

Quaternary Sediments in the Axial Zone of the Brazil Basin

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Abstract—Lithological and micropaleontological studies of sediments were carried out along the meridional profile across the Brazil Basin. Based on nannoplankton and diatom assemblages, the sediments represented by oxidized miopelagic clays, differently reduced hemipelagic clays, and clayey–siliceous (*Ethmodiscus*) and calcareous (coccolith–foraminiferal) oozes are attributed to the Pleistocene–Holocene. Specific features of sedimentary material indicate its redeposition by Antarctic bottom waters, mudflows, slumps, and rockslides. It is shown that sedimentation in the Brazil Basin corresponds to the incomplete pelagic (miopelagic) type of oceanic lithogenesis transitional to the near-continental one.

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The Brazil Basin is largely located in the equatorial–tropical zone of the South Atlantic. The eastward distribution of terrigenous material that is transported by rivers from the South American continent is restricted in deep-water layers by the South Atlantic mid-ocean ridge. Surface waters form the anticyclonic subtropical gyre consisting of the Benguela, South Trade Wind, Brazil, and South Atlantic (westerly) currents (Stepanov, 1974, 1983). Combination of anticyclonic circulation and high temperature (20–26°C) of surface waters creates complicated habitat for planktonic organisms. The prevalent annual mean primary production in the Brazil Basin is usually less than 100 mg C/m²/day and ranges from 100 to 500 mg C/m²/day in the equatorial zone (Koblentz-Mishke, 1977). The average phytoplankton abundance in the 0–100 m of water column is usually less than 100 cells/l (Volkovinskii et al., 1972), while the zooplankton biomass in the same layer varies from 25 to 100 mg/m³ (Bogorov et al., 1968). The basin is characterized by eutrophic conditions of macrobenthos habitat (Sokolova, 1986) with the C_{org} content in bottom sediments ranging from 0.25 to 0.50% (Romankevich and Bobyleva, 1990).

The Atlantic bottom water is largely produced in the Weddell Sea (Stepanov, 1974, 1983). Moving northward via the Argentine Basin and Vima and Hunter channels, cold Antarctic water masses reach the Brazil Basin to fill its deep parts. The regime of these cold currents determines to a large extent underwater erosion, hiatus, redeposition, and dissolution of calcium carbonate, the distribution of which in recent sediments of the South Atlantic is rather intricate (Fig. 1) (Berggren and von Rad, 1972). The mid-ocean ridge bordering the Brazil Basin in the east, probably, influences sedimentary processes in the basin, because the ridge serves as a potential source of endogenic matter and as barrier

preventing the eastward transport of sedimentary material.

In the present paper, we consider lithological and biostratigraphic aspects of Quaternary sediment accumulation in the deep part of the Brazil Basin under present-day sedimentation conditions.

MATERIAL AND METHODS

The examined sediments were sampled by gravity corer in the axial part of the Brazil Basin along the meridional (24° W) profile (9 stations) extending from 25°35.7' S to 0°09.7' S during Cruise 18 of the R/V *Akademik Sergey Vavilov* in 2004 (Fig. 2). The thickness of sediments sampled at depths of 3400 to 5800 m varied from 0.1 to 5.1 m. The petrographic composition of sediments, fossil diatoms, and calcareous nannoplanktons were examined in smear-slides under an optical microscope in the transmitted light. A JSM-U3 electron microscope was used to identify nannofossils. Diatom abundance in sediments was determined using the following semiquantitative scale: (5) abundant (more than 25–30 valves in one horizontal row of a preparation), (4) frequent, (3) common, (2) rare, and (1) few (less than 10 valves in the entire preparation). The relative total abundance, number of species, and their percentage in nannofossil assemblages were counted in smear-slides and residues under an optical microscope. The total coccolith abundance was estimated according to the following quantitative scale: absent, rare, few, common, abundant. The counting was controlled by measurements of CO₂ and C_{org} by the ignition method.

RESULTS AND DISCUSSION

In terms of the complex of features, the Atlantic Ocean occupies an intermediate position among ocean–

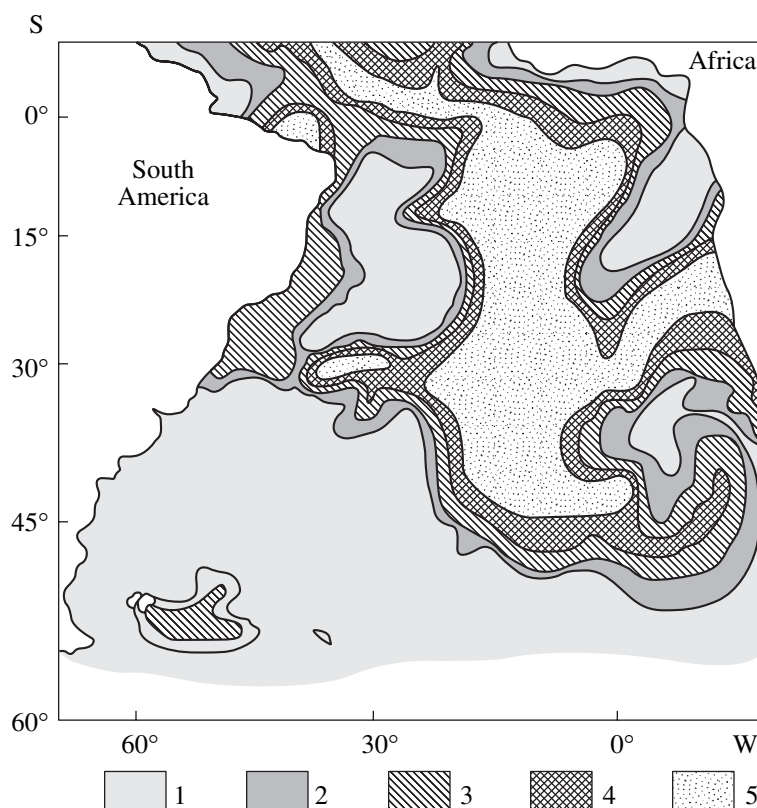


Fig. 1. Distribution of calcium carbonate (%) in recent bottom sediments of the western South Atlantic (Berggren and von Rad, 1972). (1) <20; (2) 20–40; (3) 40–60; (4) 60–80; (5) >80.

inner sea sedimentary basins. Therefore, lithogenesis developed in the deep part of this ocean can be attributed to the incomplete pelagic (miopelagic) type (Sval'nov, 1991). This is also true of the axial part of the Brazil Basin. Sediments sampled in the Brazil Basin (Fig. 2) and the distribution of siliceous and carbonate microfossil remains (diatoms and coccoliths) therein are characterized hereafter.

Station 1535 (25°35.7' S, 24°02.4' W, water depth 4500 m bsl). The sediment core is 395 cm long. The section is largely composed of oxidized miopelagic clays (CaCO_3 0.16–7.81%, C_{org} 0.06–0.14%), which is slightly calcareous (CaCO_3 13.71–30.49%, C_{org} 0.09–0.20%) at intervals 0–40, 147–215, and 270–280 cm (Fig. 3). The sediments are colored from light to dark brown with brownish gray isometric spots, lenses, and bands. Carbonate-free clays are largely composed of clay minerals (86–96%). The subordinate components are represented by foraminifers (up to 7%), coccoliths (<2%), sand- to silt-sized terrigenous detrital minerals (1–5%), Mn–Fe micromodules (up to 2%), rare spicules of siliceous sponges, and bone detritus. In the slightly calcareous clay variety, the dominant clay minerals (68–86%) are accompanied by the subordinate foraminifers (5–25%), coccoliths (3–20%), sand- to silt-sized terrigenous detrital minerals and Mn–Fe micron-

odules (approximately 1% each), and rare diatoms, bone remains, and sponge spicules.

The sediments are represented by calcareous-clayey mud (CaCO_3 36.05–47.85%, C_{org} 0.14–0.24%) at 240–270 and 280–295 cm and by clayey-calcareous mud at 210–240 cm (CaCO_3 55.16–68.19%, C_{org} 0.11–0.19%). The sediments are beige gray with gradual transitions. The content of clay minerals in the calcareous-clayey mud ranges from 54 to 64%. Foraminifers and coccoliths constitute 7–15 and 20–30%, respectively. The clayey-calcareous mud is composed of the dominant biogenic components largely represented by coccoliths (35–45%) and foraminifers (approximately 20%) and the subordinate clay minerals (34–44%). Admixtures in the calcareous-clayey and clayey-calcareous sediments are composed of terrigenous sand- to silt-sized detrital minerals (up to 1%) and rare Mn–Fe micromodules and bone detritus.

When studying the distribution of calcareous nannoplanktons through the section, we used the tropical biostratigraphic scales (Martini, 1971; Bukry, 1978; Okada and Bukry, 1980; and Gartner, 1977). The table demonstrates their correlation. The lower boundary of the *Emiliania huxleyi* Zone corresponds to the first occurrence (FO) level of the zonal species, while the *Emiliania huxleyi* Acme Zone is marked by the increased abundance of the latter fossil. The upper

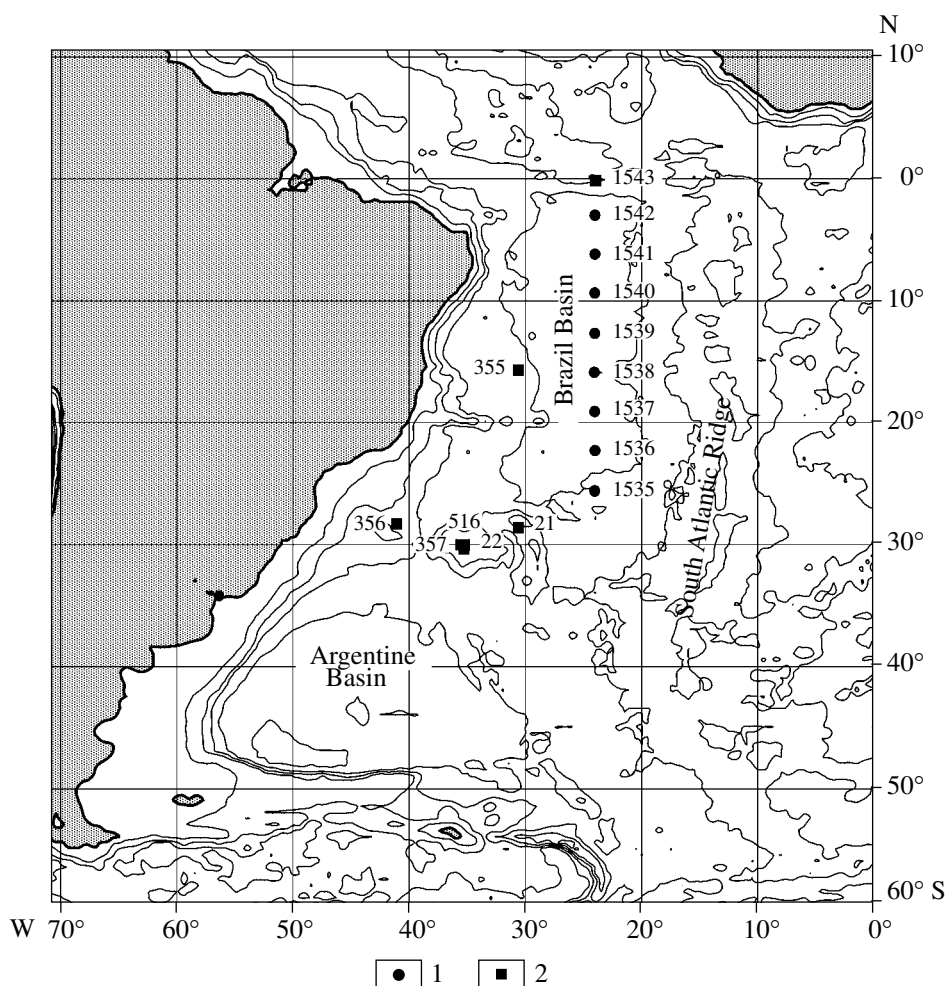


Fig. 2. Location of geological stations (1) and deep-sea drilling holes (2).

boundary of the *Pseudoemiliana lacunosa* Zone coincides with the last occurrence (LO) level of the index form. The *Gephyrocapsa oceanica* Zone is restricted by the LO level of *Pseudoemiliana lacunosa* (Kpt.) Gart. at the base and by the FO level of *Emiliana huxleyi* (Lohm.) Hay, Mohl. at the top. The zone of small *Gephyrocapsa* corresponds to the interval with increased abundance of their representatives. The Pliocene–Pleistocene boundary is drawn at the LO level of *Discoaster brouweri* Tan and the FO level of *Gephyrocapsa oceanica* Kpt. or *G. caribbeanica* Boudr., Hay. Taking into consideration intense redeposition of coccoliths in the study region, this boundary is determined by the FO level of *Gephyrocapsa* specimens.

Since the appearance of the above-mentioned biostratigraphic scales, datum levels of species, particularly forms marking biostratigraphic units, are defined and thoroughly traced to the present day. Inasmuch as these levels vary in different areas, researchers now usually refer to biohorizons defined by the FO and LO levels of species. Five such levels are used for the eastern Equatorial Pacific (Raffi and Flores, 1995); 21 levels, for the Upper Pliocene and Quaternary of the Arabian Sea (Sato et al., 1991). In the Brazil Basin, these levels are unrecognizable because of the intense dissolution of small *Gephyrocapsa* and *Reticulofenestra* forms.

At Station 1535, the almost complete Quaternary section contains approximately 50 nannoplankton species, including reworked forms (Figs. 4, 5). The distribution of coccoliths in sediments is very irregular and varies from highly abundant in the middle part of the section (interval 175–275 cm) to complete or almost complete absence at 85–125 cm and below 320 cm, where they occur as single or rare specimens (Fig. 6).

The upper part (0–85 cm) of the section is characterized by the abundance of Late Quaternary nannoplankton assemblage. Its diversity decreases from 16 to 6 species toward the base of this layer. This interval includes the following species: *Emiliana huxleyi* (accounts for 15% of total coccolith abundance at the top of the layer to single specimens at 80 cm), *Gephyrocapsa oceanica* Kpt. (1–20%), *Calcidiscus leptoporus* (Murr., Blackm.) Loeb. (1–10%), *Coccolithus*

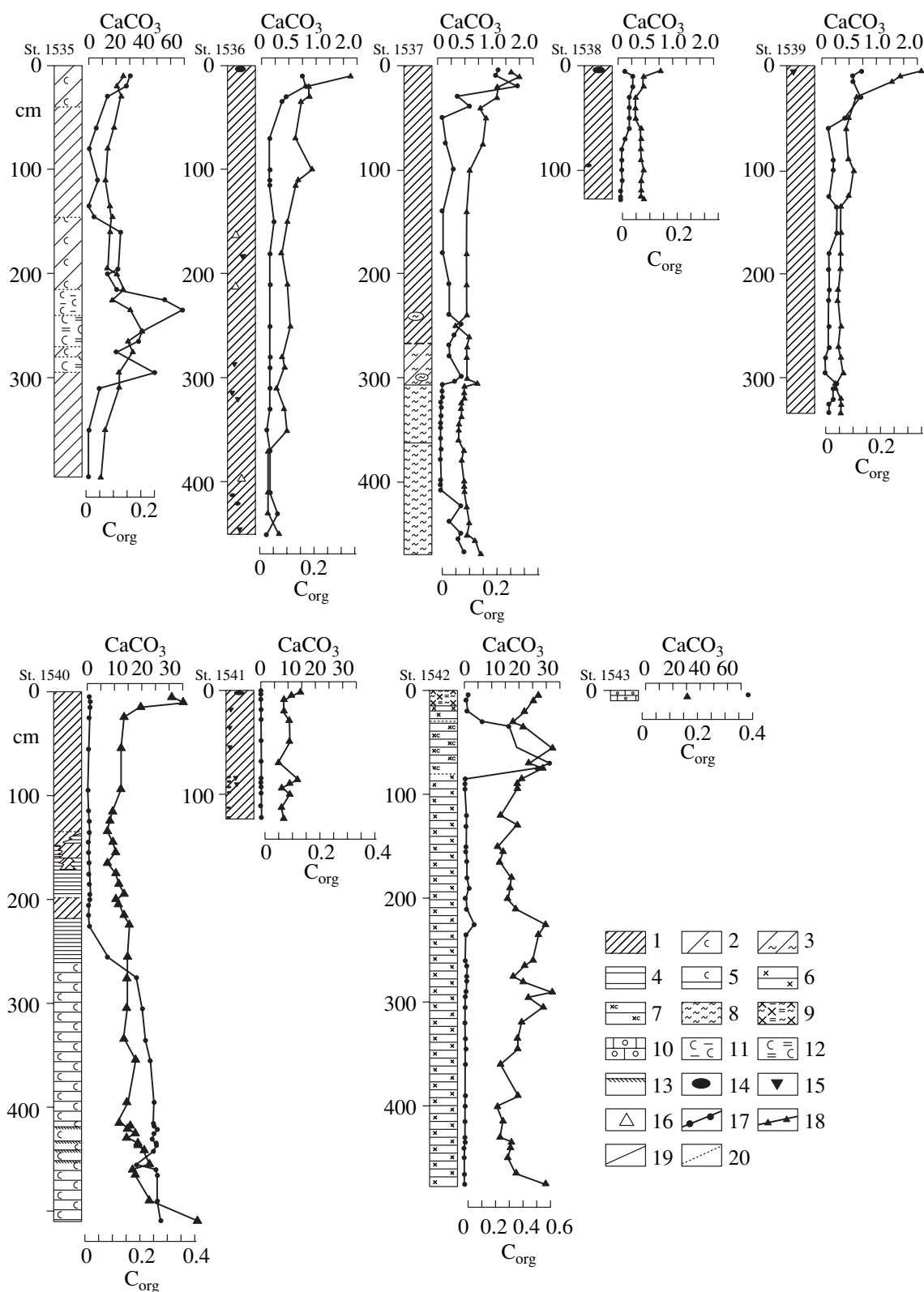


Fig. 3. Lithology of examined sediments and distribution of CaCO_3 and C_{org} in them. (1–13) Sediment types: (1) miopelagic clay; (2) the same, slightly calcareous, (3) the same, enriched in diatoms, (4) hemipelagic clay, (5) the same, slightly calcareous, (6) the same, enriched in radiolarians and diatoms, (7) the same, slightly calcareous and enriched in radiolarians and diatoms, (8) diatom (*Ethmodiscus*) ooze, (9) diatomaceous–radiolarian–clayey mud, (10) coccolith–foraminiferal ooze, (11) clayey–calcareous mud, (12) calcareous–clayey mud, (13) hemipelagic clay enriched in iron oxyhydroxides; (14) ferromanganese nodule; (15) the same, fragment; (16) bedrock fragment; (17, 18) content (%): (17) CaCO_3 , (18) C_{org} ; (19, 20) boundary: (19) sharp, (20) gradual.

Correlation of Quaternary nannoplankton zones

Gartner, 1977	Ma	Martini, 1971	Ma	Bukry, 1978		Ma
<i>E. huxleyi</i> Acme	0.07	<i>E. huxleyi</i>	0.2	<i>E. huxleyi</i>		0.2
<i>Emiliana huxleyi</i>		<i>G. oceanica</i>		<i>G. oceanica</i>	<i>Ceratolithus cristatus</i>	
<i>Gephyrocapsa oceanica</i>	0.27		<i>Emiliana ovata</i>		0.9	
	0.44	<i>Crenalithus daronicoides</i>		<i>Gephyrocapsa caribbeanica</i>		
<i>Pseudoemiliana lacunosa</i>	0.92		<i>P. lacunosa</i>		<i>Emiliana annula</i>	1.6
<i>Small Gephyrocapsa</i>	1.22	1.8		<i>Calcidiscus macintyreii</i>		
<i>Helicosphaera sellii</i>	1.51		2.0			
<i>Calcidiscus macintyreii</i>	1.65	<i>D. brouweri</i>				
<i>Discoaster brouweri</i>						

pelagicus (Wall.) Schill. (up to 10% at a depth of 60 cm bsf), *Rhabdosphaera clavigera* (Murr., Blackm.) Kpt. (from 17.5% at 0 cm to 0% at 80 cm), and *Ceratolithus cristatus* Kpt. (from 8% at 0 cm to 29% at 70 cm). The assemblage is largely composed of small placoliths (up to 34% at the top of the interval). This group of fossils includes the following species: *Umbilicosphaera sibogae* (Weber van Bosse) Gaarder, *U. foliosa* (Lohm.) Geisen, *U. anulus* (Lecal) Young, Geisen, and *Syracosphaera pulchra* Lohm. Since these forms are partly dissolved, they are poorly preserved in sediments (usually as discs lacking the central area) and cannot be used in stratigraphic interpretations. The subordinate components include *Helicosphaera carteri* (Wall.) Kpt. (up to 3%), *Umbellosphaera irregularis* Paasche (2%), and *U. tenuis* (Kpt.) Paasche (1%). The two latter species occur only in the upper part of the interval. Based on the presence of index species *Emiliana huxleyi*, the upper interval (0–85 cm) is attributed to two upper zones of the Gartner's biostratigraphic scale: *Emiliana huxleyi* Acme (interval 0–10 cm) and *Emiliana huxleyi* (10–85 cm). The FO level of *E. huxleyi* is dated back to 0.27 Ma; the sharp abundance of Acme, to 0.07 Ma (Gartner, 1977). According to the Bukry's scale (Okada and Bukry, 1980), this interval corresponds to the *Emiliana huxleyi* Zone (0–0.2 Ma). Sediments from the interval of 85–125 cm lack nannoplanktons and correspond to the lower part of the *Emiliana huxleyi* Zone and upper part of the *Gephyrocapsa oceanica* Zone.

Sediments from depths of 130 and 140 cm lack *Emiliana huxleyi* and *Pseudoemiliana lacunosa* (Kpt.) Gart. Therefore, they can be attributed to the *Gephyrocapsa oceanica* Zone with an age of 0.27–

0.44 Ma (Gartner, 1977) or 0.2–0.9 Ma (Bukry and Okada, 1980). The insignificant thickness of sediments and almost complete absence of coccoliths in them indicate unfavorable bottom conditions and hiatus during the formation of this zone.

At 150–310 cm, the content of coccoliths increases downsection from few to abundant values. Then, they almost complete disappear in underlying sediments. This interval is characterized by the elevated content of *Pseudoemiliana lacunosa* (up to 50% or more). The synonymous zone in the Martini's scale (sensu lato, NN19) corresponds to the entire Late Pleistocene. In the Gartner's scale, the age of this zone (sensu stricto) is 0.44–0.92 Ma. The upper boundary of the zone is drawn at the LO level of the zonal species at 150 cm bsf. This level includes *Calcidiscus macintyreii* (Bukry, Bram.) Loeb. Its abundance increases rapidly downsection from 1% to 10–15% and as much as 34% at the base of the interval. Like in the overlying sediments, the assemblage is mainly composed of small placoliths (30% or more). The lower part (150–230 cm) contains *Gephyrocapsa oceanica* (up to 18%) and two *Umbellosphaera* species. The latter species is restricted to Quaternary sediments. *Coccolithus pelagicus* (Wall.) Schill. is subordinate.

Sediments from 210–340 cm enclose small *Gephyrocapsa* forms. Their taxonomic affiliation is frequently uncertain because of poor preservation. Large representatives of this genus are missing from this interval. The presence of small *Gephyrocapsa* among *Pseudoemiliana lacunosa* accumulations suggests that the interval of 260–325 cm can be attributed to the zone of small

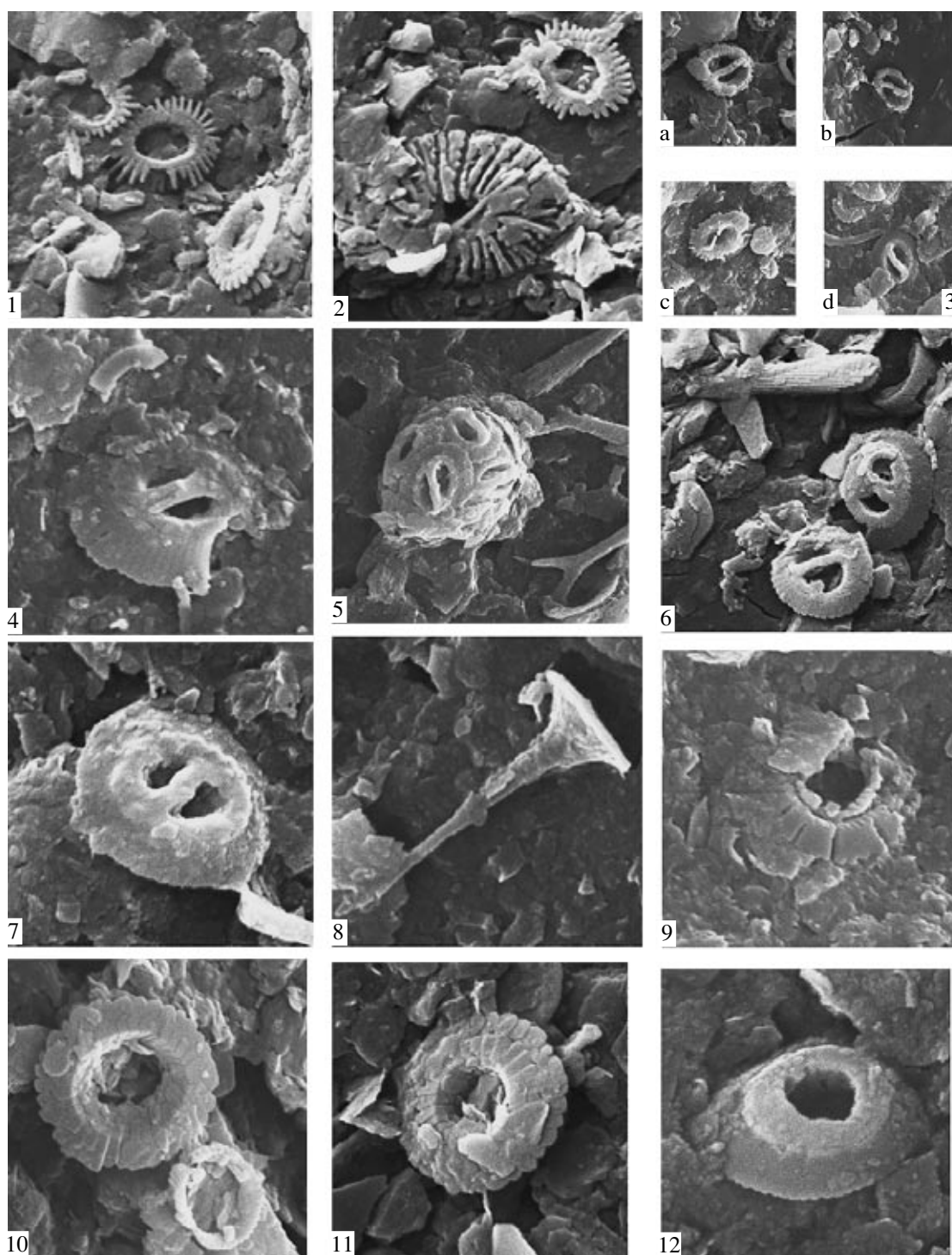


Fig. 4a. Quaternary coccoliths: (1) *Emiliana huxleyi* (Lohm.) Hay, Mohl., $\times 6000$, Station 1535, interval 0–10 cm; (2) the same with *Umbellosphaera tenuis* (Kpt.) Paasche; (3) *Gephyrocapsa* spp.: (a) *Gephyrocapsa sinuosa* Beaudry, Hay, $\times 6000$, Station 1535, interval 215–225 cm, (b) *Gephyrocapsa aperta* Kpt., $\times 6000$, Station 1535, interval 245–255 cm, (c) *Gephyrocapsa* sp., $\times 6000$, Station 1540, interval 300–310 cm, (d) *Gephyrocapsa aperta* Kpt., $\times 6000$, Station 1540, interval 460–470 cm; (4) *Gephyrocapsa oce- anica* Kpt., $\times 6000$, Station 1540, interval 460–470 cm; (5) the same (sphere), $\times 4300$, interval 300–310 cm; (6) *Gephyrocapsa oce- anica* Kpt., $\times 2600$, Station 1535, interval 0–10 cm; (7) the same, $\times 5000$, Station 1540, interval 460–470 cm; (8) *Discosphaera tub- ifera* (Murr., Blackm.) Kpt., $\times 5500$, Station 1540, interval 460–470; (9) *Neosphaera coccolithomorpha* L.-Schlaud., $\times 6000$, Station 1540, interval 300–310 cm; (10) *Umbilicosphaera sibogae* (Weber van Boose) Gaarder, $\times 6000$, Station 1535, interval 185–195 cm; (11) *Umbilicosphaera foliosa* (Lohm.) Geisen, $\times 6000$, Station 1535, interval 145–160 cm; (12) *Reticulofenestra asanoi* Sato, Tak., $\times 6000$, Station 1540, interval 300–310 cm.

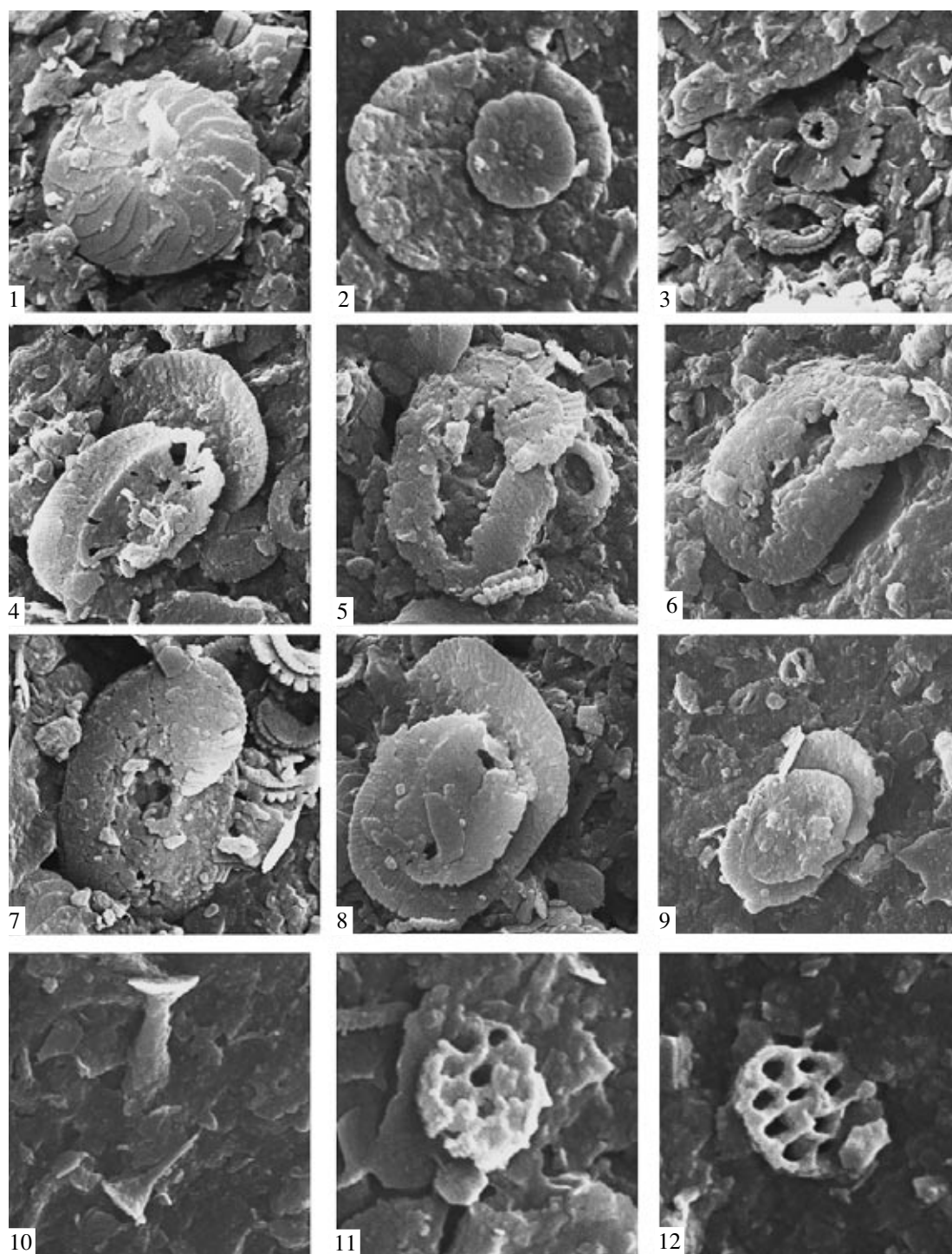


Fig. 4b. Quaternary coccoliths: (1) *Calcidiscus leptoporus* (Murr., Blackm.) Loeb., Tapp., $\times 6000$, Station 1535, interval 0–10 cm; (2) *Oolithothus* (Cohen) Rein., $\times 6000$, Station 1540, interval 460–470 cm; (3) *Umbellosphaera irregularis* Paasche, $\times 6000$, Station 1535, interval 0–10 cm; (4) *Helicosphaera* sp., $\times 3800$, Station 1535, interval 145–160 cm; (5) *Helicosphaera pavimentum* Okada, McIntyre, $\times 4300$, Station 1535, interval 145–160 cm; (6) the same, $\times 4000$, Station 1535, interval 300–310 cm; (7) the same, $\times 4300$, Station 1535, interval 215–225 cm; (8) *Helicosphaera carteri* (Wall.) Kpt., $\times 4300$, Station 1535, interval 215–225 cm; (9) the same, $\times 3000$, Station 1540, interval 460–470 cm; (10) *Rhabdosphaera clavigera* (Murr., Blackm.) Kpt., *Discosphaera tubifera* (Murr., Blackm.) Kpt., $\times 3000$, Station 1540, interval 300–310 cm; (11) *Syracolithus schilleri* (Kpt.) Loeb., Tapp., $\times 8200$, Station 1540, interval 460–470 cm; (12) the same, $\times 7100$.

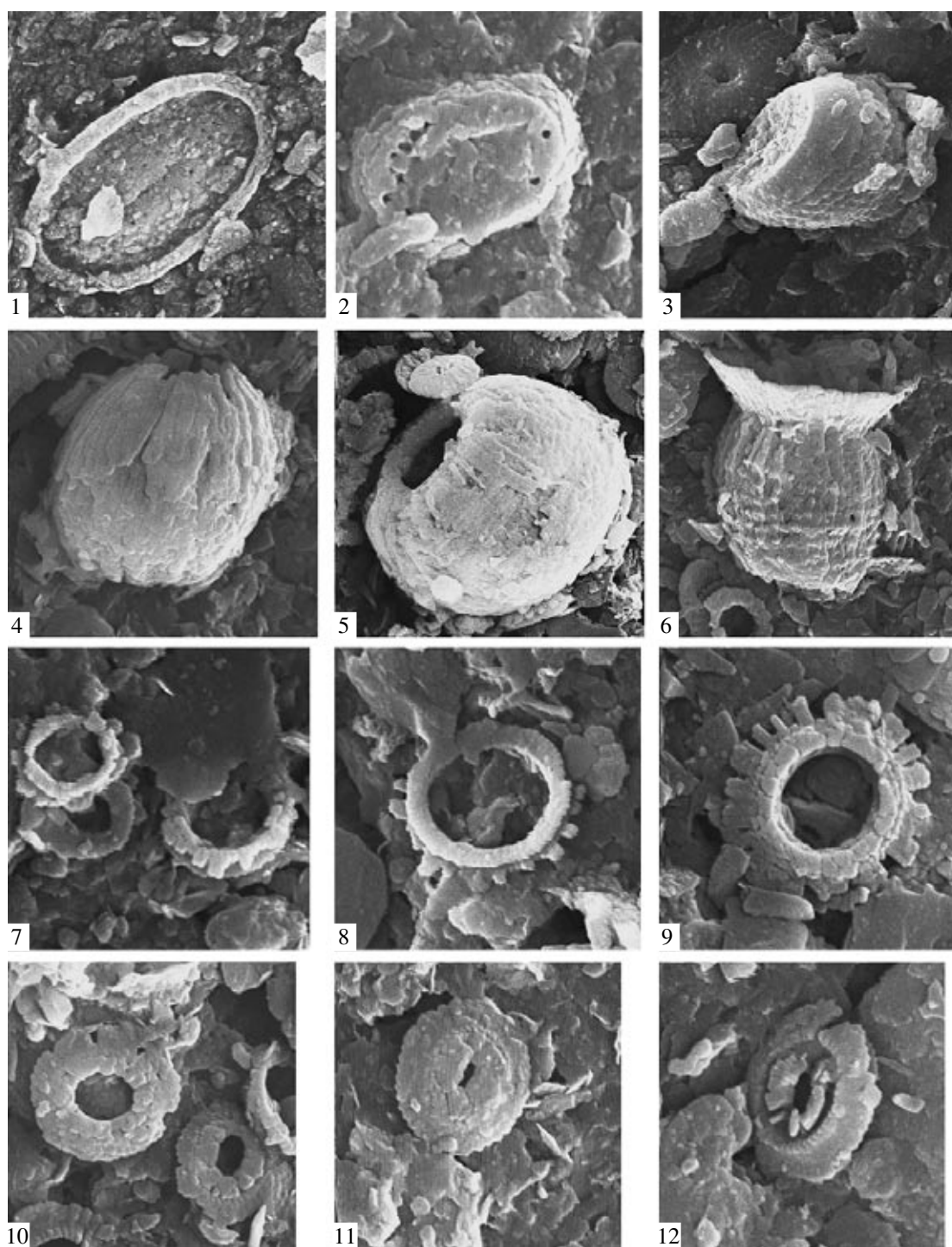


Fig. 4c. Quaternary coccoliths: (1) *Pontosphaera japonica* (Takayama) Nishida, $\times 4000$, Station 1540, interval 300–310 cm; (2) *Pontosphaera multipora* (Kpt.) Roth, $\times 6000$, Station 1540, interval 300–310 cm; (3) *Scyphosphaera recurvata* Defl., $\times 3000$, Station 1540, interval 360–370 cm; (4) *Scyphosphaera globulata* Bukry, Perc., $\times 1600$, Station 1535, interval 185–195 cm; (5) the same, $\times 1300$, Station 1535, interval 215–225 cm; (6) *Scyphosphaera amphora* Defl., $\times 1600$, Station 1535, interval 215–225 cm; (7) *Pseudoemiliana lacunosa* (Kpt.) Gart., $\times 6000$, Station 1535, interval 145–160 cm; (8) the same, interval 185–195 cm; (9) the same, interval 215–225 cm; (10) *Reticulofenestra asanoi* Sato, Takayama, *Reticulofenestra minutula* Roth, $\times 6000$, Station 1535, interval 185–195 cm; (11) *Reticulofenestra minuta* (Gart.) Berggr., $\times 6000$, Station 1535, interval 185–195 cm; (12) *Reticulofenestra minutula* Roth, $\times 6000$, Station 1535, interval 145–160 cm.

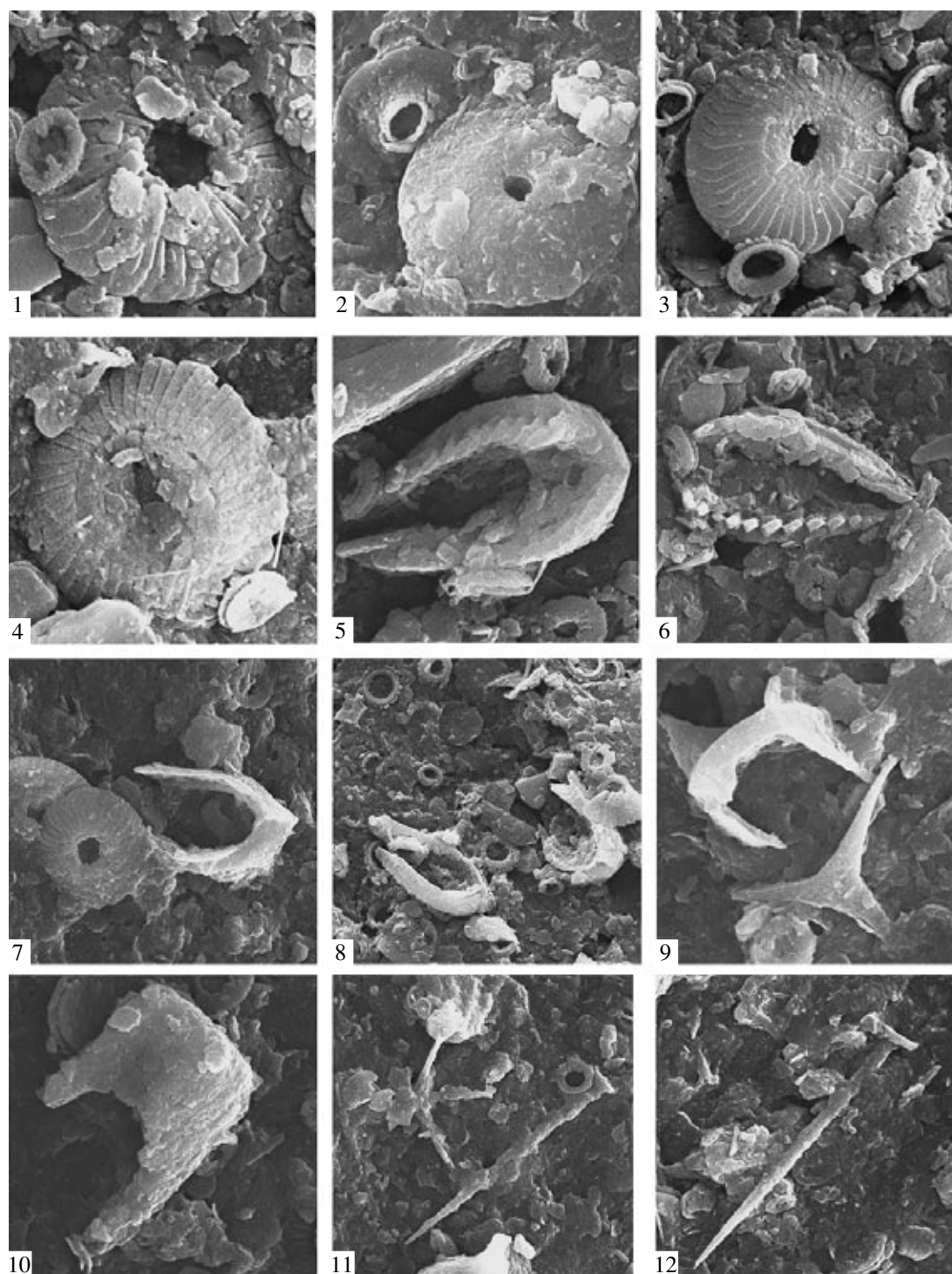


Fig. 5a. Paleogene–Pliocene (reworked) coccoliths: (1) *Calcidiscus macintyreii* (Bukry, Bram.) Loebl., Tapp., $\times 4300$, Station 1535, interval 215–225 cm; (2) the same, $\times 3300$, Station 1540, interval 460–470 cm; (3) the same, $\times 2200$, Station 1535, interval 215–225 cm; (4) *Coccolithus pelagicus* (Wall.) Schill., $\times 4300$, Station 1540, interval 460–470 cm; (5) *Ceratolithus armatus* Müller, $\times 3000$, Station 1535, interval 245–255 cm; (6) the same, $\times 2200$, Station 1535, interval 215–225 cm; (7) the same, $\times 1800$, Station 1535, interval 300–310 cm; (8) the same, $\times 900$, Station 1535, interval 185–195 cm; (9) *Ceratolithus atlanticus* P.-Niels., *Discoaster triradiatus* Tan, $\times 4300$, Station 1540, interval 300–310 cm; (10) *Amaurolithus primus* (Bukry, Perc.) Gart., Bukry, $\times 3000$, Station 1540, interval 460–470 cm; (11) *Blackites tenuis* (Bram., Sull.) Bybbel, $\times 1800$, Station 1540, interval 460–470 cm; (12) the same, $\times 2200$, Station 1540, interval 360–370 cm.

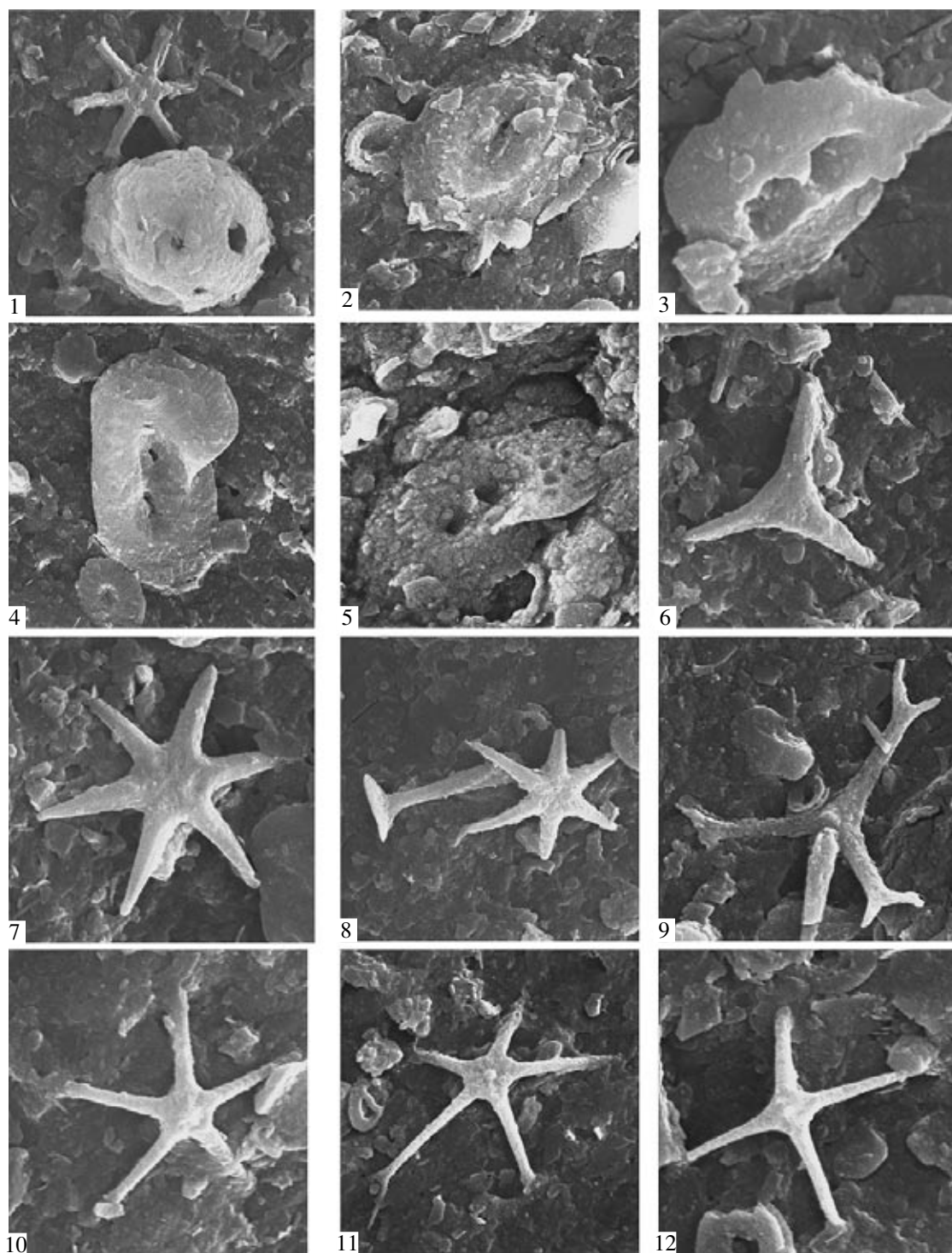


Fig. 5b. Paleogene–Pliocene (reworked) coccoliths: (1) *Reticulofenestra* sp., $\times 2200$, Station 1540, interval 460–470 cm; (2) *Reticulofenestra placomorpha* Achut., Str. $\times 3000$, Station 1540, interval 360–370 cm; (3) *Helicosphaera recta* Haq, $\times 3300$, Station 1540, interval 460–470 cm; (4) *Helicosphaera carteri* (Wall.) Kpt., $\times 4200$, Station 1540, interval 460–470 cm; (5) the same, $\times 4200$, Station 1540, interval 300–310 cm; (6) *Discoaster triradiatus* Tan, $\times 4000$, Station 1535, interval 300–310 cm; (7) the same, $\times 3000$, Station 1540, interval 460–470 cm; (8) *Discoaster brouweri* Tan, $\times 4300$, Station 1535, interval 300–310 cm; (9) the same, $\times 2200$, Station 1540, interval 300–310 cm; (10) *Discoaster pentaradiatus* Tan, $\times 4400$, Station 1540, interval 300–310 cm; (11) the same, $\times 3600$, Station 1540, interval 460–470 cm; (12) *Discoaster tamalis* Kpt., $\times 3900$, Station 1540, interval 460–470 cm.

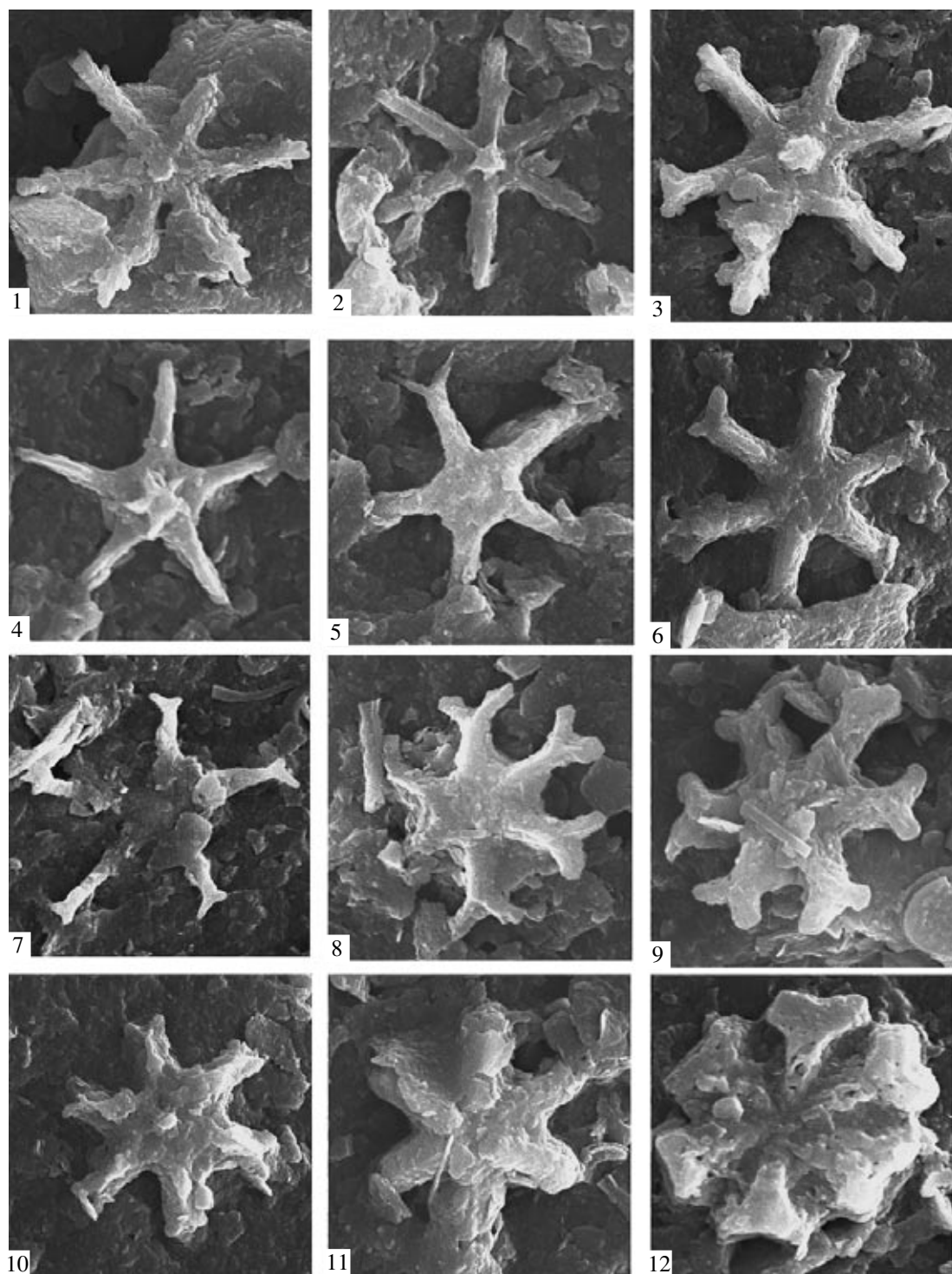


Fig. 5c. Paleogene–Pliocene (reworked) coccoliths: (1) *Discoaster surculus* Mart., Bram., $\times 3000$, Station 1540, interval 250–260 cm; (2) the same, $\times 3600$, Station 1540, interval 300–310 cm; (3) the same, $\times 2200$; (4) *Discoaster quinquedentatus* Gatt., $\times 5000$, Station 1540, interval 300–310 cm; (5) the same; (6) *Discoaster variabilis* Bram., Ried., $\times 3000$, Station 1540, interval 250–260 cm; (7) *Discoaster hamatus* Mart., Bram., $\times 3000$, Station 1540, interval 460–470 cm; (8) *Discoaster divaricatus* Hay, $\times 3600$, Station 1540, interval 460–470 cm; (9) the same, $\times 4900$; (10) *Discoaster kugleri* Hay, $\times 3000$, Station 1540, interval 250–260 cm; (11) *Discoaster* cf. *kugleri* Hay, $\times 3600$, Station 1540, interval 460–470 cm; (12) *Discoaster aulacos* Gatt., $\times 4300$, Station 1540, interval 460–470 cm.

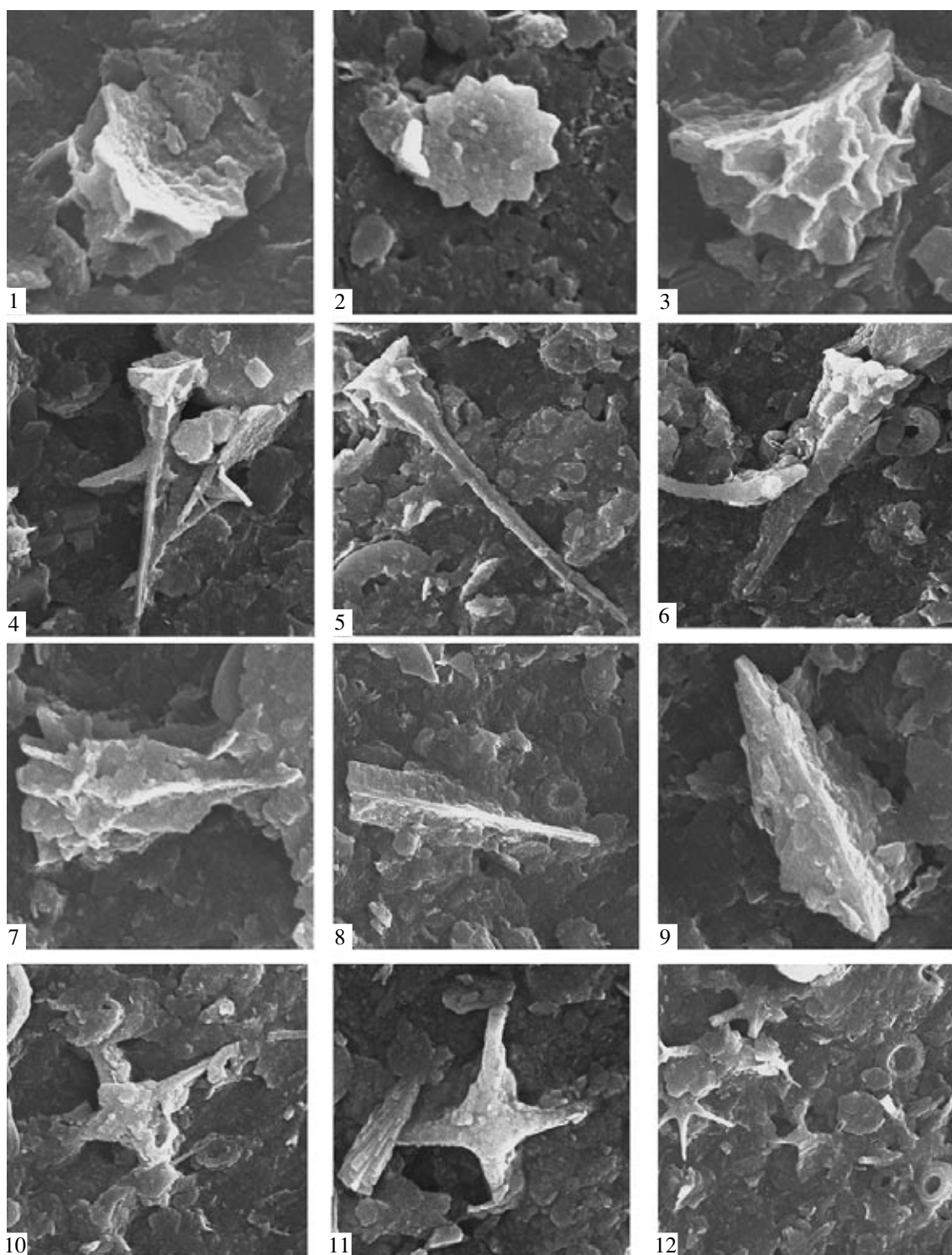


Fig. 5d. Paleogene–Pliocene (reworked) coccoliths: (1) *Sphenolithus moriformis* (Brön., Str.) Bram., Wilc., $\times 6000$, Station 1540, interval 460–470 cm; (2) the same; (3) the same, $\times 5800$; (4) *Sphenolithus heteromorphus* Defl., $\times 3000$, Station 1540, interval 460–470 cm; (5) the same, $\times 3300$; (6) the same, $\times 3800$, Station 1540, interval 300–310 cm; (7) *Sphenolithus radians* Defl., $\times 6000$, Station 1540, interval 300–310 cm; (8) *Triquetrorhabdulus* cf. *carinatus* Mart., $\times 2200$, Station 1540, interval 460–470 cm; (9) *Triquetrorhabdulus rugosus* Bram., Wilc., $\times 4300$, Station 1535, interval 300–310 cm; (10) *Nannotetrina?* (*N. cf. cristata* (Mart.) P.-Niels.), $\times 3600$, Station 1540, interval 460–470 cm; (11) the same, $\times 2200$, Station 1540, interval 300–310 cm; (12) general view of the sample, $\times 1900$, Station 1540, interval 300–310 cm.

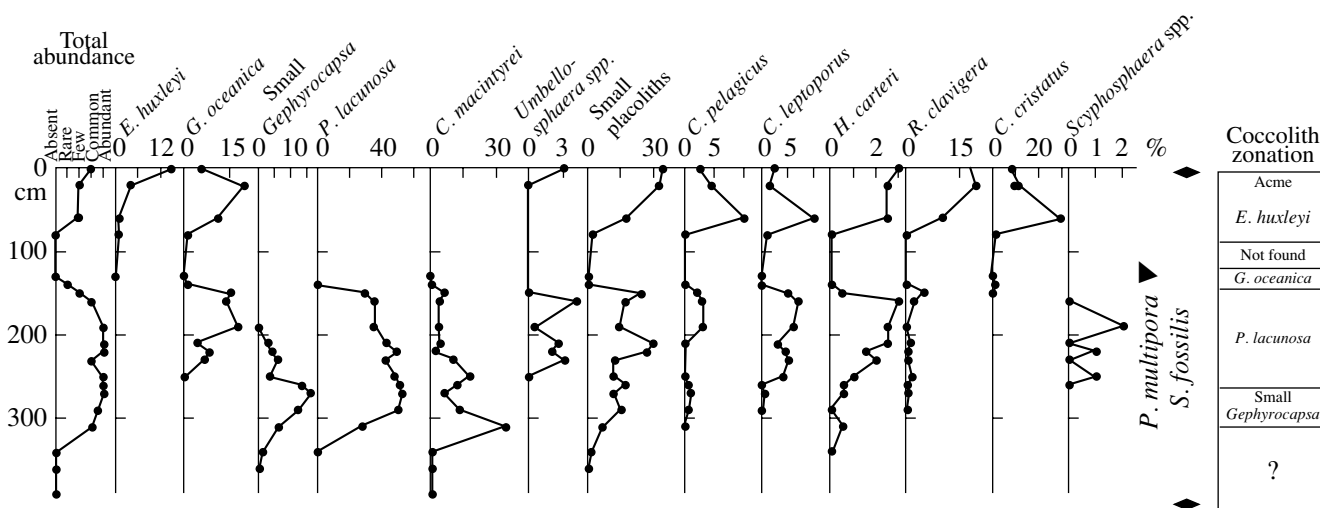


Fig. 6. Distribution of nannoplankton in Core 1535.

Gephyrocapsa in the Gartner's scale (0.92–1.22 Ma). The upper boundary of this zone is determined by the maximum abundance level of small *Gephyrocapsa*.

The lower part of the section (325–395 cm) is virtually barren of nannoplanktons. The sample taken at the depth of 360 cm contains presumably the central part of *Calcidiscus macintyreii*; the sample from the depth of 390 cm, its dissolved fragments.

Reworked species occur throughout the entire section of the core. Most abundant among them are Pliocene *Discoaster* species accompanied by rare and single specimens of Miocene and Paleogene species. In the upper part of the section (0–85 cm), their content amounts to 4.5–9.0% of the total nannoplankton abundance in the corresponding assemblages and increases downward the section (Fig. 7). The species identified among reworked species include Upper Pliocene, Miocene, and Paleogene discoasters: *Discoaster brouweri*, *D. pentaradiatus* Tan, *D. deflandrei* Bram., Ried., *D. tanii* Bram., Ried., *D. mohleri* Bukry, *D. saipanensis* Bram., Ried., and *Reticulofenestra* sp. In the lower part of the section, the abundance of reworked coccoliths increases to 5.5–26.0% of their total quantity. The allochthonous nannoplankton assemblage includes Pliocene, Miocene, and Paleogene species. *Ceratolithus armatus* Müller and *C. atlanticus* P-Niels. (Upper Miocene) are pervasive. In some intervals, Upper Pliocene species *Discoaster brouweri*, *D. pentaradiatus*, and *D. triradiatus* Tan make up large accumulations (up to 17.5% in total). Older species are represented by medium-sized Neogene *Reticulofenestra* forms and large Paleogene *R. umbilica* (Levin) Mart., Ritzk., *R. placomorpha* Achuthan, Str. (up to 7% through the entire section), discrete *Triquetrorhabdulus rugosus* Bram., Wilc., *Discoaster barbadiensis* Tan (mainly at 220–310 cm), and others.

Thus, the core recovered at Station 1535 shows Pleistocene–Holocene sediments corresponding to five Quaternary nannofossil zones (Martini, 1971; Gartner, 1977; Bukry, 1978; Okada and Bukry, 1980): *Emiliania huxleyi* Acme (0–10 cm), *Emiliania huxleyi* (10–85 cm), *Gephyrocapsa oceanica* (125–145 cm), *Pseudoemiliania lacunosa* (145–260 cm), and small *Gephyrocapsa* (260–325 cm). At 85–125 and 325–395 cm, coccoliths are virtually absent. Reworked representatives of the Paleogene–Pliocene *Discoaster*, *Ceratolithus*, *Reticulofenestra*, and other genera occur through the entire section. The average sedimentation rate in this area did not exceed 4 mm/ka.

Station 1536 (22°17.6' S, 24°01.1' W, water depth 5500 m bsl). The 450-cm-long core (Fig. 3) is composed of brown carbonate-free oxidized miopelagic clays (CaCO_3 0.09–0.91%, C_{org} 0.03–0.33%) characteristic of pelagic-type oceanic lithogenesis (Sval'nov, 1991). The clay surface contains a rounded-elongated rugged ferromanganese nodule 8.5 × 3.5 × 2.0 cm in size. The section encloses small nodules 2.3 × 1.5 × 1.1 and 1.4 × 1.0 × 0.8 cm in size (at a depth of 418 and 426 cm, respectively), nodule fragments (at 284, 320, 327, and 448 cm), and rock fragments with iron oxyhydroxides (at 171, 210, and 392 cm). The sediments are composed of clay minerals (80–96%), terrigenous sand- to silt-sized detrital minerals (1–15%), Mn–Fe micronodules (1–4%), and rare siliceous sponge spicules, diatom frustules, radiolarians, bone remains, and zeolites. The age of sediments is unknown.

Station 1537 (19°05.5' S, 24°02.9' W, water depth 5000 m bsl). The 470-cm-long core (Fig. 3) shows oxidized miopelagic clays (interval 0–307 cm) that grade at the interval of 247–307 cm into laminated diatom (*Ethmodiscus*) oozes (307–470 cm). The brown miopelagic clay (CaCO_3 0.09–1.25%, C_{org} 0.05–0.28%) is mainly composed of clay minerals (91–97%). Acces-

sory components are represented by terrigenous detrital sand- to silt-sized minerals (1–5%), diatoms (up to 2%), Mn–Fe micronodules (approximately 1%), single sponge spicules, radiolarians, coccolithophorids, and bone remains. Clays transitional to the underlying *Ethmodiscus* ooze contain small lenses and a substantial admixture of diatoms.

The laminated *Ethmodiscus* ooze (CaCO_3 0.05–0.54%, C_{org} 0.06–0.14%) is characterized by a peculiar clotted consistence. The section shows alternating laminae (3–10 mm thick) with color varying from greenish gray to dark gray and brownish gray. The ooze is largely composed of fragments of giant diatom *Ethmodiscus rex* frustules (71–84%). Clay minerals (10–20%) are usually accompanied by Mn–Fe micronodules (1–15%), sand- to silt-sized grains of terrigenous detrital minerals (up to 20%), radiolarians (1–4%), and occasional sponge spicules.

The *Ethmodiscus* ooze is rather widespread in the equatorial-tropical zone of the South Atlantic (Gardner and Burckle, 1975) and the equatorial belt of siliceous biogenic sedimentation in the Indian and Pacific oceans (Jouse et al., 1959; Sval'nov, 1974). The formation of these sediments is related to the episodic bloom of *Ethmodiscus* species and the subsequent redeposition of their frustules. Their development was maximal in the Late Pleistocene (Sval'nov, 1974, 1981). In the equatorial Atlantic Ocean, peaks of *Ethmodiscus rex* development among Pleistocene sediments coincide with glacial episodes (Gardner and Burckle, 1975).

Thus, Station 1537 area is likely composed of Upper Pleistocene sediments. The presence of thin *Ethmodiscus* ooze interbeds suggests the redeposition of sedimentary material in the axial zone of the Brazil Basin.

Station 1538 (15°52.9' S, 24°04.6' W, water depth 5200 m bsl). The first run of the corer yielded only an angular fragment of basalt (11 × 10 × 8 cm in size) with the ferromanganese crust 2–3 cm thick. The third successful run recovered a 128-cm-long core composed of brown to dark brown miopelagic clays (CaCO_3 0.07–0.32%, C_{org} 0.07–0.14%). At a depth of 45 cm, the core includes an oval ferromanganese nodule 1.8 × 1.7 × 1.5 cm in size (Fig. 3). The sediments are largely composed of clay minerals (91–97%) with sand- to silt-sized terrigenous detrital minerals (1–3%), Mn–Fe micronodules (1–5%), occasional zeolite crystals (phillipsite), and bone fragments. No identifiable microfossils are found. Igneous rocks exposed near Station 1538 could serve as a potential source of nodule nuclei.

Station 1539 (12°41.1' S, 24°02.1' W, water depth 5100 m bsl). The 333-cm-long core recovered in this area is composed of brown to dark brown miopelagic clays (CaCO_3 0.16–0.84%, C_{org} 0.05–0.36%) with occasional fragments of ferromanganese nodules (Fig. 3). Clay minerals (96–98%) are accompanied by sand- to silt-sized terrigenous detrital minerals (1–2%), Mn–Fe micronodules (1–2%), occasional zeolites, fragment of radiolarians, sponge spicules, and bones.

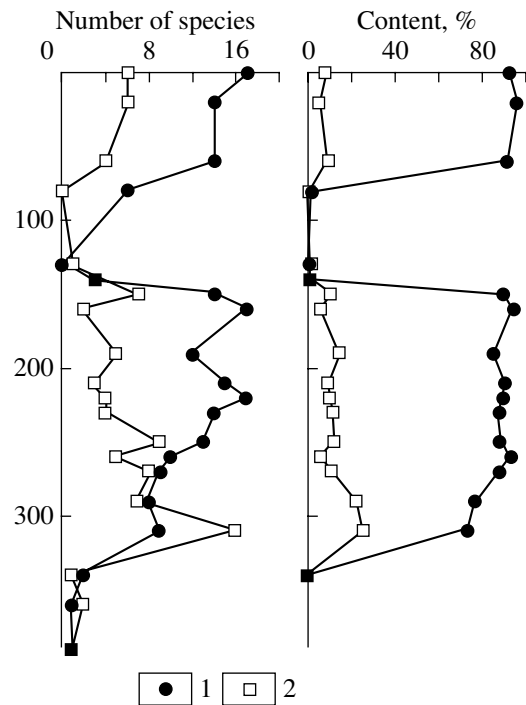


Fig. 7. Proportions of (1) local and (2) reworked coccolith species in Core 1535.

Available microfossils are insufficient for the dating of sediments.

Station 1540 (9°22.4' S, 24°02.1' W, water depth 5500 m bsl). The core recovered here is 510 cm long (Fig. 3). The upper part (0–160 cm) of the core is composed of brown to dark brown miopelagic clays (CaCO_3 0.16–1.00%, C_{org} 0.08–0.35%) with small lenses of grayish yellow hemipelagic clay at the interval of 135–160 cm. They grade downsection into grayish yellow hemipelagic clays (CaCO_3 0.32–0.60%, C_{org} 0.08–0.14%) with small lenses of dark brown miopelagic clays (interval 160–198 cm). The contact with underlying miopelagic clays (interval 198–218 cm) is sharp, uneven. The miopelagic clays are replaced downsection at the interval of 218–260 cm by their yellowish hemipelagic variety (CaCO_3 0.57–7.06%, C_{org} 0.15–0.16%). The lower part (interval 260–510 cm) consists of gray, yellowish gray, beige, and yellow hemipelagic slightly calcareous clays (CaCO_3 17.59–26.49%, C_{org} 0.12–0.40%). Sediments at 418–450 cm contain gray to dark gray small lenses, spots, and stains, as well as thin (1–3 cm) interbeds of clays enriched in iron oxyhydroxides.

Oxidized miopelagic clays at 0–160 and 198–218 cm are composed of clay minerals (91–98%), terrigenous detrital sand- to silt-sized minerals (1–7%), Mn–Fe micronodules (1–3%), and rare bone fragments. Hemipelagic carbonate-free slightly reduced clays at 160–198 and 218–260 cm contain clay minerals (89–97%), terrigenous detrital sand- to silt-sized minerals

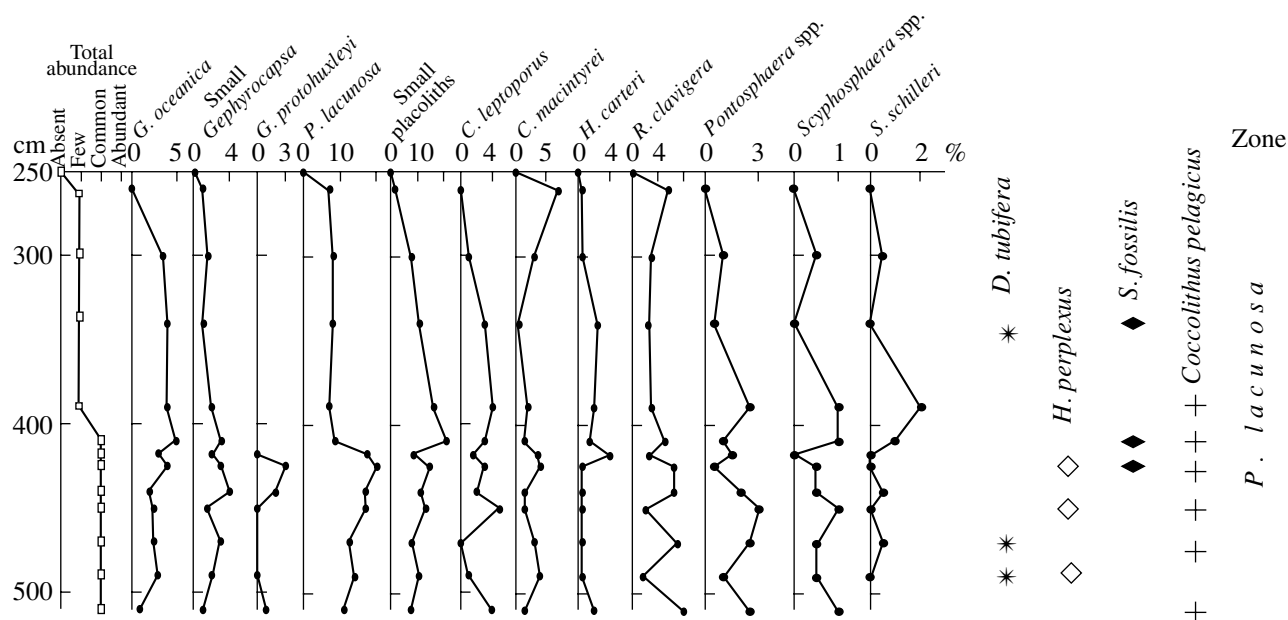


Fig. 8. Distribution of nannoplankton in Core 1540.

(1–2%), coccoliths (up to 10%), occasional fragments of foraminiferal tests, and Mn–Fe micronodules (1–7%). Slightly calcareous hemipelagic clays at the interval of 260–510 cm are composed of clay minerals (71–78%), occasional fragments of foraminiferal tests, and coccoliths (20–27%). The total content of terrigenous detrital sand- to silt-sized minerals and micronodules

does not exceed 4%. Plant remains occur beneath the level of 450 cm.

Coccoliths are absent in the upper part (0–250 cm) of Core 1540. The nannoplankton content is moderate at 250–400 cm and abundant at 400–510 cm (Fig. 8). Cores 1540 and 1535 are similar in the composition of nanofossil assemblages. Core 1540 yielded 8 to 21 Quaternary species and up to 24 reworked species (Fig. 9). *Pseudoemiliania lacunosa* is most abundant among the Quaternary species (7.0–17.5%). All levels contain small *Gephyrocapsa*, *G. oceanica*, *Calcidiscus leptoporus* (up to 3–4%), *C. macintyreii* (up to 7%), *Rhabdosphaera clavigera* (up to 8%), *Helicosphaera carteri*, *Pontosphaera multipora* (Kpt.) Roth, and *P. japonica* Tak. (up to 2%). The total share of small placoliths does not exceed 20%. Other species are characterized by discrete distribution. It should be emphasized that *Gephyrocapsa protohuxleyi* McIntyre and *Discosphaera tubifera* (Murr., Blackm.) Kpt. are confined to the lower part of the section (interval 425–510 cm). The latter species is mostly widespread in Upper Pleistocene sediments of present-day seas. The appearance of *Gephyrocapsa protohuxleyi* in the second half of the Jaramillo Chron corresponding to the *Pseudoemiliania lacunosa* Zone (0.47–1.88 Ma) coincides with the onset of the last glaciation. Coccoliths were also abundant 75–62 ka ago (McIntyre, 1969; Samtleben, 1980). The presence of these two species makes it possible to correlate the entire sequence with the basal Upper Pleistocene. The sediments also include *Hayaster perplexus* (Bram., Ried.) Bukry, *Oolithothus antillarum* (Cohen) Rein., *Scapholithus fossilis* Defl., *Syracolithus schilleri* (Kpt.) Loebli., Tapp., and *Coccolithus pelagicus*. The latter species occurs episodically

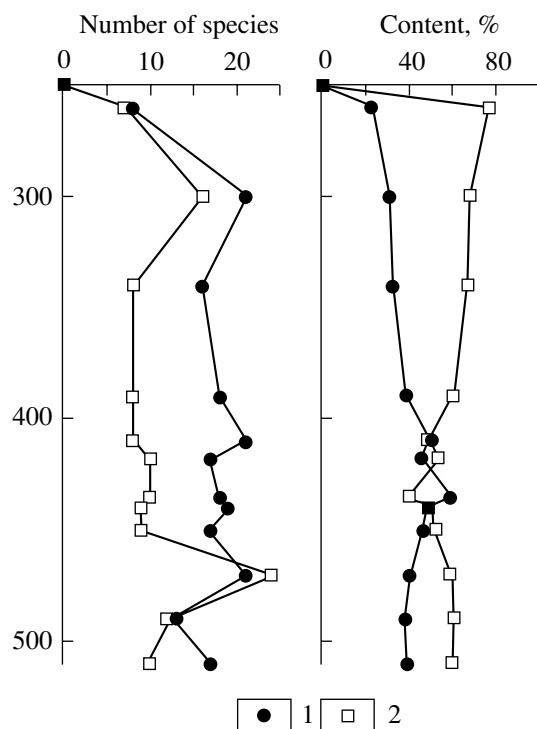


Fig. 9. Proportions of (1) local and (2) reworked nanofossil species in Core 1540.

in the section. This recent species is widespread in Cenozoic sediments, but absent in both surface waters and bottom sediments of the equatorial-tropical zone (McIntyre and Be, 1967). Its presence in Core 1540 is most likely related to the transport from southern regions by the Southern Trade Wind Current.

In Core 1540 (except the interval of 425 cm), reworked species account for 50.0–77.7% of the total abundance of coccoliths (Fig. 9). They are represented by Pliocene, Miocene, and Paleogene species (Fig. 5). For example, *Discoaster brouweri*, *D. tamalis* Kpt., and *D. pentaradiatus* constitute up to 65%. Samples from the depths of 260 and 470 cm are particularly enriched in the reworked species. Their diversity amounts to 24 species at the depth of 470 cm. The share of older coccolithophorids also increases in these samples. In addition to species determined in Core 1535, the coccolithophorids include Miocene *Discoaster quinqueramus* Gart., *D. kugleri* Hay, *D. neohamatus* Bukry, Bram., *D. hamatus* Mart., Bram., Paleogene *D. multiradiatus*, *Blackites tenuis* (Bram., Sull.) Bybell, *Chiasmolithus* sp., and others. Such a significant input of older coccoliths is probably related to their transport by both the Southern Trade Wind Current and mudflows from the South Atlantic mid-ocean ridge. Intense redeposition of Pleistocene and Paleogene–Pliocene coccolithophorids is indicated by their preservation in deep zones 1000 m below the CCD level, which is located at 4500–4600 m bsl in this area (Lisitsyn, 1978).

Thus, Core 1540 has recovered the basal Upper Pleistocene sediments. Sharp boundaries between layers suggest the redeposition of not only coccoliths, but also differently reduced hemipelagic clays. The clays could be displaced by mudflows and slumps from the western margin of the South Atlantic.

Station 1541 (6°10.8' S, 24°01.1' W, water depth 5800 m bsl). The 124-cm-long core is composed of brown miopelagic clays (Fig. 3) without identifiable biogenic remains (CaCO_3 0.05–0.25%, C_{org} 0.05–0.13%). The sediment surface includes a ferromanganese nodule (11.5 × 8.5 × 6.0 cm in size) with several nuclei. Smaller nodules (up to 4.5 × 3.0 × 0.7 cm) were found at 83, 87, 92, 99, 110, and 124 cm. Small (probably, reworked) fragments are also present at 20, 35, 56, and 87 cm. The sediments are composed of clay minerals (93–98%), terrigenous detrital minerals (2–4%), Mn–Fe micronodules (up to 2%), and occasional phillipsite crystals, bone fragments, radiolarians, and siliceous sponge spicules.

Station 1542 (2°59.1' S, 24°01.2' W, water depth 5500 m bsl). The recovered core is 478 cm long (Fig. 3). The upper part (0–15 cm) consists of dark brownish gray siliceous–clayey (diatomaceous–radiolarian–clayey) sediments (CaCO_3 1.00–1.57%, C_{org} 0.46–0.50%) that grade downsection into the variegated hemipelagic carbonate-free clays (interval 15–478 cm) enriched in radiolarians and diatoms (CaCO_3 0.16–6.40%, C_{org} 0.19–0.55%). The interval of 30–

80 cm contains a slightly calcareous variety (CaCO_3 16.19–30.89%, C_{org} 0.39–0.60%) of these clays. The general color of sediments varies from gray to beige and light brown. They include numerous gray and dark gray bands, lenses, and spots.

The siliceous–clayey mud is composed of clay minerals (52–55%), diatoms (20–23%), radiolarians (up to 25%). Fragments of foraminiferal tests, sand- to silt-sized terrigenous mineral grains and Mn–Fe micronodules are found in some places. The carbonate-free hemipelagic clay also consists of clay minerals (67–87%), radiolarians (2–25%), diatoms (2–10%). Sponge spicules, terrigenous detrital minerals, and micronodules are subordinate. The content of micronodules increases to 5–20% at some levels. Fragments of foraminiferal tests are episodic (up to 7%). Low-carbonate hemipelagic clays (clay minerals up to 61–66%) contain foraminifers (15–20%), radiolarians (10–15%), diatoms (3–7%), and micronodules 1%. Sand- to silt-sized grains of terrigenous detrital minerals are occasional.

Results of the micropaleontological study show that sediments of Core 1542 (0–478 cm) are characterized by not only the abundance of diatoms, but also their taxonomic diversity. In total, more than 50 tropical species typical of the studied Atlantic sector have been identified in the entire section. The most abundant species are as follows: *Azpeitia nodulifer*, *Rhizosolenia alata*, *Rh. styliformis*, *Hemidiscus cuneiformis*, *Nitzschia marina*, *N. interrupta*, *Thalassiosira lineata*, *Th. eccentrica*, *Planktonella sol*, *Pseudotriceratium cinnamomeum*, *Pseudoeunotia doliolus*, and others. The sediments also include occasional valves of freshwater species *Aulacoseira* spp., which were probably brought by winds.

According to the diatom zonation (Barron, 1985) based on recent views on the stratigraphic distribution of diatoms in sediments of the Atlantic tropical realm, the entire section of Core 1542 (0–478 cm) corresponds to the Pleistocene *Pseudoeunotia doliolus* Zone. The abundance of specimens of the zonal species *Pseudoeunotia doliolus* and the simultaneous absence of other stratigraphically significant species, such as *Nitzschia reinholdii* and *N. fossilis*, which occur here in sediments older than 700 ka allows us to conclude that sediments of the interval of 0–478 cm accumulated in the course of the recent 700 ka.

Thus, Core 1542 recovered Pleistocene hemipelagic sediments that are typical of oceanic lithogenesis of the near-continental type (Sval'nov, 1991). Small fragments of foraminiferal tests found in these sediments are probably reworked from a depth of 5500 m. The average sedimentation rate in this area amounts to 6.8 mm/ka.

Station 1543 (0°09.7' S, 23°58.1' W, water depth 3400 m bsl). The third run of the corer recovered an average sample (approximately 10 cm long monolith) of white to light gray and beige coccolith–foraminiferal

sediments (CaCO_3 67.03%, C_{org} 0.16%) composed of foraminifers (45–50%), coccoliths (22–30%), clay minerals (25–28%), and occasional tropical diatoms, radiolarians, and sand- to silt-sized grains of terrigenous minerals.

The data obtained indicate that the meridional transect across the axial zone of the Brazil Basin recovered Pleistocene–Holocene sediments composed of oxidized miopelagic clays, differently reduced hemipelagic clays, and carbonate (coccolith–foraminiferal) and clayey–siliceous (*Ethmodiscus*) sediments. Some cores enclose ferromanganese nodules, their fragments, detrital altered rocks (Fig. 3). The examined cores lack eupelagic clays typical of pelagic lithogenesis in the Indian and Pacific oceans (Sval'nov, 1991).

Miopelagic clays, which contain ferromanganese micro- and macronodules, bone detritus, and occasional crystals of authigenic zeolite (phillipsite), are most widespread. In some places, they are enriched in diatoms, foraminifers, and coccoliths up to the formation of clayey–calcareous sediments. The carbonate-free hemipelagic clays are supplemented with slightly calcareous varieties and sediments enriched radiolarians and diatoms. Judging from sharp interfaces in the section and the present-day water depth (5500 m), hemipelagic clays and coccoliths at Station 1540 are probably reworked. Reworked fragments of foraminiferal tests occur at Station 1542. Features indicating the redistribution of sedimentary material by bottom currents, mudflows, and slumps are observed in the lower part of Core 1537 composed of *Ethmodiscus* (diatom) oozes. In addition, some cores contain fragments of altered bedrocks and ferromanganese nodules. It is conceivable that similar rocks are exposed at the bottom near Station 1538.

Erosion and redeposition of sedimentary material are probably typical processes in western areas of the South Atlantic. The study of nannoplanktons from deep-sea drilling cores (Fig. 3) indicates that Quaternary sediments are not always preserved in this area, and hiatuses are rather common. For example, the section of DSDP Hole 355 (water depth 4896 m bsl) drilled in the western part of the Brazil Basin lack Quaternary sediments (Perch-Nielsen, 1977). Pliocene sediments are also eroded. The section recovered by DSDP Hole 21 (water depth 2113 m bsl) is crowned by the Upper Pliocene *Discoaster brouweri* Zone. In Hole 22 (water depth 2134 m bsl), the upper part of the section corresponds to the Lower Pleistocene (*Crenolithus doronicoides* Zone) and Upper Pliocene (*Discoaster brouweri* Zone). The latter is underlain with hiatus by basal Miocene sediments (Bukry, 1970). The section of Hole 356 (water depth 3203 m bsl) drilled in the Sao Paulo Plateau contains only the Upper Quaternary *Emiliana huxleyi* nannofossil zone. The basal Upper Pleistocene, Lower Pleistocene, and upper zone of the Upper Pliocene are eroded. The section of Hole 357 (Rio Grande Rise, water depth 2109 m bsl) lacks Upper

Pleistocene–Holocene sediments. The section contains only the Lower Pleistocene *Pseudoemiliana lacunosa* Zone underlain by Upper Pliocene sediments without the uppermost zone (Perch-Nielsen, 1977). The continuous Quaternary section, which includes all Quaternary coccolith zones of tropical scales (Martini, 1971; Gartner, 1977; Bukry, 1978), was penetrated by DSDP Hole 516 (water depth 1313 m bsl) on the Rio Grande Rise (Barker et al., 1983; Dmitrenko, 1987).

Clay minerals in cores recovered by DSDP holes and Quaternary sediments in cores up to 10 m long recovered by piston corer from a depth of 4468–6181 m bsl in the western South Atlantic are scrutinized in (Zimmerman, 1977). The results show that the Antarctic bottom water is not the major transporter of sedimentary material from the Antarctic region to the Argentine Basin. Moreover, the transport of sedimentary material by the Antarctic water from the Argentine Basin to the Brazil basin plays an insignificant role in the distribution of clay minerals.

Variations in proportions of clay minerals in Quaternary sediments of the examined cores are insignificant. Illite is observed in all cores. In the equatorial areas, illite is accompanied by kaolinite and smectites. At higher latitudes, illite is dominant, but its particle size is substantially smaller. The content of the clayey component is also lower than in equatorial areas. Kaolinite prevails at low latitudes and decreases toward higher southern latitudes. Chlorites demonstrate an opposite distribution pattern. The Rio Grande Rise serves as the transitional zone between the smectite-rich Brazil Basin and the smectite-poor Argentine Basin.

The South Atlantic region is characterized by two contrasting (oceanic and continental) mineral associations (Zimmerman, 1977). The oceanic association includes smectites and zeolites, while the continental association is composed of illite with variable contents of kaolinite and chlorite. The smectite–zeolite association of the Brazil Basin largely consists of volcanogenic material from the South Atlantic Ridge and Rio Grande Rise. South America is the main source of clay minerals for the continental association. When passing from the equator toward higher latitudes, chemical weathering is gradually replaced by the physical one, resulting in reduction of the share of kaolinite in sediments and increase of illite and chlorite concentrations in this direction. A small amount of the finest illite fractions is transported to the Brazil Basin by bottom waters from the Antarctic region.

Thus, the flow of cold Antarctic bottom waters into the Brazil Basin via the Argentine Basin and Vima and Hunter channels is one of the factors responsible for the redeposition of sedimentary material in the western South Atlantic. The combination of anticyclonic surface circulation and the northward flow of Antarctic bottom waters are responsible for specific features of Quaternary sedimentation in the axial part of the basin. As might be expected, miopelagic clays are developed

in deep areas, while calcareous oozes are developed above the CCD level. The Brazil Basin demonstrates hemipelagic-to-miopelagic transitional sediments, i.e., replacement of oceanic lithogenesis of the near-continental type by the incomplete pelagic (miopelagic) variety (Sval'nov, 1991). The presence of *Ethmodiscus* oozes at Station 1537 confirms the abundance of such sediments in the equatorial-tropical zone of the South Atlantic (including the Brazil Basin). This was noted in previous studies south of 5° N (Gardner and Burckle, 1975). Pleistocene glacial episodes were favorable for the bloom of giant diatom species *Ethmodiscus rex*, while the *Ethmodiscus* ooze formed in the course of multiple redepositions of its valves (Wiseman and Hendey, 1953; Sval'nov, 1974; Gardner and Burckle, 1975).

CONCLUSIONS

Oxidized miopelagic clays (C_{org} 0.03–0.36%), which commonly enclose ferromanganese nodules and their fragments, are dominant along the meridional profile across the axial zone of the Brazil Basin. Differently reduced hemipelagic, locally reworked clays (C_{org} 0.08–0.60%) are developed in the zone transitional to oceanic lithogenesis of the near-continental type. Calcareous (coccolith-foraminiferal) sediments occur above the CCD level.

The Brazil Basin is characterized by the local formation of thin-laminated *Ethmodiscus* (diatom) oozes, their erosion, and redistribution of sedimentary material. Principal agents responsible for the redeposition are cold Antarctic bottom waters and different-scale mudflows, underwater rockslides, and slumps. Bottom currents erode the seafloor and transport the suspended material to the north. Mudflows foster the preservation of calcareous nannoplankton remains and foraminiferal tests even in zones located significantly below the CCD level and the formation of *Ethmodiscus* oozes. Slumps and rockslides are responsible for the redeposition of large masses of older sediments and the supply of bed-rock fragments that serve as potential nuclei for ferromanganese nodules.

The South Atlantic mid-ocean ridge serves as a source of endogenic matter that participates in sedimentary processes in the Brazil Basin and restricts the eastward transport of terrigenous sedimentary material. The miopelagic type of oceanic lithogenesis in the axial zone of the basin is largely related to the anticyclonic circulation of surface currents, which implies unfavorable conditions for biota development.

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