we have reduced this number to 184 species belonging to 57 genera, and these are listed in generic order in Appendix 2. All the taxa are essentially benthonic; the majority are epifaunal, some are infaunal and a few are benthonic swimmers. The reduced number of taxa was arrived at by adopting the following procedures:

- i) eliminating all shallow water contaminants,
- ii) eliminating unique or exclusively juvenile occurrences,
- iii) eliminating all species which lack a fossil record. This excludes many thin-shelled taxa belonging to the Bythocyprididae, Cypridacea and Paradoxostomatidae which, to date, have been recorded only from Recent sediments.

The stratigraphical ranges of all 184 species, in terms of nannofossil zones, are given in Fig. 4. This demonstrates the

facility with which all the major classical divisions and subdivisions of the Cainozoic can be readily recognised on the basis of their ostracod faunas. Fig. 4. also demonstrates that it would be possible to erect a series of independent ostracod zones. However, the authors believe that their greatest use is in identifying stratigraphical levels within the existing nannofossil zonation scheme. Most of the NP and NN zones are capable of recognition, mainly on the basis of the first and last appearances of ostracod species.

Although some species have fairly short ranges, others range through long intervals of the Cainozoic. An additional complication is the fact that some species temporarily disappear from the record, only to reappear higher in the section. These Lazarus taxa complicate the interpretation of Fig. 4, because it is not possible to determine whether their transitory absences are brought about by environmental changes, or by inadequacy of sample size. We suspect that it is a combination of both. Certainly, sedimentary dilution and the relatively low incidence of ostracods in most bathyal and abyssal environments, coupled with the small size (50ml) of DSDP samples, can cause underrepresentation or absence of taxa.

From Fig. 4 it is possible to calculate the extent to which the diversity of the North Atlantic deep water ostracoda and their rate of taxonomic evolution have fluctuated throughout the Cainozoic. This is expressed numerically in Tables 1 and 2 and shown in Figs 2 & 3.

Table 1. Specific diversity (cumulative and recorded), originations and extinctions of Palaeogene Ostracoda from the North Atlantic.

L	PALAEOCENE									EOCENE									OLIGOCENE					NANNO-ZONE NP
	UPPER					LOWER				MIDDLE			UPPER						L	UPPER				
3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25		
7	2	-	1	7	-	6	11	8	4	6	3	25	4		5	8	3	10	7	4	8	-	ORIGINATIONS	
-	-	-	-	-	-	1	3	-	4	5		3	4		3	1	2	2	2	10	13	18	EXTINCTIONS	
7	9	9	16	16	22	32	3	41	43	41	66	69	65	70	72	77	85	91	93	90	75	CUM. DIVERSITY		
7	7	-	4	15	6	18	24	29	31	34	21	61	53	38	54	65	67	73	77	67	79	57	REC. DIVERSITY	

Table 2. Specific diversity (cumulative and recorded), originations and extinctions of Neogene and Quaternary Ostracoda from the North Atlantic.

L	LOWER				MIOCENE					UPPER			PLIOCENE					QUATERN. REC				NANNO-ZONE NN
					MIDDLE								LOWER		UPPER							
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21		
4	-	2	-	2	1	-	-	6	2	7	-	-	6	5	2	4	-	3	-	14	?	ORIGINATIONS
1	2	-	1	4	-	1	-	3	1	2	2	-	-	2	2	-	2	5	-	20	-	EXTINCTIONS
64	63	62	62	62	60	60	59	64	63	70	67	65	70	75	75	77	77	79	75	89	67	CUM. DIVERSITY
35	23	27	34	37	31	30	18	45	18	48	24	14	46	56	60	44	43	50	20	80	67	REC. DIVERSITY

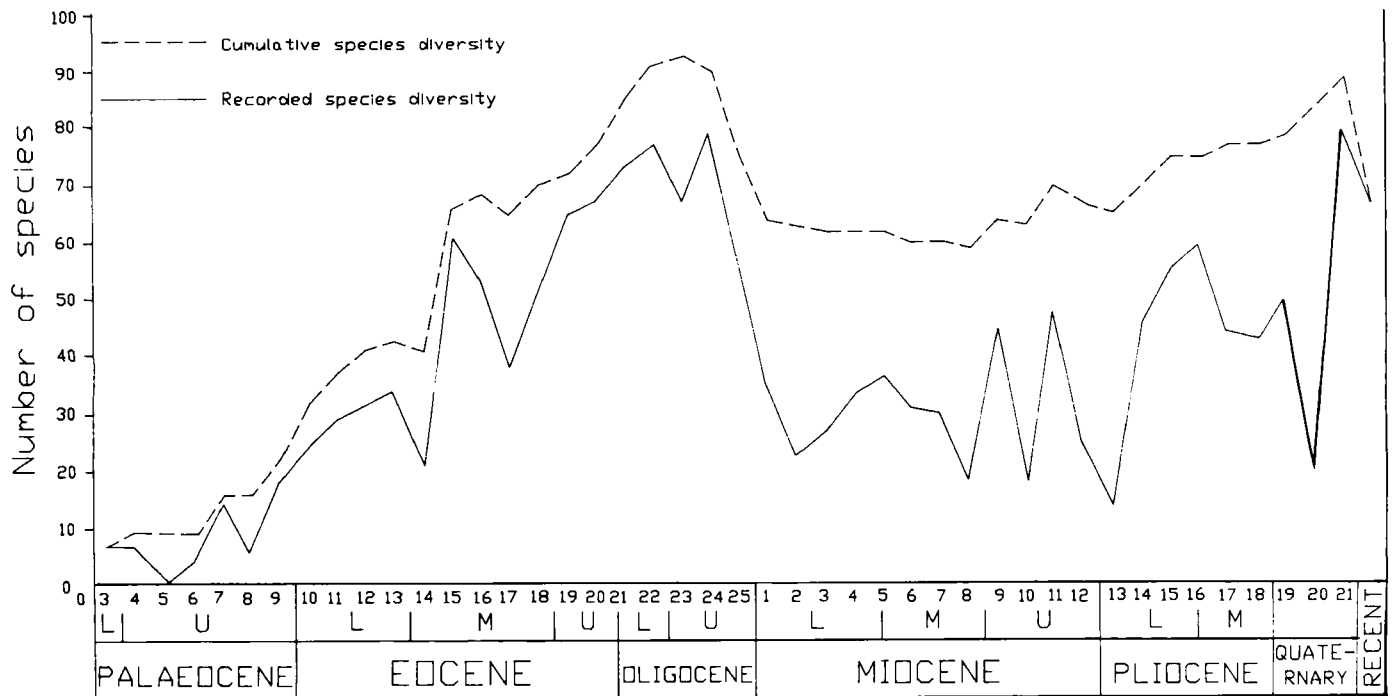


Fig. 2. Recorded and Cumulative species diversity of North Atlantic deep water Ostracoda plotted against stratigraphical age.

DIVERSITY

Because of the large number of Lazarus taxa, a distinction has been drawn between recorded and cumulative diversity. Cumulative diversity discounts temporary absences (however long) so that, for example, a species actually recorded in NN 10 and NN17, but not in the intervening zones is, nonetheless registered for those zones only. Recorded diversity registers species in those zones from which they have been actually recorded. In a study of this sort, and especially one dealing with Ostracoda, which in the deep-sea are often of low or very low incidence, cumulative diversity is probably a more reliable and meaningful index of true diversity fluctuations than recorded diversity. By this means, it is hoped that biases caused by sample size, taphonomy and sedimentary dilution, etc. can be minimised.

Fig. 2 plots both cumulative and recorded specific diversity. The former rises rather slowly through the Palaeocene, but much more steeply through the Lower Eocene. In the Middle Eocene, from NP 14 to NP 15, there is a particularly marked rise in diversity by 62%. With the exception of a single fall (from NP 16 to NP 17), diversity continues to rise through the Upper Eocene to a Palaeogene and Cainozoic maximum in the Upper Oligocene (NP 23). From its acme, cumulative specific diversity declines steeply through the late Oligocene into the early Miocene (NN 1), after which there is a very shallow decline to the Upper Miocene (NN 10). From this post-Palaeogene low, there is an irregular overall increase through the Pliocene into the post-Palaeogene maximum in the late Quaternary (NN 21). This late Quaternary diversity high is, to a certain extent, accounted for by the high level of research activity in this zone

(Porter, 1984; Harpur, 1985; Whatley & Coles, 1987). Similarly, the diversity decline into the Recent, despite the preservation of delicate taxa not readily fossilised, is a product of relatively little study of modern faunas. More extensive sampling of Recent sediments will surely reveal many, as yet unrecorded Quaternary species.

As shown in Fig. 2, recorded specific diversity, while following the same general trends as the graph for cumulative diversity, is subject to abrupt fluctuations, especially in the Neogene and Quaternary. These fluctuations reflect both sample biases and the generally longer duration of NP compared to NN zones.

The steep rise in diversity through the Palaeogene is clearly indicative of the newness of the deep water environment at this time in the North Atlantic and of the increasing sophistication of ostracod assemblages as more and more niches are occupied. This is clearly reflected in the generally low level of extinctions *versus* originations during this interval. As discussed below, much of the diversity increase is caused by immigration into the area, down a diversity gradient, from the Indo-Pacific. Down diversity gradient migration, where emigrants enter environments characterised by reduced competition, may be expected to continue apace until competition levels rise after which migration will decrease and extinction increase.

After maximum diversity had been achieved in the mid-Oligocene, the factors discussed above brought about heightened extinction levels. The essentially level diversity of the Miocene is not an artefact of the data but represents the increasing stability of the benthonic ecosystem and of the role of the Ostracoda within it.

Table 3. Mean simple specific diversity (cumulative and recorded) for the major stratigraphical divisions and subdivision of the Cainozoic.

	CUMULATIVE	RECORDED
QUATERNARY	81	50
UPPER PLIOCENE	76	49
LOWER PLIOCENE	71	44
UPPER MIOCENE	65	31
MIDDLE MIOCENE	60	29
LOWER MIOCENE	63	31
UPPER PLIOCENE	86	68
LOWER PLIOCENE	88	75
UPPER EOCENE	78	68
MIDDLE EOCENE	55	45
LOWER PLIOCENE	38	30
UPPER PALAEOCENE	14	8
LOWER PALAEOCENE	7	7

Table 4. Mean deep water ostracod species origination and extinction levels for the stratigraphical divisions and subdivisions of the North Atlantic Cainozoic.

	MEAN ORIGINATIONS	MEAN EXTINCTIONS
QUATERNARY	5.6	8.3
UPPER PLIOCENE	1.0	1.30
LOWER PLIOCENE	3.25	1.0
UPPER MIOCENE	3.0	1.6
MIDDLE PLIOCENE	1.0	1.25
LOWER PLIOCENE	1.6	1.6
UPPER OLIGOCENE	4.0	13.6
LOWER OLIGOCENE	8.5	2.0
UPPER EOCENE	7.0	1.6
MIDDLE EOCENE	7.4	2.0
LOWER EOCENE	7.2	3.0
UPPER PALAEOCENE	2.6	0.2
LOWER PALAEOCENE	7.0	0

Further evidence for these conclusions is provided by the data for mean diversity *per* stratigraphical division in Table 3.

EVOLUTION: ORIGINATIONS AND EXTINCTIONS

The origination and extinction of deep water North Atlantic ostracod species throughout the Cainozoic is presented in Fig. 3 and it can be seen that the level of evolutionary activity fluctuated considerably. Many (probably most) of the originations do not record the evolution *in situ* of species. Rather, they record the arrival in the area of immigrants, mainly from the Indo-Pacific but also from the Caribbean. The extinctions are, however, probably real enough, although some, no doubt, record emigration of species from the area.

Originations outnumber extinctions throughout the Palaeocene. Indeed, no species become extinct until the uppermost Palaeocene (NP9). There is a large origination peak at the base of the Lower Eocene (NP 10), but the highest origination level for the Palaeogene (and also the Cainozoic) occurs in the early Middle Eocene (NP 15). This is followed by a marked reduction in originations into the late Middle Eocene (NP 17), after which there is an irregular rise in the rate to NP 21, followed by a general, but irregular decline and finally a marked reduction in the uppermost Oligocene (NP 25). Lower and Middle Miocene originations are generally low. They almost double into the Upper Miocene but suffer a further marked decline in the latest Miocene-earliest Pliocene (NN 12, 13). There is a Lower Pliocene peak in NN 14 and an Upper Pliocene peak in NN 17; these are followed by a trough in NN 18. Originations rise steeply throughout the Quaternary to the

second highest peak for the Cainozoic in NN 21.

Apart from the late Quaternary peak, Fig. 3 clearly shows that speciation was generally highest in the Palaeogene and this is also shown in Table 4. While the relationship between evolutionary activity and extrinsic events is considered later, one reason for high origination levels in the Palaeogene, relative to the Neogene, is the consequence of the existence of opportunities for ostracods to expand into and colonise the newly created North Atlantic ocean floor. Less opportunities existed in the Neogene and this is reflected in the generally lower originations. This is illustrated even more clearly in Fig. 3, which also shows that, prior to the Upper Oligocene (NP 23), originations had always exceeded extinctions. Subsequently, there is generally more parity between the two and extinctions commonly exceed originations.

The maximum Tertiary extinction peak occurs in the uppermost Oligocene (NP 25), a time when many Palaeogene species disappeared. Other peaks, usually separated by troughs, occur in the Eocene (NP 10, 13, 16), the Miocene (NN 2, 2, 9, 11, 12) and the mid-Pliocene (NN 15, 16). There are two Quaternary extinction peaks, NN 19 and NN 21. The latter may largely reflect the lack of research on the Recent fauna.

Many of the extinction peaks immediately follow peaks in originations, although at other times they coincide. The former case is well illustrated where the origination peak in NP 10 is followed by an extinction peak in NP 13. Other examples are: NP 15 followed by NP 16, NP 21 followed by NP 23, NP 24 followed by NP 25, NN 1 and NN 2, NN 11 and NN 12, NN 17 and NN 19. Whatley (1986, 1988) and Whatley and Coles

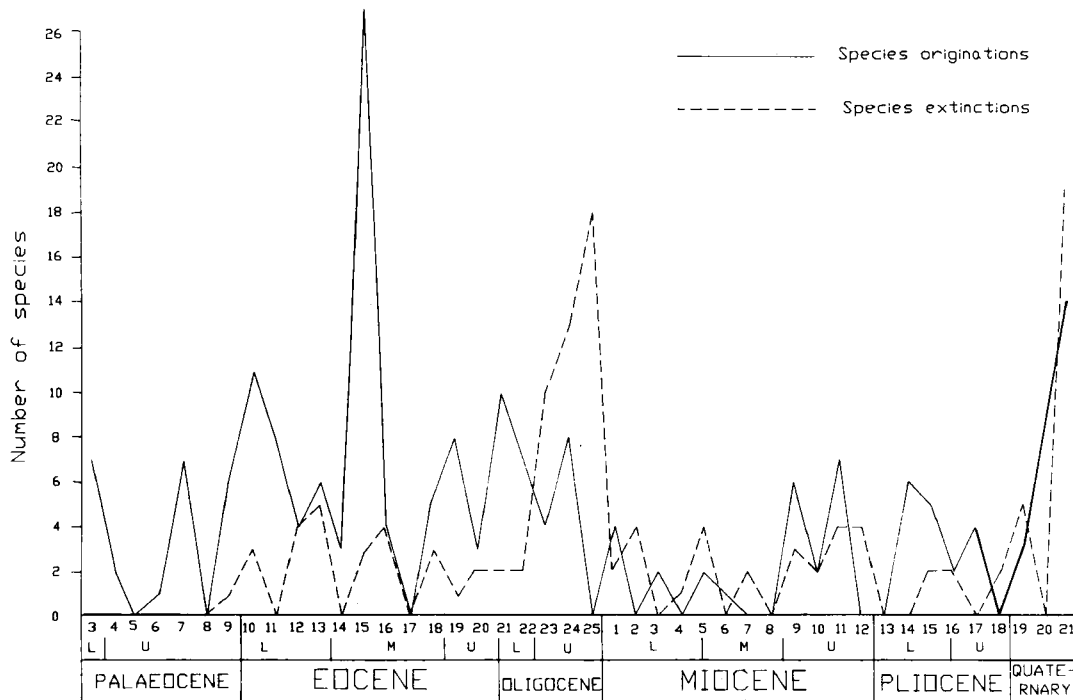


Fig. 3. Originations and Extinctions of Species of North Atlantic deep water Ostracoda plotted against stratigraphical age.

equator. The increased rate of extinctions in the mid and late Oligocene are a likely consequence of this cooling.

The reduced diversity and origination rates for Ostracoda in the Lower and Middle Miocene of the North Atlantic probably correlate with more sluggish circulation patterns consequent upon the closure of the Iberian Portal and the effective isolation of the Tethys (Whatley & Coles, 1987; Turner, 1987). The modern psychrospheric ostracod faunas became established at this time as did the benthonic foraminifera (Belanger & Berggren, 1986) although Boltovskoy (1983) found that most Recent benthonic foraminiferal species ranged back to the Oligocene.

A global temperature decrease of some 7-8°C, due to the expansion of the Antarctic Ice Cap (Stanley, 1987) and the spillage of cold North Polar bottom waters into the North Atlantic, over the subsided Greenland-Iceland-Faroes-Scotland Ridge, produced the equivalent of modern North Atlantic Deep Water (NADW) (Schnitker, 1980) and in this medium its characteristic faunas have evolved.

The subsequent history of the North Atlantic ostracod fauna has been one of a gradual increase of new species, some of which such as *Abyssocythere sulcatoperforata*, *Aratrocypis rectoporrecta*, *Cytheropteron testudo* and *Eucythere hyboma* have migrated into the area from the Indo-Pacific via the Cape of Good Hope and the South Atlantic (Whatley and Ayress, 1988). Others may have originated in the Tethys and some, especially belonging to *Krithe* and *Cytheropteron* represent the Pelasgi of the North Atlantic. Either our samples were taken at too great an interval, or the deep-sea ostracods did not respond to the glacial and interglacial cycles of the Pleistocene. Possibly a programme designed to study these phenomena, based on much more closely spaced samples, might reveal changes in the faunas. However, Thomas (1987), who studied the benthonic foraminifera of DSDP Sites 608 and 610, similarly failed to detect these cycles.

The mid-Pliocene global warming interval is also not clearly indicated by the Ostracoda although it might be possible to argue that the peak of recorded diversity in NN 16 (Fig. 2) or the origination peak in NN14 (Fig. 3) are reflections of this event.

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APPENDIX 1

The location, present day water depth (PDWD) and age of the samples used in this study.

DSDP Samples (Legs 80, 82 and 94).

Site	Age of Samples	PDWD(M)	Latitude	Longitude
549	U. Palaeocene-U. Oligocene	2515	49° 05.28'N	13° 05.88'W
550	L. Palaeocene-L. Eocene	4420	48° 30.91'N	13° 26.37'W
558	L. Oligocene-U. Miocene	3754	37° 46.02'N	37° 20.61'W
563	M.-U. Miocene	3786	33° 38.05'N	43° 64.04'W
606	L. Pliocene-L. Quaternary	3007	37° 20.32'N	35° 29.29'W
607	U. Miocene-Quaternary	3427	41° 00.07'N	32° 57.44'W
608	U. Miocene-Quaternary	3526	42° 50.21'N	23° 05.25'W
609	U. Miocene-Quaternary	3884	49° 56.67'N	24° 14.29'W
610	U. Miocene-Quaternary	3417	53° 13.30'N	18° 53.21'W
611	U. Miocene-Quaternary	3201	53° 50.47'N	30° 19.58'W

Operation Navado (1964-1971) cores. All from Harpur MS. off Mediterranean entrance. All samples Late Quaternary.

Borehole	PDWD(m)	Latitude	Longitude
BEAUMONT	1200	35° 08'N	07° 24'W
NAVADO IIB	1350	34° 35'N	07° 09'W
THEO II	1440	35° 46'N	07° 38'W
BALEN	2417	34° 56'N	08° 09'W
HAIGH	2421	36° 19'N	08° 38'W
DAY	3700	43° 56'N	09° 08'W

APPENDIX 2

Species list and biostratigraphical distribution of North Atlantic Cainozoic Deep-sea Ostracoda.

- Abyssobairdia anisolvalva* Coles & Whatley, (1989). NP 15-NN 1.
Abyssocythere atlantica Benson, 1971. NN 15-21.
A. cainozoica (Benson, 1977). NP 609.
A. trinidadensis (Van den Bold, 1957). NP 15-NN 9.
Abyssocythereis sulcatoperforata (Brady, 1880). NN 9-19.
Agrenocythere bensoni Ciampo, 1981. NP 15-25.
A. hazelae (Van den Bold, 1946). NP 21-NN 21.
A. ordinata (Deltel, 1964). NP 7-20.
Ambocythere caudata Van den Bold, 1965. NN 9-21.
A. ramosa Van den Bold, 1965. NP 15-NN 1.
A. cf. cuadata Van den Bold, 1965. NN 11-16.
A. cf. elongata Van den Bold, 1965. NP 22-25.
Anchistrocheles cf. antemacella Maddocks, 1969. NP 15-NN 21.
Aratrocypis maddocksae Whatley, Witte & Coles, (1989). NP 9-22.
A. prealta Whatley *et al.*, 1985. NP 22-24.
A. rectorrecta Whatley *et al.*, 1985. NN 15-21.
Argilloecia angulata (Deltel, 1964). NP 9
A. sp. gr. hiwanneensis Howe & Lea, 1936. NP 14-21.
A. sp. 1. Whatley & Coles, 1987. NN 14-21.
A. sp. 2. Whatley & Coles, 1987. NN 14-21.
A. sp. 5. Whatley & Coles, 1987. NN 14-21.
A. sp. 4. Coles 1989 MS. NP 7-13.
A. sp. 3. Coles 1989 MS. NP 13-16.
A. sp. 6. Coles 1989 MS. NP 15-NN 5.
A. sp. 7. Coles 1989 MS. NP 16-25.
A. sp. 8. Coles 1989 MS. NP 14-NN 2.
A. sp. 10. Coles 1989 MS. NP 19-24.
Australoecia micra (Bonaduce *et al.*, 1975). NP 19-NN 21.
A. posteroacuta Coles & Whatley 1989, NP 15-24.
A. cf. micra (Bonaduce *et al.*, 1975). NP 11-14.
Aversolvalva alveiformis (Deltel, 1964). NP 7-25.
A. atlantica Whatley & Coles, 1987. NN 1-21.
A. formosa Coles & Whatley 1989. NP 21-24.
A. hydrodynamica Whatley & Coles, 1987. NP 21-NN 19.
A. pinarensis (Van den Bold, 1946). NP 15-25.
A. sp. 1 Coles 1989 MS. NP 7-13.
Bairdia sp. gr. subcircinata Brady & Norman. 1889. NP 10-NN 21.
B. sp. 1. Coles 1989 MS. NP 15-18.
B. sp. 2. Coles 1989 MS. NP 19-25.
Baidoppilata cassida (Van den Bold, 1946). NP 14-24.
B. cf. cassida (Van den Bold, 1946). NP 3-13.
B. sp. 2. Coles 1989 MS. NP 21.
B. sp. 3. Coles 1989 MS. NP 24-NN 5.
Bathocythere audax (Brady & Norman, 1869). NN 15-21.
Bathypycrocythereis bathypycrocytheron (Coles & Whatley (1989). NP 13-28.
Bradleya dictyon (Brady, 1880). NP 23-NN 21.
B. normani (Brady, 1865). NP 21.
Buntonia pyriformis (Brady, 1880). NN 11-16.
B. textilis Bonaduce *et al.*, 1975). NP 18-NN 21.
Bythoceratina scaberrima (Brady, 1886). NN 17-21.
B. cf. umbonata (Williamson, 1847). NP 13-23.
Bythocypris aturica (Deltel, 1964). NP 15-NN 4.
B. reflexa Breman, 1975. NN 21.
B. reniformis Brady, 1880. NN 21.
B. cf. mozambiquensis Maddocks, 1969. NN 14-21.
B. sp. 1. Coles 1989 MS. NP 15-16.
B. sp. 2. Coles 1989 MS. NP 21-23.
Cardobairdia asymmetrica (Van den Bold, 1946). NP 15-NN 21.
C. ovata Van den Bold, 1960. NP 9-15.
Chejudocythere sp. 1. Coles 1989 MS. NP 11-23.
Cytherella gamardensis Deltel, 1964. NP 11-23.
C. harmoniensis Van den Bold, 1960. NP 3-24.
C. sp. gr. serratula (Brady, 1880). NP 19-NN 21.
C. sp. 1. Coles 1989 MS. NP 10-24.
C. sp. 2. Coles 1989 MS. NN 5-9.
Cytheropteron branchium Whatley *et al.*, 1986. NP 15-NN 21.
C. carolinae Whatley & Coles, 1987. NN 17-21.
C. circummaralla Whatley & Coles, 1987. NN 19.
C. garganicum Bonaduce *et al.*, 1975. NP 22-NN 21.
C. lineoporosa Whatley & Coles, 1987. NP 19-NN 21.
C. massoni Whatley & Coles, 1987. NP 22-NN 21.
C. paucipunctatum Whatley & Coles, 1987. NP 21-NN 21.
C. pheroziigzag Whatley *et al.*, 1986. NP 22-NN 21.
C. pheroziigzag Whatley *et al.*, 1986. NP 22-NN 21.
C. pinnatum Colalongo & Pasini, 1980. NN 21.
C. porterae Whatley & Coles, 1987. NN 11-21.
C. retrosulcatum Colalongo & Pasini, 1980. NN 21.
C. syntoimolatum Whatley & Coles, 1987. NP 22-NN 21.
C. tenuialatum Whatley & Coles, 1987. NN 14-21.
C. testudo Sars, 1869. NN 11-21.
C. tressleri Whatley & Coles, 1987. NN 17-21.
C. trifossata Whatley & Coles, 1987. NN 19-21.
C. cf. paucipunctatum Whatley & Coles, 1987. NP 3-13.
C. sp. 1. Coles 1989 MS. NP 21-24.
C. sp. 2. Coles 1989 MS. NP 11-21.
C. sp. 4. Coles 1989 MS. NP 15-18.
C. sp. 6. Coles 1989 MS. NP 24-25.
Dutoitella eocenica (Benson, 1977). NP 15-23.
D. preasuhmi Coles & Whatley (1989). NN 1-7.
D. suhmi (Brady, 1880). NN 11-21.
Echinocythereis echinata (Sars, 1865). NP 21-NN 21.
Eopaijenborchella cymbula (Ruggieri, 1950). NN 21.
Eucythere circumcostata Whatley & Coles, 1987. NP 11-21.
E. concinna Ciampo, 1981. NP 24-25.
E. hyboma Whatley & Coles, 1987. NN 9-21.
E. laevis Coles & Whatley (1989). NP 18-NN 5.
E. multipunctata Whatley & Coles, 1987. NP 9-NN 21.
E. paralaevis Coles & Whatley (1989). NP 7-25.
E. parapubera Whatley & Downing, 1983. NP 21-NN 21.
E. pubera Bonaduce *et al.*, 1975. NN 16-21.
E. triangula Whatley & Coles, 1987. NN 14-21.
E. sp. Coles 1989 MS. NP 21.
Eucytherura calabra Colalongo & Pasini, 1980. NP 10-NN 21.
E. mediopunctata Coles & Whatley (1989). NP 12-25.
E. pseudoantipodum Coles & Whatley (1989). NP 13-24.
E. sp. 1 Whatley & Coles, 1987. NP 18-NN 21.
E. sp. 2. Whatley & Coles, 1987. NP 23-NN 21.
E. sp. 4. Coles 1989 MS. NP 15-19.
Heinia dryppa Whatley & Coles, 1987. NP 15-NN 15.
H. sp. 2. Whatley & Coles, 1987. NP 15-NN 15.
H. sp. Coles 1989 MS. NP 11-12.
Hemiparacytheridea forteornatum Coles & Whatley (1989). NP 10-13.
Henryhowella sp. gr. asperrima (Reuss, 1850). NP 15-NN 21.
H. dasyderma (Brady, 1880). NN 3-21.
Krithe crassicaudata Van den Bold, 1946. NP 18-23.

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- K. dolichodiera* Van den Bold, 1946. NP 10-NN 21.
K. keiji Breman, 1978. NN 212.
K. morkhoveni Van den Bold, 1960. NP 10-NN 21.
K. pernoides (Bornemann, 1855). NP 15-NN 21.
K. reversa Van den Bold, 1958. NN 6-21.
K. trinidadensis Van den Bold, 1958. NP 16-NN 21.
K. cf. hiwanneensis Howe & Lea, 1936. NP 11-NN 5.
K. cf. parvula Deltel, 1964. NP 9-15.
K. sp. 1. Coles 1989 MS. NN 1-21.
K. sp. 2. Coles 1989 MS. NN 5-21.
K. sp. 3. Coles 1989 MS. NP 15-23.
K. sp. 4. Coles 1989 MS. NP 3-16.
K. sp. 5. Coles 1989 MS. NP 13-25.
K. sp. 6. Coles 1989 MS. NN 10-12.
K. sp. 9. Coles 1989 MS. NN 16-18.
K. sp. A. Coles 1989 MS. NMP 15-16.
K. sp. C. Coles 1989 MS. NP 7-10.
K. sp. D. Coles 1989 MS. NP 10.
K. sp. F. Coles 1989 MS. NP 23-24.
K. sp. G. Coles 1989 MS. NP 7-9.
Legitimocythere acanthoderma (Brady, 1880). NP 24-NN 21.
L. presequenta (Benson, 1977). NP 10-NN 19.
Loxoconchidea minima Bonaduce *et al.*, 1975. NN 21.
Macrocypris tenuicaudata Brady, 1880. NN 21.
M. cf. rhodana Van den Bold, 1960. NP 15-22.
Mayburya pulchra Coles & Whatley (1989). NP 22-NN 21.
Monoceratina (Patellacythere) insignis (Sars, 1869). NN 21.
Palmoconcha parastriata Coles & Whatley (1989). NP 9-12.
Parahemingwayella downingae Coles & Whatley (1989). NP 19-25.
P. tetrapteron (Bonaduce *et al.*, 1975). NN 21.
Parakrithē vermunti (Van den Bold, 1946). Normal overlap NP 16-NN 18.
Reversed overlap NP 20-NN 18.
P. cf. vermunti Van den Bold, 1960. NN 3-5.
Pariceratine sp. Coles 1989 MS. NP 10-18.
Pedicythere mirabilis Sissingh, 1972. NN 21.
P. phyrne Bonaduce *et al.*, 1975. NN 17-21.
P. polita Colalongo & Pasini, 1980. NN 19.
P. sp. Whatley & Coles, 1987. NP 13-NN 19.
Pelecocythere foramena Whatley & Coles, 1987. NN 9-19.
P. sylvesterbradleyi Athersuch 1979. NP 19-NN 21.
P. trinidadensis (Van den Bold, 1960). NP 20-NN 11.
Pennyella dorsoserrata (Brady, 1880). NP 24-NN 21.
P. forteditomorphica Coles & Whatley (1989). NP 10-NN 10.
P. horridus (Whatley & Coles, 1987). NN 11-21.
P. pseudodorsoserrata Coles & Whatley (1989). NP 19-NN 2.
Phacorhabdotus anterondus Coles & Whatley (1989). NP 15-23.
P. posteropunctissima Coles & Whatley (1989). NP 18-23.
P. sp. 1 Coles 1989 MS. NN 9-11.
Poseidonamicus minor Benson, 1972. NN 9-11.
P. praenudus Whatley *et al.*, 1986. NN 9-19.
P. pseudorobustus Coles & Whatley (1989). NP 21-25.
P. cf. major Benson, 1972. NN 11-21.
P. cf. pintoii Benson, 1972. NP 24-NN 21.
Profundocythere bathytatos (Whatley & Coles, 1987). NP 15-NN 21.
P. multipunctata Coles & Whatley (1989). NP 12-16.
P. splendida Coles & Whatley (1989). NP 15-NN 21.
Propontocypris sp. 1. Coles 1989 MS. NP 11-24.
Pseudocythere caudata Sars, 1865. NP 15-NN 21.
Pterygocythere mucronalatum (Brady, 1880). NP 3-NN 21.
Rectobubtonia inflata Colalongo & Pasini, 1980. NN 21.
R. miranda Bonaduce *et al.*, 1975.
Rimacytheropteron longipunctata (Breman, 1975). NN 15-21.
R. Rotundapunctata Coles & Whatley (1989). NP 12-NN 9.
Rockallia enigmatica Whatley *et al.*, 1978. NN 10-21.
Saida micropunctata Coles & Whatley (1989) NP 10-24.
Semicytherura coeca Ciampo, 1986. NP 24-25.
Trachyleberidea pisinensis (Kollmann, 1962). NP 4-25.
Xestoleberis abyssoris Whatley & Coles, 1987. NP 23-NN 16.
X. moriahensis Van den Bold, 1960. NP 15-24.
X. planoventralis Coles & Whatley (1989). NP 11-25.
X. profundis Whatley & Coles, 1987. NP 15-NN 21.
X. cf. profundis Whatley & Coles, 1987.
Xylocythere sp. 1. Coles 1989 MS.