

2. REWORKED AND REDEPOSITED LARGER FORAMINIFERS ON SLOPES AND IN BASINS OF THE BAHAMAS, LEG 101¹

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ABSTRACT

Larger shallow-water benthic foraminifers, along with planktonic foraminifers and calcareous nannofossils, occurred in turbidites and debris flows of the slopes and basins of the Bahamas. Studies of larger foraminifers can increase our understanding of platform flanks and their response to fluctuations in sea level, one of the main objectives of Leg 101. Some of these late Campanian to Pleistocene larger foraminifers were redeposited; others were reworked. These larger foraminifers lived in water depths of less than 130 m in the back- and fore-reef environments of Florida and the Bahamas. They were deposited in slopes and basins by turbidite and debris flow mechanisms. Larger foraminifers were absent on the upper slope but were present on the lower part of the slope and in the basin. The paleoecology of these foraminifers permits reconstruction of the source area of the redeposited platform material in the turbidites and debris flows. The allochthonous larger foraminifers are found mostly in the Pleistocene, Pliocene, middle and lower Miocene, Oligocene, and Campanian.

The occurrence of redeposited larger foraminifers seems to be linked to changes in sea level, while the occurrence of reworked larger foraminifers in the middle Miocene and Campanian appears related to tectonic events.

INTRODUCTION

Leg 101 of the Ocean Drilling Program had two scientific objectives: (1) to explain the modern configuration of the shallow carbonate platform of the Bahamas and the deep basins that incise it, such as the Straits of Florida, Exuma Sound, and Northeast Providence Channel (Fig. 1); and (2) "the study of platform flanks, their facies patterns and their response to sea level fluctuations that entail flooding and exposure of the bank" (Shipboard Scientific Party, 1985a). Investigation of reworked and redeposited larger foraminifers in Campanian to Quaternary turbidites and debris flows from Leg 101 can contribute to the second objective.

Two 3-hole transects were cored during Leg 101 to study platform flanks (Fig. 1). One transect was on an "accretionary" (gentle, 2°–3°) slope north of Little Bahama Bank (Sites 627, 628, and 630), and the other was on a "bypass" (steep, 10°–12°) slope, in Exuma Sound (Sites 631, 632, and 633). Other sites occupied during Leg 101 were in deep basins in the Straits of Florida (Site 626) and in the Northeast Providence Channel (Sites 634, 635, and 636).

Study of cores from the deep basins and slopes of the Bahamas (Shipboard Scientific Party, 1986) revealed the occurrence of allochthonous larger foraminifers in the Campanian to Quaternary sediments. Here, we present a detailed investigation of these larger foraminifers recovered during Leg 101.

The present array of banks and basins (Fig. 1) is the result of drowning, during latest Albian–early Cenomanian time, of a shallow-water platform in the northern part of the Straits of Florida and the southern part of the Blake Plateau, where ocean currents have eroded deep troughs (Shipboard Scientific Party, 1985a). Results of Leg 101 (Shipboard Scientific Party, 1986) in-

dicated that uppermost Albian to Holocene deep-water sediments occurred in the Straits of Florida, identified in part by seismic profiles near Site 626, Blake Plateau (Site 627), and Northeast Providence Channel (Sites 634 and 635). In contrast, Great Bahama Bank, Little Bahama Bank, and South Florida are underlain by a thick sequence of Upper Jurassic–Pleistocene shallow-water platform carbonates, known by data from many subsurface wells (Tator and Hatfield, 1975) and by submersible studies (Freeman-Lynde et al., 1981).

The larger shallow-water platform foraminifers, associated with planktonic foraminifers and calcareous nannofossils, evidently were transported by debris flows and turbidites from the carbonate platforms of Florida, Great Bahama Bank, or Little Bahama Bank. Such composite assemblages of late Oligocene and Campanian age were described by Akers (1972) and by Hottinger (1972) in the Northeast Providence Channel at DSDP Site 98 (Shipboard Scientific Party, 1972). Recently, Butterlin and Moulade (1983) also reported a similar mixed fauna of early to middle Miocene age in the Blake–Bahama Basin at DSDP Site 391 (Benson, Sheridan, et al., 1978) and of early Miocene age at DSDP Site 534 (Sheridan, Gradstein, et al. 1983) (Fig. 1), where larger foraminifers of Paleogene and Late Cretaceous age were reworked in sediments with early and middle Miocene planktonic foraminifers in the Great Abaco Member of the Blake Ridge Formation (Bliefnick et al., 1983).

Results from Leg 101 demonstrated the importance of turbidites and debris flows in carbonate slope sedimentation. However, only a few cores with turbidites and debris flows contained larger foraminifers. These microfossils, whose paleoecology is well known, can identify the provenance of the turbidites, although it is important to determine whether the larger foraminifers were penecontemporaneously redeposited or were reworked a long time after fossilization. It is also important to know if redeposited larger foraminifers were particularly abundant at certain levels and if such occurrences can be linked to fluctuations in sea level or to tectonic events. Finally, for redeposited larger foraminifers, their association with planktonic foraminifers and calcareous nannofossils can allow us to correlate between the different zonations. However, one must use these correlations

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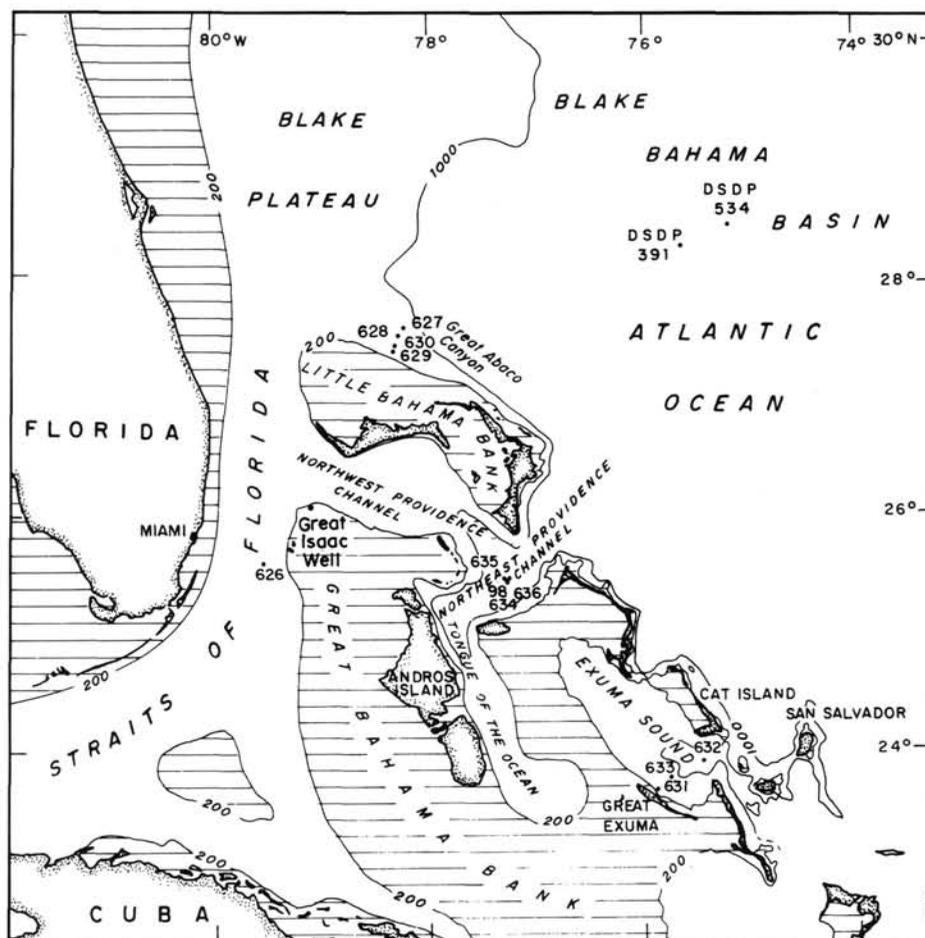


Figure 1. Location of Leg 101 sites in the Bahamas and DSDP Sites 98, 391, and 534.

cautiously, as reworking of larger foraminifers sometimes is suspected when they are associated, as in this case, with planktonic and calcareous nannofossils in turbidites.

METHODOLOGY

On the average, four samples per core were studied, when core recovery allowed it. Each 10-cm³ sample of unconsolidated sediment was boiled with Calgon and wet-sieved using two sieves having 50- and 125- μ m mesh. Only a fraction > 125 μ m was examined. The larger foraminifers (> 1 mm in size) were mounted on a glass slide with araldite and polished to obtain the required section. The foraminifer then was turned over and remounted with Canada Balsam and polished with grinding powder (Emery 800) under a binocular microscope. The larger foraminifers from cherts and lithified grainstone or boundstone were studied in thin sections.

These larger foraminifers generally were well preserved but occasionally were broken or abraded. Because of test thickness, and possibly the presence of pillars, subepidermal partitions, and/or lateral chambers, larger foraminifers have a test that strongly resists abrasion, winnowing, and erosion, which favors their presence in turbidites and debris flows. Nevertheless, the larger foraminifers redeposited in slopes and basins do not correspond exactly to the assemblage found in the source area because some of these foraminifers had a fragile test (i.e., *Sorites*) and were disaggregated while transported downslope.

All larger foraminifers found in the unconsolidated sediments of Leg 101 displayed empty chambers and no cement coating in chamber cavities or in embryonic chambers. Only the reworked *Dictyoconus* displayed evidence of crystalline calcite growth in their chambers before reworking.

LARGER FORAMINIFERS OF LEG 101

Deep Basins: Straits of Florida

Site 626 (846 m water depth)

Four holes were drilled at Site 626, and a 447-m-thick Pleistocene to late Oligocene section of winnowed and unconsolidated sediments was recovered. These sediments consisted of skeletal grainstone/packstone having planktonic foraminifers, neritic biota, and lithoclasts. An interval of debris flows from the middle Miocene (Cores 101-626C-15H through 101-626C-18H, *Globorotalia fohsi fohsi* Zone, N10/N11 part) was recognized (Shipboard Scientific Party, 1986).

The distribution of larger foraminifers (Fig. 2) in Holes 626B through 626D in the Pleistocene and from the *Praeorbulina glomerosa* Zone (N8 part/N9) of middle Miocene age to the *Globigerina ciperoensis* Zone (P22) of late Oligocene age corresponds to their known stratigraphic range. Therefore, they can be considered as having been redeposited from a shallower part of the platform to the basin. For example, the range of *Lepidocyclina* (*Nephrolepidina*) cf. *dartonia* (Pl. 5, Fig. 5) is lower Oligocene to lower Miocene, up to the base of Zone N5 (Butterlin, 1984). Only *Dictyoconus floridanus* from Section 101-626A-2, CC (Pleistocene, planktonic foraminifer Zone N22/N23), unknown above the Eocene, was undoubtedly reworked.

Broeckina discoidea (Pl. 4, Fig. 4), which has been reported only from the Holocene, appears in the lower Miocene, proba-

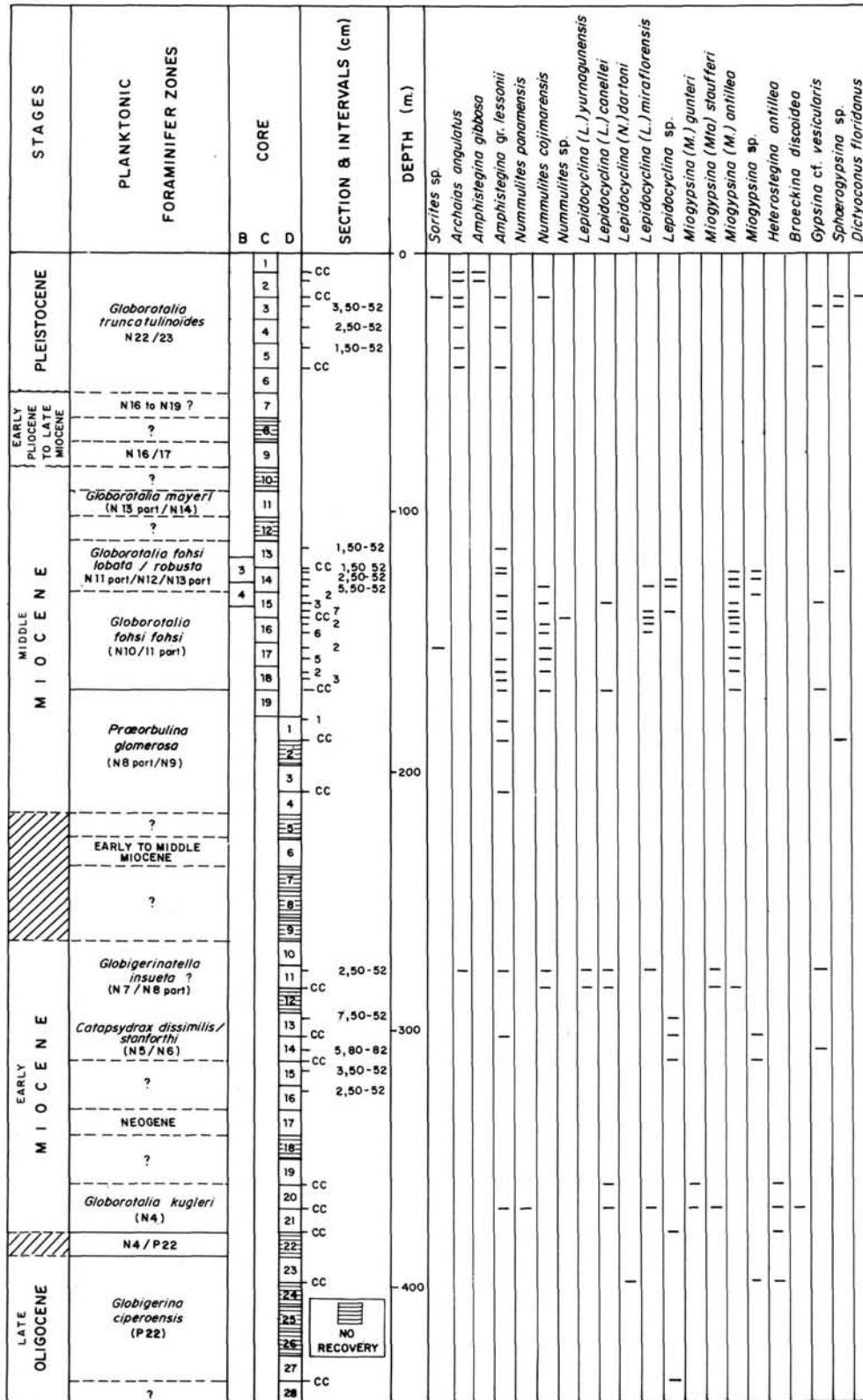


Figure 2. Occurrence of redeposited and reworked larger foraminifers from upper Oligocene to Pleistocene at Site 626 (Holes 626B, 626C, and 626D).

bly a result of downhole contamination. If *Miogypsina* (*Miogypsina*) *staufferi* (Pl. 3, Fig. 3) does not occur as a result of downhole contamination, its first appearance here is in Zone N4 instead of in Zone N5? or Zone N6, as previously reported (Cole and Applin, 1961). Otherwise, the larger foraminifers from the debris flow interval of the middle Miocene (planktonic foraminifer Zone N10/N11 part) clearly were reworked. Indeed, *Miogypsina* (*Miogypsina*) *antillea* (Pl. 4, Figs. 1–3) s.s. Drooger, 1952 (not Cole 1964, 1967, whose synonymy places this species with all *Miogypsina* having two primary auxiliary chambers) is known to occur in the lower Miocene and the base of the middle Miocene Zone N8 (Andreieff, 1985; Westercamp et al., 1985). *Lepidocyclina* (*L.*) *canellei* and *L.* (*L.*) *miraflorensis* from the debris flow interval were also reworked because no American *Lepidocyclina* has yet been confidently recognized above the lower Miocene.

Northeast Providence Channel

Site 634 (2835 m water depth)

This site was a reoccupation of DSDP Site 98 (Shipboard Scientific Party, 1972). The upper 144 m of the hole was washed; thus, no samples are available from that interval (Pliocene to lower Eocene). Akers (1972) identified the following upper Oligocene (nannofossil Zone NP25) species: *Heterostegina antillea*, *Miogypsina panamensis*, *Lepidocyclina* (*L.*) *canellei*, and *Camerina* (= *Nummulites*) cf. *C. panamensis* from Section 11-98-5, CC. Hottinger (1972) found *Pseudorbitoides israelskyi* and *Orbitoides tissoti* in the Campanian at DSDP Site 98.

Section 101-634A-6R, CC contains *Torreina torrei* and *Sulcorbitoides* sp.; 101-634A-8R, CC contains *Pseudorbitoides* sp., and 101-634A-1R, CC contains *Cuneolina* sp., *Sulcorbitoides pardoi*, and *Sulcoperculina vermunti*. These larger foraminifers from a fore-reef environment of Campanian–Maestrichtian age occur in pieces of shallow limestone intercalated with chalk that contains Campanian *Globotruncana*. These shallow Campanian limestones with *Pseudorbitoides* and *Orbitoides* probably were derived from the submarine erosion of lithified limestone from a fore-reef escarpment of the Great Bahama platform and have been reworked subsequently in the deep basin.

Site 635 (3459 m water depth)

This site, like Site 634, is near DSDP Site 98 but is in deeper water. Pleistocene ooze and platform grainstone from this site contain *Archaias angulatus*, redeposited from the shallowest part of Great Bahama Bank (<20 m depth).

Site 636 (3573 m water depth)

Only two pieces of shallow limestone were recovered at this site. These contain a Neogene assemblage with *Archaias angulatus* and *Sorites* sp. (Sections 101-636A-1R, CC and 101-636A-2R, CC). These larger foraminifers came from the shallowest part of the Great Bahama Bank and were reworked by gravity flows into the deep basin of Northeast Providence Channel.

Transect of an “Accretionary” (gentle, 2°–3°) Slope, North of Little Bahama Bank

Site 627 (1028 m water depth)

Hole 627B was cored on the distal lower slope north of Little Bahama Bank (Blake Plateau). The stratigraphic succession consists of periplatform ooze/chalk with turbidites, debris flows, slumps (Quaternary to Miocene), siliceous limestone and chert (Eocene), and argillaceous carbonate ooze (Paleocene) (Shipboard Scientific Party, 1986). Drilling ended in shallow-water carbonates and evaporites of late Albian age. Much of the recovered sediment does not contain larger foraminifers, although

a few occur with planktonic foraminifers and calcareous nannofossils in the Pleistocene, middle Miocene, and lower Miocene (Fig. 3).

Archaias angulatus is known to have occurred from the Oligocene to Holocene and to have lived at a depth of <20 m; here, the species was redeposited in basinal sediments. Other larger foraminifers in the assemblage appear to have been redeposited, except for *Lepidocyclina* (*L.*) *yurnagunensis*, which was certainly reworked as its normal stratigraphic range is older than planktonic foraminifer Zone N8, and *Miogypsina antillea*, from Sample 101-627B-14H-5, 80–82 cm (Zone N10/N11), which normally becomes extinct in Zone N8.

Site 628 (966 m water depth)

This middle-depth site on the transect north of Little Bahama Bank was located 11 km upslope from Site 627. A total of 298 m of periplatform ooze with intercalated debris flows, slumps, and turbidites was cored (Shipboard Scientific Party, 1986). Only two reworked larger foraminifer species occurred in Hole 628A: *Lepidocyclina* (*L.*) *yurnagunensis* in the lower Pliocene and *Dictyoconus* cf. *floridanus* (Pl. 3, Fig. 6) in the lower Oligocene (Fig. 4). This *Dictyoconus* is known to occur only in the middle and upper Eocene (Butterlin, 1981). However, the other larger foraminifers known to occur in the lower Oligocene, including *Lepidocyclina* (*L.*) *yurnagunensis* (Pl. 1, Figs. 6 and 7), *L.* (*L.*) *mantelli* (Pl. 3, Figs. 1 and 2), *L.* (*Eulepidina*) *undosa* (Pl. 5, Figs. 1–4), *L.* (*L.*) *canellei*, and *Heterostegina antillea*, apparently were not reworked. The three species listed first appear in planktonic foraminifer Zone P18, and the two listed last in Zone P19; their last appearance is in the lower Miocene (Cole, 1965; Butterlin, 1981; Andreieff, 1985) (Fig. 5).

Site 630 (807 m water depth)

Hole 630A is the shallowest site on the transect north of Little Bahama Bank. A total of 250 m of Pleistocene through upper Miocene periplatform ooze was drilled (Shipboard Scientific Party, 1986). Larger foraminifers generally were absent, except from Section 101-630A-25X, CC (planktonic foraminifer Zone N16/N17, upper Miocene), which contained only *Amphistegina* sp. having poor preservation.

Transect of a “Bypass” (steep, 10°–12°) Slope, Exuma Sound: Sites 631, 632, and 633

Site 632 (1996 m water depth)

Holes 632A and 632B were on the basinward end of the Exuma Sound transect. Both holes sampled a Holocene–upper Miocene sequence of periplatform ooze, chalk, and platform-derived turbidites. Hole 632A contained the greatest abundance of larger foraminifers on this transect. Sections 101-632A-1H, CC, 101-632A-3H, CC, and 101-632A-4H, CC (Pleistocene, planktonic foraminifer Zone N22/N23) contained *Archaias angulatus*, *Cyclorbiculina compressa*, and *C. americana*. The source area of these redeposited Soritidae is the back reef of Great Bahama Bank, in a nearshore restricted marine environment of <20 m depth.

Site 633 (1681 m water depth)

From this hole (on the toe of the slope) we recovered a sequence of periplatform ooze, chalk, and limestone with thin turbidites (Shipboard Scientific Party, 1986). Only rare redeposited *Amphistegina* occurred in the upper Pleistocene (Sections 101-633A-1H, CC, and 101-633A-2H, CC), in the lower Pleistocene (Sections 101-633A-3H, CC, 101-633A-2H, CC, 101-633A-3H, CC, and Sample 101-633A-4H-3, 50–52 cm) and upper Miocene (Sample 101-633A-15X-3, 50–52 cm).

PALEOENVIRONMENTAL INTERPRETATION OF LARGER FORAMINIFERS

STAGES		PLANKTONIC FORAMINIFER ZONES	CORE	SECTION & INTERVALS (cm)	DEPTH (m.)	Amphistegina sp.	Nummulites cajimarensis	Nummulites panamensis	Nummulites sp.	Archaias angulatus	Miogypsina antillea	Miogypsina sp.	Lepidocyclina (L.) yurnagunensis	Lepidocyclina (L.) canellei	Lepidocyclina (N.) dartoni	Lepidocyclina sp.	Gypsina cf. G. vesicularis	
PLEISTOCENE		N 22	1	1,50-52	0													
			2															
PLIOCENE	LATE	N 21	3															
		N 19-21	4															
	EARLY	N 19	5															
			6															
		N 18-19	7															
MIOCENE	LATE		8															
			9															
	MIDDLE MIOCENE SLUMP	N 16-17	10	3,50-52														
		N 11-13	11	2,50-52	100													
		N 13-14	12	4,50-52														
	MIDDLE		N 11-13	13	4,50-52													
			N 10-11	14	5,80-82													
			N 9	15	3,12-14													
			N 8	16	4,86-88													
				17	1,50-52													
EARLY		N 7-8	18	1,50-52														
			19	4,50-52														
		N 4	20	1,89-91														
EOCENE	LATE	P 11/P 12	21		200													
			22															
PALEOCENE	EARLY	P 7-P 8	23															
			24															
	LATE	P 4	24															
	EARLY	P 2/P 3	25															
		P 1b	26		249													

Figure 3. Occurrence of redeposited and reworked larger foraminifers from lower Miocene to Pleistocene at Site 627 (Hole 627B).

Site 631 (1081 m water depth)

Hole 631A constituted the shallow end of the Exuma Sound transect, where a thick section of Pleistocene, lower Pliocene, and upper Miocene periplatform ooze and periplatform chalk and limestone was cored. No larger foraminifers were found in this hole.

Thus, from the Pleistocene through the upper Miocene of the slope transects, the redeposited larger foraminifers were absent on the upper slope. They were very rare in the middle part of the slope, where they were represented by only one genus (*Amphistegina*) from the outer margin platform (certainly < 130 m, but probably from 50 to 80 m depth [Rose and Lidz, 1977]), and were relatively abundant and represented by several genera of Soritidae from the shallowest part of the platform (< 20 m) on the basin floor. This can be explained by the fact that the larger foraminifers from the platform of Great Bahama Bank were transported by turbidites that bypassed the upper slope during the Pleistocene and were redeposited mostly on the basin floor.

The larger foraminifers from Leg 101 and from DSDP Site 98 belong to several families: Soritidae (*Archaias angulatus* [Fichtel and Moll] [Pl. 1, Fig. 3], *Cyclorbiculina compressa* [d'Orbigny], *C. americana* Levy, *Broeckina discoidea* [Flint] [Pl. 4, Fig. 4], and very rare *Sorites* sp.), Nummulitidae (*Nummulites cajimarensis* [Palmer] [Pl. 1, Figs. 4, and 5], *N. panamensis* Cushman, *Heterostegina antillea* Cushman [Pl. 1, Figs. 1 and 2] and *H. panamensis* Gravell), Amphisteginidae (*Amphistegina gibbosa* d'Orbigny, *A. sp. gr. "lessonii"* d'Orbigny, *Sulcoperculina vermunti* Thiadens), Miogypsinidae (*Miogypsina [Miogypsina] antillea* [Cushman] [Pl. 4, Figs. 1-3], *M. [M] gunteri* Cole [Pl. 4, Fig. 6], *M. [Miogypsinita] staufferi* Koch [Pl. 4, Fig. 5], *Miogypsina [Heterosteginoides] panamensis* [Cushman]), Pseudorbitoididae (*Pseudorbitoides israelskyi* Vaughan and Cole, *Sulcorbitoides pardoi* Bronnimann), Orbitoididae (*Torreina torrei* Palmer, *Orbitoides tissoti* Schlumberger), Lepidocyclinidae (*Lepidocyclina [Lepidocyclina] yurnagunensis* Cushman [Pl. 1, Figs. 6 and 7], *L. [L.] canellei* Lemoine and Douvillé [Pl. 2, Figs. 1-3; Pl. 4, Fig. 7], *L. [L.] mantelli* [Morton] [Pl. 3, Figs. 1 and 2], *L. [L.] miraflorensis* Vaughan [Pl. 2, Fig. 4], *L. [L.] waylandvaughani* Cole, *L. [Nephrolepidina] cf. dartoni* Vaughan [Pl. 5, Fig. 5], *L. [Eulepidina] undosa* Cushman [Pl. 5, Figs. 1-4], Acervulinidae (*Gypsina vesicularis* [Parker and Jones] [Pl. 1, Figs. 8 and 9], *Sphaerogypsina* sp.), Orbitolinidae (*Dictyoconus floridanus* Cole [Pl. 3, Fig. 6]). These foraminifers are characteristic of the Caribbean biogeographic province (Adams, 1983).

To reconstruct the source area of redeposited or reworked material, one must know the paleoecology of these foraminifers, a number of which are still alive. Studies about depth distribution and environment of Holocene genera or about species in the modern shallow waters of Florida, the Bahamas (Martin, 1986; Rose and Lidz, 1977), and the Gulf of Elat or Aqaba (Hansen and Buchart, 1977; Hottinger, 1977) allow a better understanding of the distribution of the fossil genera or species before their redeposition or reworking on the slopes and basin floors of the Bahamas. However, difficulties abound when determining the paleoecology of fossil species. Many studies allow the use of these foraminifers as environmental indicators (Chaproniere, 1975; Frost and Langenheim, 1974; Hottinger, 1983; Hallock and Glenn, 1986).

Larger foraminifers are characteristic of neritic environments in equatorial and tropical areas. They are usually linked with algal symbionts in their cytoplasm, the type of which (Dinophycean, Cryptophycean, Chlorophycean, or Rhodophycean) depends chiefly on the depth of penetration of different light wavelengths. The maximum habitat depth for all symbiont-bearing organisms was observed in the Gulf of Aqaba at 130 m (Hottinger, 1983). The distribution of larger foraminifers (according to the various families) also depends on the degree of salinity, water movement, and substrate, as well as on the presence of reefs or such other organisms as sea grasses.

Archaias angulatus and *Cyclorbiculina compressa* occur on the platform margin and on the open part of the interior platform in South Florida and the Bahamas, where they proliferate in great abundance (Rose and Lidz, 1977). Hottinger (1983) stated that these species live in a water depth of between 0 and 20 m. Martin (1986) was of the opinion that *Archaias angulatus* harbors chlorophycean symbionts and is often attached to blades of *Thalassia*. This species predominates in the living foraminifer population of the relatively protected back-reef environment (between 0 and 20 m depth). The species can also be found in lesser numbers in high-energy shallow waters. After death, the empty

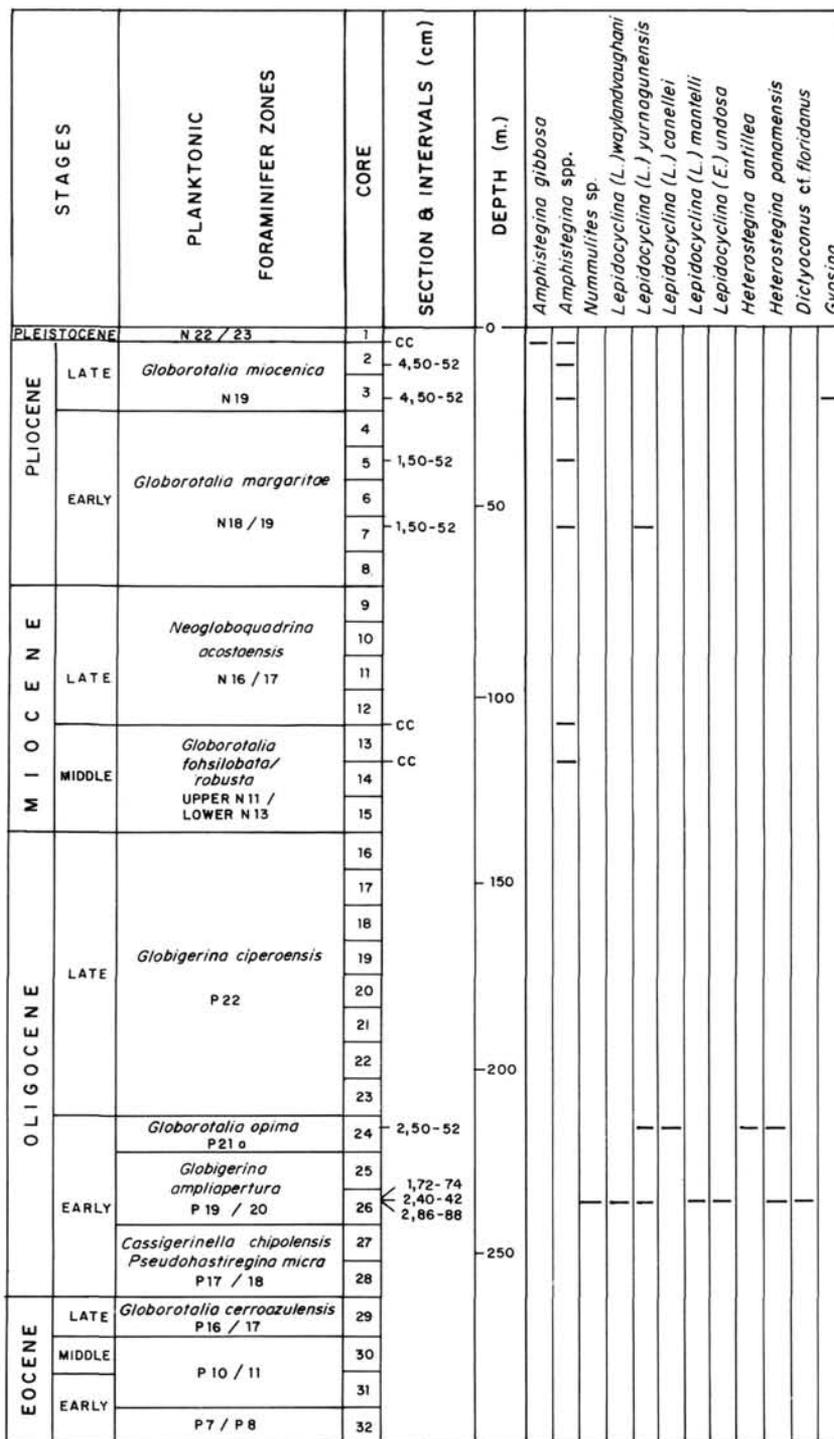


Figure 4. Occurrence of redeposited and reworked larger foraminifers from lower Oligocene to Pleistocene at Site 628 (Hole 628A).

tests of *Archaias angulatus* can be transported into the fore-reef sediment assemblage (Martin, 1986).

Heterostegina antillea is extinct in the early Miocene, but in the Gulf of Aqaba the depth distribution of the modern *Heterostegina depressa* is from 40 to 75 m on hard bottom substrate. This species also is found in pools at very shallow depths (Hottinger, 1977).

According to Hottinger (1983), *Amphistegina* sp. live from 0 to 130 m depths. Hansen and Buchart (1977) showed that in the

Gulf of Elat, the different species of *Amphistegina* are distinctly depth-distributed: *A. lobifera* does not live at depths greater than 80 m, and 122 m is the greatest depth for *A. papillosa* and *A. bicirculata*. *A. lessonii* is the dominant species from 5 to 40 m, and its maximum depth is about 80 m. In the Caribbean area, *A. gibbosa* has never been found living in abundance at depths of <10 m (Hallock et al., 1986). But according to Rose and Lidz (1977), "*Amphistegina lessonii*" (= *A. gibbosa*) is limited to the outer margin and its distribution reflects

cording to Hallock and Glenn (1986), *Lepidocyclus* was found in open-platform, reef, and foreslope environments.

Orbitoididae and Pseudorbitoididae do not occur in the back-reef environment, but mainly in the reef and foreslope environments. *Orbitoides tissoti* and *Torreina torrei*, like other Orbitoididae, apparently lived with some Zooxanthellae at depths of less than 50 m. We (Fourcade and Butterlin, unpub. data) noted that in southeast Mexico, during the Campanian to Maestrichtian, Alveolinidae were restricted to the Chiapas platform, while Orbitoididae and Pseudorbitoididae lived in the open-platform, reef, and foreslope environments. According to Van Gorsel (1978), *Pseudorbitoides* also lived in a fore-reef environment, but at depths varying from 50 to 100 m. The *Gypsina* could be indicators of a high-energy environment.

LARGER FORAMINIFERAL BIOSTRATIGRAPHY

Numerous biostratigraphic studies of the larger foraminifers of the Caribbean area (Cole, 1964; Frost and Langenheim, 1974; Butterlin, 1981, 1984; Pecheux, 1984; Andreieff, 1985; Westercamp et al., 1985; Adams et al., 1986) allow us to establish their stratigraphic range and to compare age determinations with those based on planktonic foraminifers (Shipboard Scientific Party, 1986).

As we indicated in the "Introduction" (this chapter), the co-occurrence of shallow-water larger foraminifers with planktonic foraminifers and calcareous nannofossils in turbidite materials results either from redeposition (particularly where specimens occur in a deep-water setting and no age disparities are evident) or from reworking (in the case of co-occurring specimens of different ages, or where ages are comparable but some specimens show evidence of prior fossilization). We cited numerous examples of redeposition and reworking found in Leg 101 samples.

For the Leg 101 drill holes, one must be cautious when using larger foraminifers to determine biostratigraphic ages because reworking can complicate the interpretation. The following points, however, are straightforward.

1. Redeposition is linked to turbidite and debris flow processes. These currents seem to have disturbed the shallower parts of the platform. Indeed, the order of appearance of species of larger foraminifers in these holes is not considerably affected (Table 4). *Miogypsina (M.) antillea* (Pl. 4, Figs. 1-3) appeared in the upper part of the section (planktonic foraminifer Zone N11 part/N12/N13 part), then *Miogypsina (Miogypsinita) stauferi* (Pl. 3, Figs. 3-5, Pl. 4, Fig. 5) (planktonic foraminifer Zone N7/N8 part), and then *Miogypsina (M.) gunteri* (Pl. 4, Fig. 6) even lower (planktonic foraminifer Zone N4), which seems to be the normal order of appearance. This contrasts with data presented by Cole and Applin (1961), who considered that *Miogypsina mexicana* (junior synonymus of *Miogypsina (Miogypsinita) stauferi*) was the youngest of the American *Miogypsina*, although we disagree.

Likewise, *Heterostegina antillea* (Pl. 1, Figs. 1 and 2) appeared for the first time in the Leg 101 drill holes below (corresponding to planktonic foraminifer Zone N5) the youngest *Lepidocyclus (L. [L.] canellei* [Pl. 2, Figs. 1-3] and *L. [L.] miraflorensis* [Pl. 2, Figs. 4-6]), as was also noted in PEMEX wells offshore of the Gulf of Mexico (Butterlin, unpub. data).

2. Although the order of appearance of the *Miogypsina* species in Leg 101 drill holes corresponded to our expectations, the possibility of reworking precluded the determination of the latest part of the Miocene reached by the most recent Caribbean species, i.e., *Miogypsina (M.) antillea*.

3. If not a result of downhole contamination, the range of *Miogypsina (Miogypsinita) stauferi* could be extended to correspond to planktonic foraminifer Zones N4 through N7, instead of Zone N5 of Zones N6 through N7 (Fig. 5). However, this

does not seem probable because in North America only *Miogypsina* having a single primary auxiliary chamber were reported as being from Zone N4.

4. The comparative range chart of larger foraminifers from Leg 101 and from data acquired elsewhere (Fig. 5) shows that, with the exception of *Dictyoconus floridanus*, only four species of *Lepidocyclus (L. [L.] yurnagunensis, L. [L.] canellei, L. [L.] miraflorensis, L. [Nephrolepidina] dartoni)* and one species of *Miogypsina (M. [M.] antillea)* are reworked in the middle Miocene. These were mainly foraminifers that disappeared in the lower Miocene and that are reworked in the middle Miocene at Sites 626 and 627. The other occurrences (Table 4) were identical to what would be expected, based on previously published ranges (Cole, 1964; Frost and Langenheim, 1974; Butterlin, 1981, 1984; Pecheux, 1984; Andreieff, 1985; Adams et al., 1986; and Westercamp et al., 1985).

CONCLUSIONS

The larger benthic foraminifers generally occurred as isolated, well-preserved specimens in deposits from the Bahamian slopes and deep basins cored during Leg 101. They corresponded to a shallow-water environment within the photic zone (0 to 130 m depth). Their occurrence in deep-water sediments was due to turbidite and debris flow transportation. Although turbidites and debris flows are important processes of slope sedimentation, only a few turbidites and debris flows contained larger foraminifers. The source area for these was generally the shallow area of a carbonate platform having a <80 m depth, where larger foraminifers were particularly abundant. Thus, redeposited and reworked larger foraminifers can provide a certain amount of information about the turbidites or debris flows originating from the shallow areas of a carbonate platform. The resistance of their tests explains why they can be easily found far from their source area.

Data from Leg 101 and the Blake-Bahama Basin showed that the redeposited and reworked larger foraminifers were abundant only at certain stratigraphic levels, particularly in the upper Campanian and the lower Oligocene to Pleistocene.

In the Pleistocene, redeposited larger foraminifers occurred in samples from the Straits of Florida (Holes 626A and 626C), from Northeast Providence Channel (Hole 635A), the transect north of Little Bahama Bank (Holes 627A, 627B, and 628A), and the Exuma Sound transect (Holes 632A and 633A). The *Archaias-Cyclorbiculina* assemblage showed that the redeposited material of the Florida platform (Holes 626A and 626C), Little Bahama Bank (Holes 627A, 627B, and 628A), and Great Bahama Bank (Holes 626A, 626C, 632A, 633A, and 635A) came from the shallowest part of the platform (<20 m) in back-reef and nearshore restricted marine environments.

In the middle Miocene, we found abundant reworked Miogypsinidae and Lepidocyclusinidae of early Miocene age in the Straits of Florida at Site 626 and on the Blake Plateau at Site 627. This *Miogypsina* (abundant)-*Lepidocyclusina*-*Amphistegina*-*Nummulites* assemblage showed that the reworked material came from unconsolidated lower Miocene sediments from reef and foreslope environments deposited at a depth of <50 m, although reworked larger foraminifers of Campanian and Eocene age occurred at DSDP Site 391 in the middle Miocene of the Blake-Bahama Basin.

The lower Miocene (planktonic foraminifer Zone N4) of Hole 626D (Straits of Florida) did not appear to contain reworked larger foraminifers, but rather only redeposited *Nummulites*, *Heterostegina*, *Lepidocyclusina*, and *Miogypsina* (Fig. 2). These foraminifers also seemed to come from reef, foreslope, or open-platform environments of Florida and the Great Bahama Bank (<50 m depth). Nevertheless, the occurrence of rare *Archaias* indicated that redeposited material came from the restricted plat-

form. Redeposited and reworked larger foraminifera were identified by Butterlin and Moullade (1983) in the Blake-Bahama Basin (DSDP Sites 391 and 534). Redeposited *Lepidocyclina*, *Miogypsina*, and *Nummulites* also were present at Site 627 (Blake Plateau).

In the Oligocene (except for the reworked Eocene *Dictyococcus*) all other larger foraminifera, mostly represented by abundant *Lepidocyclina* and *Heterostegina*, were redeposited. Those at Site 628 (Fig. 4) were similar to the assemblage of Pueblo Viejo reef (Chiapas, Mexico) (Frost and Langenheim, 1974) and probably came from the reef environment of Little Bahama Bank, while those at Site 626 (Straits of Florida, Fig. 2) came either from the Florida platform or from the Great Bahama Bank. The source area of redeposited foraminifera corresponded to depths of <50 m in the reef and foreslope environments.

Finally, in the upper Campanian the reworked Orbitoididae and Pseudorbitoididae from Site 634 probably came from the open-platform, reef, and foreslope environments of the Great Bahama Bank.

In the two slope transects cored during Leg 101, Exuma Sound (steep slope) and north of Little Bahama Bank (gentle slope), larger foraminifera were absent on the upper slope but were present on the lower part of the slope. This seems to be the result of "coarser material bypassing the upper slope of a bank through the gullies" (Shipboard Scientific Party, 1985a).

The Leg 101 Shipboard Scientific Party (1985b) reported that the first turbidites came from the transect north of Little Bahama Bank in the lower Oligocene of Hole 628A, while on the lowest part of the slope (in Hole 627B), the earliest appearance of turbidites was in the lower Miocene. We also found that redeposited larger foraminifera appear in the lower Miocene in Hole 627B and in the lower Oligocene in Hole 628A.

The upper part of the Florida and Bahama platform, where many larger foraminifera live, was particularly sensitive to fluctuations of sea level. Vail et al. (1977) hypothesized that during high sea levels most sediment was trapped on the inner shelf, and during low sea levels most material escaped to the deep sea. However, Droxler and Schlager (1985) reported that isolated "carbonate platforms export more material during highstands of sea level when the platform tops are flooded and produce sediments." Here, we did not intend to conduct a quantitative analysis of turbidites and debris flows, but we note that turbidites and debris flows with larger foraminifera are present during high as well as low sea levels.

In the Pleistocene, redeposited larger foraminifera were abundant. The instability created by numerous rises and falls of sea level seemed favorable for their redeposition.

Numerous reworked larger foraminifera were observed in middle Miocene core materials from the Straits of Florida (Site 626), Blake Plateau (Site 627), and the Blake-Bahama Basin (DSDP Sites 391 and 534), possibly the result of tectonic effects that caused the erosion of the lower Miocene and Oligocene reef margin. The middle Miocene debris flows, where we found numerous reworked larger foraminifera, suggest a regional tectonic event (Shipboard Scientific Party, 1986).

However, redeposited larger foraminifera also occurred at Hole 626D in the lower Miocene (planktonic foraminifer Zones N5 and N6), which corresponds to a lower sea level.

In the upper lower Oligocene, redeposited larger foraminifera from Sample 101-628A-24X-2, 50-52 cm (Zone P21a) were coeval with a lower sea level (Vail et al. 1977; Haq et al., 1987). In the mid-Pacific atoll at DSDP Site 462, Schlager and Premoli-Silva (1986) recorded redeposited larger foraminifera in turbidites from deep-water archipelagic apron carbonates of latest early Oligocene age (P21a) during a glacial low sea-level stand (Miller et al., 1985). However, in the lower Oligocene, the redeposited larger foraminifera from Sample 101-628A-26X-2,

40-42 cm (*Globigerina ampliapertura* Zone P19/P20) were coeval with a higher sea level (Vail et al., 1977; Haq et al., 1987).

Reworked larger foraminifera that occur in chalk containing *Globotruncana* of Campanian age also could be related to vertical relief in the Campanian from fractures (Shipboard Scientific Party, 1986). Reworked larger foraminifera also occurred in Campanian limestone with *Globotruncana* near the Chiapas Platform in the Tuxtla Gutierrez area (Chiapas, Mexico). These are linked to fractures of Campanian age (Michaud, 1987). Strong deformation occurred in the Campanian of Mexico (Tardy et al., 1986), Cuba (Pszczolkowski and Flores, 1986), and Hispaniola (Mercier de Lepinay et al., in press). These tectonic events of Campanian age probably caused the reworking of the larger foraminifera in the Bahamas.

Redeposition of larger foraminifera in slopes and basins of the Bahamas thus are linked to changes in sea level and can be found during low as well as high sea levels. However, the reworking of larger foraminifera seems to be linked with tectonic events.

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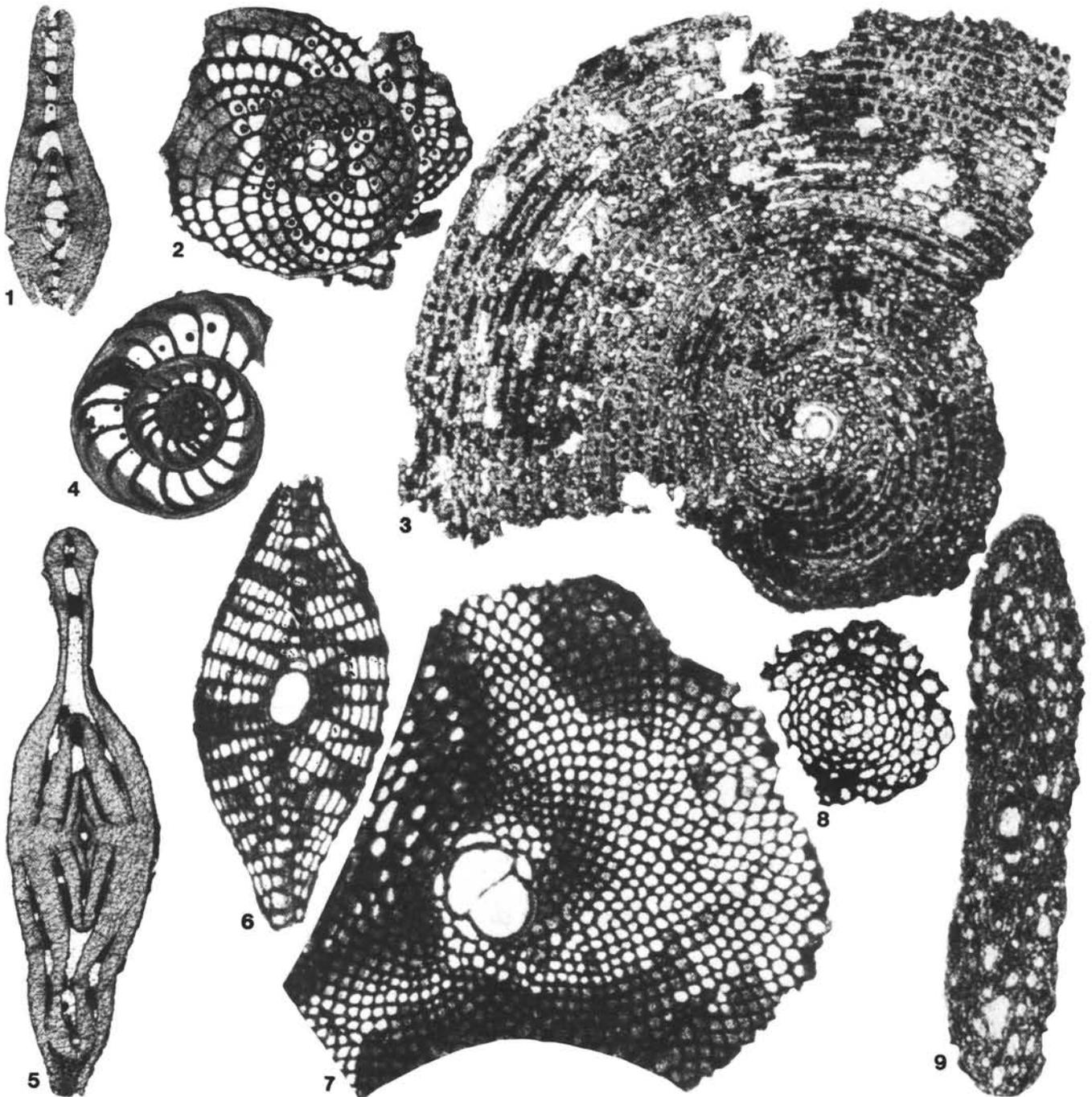


Plate 1. 1. *Heterostegina antillea* Cushman, axial sect., Section 101-626D-20R, CC (20 \times). 2. *Heterostegina antillea* Cushman, equat. sect., Section 101-626D-20R, CC (20 \times). 3. *Archaias angulatus* (Fichtel and Moll), equat. sect., Sample 101-626D-11R-2, 50-52 cm (40 \times). 4. *Nummulites cojimarensis* (Palmer), equat. sect., Sample 101-626C-16H-2, 52-54 cm (20 \times). 5. *Nummulites cojimarensis* (Palmer), axial sect., Sample 101-626D-11R-2, 50-52 cm (20 \times). 6. *Lepidocyclus* (*Lepidocyclus*) *urnagunensis* Cushman, axial sect., Sample 101-628A-26-2X-2, 40-42 cm (40 \times). 7. *Lepidocyclus* (*Lepidocyclus*) *urnagunensis* Cushman, equat. sect. Sample 101-628A-26X-2, 40-42 cm (40 \times). 8. *Gypsina* cf. *vesicularis* (Parker and Jones), equat. sect., Sample 101-627B-14H-5, 80-82 cm (40 \times). 9. *Gypsina* cf. *vesicularis* (Parker and Jones), axial sect., Sample 101-626D-11R-2, 50-52 cm (40 \times). (Photography by O. Fay)

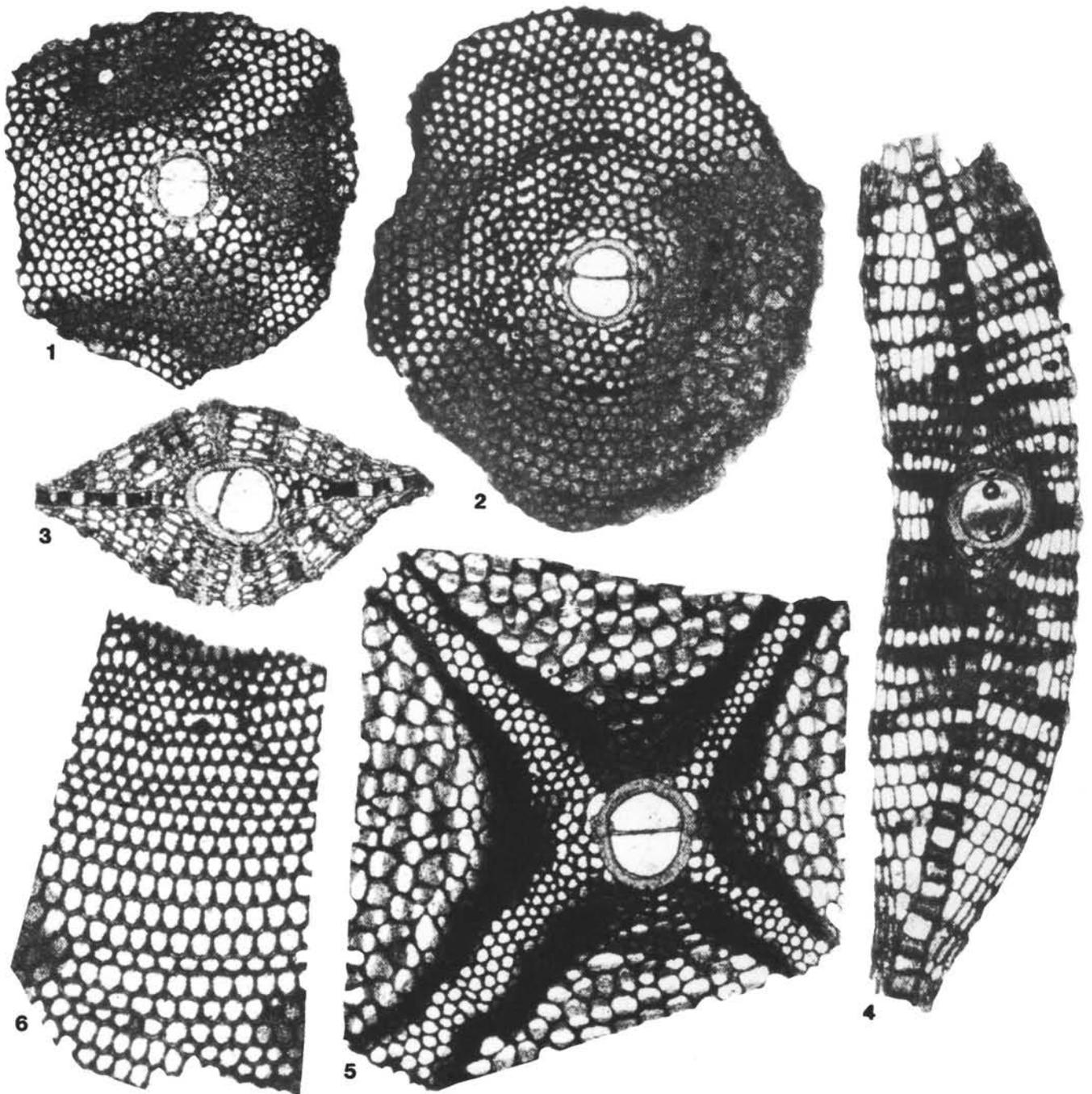


Plate 2. 1. *Lepidocyclina (Lepidocyclina) canellei* Lemoine and Douvillé, equat. sect., Section 626D-11R, CC (40×). 2. *Lepidocyclina (Lepidocyclina) canellei* Lemoine and Douvillé, equat. sect., Sample 101-626C-15H-3, 50-52 cm (40×). 3. *Lepidocyclina (Lepidocyclina) canellei* Lemoine and Douvillé, axial sect., Sample 101-626D-11R-2, 50-52 cm. (40×). 4. *Lepidocyclina (Lepidocyclina) miraflorensis* Vaughan, axial sect., Section 101-626D-20R, CC (40×). 5. *Lepidocyclina (Lepidocyclina) miraflorensis* Vaughan, equat. sect., Section 101-626D-11R, CC (40×). 6. *Lepidocyclina (Lepidocyclina) miraflorensis* Vaughan, external equat. chambers, Section 101-626D-11R, CC (40×). (Photography by O. Fay)

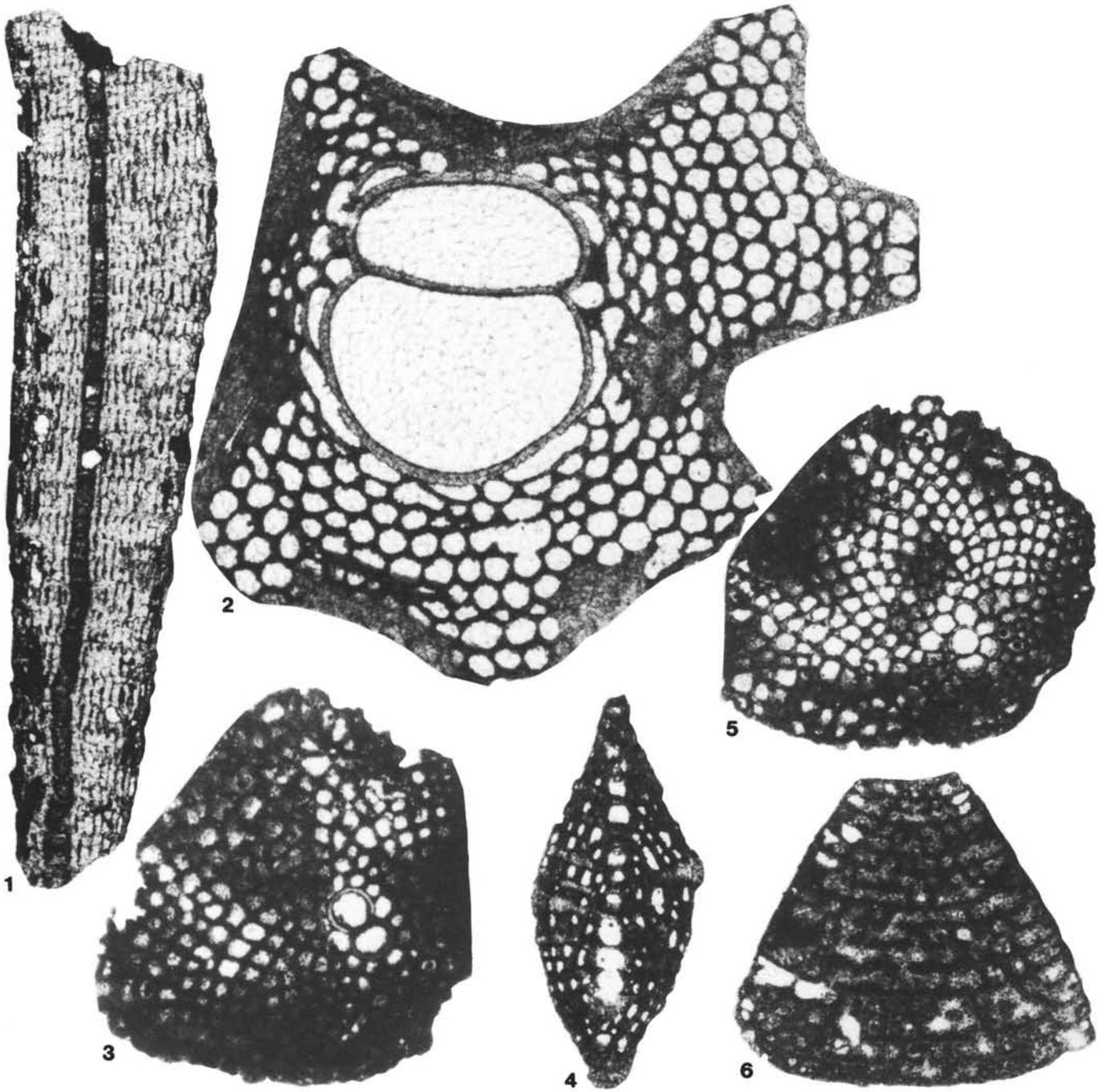


Plate 3. 1. *Lepidocyclina (Lepidocyclina) mantelli* (Morton), part of axial sect., Sample 101-628A-26X-2, 40-42 cm (40 \times). 2. *Lepidocyclina (Lepidocyclina) mantelli* (Morton), equat. sect., Sample 101-628A-26Y-2, 40-42 cm (40 \times). 3. *Miogypsina (Miogypsinita) staufferi*, equat. sect., Section 626D-20R, CC (40 \times). 4. *Miogypsina (Miogypsinita) staufferi* Koch, axial sect., Section 101-626D-11R, CC (40 \times). 5. *Miogypsina (Miogypsinita) staufferi* Koch, equat. sect., Section 101-626D-11R, CC (40 \times). 6. *Dictyoconus cf. floridanus* Cole, axial sect., Sample 101-628A-26X-2, 40-42 cm (40 \times). (Photography by O. Fay)

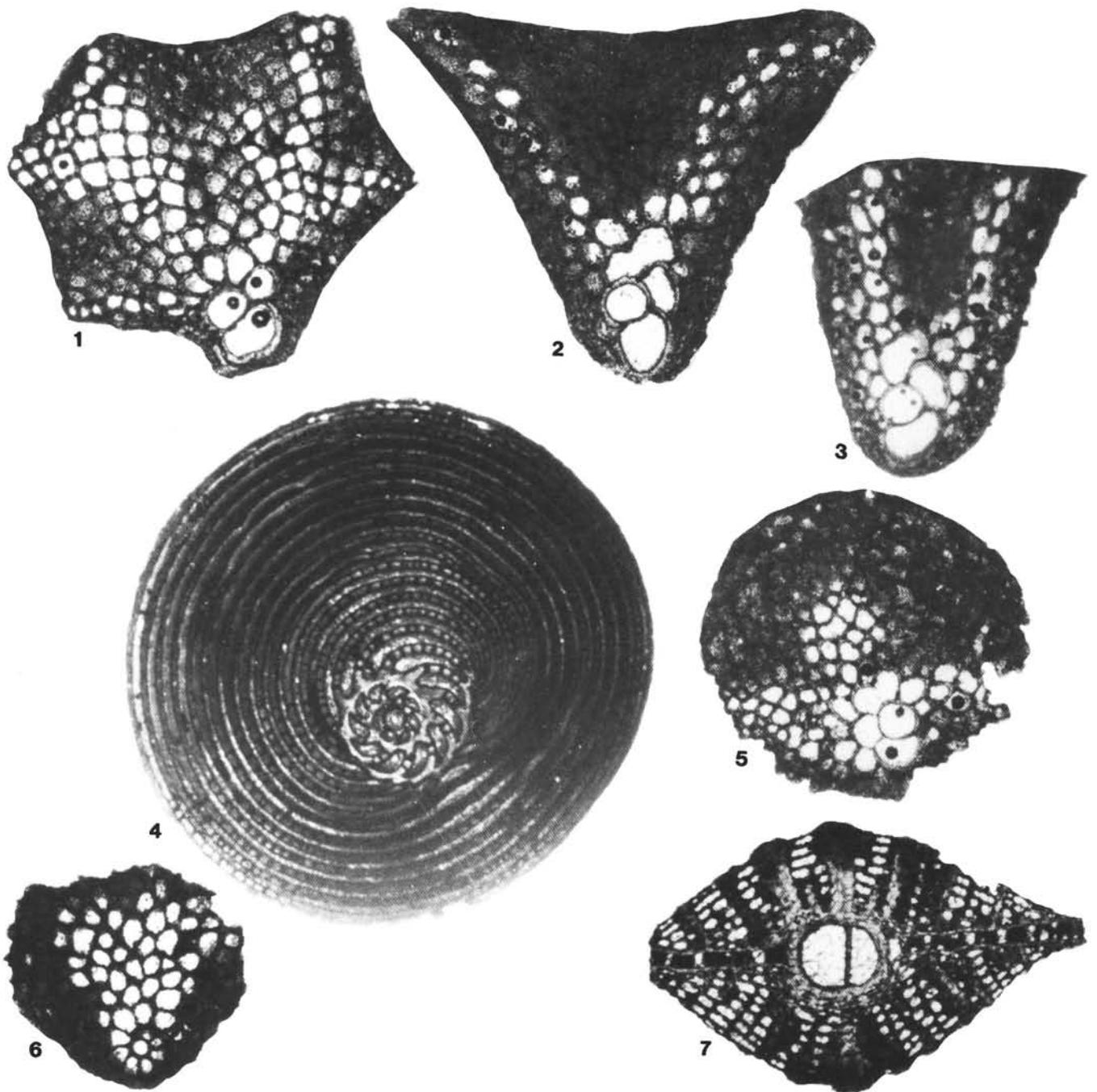


Plate 4. 1. *Miogypsina (Miogypsina) antillea* (Cushman), equat. sect., Sample 101-626C-16H-2, 50-52 cm (40 \times). 2. *Miogypsina (Miogypsina) antillea* (Cushman), equat. sect., Section 101-626C-15H, CC (40 \times). 3. *Miogypsina (Miogypsina) antillea* (Cushman), equat. sect., Sample 101-626C-16H-2, 50-52 cm (40 \times). 4. *Broeckina discoidea* (Flint), Section 101-626D-20R, CC (40 \times). 5. *Miogypsina (Miogypsinita) staufferi* Koch, equat. sect., Sample 101-626D-11R-2, 50-52 cm (40 \times). 6. *Miogypsina (Miogypsina) gunteri* Cole, equat. sect., Section 101-626D-19R, CC (40 \times). 7. *Lepidocyclina (Lepidocyclina) canellei* Lemoine and Douvill , axial sect., Section 101-626D-11R, CC (40 \times). (Photography by O. Fay)

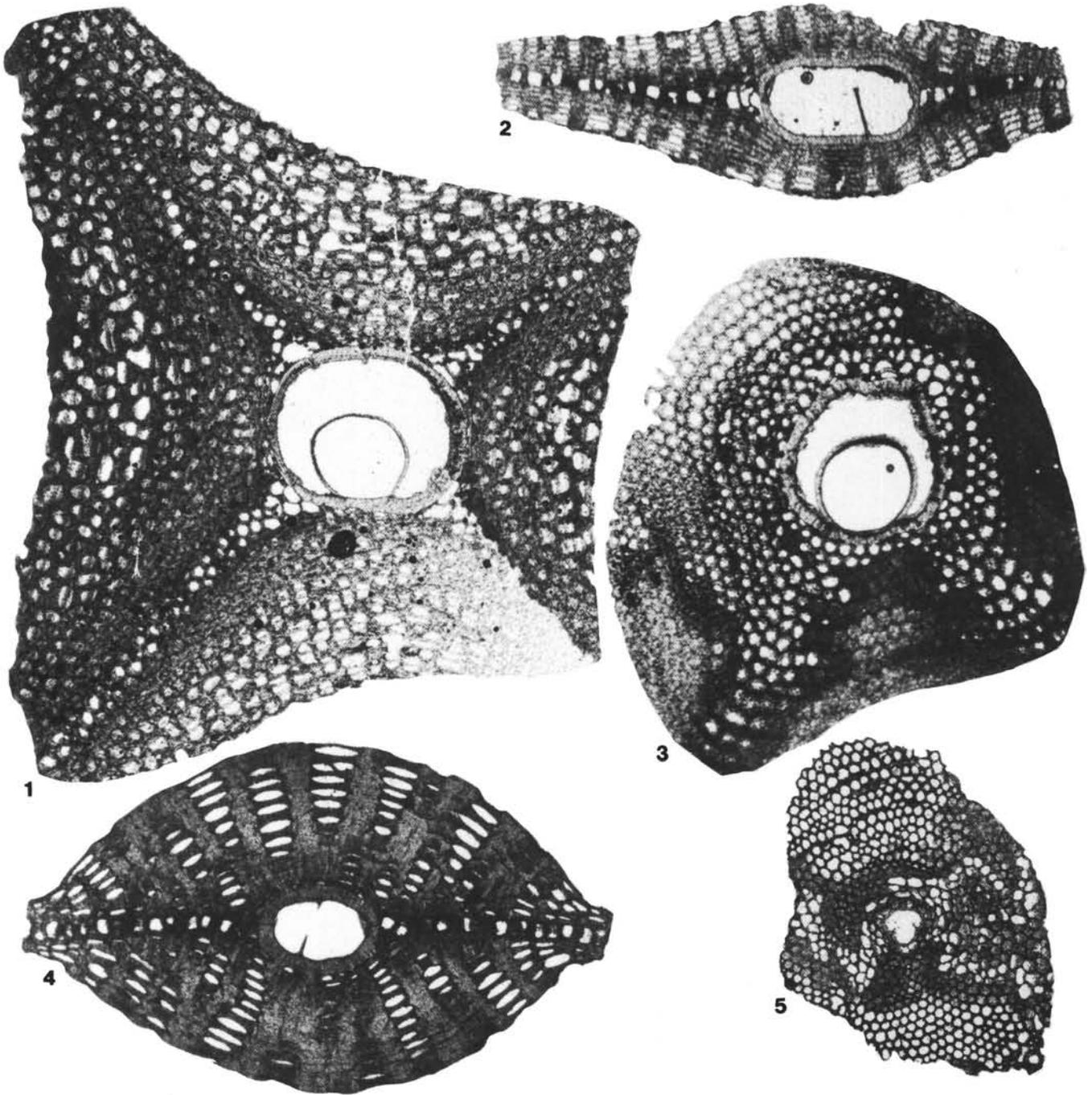


Plate 5. 1. *Lepidocyclina (Eulepidina) undosa* Cushman, equat. sect., Sample 101-628A-26X-2, 40-42 cm (20 \times). 2. *Lepidocyclina (Eulepidina) undosa* Cushman, axial sect., Sample 101-628A-26X-2, 40-42 cm (20 \times). 3. *Lepidocyclina (Eulepidina) undosa* Cushman, equat. sect., Sample 101-628A-26X-2, 40-42 cm (20 \times). 4. *Lepidocyclina (Eulepidina) undosa* Cushman, axial sect., Sample 101-628A-26X-2, 40-42 cm (20 \times). 5. *Lepidocyclina (Nephrolepidina) cf. dartoni* Vaughan, equat. sect., Section 101-626D-23R, CC (20 \times). (Photography by O. Fay)