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12. CENOZOIC BENTHIC FORAMINIFERAL BIOSTRATIGRAPHY, PALEOBATHYMETRY, PALEOENVIRONMENTS AND PALEOCEANOGRAPHY OF THE NEW HEBRIDES ISLAND ARC AND NORTH D'ENTRECASTEAUX RIDGE AREA[1]

Kazumi Akimoto[2]

ABSTRACT

This paper discusses the paleobathymetric and paleoenvironmental history of the New Hebrides Island Arc and North d'Entrecasteaux Ridge during Cenozoic time based on benthic foraminiferal and sedimentological data. Oligocene and Pliocene to Pleistocene benthic foraminiferal assemblages from Sites 827, 828, 829, and 832 of Ocean Drilling Program (ODP) Leg 134 (Vanuatu) are examined by means of Q-mode factor analysis. The results of this analysis recognize the following bathymetrically significant benthic foraminiferal biofacies: (1) *Globocassidulina subglobosa* biofacies and *Bulimina aculeata-Bolivinita quadrilatera* biofacies representing the upper bathyal zone (600–1500 m); (2) *Gavelinopsis praegeri-Cibicides wuellerstorfi* biofacies, indicating the Pacific Intermediate Water (water depth between 1500 and 2400 m); (3) *Tosaia hanzawai-Globocassidulina muloccensis* biofacies, *Valvulineria gunjii* biofacies, and the *Melonis barleeanus-Melonis sphaeroides* biofacies, which characterize the lower bathyal zone; (4) the *Nuttallides umbonifera* biofacies, which characterizes the interval between the lysocline (approximately 3500 m) and the carbonate compensation depth (approximately 4500 m); and (5) the *Rhabdammina abyssorum* biofacies representing the abyssal zone below the carbonate compensation depth.

Benthic foraminiferal patterns are used to construct paleobathymetric and paleogeographic profiles of the New Hebrides Island Arc and North d'Entrecasteaux Ridge for the following age boundaries: late Miocene/Pliocene, early/late Pliocene, Pliocene/Pleistocene, and Pleistocene/Holocene.

INTRODUCTION

The New Hebrides Island Arc is located in the western part of the equatorial Pacific Ocean and marks the boundary between the Australia-India Plate and the North Fiji Basin. Two hypotheses have been proposed to account for the origin of this island arc, including (1) a reversal in subduction polarity sometime between 8 and 6 Ma (Chase, 1971), and (2) a continuous eastward subduction zone throughout the Neogene (Luyendyk et al., 1974). Alternatively, the reconstructions of the New Hebrides Island Arc proper mainly are based on biostratigraphic, lithostratigraphic, and sedimentologic data obtained from Cenozoic sequences distributed on Espiritu Santo, Malakula, Maewo, and Pentecost islands in the central part of New Hebrides Island Arc (e.g., Macfarlane et al., 1988).

During the Ocean Drilling Program (ODP) Leg 134, drilling at seven sites (Sites 827–832) penetrated Cenozoic sediments in the New Hebrides Island Arc and on the d'Entrecasteaux Zone (DEZ) to investigate the process of ridge-arc collision and to refine the geologic history of the arc. Drilling sites are situated in two major areas including the d'Entrecasteaux-New Hebrides Island Arc collision zone and the intra-arc North Aoba Basin. Specific sites used for this study consist of Site 828 on the North d'Entrecasteaux Ridge (NDR), Sites 827 and 829 on the accretional prism off Espiritu Santo Island of the Western Belt of the New Hebrides Island Arc, and Site 832 located in the central part of the North Aoba Basin (Fig. 1 and Table 1). This study uses quantitative analysis of benthic foraminiferal biofacies at these sites to delineate Neogene faunal change in the Vanuatu region and as a basis for reconstructing the paleobathymetric history of the New Hebrides Island Arc.

LITHOSTRATIGRAPHY AND AGE

The Leg 134 Shipboard Scientific Party (Collot, Greene, Stokking, et al., 1992a–d) described the lithostratigraphy and ages of Sites 827, 828, 829, and 832 as summarized below:

Site 827

The sediment of Site 827 consists of Pleistocene volcanic silt (Unit I), and upper Pliocene siltstone (Unit II). Basal units consist of calcareous siltstone interbedded with sed-lithic conglomerate and breccia (Unit III), and volcanic sandstone (Unit IV).

Site 828

The Cenozoic strata of Site 828 are divided into three units: Unit I (Pleistocene silt or siltstone), Unit II (lower Pliocene foraminiferal ooze), and Unit III (Oligocene nannofossil chalk).

Site 829

The Cenozoic strata penetrated at Site 829 are sheared by many thrust faults, and are composed of 16 lithostratigraphic units (I to XVI) as identified in cores. The lithologic characteristic of each unit is as follows: Units I and III consist of the Pleistocene clayey volcanic silt. Unit II is represented by upper Oligocene to lower Miocene foraminiferal chalk. Units IV and V are deformed siltstone and chalk and chalk-breccia. Unit VI is characterized by middle Oligocene to lower Miocene calcareous chalk. Units VII and XVI consist of Oligocene ig-lithic breccia. Unit VIII is represented by lower Pliocene foraminiferal chalk. Unit IX contains Pleistocene volcanic silty chalk. Units X of middle to upper Oligocene age and XII of lower to upper Oligocene age are characterized by calcareous chalk. Unit XI of upper Pliocene to Pleistocene age is represented by foraminiferal chalk. Unit XIII is composed of Pliocene or lower Pleistocene volcanic sandstone. Unit XIV is mixed sedimentary rock of Oligocene nannofossil chalk and foraminiferal chalk and clay of Pliocene to Pleistocene age. Unit XV consists of Pliocene to Pleistocene sandy volcanic siltstone.

[1] Greene, H.G., Collot, J.-Y., Stokking, L.B., et al., 1994. *Proc. ODP, Sci. Results,* 134: College Station, TX (Ocean Drilling Program).
[2] Nagoya Jiyu Gakuin Junior College, Furui 281, Kumanosho, Shikatsu-cho, Nishikasugai-gun, Aichi Prefecture, 481, Japan.

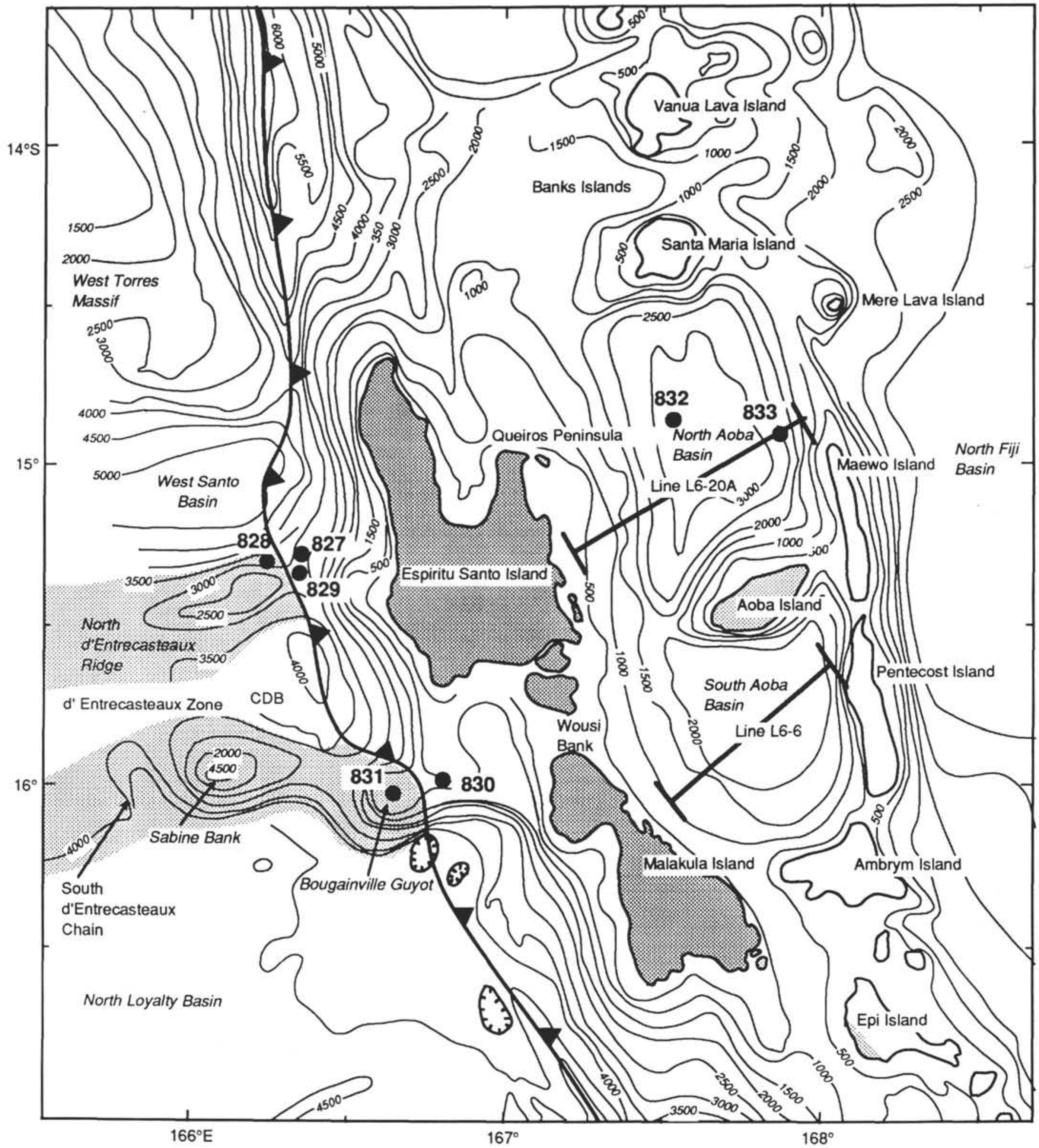

Figure 1. Location of ODP Sites 827–833. Bathymetry in meters.

Site 832

Neogene strata penetrated at Site 832 are divided into lithostratigraphic Units I to VII. The dominant lithologies in Unit I are Pleistocene sandy to clayey volcanic silts. Unit II consists of Pleistocene sandstone, siltstone, and claystone. The Pleistocene sediments of Unit III are characterized by a high abundance of calcareous biogenic materials such as nannofossils and foraminifers. Unit IV consists of upper Pliocene basaltic volcanic sand and breccia. Unit V is predominantly composed of limestone and siltstone of late Miocene to early Pliocene age. Units VI and VII consist of volcanic sandstone and basaltic breccia and volcanic sand of middle to late Miocene age, respectively.

Table 1. Location of ODP sites discussed.

Site	Latitude	Longitude	Depth (m)	Geographic position
827	15°17.741′S	166°21.16′E	2803	Accretional prism off Espiritu Santo Island
828	15°17.34′S	166°17.04′E	3087	North d'Entrecasteaux Ridge
829	15°18.96′S	166°20.7′E	2905	Accretional prism off Espiritu Santo Island
832	15°47.78′S	167°34.35′E	3089	Northwestern margin of seafloor of North Aoba Basin

SEDIMENTOLOGICAL ANALYSIS

To delineate the origin and nature of the lithostratigraphy at Sites 827, 828, 829, and 832, sediment samples were examined in the laboratory. Prior to choosing foraminifers, each sample was examined for selected biogenic and inorganic grains greater than 0.125 mm in diameter using a stereomicroscope. The occurrences of coral fragments, pteropods, bivalves, gastropods, echinoid spines, sponge spicules, radiolarians, diatoms, pellets, and plant fragments were counted along with conspicuous inorganic grains of calcite, glauconite, manganese micro-nodules, framboidal pyrite, and chalcopyrite. Figures 2 through 5 show the distribution of these selected materials at each site.

Sites 827 and 829

Plant fragments occur abundantly in the Holocene and Pleistocene sediment at Sites 827 and 829, whereas manganese micro-nodules are found only in the calcareous chalk (lithostratigraphic Units XII and XIV) in the basal part of the sequence at Site 829 (Figs. 2 and 3). Mud comprises more than 85% of most samples at Sites 827 and 829, but ranges from 45% to 90% in Units VII–X (407–436 meters below seafloor [mbsf]) and Units XIII and XIV (463.6–494.77 mbsf) at Site 829. Lower percentages of mud are accompanied by increases in volcanic materials or planktonic foraminiferal tests.

Site 828

The occurrences of plant fragments are restricted to Pleistocene sediment of Unit I, whereas manganese micronodules are restricted to Oligocene sediments of Unit III (Fig. 4). Mud comprises more than 95% of the Oligocene sediment of Unit III, about 20% of the Pliocene sediment of Unit II and from 80% to 95% of the Pleistocene strata of Unit I. This value rapidly decreases at the boundary between Units II and III, but gradually increases near the boundary between Units I and II. The samples with less mud are accompanied by abundant planktonic foraminiferal tests (Fig. 4).

Site 832

Radiolarian tests total more than 1000/g in Holocene strata, but are less abundant (>100/g) in Pliocene and upper Miocene strata (Fig. 5). Plant fragments occur in both Pleistocene and upper Miocene strata. Samples 134-832B-44R-1, 66–68 cm (lower Pleistocene volcanic clastic sediment), are marked by the occurrence of ferro-manganese oxide grains (>30/g).

Sediment between 0 and 385.84 mbsf and between 630 and 847 mbsf are characterized by high mud content (>80%), whereas mud comprises 20% to 80% of sediment between 397 and 630 mbsf and below 847 mbsf. Lower mud content is coincident with the occurrence of volcanic sediment in Units II, III, VI, and VII.

The distribution of the various grain types noted above are useful for recognizing paleogeographic and sedimentary environments by comparing with the mud content of Holocene sediment. For example, plant fragments are rare or absent around small islands (Akimoto, 1991). Thus, the occurrences of plant fragments from strata at Sites 827, 828, 829, and 832 may imply the existence of a sedimentary basin with a nearby large land area during the late Miocene and Pleistocene. The restricted occurrence of manganese micronodules at Site 829 suggests that they were reworked from Oligocene deposits on the NDR.

BENTHIC FORAMINIFERAL BIOSTRATIGRAPHY

Materials and Methods

Samples analyzed in this study were collected from cores drilled at Sites 827, 828, 829, and 832; all four sites are presently located at lower bathyal water depths (Table 1). Each sample analyzed consists of about 15 cm^3 of sediment. Unconsolidated sediment samples were washed on a 63-µm sieve screen and dried. Rock samples were dried in an oven and then treated with a saturated sodium sulfate solution and naphtha for disintegration (Maiya and Inoue, 1973) and with sodium tetraphenylborate (Yasuda et al., 1985). The samples were then wet-sieved through a 63-µm screen and redried.

Benthic foraminiferal specimens are generally rare and moderately to poorly preserved in the samples analyzed. Only samples containing better preserved specimens were quantitatively analyzed. Each sample analyzed was divided by a sample splitter into aliquot parts. In most cases, 100 or more specimens of benthic and planktonic foraminifers larger than 0.125 mm were picked from an aliquot under a binocular microscope. Finally, 102 samples were selected for benthic foraminiferal analysis based on their stratigraphic location and biohorizons of key species.

General Microfaunal Trends and Microfaunal Analysis

The distribution of foraminifers in the modern ocean is fundamentally in harmony with the distribution of water masses and patterns of surface water currents (Akimoto, 1990). To reconstruct paleoenvironments, statistical distributions of both fossil and Holocene assemblages were compared. Statistical measures applied include planktonic foraminiferal number, benthic foraminiferal number, the damaged planktonic foraminifers/total planktonic foraminifers (DPF/TPF) ratio, planktonic foraminifers/total foraminifers (P/T) ratio, and agglutinated foraminifers/total benthic foraminifers (A/T) ratio. Figure 6 includes a generalized pattern of P/T and A/T ratios in the modern tropical Pacific Ocean.

Planktonic foraminiferal numbers and benthic foraminiferal numbers represent the number of specimens of planktonic and benthic foraminifers contained in 1 g of dry sediment. The P/T ratio represents the ratio of planktonic foraminifers to total foraminifers (planktonic and benthic foraminifers) in a sample. Lower P/T ratios commonly occur beneath coastal water and in deep-water environments below the foraminiferal lysocline. The A/T ratio represents the ratio of agglutinated foraminifers to total benthic foraminifers (agglutinated and calcareous benthic foraminifers). High values of this ratio may indicate special water mass conditions such as the prevalence of low pH conditions or deposition below the carbonate compensation depth (CCD). The DPF/TPF ratio represents the difference between the number of broken foraminiferal tests to complete tests of planktonic foraminifers. High values of this ratio may reflect abrasion by strong waves or dissolution. Stratigraphic variations in the distribution of the selected sedimentary constituents (e.g., manganese micronodules, plant remains, etc.), as well as general microfaunal parameters, including planktonic and benthic foraminiferal numbers, DPF/TPF, and P/T and A/T ratios for all sites studied are illustrated in Figures 2 through 5.

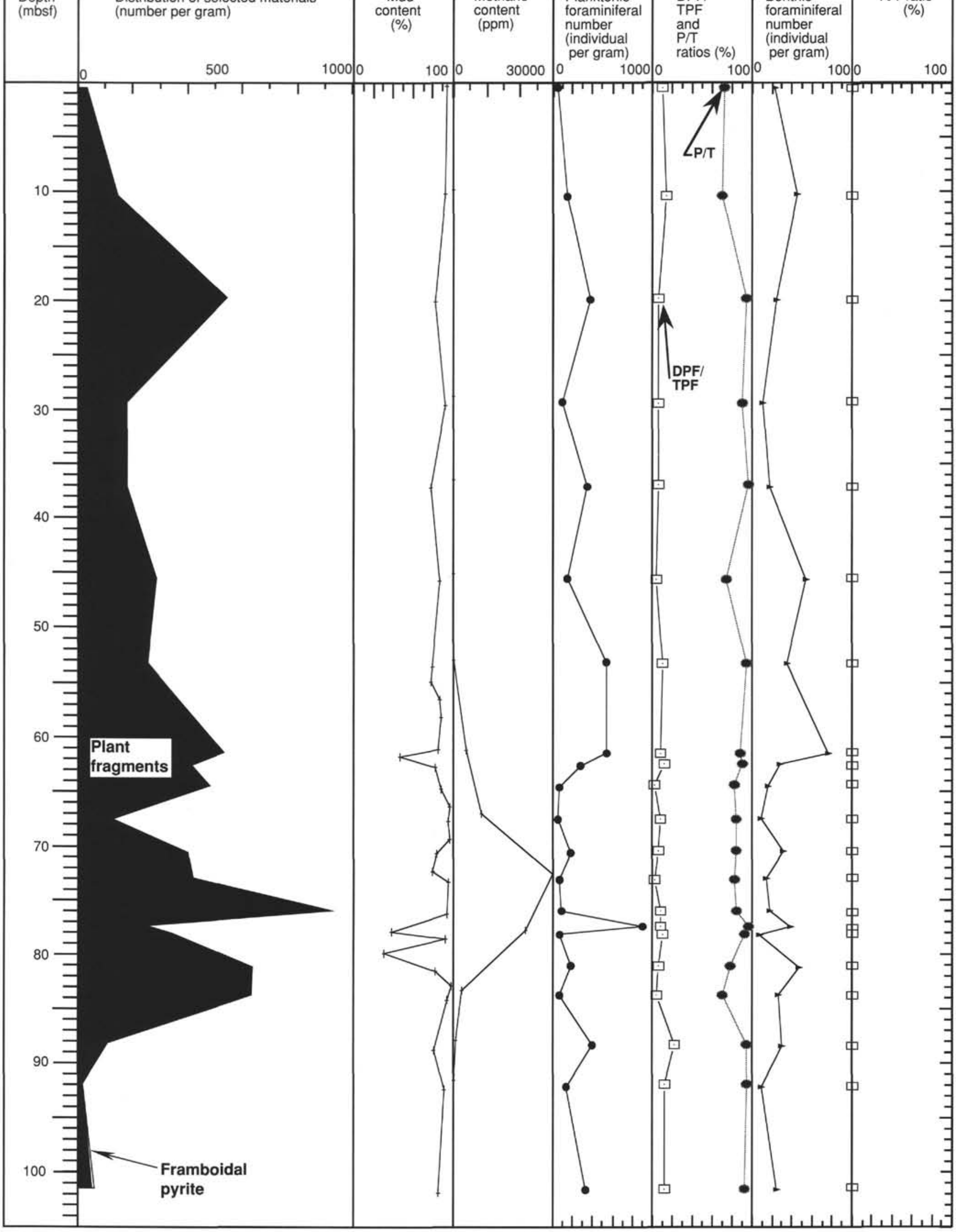

Figure 2. Stratigraphic distribution of selected sedimentary constituents, mud content, planktonic foraminiferal number, benthic foraminiferal number, damaged planktonic foraminifers/total planktonic foraminifers (DPF/TPF) ratio, planktonic foraminifers/total foraminifers (P/T) ratio, and agglutinated foraminifers/total benthic foraminifers (A/T) ratio at Site 827.

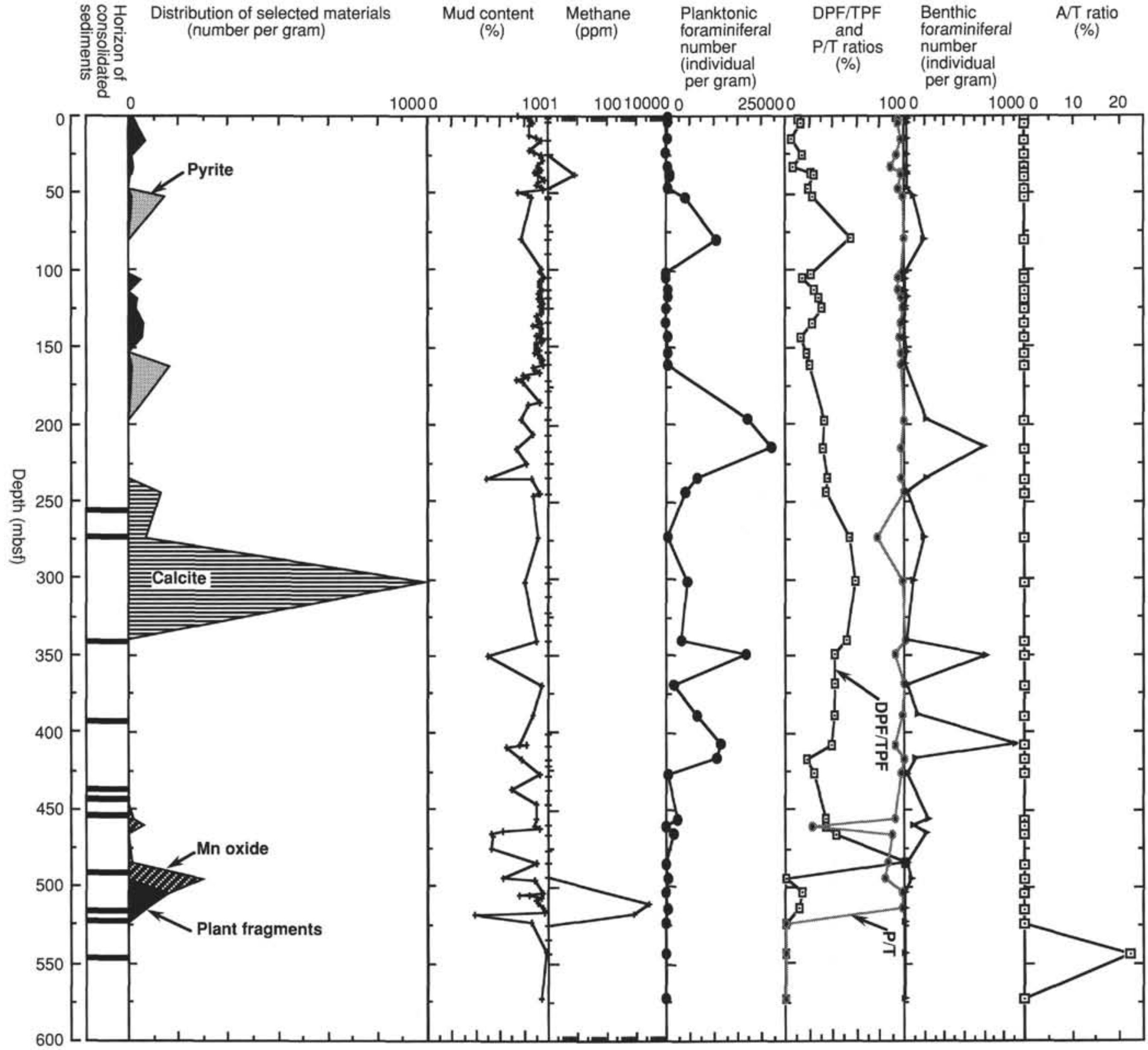

Figure 3. Stratigraphic distribution of selected sedimentary constituents, mud content, planktonic foraminiferal number, benthic foraminiferal number, damaged planktonic foraminifers/total planktonic foraminifers ratio, planktonic foraminifers/total foraminifers ratio, and agglutinated foraminifers/total benthic foraminifers ratio at Site 829.

Bathymetric Zonation and Species Distribution

Studies of benthic foraminifera in the modern Pacific Ocean have shown that foraminiferal biofacies are well correlated with individual water masses (e.g., Burke, 1981; Hermelim, 1989). Burke (1981) identified specific foraminiferal biofacies associated with the Pacific Intermediate Water (PIW), Pacific Deep Water (PDW), and Pacific Bottom Water (PBW). These latter three water masses occupy depth intervals ranging from 1200 to 2400 m, from 2500 to 3000 m, and from 3000 to 4000 m, respectively.

Several authors have reported relationships between benthic foraminiferal species and physiochemical properties such as dissolved oxygen and substrate type (Burke, 1981; Hermelim, 1989). Older studies have included information on depth distributions of living species and fossil occurrences in the Neogene sequences of the Vanuatu area (Cushman, 1921, 1932, 1933, 1942; Cushman et al., 1954; Todd, 1965).

The following depth classification was used in this study: sublittoral zone (0–150 m), upper bathyal zone (150–500 m), upper middle bathyal zone (500–1500 m), lower middle bathyal zone (1500–2000 m), lower bathyal zone (2000–4000 m), and abyssal zone (below 4000 m). Figure 6 shows the relationships between bathymetric zones, water masses, and depth distributions of the major species in the modern equatorial Pacific Ocean region. These Pacific data were used to interpret paleoenvironmental and paleobathymetric change at the sites studied.

Factor Analysis

Factor analysis (Q-mode) was used to reduce the data into meaningful groups. Factors are patterns reflecting the distribution of variables. A variable, in this case a foraminifer, can have a similarity to a factor (factor loading) ranging from +1.0 to −1.0. In this analysis, any

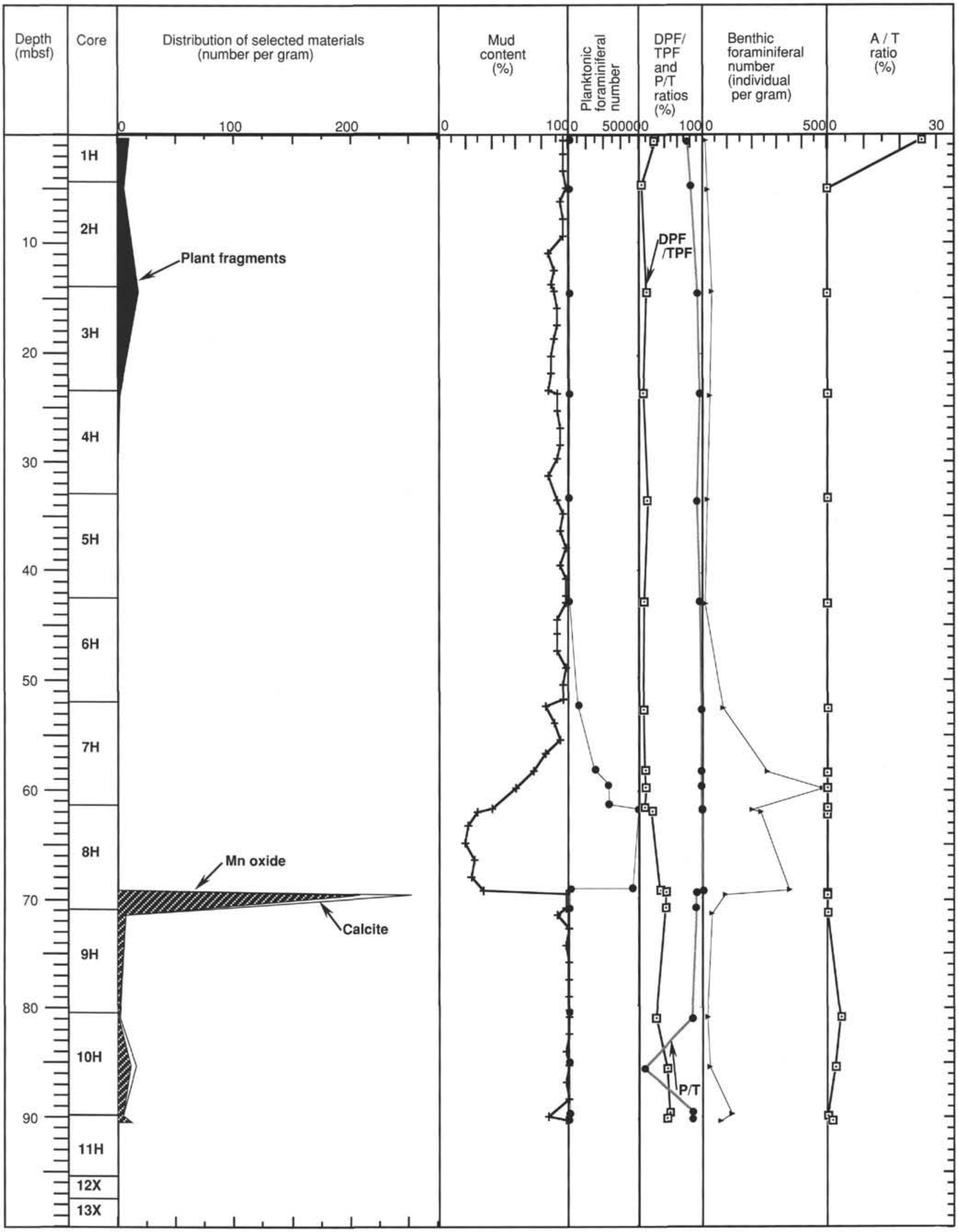

Figure 4. Stratigraphic distribution of selected sedimentary constituents, mud content, planktonic foraminiferal number, benthic foraminiferal number, damaged planktonic foraminifers/total planktonic foraminifers ratio, planktonic foraminifers/total foraminifers ratio, and agglutinated foraminifers/total benthic foraminifers ratio at Site 828.

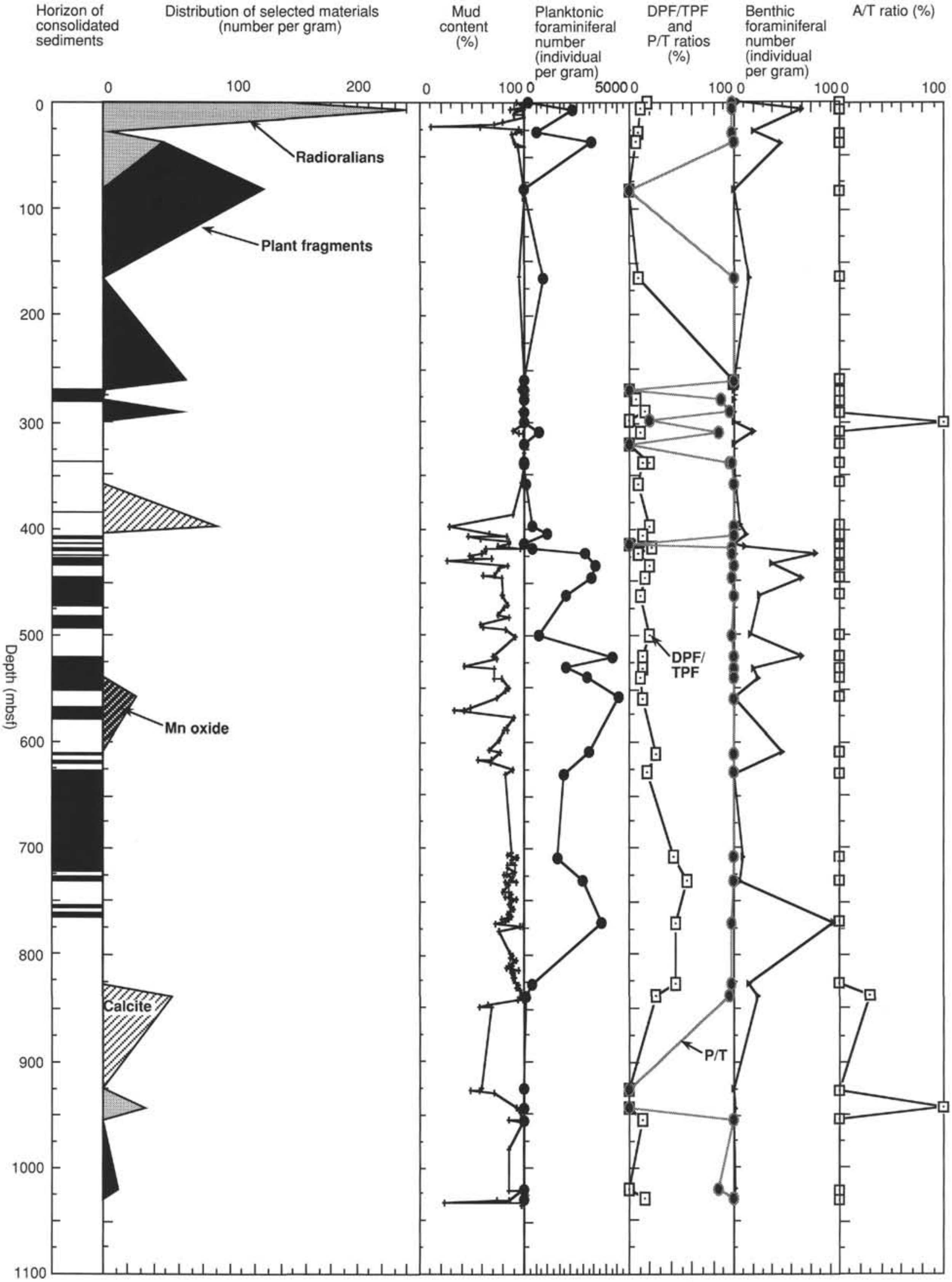

Figure 5. Stratigraphic distribution of selected sedimentary constituents, mud content, planktonic foraminiferal number, benthic foraminiferal number, damaged planktonic foraminifers/total planktonic foraminifers ratio, planktonic foraminifers/total foraminifers ratio, and agglutinated foraminifers/total benthic foraminifers ratio at Site 832.

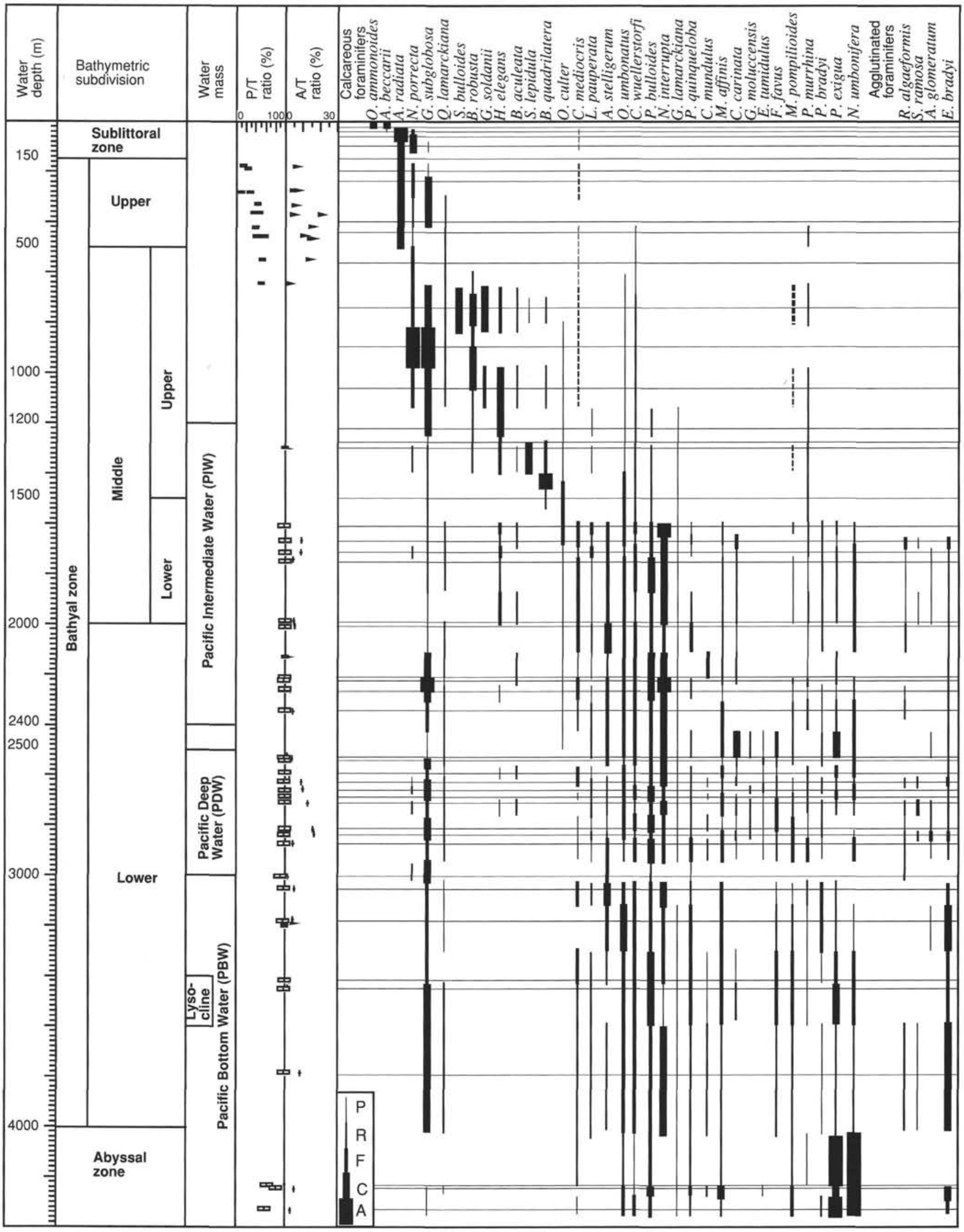

Figure 6. General bathymetric zonation, generalized water masses, foraminiferal statistics, and depth distribution of major benthic foraminiferal species in the modern tropical Pacific Ocean (Burke, 1981: Ontong Java Plateau area; Kurihara and Kennett, 1986: New Caledonia area; Oki, 1985, 1988: Fiji area).

variable with a factor loading greater than |0.5| can be said to be related to a factor. A sample can be related to a factor by factor scores. A sample is strongly related to a factor when its score exceeds 1.0. A varimax rotation of the factors produces a less abstract result because each varimax factor is constrained to have a faunal composition very similar to that actually observed in at least one sample (Davis, 1973).

In this study, benthic foraminifers from the Cenozoic sediment at Sites 827, 828, 829, and 832 were identified and listed in Tables 2 through 5 (back pocket fold out, this volume). Factor analysis with a varimax rotation was performed to detect major environmental factors that likely controlled the distribution of benthic foraminifera in the Cenozoic sequences analyzed at Sites 827, 828, 829, and 832. The data matrix for this analysis is composed of 99 samples (61 at Site 827 and 829, 17 at Site 828, and 21 at Site 832) selected from a total of over 600 sediment samples examined. In addition, the matrix includes 58 species at Sites 827 and 829, 45 species at Site 828, and 49 species at Site 832, out of 427 benthic foraminifer taxa identified, which are represented by five or more individuals in two or more samples at each site listed in Tables 2 through 5. Statistical analysis was performed using a Macintosh personal computer and US SPSS, Inc., software.

Factor analysis identified five factors that account for 70.2% of the variability of data analyzed from Sites 827 and 829 (Table 6), 4 factors that account for 59.0% of the variability at Site 828 (Table 7), and 6 factors that account for 53.2% of the variability at Site 832 (Table 8). Tables 9, 10, and 11 list the varimax factor scores for each species within each factor at Sites 827 and 829, 828, and 832, respectively.

Table 6. Summary of factor analysis at Sites 827 and 829.

Factor	Eigenvalue	Percent of variable	Cumulative percentage
1	12.05218	22.7	22.7
2	11.57922	21.8	44.6
3	3.41241	6.4	51.0
4	2.35159	4.4	55.5
5	1.86327	3.5	59.0

Table 7. Summary of factor analysis at Site 828.

Factor	Eigenvalue	Percent of variable	Cumulative percentage
1	6.48879	38.2	38.2
2	2.37768	14.0	52.2
3	1.84595	10.9	63.0
4	1.29921	7.6	70.7

Table 8. Summary of factor analysis at Site 832.

Factor	Eigenvalue	Percent of variable	Cumulative percentage
1	4.09185	19.5	19.5
2	2.10145	10.0	29.5
3	1.85353	8.0	38.3
4	1.66389	7.9	46.2
5	1.45706	6.9	53.2
6	0.90217	4.3	57.5

Sites 827 and 829

The stratigraphic distributions of the factor loadings and assemblages in the sequences at Sites 827 and 829 are illustrated in Figures 7 and 8. Assemblage I is recognized by Factor 1 at only Site 829, and it accounts for 22.7% of the variance. This assemblage is characterized by abundant *Globocassidulina subglobosa,* which dominates Unit II (Pliocene) and III (Oligocene) at Site 828. *G. subglobosa* is associated with the shallow-water mass of the modern Pacific Ocean (Woodruff, 1985), whereas Site 829 is currently located beneath the Pacific Bottom Water at a depth of 2900 m. In addition, Assemblage I is found in Unit II and within the interval of Units V to XI of Hole 829A. The samples from these lithostratigraphic units, which have high positive first factor loading, are composed of Eocene to Oligocene sediment accompanied with manganese micronodules. This suggests that Factor 1 reflects the downslope transport of Eocene and Oligocene sediments from the North d'Entrecasteaux Ridge.

Assemblage II is represented by Factor 2, and accounts for 21.8% of the variance. This assemblage is dominated by *Valvulineria gunjii* and is distributed in Pleistocene and Holocene strata at Sites 827 and 829, which are located beneath the Pacific Deep Water. On the other hand, the *V. gunjii* assemblage is poorly represented in Quarternary sediment at Site 832, which is situated at a depth of 3089 m. Thus, the *V. gunjii* assemblage indicates the boundary between the Pacific Deep Water (PDW) and Pacific Bottom Water (PBW). The subordinate species, *Uvigerina peregrina,* is also common in sediment beneath the PBW (Hermelin, 1989). Factor 2 is thus thought to express the boundary between the PDW and PBW.

The distribution of Assemblage III, which accounts for 6.4% of the variance, is restricted to Site 827. This assemblage is recognized by Factor 3, and is composed of *Cassidulina norvangi, Trifarina angulosa,* and *Gyroidinoides nipponicus.* These three species occur widely in the bathyal zone of the modern Pacific Ocean. Thus, the third factor loading is related to neither water depth nor water masses. *C. norvangi* occurs abundantly in association with low oxygen bottom waters in the modern northwest Pacific Ocean (Nishi, 1992).

This study also examined the relationship between organic carbon and sediment character. High abundance of organic carbon may be implied by the presence of plant fragments as found in the intervals from 37 mbsf (Sample 134-827A-5H-01, 50–54 cm) to 67.5 mbsf (Sample 134-827A-9H-01, 44–49 cm), and from 81 mbsf (Sample 134-827A-11H-03, 49–51 cm) to 88.3 mbsf (Sample 134-827A-13H-01, 49–51 cm) of the Pleistocene strata (Fig. 2). These latter samples are coincident with positive higher values of the third factor as shown in Figure 7. Hence, the prevalence of organic-carbon-rich conditions likely indicate positive factor loading of Factor 3. In turn, organic-rich conditions may have reduced the oxygen content of water immediately overlying sediment and of interstitial waters in sediment.

Assemblage IV is represented by Factor 4 and accounts for 4.4% of the variance. This assemblage is characterized by the occurrence of *Melonis barleeanus* and is found only in the Pleistocene and Holocene sediment. *M. barleeanus* is common in sediment beneath the Pacific Bottom Water (Woodruff, 1985). *Nuttallides umbonifera,* which is common at water depths between the lysocline and the CCD in the PBW, is absent in this assemblage. Assemblage IV is thus regarded as indicative of the upper part of the PBW.

Assemblage V accounts for 3.5% of the variance and is marked by *Bolivinita quadrilatera* and *Bulimina aculeata.* These two species are abundant in sediment beneath the Pacific Intermediate Water (Cushman, 1942). Thus Factor 5, which is recognized by Assemblage V, is considered to be indicative of the PIW.

Site 828

Based on the stratigraphic distribution of higher factor loadings, the faunas in the Site 828 sequence are divided into three assemblages: I, II, and III (Fig. 9). Assemblage I is recognized by Factor 1 and occurs in lithostratigraphic Unit III. It accounts for 38.2% of the variance and is dominated by *Turrilina brevispira,* which is accompanied by *Globocassidulina subglobosa* and *Stilostomella lepidula. T. brevispira* is most common in Paleogene bathyal deposits, but it also occurs in Eocene abyssal paleoenvironments (van Morkhoven et al., 1986). However, the lithofacies accompanying Assemblage I is a nannofossil

Table 9. Factor scores at Sites 827 and 829.

Species	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Ammobaculites sp.	–0.64026	–0.08640	1.48057	–0.11110	0.06112
Anomalinoides globulosa (Chapman and Parr)	–0.25802	–0.21195	–1.46165	–0.22894	0.52295
Astrononion stelligrum (d'Orbigny)	–0.84815	–1.61777	2.77931	–0.38626	1.18904
Bolivina robusta Brady	–0.19496	1.39173	–1.77065	–0.88250	–1.16572
B. subangularis leneata (Cushman)	–0.30606	0.27071	–1.88463	0.76667	–0.71263
Bolivinita quadrilatera (Brady)	–0.02211	0.26548	–0.40477	–0.48961	5.62382
Brizalina alata (Seguenza)	–0.26115	0.08163	2.41010	0.69897	0.68583
B. hantkeniana (Brady)	–0.27038	–1.10801	2.63937	0.18067	1.36323
B. karreriana (Brady)	–1.24146	–2.10030	1.67049	1.03283	1.60097
B. pygmea (Brady)	–0.24245	–0.34649	2.21402	–0.54413	–1.50640
B. seminuda (Cushman)	–0.19540	–0.04988	0.15125	–0.41784	–1.20688
B. sp.	–0.30230	–0.18753	–0.34653	–0.39691	–0.38087
Bulimina aculeata d'Orbigny	–1.07579	0.77239	–2.25074	–1.26492	3.46094
B. ampliaperture Belford	0.00206	0.58339	0.32599	–0.44363	–0.97649
B. glomachallengeri Tjalsma and Lohmann	1.42323	0.06083	–1.60996	–0.62891	–0.91168
B. marginata d'Orbigny	–0.25922	1.58309	–1.96553	–0.10076	–0.96051
B. striata d'Orbigny	–0.28150	–1.03893	0.72790	0.32135	–0.62061
Burseolina pacifica (Cushman)	0.84075	–0.56360	–0.83818	–0.55608	–0.87589
Cassidulina carinata Silvestri	–0.27122	0.44778	0.03267	0.27197	–0.83810
C. havanensis Cushman and Bermudez	–0.33756	–0.78082	1.46993	–0.12024	0.00522
C. norvangi Thalmann	–0.24048	–0.49977	4.61784	–1.23178	–0.46857
Cibicides wuellerstorfi (Schwager)	–1.22085	–1.99967	0.40479	0.35082	0.57621
Cibicidoides mediocris (Finlay)	1.56989	–0.11668	–0.57361	0.36259	–0.05883
Ehrenbergina hystrix Brady	–0.69871	0.27264	2.90140	0.72701	0.07199
Fijiella simplex (Cushman)	–0.12225	–0.21825	2.28681	–0.56720	–0.59113
Globocassidulina cressa (d'Orbigny)	–0.87587	–1.90568	1.72578	0.36660	0.57767
G. cf. decorata (Sidebottom)	0.72127	–0.27139	1.34662	0.00434	–0.18982
G. moluccensis (Germeraad)	–0.26330	0.45538	–1.01391	–1.15296	1.77403
G. mucronata Nomura	0.52619	0.19202	–2.54382	–0.74382	–0.14463
G. ornata (Cushman)	1.08398	0.21643	–1.77100	–0.63103	–0.62591
G. paratortuosa (Kuwano)	–0.45768	–1.16601	–3.60627	–0.48165	0.70510
G. subglobosa (Brady)	6.55854	0.39948	0.52412	0.16208	0.34510
G. subtumida (Cushman)	1.55635	0.46972	–1.56422	–0.70545	–0.67340
Gyroidina orbicularis d'Orbigny	1.53439	0.69160	–4.46278	–1.21417	–0.72793
Gyroidinoides lamarckianus (d'Orbigny)	0.09071	0.81404	–0.83339	–0.44140	–1.01606
G. nipponicus (Ishizaki)	–0.30940	–0.21647	3.13782	2.27473	1.78091
Melonis barleeanus (Williamson)	–0.06671	–0.34877	–0.47483	5.92740	–0.31632
M. pacificus (Cushman)	–0.86585	–0.10062	–1.41826	–0.00716	1.12283
Oridorsalis tener (Brady)	–0.23092	1.06944	–1.44458	1.37665	–0.80691
O. umbonatus (Reuss)	–0.69965	–0.67122	1.46575	0.07880	0.42088
Osangularia culter (Parker and Jones)	0.43765	–0.45683	0.65679	0.02412	–0.29237
Pseudoparrella exigua (Brady)	–0.14680	0.03184	1.45132	–0.28614	–1.21421
Pullenia quinqueloba (Reuss)	–1.96718	–2.01633	2.28425	0.71993	1.11164
Robulus gibbus d'Orbigny	–0.23219	2.24199	–1.23830	0.25929	–1.45779
Rutherfordoides cornuta (Cushman)	0.63002	1.08663	–0.54521	0.26019	–2.79421
Sigmavirgulina tortuosa (Brady)	–0.01406	–1.50206	–1.40281	–0.30235	0.29389
Sphaeroidina bulloides d'Orbigny	–0.11171	–0.72262	1.50948	0.24206	–1.66314
Stilostomella abyssorum (Reuss)	0.74903	0.26550	–0.86402	–0.71043	–0.30237
S. lepidula (Schwager)	0.84610	–0.68374	–0.17186	–0.32256	0.09814
S. sp. A	–0.73518	–0.05427	0.26240	–0.20314	–0.16171
Trifarina angulosa (Williamson)	–2.66156	–1.57137	3.22915	0.91942	1.39169
T. bradyi Cushman	0.67874	–0.42975	2.48458	0.21566	–0.99570
Turrilina brevispira ten Dam	–0.53895	0.02600	–1.18639	–0.60816	0.12468
Uvigerina hispidocostata Cushman and Todd	0.25593	1.11572	–1.27229	–0.06188	–0.64301
U. peregrina Cushman	0.38243	2.98401	–4.37684	–0.87327	–1.30413
U. proboscidea Schwager	0.60654	–0.27436	–1.83804	–0.61404	0.42123
U. cf. tasmana Boersma	–0.53503	–1.45115	–1.37380	–0.11888	0.77696
Valvulineria gunjii Akimoto	–0.53571	6.97919	0.31839	0.30510	0.44213

chalk. Modern analogs to the chalk lithofacies are found in the abyssal zone between the lysocline and the CCD (Kennett, 1982). The distribution of the first factor loading coincides with that of the planktonic foraminiferal numbers and P/T ratio, as shown in Figure 3. This coincidence supports the abyssal inference of variance for Factor 1. Therefore, Assemblage I is considered to be indicative of the Oligocene abyssal zone above the CCD.

Assemblage II at Site 828 accounts for 14.0% of the variance and is represented by Factor 2. This assemblage is dominated by *Globocassidulina subglobosa,* which occurs abundantly in shallow water in the modern ocean (Woodruff, 1985). Todd (1965) reported that *G. subglobosa* is distributed in water depths of 600 to 1200 m in the modern Pacific Ocean and occurs in areas of high calcium carbonate concentration surrounding islands and plateaus. This assemblage zone also corresponds to lithostratigraphic Unit II (foraminiferal ooze). Thus, Factor 2 suggests the presence of a shallow-water mass above the PIW surrounding a plateau.

Assemblages III and IV are recognized in Unit I. Assemblages III and IV, accounting for 10.9% and 7.6% of the variance, respectively, are represented by Factors 3 and 4 and are dominated by *Valvulineria gunjii* and *Oridorsalis tener,* respectively. *V. gunjii* is common in sediment beneath the boundary between Pacific Deep Water and Pacific Bottom Water. Thus, Factor 3 may imply the presence of the boundary between the PDW and PBW.

No data are available for the modern distribution of *O. tener* in the equatorial Pacific Ocean. However, this species is a typical deep water species and is distributed in the middle bathyal zone of the modern world ocean (e.g., Pflum and Frerichs, 1976; Akimoto, 1990). Although Site 828 is situated in the lower bathyal zone (about 3000 m in water depth), the sample from the top of the sequence at this site yields abundant *O. tener.* Thus, the fourth factor loading cannot be explained by water depth or water mass. On the other hand, samples having high fourth factor loadings are characterized by low mud content and include many plant fragments. These associations indicate that Assemblage IV was likely derived from the lower middle bathyal zone off Espiritu Santo Island and transported by turbidity currents. Thus, Factor 4 suggests the transport of sedimental organic matter from the island.

Table 10. Factor scores at Site 828.

Species	Factor 1	Factor 2	Factor 3	Factor 4
Astrononion stelligrum (d'Orbigny)	0.70936	−0.23461	0.05902	−0.61290
Bolivinita quadrilatera (Brady)	−0.38794	−0.13707	0.16053	−0.20350
Brizalina alata (Seguenza)	−0.31303	−0.40886	−0.10359	−0.18545
B. macella Belford	−0.38062	−0.15441	−0.38503	−0.23022
Bulimina glomachallengeri Tjalsma and Lohmann	0.60771	−0.61898	−0.45062	−0.54389
B. marginata d'Orbigny	−0.20251	−0.40356	0.43235	−0.02381
Burseolina marshallana (Todd)	−0.34105	−0.09072	−0.36124	−0.22274
B. sp.A	0.96672	−0.68839	−0.33014	−0.45257
Cassidulina norvangi Thalmann	−0.41872	−0.41303	0.44410	−0.10592
Chilostomella oolina Schwager	−0.22093	−0.40444	0.34303	0.05075
C. ovoidea Reuss	−0.22536	−0.35188	0.47273	−0.30614
Cibicides wuellerstorfi (Schwager)	−0.76744	0.68936	−0.35113	−0.09005
Cibicidoides sp.	−0.01492	−0.56237	−0.43892	−0.17216
Ehrenbergina bicornis Brady	−0.29787	−0.23593	−0.37479	−0.26722
Evolvocassidulina brevis (Aoki)	−0.38915	−0.08309	−0.10543	−0.21743
E. cf. brevis (Aoki)	−0.49368	−0.04718	−0.36122	−0.02272
Gavelinopsis praegeri (Heron-Allen and Earland)	−1.00635	1.55152	−0.30993	−0.25653
Globobulimina pacifica Cushman	−0.18294	−0.31809	0.87126	−0.37089
G. pupoides (d'Orbigny)	−0.19860	−0.40340	0.41207	−0.02676
Globocassidulina brocha (Poag)	−0.49667	0.20321	−0.25639	−0.31173
G. cressa (d'Orbigny)	−0.50757	0.08155	−0.36869	−0.07984
G. moluccensis (Germeraad)	−0.59469	0.50709	−0.37710	1.28479
G. mucronata Nomura	−0.69399	0.86417	−0.24885	0.52597
G. ornata (Cushman)	−0.44813	−0.00586	−0.39929	−0.23390
G. paratortuosa (Kuwano)	−0.40899	0.08598	−0.34169	−0.12438
G. parviapertura Nomura	−0.26861	−0.20451	−0.19656	0.24850
G. subglobosa (Brady)	2.83793	5.29493	0.17484	0.34131
G. subtumida (Cushman)	−0.36271	−0.16901	−0.40310	−0.22921
Gyroidina orbicularis d'Orbigny	−0.07816	−0.37538	−0.33520	−0.14883
Gyroidinoides lamarckianus (d'Orbigny)	0.09532	−0.43016	0.51044	−0.29737
G. nipponicus (Ishizaki)	−0.18997	−0.50658	−0.19290	0.98211
Nuttallides umbonifera (Cushman)	−0.89994	1.05028	−0.20784	−0.05453
Oridorsalis tener (Brady)	0.12320	−0.56560	0.10992	5.55251
O. umbonatus (Reuss)	1.30841	−0.28516	−0.31582	−0.92717
Osangularia culter (Parker and Jones)	−0.26802	−0.08055	−0.36031	−0.29089
Paracassidulina neocarinata (Thalmann)	−0.34778	−0.05089	−0.36548	−0.24305
Parafissurina pseudomarginata (Buchner)	−0.42422	0.16927	−0.34264	−0.36252
Pseudoparrella exigua (Brady)	−0.38293	−0.08912	−0.12444	0.26779
Pullenia bulloides (d'Orbigny)	0.56417	−0.10472	−0.36258	−0.49068
Stilostomella lepidula (Schwager)	1.66359	−0.52302	−0.34140	−0.43209
Tosaia hanzawai Takayanagi	−0.47879	0.15190	−0.34110	−0.23752
Turrilina brevispira ten Dam	4.62893	−1.69459	−0.26532	0.20433
Uvigerina hispidocostata Cushman and Todd	−0.22093	−0.40444	0.34303	−0.05075
U. proboscidea Schwager	−0.54092	0.46402	−0.34365	−0.29660
Valvulineria gunjii Akimoto	−0.05123	−0.06767	5.72909	−0.23459

Site 832

The distribution of the factor loadings in the Neogene sequence at Site 832 is illustrated in Figure 10; six assemblages are recognized in this Neogene sequence. Assemblage I, which is represented by Factor 1, accounts for 19.5% of the variance and is characterized by *Cibicides wuellerstorfi* and *Gavelinopsis praegeri.* Assemblage I is recognized in Pleistocene sediments from 397 to 461 mbsf and at 540 mbsf. The upper and lower depth limits of *G. praegeri* in the modern equatorial Pacific Ocean are 1100 m and 2000 m (Todd, 1965). *C. wuellerstorfi* is abundant below 1400 m water depth near the upper limit of the Pacific Intermediate Water (Fig. 6). Hermelin (1989) reported that *C. wuellerstorfi* is associated with the deep oxygen minimum layer of the PIW. Thus, Factor 1, represented by Assemblage I, is likely related to the presence of the PIW.

Assemblage II accounts for 10.0% of the variance and is marked by abundant *Globocassidulina subglobosa* accompanied by *Cibicidoides mediocris.* This assemblage is recognized by Factor 2 and is distributed in Pleistocene strata at this site. *G. subglobosa* is abundant in shallow waters but *C. mediocris* is common in deep waters (Woodruff, 1985). Thus, the second factor loading is not related to either water depth or water mass. According to sediment descriptions at this site (Collot, Greene, Stokking, et al., 1992d), many slumps occur in the middle and lower parts of the Pleistocene strata, which agrees with horizon having the high positive second factor loading. Thus, Factor 2 may reflect a transported fauna.

Assemblage III in Factor 3 accounts for 8.8% of the variance and is composed of *Melonis sphaeroides* and *Melonis barleeanus. M. sphaeroides* is restricted to the abyssal zone in the modern Pacific Ocean (Hasegawa, 1984), and *M. barleeanus* was common in sediment beneath the Pacific Bottom Water during the Miocene (Woodruff, 1985). Thus, Factor 3 is thought to indicate the PBW.

The fourth factor accounts for 7.9% of the variance and is dominated by *Rhabdammina abyssorum* (Assemblage IV). *R. abyssorum* is common at depths below the lysocline in the modern Pacific Ocean (Akimoto, 1990) and is abundant at depths below the CCD (Nienstedt and Arnold, 1988). In addition, the intervals represented by high positive Factor 4 loading accord with the distributions of low P/T and high A/T ratios as shown in Figure 5. Thus, Factor 4 is thought to indicate deposition below the lysocline and/or the CCD.

Assemblage V is represented by the occurrence of *Tosaia hanzawai* and *Globocassidulina moluccensis* and accounts for 6.9% of the variance. This assemblage is recognized by Factor 5. In the modern ocean, *T. hanzawai* dominates environments between depths of 3000 m and 4000 m (Akimoto, 1990). In addition, *G. moluccensis* is restricted to areas beneath the Pacific Deep Water, as shown in Figure 6. Thus, Assemblage V is related to the PDW.

Assemblage VI, which is characterized by the occurrence of *Nuttallides umbonifera,* is recognized by Factor 6 and accounts for 4.3% of the variance. *N. umbonifera* occurs most abundantly in sediment beneath the Pacific Bottom Water (Burke, 1981). Hermelin (1989) reported that this species is most common on the seafloor

Table 11. Factor scores at Site 832.

Species	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Marsipella cylindrica Brady	–0.54108	–0.38695	–0.32957	0.12509	–0.32587	–0.33208
Rhabdammina abyssorum M.Sars	–0.36682	–0.37933	–0.09329	5.80506	–0.40904	–0.11662
Trochammina globigeriniformis (Parker and Jones)	–0.57684	–0.39388	–0.32835	0.32114	–0.37619	–0.31375
Astrononion stelligrum (d'Orbigny)	2.07122	–0.48591	–0.19900	–0.35518	–0.22796	0.29526
Bolivinita quadrilatera (Brady)	–0.50302	–0.34999	–0.34097	–0.13822	–0.26076	–0.39236
Bulimina rostrata Brady	–0.41780	–0.21085	–0.47683	–0.37150	–0.28674	0.05524
Chilostomella ovoidea Reuss	–0.52160	–0.33715	–0.34595	–0.06667	–0.28051	–0.40548
Cibicides robertsonianus (Karrer)	–0.43617	0.13032	–0.35939	–0.48073	–0.33114	0.03039
C. wuellerstorfi (Schwager)	2.78452	1.75110	0.85498	–1.04859	–0.42782	–0.53905
Cibicidoides mediocris (Finlay)	–0.62513	2.52950	–0.02812	–0.95704	–0.27539	–0.74859
C. mundulus (Brady, Parker and Jones)	1.13492	–0.51882	0.38927	0.02735	–0.54638	–0.95661
Dentalina spp.	0.39309	–0.11262	–0.05775	–0.19299	–0.36249	–0.74876
Eponides tumidulus (Brady)	–0.33737	–0.14300	–0.78844	–0.28380	0.12955	–0.34722
Evolvocassidulina brevis (Aoki)	–0.39769	0.48284	–0.15748	–0.09125	–0.27065	–0.34307
Gavelinopsis praegeri	2.95705	–0.24609	–0.10285	–0.33869	–0.79531	0.22875
Globocassidulina cressa (d'Orbigny)	–0.40486	–0.17029	–0.51303	–0.39762	–0.30212	0.16123
G. elegans (Sidebottom)	–0.48613	–0.15918	–0.24164	–0.33113	–0.24969	–0.42064
G. moluccensis (Germeraad)	0.20718	–0.63940	–0.39134	–0.74874	2.71000	–0.34793
G. oriangulata (Belford)	0.10896	–0.40755	–0.04609	–0.14281	–0.23749	–0.46799
G. ornata (Cushman)	–0.17710	0.01270	–0.57079	–0.19896	–0.33225	–0.18895
G. paratortuosa (Kuwano)	–0.43721	–0.27169	–0.42252	–0.33232	–0.26367	–0.10375
G. parva (Asano and Nakamura)	–0.04474	–0.30961	–0.49592	–0.23256	–0.36025	–0.67705
G. parviapertura Nomura	–0.42621	–0.40591	0.03982	–0.05274	–0.06795	–0.21277
G. subglobosa (Brady)	–0.56348	4.60925	–0.34808	1.47387	0.34291	0.87760
G. subtumida (Cushman)	–0.48337	–0.19483	–0.25670	–0.32045	–0.24561	–0.41199
Gyroidina orbicularis d'Orbigny	0.32635	–0.33231	–0.20353	–0.37007	–0.30723	0.23666
Gyroidinoides lamarckianus (d'Orbigny)	0.08344	–0.46375	–0.71052	–0.67039	1.15507	2.05853
Melonis barleeanus (Williamson)	–0.61197	–0.72433	2.54552	–0.52602	–0.42936	0.44862
M. pacificus (Cushman)	–0.55778	–0.14504	–0.21899	–0.29822	0.01812	–0.46553
M. sphaeroides Voloshinova	–0.66295	0.09146	5.65309	0.02855	–0.30426	0.33192
Nodosaria longiscata d'Orbigny	–0.56726	0.01566	–0.20428	1.42544	–0.02768	–0.17837
Nuttallides umbonifera (Cushman)	–0.61831	–0.26744	–0.46554	–0.32893	–0.82043	4.40458
Oridorsalis tener (Brady)	–0.49558	–0.35512	–0.33898	–0.16685	–0.25286	–0.38711
O. umbonatus (Reuss)	2.19306	0.12570	–0.11660	0.76349	0.12969	1.69428
Parrelloides bradyi (Trauth)	–0.63966	–0.25930	–0.24580	–0.21620	0.37760	–0.49111
Pleurostomella alternans Schwager	0.15243	–0.52892	–0.33006	–0.53120	–0.32337	–0.01298
P. brevis Schwager	–0.68017	–0.69343	–0.00444	–0.24372	–0.40334	0.99951
Pseudoparrella exigua (Brady)	0.65890	–0.41545	–0.11550	1.17365	–0.19505	–0.42294
Pullenia bulloides (d'Orbigny)	2.38368	–0.02036	0.20193	1.11583	0.89698	–0.13482
P. quinqueloba (Reuss)	0.36465	–0.28056	–0.33803	–0.14356	–0.14800	–0.43969
P. salisburyi R.E. and R.C. Stewart	–0.42427	–0.23113	–0.45872	–0.35844	–0.27905	0.00224
Pyrgo lucernula (Schwager)	–0.79894	–0.49366	1.00225	–0.06542	–0.04612	–0.05569
P. murrhina (Schwager)	–0.01590	–0.21245	–0.75094	–0.29774	–0.11489	-0.31096
Quinqueloculina lamarckiana d'Orbigny	–0.44844	–0.43108	0.69456	–0.69600	–0.16816	–0.32064
Stilostomella abyssorum (Reuss)	–0.41176	–0.41685	0.16377	0.01869	–0.01552	–0.16078
S. lepidula (Schwager)	0.37463	2.06079	–0.39050	–0.47833	–0.55908	0.56732
Tosaia hanzawai Takayanagi	–0.16078	0.03263	0.81601	0.45630	5.12806	0.59270
Uvigerina hispidocostata Cushman and Todd	–0.33334	–0.44516	–0.42817	–0.54232	0.83846	–0.49596
U. proboscidea Schwager	–0.73465	1.96284	–0.49796	–0.34549	–0.09675	–1.03358

between the lysocline and the CCD. Factor 6 implies the PBW at depths between the lysocline and the CCD.

PALEOENVIRONMENTAL INTERPRETATION

Paleobathymetric Models

The paleodepths or paleobathymetry in the Vanuatu region during the Neogene have been evaluated on the basis of the relationship between the distributions of benthic foraminiferal assemblages and water masses (e.g., Figs. 6 and 11). Any shift in identified benthic foraminiferal assemblages and paleoenvironments implies significant variations of major physical parameters associated with the stratified nature of the water column. In turn, these faunal variations provide the basic criteria for understanding Neogene paleobathymetric and depositional history.

Nine paleoenvironments have been deduced through interpretation of sedimentological properties and ecological data on modern benthic foraminifers. Each paleoenvironment is associated with a particular benthic foraminiferal biofacies (Fig. 11). With the exceptions of the Quarternary *Valvulineria gunjii* biofacies and the Eocene *Turrilina brevispira* biofacies, all of the biofacies recognized in Neogene and Quaternary sediment at Sites 827, 828, 829, and 832 can be recognized in the modern tropical Pacific Ocean and have established bathymetric distributions.

Valvulineria gunjii dominates faunas from the top of the sequence at Sites 827 (2803.4 m water depth) and 829 (2905.2 m water depth), but it is rare at Sites 828 (3086.7 m water depth) and 832 (3089.3 m water depth) under the Pacific Bottom Water, and at Site 833 (2628.5 m water depth) under the Pacific Deep Water. The *V. gunjii* fauna has not been previously reported from the modern Pacific Ocean. However, Sites 827 and 829 are located near the boundary of the PDW and PBW. Thus, the distribution of these fauna species is thought to be related to the boundary between the PDW and PBW.

In addition, the extinct Eocene taxon *Turrilina brevispira* is most common in bathyal deposits, but also occurs in abyssal sediments (van Morkhoven et al., 1986). In this study, this species was found in Oligocene nannofossil chalks. The chalk samples have smaller planktonic foraminiferal numbers and P/T ratios (Fig. 5). The nannofossil ooze is distributed in the abyssal zone between the lysocline and the CCD in the modern ocean (Kennett, 1982). Cushman (1932, 1933, 1942) and Todd (1965) also reported that nannofossil ooze is distributed from depths of 3250 to 4500 m in the modern equatorial Pacific Ocean. Thus, this species was likely distributed in the abyssal zone between the lysocline and the CCD during the Oligocene.

Paleobathymetric History of the Vanuatu Region

The Pliocene through Holocene paleobathymetric history of the Vanuatu region (Figure 12) can be reconstructed through geological analyses, benthic foraminiferal biofacies variations, and sedimentology. Robinson (1969), Mallick and Greenbaum (1977), and Carney (1986) have outlined the basic Neogene depositional environments

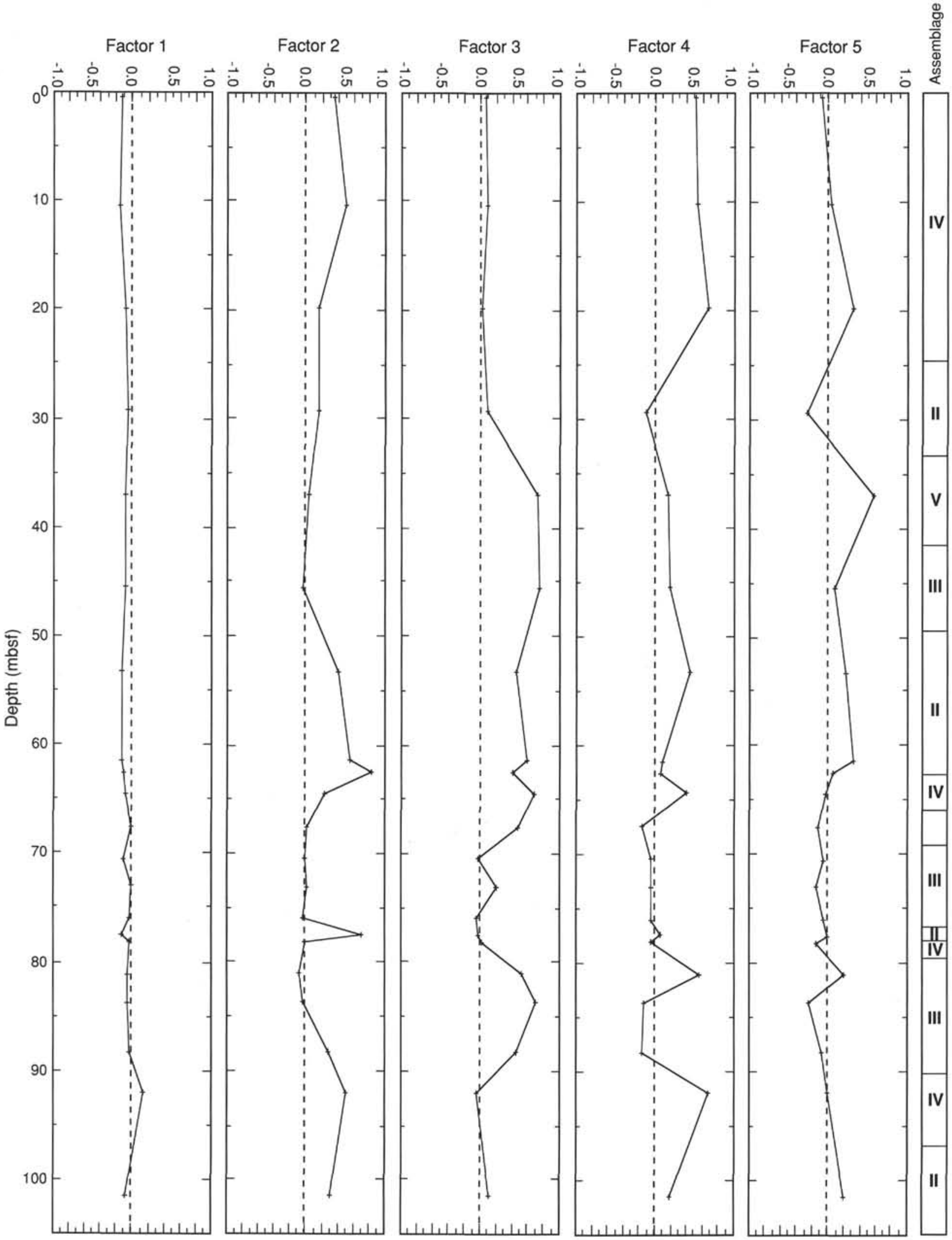

Figure 7. Stratigraphic distribution of varimax loadings for each of the first five factors at Site 827.

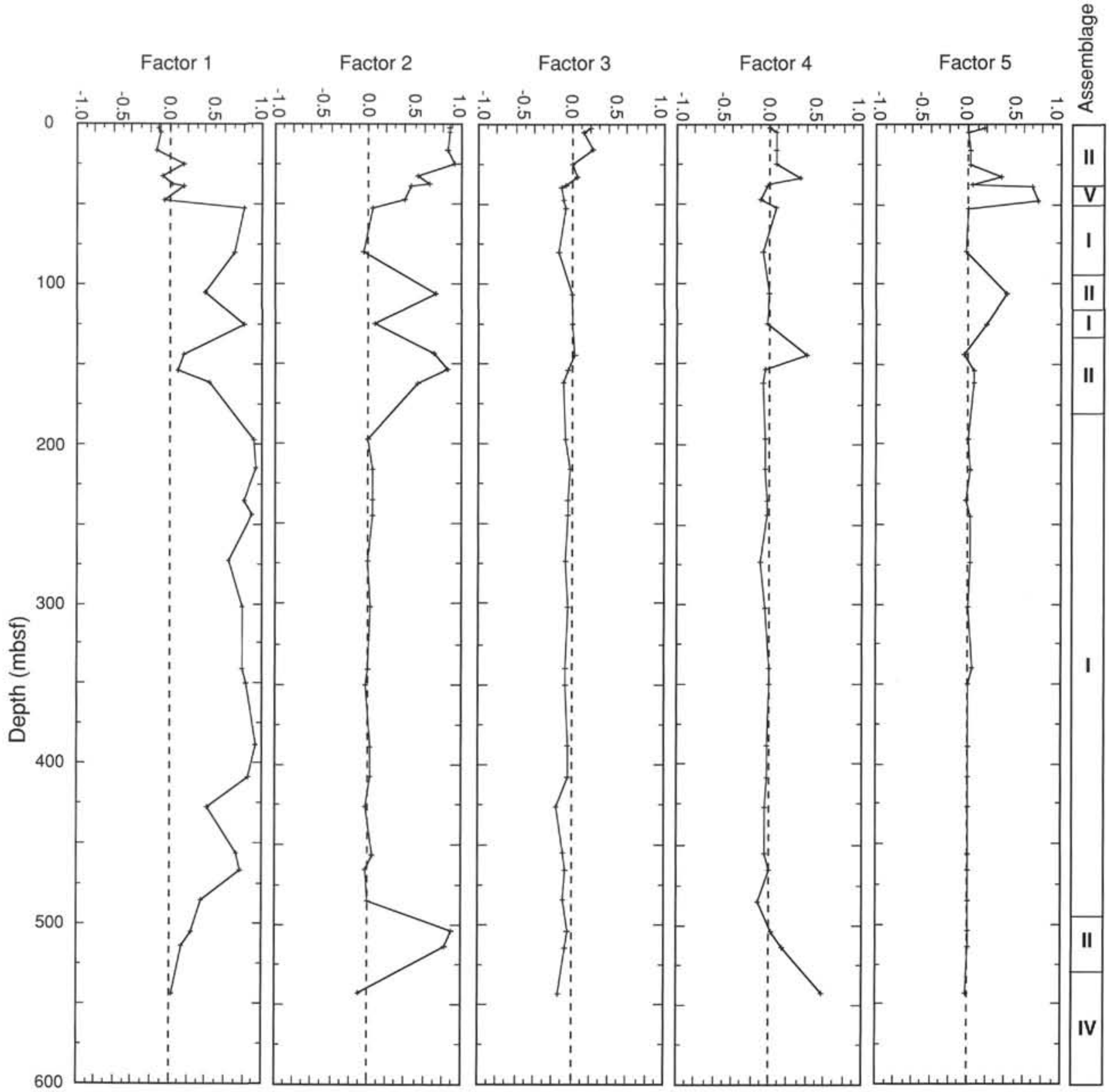

Figure 8. Stratigraphic distribution of varimax loadings for each of the first five factors at Site 829.

of Espiritu Santo and Maewo islands. The following interpretations summarize the paleobathymetric and paleoenvironmental history of the Vanuatu region based primarily on the benthic foraminiferal analysis presented above.

Early Pliocene

Benthic biofaunas indicate that the North d'Entrecasteaux Ridge was situated at upper bathyal depth (600–1200 m) during Pliocene and Pleistocene time. However, lower Pliocene sediments in the western part of Espiritu Santo Island were deposited in the sublittoral zone based on the presence of larger benthic foraminiferal species such as *Miogypsinoides dehaarti, Miogypsina polymorpha, Miogypsina thecideaeformis,* and *Lepidocyclina martini* in the Tawoli Formation (Robinson, 1969; Mallick and Greenbaum, 1977). Based on the occurrences of the *Rhabdammina abyssorum, Nuttallides umbonifera,* and *Melonis barleeanus-Melonis sphaeroides* biofacies in the lower Pliocene strata at Site 832 in ascending order, the seafloor of the North Aoba Basin was gradually elevated from a depth below the CCD (approximately 4500 m) to the middle part of the lower bathyal zone (3000–3500 m) in the early Pliocene.

Lower Pliocene sediments on Maewo Island are divided into the Tafwutmuto Formation and the Maewo Group (Carney, 1986). The paleodepth of the Tafwutmuto Formation is estimated to be within the range of the Pacific Deep Water (2500–3000 m) based on the occurrences of a typical PDW species such as *Favocassidulina favus* and *Parrelloides bradyi.* The Maewo Group is composed of planktonic foraminiferal ooze typical of depths between 1800 and 3000 m in the modern ocean. Thus, the Maewo Group was likely deposited in the lower part of the middle bathyal zone to the upper part of the lower bathyal zone during early Pliocene time.

Late Pliocene

The upper part of the Pliocene Tawoli Formation in Espiritu Santo Island yields a rich marine microfauna including bathyal species such

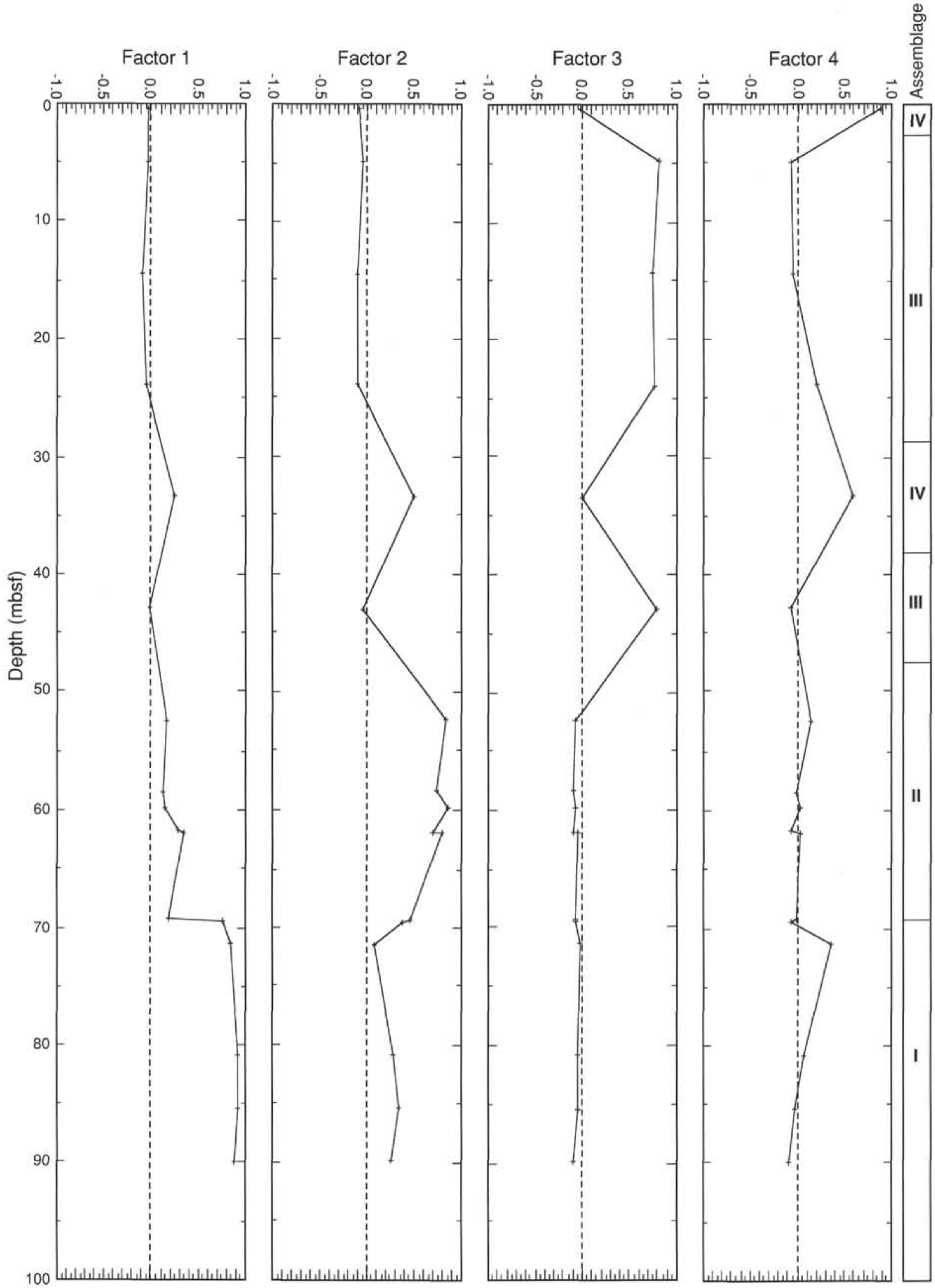

Figure 9. Stratigraphic distribution of varimax loadings for each of the first four factors at Site 828.

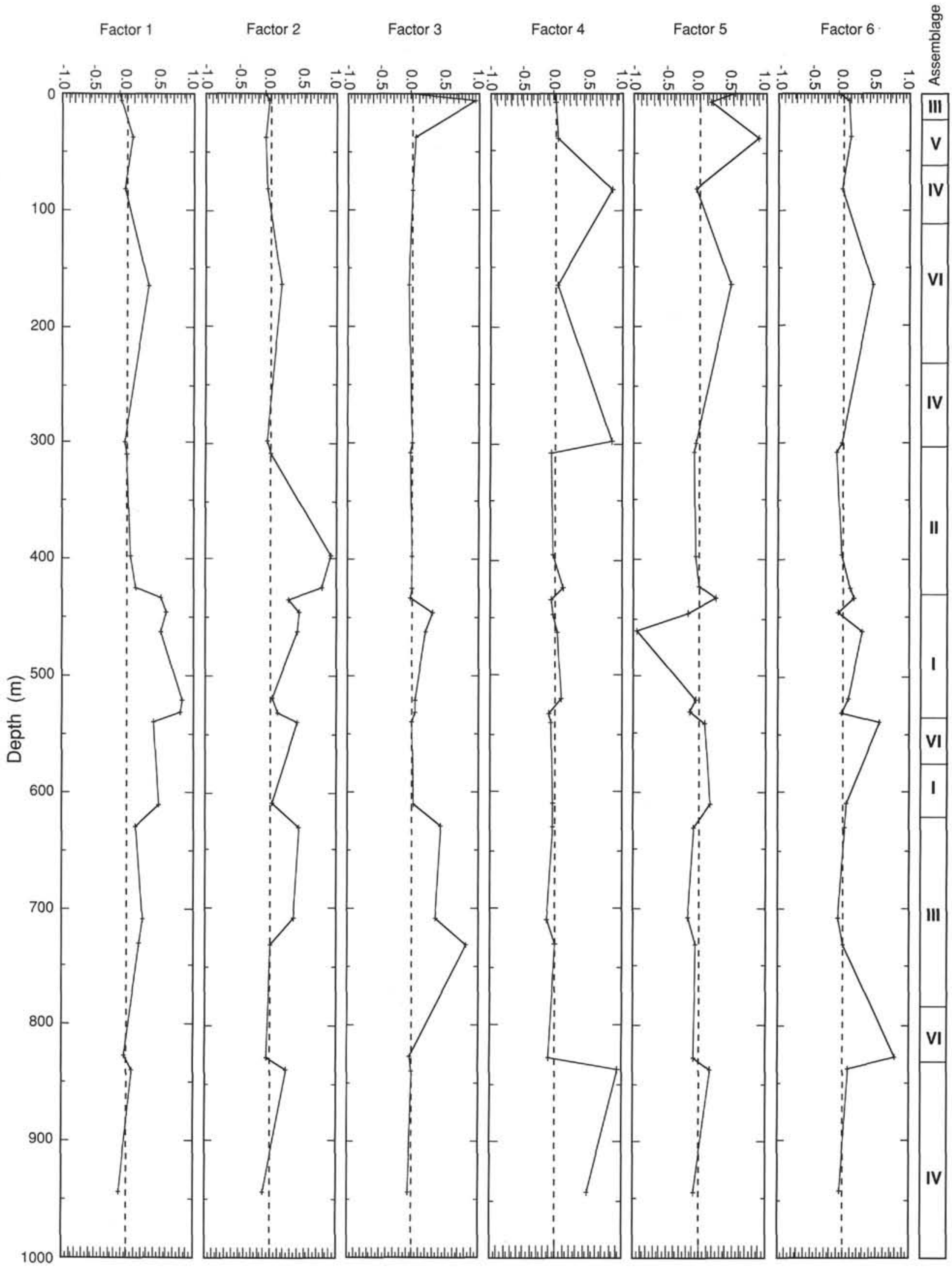

Figure 10. Stratigraphic distribution of varimax loadings for each of the first six factors at Site 832.

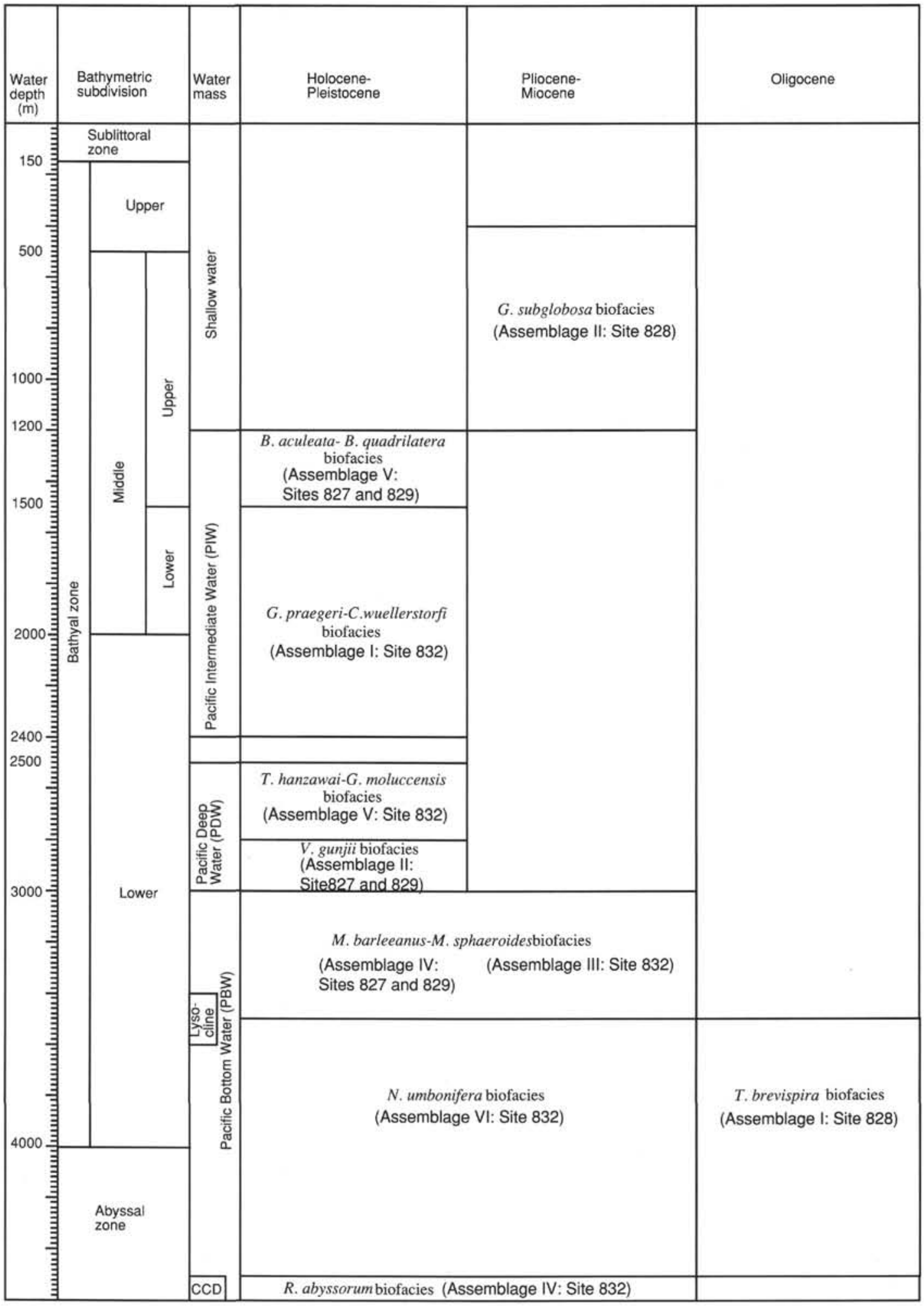

Figure 11. Relationship between bathymetry, water masses, and the distribution of Holocene, Pleistocene, Pliocene, Miocene and Oligocene benthic foraminiferal assemblages at Sites 827, 828, 829, and 832.

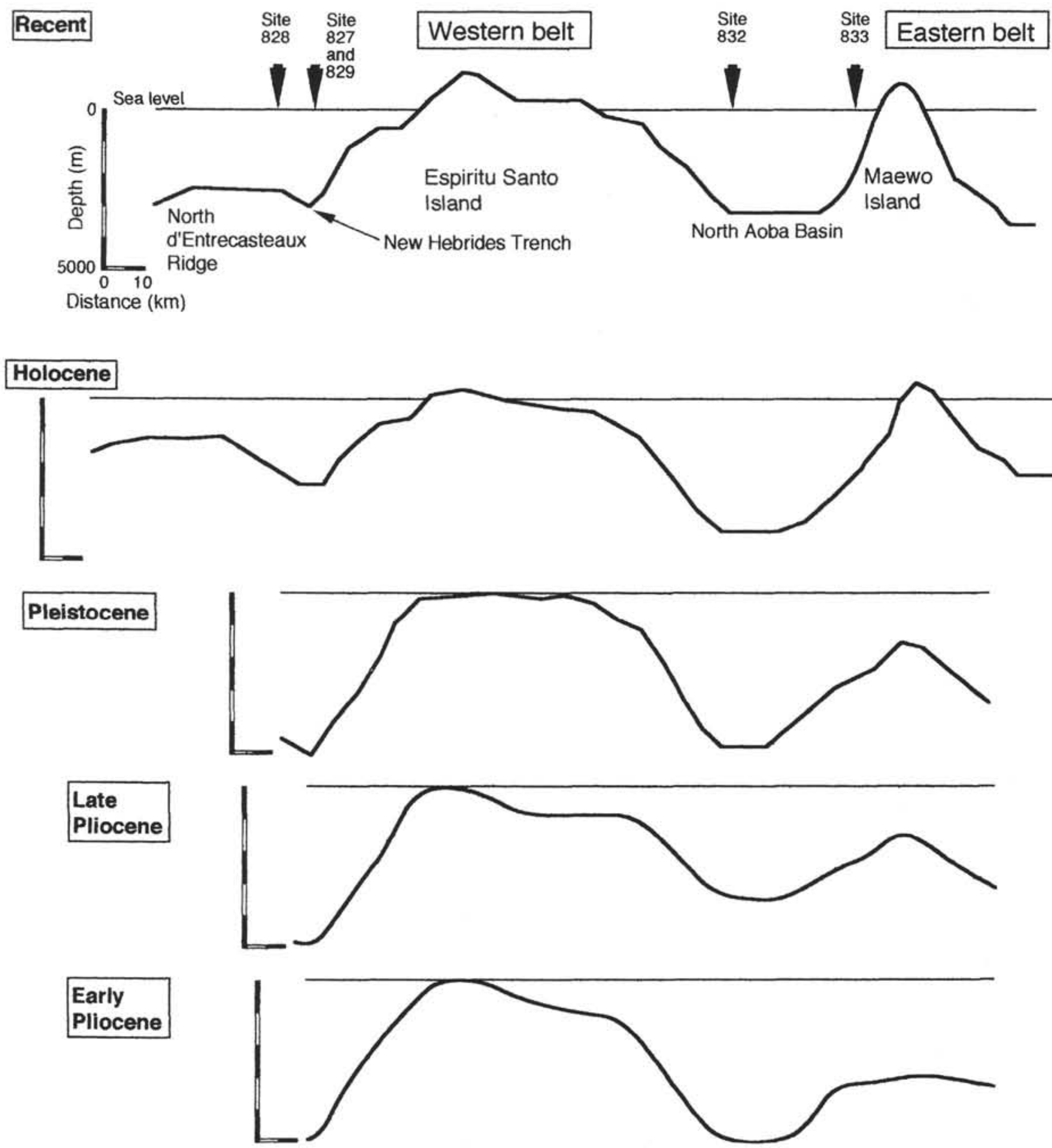

Figure 12. Schematic paleogeography and paleobathymetry of the New Hebrides Island Arc and North d'Entrecasteaux Ridge for the late Miocene/early Pliocene, early/late Pliocene, Pliocene/Pleistocene, and Pleistocene/Holocene.

as *Brizalina hantkeniana.* The Holocene distribution of this latter species is restricted to the middle bathyal zone (1200–2000 m). Thus, this formation is estimated to have been deposited in the middle bathyal zone. As discussed above, the Pliocene strata at Site 832 accumulated in the lower bathyal zone under the Pacific Bottom Water and at a depth above the lysocline. Thus, the floor of North Aoba Basin likely remained at a depth of 3000 to 3500 m through the late Pliocene.

Carney (1986) concluded that the Nasawa Formation in Maewo Island was deposited at a water depth shallower than 2550 m in the middle bathyal zone on the basis of the depth distribution of pteropod ooze in the modern ocean. According to Cushman (1932, 1933, 1942) and Todd (1965), pteropod remains are common at depths of 1000 and 2000 m in the modern tropical Pacific Ocean. Thus, the upper Pliocene of Maewo Island was deposited in the lower part of the middle bathyal zone (1000 to 2000 m).

Pleistocene

The paleodepth of Pleistocene sediment accreted to Espiritu Santo Island is interpreted to be the middle part of the lower bathyal zone (2800–3500 m) based on the occurrence of the *Valvulineria gunjii* biofacies and the *Melonis barleeanus-Melonis sphaeroides* biofacies in Pleistocene sediment cores at Site 829. Judging from Robinson's (1969) data, the western part of Espiritu Santo Island was located in the sublittoral zone (<150 m), whereas sediment in the eastern part of the island was deposited in the upper bathyal to middle bathyal zone

(500–1200 m). In addition, Factors 1 and 2, represented by upper and bathyal benthic assemblages, are present in the lower part of Pleistocene strata at Site 832.

Based on the faunal change from *Melonis barleeanus-Melonis sphaeroides* biofacies to *Nuttallides umbonifera* biofacies during the interval between the Pliocene and Pleistocene (ca. 1.9 Ma), the seafloor of the North Aoba Basin apparently subsided 500–1500 m, ultimately reaching abyssal water depths (4000–4500 m). Pleistocene sediments of Maewo Island were deposited in the sublittoral zone based on the occurrence of many neritic micro- and megafossils (Carney, 1986).

Holocene

Benthic foraminifers at Site 828 indicate that the basal Holocene strata on the North d'Entrecasteaux Ridge were deposited in the upper bathyal zone (600–1200 m), with the remainder of these sediments deposited in the lower bathyal zone (2800–3000 m). Thus, the paleodepth of these strata changed rapidly from the upper bathyal zone to the lower bathyal zone during the Holocene period.

Sediments comprising the accretionary prism at Sites 827 and 829 off Espiritu Santo Island were deposited in the middle part of the lower bathyal zone (2500–3500 m) based on the occurrence of the *Tosaia hanzawai-Globocassidulina moluccensis* biofacies, *Valvulineria gunjii* biofacies, and *Melonis barleeanus-Melonis sphaeroides* biofacies. Robinson (1969) constructed the Holocene paleogeography of Espiritu Santo Island by means of lithofacies and the distribution of larger benthic foraminifers. He concluded that the Holocene sediment distributed in the eastern part of this island was deposited in the tidal to upper sublittoral zone during the same period that the western part of island was above sea level.

During the early Holocene, the seafloor of the North Aoba Basin was at abyssal depths (below 4000 m) and has rapidly been elevated to its present depth of about 3100 m. According to Carney (1986), Maewo Island was uplifted above sea level before the beginning of the Holocene.

CONCLUSIONS

Nine benthic foraminiferal biofacies occurring in Oligocene and Miocene to Holocene sediments of the New Hebrides Arc area have been recognized based on sedimentological data and ecological data on modern benthic foraminifers. The paleodepths of the North d'Entrecasteaux Ridge, the eastern continental slope off Espiritu Santo Island, and the seafloor of the North Aoba Basin during Pliocene to Holocene time have been evaluated on the basis of the relationship between the distributions of benthic biofacies. The paleodepth of North d'Entrecasteaux Ridge is estimated to have been at the lower bathyal to abyssal depths during the Oligocene, was uplifted to upper bathyal depths during Pliocene time, and subsided to lower bathyal depths during Pleistocene to Holocene time. The paleodepth of the sea floor of North Aoba Basin is estimated to have been at abyssal depths below the CCD during the early Pliocene time, the middle part of the lower bathyal zone during the late Pliocene and the Holocene times, and the lower part of the lower bathyal zone to abyssal zone during the Pleistocene time.

TAXONOMY

Benthic foraminiferal species from the Vanuatu area are alphabetically listed below. Some selected species are illustrated with micrographs taken with a scanning electron microscope. The original references are given for each of the species.

Abditodentrix asketocomptella Patterson, 1985
Alabamina dissonata (Cushman and Renz) = *Pulvinulinella atlantisae* Cushman var. *dissonata* Cushman and Renz, 1948
Alabamina tubulifera (Heron-Allen and Earland) = *Truncatulina tubulifera* Heron-Allen and Earland, 1915
Allomorphina pacifica Hofker, 1951
Alveolophragmium subglobosum (G. O. Sars) = *Haplophragmium subglobosa* G. O. Sars, 1868
Ammomassilina alveoliformis (Millett) = *Massilina alveoliformis* Millett, 1898
Ammonia beccarii (Linné) = Nautilus beccarii Linné, 1758
Ammonia beccarii koeboeensis (LeRoy) = *Rotalia beccarii* (Linné) var. *koeboeensis* LeRoy, 1939
Amphicoryna bradii (Silvestri) = *Nodosariopsis bradii* Silvestri, 1902
Amphicoryna hirsuta (d'Orbigny) = *Nodosaria hirsuta* d'Orbigny, 1826
Amphicoryna pauciloculata (Cushman) = *Nodosaria pauciloculata* Cushman, 1921
Amphicoryna proxima (Silvestri) = *Nodosaria proxima* Silvestri, 1872
Amphicoryna scalaris (Batsch) = *Nautilus scalaris* Batsch, 1791
Amphicoryna separans (Brady) = *Nodosaria scalaris* var. *separans* Brady, 1884
Amphicoryna subleneata (Brady) = *Nodosaria hispidula* var. *subleneata* Brady, 1884
Amphistegina madagascariensis d'Orbigny, 1826
Amphistegina radiata (Fichtel and Moll) = *Nautilus radiatus* Fichtel and Moll, 1798
Anomalinoides cavus Belford, 1966
Anomalinoides glabrata (Cushman) = *Anomalina glabrata* Cushman, 1924
Anomalinoides glabulosa (Chapman and Parr) = *Anomalina glabulosa* Chapman and Parr, 1937
Anomalinoides semicribratus (Beckmann) = *Anomalina pompilioides* Galloway and Heminway var. *semicribrata* Beckmann, 1954
Articulina mayori Cushman, 1944
Aschemonella scabra Brady, 1879
Astacolus crepidulus (Fichtel and Moll) = *Nautilus crepidulus* Fichtel and Moll, 1798
Astacolus insolitus (Schwager) = *Nodosaria insolita* Schwager, 1866
Astrononion novozealandicum Cushman and Edwards, 1937
Astrononion stelligerum (d'Orbigny) = *Nonionina stelligera* d'Orbigny, 1839
Astrononion tumidum Cushman and Edwards, 1937
Baggina philippinensis (Cushman) = *Pulvinulina philippinensis* Cushman, 1921 *Bolivina earlandi* Parr, 1950
Bolivina rhomboidalis (Millett) = *Textularia rhomboidalis* Millett, 1899
Bolivina robusta Brady, 1881
Bolivina schwagerina Brady, 1881
Bolivina subangularis Brady, 1881
Bolivina subangularis leneata (Cushman) = *Bolivinita subangularis* Brady var. *leneata* Cushman, 1933
Bolivina spinescens Cushman, 1911
Bolivina subspinescens Cushman, 1922
Bolivinita compressa Finlay, 1939
Bolivinita quadrilatera (Schwager) = *Textularia quadrilatera* Schwager, 1866
Bolivinella elegans Parr, 1932
Brizalina alata (Seguenza) = *Vulvulina alata* Seguenza, 1862
Brizalina capitata (Cushman) = *Bolivina capitata* Cushman,1933
Brizalina decussata (Brady) = *Bolivina decussata* Brady, 1881
Brizalina hantkeniana (Brady) = *Bolivina hantkeniana* Brady, 1881
Brizalina karreriana (Brady) = *Bolivina karreriana* Brady, 1881
Brizalina karreriana carinata (Millett) = *Bolivina karreriana* Brady var. *carinata* Millett, 1900
Brizalina macella Belford, 1966
Brizalina plicatella (Cushman) = *Bolivina plicatella* Cushman, 1930
Brizalina pseudobeyrichi (Cushman) = *Bolivina pseudobeyrichi* Cushman, 1926
Brizalina pygmaea (Brady) = *Bolivina pygmaea* Brady, 1881
Brizalina seminuda (Cushman) = *Bolivina seminuda* Cushman, 1911
Brizalina subreticulata (Parr) = *Bolivina subreticulata* Parr, 1932
Brizalina viscistriata Belford, 1966
Bueningia creeki Finlay, 1939
Bronnimannia hiliotis (Heron-Allen and Earland) = *Discorbina hiliotis* Heron-Allen and Earland, 1924
Bulimina aculeata d'Orbigny, 1826
Bulimina ampliapertura Belford, 1966
Bulimina fijiensis Cushman, 1933
Bulimina glomachallengeri Tjalsma and Lohmann, 1983
Bulimina marginata d'Orbigny, 1826
Bulimina palmerae Parker and Bermúdez, 1937
Bulimina rostrata Brady, 1884
Bulimina striata d'Orbigny, 1826

Bulimina trinitatensis Cushman and Jarvis, 1928
Bulimina whitei Martin, 1943
Burseolina marshallana (Todd) = *Cassidulina marshallana* Todd in Cushman, Todd and Post, 1954
Burseolina pacifica (Cushman) = *Cassidulina pacifica* Cushman, 1925
Cassudulina carapitana Hedberg, 1937
Cassidulina carinata Silvestri = *Cassidulina laevigata* d'Orbigny var. *carinata* Silvestri, 1896
Cassudulina havanensis Cushman and Bermúdez, 1936
Cassidulina norvangi Thalmann = *Cassidulina islandica* Nørvang var. *norvangi* Thalmann, 1952
Cassidulina? *perumbonata* Keyzer, 1953
Cassudulina cf. *spinifera* Cushman and Jarvis = cf. *Cassudulina spinifera* Cushman and Jarvis, 1929
Ceratobulimina pacifica Cushman and Harris, 1927
Chilostomella oolina Schwager, 1878
Chilostomella ovoidea Reuss, 1850
Cibicides aknerianus (d'Orbigny) = *Rotalia akneriana* d'Orbigny, 1846
Cibicides lobatulus (Warker and Jacob) = *Nautilus lobatulus* Walker and Jacob, 1798
Cibicides refulgens Montfort, 1808
Cibicides robertsonianus (Brady) = *Truncatulina robertsoniana* Brady, 1881
Cibicides tenuimargo (Brady) = *Truncatulina tenuimargo* Brady, 1884
Cibicides wuellerstorfi (Schwager) = *Anomalina wuellerstorfi* Schwager, 1866
Cibicidoides eocaenus (Gümbel) = *Rotalia eocaena* Gümbel, 1868
Cibicidoides laurisae (Mallory) = *Cibicides laurisae* Mallory, 1959
Cibicidoides mediocris (Finlay) = *Cibicides mediocris* Finlay, 1940
Cibicidoides mundulus (Brady, Parker and Jones) = *Truncatulina mundula* Brady, Parker and Jones, 1888
Cribrorbulina serpens (Seguenza) = *Robulina serpens* Seguenza, 1880
Cyclogyra involvens (Reuss) = *Operculina involvens* Reuss, 1850
Cymbaloporetta bradyi (Cushman) = *Cymbalopora poeyi* (d'Orbigny) var. *bradyi* Cushman, 1915
Cystammina pauciloculata (Brady) = *Trochammina pauciloculata* Brady, 1879
Discorbinella bertheloti (d'Orbigny) = *Rosalina bertheloti* d'Orbigny, 1839
Discorbinella biconcavus (Jones and Parker) = *Discorbina biconcava* Jones and Parker in Carpenter, Parker and Jones, 1862
Discorbinella convexa (Takayanagi) = *Planulina convexa* Takayanagi, 1953
Discorbinella subbertheloti (Cushman) = *Discorbis subbertheloti* Cushman, 1924
Discorbis mira Cushman, 1922
Ehrenbergina albatrossi Cushman, 1933
Ehrenbergina bicornis Brady, 1888
Ehrenbergina hystrix Brady, 1881
Ehrenbergina marwicki Finlay, 1939
Ehrenbergina pacifica Cushman, 1927
Ehrenbergina trigona Goës = *Ehrenbergina serrata* Reuss var. *trigona* Goës, 1896
Elphidium advena (Cushman) = *Polystomella advena* Cushman, 1922
Elphidium cf. *crispum* (Linné) = cf. *Nautilus crispum* Linné, 1758
Elphidium jenseni (Cushman) = *Polystomella jenseni* Cushman, 1924
Elphidium poeyanum (d'Orbigny) = *Polystomella poeyana* d'Orbigny, 1839
Elphidium simplex Cushman, 1933
Eponides tumidulus (Brady) = *Truncatulina tumidula* Brady, 1884
Evolvocassidulina brevis (Aoki) = *Cassidulina brevis* Aoki, 1968
Favocassidulina favus (Brady) = *Pulvinulina favus* Brady, 1877
Fijiella simplex (Cushman) = *Trimosina simplex* Cushman, 1929
Fissurina alveolata (Brady) = *Lagena alveolata* Brady, 1884
Fissurina annectens (Burrows and Holland) = *Lagena annectens* Burrows and Holland in Jones, 1895
Fissurina auriculata (Brady) = *Lagena auriculata* Brady, 1881
Fissurina auriculata duplicata (Sidebottom) = *Lagena auriculata* Brady var. *duplicata* Sidebottom, 1912
Fissurina clathrata (Brady) = *Lagena clathrata* Brady, 1884
Fissurina crebra (Matthes) = *Lagena crebra* Matthes, 1939
Fissurina denica (Madsen) = *Lagena denica* Madsen, 1895
Fissurina fimbriata (Brady) = *Lagena fimbriata* Brady, 1881
Fissurina cf. *formosa favosa* (Brady) = cf. *Lagena formosa* Schwager var. *favosa* Brady, 1884
Fissurina kerguelenensis Parr, 1950
Fissurina lacunata (Burrows and Holland) = *Lagena lacunata* Burrows and Holland, 1895
Fissurina lucida (Williamson) = *Entosolenia marginata* (Montagu) var. *lucida* Williamson, 1848
Fissurina marginata (Montagu) = *Vermiculum marginatum* Montagu, 1803
Fissurina orbignyana Seguenza, 1862
Fissurina palliolata (Earland) = *Lagena palliolata* Earland, 1934
Fissurina quenquelatera (Brady) = *Lagena quenquelatera* Brady, 1881
Fissurina radiata Seguenza, 1862
Fissurina radiata striatula (Cushman) = *Lagena sublagenoides* var. *striatula* Cushman, 1913
Fissurina aff. *trigonomarginata* (Parker and Jones) = aff. *Lagena trigonomarginata* Parker and Jones, 1865
Fursenkoina complanata (Egger) = *Virgulina schreibersiana* Czjzek var. *complanata* Egger, 1893
Gavelinopsis praegeri (Heron-Allen and Earland) = *Discorbina praegeri* Heron-Allen and Earland, 1913
Glandulina laevigata (d'Orbigny) = *Nodosaria laevigata* d'Orbigny, 1826
Globobulimina auriculata (Bailey) = *Bulimina auriculata* Bailey, 1851
Globobulimina pacifica Cushman, 1927
Globobulimina pupoides (d'Orbigny) = *Bulimina pupoides* d'Orbigny, 1846
Globocassidulina brocha (Poag) = *Cassidulina brocha* Poag, 1966
Globocassidulina cressa (d'Orbigny) = *Cassidulina cressa* d'Orbigny, 1839
Globocassidulina decorata (Sidebottom) = *Cassidulina decorata* Sidebottom, 1910
Globocassidulina elegans (Sidebottom) = *Cassidulina elegans* Sidebottom, 1910
Globocassidulina gemma (Todd) = *Cassidulina gemma* Todd in Cushman, Todd and Post, 1954
Globocassidulina moluccensis (Germeraad) = *Cassidulina moluccensis* Germeraad, 1946
Globocassidulina mucronata Nomura, 1983
Globocassidulina neobrocha Nomura, 1983
Globocassidulina oblonga (Reuss) = *Cassidulina oblonga* Reuss, 1850
Globocassidulina oriangulata (Belford) = *Cassidulina oriangulata* Belford, 1966
Globocassidulina oribunda Belford, 1966
Globocassidulina ornata (Cushman) = *Cassidulina subglobosa* Brady var. *ornata* Cushman, 1927
Globocassidulina paratortuosa (Kuwano) = *Cassidulina paratortuosa* Kuwano, 1954
Globocassidulina parva (Asano and Nakamura) = *Cassidulina subglobosa* Brady *parva* Asano and Nakamura, 1937
Globocassidulina parviapertura Nomura, 1983
Globocassidulina patula (Cushman) = *Cassidulina patula* Cushman, 1933
Globocassidulina subglobosa (Brady) = *Cassidulina subglobosa* Brady, 1881
Globocassidulina subtumida (Cushman) = *Cassidulina subtumida* Cushman, 1933
Globulina flexa Cushman and Ozawa, 1930
Glomospira gordialis (Jones and Parker) = *Ammodiscus gordialis* Jones and Parker, 1880
Gyroidina altiformis R. E. and K. C. Stewart = *Gyroidina soldanii* var. *altiformis* R. E. and K. C. Stewart, 1930
Gyroidina cf. *broeckhiana* (Karrer) = cf. *Rotalia broeckhiana* Karrer, 1878
Gyroidina cushmani Boomgraad, 1949
Gyroidina neosoldanii Brotzen, 1936
Gyroidina orbicularis d'Orbigny, 1826
Gyroidina soldanii d'Orbigny, 1826
Gyroidinoides lamarckianus (d'Orbigny) = *Rotalia lamarckiana* d'Orbigny, 1839
Gyroidinoides nipponicus (Ishizaki) = *Gyroidina nipponica* Ishizaki, 1944
Hanzawaia mantaensis (Galloway and Molley) = *Anomalina mantaensis* Galloway and Molley, 1929
Hauerina bradyi Cushman, 1917
Heronallenia lingulata (Burrows and Holland) = *Discorbina lingulata* Burrows and Holland, 1896
Heterolepa haidingerii (d'Orbigny) = *Rotalia haidingerii* d'Orbigny, 1846
Hoeglundina elegans (d'Orbigny) = *Rotalia elegans* d'Orbigny, 1826
Hormosina globulifera Brady, 1879
Hyalina balthica (Schröter) = *Nautilus balthicus* Schröter, 1783
Islandiella norcrossi (Cushman) = *Cassidulina norcrossi* Cushman, 1933
Lagena acuticosta Reuss, 1861
Lagena advena Cushman, 1923
Lagena elongata (Ehrenberg) = *Miliola elongata* Ehrenberg, 1844
Lagena gracilis Williamson, 1848
Lagena gracillima (Seguenza) = *Amphorina gracillima* Seguenza, 1862

Lagena hispidula Cushman, 1858
Lagena laevis (Montagu) = *Vermiculum laevis* Montagu, 1803
Lagena nebulosa Cushman = *Lagena laevis* (Montagu) var. *nebulosa* Cushman, 1923
Lagena paradoxa Sidebottom = *Lagena foleolata* Reuss var. *paradoxa* Sidebottom, 1912
Lagena parri Loeblich and Tappan, 1953
Lagena perlucida (Montagu) = *Vermiculum perlucidum* Montagu, 1803
Lagena pliocenica Cushman and Gray, 1946
Lagena plumigera Brady, 1881
Lagena striata (d'Orbigny) = *Oolina striata* d'Orbigny, 1839
Lagena substriata Williamson, 1848
Lagena sulcata laevicostata Cushman and Gray = *Lagena sulcata* (Warker and Jacob) var. *laevicostata* Cushman and Gray, 1946
Lagena sulcata spicata Cushman and McCulloch = *Lagena sulcata* var. *spicata* Cushman and McCulloch, 1950
Lagena williamsoni (Alcock) = *Entosolenia williamsoni* Alcock, 1865
Lamarkina scabra (Brady) = *Pulvinulina oblonga* (Williamson) var. *scabra* Brady, 1884
Laterostomella voluta Belford, 1966
Laticarina altocamerata (Helon-Allen and Earland) = *Truncatulina altocamerata* Helon-Allen and Earland, 1922
Laticarina pauperata (Parker and Jones) = *Palvinulina repanda* Fichtel and Moll var. *menardii* d'Orbigny subvar. *pauperata* Parker and Jones, 1865
Lernella seranensis (Germeraad) = *Cassidulina seranensis* Germeraad, 1946
Marginulina glabra d'Orbigny, 1826
Marginulina subcrassa Schwager, 1866
Marginulina tenuis Bornemann, 1855
Marginulinopsis bradyi (Goës) = *Cristellaria bradyi* Goës, 1894
Marsipella cylindrica Brady, 1882
Melonis barleeanus (Williamson) = *Nonionina barleeana* Williamson, 1858
Melonis pacificus (Cushman) = *Nonionina umbilicatula* (Montagu) var. *pacifica* Cushman, 1924
Melonis parkerae (Uchio) = *Nonion parkerae* Uchio, 1960
Melonis sphaeroides Voloshinova, 1958
Miliolinella circularis (Bornemann) = *Triloculina circularis* Bornemann, 1855
Miliolinella inflata LeRoy, 1964
Neoconorbina floridensis (Cushman) = *Discorbis bertheloti* (d'Orbigny) var. *floridensis* Cushman, 1931
Neoconorbina terquemi (Rzehak) = *Discorbina terquemi* Rzehak, 1888
Nodosaria flintii Cushman, 1923
Nodosaria longiscata d'Orbigny, 1846
Nodosaria pyrula d'Orbigny, 1826
Nodosaria simplex Silvestri, 1872
Nonion depressulum (Walker and Jacob) = *Nautilus depressulum* Walker and Jacob, 1798
Nonion planatum Cushman and Thomas, 1930
Nonionella japonica mexicana Cushman and McCulloch = *Nonionella japonica* (Asano) var. *mexicana* Cushman and McCulloch, 1940
Nonionella miocenica Cushman, 1926
Nonionella miocenica stella Cushman and Moyer = *Nonionella miocenica* Cushman var. *stella* Cushman and Moyer, 1930
Nonionellina labradorica (Dawson) = *Nonionina labradorica* Dawson, 1860
Nuttallides umbonifera (Cushman) = *Pulvinulinella umbonifera* Cushman, 1933
Oolina apiopleura (Loeblich and Tappan) = *Lagena apiopleura* Loeblich and Tappan, 1953
Oolina globosa (Montagu) = *Vermiculum globosum* Montagu, 1803
Oolina hexagona (Williamson) = *Entosolenia sequamosa* (Montagu) var. *hexagona* Williamson, 1858
Oolina melo d'Orbigny, 1839
Operculina ammonoides (Gronovius) = *Nautilus ammonoides* Gronovius, 1781
Oridorsalis pauciapertura Belford, 1966
Oridorsalis tener (Brady) = *Truncatulina tenera* Brady, 1884
Oridorsalis umbonatus (Reuss) = *Rotalia umbonata* Reuss, 1851
Orthomorphina challengeriana (Thalmann) = *Nodogeneria challengeriana* Thalmann, 1937
Osangularia culter (Parker and Jones) = *Planorbulina culter* Parker and Jones, 1865
Ozawaia tongaensis Cushman, 1931
Paracassidulina miuraensis (Higuchi) = *Cassidulina miuraensis* Higuchi, 1956
Paracassidulina neocarinata (Thalmann) = *Cassidulina neocarianta* Thalmann, 1950
Paracassidulina nipponensis (Eade) = *Globocassidulina nipponensis* Eade, 1967
Paracassidulina quasicarinata Nomura, 1983
Paracassidulina sulcata (Belford) = *Cassidulina sulcata* Belford, 1966
Parafissurina arctica Green, 1959
Parafissurina lateralis Cushman, 1913
Parafissurina pseudomarginata (Bucher) = *Lagena pseudomarginata* Bucher, 1940
Parafissurina subcarinata Parr, 1950
Parafissurina uncifera (Buckner) = *Lagena uncifera* Buckner, 1940
Parafrondicularia helenae Chapman, 1940
Parrelloides bradyi (Trauth) = *Truncatulina bradyi* Trauth, 1918
Parrelloides cf. *soendaensis* (LeRoy) = cf. *Cibicides soendaensis* LeRoy, 1941
Patellinella carinata Collins, 1958
Patellinella jugosa (Brady) = *Textularia jugosa* Brady, 1884
Peneropsis pertusus (Forskal) = *Nautilus pertusus* Forskal, 1775
Pileolina patelliformis (Brady) = *Discorbina patelliformis* Brady, 1884
Pileolina tabernacularis (Brady) = *Discorbina tabernacularis* Brady, 1884
Planorbulina mediterranensis d'Orbigny, 1826
Planulina ariminensis d'Orbigny, 1826
Pleurostomella alternans Schwager, 1866
Pleurostomella brevis Schwager, 1866
Pleurostomella rapa Gümbel, 1868
Pleurostomella recens Dervieux = *Pleurostomella rapa* Gümbel var. *recens* Dervieux, 1899
Pleurostomella subnodosa (Reuss) = *Nodosaria subnodosa* Reuss, 1845
Pseudononion auricula (Heron-Allen and Earland) = *Nonionella auricula* Heron-Allen and Earland, 1930
Pseudononion grateloupi (d'Orbigny) = *Nonionina grateloupi* d'Orbigny, 1826
Pseudoparrella exigua (Brady) = *Pulvinulina exigua* Brady, 1884
Pseudopolymorphina ligua (Roemer) = *Polymorphina ligua* Roemer, 1838
Pseudorotalia gaimardii (d'Orbigny) = *Rotalia gaimardii* d'Orbigny, 1826
Pullenia bulloides (d'Orbigny) = *Nonionina bulloides* d'Orbigny, 1846
Pullenia quinqueloba (Reuss) = *Nonionina quinqueloba* Reuss, 1851
Pullenia salisburyi R.E. and R. C. Stewart, 1930
Pyrgo denticulata (Brady) = *Biloculina ringens* Lamarck var. *denticulata* Brady, 1884
Pyrgo depressa (d'Orbigny) = *Biloculina depressa* d'Orbigny, 1826
Pyrgo lucernula (Schwager) = *Biloculina lucernula* Schwager, 1866
Pyrgo murrhina (Schwager) = *Bioculina murrhina* Schwager, 1866
Quadratobuliminella pyramidalis de Klasz, 1953
Quadrimorphina laevigata (Phleger and Parker) = *Valvulineria laevigata* Phleger and Parker, 1951
Quinqueloculina akneriana d'Orbigny, 1846
Quinqueloculina bicostata d'Orbigny, 1839
Quinqueloculina costata d'Orbigny, 1826
Quinqueloculina lamarkiana d'Orbigny, 1839
Quinqueloculina seminula (Linné) = *Serpula seminulum* Linné, 1767
Quinqueloculina vulgaris d'Orbigny, 1826
Ramulina globulifera Brady, 1879
Rectobolivina columellaris (Brady) = *Sagrina columellaris* Brady, 1881
Rectobolivina dimorpha pacifica Cushman = *Siphogeneria dimorpha* (Parker and Jones) var. *pacifica* Cushman, 1926
Rectobolivina indica (LeRoy) = *Siphogeneria indica* LeRoy, 1941
Rectobolivina limbata (Brady) = *Bolivina limbata* Brady, 1881
Rectobolivina limbata costulata (Cushman) = *Bolivina limbata* Brady var. *costulata* Cushman, 1922
Rectobolivina raphana (Parker and Jones) = *Uvigerina (Sagrina) raphanus* Parker and Jones, 1865
Rectuvigerina striata (Schwager) = *Dimorphina striata* Schwager, 1866
Rectuvigerina tasmana Boersma, 1984
Reussella aculeata Cushman, 1945
Rhabdammina abyssorum M. Sars, 1868
Rhizammina algaeformis Brady, 1879
Robertina oceanica Cushman and Parker, 1947
Robulus gibbus (d'Orbigny) = *Cristellaria gibba* d'Orbigny, 1826
Robulus limbosus (Reuss) = *Robulina limbosus* Reuss, 1863
Robulus orbicularis d'Orbigny, 1826
Robulus reniformis (d'Orbigny) = *Cristellaria reniformis* d'Orbigny, 1846
Rosalina floridana (Cushman) = *Discorbis floridana* Cushman, 1922

Rosalina globularis d'Orbigny, 1826
Rosalina vilardeboana d'Orbigny, 1839
'Rotalia' murrayi Heron-Allen and Earland = *Rotalia murrayi* Heron-Allen and Earland, 1915
Rutherfordoides cornuta (Cushman) = Virgulina cornuta Cushman, 1913
Rutherfordoides tenuis (Phleger and Parker) = *Cassidulinoides tenuis* Phleger and Parker, 1951
Saracenaria italica Defrance, in Blaineville, 1824
Saracenaria latifrons (Brady) = *Cristellaria latifrons* Brady, 1884
Sigmavirgulina tortuosa (Brady) = *Bolivina tortuos* Brady, 1881
Sigmoilopsis schlumbergeri (Silvestri) = *Sigmoilina schlumbergeri* Silvestri, 1904
Siphotextularia concava (Karrer) = *Plecanium concavum* Karrer, 1868
Siphotextularia saulcyana (d'Orbigny) = *Textularia saulcyana* d'Orbigny, 1839
Sorites marginalis (Lamarck) = *Orbulites marginalis* Lamarck, 1816
Sphaeroidina bulloides d'Orbigny, 1826
Sphaeroidina compacta Cushman and Todd, 1949
Spiroloculina communis Cushman and Todd, 1944
Stanforthia exilis (Brady) = *Bulimina elegans* d'Orbigny var. *exilis* Brady, 1884
Stilostomella abyssorum (Brady) = *Nodosaria abyssorum* Brady, 1881
Stilostomella consobrina (d'Orbigny) = *Dentalina consobrina* d'Orbigny, 1846
Stilostomella cf. *fistuca* (Schwager) = cf. *Nodosaria fistuca* Schwager, 1866
Stilostomella lepidula (Schwager) = *Nodosaria lepidula* Schwager, 1866
Tappanina selmensis (Cushman) = *Bolivinita selmensis* Cushman, 1948
Thalmannammina parkerae (Uchio) = *Recurvoidella parkerae* Uchio, 1960
Tosaia hanzawai Takayanagi, 1953
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Trifarina occidentalis (Cushman) = *Uvigerina occidentalis* Cushman, 1923
Triloculina tricarinata d'Orbigny, 1826
Triloculina trigonula (Lamarck) = *Miliolites trigonula* Lamarck, 1804
Turrilina brevispira ten Dam, 1944
Trochammina conglobata Brady, 1884
Trochammina discorbis Earland, 1934
Trochammina globigeriniformis (Parker and Jones) = *Lituola nautiloidea* var. *globigeriniformis* Parker and Jones, 1865
Trochammina pacifica Cushman, 1925
Tubulogenerina zanzibarica (Cushman) = *Brizalina zanzibarica* Cushman, 1936
Uvigerina aculeata d'Orbigny, 1846
Uvigerina ampullacea Brady = *Uvigerina asperula* Czjzek var. *ampullacea* Brady, 1884
Uvigerina hispida Schwager, 1866
Uvigerina hispidocostata Cushman and Todd, 1945
Uvigerina interrupta Brady, 1879
Uvigerina peregrina Cushman, 1923
Uvigerina porrecta Brady, 1879
Uvigerina proboscidea Schwager, 1866
Uvigerina cf. *tasmana* Boersma = cf. *Uvigerina tasmana* Boersma, 1984
Vaginulinopsis tasmanica Parr, 1950
Valvulineria gunjii Akimoto, 1990

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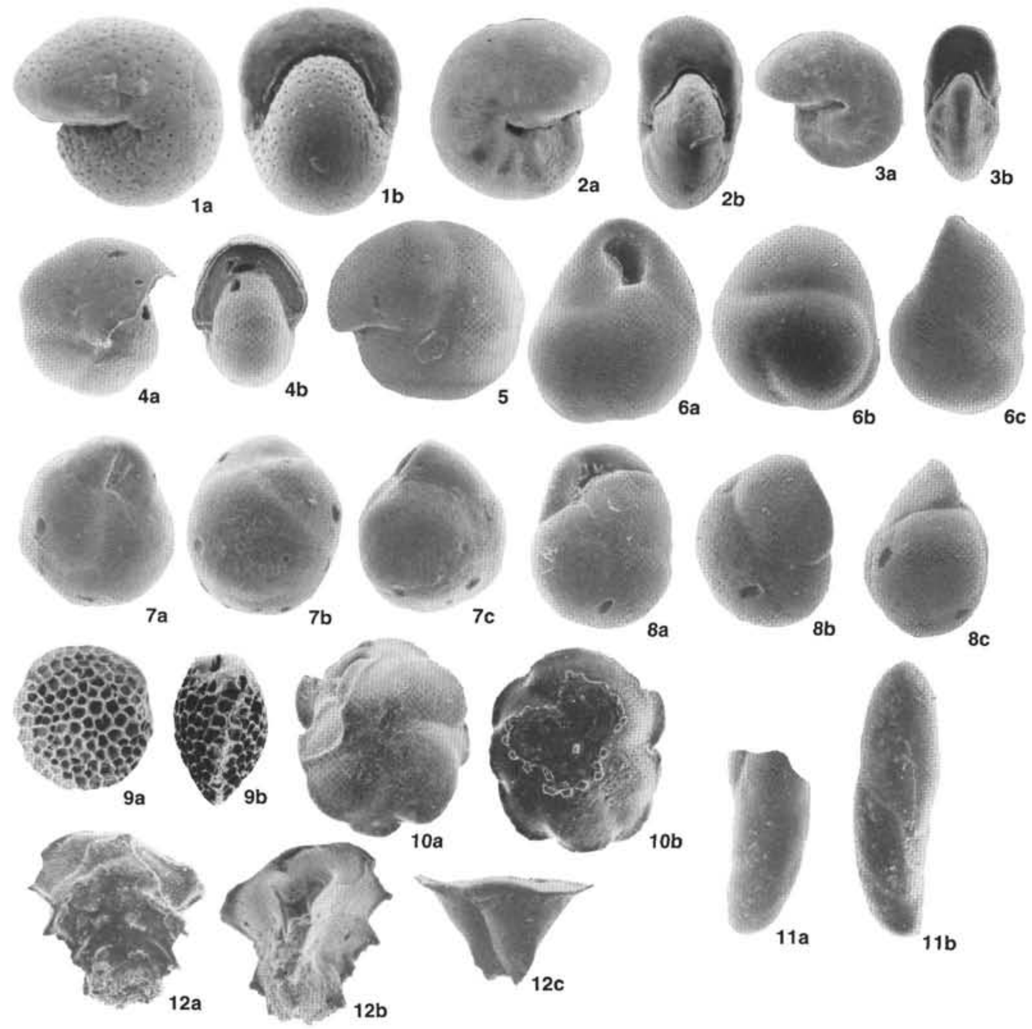

Plate 1. **1.** *Melonis sphaeroides* Voloshinova, Sample 134-832A-1H-CC, ×75, (a) side view, (b) apertural view. **2.** *Melonis barleeanus* (Williamson), Sample 134-832A-4H-CC, ×50, (a) side view, (b) apertural view. **3.** *Melonis parkerae* (Uchio), Sample 134-827A-11H-CC, ×50, (a) side view, (b) apertural view. **4.** *Pullenia quinqueloba* (Reuss), Sample 134-832A-6H-CC, ×100, (a) side view, (b) apertural view. **5.** *Pullenia bulloides* (d'Orbigny), Sample 134-832A-12H-CC, ×100. **6.** *Globocassidulina moluccensis* (Germeraad), Sample 134-832A-4H-CC, ×75, (a) apertural view, (b) and (c) side view. **7.** *Globocassidulina ornata* (Cushman), Sample 134-827A-15X-CC, ×75, (a) apertural view, (b) and (c) side view. **8.** *Globocassidulina cressa* (d'Orbigny), Sample 134-832A-8H-CC, ×150, (a) apertural view, (b) and (c) side view. **9.** *Favocassidulina favus* (Brady), Sample 134-832B-8R-CC, ×50, (a) side view, (b) apertural view. **10.** *Cassidulina carinata* Silvestri, Sample 134-827A-11H-CC, ×100, (a) and (b) side view. **11.** *Rutherfordoides cornuta* (Cushman), Sample 134-832A-2H-CC, ×75, (a) and (b) side view. **12.** *Ehrenbergina pacifica* Cushman, Sample 134-832B-32R-CC, ×75, (a) and (b) side view, (c) apertural view.

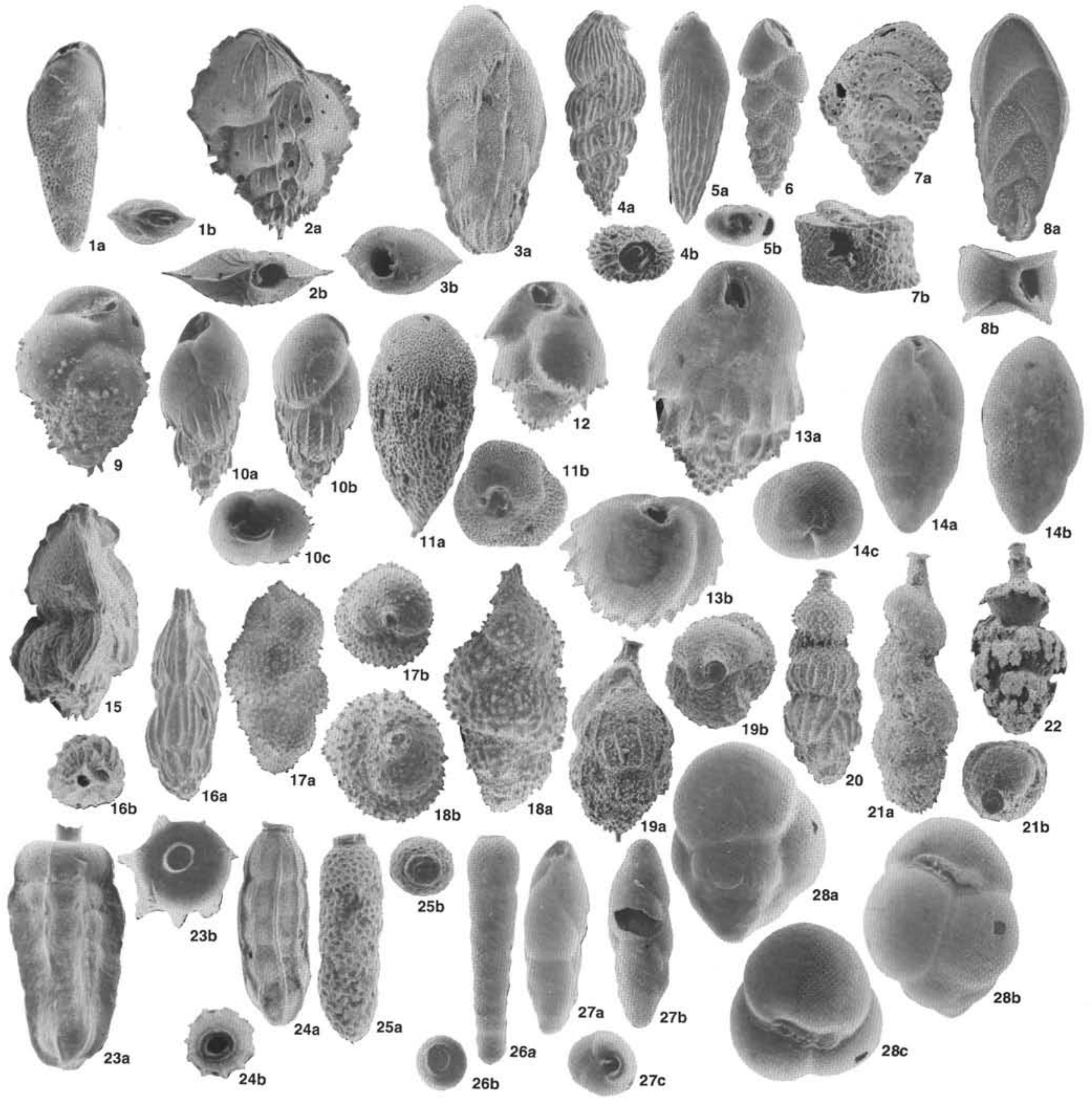

Plate 2. **1.** *Brizalina alata* (Seguenza), Sample 134-827A-8H-CC, ×100, (a) side view, (b) apertural view. **2.** *Brizalina hantkeniana* (Brady), Sample 134-832A-8H-CC, ×100, (a) side view, (b) apertural view. **3.** *Brizalina* sp., Sample 832A-6H-CC, ×150, (a) side view, (b) apertural view. **4.** *Brizalina kerreriana* (Brady), Sample 134-832A-8H-CC, ×100, (a) side view, (b) apertural view. **5.** *Brizalina vescistriata* Belford, Sample 134-832A-6H-CC, ×100, (a) side view, (b) apertural view. **6.** *Bolivina subspinescens* Cushman, Sample 134-832A-8H-CC, ×100, **7.** *Abditodentrix asketocomptella* Patterson, Sample 134-832A-2H-CC, ×150, (a) side view, (b) apertural view. **8.** *Bolivinita quadrilatera* (Schwager), Sample 134-832A-8H-CC, ×100, (a) side view, (b) apertural view. **9.** *Bulimina aculeata* d'Orbigny, Sample 134-832A-11H-CC, ×150. **10.** *Bulimina ampliaperture* Belford, Sample 134-827A-8H-CC, ×150, (a) and (b) side view, (c) apertural view. **11.** *Bulimina glomachallengeri* Tjalsma and Lohmann, Sample 134-828A-10H-CC, ×75, (a) side view, (b) apertural view. **12.** *Bulimina marginata* d'Orbigny, Sample 134-827A-7H-CC, ×150. **13.** *Bulimina striata* d'Orbigny, Sample 134-832A-2H-CC, ×75, (a) side view, (b) apertural view. **14.** *Globobulimina pupoides* (d'Orbigny), Sample 134-827A-5H-CC, ×50, (a) and (b) side view, (c) apertural view. **15.** *Trifariana angulosa* (Williamson), Sample 134-832A-2H-CC, ×75. **16.** *Trifarina occidentalis* (Cushman), Sample 134-827A-7H-CC, ×150, (a) side view, (b) apertural view. **17.** *Uvigerina hispida* Schwager, Sample 134-832A-10H-CC, ×75, (a) side view, (b) apertural view. **18.** *Uvigerina hispidocostata* Cushman and Todd, Sample 134-832A-11H-CC, ×100, (a) side view, (b) apertural view. **19.** *Uvugerina hispidocostata* Cushman and Todd, Sample 134-832A-8H-CC, ×150, (a) side view, (b) apertural view. **20.** *Uvigerina hispidocostata* Cushman and Todd, Sample 134-827A-5H-CC, ×50. **21.** *Uvigerina proboscidea* Schwager, Sample 134-832B-3R-CC, ×100, (a) side view, (b) apertural view. **22.** *Uvigerina porrecta* Brady, Sample 134-828B-1R-CC, ×100. **23.** *Rectobolivina raphana* (Parker and Jones), Sample 134-832A-6H-CC, ×75, (a) side view, (b) apertural view. **24.** *Rectobolivina* cf. *raphana* (Parker and Jones), Sample 134-832A-12H-CC, ×75, (a) side view, (b) apertural view. **25.** *Rectobolivina dimorpha* (Parker and Jones), Sample 134-832A-2H-CC, ×100, (a) side view, (b) apertural view. **26.** *Rectobolivina columellaris* (Brady), Sample 134-832A-12H-CC, ×100, (a) side view, (b) apertural view. **27.** *Stanforthia exilis* (Brady), Sample 134-827A-7H-CC, ×100, (a) and (b) side view, (c) apertural view. **28.** *Tosaia hanzawai* (Takayanagi), Sample 134-832A-7H-CC, ×75, (a) and (b) side view, (c) apertural view.

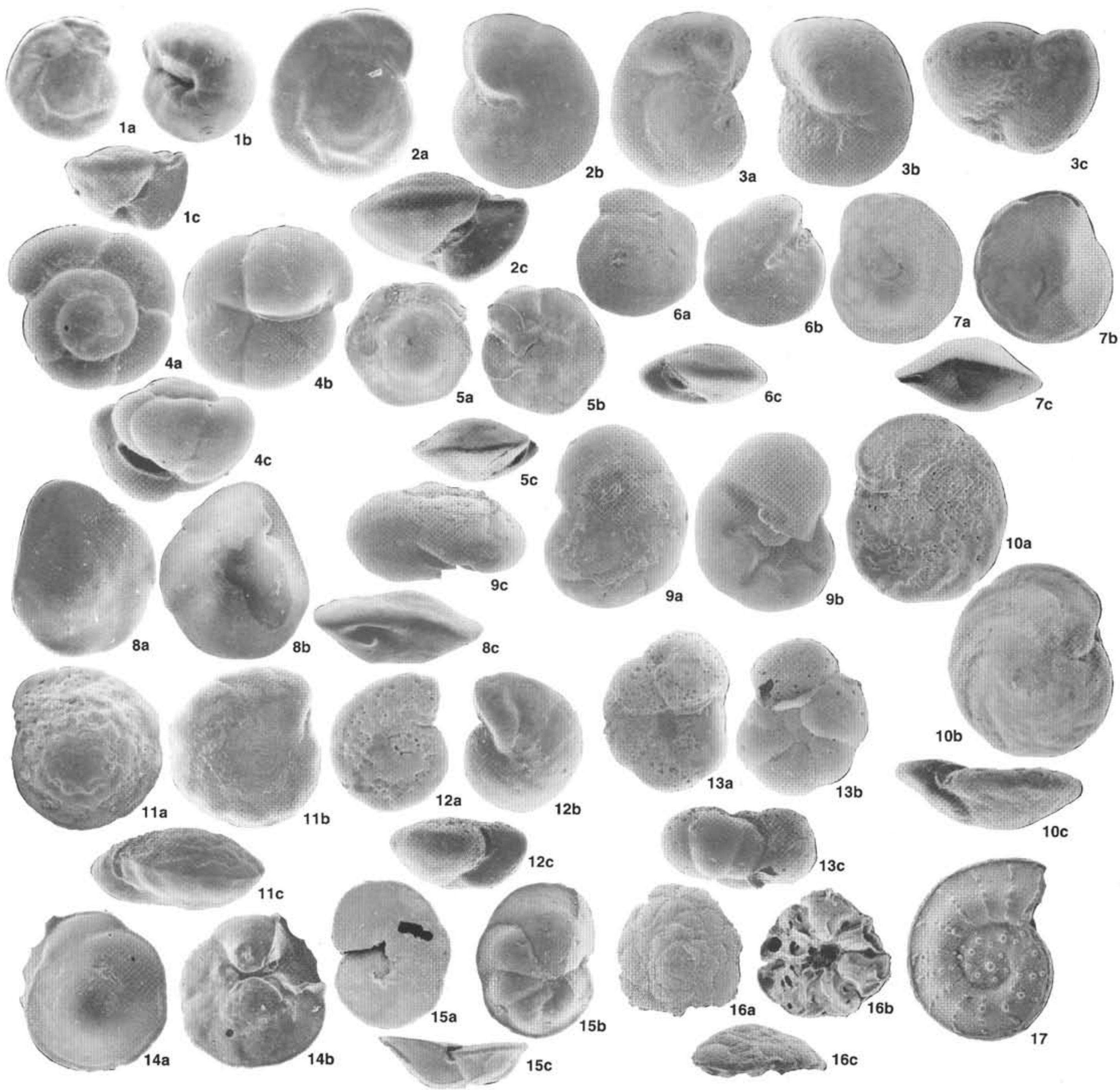

Plate 3. **1.** *Gyroidina altiformis* R.E. and K.C. Stewart, Sample 134-832A-5H-CC, ×100, (a) spiral side, (b) umbilical side, (c) lateral view. **2.** *Gyroidina orbicularis* d'Orbigny, Sample 134-827B-4R-CC, ×75, (a) spiral side, (b) umbilical side, (c) lateral view. **3.** *Gyroidina soldanii* d'Orbigny, Sample 134-832B-32R-CC, ×50, (a) spiral side, (b) umbilical side, (c) lateral view. **4.** *Gyroidinoides nipponicus* (Ishizaki), Sample 134-832A-8H-CC, ×150, (a) spiral side, (b) umbilical side, (c) lateral view. **5.** *Oridorsalis umbonatus* (Reuss), Sample 134-832A-1H-CC, ×35, (a) spiral side, (b) umbilical side, (c) lateral view. **6.** *Oridorsalis tener* (Brady), Sample 134-832A-1H-CC, ×75, (a) spiral side, (b) umbilical side, (c) lateral view. **7.** *Hoeglundina elegans* (d'Orbigny), Sample 134-832A-1H-CC, ×35, (a) spiral side, (b) umbilical side, (c) lateral view. **8.** *Pseudoparrella exigua* (Brady), Sample 134-828A-2H-CC, ×100, (a) spiral side, (b) umbilical side, (c) lateral view. **9.** *Varvulineria gunjii* Akimoto, Sample 134-827A-5H-CC, ×100, (a) spiral side, (b) umbilical side, (c) lateral view. **10.** *Cibicides wuellerstorfi* (Schwager), Sample 134-832A-1H-CC, ×50, (a) spiral side, (b) umbilical side, (c) lateral view. **11.** *Cibicidoides mundulus* (Brady, Parker and Jones), Sample 134-832B-3R-CC, ×50, (a) spiral side, (b) umbilical side, (c) lateral view. **12.** *Cibicidoides mediocris* (Finlay), Sample 134-832A-4H-CC, ×75, (a) spiral side, (b) umbilical side, (c) lateral view. **13.** *Anomalinoides glablosa* (Chapman and Parr), Sample 134-832A-2H-CC, ×50, (a) spiral side, (b) umbilical side, (c) lateral view. **14.** *Gavelinopsis praegeri* (Heron-Allen and Earland), Sample 134-832A-7H-CC, ×100, (a) spiral side, (b) umbilical side. **15.** *Discorbinella convexa* (Takayanagi), Sample 134-832A-6H-CC, ×100, (a) spiral side, (b) umbilical side, (c) lateral view. **16.** *Cymbaloporetta bradyi* (Cushman), Sample 134-832A-2H-CC, ×50, (a) spiral side, (b) umbilical side, (c) lateral view. **17.** *Operculina ammonoides* (Gronovius), Sample 134-832A-5H-CC, ×22.5.

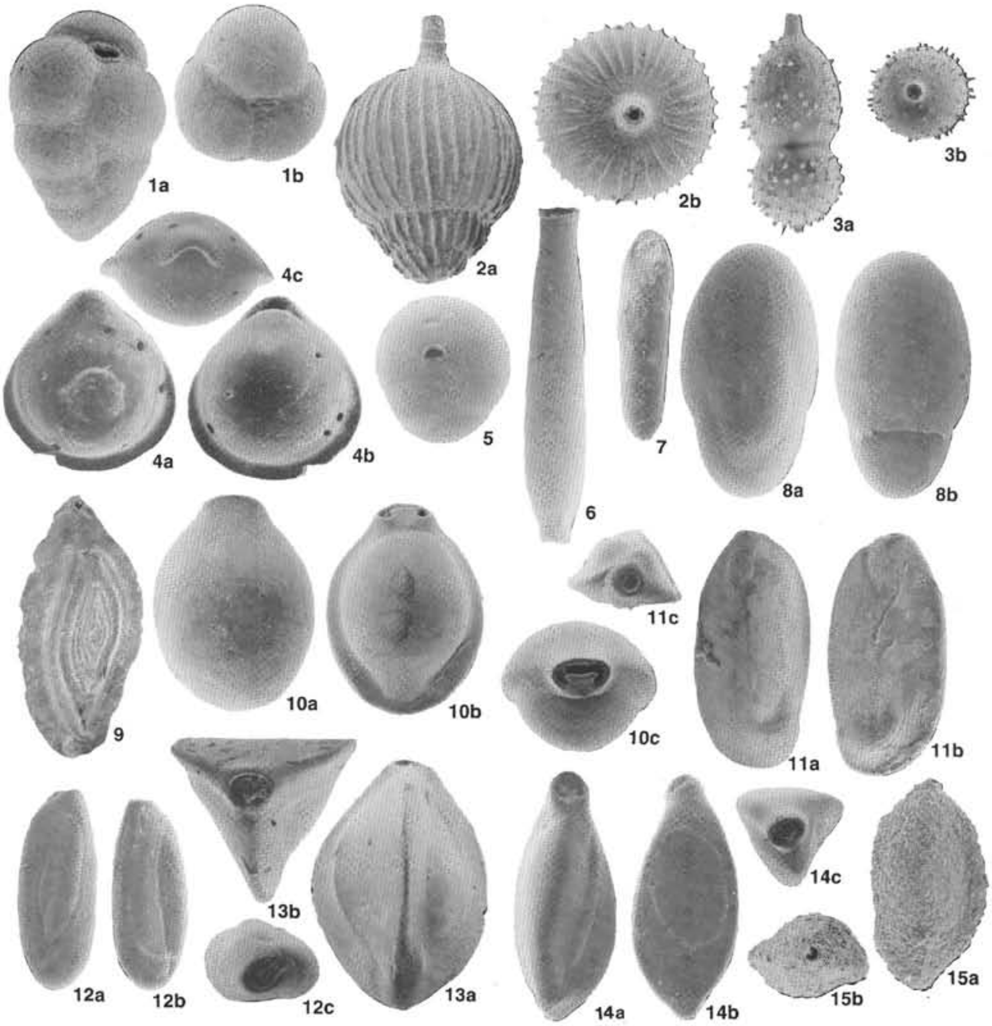

Plate 4. **1.** *Eggerella bradyi* (Cushman), Sample 134-832A-1H-CC, ×50, (a) side view, (b) apertural view. **2.** *Amphicoryna scaralis* (Batsch), Sample 134-832A-2H-CC, ×75, (a) side view, (b) apertural view. **3.** *Amphicoryna hirsuta* (d'Orbigny), Sample 134-832A-2H-CC, ×100, (a) side view, (b) apertural view. **4.** *Parafissurina pseudomarginata* (Buchner), Sample 134-832B-8R-CC, ×75, (a) and (b) side view, (c) apertural view. **5.** *Sphaeroidina compacta* Cushman and Todd, Sample 134-832A-2H-CC, ×50. **6.** *Nodosaria longiscata* d'Orbigny, Sample 134-832B-66R-CC, ×50. **7.** *Pleurostomella alternans* Schwager, Sample 134-832B-63R-CC, ×50. **8.** *Chilostomella oolina* Schwager, Sample 134-832A-4H-CC, ×50, (a) and (b) side view. **9.** *Spirophthalmidium actimargo* (Brady), Sample 134-832A-1H-CC, ×35. **10.** *Pyrgo fornasinii* Chapman and Parr, Sample 134-832A-1H-CC, ×50, (a) and (b) spiral side, (c) apertural view. **11.** *Quinqueloculina lamarckiana* d'Orbigny, Sample 134-832A-1H-CC, ×50, (a) and (b) spiral side, (c) apertural view. **12.** *Quinqueloculina seminula* (Linné), Sample 134-832A-6H-CC, ×150, (a) and (b) spiral side, (c) apertural view. **13.** *Triloculina tricarinata* d'Orbigny, Sample 134-832B-29R-CC, ×50, (a) spiral side, (b) apertural view. **14.** *Triloculina trigonula* (Lamarck), Sample 134-832A-5H-CC, ×75, (a) and (b) spiral side, (c) apertural view. **15.** *Sigmoilopsis schlumbergeri* (Silvestri), Sample 134-827A-5H-CC ×50, (a) spiral side, (b) apertural view.