

Assessing the Accuracy of Fossil Datum Levels: *Globorotalia margaritae* Foraminiferida, a Pliocene Test Case

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ABSTRACT – The stratigraphic distribution of the planktonic foraminiferal species *Globorotalia margaritae* has been determined in 34 DSDP, ODP and piston core sites from throughout the world's oceans and from one land section. All these sites have good palaeomagnetic records, and thus the age of the first and last appearance of *G. margaritae* can be determined in each case. The results show strong diachronism and indicate that this is not a good species to use for correlation. There appears to be no simple explanation for this diachronism, dissolution is probably a contributing factor in the deeper sites, and the edges of the geographical range of the species show shorter stratigraphic ranges but these factors do not explain all the data. We suggest that diachronism in planktonic foraminifera may be common, but without global arrays of palaeomagnetically dated cores it will be very difficult to distinguish reliable species from unreliable ones.

INTRODUCTION

The subdivision of geological time into small easily definable stratigraphic units is one of the long term goals of geology. Biostratigraphic zones, defined by the presence or absence of fossil taxa, provide the easiest and often most reliable method for correlating sedimentary sequences from one area to another. Such zonal schemes are relatively easy to establish for correlation of sedimentary sequences over short distances, but for global correlation it is much more difficult because of the effects of evolution, migration, and local environmental conditions. The magnitude of these problems has only recently been recognised, through the independent age assessment of datum levels in palaeomagnetically dated sediment cores. These data suggest considerable diachronism in some species and it is of prime importance to assess this phenomena so that we can establish the potential resolution of biostratigraphy.

It is only recently that a large enough data set has been collected to assess the accuracy of fossil datum levels. The early years of the Deep Sea Drilling Project produced mainly spot cores and cores which were frequently too badly disturbed by drilling to retain a palaeomagnetic signal. It was not until the advent of the Hydraulic piston corer on DSDP Leg 64 (Curry, Moore *et al.*, 1982) that continuous sequences of good quality core were regularly recovered. The use of the HPC was limited to the less consolidated upper part of the sediment column, but later refinements extended its range, and the addition of the extended core barrel from Leg 90 has allowed continuous good quality

core to be retrieved throughout the whole sediment column. Obtaining good quality cores does not, however, guarantee being able to measure palaeomagnetic signals, and many well cored sediments show poor palaeomagnetic records. This seems to be particularly true for pre-Pliocene sediments (eg Tauxe *et al.*, 1989). Thus, the largest number of continuously cored sediment sequences showing palaeomagnetic signals are from the Plio-Pleistocene interval.

Bolli and Saunders (1985) have reviewed the development of Cenozoic biostratigraphy based on planktonic foraminifera. Although they point out discrepancies between the occurrences of some species, and recognise provincialism in a few others, for the most part they present range charts and zonal schemes which they expect to be applicable throughout the tropics. This global applicability of datum levels was also implied by Berggren *et al.* (1985) who presented ages for calcareous nannofossil and planktonic foraminiferal datum levels derived from palaeomagnetically dated cores. Whilst these ages are undoubtedly accurate in the areas where they were dated, in most cases these age determinations have not been assessed in more than two or three areas. When specific datum levels are assessed in palaeomagnetically dated cores from a wide geographic area problems of diachronism become apparent. Weaver & Clement (1986) found strong diachronism in some species of planktonic foraminifera in the Pliocene of the North Atlantic. Hodell & Kennett (1986), Hills & Thierstein (1989) and Dowsett (1989) also found the same phenomena occurring globally in

the Pliocene in both planktonic foraminifera and calcareous nannofossils. None of these works, however, used the full range of palaeomagnetically dated cores available and so their interpretations can be refined further, especially in the light of new data from ODP Leg 108.

We have used all available palaeomagnetically dated cores to examine the distribution of *Globorotalia margaritae* - one of the most extensively used zonal marker species in the early Pliocene. This species has frequently been chosen as a biostratigraphic marker because of its common occurrence, wide latitudinal range and abrupt extinction. It is also an easy species to recognise, at least near its extinction since it apparently does not give rise to any descendent species with similar morphology. There should therefore be little chance of taxonomic confusion between different micropalaeontologists who have identified this last appearance datum. The FAD of *G. margaritae* has been used as a late Miocene datum (Berggren et al, 1983) and also as a Miocene / Pliocene boundary marker (Hays et al, 1969), although there are some uncertainties about its ancestry (see Bolli & Saunders, 1985). *Globorotalia margaritae* is therefore a very important species for late Neogene stratigraphy, and serves as an excellent model for analysing the accuracy of a fossil datum in global correlation.

PREVIOUS USAGE OF *Globorotalia margaritae*

Globorotalia margaritae was erected by Bolli & Bermudez (1965) from the Los Hernandez beds on Margarita Island, Venezuela. It was at first thought to be a late Miocene species, but later work suggested its occurrence was restricted almost

entirely to the early Pliocene (Cita, 1973; Bolli & Saunders, 1985). From its first recognition it was used as a zonal marker species, and Hays et al (1969) tied its extinction to the Gilbert/Gauss palaeomagnetic boundary in Indian Ocean core V20 163. Its LAD was also identified near the Gauss/Gilbert boundary in North Atlantic core RC11 252 (Saito et al, 1975). Its LAD has been used in numerous subsequent zonal schemes, such as those of Lamb & Beard (1972), Cita (1973), Bolli & Premoli Silva (1973), Berggren (1973) and Stainforth et al (1975), in all cases to mark the top of the early Pliocene.

The first occurrence of *G. margaritae* has been more widely disputed. Blow (1969) proposed an evolutionary lineage from *Globorotalia scitula* to *G. margaritae* and Stainforth et al (1975) suggested *G. juanai* as an intermediate step. This lineage was questioned by Bolli & Saunders (1985), although they offered no alternative evolutionary line. Bolli & Saunders' criticisms were based on the non overlapping ranges of the species and lack of intermediate forms.

Cita (1973) subdivided the species into three subspecies *G. margaritae margaritae*, *G. margaritae primitiva* and *G. margaritae evoluta* on the basis of statistical measurements of Mediterranean forms. She used the first occurrence of *G. margaritae evoluta* to mark a zonal boundary, although this boundary is difficult to recognise unless the same statistical analyses are carried out each time.

METHODS

The most reliable method for testing the stratigraphic range of a species is to identify its first and last occurrence in

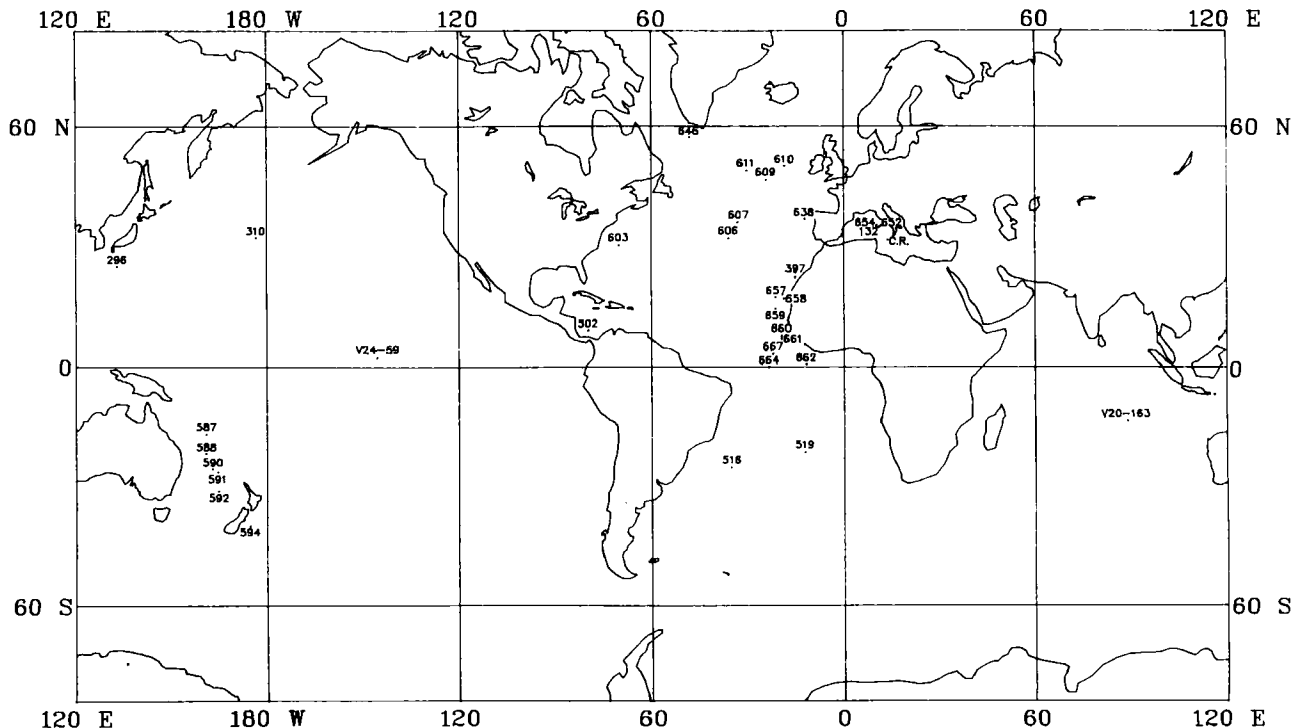


Figure 1 Location of sites used in this study. Numbers refer to DSDP and ODP sites. Sites prefixed 'V' are Vema sites and C.R.=Capo Rossello.

	Leg	Site	Position	Water depth (m)	LAD depth (m)	LAD age	FAD depth (m)	FAD age	Reference						
PACIFIC	31	296	29 20.41'N 133 31.52'E	2920	112.5- 114.0	3.6- 3.7			Keller, 1979						
	32	310	36 52.11'N 176 54.09'E	3516	49.0- 50.5	3.81- 3.93			Keller, 1979						
	90	587	21 11.087'S 161 19.99'E	1101	41.5- 42.35	3.65	50.24 50.62	4.75	Jenkins & Srinivasan, 1986						
					588		26 06.7'S 161 13.6'E			1535	53.6- 56.05	3.52- 3.56	143.90- 144.91	6.04- 6.07	Jenkins & Srinivasan, 1986
		590A	31 10.02'S 163 21.51'E	1299	76.1 77.6	3.3	194.30- 195.80	5.15	Jenkins & Kennett, 1986						
					591		31 35.06'S 164 26.92'E			2131	109.0- 118.3	3.5- 3.6*		Jenkins & Srinivasan, 1986	
		592	36 28.40'S 165 26.53'E	1098	42.9- 52.5	3.1- 3.5*	G. cf. marg G. cf. marg			Jenkins & Srinivasa, 1986					
					594						45 31.41'S 174 56.88'E	1204	No G. margaritae	4.0* = G. marg	
		V20-16317	12'S 88 41'E	2706	2.90- 3.00	3.37				Saito et al., 1975					
					V24-59 02		34'N 145 32'W				4662	10.70- 10.80	4.0		Hays et al., 1969
	ATLANTIC	47	397	26 50.7'N 15 10.8'W	2900	256- 265.5	3.14- 3.3	428	5.6	Mazzei et al., 1979					
		68	502A	11 24.4'N 79 22.7'W	3051	96.8 98.3	3.57 3.58			Keigwin, 1982					
502						"			146.2	5.25	Keigwin, 1982				
72		516	30 16.58'S 35 17.11'W	1313	18.7- 20.2	3.35- 3.6			Pujol, 1983						
73		519	26 0'S 11 40'W	3769	79.3- 83.5	3.7- 3.81	105.7- 106.92	4.77- 4.78	Poore et al., 1984						
93		603	C 35 29.78'N 70 01.86'W	4643	217.8 219.3	3.82 3.85	366 base of section	4.76	Moullade, 1987						
94		606	37 20'N 35 30'W	3022	127-129 A;121-130	3.48- 3.50	?	?	Weaver & Clement, 1986						
					607	41 07'N 32 59'W	3426	164-16 A;159-164	3.66	239- 244	5.58- 5.71	Weaver & Clement, 1986			
		609	49 53'N 24 14'W	3884	266-269 B;259-268	4.13- 4.17	342-351 B;326-336	5.50- 5.68	Weaver & Clement, 1986						
					610	53 13'N 18 53'W	2428	A;199-201 4.60	?	?	Weaver & Clement, 1986				
		611	52 15'N 30 19'W	3202	C;204-206 3.84	3.82- 3.84	300-310	5.28- 5.44	Weaver & Clement, 1986						
					105	646	58 12.559'N 48 22.147'W	3451	313.8- 323.4	3.66	516.5- 526.2	5.80	Srivastava & Arthur, 1987		
108		657A	21 19.89'N 20 56.93'W	4221	92.7- 130.7	3.35- 4.18	144.3- 146.1	5.40 5.55	Weaver & Raymo 1989						
					658A	20 44.95'N 18 34.85'W	2264	290.9- 300.4	3.60-	?	?	Weaver & Raymo, 1989			
		659A	18 04.63'N 21 01.57'W	3071	102.8- 122.3	3.45- 3.72	159.8- 182.8	6.20 8.10	Weaver & Raymo 1989						
					660A	10 00.81'N 19 14.74'W	4332	68.3- 69.4	3.8- 3.90	?	?	Weaver & Raymo 1989			
		661A	09 26.81'N 19 23.17'W	4013	58.6- 59.9	3.74- 3.80	65.1- 68.1	4.60 5.38	Weaver & Raymo 1989						
					662A	01 23.41'N 11 44.35'W	3814	197.5- 200.5	3.59-	?	?	Weaver & Raymo 1989			
		664D	0 06.44'N 23 16.5'W	3802	173.3- 182.8	3.78- 3.97	230.3- 239.8	5.72 6.22	Weaver & Raymo 1989						
					667A	4 34.15'N 21 54.68'W	3535	52.9- 55.9	3.32- 3.50	96.3- 105.8	5.50 6.34	Weaver & Raymo 1989			
MEDITERRANEAN	13	132	40 15.70'N 11 26.24'E	2813		3.56- 3.72			Rio et al., 1984						
	Capo Rossello	107	40 21.30'N 12 08.59'E	3446	126.47- 134.14	3.47- 3.70	177.62	4.70	Kastens & Masclé, 1987						
					654	40 34.76'N 10 41.80'E	2208	166.0- 166.5	3.60- 3.63	236.4	4.65- 4.75	Kastens & Masclé, 1987			

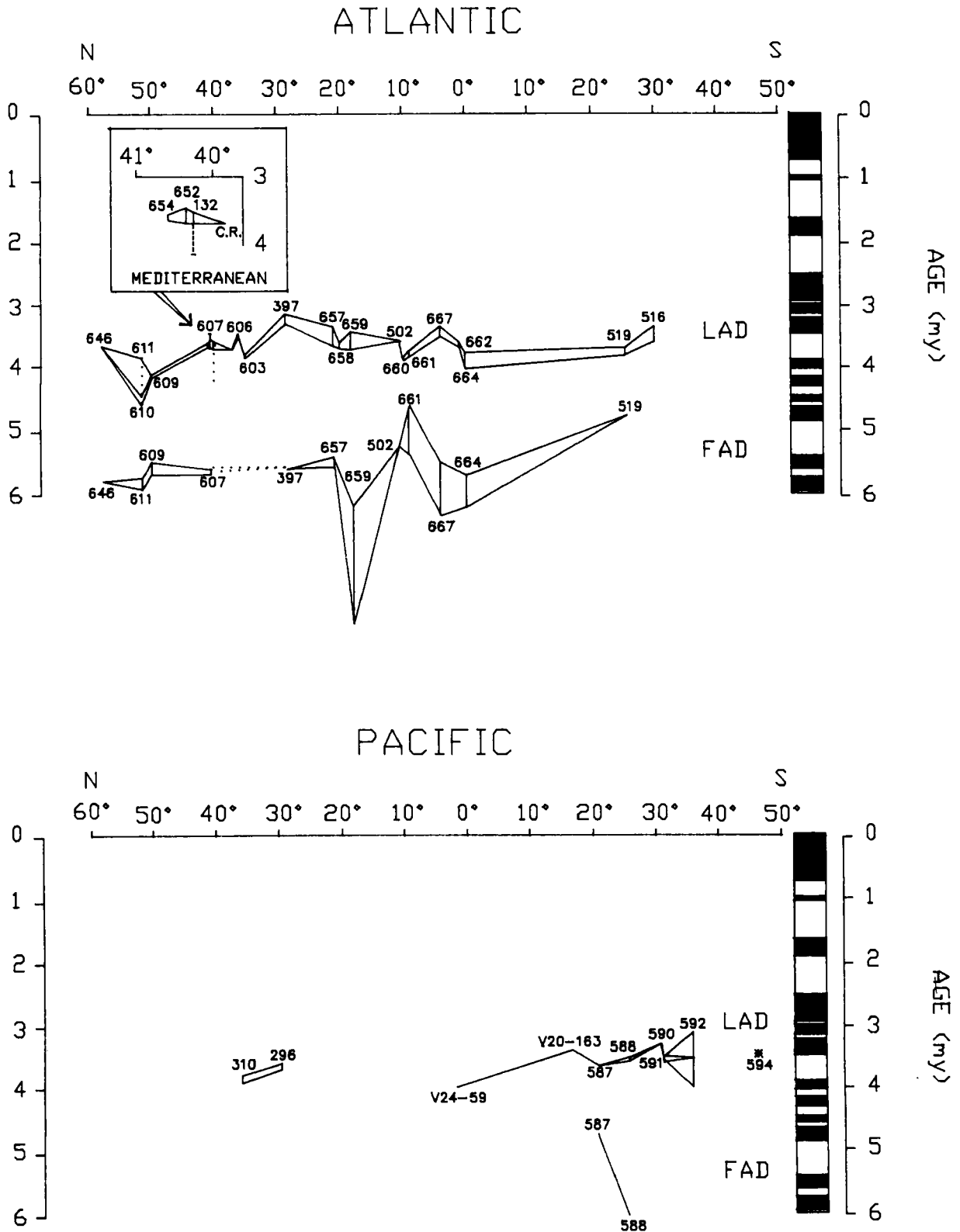


Fig 2 Ages of Last Appearance Datum (LAD) and First Appearance Datum (FAD) of *Globorotalia margaritae* in sites with independent age control. Ages have been determined in most sites from palaeomagnetic records – the standard scale is displayed in the right-hand column. The error due to sample spacing is indicated by the vertical bars at each site. * = complete absence of *G. margaritae*.

palaeomagnetically dated cores. To determine whether that species is diachronous a wide geographic spread of cores is required. We have examined the stratigraphic range of *G. margaritae* in all the cores we can identify which have good palaeomagnetic control. This gives a total of 32 cores from the Atlantic and Indo-Pacific Oceans and the Mediterranean Sea, together with two piston cores and one land section (Table 1; Fig. 1). This data base is considerably larger than those used in other investigations of fossil diachronism, such as by Weaver and Clement (1986), Hodell & Kennett (1986), Hills & Thierstein (1989) or Dowsett (1989). To standardise the data all the ages have been calculated or recalculated in accordance with the Berggren *et al* timescale (Berggren *et al*, 1985).

The distribution of *G. margaritae* has in each case been determined from the relevant DSDP or ODP volume or from the references listed in Table 1. The length of the error bars in Fig. 2 is a function of sample spacing and accumulation rate (Weaver & Clement, 1987), and may in some cases also be affected by sediment disturbances or missing core material (e.g. Site 659 FAD).

ASSESSMENT OF THE STRATIGRAPHIC RANGE OF *G. margaritae*

The ages of the first and last appearances of *G. margaritae* are plotted in Figure 2 against the latitudinal position of the sites. This figure shows the datum levels to be extremely diachronous, with LAD's ranging from 3.3 to 4.48 Ma and FAD's ranging from 4.75 to 6.07 Ma. This gives a minimum difference in age for the LAD of 1.18 m.y., and for the FAD of 1.32 m.y. Causes of apparent diachronism include dissolution, reworking / bioturbation, misidentification of specimens, and misinterpreted magnetic records. If these factors do not apply then the diachronism must be accepted and regarded as due to the species having different stratigraphic ranges in different areas. *Globorotalia margaritae* is a dissolution susceptible species and Hays *et al* (1969) suggested its early disappearance from Pacific core V24-59 was due to dissolution. The species also has a very limited abundance in Sites 572 to 574 in the tropical Pacific where dissolution is strong (Saito, 1985). A number of the sites listed in Table 1 are in water deeper than 3500 metres and some have suffered dissolution (eg 657, 660, 661). There is however, no evidence of an increase in dissolution between 4.5 and 3.4 Ma during which *G. margaritae* has an erratic distribution, and the species is present in all sites prior to 4.5 Ma. Dissolution would, therefore, only be important if the species was very rare at the end of its range, and this is not the case in the other sites. Removal of the sites in water deeper than 3500 metres from Figure 2 does not significantly improve the synchronicity of the FAD or LAD.

The effects of bioturbation on the position of biostratigraphic and palaeomagnetic datum levels was discussed by Weaver & Clement (1987). Bioturbation can move particles, such as foraminifera, up or down in the sediment column by about 30

cm. This will obviously be more critical in low deposition rate cores, but if sedimentation rates fell as low as 0.5 cm/1000 years the error would only be 60,000 years. Reworking from older horizons could account for some of the late last appearances of *G. margaritae*, but there is little evidence for other species being reworked in the cores listed in Table 1. Both *Sphaeroidinellopsis seminulina* and *Dentogloboquadrina altispira* have LAD's near to that of *G. margaritae* and neither show any evidence of reworking (Weaver & Clement, 1986; Hills & Thierstein, 1989).

It could be argued that different concepts of the species by different micropalaeontologists could lead accidentally to different stratigraphic ranges being defined (Hills & Thierstein, 1989). This is always a problem in biostratigraphy, but we believe there are unlikely to be any mis-identifications of *G. margaritae* around its LAD since it does not give rise to any descendent species with similar morphology. Blow (1969) suggested *G. margaritae* evolved into *G. hirsuta* via *G. hirsuta praehirsuta*, but Bolli & Saunders (1985) regarded *G. hirsuta praehirsuta* as a junior synonym of *G. margaritae evoluta*. Bolli & Saunders further point out that whilst *G. margaritae* s.l. is restricted to the early Pliocene, *G. hirsuta* is a Pleistocene species, and no late Pliocene specimens of either species have been recorded. We follow the Bolli & Saunders view, and along with most other micropalaeontologists, do not recognise *G. praehirsuta*. We have also used *G. margaritae* in the *sensu lato* sense to include all subspecies. The LAD of *G. margaritae* is therefore easy to recognise and rarely disputed. The FAD of *G. margaritae* is a more difficult datum to identify, since early forms of the species are morphologically similar to *G. scitula*, *G. juanai* and *G. cibaensis*. In the Pacific the 3 sites showing a FAD were studied by the same micropalaeontologists (Jenkins & Srinivasan, 1986), and in the Atlantic most of the sites showing a FAD were studied by Weaver (1986) and Weaver & Raymo (in press). Problems of misidentification should therefore be minimal in this study.

Hills & Thierstein (1989) regard the palaeomagnetic data with some scepticism. They point out that palaeomagnetic chrons are often recognised by reference to the biostratigraphic record, and thus the two data sets are not independent. Whilst these problems undoubtedly exist, they are often more severe in pre-Pliocene sediments. The LAD of *G. margaritae* occurs around or below the Gauss/Gilbert boundary - a datum which is more readily recognisable than, for example, the short duration Kaena or Mammoth events in the Gauss. The FAD of *G. margaritae* occurs in the Gilbert or Chron 5 Epochs where more confusion could arise. The accumulation rate curves produced for each site, however, account for most of the data - both palaeomagnetic and biostratigraphic - and we do not expect misinterpretation of the palaeomagnetic record to be a major source of error.

We are therefore left with the conclusion that *G. margaritae* had diachronous first and last appearances. There is no simple explanation for this diachronism. It has been suggested that

tropical and subtropical species ranges are more restricted in higher latitudes (Weaver & Clement, 1986; Hodell & Kennett, 1986), but the additional data in this study does not support this view. There is no obvious trend from the tropics to higher latitudes in either the LAD or the FAD of *G. margaritae*. Closely situated sites in the Atlantic, such as 662, 664 and 667, show a few hundred thousand years difference in age for the LAD, and in the Pacific, Sites 587, 588 and 589 show very large discrepancies for the FAD. Ocean currents can have profound effects on local oceanographic conditions, and could upset any latitudinal effects by bringing cool waters into lower latitudes. In the early Pliocene, Thunell & Belyea (1982) suggest a strong eastern boundary current extended down and along the west African margin in a similar position to today's Canary Current. This current would have influenced sites 397, 657, 658 and 659, giving them conditions similar to those between 30-40°N in the Atlantic. These sites however do not show large anomalies in the age of the LAD of *G. margaritae*.

The easiest way to describe the LAD of *G. margaritae* is to assign it an age of 3.6 Ma, which accounts for the data in 15 of the 31 sites. In some sites, notably V20-163, 590, 606 and 667 the species lingered until 3.5 or even 3.4 Ma and in Site 397 it has a quoted LAD age of 3.3 Ma. With the exception of Site 397, these sites are all situated under warm water and are dissolution-free. They do not, however, represent all the sites with those conditions. In 11 of the 31 sites *G. margaritae* has a LAD older than 3.6 Ma. These sites include Sites V24-59, 660, 661, 664 and 603 all of which are in deep water and show some signs of dissolution. The other sites showing early LAD's are 310, 519, 609, 610, 611 and 646, all in mid latitudes or under cool surface water conditions.

There is probably not enough data to explain the erratic FAD of *G. margaritae*. An age of 5.5 - 5.6 Ma would explain the data for only 5 of the 15 sites, and these are spread from near the equator to 50°N in the Atlantic. Six sites show younger ages for the FAD, including Sites 587 and 590 in the Pacific, Site 519 in the south Atlantic, Sites 502 and 661 in the tropical Atlantic and 611 in the North Atlantic. Four sites show older FAD's, including Site 588 (situated between Sites 587 and 590) in the Pacific, Site 664 in the Equatorial Atlantic, Site 659 off West Africa and Site 646 south of Greenland. No pattern can be seen in these data.

CONCLUSIONS

Globorotalia margaritae, therefore, has diachronous first and last appearance datum levels, and cannot be relied on for high resolution stratigraphy. It is impossible to assess how many other planktonic foraminifera provide similar time transgressive datum levels and how many are consistently reliable. There appear to be a few planktonic foraminifera, including the LAD's of *Sphaeroidinellopsis seminulina* and *Globoquadrina altispira*, which consistently give reliable biostratigraphic data in the Atlantic (Weaver & Clement, 1986; Hills & Thierstein,

1989). However, species such as these can only be identified by rigorous analysis of numerous independently dated cores. Below the Plio-Pleistocene these data do not exist and the selection of biostratigraphic markers must be based on subjective criteria. The accidental selection of time transgressive markers will automatically make more reliable markers appear transgressive and lead to considerable confusion.

In the absence of any method of assessing the quality of a biostratigraphic datum considerable caution must be applied in its use. We suggest the level of uncertainty provided by the *G. margaritae* LAD could be a useful model for other species. This species was after all used for many years as an early Pliocene marker fossil. This study suggests species can linger in some areas for a few hundred thousand years after their last appearance in other areas, and that they can also disappear several hundred thousand years early in some cases. Although we cannot satisfactorily explain why *G. margaritae* was time transgressive we can implicate dissolution as a possible contributing factor, particularly since this is a dissolution susceptible species. The extremities of a species geographical range may also be more prone to shorter stratigraphic ranges of that species.

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