Duncan, R. A., Backman, J., Peterson, L. C., et al., 1990
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 115

20. LATE OLIGOCENE TO LATE PLIOCENE BENTHIC FORAMINIFERS FROM DEPTH TRAVERSES IN THE CENTRAL INDIAN OCEAN[1]

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ABSTRACT

Late Oligocene to late Pliocene vertical water-mass stratification along depth traverses in the northern Indian Ocean is depicted in this paper by benthic foraminifer index faunas. During most of this time, benthic faunas indicate well-oxygenated, bottom-water conditions at all depths except under the southern Indian upwelling and in the Pliocene in the southern Arabian Sea.

Faunas suggest the initiation of lower oxygen conditions at intermediate depths in the northern Indian Ocean beginning in Oligocene Zone P21a. Lower oxygen conditions intensified during primary productivity pulses, possibly related to increased upwelling vigor, in the latest Oligocene and throughout most of the late middle through late Miocene. During times of elevated primary production, there may be more oxygen flux into sedimentary pore waters and the shallow infaunal habitat may become more oxygenated.

One criterion for locating the source of "new" water masses is vertical homogeneity of benthic foraminifer indexes for well-oxygenated water masses from intermediate through abyssal depths. In the northern Mascarene Basin, this type of faunal homogeneity with depth corroborates the proposal that the northern Indian Ocean was an area of sinking well-oxygenated waters through most of the Miocene before Zone N17.

Oxygenated, possibly "new" intermediate-water masses in the low- to middle-latitude Mascarene and Central Indian basins first developed in the late Oligocene. These well-oxygenated waters were probably more fertile than the Antarctic Intermediate Waters (AAIW) that cover intermediate depths in these areas today. Production of intermediate waters more similar to modern AAIW is indicated by the sparse benthic population of epifaunal rotaloid species in the northern Mascarene Basin during middle Miocene Zone N9 and from early through late Pliocene time.

Deep-water characteristics are more difficult to interpret because of the extensive redeposition at the deeper sites. Redeposited intermediate, rather than shallow, water fossils and erosion from north to south in the Mascarene Basin are incompatible with the sluggish circulation from south to north through the western Indian Ocean basins today. Such erosion could result from the vigorous sinking of an intermediate-depth water mass of northern origin.

Before late Oligocene Zone P22, benthic faunas indicate a twofold subdivision of the troposphere, with the boundary between upper and lower well-oxygenated water masses located from 2500–3000 mbsl. No characteristic bottom-water fauna developed before the end of late Oligocene Zone P22.

Deep and abyssal benthic indexes suggest the development of water masses similar to those of the present day in the latest Miocene. Faunas containing deep-water benthic indexes, including the uvigerinids, suggestive of a water mass similar to modern Indian Deep Water (IDW), appeared during the late Miocene in the northern Mascarene and Central Indian basins. In the early Pliocene, this deep-water fauna was found only in the Central Indian Basin, whereas a fauna typical of modern Antarctic Bottom Water (AABW) spread through deep waters at 2800 mbsl in the Mascarene Basin. By late Pliocene Zone N21, however, deep-water faunas similar to their modern analogs were developed in both the eastern and western basins.

Abyssal faunas, studied only in the Mascarene Basin, show more or less similarity to those under modern AABW. Bottom-water faunas containing *Nuttallides umbonifera* or *Epistominella exiguua* were first differentiated at the end of Zone P22, then appeared episodically during the early Miocene. These AABW-type faunas reappeared and migrated updepth into deep waters during the glacial episodes at the end of the Miocene and at the beginning of the Pliocene. By late Pliocene Zone N21, however, a bottom-water fauna similar to that under eastern Indian Bottom Water (IBW) developed in the Mascarene Basin. Modern bottom-water characteristics of the Mascarene Basin must have developed after Zone N21.

INTRODUCTION

Benthic foraminifers were recovered at 12 sites cored during Ocean Drilling Program (ODP) Leg 115 to the north central Indian Ocean. Benthic faunas from all these sites have been discussed previously (Backman, Duncan, et al., 1988). Because these sites penetrated the water column from 1,500 to 4,000 m below sea level (mbsl), they sampled the major bathymetric zones and presumably their unique bottom conditions and water masses. In this paper I will use quantitative study of the benthic foraminifers along several traverses to describe faunal segregation through depth. Environmental index faunas will be used to suggest the evolution of paleoenvironments in intermediate, deep, and abyssal areas of the central equatorial Indian Ocean. Key questions involve the differing histories of low-oxygen northern water vs. well-oxygenated intermediate water of southern origin; the source of deep waters before the evolution of true North Atlantic Deep Water (NADW); the possible effects of the increasing closure of the Middle Eastern Strait; and the effects of global glaciation.

Stable isotope analyses provided by N. Shackleton (see Boersma and Mikkelsen, this volume) and Woodruff et al. (this volume), augmented by published data (Vincent et al., 1985; Oberhänsli, 1986; Keigwin and Corliss, 1986; Woodruff and Savin, 1989) are evoked to test interpretations of water-mass stratification and benthic paleoenvironment suggested by the benthic foraminifers.

[1] Duncan, R. A., Backman, J., Peterson, L. C., et al., 1990. *Proc. ODP, Sci. Results*, 115: College Station, TX (Ocean Drilling Program).
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METHODS

In the northwest central Indian Ocean, a traverse from 1500 to 3800 m down the Mascarene Ridge into the Mascarene Basin (Fig. 1) included Site 707 (1541 m), Site 709 (3038 m), and Site 710 (3812 m). This data base was augmented by sample sets from other western deep and intermediate-depth sites, including Sites 237, 238, 236, 241, and 219 (Table 1).

To the east, depth-graded sites were recovered both from the southern (Site 713) and northeast Chagos-Laccadive Ridge (Sites 714 and 715). Additional samples were studied from the southwest of India in the southeastern Arabian Sea (Site 219) and on Ninetyeast Ridge, including Sites 217 and 218 in the Bay of Bengal, 215 and 253 in the eastern Central Indian Basin, and 214 and 216 in the western Wharton Basin (Table 1).

Samples of 20 cm^3 were washed on a 63-μm sieve and air dried. Approximately 1 mg of each sample was used for counts of all species in the >63-μm size fraction, thus producing an approximation of benthic abundance in a standardized sample. Benthic foraminifers were counted according to the following scheme: 1 = present, 2 = 2 or more, 3 = 3–5, 4 = 5–10, 6 = 10–30, 7 = 30–50, 8 = 50–75, and 9 = 75–150. Because benthic foraminifers are not common in most samples, in many instances the numbers represent their true abundance in a sample. Only the bolivinids reached abundances of 6 or greater.

Estimates of abundance were used to determine paleobathymetric index faunas. A species was included in the index fauna

Table 1. Locations and depths of all Indian Ocean sites included in this study.

Site	Latitude, longitude	Depth (mbsl)
214	11°S, 88°E	1761
215	8°S, 86°E	5321
216	1°N, 90°E	2262
217	8°N, 90°E	3030
218	8°N, 86°E	3737
219	9°N, 72°E	1764
236	1°S, 57°E	5146
237	7°S, 58°E	1640
238	11°S, 70°E	2844
241	2°S, 44°E	4054
242	15°S, 41°E	2275
253	24°S, 87°E	1962
707	7°S, 59°E	1541
709	3°S, 60°E	3038
710	4°S, 60°E	3812
713	4°S, 73°E	2090
714	5°N, 73°E	2038
715	5°N, 73°E	2262

Note: Data from Heirtzler et al. (1977) and Backman, Duncan, et al. (1988).

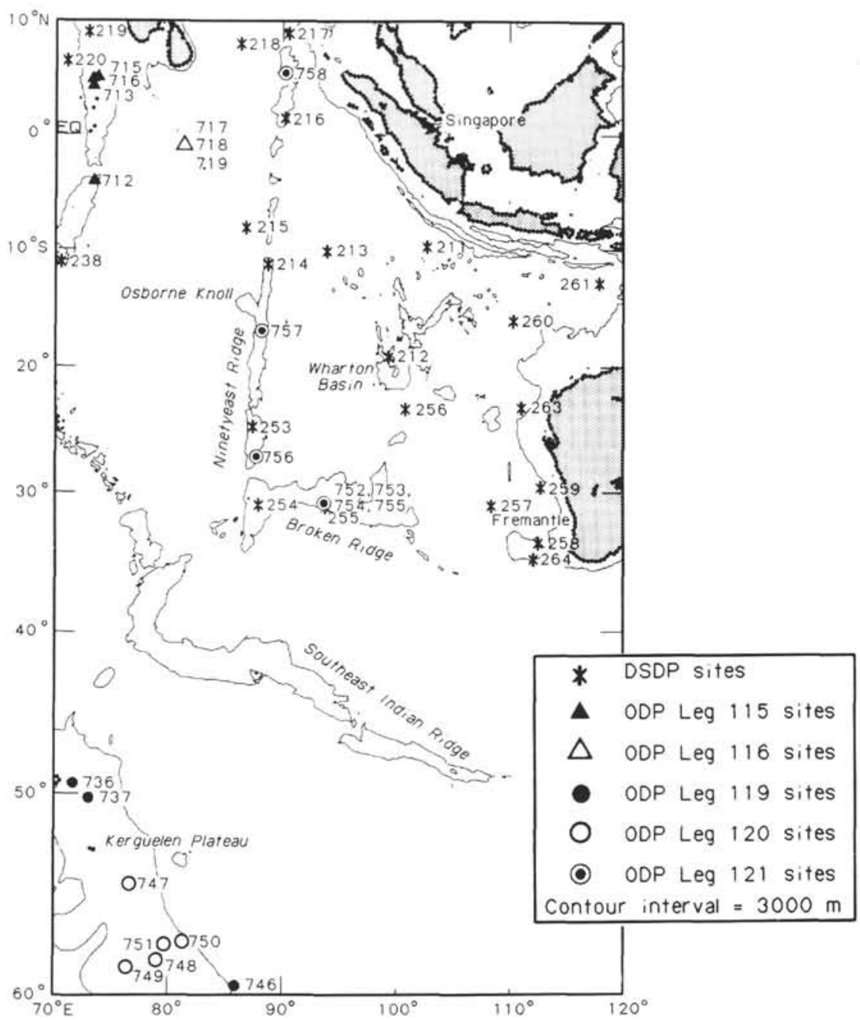

Figure 1. Location map of the eastern Indian Ocean showing DSDP and ODP sites.

if it (1) occurred in greatest abundance throughout the sample interval, (2) occurred consistently throughout the sample interval, (3) first appeared or disappeared in the sample interval, or (4) transgressed its usual bathymetric range.

Not only the abundance of key species but also the diversity (species richness) and numbers of infauna and epifauna (Corliss and Chen, 1988) are used in this environmental interpretation. The infaunal-epifaunal ratio was computed for all samples from the Leg 115 sites by two methods. Both the numbers (species richness) and abundances of infauna compared with the numbers and abundances of epifauna are tabulated. Although we do not know all the species that belong to these categories, all genera presently assigned to the infauna, whether the deeper or shallower dwelling types, as well as the stilostomellids were attributed to infauna. The epifaunal genera of Corliss and Chen (1988) were counted as epifauna, and all agglutinants were excluded from consideration in this study.

Ten time slices from the Oligocene-Pliocene sequence were chosen for this study because they were represented at the largest number of sites along the two traverses. Because of extensive published reports of largely deep-water Miocene benthic faunas (Woodruff and Douglas, 1981; Woodruff, 1985; Woodruff and Savin, 1989), this study focuses on Oligocene and Pliocene age sediments and the eastern traverse of intermediate-depth sites.

Biostratigraphy (Backman, Duncan, et al., 1988), but no paleomagnetics, formed the basis of inter-site correlation. Therefore, site-to-site correlation of specific events is speculative. Biozonation was confounded by redeposition and hiatuses throughout all sections, with all abyssal samples containing some redeposited materials. Continuous stable isotope records were not produced because of the poor preservation, numerous hiatuses, and low rates of sediment accumulation. Global events recognizable in the stable isotope records, such as the late Miocene carbon shift (Vincent et al., 1980), the late Miocene glacial episode (Elmstrom and Kennett, 1985), and the late Oligocene Zone P22 warming (Boersma and Shackleton, 1977) allowed some intersite correlation.

PALEOENVIRONMENTAL INDEXES

Paleoenvironmental interpretation requires the use of species with well-established environmental preferences. A number of benthic foraminifer indexes, related to edaphic variables either in the water or in the sediment, are listed in Table 2. Two types of foraminiferal associations identified in modern settings are useful in an interpretation of past environments: (1) species that occur under specific environmental conditions (Table 2), and (2) groupings of species produced by factor analysis, which are associated with a particular water mass (hereafter called factor-species, factor-faunas, or factor-associations).

Paleobathymetric Index Species

In the Indian Ocean data set, there are a large number of species restricted to intermediate-depth, but not deeper, water sites. These include *Discanomalina semipunctata, Cassidulinoides cornuta, Uvigerina spinulosa, Rectuvigerina striata, Discorbis villardeboanus, Planulina marialanna, Planulina gigas, Planulina renzi, Astrononion* spp., *Bulimina glomarchallengeri, Lenticulina nicobarensis, Bolivinita quadrilatera, Bolivina peregrina, Dyocibicides* sp., *Rectuvigerina spinea, Ceratobulimina pacifica, Planulina ariminensis, Textularia lythostrata, Martinotiella variabilis, Bolivina pseudobeyrichi, Bolivina pseudoplicata, Bolivina villaverniensis, Bolivina serranensis, Bolivina dilatata, Bolivina pukeuriensis, Bolivina finlayi, Bolivina goessi, Heterolepa rugosa, Bolivina tortuosa, Uvigerina porrecta,* and *Cassidulina ornata.*

Species confined to deep or abyssal sites are few, and most are abyssal forms such as *E. exiguua, P. quinqueloba,* or *N. um-*

Table 2. Benthic foraminifers and the oceanographic parameters to which their occurrence has been related.

Species/characteristic	Parameter	Reference
Bolivinid ornament	Low energy bottom	5
Bolivina diversity	Low oxygen	1
Bolivina shape	Low oxygen	2
Thick, crenulate bolivinids	Moderate oxygenation	2
Smooth flat bolivinids	Low oxygen	2
Delicate bolivinids	Lowest oxygen	2
Shape *B. albatrossi*	Paleodepth	3*
B. aenariensis	Oxygen minimum, not organic carbon maximum	22*
Uvigerinid abundance	More organic carbon	2
Uvigerinid abundance	More phosphorous	4*
Rectuvigerinids	Heightened production	11*
Uvigerinid ornament	Paleodepths	6, 7
Uvigerina, Hoeglundina	Solution susceptible	13*
U. peregrina s.l.	Indian Deep Water	10*
U. peregrina, G. subglobosa, Pyrgo	Old water, infauna	14*
Uvigerinids	High sedimentation rate	15
Trifarina spp.	High salinity	20
Uvigerina–E. exiguua–M. pompilioides–G. soldanii	Indian Bottom Water	26*
E. exiguua	Oxic conditions	1
E. exiguua	Specific volume anomaly	10*
E. exiguua, N. umbonifera	Lysocline	16
E. exiguua	NADW	18*
G. subglobosa, U. peregrina	CPDW	19*
Large size *G. subglobosa*	Less corrosive waters	12*
M. sphaeroides, P. quinqueloba, N. umbonifera	Bottom waters	15
P. murrhina, C. wuellerstorfi, Nuttallides	Corrosive bottom water	8*,9
N. umbonifera	AABW	8, 10, 18*
N. umbonifera–O. umbonatus, G. subglobosa	Antarctic Bottom Water	26*
E. umbonifera, P. bulloides, C. wuellerstorfi	AABW	25
C. kullenbergi, N. umbonifera, Gyroidinoides	More dissolution resistance	13*
Gyroidina, Glomospira	Low oxygen, corrosivity	21*
Gyroidina + Hoeglundina	Poor ventilation, noncorrosive	21*
Lenticulinid ornament	Paleodepths	6
Infauna	Higher organic carbon, low oxygen	17*
Epifauna	Oxic conditions	17*
Articulina, miliolids	Low ph minerals	21*
Cibicidids replace eponidids	Terrigenous, not marine, organic matter	23*
Smooth cassidulinids	Low oxygen	2, 5, 16
Bulimina spp.	Low oxygen, high organic carbon, pollution	24*
C. wuellerstorfi, G. subglobosa, C. kullenbergi	Highly oxic NADW	25
M. barleeanum, C. wuellerstorfi	Moderately high surface-water productivity	25
O. umbonatus, C. kullenbergi	Moderately low surface-water production	25
Astrononion, M. barleanuum, Uvigerina	Corrosive, high surface productivity	27
Astrononion	Corrosive, less highly productive	27
		27

Notes: Relations based on core-top studies are indicated with an asterisk (*). References are as follows: 1, Poag and Low, 1984; 2, Douglas, 1981; 3, Gary, 1985; 4, Lutze and Coulbourn, 1984; 5, Hendrix, 1958; 6, Boersma, 1984; 7, Boersma, 1985b; 8, Bremer and Lohmann, 1982; 9, Tjalsma and Lohmann, 1983; 10, Peterson, 1984; 11, Lutze, 1977; 12, Corliss, 1980; 13, Corliss and Honjo, 1980; 14, Murray, 1973; 15, Boersma, 1985c; 16, Burke, 1981; 17, Corliss and Chen, 1988; 18, Schnitker, 1974; 19, Lohmann, 1978; 20, Oberhänsli et al., 1983; 21, Cita and Zocchi, 1978; 22, Saunders et al., 1985; 23, Poag, 1981; 24, Seiglie, 1968; 25, Woodruff and Savin, 1989; 26, Corliss, 1979; 27, Woodruff and Douglas, 1981.

bonifera that migrate updepth during discrete episodes in both the Paleogene and Neogene. Species with upper depth limits in deep-water sites were not found, but the following species were largely restricted to deep-water or abyssal sites: *Pullenia quinqueloba, Melonis sphaeroides, N. umbonifera, E. exiguua, Heterolepa grimsdalei,* smooth *Buliminella* sp., *Favocassidulina fava,* and *Martinotiella cojimarensis.*

Size of *Globocassidulina subglobosa*

To test the causal relationship between increased size of *Globocassidulina subglobosa* and increased carbonate saturation proposed for Indian Ocean populations by Corliss (1979), three sizes of *G. subglobosa* were counted separately at Sites 707, 709, 710, and 713. Small-sized forms occurred in the >63-<125-μm size fraction, and medium-sized forms were approximately two-thirds the size of large forms, with the latter categories both occurring in the >250-μm size fraction. Plots of relative abundance of the two extreme size classes and the numeric expression of preservation are shown in Figure 2.

In both the Oligocene and Neogene data sets at shallow and deep sites, there is a direct relation between estimates of good carbonate preservation and higher abundances of large size *G. subglobosa,* but no apparent relation between better preservation and small-size *G. subglobosa*. Although this does not confirm the hypothesis of Corliss (1979), it does corroborate his supposition that the abundance of large *G. subglobosa* is directly related to improved carbonate preservation in the western Indian Ocean.

Temporal and Spatial Evolution of the Infaunal-Epifaunal Ratio

The abundance of infauna in the modern North Sea has been related to conditions where the flux of organic carbon is higher. Inversely, modern epifauna in this basin proliferate under well-oxygenated conditions when the organic carbon flux is lower. The ratio between infauna and epifauna may, therefore, provide an index of more or less oxygenated bottom conditions and relative rates of organic carbon accumulation in ancient sediments (Corliss and Chen, 1988).

Faunas from Leg 115 traverses revealed two main trends in the infaunal-epifauna ratio (Figs. 3, 4, and 6). First, infaunal numbers parallel diversity at high and low sedimentation rate sites. And, second, infauna have predominated at all depths throughout the late Paleogene and most of the Tertiary, even in faunas that suggest well-oxygenated conditions (Table 2). The shallower the site, the greater this predominance. Epifauna predominate only in deep-water and abyssal areas after the early Pliocene.

Figures 3, 4, and 6 demonstrate the elegant correlation and parallelism between infaunal number and diversity (species richness) at intermediate-depth Sites 714 (relatively high sediment accumulation rates) and 707 (low accumulation rates) and deep-water Site 709. At Site 219 in the southern Arabian Sea, diversity is always maximal and infauna outnumber epifauna by as much as 4:1. Clearly, a large portion of the diversity is made up by infaunal species in the central Indian Ocean.

The infaunal-epifaunal ratios indicate the relative scarcity of epifauna before the Pliocene. Throughout the late Paleogene and Neogene, epifauna only increase in number: (1) during Zone P21 before the spread of lower oxygen index species in the Mascarene and Central Indian basins; (2) in the Pliocene at deep and abyssal sites in the Mascarene Basin; (3) during episodes of redeposition; or (4) during Zones N9 and N22 at Site 707. By early Pliocene Zone N18, epifaunal numbers increase first in abyssal areas. By Zone N21, epifauna are more abundant than infauna at deep- and bottom-water sites and episodically dominate faunas at intermediate-depth Site 707.

PALEOCLIMATIC EVENTS DURING TIME SLICES

Paleoceanographic interpretation of the late Paleogene–Neogene time slices is based on oxygen and carbon isotope analysis of planktonic and benthic foraminifers from the tropical Indian Ocean (Vincent et al., 1985; Oberhänsli, 1986; Woodruff et al., 1989; Woodruff and Savin, this volume; Boersma and Mikkelsen, this volume).

Late Oligocene Time Slices P21 and P22

Late Oligocene data are derived from Site 253 located at middle latitudes at the southern end of Ninetyeast Ridge. Benthic oxygen isotope data indicate a gradual enrichment through the early Oligocene, followed by an enrichment event near the top of Zone NP23. At the Oligocene/Miocene boundary both benthic and planktonic oxygen isotope values become depleted by just under 1‰. The surface to bottom carbon isotope gradients increase slightly in the latest Oligocene.

A benthic carbon isotope enrichment event at intermediate-depth sites at the Oligocene/Miocene boundary results in uniform carbon isotope values through a depth range of 1500–2500 mbsl. At Site 714 in the southern Indian upwelling zone, despite little change in benthic oxygen isotope values, benthic carbon isotope data from *Planulina renzi* indicate a 0.5‰ enrichment at the beginning of the Miocene (Boersma and Mikkelsen, this volume). An enrichment of almost identical values is registered by *Cibicidoides* across the Oligocene/Miocene boundary at Site 253 (Oberhänsli, 1986). Little change occurs in values of *Cibicidoides* at Site 707, which were already slightly enriched relative to those at other sites (Boersma and Mikkelsen, this volume). Because of variability in the differences of the values of *Oridorsalis* vs. the cibicidids, the Indian Ocean data of Vincent et al. (1985) are presently not comparable. Those data do, however, demonstrate the same pattern as the cibicidid data. There is little change at Mascarene Basin Site 237, immediately adjacent to Site 707, but an excursion is recorded at intermediate-depth Sites 214 and 216 on Ninetyeast Ridge. In summary, by the beginning of the Miocene, cibicidid carbon isotope values in western sites from 1500 to 2500 mbsl approximate 1.6‰–1.7‰. This increased the intermediate- to deep-water carbon isotope gradient to 1‰.

Early Miocene Time Slices N4 and N9

The lack of stable isotope analyses from early Miocene Zones N4–N7 reflects generally poor sediment preservation and the small size of benthic fossils. The major shift between early Miocene Zone N4 and middle Miocene Zone N9 involves carbon isotope values that become more positive at the surface and bottom during the Epoch 16 carbon shift (Vincent et al., 1985). This shift is apparent also in the cibicidid data from Site 709 (Woodruff et al., this volume) and in the difference between cibicidid values from Zones CN1 (N4 time slice) to CN4 (N9 time slice) at Site 714 (Boersma and Mikkelsen, this volume). This excursion has been attributed to the extraction of organic carbon from the ocean into another reservoir (Vincent et al., 1985).

The Indian Ocean may have served as the source for deep waters to both the Atlantic and Pacific oceans at this time (Woodruff and Savin, 1989). Intermediate- and deep-water carbon isotope values in all three oceans suggest "aging" of water from the Indian Ocean to the deep Pacific and Atlantic. These authors propose that a Tethyan Indian Saline Water, mixed with circumpolar water in the Antarctic, served as the source of deep water to the world's oceans. A similar process operative from middle to late Miocene was proposed by Johnson (1985).

Time Slice N17

The late Miocene Epoch 6 carbon shift and the glacial buildup at the end of the Miocene are discernible in Indian Ocean rec-

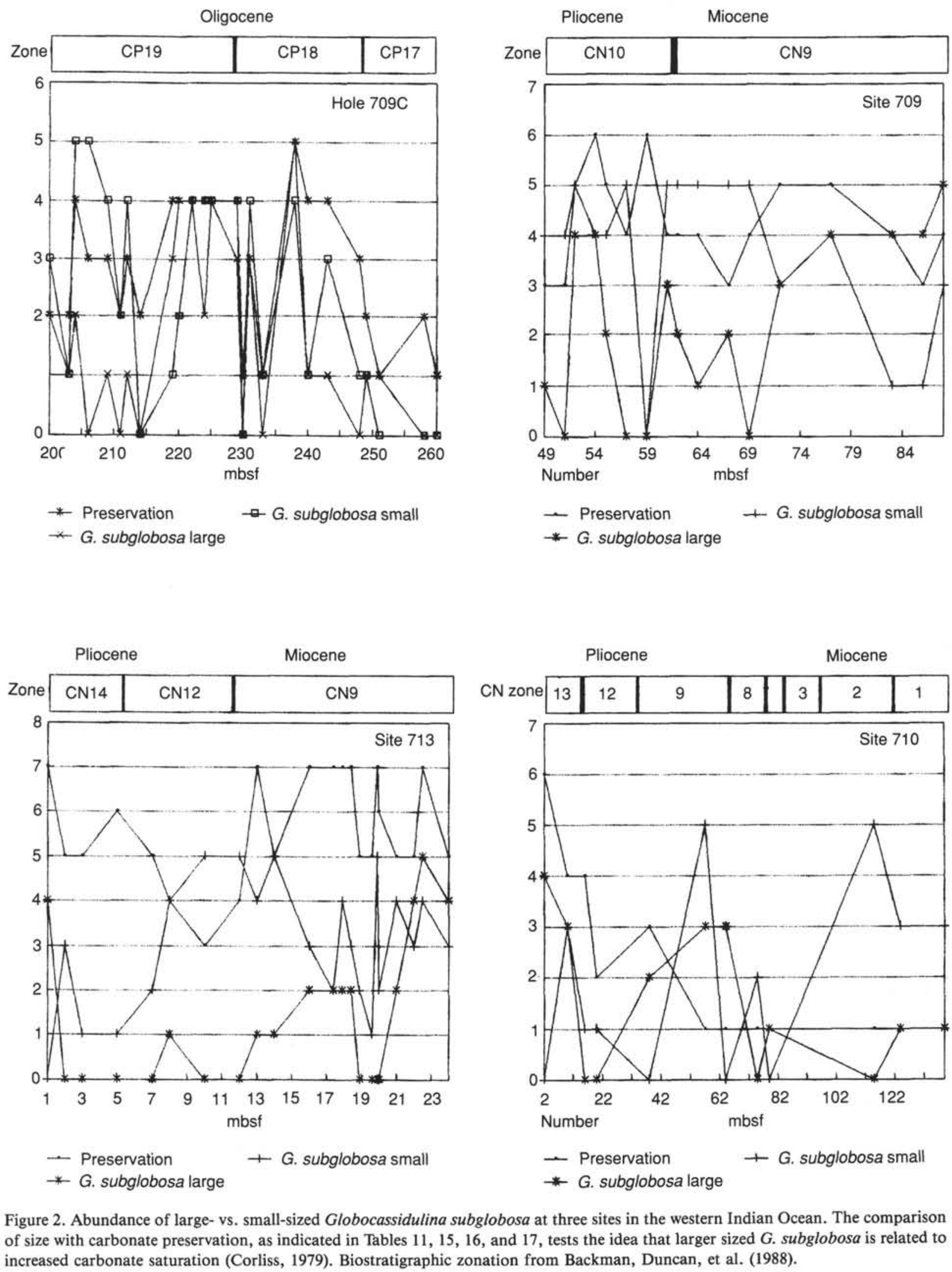

Figure 2. Abundance of large- vs. small-sized *Globocassidulina subglobosa* at three sites in the western Indian Ocean. The comparison of size with carbonate preservation, as indicated in Tables 11, 15, 16, and 17, tests the idea that larger sized *G. subglobosa* is related to increased carbonate saturation (Corliss, 1979). Biostratigraphic zonation from Backman, Duncan, et al. (1988).

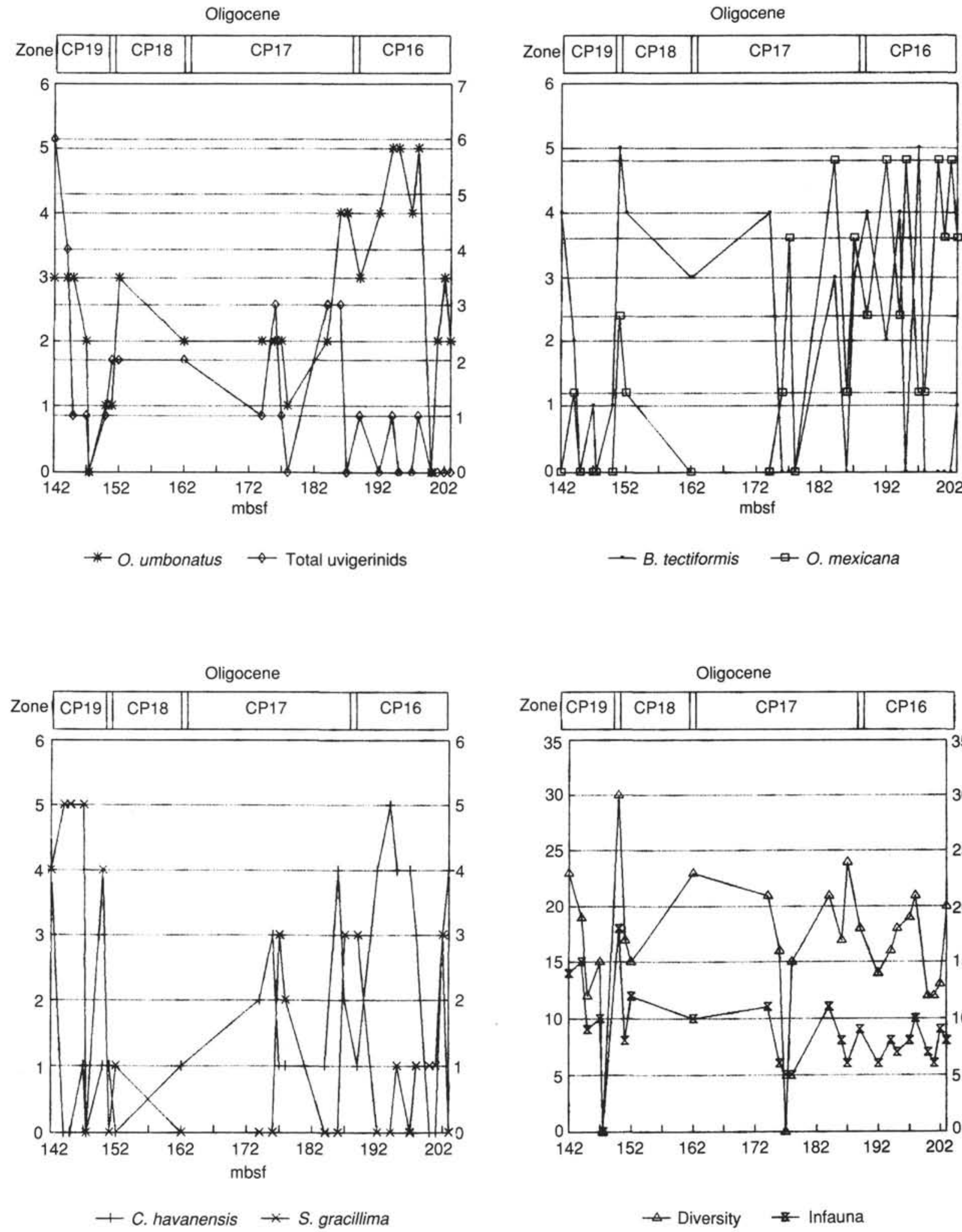

Figure 3. Relative abundances of most common benthic foraminifers during the Oligocene at Site 707. Species include *Osangularia mexicana, Uvigerina* spp., *Bolivina tectiformis, Oridorsalis umbonatus, Cibicidoides havanensis*, and *Stilostomella gracillima*. Total infaunal number is plotted against total diversity for each sample in Table 3. Zonation from Backman, Duncan, et al. (1988).

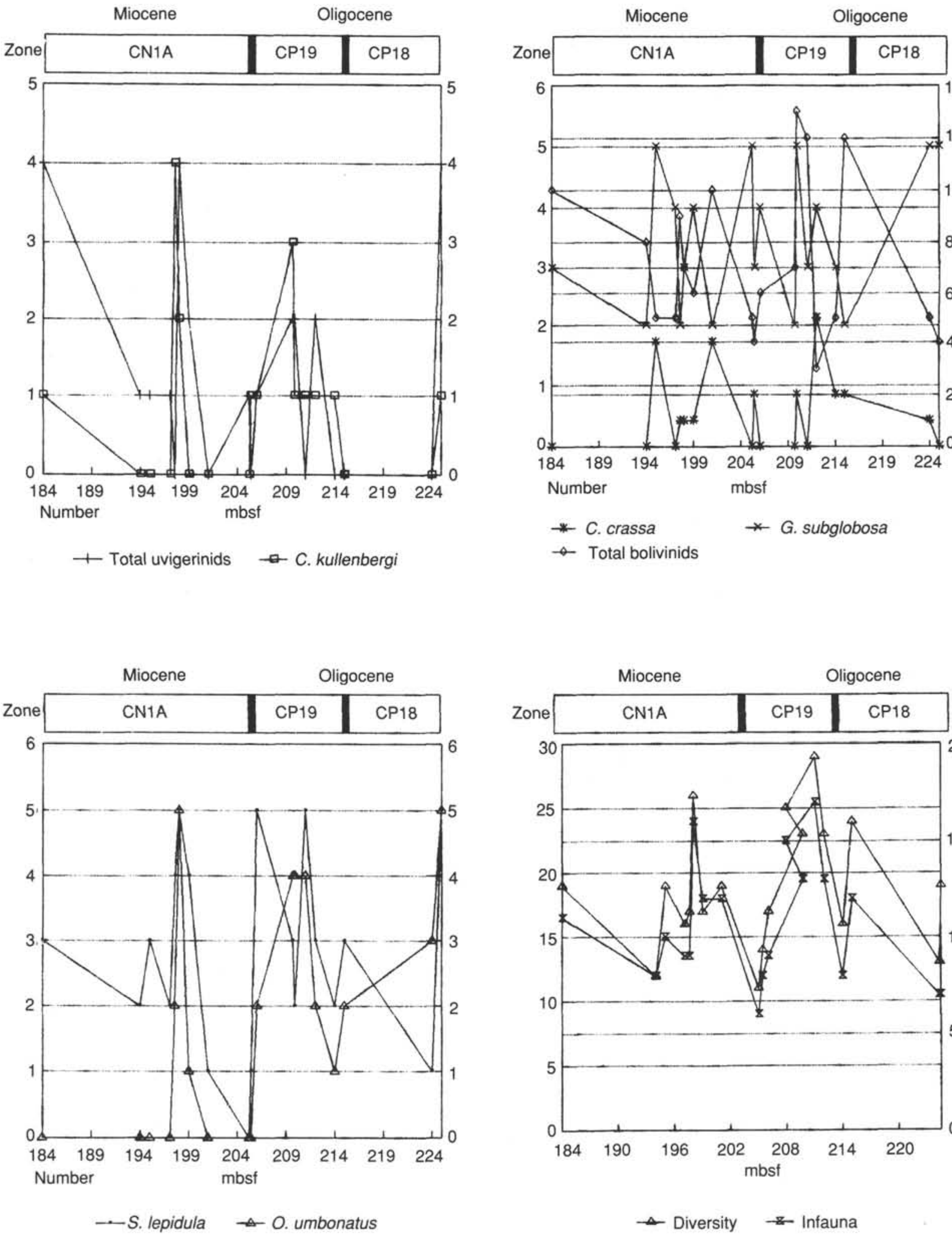

Figure 4. Relative abundance of most common benthic foraminifers from the late Oligocene into the early Miocene in Hole 714A. Species include *Uvigerina* spp., *Cassidulina crassa, Stilostomella lepidula, Cibicidoides kullenbergi, Globocassidulina subglobosa, Oridorsalis umbonatus*, and total bolivinids combined. Relative abundances of all bolivinids combined vs. total benthic diversity (species richness) vs. total abundance of infauna indicate that, with the exception of one peak, all indexes are lower in the early Miocene. Abundance of infauna is related to elevated carbon rain rates and organic carbon content of sediments (Corliss and Chen, 1988). This organic carbon serves as food for the foraminifers and may be partially responsible for supporting a greater number of benthic species. High bolivinid abundances have been attributed to the development of low-oxygen conditions. Zonation from Backman, Duncan, et al. (1988).

ords from Zone N17 (Vincent et al., 1985). The well-known 1‰ negative shift in Epoch 6 has been attributed to erosion of organic matter into the ocean and the expansion of the oxygen minimum during that portion of Zone N17 equivalent to nannofossil Zone CN9b (Vincent et al., 1985; Woodruff, 1985). In Hole 709B, this event is recorded from 92 to 98 m below seafloor (mbsf), dated around 6.3–6.5 Ma (Woodruff et al., this volume).

The terminal Miocene benthic oxygen isotope excursion is clearly recorded at middle latitude Site 253 where *Uvigerina* values become approximately 0.6‰ heavier at the end of Zone NN11 (Oberhänsli, 1986). This event is well recorded in the Pacific realm (Elmstrom and Kennett, 1985; Boersma, 1985c), but it is not visible in the *Oridorsalis* or cibicidid data from the Indian Ocean (Vincent et al., 1985; Woodruff et al., this volume). The lack of a benthic oxygen-isotope enrichment event, combined with the low abundance of *Uvigerina hispidocostata* usually associated with this event, suggests that there may be a hiatus in several Mascarene Basin sites through this interval.

Analysis of global benthic carbon-isotope values indicates that Atlantic deep-water masses were no longer "aged" and that the source of deep waters probably resided in the North Atlantic after 10 Ma (Woodruff and Savin, 1989). This means that the Indian Ocean was no longer a source area of deep water to the Atlantic and Pacific oceans in Zone N17.

Time Slices N18 and N21

Although an early Pliocene glacial event has been recorded in the Pacific, the low-amplitude stable isotope fluctuations suggest less buildup of glacial ice and warmer temperatures than in the late Pliocene or Pleistocene. An ~1‰ Pacific-Atlantic carbon isotope gradient in the early Pliocene (Shackleton et al., 1984) suggests that the Indian Ocean no longer served as a source area for Atlantic deep waters and that the predecessor of NADW was producing deep water as vigorously as it does today (Shackleton et al., 1984; Hodell et al., 1985). Global cooling combined with a benthic carbon-isotope-depletion episode characterize the N21 time slice equated roughly to the Gauss.

DEVELOPMENT OF BENTHIC FAUNAS THROUGH TIME AND SPACE

Oligocene

Oligocene biozones are not well represented at most sites, and sediments are well preserved only from the climatically warmer intervals late in Zones P19, P21a, and P22. Although the Eocene/Oligocene transition occurs in a siliceous facies in the Mascarene area, early Oligocene age faunas are rarely found in this data set from Ninetyeast Ridge, or at Sites 214 and 219. The shortness of Zone P21b, found only at deep-water Sites 217 (3020 m) and 709 and intermediate-depth Site 707, suggests an extensive hiatus in this zone.

Redeposition occurs at all depths. At the deepest western basin Sites 710, 241, and 236, most levels contain material redeposited from intermediate depths rather than from shallow waters. Most of the Oligocene sediments at Site 712 are reworked, mixed, and disturbed. On Ninetyeast Ridge, an extended erosional event interrupted Zone P20, as this zone is commonly missing or contains levels with reworked Eocene fossils at several sites.

Intermediate-depth Sites

Although the CP16–CP17 (P18–P19) zonal interval was not well preserved, it was recovered at Wharton Basin Site 214 and Mascarene Basin Site 707 within the 1500–1700-m depth range. At Site 707 (Fig. 3), faunas consistently contain *Osangularia mexicana, G. subglobosa* (large form), *Bolivina tectiformis, Cibicidoides havanensis, Oridorsalis umbonatus, Bulimina alazanensis,* and an elongate buliminid with fine costulae. Crenulate bolivinids, such as *Bolivina* cf. *B. pseudoplicata,* occur in some numbers only in the earliest part of Zone P18 (= Zone CP16) (Table 3). Infauna fluctuate in number but are generally more numerous than epifauna. There is a clear trend to reduction in abundance of epifaunal species, such as *O. mexicana, C. havanensis,* and *O. umbonatus,* and a gradual increase in abundance of infaunal species, such as the bolivinids, uvigerinids, and stilostomellids.

Although more species occur consistently at Site 214, a *G. subglobosa–C. havanensis*–costulate buliminid–*O. umbonatus* index fauna (Fig. 5) also prevails there (Table 4). At both sites, epifaunal and infaunal diversity are equal, even though the relative abundance of infauna is greater at Site 214.

Zone P20 (= Zones CP17–CP18) age material was retrieved only at Site 707 (Fig. 3) where the poorly preserved faunas are low in diversity and dominance, redeposited material is common, a hiatus is clearly indicated, and most species occur in only one sample. Bolivinids are absent and the only consistently occurring form is the elongate costulate buliminid. Epifaunal diversity continues to equal infaunal diversity throughout this time period.

Zone P21a (= Zone CP18) age faunas were recovered to the east at Sites 714, 216,and 253, and to the west at Site 707. In the northern Central Indian Basin Site 714 (2038 mbsl), faunas rich in *O. umbonatus* and *G. subglobosa* are replaced by a *B. tectiformis–Uvigerina spinulosa–G. subglobosa* index fauna with *Stilostomella lepidula* (Fig. 5 and Table 5).

At the deeper Wharton Basin Site 216 (2252 mbsl), faunas contain *Cibicidoides praemundulus, O. umbonatus, C. havanensis, Vulvulina spinosa, Stilostomella nuttalli,* and, at the top of the interval, the abyssal form *Nuttallides umbonifera* and the deep-water taxon *Pullenia quinqueloba* (Table 6). Central Indian Basin middle-latitude Site 253 contains a different fauna, with *O. umbonatus, Stilostomella gracillima, C. havanensis, Gyroidinoides altispirus,* reticulate *C. havanensis,* and uvigerinids, including the usually deeper water form, *Uvigerina spinicostata* (Table 7). Infaunal diversity and abundance are consistently greater except at Site 216, in which epifaunal abundance is equal to or greater than infaunal abundance (Fig. 5).

By Zone P21a at Site 707, although siliceous fossils predominate, benthic species *C. praemundulus, B. tectiformis, Bolivinopsis gryzbowski, G. subglobosa* (small form), and the uvigerinids become more abundant than rotaloid species (Fig. 3). Buliminids include both the reticulate *Bulimina semicostata* and the finely porous *Bulimina macilenta.*

Faunas of Zone CP19 (Zone P21b) age could be definitely identified only at Site 707. With the loss of *O. mexicana, B. tectiformis* predominates (Table 3), accompanied by *S. gracillima* and *Siphonodosaria modesta. Uvigerina spinicostata* is occasionally present. Diversity reaches a maximum at this time and dominance is low.

Faunas of Zone CP19 (Zone P22) age were recovered at Sites 714, 217, and 253 to the east and Site 707 to the west. This is the most consistently recovered zone of the Oligocene, especially in deeper sites. Beginning in Zone CP19, faunas develop remarkable similarity; an *S. gracillima–O. umbonatus* index fauna proliferates with depth in the Mascarene Basin and to the east and west of Ninetyeast Ridge (Fig. 6).

Different species characterize the early and later part of Zone P22. For example, at Site 253 *Uvigerina spinicostata* and *N. umbonifera,* which occur in early Zone P22, are replaced by *E. exiguua* and *U. spinulosa* at the end of this interval (Table 7). At Site 714, *U. spinulosa, Planulina renzi, Cassidulina crassa,* and osangularids occur at the beginning of the zone but are largely absent by its end when *P. quinqueloba* first occurs (Table 5).

Site 714 offshore southern India on the Chagos-Laccadive Ridge stands out in contrast to all other sites because large numbers of bolivinids occur the most consistently of all species. Intrageneric diversity is highest in this genus, and species richness is highest at this site. Bolivinid abundance is episodic at the beginning of this zone but is consistent toward its end (Sections 115-714A-23X-6 to 115-714B-23X-1) (Table 5). Crenulate types with large pores replace the reticulate group and *B. tectiformis* in abundance in Zone CP19, but there is a diversity maximum and an acme of smoother, thinner forms with smaller pores in 115-714B-23X-6 (Fig. 7). Bolivinids and *C. crassa,* which vary directly but inversely with *G. subglobosa,* reach abundance maxima in this interval (Fig. 4). *Oridorsalis umbonatus* and *S. lepidula* vary synchronously and directly, reaching maxima later in this zone. The Neogene forms, *C. kullenbergi* and *O. culter,* which appear to occur here earlier than at other locations, alternate with an *O.umbonatus–S. lepidula* index fauna in which *G. subglobosa* is abundant (Fig. 5).

Faunas at Site 216 are characterized by large faunal turnover, with 12 species disappearing near the top of the Oligocene, including the costulate buliminid, *Pullenia quinqueloba, N. umbonifera, S. nuttalli, V. spinosa,* and the bolivinids (Table 6). The *S. lepidula–O. umbonatus* index fauna here includes also *Gyroidinoides planulatus, G. subglobosa* (large form), fewer *C. praemundulus,* and *U. spinicostata* (Fig. 5).

At Site 253 to the south in the middle latitudes, a similar fauna consistently contains *B. semicostata,* fewer *C. havanensis* than previously, *O. mexicana, P. quinqueloba,* increased numbers of bolivinids and buliminids, and *N. umbonifera* followed by *Uvigerina spinulosa* near the end of the zone (Table 7). Infaunal species outnumber epifaunal species 4 to 3 in the youngest levels, but infauna are almost two times more abundant than epifauna. A similar *S. gracillima–O. umbonatus* index fauna with *B. semicostata* and a uvigerinid-rich level near the end of Zone P22 occurs also at Site 707 to the west (Fig. 5). Uvigerinid diversity is greatest here of all sites, involving the species *U. spinulosa, Uvigerina havanensis, Uvigerina subproboscidea,* and the New Zealand form, *Uvigerina ongleyi.* Uvigerinids are particularly abundant at the end of this time when infaunal diversity exceeds epifaunal diversity by 7 to 1, and infauna are three times more abundant than epifauna (Table 3).

Deep-water Sites

Oligocene deep-water faunas were recovered at few deep sites: Sites 217 and 712 to the east, and Sites 238 and 709 to the west. Abyssal faunas were counted only from the Mascarene Basin at Site 710. In the deepest sites, redeposition and dissolution are extreme even at depths close to 3000 m. Faunas are dominated by generalists, but include such deep-water forms as *Heterolepa grimsdalei, P. quinqueloba, S. nuttalli,* and to a lesser degree, *N. umbonifera.* Either through dissolution, redeposition, or ecology, bottom-water faunas close to 3800 mbsl differ from their southern Atlantic analogs (Tjalsma, 1983; Clarke and Wright, 1984; Boersma, 1985a) in their scarcity of *N. umbonifera.*

The early Oligocene interval was not often recovered in deep or abyssal sites. Relatively well-preserved faunas of Zone CP16 (= Zone P19) recovered only at Site 217 in the Bay of Bengal contain *O. umbonatus, C. praemundulus, G. altispirus, H. grimsdalei, U. havanensis,* and, in one level, *N. umbonifera* (Table 8). Faunas of Zones CP17–CP18 (Zone P20) at deep-water Site 709 are characterized by poor preservation, but greater diversity and low dominance (Fig. 8). Typical are *S. gracillima, G. subglobosa* (small form), and in one level, *N. umbonifera.*

Late Oligocene faunas of Zone CP18 (Zone P21a) age, retrieved at all sites, are characterized by improved preservation, especially at abyssal depths along the Mascarene traverse. At the deepest Site 710, *G. subglobosa* (large form), *O. umbonatus,* and *C. praemundulus* occur at more than one level, and a slight increase in *N. umbonifera* occurs in Sample 115-710C-20X-CC (Table 9). At deep-water Site 709, despite the poor preservation, diversity is at a maximum lower in the zone, whereas dominance remains low (Fig. 8). Faunas consistently contain *C. praemundulus, S. gracillima,* and *G. subglobosa* (small form), with one sample enriched in *N. umbonifera.* Stratigraphic resolution is not fine enough, however, to determine whether this *N. umbonifera* enrichment event is coeval with that at abyssal Site 710 (Fig. 5).

Samples from Site 217 (3020 m) to the east in the Bay of Bengal contain high-diversity faunas with common *G. subglobosa* (large and small), *O. umbonatus, C. praemundulus,* and *S. nuttalli* (Table 8). Both *N. umbonifera* and the costulate bolivinids are present, but in low numbers (Fig. 5).

At Site 238 (2826 m) in the Central Indian Basin, preservation is poor and fossil abundance low (Table 10). One diverse fauna contains *S. nuttalli, S. gracillima, O. umbonatus,* and *B. semicostata.* Deep-water faunas of both the northern Mascarene and Central Indian basins are similar to the *O. umbonatus–S. gracillima* index faunas found at nearby intermediate-depth sites (Fig. 5). It is not certain, therefore, whether intermediate-water fossils have moved downslope via migration or redeposition.

A short interval of Zone CP19 (Zone P21b) was recovered in the 3,000 m depth range at Site 709 to the west and at Bay of Bengal Site 217 to the east. At Site 709 (Fig. 8), preservation improves and the fauna is somewhat diverse, containing the maximum of *C. praemundulus,* consistent *O. umbonatus, G. subglobosa* (small form), *S. nuttalli, B. tectiformis,* and *U. spinicostata.* The only truly deep-water heavily calcified bolivinid, called *Bolivina huneri* (Tjalsma and Lohmann, 1983), occurs at this site (Table 11). The dissolved faunas at Site 217 are very small, the only consistent species being *O. umbonatus* and *P. quinqueloba* (Table 8).

Faunas of Zone CP19 (= Zone P22) were recovered at all sites, although the samples from Site 710 were minute and badly dissolved (Table 9). Present at this site was a new dissolution residue consisting of *O. umbonatus, G. planulatus,* and *P. bulloides.* Gyroidinids increase in abundance in the top samples of this zone. At deep-water Site 709 (Fig. 8), *O. umbonatus, G. girardanus, G. subglobosa* (small form), and *Anomalinoides semicribratus* accompany reticulate cassidulinids in small, very dissolved samples. It is difficult to know if this fauna is in place.

At Site 238 (2826 mbsl) in the western Central Indian Basin, Zone P22 (Zone CP19) is almost 10 cores long but only fairly well to poorly preserved. *Nuttallides umbonifera* is more common here than at all other sites (Table 10). Present are *S. modesta, S. gracillima,* an increased number of *G. subglobosa,* pleurostomellids, and some *S. subspinosa.* A short bolivinid-rich level may be the result of redeposition. At the end of the Oligocene, *N. umbonifera, P. quinqueloba, C. praemundulus,* and *E. exiguua* either increase in numbers or first appear (Fig. 6). A clear faunal succession can be recognized. A low-dominance, low-diversity, large *G. subglobosa–O. umbonatus* index fauna is replaced by an *S. gracillima–O. umbonatus*–pleurostomellid index fauna, then a second low-diversity, low-dominance *O. umbonatus–S. gracillima* index fauna, followed by the arrival of more common *N. umbonifera, E. exiguua,* or *P. quinqueloba* in the top four samples of the zone.

To the north in the Bay of Bengal in Hole 217A, the *B. tectiformis–S. lepidula–G. subglobosa* index fauna resembles those from Central Indian Basin Site 238, located at equivalent water depths (Fig. 6). Noteworthy is the proliferation of the costulate bolivinid, *B. tectiformis,* at these deep-water sites. The occurrence of the bolivinids and *Cibicides laurisae,* usually an intermediate-depth form, may indicate redeposition through this interval (Table 8). If these bolivinids are not redeposited, then

Table 3. Ranges of benthic foraminifers from the late Eocene through the Oligocene in Hole 707A.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Bulimina alazanensis*	*Stilostomella gracillima*	*Uvigerina subproboscidea*	*Uvigerina ongleyi*	*Bolivinopsis gryzbowski*	*Cibicidoides havanensis*	*Lenticulina vortex*	*Martinotiella cojimarensis*	*Oridorsalis umbonatus* (smooth margined)	*Pleurostomella chapapotensis*(?)	*Pullenia bulloides*	*Stilostomella nuttalli*	*Uvigerina havanensis*	*Planulina renzi*	*Anomalinoides semicribratus*	*Planulina* sp.	*Bulimina semicostata*	*Globocassidulina subglobosa*	*Uvigerina spinulosa*	*Eggerella bradyi*	*Vulvulina spinosa*	*Bolivina tectiformis*	*Bolivina* cf. *B. pseudoplicata*	*Oridorsalis umbonatus* (scallopped margin)	*Globocassidulina subglobosa* (large form)
				16H-1, 120	142.5	6	2	4	1	1	2	4	1	1	3	3	1	4	3	cf.	cf.	1	1	1	1	1	2	4	2		
				16H-2, 121	144.0	6		5	1	1	1			1	3			1					2	1	1			2	1	1	2
		CP19		16H-3, 121	145.5	5		5			1			3	3	1	1						1	3					1		
			P22	16H-4, 121	147.0	5	2	5		1		1		1	2						2		1					1	1		
	late			16H-5, 21	147.5																										
			P21b	16H-6, 121	150.0	5		4			2	1	1		1	1	1	2		cf.	cf.	2		3			1	1	1		1
				17H-1, 6	151.0	4					4	1	1	1	1	1		2				1		1	2		1	5			
				17H-CC	152.3	5		1						1	3	1	1	2					1	3				4			
		CP18	P21a	18H-CC	162.0	4					1	1	1		2	4			2				3	1			1	3	4		1
Oligocene				20X-1, 121	174.9	4					1	2	2	2	2	2		1		1				4			2	4			3
		CP17–CP18		20X-2, 121	176.4	2						3			2					cf.							1				
				20X-3, 121	177.9	4		3				1	1		2			3	1	3							1				
			P20	20X-CC	178.2	4		2				1	1	1	1			3		cf.											
				21X-1, 121	184.6	5	2					1	1	1	2	1		1	3	3			1	1				3		1	1
	early			21X-2, 121	186.1	1	3					4			4	3	1	1				3									4
			P19	21X-3, 121	187.6	2	2	3				2	1		4	2				2								3		2	2
				21X-4, 121	189.1	1		3			1	1			3				1				1					4		2	
				21X-6, 121	192.1	1						4			4			4					3	1			4	2			3
		CP16		22X-1, 121	194.3	1						5	1		5			2	1								1	4		1	2
			P18	22X-2, 121	196.8	1	3	1				4	1		5			4									2		6	3	4
		CP16a	P17	22X-3, 121	197.3	1						4	1	2	4		5	2									1	5			1
				22X-4, 121	198.8	1	4	1				3			5			2	1				4				2				3
Eocene	late			22X-5, 121	200.3	2		1			1							4					4								
				22X-6, 121	201.8	2		1			1				2	2							1							1	1
				22X-7, 6	202.2	2		3				4	1		3			3					4								4
				23X-1, 120	203.9	2					1	2			2			4					3	1			4	1		1	1

Notes: Preservation was assessed according to the following scheme: 1, very very poor; 2, very poor; 3, poor; 4, fair; 5, good; 6, very good; 7, excellent. Number of infauna, epifauna, total species diversity, and abundance of infaunal vs. epifaunal species for each sample are tabulated to the right. Biozonation is based on nannofossils, but planktonic foraminifer zones are also shown (Backman, Duncan, et al., 1988)

their occurrence at Site 217 suggests that the bolivinid-rich level at Site 238 is also in place and that the lower depth limit of intermediate-depth faunas has been depressed to 2800 mbsl.

Neogene Deep-water and Intermediate-depth Sites

Miocene

All basinal samples from Sites 251 (3498 m), 236 (5140 mbsl), and 241 (4054 m) contain material redeposited from intermediate depths. At Site 236 in the Mascarene Basin, an abundance of crenulate bolivinids suggests a more northerly origin for the sediments, as these bolivinid-rich faunas do not occur at intermediate depths on the Mascarene Plateau, but farther north at sites on the Chagos-Laccadive Ridge.

Faunas of early Miocene Zones CN1–CN3 (= Zones N4–N7) were recovered both along the Mascarene depth traverse and to the northeast at Sites 714 and 715. Preservation is fair except at Site 710, where it is generally poor as a result of extreme dissolution. Benthic foraminifers are less numerous than previously at all sites, fewer species dominate the samples, and many species are small in size. Benthic foraminifers are least common and diversity is lowest at intermediate-depth Site 707. Even at Site 714, in which diversity is greater, the number of specimens per mg/sediment is low.

This interval is unique because of the similarity of faunas along the Mascarene depth traverse. *Cibicidoides kullenbergi, O. umbonatus, G. subglobosa, S. lepidula,* and *S. nuttalli* are found at all depths (Fig. 9). *Nuttallides umbonifera* occurs in the deeper two sites, 709 and 710 (Tables 9 and 11), and migrates updepth to Site 707 during one short episode midway through the zone (Table 12). Mixed tan and grey sediments at Sites 707 and 709 give evidence of oxidation or sediment mixing by burrowing organisms through this interval. Oxidation may be primary or may have occurred during episodes of sediment mixing or redeposition.

As in the Oligocene, the earliest Miocene age faunas at Central Indian Basin Sites 714 and 715 are entirely different from those along the Mascarene traverse. Bolivinids are the most common forms at both sites, but the crenulate bolivinids with large pores, such as *B. pseudoplicata,* predominate (Fig. 7). Although pleurostomellids are more common in the small faunas at Site 714 (Table 5), *Bolivinita quadrilatera, G. subglobosa,* and the flat, costulate bolivinid *Bolivina striatocola* characterize the higher diversity faunas at the slightly deeper Site 715 (Table 13). Dominance and benthic abundance are greater at Site 715.

Middle Miocene Zone CN4 (= Zone N9) age faunas were identified only at the intermediate sites. At Site 707, the only forms present were large and small *G. subglobosa, O. umbonatus,* and *O. bengalensis.* Bolivinids were absent (Table 12).

Table 3 (continued).

Pleurostomella subcylindrica	*Anomalinoides* cf. *A. alazanensis*	*Osangularia mexicana*	*Uvigerina spinicostata*	*Pullenia quadriloba*	*Bolivina reticulata*	*Siphonodosaria modesta*	*Pullenia coryelli*	*Frondicularia* sp.	*Uvigerina auberiana*	*Bulimina macilenta*	*Cibicidoides praemundulus*	*Orthomorphina perversa*	*Gyroidinoides girardanus*	*Stilostomella verneuli*	*Siphonina* sp.	*Karreriella* sp.	*Pullenia quinqueloba*	*Uvigerina pigmea*	"*Trifarina*" *pigmea*	*Stilostomella subspinosa*	*Hanzawaia ammophila*	*Cibicidoides haitiensis*	*Gyroidinoides planulatus*	*Cibicides laurisae*	*Bulimina* sp. (striate)	*Spiroplectammina spinosa*	*Cibicidoides trincherasensis*	*Plectofrondicularia lirata*	*Gyroidinoides altiformis*	*Bulimina miolaevis*	*Cassidulina crassa*	*Cibicidoides* cf. *C. ungerianus*	*Heterolepa grimsdalei*	*Hanzawaia cushmani*	*Buliminella* sp.	*Bulimina macilenta*	Diversity	Epifauna	Infauna	Total uvigerinids	Abundance (infauna)	Abundance (epifauna)
																																					21	2	14	6	30	7
1	1	1	1	1																																	19	2	15	4	22	2
	1		1																																		11	0	9	1	15	3
	1				1	1	1																														14	2	12	1	15	5
																																					0	0	0	0		
	1			1	1	4		1	1	1	1	1	2		1	1																					28	6	18	1	26	6
		2									1		1	2			1																				17	5	8	2	18	6
		1				1		1		1		1						2																			15	1	12	2	19	1
3	1				2						1	1	1			1			1	2	1	1															23	5	10	2	19	5
			1								1	2	2			2				4				1	5	1											22	6	11	1	27	6
		1	2										1	1		1		1							5	·1	1	2	1	1							16	5	6	3	12	4
		3				2										1									2	1							1	1			17	5	5	1	11	9
												2				1				2					5												15	2	5	0	19	11
1		4																							2				2			1	1			1	21	6	11	3	16	11
		1										1	3			2				1	3			1				1		3							17	6	8	3	19	15
		3				1					1		1			3							1			1			3			1	1	3	1		24	10	6	0	14	17
		2										1		1									1						3	2		1	2	1		1	12	7	9	1	15	10
		4										2	4								1		3							2							14	5	6	0	17	16
		2											1	1			1							1							2						16	5	8	1	11	12
		4		1								3	1							1	1				3												18	5	7	0	23	13
		1				1				2				1		2				1					4		1	2				1					19	4	8	0	22	7
		1								1		1	4	1		1					1		1				2	3		1			3				21	7	10	1	22	15
		4								1			3			2					2										1		1				12	4	7	0	12	10
		3										2												1						2			1				12	4	6	0	12	6
		4								1						4				1	1												1				13	4	9	0	16	10
		3										1	4	2							1		2				1			1		2		1			20	9	8	0	15	17

A different faunal stratification characterizes Sites 714 and 715 at this time (Fig. 10). Faunas at Site 714 become dominated by smoother, flatter, finely porous bolivinids such as *Bolivina pukeuriensis, Bolivinita,* several crenulate bolivinids, *S. lepidula,* and *G. subglobosa* (Table 14). Richer faunas at Site 715 are dominated by *U. auberiana, C. kullenbergi, C. wuellerstorfi, E. hystrix, G. subglobosa,* and increased numbers of cibicidids, but the bolivinids are virtually gone. *Pullenia quinqueloba* occurs in only one interval (Table 13). Clearly, different conditions developed between Site 714 at 2038 mbsl and Site 715, located at 2262 mbsl.

Late Miocene Zone CN9 (= Zone N17) was recovered at all three sites along the Mascarene traverse and to the east at Central Indian Basin Site 713 and Arabian Sea Site 219, but was represented by a hiatus at the northeastern Chagos-Laccadive Sites 714 and 715. Most samples are characterized by high benthic foraminifer diversity and improved carbonate preservation. Along the Mascarene depth traverse (Fig. 11), uvigerinids, miliolids, and lagenids increase through this time. At intermediate-depth Site 707, very well-preserved *U. auberiana,* small *G. subglobosa,* lagenids and *C. wuellerstorfi* predominate (Table 12). In Zone CN9b (Zone N17b), an index fauna containing uvigerinids, *Rectuvigerina spinea,* and *E. exiguua* characterizes the end of the Miocene (Fig. 11).

At deep-water Site 709, both small- and large-sized *G. subglobosa* predominate along with *O. umbonatus, U. proboscidea, N. umbonifera* and fluctuating numbers of uvigerinids (Table 15). Present also are several large species first named in Car Nicobar, for example, *Nodosaria skobina* and *Chrysalogonium setosum,* together with the intermediate-water uvigerinid *R. spinea* (Boersma, 1984, 1985c). Because sediments throughout this interval are white and oxidized tan, some specimens are unusually large, and uvigerinid species usually restricted to intermediate depths are present, it is again unclear whether the sediments at Site 709 are in place. Redeposition or burrowing activity is suggested by the mottled sediments. The interval closes with an increase in the numbers of uvigerinids and *Pyrgo* spp. (Fig. 11).

At abyssal Site 710 (Table 16), preservation improves, diversity increases, and *E. exiguua, N. umbonifera,* and *O. umbonatus* occur in some number along with *C. wuellerstorfi.*

To the east, in the Central Indian Basin at deep-water Site 713, the dominant species are the crenulate bolivinids, lagenids, *G. subglobosa, B. alazanensis, O. umbonatus, U. auberiana, C. kullenbergi,* and *Favocassidulina fava* (Table 17). Diversity is high (27–30 species), and dominance is high. It is possible that intermediate-water faunas represented by the crenulate bolivinids are mixed into deep-water faunas at Site 713. Near the end of this time, *N. umbonifera* appears, together with increased numbers of uvigerinids, *Pyrgo murrhina,* and *F. fava,* the loss of all crenulate bolivinids, and faunal overturn involving the loss of 11 species (Fig. 11).

To the north in the Arabian Sea, at intermediate-depth Site 219, diversity reaches its Neogene maximum for all sites (46 species). These rich, moderately well-preserved faunas are domi-

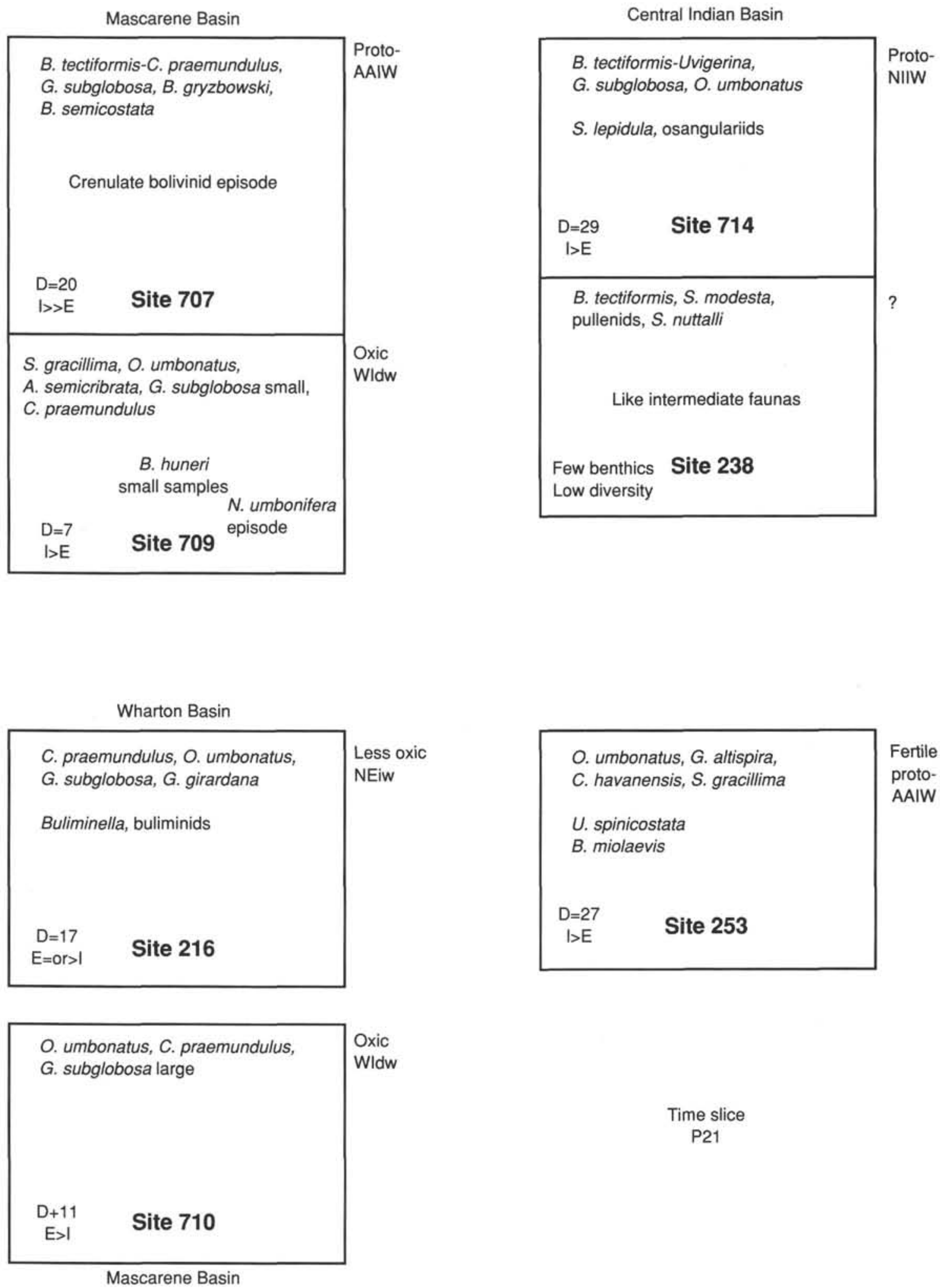

Figure 5. Benthic foraminifer index faunas of late Oligocene Zone P21 (= Zone CP18) from seven sites in the western and central Indian Ocean. Indexes, listed at top, were most abundant or most consistently present. Index forms that occurred only in pulses or discrete episodes are shown below. Total sample diversity and the relation of infaunal to epifaunal abundance are shown at bottom left of each box. The faunal name assigned to each index fauna is listed to the right of each box. Data from Tables 3–11.

Table 4. Ranges of benthic foraminifers from the early Oligocene to the early Miocene at Site 214.

Age		Zone		Core, section, interval (cm)	Preservation	*Uvigerina subproboscidea*	*Uvigerina auberiana*	*Oridorsalis umbonatus*	*Pullenia bulloides*	*Gyroidinoides neosoldanii*	*Stilostomella lepidula*	*Stilostomella insecta*	*Melonis affinis*	*Karreriella bradyi*	*Cibicides wuellerstorfi*	*Cassidulina laevigata*	*Eggerella bradyi*	*Osangularia bengalensis*	*Globocassidulina subglobosa*	*Nuttallides umbonifera*	*Bulimina alazanensis*	*Bolivina* sp. (encrusted sutures)	*Orthomorphina koina*	*Pullenia quinqueloba*	*Pyrgo murrhina*	*Melonis barleeanum*	*Anomalinoides semicribratus*	*Rectuvigerina spinea*	*Epistominella exigua*	*Textularia lythostrota*
				4-3, 91	7	5	3	4	2	2	5	3	2	1	1	1	1	1	1	1										
				5-3, 83	7	1			1						1				3	2	4	1	1	1	1	2	1	1	1	
				9-3, 91	7	5	1			1	1		2								2									2
Miocene	early	CN1a		10-3, 57	5	5	1	1					3	1							5						1			
				12-2, 51	7		1	2			4	1		1	1			1					1			1	2			
				16-3, 41	5			3	2	2	1				4	1			2								1			
			N4	24-2, 124	4			5			2								5		2									
Oligocene	early	CP17	P18–P19	25-6, 10	4			1	2		5						1		2		1									
				27-2, 82	2			5	2		3								6		1									

Age		Zone		Core, section, interval (cm)	Preservation	*Cibicidoides kullenbergi*	*Bolivina pusilla*	*Orthomorphina perversa*	*Uvigerina hispidocostata* (spinose)	*Stilostomella subspinosa*	*Bolivina* cf. *B. pulchra*	*Bulimina striata*	*Gyroidinoides altispirus*	*Vulvulina spinosa*	*Planulina* sp. (loosely coiled)	*Pleurostomella subcylindrica*	*Bulava* sp.	*Planulina renzi*	*Sphaeroidina bulloides*	*Spiroplectammina spinosa*	Small virgulinids	*Bulimina semicostata*	*Uvigerina subproboscidea*	*Cibicidoides praemundulus*	*Gyroidinoides girardanus*	*Stilostomella gracillima*	*Cibicidoides havanensis*	*Uvigerina spinulosa*	*Stilostomella nuttalli*	*Hanzawaia cushmani*
				4-3, 91	7																									
				5-3, 83	7																									
				9-3, 91	7	1	1																							
Miocene	early	CN1a		10-3, 57	5																									
				12-2, 51	7		1	1	1	2	1	1																		
				16-3, 41	5					1			1	3	1	1	1	1	1	3	5									
			N4	24-2, 124	4																	4	2	2	3	3	1	1		
Oligocene	early	CP17	P18–P19	25-6, 10	4			2		4			1	1		2						2			1	1	1	1	4	1
				27-2, 82	2			2					5									4		1	1		5		3	3

Age		Zone		Core, section, interval (cm)	Preservation	*Discorbis* sp.	*Orthomorphina rohri*	*Bolivina tectiformis*	*Buliminella* sp.	Pleurostomellids	*Bulimina macilenta*	*Cibicidoides* cf. *C. ungerianus*	*Chrysalogonium equiseliformis*	*Vulvulina pennatula*	*Bulimina* sp. (striate)	*Cibicidoides tuxpamensis*	*Heterolepa mexicana*	*Gyroidinoides planulatus*	*Pullenia eocenica*	*Anomalinoides alabamensis*	*Marginulina* sp.	*Cibicides laurisae*	*Karreriella chapapotensis*	*Siphonodosaria modesta*	Diversity	Infauna	Epifauna	Abundance (epifauna)	Abundance (infauna)
				4-3, 91	7																				15	8	5	9	22
				5-3, 83	7																				14	9	4	6	15
				9-3, 91	7																				9	6	2	2	12
Miocene	early	CN1a		10-3, 57	5																				7	4	1	2	14
				12-2, 51	7																				16	10	4	6	15
				16-3, 41	5																				18	8	8	13	14
			N4	24-2, 124	4																				12	7	5	8	19
Oligocene	early	CP17	P18–P19	25-6, 10	4	5	1	3	1	4	1	2	1	1											27	17	7	12	35
				27-2, 82	2		2			5		2			6	2	4	4	3	2	1	1	1	1	25	13	12	28	41

Note: Explanation as in Table 3.

Table 5. Ranges of benthic foraminifers from the late Oligocene to the early Miocene in Hole 714A.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Globocassidulina subglobosa*	*Bolivina striatocola*	*Bolivina tortuosa*	*Cibicidoides kullenbergi*	*Bolivina pseudoplicata*	*Uvigerina proboscidea*	*Stilostomella lepidula*	*Bolivinita quadrilatera*	*Pullenia bulloides*	*Pleurostomella* spp.	*Planulina renzi*	*Bulimina glomarchallengeri*	*Melonis affinis*	*Martinotiella variabilis*	*Vulvulina pennatula*	*Lenticulina vortex*	*Karreriella bradyi*	*Hanzawaia cushmani*	*Cibicidoides* sp. (turbinate)	*Bulimina nuda*	*Gyroidinoides girardanus*	*Bolivina reticulata*	*Uvigerina spinulosa*	*Cibicides lobulatus*	*Nuttallides umbonifera*
Miocene	early	CN1a		20X-CC	184.7	4	3	5	2	1	5	1	3	1	1	2	1	1	1	2	1	1	2	1	1						
				21X-CC	194.4	3	2	4			4		2			2	2		3							1	1	1	1	1	
				22X-1, 120	195.6	3	5				5		3			2						3		3		1	4	1		1	1
				22X-2, 120	197.1	3	4				5		2			2	1				1							5	1	1	
				22X-3, 20	197.6	3	2	5		4	4		4			4				1		1					1				
				22X-3, 110	198.5	3	3			2	7		5			1	3		1									2	4		
				22X-4, 103	199.9	3	4	2			1		4			1	1										1		1		
				22X-5, 65	201.0	4	3	5			5		1			3			1			4					2				
				23X-1, 110	205.2	3	5	3			2	1				3											1	2			
			N4	23X-1, 125	205.4	3	3	1		1			1		1	1						1					2				
Oligocene	late	CP19b	P22	23X-2, 125	206.9	3	6	5	1	1			5			2					1		1								
				23X-4, 110	209.7	2	2	3		3	2		4	1	1		1					1	1				2		2		
				23X-4, 125	209.9	4	5	5	1	1	5		2	1	1	1	1			1		2		1					1	1	
				23X-6, 25	211.9	4	3	4	1	1	7		5				1										1				
				23X-6, 125	212.9	3	4			1	2		2	1			3					1					1		1		
				24X-1, 110	214.9	4	3			1			2		1		1					2		1							
				24X-1, 125	215.1	3	3				5		3			3				1							1				
	early	CP18	P21a	25X-1, 105	224.4	4	5		1				1	1								1					1				
				25X-1, 120	224.5	3	5		2	1			5		1		3					4		1		1			4		1

Note: Explanation as in Table 3.

nated by *Uvigerina proboscidea, B. alazanensis, O. umbonatus, G. subglobosa, S. lepidula, Rectuvigerina multicostata* (Table 18), and the smooth, lenticular bolivinid with large pores, *B. pulchra. Epistominella exiguua* occurs for the first time in this zone, and *O. bengalensis* disappears. The end is characterized by the only appearance of *N. umbonifera* and the replacement of the large-pored and crenulate bolivinids by the smooth, flat costulate types, together with increased numbers of uvigerinids and faunal overturn involving the loss of 7 species, including *Hoeglundina elegans* and *Ehrenbergina trigona* (Fig. 11).

Pliocene

Early Pliocene zonal interval CN10–CN11 (= Zones N18–N19) faunas were identified at all three sites along the Mascarene traverse, as well as at Site 238 in the Central Indian Basin. At the shallowest Site 707, benthic foraminifers become scarcer and remain so throughout the remainder of the Cenozoic. Lagenids, *G. subglobosa, O. umbonatus,* and *Melonis pacificum* occur consistently, while crenulate bolivinids occur episodically (Table 19). The finely hispid uvigerinids vary inversely with *G. subglobosa* throughout this interval, with the uvigerinids more numerous when diversity and numbers of infauna are also greater (Fig. 12).

Miliolids, all size classes of *G. subglobosa,* lagenids, *O. umbonatus, F. fava,* and *G. neosoldanii* are typical at deeper Site 709 (Table 20), along with several large forms attributable to the Car Nicobar fauna (Fig. 13). It is again not clear how much of this fauna is in place. In general, the finely hispid uvigerinids and *G. subglobosa* vary inversely at this site, while the abundance of *N. umbonifera* varies directly with that of the epifauna (Fig. 14). Diversity and the numbers of infauna and epifauna all decrease through this time.

Despite improved preservation, abyssal faunas at Site 710 remain small, but they do include a new group of solution-resistant forms including *Melonis pompilioides, G. neosoldanii, P. quinqueloba,* and *O. umbonatus* (Table 16). Redeposited fossils still occur in this abyssal fauna.

At Arabian Sea Site 219, intermediate depths are characterized by high-diversity faunas similar to those of the late Miocene, but are typified by such flat, smooth, costulate bolivinids as *B. pusilla* and by miliolids. In Zone N18, an abundance pulse of *E. exiguua* and *P. quinqueloba* accompanies increased numbers of *Rectuvigerina multicostata* and the lenticular, large-pored bolivinid, *B. pulchra* (Fig. 14).

Deep-water Central Indian Basin Site 238 faunas are characterized by *G. subglobosa* (small form), *M. pompilioides, F. fava,* a triangular-shaped uvigerinid related to *Uvigerina pigmea* (tentatively called "*Trifarina*" *pigmea* here), miliolids, turbinate cibicidids, *P. bulloides,* and *C. wuellerstorfi* (Table 10). Such Car Nicobar species as *N. skobina* and *S. setosum* are not present at this site, thus differentiating it from Site 709 located to the west at almost identical depths (Table 15).

A new *U. auberiana-F. fava* index fauna with high numbers of *G. subglobosa* develops at nearby Site 713. An abundance pulse of *N. umbonifera* at this site may correspond with pulses of *N. umbonifera,* uvigerinids, and miliolids registered at all other sites early in Zone N18 (Fig. 15).

Late Pliocene Zone CN12 (= Zone N21) along the Mascarene depth traverse is characterized by short sections and similar faunas at the two deeper Sites 709 and 710. Site 709 contains a

Table 5 (continued).

Cassidulina crassa	*Uvigerina subproboscidea*	*Cibicides pseudowuellerstorfi*	*Bulimina alazanensis*	*Melonis barleeanum*	*Anomalinoides globulus*	*Bolivinopsis gryzbowski*	Redeposited benthic foraminifers	"*Trifarina*" *pigmea*	*Cassidulina cornuta*	*Osangularia culter*	*Textularia mexicana*	*Orthomorphina rohri*	*Oridorsalis umbonatus*	*Saracenaria triangulata*	*Discorbis villardeboanus*	*Siphonodosaria modesta*	*Frondicularia* sp.	*Heterolepa mexicana*	*Valvulineria* sp.	*Bulimina semicostata*	*Gyroidinoides planulatus*	*Cibicidoides haitiensis*	*Lenticulina* cf. *L. cibaoensis*	*Gyroidinoides altiformis*	*Anomalinoides semicribratus*	*Bulimina miolaevis*	*Siphonina* sp.	*Osangularia* cf. *O. bengalensis*	*Cibicidoides* cf. *C. havanensis*	*Anomalinoides alabamensis*	*Bolivina* cf. *B. pseudoplicata* (fine ornament)	*Uvigerina pigmea*	*Bolivina reticulata*	*Cassidulina* sp.	*Bulimina macilenta*	*Pullenia quinqueloba*	*Cibicides vortex*	*Bolivina tectiformis*	*Stilostomella nuttalli*
4	1	1	2	1	1	1	1																																
			1			1		1	1	1	1	1																											
1					1	2						1	2	1	1	1																							
1							1					1	5		1	1			1	4	1		1		1	1	1	1	1	1									
1													1			1	1	1													2	1	3	1					
4						3	1	1									1	1	2	1	1	1	1																
		2				1		1																1															
2						2	1		1						1	1																							
	1	1								1			2																	1			1		1	1	1		
									2			1	4		1									1			1						1			1	2	1	2
1		1					1					1	4																	1	2	1	3					1	
	2						2		1	2			4		1		1		1		1									1	5			3		1		1	1
5	1									1		1	2	1													1	1		1							3	1	
2							3						1			1				1		1											2					3	
2			2			1			1	1			2							1	1	1				1		1			2							3	1
1		1								1			3																				1					4	
							1			3			5		3			1				1																5	

cibicidid-*Pyrgo* index fauna, including also *F. fava, G. subglobosa, O. umbonatus, N. umbonifera* and *G. soldanii* (Fig. 16). At Site 710, lagenids and *M. pompilioides* are also typical. For the first time, epifaunal numbers become equal to or greater than infaunal numbers in abyssal and deep-water sites (Table 16).

Uvigerinids and bolivinids are more common at intermediate-depth sites. Both uvigerinids and cibicidids increase in number at the shallower Site 707 where crenulate bolivinids occur episodically for the last time (Fig. 16). By the end of the zone, infaunal numbers begin to drop toward values more typical of modern faunas. Farther north in the Arabian Sea at Site 219, uvigerinids predominate along with the smooth, costulate bolivinid *B. pusilla*, *S. marginata*, and small numbers of *Epistominella exiguua* and *P. quinqueloba*.

DISCUSSION

Subsurface water masses of the western Indian Ocean are produced from several source regions. Deep and bottom waters are derived from the Atlantic Ocean, as there is no evidence for formation of bottom water along the portion of the Antarctic continent south of the Indian Ocean. Intermediate waters, however, have two sources. Because of the landlocked character of the northern Indian Ocean and the lack of a connection to cool higher latitude seas, advection is slow and surface waters tend to evaporate, become highly saline, and sink to intermediate depths. Because of the fertility and high primary productivity of the northern Indian Ocean, there is such a high demand for oxygen in the water column that intermediate waters also tend to be low in oxygen. The lowest oxygen intermediate waters are currently found in the Bay of Bengal and the Andaman and Arabian seas. Intermediate water of Antarctic origin can be traced by its salinity minimum as far north as 10°S. Because this water is formed by intense mixing and sinking of Antarctic surface water along the Polar Front, it is oxygen rich and low in nutrients (Wyrtki, 1973; Warren, 1981).

Modern intermediate-depth benthic foraminifer faunas in the northern Mascarene Basin, the southern Indian upwelling zone, and the southern Arabian Sea reflect these two different intermediate-depth water masses. At Site 219 in the southern Arabian Sea and Site 714 in the southern Indian upwelling zone underlying high-fertility surface waters, benthic foraminifer faunas are high in diversity and rich in infauna; the number of specimens per mg/sediment is high; and large numbers of spinose uvigerinids, stilostomellids, buliminids, and diverse bolivinids are found. In contrast, modern intermediate-depth faunas in the area of Site 707 underlying AAIW contain few specimens and few species per genus per mg/sediment, and no uvigerinids or bolivinids. Epifauna are more numerous in these samples and diversity is low. Such a faunal contrast should be useful for interpreting the development and geography of low-oxygen conditions from ancient sediments and faunas in the northern Indian Ocean.

Foraminifer tracers depict relative oxygenation at intermediate depths. Because low-oxygen levels develop in fertile areas where high primary production results in high organic carbon flux to the bottom, sediments underlying low-oxygen intermediate waters are often organic-carbon rich (Banse, 1968). Indexes for elevated levels of organic carbon in the sediment include species of the infaunal genera *Uvigerina, Hopkinsina,* and *Rectuvigerina,* the abundances of which correlate with high phosphate concentrations in the sediments under modern upwelling zones (Lutze, 1977; Douglas, 1981; Miller and Lohmann, 1982; Lutze and Coulbourn, 1984; Corliss and Chen, 1988).

Table 5 (continued).

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Bolivina pukeuriensis*	*Bolivina arta*	*Nodosaria* cf. *N. stiliformis*	*Siphonina tenuicarinata*	*Cibicides laurisae*	*Alabamina* sp.	*Cibicidoides subspiratus*	*Uvigerina porrecta*	*Pullenia coryelli*	*Stilostomella subspinosa*	*Chrysalogonium equisetiformis*	*Spiroplectammina spinosa*	Diversity	Infauna	Epifauna	Total uvigerinids	Abundance (infauna)	Abundance (epifauna)
Miocene	early	CN1a		20X-CC	184.7	4													19	11	5	4	29	4
				21X-CC	194.4	3													12	8	4	1	22	4
				22X-1, 120	195.6	3													19	10	7	1	28	11
				22X-2, 120	197.1	3													16	9	4	1	23	2
				22X-3, 20	197.6	3													17	9	6	0	2	9
				22X-3, 110	198.5	3													26	16	9	4	55	15
				22X-4, 103	199.9	3													17	12	5	2	23	2
				22X-5, 65	201.0	4													19	12	5	0	31	4
				23X-1, 110	205.2	3													11	6	4	1	16	4
			N4	23X-1, 125	205.4	3													14	8	4	0	12	6
Oligocene	late	CP19b	P22	23X-2, 125	206.9	3													17	9	5	1	24	5
				23X-4, 110	209.7	2													23	13	8	2	24	13
				23X-4, 125	209.9	4													25	15	8	2	32	10
				23X-6, 25	211.9	4	7	7	1	2	1	1							29	17	11	0	53	24
				23X-6, 125	212.9	3			1				1	1					23	13	9	2	23	11
				24X-1, 110	214.9	4									1				16	8	7	0	15	8
				24X-1, 125	215.1	3						1	1			1			24	12	10	0	25	12
		CP18	P21a	25X-1, 105	224.4	4										2			13	7	6	0	13	10
				25X-1, 120	224.5	3											1		19	7	11	4	23	24

Globobuliminids and buliminids are factor-genera associated with low oxygen in the water column overlying areas with lower organic carbon in the surface sediment. In these areas, *Uvigerina* is the factor-genus correlated with organic carbon and silt maxima in sediments (Miller and Lohmann, 1983). *Ehrenbergina, Bulimina,* cassidulinids, *Eponides, Laticarinina,* porous melonids, miliolids, and *C. wuellerstorfi* have all been related to productivity and organic carbon accumulation in various oceanic settings (Douglas, 1981; Poag, 1981; Woodruff and Savin, 1989).

Infaunal abundance has been related to high organic carbon flux and organic carbon content in sediments in the modern North Sea. It is assumed that such sediments will also be less aerated (Corliss and Chen, 1988). Because of the complex processes determining pore-water oxygenation, however, only the association of infauna with higher organic carbon and organic carbon flux is assumed in this paper.

The relation between bolivinids and lowered oxygen levels in silled basins is well known (Hendrix, 1958; Phleger and Soutar, 1973; Leutenegger and Hansen, 1979; Douglas, 1981; Ross and Kennett, 1983). In the California offshore basins, bolivinids are correlated with low-oxygen levels in bottom waters, but not with anoxia in sediments (Douglas, 1981). They are typical in estuarine muds—for example, the Niger Delta (Brun et al., 1982)—but decrease in diversity and abundance offshore, being rarely found in abyssal areas.

Specific bolivinid morphological types are associated with different relative oxygenation levels. Thick, crenulate forms with rhomboidal cross-sections and large pores usually inhabit more oxygenated waters than flat, unornamented types with small pores (Lutze, 1977; Douglas, 1981; Boersma and Mikkelsen, this volume). Flat, unkeeled, and unornamented types with small pores are typical of quiet sedimentation under low-oxygen bottom waters where the organic carbon content of the sediments is high (Hendrix, 1958; Douglas, 1981). The modern flat, lenticular, but ornamented species *Bolivina aenariensis* has been associated with lowered oxygen levels at the bottom, not corresponding to the area of the organic carbon maximum (Poag, 1981). This means that this costulate form occurs at somewhat higher oxygen concentrations than species associated with the organic carbon maximum in the sediments.

In areas with low oxygen, but not anoxic conditions at the bottom, small, thin, delicate, and finely porous bolivinids proliferate (Douglas, 1981). In the Miocene of the North Atlantic and northern Indian Ocean during apparent low-oxygen episodes, the more delicate, thin, and finely porous species predominated and fluctuated together with the uvigerinids (Thomas, 1985; Boersma and Mikkelsen, this volume).

A number of other genera are associated with low-oxygen conditions at intermediate or shoaler depths. For example, the reducing, brownish-black, slope-depth sediments of Miocene age offshore West Africa contain, together with the diatoms and abundant uvigerinids, elevated numbers of *Gyroidina, Praebulimina, Cassidulina, Melonis, Bulimina,* allomorphinids, *Valvulineria,* and, in areas of very low oxygen and probably high turbidity, agglutinants such as *Haplophragmoides, Cyclammina, Pavonita, Textularia, Spiroplectammina, Eggerella,* and *Karreriella* (Brun et al., 1982, and pers. observ.).

Increased oxygenation of the intermediate depths, signaled by a decrease in low-oxygen indexes, should produce elevated abundances of benthic indexes associated with well-oxygenated conditions. Increased epifaunal abundance occurs in well-oxygenated (hereafter called oxic) areas of low-carbon rain rates in the Norwegian Sea (Corliss and Chen, 1988). In the southwest

Table 6. Ranges of benthic foraminifers through the Oligocene at Site 216.

Age		Zone		Core, section, interval (cm)	Preservation	*Globocassidulina subglobosa* (large form)	*Cibicidoides praemundulus*	*Globocassidulina subglobosa* (small form)	*Orthomorphina perversa*	*Stilostomella lepidula*	*Uvigerina spinicostata*	*Oridorsalis umbonatus*	*Nonion havanense*	*Cassidulina* cf. *C. laevigata*	Reticulate cassidulinid	*Hanzawaia cushmani*	*Gyroidinoides girardanus*	*Bulimina* cf. *B. mexicana*	*Anomalinoides semicribratus*	*Bolivina* sp. (reticulate)	*Gyroidinoides globosus*	*Pleurostomella* spp.	*Buliminella*	*Cibicidoides perlucidus*	*Nuttallides umbonifera*	*Bulimina alazanensis*	*Spiroplectammina spinosa*	*Bolivina* cf. *B. huneri*	*Gyroidinoides planulatus*	*Karreriella chapapotensis*
Oligocene	late	CP19		9-3, 10	4	2	1	2	1	4	1	5	3	1	2	1	2	1	1	1	1	2	1	1						
				10-1, 100	4	3	5	2		4	2	4					1		1		1	1	1		3	1	2	1	2	1
			P22	10-2, 10	3	4	2			4		4				1					1	1								
	early	CP18	P21a	11-1, 100	5	1	5	4				5					3		1		1	2			5	1			1	
				12-2, 3	4	3	4		1	3		5				1	1		cf.			1								1
				14-2, 10	2	1	4			2		5				1	2					1	3							

Age		Zone		Core, section, interval (cm)	Preservation	*Cibicidoides havanensis*	*Chrysalogonium equisetiformis*	*Vulvulina pennatula*	*Vulvulina* sp.	*Bulimina macilenta*	*Siphonodosaria modesta*	*Discorbis villardeboanus*	*Gyroidinoides altispirus*	*Vulvulina spinosa*	*Bolivina tectiformis*	*Stilostomella nuttalli*	*Pullenia bulloides*	*Pullenia quinqueloba*	*Bulimina* sp. (striate)	*Planulina renzi*	*Orthomorphina rohri*	*Heterolepa grimsdalei*	*Osangularia mexicana*	Diversity	Infauna	Epifauna	Abundance (infauna)	Abundance (epifauna)
Oligocene	late	CP19		9-3, 10	4																			19	10	9	21	9
				10-1, 100	4	1	1	2	1	1	1													23	12	8	19	13
			P22	10-2, 10	3							2												8	3	5	10	9
	early	CP18	P21a	11-1, 100	5	2				1			3	2	1	1	1	1	2					19	10	9	15	20
				12-2, 3	4	3		3						1		4		1	3	2	1			18	8	6	17	13
				14-2, 10	2	1							1	1		1						1	1	15	5	8	12	11

Note: Explanation as in Table 3.

Atlantic, species characterizing well-oxygenated, "new" AAIW include *G. subglobosa, U. auberiana, B. alazanensis, C. wuellerstorfi, H. elegans,* eggerellids, and various intermediate-dwelling planulinids (Corliss, 1983; Boersma, 1985a). The AAIW is well oxygenated, but less so than the NADW (Reid et al., 1977). Atlantic factor-species related to oxic conditions in NADW include *C. kullenbergi, E. exiguua, N. umbonifera, G. subglobosa, O. umbonatus* and *H. elegans* (Fig. 5). Of these, *C. kullenbergi* is associated with the highest oxygen values in the NADW (Woodruff and Savin, 1989). Although such forms as *E. exiguua* are found in abyssal waters, even at lower intermediate depths in the Norwegian Sea, *E. exiguua* inhabits well-oxygenated waters (Schnitker, 1974).

Oxygenation of Intermediate Waters

Zones CN18–CN19 (= Zone P21) Time Slice

The absence of bolivinids and a paucity of buliminids and uvigerinids in all areas, even to the north under the upwelling zone at Site 714, indicate that low-oxygen conditions in the sediments at intermediate depths did not exist in the north central Indian Ocean before the late Oligocene. The costulate index *B. tectiformis* first appeared in abundance in both the Mascarene and northern Chagos-Laccadive areas in Zone CN18 (= Zone P21a). Because of its lenticular cross-section and moderate-sized pores, and because this species is the Paleogene analog of the lenticular, finely porous, costulate bolivinid *B. pusilla*, which is common in the Arabian Sea today, it is considered an index for lower oxygen conditions in the sediment.

In the Mascarene and Wharton basins, intermediate-depth faunas contained abundant deep-water indexes, such as *P. quinqueloba* and *C. praemundulus*, together with buliminids and buliminellids, but rare bolivinids. Because *C. praemundulus* is the predecessor of the NADW index, *C. kullenbergi*, it is interpreted to represent well-oxygenated, deep-water conditions. At Site 707, *C. praemundulus* occurs together with *G. subglobosa* and alternates in abundance with the bolivinids. This suggests alternating episodes of well-oxygenated bottom waters and times

Table 7. Ranges of benthic foraminifers through the Oligocene at Site 253.

Age		Zone		Core, section, interval (cm)	Preservation	*Bulimina semicostata*	*Oridorsalis umbonatus*	*Cibicidoides* cf. *C. ungerianus*	*Gyroidinoides planulatus*	*Bulimina mexicana*	*Cibicidoides praemundulus*	*Globocassidulina subglobosa* (small form)	*Pullenia quinqueloba*	*Pleurostomella* spp.	*Bolivina tectiformis*	*Epistominella exiguua*	*Uvigerina spinulosa*	*Stilostomella gracillima*	*Bulimina* cf. *B. glomarchallengeri*	*Hanzawaia cushmani*	*Stilostomella nuttalli*	*Pullenia bulloides*	*Planulina renzi*	*Globocassidulina subglobosa* (large form)	*Osangularia mexicana*	*Cibicidoides havanensis*	*Gyroidinoides altispirus*	*Laticarinina bullbrooki*	*Pullenia eocaena*	*Anomalinoides alabamensis*
Oligocene	late	CP19b		10-3, 89	6	5	3	1	1	1	5	5	4	4	2	1	5	5	2	1	5	4	1	2	4	2	1	1	1	1
				11-2, 80	5	3	4		2		4	5			2		2	4			4			4	2	1	2	1	2	
			P22	12-2, 84	4		3	4	1		3	2						5		2	4	1		1	1	5	3			
		CP19a	P21	13-2, 60	3		5	1	2			1		2				5				1		2	2	5	4		1	1

Age		Zone		Core, section, interval (cm)	Preservation	*Bulimina macilenta*	*Orthomorphina rohri*	*Nuttallides umbonifera*	*Vulvulina spinosa*	*Gyroidinoides girardanus*	*Stilostomella subspinosa*	*Heterolepa mexicana*	*Planulina renzi*	*Siphonodosaria modesta*	*Anomalinoides semicribratus*	*Anomalinoides aragonensis*	*Orthomorphina perversa*	*Marginulina* sp.	*Bulimina alazanensis*	*Martinotiella cojimarensis*	*Cibicidoides trincherasensis*	*Planulina* sp. (loosely coiled)	*Cassidulina cornuta*	*Chrysalogonium equisetiformis*	*Lenticulina vortex*	*Cibicidoides havanensis* (reticulate)	*Bulimina miolaevis*	*Spiroplectammina spinosa*	*Uvigerina spinicostata*
Oligocene	late	CP19b		10-3, 89	6	1																							
				11-2, 80	5		1	4	2	2	2	1	1	1	1														
			P22	12-2, 84	4	1			2		2		4	2		1	2	1	1	1	1	1	1	1	1	4	1		
		CP19a	P21	13-2, 60	3	2	1			1				2				1	1	1	2			1	2	5	1	2	1

Note: Explanation as in Table 3.

of lowered oxygen at the bottom and in the sediment. Based on the similarity to modern AAIW associations, intermediate-depth faunas containing these oxic indexes are called proto-AAIW water faunas (Fig. 5).

A faunal association typified by common costulate bolivinids, but infrequent uvigerinids and rare to no *C. praemundulus*, developed during Zone CN19 under the southern Indian upwelling zone. At Site 714, an association, representing lower oxygen conditions in the sediment, but moderate organic carbon flux to the bottom under moderately low-oxygen bottom waters, is suggested by the absence of *C. praemundulus*, but frequency of the gyroidinids, and is called a proto-North Indian Intermediate Water (or proto-NIIW) fauna (Fig. 5). That *G. subglobosa* alternates in abundance with the bolivinids in these faunas may be a criterion for recognizing the alternation of fertile, low-oxygen conditions with only moderately fertile, moderately low-oxygen conditions under the upwelling zone.

The bolivinids and *C. praemundulus* are absent, and *G. subglobosa* is rare, in Site 253 faunas, which, however, include spinocostate uvigerinids, including the predecessor of the modern species, *U. peregrina*, together with abundant *C. havanensis*. Although the meaning of this fauna is unclear, the absence of the oxic indicators suggests that it may represent less well-oxygenated intermediate waters in an area of organic carbon accumulation underlying cool, fertile surface waters, as suggested by the spino-costate uvigerinids. Because of its southerly location, this fauna is called a fertile, proto-AAIW fauna (Fig. 5).

Zone CN19 (Zone P22) Time Slice

A proto-NIIW fauna characterizes all intermediate-depth sites in the Mascarene, Wharton, and Central Indian basins during late Oligocene Zone CN19. Present at all sites (216, 714, 715, and 707) are the oxic indexes *G. subglobosa, C. praemundulus,* or *O. umbonatus*, but the cibicidids are rare. Stilostomellids proliferate, accompanied by high numbers of a different group of bolivinids, the thick, subrhomboid forms with crenulate ornament and large pores such as *B. pseudoplicata. Uvigerina spinulosa* and other uvigerinids are present throughout, but most common at the very end of this time (Fig. 6). *Nuttallides umbonifera* and *E. exiguua* occur in pulses during this zone, but are consistently present at its end. Because of the number of epifaunal oxic indexes and the association of thick, crenulate, large-pored bolivinids with moderately high oxygen concentrations in the sediment, these proto-NIIW faunas suggest elevated organic carbon contents and moderately aerated conditions in the sediments.

The association of large-pored bolivinids and uvigerinids, suggestive of high-carbon rain rates, may be related to the pene-

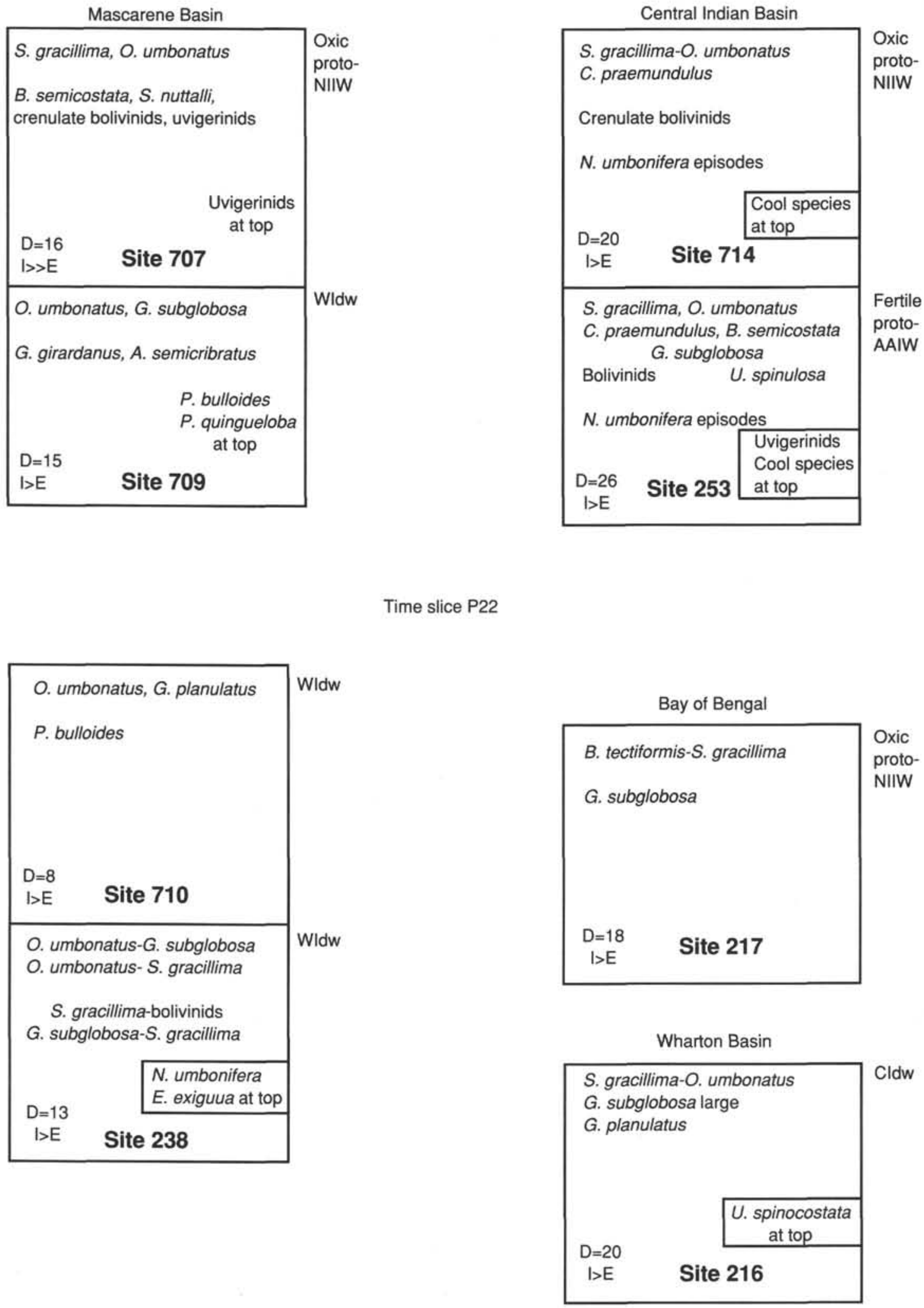

Figure 6. Benthic foraminifer index faunas of late Oligocene Zone P22 (Zone CP19) from eight sites in the western and central Indian Ocean. Indexes, listed at top, were most abundant or most consistently present. Index forms that occurred only in pulses or events are shown below. Total sample diversity and the relation of infaunal to epifaunal abundance are shown at bottom left of each box. The faunal name assigned to each index fauna is listed to the right of each box. Data from Tables 3–11.

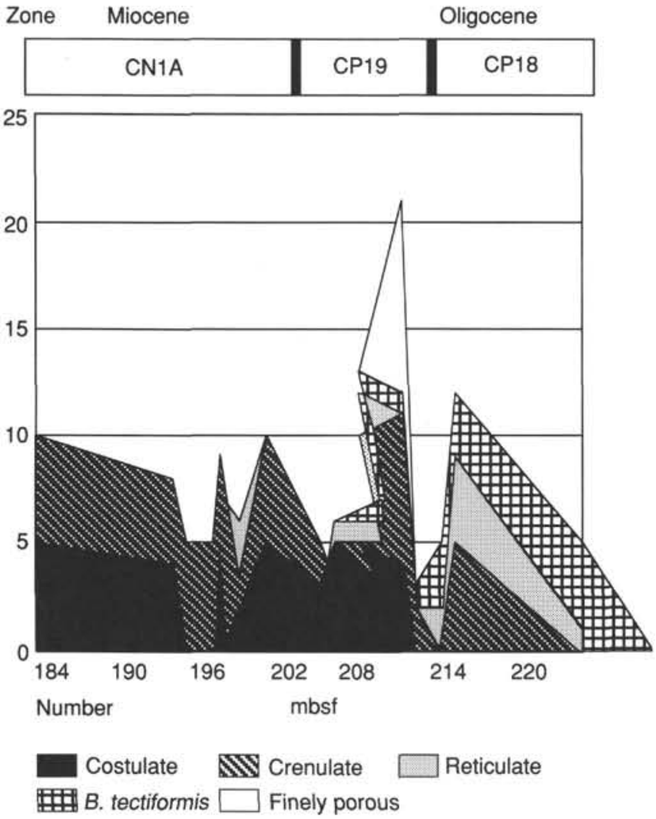

Figure 7. Relative abundances of bolivinid species, *B. pseudoplicata, B. reticulata, B. tectiformis*, and all smooth forms with small pores combined in Hole 714A across the Oligocene/Miocene boundary. The diversity maximum in Zone CP19b may reflect the development of an oxygen minimum in the sediments. Data from Table 5 and zonation from Backman, Duncan, et al. (1988).

tration of oxygen into sediments. When the carbon rain rate is high or bottom waters are lower in oxygen, the depth of the aerated zone in the sediment decreases (Archer et al., 1989). Oxygen demand, generated by the organic carbon, increases oxygen flux into the sediment, thus increasing the oxygen content of the upper few centimeters of sediment (Jahnke et al., 1982). The large-pored bolivinids may be tracers for increased oxygen content of the upper infaunal habitat before the development of an oxygen minimum when oxygen is depleted (Boersma and Mikkelsen, this volume.

Zones CN2–CN3 (Zones N4–N7) Time Slice

More oxygenated, lower fertility conditions develop in the Mascarene Basin than in the northern Central Indian and Wharton basins at this time. Faunas containing the oxic indexes *O. umbonatus, G. subglobosa*, and *C. kullenbergi*, together with the moderately low-oxygen infaunal index *B. pusilla*, continue at Site 707 (Fig. 9). Because of the elevated numbers of displaced benthic foraminifers, it is unclear if the bolivinids at Site 707 are in place. If not, then a proto-AAIW fauna occupies intermediate depths in the northern Mascarene Basin. Because of the presence of the uvigerinids and bolivinids, this is termed a fertile, proto-AAIW fauna. This area cannot have been a source of saline, low-oxygen waters. If intermediate waters were saline, then they were a saline, oxic, or "new" water type in Zone N4.

Proto-NIIW faunas develop in the Central Indian and Wharton basins in Zone CN1 (= Zone N4) (Fig. 9). Bolivinids, pleurostomellids, stilostomellids, and infrequent uvigerinids, together with consistently high numbers of globocassidulinids, characterize most faunas from 1600 to 2300 mbsl. Absent is the oxic index *C. kullenbergi*, and epifauna are infrequent. Crenulate bolivinids suggest that the sediment was moderately oxic, uvigerinids indicate moderate organic carbon content, and the lack of epifaunal oxic indexes suggest that the bottom water was only moderately oxic.

Zone CN4 (Zone N9) Time Slice

After Zone CN1 and continuing into Zone CN4 time, faunas in all areas are more similar to those under modern AAIW (Fig. 10). Benthic foraminifers are scarce, diversity is low, no uvigerinids except the oxic type *U. auberiana* are present at any site, and epifauna become more numerous than infauna for the first time at Site 707. Even in the Arabian Sea, a low-diversity fauna lacking uvigerinids, bolivinids, and buliminids develops. During the early to middle Miocene, therefore, the southern Arabian Sea did not produce high-salinity, low-oxygen intermediate waters as it does today.

Under the southern Indian upwelling zone at Site 714, a new group of bolivinids appears, albeit in low numbers, in small benthic foraminifer faunas composed of small-sized individuals. Finely porous, relatively robust bolivinids referable to *B. pukeuriensis* are accompanied by lenticular forms of *B. striatocola*, a Miocene analog of the modern species *B. aenariensis*. This species today is associated with an oxygen minimum and not the organic carbon maximum (Table 2), whereas the finely porous bolivinids are not the same as those delicate, thin types associated with the oxygen minimum (Douglas, 1981). This suggests that intermediate waters in the upwelling zone were moderately oxygenated, but that the upper pore waters had only moderately low oxygen levels. Because of the small faunas, low-diversity, small-sized individuals, and bolivinids, this fauna is called a moderately low-oxygen, proto-AAIW fauna (Fig. 10).

Zone CN9 (= Zone N17) Time Slice

In Zone CN9, a different faunal pattern develops in the Arabian Sea than at intermediate depths in the Mascarene Basin (Fig. 11). To the north at Site 219, an abundance pulse of spinose uvigerinids accompanies buliminids, stilostomellids, melonids, and bolivinids in very high-diversity faunas containing 46 species. In these faunas, the crenulate bolivinids are replaced by the costulate group, and the deep- and bottom-water indexes *P. quinqueloba* and *E. exiguua* migrate updepth, where they join the oxic indexes *C. kullenbergi* and *G. subglobosa*. The combined indexes suggest the development of oxygenated intermediate waters overlying sediments moderately low in oxygen, but rich in organic carbon. The presence of this fauna, called an oxic proto-NIIW fauna, suggests that saline, low-oxygen waters were not produced in the southern Arabian Sea at this time.

In contrast, a fauna containing the oxic indexes *G. subglobosa* and *U. auberiana* proliferates in the Mascarene Basin. Bolivinids, buliminids, and other indexes for lowered oxygen or greater organic carbon accumulation are absent. This fauna is called a fertile proto-AAIW fauna because uvigerinids are present and faunas are more diverse than modern faunas underlying AAIW at this site.

Zones CN10–CN11 (Zones N18–N19) Time Slice

During Zones CN10–CN11, the faunas of the Mascarene Basin and southern Arabian Sea diverged, a proto-AAIW fauna occurring to the south of the proto-NIIW fauna at Site 219 (Fig. 14). In the Arabian Sea, uvigerinids, bolivinids, buliminids, and stilostomellids occur in high-diversity faunas where the oxic cibicidid indexes and *E. exiguua* were scarce to absent, and infauna were almost four times as abundant as epifauna. Lenticular, costulate bolivinids represent moderately low-oxygen pore

Table 8. Ranges of benthic foraminifers through the Oligocene at Site 217.

Age		Zone		Core, section, interval (cm)	Preservation	*Nuttallides umbonifera*	*Bolivina tectiformis*	*Stilostomella lepidula*	*Pleurostomella* spp.	*Cibicidoides havanensis*	*Cibicides laurisae*	*Oridorsalis umbonatus*	*Anomalinoides alazanensis*	*Globocassidulina subglobosa* (large form)	*Gyroidinoides planulatus*	*Cibicidoides* sp.	*Osangularia mexicana*	*Stilostomella subspinosa*	*Cibicidoides praemundulus*	*Globocassidulina subglobosa* (small form)	*Bulimina* sp. (striate)	*Pleurostomella alternans*	*Stilostomella nuttalli*	*Orthomorphina perversa*	*Bolivinopsis gryzbowski*
Oligocene	late	CP19	P22	8-1, 2	4	1	5	5	2	2	1	2	1	2	1	1	1	1	1	2	1	2	2		
Oligocene	late	CP19	P21b	8-2, 3	2	1		2			2	1						1		1				1	1
Oligocene	early	CP19	P21a	8-3, 4	4	1						1		2	1				4	2					1
Oligocene	early	CP19	P21a	8-5, 60	4	1	2	2	1	1	1	5	1	4			1	1	3	3			5		
Oligocene	early	CP18	P19	9-1, 80	5	2					1	3	1				2		3	2			2		

Age		Zone		Core, section, interval (cm)	Preservation	*Pullenia quinqueloba*	*Nonion havanense*	*Gyroidinoides altispirus*	*Vulvulina spinosa*	*Gyroidinoides girardanus*	*Hanzawaia cushmani*	*Heterolepa grimsdalei*	*Marginulina* sp.	*Bulimina semicostata*	*Martinotiella cojimarensis*	*Cibicidoides haitiensis*	*Saracenaria* sp.	*Uvigerina havanesis*	*Bulimina consanguinea*	Diversity	Infauna	Epifauna	Abundance (epifauna)	Abundance (infauna)
Oligocene	late	CP19	P22	8-1, 2	4															18	10	8	9	24
Oligocene	late	CP19	P21b	8-2, 3	2	2	1													10	5	3	4	8
Oligocene	early	CP19	P21a	8-3, 4	4			3												10	3	6	10	1
Oligocene	early	CP19	P21a	8-5, 60	4		1	2	2	2	1	1	1	1	1					23	8	10	19	21
Oligocene	early	CP18	P19	9-1, 80	5	1		3				2				1	1	2	1	16	7	8	16	9

Note: Explanation as in Table 3.

waters that the presence of uvigerinids indicates are organic-carbon rich. Buliminid abundance may suggest low-oxygen intermediate waters (Table 2), in which case conditions similar to those under modern NIIW first developed in the southern Arabian Sea in the warm part of the early Pliocene (Fig. 14).

In contrast, oxic (Table 3) and bolivinid indexes for aerated pore waters occur at Site 707. These well-preserved carbonates, suggested by the presence of the lagenids, apparently underlay well-oxygenated intermediate waters, called here proto-AAIW (Fig. 14).

Zone CN12 (Zone N21) Time Slice

For the first time, a NIIW fauna occupied intermediate depths at sites ranging from the southern Arabian Sea to the northern Mascarene Basin (Fig. 16). Uvigerinids, bolivinids, stilostomellids, and *C. wuellerstorfi* are abundant, but the costulate, finely porous bolivinid *B. pusilla* typifies Site 219. These indexes suggest that sediments were organic carbon rich and moderately low in oxygen.

The bottom-water species *E. exiguua* again migrates updepth into Site 219, then persists into the youngest levels. The occurrence of *E. exiguua* at intermediate depths is anomalous, as this species today occurs in the factor correlated with oxygen-rich bottom waters (Fig. 5). In the southeastern Indian Ocean, its presence in IBW, in which it is co-dominant with the uvigerinids, has been related to conditions of carbonate undersaturation and low nitrite concentrations (Corliss, 1979; Peterson, 1984). The fact that *E. exiguua* migrates upward to depths near 2,000 mbsl during the coolest part of Zone N17, then again in the cooler part of the Pliocene, suggests updepth penetration of conditions typical of IBW. In the southern Arabian Sea, this water type was cool, probably well-oxygenated, and overlay low-oxygen, organic-carbon-rich sediments.

In the Mascarene Basin, elevated numbers of spinose uvigerinids occur in small, low-diversity faunas that also contain the oxic index *G. subglobosa* and crenulate bolivinids. Faunas containing infauna and uvigerinids suggestive of organic-carbon-rich sediments that are oxic in the upper 1–2 cm and the underlying oxic intermediate waters are called oxic NIIW faunas.

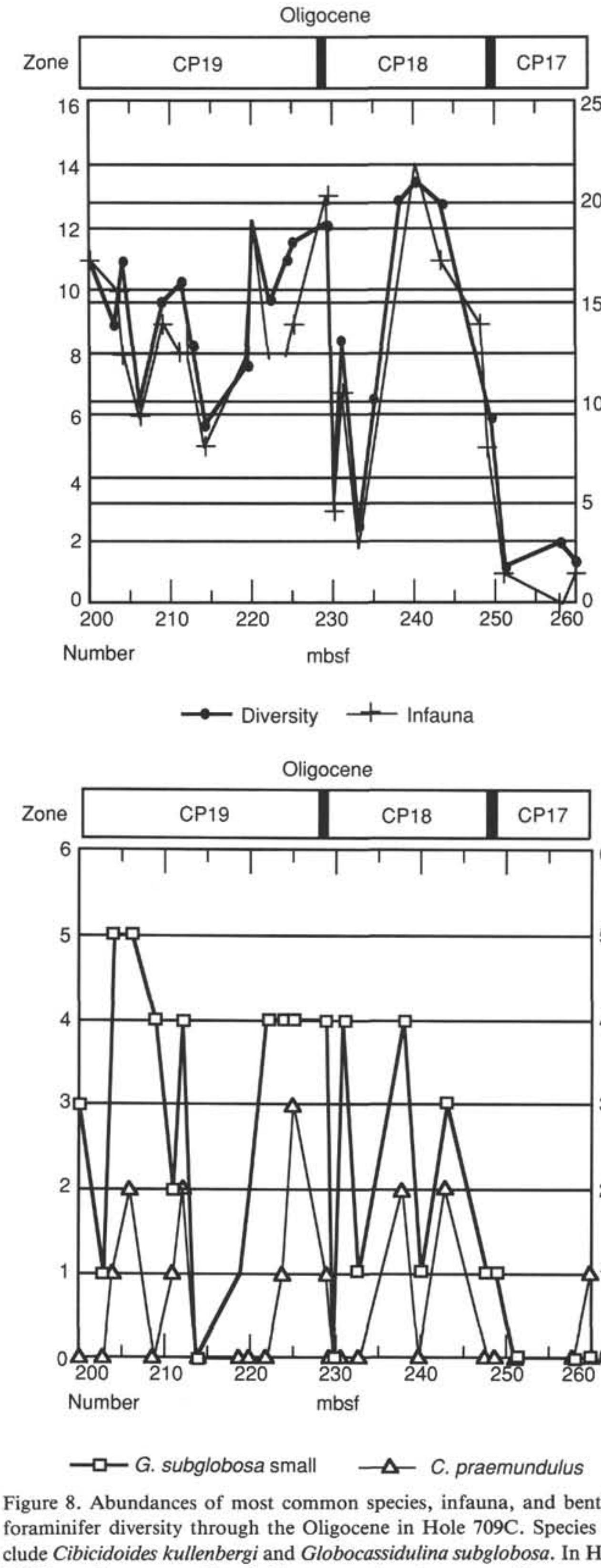

Figure 8. Abundances of most common species, infauna, and benthic foraminifer diversity through the Oligocene in Hole 709C. Species include *Cibicidoides kullenbergi* and *Globocassidulina subglobosa*. In Hole 709C samples were small and siliceous; carbonate preservation was generally poor. High infaunal abundance has been related to high carbon rain rates and elevated organic carbon content in sediments (Corliss and Chen, 1988). Because organic carbon serves as food for the foraminifers, high organic carbon content may support the higher diversity faunas. Zonation from Backman, Duncan, et al. (1988).

Oxygenation Patterns and Stable Isotope Studies

Predictions based on this study of benthic foraminifer faunas can be compared with stable isotope studies of water mass "aging" patterns through the Miocene. Benthic carbon isotope gradients from the northern Indian Ocean to the Pacific and Atlantic basins indicate that surface waters in the northern Indian Ocean were young and well oxygenated in the early and middle Miocene (Woodruff and Savin, 1989). These waters, which became oxygenated at the surface, were probably warm, yet saline enough to sink to intermediate depths. Carbon isotope gradients indicate the continuation of this pattern until 10 Ma (in Zone CN7 = Zone N16) when new deep-water source areas developed in the Atlantic Ocean. Indian Ocean benthic foraminifer fauna patterns support the predictions of carbon isotope studies by indicating the presence of well-oxygenated waters at intermediate depths in the southern Arabian Sea and northern Mascarene Basin after Zone CN1 through the remainder of the early and early middle Miocene. In agreement with the carbon isotope data, an entirely new intermediate fauna indicating less oxic intermediate- and deep-water conditions had developed by time slice N17 (= Zone CN9) throughout the central Indian Ocean.

Indian Deep-water Formation

Although deep water in the Indian Ocean is formed today from "aged" North Atlantic Deep Water entering to the southwest, Johnson (1985) proposed that the high salinity of intermediate and deep waters in the Arabian Sea rendered them a prime deep-water source to stimulate AABW formation, especially at times when NADW formation may have been weakened or suppressed. He suggested that because evaporation in the Arabian Sea forms the deep northern salinity maximum, this saline deep-water source probably originated with the final closure of the Middle Eastern Strait, about 16 Ma, and has been operating as a deep-water source intermittently since that time.

Woodruff and Savin (1989) interpreted Miocene-age benthic carbon isotope gradients to indicate that "new," oxygen-rich, saline waters formed in the Indian Ocean, providing a deep-water source to the two adjacent oceans, from the beginning of the Miocene (24 Ma) until the late Miocene (10 Ma) when the North Atlantic became the source of deep waters in the Atlantic basins.

Deep-water faunas and sediments from Leg 115 lend several types of evidence supporting the idea of a descending northern Indian source water. Redeposition is apparently occurring at all depths throughout the Indian Ocean (Boltovskoy, 1977; Premoli Silva and Spezzaferi, this volume). In the Mascarene Basin, redeposited intermediate-water fossils pollute the deep-water section at Site 709. More significantly, intermediate-water fossils are found redeposited throughout abyssal areas where Sites 236, 242, and 710 were drilled (Fig. 1). This erosion might be attributable to the interaction of rugged topography and a western boundary current, as in the modern Mascarene and Central Indian basins (Warren, 1981; Corliss, 1979). The displaced intermediate-depth bolivinid faunas at Site 236 in the deep Mascarene Basin, however, suggest transport not just downslope from the margin of the Mascarene Basin, but from far north on the Chagos-Laccadive Ridge because only in the northern Chagos sites do such rich and diverse bolivinid faunas occur. These patterns could be used as evidence for a vigorously sinking intermediate-water mass and a northern origin for deep waters.

DEEP- AND BOTTOM-WATER STRATIFICATION

Deep and bottom waters in the modern western Indian Ocean are derived from the Atlantic Ocean and the Atlantic sector of the Antarctic. Cold, low-salinity AABW flows north through the western basins and into the Mascarene Basin as a western

Table 9. Ranges of benthic foraminifers through the Oligocene in Hole 710A.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	Siliceous remains	*Globocassidulina subglobosa* (small form)	*Gyroidinoides girardanus*	*Pullenia coryelli*	*Oridorsalis umbonatus*	*Pullenia bulloides*	*Sphaeroidina bulloides*	*Pleurostomella* sp.	*Globocassidulina subglobosa* (large form)	*Cibicidoides havanensis*	*Stilostomella gracillima*	*Praebulimina* sp.	*Stilostomella nuttalli*	*Gyroidinoides planulatus*	*Stilostomella subspinosa*	*Cibicidoides praemundulus*	*Chrysalogonium equisetiformis*	*Anomalinoides semicribratus* (poreless)	*Heterolepa grimsdalei*	*Lenticulina vortex*	*Pullenia subcylindrica*	*Nuttallides umbonifera*	*Vulvulina spinosa*	*Bolivinopsis gryzbowski*	Diversity	Epifauna	Infauna	Abundance (epifauna)	Abundance (infauna)
Oligocene	late	CP19	P22	16X-1, 120	143.3	1	7	1	1	1	4	1	1	2																	7	2	5	5	6
				17X-1, 120	153.0	1	7	3	4		4				1	1	1	1	1	3											9	4	4	8	9
				18X-1, 120	162.6	1	7	4			4	1	1							1	2	3	1	1							9	4	5	5	9
			P21b	19X-1, 120	172.3	1	8	4	1		4	4				2				2					1	1	1				9	5	4	3	9
	early	CP18	P21a	20X-CC	789.5	1	10	4	4		4	3			4	4		4	2	2		5			1			4	3		13	7	4	23	5
				21X-CC	199.4	1	10	3		1	2				3				1		1	2			1				1		9	3	4	5	6
			P20	20X-CC	208.8	1	10	4		1	4				3	1					1	4			1					1	9	4	3	10	9

Note: Explanation as in Table 3.

Table 10. Ranges of benthic foraminifers through the Oligocene at Site 238.

Age		Zone		Core, section, interval (cm)	Preservation	*Dentalina consobrina*	*Epistominella exigua*	*Cibicidoides praemundulus*	*Pullenia bulloides*	*Pullenia quinqueloba*	*Globocassidulina subglobosa* (small form)	*Eggerella bradyi*	*Nuttallides umbonifera*	*Buliminella* sp.	*Karreriella chapapotensis*	*Gyroidinoides planulatus*	*Gyroidinoides altispirus*	*Stilostomella marginata*	*Pleurostomella* sp.	*Stilostomella lepidula*	*Orthomorphina rohri*	*Oridorsalis umbonatus*	*Siphonodosaria modesta*	*Bulimina alazanensis*	*Siphotextularia* sp.	*Stilostomella subspinosa*	*Bolivina* cf. *B. pulchra*	*Stilostomella gracillima*	*Anomalinoides* sp.	*Bolivina tectiformis*
Oligocene	late	CP19b		43-2, 85	5	1	3	2		1	2	1	1	1	1	1	1	1	1											
				43-5, 85	5		1		1	2	3								1	4	1	1	1	1	1	2				
				44-2, 85	4	2					4				1	1				1		1	3		1	2	2	1	1	
				44-5, 135	3						4		1			1						1		2						
				45-CC	1						1		1							1				1						
				46-2, 26	4	1		1					1		1					1		1				1	1			1
				46-CC	5							2	1	1	1					4		3	1			1	1			
				47-1, 124	4						1								1	4		1	2	1			1	1		
				47-3, 42	4			2							1				1	3		4	2							1
				47-CC	3				1		3					1			1			3								
				48-CC	3					1	4					1			4	3		2				2			2	
				49-2, 110	3					1	3					1			3	4		2							1	1
				49-CC	4					1	3						2		2	4	1	4	1	1		1	1			1
				50-2, 59	4			1												3			1			1				
			P22	51-CC	5			1			1	1				1					1	2	1			2		1		1
				52-2, 115	4						1						1		1			3								
	early	CP19a		52-5, 90	4				1	1	1			1		1						2		1					1	3
				52-CC	4			1		2				1	1				2	1				1						2
				53-CC	3								1							3		1	1							
			P21a	54-1, 120	3																		2							1

Age		Zone		Core, section, interval (cm)	Preservation	*Globocassidulina subglobosa* (large form)	*Bulimina semicostata*	"*Trifarina*" *pigmea*	*Uvigerina pigmea*	*Cassidulina* cf. *C. laevigata*	*Discorbis villardeboanus*	*Stilostomella nuttalli*	*Cibicidoides haitiensis*	*Cassidulina crassa*	*Cibicidoides havanensis*	*Cibicidoides trincherasensis*	*Gyroidinoides girardanus*	*Osangularia mexicana*	*Lenticulina vortex*	*Martinotiella cojimarensis*	*Bolivina cancellata*	*Pleurostomella subcylindrica*	*Pullenia eocenica*	*Bulimina macilenta*	*Uvigerina semivestita*	*Bulimina miolaevis*	*Heterolepa grimsdalei*	Diversity	Epifauna	Infauna
Oligocene	late	CP19b		43-2, 85	5																							15	5	6
				43-5, 85	5																							14	2	8
				44-2, 85	4																							14	2	7
				44-5, 135	3																							7	3	1
				45-CC	1																							6	1	2
				46-2, 26	4	1	1	1	1																			15	3	9
				46-CC	5		1																					12	2	6
				47-1, 124	4					1																		10	1	7
				47-3, 42	4	1	1				2	2																13	3	7
				47-CC	3																							7	2	2
				48-CC	3		1					1																12	2	7
				49-2, 110	3																							10	2	5
				49-CC	4							2	2	1	1	1	1											20	6	11
				50-2, 59	4	1	1						1					1										10	3	5
			P22	51-CC	5	3					1	1							2	1								17	4	8
				52-2, 115	4	3																						7	2	2
	early	CP19a		52-5, 90	4				1			1			1		1				1	1	1					18	4	11
				52-CC	4	1	1					1											1					14	1	10
				53-CC	3		1					3							1			2		1	1			12	2	8
			P21a	54-1, 120	3																					1	1	6	1	3

Note: Explanation as in Table 3.

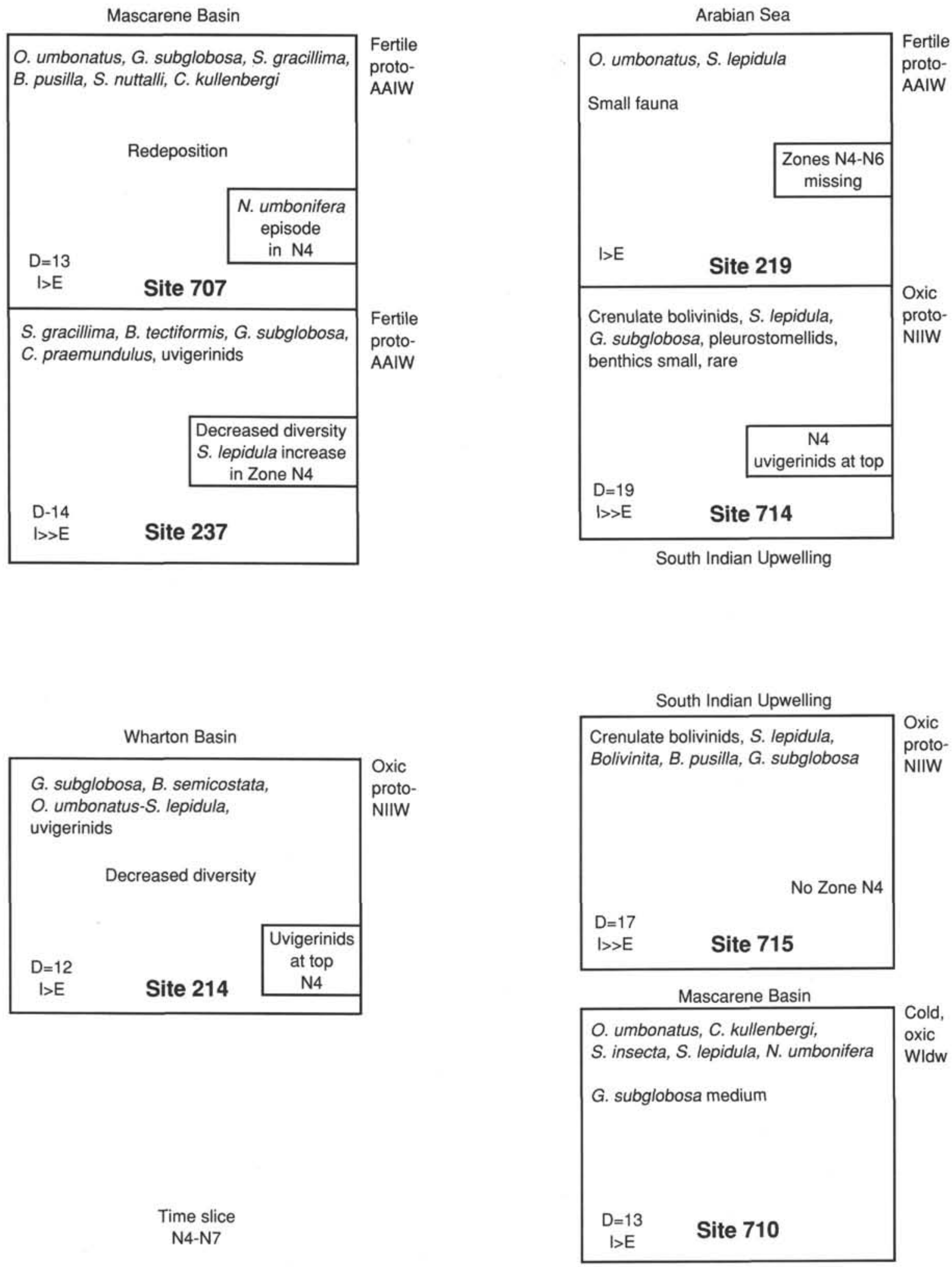

Figure 9. Benthic foraminifer index faunas of early Miocene Zones N4–N7 (= Zones CN1–CN3) from seven sites in the western and central Indian Ocean. Indexes, listed at top, were most abundant or most consistently present. Index forms that occurred only in pulses or events are shown below. Total sample diversity and the relation of infaunal to epifaunal abundance are shown at bottom left of each box. The faunal name assigned to each index fauna is listed to the right of each box. Data from Tables 12–16.

Table 11. Ranges of benthic foraminifers through the Oligocene in Hole 709C.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	Siliceous remains	*Gyroidinoides girardanus*	*Globocassidulina subglobosa* (large form)	*Stilostomella nuttalli*	*Bulimina semicostata*	*Oridorsalis umbonatus*	*Pullenia bulloides*	*Stilostomella subspinosa*	*Pullenia quinqueloba*	*Gyroidinoides planulatus*	*Anomalinoides* cf. *A. alazanensis*	*Praebulimina* sp.	*Heterolepa grimsdalei*	*Bulimina macilenta*	*Globocassidulina subglobosa* (small form)	*Vulvulina spinosa*	*Trifarina* sp.	*Karreriella* sp.	*Anomalinoides semicribratus*	*Stilostomella gracillima*
				22X-2, 20	200.4	2	8	1	2	1	1	5	3	1	1	2	1	1	1	1	3	1	1	1		
				22X-4, 20	203.4	2	7	3	1		1	4		1							1		1		1	2
				22X-4, 130	204.5	4	7	4	2			3			1	2				1	5	1				1
				22X-5, 130	206.0	3	8			1	1	5		3	1						5				1	
				23X-1, 120	209.6	3	7	2	1		4	5		1				1			4	1	1		2	
				23X-2, 120	211.1	2	7	3		2		5		2		2		2	1	1	2	2			2	
				23X-3, 120	213.6	3	4	4	1	2	1	5	1	2	1						4				2	
	late	CP19	P22	23X-4, 120	214.1	1	10					1	1	1		3										1
			P21b	24X-1, 125	219.2	4	7	4	3					1	1	2					1					3
				24X-2, 120	220.7	4	4	4	4	4	2	4	1	4		4					2					1
				24X-3, 120	222.2	4	4	1	4	4	4	5	4	4		2			1		4					
				24X-4, 120	224.2	4	4	2	2	1		4		2		1			1		4					2
				24X-5, 120	225.2	4	7	1	4	4	2	4		2					1		4	1		1		4
Oligocene			P21a	25X-1, 125	229.0	4	7		3		2	3	1		1	4	1	1			4					4
				25X-2, 125	230.5	1	9					4		1												
				25X-3, 120	231.9	3	9		3	2	2	4		2	2	2					4	1				4
				25X-4, 125	233.5	1	10														1					
				26X-1, 125	238.7	5	10	1	5	3		2		2	2	1			4		4					5
		CP18		26X-2, 10	240.2	4	7	1	1	3	1	4	1	1	4		1		4		1					4
				26X-4, 125	243.2	4	9		1	4		5		4		1			1		3	2				5
				27X-1, 125	248.3	3	8			1		3		1			1				1					
				27X-2, 125	249.8	2	9		1	3		1			1	1					1	1				3
	early		P20	27X-3, 125	251.3	1	8		1																	
		CP17	P19	28X-1, 125	258.0	2	10																			
				28X-3, 125	266.0	1	0				1															

Note: Explanation as in Table 3.

boundary current. Warm, high-salinity deep waters, produced by "aging" of NADW that enters to the south of South Africa, also flow northward through the Mascarene Basin as a western boundary current. Circumpolar water flows northward along the Central Indian Ridge (Wyrtki, 1973; Warren, 1981; Corliss, 1983; Peterson, 1984; Johnson, 1985).

Modern deep and abyssal faunas associated with these water types resemble their Atlantic and southeast Indian ocean counterparts. *Nuttallides umbonifera* characterizes the coldest bottom water of Antarctic origin, distinguished from the overlying deep water largely by its temperature and salinity minimum. This cold AABW is undersaturated with respect to calcite because of the high CO_2 productivity on the Antarctic continental shelf. Cold, "new" bottom waters in the abyssal northeastern Atlantic are associated with the factor-species *E. exiguua, C. wuellerstorfi, O. umbonatus, N. umbonifera, N. pompilioides, M. barleanuum, P. bulloides, C. robertsonianus, E. bradyi*, and *C. kullenbergi*. During glacial episodes, this abyssal factor-association includes the uvigerinids, globobuliminids, and *B. alazanensis* (Schnitker, 1979).

In the southeast Indian Ocean, well-oxygenated AABW derived from the southern Indian Basin is associated with the factor-species *P. wuellerstorfi, N. umbonifera, P. bulloides, M. pompilioides*, and *O. umbonatus*. No uvigerinids or *Nonion* are found in faunas in this water mass. An overlying, warmer AABW that fills most of the eastern abyssal basins is characterized by the factor-species *G. subglobosa, Astrononion* sp., *O. umbonatus, G. soldanii, P. bulloides*, and *C. wuellerstorfi* (Corliss, 1979).

In both the southeast Indian Ocean and Central Indian Basin, Indian Bottom Water (IBW), produced from a mixture of CPDW and AABW, is slightly higher in temperature and salinity, but slightly lower in dissolved oxygen. This water is less undersaturated with respect to calcite because of its production in warmer water at shoaler depths (Corliss, 1979). Characteristic factor-species include the uvigerinids and *E. exiguua*, with *Pyrgo* spp., *Astrononion* sp., *C. kullenbergi, O. umbonatus*, miliolids, and lagenids. Dominance of this factor-association suggests decreased AABW input to the South Indian Basin (Corliss, 1979). Shoaling of the AABW fauna, in contrast, suggests increased bottom-water circulation (Corliss, 1979).

Warm, high-salinity deep water in the southwest Indian Ocean is characterized by the factor-species *Astrononion echolsi, P. bulloides, G. subglobosa*, and *C. wuellerstorfi* (Corliss, 1983). This water type is formed by the "aging" of NADW, which is associated with the factor-species *G. subglobosa, U. peregrina, O. umbonatus, C. wuellerstorfi, C. kullenbergi, H. elegans*, and the miliolids in the southwest Atlantic Ocean (Lohmann, 1978; Corliss, 1983). Less saline deep waters in the southeastern

Table 11 (continued).

Oridorsalis umbonatus (scalloped margin)	*Orthomorphina perversa*	*Cassidulina* sp. (scalloped margin)	*Cassidulina crassa*	*Bulimina alazanensis*	*Cibicides pseudowuellerstorfi*	*Cibicidoides havanensis*	*Lenticulina vortex*	*Bolivinopsis gryzbowski*	*Siphonodosaria modesta*	*Cibicidoides praemundulus*	*Osangularia mexicana*	*Pullenia quadriloba*	*Uvigerina spinicostata*	*Pleurostomella* spp.	*Chrysalogonium equisetiformis*	*Nuttallides umbonifera*	*Bolivina tectiformis*	*Karreriella chapapotensis*	*Pullenia coryelli*	*Hopkinsina mioindex*	*Spiroplectammina spinosa*	*Hanzawaia cushmani* (flat form)	*Textularia leuzingeri*	*Cibicides laurisae*	*Bolivina* cf. *B. huneri*	*Orthomorphina rohri*	*Gyroidinoides altispirus*	*Eggerella bradyi*	*Cibicidoides trincherasensis*	*Martinotiella petrosa*	*Pleurostomella* cf. *P. alternans*	*Plectofrondicularia* cf. *P. lirata*	*Anomalinoides alabamensis*	Diversity	Infauna	Epifauna	Abundance (infauna)	Abundance (epifauna)
																																		17	11	4	10	8
1	1	1	1	1																														14	10	4	11	8
		3			1	2	1	1	1	1	1																							17	8	7	14	12
								1		2		1																						10	6	3	12	8
2						2			2				1	4																				15	9	5	19	13
	1				1		2			1					3																			16	8	7	15	15
			2							2						3																		13	8	5	14	16
1											1	1					3																	9	5	4	7	6
						1								3			2	1	1															12	8	3	15	7
1						1	1	2						4	1		2			1														18	12	5	27	14
1						3								3		1				1														15	8	7	28	14
1						4	1		1	1	1						2				1													17	8	8	15	15
						1		1	1	3				4			4					2												18	9	6	29	12
								1		1				4			1			1			1	4	4	1								19	13	4	28	12
						2								3												2								5	3	2	6	6
						1										1						1												13	7	6	15	7
														1										1			1							4	2	2	2	2
									2	2								1	1					1		2	1	1	1	1				20	10	7	22	13
	1					4			2		1								1			1				1	1				1			21	14	7	21	16
			1			4	1			2			1						1							1		1				4	1	20	11	5	24	13
	1			1		2			1					3				1									1			1				13	9	3	9	3
																											1							9	5	2	8	2
						1																												2	1	1	1	1
											1																1		1					3	0	3	0	3
										1																								2	1	1	1	1

Indian Ocean, however, are associated with factor-species of uvigerinids, together with miliolids and *G. subglobosa* (Peterson, 1984).

Circumpolar deep waters are lower in oxygen and higher in temperature and display a salinity maximum. Most typical of this water type are the uvigerinids, which occur in the higher latitude South Atlantic and the southeastern Indian Oceans, but not in the modern Mascarene Basin. Indexes for this water mass include *C. carinata, P. bulloides, B. aculeata*, and in the South Atlantic *Astrononion* (Corliss, 1983; Hodell et al., 1985; Clarke and Wright, 1984; Boersma, 1985b; Mead, 1985).

Deep and abyssal faunas from the Leg 115 traverses, although reduced by dissolution and polluted by redeposition, retain unique signatures resulting in more or less faunal similarity with depth and between basins. Faunal similarity with depth increases: (1) during the early late Oligocene and most of the early to middle Miocene when deep-water indexes expanded into abyssal depths; and (2) in the latest Oligocene, episodically in the earliest Miocene, and in the late Pliocene when abyssal indexes migrated upslope. Similarity of deep and abyssal faunas has been interpreted to indicate the diminution of either deep- or bottom-water formation (Hodell et al., 1985), or similarity of source regions (Woodruff and Savin, 1989).

Oligocene

By Zone CN18 time, there was an expansion to all depths of indexes for well-oxygenated waters, such as *C. praemundulus*, the progenitor of the modern, well-oxygenated NADW index, *C. kullenbergi* (Fig. 5). Also present are other oxygenated-water-mass indexes, including *N. umbonifera, G. subglobosa*, and the pullenids. These faunas, suggesting a well-oxygenated, deep-water mass, range in depth from Site 709 to abyssal Site 710 (2800–3800 mbsl) in the Mascarene Basin and are termed oxic Western Indian deep water (WIdw) faunas (Fig. 5). Homogeneity with depth of deep-water indexes for well-oxygenated conditions may indicate a similar and local source region for deep and bottom waters in the Mascarene Basin. Clearly, in the Oligocene they were not formed by aging of a deep-water mass derived from the Atlantic.

The development of a *G. subglobosa–O. umbonatus–N. umbonifera* bottom-water index fauna in one episode at Site 709 (Fig. 5) suggests increased bottom-water formation or decreased deep-water formation (Hodell et al., 1985), and/or dissimilar source regions. This fauna is similar to the faunal-factor associated with modern IBW in the southeastern Indian Ocean, a water mass that is cold, low in salinity, and well oxygenated (Peterson, 1984).

In the Mascarene and Central Indian basins, deep-water faunas such as those found at Site 238 (2826 mbsl) resemble faunas updepth and contain such intermediate-depth indexes as *Uvigerina semivestita* (Boersma, 1984). If these species are in place, then homogeneity from intermediate to abyssal areas of faunas suggesting well-oxygenated conditions may indicate that the source area of these water masses is localized in the northern Indian Ocean beginning in the late Oligocene.

Table 12. Ranges of benthic foraminifers through the Miocene in Hole 707A.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Globocassidulina subglobosa* (small form)	*Uvigerina auberiana*	*Bolivina pseudoplicata*	*Oridorsalis umbonatus*	*Nuttallides umbonifera*	*Bulava* sp.	*Bolivina striatocola*	*Cibicides wuellerstorfi*	*Planulina renzi*	*Globocassidulina subglobosa* (large form)	*Melonis barleeanum*	*Stilostomella subspinosa*	*Ehrenbergina hystrix*	*Karreriella* sp.	*Cibicides lobatulus*	*Anomalinoides globulosus*	Miliolids	*Pleurostomella subcylindrica*	*Planulina* cf. *P. renzi*	*Orthomorphina perversa*
Miocene	late	CN8	N13–N15	11H-1, 70	93.9	7	5	4	4	3		5	3	2	1	1	1	1								
				11H-CC, 120	?	7		1				2				3			1	1	1	1	1	1	1	1
				12H-1, 120	104.0	6	1		4			2		1		1										
				12H-2, 120	105.5	6	3	3							1									1		
		CN7		12H-3, 120	107.0	5	4	1		1		1		1	1										3	
				12H-4, 120	108.5	5	4			5	1	5		3	1			2						1	1	
				12H-3, 121	110.0	6			1	1		3		2	1	1		1		1					1	
				12H-6, 114	111.4	6				2				1			1	5								1
		CN5b–CN5c		13H-1, 120	113.6	6								3	1	1									3	
				13H-2, 120	115.1	6	4		1	1	1	1	3	3		1									4	
				13H-3, 170	116.6	6		1		1				3		1										
				13H-4, 120	118.1																					
		CN5a	N13	13H-5, 121	119.6	5	1	1	5	1			5	1												1
	middle	CN4	N10–N12	11H-1, 120	123.2	5								1	1											
				11H-2, 120	124.7	5	1											1								
				11H-3, 120	126.2	5	2		1			2				1		1								
	early	CN3	N5–N7	15H-2, 121	134.3	4	4			1						4			1							1
		CN2		15H-3, 120	135.8	4	5			1			1													
				15H-4, 120	137.3	3	4			4	1		1													
				15H-5, 120	138.8	6				4			2					1						1		
		CN1a	N4	15H-6, 56	139.7	6				1			4													

Note: Explanation as in Table 3.

After the early warm part of Zone CP19 (Zone P22), a homogeneous benthic fauna again developed at deep and abyssal depths in the western Indian Ocean (Fig. 6). The preservation of carbonate became poorer, despite which diversity increased. Widespread development with depth and latitude of *O. umbonatus, G. subglobosa*, and the gyroidinids suggests expansion of an oxygenated deep-water mass. Because gyroidinids are associated with only moderately ventilated water masses today (Table 3), the troposphere was possibly less well oxygenated than earlier in Zone CP18 when *C. praemundulus* was ubiquitous. This fauna is called the moderately oxic WIdw fauna.

Deep-water faunas of the Central Indian Basin and Bay of Bengal were similar to lower intermediate water (2252–2262 mbsl) faunas living in the Wharton and Mascarene basins, and to the south on the middle latitude portion of the Ninetyeast Ridge (Fig. 6). These faunas contain more infauna and numerous indexes for lower oxygen conditions, including bolivinids and buliminids (Table 2). Deep-water faunas at Sites 709 and 710 in the Mascarene Basin do not include these indexes, being dominated instead by such indexes for moderately well-oxygenated water masses as *G. subglobosa, O. umbonatus*, and *P. bulloides*. The deep-water faunas of the Bay of Bengal and Central Indian Basin, called here the Central Indian deep-water fauna, indicate lower oxygen at the bottom, while a moderately oxic WIdw fauna persisted through depth in the western basin.

The absence of a bottom-water fauna is indicated by the widespread development of deep-water indexes through depth and by the scarcity of *N. umbonifera* and *E. exiguua* in the Oligocene (Fig. 6). At the end of Zone CN19, however, several species associated with AABW today, including *N. umbonifera, E. exiguua*, and *P. quinqueloba* migrated upward into deep-water sites of the Mascarene and Central Indian basins. This indicates that cold, low-salinity bottom water with characteristics like modern AABW first entered the northern Indian Ocean in pulses near the end of the Oligocene. The updepth expansion of bottom-water indexes reflects either increased bottom water or decreased deep-water formation; a southern source for oxygenated bottom waters was apparently developed at this time.

Miocene

The early Miocene is characterized by faunal homogenization with depth, which is mirrored by the continuing low thermal and carbon isotope contrasts through the water column (Vincent et al., 1985). Faunas at Site 710 in the Mascarene Basin contain the modern NADW index *C. kullenbergi*, associated with *G. subglobosa* and *N. umbonifera*. The presence of these indexes indicates that a well-oxygenated, deep-water mass extended from 2800 mbsl to 3800 mbsl in the Mascarene Basin through most of the early Miocene. This fauna is called the cold, oxic Western Indian Deep Water (WIdw) fauna (Fig. 9).

Continuing from Zone CN1 through most of the early Miocene and earliest middle Miocene Zone CN4, abyssal and deep-water faunas displayed a high degree of similarity, indicated by the widespread distribution of the *O. umbonatus–C. kullenbergi* index fauna and the updepth migration of *N. umbonifera* into deep-water sites (Fig. 9). This fauna indicates well-oxygen-

Table 12 (continued).

Karreriella bradyi	*Spiroplectammina spinosa*	*Cibicides wuellerstorfi* (atypical)	*Bulimina tuxpamensis*	*Uvigerina proboscidea*	*Gyroidinoides planulatus*	*Cassidulinoides* sp.	*Globocassidulina subglobosa* (medium size)	*Sigmoilopsis schlumbergeri*	*Vulvulina spinosa*	*Pullenia bulloides*	*Cibicidoides kullenbergi*	*Textularia* sp.	*Siphonodosaria modesta*	*Cibicidoides havanensis*	*Stilostomella lepidula*	*Stilostomella nuttalli*	*Osangularia bengalensis*	*Bulimina alazanensis*	*Heterolepa rugosa*	*Orthomorphina rohri*	*Gyroidinoides soldanii*	*Melonis pacificum*	*Gyroidinoides altispirus*	Redeposited nodosariids	*Epistominella exiguua*	*Eggerella bradyi*	*Martinotiella variabilis*	*Ehrenbergina trigona*	*Bolivina villavernensis*	*Rectuvigerina spinea*	*Laticarinina pauperata*	*Siphotextularia catenata*	*Loxostomum* sp.	*Bolivina peregrina*	*Melonis affinis*	*Pullenia quinqueloba*	*Uvigerina pigmea* (spinose form)	*Cibicidoides trincherasensis*	*Osangularia culter*
1	1																																						
		1	1	1	1	1	2	1																															
					1			1	1	1	2	2	1	1	1	1																							
				1	1	1		3		1			1		4		1	1	1																				
					1		3			1					3					1	2	3	1	3	3	1													
								2							5												3	1	1	1	1								
				1					1		2	1			3		1														1	1	1	1	1	1			
		1		2											1															1							1	1	
									1		2				1		1		1												1						1	1	1
							2				1				2	2					1																2		
															3								1														1		
						1									4						1									1		1							
											1		2									1																	
					1	1					1																1			2							4		
			1		1		1			1	1				2																						4		
											2						1																						
							1		1	1					3		1						1	3													1		
					1						1	1	1		2		1																				1		
							2								3			1		1						1								1		1			

ated deep and bottom waters (Table 2) that may have been corrosive to carbonates (Bremer and Lohmann, 1982). Deep-water faunas at Sites 709 and 237, however, contain numerous forms in common with overlying intermediate-depth faunas. These include the infaunal indexes for lower oxygen conditions and elevated sediment organic carbon content, the bolivinids, stilostomellids, and uvigerinids. The prevalence of mottled sediment throughout this interval indicates that infaunal predators were common and, hence, that their food supply was high. The similarity between deep- and intermediate-depth faunas, then, suggests episodes either of increased redeposition or of enhanced preservation of organic carbon and lower oxygen conditions in the sediment, possibly resulting from redeposition as well.

Late Miocene Zone CN9 is characterized by faunal heterogeneity and the development of modern water-mass types in both the Central Indian and Mascarene basins. Bolivinids increase in deep-water Sites 709 and 713 early in the zone, suggesting lowered oxygen levels in the sediments (Fig. 11). The proliferation of spinose uvigerinids midway through the zone, although in generally low numbers, is coeval with the Epoch 6 carbon shift (Lutze, 1977; Vincent et al., 1980; Woodruff, 1985; Vincent et al., 1985; Boersma, 1985c; Woodruff et al., this volume). It has been proposed that more organic carbon was deposited in the ocean at this time, increasing oxygen demand in the water column and producing a widespread oxygen minimum zone under which carbonate preservation improved.

At Site 713, an *O. umbonatus–B. alazanensis–Uvigerina–C. kullenbergi* index fauna containing lagenids and crenulate bolivinids develops in Zone CN9 (Fig. 11). This expansion of uvigerinids and other infaunal indexes for lower oxygen and enhanced organic carbon preservation in the sediments, as well as increased overhead primary production, is related to the increased rates of carbonate accumulation registered in the Mascarene Basin and elsewhere (Lutze, 1977; Vincent et al., 1980; Boersma, 1985c; Peterson and Backman, this volume). Because of the presence of uvigerinids and its similarity to the factor-fauna associated with modern IDW in the Central Indian Basin, this fauna is called a less oxygenated, proto-IDW fauna. Its dissimilarity from modern IDW-related assemblages is based on the crenulate bolivinids that are not present today, and so suggest only moderately oxygenated, not well-oxygenated, pore waters in Zone CN9. Modern IDW is less undersaturated with respect to calcium carbonate; the evolution of this well-saturated water type may also be related to the improved carbonate preservation registered in Zone CN9 (Heirtzler et al., 1977; Corliss, 1983; Peterson and Backman, this volume).

Near the end of Zone CN9, when bolivinids disappear from deep-water faunas, the remaining indexes suggest increased oxygenation at the bottom (Fig. 11). In the abyssal Mascarene Basin, a fauna typical of modern AABW, including *N. umbonifera, C. wuellerstorfi, E. exiguua*, and *O. umbonatus*, developed at abyssal Site 710. Because these factor-species are associated with low salinity, corrosive, and very cold Weddell Sea Water and AABW today (Bremer and Lohmann, 1982; Corliss, 1983; Mead, 1985), this water mass at Site 710 is called proto-AABW.

Factor-species related to IDW, such as *F. fava, O. umbonatus*, and *G. subglobosa*, proliferated upslope at Site 709, although uvigerinids, lagenids, miliolids, and *C. kullenbergi* are

Table 12 (continued).

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Favocassidulina fava*	*Anomalinoides semicribratus*	*Saracenaria* sp.	*Bolivina pulchra*	*Bolivina arta*	*Eggerella bradyi*	*Bolivina subreticulata*	*Cassidulina laevigata*	*Bolivinopsis gryzbowski*	*Discorbis villardeboanus*	*Cassidulina laevigata carinata*	*Bulimina macilenta*	*Bulimina semicostata*	Redeposited benthic foraminifers	*Rectuvigerina striata*	Diversity	Infauna	Epifauna	Abundance (infauna)	Abundance (epifauna)
Miocene	late	CN8	N13–N15	11H-1, 70	93.9	7																12	7	4	24	7
				11H-CC, 120	?	7																13	7	2	10	3
				12H-1, 120	104.0	6																13	8	3	13	3
				12H-2, 120	105.5	6																15	7	4	11	5
		CN7		12H-3, 120	107.0	5																17	9	6	15	8
				12H-4, 120	108.5	5																20	11	8	29	15
				12H-3, 121	110.0	6																16	9	4	15	5
				12H-6, 114	111.4	6																17	10	4	16	6
		CN5b–CN5c		13H-1, 120	113.6	6																10	5	5	6	9
				13H-2, 120	115.1	6																18	8	8	13	14
				13H-3, 170	116.6	6	1	1														13	8	4	12	6
				13H-4, 120	118.1																	0	0	0	0	0
		CN5a	N13	13H-5, 121	119.6	5			1	4												12	8	3	21	3
	middle	CN4	N10–N12	11H-1, 120	123.2	5					1											8	4	3	7	3
				11H-2, 120	124.7	5						1										6	4	1	5	1
				11H-3, 120	126.2	5																11	7	2	14	2
	early	CN3	N5–N7	15H-2, 121	134.3	4							1	1								14	10	3	20	3
		CN2		15H-3, 120	135.8	4									1							6	3	3	7	4
				15H-4, 120	137.3	3									1	2						14	8	5	15	8
				15H-5, 120	138.8	6											1	1	2			15	9	4	12	6
		CN1a	N4	15H-6, 56	139.7	6									2					3	1	13	9	1	14	1

not found at this time (Fig. 11). Because uvigerinids are not found in IDW in the Mascarene Basin today and the indexes suggest oxic, but not well-oxygenated conditions, these faunas are called less oxic, western proto-IDW faunas. Together, the faunas at Sites 710 and 709 suggest that a well-oxygenated, low-salinity, cold eastern Indian Ocean AABW-type bottom water underlying a moderately oxygenated deep water like eastern Indian Ocean IDW were present in the Mascarene Basin during the glacial at the end of the Miocene (Corliss, 1983; Peterson, 1984; Elmstrom and Kennett, 1985).

In summary, signals for the terminal Miocene glaciation include the development of modern eastern Indian Ocean-type IDW faunas at deep-water depths overlying eastern-Indian-Ocean-type AABW faunas at abyssal depths in both the Central Indian and Mascarene basins. Faunas indicate the presence of moderately well-saturated, warm, oxygenated deep waters, with elevated organic carbon contents in the underlying sediments, and cold, corrosive, oxic, low-salinity bottom waters.

Pliocene

In the early Pliocene a new abyssal fauna develops, although deep-water faunas reflect a clear partitioning between the Mascarene and Central Indian basins (Fig. 14). Deep-water faunal homogeneity is based on the presence of such forms as *F. fava, P. murrhina*, lagenids, and other miliolids that reflect the improvement in carbonate preservation at all sites (Table 3). The key to deep-water faunas in the Central Indian Basin, however, is the abundance of such uvigerinids as *U. auberiana* and some trifarinids, typical of IDW or CPDW today (Corliss, 1979; Peterson, 1984). Similarly, faunas at Site 709, lacking uvigerinids and *C. wuellerstorfi* but containing miliolids and *O. umbonatus*, resemble those under IDW in the western Indian Ocean today (Corliss, 1979; Peterson, 1984). The Central Indian Basin faunas are called eastern proto-IDW faunas, whereas those at Site 709 are termed less fertile, western proto-IDW faunas because of the lack of *C. wuellerstorfi*.

The partitioning of deep-water faunas between the Mascarene and Central Indian basins in Zones CN10–CN11 suggests two possibilities:

1. Deep waters entering these basins had different source regions and/or different "aging" histories. Because western deep waters today experience a longer "aging" process because of their more circuitous routes through the western basins (Warren, 1981), this circulation route may have been initiated in the warmer, early Pliocene.
2. When the northern Indian Ocean ceased to be a source for intermediate and deep waters, deep waters in the Central Indian Basin were renewed by leakage from the southern Indian Basin, as happens today.

The presence of less oxygenated deep waters in the Mascarene Basin may be reflected in the deep-water benthic carbon isotope depletion between the late Miocene and early Pliocene (Shackleton et al., 1984) also registered in Hole 709B. Average early Pliocene benthic carbon isotope values, slightly depleted relative to those of latest Miocene Zone N17b (see Woodruff et al., this volume), indicate that an "aged" water mass is occupy-

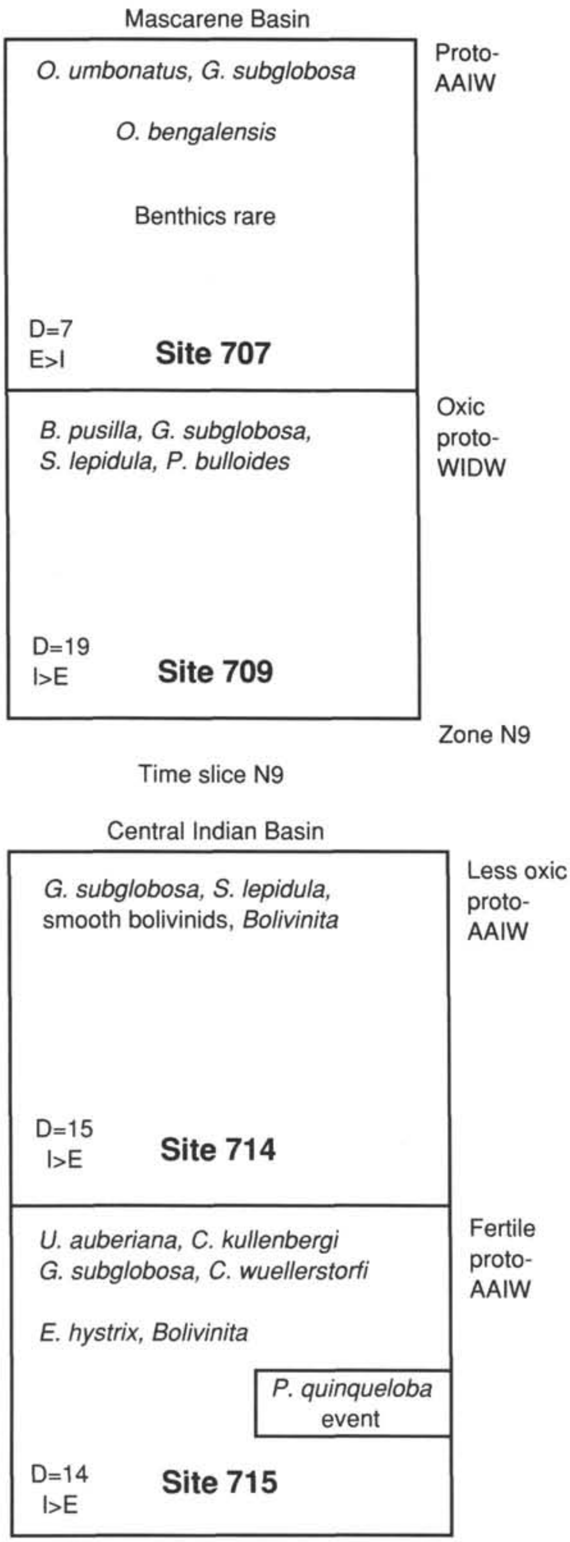

Figure 10. Benthic foraminifer index faunas of middle Miocene Zone N9 (= Zone CN4) from four sites in the western and central Indian Ocean. Indexes, listed at top, were most abundant or most consistently present. Index forms that occurred only in pulses or events are shown below. Total sample diversity and the relation of infaunal to epifaunal abundance are shown at bottom left of each box. The faunal name assigned to each index fauna is listed to the right of each box. Data from Tables 12–17.

ing deep-water areas of the Mascarene Basin beginning in the early Pliocene. The ~1‰ early Pliocene Atlantic-Pacific benthic carbon isotope gradient is similar to today's, suggesting that NADW formation was as active then as now (Shackleton et al., 1984). Thus, NADW production could have been responsible for "aged" deep waters in the northern Mascarene Basin at least by the early Pliocene.

Early Pliocene abyssal faunas at Site 710 in the Mascarene Basin were typified by *P. quinqueloba* and *M. pompilioides*, together with *O. umbonatus* and the gyroidinids, whereas such indexes for cold, low-salinity, and better oxygenated conditions as *N. umbonifera* and *E. exiguua* were absent. Although this fauna resembles the factor-species associated with warmer AABW in the eastern Indian Ocean today, the presence of the gyroidinids also suggests that bottom waters were less oxygen rich at this time (Fig. 14). This faunal type is termed the less oxic, warmer proto-AABW fauna. In summary, water masses similar to those in the modern eastern Indian Ocean basins occupied deep and abyssal depths in the Mascarene Basin in the early Pliocene.

By Zone CN12, the interstratification of more oxygen-rich deep water with lower oxygen intermediate and abyssal waters is suggested by the benthic index faunas (Fig. 16). Faunas at Site 710 contain indexes typical of eastern Indian Bottom Water, a lagenid–*M. pompilioides–G. subglobosa–F. fava* fauna with increasing numbers of uvigerinids. This water type is characterized by higher temperature, higher salinity, and lower dissolved oxygen contents than AABW (Corliss, 1979), and the fauna is here called an eastern proto-IBW fauna. Uvigerinids, which flourish in IDW, CPDW, and IBW in the Central Indian Basin, indicate increased accumulation of organic carbon, presumably resulting from the higher fertility of the southern source region. Lack of bolivinids and buliminids indicate well-oxygenated bottom waters and upper pore waters.

Deep-water faunas at Site 709 resemble those under AABW in the modern eastern Indian Ocean (Corliss, 1979). Index species include *N. umbonifera* and *G. neosoldanii*, whereas the lagenids, miliolids, and *F. fava* reflect improved carbonate preservation. This fauna appears intermediate between those factor-faunas in the eastern Indian Ocean today (Corliss, 1979) and those that underlie western Indian deep waters (Corliss, 1983). This fauna may represent the transition between water masses of eastern affinities and the development of typical western Indian IDW, which must then have occurred after late Pliocene Zone N21 time. This fauna is called, therefore, the transitional western Idw fauna.

Deep-water faunas at Site 238 in the Central Indian Basin are typical of those at equivalent depths under IDW today. Although the miliolids may reflect improved preservation of carbonates (Table 2), the occurrence of the uvigerinid-miliolid index fauna in samples lacking *N. umbonifera* or *E. exiguua* indicates the presence of an "aged," possibly less corrosive, deep water like the modern IDW of the Central Indian Basin (Bremer and Lohmann, 1982; Peterson, 1984). This fauna, therefore, is called the eastern proto-IDW fauna.

CONCLUSIONS

A quantitative census of benthic foraminifers from 20 sites in the Mascarene, Arabian, Central Indian, and Wharton basins and the Bay of Bengal produced index faunas indicative of oceanographic and water-mass reorganization from the late Oligocene to the late Pliocene in the tropical-subtropical Indian Ocean.

Indexes associated with modern bottom waters can be used to trace the history of abyssal areas of the Mascarene Basin. These include *N. umbonifera, E. exiguua, M. pompilioides,* and *P. quinqueloba*. A distinct bottom-water fauna cannot be

Table 13. Ranges of benthic foraminifers through the early to middle Miocene in Hole 715A.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Bulimina alazanensis*	*Globocassidulina subglobosa* (small form)	*Sphaeroidina bulloides*	*Pullenia quinqueloba*	*Oridorsalis umbonatus*	*Melonis pacificum*	*Pleurostomella subcylindrica*	*Bolivinita quadrilatera*	*Bulimina tuxpamensis*	*Ehrenbergina hystrix*	"*Trifarina*" *pigmea*	*Stilostomella lepidula*	*Bolivina* sp.	*Globocassidulina subglobosa* (large form)	*Bolivina tortuosa*	*Cassidulina laevigata*	*Globocassidulina subglosa* (medium size)	*Gyroidinoides soldanii*	*Planulina* cf. *C. wuellerstorfi*	*Bolivina striatocola*	*Uvigerina auberiana*	*Cibicidoides haitiensis*	*Cibicides wuellerstorfi*	*Anomalinoides semicribratus*	*Martinotiella petrosa*
Miocene	middle	CN5		6R-1, 120	48.0	6	1	4	1	1	1	1	1	3	1	1	1	2	2	2											
				6R-2, 120	49.5	7		4	1		1			3	1	3	1			2	1	2	1	1	1	1	2	1	1	1	
				6R-3, 120	51.0	6	1	2			1		1							2			1				1		1		1
				6R-4, 69	52.0	5		4	1	1				2				2													
				6R-5, 120	53.0																										
			N9	6R-6, 120	55.5	5		4			3			4				2				1	2	1							
	early	CN4		7R-1, 120	57.7	5		4			3	1		5				1				1				2					
				7R-2, 120	59.2	6		1		1	1			3				2		1			1			2	1				
				7R-3, 120	60.7	6	3	3						1				1			1					1			1		
				7R-4, 120	62.2	7		4						4				1	1				1	1						1	
				7R-5, 120	63.7	5	1	1			3			4		1		2	2				1				1				
				7R-6, 120	65.2	5		1	1		1			5				1		1						1					
				8R-2, 120	68.8	6		1			1			5				1					1	1		1					
				8R-3, 120	70.3	6		1						5				1		1	1					1					
				8R-5, 120	73.3	7					1			4				1					1							1	
			N8	8R-6, 120	74.8	7								2				3				1				1				1	
		CN3	N5–N7	9R-1, 120	76.9	5		2			1						1	2		2		1		1	1	3	2	1			
				9R-2, 120	78.4	5		2				1		5												1					
				9R-3, 120	79.9	6		5						5				1				1			1	1					
				9R-4, 120	81.4	5		1			1			4	1			3				1									
				9R-5, 120	83.9	5		2						4				3				1	1			3					
				9R-6, 120	84.4	5												2				1				1					
				10R-1, 120	86.5	5		1			8			6				4	4							4					
				10R-2, 120	88.0	5	2				1			4				1				1				2					
		CN2		10R-3, 120	89.5	4		1				1		3				2									1				
				10R-4, 120	91.0	5		3						4				4	4												
				10R-6, 120	94.0	6	1	4	1			1		5				5									1				
				11R-1, ?	?	6		1						8				5								3	2				
			N4	11R-2, 120	97.6	5		4						4																	
		CN1		11R-3, 120	99.1	6	1				4	1	1	3				4													
				11R-4, 120	100.6	6		2			1	1		5				3		1			1							1	
				11R-5, 120	102.1	6		1			3	1		5				1		2			1			1					

Note: Explanation as in Table 3.

identified in the late Oligocene and early Miocene when deep-water indexes associated with well-oxygenated waters, such as *C. kullenbergi*, were ubiquitous in the Mascarene Basin.

Infaunal indexes can be used to interpret conditions within the sediment. Indicative of organic-carbon-rich sediments are the uvigerinids, trifarinids, rectuvigerinids, high ratios of infauna:epifauna, and high benthic foraminifer diversity. Buliminid and bolivinid abundance is associated with the development of low-oxygen conditions. Low biomass of largely rotaloid benthic foraminifers is associated with well-oxygenated, low-fertility conditions under waters similar to modern AAIW.

Evidence of the formation of intermediate and deep waters within the Indian Ocean beginning in Zone CP18 (Zone P21) of the late Oligocene, and continuing from early to later Miocene, derives not only from the fossils but also from the redeposition patterns. Materials redeposited to deep and abyssal areas come from intermediate, not shallow water depths. One explanation for this pattern is that the materials derive from a vigorously sinking intermediate water mass. Redeposition of northern-source intermediate water fossils into the abyssal Mascarene Basin indicates north-south redeposition of material from intermediate depths. A northern source of sinking, well-oxygenated, saline waters based on carbon isotope data (Woodruff and Savin, 1989) is also indicated by the fossil data.

Faunal criteria for recognizing the source region of sinking intermediate- and deep-water masses include development of (1) vertical faunal homogeneity from intermediate through abyssal areas, and (2) index faunas for well-oxygenated water masses and aerated conditions in the sediments from intermediate into abyssal areas.

Infaunal indexes indicate the evolution of conditions underlying intermediate waters in the northern Indian Ocean:

1. Less oxygenated conditions in the sediment in the northern Indian Ocean beginning in late Oligocene Zone CP18;
2. Oxygen-rich, "new" waters and aerated conditions in the sediment from the latest Oligocene through most of the early Miocene after Zone CN1 and into the early middle Miocene; these waters may have been more fertile than their late Neogene analogs;
3. Organic-carbon-rich, less oxygenated bottom sediments and water masses early in late Miocene Zone CN9;
4. Beginning in early Pliocene Zones CN10–CN11, oxygen-rich, probably low-nutrient conditions in the northern Masca-

Table 13 (continued).

Cibicidoides kullenbergi	*Stilostomella insecta*	*Siphonodosaria modesta*	*Nuttallides umbonifera*	*Cibicidoides bradyi*	*Lenticulina vortex*	*Gyroidinoides altispirus*	*Bolivina pulchra*	*Bolivina* cf. *B. pulchra*	*Bulimina semicostata*	*Osangularia bengalensis*	*Bolivina* sp. (inflated)	Crenulate bolivinids	*Gyroidinoides planulatus*	*Bolivina subreticulata*	*Bulava* sp.	*Planulina renzi*	*Pullenia bulloides*	*Bolivina peregrina*	*Eggerella bradyi*	*Siphonina tenuicarinata*	*Uvigerina pigmea* (spinose)	*Laticarinina pauperata*	*Recturvigerina spinea*	*Heterolepa rugosa*	*Bolivina pseudoplicata*	*Cassidulina crassa*	*Stilostomella subspinosa*	*Bolivinopsis gryzbowski*	*Gaudryina* sp.	*Cassidulinoides bradyi*	*Orthomorphina perversa*	*Planulina marialanna*	*Karreriella subrotundata*	*Pullenia* sp.	*Bulimina macilenta*	*Bolivina tongi*	*Pullenia quadriloba*	*Heterolepa dohmi*	*Lenticulina* cf. *L. calcar*
2	1	1	1	1	1																																		
1			1			1	1																																
							4	2	1	1	2	3																											
							5		1			3	2	1	1	1																							
							4		2			4			4		2																						
2										1		1					1	1																					
		1				2							1		1	2	1		1																				
2							4					3	1		1					1	1																		
1					1		4					4		1	5			1				1	1	1	1														
		1					6					5						5							1	2	1												
		1					5					5						4							1	2		1	1	1									
							4					4															1	1											
		1					2					5																1			1								
												4					1														1	1	1	1					
	1											5									1				3														
							4					3	1															1							1				
1				1		1						4						1	1																	1	1		
						1						3						1			1							1											
												4																										1	1
		1	1				4			1		5		1											4														
2							4					4						1							1						1			1					
1							3					3																											
		1				1	5					4					1	1							2			1											
							6					5																											
1							8			1		8		3				4			2						3												
1		1			2		3					7									2		2		3														
						1	4			2		6				1					3						3	1											
2					1		4					7				1	1				1														1				
1						1	4			1		7									1					1		1			1								

rene Basin, but fertile, oxygen-depleted sediments and water masses to the north in the Arabian Sea and under the southern Indian upwelling zone.

Benthic signals for the late Miocene glaciation in the northern Indian Ocean include (1) increased numbers of bottom-water indexes in abyssal areas and updepth migration of bottom water indexes; (2) increased numbers of bottom-water indexes at intermediate depth sites; (3) increased numbers of spinocostate uvigerinids and miliolids at intermediate- and deep-water sites; and (4) decreased numbers of bolivinids and buliminids at intermediate depths.

Water-mass stratification during the latest Miocene and earliest Pliocene glacial episodes reflected the expansion of well-oxygenated intermediate waters throughout the northern Mascarene Basin and southern Arabian Sea. This means that the less well-oxygenated waters and conditions prevalent at the time of the Epoch 6 carbon shift were eventually replaced by well-oxygenated conditions at intermediate depths. A well-oxygenated intermediate water spread not only through the Mascarene Basin, but as far north as the southern Arabian Sea during this glacial episode. This water mass was more fertile than modern AAIW.

By the end of the Miocene, deep- and bottom-water faunas resembled their modern counterparts. Deep-water masses first resembled eastern IDW in both the Mascarene and Central Indian basins before the glacial episode in late Miocene Zone CN9. When the northern Indian Ocean ceased to be a region of deep-water formation, the "aged," less oxygen-rich deep waters of both northern basins probably came from the south. By the early Pliocene, however, proto-IDW-type faunas were sequestered in the Central Indian Basin, presumably as the result of deep-water inflow from the southern Indian Basin, as occurs today.

Early Pliocene faunas of the Mascarene Basin indicate a different southern influence: a fauna similar to those under modern AAIW existed at intermediate depths, while a warmer, moderately well-oxygenated AABW type fauna expanded throughout the northern Mascarene Basin from abyssal to deep-water depths. Updepth expansion of abyssal indexes implies either decreased deep-water or increased bottom-water circulation through the Mascarene Basin in the warmer part of the early Pliocene.

Table 13 (continued).

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Cibicidoides havanensis*	*Melonis affinis*	*Cibicidoides* cf. *C. perlucidus*	*Loxostomum* sp.	*Martinotiella variabilis*	*Bolivina arta*	*Hanzawaia cushmani*	*Chrysalogonium equisetiformis*	*Bulimina semicostata*	*Karreriella bradyi*	*Eggerella propinqua*	*Bulimina striata*	Diversity	Epifauna	Infauna	Abundance (infauna)	Abundance (epifauna)
				6R-1, 120	48.0	6													14	2	12	20	2
				6R-2, 120	49.5	7													18	7	11	21	7
	middle			6R-3, 120	51.0	6													15	5	9	11	5
		CN5		6R-4, 69	52.0	5													9	4	5	10	4
				6R-5, 120	53.0														0	0	0	0	0
			N9	6R-6, 120	55.5	5													13	3	10	24	5
				7R-1, 120	57.7	5													14	3	11	29	6
				7R-2, 120	59.2	6													14	1	13	28	11
				7R-3, 120	60.7	6													12	3	9	13	4
				7R-4, 120	62.2	7													14	5	9	15	6
		CN4		7R-5, 120	63.7	5													17	3	13	23	6
				7R-6, 120	65.2	5													18	5	13	27	5
				8R-2, 120	68.8	6													14	2	12	30	2
				8R-3, 120	70.3	6													14	0	12	29	0
				8R-5, 120	73.3	7													9	2	5	15	2
Miocene			N8	8R-6, 120	74.8	7													10	1	8	16	1
			N5–N7	9R-1, 120	76.9	5													18	5	11	20	5
				9R-2, 120	78.4	5													8	0	8	19	0
	early			9R-3, 120	79.9	6													11	2	8	23	2
		CN3		9R-4, 120	81.4	5													14	4	10	18	4
				9R-5, 120	83.9	5													11	1	9	19	1
				9R-6, 120	84.4	5	1												7	2	5	9	2
				10R-1, 120	86.5	5		1	1										15	4	11	35	11
				10R-2, 120	88.0	5				1									14	2	12	23	3
				10R-3, 120	89.5	4													8	1	7	14	1
				10R-4, 120	91.0	5													14	1	11	29	1
		CN2		10R-6, 120	94.0	6		3											10	1	9	24	1
				11R-1, ?	?	6		1		1	1	8	1						18	14	1	1	14
			N4	11R-2, 120	97.6	5					1			1					12	1	10	29	1
				11R-3, 120	99.1	6					1			1	3	1	1		19	4	11	30	8
		CN1		11R-4, 120	100.6	6	1											1	18	5	13	32	4
				11R-5, 120	102.1	6									2				18	4	13	31	3

By late Pliocene Zone CN12, index faunas in the Mascarene Basin suggest the stratification of a well-oxygenated deep water between intermediate and abyssal water masses that were more organic carbon rich, but lower in oxygen. Deep and abyssal faunas resemble those from the eastern basins today. The modern western basin faunas had not developed in the Mascarene Basin by Zone CN12 time.

ACKNOWLEDGMENTS

I would like to thank J. Backman, the Ocean Drilling Program, and USSAC for inviting me to participate on Leg 115. Support provided for post-cruise studies by USSAC and W. A. Berggren, Woods Hole, is gratefully acknowledged. Additional samples were kindly provided by C. Mato from the ODP Core Repository in College Station. I. Premoli Silva, University of Milan, kindly offered the use of the scanning microscope laboratory, and the photographs were taken by A. Rizzi, CNR of Milano. Special thanks go to B. Corliss for reviewing this paper, and to F. Woodruff, whose relentless pursuit of clarity greatly improved the manuscript.

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Date of initial receipt: 1 June 1989
Date of acceptance: 15 January 1990
Ms 115B-146

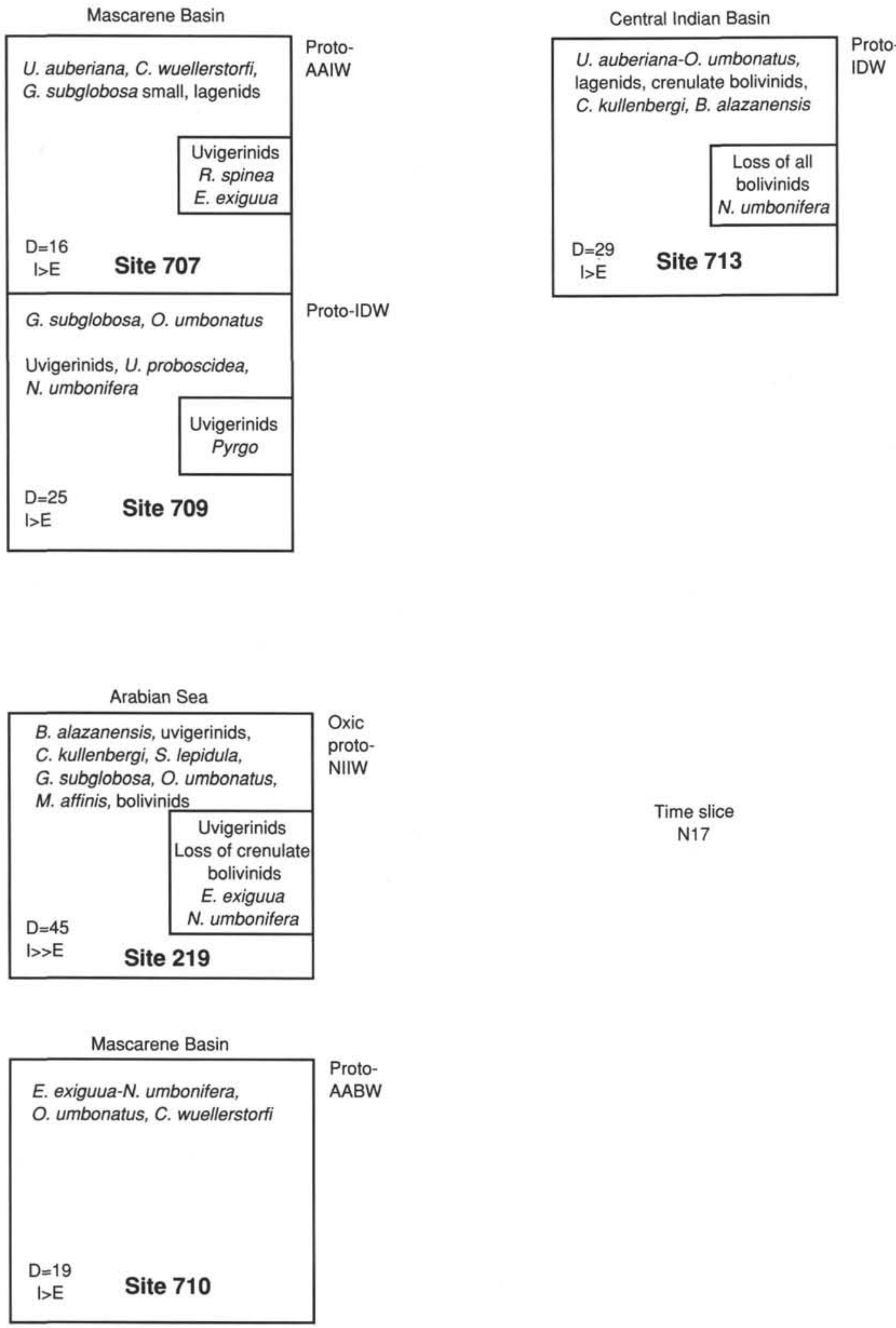

Figure 11. Benthic foraminifer index faunas of late Miocene Zone N17 (= Zone CN9) from five sites in the western and central Indian Ocean. Indexes, listed at top, were most abundant or most consistently present. Index forms that occurred only in pulses or events are shown below. Total sample diversity and the relation of infaunal to epifaunal abundance are shown at bottom left of each box. The faunal name assigned to each index fauna is listed to the right of each box. Data from Tables 12–17.

Table 14. Ranges of benthic foraminifers through the Neogene in Hole 714B.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Uvigerina auberiana*	*Dentalina consobrina*	*Bolivinita quadrilatera*	*Uvigerina hispida*	*Pullenia bulloides*	*Stilostomella lepidula*	*Uvigerina proboscidea*	*Uvigerina hispidocostata*	*Bolivina tortuosa*	*Textularia lythostrota*	*Bolivina striatocola*	*Bolivina striatocola* (elongate)	*Bolivina* cf. *B. finlayi*	*Rectobolivina* sp.	*Pleurostomella alternans*	*Globocassidulina subglobosa*	*Trifarina* cf. *T. bradyi*	*Cibicidoides kullenbergi*	*Sigmoilopsis schlumbergeri*	*Bolivina robusta*	*Sphaeroidina bulloides*	*Bulimina alazanensis*	*Astrononion* sp.	*Gaudryina* sp.	*Bolivina peregrina*
				3H-1, 120	17.6	G	3	1	3	3	1	3	1	3	3	1	1	5	5	1	1	1	1	1	1	1		1	1	1	1
Pleistocene		CN14		3H-2, 120	19.1	M	1	1	1		1	3	1				1		1	1		1					1	1			
			N22	3H-3, 120	20.6	M	1					3				1			1			1						1			
				3H-4, 120	22.1	M	1	1	1				1			1			1			1			1		1				
				3H-5, 120	23.6	M	1	1					1			1			1			1			1		1				
				3H-6, 120	24.4	M	1		1			3			1		1														1
				4H-1, 50	26.5	F	1	1	3	2		4			3	1		1	5			2			2	4	1	2	1		2
				4H-1, 120	27.2	F	1		2				1		1	1			4		1	1	1	1	1		1	3		1	
				4H-2, 50	28.0	F	1	2		2	1	4					2		3			4	1	1				2	1	1	1
		CN8		4H-2, 120	28.7	P	1			2	1	4			2		4	1	3			4			1	3		4			
				4H-3, 50	29.5	M	1		1	2		5			2		4		4			1		1	1			1		1	2
				4H-3, 120	30.2	M	2					4	3		2	3			3						1		1	4			2
				4H-4, 50	31.0	M	1	2	1		1	5				1	1		2		1							4			2
				4H-4, 120	31.7	M	2	2	2			3			1		4		4					1	2			1			3
				4H-5, 50	33.0	M	1					4	2		1	1	1		3		1	2			1	1	1	4			3
			N17	4H-5, 120	33.2	P	2					4	3		1	1		1	2			2						3	1	1	
				5H-1, 105	36.7	M	2					4			1	1		2	1			1			1			2			
				5H-1, 120	36.9	M	2				1	4					1	1	1			3			1		1	2			
				5H-2, 50	37.7	M	1	1			1	4			2		1	3	4		1	1	1	1		1	1	1	1	1	1
				5H-2, 120	38.4	F	2		1			1	4				1	2	3			1				4		4			
	late			5H-3, 50	39.2	G	1	1	1			5	4		2	1	1	1	1	1						2	1	1	1		
		CN7b		5H-3, 105	39.7	M	2	1				5	4				1		1			3			1	1	1	4			2
				5H-3, 120	39.9	M		2				5	2				4	2	2			4				4					5
				5H-4, 50	40.7	M	1	1				5	5		1	1	1		1		1	1	1	2	1	1		4		1	1
				5H-4, 105	41.2	F	1	1				4	4		1		1	1	2		1	1		2		1		2	1		4
				5H-4, 120	41.4	M	1	1	1			3	3		3		1	1	1				1			2		4	1		4
				5H-5, 50	42.2	M	1		1			5	5		1			1	1		1	1			1	1		1			
			N16	5H-5, 120	42.7	F						5	2		2	1	4	3	3			2			1	3	1	4			4
				5H-6, 105	43.7	G	1	1			1	5	5		2	1	4	3	2			2		1				5			3
				5H-6, 120	44.2	F	1					5	2		2		4	2	5			2				2		1			4
				6H-1, 50	45.9	M	1			1	1	5	5		1	1	1				1	5			2		1	3			
				6H-1, 120	46.6	F				1		4	3		2		4	2	4			3			2	3		1		1	4
Miocene				6H-2, 50	47.4	M						5	3		1	1	2	2	4		1	2		3	2	1	1	3	1		4
				6H-2, 120	48.1	F	1	1	2			5	1		2	2		4	3		1	1	1			3	1	3			7
		CN7		6H-3, 120	49.6	M	1	1			1	5	3		1		3	1	5			5		1			2	5	1	1	5
				6H-4, 50	50.4	F	1	1	1			5	3		1			4				4			1		1	1			5
				6H-4, 120	51.1	F	1		1			5	4		1				5			3	1			2	2	1			4
				6H-5, 50	51.9	M	1		1		1	5	2		2	1		3	4			1		1				3			3
				6H-5, 120	52.6	M	1					3	1				1		3			2									
				6H-6, 50	53.4	M	1					2	3				3		4			1		1				1		1	
				6H-6, 120	54.1	F	1					5	2		1		3		4			4									
			N15–N16	6H-7, 50	54.9	M	1	1				3	4				3		4									1	1		
				7H-1, 120	56.2	G	2	2			1	3	1		1		5		1									3			
		CN6		7H-2, 120	57.7	G	1					1	1		1		1		1			2		1				1			
				7H-3, 120	59.2	G	1				1	5			5		4		2			2	1			2		1			
				7H-4, 120	60.7	G	2								2		1					2						1			
				7H-5, 50	61.5	G	1				1	6	5			2	2		3			5					2	2	1		
				7H-6, 50	63.0	M	1					1				1	1		1			2		1				2			1
				7H-7, 50	64.5	F	2					3					1					4						2	1		5
		CN5b		8H-1, 50	65.1	G		1	5			5					5	3	1			2				1		3	3		5
				8H-2, 120	67.3	M					.	1	2									1									
				8H-3, 50	68.1	F	1		2		1	5	1				3					3			1			1			
				8H-4, 8	69.1	G	2		6		1	6			1				4		1	2		1	1				1		
	middle			8H-4, 30	69.3	G	1		7		2	5	1		1		5				1	5					1	1		1	6
			N13	8H-4, 120	70.3	G	2		1		1	1	2				2					2			1				1		2
				8H-5, 120	71.8	G	2		7			5	3		3		4					5		1	1						
				8H-6, 50	72.6	G			5		1	5			4							3		1	2						2
				9H-1, 50	74.8	F						5	1									4			2		1	2			4
		CN5a		9H-2, 50	76.3	M	1		3				1									1	1					3			4
				9H-3, 50		G	1		6		1	5					5		1			3		1		1		1	1		2
				9H-4, 50	79.3	M	1		1			5			1		1					4	1	1		1			1		5
			N11	9H-5, 50		G	5		5			5	3		4		5											2			5
				10H-4, 120	89.6	F						1										3									
		CN4		11H-3, 120		G			5			5					4		4			2									4
				12H-2, 120		M			4		1	1										2					2	1			
				13H-5, 50		P																4									

Note: Explanation as in Table 3.

Table 14 (continued).

Cassidulina sp. (granular wall)	*Orthomorphina glandigena*	*Osangularia bengalensis*	*Anomalinoides semicribratus*	*Melonis affinis*	*Pyrgo murrhina*	*Cassidulina ornata* (with costae)	*Lenticulina nicobarensis*	*Planulina renzi*	*Oridorsalis umbonatus*	*Bulimina mexicana*	*Melonis barleeanum*	*Martinottiella variabilis*	*Ehrenbergina hystrix*	*Eggerella subovale*	*Cibicides wuellerstorfi*	*Siphonodosaria modesta*	*Pleurostomella subcylindrica*	*Hopkinsina mioindex*	*Trifarina bradyi*	*Bulava* sp.	*Chrysalogonium* sp.	*Bolivina pseudobeyrichi*	*Vulvulina spinosa*	*Karreriella bradyi*	*Stilostomella insecta*	*Cibicides lobatulus*	*Dyocibicides* sp.	*Chrysalogonium equisetiformis*	*Bolivinopsis praelonga*	*Gyroidinoides planulatus*	*Eggerella bradyi*	*Gyroidinoides altiformis*	*Stilostomella fistuca*	*Triloculina lucernula*	*Dentalina hiricornia*	*Bolivina villaverniensis*	*Cassidulinoides bradyi*	*Bolivina pseudogemma*	*Orthomorphina perversa* (crinkled costulae)	*Nodosaria* sp.	*Nuttallides umbonifera*	*Cibicidoides bradyi*	*Siphotextularia catenata*	*Hoeglundina elegans*
1	1	1	1	1	1	1	1																																					
			1		1		1	1	1	1	1	1	1	1	1	1	1	1	1																									
																1				1	1	1	1	1																				
	1		1		1			1	1	1	1	1		1	1	1				3	1		1	1	1	1	1																	
	1		1		1			1	1	1	1	1		1	1	1				3	1		1	1	1	1	1																	
		1	1					1									1	1							1		1																	
	1				1			1		1	4				3	2			1	3	1			1	2	1	1															1	1	1
	1		1	1	1			1		1		1			1	1	1			2	1										1											1		1
	1	1	1	1	3				1		4				1		2	1										1			1	1										1		
			2		1				1	1					2						1		1		1				1												1		1	
					3		1	1		1	1	1			2	1																												
	1		1		3			1	2	1					3	1				2		2		1		1		1					1	1						1				1
						1			1			1				1				4		2						1						1				1				1		
			1							1										3										1			1	1	1			1				1		
					4				1	1						1	2			3	1	2						1					1										
		1			1			1	1	1			1	1	1	1		1		3				2		1				1			1			2			1			1		
		1	1	1	1			1	1			1		2	1			1		2	1	4		1		1			1		1				1				1					
												1			1		1			1			1			1							1									1		
	1		1		1							1										5					1						1						1			1		
		1	1		3							1					1			1	1		1	1							1		1		1				1					1
				1	2	1	1	1	1									1		5	1				1							1		1	1				1				
			1		2	1	1	1	1	1	3				2			2		3		1		1			1					1	1					3	1				1	
					2			2												3																		4					
	1	1	1	1	3			4	1	1					1	1	1	1		4			1							1	1			1	1			3	1					
												1								4		2	1									1			1			4						
											1	1			1	1				5		4		1										1	1			4	1					1
1		1			1	1		1	1		1	1			1					5		5		1			1			1	1				1		1	4	1					1
	1						1	1		1	1									5	1	4		1													5	1					
					4			2	1						2	1				3		4																4	1	1		1		
		1	1	1	1			1							4					3		4	1				1						1					4					
			1	3	5		1	1	1	1					3							3	1		1	3							1	1			2						1	
		2			4					1	1				1	1	1		1	1		5		1			1			1	1		1					4	1		1			1
				1	1				1			2			2	2	1			1		3							3	1	1			1	1			1	3				1	1
					3			3			1					1			1	2		4		1									1	1				1		1			
		1			3						1				1	1	2			1		1			1							1	1			1	1	1			1	1	
2			1		3				1		1	1			1					1	1	5										1						1					
2					3					1	1					1	1		1	1	1	5				1			1			1						3		1			
				1	2										2		1					5							1								1	3					1	
4		1	1		2			1	3	1						1	1			5		3							1							1		3					
		1			1				1						1	1			1											1													
		1	1		5			1	1		2	1			1	1																1										
					1				1	4					1						1	2		1						1								3					1	
					1			3								2						5			2																		
			1		1										1	1	1								3																	1		
			2						1	1					2	1				2					2	1											1						
		1	1	1				1																																			
		1		1	2				1							1									2																		
															1	2								1	1																		
		1	2		1				2	1	1	1			1																											1		
			1																	1																							
					5			1	1						1										1			1									1					1		
		3			2					1						1																											
		2	3	1	2				2		3				1	1									1																		
					3			1	1	1																																	
		1		3	4						1	1			1									1																			
			1		2				1							1												1								1					3		
			1					1			1		1		1																1						1	4						
									3		1					1				2				1																			
					2			2		1	1													1	1				1													3		
			3		1											1											1														1		
					1						1									1					1				1														
		1																																									
									2																												4						
				1				1																																			
									1			1																															

Table 14 (continued).

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Cibicidoides cicatricosus*	*Pleurostomella brevis*	*Uvigerina hispidocostata*	*Laticarinina pauperata*	*Uvigerina ongleyi*	*Pullenia* sp.	*Frondicularia* sp.	*Stilostomella subspinosa*	*Gyroidinoides altispirus*	Small virgulinids	*Elphidium* sp.	*Nodosaria hochstetteri*	*Ehrenbergina trigona*	*Cibicides vortex*	*Karreriella baccata*	*Bolivina* sp. (encrusted sutures)	*Planulina* sp. (loosely coiled)	Unidentified agglutinants	*Rectuvigerina spinea*	*Bolivina optima*	*Chyrsalogonium setosum*	*Nonion* cf. *N. centrosulcatum*	*Ceratobulimina pacifica*	*Cassidulina laevigata*	*Asterigerina* sp.
				3H-1, 120	17.6	G																									
Pleistocene		CN14		3H-2, 120	19.1	M																									
			N22	3H-3, 120	20.6	M																									
				3H-4, 120	22.1	M																									
				3H-5, 120	23.6	M																									
				3H-6, 120	24.4	M																									
				4H-1, 50	26.5	F	1																								
				4H-1, 120	27.2	F		1	1	1	1	1	1	1																	1
				4H-2, 50	28.0	F				1	1				1	1	1														3
		CN8		4H-2, 120	28.7	P			1	1	1	1	1	1																	3
				4H-3, 50	29.5	M																									
				4H-3, 120	30.2	M			1						1	1					1										
				4H-4, 50	31.0	M										1		1													
				4H-4, 120	31.7	M				1					1	1					1										
				4H-5, 50	33.0	M				1										1		1	1								
				4H-5, 120	33.2	P								1										1							
				5H-1, 105	36.7	M									1	1										1					
				5H-1, 120	36.9	M										1						1		2							
				5H-2, 50	37.7	M		1								1					1						1				
				5H-2, 120	38.4	F		1	1						1	1	1							2	1						
	late			5H-3, 50	39.2	G											1								1						
		CN7b		5H-3, 105	39.7	M		1								1						1				2	1	1			
				5H-3, 120	39.9	M									3																
				5H-4, 50	40.7	M		1	1			1		1	3	1	1		1			1					1		1	1	1
				5H-4, 105	41.2	F										1					1	1					1			1	
				5H-4, 120	41.4	M			1	1						1						1				4	1	1		1	
				5H-5, 50	42.2	M																1					1			1	
			N16	5H-5, 120	42.7	F																				2					
				5H-6, 105	43.7	G									1	1										4					
				5H-6, 120	44.2	F										1						1									
				6H-1, 50	45.9	M	3	1				4				1		1				1	1								
				6H-1, 120	46.6	F								1					1			1	1								
Miocene				6H-2, 50	47.4	M								1								1			1		1			1	
				6H-2, 120	48.1	F		1							2				1		1			1		1					1
		CN7		6H-3, 120	49.6	M		1				1			2		3				1			1							1
				6H-4, 50	50.4	F									2		2					1							1		1
				6H-4, 120	51.1	F		1							1	1					1										
				6H-5, 50	51.9	M									1																1
				6H-5, 120	52.6	M					1																				
				6H-6, 50	53.4	M																									
				6H-6, 120	54.1	F		1			1				1											1					1
			N15–N16	6H-7, 50	54.9	M	1				1	1									1			1							
				7H-1, 120	56.2	G										1															3
		CN6		7H-2, 120	57.7	G																									
				7H-3, 120	59.2	G									1			1		1											3
				7H-4, 120	60.7	G														1											2
				7H-5, 50	61.5	G									1																
				7H-6, 50	63.0	M					1															1					
				7H-7, 50	64.5	F																									
				8H-1, 50	65.1	G									1																
		CN5b		8H-2, 120	67.3	M									1																
				8H-3, 50	68.1	F																									1
				8H-4, 8	69.1	G																1				1					1
	middle			8H-4, 30	69.3	G																									1
			N13	8H-4, 120	70.3	G																									
				8H-5, 120	71.8	G									1																
				8H-6, 50	72.6	G																									
				9H-1, 50	74.8	F		2																1							
		CN5a		9H-2, 50	76.3	M																									
				9H-3, 50		G					1										1										
				9H-4, 50	79.3	M									1												1				1
			N11	9H-5, 50		G									1																
				10H-4, 120	89.6	F																									
		CN4		11H-3, 120		G																		1		1					
				12H-2, 120		M																		1							
				13H-5, 50		P																									

Table 14 (continued).

Melonis sp.	*Cassidulinella* sp.	*Heterolepa rugosa*	*Cibicides americanus*	*Eggerella propinqua*	*Anomalinoides* sp.	*Pullenia quinqueloba*	*Bolivina pseudoplicata* + *B. hebes*	*Planulina* sp.	*Nodosaria* sp. (spinose)	*Planulina* sp. (tightly coiled)	*Bolivina finlayi*	*Martinotiella communis*	*Cyclammina* sp.	*Melonis pompilioides*	*Bolivina* cf. *B. pulchra*	*Bolivina goessi*	*Spiroplectammina spinosa*	*Uvigerina pigmea*	*Osangularia culter*	*Gyroidinoides neosoldanii*	*Cibicides laurisae*	*Orthomorphina koina*	*Cassidulina crassa*	*Bolivina pseudobeyrichi*	*Loxostomum* sp.	*Planulina ariminensis*	*Anomalinoides globulosus*	*Bolivina* sp. (inflated)	*Epistominella exigua*	*Discanomalina semipunctata*	*Anomalinoides aragonensis*	*Hanzawaia cushmani*	*Bolivina subreticulata*	*Epistominella exigua* (high spired)	*Planulina gigas*	*Pullenia coryelli*	*Cassidulina laevigata carinata*	*Heterolepa grimsdalei*	*Bulimina semicostata*
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								4																															
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1				1	1	1	1	7			1					2																							
1					1			8	1	1	4	1				2																							
						1		8		1	4	1	1			5																							
								7	1		3	1		1	1	3																							
	1							7		1	3				2	5																							
1	1							7			2	1				5																							
1								6		1	3					1																							
1								7			3					5																							
								7	1		3	1				2					3																		
								7	1		4					3					3																		
					1			6	1		7										3																1		
			1					5	1		5					5			1												1								
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								4			3																												
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								6							5						1		1																
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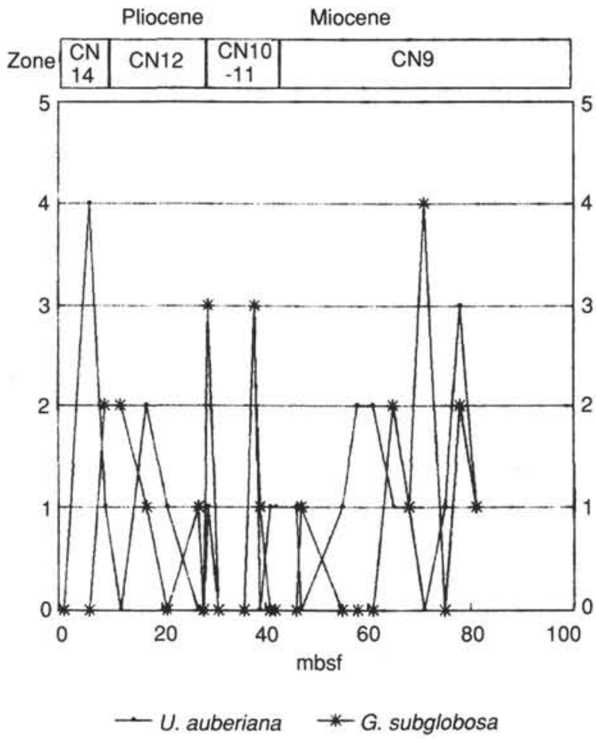
				1				5							1			1		1							1	1											
								3							4			1	1					1					1										
								5							5							1																	
								7							7			1										1			1	1							
								7							7																		1						
								1							1			1									1			1	1								
								7							7		1	1													1	1		1	1				
								6							6																		1			1			
																2						1																	
								4							3	2																							
								7							7				1			1						1			1								
								7							8			1																		1			
								6							6			1																					
																						1																	
															2							1																	1
															5																1	1							
																			2																	1	1	1	1

Table 14 (continued).

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Alabamina* sp.	*Siphonina* sp.	*Uvigerina porrecta*	Redeposited benthic foraminifers	Bolivinids	Diversity	Infauna	Epifauna	Coarse fraction uvigerinids	Total uvigerinids
				3H-1, 120	17.6	G				0	19	33	22	5	0	7
Pleistocene		CN14		3H-2, 120	19.1	M				0	3	26	13	5	0	2
			N22	3H-3, 120	20.6	M				0	2	11	7	0	0	1
				3H-4, 120	22.1	M				0	2	26	12	7	0	2
				3H-5, 120	23.6	M				0	2	26	12	7	0	2
				3H-6, 120	24.4	M				0	2	13	8	7	0	0
				4H-1, 50	26.5	F				0	16	34	16	9	2	5
				4H-1, 120	27.2	F				0	0	38	22	8	2	6
				4H-2, 50	28.0	F				2	13	36	4	11	0	4
		CN8		4H-2, 120	28.7	P				4	13	32	14	6	0	5
				4H-3, 50	29.5	M				0	17	23	14	4	0	3
				4H-3, 120	30.2	M				0	10	32	18	9	0	5
				4H-4, 50	31.0	M				0	11	24	14	5	0	1
				4H-4, 120	31.7	M				0	10	25	16	7	0	3
				4H-5, 50	33.0	M				0	12	29	19	2	0	4
				4H-5, 120	33.2	P				0	7	32	17	10	0	5
				5H-1, 105	36.7	M				0	7	32	16	8	0	3
				5H-1, 120	36.9	M				0	11	22	12	5	5	5
				5H-2, 50	37.7	M				0	17	33	20	9	0	1
				5H-2, 120	38.4	F				0	18	33	21	6	0	6
	late			5H-3, 50	39.2	G				0	9	34	21	4	0	5
		CN7b		5H-3, 105	39.7	M				0	13	40	23	10	0	8
				5H-3, 120	39.9	M				0	31	17	14	2	6	8
				5H-4, 50	40.7	M				0	11	51	32	15	6	13
				5H-4, 105	41.2	F				0	25	35	21	9	3	8
				5H-4, 120	41.4	M				0	22	41	27	7	4	12
				5H-5, 50	42.2	M				0	26	40	24	8	0	6
			N16	5H-5, 120	42.7	F				0	36	30	24	2	0	4
				5H-6, 105	43.7	G				0	33	33	21	7	0	10
				5H-6, 120	44.2	F				0	35	32	18	8	0	3
				6H-1, 50	45.9	M				0	23	41	26	12	2	12
				6H-1, 120	46.6	F				0	37	38	26	6	2	5
Miocene				6H-2, 50	47.4	M				0	28	42	26	9	0	4
				6H-2, 120	48.1	F				0	37	41	36	8	6	15
		CN7		6H-3, 120	49.6	M				0	28	41	10	12	1	5
				6H-4, 50	50.4	F				0	29	37	24	10	0	4
				6H-4, 120	51.1	F				0	29	33	24	6	0	5
				6H-5, 50	51.9	M				0	28	28	20	4	0	3
				6H-5, 120	52.6	M				2	17	23	16	6	0	2
				6H-6, 50	53.4	M				0	8	21	13	8	0	4
				6H-6, 120	54.1	F				0	15	28	13	11	1	5
			N15–N16	6H-7, 50	54.9	M				0	10	26	13	11	1	6
				7H-1, 120	56.2	G				0	11	20	16	4	0	4
		CN6		7H-2, 120	57.7	G				0	13	22	13	8	0	1
				7H-3, 120	59.2	G				0	13	21	18	6	1	2
				7H-4, 120	60.7	G				0	20	14	10	3	0	0
				7H-5, 50	61.5	G				0	11	23	18	5	0	6
				7H-6, 50	63.0	M				0	8	18	12	3	0	2
				7H-7, 50	64.5	F				0	15	10	8	1	2	4
		CN5b		8H-1, 50	65.1	G				0	12	29	17	10	2	4
				8H-2, 120	67.3	M				0	22	29	9	2	0	1
				8H-3, 50	68.1	F				0	10	22	12	5	0	2
				8H-4, 8	69.1	G				0	17	23	5	6	2	5
	middle			8H-4, 30	69.3	G				0	18	27	18	5	10	12
			N13	8H-4, 120	70.3	G				0	13	20	12	6	0	5
				8H-5, 120	71.8	G				0	19	25	12	6	0	6
				8H-6, 50	72.6	G				0	24	21	13	6	0	0
				9H-1, 50	74.8	F				0	17	23	14	6	0	1
		CN5a		9H-2, 50	76.3	M				0	21	16	12	1	0	2
				9H-3, 50		G				0	26	18	17	10	0	1
				9H-4, 50	79.3	M				0	29	23	16	5	0	2
			N11	9H-5, 50		G				0	20	17	14	1	0	4
				10H-4, 120	89.6	F				0	15	7	2	1	0	0
		CN4		11H-3, 120		G		1	1	0	2	15	13	3	0	0
				12H-2, 120		M				0	22	12	8	3	0	0
				13H-5, 50		P	1			0	4	9	3	4	0	0



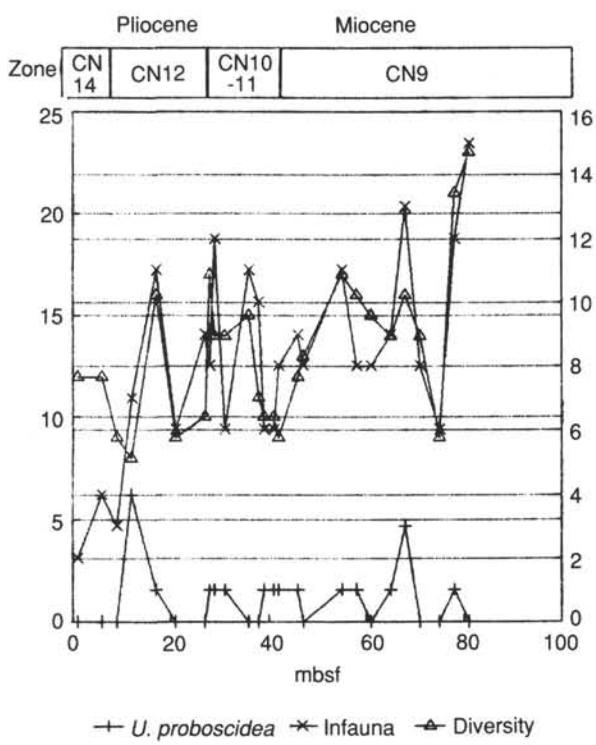


Figure 12. Relative abundances of most common benthic foraminifers from the late Miocene through the Pliocene at Site 707. Species include *Uvigerina auberiana, Globocassidulina subglobosa*, and *Uvigerina proboscidea*. Total infaunal number and total benthic foraminifer diversity in each sample are also plotted. As at other sites, there is generally an inverse relation between abundances of *U. auberiana* and *G. subglobosa*. Data from Table 19. Zonation from Backman, Duncan, et al. (1988).

Table 15. Ranges of benthic foraminifers through the early-middle Miocene in Hole 709A.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Gyroidinoides altispirus*	*Oridorsalis umbonatus*	*Bulava* sp.	*Anomalinoides globulosus*	*Globocassidulina subglobosa* (small form)	*Ehrenbergina hystrix*	*Gyroidinoides soldanii*	*Stilostomella lepidula*	*Uvigerina auberiana*	*Globocassidulina subglobosa* (medium size)	*Globocassidulina subglobosa* (large size)	*Cibicidoides bradyi*	*Bolivina striatocola*	*Textularia* cf. *T. flintii*	*Bulimina alazanensis*	*Bolivina villavernensis*	*Pullenia quinqueloba*	*Cibicidoides kullenbergi*	*Epistominella exigua*	*Pullenia bulloides*	*Gyroidinoides planulatus*	*Orthomorphina rohri*	*Uvigerina pigmea* (spinose)	*Cassidulina laevigata*	*Stilostomella insecta*
Miocene	middle	CN5	N13	13H-5, 120	123.4	5	1	5	1	2	1	1	1	1	1	4	3	1	cf.	1	1	1									
	early	CN4	N7–N9	14H-4, 120	131.5	5		3		1				1		1	1		1		1		1	1	1	2	1	1	1	1	
		CN3		14H-6, 120	134.5	6	1	4		1	2			2			2		4		1		3	1		4	3				1
		CN1b		15H-2, 120	138.2	3		4		1	5		2	5		2	5		4					1	1	4	1		1		
				16H-1, 120	146.4	5	1	3					1	3		1	1		1					2	1			1			
				16H-6, 120	153.9	5	1	4			1			2		1			4							2		7			
				17H-1, 120	156.1	6		3			4			4			1		2		1		1			1					
				17H-2, 120	157.6	5	1	4			4		1	4		4	4		1		1		2	4		3			2		
				17H-3, 120	159.1	6	2	4			4			4		1	2		4		1		4			4	1		1		
				17H-4, 120	160,6	5	3	5			5		3	4		4	4	1	3	1			4	4		4		1	1		1
				17H-5, 120	162.1	6		4			4		1	1			2		2	1			3		1	1	3	2			
		CN1a	N4–N6	17H-6, 120	163.6	6	1	4			5			1		2	1	1					3	1		3	1	1			
				18H-1, 120	165.8	5		3	1		4			2		1	1						3			3	1		2		
				18H-2, 120	167.3	6	1	3			4			4			3		1	1				1		1		1			
				18H-3, 120	168.8	1	1	5			5			4		2	4	1	5		1		4	3		4	1				1
				18H-4, 120	170.3	2	1	5			5			5		5			5				4	1		3	2				
				18H-6, 120	173.3	6	3				5		1	2		2	1		4	2			1	2	2		1				
				19H-1, 120	175.5	6					5			4		2			2	1			2		1	1			1		
				19H-2, 117	177.0	4	1	4			5		2	4		2	1		5				2	1	1	2	1	1	1		1
				19H-3, 120	178.5	4	1	1			5		1	3		1	3						4								3
				19H-4, 69	179.5	3		2			5		3	3		1	5						4	3		4	3		1		
				20H-1, 120	185.1	4	5						1	2		3	1	1					2	3			1				
				20H-2, 140	186.3	4	2				1			4			1										1				
				20H-3, 120	188.1	5					1		2	3		1															
				20H-5, 120	191.1	6	1						1	1			1	1								1		1			
				20H-6, 82	192.2	5	4				2			2		1	1							1		1	1				
				21H-CC	202.0	5	4						1	4		1															

Note: Explanation as in Table 3.

Table 15 (continued).

Melonis pacificum	*Pleurostomella alternans*	*Bulimina semicostata*	Redeposited benthic foraminifers	*Pleurostomella subcylindrica*	*Stilostomella modesta*	*Siphotextularia catenata*	*Favocassidulina fava*	*Cibicidoides perlucidus*	*Planulina renzi*	Large nodosariid fragments	*Spiroplectammina spinosa*	*Bulimina macilenta*	*Karreriella bradyi*	*Cibicidoides trincherasensis*	*Orthomorphina perversa*	*Nodosaria stiliformis*	*Melonis barleeanum*	*Eggerella bradyi*	*Bolivina tortuosa*	*Karreriella subrotundata*	*Martinotiella petrosa*	*Nuttallides umbonifera*	*Bolivina pseudoplicata*	*Pullenia* sp.	*Chrysalogonium equisetiformis*	*Bolivina pulchra*	*Pullenia quadriloba*	*Pleurostomella brevis*	*Anomalinoides semicribratus*	*Bolivina* cf. *B. pulchra*	*Bolivinopsis gryzbowski*	*Stilostomella subspinosa*	*Vulvulina spinosa*	Small virgulinids	*Pleurostomella* sp.	*Buliminella* sp.	*Stilostomella fistuca*	*Uvigerina pigmea*	*Cassidulina ornata*
1	1	3	3	2	1																																		
1					3	1	1	1	1	3	1	1	1	1	1																								
		1			1		1									1	1																						
2		1								1								1	1	1	1																		
	2			1			1																																
										1	1				1							3	1	2															
	3	1		2								1	1					1			1				1	1	1	1	2										
1	4			2	1					1	2					2										1		2	1	2	1	3	1						
	1														1			1					1	1	1			1	1					1	3				
		2		1	1										1													1							4	1	1	1	
				1									3	1														2	1			3			1		1		
				1				2								1													1			1		1	3				1
		2		1														1				4							3				1	1	4	3			1
		2			1										1						1	5													4		1		
		1																			1	1													3				2
	1	1		1	1								1									3							1				1		3			1	
								1	1													3							2						3			1	
									2						1						1		1												3				1
		2		1					2													4							2				1		4	2			
					1						1		1								2								4				2		5				
1		2							3												1		1	1	1				1				1		4				
1				1											1						2	2						1	1						3			1	1
	1	1											2		1														3						3	1			
1				1					1				1		2														1						3	1			1
1	1	1			1																							2	1		1	3						2	

Table 15 (continued).

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Gyroidinoides altiformis*	*Lenticulina vortex*	*Cibicidoides* sp.	*Cibicidoides cicatricosus*	*Cibicidoides havanensis*	*Heterolepa dohmi*	*Cassidulina crassa*	*Melonis affinis*	*Cibicides vortex*	*Alabamina haitiensis*	Diversity	Infauna	Epifauna	Abundance (infauna)	Abundance (epifauna)
Miocene	middle	CN5	N13	13H-5, 120	123.4	5											16	11	5	16	10
	early	CN4	N7–N9	14H-4, 120	131.5	5											15	10	5	11	5
		CN3		14H-6, 120	134.5	6											19	14	5	30	10
		CN1b		15H-2, 120	138.2	3											25	16	9	36	12
				16H-1, 120	146.4	5											15	10	5	12	8
				16H-6, 120	153.9	5											15	11	2	23	5
				17H-1, 120	156.1	6											11	10	1	18	3
				17H-2, 120	157.6	5											20	14	5	30	13
				17H-3, 120	159.1	6											24	18	4	37	9
				17H-4, 120	160.6	5											30	21	6	52	17
				17H-5, 120	162.1	6											22	15	5	26	10
		CN1a	N4–N6	17H-6, 120	163.6	6											21	16	5	29	8
				18H-1, 120	165.8	5											18	13	4	25	6
				18H-2, 120	167.3	6	1										19	12	6	22	9
				18H-3, 120	168.8	1		1									25	17	7	44	18
				18H-4, 120	170.3	2											17	12	5	37	14
				18H-6, 120	173.3	6			2								18	10	7	22	12
				19H-1, 120	175.5	6		2	1								21	15	4	28	6
				19H-2, 117	177.0	4				1							23	12	11	28	18
				19H-3, 120	178.5	4					1						16	11	5	26	6
				19H-4, 69	179.5	3			1								20	12	8	28	20
				20H-1, 120	185.1	4			3		1	2					19	8	9	33	21
				20H-2, 140	186.3	4					1		3	1			18	13	5	22	8
				20H-3, 120	188.1	5							1				15	12	3	17	5
				20H-5, 120	191.1	6									1		15	9	5	11	7
				20H-6, 82	192.2	5										2	18	11	6	16	6
				21H-CC	202.0	5											13	9	3	16	6

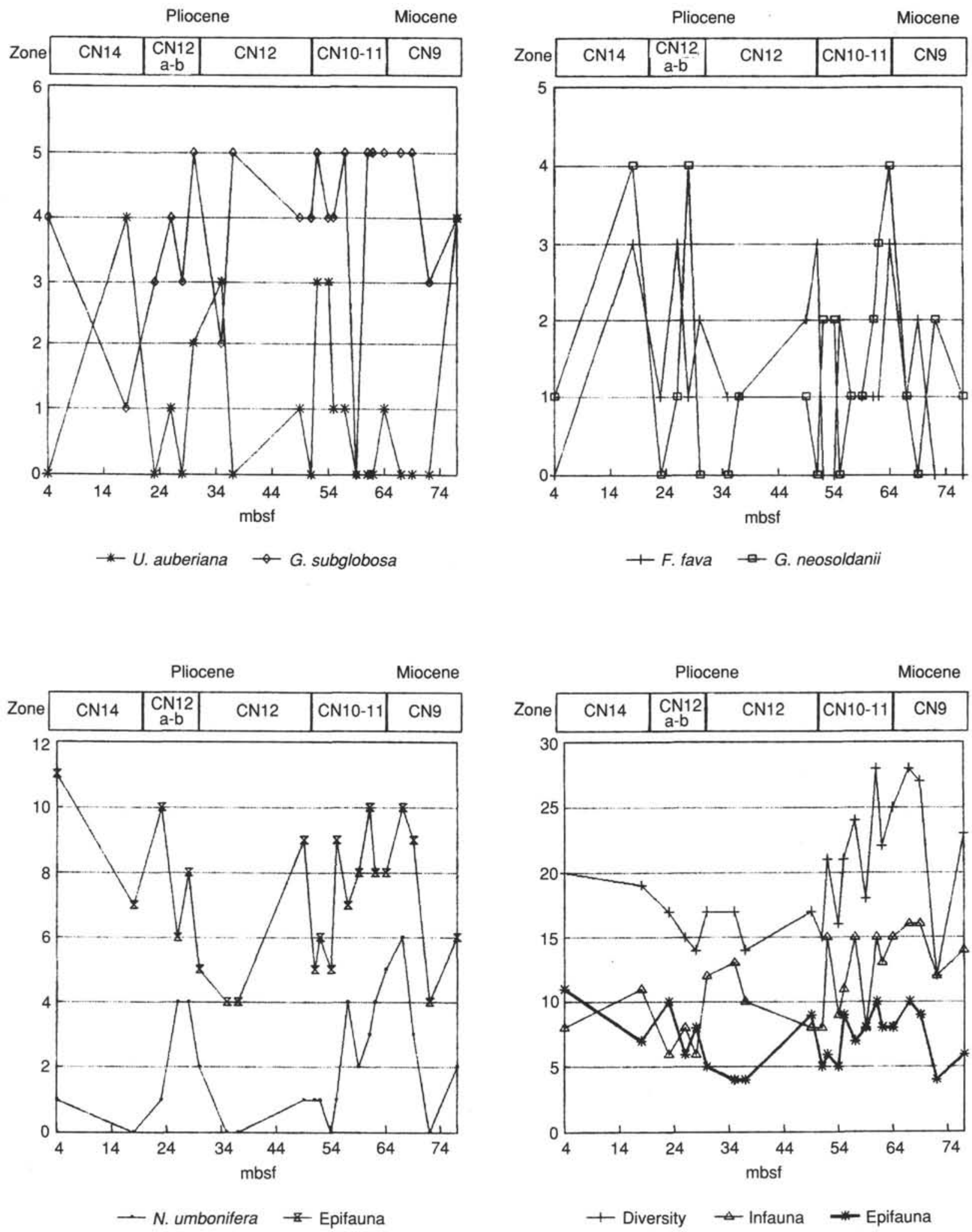


Figure 13. Relative abundances of the most common benthic foraminifers from the late Miocene through the Pliocene at Site 709. Species include *Uvigerina auberiana, Globocassidulina subglobosa, Favocassidulina fava, Gyroidinoides neosoldanii,* and *Nuttallides umbonifera*. Diversity and number of epifaunal and infaunal species are also shown. Data from Table 15. Zonation from Backman, Duncan, et al. (1988).

Table 16. Ranges of benthic foraminifers through the Neogene in Hole 710A.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	Miliolids	*Globocassidulina subglobosa* (medium size)	*Gyroidinoides neosoldanii*	*Nuttallides umbonifera*	*Oridorsalis umbonatus* (smooth margin)	*Pyrgo murrhina*	*Melonis pompilioides*	*Pullenia bulloides*	Lagenids	*Uvigerina interruptacostata*	*Favocassidulina fava*	*Globocassidulina subglobosa* (large form)	*Uvigerina hispidocostata*	*Karreriella bradyi*	*Cibicides wuellerstorfi*	*Eggerella bradyi*	Large nodosariid fragments	*Textularia* cf. *T. flinti*	*Siphotextularia catenata*	*Globocassidulina subglobosa* (small form)
Pliocene	late	CN13		1H-CC	9.5	6	3	3	1	1	5	3	3	1	2	4	3	4	2	1	1	1	3			
				2H-1, 120	10.7	4	4	3	2	2	4		3	4	3		1	3			1	1		2	3	3
			N21	2H-5, 120	16.7	4					3	1	5	1	5		2			2		4		2		1
	early	CN12	N18–N19	3H-1, 120	20.4	2			3	2	3		4	3									2			1
				4H-CC	38.3	3		3	3	1	5		1				1	2			3	2	2			
Miocene	late	CN9b	N17b	6H-CC	57.2	1	2		2	2	6		2	3	2			3			3	2	3			5
		CN9a	N17	7H-5, 120	64.7	1		1	1	4	3	1		1	3			3			3					
		CN8		8H-6, 120	75.8	1			2	1	4		1	3							3		1			2
		CN7	N16	9H-2, 120	79.3	1			1	1	4			1				1			1		3			
	early	CN3–CN4	N5–N7	12H-CC	115.2	1			5	5	6			5								1				5
		CN2		13H-CC	124.8	1		5	5	5	5			3			2	1					3			3
		CN1	N4	15X-CC	139.4	1		5			5							1								3

Note: Explanation as in Table 3.

Table 16 (continued).

Pleurostomella alternans	*Anomalinoides semicribratus*	*Lenticulina* sp.	*Melonis affinis*	*Oridorsalis umbonatus* (scalloped margin)	*Gyroidinoides planulatus*	*Triloculina lucernula*	*Sphaeroidina bulloides*	*Epistominella exigua*	*Pullenia quinqueloba*	*Cibicidoides kullenbergi*	*Laticarinina pauperata*	*Dentalina communis*	*Nodosaria tholigera*	*Chrysalogonium equisetiformis*	*Ehrenbergina trigona*	*Cibicidoides bradyi*	*Nodosaria stiliformis*	*Discanomalina semipunctata*	*Planulina renzi*	*Pleurostomella brevis*	*Bolivinopsis praelonga*	*Pleurostomella subcylindrica*	*Stilostomella subspinosa*	*Melonis pacificum*	*Stilostomella insecta*	*Stilostomella lepidula*	*Vulvulina spinosa*	*Heterolepa grimsdalei*
2	1	2	1	2	2	1	1																					
			1	2		1		4	1	1	1																	
					2			3	4		2	1																
	1			1	2		1			3	1		1	1	1	1												
		1			1			2			4			2			1	2	2	1	1	1						
					1			3	2	1	1											1	2	1				
			1				2			1	1			1					1		1			1				
							2																	1	2			
5								5		5													5		4	5		
										3																5	2	
	1			1					1	4									1						5			

Table 17. Ranges of benthic foraminifers through the late Neogene in Hole 713A.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Uvigerina interruptacostata*	*Oridorsalis umbonatus* (smooth margin)	*Bulimina alazanensis*	*Pullenia bulloides*	*Globocassidulina subglobosa* (large size)	*Favocassidulina fava*	*Pyrgo murrhina*	*Uvigerina auberiana*	*Cibicides wuellerstorfi*	*Gyroidinoides planulatus*	*Lenticulina* sp.	*Cibicidoides* sp.	*Globocassidulina subglobosa* (small form)	*Cibicidoides bradyi*	*Osangularia bengalensis*	*Melonis pompilioides*	*Globocassidulina subglobosa* (medium size)	*Anomalinoides semicribratus*	*Cibicides wuellerstorfi* (atypical)	*Textularia* cf. *T. flintii*	*Uvigeirna proboscidea*	*Eggerella bradyi*	*Stilostomella lepidula*	*Melonis affinis*
Pleistocene		CN14	N22	1R-CC	1.6	7	1	1	1	1	4	4	2	3	1	1														
				2R-1, 120	2.6	5	1			2				3	1	2	1	1	3	1	1	1	1	1	1	2				
				2R-2, 75	3.8	5	1							3					1			1	2			1	1	1	1	1
Pliocene		CN12	N18–N19	2R-3, 120	5.8	6						2	1			1			1				1			1	3		1	
				2R-4, 120	7.3	5		2				1		4	1				2									1	2	
				2R-5, 75	8.3	4		4		1	1	4		4					4					1		1	2	1	1	2
				2R-6, 75	10.3	3		1				3	1	1					5				1							1
Miocene	late	CN9b	N17b	3R-1, 120	12.2	4		2		3		4			2		1		5				2				1	1	1	2
				3R-2, 25	13.4	7		3		2	1	1	1	2					4		1		3		1		2			1
				3R-3, 20	14.4	5		1			1	2		3	3				5		1		1		3			1	1	1
				3R-4, 75	16.4	7		5		1	2		1	3	1				3				2	2	3				2	2
				3R-5, 20	17.4	7		2		3	2	3	2		3	1			2				1	2	1		1			1
				3R-5, 65	17.9	7		3		1	2	1	1		1				4			1		2					1	
				3R-5, 120	18.4	7		4		2	2			5	1				3				2	2	2	1	5		1	3
				3R-6, 70	18.9	5		2		2				4	1				2				2				5			1
				3R-6, 75	19.6	5				1		1	1	3					1										1	1
				3R-6, 120	19.9	7		1		1				3	1	1			5						1		1			
				3R-7, 20	20.6	6		5		2		1		2	1				2						1	1	1	1	2	
				4R-1, 20	21.0	5		3		1	2	2	4	4		1			4	1	1			3			1		1	
				4R-1, 120	22.0	5		1		1	4			4	1	1			3	1							1	1		2
				4R-2, 20	22.5	7		2		1	5			3	2	1			4	1	4		3	1	1		2	1		1
				4R-3, 75	24.5	5		3			4		1	2					3	1	4			1	3		2			2
				4R-4, 75	26.0	7		2			4			1	1				3											4
				4R-5, 75	27.5	7		1		1	1		1	4	2				2					1						
				4R-6, 75	29.0	7		4			5		1	5	3	1			2	2	1		2	3			3		1	1
				4R-6, 120	29.5	6		2			5			5	5	3			5		1			1					2	
				4R-7, 20	30.0	6		4		2	2		4	5	2				5	1	1		2	1	1				1	3

Note: Explanation as in Table 3.

Table 17 (continued).

Laticarinina pauperata	Lagenids	*Nuttallides umbonifera*	*Gyroidinoides neosoldanii*	*Pleurostomella* sp.	*Ehrenbergina trigona*	Miliolids	*Pleurostomella alternans*	*Triloculina lucernula*	*Epistominella exiguua*	*Stilostomella lepidula* (smooth)	*Heterolepa dohmi*	*Dentalina communis*	*Oridorsalis umbonatus* (scalloped margin)	*Orthomorphina koina*	*Cibicidoides kullenbergi* (flat)	*Melonis pacificum*	*Allomorphina* sp.	*Discorbis villardeboanus*	*Bolivina villaverniensis*	*Stilostomella subspinosa*
1	2	1	1	1	1															
1	2	1			1	1	1	1	1											
		4							1	1										
		4			1					1	1	1	1							
		3	1				1							1	1	1	1	1		
1	1	2	1	4	1		2			1									3	
	2	2	1	3	1								1			1				1
	2		3	3												3			1	1
	2			3			1			1				1						1
			1	2		3							1		1					4
												1			2	1			1	
	2		1	4	1			1		1					2	3				
	4		1			2				1						2				
	2		1							1				1						
				1		1								2		3				
1	2			2		1				1			2	2	1	3				
	4	1		1								1				1				
	3	2		2		1				1					1	1				
	4	1		2											1	2	1			
1	2					4				1					1	2				
	4									2										
	2	1								4						1				1
1	4		1			5	1			1						2				1
	2	4		2						3		1								1
1	5		1	1			1			1				1						

Bolivina pseudoplicata	*Cibicidoides kullenbergi*	*Karreriella bradyi*	*Buliminella* sp.	*Stilostomella insecta*	*Sigmoilopsis schlumbergeri*	*Bulimina alazanensis*	*Siphonodosaria modesta*	*Rotalia translucens*	*Bolivina striatocola*	*Hopkinsina mioindex*	*Bulava* sp.	*Haplophragmoides* sp.	*Martinotiella variabilis*	*Ehrenbergina hystrix*	*Chrysalogonium equisetiformis*	*Pullenia quinqueloba*	*Martinotiella communis*	*Discanomalina semipunctata* (atypical)	*Textularia* sp.
2	1	1	1	1	1	7	4	1	1										
1						2	1			2	2	1	2	1					
1	1			2	1	4	2			1			1	1					
	3	3	1	1		1										2	1	2	
		1			1						1		1	1				1	1
	1				3	1				1			1	2					
1							2		1										
1	1												1						
4						1			1	1									
1	2			2		3	1		1	1			1	4		1			
1	1			1										4					
1	1	1								2				5		1			
				1	2	3	1		1										
3				1	1	1								1				1	
5		1		1		4	1							2					
2	1			2	1	2			2										
				3		3							1	2					
5					1	4			4				4	1		1			
5		1		2	1	3			1	1			2	1	1				

Table 17 (continued).

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Orthomorphina perversa*	*Pleurostomella brevis*	*Anomalinoides globulosus*	*Gyroidinoides altispirus*	*Bolivinita quadrilatera*	*Rectuvigerina spinea*	*Siphotextularia catenata*	*Pullenia quadriloba*	*Sphaeroidina bulloides*	*Bulimina mexicana*	*Cassidulinoides bradyi*	*Cibicidoides* sp. (turbinate)	Diversity	Epifauna	Infauna	Abundance (infauna)	Abundance (epifauna)
Pleistocene		CN14	N22	1R-CC	1.6	7													15	7	7	15	5
				2R-1, 120	2.6	5													20	9	7	11	8
				2R-2, 75	3.8	5													14	2	9	14	2
Pliocene		CN12	N18–N19	2R-3, 120	5.8	6													16	5	9	12	5
				2R-4, 120	7.3	5													10	3	5	9	7
				2R-5, 75	8.3	4													18	5	9	19	11
				2R-6, 75	10.3	3													15	6	9	15	8
Miocene	late	CN9b	N17b	3R-1, 120	12.2	4													20	4	13	26	7
				3R-2, 25	13.4	7													30	10	16	37	12
				3R-3, 20	14.4	5													27	5	17	31	11
				3R-4, 75	16.4	7													26	6	16	31	13
				3R-5, 20	17.4	7													27	12	12	23	22
				3R-5, 65	17.9	7	1												22	6	11	15	10
				3R-5, 120	18.4	7		1	1	1									28	9	16	32	14
				3R-6, 70	18.9	5				2	1								19	4	13	28	6
				3R-6, 75	19.6	5		1			1								17	3	11	15	3
				3R-6, 120	19.9	7	1				1								19	5	13	25	5
				3R-7, 20	20.6	6					1	1							32	7	19	32	12
				4R-1, 20	21.0	5				1									23	8	11	24	15
				4R-1, 120	22.0	5				1	1		1						29	8	16	32	9
				4R-2, 20	22.5	7								1	1	1			29	9	16	32	14
				4R-3, 75	24.5	5										1			23	9	12	23	19
				4R-4, 75	26.0	7				1				1			1		18	2	11	28	7
				4R-5, 75	27.5	7				1					4			1	22	7	11	29	8
				4R-6, 75	29.0	7									1		1	2	21	9	15	32	23
				4R-6, 120	29.5	6	1		1			1	2						27	6	15	41	16
				4R-7, 20	30.0	6					1			1	4			2	37	9	22	48	17

Table 18. Ranges of benthic foraminifers through the Neogene at Site 219.

Age		Zone		Core, section, interval (cm)	Preservation	*Bolivina pusilla*	*Uvigerina proboscidea*	*Stilostomella marginata*	*Pyrgo murrhina*	Costate pleurostomellids	*Stilostomella insecta*	*Gyroidinoides neosoldanii*	Reticulate cassidulinid	*Uvigerina hispidocostata*	*Chyrsalogonium equisetiformis*	*Sphaeroidina bulloides*	*Eggerella bradyi*	*Melonis affinis*	*Nodosaria stiliformis*	*Melonis pacificum*	*Bulimina alazanensis*	*Oridorsalis umbonatus*	*Globocassidulina subglobosa*	*Dentalina consobrina*	*Bulimina* cf. *B. aculeata*	*Pullenia bulloides*	*Sigmoilopsis schlumbergeri*	*Pullenia quinqueloba*	*Epistominella exigua*	Pleurostomellids
Pliocene	late	CN12	N21	4-3, 98	5	5	5	5	2	2	2	2	1	4	1	1	1	2	2	4	4	3	1	2	1	2	4	1	3	4
	early	CN11	N19–N20	5-1, 70	4	5	5	5	1		1	1		5	2		1	1	1	1	5	5	3	3		2	1	1	1	1
				5-2, 97	5	6	6	5	3			3		1				1			5	2	3	3		1	1	1	5	4
				5-3, 73	3	6	5	4	2		5	3		5	1			4		1	5	3	5			4	2		3	
		CN10	N18	6-2, 65																										
				6-5, 73	3	5	4	1					3		1	2		5			5	3	5				1	4		2
				7-4, 73	5	5	4	2	1		1	1	1	1	2	3	2	3	1		5	5	6			1	2	1	3	3
				8-3, 67	5	5	5	1	1			2			1			2			5	1	5	2		1	2		2	5
Miocene	late	CN9	N17	8-4, 70	5	2	5	2	3		3	1	1	1	2	1	1	5			5	4	5	1		2		2	1	3
				10-6, 70	4	1	5	5				1		2	1		1	5	1	1	5	5	5	1		1	1	1		3
	middle	CN5	N10	13-1, 24	6		1									2		1					5							1
				13-1, 130	5			1											cf.				1							
				13-6, 95	5			1															5			2				
	early	CN4	N7–N8	14-3, 102	5						1				1	1		1				3								

Age		Zone		Core, section, interval (cm)	Preservation	*Cibicides wuellerstorfi*	*Osangularia bengalensis*	*Uvigerina hispida*	*Gyroidinoides pennatulus*	*Planulina ariminensis*	Miliolids	*Bulimina striata*	*Cibicidoides cicatricosus*	*Cibicidoides* cf. *C. ungerianus*	*Uvigerina auberiana*	*Pleurostomella alternans*	*Rotalia translucens*	*Anomalinoides semicribratus*	*Melonis barleeanum*	*Laticarinina pauperata*	*Cibicides lobatulus*	*Cibicidoides kullenbergi*	*Stilostomella lepidula*	*Bolivina robusta*	*Pleurostomella bierigi*	*Cibicidoides bradyi*	*Gyroidinoides planulatus*	*Cassidulina laevigata*	*Karreriella bradyi*	*Karreriella subrotundata*
Pliocene	late	CN12	N21	4-3, 98	5	1	1	1	1																					
	early	CN11	N19–N20	5-1, 70	4			5	1	3		1	1	1	2	1	1	2	1	1	1	1								
				5-2, 97	5			3				1			1			1	4				5	1	1	1	1	1		
				5-3, 73	3			2		2			2					1	3		1		4						1	1
		CN10	N18	6-2, 65																										
				6-5, 73	3	1			1	1	1							1		1		2	5			1	1			
				7-4, 73	5	1	1	1	1	1	1		4			1		2	2				5		1	1	1			
				8-3, 67	5		2	1			1							2		1		2	5	1		1	4			1
Miocene	late	CN9	N17	8-4, 70	5	1	4	4		2	1	1			1			4	1	1		3	5			3			2	2
				10-6, 70	4		1	2		2	1	2	1		2								5	1		1	2	1		
	middle	CN5	N10	13-1, 24	6		1													1		1								
				13-1, 130	5		1																4							
				13-6, 95	5		1																							
	early	CN4	N7–N8	14-3, 102	5																	1	5							

Note: Explanation as in Table 3.

Table 18 (continued).

Age		Zone		Core, section, interval (cm)	Preservation	*Lenticulina vortex*	*Martinotiella variabilis*	Costate *Buliminella*	Redeposited benthic foraminifers	*Bolivina* cf. *B. pulchra*	*Siphonodosaria modesta*	*Siphogenerina multicostata*	*Gyroidinoides altiformis*	"*Trifarina*" *pigmea*	*Ehrenbergina trigona*	*Hoeglundina elegans*	*Vulvulina spinosa*	*Nuttallides umbonifera*	*Bolivinita quadrilatera*	*Textularia lythostrota*	*Orthomorphina perversa*	*Osangularia culter*	*Spiroplectammina spinosa*	*Saracenaria triangulata*	*Textularia flintii*	*Rectuvigerina striata*	*Siphotextularia catenata*	*Stilostomella subspinosa*	*Heterolepa rugosa*	*Hanzawaia cushmani*
Pliocene	late	CN12	N21	4-3, 98	5																									
	early	CN11		5-1, 70	4																									
				5-2, 97	5																									
			N19–N20	5-3, 73	3																									
		CN10	N18	6-2, 65																										
				6-5, 73	3	1	1	1	1	1																				
				7-4, 73	5		1	3	1	5	2	4	2	1	1	1	1													
				8-3, 67	5		1	1			5	2			1	1		1	1											
Miocene	late	CN9	N17	8-4, 70	5		1	5		5	2	4	1	1			1			3	1	2								
				10-6, 70	4		1	2	4	3	1				1					1	1		1	1	1					
	middle	CN5	N10	13-1, 24	6	1	2																1			1	1	1	1	1
				13-1, 130	5	2	1		1			1					1				1							1		
				13-6, 95	5	1					1										1								1	1
	early	CN4	N7–N8	14-3, 102	5								1																	

Age		Zone		Core, section, interval (cm)	Preservation	*Gaudryina* sp.	*Bulimina miolaevis*	*Planulina renzi*	*Bolivina subreticulata*	*Frondicularia* sp.	*Bulimina semicostata*	*Nuttallides umbonifera*	*Bolivina pseudogemma*	*Bulimina macilenta*	Diversity	Infauna	Epifauna	Abundance (infauna)	Abundance (epifauna)
Pliocene	late	CN12	N21	4-3, 98	5										29	18	8	14	49
	early	CN11		5-1, 70	4										35	17	13	20	46
				5-2, 97	5										27	17	7	16	47
			N19–N20	5-3, 73	3										25	12	8	17	46
		CN10	N18	6-2, 65											0	0	0	0	0
				6-5, 73	3										28	13	11	15	39
				7-4, 73	5										46	22	16	29	39
				8-3, 67	5										34	17	13	21	44
Miocene	late	CN9	N17	8-4, 70	5										46	23	15	23	64
				10-6, 70	4										40	26	7	13	31
	middle	CN5	N10	13-1, 24	6	1	1								18	7	6	7	9
				13-1, 130	5		1	1	1	1	1	2			18	11	3	4	15
				13-6, 95	5						1	1	1		12	7	4	4	8
	early	CN4	N7–N8	14-3, 102	5									1	9	5	4	6	9

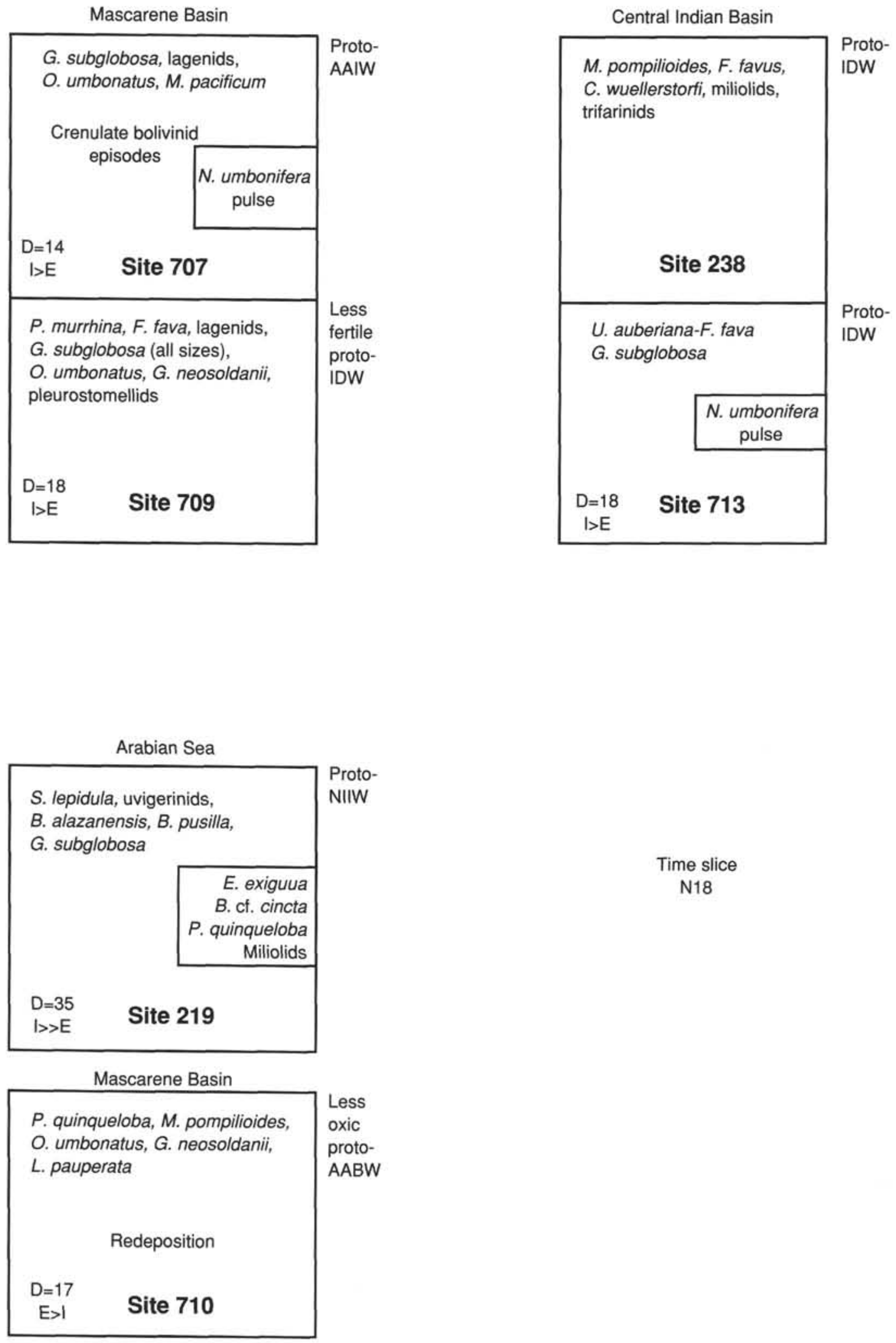


Figure 14. Benthic foraminifer index faunas of early Pliocene Zone N18 (= Zones CN10–CN11) from six sites in the western and central Indian Ocean. Indexes, listed at top, were most abundant or most consistently present. Index forms that occurred only in pulses or events are shown below. Total sample diversity and the relation of infaunal abundance to epifaunal abundance are shown at bottom left of each box. The faunal name assigned to each index fauna is listed to the right of each box. Data from Tables 15–19.

Table 19. Ranges of benthic foraminifers from the late Miocene through the Pleistocene in Hole 707A.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Stilostomella lepidula* (smooth)	*Karreriella baccata*	*Cibicides wuellerstorfi*	*Oridorsalis umbonatus*	*Discorbis villardeboanus*	*Uvigerina auberiana*	*Orthomorphina perversa*	*Bulimina alazanensis*	*Sigmoilopsis schlumbergeri*	Lagenids	*Globocassidulina subglobosa* (small form)	*Hoeglundina elegans*	*Cibicidoides bradyi*	*Uvigerina proboscidea*	*Cibicidoides robertsonianus*	*Pleurostomella subcylindrica*	*Siphonodosaria modesta*	*Anomalinoides semicribratus*	*Dentalina neugeboreni*	*Bolivina pseudoplicata*
Pleistocene		CN14		1H-1, 120	1.2	6	1	1	1	1																
				1H-5, 41	6.4	7			3		1	4	1	1	1											
			N22	2H-2, 120	9.3	7		1	3		1	1					2	1	2							
Pliocene	late	CN12b	N21	2H-4, 120	12.3	7											2			4	2	1	1	1	1	3
	early	CN12a		3H-1, 120	17.4	6			1	1		2	1			1	1			1			1			
				3H-4, 120	21.9	7						1														
				4H-1, 120	27.0	7	3							1			1									3
		CN11-CN10c		4H-2, 120	28.5	7			1											1						
				4H-3, 120	29.0	6						1			1	1	3			1						2
				4H-4, 11	31.5	7			1					1		1				1					1	
				5H-1, 121	36.7	6	1								1	3									2	
				5H-2, 120	38.2	7						3					3					1				3
				5H-3, 121	39.7	6	1										1			1			1			
				5H-4, 121	41.2	6						1								1						
			N18-N19	5H-5, 121	42.2	6	1					1		2		2				1			1			
Miocene	late	CN9	N17b	6H-1, 121	46.3	6	1				1	1				1				1						3
				6H-2, 121	47.8	6	1			1	1						1						1			
			N17a	7H-1, 121	55.9	6				1		1		1	1					1				1	1	
				7H-2, 121	57.4	7	1		2			2		1	3	3				1						
				7H-3, 121	58.9	6						2		1	1								1	1		1
				7H-5, 121	61.9	5			1			1				2	2			1						2
				8H-1, 121	65.5	6				1		1		1			1			3			2		1	
				8H-3, 121	68.5	5	1		1						1		4							1	1	
				8H-5, 121	71.5	6						1				1								1	1	
				9H-1, 121	75.2	6	2		3	1		3			2	2	2		1	1			1			
				9H-3, 121	78.2	6			2			1					1					1	1	2		2
				9H-5, 121	81.2	6	1		2			3			1	2	2									1

Note: Explanation as in Table 3.

Table 19 (continued).

Textularia lythostrota	*Cibicides* sp.	*Bolivina villavernensis*	*Bulimina mexicana*	*Globocassidulina subglobosa* (medium size)	*Pullenia bulloides*	*Gyroidinoides planulatus*	*Uvigerina porrecta*	*Orthomorphina koina* (smooth form)	*Pleurostomella* cf. *P. alternans*	*Bolivina optima*	*Melonis barleeanum* (poreless)	*Cibicidoides cicatricosus*	*Saracenaria jamaicensis*	*Planulina renzi* (atypical)	*Eggerella bradyi*	*Osangularia bengalensis*	*Bolivina* sp. (crenulate, triangular shape)	*Ehrenbergina hystrix*	*Globocassidulina subglobosa* (large size)	*Martinottiella variabilis*	*Karreriella bradyi*	*Buliminella* sp. (costate)	*Gyroidinoides neosoldanii*	*Pullenia quadriloba*	*Pleurostomella bierigi*	*Uvigerina hornibrooki*	*Nuttallides umbonifera*	*Cibicidoides kullenbergi*	*Sphaeroidina bulloides*	*Bulava* sp.	*Planulina renzi*	*Nodosaria skobina*	*Bulimina* sp. (striate)	*Loxostomum* sp.	*Cassidulina ornata*	*Epistominella exiguua*	*Rectuvigerina spinea*	*Cassidulina carinata*
1	1	1	2	1	1	1	1																															
1					1			1	1	2	1	1																										
										1			3	1	1	1																						
				1	1	1		1				1					1	1	1	1	1	1	1															
				1	1					1		2					1						1	1	3													
3																1				3	1	1			1	1	1											
				2					4	1	1	2				1	4			1								1	2	1								
											1						1								2						1	1						
				1								1					1					1											1					
				1									1								1													1	1	1	1	
													2		1																							
								1									1								1				1									
					2							3					2																	cf.				1
1					1				1	1						1					1				2												1	
								1		1								1								1								1				
					2	1											2									1							1				2	
								1									1				1		1															
				1							1						1				1				1				1									1
				1	1						2	3	2							1							1								1			
																1					1										1						1	
	1					2				2			1					1							3										3		1	1
1				1		1		1		2		1	2												2	1	1			1		1					1	
					1							2					2				1			1	1				1					1		3		1

Table 19 (continued).

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Textularia* sp.	*Cibicidoides* sp.	*Osangularia* sp.	*Pullenia quinqueloba*	*Cibicidoides* cf. *C. hemingwayi*	*Cibicides* sp. (flat)	*Stilostomella subspinosa*	*Bolivinita* sp.	*Anomalinoides globulosus*	*Osangularia culter*	"*Trifarina*" *pigmea*	Diversity	Infauna	Epifauna	Abundance (infauna)	Abundance (epifauna)
Pleistocene		CN14	N22	1H-1, 120	1.2	6												12	2	10	1	2
				1H-5, 41	6.4	7												12	4	8	6	5
				2H-2, 120	9.3	7												9	3	6	3	7
Pliocene	late	CN12b	N21	2H-4, 120	12.3	7												8	7	1	13	0
	early	CN12a	N18–N19	3H-1, 120	17.4	6												16	11	5	13	4
				3H-4, 120	21.9	7												9	6	3	7	1
				4H-1, 120	27.0	7												10	9	1	15	0
		CN11–CN10c		4H-2, 120	28.5	7												17	8	9	6	8
				4H-3, 120	29.0	6												14	12	2	14	3
				4H-4, 11	31.5	7												14	6	8	6	5
				5H-1, 121	36.7	6												15	11	4	21	4
				5H-2, 120	38.2	7												11	10	0	16	13
				5H-3, 121	39.7	6												10	6	4	6	3
				5H-4, 121	41.2	6												10	6	4	6	2
				5H-5, 121	42.2	6												9	8	1	11	0
Miocene	late	CN9	N17b	6H-1, 121	46.3	6												12	9	3	12	1
				6H-2, 121	47.8	6												13	8	5	10	6
			N17a	7H-1, 121	55.9	6	1											17	11	6	15	2
				7H-2, 121	57.4	7		1	1	1	1							16	8	8	12	9
				7H-3, 121	58.9	6					1	1						15	8	7	10	6
				7H-5, 121	61.9	5	1	1					1					14	9	5	12	3
				8H-1, 121	65.5	6								1	1			16	13	3	16	1
				8H-3, 121	68.5	5												14	8	6	14	6
				8H-5, 121	71.5	6												9	6	3	6	1
				9H-1, 121	75.2	6										1	2	21	12	9	22	13
				9H-3, 121	78.2	6	1						1	1	1			23	15	8	21	4
				9H-5, 121	81.2	6								2				20	14	6	22	6

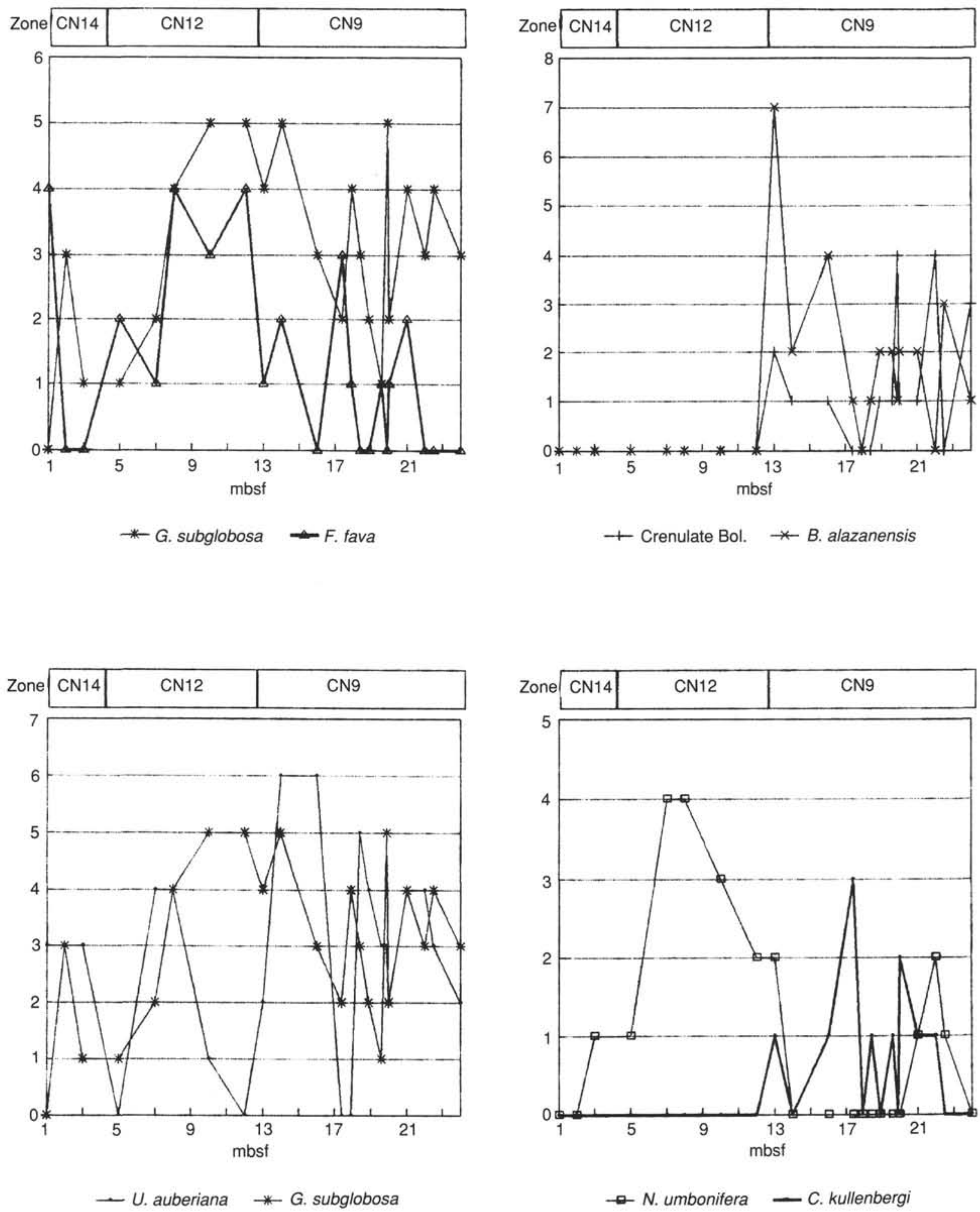


Figure 15. Relative abundances of most common species during the late Miocene through the Pliocene at Site 713. Species include *Globocassidulina subglobosa, Favocassidulina fava, Bulimina alazanensis, Uvigerina auberiana, Nuttallides umbonifera*, all crenulate bolivinids counted together, and *Cibicidoides kullenbergi*. Data from Table 17. Zonation from Backman, Duncan, et al. (1988).

Table 20. Ranges of benthic foraminifers from the late Miocene through the Pliocene in Hole 709A.

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Alabamina* sp.	Lagenids	*Stilostomella lepidula* (smooth)	*Globocassidulina subglobosa* (small form)	*Eggerella bradyi*	*Nuttallides umbonifera*	*Cibicidoides kullenbergi*	*Oridorsalis umbonatus* (scalloped margin)	*Gyroidinoides planulatus*	*Oridorsalis umbonatus* (smooth margin)	*Pleurostomella subcylindrica*	*Pyrgo murrhina*	*Cibicidoides cicatricosus*	*Cibicides wuellerstorfi*	*Triloculina lucernula*	*Favocassidulina fava*	*Dentalina* sp.	*Globocassidulina subglobosa* (large form)	*Planulina renzi* (atypical)	*Uvigerina auberiana*
Pleistocene		CN14		1H-3, 120	4.2	6	4	4		4	3	1			2	1		4	1	1	2			5		
			N22	2H-6, 60	18.1	6	1	2		1	1			1	1			3		1	1	3		1		4
Pliocene	late	CN12a–CN12c		3H-3, 120	23.9	6	1	2	1	3	1	1	1	1	1	2	cf.	4	cf.	1	1	1	1			
				3H-5, 120	26.9	5			1	4	3	4		1		4		4			1	3				1
			N21	3H-6, 120	28.4	6	1	2		3		4				1		4				1				
	early	CN12a		4H-1, 120	30.6	4		2	1	5		2				1		4				2	1	5	1	3
		CN11		4H-4, 120	35.1	4		3		2	1					4	cf.	4				1				2
				4H-5, 120	?	3				5						1		4			1	1	1	1		
		CN10c		6H-1, 120	49.9	3		3		4		1			1	3		1		1		2		1		1
				6H-2, 120	51.4	3		2		4	1	1		1	1	4		2		3		3				
				6H-3, 120	52.9	5		2	2	5		1			1	4		1	1				2	4		3
				6H-4, 120	54.4	6		2		4	1				1	3		3		1			1	4		3
		CN10a–CN10b		6H-5, 120	55.9	5	1			4		1	1		4	4		1	2	1		2		2		1
				6H-6, 120	57.4	4	2	1	1	5	1	4				2		4		1	1	1				1
				7H-1, 120	59.5	6		3			1	2				1		4		1	1	1				
			N18–N19	7H-2, 120	61.0	4		1		5	1	3			2	2		4		4		1		3	1	
Miocene	late	CN9	N17b	7H-3, 120	62.5	4		3		5	2	4		1	2	5		1	1			1	3	2		
				7H-4, 120	64.0	4	1	1	1	5		5	cf.		5			5		5		3	2	1		1
				7H-6, 120	67.0	3		1		5	1	6	2	1	4	4	cf.	2		4		1	1	2		
				8H-1, 120	69.2	4		3	3	5		3		1	2	5				1		2				
				8H-3, 120	72.2	5				3			1			1								3		
				8H-CC	77.5	5		2		4	2	2			4	2				1				4		4
				9H-4, 120	83.3	4	1			1	3	1				4				1			1	4		
				9H-6, 120	86.3	3		2		1	4	1	2			4		1		2		3	1	4	3	4
				10H-1, 120	88.5	4		4	1	3	2	1		1	1	3	1	1				2		5	1	

Note: Explanation as in Table 3.

Table 20 (continued).

Uvigerina hispidocostata	*Pullenia bulloides*	Miliolids	*Pleurostomella* spp.	*Laticarinina pauperata*	*Hopkinsina mioindex*	*Globocassidulina subglobosa* (medium size)	*Pullenia quinqueloba*	*Melonis pacificum*	*Anomalinoides semicribratus*	*Sphaeroidina bulloides*	*Ehrenbergina trigona*	*Cassidulinoides bradyi*	*Gyroidinoides neosoldanii*	*Buliminella* sp.	*Karreriella bradyi*	*Cibicidoides kullenbergi* (flat)	*Chrysalogonium equisetiformis*	*Martinotiella communis*	*Stilostomella lepidula*	*Melonis barleeanum*	*Stilostomella* cf. *S. fistuca* (striate)	*Bolivinopsis praelonga*	*Dentalina neugeboreni*	*Martinotiella variabilis*	*Bolivina pseudoplicata*	*Allomorphina* sp.	*Uvigerina interruptacostata*	*Cibicidoides* sp.	*Osangularia bengalensis*	*Dentalina stimulea*	*Orthomorphina koina*	*Stilostomella insecta*	*Pullenia quadriloba*	*Pleurostomella alternans*	Juvenile lenticulinid	*Uvigerina proboscidea*	*Ehrenbergina hystrix*	*Orthomorphina perversa*	*Melonis pompilioides*
		2		1				1					1			1				2							3						1						1
1	1					2		1		1			4							1																			
								1					1				1										1					1							
	1	2				4			2		1		4			1																							
2	1	1	3	1	1																																		
1	1	1	2			2	1	1	1																														
	2		1							1	1	1	1	1																									
	4		3			1							1		1	1	1																						
	1			2		2												1	1	1																			
			2			2		1		3	1	1	2	1						1	1																		
						2		4					2		1							1	3	1															
		1	4		1	1	1	1						1	2										1														
	cf.		3		1			2			2		1	1				2		1					1	3	1												
			3	1							2		1					1	1	1	1							2	1										
	2			1	4	4	1	1	3		1		2			1		1						2	1		1	1		1	1	1							
	1		3	3		5	2	3					3												1			1					1						
	1	1	2	3	5		1						4											1	1									1	1	2			
1	3	1			1		1	3					1			1	1	1															1				3	2	1
		1				1		1	2	2															1		1				1				1	1	1	1	
	2	4				3		1					2				2	1		1							1									1			
			3			2		1					1			2		1		2				3			4									4	1	1	
			2									1	2			2									1						2					1			
						2		1								3			1								5				1					3			
1	1	1	4	1		5		3	2		3			1					2	1					3							1							

Table 20 (continued).

Age		Zone		Core, section, interval (cm)	Depth (mbsf)	Preservation	*Cibicides* cf. *C. notocenicus*	*Bulimina alazanensis*	*Bolivina villaverniensis*	*Lenticulina cushmani*	*Cibicidoides* sp.	*Stilostomella subspinosa*	*Cibicidoides bradyi*	*Bulava* sp.	Diversity	Epifauna	Infauna	Abundance (infauna)	Abundance (epifauna)
Pleistocene		CN14	N22	1H-3, 120	4.2	6									20	11	8	22	20
				2H-6, 60	18.1	6									19	7	11	18	12
Pliocene	late	CN12a–CN12c	N21	3H-3, 120	23.9	6									17	10	6	8	13
				3H-5, 120	26.9	5									15	6	8	13	15
				3H-6, 120	28.4	6									14	8	6	12	19
	early	CN12a		4H-1, 120	30.6	4									17	5	12	27	9
		CN11		4H-4, 120	35.1	4									17	4	13	16	10
				4H-5, 120	?	3									14	4	10	15	7
		CN10c		6H-1, 120	49.9	3									17	9	8	20	9
				6H-2, 120	51.4	3									15	5	8	17	12
				6H-3, 120	52.9	5									21	6	15	29	10
				6H-4, 120	54.4	6									16	5	9	23	10
		CN10a–CN10b	N18–N19	6H-5, 120	55.9	5									21	9	11	19	16
				6H-6, 120	57.4	4									24	7	15	25	12
				7H-1, 120	59.5	6									18	8	8	13	13
				7H-2, 120	61.0	4									28	10	15	29	23
Miocene	late	CN9	N17b	7H-3, 120	62.5	4									22	8	13	34	17
				7H-4, 120	64.0	4									25	8	15	31	27
				7H-6, 120	67.0	3									28	10	16	28	26
				8H-1, 120	69.2	4	1	1	1	2	1	1			27	9	16	26	17
				8H-3, 120	72.2	5		2	1			1			12	4	12	19	8
				8H-CC	77.5	5			4			5			23	6	14	44	12
				9H-4, 120	83.3	4							1		16	7	7	12	14
				9H-6, 120	86.3	3					1		1		22	9	12	29	18
				10H-1, 120	88.5	4			5						28	8	19	41	9

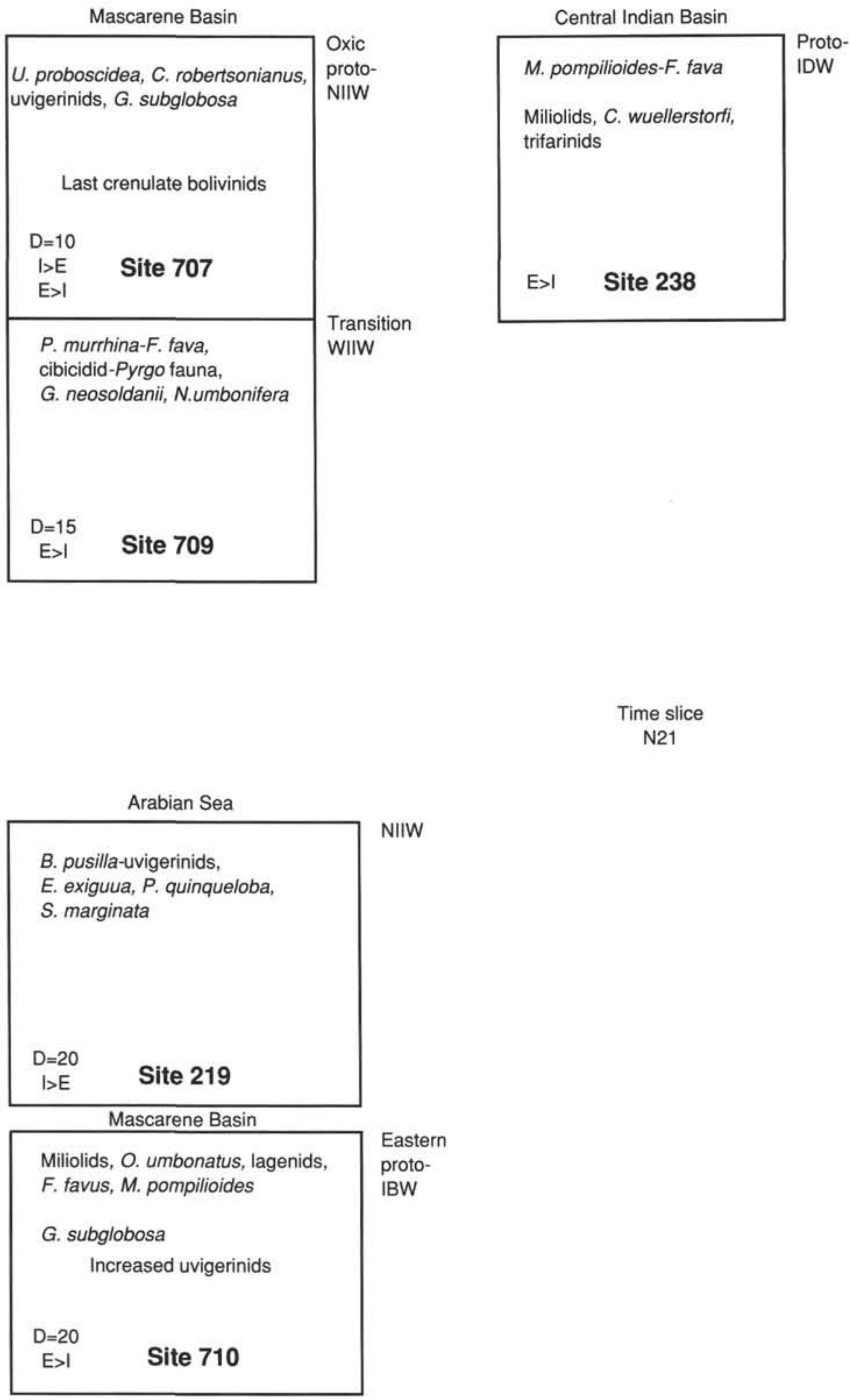


Figure 16. Benthic foraminifer index faunas of late Pliocene Zone N21 (= Zone CN12) from five sites in the western and central Indian Ocean. Indexes, listed at top, were most abundant or most consistently present. Index forms that occurred only in pulses or events are shown below. Total sample diversity and the relation of infaunal to epifaunal abundance are shown at bottom left of each box. The faunal name assigned to each index fauna is listed to the right of each box. Data from Tables 15–19.

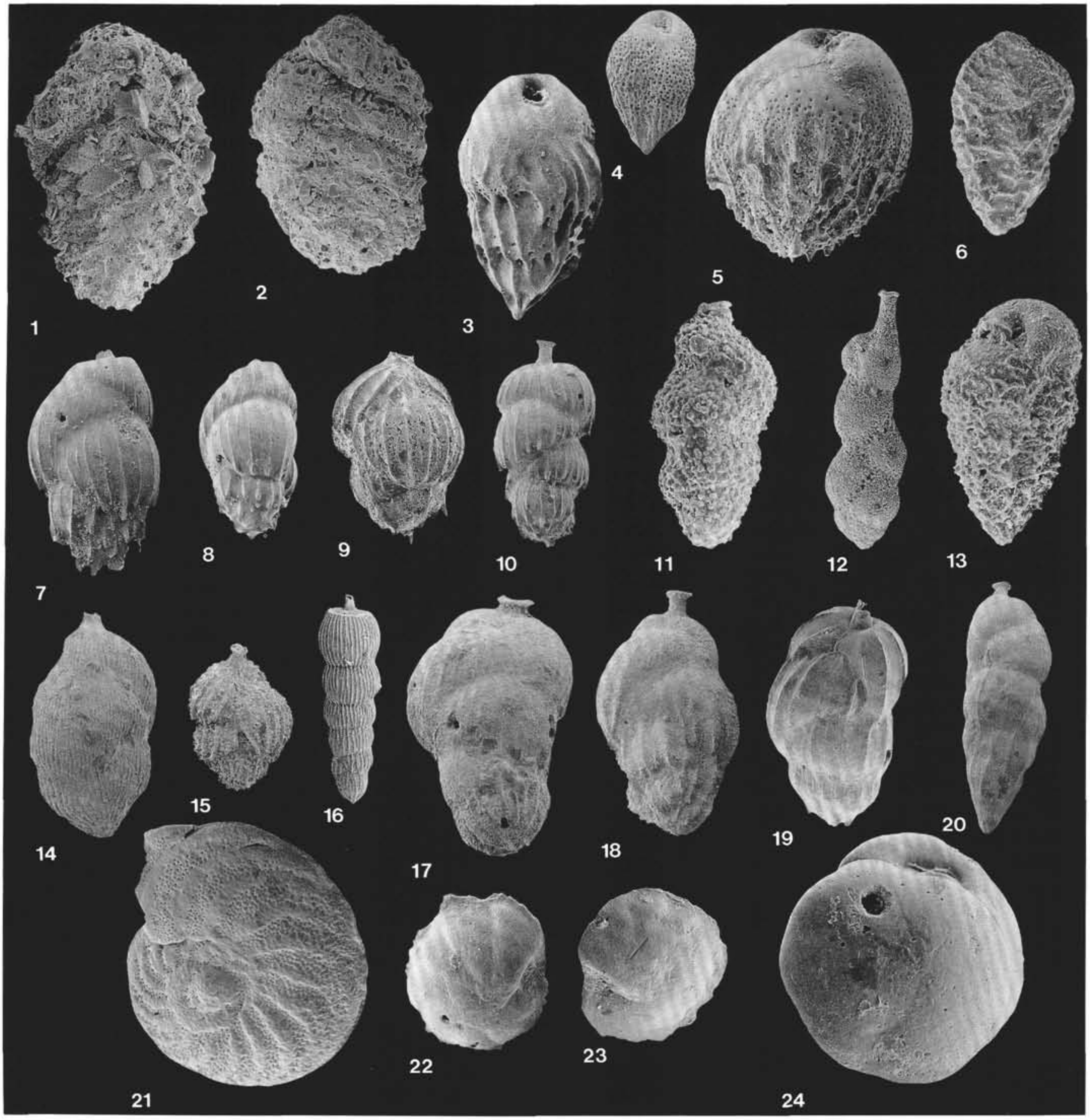


Plate 1. Benthic foraminifers typical at intermediate-depth Sites 707, 714, and 716. **1, 2.** *Textularia lythostrota* Schwager; (1) Sample 115-707A-5H-CC, ×100; (2) Sample 115-707A-2H-CC, ×100. **3.** *Bulimina alazanensis* Nuttall; Sample 115-707A-17H-CC. **4.** *Bulimina semicostata* Nuttall; Sample 115-707A-17H-CC. **5.** *Bulimina mexicana* Cushman; Sample 115-707A-5H-CC. **6.** *Bolivina pseudoplicata* Herron-Allen and Earland; Sample 115-708A-11X-CC, ×200; although this species is typical of intermediate depths, this specimen is probably redeposited downdepth to Site 708. **7, 8, 9, 10.** *Uvigerina spinulosa* Hadley. (7) Sample 115-714A-23X-CC, ×100. (8) Sample 115-707A-17H-CC, ×100. (9) Sample 115-707A-22X-5, 121 cm, ×100. (10) Sample 115-707A-11H-CC, ×100. **11.** *Uvigerina* sp.; Sample 115-714A-23X-CC, ×100. **12.** *Uvigerina proboscidea* Schwager; Sample 115-707A-11H-CC, ×100. **13.** *Bolivina* cf. *B. huneri* Howe; Sample 115-707A-15H-CC, ×400; although similar to the new genus, *Abditodendrix*, these heavily calcified forms lack the most distinctive feature of that genus, the truncated sides and rectangular cross-section; they are not strictly *B. huneri*, which is described as having delicate reticulation, but resemble *B.* cf. *B. huneri*, pictured by Tjalsma and Lohmann (1983). **14.** *Uvigerina flintii* Cushman; Sample 115-716A-13H-CC, ×100. **15.** *Uvigerina pigmea* d'Orbigny; Sample 115-716A-13H-CC, ×100. **16.** *Rectuvigerina striata* (Schwager); Sample 115-716A-13H-CC, ×100. **17.** *Uvigerina* sp., possibly *Uvigerina gemmaeformis* Schwager; Sample 115-716A-13H-CC, ×100. **18, 19, 20.** *Uvigerina schwageri* Brady. (18) Sample 115-716A-26H-CC. (19) Sample 115-707A-5H-CC, ×100. (20) Sample 115-716A-26H-CC, ×100. **21.** *Planulina marialanna*; Sample 115-707A-11H-CC, ×50. **22.** *Osangularia bengalensis* Schwager; Sample 115-709A-12H-CC, ×100; note counterclockwise coiling of Miocene-age deep-water specimen from the Mascarene Basin. **23.** *Osangularia bengalensis* Schwager; Sample 115-714A-23X-CC, ×200; note smaller size and clockwise coiling of specimen from the latest Oligocene in the southern Indian upwelling zone. **24.** *Cassidulina crassa* d'Orbigny; Sample 115-707A-15H-CC, ×200.

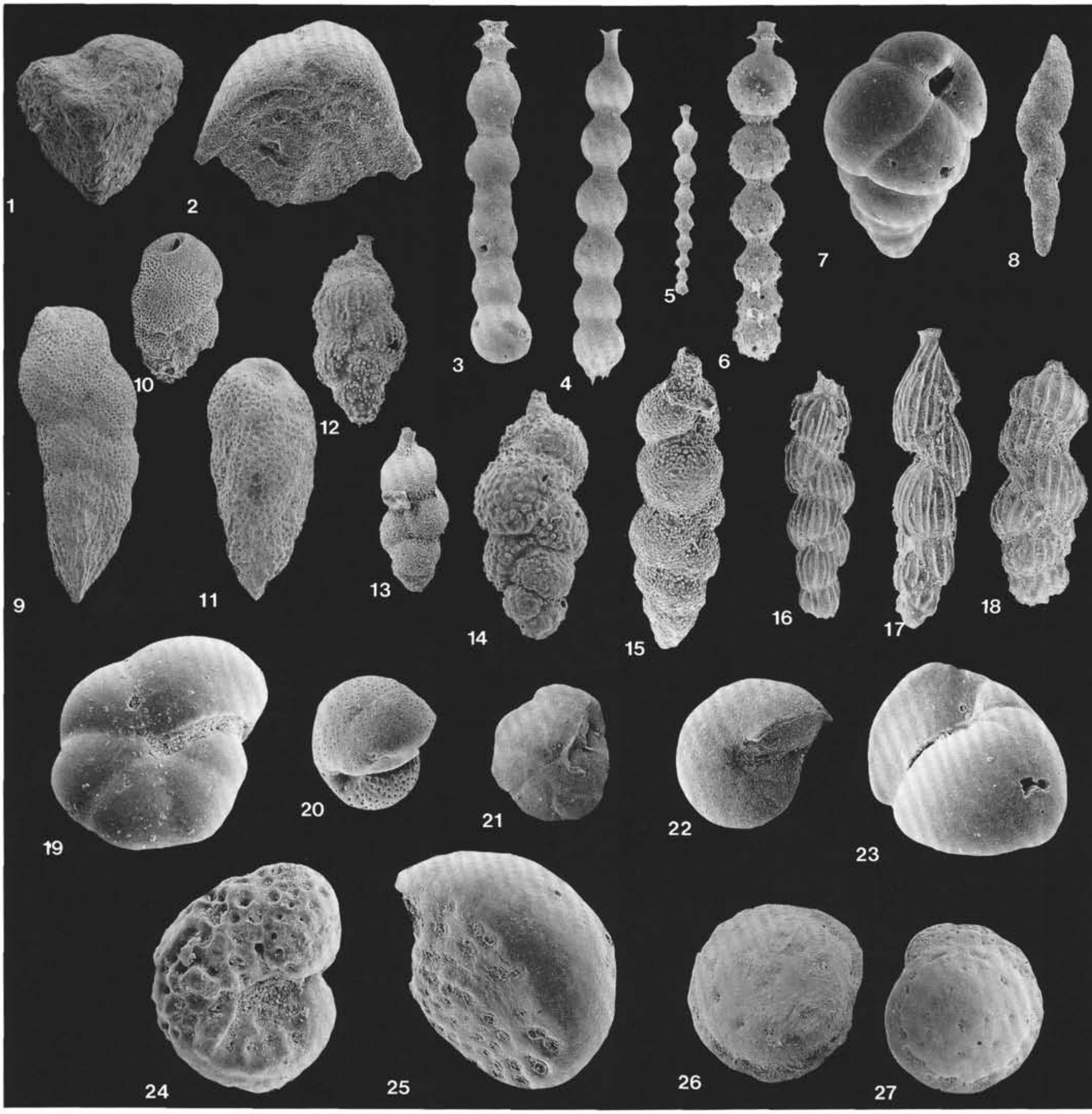


Plate 2. Typical lower bathyal and abyssal depth benthic foraminifers from Mascarene Basin Sites 708, 709, 710, and 711. **1.** *Gaudryina pyramidata* Cushman; Sample 115-711A-21X-CC, ×100. **2.** *Vulvulina spinosa* Cushman; Sample 115-708A-20X-CC, ×100. **3.** *Stilostomella nuttalli* (Cushman and Jarvis); Sample 115-711A-21X-CC, ×100. **4.** *Stilostomella insecta* (Schwager); Sample 115-711A-8H-CC, ×100. **5, 6.** *Stilostomella lepidula* (Schwager). (5) Sample 115-711A-11H-CC, ×50. (6) Sample 115-709A-6H-CC, ×100. **7.** *Buliminella* sp.; Sample 115-709A-7H-CC, ×100. **8.** *Pleurostomella alternans* Schwager; Sample 115-711A-8H-CC, ×100. **9, 11.** *Bulimina jarvisi* Cushman and Parker. (9) Sample 115-709C-29X-CC, ×100. (11) Sample 115-709C-22X-CC, ×100. **10.** *Bulimina macilenta* Cushman and Parker; Sample 115-709A-6H-CC, ×100. **12.** *Uvigerina hispidocostata* Cushman and Todd; Sample 115-709A-4H-CC, ×100. **13.** *Uvigerina* sp.; Sample 115-710A-2H-5, 20 cm, ×100. **14.** *Uvigerina hispida* Schwager; Sample 115-709A-4H-CC, ×100. **15.** *Uvigerina* sp.; Sample 115-709A-9H-CC, ×100. **16, 17.** *Hopkinsina mioindex* Finlay. (16) Sample 115-709A-9H-CC, ×100. (17) Sample 115-709A-4H-CC, ×100. **18.** *Uvigerina spinicostata* Cushman and Bermudez; Sample 115-709C-29X-CC, ×100; this elongate specimen with few spines closely resembles the younger form, *H. mioindex*. **19.** *Pullenia quinqueloba* (Reuss); Sample 115-711A-11H-CC, ×200. **20.** *Melonis sphaeroides* Voloshnaya; Sample 115-709A-9H-CC, ×100. **21.** *Nuttallides umbonifera* Cushman; Sample 115-710A-2H-5, 20 cm, ×100. **22.** *Gyroidinoides planulatus* (Cushman and Renz); Sample 115-708A-20X-CC, ×100. **23.** *Gyroidinoides soldanii* (d'Orbigny); Sample 115-711A-8H-CC, ×200. **24.** *Anomalinoides aragonensis* (Cole); Sample 115-711A-21X-CC, ×100. **25.** *Heterolepa grimsdalei* (Nuttall); Sample 115-710A-17X-CC, ×100. **26, 27.** *Cibicidoides havanensis* (Cushman and Bermudez). (26) Sample 115-711A-7H-CC, ×100. (27) Sample 115-709C-22X-CC, ×50.