Suess, E., von Huene, R., et al., 1990
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 112

16. BENTHIC FORAMINIFERAL STRATIGRAPHY AND PALEOENVIRONMENTS OFF PERU, LEG 112[1]

Johanna M. Resig[2]

ABSTRACT

Stratigraphic assemblages of Quaternary through early Eocene benthic foraminifers were recovered among 10 Peru margin drill sites. Various hiatuses and intervals barren in foraminifers characterize the sections, but numerous samples contain abundant, well-preserved benthic foraminifers.

Bathymetry of the extant species and California-based estimates of the paleobathymetry of the extinct species permit recognition of Quaternary sea-level fluctuations between shelf and upper bathyal depths that produced vertical migrations of oxygenated and low-oxygen habitats at the six shallow sites. Assemblages from lower-slope sites at about 9° and 11°S indicate a general subsidence of the continental margin from shelf or upper bathyal depths in Eocene time to the present lower bathyal depths. Data from 11°S suggest a major part of this subsidence occurred in late Oligocene to early Miocene time. Downslope-transported shelf specimens, particularly the small biserial species, *Bolivina costata* and *B. vaughani*, are major contributors to these lower bathyal assemblages from the middle Miocene through Quaternary time.

INTRODUCTION

Scope of Research

Water masses, currents, changes in eustatic sea level, upwelling with consequent high primary productivity, low oxygen, diagenesis, phosphatization, downslope transport, and vertical tectonic displacement are the primary forces that affect the composition of modern and fossil benthic foraminiferal assemblages. Leg 112 Sites 679 through 688 were drilled in three transects off Peru (Fig. 1) to investigate the effect of these forces on the substance and configuration of the continental margin in historical perspective. In this research, foraminifers are principally indicators of paleobathymetry and oxygen levels; although stratigraphic assemblages are recognized, resolution is low relative to diatom and nannofossil stratigraphies (Schrader, Martini, this volume), which form the basis of ordering events for this study.

These drill sites fall into shallow- (150 to 450 m) and deep-water (3000 to 5000 m) groupings. Shallow sites (679, 680, 681, 684, 686, and 687) provide a record of upwelling and low-oxygen bottom conditions, as well as changes in sea level; deep sites (682, 683, 685, and 688) record tectonic development of the margin. Because different assemblages of benthic foraminifers characterize the shallow- vs. deep-water sites and because of the different kinds of information derived from the two groupings, they are handled separately here. However, the results are combined ultimately to produce a summary of margin events along the three sampling transects at 9°, 11°, and 13°S.

The research is introduced by a discussion of the modern environment in which the samples were taken, followed by a summary of previous studies of benthic foraminifers off western South America and other areas having similar assemblages. Benthic foraminifers off Peru are not well known and research about their distribution in other areas must be referenced for paleoecologic interpretation. Consequently, this research extends the known biogeographic and stratigraphic occurrence of several species of benthic foraminifers.

Physical Environment

Biotopes and Overlying Water Masses and Currents

Modern temperature profiles off Peru (National Oceanographic Data Center—NODC data), as well as water structure (Wyrtki, 1964, 1966, 1967) and benthic foraminiferal biotopes (Ingle et al., 1980), are shown in Figure 2 and summarized below.

The shelf biotope (0–150 m) lies beneath the northward-flowing Peru Current to mid-shelf depths and beneath the southward-flowing countercurrent farther seaward. The inner shelf subdivision (0–50 m) corresponds with the seasonal thermocline and also the maximum depth of the mixed layer. Biotas are subject to water temperatures of about 17° to 24°C. The outer shelf subdivision (50–150 m) corresponds with a permanent, poorly developed thermocline. Upwelling occurs when southeast trade winds blowing nearly parallel to the coast move surface water offshore and cold water rises from 50 to 350 m (mean depth of about 130 m) on the outer shelf (Gunther, 1936). This flow reduces the surface-water temperature about 3° or 4°C (e.g., Fahrbach et al., 1981). During Pleistocene glacial expansion, steepening of the temperature gradient in the subantarctic region may have increased transport volume and the northward extension of cooler waters in the Peru Current System (CLIMAP, 1976), substantially modifying conditions in the shelf biotope.

The upper bathyal biotope (150–500 m) lies beneath the southward-flowing countercurrent that transports equatorial subsurface water in which salinity is high and oxygen is low. Oxygen is further depleted in this biotope through decay of the organic products of upwelling. Temperature decreases from 15° to 10°C from the top to the bottom of the biotope. All shallow sites of Leg 112 were drilled in this depth range.

The upper middle bathyal biotope (500–1500 m) is bathed in northward-flowing Antarctic Intermediate Water (AIW) in its upper half, which is also low in oxygen because of high surface productivity, and southward-flowing Pacific Deep

[1] Suess, E., von Huene, R., et al., 1990. *Proc. ODP, Sci. Results*, 112: College Station, TX (Ocean Drilling Program).

[2] Hawaii Institute of Geophysics and Department of Geology and Geophysics, University of Hawaii, Honolulu, HI 96822.

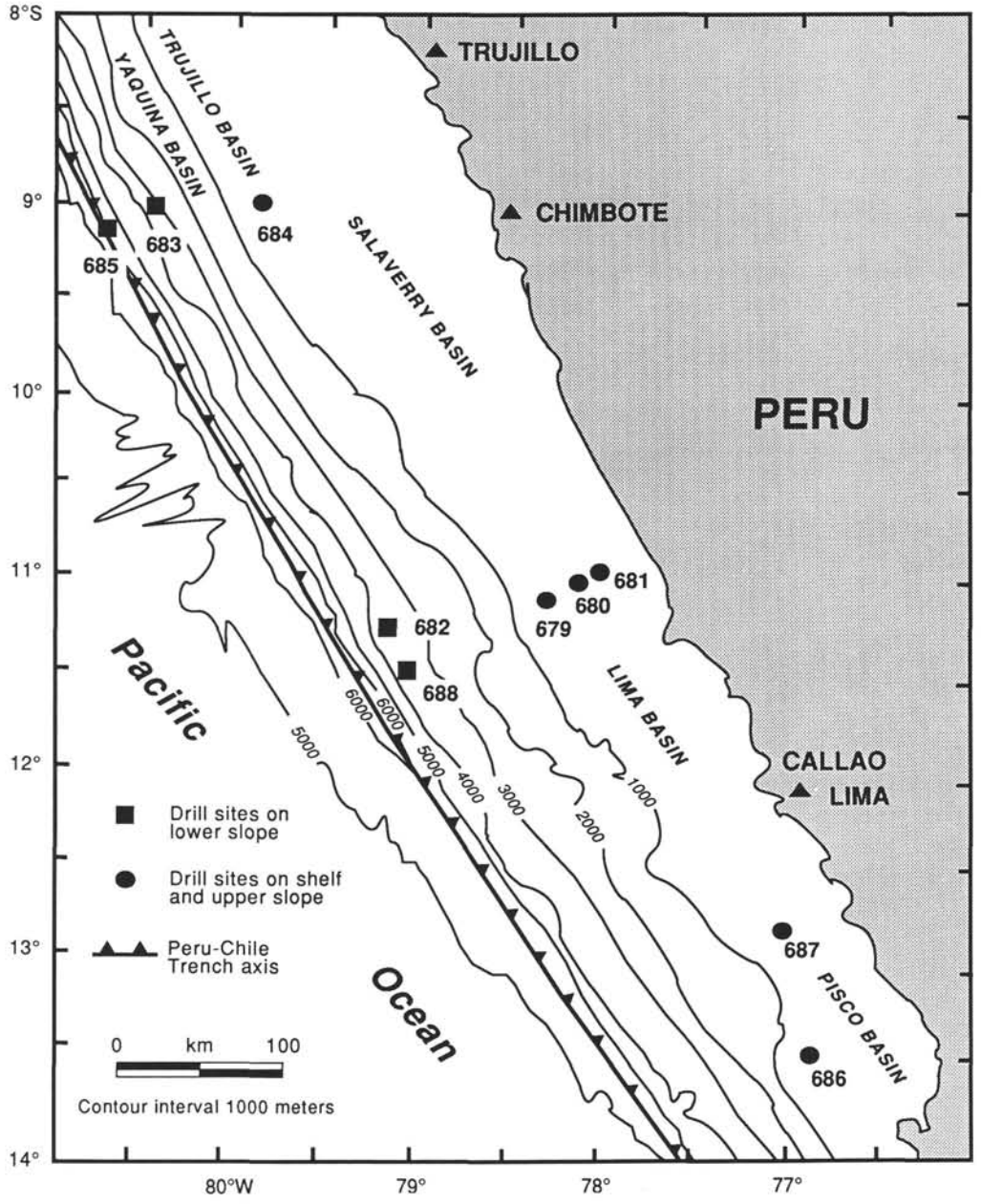


Figure 1. Site locations, Leg 112.

Water (PDW) with increasing oxygen content below. Bottom temperatures are about 8° to 4°C from the top to the bottom of the biotope.

The lower middle bathyal biotope (1500–2000 m) and lower bathyal biotope (2000–4000 m) lie under PDW and Antarctic Bottom Water (AABW). The boundary between these two water masses occurs at approximately 3300 m, the approximate depth of the lysocline (Berger, 1970). Physical conditions are uniform throughout. Three of the deep sites were drilled into this unit.

The abyssal biotope (4000–6000 m) is under AABW and beneath the carbonate compensation depth (CCD) so that only agglutinated assemblages live there (Resig, 1981). The environment is uniformly cold (~2°C). One deep site was drilled into this biotope.

Primary Productivity and the Oxygen-Minimum Zone

Phytoplankton productivity, monitored seasonally over a 10-yr period (Rojas de Mendiola, 1981), shows an average Spring concentration in excess of 1×10^5 cells per liter in a band extending about 225 km from the coast of Peru (Fig. 3). Within this band, highest productivity exceeds 5×10^5 cells per liter in the Pisco Basin area, an upwelling center within about 115 km of shore. The recurrent high productivity contributes in excess of 50×10^6 diatom valves to each gram of sediment underlying the most productive areas and affects deposition on the seafloor to a water depth of 3600 m (Schuette and Schrader, 1981). The nearshore regions of high productivity each bear distinctive diatom floras that are preserved in the fossil record (Schrader, this volume).

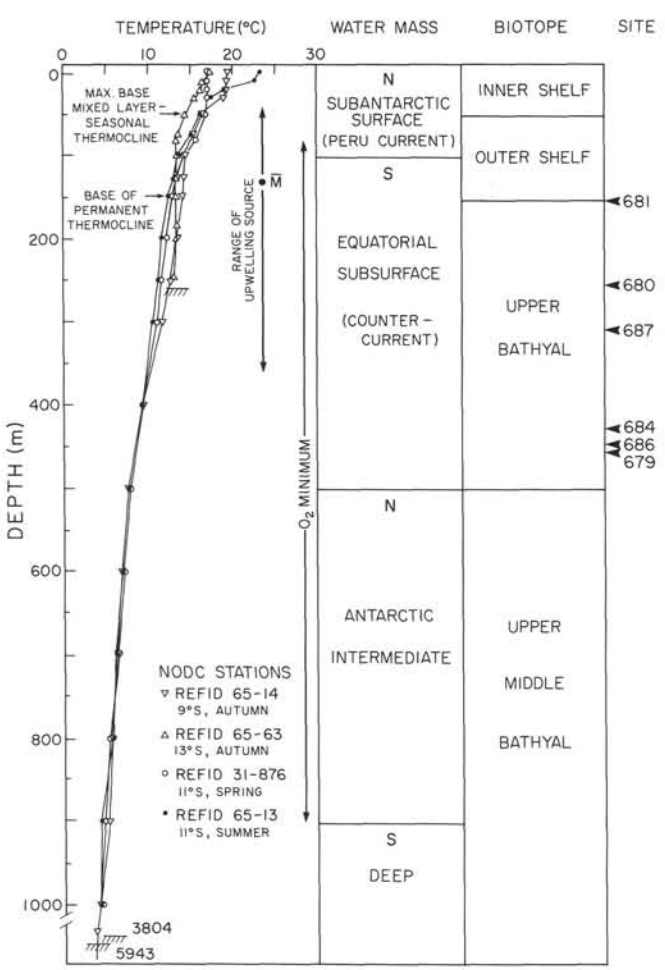


Figure 2. Bathymetric distribution of shallow sites in relation to modern temperatures, water masses, and benthic foraminiferal biotopes off Peru.

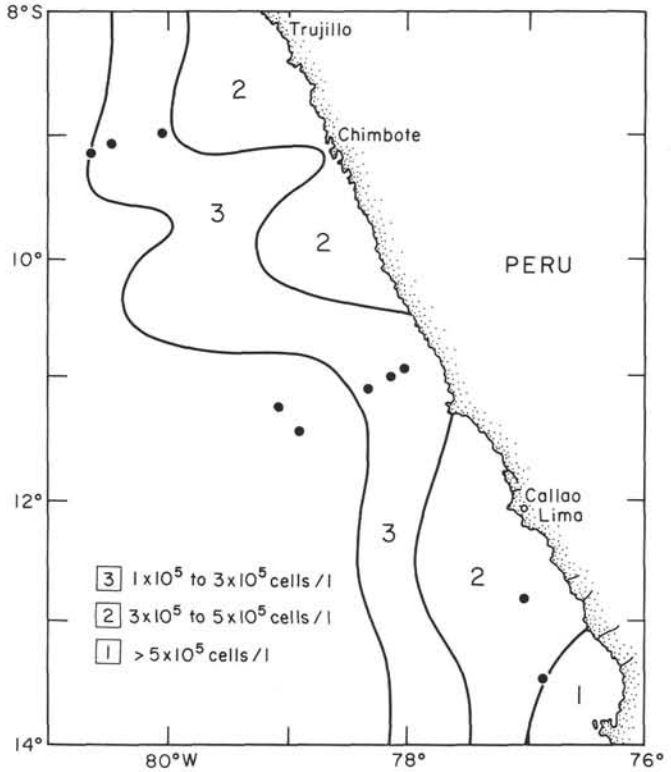


Figure 3. Primary productivity of phytoplankton sampled at 10 m water depth in the study area, Spring 1961 through 1970 (after Rojas de Mendiola, 1981). ODP sites as in Figure 1.

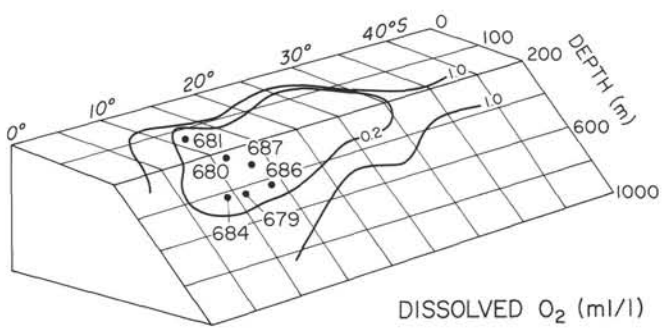


Figure 4. Location of sites in relation to the oxygen-minium zone. Bottom water dissolved oxygen less than 1.0 mL/L, after Burnett et al. (1980). Phosphorite deposition occurs between the 1.0 mL/L contour and the anaerobic core of the oxygen-minimum zone.

Oxidation of organic matter depletes oxygen on the seafloor beneath the highly productive areas over a depth range of about 100 to 900 m in the study area (Fig. 4). Low oxygen effectively discourages macroinvertebrates, leading to laminated diatomaceous sediments; however, certain foraminifers are adapted to that habitat (summary in Ingle and Keller, 1980) and occur there abundantly. These sediments contain up to 6.9% organic carbon (Rosato et al., 1975), which might form part of the food supply. All the shallow ODP sampling sites were drilled in the core of the oxygen-minimum zone (<0.2 mL/L), where the effect of the influx of decaying organic matter is fortified by the initial low-oxygen content of the water of the countercurrent.

Another consequence of the low-oxygen condition is the deposition of phosphorite. A mat of sulfur bacteria covers the low-oxygen seafloor (Rowe, 1981). The oxidation of organic matter during sulfate reduction by these bacteria releases phosphate to the interstitial fluids (Burnett, 1977). Phosphorite is deposited in the low-oxygen environment when calcite from the dissolution of foraminifers combines with the phosphate at pH 7.0 to 7.8 (Brooks et al., 1968). Whereas foraminifers are often destroyed in the phosphatization process, in some instances phosphatized remains of foraminifers give evidence of the former bottom assemblage (Manheim et al., 1975).

Sediment Textures

On the Peruvian margin, brownish green to gray green diatomaceous mud and sand or larger-grained sediments are common (reviewed by Rosato et al., 1975), sometimes alternating temporally, as seen in cores (Zen, 1959). Although the median grain size tends to decrease seaward, grain size, sorting, and composition are variable and reflect heterogeneous sources, including Andean detritus with abundant quartz, volcanic glass shards, shells that commonly occur near the shore, and authigenic glauconite and phosphorite. Rates of accumulation of these margin sediments range from 10 to 30 mm/10^3 yr (Rosato et al., 1975).

Sediment distribution patterns are further complicated through redeposition of grains following downslope transport. Although detrital grains are difficult to trace, the foraminiferal

distribution data of Bandy and Rodolfo (1964) and Resig (1981) revealed that this process is active on the Peru margin. Recently, using SeaMARC side-scanning sonar, Coulbourn and Moberly (1988) mapped a distributary system for turbidites entering the Peru-Chile Trench from the margin near the Arica Bight.

Background Studies

In summarizing Holocene foraminiferal distribution along the South American coast, Boltovskoy (1976) designated the assemblages of the study area as only partially or poorly known and assigned the principally shelf species known at that time to a temperate Peruvian subprovince. Subsequent research has shown that many of the characteristic outer-shelf and upper-slope species extend southward along the Chilean coast at least as far as Valparaiso (Ingle et al., 1980) and northward to Central America (Smith, 1964). Deeper water species are even more widely distributed.

Depth distribution of Holocene benthic foraminifers in the study area was shown in a single composite profile by Resig (1981) and in composite profiles of Peru-Chile data by Bandy and Rodolfo (1964). These data, plus depth profiles of species off Chile in shelf (Boltovskoy and Theyer, 1970) and outer shelf to abyssal habitats (Ingle et al., 1980) and off El Salvador (Smith, 1964), provide the basic information for determining paleobathymetry based on modern species. Ingle (1980) interpreted paleobathymetry for extinct Paleogene and Neogene species from California stratigraphic sections that contain some of the species found off Peru.

Living specimens from the Peruvian oxygen-minimum zone (Phleger and Soutar, 1973; Khusid, 1984) consist principally of bolivinids, with one strongly dominant species in standing crops that exceed 1200 specimens/20 cm^2 of surface sediment (Phleger and Soutar, 1973). An assemblage change toward greater diversity, including an increase in abundance of *Cancris* and *Epistominella*, as well as larger, more robust species, occurs in the lower part of the oxygen-minimum zone (Khusid, 1984).

ANALYTICAL METHODS

Sample Preparation

The core-catcher samples, which are variable in volume, were processed aboard ship directly after or within 12 hr of core recovery, whereas the 10- or 20-cm^3 samples from one or more sections per core were sealed in plastic until immediately before they were processed in the shore-based laboratory, 8 months after recovery. It was noted subsequently that many of the samples processed onshore contained large crystals of gypsum, whereas these were rare in the core-catcher samples. In view of the hypersaline brine in pore waters of the study area (Kastner, this volume), it is likely that this precipitation of gypsum resulted from dehydration of the samples, in spite of their encasement in plastic. Zen (1959) reported similar occurrences of halite and gypsum in cores from the Peruvian margin, which he attributed to dehydration.

Semiconsolidated and lithified sediment was crushed to pellet-size particles and soaked in water before sieving, but no chemicals were used to disaggregate the material. All samples were wet-sieved on a screen with 62 μm openings, and the dried sand fraction was divided by an OTTO-style microsplitter until roughly 200 to 500 benthic specimens remained. These were identified and counted and their percentage frequencies entered in data tables. Census data for those samples containing fewer than 100 specimens were not entered in the tables, as the results were considered biased by preservation. Poor preservation of tests is noted in the text.

Taxonomy

Where possible, taxonomy follows the generic classification adopted by Loeblich and Tappan (1987). In some instances, this has resulted in nomenclature differing from that used in Suess, von Huene, et al. (1988). Species that have undergone taxonomic changes are listed in the Appendix. Illustrated publications that were used extensively for benthic species identifications include those of the following researchers, grouped here according to age of study material: Quaternary (d'Orbigny, 1839; Natland, 1950; Uchio, 1960; Bandy, 1961; Smith, 1964; Boltovskoy and Theyer, 1970; McCulloch, 1977; Ingle et al., 1980; and Resig, 1981), Neogene (Kleinpell, 1938; Coryell and Mossman, 1942; Cushman and Gray, 1946; Cushman and Stevenson, 1948; Renz, 1948; Parker, 1964; Kleinpell, 1980; Haller, 1980), and Paleogene (Cushman and Stone, 1947; Stainforth, 1948; Cushman and Stone, 1949a and 1949b; Todd and Kniker, 1952; and Hofker, 1956).

Paleobathymetry

Species depth distribution data from various sources are used here to evaluate paleobathymetry (Fig. 5). Water depth curves are reconstructed from these data on the basis of the average depth or the tops or bottoms of biotopes, depending on whether species representation is indicative of boundary conditions, i.e., transition of one biotope to another. Interpretation of the paleobathymetry of the shallow sites relies further on modern species distribution in the area, as determined from near-surface samples of the Leg 112 cores combined with other core-top data from the area (Resig, 1981) (Fig. 6). Three principal assemblages occur over the depth interval of these samples, each characterized by well-defined species. *Bolivina costata* dominates the mid- to outer-shelf biotope to about 110 m and becomes rare below 150 m. *Bolivinellina humilis* composes more than one-half of the benthic foraminifers on the outermost shelf and in the upper bathyal biotope to a depth of about 300 m; this species becomes rare below about 500 m. This assemblage, which occurs in laminated diatomaceous mud, is coincident with upwelling and benthic oxygen-minimum conditions. A third assemblage, showing less species dominance but in which *Bolivina plicata* and *Angulogerina carinata* are conspicuous components, occurs from about 300 to 630 m or more. (Data from the 1964 report of Bandy and Rodolfo suggest an assemblage change by 800 m.) This third assemblage comprises foraminiferal sand layers that result from periodic current activity in the lower part of the countercurrent regime.

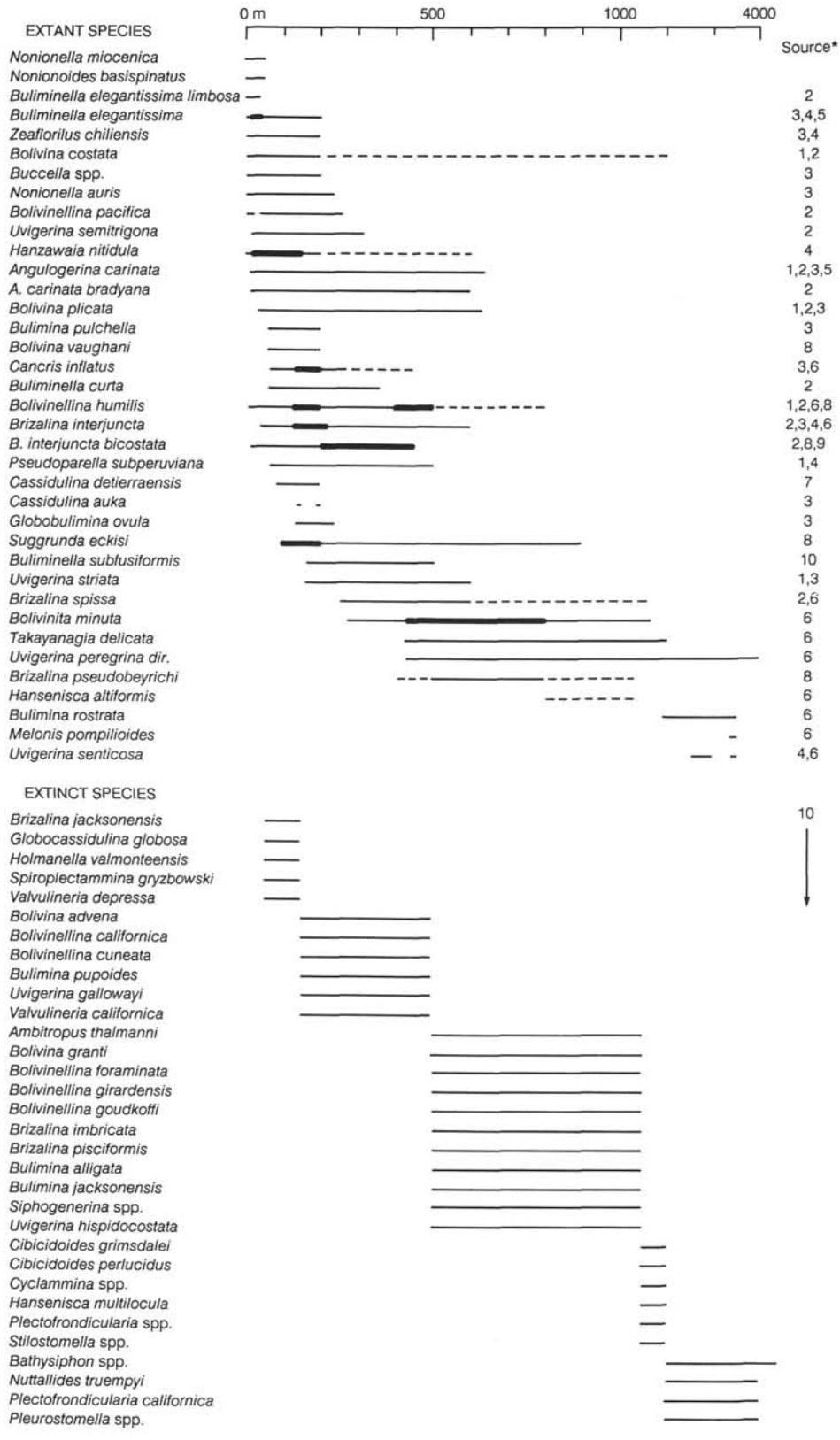
In addition to the *in-situ* assemblages, downslope displacement of individual species is recognized through occurrences that are apart from their distributional continuity and, for the most part, their maximum frequency. Turbidite deposits are identified through abrupt stratigraphic assemblage changes, combined with sedimentological evidence.

UPPER-SLOPE SITES

Percentage frequencies of species occurring at the six shallow sites (Tables 1 through 6) reveal intersite differences in species composition and representation, according to water depth and temporal assemblage changes. These sites are discussed in order of descending water depth.

Hole 681A (151 m, Lima Basin)

Quaternary benthic foraminifers recovered at this site are predominantly mid- to outer-shelf assemblages in which *Bolivina costata*, *Nonionella auris*, and *Buliminella elegantissima* are the dominant species (Fig. 7). High frequencies of *Bolivinellina humilis* near the surface and in some deeper



*REFS.1) Resig (1981), 2) Cushman and McCulloch (1940,-42,-48),
3) Boltovskoy and Theyer (1970), 4) Bandy (1961), 5) Uchio (1960),
6) Ingle, Keller, and Kolpack (1980), 7) McCulloch (1977),
8) Smith (1963), 9) Smith (1964), 10) Ingle (1980).

Figure 5. Reported depth ranges of some Peru margin benthic foraminiferal species.

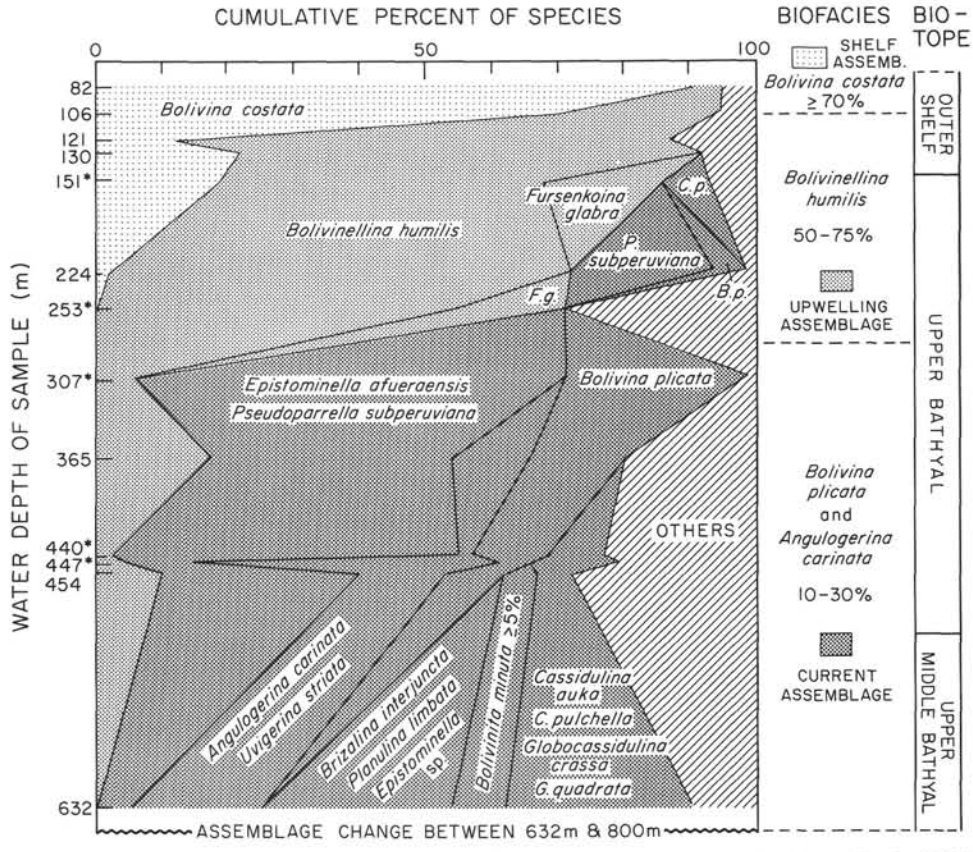


Figure 6. Bathymetry of modern species in the study area. Samples from Leg 112 (*) and Resig (1981).

horizons indicate present and past intervals of low-oxygen conditions in the outermost shelf to upper bathyal environment.

The stratigraphic progression of assemblages shows fluctuations in sea level throughout the section, with the lowest stand at about 45 mbsf. This stand is characterized by a mid-shelf assemblage having high percentage of *Buliminella elegantissima* and *B. elegantissima limbosa* and a 5% to 6% occurrence of *Buccella peruviana*. The highest stands of sea level occur at about 30 mbsf and in the upper 9 m of the section, as defined by high percentages of *Bolivinellina humilis*, which dominates outer-shelf to upper bathyal foraminiferal assemblages. Silty sand at the base of the section is mostly barren of foraminifers, except for two samples at about 160 and 170 mbsf that contain shelf to upper bathyal species. Sample 112-681A-19X-CC (170 mbsf) contains 52% *B. humilis*, which denotes deeper water than is indicated by the lithology of the sample, a gravelly deposit with sand. This sample is probably a shallow shelf deposit with reworked foraminifers. *Ammobaculites sp.*, which is present at 4%, occurs only in this sample and in the late Miocene shallow-water section of Site 679. The genus is a frequent inhabitant of brackish water environments (summarized by Boltovskoy and Wright, 1976). Its presence at Site 681 near the base of the cored section may result from shallow coastal conditions there, or to reworking, or both. Reworked Eocene/Oligocene diatoms occur in the sample (Schrader, this volume).

Hole 680B (253 m, Lima Basin)

Foraminiferal assemblages were recovered from the Quaternary section and from a single sample taken from near the top of the Pliocene section (Fig. 8). All other Pliocene samples, as well as several from the lower Quaternary, were barren of foraminifers. Aside from two foraminiferal sand layers bearing mollusk fragments and an *Angulogerina carinata–Uvigerina striata* assemblage indicative of current-generated deposition in the lower upper bathyal countercurrent regime, the Quaternary assemblages are dominated by *Bolivinellina humilis*, deposited under upwelling, oxygen-minimum conditions. Variation in the proportion of components suggests changes in sea level. The late Pliocene assemblage with 33% *Buliminella elegantissima* is characteristic of the mid-shelf. The depth differential between this and subsequent deposits is too great to be accounted for by fluctuations in sea level alone. Therefore, subsidence of 100 m or more is indicated between the Pliocene and Quaternary deposition.

Hole 687A (307 m, South Lima Basin)

Assemblages in this hole are dominated by shelf species in the Pliocene and early Quaternary, with deposits as shallow as mid- to inner-shelf depths characterized by high percentages of *Buliminella elegantissima* and sandy, shell-bearing sediments (Fig. 9). The late Quaternary assemblages represent upwelling conditions in which upper bathyal low-oxygen substrates are dominated by *Bolivinellina humilis* and *B. rankini*. In this part of the section, some sandy turbidite layers contain shelf species. The most recent assemblage (Sample 112-687A-1H-4, 110–114) is dominated by *Bolivina plicata* and *Epistominella afueraensis* that occur in foraminiferal sands indicative of current-modified deposition.

The magnitude of the paleobathymetric increase from about 50 m to 250 or 300 m that occurs between the early and late Quaternary Cores 112-687A-8X and -7X is too large to be accounted for by fluctuations in sea level alone. Subsidence of

Table 1. Percentage of species representation, Hole 679D (440 m).

Age	Quaternary											e. Pliocene			late Miocene									
Depth (mbsf)	3.8	7.7	11.6	17.1	20.2	20.7	26.8	29.2	36.1	40.2	64.6	73.9	82.9	87.6	104.3	105.7	106.3	124.9	132.9	144.6	156.0	162.6	164.7	172.7
Hole 679D (440 m) Core[1,2] Section Interval (cm)	1H-3, 82-86	1H-CC	2H-3, 68-71	2H-CC	3H-2, 130-135	3H-3, 30-36	3H-CC	4H-2, 76-80	4H-CC	5H-3, 80-85	7H-CC	8H-CC	9H-CC	10H-3, 67-71	12H-CC	13X-1, 135-139	13X-CC	15X-CC	16X-CC	17X-CC	18X-CC	19X-1, 124-127	19X-CC	20X-CC
Species																								
Ammobaculites sp.																1		30	1	7	37		1	
Angulogerina carinata	1	7	2					9																
Bolivina costata	1	1	1	+			+	2	1	1	98													
Bolivina floridana				10	11	11	4	1	5	7														
Bolivina plicata	10	4	3	+				7				17	5						1					
Bolivina vaughani												31	48		33	41	30	32	42	82	14	22	18	3
Bolivinellina humilis	2	12	8	4	3	5	14	17	37	22	1	8	18		23		+	1	3	+	+			
Bolivinellina pacifica	+																							
Bolivinellina seminuda	+																							
Bolivinita minuta	2	3	1					3																
Brizalina interjuncta		10	2					3																
Brizalina interjuncta bicostata	8																							
Brizalina pseudobeyrichi	+																							
Brizalina spissa		5	4					3																
Buccella peruviana																				+				
Bulimina montereyana								+																
Buliminella curta basispinata	1	+																						
Buliminella elegantissima	+				+	3	+	7	2	+					30	23	65	33	39	8	47	72	80	88
Buliminella elegantissima limbosa			1	+																				
Buliminella subfusiformis			4	22	44	41	16	1	18	40	+	4	7			+		1	1	1	+			1
Cancris auricula		+																						
Cancris carmenensis	+	+						1																
Cancris inflatus	2	12	2					2																1
Cassidulina detierraensis		17	16					6																+
Cassidulina pulchella	9							5																
Coryphostoma clippertonensis	1	+																						
"Ellipsoglandulina" fragilis				2	2	+	+		+															
Epistominella afueraensis	53	+	7		+	1		9	+						10									
Eponides ecuadorana													1											
Fursenkoina californiensis												+				+								
Fursenkoina glabra						1		+				1	+		2	17	2	1	1	1			1	
Galliherina cf. delreyensis											+													
Galliherina uvigerinaformis												27	15	1										
Globobulimina pacifica		+	+					+																
Globocassidulina crassa								1																
Globocassidulina subglobosa								1																
Gyroidina rothwelli	8	25	12					12																
Hansenisca multilocula	+							+																
Hanzawaia nitidula			+																					
Nonionella auris			5	1	2		4	+	1	+	+					12	3	2	10	1	+	6		7
Nonionoides basispinatus								+																
Parabolivina peruensis			22	61	37	41	52		30	27					2									
Planulina limbata	+	+						1																
Planulina ornata	+	+																						
Pullenia subcarinata	+																							
Rutherfordoides cornutus	+																							
Suggrunda eckisi								1																
Takayanagia delicata								3											1					
Uvigerina semitrigona		1	3					1																
Uvigerina striata		3	6					9																
Valvulineria californica											+	11	6	99					1		+			
Virgulinella peruensis							6		1							5					+			
Count	575	332	219	534	428	391	296	422	665	363	432	223	249	167	172	854	158	323	135	688	363	128	289	126
Planktonic/Benthic Ratio × 100	46	62	25	0	0	0	<1	91	<1	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0

[1] Barren of foraminifers: 5H-CC; 6H-3, 66–68; 6H-CC; 7H-3, 78–80; 8H-3, 66–70; 9H-3, 66–69; 10H-CC; 11H-3, 64–68; 14X-2, 50–54; 15X-1, 112–116; 18X-1, 113–116; 20X-1, 81–85; 21X-CC; 22X-CC; 24X-1, 13–17; 25X-CC; 26X-1, 60–64; 26X-CC; 27X-CC.

[2] Counts less than 100: 11H-CC; 14X-CC; 17X-1, 91–95; 23X-CC.

at least 150 m or more must have occurred in the middle of the Quaternary section.

Hole 684A (426 m, Trujillo Basin)

The section at this site registers more disruption of habitats and stratigraphy than the previously discussed Lima Basin sections. The late Miocene assemblage with high percentages of *Buliminella subfusiformis*, *Bolivina vaughani*, and other bolivinids, combined with lesser percentages of *Valvulineria* cf. *compressa* and V. cf. *depressa*, represents a transitional outer-shelf to upper bathyal environment (Fig. 10). After an erosional event that produced a 5.4-m.y. hiatus (Schrader, Martini, this volume), deposition resumed in the middle Pliocene in an upper middle bathyal biotope characterized by *Uvigerina peregrina*, *Cassidulina cushmani*, *Takayanagia delicata*, and *Epistominella smithi*. This deposition was truncated by another hiatus (duration of about 2 m.y.). The overlying late Quaternary deposits contain a current-dominated foraminiferal sand containing mollusk shells and an *Angulogerina carinata–Uvigerina striata* assemblage. This sand may have been deposited somewhat shallower than the present water depth because *Bolivinita minuta* is rare. The youngest Quaternary deposits at this site contain the upwelling-dominated, low-oxygen assemblage characterized by high percentages of *Bolivinellina humilis*. The change from current to upwelling-dominated regime, indicated by the assemblages, contrasts with the circulation pattern of the southern sites in approximately the same water depth, where the current-dominated assemblage occupies the uppermost layers. The difference in paleobathymetry between the late Miocene and the middle Pliocene deposition is too great to be attributed to changes in sea level, and the section was apparently down-dropped about 400 m during that interval. Habitat displacement across the mid-Pliocene to late Quaternary hiatus might be attributed, at least in part, to changes in sea level.

Holes 679D and 679E (440 m, Lima Basin)

Long stratigraphic intervals at this site were barren of benthic foraminifers (Fig. 11), which prevented continuity in the paleobathymetric interpretation. The oldest strata of the hole, Cores 112-679E-11X through -13X (340 to 360 mbsf) are

Table 2. Percentage of species representation, Hole 680B (253 m).

Hole 680B (253 m) Species	Age	Quaternary									Plio.
	Depth (mbsf)	3.7	5.3	9.1	15.2	18.7	24.7	28.2	34.1	43.6	62.4
	Core[1,2] Section Interval (cm)	1H-3, 67-71	1H-CC	2H-3, 60-64	2H-CC	3H-3, 69-73	3H-CC	4H-3, 69-73	4H-CC	5H-CC	7H-CC
Angulogerina carinata bradyana									6		
Bolivina costata		1	1	7	12	1	+	1	2	2	12
Bolivina plicata		+	2					1	1		
Bolivina vaughani											+
Bolivinellina humilis		53	60	30	48	55	11	46	6	84	5
Bolivinellina pacifica		1	9	+	4	+	+	2			2
Bolivinita minuta		+	+			1		+			
Brizalina interjuncta							3		+		
Brizalina interjuncta bicostata		+									
Brizalina spissa									6		
Bulimina exilis tenuata		+									
Bulimina montereyana		+	3			+		+			
Bulimina patagonica							+				
Buliminella curta basispinata		+				1					
Buliminella elegantissima		7	3	+		+	+	5		3	33
Buliminella subfusiformis			2					+		+	24
Cancris auricula							+	+			
Cancris carmenensis			+			+		+		+	
Cancris inflatus		+	+		+		6	+	3	1	
Cassidulina detierraensis							59	+	23		
Cassidulina pulchella		3	2	+		1		1		1	
Epistominella afueraensis									34		
Fursenkoina glabra		17	9	23	19	7	1	15	+	4	3
Gyroidina rothwelli							8	2	5		
Nonionella auris		3	1	37	15	7	1	2	2	4	10
Nonionoides basispinatus											3
Pseudoparrella sandiegoensis							+	1			7
Pseudoparrella subperuviana		14	3	+	+	6		3	+	1	
Pullenia subcarinata							+				
Suggrunda eckisi			5		+	19		13	2		
Takayanagia delicata						2	+	8	+		
Textularia sp.							+		+		
Uvigerina semitrigona							8		5		
Uvigerina striata							1		2		
Valvulineria inaequalis							+				
Virgulinella peruensis		+	+	2							+
Count		663	315	403	421	371	367	721	189	357	502
Planktonic/Benthic Ratio × 100		3	2	23	15	<1	24	4	34	1	0

[1] Barren of foraminifers: 5H-3, 10–14; 6H-3, 58–62; 7H-3, 37–41; 8H-5, 43–47; 8H-CC; 9H-3, 69–73; 9H-CC; 10H-4, 55–58; 10H-CC; 11H-1, 71–72; 11H-CC; 12X-CC; 14X-1, 39–43; 14X-CC; 18X-CC; 19X-CC; 20X-CC; 21X-1, 69–73; 21X-CC; 22X-CC.

[2] Counts less than 100: 6H-CC.

middle Miocene black shale containing *Valvulineria* cf. *depressa*, *Bolivina* cf. *costata*, *Bulimina* sp., *Brizalina* sp., and *Buliminella elegantissima*, indicating an outer-shelf, low-oxygen environment. The next foraminifer-bearing strata occur in Cores 112-679D-15X through -20X (125 to 173 mbsf), are late Miocene in age, and contain high percentages of *Buliminella elegantissima* and *Bolivina vaughani*, indicating shelf depths. Following a hiatus at the top of the late Miocene, early Pliocene deposition shifted to an outermost shelf to uppermost bathyal environment, dominated by *Valvulineria californica, Galliherina uvigerinaformis,* and *Bolivina vaughani*. The next stratigraphically higher strata containing foraminifers are of Quaternary age, with upper bathyal assemblages showing fluctuations, current- and upwelling-dominated environments. This could be the result of eustatic fluctuations or shifting upwelling cells, or both. The youngest strata contain the current-influenced assemblage with *Angulogerina carinata* and *Epistominella afueraensis*, *Bolivina plicata*, and *Uvigerina striata*. The upwelling-controlled assemblage has *Bolivinellina humilis*, *Buliminella subfusiformis*, and *Parabolivina peruensis*.

Subsidence of the site from shelf through the upper bathyal biotope occurred during the course of early Pliocene through Quaternary deposition.

Hole 686A (447 m, Pisco Basin)

Except for one deeper excursion, the Quaternary section (150 and 211 mbsf) of Site 686 was deposited on the shelf. The sediment consists of silt, sand, and shell debris, and the foraminiferal assemblage contains *Buliminella elegantissima*, *Nonionella* spp., *Bolivina costata* and *Alexanderina viejoensis*. Concurrent high frequencies of *Bolivinellina humilis* indicate low-oxygen conditions (Fig. 12). From 150 to 90 mbsf, an upper bathyal environment influenced by upwelling and low-oxygen substrate is indicated by high frequencies of *Bolivinellina humilis* and associated species. The stratigraphic section between 90 and 25 mbsf is mostly barren of benthic foraminifers, except for an interval between 75 and 60 mbsf that

Table 3. Percentage of species representation, Hole 681A (151 m).

[1] Barren and [2] Low count samples listed below. + = less than 1%

Hole 681A (151 m) / Species	Age	Quaternary																																?		
	Depth (mbsf)	6.3	10.1	16.1	19.7	25.2	29.1	40.4	44.6	44.7	57.3	63.1	68.4	73.3	73.9	76.5	82.7	85.6	88.2	95.3	97.0	99.2	104.9	106.9	110.9	114.3	115.0	121.4	122.3	122.6	124.8	133.5	158.5	168.0
	Core[1,2] Section Interval (cm)	1H-CC	2H-3, 90-95	2H-CC	3H-3, 106-110	3H-CC	4H-3, 84-88	5H-4, 128-130	5H-CC	6H-CC	7H-3, 41-45	7H-CC	8H-4, 56-60	8H-CC	9H-1, 130-134	9H-3, 76-80	9H-CC	10H-3, 64-68	10H-CC	11H-3, 45-47	11H-4, 118-122	11H-CC	12H-3, 66-71	12H-4, 138-142	12H-CC	13X-3, 32-36	13X-CC	14X-1, 140-144	14X-2, 46-50	14X-2, 91-94	14X-CC	15X-3, 72-76	18X-CC	19X-CC
Alexanderina viejoensis		1	1						5			4		+	2	2	+	1	1			+			2						2			1
Ammobaculites sp.																																			4
Angulogerina carinata bradyana		+																																	
Bolivina costata		19	32	26	47	32	10	2	16	9	13	4	14	31	17	34	39	22	34	26	50	9	45	43	24	41	36	83	72	79	50	88	58	22
Bolivina plicata										+																									
Bolivinellina humilis		49	7	35	7	46	35	74	2	6	66	69	41	9	39	19	47	19	34		9	24	7	3	11	2	4	+	1		2	3	8	52
Bolivinellina quadrata									+	+																									
Brizalina cf. acutula									+	1																									
Brizalina interjuncta bicostata														+																					
Buccella peruviana									5	6		+				+			+															+
Bulimina patagonica		1										1	1	9	7	+			+	2														
Bulimina pulchella									2	1		+																							
Buliminella elegantissima						+	1	+	34		14	12	18	12	16	24	1	14	9	11	16	15	+	20	16	7	14	2	8	2	28	5	32	12
Buliminella elegantissima limbosa				12						55																									
Buliminella subfusiformis									+	+		+	3	3	3		+	+	+		6	45	11	7	14	5	7	1	2	1	3	4	1	1
Cancris inflatus								+	1	+	1	+		+					+						+									
Cassidulina auka								6	+	1	1	+																						
Cassidulina detierraensis		+																																	
Cassidulina pulchella		7																																	
Cassidulina sp.						+																													
Epistominella afueraensis								10	1	2		2				+			3																
Fursenkoina glabra		18	3	7	1	14	30	3			1		9	16	5			14	+	+			13	9	6	14	19								1
Globobulimina ovula												+																							
Globocassidulina depressa									+	+				+					+																
Hanzawaia nitidula									+	+		+						+																	
Nonionella auris		4	56	16	45	5	18	5	31	12	4	4	14	16	11	17	13	29	18	60	18	7	22	17	25	31	20	6	12	3	15		1	1
Nonionoides basispinatus														1						1															
Parabolivina peruensis																									1		+								
Planulina depressa										+																									
Pseudoparrella sandiegoensis				4		1	3			3				2		1			+																6
Rosalina sp.																2			1							+									
Suggrunda eckisi						1	1					2				+							+												
Uvigerina semitrigona									+	+																									
Virgulinella peruensis		+	+	+			2							1				+	+		+			1	+	+		8	5	15	+			
Zeaflorilus chiliensis									3	4																									
Count		833	462	598	178	549	738	216	659	393	209	462	287	472	382	362	581	302	402	312	301	229	279	410	307	431	609	578	432	417	1003	116	152	376
Planktonic/Benthic Ratio × 100		1	4	6	7	3	6	2	5	5	0	1	<1	2	<1	2	5	1	3	0	0	0	<1	<1	1	1	0	<1	<1	2	2	0	0	<1

[1] Barren of foraminifers: 1H-3, 35–39; 15X-CC; 16X-CC; 20X-CC.
[2] Counts less than 100: 4H-CC; 16X-1, 49–53.

Table 4. Percentage of species representation, Hole 684A (426 m).

Hole 684A (426 m) Species	Age	Quaternary				late Pliocene					late Miocene					
	Depth (mbsf)	3.7	5.2	9.0	15.0	29.3	33.7	35.8	43.2	45.7	62.9	69.5	71.6	79.1	88.6	107.6
	Core[1,2] Section Interval (cm)	1H-3, 70-74	1H-CC	2H-3, 70-74	2H-CC	4H-4, 58-62	4H-CC	5H-2, 58-61	5H-CC	6H-2, 98-102	8H-1, 65-69	8H-CC	9H-CC	10H-CC	11X-CC	13X-CC
Alexanderina viejoensis		+														
Angulogerina carinata bradyana			+	17												
Angulogerina sp.						2	1	5								
Bolivina cf. advena											2	+	4	5	17	9
Bolivina costata		1	1	+		2	2	2	9	5						
Bolivina plicata		+	+	7	6											
Bolivina sinuata						+	2		+	+						
Bolivina vaughani											5	3	16	17	13	32
Bolivinellina humilis		62	61	1	13											
Bolivinellina pacifica		1	2		1		8	3	11	1	1	15	32	9	7	3
Bolivinita minuta		+		+		1	4	17	2	2						
Brizalina argentea									+							
Brizalina girardensis																+
Brizalina imbricata											+	+				
Brizalina interjuncta				10	+											
Brizalina interjuncta bicostata				+				+	1	+						
Brizalina pseudobeyrichi								+	+	2						
Brizalina spissa				+		1	3	2	3	1						
Bulimina alazanensis								+	1	1						
Bulimina striata mexicana							1		+							
Bulimina sp.											+	+	1	+	1	4
Buliminella curta basispinata		+														
Buliminella elegantissima									+			+			1	
Buliminella elegantissima limbosa		1	1		+						1					
Buliminella subfusiformis			+	+		17	6	2	7	3	86	77	27	56	51	48
Cancris auricula				+												
Cancris inflatus		+	+	5	2											
Cassidelina nodosa							+									
Cassidulina cushmani				1		23	35	44	15	27						
Cassidulina detierraensis		+		+	4											
Cassidulina aff. detierraensis				21	2											
Cassidulina cf. modeloensis										+						
Cassidulina pulchella		5	2		1											
Cibicides sp.										+					1	
Eilohedra levicula							1	4	3	1						
Epistominella afueraensis		8	2	20	22											
Epistominella smithi				+		2	6	5	12	11		+				
Fursenkoina bramlettei							+		1	+						
Fursenkoina glabra		17	1										+	1		1
Galliherina uvigerinaformis											+	+	+	+	+	+
Globobulimina ovula		+							+	+						
Globobulimina pacifica			+													
Globocassidulina californica				+												
Globocassidulina cf. lomitensis							+		+							
Globocassidulina quadrata				+												
Gyroidina rothwelli				2	3	+			+	+						
Gyroidina sp.				+												
Hansenisca altiformis									+							
Hanzawaia nitidula				+												
Nonion obducum											+	+	+	+		
Nonion sp.						1			+							
Nonionella miocenica stella		2	+													
Nonionella sp.						1	2		1							
Nonionoides basispinatus								3		1						
Planulina limbata				1					+							
Planulina ornata				+												
Plectofrondicularia californica						+	1		1	+						
Praeglobobulimina spinescens						+		+	1	+						
Proxifrons advena						+		1	+	1						
Pseudoparrella sandiegoensis									2	2						
Pseudoparrella subperuviana			22	8	45	5	4	+	8	1	+	+			1	
Pullenia subcarinata				+												
Robulus cf. americanus											+	+	+	+		
Rutherfordoides cornutus						+		1	+	+						
Stilostomella sp.						+			+	+						+
Suggrunda eckisi		2	8		1				+	+						
Takayanagia asanoi						18	1		1	+						
Takayanagia delicata											1	+		5	1	
Uvigerina asperula							1									
Uvigerina auberiana									+	+						
Uvigerina peregrina + dirupta						25	20	11	20	39						
Uvigerina ? semitrigona			+		+											
Uvigerina striata			+	6	+											
Uvigerina sp.							1									
Valvulineria californica							+									
Valvulineria cf. compressa											1	2	16	5	1	1
Valvulineria cf. depressa											1	2	3	1	4	1
Count		554	1286	389	299	264	449	382	474	415	523	415	368	265	210	256
Planktonic/Benthic Ratio × 100		6	<1	6	<1	0	0	0	0	0	1	1	16	20	5	55

[1] Barren of foraminifers: -3H-3, 74–78 cm; -3H-CC; 6H-CC; 7H-1, 77–81 cm; -7H-CC.
[2] Downhole contamination: -11X-CC; -12X-CC; -14X-CC.

Table 5. Percentage of species representation, Hole 686A (447 m).

Age	Quaternary																														
Depth (mbsf)	0	8.8	14.5	15.7	24.6	62.6	64.7	70.9	71.6	95.8	111.1	111.5	113.2	130.8	133.3	138.2	140.4	148.7	152.3	155.9	159.7	158.3	167.6	177.2	178.1	186.7	187.1	199.9	204.6		
Hole 686A (447 m) Core[1,2] Section Interval (cm)	1H-1, 0-1	2H-3, 69-73	2H-7, 36-39	3H-1, 112-116	4H-1, 48-52	8H-1, 51-55	8H-CC	9X-5, 23-27	9X-CC	12X-2, 81-85	13X-CC	14X-1, 77-79	14X-CC	15X-8, 44-48	15X-CC	16X-7, 60-64	16X-CC	17X-CC	18X-3, 60-64	18X-5, 126-130	18X-CC	19X-1, 9-12	19X-CC	20X-CC	21X-1, 87-91	21X-CC	22X-CC	23X-3, 75-78	23X-CC		
Species																															
Alexanderina viejoensis													+						36	11	3		+		+		33	19	5		
Angulogerina carinata	8																														
Bolivina costata			1	2	1	+	2		5	1	1	1	+	1	+	4	2		3	6	5		11	13	5	9	16	6	52		
Bolivina plicata	6				1																										
Bolivinellina foraminata	4													1	6	1															
Bolivinellina humilis				50					64	74	80	69		21	55				40	58	79	99	66	60	64	69	2	43	8		
Bolivinellina pacifica													+						+								2				
Bolivinellina rankini	5	85	20		49	98	32	31					66			53	79	99													
Bolivinellina seminuda	+			+					1																						
Bolivinita minuta	+		3	1																											
Brizalina interjuncta	5			2																											
Brizalina interjuncta bicostata				13																											
Brizalina pseudobeyrichi	+																														
Brizalina spissa	+		+		1				+																						
Buccella peruviana																			1	+								1	+		
Buliminella curta basispinata			1		3																										
Buliminella elegantissima + limbosa						+	6						4		+		1		12	6	4	1	1	15	22	1	26	13	14		
Buliminella subfusiformis	1			+									+	60	27	37			1				+			+	+				
Buliminella sp.			+																												
Cancris carmenensis	4		+	1					+																						
Cancris inflatus	1	1	+	2	14			+	+	1	1				+	+	+			+	+		1		+			+			
Cassidulina detierraensis		5																													
Cassidulina aff. detierraensis		}	20		19																										
Cassidulina pulchella	7	1				+	+	3	19	3		2	6	4	4	2			+	+		1									
Coryphostoma clippertonensis			+																												
Epistominella afueraensis	10				8	+	59								1						1										
Epistominella cf. pacifica								+		1																					
Fursenkoina glabra		2	25	7	1			5	4				2	3	2								+	3	3	10					
Fursenkoina sp.									1																						
Globobulimina ovula			2	26					+																						
Globobulimina pacifica			+																												
Globocassidulina crassa	6																														
Gyroidina rothwelli		2	4	+																											
Hanzawaia nitidula																											+				
Nonion sp.			1	+																											
Nonionella auris									3	1	1		7						6				+	7	5	7	9	4	14		
Nonionella miocenica														7	1		11	+	1	18	8		7	2	1	4	4	5	+		
Nonionoides basispinatus		1																													
Planulina limbata	+		+																												
Planulina ornata			+		3																										
Pseudoparella obesa	+																														
Pseudoparella subperuviana							1		1	1	+	5	21	5	1	2		5	+		1	+		11				3	7		
Pullenia subcarinata	1		+																												
Quinqueloculina sp.																														+	
Rosalina peruviana																				+							4	2	5		
Rutherfordoides cornutus	+																														
Suggrunda eckisi								63	17	3	9	9	13	1	1																
Takayanagia delicata		3	10	7					+					+	+	1							+								
Uvigerina striata	38																														
Valvulineria inaequalis	1																														
Virgulinella peruensis							1		1																						
Count	424	141	497	283	130	601	161	351	286	237	481	152	399	521	502	309	313	150	325	454	277	161	466	318	316	552	242	261	215		
Planktonic/Benthic Ratio × 100	<1	1	<1	0	0	0	1	1	<1	0	<1	0	1	1	0	<1	1	0	0	<1	0	0	1	1	<1	0	3	2	0		

[1] Barren of foraminifers: 1H-3, 64–68; 1H-CC; 3H-CC; 4H-CC; 5H-2, 136–140; 5H-3, 69–73; 5H-CC; 6H-3, 76–80; 6H-CC; 7H-2, 38–42; 7H-CC; 10X-3, 102–106; 10X-CC; 11X-1, 62–66; 11X-CC; 17X-3, 73–77; 20X-3, 74–78.
[2] Counts less than 100: 2H-CC; 19X-6, 59–63.

contains an assemblage indicative of upper bathyal, low-oxygen conditions. The upper 25 m of the section was deposited in the lower part of the upper bathyal under current-dominated conditions, with signature species *Angulogerina carinata*, *Uvigerina striata*, *Bolivina interjuncta*, and *Cassidulina detierraensis*.

Fluctuations in sea level are registered in the early part of the stratigraphic section, but are not detectable in the later assemblages from the upper bathyal because no change in biotopes was involved. Subsidence of Site 686 from 100 m or less to its present depth of 447 m apparently occurred gradually, during the Quaternary.

LOWER-SLOPE SITES

Percentage frequencies of species occurring at the three deep sites and estimates of species abundance at the fourth deep site (Tables 7 through 10) reveal temporal assemblage changes that also reflect sediment redeposition and subsidence of the outer continental margin. The sites of the 9°S transect are discussed first, followed by the sites of the 10°S transect.

Holes 683A and 683B (3072 m, offshore Trujillo)

This lower-slope site lay in upper bathyal depths during the middle Eocene. The assemblages are characterized by various bolivinids, buliminids, and buliminellids, along with traces of some species having deeper water affinities, such as *Asterigerina crassaformis* and *Nuttallides truempyi*. Well-represented species include *Bolivina maculata*, *Bolivinellina basisenta*, *Bulimina chirana*, *Buliminella peruviana*, *Buliminellita mirifica*, *Globocassidulina globosa*, and *Stichocassidulina thalmanni*.

Following an unconformity, middle Miocene deposits contain lower bathyal assemblages, indicating subsidence of about 1500 m in 26 m.y., or about 60 m/m.y. Species identifying these lower bathyal deposits include *Cibicidoides trinitatensis*, *Hansenisca zealandica*, *Melonis pompilioides*, and *Planulina renzi*, among others.

These middle Miocene lower bathyal assemblages are separated by a barren interval from a section containing a middle bathyal assemblage with *Bolivina alazanensis*, *Uvigerina gallowayi*, *U. mantaensis*, and *U. rustica*. Associated high numbers of the *Bolivina vaughani* Gr. might have been transported from the shelf. Data from planktonic microfossils (Schrader, Martini, this volume) indicate that this middle Miocene section represents a slump deposit that contains blocks of intact sediment.

Lower bathyal sedimentation continued in the late Pliocene and Quaternary, with an assemblage in which *Uvigerina senticosa* is prominent. Up to 85% *Bolivina costata* and some other shelf and upper-slope species indicate high amounts of

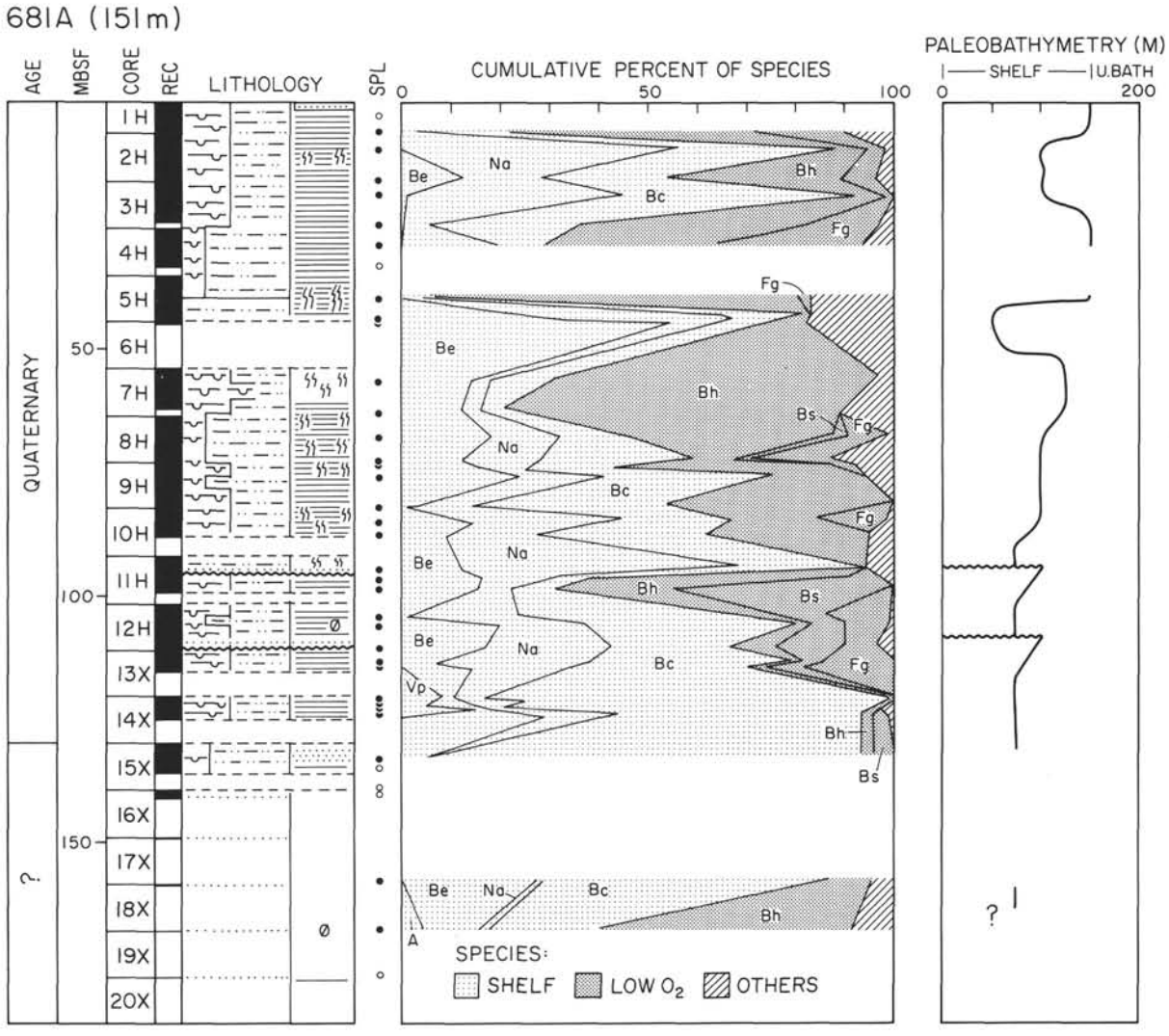


Figure 7. Lithofacies, biofacies, and paleobathymetry at Hole 681A. Shelf species: A = *Ammobaculites* sp., Bc = *Bolivina costata*, Be = *Buliminella elegantissima*, Na = *Nonionella auris*, Vp = *Virgulinella peruensis*. Low-oxygen species: Bh = *Bolivinellina humilis*, Bs = *Buliminella subfusiformis*, Fg = *Fursenkoina glabra*.

downslope sediment transport, particularly in the middle to late Quaternary.

Hole 685A (5071 m, offshore Trujillo)

The Quaternary and upper Miocene section recovered at this site, which is located below the present CCD, is mostly barren of benthic foraminifers or these are rare. Horizons containing common foraminifers consist of species transported from various shelf to lower bathyal biotopes, mostly the shelf species *Bolivina costata* (to 95%) in the Quaternary and *Bolivina vaughani* (to 50%) in the late Miocene. Data from planktonic microfossils (Schrader, this volume) indicate that the lower upper Miocene deposits represented here are part of the slump that affected the Site 683 section.

Hole 682A (3789 m, offshore Lima)

Middle Eocene deposits at the base of the cored section contain an outermost shelf–upper bathyal assemblage similar to that recovered at Site 683, with *Bolivinellina basisenta*, *Bulimina chirana*, *Cyclammina simiensis*, *Globocassidulina globosa*, and *Stichocassidulina thalmanni* as principal components, and other species described from formations exposed in northern Peru. Sample 112-682-44X-CC, above a late Eocene hiatus, contains reworked, silicified Eocene foraminifers as well as reworked nannofossils, including Late Cretaceous, nearshore, and shallow-water species (Martini, this volume). Following the hiatus and subsidence, the Oligocene and lower Miocene sections were deposited at middle bathyal depths. The Oligocene assemblage resembles that of the Goajira Peninsula, Columbia (Becker and Dusenbury, 1958) and the early Miocene assemblage that of the Agua Salada Formation (Renz, 1948). *Uvigerina gallowayi*, *U. mantaensis*, and *U. rustica* occur in the early Miocene section, rather than in the middle Miocene, as at Site 683.

A late Miocene slump is indicated by diatoms and nannofossil data similar to that reported for the other sites. Discrete benthic foraminiferal assemblages are found throughout this interval, suggesting material transported from outer-shelf as well as upslope bathyal sources. The presence of high percentages of *Buliminella elegantissima limbosa* throughout the late and middle Miocene section indicates persistent transport from a shallow source. Middle bathyal indicator species include *Ambitropus thalmanni*,

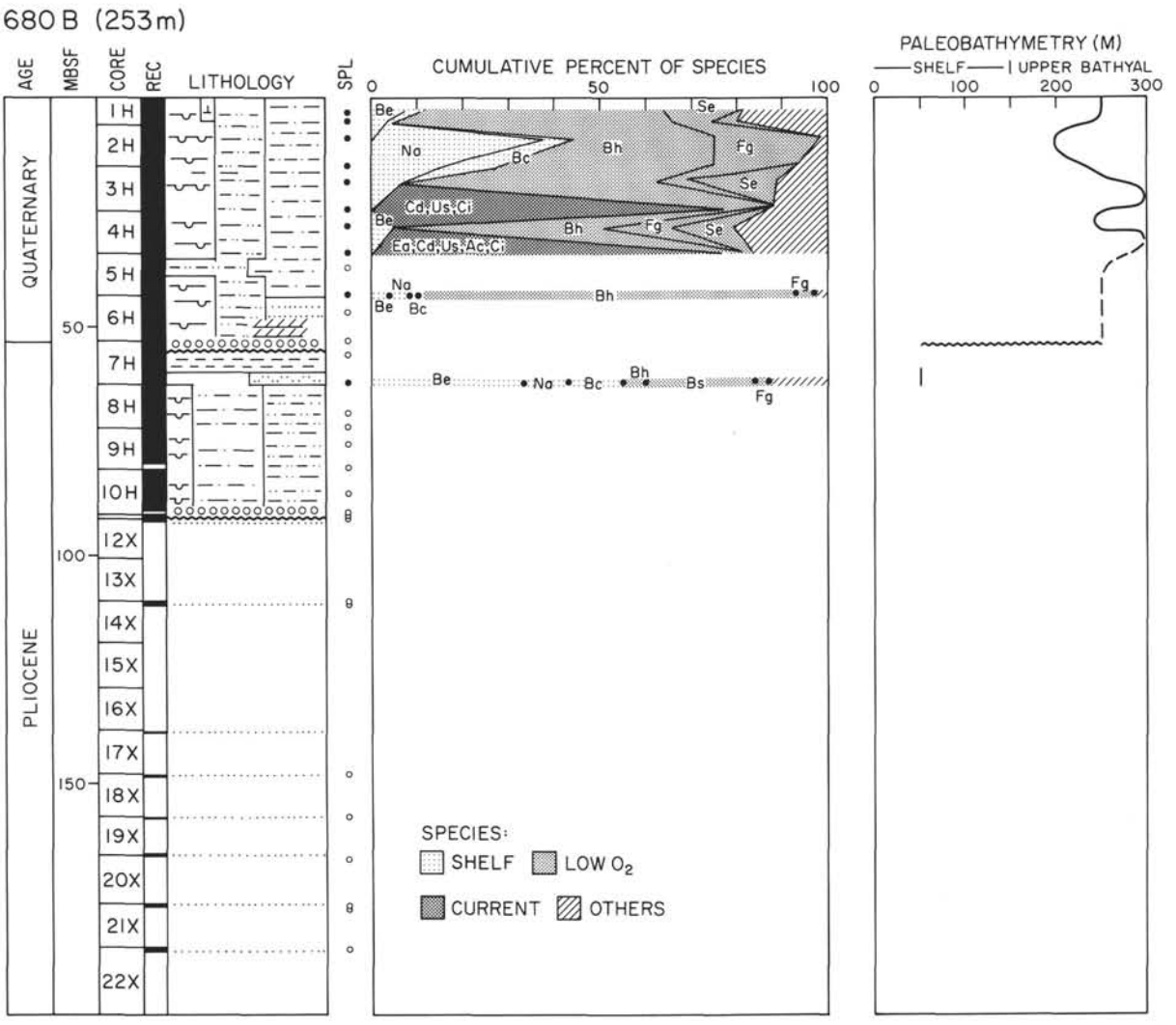


Figure 8. Lithofacies, biofacies, and paleobathymetry at Hole 680B. Shelf species: Bc = *Bolivina costata*, Be = *Buliminella elegantissima*, Na = *Nonionella auris*. Low-oxygen species: Bh = *Bolivinellina humilis*, Bs = *Buliminella subfusiformis*, Fg = *Fursenkoina glabra*, Se = *Suggrunda eckisi*. Current species: Ac = *Angulogerina carinata*, Ci = *Cancris inflatus*, Cd = *Cassidulina detierraensis*, Ea = *Epistominella afueraensis*, Us = *Uvigerina striata*.

Epistominella smithi, *Hansenisca multilocula*, and *Uvigerina peregrina dirupta*. Sample 112-682A-15X-CC is dominated by *Bolivina granti*. Sample 112-682A-8X-CC, a discordant early Pliocene sample with high percentages of *Bolivinellina girardensis* and *B. goudkoffi*, also was displaced.

The late Pliocene and Quaternary sections contain *Uvigerina senticosa*-bearing lower bathyal assemblages. Up to 27% transported *Bolivina costata* and several slope species are mixed with the *in-situ* assemblage.

Holes 688A and 688E (3819 m, offshore Lima)

The Eocene section penetrated at the base of this lower bathyal site contains a history of shallow-water deposition in shelf and upper bathyal environments. The shallowest biofacies, containing rare specimens of *Spiroplectammina gryzbowski*, *Cyclammina* sp., and *Virgulinella* sp., occurs in Sample 112-688E-45R-CC. Plant debris was also noted in this sample. Subsequent early Eocene deposits indicate deepening to upper bathyal conditions in Sample 112-688E-43R-CC, where deep-sea species, such as *Cibicidoides grimsdalei* and *Oridorsalis umbonatus*, are coincident with shelf-dwelling *Globocassidulina globosa*, and then a shallowing again to shelf conditions in Core 112-688E-36R, where a buliminid assemblage predominates. Following a hiatus, middle Eocene deposition is characterized by sparse faunas in sandy matrix that may be reworked under shallow shelf conditions and/or represent downhole contamination. *Bathysiphon eocenica*, *Nodosaria lonqiscata*, *Oridorsalis umbonatus*, and *Stilostomella* spp. are represented (by single specimens), as well as some Eocene indexes, such as *Bulimina chirana*.

After a hiatus, early Miocene assemblages in which *Uvigerina gallowayi* and *Uvigerina mantaensis* occur with *Bulimina alazanensis*, *Hansenisca altiformis*, and *Oridorsalis umbonatus* suggest upper middle bathyal conditions and subsidence of 400 to 1400 m, following Eocene deposition. Late Miocene samples are barren of benthic foraminifers at this site.

In the Quaternary, lower bathyal assemblages with common to abundant *Uvigerina senticosa*, *Melonis affinis*, *Melonis pompilioides*, and *Pullenia bulloides* prevailed. Transported species, particularly *Bolivina costata*, compose up to 50% of some of the layers sampled; however, other samples contain only 5% (112-688A-4H-CC) to 10% (112-688A-7H-

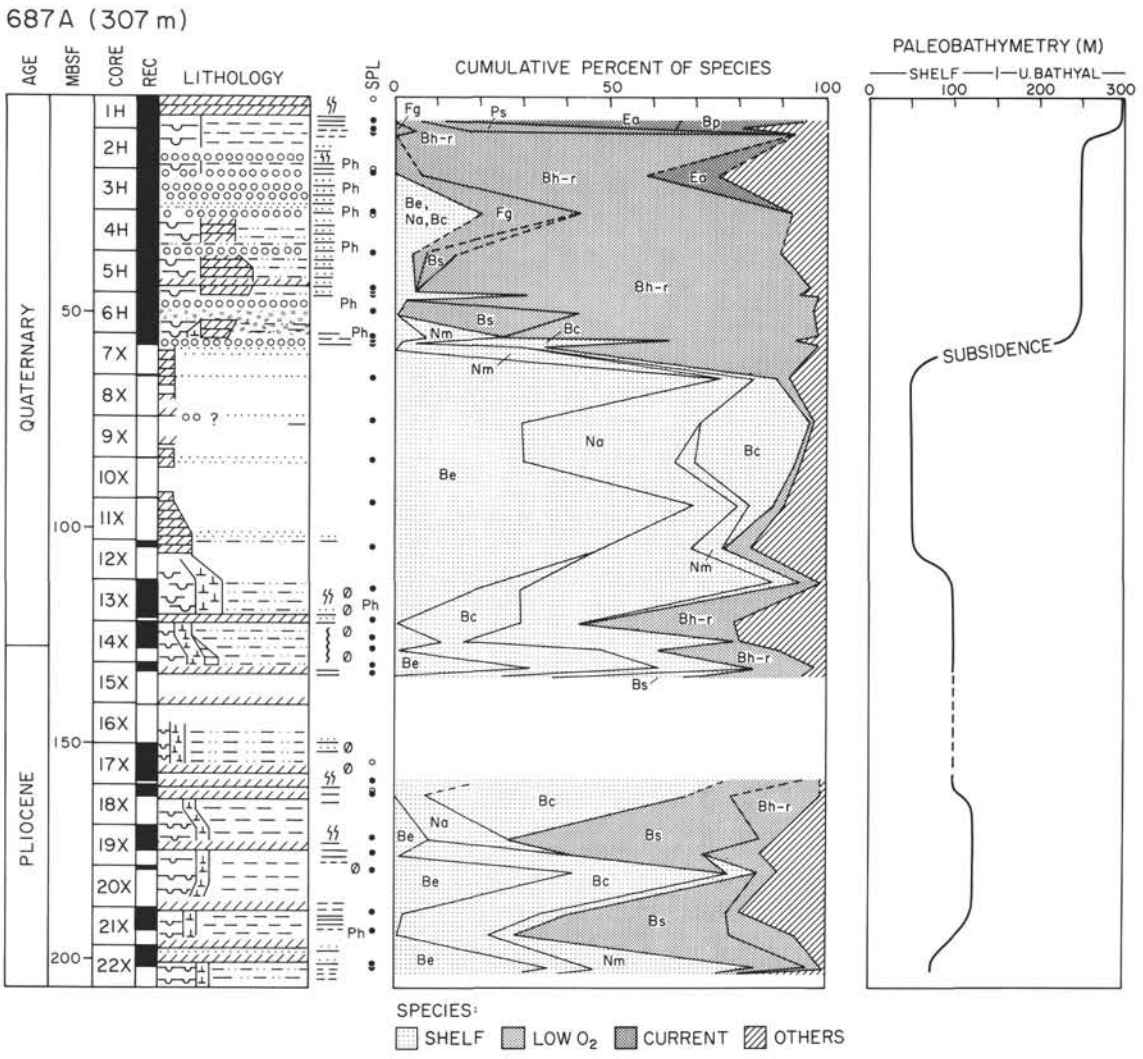


Figure 9. Lithofacies, biofacies, and paleobathymetry at Hole 687A. Shelf species: Bc = *Bolivina costata*, Be = *Buliminella elegantissima*, Na = *Nonionella auris*, Nm = *Nonionella miocenica*. Low-oxygen species: Bh-r = *Bolivinellina humilis-rankini*, Bs = *Buliminella subfusiformis*, Fg = *Fursenkoina glabra*, Ps = *Pseudoparrella subperuviana*. Current species: Bp = *Bolivina plicata*, Ea = *Epistominella afueraensis*.

CC) transported tests. In Sample 112-688A-4H-CC, specimens of the *Angulogerina carinata–Cancris inflatus* biofacies prevail among the 50% transported tests, which is unusual because small, rather than large, tests are generally transported as far as the lower slope.

PERU MARGIN ASSEMBLAGES

A number of benthic foraminiferal biofacies, characterized by one or more dominant species with distinctive associated species, were sampled, sometimes repeatedly, in the Peru margin boreholes. Some key species, grouped according to age and paleobathymetry, are illustrated in Plates 1 through 5. These biofacies, with their dominant species shown by asterisk, are given below:

Quaternary and Late Tertiary Shelf Biofacies (Pl. 1)

Alexanderina viejoensis
**Bolivina costata*
Buccella peruviana
**Buliminella elegantissima*
**Buliminella elegantissima limbosa*
Hanzawaia nitidula
**Nonionella auris*
**Nonionella miocenica*
Nonionoides basispinatus
Rosalina peruviana
Virgulinella peruensis

This assemblage occurs in all of the shallow sites. Large-size *Bolivinellina humilis* are concurrent with these species up to about mid-shelf paleodepths, which may have represented the shoreward extent of low-oxygen conditions. *Bolivina costata*, a small, lightweight, yet structurally sound species because of its longitudinal costae, tends to be winnowed from the shelf and redeposited offshore, perhaps from suspension. This species is the dominant transported species reaching the lower slope, where it composes up to 94% of the total benthic foraminifers in some horizons of Site 685 and up to 85% at Site 683, both in the 9°S transect; transported *B. costata* makes up to 27% of the benthic foraminifers at Site 682 and an estimated 50% at Site 688, in the lower slopes of the 11°S transect. *Bolivina costata* did not occur stratigraphically below the Pliocene; however, Miocene assemblages show downslope displacement of members of the morphologically similar *B. vaughani* group.

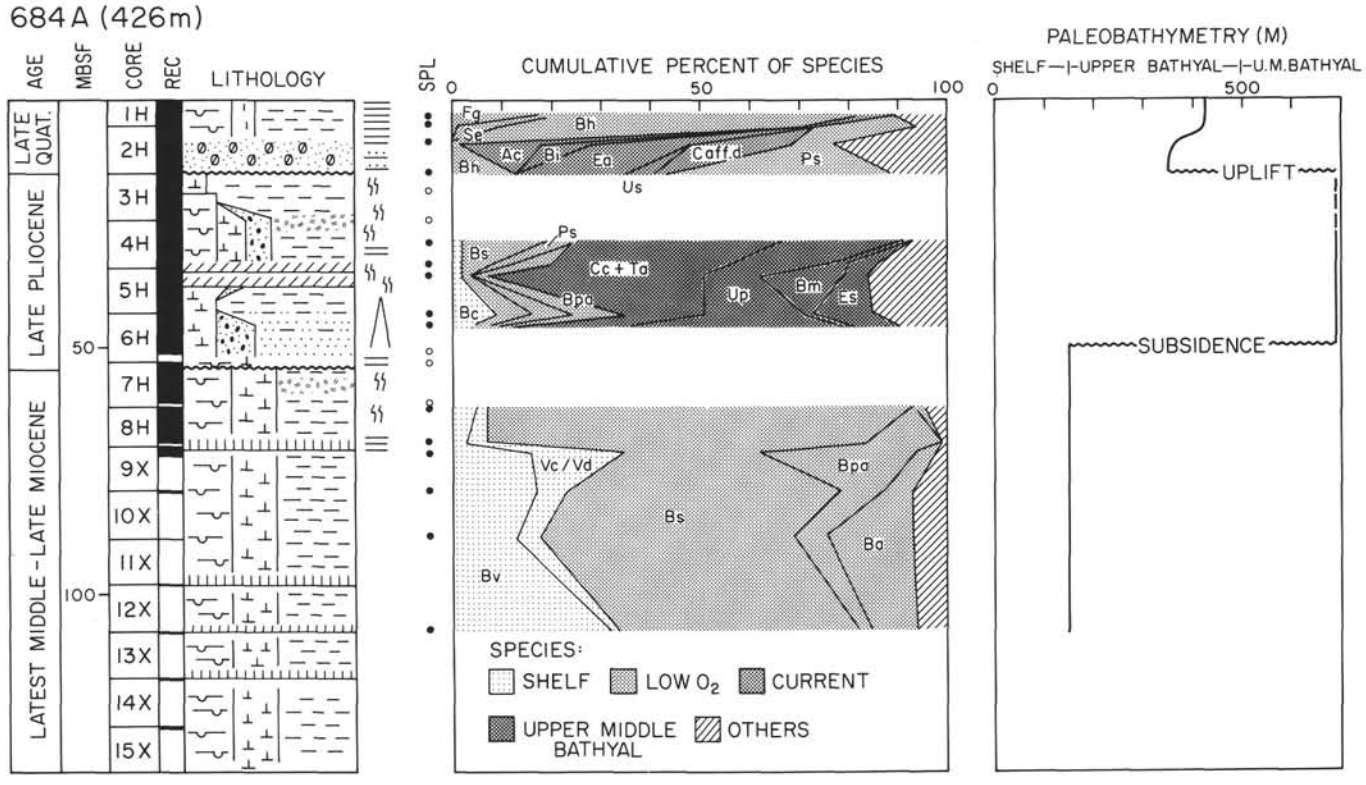


Figure 10. Lithofacies, biofacies, and paleobathymetry at Hole 684A. Shelf species: Bc = *Bolivina costata*, Bv = *Bolivina vaughani*, Vc = *Valvulineria* cf. *compressa*, Vd = *Valvulineria* cf. *depressa*. Low-oxygen species: Ba = *Bolivina* cf. *advena*, Bh = *Bolivinellina humilis*, Bp = *Bolivinellina pacifica*, Bs = *Buliminella subfusiformis*, Fg = *Fursenkoina glabra*, Ps = *Pseudoparrella subperuviana*, Se = *Suggrunda eckisi*. Current species: Ac = *Angulogerina carinata*, Bi = *Brizalina interjuncta*, Cd = *Cassidulina* aff. *detierraensis*, Ea = *Epistominella afueraensis*, Us = *Uvigerina striata*. Upper-Middle Bathyal species: Bm = *Bolivinita minuta*, Cc = *Cassidulina cushmani*, Es = *Epistominella smithi*, Ta = *Takayanagia asanoi*, Up = *Uvigerina peregrina* and *U. dirupta*.

Quaternary Outer-Shelf–Upper Bathyal, Oxygen-Minimum Biofacies (Pl. 2, Figs. 1–8)

**Bolivinellina humilis*
Buliminella subfusiformis
"Ellipsoglandulina" fragilis
Fursenkoina glabra
Parabolivina peruensis
Suggrunda eckisi

"Ellipsoglandulina" fragilis and *Parabolivina peruensis* occur predominantly in the Quaternary section of Site 679 and may favor a particular level of the gradient in low-oxygen conditions. *Suggrunda eckisi* does not occur at Site 681, the shallowest site. Otherwise, this assemblage occurs in all of the shallow sites; some of its members extend back to late Miocene time.

Quaternary Lower-Upper Bathyal Current Biofacies (Pl. 2, Figs. 9–17)

**Angulogerina carinata*
Bolivina plicata
Brizalina interjuncta
Cancris carmenensis
Cancris inflatus
Cassidulina detierraensis
Epistominella afueraensis
Gyroidina rothwelli
Uvigerina semitrigona
Uvigerina striata

This assemblage represents a collection of robust species concentrated in foraminiferal sands through current action during the Quaternary in certain horizons of shallow sites in all three traverses. Comparable assemblages occur in the Pliocene Charco Azul Formation of Panama (Coryell and Mossman, 1942) and in upper Pliocene exposures in the Gulf of California (Natland, 1950).

Quaternary Lower Bathyal Biofacies (Pl. 3, Figs. 1–6)

Globocassidulina depressa
Melonis pompilioides
Oridorsalis umbonatus
Pseudoparrella exigua
Pullenia bulloides
Uvigerina senticosa

This species association occurs in the Quaternary and Pliocene sections of all of the deep sites. The *in-situ* lower bathyal assemblage is mostly outnumbered by *Bolivina costata* that has been transported from the shelf biofacies, as mentioned previously.

Pliocene Upper-Middle Bathyal Biofacies (Pl. 3, Figs. 7–10)

Bolivinita minuta
Cassidulina cushmani
Epistominella smithi
Plectofrondicularia californica

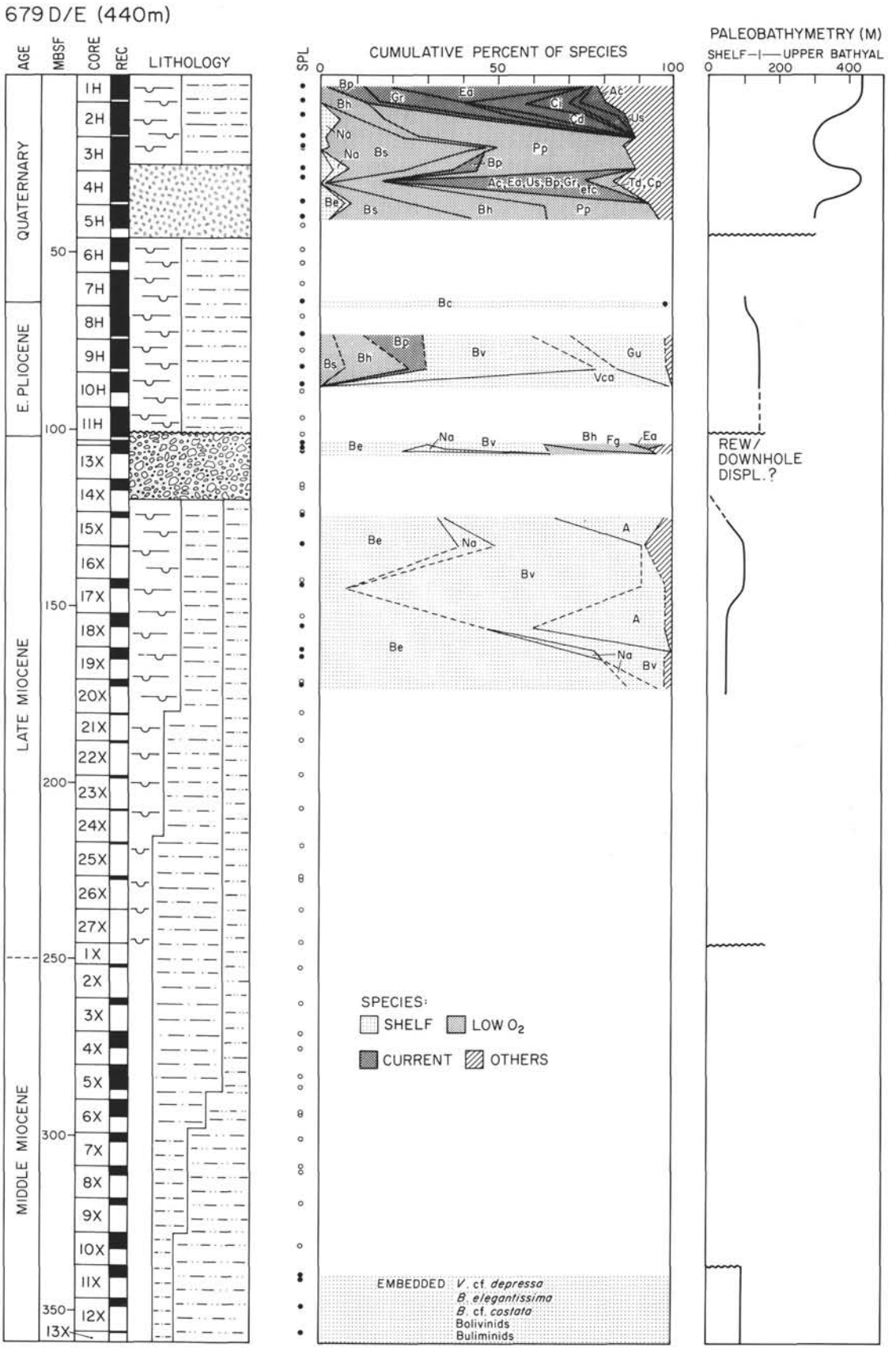


Figure 11. Lithofacies, biofacies, and paleobathymetry at Holes 679D and 679E. Shelf species: A = *Ammobaculites* sp., Bv = *Bolivina vaughani*, Be = *Buliminella elegantissima*, Gu = *Galliherina uvigerinaformis* (shelf edge), Na = *Nonionella auris*, Vca = *Valvulineria californica* (shelf edge). Low-oxygen species: Bh = *Bolivinellina humilis*, Bs = *Buliminella subfusiformis*, Pp = *Parabolivina peruensis*.

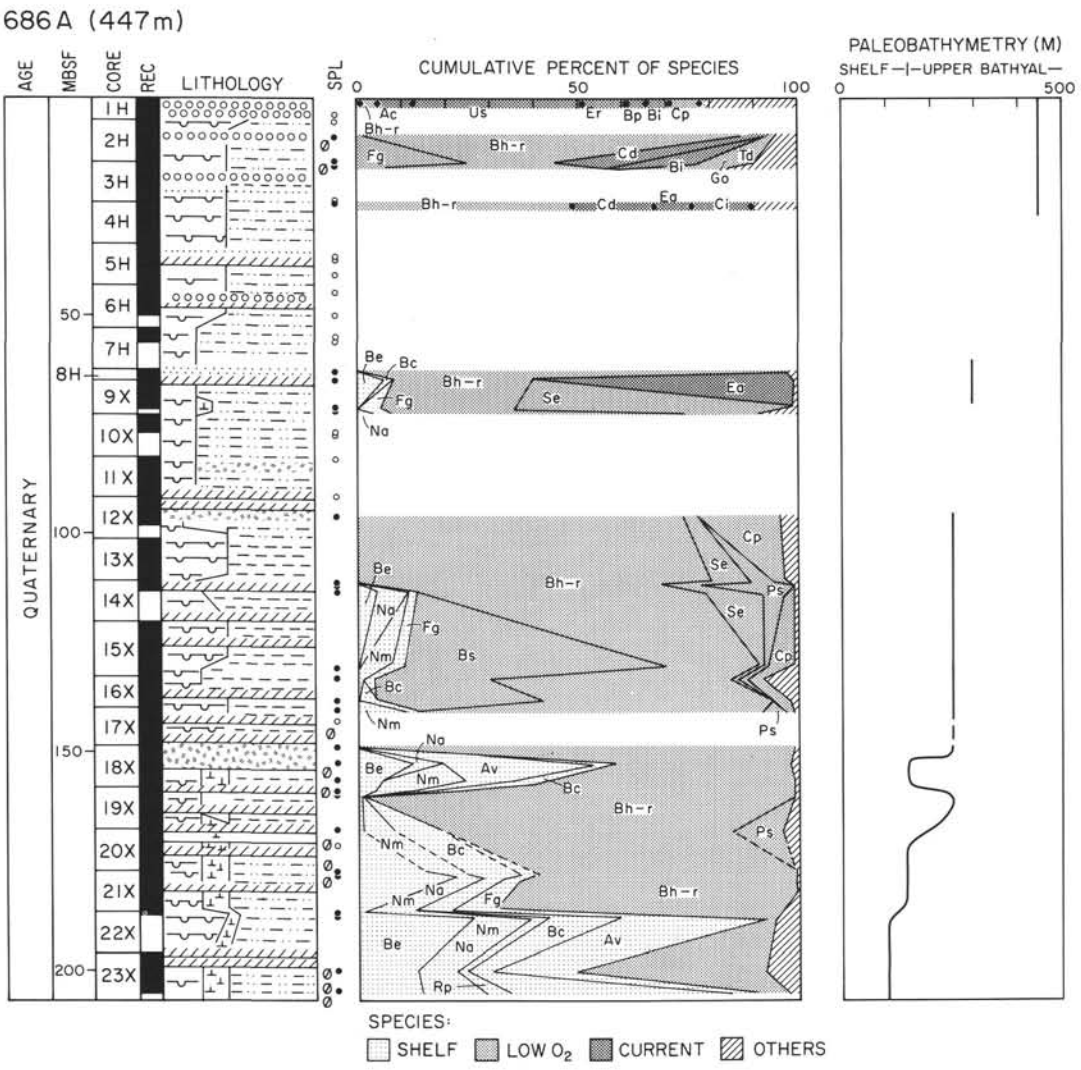


Figure 12. Lithofacies, biofacies, and paleobathymetry at Hole 686A. Shelf species: Av = *Alexanderina viejoensis*, Bc = *Bolivina costata*, Be = *Buliminella elegantissima*, Na = *Nonionella auris*, Nm = *Nonionella miocenica*, Rp = *Rosalina peruviana*. Low-oxygen species: Bh-r = *Bolivinellina humilis-rankini*, Bs = *Buliminella subfusiformis*, Cp = *Cassidulina pulchella*, Fg = *Fursenkoina glabra*, Go = *Globobulimina ovula*, Ps = *Pseudoparrella subperuviana*, Se = *Suggrunda eckisi*, Td = *Takayanagia delicata*. Current species: Ac = *Angulogerina carinata*, Bp = *Bolivina plicata*, Bi = *Brizalina interjuncta*, Ci = *Cancris inflatus*, Cd = *Cassidulina detierraensis*, Ea = *Epistominella afueraensis*.

Takayanagia delicata

This assemblage, which consists of long-ranging species, was recovered intact only at Site 684 in the 9°S transect, but its individual components occur frequently in deposits of the deep sites, where they accumulated as a result of downslope transport. *Plectrofrondicularia californica* was assigned to the lower bathyal biofacies by Ingle (1980), but its association in the Pliocene deposits off Peru indicates a shallower habitat there.

Late Miocene–Early Pliocene Outermost Shelf Biofacies (Pl. 3, Figs. 11–19)

**Galliherina uvigerinaformis*
Valvulineria californica
Valvulineria cf. *compressa*
Valvulineria cf. *depressa*

This assemblage was sampled at Hole 684A in the 9°S transect and at Hole 679D in the 11°S transect.

Late Miocene Middle Bathyal Biofacies (Pl. 4, Figs. 11–12)

Ambitropus thalmanni
Bolivina granti
Brizalina girardensis
Hansenisca multilocula
Rotorbinella garveyensis
Uvigerina mantaensis
Uvigerina marksi
Uvigerina peregrina dirupta

These species were sampled at Site 682. *Bolivina vaughani* Gr., interpreted as being transported from the shelf, is commonly associated with these species. A similar assemblage

Table 6. Percentage of species representation, Hole 687A (307 m).

Age	Quaternary																								Pliocene									
Depth (mbsf)	5.6	7.4	8.2	18.0	26.6	36.1	44.2	45.4	45.6	49.7	55.1	56.1	57.0	65.0	75.0	84.0	94.0	104.2	114.0	121.2	125.3	127.9	131.9	133.4	158.3	161.7	171.5	175.0	179.3	188.9	193.4	201.4	202.0
Hole 687A (307 m) Core[1,2] Section Interval (cm)	1H-4, 110–114	1H-CC	2H-1, 70–74	3H-1, 95–99	3H-CC	4H-CC	5H-6, 67–71	5H-CC	6H-1, 8–12	6H-3, 124–128	6H-CC	7X-1, 113–117	7X-CC	8X-CC	9X-CC	10X-CC	11X-CC	12X-CC	13X-2, 48–52	13X-CC	14X-3, 83–84	14X-CC	15X-1, 86–89	15X-CC	17X-CC	18X-CC	19X-2, 102–106	19X-4, bot.	20X-CC	21X-1, 89–93	21X-CC	22X-3, 98–102	22X-CC
Species																																	
Alexanderina viejoensis					1	+		2						2			2	2		+		+							+				+
Angulogerina carinata	1	+		+																													
Angulogerina sp.		+		1																													
Bolivina costata	+	+	3	+	8	+	4	2	1	+	3	6	1	5	25	24	7	+	10	28	5	49	30	26	57	61	1	39	36	32	22	11	9
Bolivina plicata	28	16		1																		1											
Bolivinellina foraminata																																	
Bolivinellina humilis-rankini	6	17	92	52	49	75	91	62	95	55	70	26	63	3	1	1	3	6	5	36	1	28	14	28	4	21	4	13	5	3	15	3	1
Bolivinellina pacifica		1		3		1										+		14	+														
Bolivinita minuta	1			+																													
Brizalina interjuncta	1																																
Brizalina interjuncta bicostata				+																													
Brizalina pseudobeyrichi		+																															
Brizalina spissa				1																													
Buccella peruviana						1								3	+	3	5												3				
Bulimina pulchella						3		+								1					14												
Buliminella curta basispinata		+						2			1																						
Buliminella elegantissima	+			1		2		1			2	1									11	1	31	+			8	1	41	2		35	30
Buliminella elegantissima limbosa					9									75	29	30	69	48	19														
Buliminella subfusiformis			+			7				42		61	4		+	+				1		1	1	30	19	10	59	32	1	37	50	12	5
Cancris carmenensis	+	+		1																													
Cancris inflatus	+	+	+	1			1	+			+	+				+																	
Cassidulina detierraensis	1																																
Cassidulina pulchella		+	2	1	4	1	1	+			+																						
Coryphostoma clippertonensis		+																															
Epistominella afueraensis	55			16		2	2	2		+																							
Fursenkoina glabra		5		6	23	2		+				+				1	2	+		8	2	+		2			2	4	3	11	3	1	8
Globobulimina pacifica	+		+																														
Globocassidulina quadrata	+																																
Gyroidina rothwelli		1		5																													
Nonionella auris			2	+	4	3	1	12	3		5			8	42	35	11	21	59	13	63	13	22	11	19	7	18	4	2	6	2	+	
Nonionella miocenica								17	+	+	18	4	30		+	4	1	7	6	5	4	7	2	3	+	+	5		7	6	6	38	46
Parabolivina peruensis																									+	1	3	7		3	2	+	
Planulina limbata	+																																
Planulina ornata		+																															
Pseudoparella sandiegoensis																																	
Pseudoparella subperuviana	5	48	1		2	1				2		+						+		7		+							+				
Pullenia subcarinata	+																																
Quinqueloculina araucana															2	+																	
Rosalina peruviana			+											4	+	+																	
Suggrunda eckisi		12		8																1													
Takayanagia delicata				+																													
Uvigerina striata	2	+																															
Uvigerina sp.																						+	+										
Virgulinella peruensis													2																				
Count	302	348	247	501	220	383	217	240	262	464	254	285	128	180	578	417	100	225	399	195	130	306	202	261	180	287	237	501	313	814	215	256	322
Planktonic/Benthic Ratio × 100	0	1	20	3	1	1	0	<1	0	0	2	0	0	2	2	<1	0	2	0	0	0	3	0	<1	0	<1	<1	1	0	0	0	0	0

[1] Barren of foraminifers: 2H-CC; 4H-1, 49–53.
[2] Counts less than 100: 1H-1, 13–17; 17X-3, 130–134; 18X-2, 56–60.

occurs in the Miocene Charapoto Formation of Ecuador (Cushman and Stevenson, 1948).

Middle Miocene Middle Bathyal Biofacies (Pl. 4, Figs. 13–16)

Brizalina pisciformis
Siphonodosaria paucistriata

**Uvigerina gallowayi*
Uvigerina mantaensis
**Uvigerina rustica*

These species occur in the three sites that were drilled deep enough to tap middle Miocene strata. A similar assemblage occurs in the Manta Shale of Ecuador and in Venezuelan material (Cushman, 1929), as well as in the Venezuelan Agua Salada Group (Renz, 1948).

Middle Miocene Lower Bathyal Biofacies (Pl. 4, Figs. 17–20)

Cibicidoides kullenbergi
**Cibicidoides trinitatensis*
Hansenisca zealandica
**Planulina renzi*

This species association occurs at Site 683 and is considered to be the deepest facies sampled, with many of the associated species occurring in the deep sea (Parker, 1964; Douglas, 1973).

Middle Eocene Shelf and Upper Bathyal Biofacies (Pl. 5, Figs. 1–5)

Asterigerina crassaformis
Bolivinellina basisenta
Bulimina chirana
Buliminella peruviana
Cyclammina simiensis
Globocassidulina globosa
Stichocassidulina thalmanni

Various combinations of species, described from the Eocene formations of northern Peru (Cushman and Stone, 1947, Chira Shale; Cushman and Stone, 1949b, Verdun Formation), coastal Ecuador (Cushman and Stainforth, 1947), and Chile (Todd and Kniker, 1952), occur in the basal rocks drilled at Sites 682, 683, and 688. These assemblages are variously considered shelf or upper bathyal deposits because of the preponderance of buliminids and bolivinids. The interpreted shallowest shelf biofacies contains the agglutinates *Cyclammina simiensis* and *Bathysiphon eocenica*, in contrast to the modern deep-water habitats of these genera.

SUMMARY AND CONCLUSIONS

Benthic foraminiferal biofacies in the 9°S transect off Trujillo indicate an upper bathyal environment at lower slope Site 683 during middle Eocene time that is characterized by species reported in northern Peru formations. During the succeeding 26 m.y., for which no sedimentary record was preserved, this part of the margin subsided about 1500 m to lower bathyal depths. Evidence from diatoms and nannofossils suggests that middle Miocene, middle bathyal assemblages of benthic foraminifers were emplaced at Site 683 as part of a slump. Late Miocene deposits of Site 684 contain outer-shelf to upper-slope benthic foraminifers, a somewhat shallower biofacies than that now present, indicative of a low stand of sea level during the late Miocene. No deposits of late Miocene age occur at Site 683, and deposits of this age are partly missing at Site 685, which has been situated below the CCD from late Miocene to the present time. Intervals barren of benthic foraminifers characterize the Pliocene sections at the three sites. However, at Site 684, a well-preserved late Pliocene upper-middle bathyal biofacies indicates subsidence of about 400 m from the late Miocene outer-shelf to upper bathyal biofacies. An oxygen-minimum environment, indicated by *Bolivinellina humilis*, occurs in the late Quaternary section of Site 684.

The small shelf species, *Bolivina costata*, is preferentially transported downslope and is a substantial contributor to Pliocene and Quaternary assemblages of the deep sites, where turbidite sedimentation is prevalent.

Benthic foraminiferal biofacies of the 11°S transect also record shelf or upper bathyal biotopes at lower-slope Sites 688 and 682 during the Eocene and subsequent subsidence of this margin to lower bathyal depths in late Oligocene to early Miocene time. Middle Miocene middle bathyal biofacies occur sporadically at these deep sites and may have been emplaced through slumping, as in the northern transect. Early Pliocene sedimentation also may have been affected by the slumping, as indicated by the middle bathyal assemblages at deep Site 682. Middle and late Miocene deposits at Site 679 reflect deposition on the outer shelf, with subsequent deposits indicating subsidence to the present upper bathyal oxygen-minimum environment. The shallow sites of this traverse reflect changes in sea level as shifts between shelf biofacies, with abundant *Nonionella*, and oxygen-minimum biofacies, with abundant *Bolivinellina humilis*.

The 13°S Pisco Basin Sites 686 and 687 reveal general subsidence of late Pliocene and Quaternary sections of shifting shelf and upper bathyal environments, related to changes in sea level.

These paleobathymetric analyses of benthic foraminifers thus provide evidence of the seaward extent of continental margin deposits off Peru and of their subsidence. Environmental, evolutionary, and biogeographic implications of the assemblages must be evaluated further.

ACKNOWLEDGMENTS

The shipboard scientific party and crew of the *Joides Resolution* provided the inspiration and material for this research, which was supported by the Ocean Drilling Program in a post-cruise grant. Don Sims photographed the foraminifers on the shipboard ISI-SX-25 scanning electron microscope. Scot Izuka and Bryant Waters prepared samples in the shore laboratory. The in-house reviews by my colleague, William Coulbourn and by Hawaii Institute of Geophysics Editor Diane Henderson as well as external reviews by James Ingle and Kristin McDougall improved the manuscript. I gratefully acknowledge the help of these supporters and of Roland von Huene, whose prodding brought this report to completion. This is Hawaii Institute of Geophysics Contribution 2229.

REFERENCES

Bandy, O. L., 1961. Distribution of foraminifera, radiolaria and diatoms in sediments of the Gulf of California. *Micropaleontology*, 7:1–26.

Bandy O. L., and Rodolfo, K., 1964. Distribution of foraminifera and sediments, Peru-Chile Trench area. *Deep-Sea Res.*, 11:817–837.

Becker, L., and Dusenbury, A. N., Jr., 1958. Mio-Oligocene (Aquitanian) foraminifera from the Goajira Peninsula, Colombia. *Cushman Found. Foram. Res. Spec. Publ.*, 4:1–48.

Berger, W., 1970. Planktonic foraminifera: selective solution and the lysocline. *Mar. Geol.*, 8:111–138.

Boltovskoy, E., 1976. Distribution of foraminifera of the South American region. *In* Hedley, R. H., and Adams, C. G. (Eds.), *Foraminifera*, Vol. 2: New York (Academic Press), 171–236.

Boltovskoy, E., and Theyer, F., 1970. Foraminiferos Recientes de Chile Central. *Revista del Museo Argentino de Ciencias Naturales, Hidrobiologia,* 2:279–378.

Boltovskoy, E., and Wright, R., 1976. *Recent Foraminifera*: The Hague (W. Junk).

Brooks, R., Presley, B., and Kaplan, I., 1968. Trace elements in the interstitial waters of marine sediments. *Geochim. Cosmochim. Acta,* 32:397–414.

Burnett, W., 1977. Geochemistry and origin of phosphate deposits off Peru and Chile. *Geol. Soc. Am. Bull.,* 88:813–823.

Burnett, W., Veeh, H., and Soutar, A., 1980. U-series oceanographic and sedimentary evidence in support of Recent formation of phosphate nodules off Peru. *Soc. Econ. Paleontol. Mineral. Spec. Publ.,* 29:61–71.

CLIMAP, 1976. The surface of the Ice-Age Earth. *Science,* 191:1131–1137.

Coryell, H., and Mossman, R., 1942. Foraminifera from the Charco Azul Formation, Pliocene of Panama. *J. Paleontol.,* 16:233–246.

Coulbourn, W., and Moberly, R., 1988. Deposition and erosion in a submarine canyon system, Arequipa fore-arc basin, off southern Peru. *Geol. Soc. Am. Abstr. Programs,* 20:A197. (Abstract).

Cushman, J. A., 1929. A later Tertiary fauna of Venezuela and other related regions. *Contr. Cushman Lab. Foram. Res.,* 5:77–105.

Cushman, J. A., and Gray, H., 1946. A foraminiferal fauna from the Pliocene of Timms Point, California. *Cushman Lab. Foram. Res. Spec. Publ.,* 19:1–46.

Cushman, J. A., and McCulloch, I., 1940. Some Nonionidae in the collections of the Allan Hancock Foundation. *Allan Hancock Pacific Exped.,* 6:145–178.

_____, 1942. Some Virgulininae in the collections of the Allan Hancock Foundation. *Allan Hancock Pacific Exped.,* 6:179–230.

_____, 1948. The species of *Bulimina* and related genera in the collections of the Allan Hancock Foundation. *Allan Hancock Pacific Exped.,* 6:231–294.

Cushman, J. A., and Stainforth, R., 1947. A new genus and some new species of foraminifera from the Upper Eocene of Ecuador. *Contr. Cushman Lab. Foram. Res.,* 23:77–80.

Cushman, J. A., and Stevenson, F., 1948. A Miocene foraminiferal fauna from Ecuador. *Contr. Cushman Lab. Foram. Res.,* 24:50–68.

Cushman, J. A., and Stone, B., 1947. An Eocene foraminiferal fauna from the Chira Shale of Peru. *Cushman Lab. Foram. Res. Spec. Publ.,* 20:1–27.

_____, 1949a. Foraminifera from the Eocene, Chacra Formation, of Peru. *Contr. Cushman Lab. Foram. Res.,* 25:49–58.

_____, 1949b. Foraminifera from the Eocene, Verdun Formation, of Peru. *Contr. Cushman. Lab. Foram. Res.,* 25:73–84.

Douglas, R., 1973. Benthonic foraminiferal biostratigraphy in the central North Pacific, Leg 17, Deep Sea Drilling Project. *In* Winterer, E. L., Ewing, J. I., et al., *Init. Repts. DSDP,* 17: Washington (U.S. Govt. Printing Office), 607–694.

Fahrbach, E., Brockmann, C., Lostaunau, N., and Urquizo W., 1981. The northern Peruvian upwelling system during the ESACAN experiment. *In* Richards, F. A. (Ed.), *Coastal Upwelling*: Washington (Am. Geophys. Union), 134–145.

Gunther, E., 1936. A report on oceanographical investigations in Peru Coastal Current. *Discovery Repts.,* 13:107–276.

Haller, C., 1980. Pliocene biostratigraphy of California. *In* Kleinpell, R., *The Miocene Stratigraphy of California Revisited:* Tulsa (Am. Assoc. Pet. Geol.), 183–341.

Hofker, J., 1956. Tertiary foraminifera of coastal Ecuador: Part II, Additional notes on the Eocene species. *J. Paleontol.,* 30:891–958.

Ingle, J. C., Jr., 1980. Cenozoic paleobathymetry and depositional history of selected sequences within the southern California continental borderland. *Cushman Found. Foram. Res. Spec. Publ.,* 19:163–195.

Ingle, J. C., Jr., and Keller, G., 1980. Benthic foraminiferal biofacies of the eastern Pacific margin between 40°S and 32°N. *Pacific Coast Paleogeography, Symp. 4.* Soc. Econ. Paleontol. Mineral., 341–355.

Ingle, J. C., Jr., Keller, G., and Kolpack, R. L., 1980. Benthic foraminiferal biofacies, sediments and water masses of the southern Peru-Chile Trench area, southeastern Pacific Ocean. *Micropaleontology,* 26:113–150.

Khusid, T. A., 1984. On dissolution of carbonate tests of benthic foraminifera on the Pacific shelf of South America. *Oceanology,* 24:85–91.

Kleinpell, R., 1938. *Miocene Stratigraphy of California*: Tulsa (Am. Assoc. Pet. Geol.).

_____, 1980. *The Miocene Stratigraphy of California Revisited*: Tulsa (Am. Assoc. Pet. Geol.), 1–182.

Loeblich, A. R., and Tappan, H., 1987. *Foraminiferal Genera and Their Classification*: New York (Van Nostrand).

Manheim, F., Rowe, G., and Jipa, D., 1975. Marine phosphorite formation off Peru. *J. Sediment. Petrol.,* 45:243–251.

McCulloch, I., 1977. *Qualitative Observations on Recent Foraminiferal Tests with Emphasis on The Eastern Pacific, Parts I–III:* Los Angeles (University of Southern California).

Natland, M., 1950. 1940 *E.W. Scripps* cruise to the Gulf of California. Part IV–Report on the Pleistocene and Pliocene foraminifera. *Geol. Soc. Am. Mem.,* 43:1–55.

Orbigny, A. d', 1839. *Foraminiféres, Voyage dans l'Amèrique Meridionale:* Paris (Pitois-Levrault et C).

Parker, F., 1964. Foraminifera from the experimental mohole drilling near Guadalupe Island, Mexico. *J. Paleontol.,* 38:617–636.

Phleger, F., and Soutar, A., 1973. Production of benthic foraminifera in three east Pacific oxygen minima. *Micropaleontology,* 19:110–115.

Renz, H., 1948. Stratigraphy and fauna of the Agua Salada group, State of Falcon, Venezuela. *Geol. Soc. Am. Mem.,* 32:1–219.

Resig, J., 1981. Biogeography of benthic foraminifera of the northern Nazca plate and adjacent continental margin. *Geol. Soc. Am. Mem.,* 154:619–666.

Rojas de Mendiola B., 1981. Seasonal phytoplankton distribution along the Peruvian coast. *In* Richards, F. A. (Ed.), *Coastal Upwelling:* Washington (Am. Geophys. Union), 348–356.

Rosato, V. J., Kulm, L. D., and Derks, P. S., 1975. Surface sediments of the Nazca plate. *Pacific Sci.,* 29:117–130.

Rowe, G. T., 1981. The benthic processes of coastal upwelling ecosystems. *In* Richards, F. A. (Ed.), *Coastal Upwelling:* Washington (Am. Geophys. Union), 464–471.

Schuette, G., and Schrader, H., 1981. Diatoms in surface sediments: a reflection of coastal upwelling. *In* Richards, F. A. (Ed.), *Coastal Upwelling:* Washington (Am. Geophys. Union), 372–380.

Smith, P., 1963. Quantitative and qualitative analysis of the Family Bolivinidae. *U.S. Geol. Surv. Prof. Pap.,* 429-A:1–39.

_____, 1964. Ecology of benthonic species. *U.S. Geol. Surv. Prof. Pap.,* 492-B:1–55.

Stainforth, R., 1948. Applied micropaleontology in coastal Ecuador. *J. Paleontol.,* 22:113–151.

Suess, E., von Huene, R., et al., 1988. *Proc. ODP, Init. Repts.,* 112: College Station, TX (Ocean Drilling Program).

Todd, R., and Kniker, H., 1952. An Eocene foraminiferal fauna from the Agua Fresca Shale of Magallanes Province, southernmost Chile. *Cushman Found. Foram. Res. Spec. Publ.,* 1:1–28.

Uchio, T., 1960. Ecology of living benthonic foraminifera from the San Diego, California area. *Cushman Found. Foram. Res. Spec. Publ.,* 5:1–72.

Wyrtki, K., 1964. The thermal structure of the eastern Pacific Ocean. *Deut. Hydrogr. Z. Ergaenzunqsh. A,* 6:1–84.

_____, 1966. Oceanography of the eastern equatorial Pacific Ocean. *Oceanogr. Mar. Biol., Annu. Rev.,* 4:33–68.

_____, 1967. Circulation and water masses in the eastern equatorial Pacific Ocean. *Int. J. Oceanol. Limnol.,* 1:117–147.

Zen, E-An, 1959. Mineralogy and petrology of marine bottom sediment samples of the coast of Peru and Chile. *J. Sediment. Petrol.,* 29:513–539.

Date of initial receipt: 12 January 1989
Date of acceptance: 3 August 1989
Ms 112B-186

APPENDIX

The American Museum of Natural History's Catalogue of Foraminifera contains type references for the species cited in this study. Listed below are only the species that have undergone taxonomic changes, and the original names under which they are catalogued.

Alabamina atlantisae (Cushman) = *Pulvinulinella atlantisae*
Ambitropus thalmanni (Stainforth and Stevenson) = *Palmerinella thalmanni*
Amiphimorphina stainforthi (Cushman and Renz) = *Nodosaria stainforthi*
Angulogerina angulosa (Williamson) = *Uvigerina angulosa*
Anomalinoides alazanensis (Nuttall) = *Anomalina alazanensis*
Anomalinoides mantaensis (Galloway and Morrey) = *Anomalina mantaensis*
Anomalinoides pompilioides (Galloway and Hemingway) = *Anomalina pompilioides*
Astrononion schwageri (Cushman) = *Nonion schwageri*
Bolivinellina basisenta (Cushman and Stone) = *Bolivina basisenta*
Bolivinellina californica (Cushman) = *Bolivina californica*
Bolivinellina cuneata (Kleinpell) = *Bolivina tumida cuneata*
Bolivinellina ecuadorana (Cushman and Stevenson) = *Bolivina ecuadorana*
Bolivinellina foraminata (R.E. and K.C. Stewart) = *Bolivina seminuda foraminata*
Bolivinellina goudkoffi (Rankin) = *Bolivina goudkoffi*
Bolivinellina humilis (Cushman and McCulloch) = *Bolivina seminuda humilis*
Bolivinellina pacifica (Cushman and McCulloch) = *Bolivina acerosa pacifica*
Bolivinellina quadrata (Cushman and McCulloch) = *Bolivina quadrata*
Bolivinellina rankini (Kleinpell) = *Bolivina rankini*
Bolivinellina seminuda (Cushman) = *Bolivina seminuda*
Bolivinita minuta (Natland) = *Bolivina minuta*
Brizalina cf. *acutula* (Bandy) = *Bolivina advena acutula*
Brizalina argentea (Cushman) = *Bolivina argentea*
Brizalina girardensis (Rankin) = *Bolivina girardensis*
Brizalina cf. *gladius* (Garrett) = *Bolivina gladius*
Brizalina imbricata (Cushman) = *Bolivina imbricata*
Brizalina interjuncta (Cushman) = *Bolivina costata interjuncta*
Brizalina interjuncta bicostata (Cushman) = *Bolivina costata bicostata*
Brizalina cf. *jacksonensis* (Cushman and Applin) = *Bolivina jacksonensis*
Brizalina mantaensis (Cushman) = *Bolivina mantaensis*
Brizalina pisciformis (Galloway and Morrey) = *Bolivina pisciformis*
Brizalina pseudobeyrichi (Cushman) = *Bolivina pseudobeyrichi*
Brizalina spissa (Cushman) = *Bolivina subadvena spissa*
Buccella oregonensis (Cushman, Stewart, and Stewart) = *Eponides mansfieldi oregonensis*
Buccella peruviana (d'Orbigny) = *Rotalina peruviana*
Bulimina alligata Cushman and Laiming = *Bulimina inflata alligata*
Bulimina exilis tenuata (Cushman) = *Buliminella subfusiformis tenuata*
Bulimina hebespinata (R.E. and K.C. Stewart) = *Bulimina pagoda hebespinata*
Bulimina striata mexicana (Cushman) = *Bulimina inflata mexicana*
Buliminella elegantissima (d'Orbigny) = *Bulimina elegantissima*
Cancris auricula (Fichtel and Moll) = *Nautilus auricula*
Cancris inflatus (d'Orbigny) = *Valvulina inflata*
Cassidelina complanata (Egger) = *Virgulina schreibersiana complanata*
Cassidelina nodosa (R.E. and K.C. Stewart) = *Virgulina nodosa*
Cassidulinoides bradyi (Norman) = *Cassidulina bradyi*
Chilostomella serrata (Cushman and Stone) = *Chilostomella ovoidea serrata*
Cibicidoides cicatricosus (Schwager) = *Anomalina cicatricosa*
Cibicidoides compressus (Cushman and Renz) = *Cibicides floridanus compressa*
Cibicidoides cf. *grimsdalei* (Nuttall) = *Cibicides grimsdalei*
Cibicidoides cf. *havanensis* (Cushman and Bermudez) = Cibicides havanensis
Cibicidoides kullenbergi (Parker) = *Cibicides kullenbergi*
Cibicidoides martinezensis (Cushman and Barksdale) = *Cibicides martinezensis*
Cibicidoides mundula (Brady, Parker and Jones) = *Truncatulina mundula*
Cibicidoides perlucidus (Nuttall) = *Cibicides perlucidus*
Cibicidoides cf. *pseudoungerianus* (Cushman) = *Truncatulina pseudoungeriana*
Cibicidoides trinitatensis (Nuttall) = *Truncatulina trinitatensis*
Cribromiliolinella subvalvularis (Parr) = *Triloculina subvalvularis*
Dorothia asiphonia (Andreae) = *Gaudryina siphonella asiphonia*
Eggerella bradyi (Cushman) = *Verneuilina bradyi*
Ehrenbergina trigona (Goes) = *Ehrenbergina serrata trigona*
Eilohedra levicula (Resig) = *Epistominella levicula*
Epistominella pacifica (Cushman) = *Pulvinulinella pacifica*
Epistominella smithi (R.E. and K.C. Stewart) = *Pulvinulinella smithi*
Fontbotia wuellerstorfi (Schwager) = *Anomalina wuellerstorfi*
Fursenkoina bramlettei (Galloway and Morrey) = *Virgulina bramlettei*
Fursenkoina californiensis (Cushman) = *Virgulina californiensis*
Fursenkoina glabra (Cushman and Wickenden) = *Bulimina patagonica glabra*
Fursenkoina nuda (of Hofker, 1956), not *Buliminella basistriata nuda* (Howe and Wallace)
Fursenkoina restinensis (Berry) = *Bolivina restinensis*
Galliherina cf. *delreyensis* (Cushman and Galliher) = *Bulimina delreyensis*
Galliherina uvigerinaformis (Cushman and Kleinpell) = *Bulimina uvigerinaformis*
Galliherina uvigerinaformis charapotoensis (Cushman and Stevenson) = *Bulimina uvigerinaformis charapotoensis*
Glandulina laevigata (d'Orbigny) = *Nodosaria (Glandulina) laevigata*
Globobulimina affinis (d'Orbigny) = *Bulimina affinis*
Globobulimina diversa (Cushman and Stone) = *Bulimina (Desinobulimina) diversa*
Globobulimina ovula (d'Orbigny) = *Bulimina ovula*
Globobulimina pseudovata (Hofker) = *Bulimina pseudovata*
Globocassidulina crassa (d'Orbigny) = *Cassidulina crassa*
Globocassidulina depressa (Asano and Nakamura) = *Cassidulina subglobosa depressa*
Globocassidulina globosa (Hantken) = *Cassidulina globosa*
Globocassidulina cf. *lomitensis* (Galloway and Wissler) = *Cassidulina lomitensis*
Globocassidulina quadrata (Cushman and Hughes) = *Cassidulina subglobosa quadrata*
Globocassidulina sublaevigata (Hofker) = *Cassidulina sublaevigata*
Globocassidulina subglobosa (Brady) = *Cassidulina subglobosa*
Globocassidulina subglobosa horizontalis (Cushman and Renz) = *Cassidulina subglobosa horizontalis*
Guttulina irregularis (d'Orbigny) = *Globulina irregularis*
Gyroidina octocamerata (Cushman and Hanna) = *Gyroidina soldanii octocamerata*
Gyroidina perampla (Cushman and Stewart) = *Gyroidina girardana perampla*
Gyroidina turgida (Phleger and Parker) = *Eponides turgidus*
Hansenisca altiformis (R.E. and K.C. Stewart) = *Gyroidina soldanii altiformis*
Hansenisca multilocula (Coryell and Mossman) = *Gyroidina soldanii multilocula*
Hansenisca soldanii (d'Orbigny) = *Gyroidina soldanii*
Hansenisca zealandica (Finlay) = *Gyroidina zealandica*
Hanzawaia cf. *mantaensis* (Galloway and Morrey) = *Anomalina mantaensis*
Hanzawaia nitidula (Bandy) = *Cibicidina basiloba nitidula*
Heterolepa? *crebbsi* (Hedberg) = *Eponides crebbsi*
Hoeglundina elegans (d'Orbigny) = *Rotalia elegans*
Hofkerina smithi (Kleinpell) = *Siphogenerina smithi*
Holmanella cf. *valmonteensis* (Kleinpell) = *Discorbinella valmonteensis*
Hopkinsina cf. *danvillensis* (Howe and Wallace) = *Uvigerina danvillensis*
Karreriella bradyi (Cushman) = *Gaudryina bradyi*
Laticarinina pauperata (Parker and Jones) = *Pulvinulina repanda menardii pauperata*
Lenticulina subpapillosa (Nuttall) = *Cristellaria subpapillosa*
Martinottiella communis (d'Orbigny) = *Clavulina communis*

Martinottiella cyclostomata (Galloway and Morrey) = *Verneuilina cyclostomata*
Martinottiella nodulosa (Cushman) = *Clavulina communis nodulosa*
Melonis affinis (Reuss) = *Nonionina affinis*
Melonis pompilioides (Fichtel and Moll) = *Nautilus pompilioides*
Nodogenerina spinea (Cushman) = *Ellipsonodosaria curvatura spinea*
Nodosaria aff. *consobrina* (d'Orbigny) = *Dentalina consobrina*
Nonionella auris (d'Orbigny) = *Valvulina auris*
Nonionoides basispinatus (Cushman and Moyer) = *Nonion pizarrense basispinata*
Nuttallides cf. *decorata* (Phleger and Parker) = *Pseudoparrella decorata*
Nuttallides truempyi (Nuttall) = *Eponides truempyi*
Oridorsalis umbonatus (Reuss) = *Rotalia umbonata*
Osangularia culter (Parker and Jones) = *Planorbulina culter*
Parrelloides bradyi (Trauth) = *Truncatulina bradyi*
Planulina depressa (d'Orbigny) = *Truncatulina depressa*
Planulina ornata (d'Orbigny) = *Truncatulina ornata*
Praeglobobulimina spinescens (Brady) = *Bulimina pyrula spinescens*
Proxifrons advena (Cushman) = *Frondicularia advena*
Pseudoparrella exigua (Brady) = *Pulvinulinella exigua*
Pseudoparrella obesa (Bandy and Arnal) = *Epistominella obesa*
Pseudoparrella sandiegoensis (Uchio) = *Epistominella sandiegoensis*
Pseudoparrella subperuviana (Cushman) = *Pulvinulinella subperuviana*
Pullenia bulloides (d'Orbigny) = *Nonionina bulloides*
Pullenia quinqueloba (Reuss) = *Nonionina quinqueloba*
Pullenia subcarinata (d'Orbigny) = *Nonionina subcarinata*
Pyrgo murrhyna (Schwager) = *Biloculina murrhina*
Pyrgo serrata (Bailey) = *Biloculina serrata*
Rectuvigerina cf. *multicostata* (Cushman and Jarvis) = *Siphogenerina multicostata*
Robulus cf. *americanus* (Cushman) = *Cristellaria americana*
Robulus aff. *brevispinosus* (Nuttall) = *Cristellaria brevispinosa*
Rotorbinella garveyensis (Natland) = *Rotalia garveyensis*
Rutherfordoides cornutus (Cushman) = *Virgulina cornuta*
Sigmoilopsis schlumbergeri (Silvestri) = *Sigmoilina schlumbergeri*
Siphonodosaria paucistriata (Galloway and Morrey) = *Nodosarella paucistriata*
Stilostomella fistuca (Schwager) = *Nodosaria fistuca*
Takayanagia asanoi (Uchio) = *Cassidulina asanoi*
Takayanagia delicata (Cushman) = *Cassidulina delicata*
Valvulineria depressa (Cushman) = *Valvulineria miocenica depressa*
Valvulineria glabra (Cushman) = *Valvulineria vilardeboana glabra*
Valvulineria inaequalis (d'Orbigny) = *Valvulina inaequalis*
Valvulineria rugosa minuta (Schubert) = *Dicorbina rugosa minuta*
Zeaflorilus chiliensis (Cushman and Kellett) = *Nonionella chiliensis*

Table 7. Percentage of species representation, ODP Holes 683A and 683B (3071 m).

	Age	Pleistocene								Plio.
	Depth (mbsf)	2.1	19.2	35.3	59.2	78.5	88.9	107.6	145.7	164.5
Hole 683A (3071 m) Species	Core[1,2] Section Interval (cm)	1H-CC	3H-CC	5H-CC	7H-CC	9H-CC	11X-CC	13X-CC	17X-CC	19X-CC
Alexanderina viejoensis		1								1
Amphimorphina sp.								1		
Angulogerina angulosa										1
Angulogerina carinata							1			+
Astrononion schwageri					+					
Bolivina costata		53	64	85	63	4	23	21	1	36
Bolivinellina pacifica			+	+	+	11	7	3		
Bolivinita minuta		+	1				1			6
Brizalina spissa							3			1
Bulimina barbata				+	+					
Bulimina exilis tenuata		1		1	4	56	4	8	4	+
Bulimina pyrula spinescens							+			
Bulimina subacuminata							+	1		2
Buliminella curta										1
Cassidelina complanata		1	+	1		1	2			
Cassidulina cushmani							15			12
Cassidulinoides bradyi					+	5	2	2		
Cassidulinoides sp.		+	1							
Chilostomella oolina		1			+					
Cibicidoides mundula					+					
Eggerella bradyi			+		1					
Ehrenbergina trigona					1					
Eilohedra levicula		15	7	3	2	1	2	14	1	11
Epistominella smithi							17			4
Fontbotia wuellerstorfi		+		1		1	1			
Globobulimina affinis		1	+	+	3			1		
Globobulimina pacifica			+	+			+			+
Globocassidulina depressa		14	6	+	7	17	2	4	1	3
Globocassidulina subglobosa			+	+						+
Gyroidina lamarckiana			1	2	4				1	
Gyroidina neosoldanii			+	+						
Gyroidina turgida										
Gyroidina sp.		+								
Hoeglundina elegans			+	1	+					+
Hansenisca altiformis										1
Laticarinina pauperata			+		+					
Martinottiella communis			+	+						
Melonis affinis			+	+	3					1
Melonis pompilioides			+		+					
Nodogenerina spp.							7	1		5
Nodosaria catesbyi										+
Nodosaria longiscata										
Nonionella auris		+		1		3		1		
Nonionella miocenica		+				1				
Oridorsalis umbonatus		2	1	1	3					
Parrelloides bradyi			+						1	
Plectofrondicularia advena							+	+		1
Plectofrondicularia californica										+
Pseudoparrella exigua		+	+	+			1			
Pseudoparrella sandiegoensis										2
Pseudoparrella subperuviana		1			+					
Pullenia bulloides		+	+	+	1			1	3	+
Pyrgo murrhyna		+			+			+		
Pyrgo serrata							+			
Sphaeroidina bulloides			+		+					+
Triloculina sp.			1	+						
Uvigerina auberiana		1	2	+	2		2			7
Uvigerina bradyana			1	+	+		2			+
Uvigerina peregrina		+						1		
Uvigerina senticosa		6	10	2	2	+	7	37	83	2
Valvulineria glabra			+							
Valvulineria rugosa minuta		+	+	+						
unilocular spp.		1	2	+	3		1	4	5	1
Count		324	306	325	258	205	213	196	81	265
Planktonic/Benthic Ratio × 100		60	10	6	2	<1	0	10	0	0

[1] Barren of foraminifers: 15X-CC; 16X-CC; 18X-CC; 20X-CC; 21X-CC; 23X-CC; 26X-CC; 27X-CC.
[2] Counts less than 80: 22X-CC; 24X-CC; 25X-CC.

Table 7 (continued).

Age	middle Miocene												
Depth (mbsf)		252.1	260.0	270.5	279.4	288.2	305.4	360.5	373.1	382.0		424.5	443.9
Hole 683A/B Core[1,2] Section Interval (cm)	683A-	28X-CC	29X-CC	30X-CC	31X-CC	32X-CC	33X-CC	39X-CC	40X-CC	41X-CC	683B-	3X-CC	5X-CC
Species													
Alabamina polita					17				25	6		1	
Amphimorphina stainforthi		1	+	1	9	9	2	17	2	6		3	3
Anomalinoides pompilioides							4		+	+		1	2
Astrononion schwageri		1					1						
Bolivina decussata		4										2	
Bolivina vaughani Gr.		8	53	57			1					4	6
Brizalina cf. gladius				7				1	1				4
Bulimina alazanensis		57		1			9	3	11			9	1
Bulimina alligata		1	+	1	1	2	5						
Bulimina pupoides auct.		+											
Bulimina striata									+	1		2	1
Bulimina translucens			+									3	2
Buliminella curta				+									
Cibicidoides kullenbergi					1	9			4	9		7	3
Cibicidoides trinitatensis									1				2
Ehrenbergina sp.		+	2	1									
Fontbotia wuellerstorfi			+										
Globocassidulina subglobosa horizontalis		1	+	2	1	3						1	
Guttulina irregularis									+	1			
Gyroidina turgida		3	10	2	11	9	1		+			4	
Hansenisca altiformis								2	1			1	1
Hansenisca soldanii		2	+	1		1		7	12	19		5	5
Hansenisca zealandica		1	1	1	6	2	2	12	2	2		4	
Hoeglundina elegans			1	2	1				+				
Hofkeruva smithi		+					1						
Lagenoglandulina sp.					3								
Laticarinina pauperata								4					
Martinottiella cyclostomata		1	1	4		3	8	2	+	1		2	1
Melonis affinis		1	3	1	5	3	4	1		4		5	3
Melonis pompilioides					1			9	5	3		3	1
Nodogenerina spinea								1				2	
Nodogenerina spp.						3		1					7
Nodosaria cf. consobrina		4	5	3	5	3							2
Nodosaria longiscata				1		12	4	2	1	16		1	22
Nuttallides cf. decorata									3				14
Oridorsalis umbonatus		+	+	1	15	20	4	7	5	2		17	2
Osangularia culter		1	1	1	1		2		+			3	
Parrelloides bradyi		1	+	1	4		2		3			3	3
Planulina renzi							3	13	5	7		1	
Plectofrondicularia morreyae					1	1		2	1				
Plectofrondicularia sp.								2					2
Pleurostomella alternans		+	1	1			2						
Pseudoparrella exigua			8	+									
Pseudoparrella sp.						3							
Pullenia bulloides		1	1		5	5	7	9	12	17		3	2
Pyrgo murrhyna			+										
Quinqueloculina venusta			+										
Rotorbinella cf. garveyensis												2	
Sigmoilopsis schlumbergeri		+					1						
Siphonodosaria paucistriata		3	1	2	6	6	8	2	1	1		1	1
Sphaeroidina bulloides		1	+	1			2		1			3	
Spirolocammina tenuis							2					1	2
Spirosigmoilinella compressa				+									
Uvigerina auberiana			3	3	1	1	2						
Uvigerina gallowayi			+		1	1	1		+				
Uvigerina mantaensis		2	3	4		1	13			1		2	
Uvigerina cf. postica		3	2		2								2
Uvigerina rustica				1	2		6					1	1
Vulvulina sp.									+	1			1
unilocular spp.		4	4	+	1	3	3	3	2	3		2	4
Count		138	270	212	139	152	119	181	355	140		179	106
Planktonic/Benthic Ratio × 100		1	1	14	2	0	0	0	0	15		3	71

[1] Barren of foraminifers: 34X-CC; 35X-CC; 44X-CC.
[2] Counts less than 100: 36X-CC; 37X-CC; 38X-CC; 42X-CC; 43X-CC; 45X-CC.

Table 7 (continued).

Hole 683B Species	Age	middle Eocene			
	Depth (mbsf)	462.8	462.9	478.3	478.5
	Core[1,2] Section Interval (cm)	7X-3, 26-29	7X-CC	8X-CC	9X-CC
Alabamina atlantisae		4		3	7
Anomalina chirana					+
Anomalinoides mantaensis		1	+		
Asterigerina crassaformis				4	
Bathysiphon eocenica			+		+
Bolivina chirana			1		
Bolivina cf. ignara				1	
Bolivina maculata		6	+	1	3
Bolivinellina basisenta		10	17		7
Bolivinellina sp.		4	5	1	6
Brizalina cf. jacksonensis				7	
Bulimina chirana		3	9	9	14
Bulimina peruviana		+	+	1	1
Bulimina stalacta			1		
Bulimina truncanella		6			
Buliminella chirana		1			+
Buliminella peruviana		11	21	24	5
Buliminellita mirifica		26	17		
Chilostomella serrata			+		
Cibicides cf. martinezensis			+		
Cibicidoides cf. grimsdalei				1	
Cibicidoides cf. havanensis				1	
Cibicidoides sp.			3		
Cyclammina simiensis			+		
Dorothia principensis			+		
Eponides cf. minimus				6	8
Fursenkoina sp.				16	
Glandulina laevigata			+		+
Globobulimina cf. oregonensis				9	
Globobulimina pseudovata			+		2
Globocassidulina globosa		7	+	1	3
Globocassidulina subglobosa					+
Globocassidulina sp.		2			
Gyroidina octocamerata		1	3		+
Hopkinsina cf. danvillensis					3
Nodogenerina sp.		4	1		3
Nodosaria longiscata		5	+		1
Nuttallides truempyi			+		
Oridorsalis umbonatus		+			3
Parrelloides bradyi		+			
Plectofrondicularia volkesi			+		
Pleurostomella sp.				3	
Pullenia duplicata		+	+		
Quinqueloculina cf. naheolensis			+		
Robulus spp.		2		1	
Stichocassidulina thalmanni		5	15		24
Uvigerina ecuadorensis		1	4	1	
Vaginulina sp.				1	
Valvulineria welcomensis			+		10
unilocular spp.				1	
Count		499	1312	138	291
Planktonic/Benthic Ratio × 100		30	5	66	5

[1] Counts less than 100: 8X-1, 32–35.

Table 8. Pecentage of species representation, Hole 682A (3789 m).

Hole 682A (3789 m) Species	Age	Quat.					l. Plio.	
	Depth (mbsf)	3.7	9.7	14.9	18.8	24.6	55.5	59.7
	Core[1,2] Section Interval (cm)	1H-3, 71-75	1H-CC	2H-4, 55-58	2H-CC	3H-4, 80-84	6H-CC	7X-CC
Astrononion schwageri				2	8	+		
Bolivina costata		27	16	24	12	9	4	14
Bolivinellina humilis		5			+			
Bolivinellina pacifica		2		+	+	+		
Bolivinita minuta		1		+	1			
Bulimina alazanensis				+	+	1		
Bulimina exilis tenuata							13	
Bulimina striata mexicana							+	
Buliminella curta		4			+			
Buliminella elegantissima limbosa		4	+		+	1		
Cassidelina complanata		1	+	1	1	3		2
Cassidulina cushmani		2						
Cassidulinoides bradyi					2	1	2	
Eggerella bradyi				3	1	1		1
Ehrenbergina trigona				11	4	9		
Eilohedra levicula		2	10	19	5	7	39	29
Epistominella smithi						1		
Eponides tumidulus				2	2	2		
Fontbotia wuellerstorfi		+	+		+	1	1	
Fursenkoina glabra						1		
Globobulimina affinis				+	+			
Globobulimina pacifica		+					1	
Globocassidulina depressa			31	3	4	3	17	4
Globocassidulina subglobosa		+	2	1	1	5		
Gyroidina lamarckiana		2	1	4	1	7	8	
Gyroidina turgida		5						
Hansenisca altiformis					+		1	
Hoeglundina elegans		2			+	1		
Martinottiella communis				+	+		+	1
Melonis affinis			1	3	+	2		+
Melonis pompilioides		1	2					
Nodogenerina sp.							+	1
Nodosaria calomorpha				+				
Nodosaria consobrina							1	3
Nodosaria longiscata							3	34
Nonionella auris		+	+			3		
Oridorsalis umbonatus		2	2	2	+	5		
Parrelloides bradyi				+	+			
Plectofrondicularia spp.					+			
Pleurostomella alternans					+			1
Pseudoparrella exigua		26	+	7	49	1		
Pseudoparrella subperuviana		9						
Pullenia bulloides		+	3	1	+	1		
Pullenia quinqueloba		2	2	3	1	+	2	1
Pyrgo murrhyna		+	+	+	+	1		
Robulus sp.							+	
Sphaeroidina bulloides				1			4	1
Spirolocammina tenuis					+	2		
Stilostomella fistuca								1
Triloculina trigonula								1
Triloculina sp.		2						
Uvigerina auberiana			1	3	4		1	4
Uvigerina senticosa		+	25	2	2	6	1	
unilocular spp.		1	5	5	1	3	2	1
Count		125	183	582	615	106	144	139
Planktonic/Benthic Ratio × 100		61	15	2	15	611	0	22

[1] Barren of foraminifers: 3H-CC; 4H-3 (71–75); 4H-CC.
[2] Counts less than 100: 5X-CC.

Table 8 (continued).

Hole 682A Species	Age	e. Plio.	late Miocene											m. Mio.			e. Mio.
	Depth (mbsf)	67.3	77.5	134.7	143.1	153.8	164.3	171.9	183.3	202.1	210.5	220.2	229.0	238.7	257.2	266.9	295.3
	Core[1,2] Section Interval (cm)	8X-CC	9X-CC	15X-CC	16X-CC	17X-CC	18X-CC	19X-CC	20X-CC	22X-CC	23X-1, 107-112	24X-CC	25X-CC	26X-CC	28X-CC	29X-CC	33X-CC
Ambitropus thalmanni					22	+	4	1	+		1		2	2	+		
Amphimorphina stainforthi						1	10			+				2	+	9	3
Amphimorphina sp.							5	+	38		1		1	+			1
Anomalinoides sp.		2															
Bolivina costata		2	1		1												
Bolivina decussata				1	+	+											
Bolivina granti		+		6													
Bolivina sinuata		+				5	2	1			1	2	5	1			
Bolivina sinuata alisoensis				1													
Bolivina vaughani				3	12	1	1	26	7	4	1	1		+	8		
Bolivinellina californica		2															
Bolivinellina ecuadorana						+	6	11	1	1	1				+		
Bolivinellina foraminata					5												
Bolivinellina girardensis		40															
Bolivinellina goudkoffi		14															
Bolivinellina seminuda var.				4	15	+			3				1		+	+	
Bolivinellina sp.										3	2						
Bolivinita minuta		4							+					+	3		
Brizalina imbricata								3		+							
Brizalina pisciformis													5	1	+	3	4
Buccella oregonensis						+	+	+		+							
Bulimina alazanensis				+							1		2	1		2	
Bulimina alligata														3	+	1	1
Bulimina elongata														1		9	
Bulimina exilis tenuata		3															
Bulimina hebespinata								+			+	1	4				
Buliminella curta		1		+							21		12	5	4	4	3
Buliminella elegantissima limbosa				+		4	12	21	14	63	45	77	25	45	69	4	
Buliminella subfusiformis					34	14	12	8	12		27		14	7			
Cassidulina cushmani		1		1		5	2	3	3	+	1	4		2	2	1	
Cassidulinoides bradyi		+															
Cibicidoides compressus																	6
Eilohedra levicula		10	3	3	1	2										5	
Epistominella smithi					19	25	5	1	3	9	1	6	9	10	3	1	
Fontbotia wuellerstorfi														+			
Fursenkoina restinensis				2													
Galliherina uvigerinaformis charapatoensis								3									
Globocassidulina subglobosa						1										1	
Gyroidina lamarckiana		1	2													1	
Hansenisca altiformis							+		1	1	1		4	2			
Hansenisca multilocula				+	3	+											
Hansenisca zealandica																1	
Holmanella cf. *valmonteensis*				+			+										
Lagenoglandulina sp.			4			+		+									
Melonis affinis			1														
Melonis pompilioides			1														
Nodogenerina sp.		2	4			1	+	+	1					2		1	
Nodosaria consobrina		1	5	+													
Nodosaria longiscata			43										+				10
Nonionella ecuadorana								1									
Oridorsalis umbonatus													2	+			1
Planulina ornata						1	+	+	4								
Planulina renzi																	1
Plectofrondicularia advena		1							+	+	+			2			2
Plectofrondicularia californica				+		1	+	+									2
Plectofrondicularia spp.			5			+								3			
Pleurostomella alternans			2														
Pseudoparrella subperuviana				68	4	9	6	5	5	1	3		+	2	4	24	
Pullenia bulloides		+	1														
Robulus spp.				2	+												1
Rotorbinella garveyensis				1		4	2	1	2	1	2		9	5		5	
Siphonodosaria paucistriata																	8
Sphaeroidina bulloides		3	6														
Stilostomella fistuca			4														
Uvigerina auberiana		12	14	3		2			1				2	2	+	6	
Uvigerina gallowayi																	5
Uvigerina hispido-costata									4		1		7	4		8	
Uvigerina mantaensis				1		24	4	1	1	1	1	1				5	51
Uvigerina marksi				4	3			1		+			+				
Uvigerina peregrina + dirupta						3	3	+					4				
Uvigerina rustica																	4
Valvulineria compressa						1	4	9	1		2	1		1	1		
unilocular spp.			4			1	2			+		1	+		+	1	1
Count		154	120	544	318	211	192	163	160	433	213	148	125	257	525	150	100
Planktonic/Benthic Ratio × 100		0	<1	<1	<1	1	1	4	0	1	<1	0	0	<1	<1	0	0

[1] Barren of foraminifers: 10X-CC; 11X-CC; 12X-CC; 13X-CC.
[2] Counts less than 100: 14X-CC; 21X-CC; 27X-CC.

Table 8 (continued).

Hole 682A Species	Age	e. Olig.
	Depth (mbsf)	344.4
	Core[1,2] Section Interval (cm)	38X-CC
Alabamina polita		4
Amphimorphina stainforthi		2
Bathysiphon sp.		2
Brizalina mantaensis		13
Brizalina pisciformis		9
Bulimina alazanensis		9
Bulimina bleeckeri		1
Buliminella cf. *curta*		13
Globocassidulina subglobosa		2
Guttulina irregularis		+
Hansenisca altiformis		5
Heterolepa ? crebbsi		6
Lenticulina subpapillosa		+
Martinottiella nodulosa		1
Melonis cf. *pompilioides*		3
Nodosaria longiscata		6
Oridorsalis umbonatus		2
Osangularia interrupta		4
Plectofrondicularia sp.		+
Pseudoclavulina bullbrooki		6
Pullenia bulloides		+
Robulus americanus		7
Robulus cristobalensis		+
Robulus spp.		2
Sigmomorphina trinitatensis		+
Sphaeroidina chilostoma		+
Uvigerina auberiana		+
Uvigerina gallowayi basicordata		+
Uvigerina mexicana		+
Vaginulina elegans mexicana		+
unilocular spp.		+
Count		164
Planktonic/Benthic Ratio × 100		30

[1] Foraminifera in matrix: 41X-CC; 42X-CC.
[2] Counts less than 100: 34X-CC; 35X-CC; 36X-CC; 37X-CC; 39X-2, 41–43; 40X-2, 43–47; 40X-CC.

Table 8 (continued).

Hole 682A Species	Age	e. Olig.	middle Eocene		
	Depth (mbsf)	397.1	410.0	421.0	427.6
	Core[1,2] Section Interval (cm)	44X-CC	46X-CC	47X-CC	48X-CC
Alabamina atlantisae		3			4
Amphimorphina stainforthi				2	+
Anomalinoides alazanensis			1	1	
Anomalinoides pompilioides			+		
Asterigerina crassaformis			1	1	
Bathysiphon eocenica				1	2
Bolivina maculata		+			1
Bolivinellina basisenta		17	25	20	27
Brizalina sp.					1
Buccella sp.					5
Bulimina alazanensis			+		
Bulimina chirana		3	20	1	8
Bulimina peruviana					1
Bulimina stalacta			+		
Buliminella chirana		5			
Buliminella peruviana		2			
Buliminellita mirifica					1
Cibicides sp.					2
Cibicidoides martinezensis			+		
Cibicidoides perlucidus			1		
Cibicidoides spp.			4		
Cyclammina simiensis				30	6
Dorothia asiphonia					1
Eponides sp. (small)			19	2	7
Fursenkoina nuda (of Hofker)		4		2	+
Globobulimina diversa			1	5	1
Globocassidulina globosa			10	2	18
Globocassidulina subglobosa				2	1
Globocassidulina sublaevigata			+		1
Gyroidina perampla			+		
Gyroidina sp.				7	
Hansenisca multilocula			+		1
Hansenisca soldanii					
Haplophragmoides sp.		7			5
Nodogenerina sp.			1		
Nodosaria longiscata			5	8	
Nonionella cf. *ecuadorana*		3			
Oridorsalis umbonatus			5	4	2
Plectofrondicularia vaughani				3	
Plectofrondicularia spp.			1		
Quinqueloculina sp.				1	
Spirolocammina tenuis				1	
Stichocassidulina thalmanni		53		4	2
Stilostomella sp.			2		
Triloculina sp.					1
Uvigerina ecuadorensis			2	1	2
Uvigerina peruviana		3	+		
Valvulineria peruviana			2		
unilocular spp.				2	
Count		101	105	101	111
Planktonic/Benthic Ratio × 100		3	13	36	21

[1] Counts less than 100: 45X-CC (*Cyclammina simiensis* only).

Table 9. Percentage of species representation, Hole 685A (5071 m).

Hole 685A (5071 m) Species	Age	Quaternary											late Mio.
	Depth (mbsf)	33.0	40.2	51.4	70.5	88.0	110.0	123.1	142.2	168.3	166.3	195.3	338.6
	Core[1,2] Section Interval (cm)	4-CC	5-CC	6-CC	8-CC	10-CC	12-CC	14-CC	16-CC	18-CC	19-CC	21-CC	38-CC
Alexanderina viejoensis							1	1	1				
Astrononion schwageri		+			+								
Bolivina costata		73	10	57	88	90	70	73	83	68	94	52	
Bolivinita minuta		+			1		+					+	
Brizalina spissa		3			+								
Bulimina alazanensis		+			+								
Bulimina exilis tenuata		5			+	1		2	+	1		1	
Bulimina subacuminata		+											
Cassidelina complanata		1	6			1	+	+	1	2		1	
Cassidulina cushmani		11			1			+				1	
Cassidulina neocarinata		+											
Cribromiliolinella subvalvularis				3									
Ehrenbergina trigona								1					
Eilohedra levicula		2	67	12	3	3	14	5	1			20	
Epistominella smithi		3											
Fontbotia wuellerstorfi								+	1			1	
Globobulimina affinis								+					
Globocassidulina depressa					2	2	11	5	7	13	2	7	
Gyroidina lamarckiana					1			3	1			+	
Melonis affinis		+			+		1	2	2	3		6	4
Melonis pompilioides		+					1	2	1	7	2	4	
Nonionella auris		+											
Oridorsalis umbonatus			6		+								
Pseudoparrella sandiegoensis					1								
Pullenia bulloides		+			1		1	1	+				+
Pullenia quinqueloba			1	13		1				4		+	4
Pyrgo murrhyna			9	2				+					
Pyrgo spp.		+			+					1		+	1
Quinqueloculina spp.						+	1			1			1
Sigmoilina edwardsi				6									
Sphaeroidina bulloides								+	+				1
Takayanagia delicata					+								
Triloculina sp.						1				+			
Uvigerina auberiana					2	1						+	1
Uvigerina peregrina		1											
Uvigerina senticosa		1					+	4	1			5	
unilocular spp.		+	+	7	+	+		1	1		2	1	3
Alabamina polita													2
Bolivina vaughani													50
Bolivinellina cuneata													2
Bolivinita aff. minuta													+
Buliminella curta													1
Fursenkoina sp.													1
Globocassidulina sp.													2
Gyroidina turgida													22
Gyroidina sp.													+
Laticarinina pauperata													1
Nodosaria consobrina													3
Pleurostomella sp.													+
Count		957	171	128	434	205	216	833	140	100	100	197	169
Planktonic/Benthic Ratio × 100		1	11	134	<1	6	19	30	1	711	100	0	11

[1] Barren of foraminifers: 20X-CC; 27X-CC; 28X-CC; 29X-CC; 30X-CC; 31X-CC; 32X-CC; 33X-CC; 34X-CC; 35X-CC; 36X-CC; 37X-CC; 39X-CC; 40X-CC; 41X-CC; 42X-CC; 43X-CC; 45X-CC; 46X-CC; 47X-CC; 48X-CC; 49X-CC.

[2] Counts less than 100: 1H-CC; 2H-CC; 3H-CC; 23X-CC; 25X-CC; 44X-CC; 50X-CC; 51X-CC.

Table 10. Species abundance Holes 688A and 688E (3820 m).

Age	Quaternary							
Depth (mbsf)	8.3	17.9	27.6	36.9	46.4	56.2	176.7	274.2
Hole 688A (3820 m) Core[1,2] Section Interval (cm) Species	1H-CC	2H-CC	3H-CC	4H-CC	5H-CC	6H-CC	19X-CC	29X-CC
Astrononion schwageri			C		A			
Cassidelina complanata		F	F			C		
Cibicidoides cicatricosus				R				
Cibicidoides mundula	R							
Ehrenbergina trigona		R		R				
Eilohedra levicula	F			F	C	C	F	C
Fontbotia wuellerstorfi				R				
Hansenisca zealandica	R		F	F				
Hoeglundina elegans			C	F	A		R	
Martinottiella communis			R	R	R			
Melonis affinis	C	C	C	C	A	C	A	C
Melonis pompilioides	C	A		A	A	C	F	
Karreriella bradyi	R							
Oridorsalis umbonatus	C		F	F	F		C	
Pseudoparrella exigua	F		C	C	A			
Pullenia bulloides	C	C	C	F	F		F	
Pyrgo murrhyna			R		F			
Pyrgo sp.		R					F	
Uvigerina auberiana								C
Uvigerina senticosa	C	A	A	A	A	C	A	A
unilocular spp.	C		F	F				F
Bolivina costata	C	C	C	F	C	A	C	A
Other transported species		C				C	R	

[1] Barren of foraminifers: 23X-CC, 26X-CC, 31X-CC, 35X-CC, 36X-CC, 37X-CC.
[2] Less than 100 specimens/spl: 14X-CC, 15X-CC, 16X-CC, 17X-CC, 18X-CC, 20X-CC, 21X-CC, 22X-CC, 25X-CC, 32X-CC, 33X-CC, 34X-CC.

Table 10 (continued).

Age	m. Mio.	e. Mio.	
Depth (mbsf)	482.0	545.8	559.5
Hole 688E (3826 m) Core[1,2] Section Interval (cm) Species	15R-CC	22R-CC	23R-CC
Amphimorphina stainforthi	C	R	
Brizalina pisciformis	R		C
Bulimina alazanensis			C
Bulimina alligata	A	R	
Cibicidoides cf. *pseudoungerianus*			R
Eilohedra levicula	C		
Fursenkoina sp.	F		
Hansenisca altiformis	R	R	A
Hanzawaia cf. *mantaensis*			R
Heterolepa ? crebbsi			A
Heterolepa sp.			F
Melonis affinis	C	R	
Melonis pompilioides			F
Nodosaria longiscata	C	R	A
Oridorsalis umbonatus		R	C
Osangularia interrupta	F		
Planulina sp.			F
Plectofrondicularia advena	F		
Plectofrondicularia spp.	F		R
Pleurostomella spp.	F		
Pullenia bulloides	F	R	
Rectuvigerina cf. *multicostata*			F
Robulus aff. *brevispinosus*			F
Stilostomella spp.	A	R	F
Uvigerina gallowayi		R	R
Uvigerina mantaensis		F	A
unilocular spp.	R	R	

[1] Barren of foraminifers: 1R-CC, 2R-CC, 3R-CC, 4R-CC, 5R-CC, 6R-CC, 7R-CC, 8R-CC, 9R-CC, 10R-CC, 11R-CC, 19R-CC, 20R-CC, 26R-CC.
[2] Less than 100 specimens/spl: 12R-CC, 13R-CC, 14R-CC, 16R-CC, 24R-CC, 25R-CC.

Table 10 (continued).

Age	m. Eoc.	e. Eoc.		
Depth (mbsf)	661.9	681.5	750.5	757.0
Hole 688E (3826 m) Core[1,2] Section Interval (cm)	34R-CC	36R-1, 66-70	43R-CC	44R-CC
Species				
Anomalina chirana	+			
Anomalina venezuelana			C	
Asterigerina crassaformis			F	R
Bathysiphon eocenica		F	F	
Bolivinellina basisenta		R		
Bolivinellina spp.		C		
Bulimina cf. *chirana*		C		
Bulimina jacksonensis				R
Bulimina peruviana		A	R	R
Bulimina cf. *stalacta*		R		
Buliminella chirana		F		F
Cibicides sp.				
Cibicidoides grimsdalei		R	C	R
Cibicidoides martinezensis			C	
Cibicidoides perlucidus			F	R
Cyclammina sp.			F	
Globocassidulina globosa			C	A
Guttulina irregularis	+			
Hanzawaia sp.		F		
Nodosaria longiscata	+	R		
Oridorsalis umbonatus	+		C	R
Plectofrondicularia vaughani	+			
Plectofrondicularia spp.	+			
Quinqueloculina sp.		F		
Spiroloculina sp.				
Spiroplectammina gryzbowski		R		
Stilostomella spp.	+	A		
Uvigerina ecuadorensis	+	F		
Valvulineria cf. *samanica*		R		A
Vulvulina cf. *curta*			F	

[1] Barren of foraminifers: 29R-CC, 33R-CC, 37R-CC, 40R-CC.
[2] Less than 100 specimens/spl: 27R-CC, 30R-CC, 31R-CC, 32R-CC, 35R-CC, 36R-CC, 38R-CC, 39R-CC, 41R-CC, 42R-CC, 45R-CC.

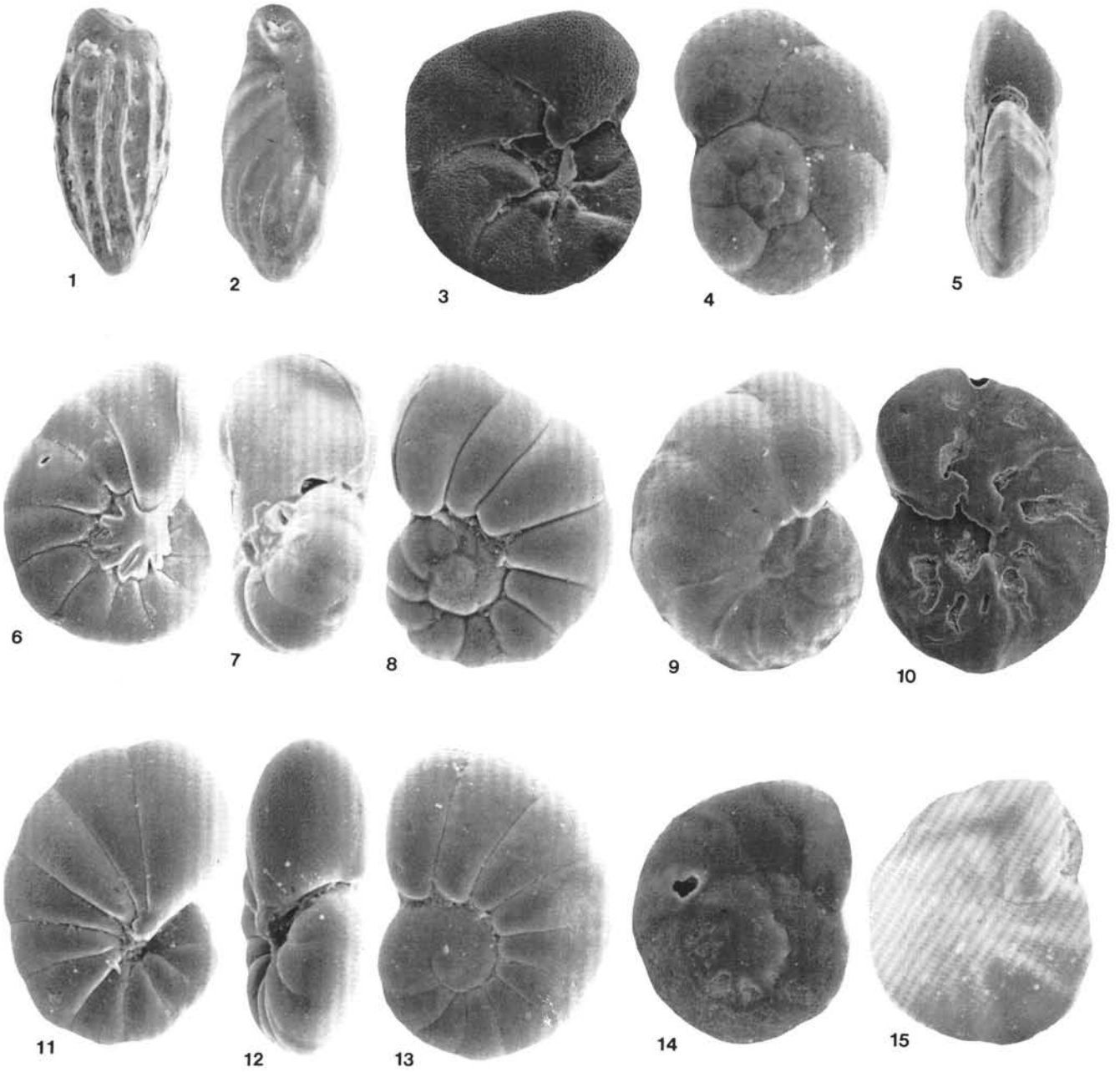


Plate 1. Quaternary shelf species. **1.** *Bolivina costata* d'Orbigny, ×106, Sample 112-687A-22X-CC. **2.** *Buliminella elegantissima limbosa* Cushman and McCulloch, ×137, Sample 112-686A-22X-CC. **3–4.** *Rosalina peruviana* d'Orbigny, (3) ventral, ×96, Sample 112-686A-22X-CC, (4) dorsal, ×117, Sample 112-686A-22X-CC. **6–8.** *Nonionella miocenica* Cushman, (6) ventral, ×124, Sample 112-687A-22X-CC, (7) edge, ×130, Sample 112-687A-22X-CC, (8) dorsal, ×143, Sample 112-687A-22X-CC. **5, 9–10.** *Hanzawaia nitidula* (Bandy), (5) edge, ×45, Sample 112-686A-22X-CC, (9) ventral, ×46, Sample 112-686A-22X-CC, (10) dorsal, ×57, Sample 112-686A-22X-CC. **11–13.** *Nonionella auris* (d'Orbigny), (11) ventral, ×119, Sample 112-686A-22X-CC, (12) edge, ×124, Sample 112-686A-22X-CC (13) dorsal, ×129, Sample 112-686A-22X-CC. **14,15.** *Alexanderina viejoensis* McCulloch, (14) dorsal, ×177, Sample 112-686A-22X-CC, (15) ventral, ×198, Sample 112-686A-22X-CC.

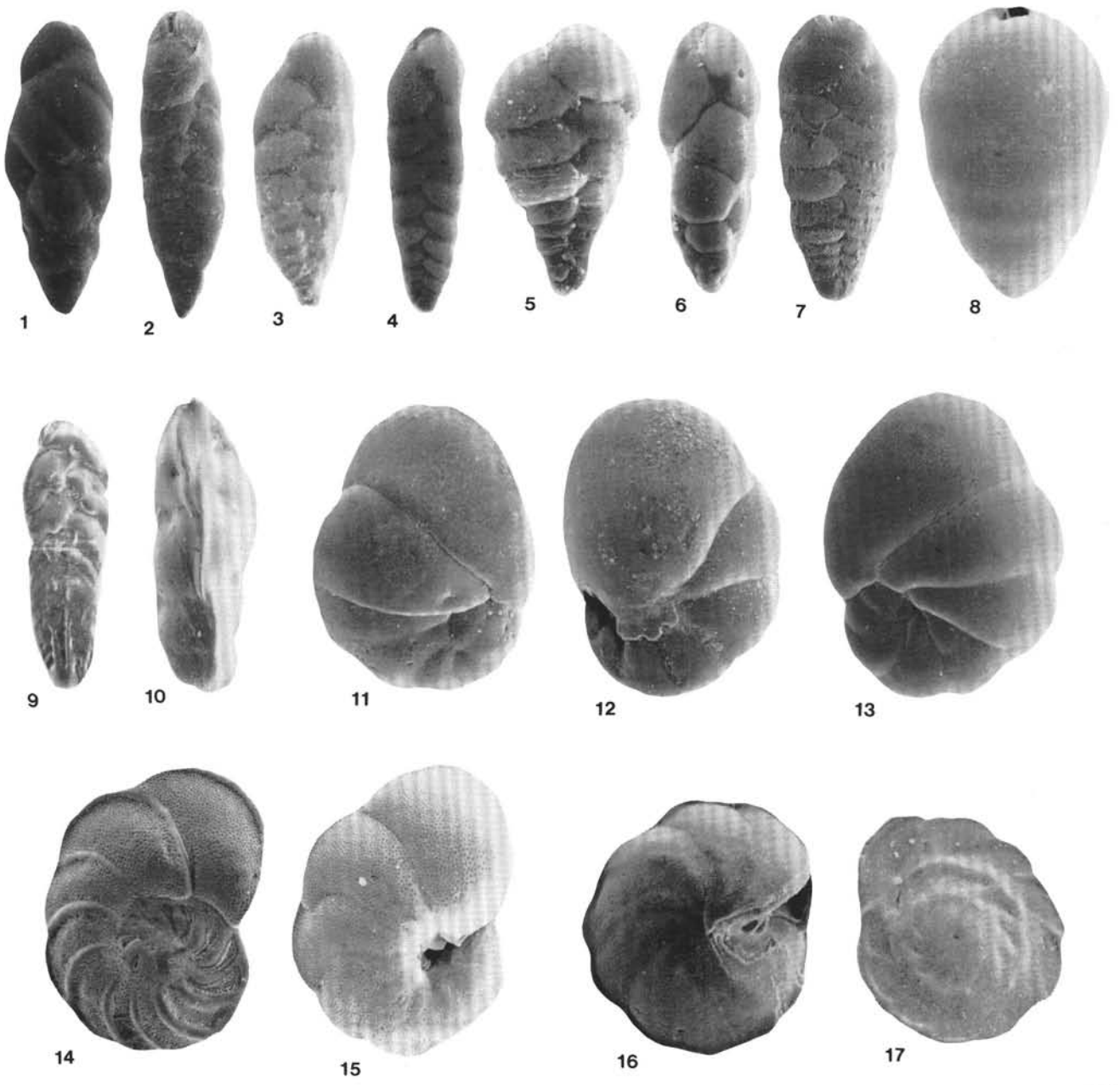


Plate 2. Quaternary outer-shelf–upper-bathyal oxygen-minium species. **1.** *Buliminella subfusiformis* Cushman, ×54, Sample 112-187A-15X-CC. **2,3.** *Bolivinellina humilis* (Cushman and McCulloch), (2) ×53, Sample 112-687A-15X-CC, (3) ×81, Sample 112-680A-3H-CC. **4.** *Bolivinellina pacifica* (Cushman and McCulloch), ×108, Sample 112-680A-3H-CC. **5.** *Suggrunda eckisi* Natland, ×165, Sample 112-680A-3H-CC. **6.** *Fursenkoina glabra* (Cushman and Wickenden), ×148, Sample 112-680A-3H-CC. **7.** *Parabolivina peruensis* Resig, ×35, Sample 112-679B-2H-CC. **8.** "*Ellipsoglandulina*" *fragilis* Bramlette, ×25, Sample 112-679B-2H-CC. Quaternary upper bathyal current species. **9.** *Brizalina interjuncta* (Cushman), ×32, Sample 112-679B-1H-CC. **10.** *Angulogerina carinata* Cushman, ×33, Sample 112-680A-5H-CC. **11–13.** *Cancris carmenensis* Natland, (11) dorsal, ×45, Sample 112-679B-1H-CC, (12) ventral, ×45, Sample 112-679B-1H-CC, (13) dorsal, ×38, Sample 112-679B-1H-CC. **14,15.** *Cancris inflatus* (d'Orbigny), (14) dorsal, ×55, Sample 112-680A-5H-CC, (15) ventral, ×48, Sample 112-680A-5H-CC. **16,17.** *Epistominella afueraensis* McCulloch, (16) ventral, ×103, Sample 112-680A-5H-CC (17) dorsal, ×88, Sample 112-680A-5H-CC.

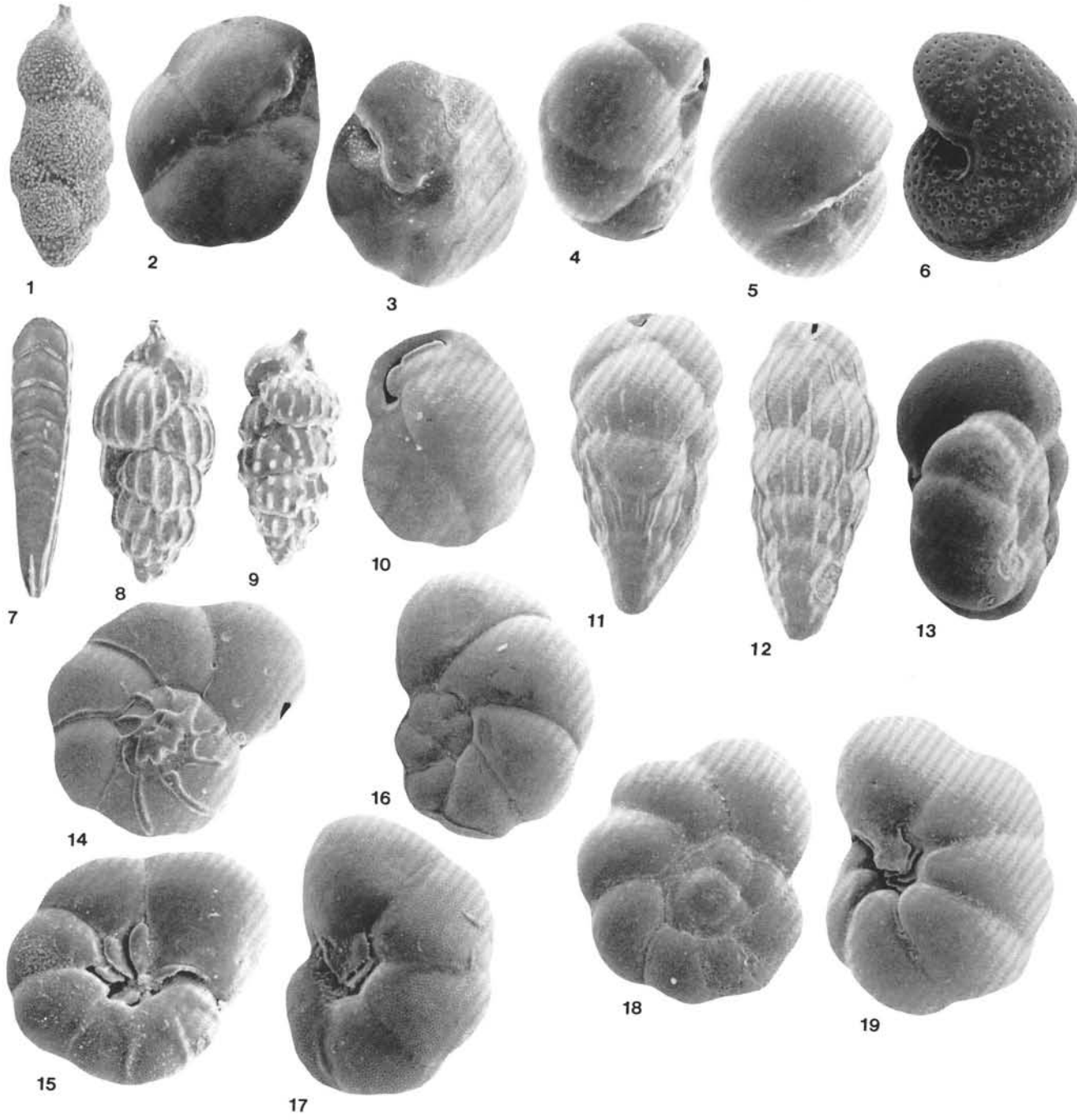


Plate 3. Quaternary lower bathyal species. **1.** *Uvigerina senticosa* Cushman, ×48, Sample 112-682A-1H-CC. **2.** *Pseudoparrella exigua* (Brady), ventral, ×150, Sample 112-682A-2H-CC. **3.** *Oridorsalis umbonatus* (Reuss), ventral, ×80, Sample 112-682A-1H-CC. **4.** *Globocassidulina depressa* (Asano and Nakamura), ×160, Sample 112-682A-1H-CC. **5.** *Pullenia bulloides* (d'Orbigny), ×96, Sample 112-682A-1H-CC. **6.** *Melonis pompilioides* (Fichtel and Moll), ×100, Sample 112-685A-14X-CC. Pliocene upper-middle bathyal species. **7.** *Plectofrondicularia californica* Cushman and Stewart, ×36, Sample 112-684A-5H-CC. **8,9.** *Uvigerina peregrina* Cushman, (8) ×50, Sample 112-684A-5H-CC, (9) ×41, Sample 112-684A-5H-CC. **10.** *Cassidulina cushmani* R.E. and K.C. Stewart, ×78, Sample 112-684A-5H-CC. Late Miocene–early Pliocene outer-shelf species **11.** *Galliherina* cf. *delreyensis* (Cushman and Galliher), ×42, Sample 112-679B-8H-CC. **12.** *Galliherina uvigerinaformis* (Cushman and Keinpell), ×67, Sample 112-684A-8H-CC. **14,15.** *Valvulineria* cf. *compressa* Stone, (14) dorsal, ×61, Sample 112-684A-8H-CC, (15) Ventral, ×75, Sample 112-684A-8H-CC. **16,17.** *Valvulineria* cf. *depressa* Cushman, (16) dorsal, ×61, Sample 112-684A-8H-CC, (17) ventral, ×99, Sample 112-684A-8H-CC. **13, 18,19.** *Valvulineria californica* Cushman, (13) edge, ×37, Sample 112-679B-8H-CC, (18) dorsal, ×41, Sample 112-679B-8H-CC, (19) ventral, ×41, Sample 112-679B-8H-CC.

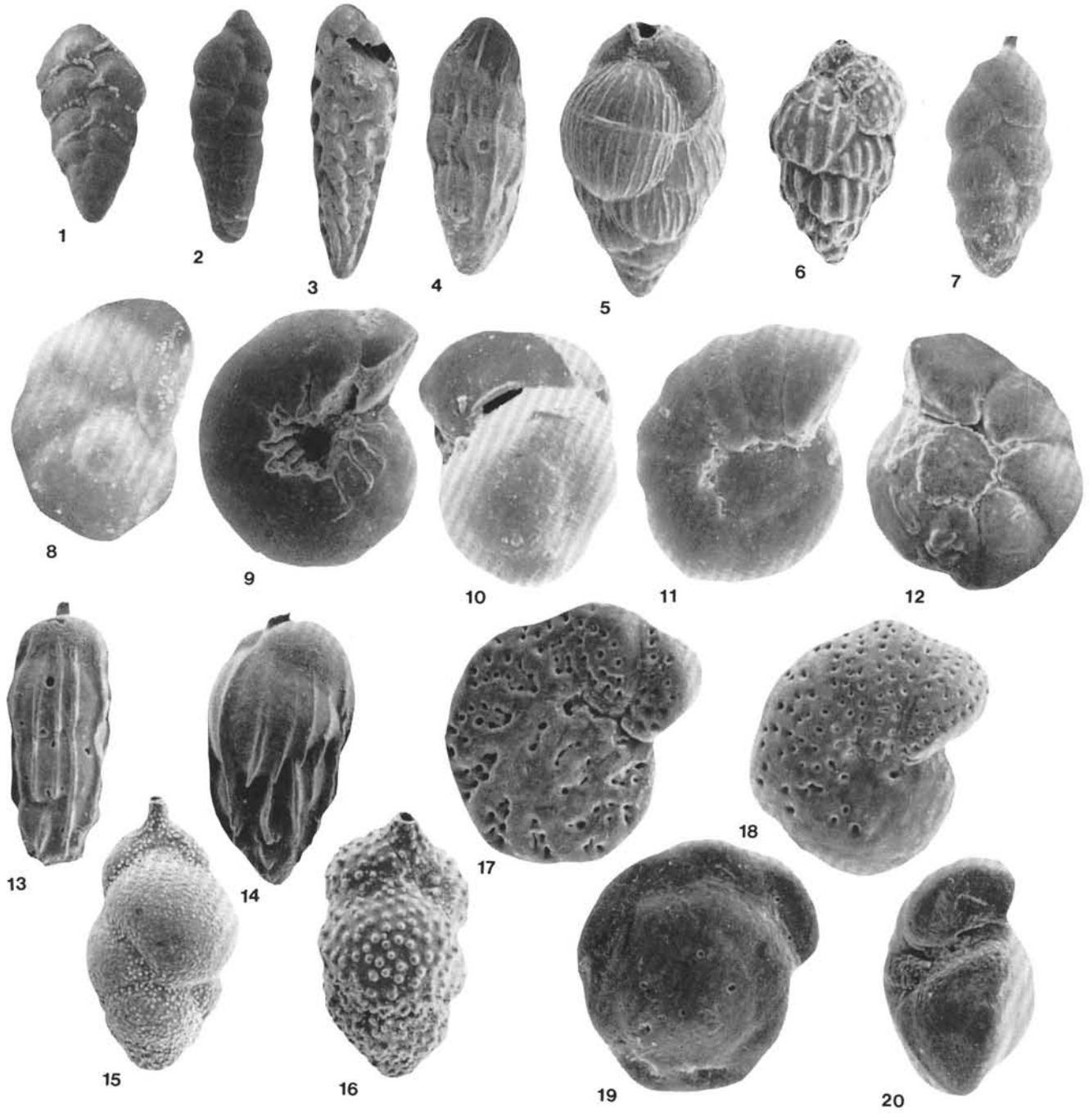


Plate 4. Late Miocene middle bathyal species. **1.** *Brizalina girardensis* (Rankin), ×90, Sample 112-682A-8H-CC (early Pliocene). **2.** *Bolivina granti* Rankin, ×50, Sample 112-682A-15X-CC. **3.** *Bolivina sinuata* Galloway and Wissler, ×40, Sample 112-682A-17X-CC. **4.** *Fursenkoina restinensis* (Berry), ×100, Sample 112-682A-15X-CC. **5.** *Uvigerina marksi* Cushman and Stevenson, ×41, Sample 112-682A-15X-CC. **6.** *Uvigerina peregrina dirupta* Todd, ×44, Sample 112-682A-17X-CC. **7.** *Uvigerina mantaensis* Cushman and Edwards, ×55, Sample 112-682A-17X-CC. **8.** *Ambitropus thalmanni* (Stainforth and Stevenson), dorsal, ×158, Sample 112-682A-16X-CC. **9–11.** *Hansenisca multilocula* Coryell and Mossman, (9) ventral ×83, Sample 112-682A-16X-CC, (10) edge, ×126, Sample 112-682A-16X-CC, (11) dorsal, ×108, Sample 112-682A-16X-CC. **12.** *Rotorbinella garveyensis* (Natland), ventral, ×117, Sample 112-682A-16X-CC. Middle Miocene middle bathyal species. **13.** *Uvigerina gallowayi* Cushman, ×45, Sample 112-682A-33X-CC. **14.** *Uvigerina gallowayi basicordata* Cushman and Renz, ×60, Sample 112-682A-34X-CC. **15.** *Uvigerina mantaensis* Cushman and Edwards, ×69, Sample 112-682A-34X-CC. **16.** *Uvigerina rustica* Cushman and Edwards, ×78, Sample 112-682A-34X-CC. Middle Miocene lower bathyal species. **17,18.** *Cibicidoides trinitatensis* (Nuttall), (17) dorsal, ×92, Sample 112-683A-40X-CC, (18) ventral, ×66, Sample 112-683A-40X-CC. **19,20.** *Hansenisca zealandica*, (Finlay), (19) dorsal, ×59, Sample 112-683A-40X-CC, (20) edge, ×66, Sample 112-683A-40X-CC.

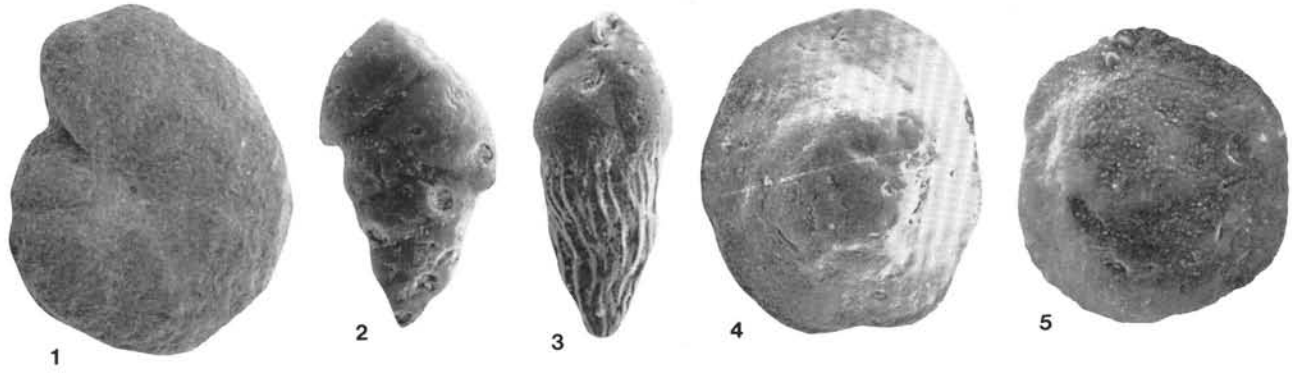


Plate 5. Middle Eocene shelf and upper bathyal species. **1.** *Cyclammina simiensis* Cushman and McMasters, ×24, Sample 112-682A-45X-CC. **2.** *Bolivinellina basisenta* Cushman and Stone, ×158, Sample 112-682A-46X-CC. **3.** *Bulimina chirana* Cushman and Stone, ×98, Sample 12-682A-46X-CC. **4,5.** *Asterigerina crassaformis* Cushman and Siegfus, (4) dorsal, ×119, Sample 112-682A-46X-CC, (5) ventral, ×95, Sample 112-682A-46X-CC.