5. SHALLOW-WATER SKELETAL DEBRIS AND LARGER FORAMINIFERS FROM DEEP SEA DRILLING PROJECT SITE 462, NAURU BASIN, WESTERN EQUATORIAL PACIFIC

Isabella Premoli Silva and Chiara Brusa, Istituto di Paleontologia, Università di Milano, Piazzale Gorini 15, Milano, Italy

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 nanoplankton). 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, and middle Miocene). Foraminifers cover a long time interval, but are few and mainly restricted to the upper levels, are probably Neogene or younger.

The most commonly represented taxonomic groups are larger foraminifers, including Discocyclinidae, Mio-gypsiniidae, 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-µm 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-µm fraction.

2) Layers corresponding to the typical foraminifer sands, in which shallow-water material is scarce, poorly diversified, never exceeding 15% of the > 63-µm fraction, dominated by planktonic foraminifers. The larger foraminifers cover a long time interval, but are few and mainly restricted to small fragments, often with very chalky, poorly preserved inner parts. Volcanic material is present as a minor component of the > 63-µm 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
material is highly diversified and belongs to more-differentiated 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 pseudorbitoides, 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 Asteroorbis, 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 *Globotruncanina subspinitos* and *Globotruncanina 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 *Lepidorbitoideis 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 planktonic-foraminifer assemblages in Core 48 are characteristic of the *Globotruncanina gansseri Zone,* of middle Maestrichtian age; among the *Lepidorbitoideis,* the identified species *L. bisambergensis, L. minor,* and *L. socialis,* according to van Gersel (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. bisambergensis,* the oldest species, ranging from the early Maestrichtian *Globotruncanina tricarinata Zone* through the middle part of the *Globotruncanina 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 Maastrichtian).

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 Maastrichtian *G. gansseri* Zone, are also reworked into the late Maastrichtian. Planktonic foraminifers indicating the *Abathomphalus mayaroensis* Zone, or even the underlying *Globotrichia 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 rudist 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 leymerei*, *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. leymerei* 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*, *Spirocyclus* sp. cf. *S. vermicularis*, *S. sp. cf. S. alpapatula*, *Asterocyclina matazensis*, *A. penuria*, *Polypleidina 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, *Polypleidina 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*, *Spirocyclus vermicularis*, and *S. alpapatula* 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 *Spirocyclus*, 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. ephippioidea*, 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 *Eupelidina ephippioidea* 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-
Reef Skeletal Debris and Larger Foraminifers | Planktonic and Bathyal to Abyssal Benthic Foraminifers | Volcanic Material | Age
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Late Cretaceous through Miocene transported planktonic foraminifers, Late Miocene (N17) assemblages dominate.
Late Cretaceous through late Miocene transported planktonic foraminifers, Middle Miocene (N12–N13) assemblages dominate.
Late Cretaceous, late Paleocene–early Eocene, early Oligocene transported planktonic foraminifers, Early Miocene (N4, N7) and middle Miocene (N10–N13) assemblages dominate.
Late Cretaceous, late Paleocene, early 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, middle and late Oligocene transported planktonic foraminifers, Middle Oligocene assemblages dominate.
Late Cretaceous, late Paleocene–early Eocene, early Oligocene transported planktonic foraminifers with few small benthic foraminifers, Early Oligocene assemblages dominate.
Late Cretaceous, late Paleocene–early Eocene, early Oligocene transported planktonic foraminifers, Abundant volcanic glass and rock fragments.
Rare Aptian–Albian transported planktonic foraminifers associated with Late Cretaceous, late Paleocene–early Eocene, late Eocene displaced planktonic foraminifers.
Volcanic glass and rock fragments.
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<td>Late Cretaceous, late Paleocene, early Eocene transported planktonic foraminifers.</td>
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<td>Abundant volcanic glass and rock fragments. Very abundant volcanic glass, pyroxene and rock fragments.</td>
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<td>Late Cretaceous and late Paleocene (P4) transported planktonic foraminifers.</td>
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<td>Abundant volcanic material: fresh to altered glass, pyroxene, biotite, zeolite, and rock fragments.</td>
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<td>First occurrence of transported planktonic and small bathyal benthic foraminifers of Cenomanian age.</td>
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**Figure 1.** Distribution in DSDP Hole 462 of transported and reworked material, including larger foraminifers and reef skeletal debris, planktonic and bathyal to abyssal benthic foraminifers, and volcanic material, plotted against depth, lithology, and age.
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.
eroestegina 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−P* angle (~400°), 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 biostatigraphic 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 *Miogypsinoides* 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, ~37 m.y. ago, to topmost Oligocene, ~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 (*Alcyonocan), and to cyclotomate 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), Tuamoto Ridge (Site 318), Mid-Pacific Mountains (Sites 171, 313), Caroline Ridge (Site 58), and Western Pacific Seamounts (Site...
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 Solenoporaceae. 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*, *Sulcroperculina*, 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 *Globotruncanca calcarata* Zone. At Site 315, only pelagic sediments are recorded from this interval.

Assemblage (2), with *Lepidorbitoides*, *Sulcroperculina*, and some pseudorbitoids, is recorded at Site 315 (Cores 17A and 18A) in the middle Maestrichtian *Globotruncanca 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-Asterocyclus* assemblage recovered at Site 318, Core 32 (Tuamotu Ridge). In this core, the shallow-water 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 seminivalvula 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, representative of Eocene assemblages (e.g., Discocyclina and Asterocyclina) are reworked in the early 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 25 and 26).

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 7 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 coralline 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 volcanioclastic breccia containing coarse, shallow-water debris, including Lepidocyclina, as mentioned above, recorded at Site 318, Core 10, Section 1. This breccia, underlain by foraminifer-nannofossil 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.

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 magnetic-anomaly 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-
### 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.
Figure 4. (Continued).
finities with the Caribbean province. Only one element of the Caribbean faunas, Polypletidina (Adams, 1967), is surely recorded in the Marshall Island area during the middle Eocene; Polypletidina 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, Spiroclipeus), 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 widespread 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–Asterobis 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 Polyplepidina antillea and N. sp. cf. N. bagelensis (Nauru Basin);

7) Late Eocene, on the basis of Nummulites–Asterocyclina–Spiroplectus assemblages (Nauru Basin, Tuamotu Ridge);

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

9) Late Oligocene, on the basis of Heterostegina boreensis–Nephrolepidina sumatrensis assemblages, probably associated with Miogypsinoideae ubaghsi and M. grandisputula (Nauru Basin, Tuamotu Ridge?).

Moreover, the occurrence of transported shallow-water 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 nanoplankton). The main erosional events were:

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

2) 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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REFERENCES


N. bagelensis

N. vascus(B)-N. bouillleii

N. miliaris{B)-N. ramosiformis{A)

N. incrassatus{B)-N. ramondiformis{A)


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


Family Rotaliidae

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

Family Nummulitidae

Assinia leymerieuxi (d’Archiac and Haire), 1853. See: Schaub, 1951, p. 178, pl. 3, figs. 1-8; pl. 4, figs. 1-16.

Nummulites sp. cf. N. bagelensis (Veever), 1891. See: Ellis and Messina, 1940 et seq.; Doornink, 1932, p. 277, pl. 2; figs. 3-9.

Nummulites bouilli (de la Harpe), 1879. See: Herb et al., 1975, p. 125, pl. 1, figs. 9-11.

Nummulites burgdorferi minor (de la Harpe), 1926. See: Schaub, 1951, pl. 118, pl. 3, figs. 8-9; text figs. 89-91.

Nummulites partchii (de la Harpe), 1880. See: Schaub, 1951, pl. 140, pl. 4, figs. 4-17.


Neumulites sp. aff. *N. variolarius* (Lamarck), 1804. See: Beckmann, 1976, p. 469, pl. 7, figs. 10-12; pl. 8, figs. 7-8, 10-11.
Neumulites 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.
Sulcoperculina cubensis (Palmer), 1934. See: Ellis and Messina, 1940, et seq.
Sulcoperculina vermunti (Thiadas), 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.
Spirocyclus higgsii Cole, 1939. See: Cole, 1957, p. 763, pl. 239, figs. 11-12, 14.
Spirocyclus 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 Lepidocyclinidae

Lepidocycla (Nephrolepidina) sumatrensis (Brady), 1953. See: Cole, 1953, p. 32, pl. 10, fig. 7, pl. 11, figs. 4, 5.
Polylepidina antillae (Cushman), 1919. See: Ellis and Messina, 1940 et seq.; Caudri, 1974, p. 310, pl. 8, figs. 6, 7.

Family Pseudorbitoididae

Pseudorbitoides israelskyi Vaughan and Cole, 1932. See: Beckmann, 1976, p. 469, pl. 1, figs. 1, 2, 4; pl. 4, figs. 1-9.
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 cubsensis* Palmer. Leg 61, Site 462, Core 51-3, 91-96 cm, late Campanian. External view, ×40.

Figure 6. *Vaughanina cubsensis* 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. *Suiceratina 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.
Figure 1. *Pseudorbitoides* sp. Leg 61, Site 462, Core 51-3, 44-47 cm, late Campanian. Equatorial section, not centered, ×55.5.

Figure 2. *Vaughania* 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.
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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, ×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 Maestrichian. Equatorial section, not centered, ×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, 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. Neptic stage of specimen figured in B, x155. B. Equatorial section, x65.

Figure 2. *Vaughanina* sp. Leg 61, Site 462, Core 48, CC, middle Maestrichtian. Tangent section through lateral chambers, x55.

Figure 3. *Pseudorbitoides israelski* Vaughan and Cole. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. Oblique equatorial section, x92.

Figure 4. *Vaughanina cubensis* Palmer. Leg 61, Site 462, Core 52-1, 98-101 cm, late Campanian. A. Neptic spira of specimen in B, x110. B. Equatorial section, x55.
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.

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, x55.

Figure 2. *Polylepidina antillea* (Cushman). Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Equatorial section of form B, x46.

Figure 3. *Orbitocyclina* sp. Leg 61, Site 462, Core 48 soup, middle Maestrichtian. Equatorial section of poorly preserved specimen, x46.

Figure 4. *Lepidocyclina (Nephrolepidina) sumatrensis* Cole. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Slightly oblique equatorial section, x23.

Figure 5. *Lepidocyclina (Nephrolepidina) sumatrensis* Cole. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Slightly oblique equatorial section, x23.

Figure 6. *Discocyclina* sp. Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Oblique axial section, x18.5.


Figure 8. *Sulcoperculina cubensis* Palmer. Leg 61, Site 462, Core 48-2, 78-81 cm, middle Maestrichtian. Equatorial section, x46.
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, ×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. *Asteroritis 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 Maastrichtian. A. Detail of the embryonic 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, ×55. B. Detail of A, ×145.
Plate 12. Photomicrographs.

Figure 1. *Spiroclupeus* sp. cf. *S. vermicularis* Tan. Leg 61, Site 462, Core 22-1, 69-71 cm, late Oligocene. Equatorial section, ×20.

Figure 2. *Spiroclupeus* 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. *Spiroclupeus higginsi* Cole. Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Equatorial section, ×50.

Figure 5. *Operculina subformai* (Provalle). Leg 61, Site 462, Core 32-1, 5-8 cm, early Oligocene. Equatorial section, not centered, ×50.

Figure 6. *Heterostegina suborbiculatris* (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 havanensis* 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, ×30.

Figure 11. *Miogypsinoides ubaghsi* Tan. Leg 61, Site 462, Core 32-1, 5-10 cm, early Oligocene. Equatorial section, ×50.

Figure 12. *Miogypsinoides ubaghsi* Tan. Leg 61, Site 462, Core 32-1, 5-10 cm, early Oligocene. Equatorial section, ×50.

Figure 13. *Miogypsinoides ubaghsi* Tan. Leg 61, Site 462, Core 34,CC, late Eocene. Equatorial section, ×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. *Polyplectinos* 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. salpanensis* Cole. Leg 61, Site 462, Core 21-1, 2-3 cm, late Oligocene. Oblique section, ×30.
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 32-1, 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.
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 subformata* (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, ×60.
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. Rotala 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. Vulvalina 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, ×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, ×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, ×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. Syllopora. 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.