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Distribution of recent benthic foraminifera off western Costa Rica in the eastern equatorial Pacific Ocean

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Running title: Recent benthic foraminifera off Costa Rica

Abstract

Benthic foraminifera provide essential information for paleobathymetric reconstructions. However, the modern distribution of benthic foraminifera, especially at depths below 1000 mbsl, is still obscure in the offshore regions near Central and South America. To characterize the bathymetric scale in the eastern equatorial Pacific Ocean, we examined the depth distribution of benthic foraminifera using piston core samples taken off the coast of Costa Rica. Foraminiferal assemblages vary according to water depth: 1) U1 (mainly composed of *Ammonia beccarii*, *Cancris sagra*, *Elphidium tumidum*, *Hanzawaia concentrica*, *Pseudononion basispinata*, and *Planulina exorna*) represent inner shelf faunas (shallower than 50 mbsl). 2) U2 (mainly composed of *Ammobacculites foliaceu*, *Bolivina striatula*, *Cassidulina minuta*, *Hanzawaia concentrica*, *Uvigerina incilis*, *Bulimina denudata*, and *Cancris sagra*) is correlated with mid shelf depth assemblages, from 50 to 100 mbsl. 3) U3 (mainly composed of *Uvigerina incilis*, *Hanzawaia concentrica*, *Angulogerina semitrigona*, *Bolivina acuminata*, *Bolivina bicostata*, and *Cibicorbis inflatus*) is assigned to outer shelf assemblages from 100 to 200 mbsl. 4) U4 (mainly composed of *Bolivina humilis*, *Bolivina seminuda*, *Bolivina subadvena*, *Cassidulina tumida*, *Epistominella obesa*, *Angulogerina carinata*, and *Cibicorbis inflatus*) is the upper bathyal faunas (200–600 mbsl). 5) U5 (mainly composed of *Brizalina argentea*, *Uvigerina peregrina*, *Uvigerina auberiana*, *Brizalina seminuda*, *Bulimina striata*, *Epistominella smithi* and *Globocassidulina subglobosa*) is the mid bathyal faunas (600–1000 mbsl). 6) U6 (mainly composed of *Uvigerina auberiana*, *Uvigerina peregrina*, *Brizalina argentea*, *Bulimina mexicana*, *Cassidulina carinata*, *Epistominella smithi*, and *Lenticulina cushmani*) represent the lower bathyal assemblage (1000–2000 mbsl). 7) U7 (mainly composed of *Uvigerina auberiana*, *Brizalina argentea*, and *Eubuliminella tenuata*) represent upper abyssal faunas (2000-3000 mbsl). 8) U8 (mainly composed of

Glomospira sp.A, *Lagenammina arenulata*, *Chilostomella oolina*, *Hoeglundina elegans*, *Melonis barleeanum*, *Nonion affine*, *Oridorsalis umbonatus*, *Pullenia bulloides*, and *Uvigerina proboscidea*) is characterized by deep-water cosmopolitan faunas (deeper than 3000 mbsl). On the basis of a comparison with several environmental parameters, dissolved oxygen concentrations are likely to be the most effective factor controlling foraminiferal depth distributions in the eastern equatorial Pacific especially the below oxygen minimum zone (OMZ). Around OMZ, nitrate concentration also might be related with the benthic assemblage due to the nitrate respiration.

Keywords: Benthic foraminifera, Bathymetric scale, Cluster analysis, Recent, Costa Rica

Introduction

The assemblages of dominant faunas in benthic foraminifera are the most reliable tools for determination of marine bathymetry. These depth distributions of benthic foraminifera enable past depositional depths of sediments to be reconstructed. However, the bathymetric scales of benthic fauna are not always the same in each region. For example, Akimoto and Hasegawa (1988) reported that the seas around the islands of Japan contain different bathymetric distributions of benthic foraminifera, and they proposed three different bathymetric scales for the Pacific Ocean areas off the southwest and the northeast and off the coast of the Japan Sea. Therefore, collecting data on modern distributions of benthic foraminifera from each region is important for bathymetric scale reconstructions.

The Pacific Ocean is the world’s largest ocean and is characterized by spatially variable oceanographic conditions, especially between the western and eastern margins.

Warm-water pools exist in the western margin near the equator, whereas relatively cool waters are transported to the eastern margin, where they are associated with upwelling in regions such as the California Current and the Peru Current (Tomczak and Godfrey, 1994). In the eastern Pacific continental margin, most of the foraminiferal studies have been conducted off North America (e.g., Uchio, 1960). The abundance of published reports on this region provides sufficient information for studies on the taxonomic and ecological distribution of benthic foraminifera in the area. However, there are few faunal reports on modern benthic foraminiferal distributions from the regions around the west coasts of South America (e.g. Bandy and Rodolfo, 1964; Ingle et al., 1980; Resig and Glenn, 1997), North America (Uchio, 1960) and over all Central America (Bandy and Arnal, 1957; Heinz *et al*., 2008). Therefore, more data on modern distributions of benthic foraminifera are needed for bathymetric scale reconstruction based on benthic faunas off Central and South America.

Off Central America, previous studies on the modern faunal distributions of benthic foraminifera was conducted on the west coast of Central America (Bandy and Arnal, 1957; Smith, 1963; 1964, Heinz *et al*., 2008), and in the Gulf of Panama (Golik and Phleger, 1977). However, there are very few data especially off Costa Rica despite the tectonic importance of this area (e.g., Ranero and von Huene, 2000; Vannucchi et al., 2004; see following section). For example, Heinz *et al*. (2008) examined only 7 samples related mud volcanoes, and it could not be enough to construct the depth-scale. Bandy and Arnal (1957) studies also only 5 samples in this area because they focused on an entire region of Central America. Golik and Phleger (1977) investigated an inner bay of Panama, shallower than 200 mbsl, and missed deeper data. Smith (1963; 1964) represented continues data at this area, off Nicaragua, however these studies were also absence of deeper data, especially deeper than 1000 mbsl.

Research cruises by the RV METEOR M54 in 2002 and the RV SONNE in 2003 took box and piston core samples off the Peninsula de Nicoya of Costa Rica in order to examine tectonic system of subduction zone. In this study, we used core-top sediments recovered from selected piston cores taken from these cruises to describe the benthic foraminiferal assemblages in the sediments (Figure 1). We also report bathymetric distributions of benthic foraminifera and propose a bathymetric scale for Central America near Costa Rica.

Materials and methods

Geological setting

Costa Rica is located at the eastern margin of the Pacific Ocean (Figure 1). This area is a tectonically active zone where the Cocos plate is subducting beneath the Caribbean and North American plates. Erosion related to active subduction occurs from Guatemala to Costa Rica, according to seismic data (Ranero and von Huene, 2000; Vannucchi *et al.*, 2004). The topography of the continental margin here is smooth and is covered by sediments with thicknesses of 0.5–2 km (Shipley *et al.*, 1992). Within this sedimentary cover, deformed sedimentary prisms are shaped and cut by landward-dipping thrust faults in the middle and lower slope regions of this area.

The oceanography around this region is dominated by the Equatorial Undercurrent (EUC), which originates from the southern hemisphere and flows eastward, with one EUC path that flows to the study area (Tomczak and Godfrey, 1994). The strong upwelling of the EUC results in extremely high primary productivity (>250 gC/m^2/yr, Couper, 1983) and large benthic biomass (>10 mg/m^2). The study area is located east of the Costa Rica Dome, the area of the strongest upwelling off of western Costa Rica located at around 9°N and 89°W (Fiedler and Talley, 2006). The dome is related to the end of the equatorial current system and mesoscale coastal eddies and produces strong upwelling and a shallowing thermocline (Fiedler and Talley, 2006). To visualize the water-mass structure in this area, we chose six types of data from the NOAA (National Oceanic and Atmospheric Administration) database (https://www.nodc.noaa.gov/OC5/woa13/woa13data.html) (Figure 2). According to these data, the oxygen minimum zone (OMZ) ranges from a depth of 300 m to 600 m, this relatively shallow depth might be related to the high productivity in this area.

Materials and Laboratory works

To examine the variations in water depth in the western Pacific margin off Costa Rica, we selected 24 GEOMAR piston core samples ranging from a water depth of 54 m to 3535 m (Figure 1, Table 1). These core samples were obtained from the area off western Central America during the RV METEOR M54 in 2002 and the RV SONNE in 2003 cruises. The upper 0–2 cm of each piston core was sampled. The sediment samples were freeze-dried and weighed. Then, they were washed in a 250-mesh sieve (63 µm) and dried. The dried fractions >63 µm were reweighed for mud content determination (Figure 3). The samples were divided into aliquots for picking using a microsplitter, and all foraminifera (at least 200 specimens) were picked out. Each specimen was identified and counted for assemblage analysis using taxonomy, according to the method proposed by Loeblich and Tappan (1988). Species diversity of benthic foraminifera was calculated using the Shannon–Weaver index (Shannon and Weaver, 1963) (Figure 3). In addition, numerical foraminiferal parameters (abundance of benthic foraminifera; species richness, which is species number of benthic foraminifera per sample; ratio of planktonic foraminifera to benthic foraminifera; and percentage of hyaline, porcellaneous, and agglutinated benthic foraminifera) were calculated (Figure 3). Additionally, scanning electron microphotographs (SEM) were taken for selected species (Figure 4, Figure 5).

Statistical analysis

To determine the dominant assemblage of benthic foraminifera in each sample, cluster analysis (Q-mode) was conducted on the abundances of 24 sediment samples. Similarities between the samples were determined using Horn's index of overlap (Horn, 1966), and clustering was performed using the unweighted pair group method with an arithmetic average in a program developed by Davis (1973) and modified by Hasegawa (1988).

Results

Foraminiferal parameters

The abundance of foraminiferal tests ranges from 5 to 16057 individuals per gram of sediment (g^{-1}). Specimens with abundances of more than 4000 individuals g^{-1} are ME54-1 (148 mbsl), ME54-105 (414 mbsl) (Figure 3). Overall species richness is between 11 and 48 through the investigated samples, and more than 30 species are recorded at sites ME54-40 (230 mbsl), ME54-63 (815 mbsl), ME-54-92 (1012 mbsl), SO173-81 (2272 mbsl), and ME54-57 (3462 mbsl). The maximum value of 48 species occurs at SO173-81 (2272 mbsl). In addition, the Shannon–Weaver diversity index was calculated for all samples. The diversity values range from 1.9 to 4.6, with the minimum value recorded at site ME54-64 (750 mbsl) and the maximum at ME54-57 (3462 mbsl) (Figure 3). The species diversity is calculated based on the species richness and equitabilities of the assemblages. The results of species diversity in the study area suggest that the controlling factor may be different at each site.

Distribution and trend of each species

In the study area, benthic foraminifera species present significant depth-dependent distributions (Figure 6). To examine foraminiferal habitation, we calculated the relative abundance (%) and absolute abundance (g^{-1}) of each species.

Textularia agglutinans exhibit a peak at 54 m (7.4%) and thereafter consistently occur above 750 m with less than 2% abundance (Figure 6). *Cancris sagra* also shows the shallowest habitation. It suggests that the occurrences of these species are characterized by the shallow depth. *Uvigerina incilis* has two shallow peaks at ME54-68 (54 mbsl; 17.2%) and ME54-1 (148 mbsl; 22.4%) and shows less than 5% abundance at deeper than 148 mbsl. *Bulimina denudata* exhibits a similar trend to *Uvigerina incilis*. Both *Planulina exorna* and *Brizalina alata* also showed the shallow habitation, up to 750 mbsl (Figure 6).

Cibicorbis inflatus and *Bolivina bicostata* represent the maximum value of 13% (148m; 3453 individuals g^{-1}) and 18% (148m; 4709 individuals g^{-1}), respectively. On the other hand, they show significant low density 3–278 and 3–577 specimens g^{-1}, respectively at other depths, and they do not appear the shallowest site (54 mbsl). *Angulogulina carinata* are abundant around 230 mbsl. *Psedoparrella exigua* present the wide range from the shallowest depth (ME54-68; 54 mbsl) to the deepest (ME54-56; 3535 mbsl) with a prominent peak at 654 mbsl (28%). They mainly distributed between 400 and 750 mbsl (more than 10%), and less abundance at deeper than 2000 mbsl (less than 1%). Both *Epistominella smithi* and *Epistominella bradyana* do not show the significant depth distribution, however, these two species are characteristic distribution, observed only in the eastern Pacific (Smith, 1964).

Uvigerina peregrina display distinctive two maxima; 750–1000 mbsl and 1550–1650 mbsl with high abundance (more than ~15%). *Globocassidulina subglobosa* ranges from

654 mbsl to 2272 mbsl, exhibit the relatively high value at 750–1000 mbsl (< 5%), and disappear at deeper than 3000m. *Uvigerina auberiana* also represent the two peaks (more than 10%), shallower one is 815–825 mbsl and deeper 1450–1650 mbsl. *Brizalina seminuda*, *Cibicidoides mckannai*, and *Bulimina mexicana* exhibit the similarly trend with relatively wide range distribution. They peaked around 800–1200 mbsl and gradually decrease to deeper depths. On the other hand, *Globobulimina affinis* do not show continues occurrences. This species display three maximum depths, 1000–1200 mbsl, 1550–1650 mbsl, and 3462 mbsl with more than 3% abundance. *Cassidulina carinata* shows significant high value between 1200 mbsl (ME54-13) and 1567 mbsl (SO173-98) with 6–15% relative abundance despite long-range occurrences (148–3535 mbsl). *Lenticulina cushmani* is also abundant at similar depth, 1447 mbsl (more than 5%). The shallowest distribution of *Eubuliminella tenuata* is 654 mbsl, however, the peak is 1802 mbsl and the abundance is 11.0%.

Pullenia bulloides, *Melonis barleeanum*, and *Oridorsalis umbonatus* represent relatively deep habitation; peak at 3535 mbsl (8.0%), 1447 mbsl (3.8%) to 3535 mbsl (3.5%), and ~1000 mbsl (<~2.6%) to 3462 mbsl (4.9%), respectively. *Uvigerina proboscidea* and *Glomospira* sp.A are observed deeper than 1567 mbsl (SO173-98), and abundant at 3535 mbsl (ME54-56) with 8.0% relative abundance and at 3462 mbsl (ME54-57) with 5.8%, respectively. Although *Lagenammina arenulata* shows a wide distribution, it was abundant at the deeper depth (~3500 mbsl); relative abundance is less than 2% at shallower depth of 3462 mbsl (ME54-57), while 11.7% and 7.1% at 3462 mbsl and 3535 mbsl (ME54-56), respectively.

Results of the cluster analysis

The Q-mode cluster analysis resulted in the grouping of samples into six main clusters (Figure 7). We used 24 samples for the analysis with total 120 foraminiferal taxa. In this study, these cluster assemblages are clearly consistent with the depth-distribution results described above. Cluster I is assigned to the shallowest site (54 mbsl). It is characterized by common agglutinated species that compose 16.5% of the total fauna. Three species, *Uvigerina incilis*, *Pseudononion basispinata*, and *Cancris sagra*, are major calcareous taxa, and their abundances are 17.2%, 13.8%, and 11.7%, respectively. Agglutinated foraminifera accounted for approximately 59.3% of Cluster I.

Cluster II comprised two samples (148 mbsl and 414 mbsl). This cluster contain *Uvigerina incilis*, *Bolivina bicostata*, and *Cibicorbis inflatus*. At 148 mbsl, the abundant species are *Uvigerina incilis* (22.3%), *Bolivina bicostata* (18.0%), *Cibicorbis inflatus* (13.2%), and *Brizalina alata* (10.4%), amounting to a total of 53.5%. At 414 mbsl, the species richness is higher (23 species), and the relative abundance of each species is lower than those at 148 mbsl. *Brizalina spissa* (7.0%), *Bolivina bicostata* (7.0%), and *Epistominella bradyana* (10.2%) are abundant species, while *Uvigerina incilis* decreases to 4.6% (see Table 2). Foraminiferal shells of this cluster exhibit extremely high abundant value of more than 4000 individuals g^{-1}.

Cluster III is composed of three samples; MA54-40 (230 mbsl), ME54-48 (761 mbsl), and SO173-110-1 (1006 mbsl). The common and characteristic species of these samples are *Bolivina bicostata* (1.6%–7.2%), *Cassidulina tumida* (3.2%–6.8%), *Epistominella bradyana* (1.2%–19.5%) and *Epistominella smithi* (1.0%–1.6%). Other common occurring species of MA54-40 (230 mbsl) and ME54-48 (761 mbsl) are *Cibicorbis inflatus* (1.3%–3.6%), *Angulogerina carinata* (0.5%–5.9%), and *Cancris sagra* (1.9%–2.8%). MA54-40 (230 mbsl) and SO173-110-1 (1006 mbsl) contain *Brizalina spissa*. In these species, *Bolivina bicostata*, *Angulogerina carinata*, *Cibicorbis inflatus* and *Cancris sagra* are the fauna on shelf edge (e.g., Smith, 1963; 1964; Ingle et al., 1980).

Without these shallow species, the rest of the assemblages of ME54-48 (761 mbsl) and SO173-110-1 (1006 mbsl) is huge similar to Cluster IV one (see below). In addition, the common species of ME54-48 (761 mbsl) are *Uvigerina peregrina* (6.8%) and *Oridorsalis umbonatus* (0.5%), and also SO173-110-1 (1006 mbsl) contains *Uvigerina peregrina* (7.0%) and *Uvigerina auberiana* (2.3%). *Uvigerina peregrina* and *Uvigerina auberiana* are the main species of Cluster IV (see below) and also the typical bathyal fauna (Smith, 1963; 1964; Ingle et al., 1980). This facts suggests that MA54-40 (230 mbsl) is an original assemblage, but it is that the assemblage of ME54-48 (761 mbsl) and SO173-110-1 (1006 mbsl) contain "reworked-shallow" species. It also suggests this cluster is strongly affected by reworked species, thus we exclude this cluster in the following discussion section.

A total of 13 samples (from 654 to 1656 mbsl water depth) are included in Cluster IV. This cluster is divided into two subclusters, IVa (ten samples) and IVb (three samples of ME54-78, SO173-98, and ME54-32), bounded by a similarity of 0.5, which the range is between 1012 and 1447 mbsl. This cluster is characterized by abundant occurrences of the genus *Uvigerina*. The major species are *Uvigerina peregrina* in Subcluster IVa and *Uvigerina auberiana* in Cluster IVb. Other abundantly occurring species are *Paracassidulina* sp. (5.3%–12.9%), *Globocasidulina subglobosa* (5.6%–8.6%), and *Bulimina mexicana* (5%–10.4%). For Subcluster IVa, the common species are *Cassidulina tumida* (0%–6.8%), *Bolivina bicostata* (7%–7.2%), *Brizalina spissa* (5.4%–7.0%). Subcluster IVb includes high abundances of *Cassidulina carinata* (5.6%–15.3%) and *Cibicidoides mckannai* (6.2%–11.3%). In addition, *Brizalina* species (*B. seminuda*, 27.8%; *B. semiperforata*, 5.4%; and *B. argentea*, 5.2%) also display several peaks within Subcluster IVb.

Cluster V (1802 mbsl and 2272 mbsl, two samples) is also characterized by abundant occurrences of both genera *Uvigerina* and *Brizalina*. Abundant species are *U.*

auberiana (22.0%–27.0%), *U. peregrina* (7.5%–15.0%), and *U. excellens* (9.8%). *Bolivina bicostata* (8.6%), *Brizalina argentea* (11.0%), and *Eubuliminella tenuata* (11.0%) are also present in relatively high numbers. Other common species are *Globobulimina affinis* (5.0%) and *Cibicidoides mckannai* (5.0%).

Cluster VI comprises deep-water samples (at 3462 mbsl and 3535 mbsl) and is characterized by high species diversity and common occurrences of deep-cosmopolitan fauna such as *Pullenia*, *Oridorsalis*, *Gyroidina*, and *Melonis*. Agglutinated species account for 24.3% of this sample, and abundant species are *Lagenammina arenulata* (7.0%–11.0%) and *Glomospira* spp. (5.8%). *Uvigerina proboscidea* and *Uvigerina senticosa* amount to 8% and 4%, respectively.

Discussion

Bathymetric model of benthic foraminifera in the Costa Rica region

On the basis of the results of the faunal and cluster analyses, the distribution of modern benthic foraminiferal assemblages in the study area can be classified into seven assemblages (Table 2). Each cluster and subcluster represents a bathymetric assemblage for each water depth except for Cluster III (including reworked fauna). Clusters I and II are assigned to continental shelf and continental shelf edge faunas at depths shallower than 414 mbsl. Cluster IV represents assemblages at bathyal depths ranging from 654 to 1802 mbsl, and two subclusters (a and b) are bounded by the 1200–1447 m depth, close to the boundary of the upper-middle/lower-middle bathyal depth threshold. Cluster V is correlated with the lower-middle bathyal assemblages at depths ranging from 1800 to 2272 mbsl. Cluster VI is characterized by deep-water cosmopolitan faunas, which are comparable to a abyssal assemblage, occurring at depths of more than 3462 mbsl in the

Pacific Ocean.

Comparison with previous results for benthic foraminifera off Central America

We recognize the five fauna depending water depth as described above. On the other hand, Smith (1964) distinguished six faunal zones of benthic foraminifera off El Salvador termed as Zone A (0–30 mbsl), B (30–60 mbsl, near the bottom of the thermocline), C (60–150 mbsl, below the thermocline) and three continental slope zones, Zone D (150–600 mbsl), E (600–1300 mbsl), and F (1300 to 3200 mbsl and over). In order to establish the integrated bathymetric scale, we compared our results with Smith's one (Figure 8). It suggests that the former conducted high-resolution sampling at relatively deeper depth (>500 mbsl), while the latter shallower (<1000 mbsl). Another distribution summary was published by Bandy and Arnal (1957) for the sites in the Central America margin off the Pacific Coast from El Salvador to Costa Rica. Although they examined only 5 sites, these data provide critical information about modern benthic foraminiferal distributions off Central America. Thus based on these results, we proposed the new bathymetric scale off Costa Rica (Figure 8, Table 3). To compile bathymetric scale, bathymetric terminology based on van Morkhoven et al. (1986): inner shelf is 0-50 m, mid shelf is 50-100 m, outer shelf is 100-200 m, upper bathyal is 200-600 m, mid bathyal is 600-1000 m, lower bathyal is 1000-2000 m, upper abyssal is 2000-3000 m, lower abyssal is 3000-6000 m.

1) U1 (~50 mbsl): Inner shelf zone

Smith (1964) reported that faunal assemblages at shallow depths of less than 20–30 mbsl comprise *Ammonia beccarii*, *Elphidium tumidum*, and *Nonionella* (*Pseudononion*) *basispinata* in El Salvador. Bandy and Arnal (1957) also reported that porcelaneous species such as *Quinqueloculina*, *Milionella*. *Hanzawaia nitidula*, and *Bolivina denudata* are common species. At greater depths (~50 m) the assemblages become more diverse, comprising *Nonionella atlantica* (Bandy and Arnal, 1957), *Hanzawaia concentrica*, *Cancris sagra*, *Planulina exorna*, and *Bulimina denudata*, *Textularia panamensis* (Smith, 1964). Unfortunately, we do not have the less than 50 mbsl data in this study.

Smith (1964) divided the zonation into two; one (zone A) is around 0-30 mbsl and the other (zone B) is around 30-50 mbsl. However, we decided that these two zonation could be unified to one zonation (U1) because the component species of the samples in zone A and B are almost same.

2) U2 (50~100 m): Mid shelf zone

From a depth of 50 to 100 mbsl off Central America, the common to abundant species are *Hanzawaia nitidula* (~80 mbsl), *Bolivina acutula*, *Discorbis communis*, and *Uvigerina incilis* (Bandy and Arnal, 1957). At El Salvador (64–82 mbsl), the abundant species are *Hanzawaia concentrica*, *Cassidulina minuta*, *Bolivina striatula*. And also *Uvigerina incilis*, *Cancris sagra*, and *Bulimina denudata* are common (Smith. 1964).

In this study, the abundant species are *Uvigerina incilis*, *Ammobacculites foliaceus*, *Cancris sagra*, and *Textularia agglutinans* (54 mbsl). The shallow buliminid form (*Bulimina denudata*) and *Planulina exorna* are also common.

3) U3 (100~200 m): Outer shelf zone

The continental shelf assemblages are slightly different in the two regions. *Bolivina acutula* (103–110 mbsl), *Discorbis panamensis* (shallower than 103 mbsl), and *Uvigerina incilis* (shallower than 103 mbsl) are common to abundant in Central America (Bandy and Arnal, 1957). At El Salvador (about 140 mbsl), *Hanzawaia concentrica, Uvigerina incilis* are abundant. In addition, *Bolivina interjuncta bicostata*, *Cancris sagra*, *Angulogerina* *semitrigona*, *Bolivina acuminata*, and *Epistominella bradyana* are common (Smith 1964).

In this study, ME54-1 (148 mbsl), *Uvigerina incilis* is still abundant. Other characteristic species are *Bolivina bicostata*, *Brizalina alata*, and *Cibicorbis inflatus*.

4) U4 (200–600 mbsl): Upper bathyal zone

Within the upper bathyal zone, ranging from 200 to 600 mbsl, samples were previously taken from a depth of ~300-450 mbsl (Bandy and Arnal, 1957; Smith, 1964). These assemblages include abundant *Bolivina seminuda*, *Epistominella bradyana*, *Epistominella obesa* (in Brady and Arnal, 1957) and *Bolivina humilis*, *Bolivina subadvena*, *Bolivina seminuda*, *Cassidulina tumida*, and *Epistominella obesa* (Smith, 1964). *Angulogerina carinata*, *Cancris inflatus*, and *Epistominella bradyana* are common. In the site at the edge of the continental shelf (ME-54-4, 230 mbsl), the benthic assemblage is composed of abundant *Cibicorbis inflatus* and *Epistominella bradyana*, with subordinate *Angulogerina carinata* (this study).

5) U5 (600–1000 m): Mid bathyal zone

In the middle bathyal, ranging from 600 to 1000 mbsl, the abundant species are *Epistominella bradyana* (shallower than 640 mbsl), *Bolivina minuta* (shallower than 640 mbsl), *Cassidulina delicata* (shallower than 777 mbsl), *Bolivina spissa* (deeper than 822 mbsl), *Bolivina tumida* (about 822 mbsl), and *Uvigerina peregrina* (more than 777 mbsl) (Bandy and Arnal, 1957). At a depth of ~800 m off El Salvador, *Bulimina* (*Eubuliminella*) *tenuata* (deeper than 800 mbsl), *Uvigerina peregrina* (deeper than 800 mbsl), *Uvigerina excellens* (about 800 mbsl), and *Bolivina argentea* (about 800 mbsl) are commonly observed. The assemblages of the lower-middle bathyal depths (1000–1500 mbsl) are characterized by *Bolivina plicata* and *Uvigerina excellens* (deeper than 1025 mbsl) and

Uvigerina proboscidea (Bandy and Arnal, 1957).

In this study, below 600 m, the assemblages are characterized by abundant occurrences of *Uvigerina* species. *Uvigerina peregrina* is consistently abundant at 654–1802 m, and exceeds 15% at 700–1000 mbsl, while *Uvigerina auberiana* is abundant around 800 m. Other common species are *Brizalina semiperforata*, *Brizalina seminuda*, and *Bolivina bicostata*. *Bulimina mexicana* is common to abundant at 815–1000 m. Occurrence of *Psedoparrella exigua* abundances is more than 10%. Occurrences of *Epistominella bradyana* and *Epistominella smithi* abundances also reach more than 10%. *Cassidulina carinata*, and *Globocassidulina subglobosa* are common to abundant.

6) U6 (1000–2000 mbsl): Lower bathyal zone

In the lower middle bathyal (deeper than 1200 mbsl), the *Uvigerina* genus (*peregrina*, *proboscedea*, and *auberiana*) is common to abundant, with subordinate amounts of other characteristic species including *Epist*ominella *smithi*, *Cassidulina cushmani* and *Bulimina* (*Eubuliminella*) *tenuata* (Smith, 1964).

In this study, from 1200 to 1500 mbsl, *Uvigerina peregrina* remains a common to abundant species. The abundance of *Uvigerina auberiana* also increases at 1447 m. *Bulimina mexicana* and *Cassidulina carinata* commonly occur. *Cibicidoides mckannai* and *Epistominella bradyana* is common. *Paracassidulina* spp. and C*assidulina carinata* have abundances of 5.6%–15.3% at 1200–1447 mbsl, respectively. *Brizalina* species (*B. semiperforata*, *B. seminuda*, and *B. argentea*) and *Lenticulina cushmani* are common. *Globobulimina affinis* and *Chilostomella oolina* are recognized as the species associated with oxygen-depleted conditions in modern oceans, but they are very few in number, amounting to less than 3% at many studied sites.

7) U7 (2000–3000 m): Upper abyssal zone

In this study, Between 1800 and 3000 mbsl, the assemblages are also characterized by abundant *Uvigerina* species. The most abundant species is *Uvigerina auberiana* (more than 20%). *Uvigerina peregrina*, *Uvigerina proboscedea* and *Uvigerina excellens is* common at 1802 mbsl. Other common species are *Bolivina bicostata*, *Brizalina argentea*, and *Eubuliminella tenuata* at 1802 mbsl. There are no data in Smith (1964) and Bandy and Arnal (1957).

8) U8 (deeper than 3000 mbsl): Lower abyssal zone

In this study, abundant species in this zone are *Lagenammina arenulata*, *Chilostomella oolina* and *Uvigerina proboscidea* are common. The cosmopolitan deep faunas are *Melonis barleeanum*, *Oridorsalis umbonatus*, and *Pullenia bulloides*. However, these species abundances are not high (generally less than 5%). The high abundances of agglutinated species would be associated with the Calcite compensation depth (CCD) and/or carbonate dissolution, because the depth range of CCD is 3-3.5 km in the area (Adelseck and Berger, 1975).

Off El Salvador, *Hoeglundina elegans* are common (Smith, 1964). Smith (1964) reported there are living specimen of *Pullenia bulloides* and *Nonion affine*.

Environmental factors controlling depth distribution of benthic foraminifera

Bottom-water oxygenation and food availability are the most significant factors determining foraminiferal distributions in the Arabian Sea (e.g., Jannink *et al.*, 1998; Schumacher *et al.*, 2007). Therefore, we examined the relationship between foraminiferal assemblages and environmental parameters (temperature, salinity, dissolved oxygen, phosphate, silicate, and nitrate). The long-term annual mean values of each parameter

(0.5° latitude–longitude grid data) are available from the NOAA database (https://www.nodc.noaa.gov/OC5/woa13/woa13data.html), from which we used data for these six factors around our study sites (Figure 2). Dissolved oxygen concentrations display minimum values of 0.05–0.12 ml L^{-1} at ~400 m. If a value of 0.2 ml L^{-1} is adopted as a boundary for the OMZ, the OMZ ranges from a depth of 300 mbsl to 600 mbsl and corresponds to Cluster II and IV. The relationships between other Culster were also examined (Table 2). Dissolved oxygen concentrations values were almost same, however, each cluster is constituted by different species. It suggests another environmental factor would control this in addition to the oxygen. Silicate increased constantly with depth despite the OMZ, while the nitrate concentrations rapidly increase at a depth of ~400 mbsl near the oxygen minimum value. Recently, nitrate respiration has been observed to be common among foraminifera (e.g. Koho and Pina-Ochoa, 2012). Therefore, the nitrate profiles might be related with the benthic assemblage. However, nitrate respiration in benthic foraminifera is still not well-known (e.g. Koho and Pina-Ochoa, 2012). Further research is required to determine how foraminiferal depth-distributions are related to nitrate and low-oxygen concentrations. Below the OMZ, oxygen concentrations gradually increase toward greater depths up to >3000 mbsl, while temperature, salinity, and phosphate remain at relatively stable values; within 4°C, 0.2, 0.3 μ mol L^{-1}, respectively (Figure 2). Therefore, dissolved oxygen concentrations are likely to be one of the most effective factors controlling foraminiferal depth-distributions, especially below OMZ depth in the eastern equatorial Pacific (Table 2).

Conclusions

To establish a bathymetric scale for the eastern equatorial Pacific, we investigated the depth-distribution of benthic foraminifera using piston core sediments. On the basis of the faunal and cluster analyses and results from previous studies, modern benthic foraminifera can be classified into eight bathymetric assemblages: 1) U1 (mainly composed of *Ammonia beccarii*, *Cancris sagra*, *Elphidium tumidum*, *Hanzawaia concentrica*, *Pseudononion basispinata*, and *Planulina exorna*) represent inner shelf faunas (shallower than 50 mbsl). 2) U2 (mainly composed of *Ammobacculites foliaceu*, *Bolivina striatula*, *Cassidulina minuta*, *Hanzawaia concentrica*, *Uvigerina incilis*, *Bulimina denudata*, and *Cancris sagra*) is correlated with mid shelf depth assemblages, from 50 to 100 mbsl. 3) U3 (mainly composed of *Uvigerina incilis Hanzawaia concentrica*, *Angulogerina semitrigona*, *Bolivina acuminata*, *Bolivina bicostata*, and *Cibicorbis inflatus*) is assigned to outer shelf assemblages from 100 to 200 m depth. 4) U4 (mainly composed of *Bolivina humilis*, *Bolivina seminuda*, *Bolivina subadvena*, *Cassidulina tumida*, *Epistominella obesa*, *Angulogerina carinata*, and *Cibicorbis inflatus*) is the upper bathyal faunas (200–600 mbsl). 5) U5 (mainly composed of *Brizalina argentea*, *Uvigerina peregrina*, *Uvigerina auberiana*, *Brizalina seminuda*, *Bulimina striata*, *Epistominella smithi* and *Globocassidulina subglobosa*) is the mid bathyal faunas (600–1000 mbsl). 6) U6 (mainly composed of *Uvigerina auberiana*, *Uvigerina peregrina*, *Brizalina argentea*, *Bulimina mexicana*, *Cassidulina carinata*, *Epistominella smithi*, and *Lenticulina cushmani*) represent the lower bathyal assemblage (1000–2000 mbsl). 7) U7 (mainly composed of *Uvigerina auberiana*, *Brizalina argentea*, and *Eubuliminella tenuata*) represent upper abyssal faunas (2000-3000 mbsl). 8) U8 (mainly composed of *Glomospira* sp.A, *Lagenammina arenulata*, *Chilostomella oolina*, *Hoeglundina elegans*, *Melonis barleeanum*, *Nonion affine*, *Oridorsalis umbonatus*, *Pullenia bulloides*, and *Uvigerina proboscidea*) is characterized by deep-water cosmopolitan faunas (deeper than 3000 mbsl).

We also demonstrated a relationship between environmental parameters, such as oxygen concentration. Our results suggest that dissolved oxygen concentrations are one of the most effective factors controlling foraminiferal depth-distributions in the eastern equatorial Pacific especially below oxygen minimum zone (OMZ). Around OMZ, nitrate concentration also might be related with the benthic assemblage due to the nitrate respiration.

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Figure and Table captions

Figure 1. Geological setting and sampling locations for this study.

Figure 2. Water column properties: **(a)** temperature, **(b)** salinity, (**c**) dissolved oxygen, (**d**) silicate, **(e)** nitrate.

Figure 3. Results of the numerical foraminiferal parameters. (**a**) absolute abundance (g^{-1}) as an abundance of benthic foraminifera in individuals per g dry sediment; **(b)** species

number of benthic foraminifera; **(c)** species diversity of Benthic foraminifera (H); **(d)** mud content (%) as a percentage of dry mud weight (g) per total sample dry weight (g); **(e)** ratio of planktonic foraminifera to benthic foraminifera (%); **(f)** percentages of hyaline, porcellaneous, and agglutinated benthic foraminifera (%).

Figure 4. Scanning electron micrographs of benthic foraminifera in this study. **1,** *Ammobaculites foliaceus* (Brady); **2,** *Textularia agglutinans* (d'Orbigny); **3,** *Lagenammina arenulata* (Skinner) ; **4,** *Bulimina denudata* (Cushman and Parker); **5,** *Bulimina striata* (d'Orbigny in Guérin-Méneville); **6,** *Bolivina bicostata* (Cushman); **7,** *Uvigerina incilis* (Todd); **8,** *Uvigerina proboscidea* (Schwager); **9,** *Uvigerina peregrina* (Cushman); **10,** *Angulogerina carinata* (Cushman); **11,***Cibicorbis inflatus* (Cushman); **12,** *Ehrenbergina pupa* (d'Orbigny) **13,** *Pseudononion basispinata* (Cushman and Moyer) **14,** *Cancris sagra* (d'Orbigny). Scale bars are 100µm.

Figure 5. Scanning electron micrographs of benthic foraminifera in this study. **1,** *Epistominella bradyana* (Cushman); **2,** *Cassidulina carinata* (Silvestri); **3,** *Epistominella smithi* (R.E. & K.C. Stewart); **4,** *Gyroidina soldanii* (d'Orbigny); **5,** *Eubuliminella tenuata* (Cushman); **6,** *Globocassidulina subglobosa* (Brady); **7,** *Pullenia bulloides* (d'Orbigny) ; **8,** *Melonis barleeanus* (Williamson, 1858); **9,** *Oridorsalis umbonatus* (Reuss); **10,** *Planulina exorna* (Phleger and Parker). Scale bars are 100µm.

Figure 6. Relative abundances of the significant species in benthic foraminifera in different zones off the Pacific Coast of Western Costa Rica.

Figure 7. Results of the cluster analyses.

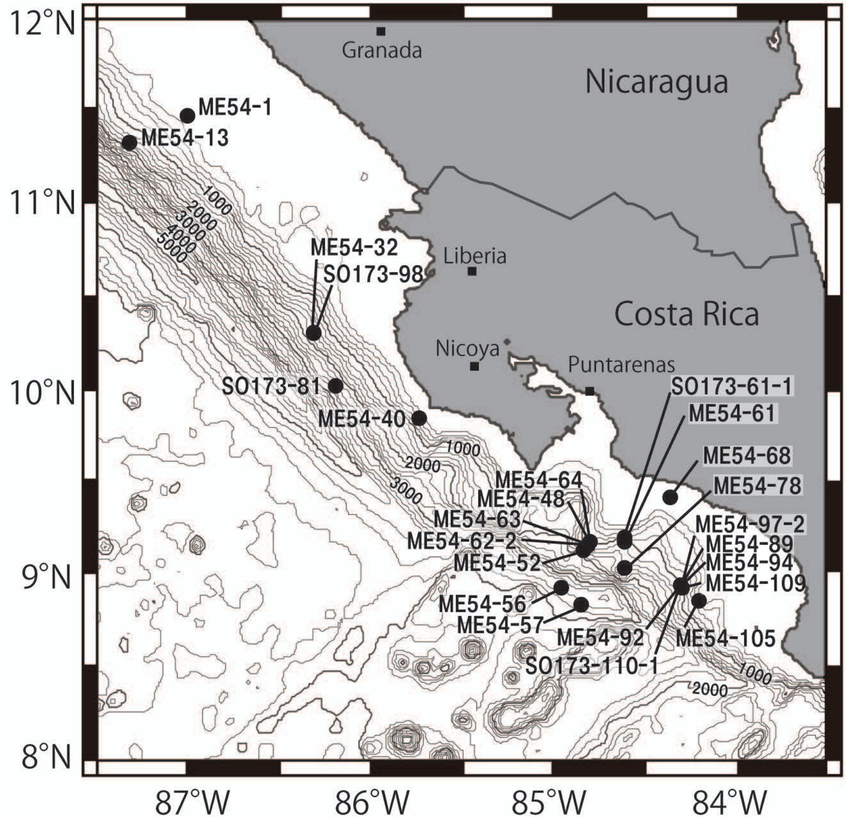
Figure 8. Compiled range chart of the results of Smith (1964) and this study.

Table 1. Distributions for each sample. ME54 samples were taken by the cruise of the RV METEOR M54 in 2002, and also SO173 samples were taken by the cruise of the RV

SONNE in 2003.

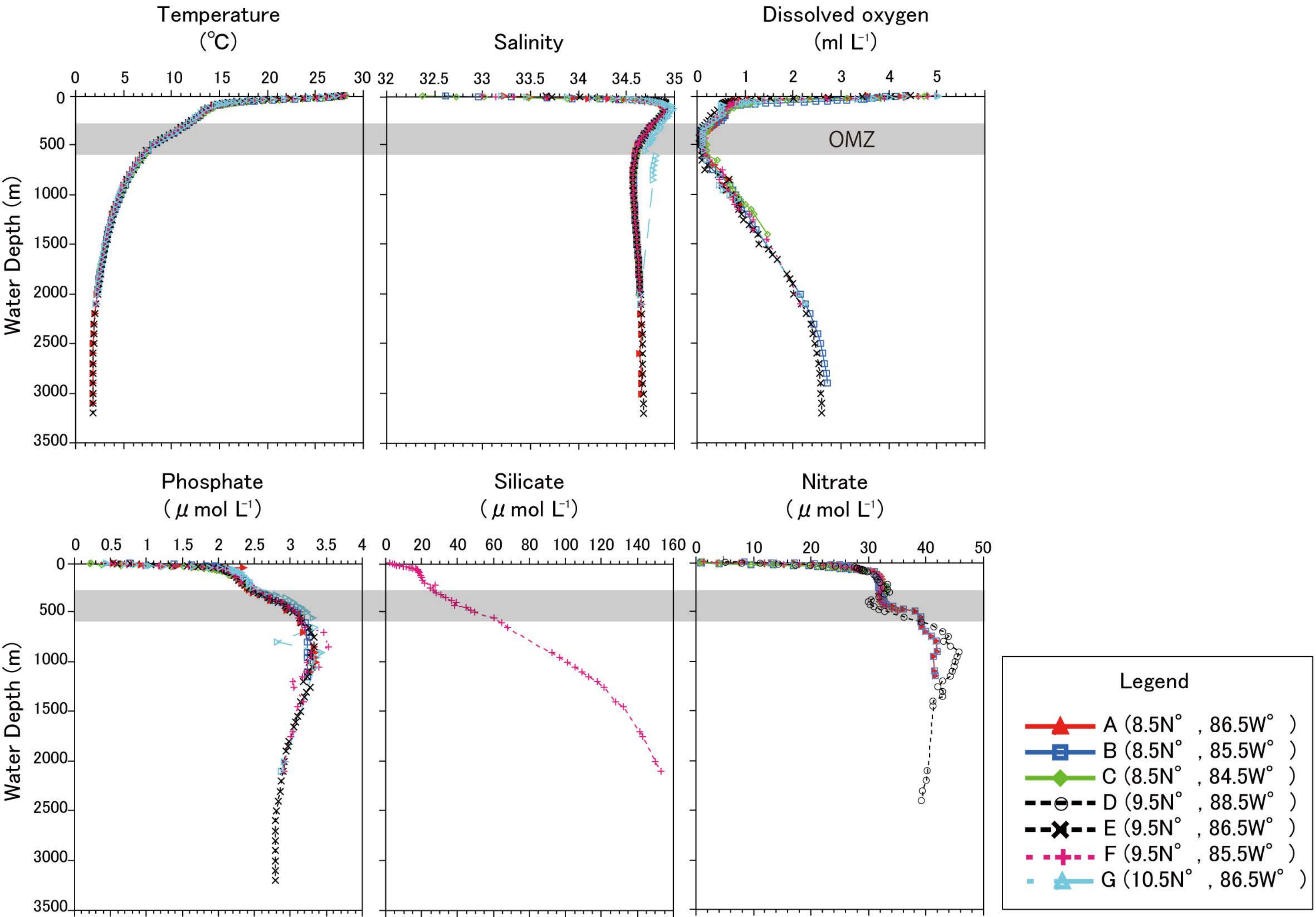
Table 2. Features of cluster I - VI with Dissolved oxygen value.

Table 3. Integrated bathymetric scale off western Costa Rica. The species of the circles are abundant.

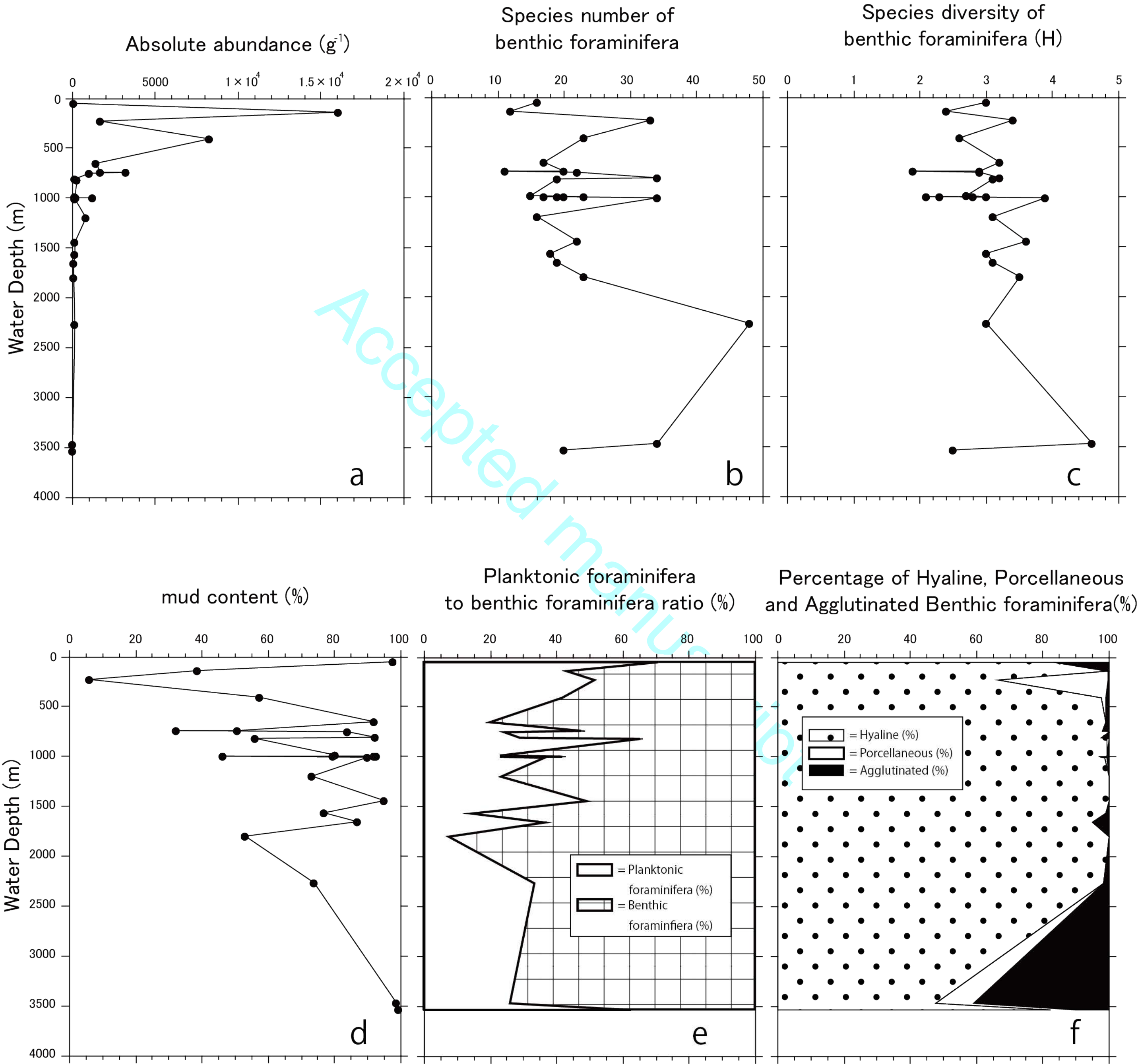


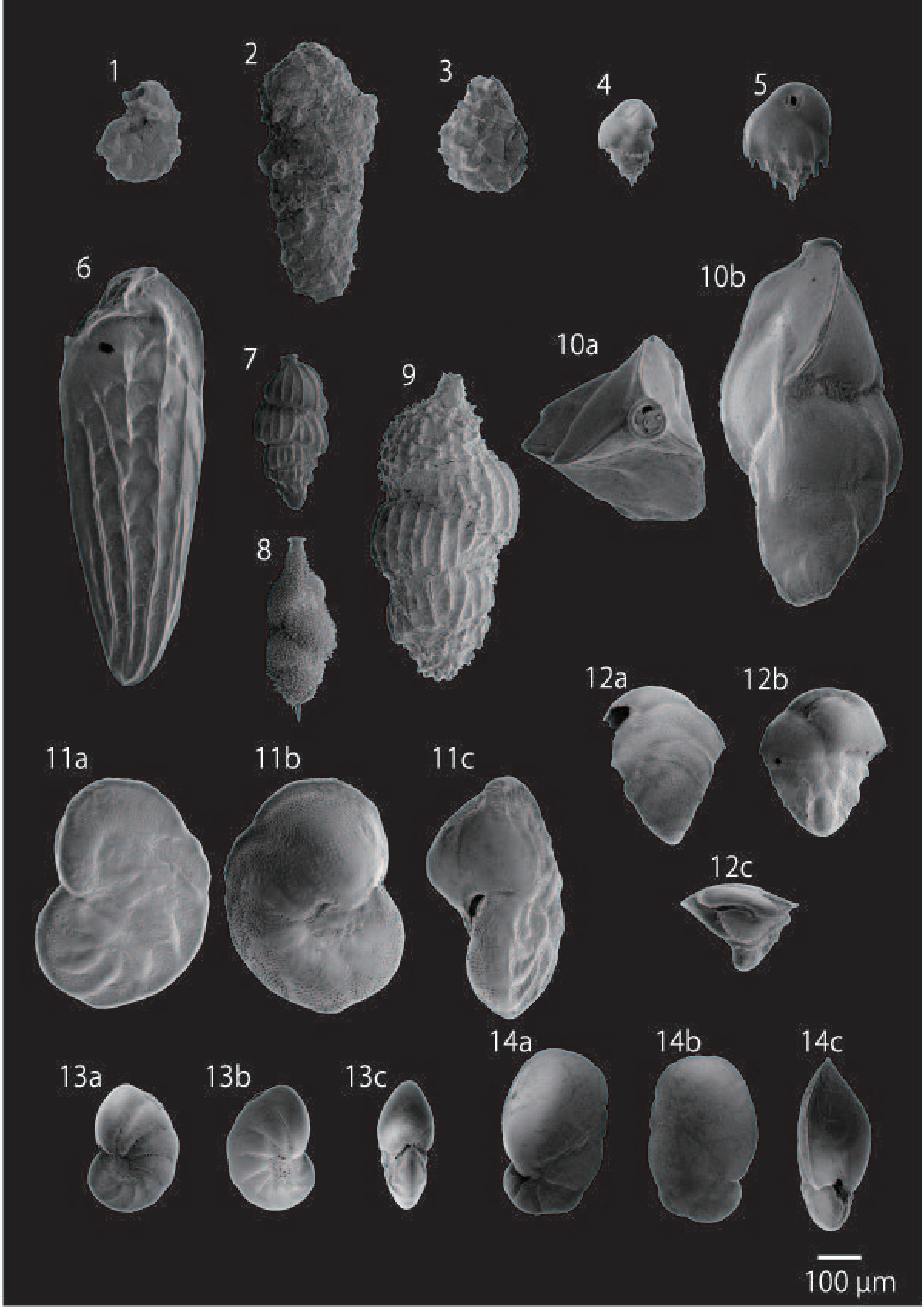
12°N
11°N
10°N
9°N
8°N
87°W
86°W
85°W
84°W
Granada
Nicaragua
Liberia
Costa Rica
Nicoya
Puntarenas
ME54-1
ME54-13
ME54-32
SO173-98
SO173-81
ME54-40
SO173-61-1
ME54-61
ME54-68
ME54-78
ME54-64
ME54-48
ME54-63
ME54-62-2
ME54-52
ME54-97-2
ME54-89
ME54-94
ME54-109
ME54-56
ME54-57
ME54-92
ME54-105
SO173-110-1
1000
2000
3000
4000
5000

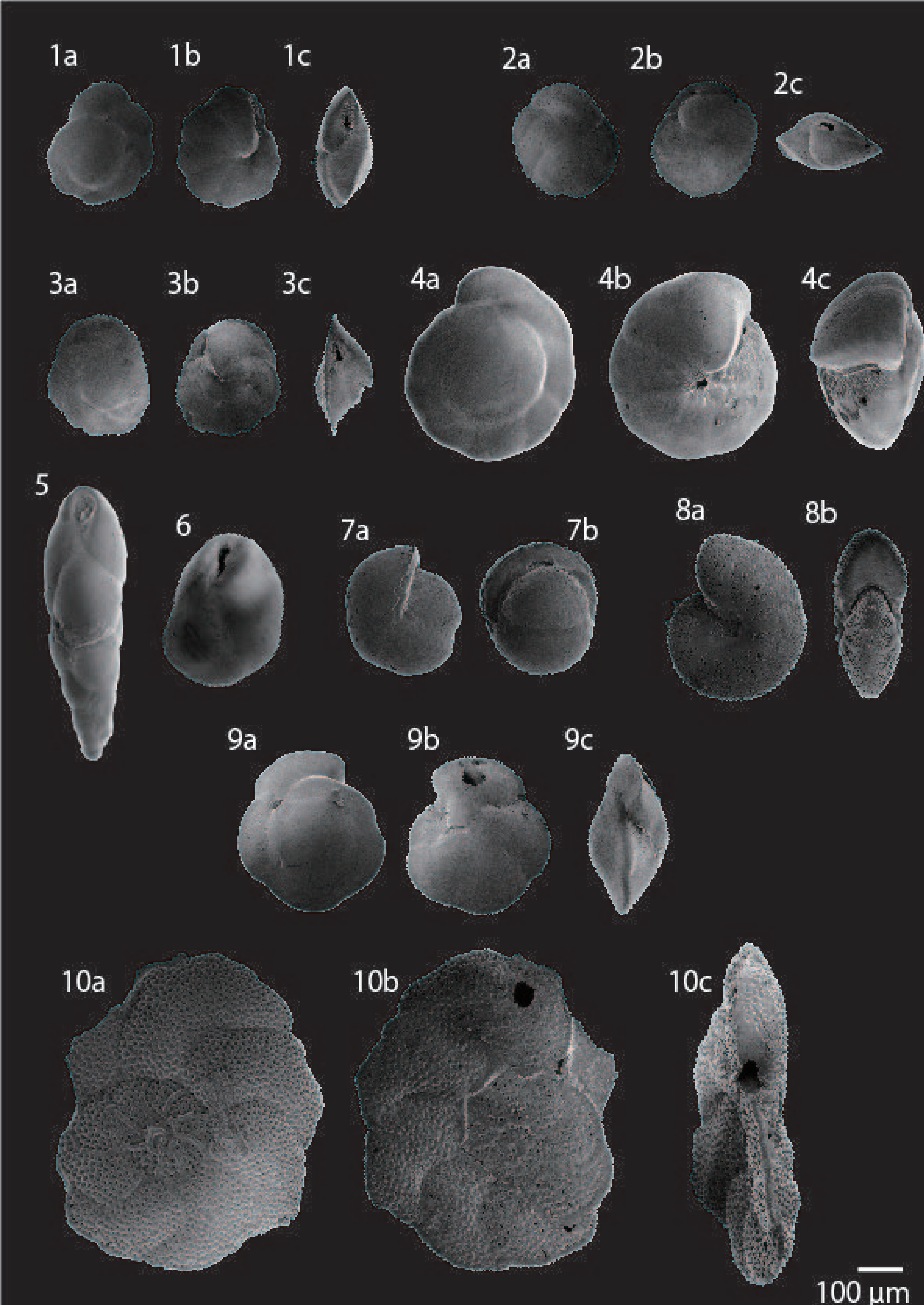
Fig. 2

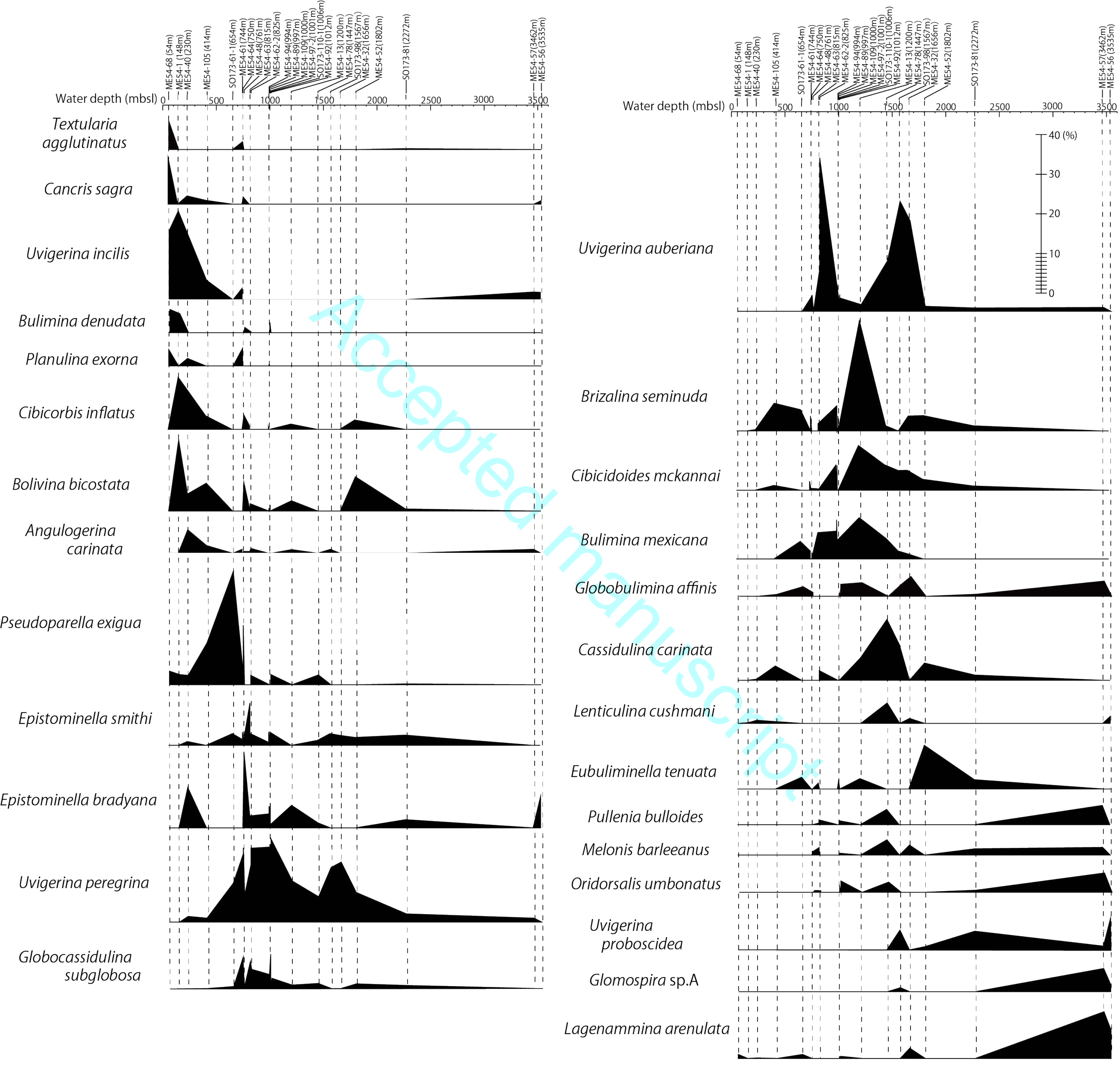


Temperature
(°C)
Salinity
Dissolved oxygen
(ml L⁻¹)
OMZ
Water Depth (m)
Phosphate
(μ mol L⁻¹)
Silicate
(μ mol L⁻¹)
Nitrate
(μ mol L⁻¹)
Legend
A (8.5N° , 86.5W°)
B (8.5N° , 85.5W°)
C (8.5N° , 84.5W°)
D (9.5N° , 88.5W°)
E (9.5N° , 86.5W°)
F (9.5N° , 85.5W°)
G (10.5N° , 86.5W°)

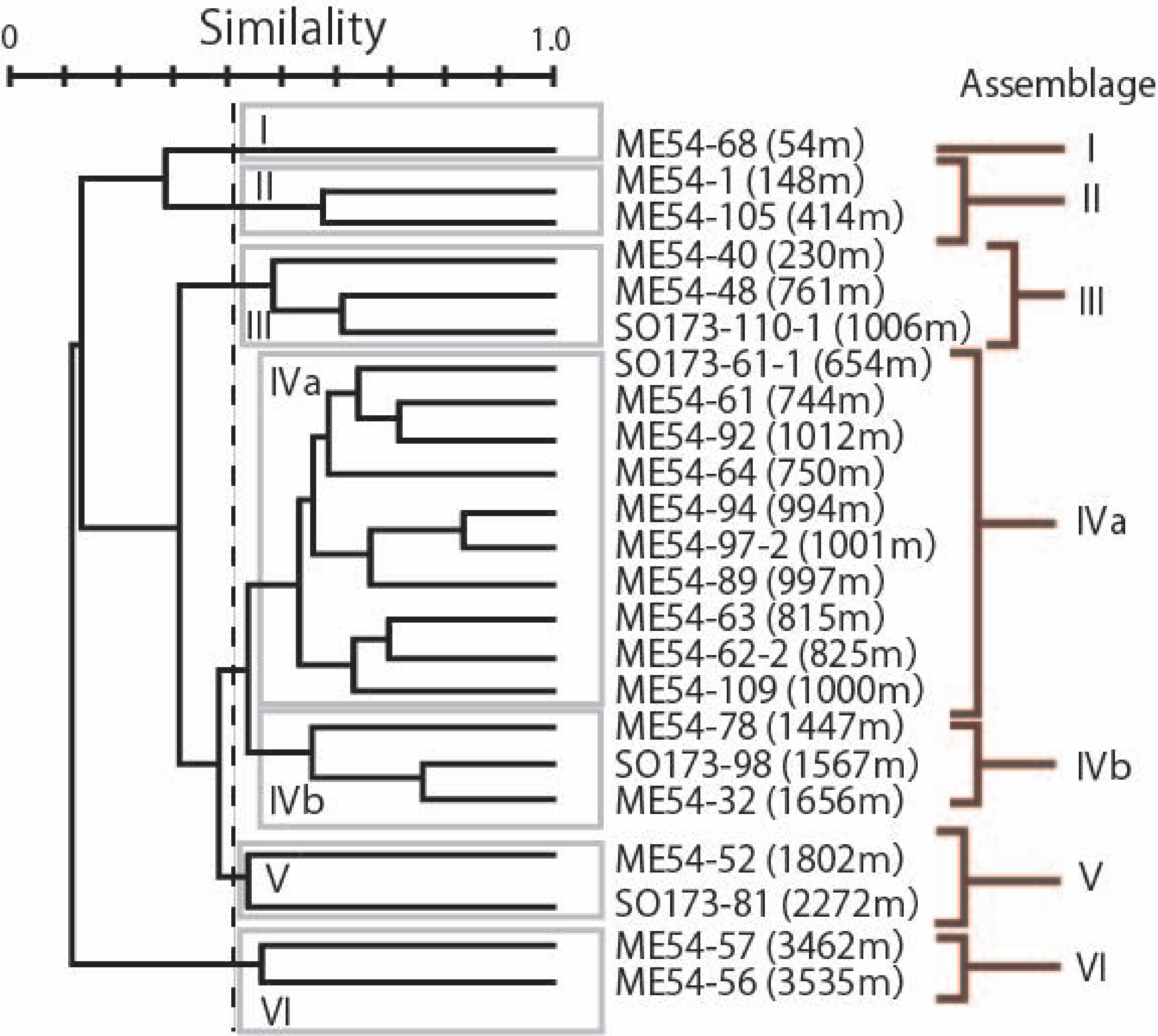

Absolute abundance (g-1)
Species number of benthic foraminifera
Species diversity of benthic foraminifera (H)
Water Depth (m)
a
b
c
mud content (%)
Planktonic foraminifera to benthic foraminifera ratio (%)
Percentage of Hyaline, Porcellaneous and Agglutinated Benthic foraminifera(%)
= Planktonic foraminifera (%)
= Benthic foraminfiera (%)
= Hyaline (%)
= Porcellaneous (%)
= Agglutinated (%)
d
e
f


1
2
3
4
5
6
7
8
9
10a
10b
11a
11b
11c
12a
12b
12c
13a
13b
13c
14a
14b
14c
100 µm


1a
1b
1c
2a
2b
2c
3a
3b
3c
4a
4b
4c
5
6
7a
7b
8a
8b
9a
9b
9c
10a
10b
10c
100 µm



Water depth (mbsl)
0
500
1000
1500
2000
2500
3000
3500
ME54-68 (54m)
ME54-1 (148m)
ME54-40 (230m)
ME54-105 (414m)
SO173-61-1(654m)
ME54-61(744m)
ME54-64(750m)
ME54-48(761m)
ME54-63(815m)
ME54-62-2(825m)
ME54-94(994m)
ME54-89(997m)
ME54-109(1000m)
ME54-97-2(1001m)
SO173-110-1(1006m)
ME54-92(1012m)
ME54-13(1200m)
ME54-78(1447m)
SO173-98(1567m)
ME54-32(1656m)
ME54-52(1802m)
SO173-81(2272m)
ME54-57(3462m)
ME54-56 (3535m)
Textularia agglutinatus
Cancris sagra
Uvigerina incilis
Bulimina denudata
Planulina exorna
Cibicorbis inflatus
Bolivina bicostata
Angulogerina carinata
Pseudoparella exigua
Epistominella smithi
Epistominella bradyana
Uvigerina peregrina
Globocassidulina subglobosa
40 (%)
30
20
10
0
Uvigerina auberiana
Brizalina seminuda
Cibicidoides mckannai
Bulimina mexicana
Globobulimina affinis
Cassidulina carinata
Lenticulina cushmani
Eubuliminella tenuata
Pullenia bulloides
Melonis barleeanus
Oridorsalis umbonatus
Uvigerina proboscidea
Glomospira sp.A
Lagenammina arenulata


Similality
0
1.0
Assemblage
I
II
III
IVa
IVb
V
VI
ME54-68 (54m)
ME54-1 (148m)
ME54-105 (414m)
ME54-40 (230m)
ME54-48 (761m)
SO173-110-1 (1006m)
SO173-61-1 (654m)
ME54-61 (744m)
ME54-92 (1012m)
ME54-64 (750m)
ME54-94 (994m)
ME54-97-2 (1001m)
ME54-89 (997m)
ME54-63 (815m)
ME54-62-2 (825m)
ME54-109 (1000m)
ME54-78 (1447m)
SO173-98 (1567m)
ME54-32 (1656m)
ME54-52 (1802m)
SO173-81 (2272m)
ME54-57 (3462m)
ME54-56 (3535m)

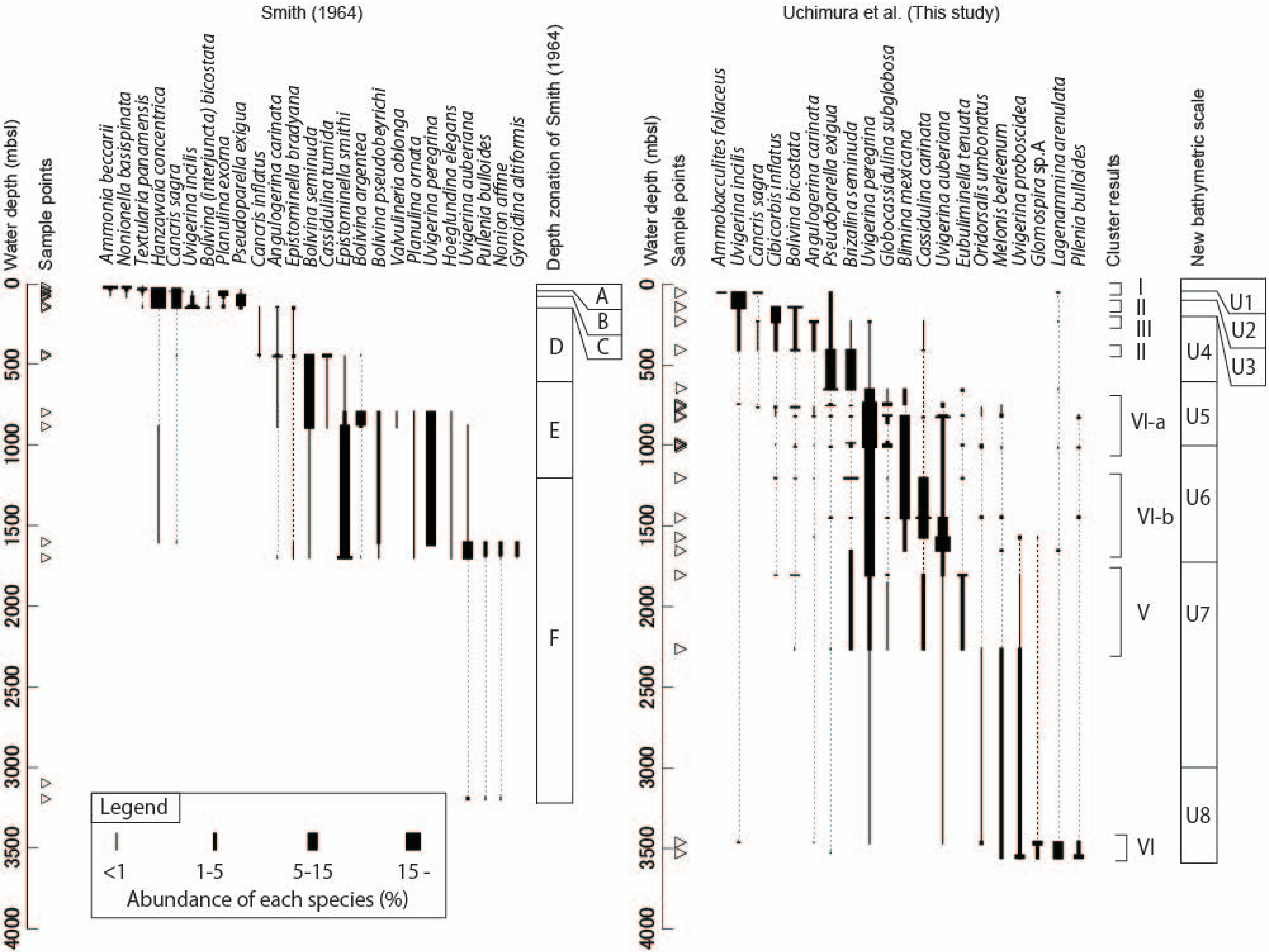

Smith (1964)
Uchimura et al. (This study)
Water depth (mbsl)
Sample points
Ammonia beccarii
Nonionella basispinata
Textularia panamensis
Hanzawaia concentrica
Cancris sagra
Uvigerina incilis
Bolivina (interjuncta) bicostata
Planulina exorna
Pseudoparella exigua
Cancris inflatus
Angulogerina carinata
Epistominella bradyana
Bolivina seminuda
Cassidulina tumida
Epistominella smithi
Bolivina argentea
Bolivina pseudobeyrichi
Valvulineria oblonga
Planulina ornata
Uvigerina peregrina
Hoeglundina elegans
Uvigerina auberiana
Pullenia bulloides
Nonion affine
Gyroidina altiformis
Depth zonation of Smith (1964)
A
B
C
D
E
F
Legend
<1
1-5
5-15
15 -
Abundance of each species (%)
Ammobaccullites foliaceus
Uvigerina incilis
Cancris sagra
Cibicorbis inflatus
Bolivina bicostata
Angulogerina carinata
Pseudoparella exigua
Brizalina seminuda
Uvigerina peregrina
Globocassidulina subglobosa
Blimina mexicana
Cassidulina carinata
Uvigerina auberiana
Eubuliminella tenuata
Oridorsalis umbonatus
Melonis berleenum
Uvigerina proboscidea
Glomospira sp.A
Lagenammina arenulata
Pllenia bulloides
Cluster results
I
II
III
II
VI-a
VI-b
V
VI
New bathymetric scale
U1
U2
U3
U4
U5
U6
U7
U8
0
500
1000
1500
2000
2500
3000
3500
4000

Table 1

Station	water depth (m)	Latitude (N°)	Longitude (W°)
ME54-68	54	09°24.71'	84°22.51'
ME54-1	148	11°28.91'	87°00.02'
ME54-40	230	09°50.27'	85°44.07'
ME54-105	414	08°51.20'	84°13.01'
SO173-61-1	654	09°12.00'	84°37.24'
ME54-61	744	09°10.46'	84°47.76'
ME54-64	750	09°10.54'	84°48.27'
ME54-48	761	09°10.41'	84°48.25'
ME54-63	815	09°09.11'	84°49.28'
ME54-62-2	825	09°09.02'	84°49.18'
ME54-94	994	08°55.81'	84°18.64'
ME54-89	997	08°55.89'	84°18.69'
ME54-109	1000	08°55.31'	84°18.26'
ME54-97-2	1001	08°55.90'	84°18.70'
SO173-110-1	1006	08°55.74'	84°18.81'
ME54-92	1012	08°55.88'	84°18.77'
ME54-13	1200	11°20.12'	87°18.30'
ME54-78	1447	09°02.01'	84°37.25'
SO173-98	1567	10°17.79'	86°18.59'
ME54-32	1656	10°18.06'	86°18.55'
ME54-52	1802	09°07.23'	84°50.65'
SO173-81	2272	10°00.51'	86°11.39'
ME54-57	3462	08°49.70'	84°51.21'
ME54-56	3535	08°55.61'	84°58.01'

Table 2. Features of cluster I - VI with Dissolved oxygen value.

Cluster	Ⅰ	Ⅱ	Ⅲ	Ⅳ a	Ⅳ b	Ⅴ	Ⅵ
Water depth (mbsl)	54	148, 414	230, 761, 1006	654-1012	1447-1802	1802-2272	3462〜
Major species	*Ammobacculites foliaceus* *Textularia agglutinans* *Uvigerina incilis* *Pseudononion basispinata* *Cancris sagra*	*Uvigerina incilis* *Brizalina bicostata* *Cibicorbis inflatus* *Brizalina alata* *Epistominella bradyana*	*Epistominella bradyana* *Cassidulina tumida* *Epistominella smithi* *Brizalina bicostata*	*Uvigerina peregrina* *Globocassidulina subglobosa* *Bulimina mexicana* *Cassidulina tumida* *Uvigerina auberiana*	*Uvigerina auberiana* *Uvigerina peregrina* *Cassidulina carinata* *Cibicidoides mckannai*	*Uvigerina auberiana* *Uvigerina peregrina* *Uvigerina excellens* *Brizalina argentea* *Eubuliminella tenuata*	*Oridorisalis umbonatus* *Pullenia bulloides* *Melonis barleeanus* *Lagenammina arenulata* *Uvigerina proboscidea*
Dissolved oxygen (ml/L)	1.2 - 1.4	0.1 - 0.5	0.3 - 0.7	0.2 - 0.8	1.4 - 1.7	1.9 - 2.4	~2.6

Table 3. Integrated bathymetric scale off western Costa Rica. The species of the circles are abundant.

Unit name	U1	U2	U3	U4	U5	U6	U7	U8
Bathymetric zone (mbsl)	Inner shelf 0-50	Mid shelf 50-100	Outer shelf 100-200	Upper bathyal 200-600	Mid bathyal 600-1000	Lower bathyal 1000-2000	Upper abyssal 2000-3000	Lower abyssal 3000-
Main species	○ *Ammonia beccarii*	○ *Ammobacculites foliaces*	○ *Uvigerina incilis*	○ *Bolivina humilis*	○ *Brizalina argentea*	○ *Uvigerina auberiana*	○ *Uvigerina auberiana*	○ *Glomospira sp.A*
	○ *Cancris sagra*	○ *Bolivina striatula*	○ *Hanzawaia concentrica*	○ *Bolivina seminuda*	○ *Uvigerina peregrina*	○ *Uvigerina peregrina*	*Brizalina argentea*	○ *Lagenammina arenulata*
	○ *Elphidium tumidum*	○ *Cassidulina minuta*	*Bolivina (interjuncta) bicostata*	○ *Bolivina subadvena*	*Uvigerina auberiana*	*Brizalina argentea*	*Cibicidoides mckannai*	*Chilostomella oolina*
	○ *Hanzawaia concentrica*	○ *Hanzawaia concentrica*	*Angulagerina semitrigona*	○ *Cassidulina tumida*	*Brizaliana seminuda*	*Bulimina mexicana*	*Eubuliminella tenuata*	*Hoeglundina elegans*
	○ *Pseudononion basispinata*	○ *Uvigerina incilis*	*Bolivina acuminata*	○ *Epistominella obesa*	*Bulimina striata*	*Cassidulina carinata*	*Globobulimina affinis*	*Melonis barleeanus*
	Bulimina denudata	*Bulimina denudata*	*Brizalina alata*	*Angulogerina carinata*	*Epistominella bradyana*	*Cibicidoides mckannai*	*Uvigerina excellens*	*Nonion affine*
	Planulina exorna	*Cancris sagra*	*Cancris sagra*	*Cibicorbis inflatus*	*Epistominella smithi*	*Epistominella bradyana*	*Uvigerina peregrina*	*Oridorsalis umbonatus*
	Textularia panamensis	*Planulina exorna*	*Cibicorbis inflatus*	*Epistominella bradyana*	*Globocassidulina subglobosa*	*Epistominella smithi*	*Uvigerina proboscedea*	*Pullenia bulloides*
		Textularia agglutinans	*Epistominella bradyana*		*Psedoparrella exigua*	*Lenticulina cushmani*		*Uvigerina proboscidea*

The result of bathymetrical scale of Smith (1964) and Uchimura et al. (this study).

Station	ME54-68	ME54-1	ME54-40	ME54-105	SO173-61-1	ME54-61	ME54-64	ME54-48	ME54-63	ME54-62-2	ME54-94	ME54-89	ME54-109	ME54-97-2	SO173-110-1	ME54-92	ME54-13	ME54-78	SO173-98	ME54-32	ME54-52	SO173-81	ME54-57	ME54-56
Water depth (m)	54	148	230	414	654	744	750	761	815	825	994	997	1000	1001	1006	1012	1200	1447	1567	1656	1802	2272	3462	3535
Ammobacculites foliaceus	21																							
Ammodiscus sp.A									1															
Ammodiscus sp.B														1										
Angulogerina carinata			37	8		2		1	2	2			2				2		1				1	
Anomalinoides sp.																						6		
Arenobulimina sp.																			1	1				
Bathysiphon archaceus																						2	5	
Brizalina humilis		7	8	5									5			5								
Brizalina alata		52		1		2																		
Brizalina argentia			5	1	8	2	2		8	3		4	16	5		13	12	1		1	28	6	1	
Bolivina bicostata		9	27	29				16		3		1		1	2		6				22	2		
Brizalina pseudobeyrichi									3					5			2							
Brizalina pseudobeyrichi aff.			7							1											1	2	1	
Brizalina sp.H																		1				1		
Brizalina sp.I																					2			
Brizalina sp.J																						1		
Brizalina spissa			2	29	11		1			3	9	2		2	5		64	1		3	1	5		
Brizalina seminuda	6		8		4	2	2	41	8						7	4					11	4		
Bulimina cf. *denudata*	3	13		1	6				1		3													
Bulimina denudata	17	24						3	1			4												
Bulimina mexicana					9	4			31	11	1	5	38	7	1	19	24	4	2	1				
Bulimina sp.D																		2					1	
Buliminella elegantissima		3																						
Cancris sagra	34		13	4				4																1
Cancris sp.																						1		
Cassidulina carinata			2	15						4							13	12	9		11	5		
Cassidulina tumida			24	2				15							4					2	3			
Chilostomella oolina				7				2	9		4	9	1	9	4	14			1			3	8	1
Cibicides reflugens									2															
Cibicides sp.			4																			1		
Cibicidoides mckannai				5			6	1	2		9			12			26	5	5	4	7	4		
Cibicidoides sp.B					1	7				1		7	5		1	45					2			
Cibicidoides sp.C																							2	
Cibicorbis inflatus		66	63	14				8	4			1					3				6			
Cribrostomoides subglobosum																							3	
Discorbis spp.			13					4								3								
Eggerellina sp.																			2					
Ehrenbergina pupa			5	8															2	1				
Ehrenburgina pacifica																						4		
Elphidium sp.																1								
Epistominella bradyana			64					42	7	5	5	3	21	8	8	3	13	1				8		
Epistominella smithi			6		6	3	9	3	5	5	1		13		2	13		1	3	2	5	1		
Fissulina sp.A																						3		2
Fissulina sp.B																						4		
Fissulina sp.C																						1		2
Flondicularia sp.																						1		
Fontbotia wuellustrofi												1	5											1
Globobulimina affinis				2	5	2						1		4	2	12	8		3	4		2	4	
Globocassidulina bisecta			6								4	5		1		17								
Globocassidulina subglobosa					1	16	15	1	32	8	5	13	6	9		1	2	1			3	3		
Glomospira charoides																							3	
Glomospira gordialis																							3	
Glomospira sp.A																			1				6	2
Gyroidina soldanii					3	2	1	4				1	5			13		3			4	11	3	
Haplophragmoides sp.A															1									
Haplophragmoides sp.B																							3	
Hoeglundina elegans					3			1	5							1							2	
Lagena acuticosta	2									2	2	2		1		1		1						

(continued on next page)

Station	ME54-68	ME54-1	ME54-40	ME54-105	SO173-61-1	ME54-61	ME54-64	ME54-48	ME54-63	ME54-62-2	ME54-94	ME54-89	ME54-109	ME54-97-2	SO173-110-1	ME54-92	ME54-13	ME54-78	SO173-98	ME54-32	ME54-52	SO173-81	ME54-57	ME54-56
Water depth (m)	54	148	230	414	654	744	750	761	815	825	994	997	1000	1001	1006	1012	1200	1447	1567	1656	1802	2272	3462	3535
Lagena elongata									4							1				1		1	1	
Lagena laevis	1								1			6				1	1	1	2	2		1		2
Lagena sp.F									1		1			1		3							1	
Lagena sp.G									1															
Lagena sp.H																3								
Lagena sp.I																1								
Lagena striata	1																						1	1
Lagenammina arenulata	3				2															2			12	8
Lenticulina cushmani		1	5	2														4		1				2
Lenticulina gibba																						1		
Loxostomum subrostratum																						1		
Melonis pompilioides									1													1		
Melonis barleeanus								2	9							2		3		2		6	2	4
Nonion sp.	4								8					1									2	
Nonionella spp.												4		4	4									
Oridorsalis umbonatus								1	2			2				11		2				2	5	
Paracassidulina sp.					5	22		1			12	8		19		5								
Parreroidina bradyi								4										3			3			
Phammosphaera sp.A			1						6							2				4				
Planulina exorna	12		12			9							1											
Plectofrondicular sp.A																					2			
Pseudobrizalina lobata	4																							
Pseudoparrella exigua	1	13	15	44	58	6	4			4						1		2				1		1
Pseudouvigerina sp.						1																		
Pullenia bulloides									2	2						4		3					5	9
Pullenia salisburyi					1	1								1		2						2		
Pullenia subcarinata								1																
Pullenia sp.																						2		
Pyrgo depressa															1								1	
Pyrgo serrate															1								4	1
Quinqueloculina aqueriana			12																					
Quinqueloculina seminuda			1	4									1										5	2
Quinqueloculina sp.A			2																					
Quinqueloculina sp.B			3																					
Quinqueloculina sp.C			1																					
Rectobolivina sp.A						6			12	2									1		1	8		
Reophax sp.A																								6
Reussella sp.A			3																					
Rhabdammina sp.A									1		1											2	4	
Rhabdammina sp.B									1															
Rhizammina sp.A																				1				
Sckenckiella primaeva																1			1	2		1		
Sckenckiella sp.A																						1		
Silicosigmoilina sp.									2				3		1									
Spiroloculina communis			2	1						1						2								
Stainforthia complanata					6				7			3			3		6				28	9		
Stilostomella spp.																						8		
Suggrunda eckisi		12						2								1		1				6		
Textularia agglutinans	21					4	3															1		
Textularia candeiana		1	1	4																		1	1	1
Textularia foliacia	3																							
Textularia sp.D																						1		
Triloculina sp.																							2	
Uvigerina asperula																						1		
Uvigerina auberiana						8	6		5	64	5	2	2	8	3	13	4	1	28	18	3	3	1	
Uvigerina excellens			6	1																	25			
Uvigerina incilis	5	112	1	19		6																	2	
Uvigerina peregrna			9	4	2	35	5	15	68	31	27	1	76	33	9	82	24	5	14	12	19	8	1	
Uvigerina proboscidea																			5		2	18	1	9
Uvigerina sp.A			27																					
Uvigerina.senticosa									3	4		1	4		1	7			4	4	5		2	5
Vaginulina trilobata aff.																								1
others	53	107	179	187	0	61	121	49	123	0	44	56	181	60	69	18	20	9	16	16	42	13	3	52
total population	290	501	628	415	203	201	265	221	468	165	142	151	385	192	129	388	230	78	101	79	254	383	103	113
Total Arenaceous species	48	1	2	4	2	4	3	0	11	0	1	0	3	1	2	3	0	0	1	4	0	6	42	17
Total Porcellaneous species	0	0	30	5	0	0	0	0	0	1	0	0	1	0	2	2	0	0	0	0	0	0	12	3
Total Hyaline species	242	500	417	406	201	197	262	221	457	164	141	151	381	191	125	383	230	78	100	75	254	377	49	93