# 5. SHALLOW-WATER SKELETAL DEBRIS AND LARGER FORAMINIFERS FROM DEEP SEA DRILLING PROJECT SITE 462, NAURU BASIN, WESTERN EQUATORIAL PACIFIC<sup>1</sup>

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## ABSTRACT

Shallow-water larger foraminifers and associated forms adapted to a reef environment were recovered from Deep Sea Drilling Project Hole 462, drilled in 5181 meters water depth in the Nauru Basin, south of the Marshall Islands. Shallow-water material, mainly reworked, (1) is frequently associated with volcaniclastic breccias to coarse sands, (2) occurs episodically interbedded within a turbiditic sequence whose clasts are pelagic components (planktonic foraminifers, radiolarians, and calcareous nannoplankton). More than 60 species of larger foraminifers were identified, and most of them are age-diagnostic. They range in age from Campanian to late Oligocene; only a few forms are attributable to the mid-Cretaceous.

A comparison was made with similar shallow-water assemblages recovered from deep sites previously drilled in the central western Pacific (Line Islands, Tuamotu Ridge). On the basis of the occurrence of larger foraminifers (1) the existence of volcanic edifices capped by reefs is demonstrated for the mid-Cretaceous; late Campanian through late Maestrichtian; early, middle, and late Eocene; early Oligocene; and late Oligocene; (2) five main discrete erosional events are identified since the late Cretaceous; they are dated at middle(?)-late Maestrichtian, late(?) Eocene, early late Oligocene, and middle Miocene; (3) larger-foraminifer assemblages display great affinities with the Caribbean bioprovince during the Cretaceous, whereas they contain mainly Tethyan and/or Indo-Pacific elements during the Tertiary; and (4) the main direction of faunal migration from westward (Caribbean) during the Late Cretaceous was reversed during the Tertiary.

# **INTRODUCTION**

The present chapter treats larger foraminifers and other shallow-water debris, primarily recovered from DSDP Hole 462, drilled at 5181 meters water depth, in the Nauru Basin, western equatorial Pacific.

Shallow-water faunas and floras with forms adapted to the reef environment, anomalously occurring at such oceanic depth, are frequently associated with volcaniclastic material and are contained in generally graded layers, including volcaniclastic breccias, fine conglomerates, and coarse foraminifer sands. Such coarse layers are episodically interbedded in a turbiditic sequence, where the dominating grain-size ranges from a foraminifer and/or radiolarian sand to a nannofossil silt (see Premoli Silva and Violanti, this volume).

The age of planktonic faunas and floras associated and/or containing the coarse layers ranges from late Campanian through Quaternary. Such layers are unevenly distributed throughout the stratigraphic column: they are more common during intervals of major erosion (late Campanian, middle-late Maestrichtian, late Eocene, early late Oligocene, late Oligocene, and middle Miocene.

Autochthonous sediments are red clay, yielding mainly fish debris and abyssal, non-calcareous, benthic foraminifers, and occasionally possible autochthonous radiolarians (see Premoli Silva and Violanti, and Premoli Silva and Sliter, this volume). The oldest shallow-water fossils are Late Cretaceous (Campanian-Maestrichtian); they are partly reworked into the Tertiary. Shallow-water fossils are also diagnostic of early Eocene, middle and late Eocene, early late Oligocene and late Oligocene ages. A few forms, mainly in the upper levels, are probably Neogene or younger.

The most commonly represented taxonomic groups are larger foraminifers, including Discocyclinidae, Miogypsinidae, Nummulitidae, Orbitoididae, Pseudorbitoididae, bryozoans, and more rarely coralline algae. Mollusks, corals, and echinoids are minor components and commonly very fragmented.

# **COMPOSITION OF THE COARSER LAYERS**

On the basis of their composition, both organogenic and inorganic, the coarser layers can be grouped as follows:

1) Layers from the upper (younger) part of the sequence (mainly from Core 5, Section 7, through Core 6, Section 2), in which shallow-water material is scarce, poorly diversified, never exceeding the 3 to 5% of the >63- $\mu$ m fraction. Volcanic material mainly consists of fresh glass and ash, which sometimes cements planktonic foraminifers and radiolarians. Volcanic material may represent 50% of the >63- $\mu$ m fraction.

2) Layers corresponding to the typical foraminifer sands, in which shallow-water material is scarce, poorly diversified, never exceeding 15% of the >63- $\mu$ m fraction, dominated by planktonic foraminifers. The larger foraminifers cover a long time interval, but are few and mainly reduced to small fragments, often with very chalky, poorly preserved inner parts. Volcanic material is present as a minor component of the >63- $\mu$ m fraction. Those layers are common in Cores 14, 23, 25, and 27.

3) Layers, recorded from Core 21, Section 1; Core 22, Section 1; Core 32, Sections 1 and 2; and Core 34, Sections 1 and core catcher in which the shallow-water

<sup>&</sup>lt;sup>1</sup> Initial Reports of the Deep Sea Drilling Project, Volume 61.

material is highly diversified and belongs to moredifferentiated paleo-environments. The identified foraminifer assemblages range from Late Cretaceous to late Oligocene. Volcanic material includes glass in various stages of alteration and a large amount of fragments of volcanic rocks, dominated by basalts. Lithic fragments, both calcitic and cherty, are also present.

4) In the oldest layers, recorded from Core 48, Sections 1 and 2; Core 51, Section 3; and Core 52, Section 1, (Late Cretaceous), shallow-water material is homogeneous, mainly larger foraminifers of similar age. Other biogenic components are possibly represented by minute calcitic fragments, which are undiagnostic. In Core 48, Sections 1 and 2, inorganic material, mainly consisting of small fragments of volcanic glass and opaline silica, is a minor component. In Core 51, Section 3; and Core 52, Section 1, shallow-water forms are included in graded layers of coarse to very coarse volcaniclastic breccia, passing upwards into volcaniclastic sandstone. Biogenic components are similar to those described from Core 48, and include larger foraminifers, together with small calcitic biogenic fragments. Inorganic components are abundant and include relatively large blocks of basalts, pyroxenes, and abundant glass. The lowermost breccia, recorded from Core 52, Section 1, 110-150 cm, of late Campanian age, contains only undiagnostic but possibly older biogenic fragments (mid-Cretaceous?).

The distribution of biogenic and inorganic components throughout the sedimentary succession recovered at Hole 462 is shown in Figure 1.

# FOSSIL ASSEMBLAGES

The shallow-water material recovered from Hole 462 represents one of the largest assemblages ever recorded from Pacific drill sites; it is outstanding in diversity, number of species, taxonomic groups, and stratigraphic range. More than 60 species of foraminifers, red algae, corals, hydrozoans, bryozoans, etc. have been identified. Their occurrence and abundance are reported in the range chart in Figure 2.

In some cases, the poor state of preservation prevented full identification of the species; some identifications must be considered only as preliminary. Larger forms (>3/4 mm) were found broken, commonly with eroded edges; relatively smaller forms display different stages of recrystallization even at the same levels: a positive correlation exists between age and state of preservation, the oldest forms being more chalky than the younger ones. Among the nummulitids, the older specimens are chalky and filled with calcite, whereas the younger representatives are empty and relatively well preserved. Some other foraminifers, such as pseudorbitoidids, are externally well preserved, although the inner characters are unrecognizable.

All the examined specimens were first studied under the binocular microscope, then described. Some forms displaying characteristic outer features, such as *Asterorbis*, *Asterocyclina*, and *Vaughanina*, could be identified at the generic level in this first observational stage. Oriented thin sections were prepared from most specimens. Additional information was obtained from thin sections made randomly from the coarser fractions of washed residues. In some cases, regular thin sections were prepared, mainly from the indurated samples of Hole 462A. Specimens belonging to the genera Nummulites and Assilina were opened along the periphery (marginal cord) after being strongly heated and then soaked in cold water. Both external and internal characters can be observed in this way. More than 300 isolated specimens were prepared with the methods mentioned above; however, only 50% of them could be identified at the specific level because of poor preservation.

# DISCUSSION ON THE AGE OF SHALLOW-WATER DEBRIS

Larger foraminifers are by far the most conspicuous components among the reef-derived skeletal debris. Moreover, several identified species are stratigraphically important. Other reef-derived skeletal debris is too fragmentary to be stratigraphically diagnostic. This study therefore concentrates on the larger foraminifers, among which a relatively large number of age-diagnostic assemblages can be recognized. They are as follows (from bottom to top):

# Late Cretaceous

In the late Campanian to middle Maestrichtian, two assemblages are distinguishable: (1) an older one, occurring in Core 5, Section 1; and Core 51, Section 3, is characterized by Pseudorbitoides israelskyi, Sulcoperculina vermunti, and Vaughanina cubensis. They are associated with planktonic-foraminifer faunas of the Globotruncana subspinosa and Globotruncana calcarata Zones (in Cores 52 and 51, respectively), dated as late Campanian; the age suggested by the "guest" planktonic assemblages is consistent with the stratigraphic range known for P. israelskyi and S. vermunti (Brönnimann, 1957); Brönnimann (1957) however claims that true P. israelskyi never overlaps the range of V. cubensis, a species confined to the Maestrichtian; the material from Hole 462, being displaced, does not help to resolve this problem; (2) the second (younger) assemblage (Core 48, Sections 1 and 2) is characterized by Lepidorbitoides bisambergensis, L. minor, L. socialis, Orbitocyclina minima, Asterorbis havanensis, and A. rooki, associated with Sulcoperculina vermunti, S. cubensis, and rare representatives of Pseudorbitoides and poorly preserved Vaughanina. The planktonicforaminifer assemblages in Core 48 are characteristic of the Globotruncana gansseri Zone, of middle Maestrichtian age; among the Lepidorbitoides, the identified species L. bisambergensis, L. minor, and L. socialis, according to van Gorsel (1975), represent three evolutionary stages of the same lineage, L. socialis being the end member, confined to the uppermost Maestrichtian, thus corresponding to the planktonic-foraminifer zone of Abathomphalus mayaroensis and L. bisamergensis, the oldest species, ranging from the early Maestrichtian Globotruncana tricarinata Zone through the middle part of the Globotruncana gansseri Zone (middle Maestrichtian in this volume), and L. minor between the two

mentioned species, ranging from the upper part of the G. gansseri Zone to the base of the A. mayaroensis Zone (= late middle Maestrichtian).

This being so, it seems likely that the co-occurrence of the three species in Core 48, Sections 1 and 2 is an artifact, and both L. bisambergensis and L. minor (the latter with less certainty) must be reworked. Moreover, if the correlation between species ranges within the Lepidorbitoides and planktonic-foraminifer zones is confirmed by further studies, we must assume also that the planktonic-foraminifer faunas co-occurring with L. socialis, attributed to the middle Maestrichtian G. gansseri Zone, are also reworked into the late Maestrichtian. Planktonic foraminifers indicating the Abathomphalus mayaroensis Zone, or even the underlying Globotruncana contusa Zone, are lacking in Core 48 (see Premoli Silva and Sliter, this volume), but are found reworked in several Tertiary layers (see Premoli Silva and Violanti, this volume).

Rare Late Cretaceous larger foraminifers and rudistid fragments occur also in Core 21, Section 1, 2-3 cm; and in Core 22, Section 1, 69-71 cm, dated as late Oligocene (*Globigerina angulisuturalis* Zone = Zone P22).

A single specimen belonging to the Family Orbitolinidae was found in Core 32, Section 1, 5-8 cm, and dated as late early Oligocene. Precise identification was prevented (the specimen was lost in transit), but it possibly belonged to the mid-Cretaceous stock.

# Tertiary

The following assemblages occur mainly mixed together in some samples from Core 34, Sections 1 and CC; Core 32, Section 1; Core 22, Section 1; and Core 21, Section 1, 2-3 cm (numbering continued from Late Cretaceous section): (3) an older Tertiary assemblage characterized by nummulitids, among which Assilina leymeriei, Nummulites pernotus, N. burdigalensis minor, N. partschi, and N. rotularius have been identified after a comparison with topotype material; all are described from early Eocene strata of the Mediterranean area and have not been reported from the Indo-Pacific; according to Schaub (1951, 1961, 1963), A. leymeriei and N. pernotus characterize the lower part of the early Eocene, while the other two species occur primarily in the middle to late early Eocene; at Hole 462, the two first forms occur in Core 34, Section 1, which contains late Eocene planktonic foraminifers of the Turborotalia cerroazulensis Zone, and in Core 32, Section 1; Core 22, Sections 1 and 21 (early late and late Oligocene), where they are associated with the other three species; (4) other species, still Eocene in age, but younger than assemblage (3), have been identified in Core 32, Section 1, and in Core 22, Section 1, 69-71 cm, dated on the basis of the associated planktonic foraminifers as late early Oligocene (P19/P20 zone boundary), and as late Oligocene (P22), respectively; they are Nummulites sp. aff. N. variolarius, N. problematicus, N. sp. cf. N. bagelensis, Operculina eniwetokensis, Heterostegina saipanensis, Spiroclypeus sp. cf. S. vermicularis, S. sp. cf. S. albapustula, Asterocyclina matazensis, A. penuria,

Polylepidina antillea, and P.? sp. aff. P. paucispira; those species have a different range within the middle to late middle Eocene, and moreover are known from different bioprovinces; in particular, Polylepidina antillea characterizes middle to late middle Eocene layers of the Caribbean, whereas Nummulites bagelensis, possibly a junior synonym of N. javanus according to Adams (1970), is recorded throughout the middle Eocene of the Indo-Pacific region; Asterocyclina penuria, A. matazensis, Operculina eniwetokensis, Spiroclypeus vermicularis, and S. albapustula are all recorded in the late Eocene portion of the Eniwetok drill hole (Cole, 1957): all the species except Operculina eniwetokensis are characteristic of the late Eocene of the Indo-Pacific region, or have even larger distribution, such as the Spiroclypeus, known also from the Mediterranean area; among the nummulitids, the identified species are Nummulites problematicus and N. sp. aff. N. variolarius: the former is known from the Mediterranean region, where its range spans the late Eocene and the early Oligocene (Pavlovec, 1966); the latter is the only Nummulites recorded from the central Pacific (see Beckmann, 1976, on DSDP Site 318, Tuamotu), but occurs also in the Indo-Pacific region in layers dated as late Eocene (Doornink, 1932); however, N. variolarius is known from the middle Eocene of the Paris Basin (Blondeau, 1980); many other specimens which could not be identified specifically broadly indicate an Eocene age: most of them belong to the genera Discocyclina, Asterocyclina, Nummulites, and Operculina; they could not be assigned to a specific stratigraphic level; this group also included a single alveolinid, probably attributable to Fasciolites (= Alveolina); the very poor state of preservation prevented better identification; (5) in Core 32, Sections 1 and 2, other species of Nummulites, such as N. bouillei and N. vascus, also occur; their range is restricted to the early-middle Oligocene (P18 to top P20; see Haak and Postuma, 1975); their presence in Core 32, Sections 1 and 2 (early Oligocene, P19/P20 zone boundary) is in agreement with the age inferred from planktonic foraminifers; Nummulites problematicus, whose range, as mentioned above, straddles the Eocene/Oligocene boundary, could also belong to this assemblage; the species mentioned above occur reworked in Core 22, Section 1, 69-71 cm, and Core 21, Section 1, 1-3 cm, dated as late Oligocene; the Globigerina angulisuturalis Zone (P22) is younger than the extinction level of Nummulites in the Indo-Pacific region, as well as in the Mediterranean; (6) Heterostegina borneensis, Lepidocyclina (Eulepidina) sp. cf. L. ephippioides, and Nephrolepidina sumatrensis occur only in Core 22, Section 1, 69-71 cm, attributed to the late Oligocene Globigerina angulisuturalis Zone (P22); according to Adams (1970), H. borneensis occurs primarily in the late Oligocene (P21/P22); N. sumatrensis appears in the uppermost part of P22, then continues into the Miocene; Eulepidina and possibly Eulepidina ephippioides appear at the base of P19 (early Oligocene) according to Haak and Postuma (1975), and are still recorded from Miocene layers; these species represent a late Oligocene assemblage; other species, such as Het-

8		2		TRAM	SPORTED AND REWORKED MATERIAL		
Depth (m)		Recover		Reef Skeletal Debris and Larger Foraminifers	Planktonic and Bathyal to Abyssal Benthic Foraminifers	Volçanic Material	Age
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1 1	4 5 6 7 8		++++++++  ++++++++++++++++++++++++++++	Rare shallow-water debris, miliolids, Amphistegina, echinoid fragments. Age: Coeval ?	Late Cretaceous through late Miocene transported planktonic foraminifers. Middle Miocene (N12–N13) assemblages dominate. Late Cretaceous, late Paleocene—early Eccene, late Oligocene through early	Ash and volcanic glass.	Pliocene
	9		++		Miocene transported planktonic foraminifers. Early Miocene (N4, N7) and		~
	10 11 12 13 14 15 16		<u>5</u> +++}	Miogypsinoides, Discocyclina, Heterostegina, miliolids, bryozoan debris. Age: Eocene, Oligocene.	middle Miccene (N10–N13) assemblages dominate. Late Cretaceous, late Paleocene–early Eocene, late Oligocene, and early Miocene (N7) transported planktonic foraminifers with few small benthic foraminifers. Late Oligocene and early Miocene assemblages dominate. Late Cretaceous, late Paleocene–early Eocene, mid- and late Oligocene	Common volcanic glass and rock fragments.	E.   middle   late
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	26 27 28		╢ ╢	Rudistid fragments. Age: mid-Cretaceous(?). Few larger foraminifers, as in Cores 21, 22, and 32.	Rare Aptian—Albian transported planktonic foraminifers associated with late Cretaceous, late Paleocene—early Eocene, late Eocene displaced planktonic foraminifers.	Ash ? Volcanic plass and rock fragments.	





Core	Section	Interval (cm)	hanina sp. indet. Nanina cubensis	perculina vermunti orbitoides israelskyi	orbitoides sp. indet. Nanina jordanae	lorbitoides sp. aff. P. israelskyi perculina sp. indet.	orbis sp. indet.	perculina cubensis	orbis cubensis	orbis rooki	ocyclina minima ocyclina sn indet	orbitoides bisambergensis	orbitoides minor	orbitoides socialis	nulites sp. indet.	ulina sp. indet.	numes permotas na leymeriei	ostegina sp. indet.	nulites rotularius	rpsinoides ubaghsi	ia sp. aff. R. viennoti	crypeus sp. indet.	ocyclina sp. indet.	idae	ocyclina matanzensis rosinoides arandipustula	clypeus sp. cf. S. vermicularis	ia sp. indet.	otalia sp. att. P. pyramensis	nulites burdigalensis minor	nulites problematicus	nulites vascus vilina eniwetokensis	ulina subformai	ostegina suborbicularis	clypeus higginsi	ocyclina sp. inget.	nulites bagelensis	mulites partscni mulites veriolarius	culina sp. cf. O. complanata	ostegina borneensis	ostegina aff. borneensis	dsteyina saipanensis ciypeus sp. cf. S. albapustula	epidina antillea	idina sp. cf. E. ephippioides	ocyclina manadai ocyclina penuria	rolepidina sumatrensis	olites?	histegina sp. indet.	progypsina sp. indet.	oconus sp. att. D. salpanensis visoira?	r foraminifers indet.	P SUBOT	tids	mollusks	course manus	codes	lgae nic fragments	ue minerals	nic glass nic rock frammats	Plant Plant	E	SDP	SITI	5 462	
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Figure 2. Distribution of larger foraminifers, other shallow-water debris, and volcanic material in Hole 462. Numbers refer to quantitative analysis done for some samples treated on shore (see Premoli Silva and Violanti, this volume). Sample 46,CC was studied in thin section.

erostegina suborbicularis, H. subformai, and some rotaliids, have such long ranges that they are not indicative of a specific stratigraphic level; (7) some amphisteginids and miliolids occur in Cores 6 and 5, which are attributed to the Pleistocene; they may represent a Plio-Pleistocene assemblage.

## The Occurrence of Miogypsinoides

Two species of *Miogypsinoides* were identified in Hole 462: *Miogypsinoides ubaghsi* in Core 34, Sections 1 and CC; Core 32, Section 1; and Core 22, Section 1, 69–71 cm; and *M. grandipustula* in Core 32, Section 1. A few fragments possibly attributable to *M. ubaghsi* were also recorded from Cores 17, 15, and 14, higher in the sequence (Miocene). As mentioned above (see also Figs. 1 and 2), Cores 34 and 32 are dated on the basis of planktonic faunas (foraminifers and radiolarians) and floras as late Eocene (*Turborotalia cerroazulensis* Zone) and late early to early late Oligocene (P19/P20), respectively. Core 22 belongs to the late Oligocene *Globigerina angulisuturalis* Zone (P22).

Drooger (1963) regarded Miogypsinoides ubaghsi as a junior synonym of M. complanatus. Direct comparison with the original material from the Eniwetok drill hole allows us to state that our specimens belong to the same species from Eniwetok found in Cole's (1957) collection. Moreover, the spiral length, the very large A-Pangle ( $\sim 400^{\circ}$ ), and the shape of the equatorial chambers differentiate both ours and Cole's specimens from either M. complanatus or M. bantamensis (see Hanzawa, 1962). The characters above-mentioned would make instead our specimens closer to M. ubaghsi, to which species the specimens from Hole 462 are attributed. According to the literature (Adams, 1970; Haak and Postuma, 1975; etc.), Miogypsinoides ubaghsi is mainly confined to the late Oligocene. Then, its occurrence in Core 22, Section 1, 69-71 cm, is consistent with the age inferred from the host foraminifer faunas, attributed to the late Oligocene Globigerina angulisuturalis Zone (P22).

On the other hand, *Miogypsinoides* in Core 34, Section 1 (late Eocene) and in the Core 32, Sections 1 and 2 (early/late Oligocene boundary) has important biostratigraphic implications.

The oldest record of *Miogypsinoides* is from middle Oligocene strata of Java (Tan, 1932). Tan's finding, however, was never confirmed elsewhere. Adams (1970) seriously doubts that Tan's identification of *Miogypsinoides* could be correct (the specimen was neither figured nor described), and secondly he remarks that the age of the formation in which *Miogypsinoides* occurs is very questionable. According to Adams (1970), no true *Miogypsinoides* have been proved to occur earlier than the late Oligocene.

The occurrence of verifiable representatives of *Mio-gypsinoides* in Hole 462 within layers dated as late Eocene and early/late Oligocene would make the first appearance of this genus much earlier than was previously believed. However, this reasoning would imply that *Miogypsinoides*, a genus displaying very rapid evolution

throughout the late Oligocene, at the beginning of its range evolved only very slowly. In particular, the species M. ubaghsi would maintain the same nepionic acceleration stage for about 10 m.y. (from late Eocene at,  $\sim 37$ m.y. ago, to topmost Oligocene,  $\sim 23$  m.y. ago): that is to say an unprecedented, totally unexpected behavior among the larger foraminifers. More reasonably, we can think that because of the turbiditic character of the whole sedimentary sequence of Hole 462, all planktonic components (calcareous nannofossils, planktonic foraminifers, and radiolarians) associated with *Miogypsinoides* may not only be transported, but might be totally reworked (see Premoli Silva and Violanti, this volume). Therefore, they would lead to a dating of the sediments much older than they in fact are.

In conclusion, at Hole 462 the sediments yielding *Miogypsinoides ubaghsi* cannot be older than the first appearance of the genus *Miogypsinoides*, which according to Adams (1970) would occur at the base of the late Oligocene (= lower Te = P21; *Globorotalia opima opima* Zone; Haak and Postuma, 1975) (Fig. 3). Consequently, Core 34 must be dated at least as late Oligocene (P21), and it would be not late Eocene in age, as inferred from the planktonic components; the overlying cores, at least up to Core 27, have to be rejuvenated as well. The representatives of *Miogypsinoides* become a conspicuous component of the late Oligocene assemblage (6).

## **Skeletal Debris**

Few fragments of shallow-water skeletal debris display enough characters to make them identifiable (Plates 19 and 20). They belong to milleporinid hydrozoans (Axopora?), to Scleractinia (Stylophora, Porites, Actinastrea?, Seriatopora), to Octocorallia (Alcyonocean), and to cyclostomate bryozoans (determination by S. Frost). They occur primarily in Core 22, Section 1, 69-71 cm (late Oligocene) except Stylophora from Core 34,CC. Their distribution is mainly from Eocene, or even older levels, to Recent. A more restricted range (Eocene-Oligocene) is known from the genus Axopora. Their range is consistent with those of the associated larger foraminifers, except for Seriatopora, known only from Miocene to Recent in the Indo-Pacific region. As already mentioned, rare rudistid fragments occur in Cores 21 and 22 (Plate 19), reworked along with Late Cretaceous larger foraminifers. In the Late Cretaceous of Cores 48, 51, and 52, very rare fragments can be only doubtfully referred to the rudistids. Those fragments suggest a Cretaceous age.

## OCCURRENCE OF REEF-DERIVED SKELETAL DEBRIS AT OTHER PACIFIC DRILL SITES

Allochthonous, reef-derived skeletal debris was recorded from several drill sites during previous DSDP legs in the central and western Pacific. Most of those drill sites are close to volcanic island chains, such as Line Island (Sites 165, 315, 316), Tuamotu Ridge (Site 318), Mid-Pacific Mountains (Sites 171, 313), Caroline Ridge (Site 58), and Western Pacific Seamounts (Site

		HAA	K and PC	OSTUMA (1975)				HARDENBOL and BERGGREN (	1978	)		
chs	F	n.y.) ren		Foraminifer Zones	Lette	r Code		Foraminifer Zones	sag	4	cus	
Epo	European Stages	Age (r Bergg (197	Blow (1969)	Postuma (1971)	(Far	East)	Blow (1969)	Bolli (1966); Stainforth et al. (1976)	Sta	ł	Ebo	
Miocene	Aquitanian	- 22 -	N4	Globorotalia kugleri		Upper (=Te 5)			Aquit.	early	iocene	
		- 24 -	N3 =			4)	N4	Globigerina ciperoensis	Ĺ		Σ	
епе		- 26 -	P22		Té	Te 1-	P22					
	Chattian	- 28 -	N2 = P21	Globigerina angulisuturalis		Lower (=	b P21— a	"Globorotalia" opima opima	Chattian	late		
goc		- 30 -			+						docen	LAD of Nummulites
011	Rupelian	- 32 -	N1 =		1	ď	P20	Globigerina ampliapertura			Olio	
0		- 34 -	P20/P19	Globigerina ampliapertura			P19	Cassigerinella chipolensis	elian	rly		
	Lattorfian	- 36 -	P18		1	ſc	P18	Pseudohastigerina micra	Rupe	ea		
- <u>e</u> -		- 38 -					P17		ab.	e	ene	
Eocer	Priabonian		P16	Globorotalia cerroazulensis	ТЬ		P16	Turborotalia cerroazulensis s.l.	Pri	la	Eoc	

Figure 3. Zone scheme. Note that in Hardenbol and Berggren (1978) the age of the Eocene/Oligocene and Oligocene/Miocene boundaries changed to 37 m.y. and to 24 m.y., respectively.

202). At some of these sites, such as Sites 202, 313, 171, and 58, shallow-water material is poorly age-diagnostic, and correlations with Hole 462 are only tentative.

On the other hand, sites drilled close to the Line Islands, and to a lesser degree those closer to the Tuamotu Ridge, show a striking similarity to Hole 462 insofar as the faunas and age determinations are concerned.

The correlations presented in Figure 4 are based on the original *Initial Reports* descriptions completed by new observations (1) of the original cores (visual), (2) on direct comparison between Hole 462 material and the original material studied by Beckmann (1976) for his Leg 33 Report, and (3) on a set of thin sections prepared by E. L. Winterer for petrographic purposes, which were kindly made available for the present study.

Starting from the older levels, the first correlation concerns the volcaniclastic sequence, dated as early(?)late Campanian. This sequence is poorly fossiliferous at its base. However, at Site 315, Core 22, Section 4, 145– 150 cm, representing the coarser part of a graded volcaniclastic sandstone, contains little shallow-water debris and other intraclasts of older age, including fragments of mid-Cretaceous *Cuneolina* and Solenoporacea. The same forms also occur at Site 171, Cores 29 to 31, dated on the basis of planktonic foraminifers as late Cenomanian. Of comparable age are also some fragments of *Orbitolina* dredged at Isakov Guyot (Heezen et al., 1973) and the single orbitolinid recorded at Hole 462, reworked in the early late Oligocene of Core 32.

Assemblage (1), of Hole 462, characterized by Pseudorbitoides, Sulcoperculina, and Vaughanina, also occurs at Site 165 (Core 17A), close to the Campanian/ Maestrichtian boundary, and at Site 316 (Cores 27-23) in the late Campanian *Globotruncana calcarata* Zone. At Site 315, only pelagic sediments are recorded from this interval.

Assemblage (2), with Lepidorbitoides, Sulcoperculina, and some pseudorbitoidids, is recorded at Site 315 (Cores 17A and 18A) in the middle Maestrichtian Globotruncana gansseri Zone, and at Site 165 (Core 16A,CC); the microfacies of the latter sample is identical to that of Core 46,CC at Hole 462. According to Douglas (1973), Core 16A,CC (Site 165) is attributable to the late Maestrichtian Abathomphalus mayaroensis Zone, but this age assignment is weak, because of the poor planktonic fauna.

The same assemblage, as rich in species as in Core 48 (Hole 462), is recorded at Site 315, reworked in Core 10A (early Oligocene) and in Core 9A (late Oligocene), associated with representatives of assemblage (1). A few Late Cretaceous forms are also recorded from Site 462, reworked in the same intervals.

Assemblage (3), dated as early Eocene, and composed mainly of *Nummulites*, previously has not been recorded from Pacific drill sites. The assemblage which best approximates the faunas of Hole 462 is the *Discocyclina-Asterocyclina* assemblage recovered at Site 318, Core 32 (Tuamotu Ridge). In this core, the shallowwater fauna and flora are associated with a planktonic fauna attributed to the late early Eocene *Acarinina pentacamerata* Zone (= *A. densa* in Schlanger, Jackson, et al., 1976); they appear a little younger than the *Nummulites* assemblage. Assemblage (4), dated as late Eocene, occurs only at Site 318 in Cores 18 and 19 (*Globigerinatheka semiinvoluta* Zone, late Eocene). The only *Nummulites* yet recorded from the central Pacific occur in this interval.

At the other sites, the corresponding late Eocene interval is not recorded because of poor recovery (Site 315), because it was not cored (Site 165), or because it is missing (hiatus) (Site 316). However, at Site 165, representatives of Eocene assemblages (e.g., *Discocyclina* and *Asterocyclina*) are reworked in the late Oligocene (Core 3A). Discocyclinids were also recovered in piston cores taken close to the pedestal of the Line Islands, reworked in coarse foraminifer sands of Pleistocene age, during a cruise of the R/V *Kana Keoki* in the summer of 1979 (personal observation).

At Site 318, a discocyclinid assemblage associated with frequent coralline algae and *Sphaerogypsina* occurs also in the earlier two planktonic-foraminifer zones of the middle Eocene (Cores 26 and 23).

Assemblages (5) and (6), of the early and possibly late Oligocene respectively, were not recovered from other drill sites. Post-Eocene species are recorded from Site 318; there *Heterostegina* sp. cf. *H. suborbicularis* and an unidentified *Lepidocyclina* occur in Core 10 and are attributed to the early Miocene. Beckmann (1976) stated that their occurrence did not conflict with the age inferred from the planktonic faunas. On the other hand, those two species could also be late Oligocene in age and be reworked in the Miocene.

Although faunas of Assemblages (5) and (6) are not recorded from the other sites, there is clear evidence that coarser layers occur at similar stratigraphic levels, but contain only reworked or undiagnostic faunas (Site 165, late Oligocene; Site 315, early and late Oligocene), or else are unfossiliferous and volcanogenic (Sites 316 and 165, early Oligocene). At Hole 462, Core 15, a reworked, shallow-water fauna occurs together with relatively abundant volcanic elements. This level was not recorded at sites close to the Line Islands chain. It could instead be correlated with the volcaniclastic breccia containing coarse, shallow-water debris, including Lepidocyclina, as mentioned above, recorded at Site 318, Core 10, Section 1. This breccia, underlain by foraminifernannofossil chalk, is dated as early Miocene (Globorotalia kugleri Zone). Because the next core (Core 9) belongs to the upper part of the middle Miocene, a gap representing most of the early Miocene and lower part of the middle Miocene is hypothesized (Schlanger, Jackson, et al., 1976). In the absence of direct evidence of an early Miocene age, we suggest that the breccia was possibly deposited during the middle Miocene, just predating the pelagic ooze of Core 9. If this interpretation is correct, then the occurrence of the coarse, shallow-water material of Hole 462 in the middle Miocene is not a local sedimentary feature, but has a wider significance.

Finally, Assemblage (7) and the associated volcanic ash recorded at Site 462 (Cores 5 and 6) could be correlated with the shallow-water assemblage described by Beckmann (1976) at Site 318, Core 2, dated as Pliocene/Pleistocene boundary.

## BIOPROVINCIAL AFFINITIES OF THE REEF-DERIVED FAUNAS

Besides the interesting implications for tectonic and volcanic reconstruction of the Pacific Plate (see Schlanger and Premoli Silva, this volume), the reef faunas recovered at the Pacific drill sites provide information on the distribution of larger foraminifers, greatly increasing our knowledge about the early bioprovinces.

The oldest records (*Cuneolina*, orbitolinids, etc.), of mid-Cretaceous age, confirm the cosmopolitan character of the low-latitude foraminifer assemblages associated with rudistid reefs.

During the Late Cretaceous, as already pointed out by Beckmann (1976), the larger foraminifers of the central Pacific display great affinities with the Caribbean-Central American province (van Gorsel, 1978). Pseudorbitoididae and Sulcoperculina, conspicuous elements of the Caribbean province, are the most important components of the faunas here described. They are associated with faunal elements, such as representatives of Lepidorbitoides evolutionary lineage, which according to van Gorsel (1978) should be restricted to the "Eurasian" bioprovince. Consequently, this genus has a much wider distribution than was previously thought, unlike the family Orbitoididae, which is not represented in our assemblages. Thus, during Late Cretaceous time, a bioprovince was differentiated in the central Pacific, characterized by the association of Pseudorbitoididae, Sulcoperculina, and Lepidorbitoides.

To explain the occurrence of elements from both bioprovinces, we have to assume that the direction of migration towards the Line and Marshall Islands areas was from both sides of the Pacific, from the east (*Lepidorbitoides*), and mainly from the west (Pseudorbitoididae and *Sulcoperculina*). Orbitoididae, which are present both in the west Pacific area (Papua; Glaessner, 1960) and in the Caribbean, have not been recorded from the central Pacific province.

The eastward migration of Lepidorbitoides is relatively easy to explain (many islands or "stepping stones" were probably available at that time in the western Pacific). The seemingly rapid westward migration of the Caribbean faunas suggests that the Caribbean and Line-Marshall Islands areas were much closer during the Cretaceous than they are today. It is well known that shallow-water faunas cannot easily migrate across a large, deep ocean, such as the present eastern Pacific, which would act as a barrier. Figure 5 presents a simplified paleogeographic reconstruction of the eastern Pacific at the end of the Cretaceous, based on magneticanomaly lineations (Pittman et al., 1974). The present Caribbean Plate is back-tracked close to those segments of the Pacific Plate where Line and Marshall Islands formed. If this reconstruction is correct, in Cretaceous time shallow "stepping stones" existed to permit a rapid colonization of the Line-Marshall Island areas by the Caribbean faunas.

During the Early Tertiary, the direction of the main faunal migration was reversed. Rapid ocean spreading in the eastern Pacific resulted in a rapid decrease of af-

AGE		cor	ē	Hole 462	core	Hole 462A	coré	Hole 165A	core	Hole 315A		
	PLE	EISTOCEN		Amo	historinid_miliolid escomblero							
	P	LIOCENE	56									
	MIOCENE	early middle late	14/15	Di: ass He	secocyclinid <i>—Miogypsinoides</i> semblage <i>terostegina</i> assemblage							
	m	P22	21	Heter assem N. bo Astern assem assem	rostegina—Nephrolepidina holage. Nummulites vascus— uillei assemblage; Nummulites— occyclina—Spiroclypeus holage; Nummulites—Assilina holage; Pseudorbitoides holage; Rudistid fragments			1 3	Reef-skeletal debris Discocyclinid	9	Asterorbis—Sulcoperculina assemblage; <i>Pseudorbitoides</i> assemblage	
	OLIGOCEN	P21	32	Nun asse	nmulites vascus—N. bouillei mblage. Numulites—					10	Lepidorbitoides—Asterorbis assemblace; Pseudorbitoides	
ZOIC		P19		Aste asse asse asse	erocycina—>procypeus emblage; <i>Nummulites—Assilina</i> emblage; orbitolinid—rudistid emblage			4⁄5	Rare benthic foraminifers		assemblage	
CENO	- 13	P17	34	N a: Nun	<i>lummulites—Asterocyclina</i> ssemblage n <i>mulites—Assilina</i> assemblage	H2	Nummulites—Asterocyclina assemblage					
	OCENE	P15 P14 P13										
	ш	P12 P11 P10										
	6	64 89 89										
O U S		G. gansseri	46 48	Lep asse Le Ol Ps	Lepidorbitoides-Sulcoperculina assemblage Lepidorbitoides-Asterorbis- Orbitocyclina assemblage Peudorbindes seamblana		Lepidorbitoides assemblage Pseudorbitoides assemblage	16 17	Pseudorbitoides – Vaughanina assemblage Lepidorbitoides – Sulcoperculina assemblage. Pseudorbitoides? assemblage	17 18	<i>Sulcoperculina</i> —Pseudorbitoididae assemblage. Rudistid fragments.	
RETACE	G	, tricarinat. G. calcarata	51	Ps as	Pseudorbitoides—Vaughanina		Volcanic foraminifer sandstone Pseudorbitoides— Vaughanina assemblage					
C R	G.	. subspinos				8	Volcanic sandstone			22	Cuneolina	
¢	MI	IOMANIAN D-APTIAN										

Figure 4. Distribution of shallow-water assemblages at the major DSDP Sites, Eniwetok drill hole, and Isakov Guyot (central Pacific), plotted against age and planktonic-foraminifer zones. Absolute age is after Hardenbol and Berggren (1978) and Berggren and Van Couvering (1972). Note that the late(?) Eocene assemblage comprehends middle and late Eocene assemblages.

•	0.y. AGE	462 O	462A	165A	315A	316A	318	Enewetak Atoll (drill hole F1)	cor	Hole 318	core	Eniwetok Atoll drill Hole F1
	10	•#					•	■?	5	Amphisteginid—bryozoan—coral assemblage. <i>Heterostegina</i> assemblage		
	30 - 00	●CIEŔ•X			*•		-					
	40 1 40 50	<b>⊡∎</b> ¥×		7	xettr.		+ +	Inferred location of basal sediments overlying basalts	10	Heterostegina—Lepidocyclina assemblage		
	60 - 60 Mae.	*•	*•	*	★x •				F			
	70 Cam.			•?	x		-					
	+ LA ★ EA ★ EA * LA × MII	TE EARL RLY EOC RLY-MIC TE CAMP D-CRETAC	Y-MIDD ENE: Nur DDLE MA ANIAN: F CEOUS: C	LE EOCEI mmulites- ESTRICH Seudorbitu Cuneolina-	NE: Disco Assilina as TIAN: Lep bides- Val Orbitolini	cyclinid—A semblage bidorbitoio ghanina a id assembla	Asterocycli des-Astero ssemblage age	d assemblage orbis assemblage				
core		Hole 3	816		cor	1	Isako	ov Guyot	-			
									18	Nummulites—Asterocyclina assemblage		
									26	Discocyclina—Asterocyclina assemblage	F14 F15	? Inferred age of sediments overlying the basalt.
									27	Discocyclina—Asterocyclina assemblage		
									32	Discocyclina—Asterocyclina assemblage		
									1			
27	Pseu	udorbito	<i>ides</i> asse	emblage								
Ħ					1	Cune	olina-0	<i>rbitolina</i> assemblag	e			

Figure 4. (Continued).



Figure 5. Simplified reconstruction of the eastern Pacific at the end of the Cretaceous (~65 m.y. ago), made by following the Caribbean hypothetically back-tracked westward. Note that Australia, New Guinea, etc., have been drawn in their present position. Although the Tuamotu Ridge is considered a Tertiary feature, Site 318 location was included. Asterisk in Papua indicates the westernmost occurrence of *Pseudorbitoides israelskyi*, a species characteristic of the Caribbean bioprovince during the Late Cretaceous.

finities with the Caribbean province. Only one element of the Caribbean faunas, *Polylepidina* (Adams, 1967), is surely recorded in the Marshall Island area during the middle Eocene; *Polylepidina* seems to have played the same role in the Tertiary as *Lepidorbitoides* did in the Cretaceous.

All the other foraminifer taxa are known from the Indo-Pacific region (Indonesia, Mariana Islands, etc.), and from the Tethys.

Discocyclinids are almost the only components of the early and middle Eocene faunas of the Tuamotu Ridge and Line Islands areas: they are particularly abundant at Tuamotu, much rarer at the Line Islands. In the Marshall Islands area, foraminifer assemblages are dominated by nummulitids: *Nummulites* and *Assilina* in the early Eocene, *Nummulites* alone in the late Eocene and early Oligocene. All the identified forms are typically Tethyan elements, except for *Nummulites* sp. cf. *N. bagelensis*, described from the Indo-Pacific region, which is however a possible junior synonym of *N. javanus* or *N. perforatus*(?) (Adams, 1970). Only late in the Eocene did *Nummulites* and *Heterostegina* colonize the Tuamotu area.

It appears that the late Eocene was when the Tethyan and Indo-Pacific provinces (Adams, 1970) had their maximum expansion, that is to say, when *Nummulites* sp. aff. *N. variolarius* reached the Tuamotu area to the east. Other nummulitids (Operculina, Heterostegina, Spiroclypeus), mainly described from the Indo-Pacific region, are again among the components of late Eocene and Oligocene assemblages in the Marshalls area, along with rare lepidocyclinids. Very few representatives of some of these genera migrated so far east as the Tuamotu area. If our interpretation of the age of Lepidocyclina and Heterostegina at Site 318 (Core 10) is correct, such migration occurred during the late Oligocene.

We did not record *Biplanispira* and *Pellatispira*, previously described at Eniwetok (Cole, 1957) and wide-spread in the Indo-Pacific region.

# PALEOGEOGRAPHIC IMPLICATIONS

The shallow-water skeletal debris recorded in the central and western Pacific from the Pacific Plate testifies to the presence during the Cretaceous and Cenozoic of edifices rising from the sea floor which reached the euphotic zone and rested close to the surface (sea level) long enough to be colonized by shallow-water faunas and floras. This process was repeated several times.

The high stratigraphic resolution of larger foraminifers, even if they are scattered and randomly distributed throughout the various sequences, allowed us to assign a precise age to those events. There is evidence for reefs or shallow carbonate platforms during the following time intervals (from older to younger): 1) Mid-Cretaceous, on the occurrence of *Cuneolina* and orbitolinids (Line Islands, Mid-Pacific Mountains, Nauru Basin, Pacific Seamounts); plant remains, recovered in Hole 462A, Core 40, Section 1, and dated on the basis of radiolarians as Aptian-Albian, indicate the existence of islands;

2) Late Campanian, on the basis of *Pseudorbitoides* assemblages (Line Islands, Nauru Basin);

3) Middle to late Maestrichtian, and possibly early Maestrichtian, on the basis of *Lepidorbitoides-Asterorbis* assemblages (Line Islands, Nauru Basin);

4) Early Eocene, on the basis of a Nummulites-Assilina assemblage (Nauru Basin);

5) Late early to early middle Eocene, on the basis of a *Discocyclina-Asterocyclina* assemblage (Tuamotu Ridge), associated with planktonic foraminifers of that age;

6) Middle Eocene, on the basis of the occurrence of *Polylepidina antillea* and *N.* sp. cf. *N. bagelensis* (Nauru Basin);

 Late Eocene, on the basis of Nummulites-Asterocyclina-Spiroclypeus assemblages (Nauru Basin, Tuamotu Ridge);

8) Early Oligocene, on the basis of a *Nummulites* vascus or *N. bouillei* assemblage (Nauru Basin);

9) Late Oligocene, on the basis of *Heterostegina bor*neensis-Nephrolepidina sumatrensis assemblages, probably associated with *Miogypsinoides ubaghsi* and *M.* grandipustula (Nauru Basin, Tuamotu Ridge?).

Moreover, the occurrence of transported shallowwater skeletal debris which accumulated as sediments at oceanic depths permits precise dating of erosional events by larger-foraminifer faunas and associated and/ or overlying-underlying planktonic faunas (foraminifers and radiolarians) and floras (calcareous nannoplankton). The main erosional events were:

1) Late Campanian, with the beginning of volcaniclastic sedimentation (Nauru Basin, Line Islands, Mid-Pacific Mountains);

 Middle(?)-late Maestrichtian (Nauru Basin, Line Islands);

3) Late early to early middle Eocene (Tuamotu Ridge);

4) Late Eocene (Line Islands?, Nauru Basin?, Tuamotu Ridge);

5) Early late Oligocene (Nauru Basin, Line Islands);

6) Late Oligocene (Nauru Basin, Line Islands);

7) Middle Miocene (Nauru Basin, Tuamotu Ridge?);

8) Pleistocene (Nauru Basin, Tuamotu Ridge).

Minor erosional events are recorded throughout the Oligocene part of the sequence at Hole 462 (Nauru Basin).

At some stratigraphic levels, shallow-water skeletal debris is associated with abundant volcanic material, consisting of glass (fresh to altered), rock fragments, and rare ash. This association suggests that the volcanic activity provided the necessary pedestals on which reefs and carbonate platforms could grow (see Schlanger and Premoli Silva, this volume). The shallow-water debris provides a basis for dating the volcanic activity; the best estimates for the central Pacific are: 1) Early(?)-late Campanian, based on the thick volcaniclastic sequence, containing in its upper portion the late Campanian larger foraminifers; this phase is widespread in the Line Islands, Nauru Basin, and Mid-Pacific Mountains;

2) Early(?)-middle Eocene, based on basalts recovered from the bottom of the Eniwetok drill hole (Marshall Islands) and dated at about 49 m.y.; of the same age is the beginning of volcanism in the Tuamotu Ridge, where it continued during at least part of the middle Eocene (Schlanger, Jackson, et al., 1976);

3) Middle Miocene(?) (Nauru Basin [Core 15], and Tuamotu);

Volcanic material occurs also in late(?) Eocene, early late, and late Oligocene sediments. However, this material is interpreted as being reworked along with the associated shallow-water debris, and is not therefore indicative of additional volcanic activity.

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## APPENDIX

#### **Fossil List**

Most of the larger-foraminifer taxa encountered in Hole 462 previously have not been described or illustrated from deep-sea sediments. Poor preservation often has made identification difficult; they are all illustrated and only tentatively identified.

The classification used in the present paper is that by Loeblich and Tappan (1964) at least at the family level. For the nummulitids, Cushman's classification (1949) is followed. Species will be described in a separate paper now in preparation.

### Family Orbitolinidae

Dictyconus sp. aff. D. saipanensis Cole, 1958. See: Cole, 1957, p. 329, pl. 101, fig. 3.

Family Rotaliidae

Pararotalia sp. aff. P. byramensis (Cushman), 1922. See: Ellis and Messina, 1940, et seq.

#### Family Nummulitidae

- Assilina leymeriei (d'Archiac and Haime), 1853. See: Schaub, 1951, p. 178, pl. 3, figs. 1-8; pl. 4, figs. 1-16.
- Nummulites sp. cf. N. bagelensis (Veerbeck), 1891. See: Ellis and Messina, 1940 et seq.; Doornick, 1932, p. 277, pl. 2, figs. 3-9.
- Nummulites bouillei (de la Harpe), 1879. See: Herb et al., 1975, p. 125, pl. 1, figs. 9-11.
- Nummulites burdigalensis minor (de la Harpe), 1926. See: Schaub, 1951, p. 118, pl. 3, figs. 8–9; text figs. 89–91.
- Nummulites partschi (de la Harpe), 1880. See: Schaub, 1951, p. 140, pl. 4, figs. 4-17.
- Nummulites pernotus Schaub, 1951. See: Schaub, 1951, p. 108, pl. 1, figs. 7-12; text figs. 59-61.
- Nummulites problematicus (Tellini), 1908. See: Roveda, 1970, p. 277, pl. 25, figs. 10-15.
- Nummulites rotularius Deshayes, 1838. See: Schaub, 1951, p. 125, figs. 111-116.

Nummulites sp. aff. N. variolarius (Lamarck), 1804. See: Beckmann, 1976, p. 469, pl. 7, figs. 10-12; pl. 8, figs. 7-8, 10-11.

- Nummulites vascus (Joly and Leymerie), 1848. See: Lanterno and Roveda, 1957, p. 157, pl. 2, figs. 1-10.
- Operculina sp. cf. O. complanata (Defrance), 1822. See: Ellis and Messina, 1940 et seq.
- Operculina eniwetokensis Cole, 1957. See: Cole, 1957, p. 232, pl. 103, figs. 15-23.
- Operculina subformai (Provale), 1908. See: Cole, 1963, p. E16, pl. 2, figs. 1-4.
- Sulcoperculina cubensis (Palmer), 1934. See: Ellis and Messina, 1940, et seq.
- Sulcoperculina vermunti (Thiadens), 1937. See: Beckmann, 1976, p. 469, pl. 1, figs. 8–9; pl. 2, figs. 9–10.
- Heterostegina borneensis Van der Vlerk, 1929. See: Cole 1958, p. 331, pl. 95, figs. 16-20.
- Heterostegina saipanensis Cole 1953. See: Cole, 1958, p. 331, pl. 102, figs. 17-19.
- Heterostegina suborbicularis (d'Orbigny), 1826. See: Cole 1957, p. 762, pl. 235, figs. 14-20.
- Spiroclypeus sp. cf. S. albapustula Cole, 1957. See: Cole, 1957, p. 762, pl. 238, figs. 7, 13, 18.
- Spiroclypeus higginsi Cole, 1939. See: Cole, 1957, p. 763, pl. 239, figs. 11-12, 14.
- Spiroclypeus sp. cf. vermicularis Tan, 1937. See: Cole, 1957, p. 764, pl. 238, figs. 1-6, 8-12.

#### Family Miogypsinidae

Miogypsinoides grandipustula (Cole), 1954. See: Cole, 1954, p. 602, pl. 221, figs. 2-4, 19-22; pl. 222, figs. 12-14.

Miogypsinoides ubaghsi Tan, 1936. See: Cole, 1957, p. 603, pl. 221, figs. 5-9; pl. 222, figs. 13-15.

## Family Lepidorbitoididae

- Lepidorbitoides bisambergensis (Jaeger), 1914. See: van Gorsel, 1978, p. 46, fig. 16d, text-fig. 15.
- Lepidorbitoides minor (Schlumberger), 1902. See: van Gorsel, 1978, p. 46, fig. 16e, text-fig. 15.

- Lepidorbitoides socialis (Leymerie), 1851. See: van Gorsel, 1978, p. 46, fig. 16f, text-fig. 15.
- Orbitocyclina minima (Douvillé), 1927. See: van Gorsel, 1978, p. 55, fig. 18.
- Asterorbis cubensis Palmer, 1934. See: Ellis and Messina, 1940, et seq.
- Asterorbis havanensis Palmer, 1934. See: Beckmann, 1976, p. 469, pl. 1, figs. 3, 5, 6.
- Asterorbis rooki Vaughan and Cole, 1932. See: Ellis and Messina 1940 et seq.

### Family Discocyclinidae

- Asterocyclina malladai Gómez Llueca, 1927. See: Ellis and Messina, 1940, et seq.
- Asterocyclina matanzensis Cole, 1957. See: Cole, 1957, p. 350, pl. 117, figs. 6-10; pl. 118, figs. 9-18.
- Asterocyclina penuria Cole, 1957. See: Cole, 1957, p. 350, pl. 116, figs. 1-10.

### Family Lepidocyclinidae

- Lepidocyclina (Eulepidina) sp. cf. L. ephippioides (Jones and Chapman), 1900. See: Ellis and Messina, 1965.
- Lepidocyclina (Nephrolepidina) sumatrensis (Brady), 1953. See: Cole, 1953, p. 32, pl. 10, fig. 7, pl. 11, figs. 4, 5.
- Polylepidina antillea (Cushman), 1919. See: Ellis and Messina, 1940 et seq.; Caudri, 1974, p. 310, pl. 8, figs. 6, 7.
- Polylepidina? sp. aff. P. paucispira Barker and Grimsdale, 1936. See: Ellis and Messina, 1940, et seq.

### Family Pseudorbitoididae

- Pseudorbitoides israelskyi Vaughan and Cole, 1932. See: Beckmann, 1976, p. 469, pl. 1, figs. 1, 2, 4: pl. 4, figs. 1–9.
- Vaughanina cubensis Palmer, 1934. See: Bronnimann, 1954, p. 91, pl. 18, figs. 1-4.
- Vaughanina jordanae Brönnimann, 1958. See: Ellis and Messina, 1965.



Plate 1. Photomicrographs.

- Figure 1. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 91-96 cm, late Campanian. External view, ×40.
- Figure 2. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 44-47 cm, late Campanian. External view, ×40.
- Figure 3. Vaughanina sp. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. External view, ×40.
- Figure 4. Vaughanina cubensis Palmer. Leg 61. Site 462, Core 52-1, 98-101 cm, late Campanian. External view, ×40.
- Figure 5. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 91-96 cm, late Campanian. External view, ×40.
- Figure 6. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 44-47 cm, late Campanian. External view, ×45.

- Figure 7. Asterorbis rooki Vaughan and Cole. Leg 61, Site 462, Core 48-2, 78-81 cm, middle Maestrichtian. External view, ×40.
- Figure 8. Asterorbis rooki Vaughan and Cole. Leg 61, Site 462, Core 48-2, 78-81 cm, middle Maestrichtian. External view, ×45.
- Figure 9. Asterorbis havanensis Palmer. Leg 61, Site 462. Core 48-1, 11-13 cm, middle Maestrichtian. External view, ×45.
- Figure 10. Asterorbis cubensis Palmer. Leg 61. Site 462, Core 48 soup, middle Maestrichtian. External view, ×40.
- Figure 11. Asterorbis havanensis Palmer. Leg 61, Site 462, Core 48 soup, middle Maestrichtian. External view, ×40.
- Figure 12. Sulcoperculina cubensis Palmer. Leg 61, Site 462, Core 48-2, 78-81 cm, middle Maestrichtian. External view, ×50.



Plate 2. Photomicrographs.

- Figure 1. Vaughanina sp. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. External view, ×46.
- Figure 2. Vaughanina sp. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. External view, ×55.
- Figure 3. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 44-47 cm, late Campanian. External view, ×46.
- Figure 4. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 91-96 cm, late Campanian. Axial section of broken specimen, ×92.
- Figure 5. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 91-96 cm, late Campanian. External view, ×55.
- Figure 6. Vaughanina jordanae Brönnimann. Leg 61, Site 462, Core 51-3, 91-96 cm, late Campanian. External view, ×46.
- Figure 7. Vaughanina cubensis Palmer. Leg 61, Site 462. Core 51-3, 91-96 cm, late Campanian. External view, ×46.
- Figure 8. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 44-47 cm, late Campanian. External view, ×55.
- Figure 9. Sulcoperculina sp. Leg 61, Site 462, Core 48-1, 11-13 cm, middle Maestrichtian. Side view, ×64.



Plate 3. Photomicrographs.

- Figure 1. Asterorbis havanensis Palmer. Leg 61, Site 462, Core 48 soup, middle Maestrichtian. External view, ×23.
- Figure 2. Asterorbis havanensis Palmer. Leg 61, Site 462, Core 48 soup, middle Maestrichtian. External view, ×23.
- Figure 3. Sulcoperculina vermunti Thiadens. Leg 61, Site 462, Core 48-2, 78-81 cm, middle Maestrichtian. Spiral section of broken specimen, ×45.
- Figure 4. Sulcoperculina vermunti Thiadens. Leg 61, Site 462, Core 48-2, 78-81 cm, middle Maestrichtian. Side view, ×45.
- Figure 5. Vaughanina jordanae Brönnimann. Leg 61, Site 462, Core 51-3, 91-96 cm, late Campanian. External view, ×27.
- Figure 6. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 91-96 cm, late Campanian. External view, ×45.
- Figure 7. Fragment of Axopora? Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene, ×23.
- Figure 8. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 44-47 cm, late Campanian. External view, ×45.
- Figure 9. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 91-96 cm, late Campanian. External view, ×45.



Plate 4. Photomicrographs.

- Figure 1. Pseudorbitoides sp. Leg 61, Site 462, Core 51-3, 44-47 cm, late Campanian. Equatorial section, not centered, ×55.5.
  Figure 2. Vaughanina sp. Leg 61, Site 462, Core 52-1, 101-107 cm,
- Figure 2. Vaughanina sp. Leg 61, Site 462, Core 52-1, 101-107 cm, late Campanian. Detail of marginal portion, same specimen as at Plate 5, Fig. 1, ×110.
- Figure 3. Pseudorbitoides israelskyi Vaughan and Cole. Leg 61. Site 462, Core 52-1, 98-101 cm, late Campanian. A. Equatorial section, ×65. B. Detail of the marginal portion, ×170. C. Detail of nepionic stage, ×130.
- Figure 4. Orbitocyclina sp. Leg 61, Site 462, Core 48 soup, middle Maestrichtian. Detail of nepionic stage, same specimen as at Plate 9, Fig. 3, ×110.



Plate 5. Photomicrographs.

- Figure 1. Vaughanina sp. Leg 61, Site 462, Core 52-1, 101-107, late Campanian. Equatorial section, not centered, ×70.
- Figure 2. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. Equatorial section, ×60.
- Figure 3. Pseudorbitoides sp. aff. P. israelskyi Vaughan and Cole. Leg 61, Site 462, Core 51-3, 44-47 cm, late Campanian. Equatorial section of poorly preserved specimen, ×60.
- Figure 4. *Pseudorbitoides* sp. aff. *P. israelskyi* Vaughan and Cole. Leg 61, Site 462, Core 21-1, 2-3 cm, late Oligocene. Axial section, × 120.
- Figure 5. Pseudorbitoides israelskyi Vaughan and Cole. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. Equatorial section,  $\times$  50.
- Figure 6. Lepidorbitoides socialis (Leymerie). Leg 61, Site 462, Core 48 soup, middle Maestrichtian. Equatorial section, not centered, ×80.
- Figure 7. Lepidorbitoides socialis (Leymerie). Leg 61. Site 462, Core 48 soup, middle Maestrichtian. Equatorial section, not centered,  $\times 60$ .



Plate 6. Photomicrographs.

- Figure 1. Lepidorbitoides socialis (Leymerie). Leg 61, Site 462, Core 48 soup, middle Maestrichtian: Details of the marginal portion, same specimen as at Plate 5, Fig. 7. A. ×190. B. ×92.
  Figure 2. Lepidorbitoides minor (Schlumberger). Leg 61, Site 462,
- Figure 2. Lepidorbitoides minor (Schlumberger). Leg 61, Site 462, Core 48 soup, middle Maestrichtian. Equatorial section passing through lateral chambers, ×74.
- Figure 3. Sulcoperculina cubensis Palmer. Leg 61, Site 462, Core 48-2, 78-81 cm, middle Maestrichtian. Part of equatorial section, ×92.
- Figure 4. Lepidorbitoides socialis (Leymerie). Leg 61, Site 462, Core 48 soup, middle Maestrichtian. Equatorial section, not centered, ×92.
- Figure 5. Asterorbis havanensis Palmer. Leg 61, Site 462, Core 48 soup, middle Maestrichtian. Equatorial section, not centered, ×65.



Plate 7. Photomicrographs.

- Figure 1. Lepidorbitoides bisambergensis (Jaeger). Leg 61, Site 462, Core 48 soup, middle Maestrichtian. A. Nepionic stage of specimen figured in B, ×155. B. Equatorial section, ×65.
   Figure 2. Vaughanina sp. Leg 61, Site 462, Core 48,CC, middle Maestrichtian. Tangent section through lateral chambers, ×55.
- Figure 3. Pseudorbitoides israelskyi Vaughan and Cole. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. Oblique equatorial section,  $\times 92$ .
- Figure 4. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. A. Nepionic spira of specimen in B, ×110. B. Equatorial section, ×55.



Plate 8. Photomicrographs.

Figure 1. Helicolepidina sp. aff. H. paucispira Barker and Grimsdale. Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. A. Slightly oblique equatorial section, ×83. B. Detail of nepionic stage, ×200. Figure 2. Lepidocyclina (Eulepidina) sp. cf. L. ephippioides Jones and Chapman. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Section of the marginal portion (fragment), ×18.5.

Figures 3, 4. Lepidorbitoides minor (Schlumberger). Leg 61, Site 462; Core 48,CC, middle Maestrichtian. 3. Equatorial section of poorly preserved specimen, ×28. 4. Detail of 3, ×80.



Plate 9. Photomicrographs.

- Figure 1. Fasciolites? Leg 61. Site 462, Core 22-1, 69-71 cm, late Oligocene. Axial section with inside part destroyed and filled by extraneous material, same specimen as at Plate 17, Fig. 11 and Plate 14, Fig. 6, ×55.
- Figure 2. Polylepidina antillea (Cushman). Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Equatorial section of form B, ×46.
- Figure 3. Orbitocyclina sp. Leg 61, Site 462, Core 48 soup, middle Maestrichtian. Equatorial section of poorly preserved specimen, ×46.
- Figure 4. Lepidocyclina (Nephrolepidina) sumatrensis Cole. Leg 61, Site 462, Core 22-1, 69–71 cm, late Oligocene. Slightly oblique equatorial section,  $\times 23$ .
- Figure 5. Lepidocyclina (Nephrolepidina) sumatrensis Cole. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Slightly oblique equatorial section,  $\times 23$ .
- Figure 6. Discocyclina sp. Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Oblique axial section ×18.5.
- Figures 7. Lepidorbitoides bisambergensis (Jaeger). Leg 61, Site 462, Core 48 soup, middle Maestrichtian. A. Equatorial section, ×45. B. Detail of the nepionic stage, ×115.
- Figure 8. Sulcoperculina cubensis Palmer. Leg 61, Site 462, Core 48-2, 78-81 cm, middle Maestrichtian. Equatorial section, ×46.



Plate 10. Photomicrographs.

- Figure 1. *Miogypsinoides grandipustula* Cole. Leg 61, Site 462, Core 32-1, 5-10 cm, early Oligocene. External view, ×56.
- Figure 2. Asterocyclina matanzensis Cole. Leg 61, Site 462, Core 32-1, 73-75 cm, early Oligocene. External view, ×47.
- Figure 3. Asterocyclina penuria Cole. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. External view, ×24.
- Figure 4. Miogypsinoides ubaghsi Tan Sin Hok, Leg 61, Site 462, Core 32-1, 5-10 cm, early Oligocene. Fragment of the equatorial layer, ×37.
- Figure 5. Pseudorbitoides sp. Leg 61, Site 462, Core 48 soup, middle Maestrichtian. External view, ×28.

- Figure 6. Orbitocyclina minima (Douvillé). Leg 61, Site 462. Core 48-2, 78-81 cm, middle Maestrichtian. Equatorial layer, ×28.
- Figure 7. Orbitocyclina sp. Leg 61, Site 462, Core 48-2, 78-81 cm, middle Maestrichtian. Axial section of broken specimen, ×47.
- Figure 8. Pseudorbitoides sp. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. Broken specimen along about the axial section,  $\times 58$ .
- Figure 9. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 51-3, 44-47 cm, late Campanian. External view, ×37.
- Figure 10. Vaughanian sp. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. External view, ×47.
- Figure 11. Rotalia sp. Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Spiral view, ×37.
- Figure 12. Asterorbis cubensis Palmer. Leg 61, Site 462, Core 48-2, 78-81 cm, middle Maestrichtian. External view, × 56.



Plate 11. Photomicrographs.

- Figure 1. Lepidocyclina (Nephrolepidina) sumatrensis Cole. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. A. Portion of equatorial section, ×46. B. Equatorial section of nepionic stage, ×46.
- Figure 2. Lepidorbitoides minor (Schlumberger). Leg 61, Site 462, Core 48,CC, middle Maestrichtian. A. Detail of the embrionic portion, ×115. B. Equatorial section, ×46. C. Detail of the marginal portion, ×135.
- Figure 3. Lepidocyclina sp. Leg 61, Site 462, Core 22-1, 69–71 cm, late Oligocene. A. Slightly oblique equatorial section,  $\times 55$ . B. Detail of A,  $\times 145$ .



Plate 12. Photomicrographs.

- Figure 1. Spiroclypeus sp. cf. S. vermicularis Tan. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Equatorial section, ×20.
- Figure 2. Spiroclypeus sp. cf. S. vermicularis Tan. Leg 61, Site 462, Core 32-1, 5-10 cm, early Oligocene. Oblique equatorial section, ×25.
- Figure 3. *Heterostegina saipanensis* Cole. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Equatorial section, ×20.
- Figure 4. Spiroclypeus higginsi Cole. Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Equatorial section, × 50.
- Figure 5. Operculina subformai (Provale). Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Equatorial section, not centered, × 50.
- Figure 6. *Heterostegina suborbicularis* (d'Orbigny). Leg 61, Site 462, Core 22-1, 69-71 cm, early Oligocene. Equatorial section, ×50.

- Figure 7. Asterocyclina matanzensis Cole. Leg 61, Site 462, Core 32-1, 73-75 cm, early Oligocene. Equatorial section, not centered, ×40.
- Figure 8. Asterorbis havanesis Palmer. Leg 61, Site 462, Core 48 soup, middle Maestrichtian. Equatorial section, not centered, ×40.
- Figure 9. *Polylepidina* sp. Leg 61, Site 462, Core 34,CC, late Eocene. Oblique section, ×25.
- Figure 10. Vaughanina cubensis Palmer. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. Equatorial section, not centered,  $\times 30$ .
- Figure 11. *Miogypsinoides ubaghsi* Tan. Leg 61, Site 462, Core 32-1, 5-10 cm, early Oligocene. Equatorial section,  $\times$  50.
- Figure 12. *Miogypsinoides ubaghsi* Tan. Leg 61, Site 462, Core 32-1, 5-10 cm, early Oligocene. Equatorial section,  $\times$  50.
- Figure 13. *Miogypsinoides ubaghsi* Tan. Leg 61, Site 462, Core 34,CC, late Eocene. Equatorial section,  $\times$  50.



Plate 13. Photomicrographs.

- Figure 1. Miogypsinoides ubaghsi Tan. Leg 61, Site 462, Core 32-1, 5-10 cm, early Oligocene. Tangent section, ×70.
- Figure 2. *Polylepidina* sp. Leg 61, Site 462, Core 34,CC, late Eocene. A. Oblique equatorial section, ×88. B. Detail of A, ×210.
- Figure 3. Miogypsinoides ubaghsi Tan. Leg 61, Site 462, Core 32-1, 5-10 cm, early Oligocene. Equatorial section, marginal portion, ×60.
- Figure 4. Miogypsinoides grandipustula Cole. Leg 61, Site 462, Core 32-1, 5-10 cm, early Oligocene. Equatorial section, not centered, ×55.

Figure 5. Miogypsinoides ubaghsi Tan. Leg 61, Site 462, Core 32-1, 5-10 cm, early Oligocene. Equatorial section, ×53.

- Figure 6. Miogypsinoides grandipustula Cole. Leg 61. Site 462, Core 32-1, 5-10 cm, early Oligocene. Oblique section, ×55. Figure 7. *Dictyoconus* sp. aff. *D. saipanensis* Cole. Leg 61, Site 462,
- Core 21-1, 2-3 cm, late Oligocene. Oblique section, ×50.



Plate 14. Photomicrographs.

- Figure 1. Heterostegina saipanensis Cole. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Slightly oblique equatorial section, ×46.
- Figure 2. Spiroclypeus cf. vermicularis Tan. Leg 61, Site 462, Core
- 22-1, 69-71 cm, late Oligocene. Equatorial section, ×27.5
   Figure 3. Spiroclypeus sp. cf. S. vermicularis Tan. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Equatorial section, ×46.
- Figure 4. Lepidocyclina (Nephrolepidina) sumatrensis (Brady) Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Slightly oblique equatorial section, ×46.
- Figure 5. Polylepidina antillea (Cushman). Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Equatorial section of form B, ×92.
- Figure 6. Fasciolites? Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Detail of Plate 9, Fig. 1, same specimen as in Plate 17, Fig. 11, ×110.



Plate 15. Photomicrographs.

- Figure 1. Operculina eniwetokensis Cole. Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Spiral view, ×65.
- Figure 2. Nummulites rotularius Deshayes. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. A. External view, ×55. B. Spiral view, ×55. Figure 3. Nummulites sp. Leg 61, Site 462, Core 32-1, 5-8 cm, early
- Oligocene. Spiral view, ×28.

Figure 4. Nummulites sp. Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Spiral view, ×46.

Figure 5. Nummulites burdigalensis minor (de la Harpe). Leg 61, Site

- 462, Core 32-1, 5-8 cm, early Oligocene. External view, ×46. Figure 6. *Heterostegina* sp. Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Spiral view, ×55.
- Figure 7. Nummulites problematicus (Tellini). Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. A. External view, ×55. B. Spiral view, ×55.



Plate 16. Photomicrographs.

- Figure 1. Nummulites partschi (de la Harpe). Leg 61, Site 462, Core 21-1, 2-3 cm, late Oligocene. A. Spiral view, ×55. B. External view, ×55.
- Figure 2. *Heterostegina borneensis* Van der Vlerk. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Spiral view, ×46.
- Figure 3. Heterostegina suborbicularis (d'Orbigny). Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Spiral view, ×46.

Figure 4. Heterostegina sp. aff. H. borneensis. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Spiral view, ×46.

Figure 5. *Heterostegina saipanensis* Cole. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Spiral view, ×23.

Figure 6. *Heterostegina borneensis* Van der Vlerk. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Spiral view, ×55.

- Figure 7. Spiroclypeus? sp. Leg 61, Site 462, Core 34,CC, late Eocene. External view, ×28.
- Figure 8. Assilina leymerieri (d'Archiac and Haime). Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Spiral view, ×55.



Plate 17. Photomicrographs.

- Figure 1. Nummulites pernotus Schaub. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. A. Spiral view, ×40. B. External view, ×40.
- Figure 2. Nummulites sp. aff. N. variolarius (Lamarck). Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. A. Spiral view, ×40. B. External view, ×40.
- Figure 3. Nummulites sp. cf. N. bagelensis (Veerbek). Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Spiral view, fragment, ×40.
- Figure 4. Assilina leymeriei (d'Archiac and Haime). Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. External view, ×25.
- Figure 5. Nummulites bouillei (de la Harpe). Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Partially peeled specimen, × 50.

- Figure 6. Nummulites burdigalensis minor (de la Harpe). Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Spiral view, ×20.
- Figure 7. Operculina subformai (Provale). Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Spiral view, × 50.
- Figure 8. Spiroclypeus sp. cf. vermicularis Tan. Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Spiral view, ×20.
- Figure 9. Operculina sp. cf. O. complanata (Defrance). Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. External view, ×15.
- Figure 10. Heterostegina suborbicularis (d'Orbigny). Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Spiral view, ×15.
- Figure 11. Fasciolites? Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. External view, same specimen as at Plate 9, Fig. 1, and Plate 14, Fig. 6,  $\times$  60.



Plate 18. Photomicrographs.

- Figure 1. Spiroclypeus sp. cf. S. vermicularis Tan. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Equatorial section, ×23.
- Figure 2. Spiroclypeus sp. cf. S. albapustula Cole. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Equatorial section, not centered, ×18.5.
- Figure 3. Rotalia sp. Leg 61, Site 462, Core 14-5, 78-81 cm, middle Miocene. Ventral view, ×18.5.
- Figure 4. Pararotalia sp. aff. P. byramensis (Cushman). Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Ventral view, ×18.5.

Figure 5. Asterocyclina malladai Gomez Llueca. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. External view, ×18.5.

- Figure 6. Asterocyclina matanzensis Cole. Leg 61, Site 462, Core 32-1, 73-75 cm, early Oligocene. External view, ×28.
- Figure 7. Asterocyclina malladai Gomez Llueca. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. External view, ×28.
- Figure 8. Asterocyclina penuria Cole. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. External view, ×18.5.
- Figure 9. Vulvulina sp. Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene, ×28.



Plate 19. Photomicrographs.

- Figures 1, 2. Leg 61, Site 462A, Core H2-1, 125-131 cm, late Oligocene. Thin sections. 1. Bottom. 2. Top of a coarser layer containing heavily recrystallized larger foraminifers (arrows), possibly discocyclinids, ×25.
- Figure 3. Discocyclina sp. Leg 61, Site 462, Core 14-5, 79-81 cm, early Miocene. Thin section tangent to surface,  $\times 20$ .
- Figure 4. Sphaerogypsina sp. Leg 61, Site 462, Core 21-1, 2-3 cm, late Oligocene. Thin section, ×24.
- Figure 5. Fragment of rudistid. Leg 61, Site 462, Core 21-1, 2-3 cm, late Oligocene. Thin section, ×24.

Figure 6. Fragment of rudistid. Leg 61 Site 462, Core 22-1, 69-71 cm, late Oligocene. Thin section, ×24.

- Figure 7. Leg 61, Site 462, Core 48,CC, middle Maestrichtian. Thin section of coarse layer,  $\times 30$ .
- Figure 8. Leg 17, Site 165A, Core 16,CC, middle(?) Maestrichtian. Fragment of *Pseudorbitoides* sp. Axial section, ×65.
- Figure 9. Leg 17, Site 165A, Core 16,CC, middle(?) Maestrichtian. Fragment of Vaughanina? sp. Axial section, ×65.
- Figure 10. Leg 61, Site 462, Core 22-1, 69–71 cm, late Oligocene. Equatorial section of badly preserved specimen of orbitoidal foraminifer,  $\times$  50.



Plate 20. Photomicrographs.

- Figures 1, 2. Bryozoan. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. ×18.5.
- Figure 3. Axopora? sp., milleporine hydrozoan. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. ×18.5. Figures 4, 7. Cyclostomate bryozoan. Leg 61, Site 462, Core 22-1, 69-
- 71 cm, late Oligocene. 4. ×37. 7. ×50.
- Figure 5. Stylopora. Leg 61, Site 462, Core 34, CC, late Eocene × 55. Figure 6. Seriatopora. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. ×53.
- Figure 8. Porites. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. ×18.5.
- Figure 9. Echinoid spine. Leg 61, Site 462, Core 51-3, 44-47 cm, late Campanian. ×45.
- Figure 10. Echinoderm articulate plate. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. ×14.
- Figures 11, 12. Actinastrea? Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. ×18.5.
- Figure 13. Alcyonacean, octocorallia. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. × 55.