28. FORAMINIFERAL STRATIGRAPHY OF CENOZOIC SEDIMENTS OF THE MARIANA TROUGH AND FORE-ARC REGION, DEEP SEA DRILLING PROJECT LEG 60[1]

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ABSTRACT

Deep-water Pliocene and Quaternary turbidites, hemipelagic mudstones, and volcaniclastic sediments of the Mariana Trough contain poor assemblages of planktonic foraminifers (Sites 454, 455, and 456); at Site 453 they were almost completely destroyed by selective dissolution. On the eastern flank of the Mariana island arc, siliceous mud, nannofossil ooze, and chalk with ash layers are characterized by impoverished associations of planktonic foraminifers of Oligocene, Miocene, Pliocene, and Quaternary age (Site 458). They become very scarce in deep-water Oligocene, Miocene, and Quaternary siliceous claystones, volcaniclastic turbidites, siliceous and nannofossil oozes of Site 459, disappearing completely in abyssal sediments of the inner wall of the Mariana Trench (Sites 460 and 461). Quaternary pelagic clays and Cretaceous porcellanites and cherts located on the Pacific plate crust (Site 452) are barren of foraminifers. Comparison is made with the stratigraphic results of previous drilling in the West Mariana Basin (Leg 6) and land section of the Mariana Islands (Guam, Saipan).

INTRODUCTION

Drilling on Leg 60 of the Deep Sea Drilling Project took place in the South Philippine Sea and had as its main objective to study the structural evolution, back-arc spreading, and subduction processes of the Pacific Ocean active margin. The area investigated is composed of the following structural elements: the actively spreading inter-arc basin—the Mariana Trough; the presently active island arc—the Mariana Ridge, including its fore-arc region; the Mariana Trench; and the Pacific oceanic plate—the northern Mariana Basin. Accordingly, 10 sites were selected for the drilling of 17 holes along the transect at about 18°N latitude (Figure 1): Sites 453 through 456 in the Mariana Trough; Site 457 on the axis of the active volcanic arc; Sites 458 and 459 on the eastern flank of the Mariana island arc: Sites 460 and 461 on the inner wall of the Mariana Trench; and Site 452 on the old oceanic crust of the Pacific. Data on the Leg 60 holes are summarized in Table 1.

A number of samples (474) were washed and investigated for foraminifers. In general, foraminifers are very scarce and assemblages are not diverse in the predominantly deep-water sediments. Many samples are barren. The ordinarily high stratigraphic resolution based on planktonic foraminifers is therefore not possible.

SITE SUMMARIES

The data on stratigraphic subdivision of Cenozoic deposits of the South Philippine Sea are presented in the following sections in accordance with the west to east disposition of the drill sites—that is, from the Mariana Trough to the Pacific plate.

Site 453

This site is located near the western edge of the Mariana Trough. Coarse, poorly sorted igneous polymict breccias of the "basement" are overlain by a thick pile of volcanogenic detrital sediments (sands, silts, clays, and silty clays). Based on nannofossils, sediments belong to the Pliocene-Quaternary. Only three samples contain planktonic foraminifers. Very scarce, small *Sphaeroidinella dehiscens, Sphaeroidinellopsis seminulina, Globorotalia tumida, Globigerinoides ruber,* and *Globigerina* sp. were found in Samples 453-37-5, 19–20 cm and 453-37-2, 29–31 cm, indicating an early Pliocene age (within the *Globorotalia margaritae evoluta* Zone). Sample 453-3-1, 50–52 cm is characterized by scarce *Sphaeroidinella dehiscens, Globigerinoides trilobus, G. ruber,* and debris of *Globorotalia tumida* (Pliocene-Quaternary). The remaining 114 samples are barren of planktonic foraminifers.

The sedimentary environment throughout the Pliocene and Quaternary seems to have been deep-water, similar to the recent depth conditions (4693 m), and planktonic foraminifers have been dissolved.

A peculiarity of the microfauna at Site 453 is the general absence of benthonic foraminifers. Only in Sample 453-3-1, 50–52 cm were scarce specimens of deep-sea *Pullenia, Cassidulina, Polymorphina,* and *Hyperammina* encountered. Absence of representatives of this group may be related to the high rate of sedimentation (thickness of Pliocene-Quaternary clastic sediments is 455.5 m).

Site 454

This site is located near the center of the Mariana Trough, at a shallower depth (3819 m) than Site 453. Hemipelagic sediments (mud, vitric mud, volcanic ash, and siliceous ooze) are more calcareous here, with intercalations of nannofossil and siliceous nannofossil oozes. They rest on basaltic rocks with some interbeds of vitric mudstones and silty tuff. Planktonic foraminifers were identified in almost all samples, but specimens are not numerous and diversity is very low. It appears that they have been affected by selective dissolution. The assemblage consists of *Globorotalia truncatulinoides, G. tumida, G. menardii, G. inflata* (very

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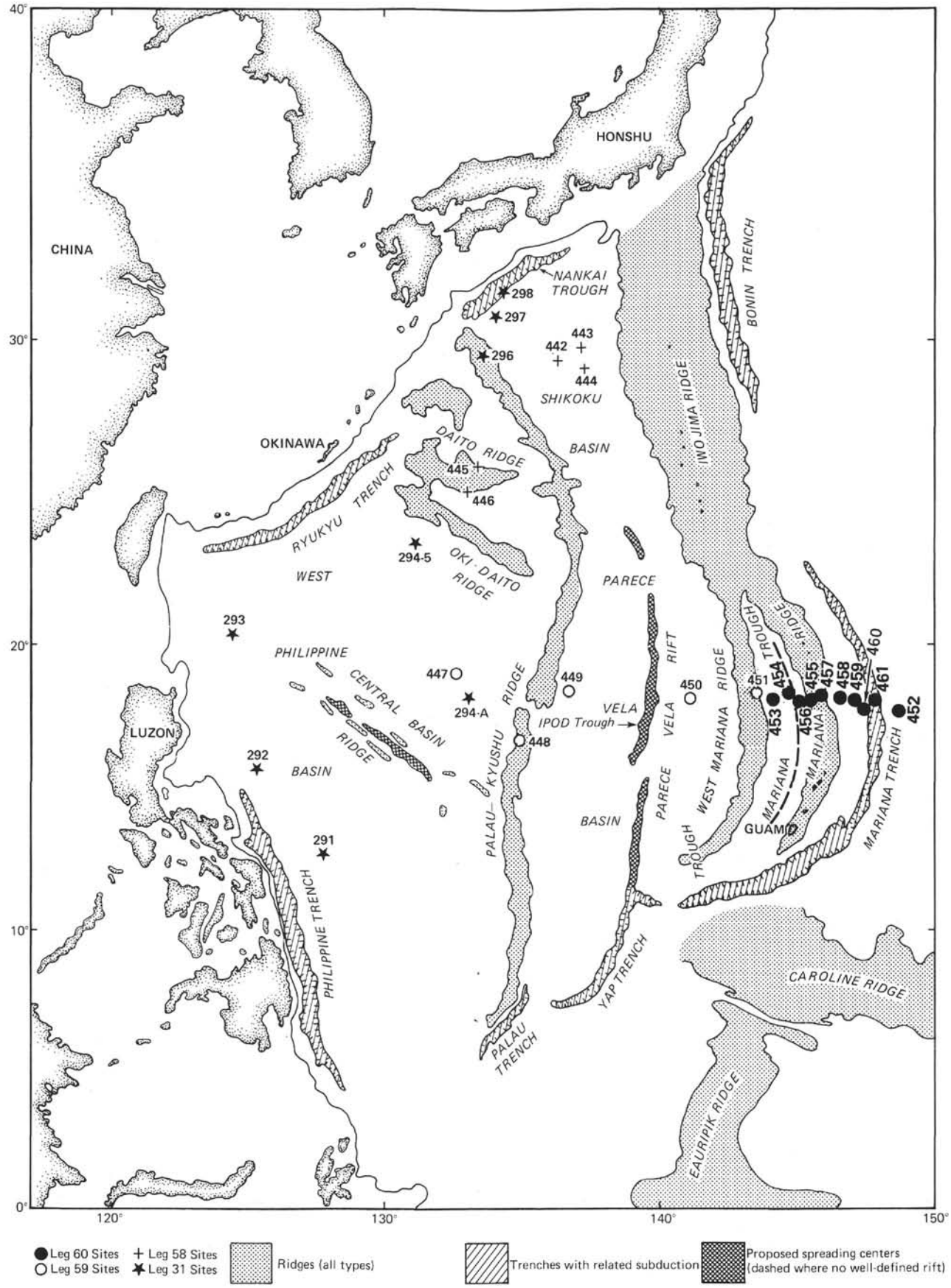

Figure 1. Location of sites drilled during Leg 60.

Table 1. Data on Leg 60 holes.

Hole	Latitude (N)	Longitude (E)	Water Depth (m)	Penetration (m)	Thickness of Cenozoic Sediments (m)	Number of Samples
452	17°40.19′	148°37.73′	5858	28.0	28.0	20
452A	17°40.17′	148°37.75′	5862	46.5	27.5	24
453	17°54.42′	143°40.95′	4693	605	455.5	117
454	18°00.78′	144°31.92′	3818.5	38.5	38.5	16
454A	18°00.78′	144°31.92′	3819	171.5	67	11
455	17°51.26′	145°21.48′	3468	104	104	15
456	17°54.68′	145°10.77′	3590.5	169	134	19
456A	17°54.71′	145°10.88′	3591	159	114	26
457	17°49.99′	145°49.02′	2637	61	61	4
458	17°51.84′	146°56.06′	3449	465.5	256.5	43
459B	17°51.75′	147°18.09′	4115	691.5	559	117
460	17°40.14′	147°37.92′	6451	85	74.5	20
460A	17°40.02′	147°35.16′	6443	99.5	76	22
461	17°46.05′	147°41.18′	7029	20.5	20.5	9
461A	17°46.01′	147°41.26′	7034	15.5	15.5	10

scarce), *G. crassaformis crassaformis, G. crassaformis ronda, G. crassaformis oceanica, Sphaeroidinella dehiscens, Orbulina universa, Globigerinella siphonifera, Pulleniatina obliquiloculata, Neogloboquadrina dutertrei, Globigerinita uvula, Globigerinoides conglobatus, G. trilobus, G. ruber, G. sacculifer,* and *Globigerina calida.* They indicate the age of the sediments to be Quaternary (undifferentiated).

Benthonic foraminifers, unlike at Site 453, are more numerous and diverse; they are representative of a deep-sea assemblage (*Pullenia, Melonis, Lagena, Cassidulina, Eponides, Cibicides, Planulina, Alabamina, Saccammina,* and *Adercotryma*).

Interval: from Section 454-3-1, 50–52 cm to Section 454-5-6, 30–32 cm and from Section 454A-1-1, 50–52 cm to Section 454A-4-3, 50–52 cm.

Site 456

Two holes of this site in the eastern part of the Mariana Trough penetrated Quaternary semi-lithified vitric mudstones, nannofossil chalk and tuffs resting on basalts and passing up-section to unlithified vitric mud, and nannofossil and siliceous oozes with vitric ash layers.

Planktonic foraminifers here are more common than at Site 454. Nevertheless, they are not abundant and can be characterized by the term "scarce" and, in some cases, "common." Quaternary planktonic foraminifers are represented by *Globorotalia truncatulinoides, G. tumida, G. menardii, G. crassaformis, G. scitula, G. ungulata, Neogloboquadrina dutertrei, Pulleniatina obliquiloculata, Sphaeroidinella dehiscens, Orbulina universa, Hastigerina pelagica, Globigerinella siphonifera, Globorotaloides hexagonus, Candeina nitida, Globigerinoides conglobatus, G. ruber, G. sacculifer, G. trilobus, Globigerinita glutinata,* and *Globigerina bulloides.*

The presence of scarce specimens of *Globigerina calida calida* and *Globorotalia tosaensis* allows subdivision of the Quaternary deposits.

Interval: from Section 456-1-1, 50–52 cm to Section 456-2-3, 62–64 cm—late Quaternary [the *Globigerina calida calida* Zone (N23) in Blow's sense].

Interval: from Section 456-2-4, 62–64 cm to Section 456-6-2, 50–52 cm—Quaternary undifferentiated.

Interval: from Section 456-6-3, 50–52 cm to Section 456-10-3, 63–65 cm—early Quaternary with both *Globorotalia truncatulinoides* and *G. tosaensis* [the *Globorotalia truncatulinoides* Zone (N22) in Blow's sense].

Interval: from Section 456A-1-1, 50–52 cm to Section 456A-9-2, 25–27 cm—Quaternary undifferentiated.

Interval: from Section 456A-10-1, 66–68 cm to Section 456A-10-4, 32–34 cm—early Quaternary [the *Globorotalia truncatulinoides* Zone (N22) in Blow's sense].

Site 455

This is the most easterly site in the Mariana Trough. Quaternary volcanogenic sediments are composed of vitric mud, sandy ash, and volcanic sands and gravel with thin intercalations of vitric nannofossil oozes. Volcaniclastic material is derived from the nearby islands of the active Mariana volcanic arc.

Bionomic conditions apparently were unfavorable for planktonic foraminifers. The following species are very scarce in these sediments: *Globorotalia truncatulinoides, G. menardii, G. inflata, G. crassaformis, G. tumida, G. scitula, Globigerinoides conglobatus, G. ruber, G. sacculifer, G. trilobus, Orbulina universa, Neogloboquadrina dutertrei, Sphaeroidinella dehiscens, Globigerinita glutinata, Pulleniatina obliquiloculata, Globigerinella siphonifera, Globorotaloides hexagonus, Globigerina calida,* and *G. rubescens.*

Scarce specimens of *Globigerina calida calida* in the interval from Section 455-1-1, 50–52 cm to Section 455-1-2, 50–52 cm indicate the late Quaternary *Globigerina calida calida* Zone (N23) in Blow's sense. The interval from Section 455-1-3, 50–52 cm to Section 455-3-2, 50–52 cm is assigned to undifferentiated Quaternary.

Benthonic foraminifers are represented by scarce specimens of deep-water *Cassidulina, Pullenia, Melonis, Pyrgo, Laticarinina,* and *Cibicides.*

Site 457

This site is situated on the axis of the Mariana island arc, near Alamagan island. Quaternary sediments consist of coarse volcanic sands which appear to alternate with muddy vitric ash.

In Sample 457-2-1, 23–25 cm, the planktonic foraminiferal assemblage includes *Globorotalia truncatulinoides, G. menardii, G. scitula, G. tumida, Globigerinoides conglobatus, G. trilobus, G. ruber, G. sacculifer, Neogloboquadrina dutertrei, Orbulina universa, Globorotaloides hexagonus,* and *Globigerinella siphonifera* together with white and pink *Globigerina rubescens* and *G. calida calida* (late Quaternary, the *Globigerina calida calida* Zone in Blow's sense).

In the interval from Section 457-3-1, 29–31 cm down to Section 457-4-2, 40–42 cm, the last two guide fossils are missing and the poor planktonic foraminiferal assemblages can be assigned to the Quaternary (undifferentiated).

Shallow-water benthonic foraminifers with thick-walled shells are clear indication of displacement from the shelf area.

Site 458

This site is located in the fore-arc region midway between the Mariana volcanic arc and the Mariana Trench axis. Pillow and massive volcanic flows of the basement are overlain by Oligocene vitric siltstone and sandstone. They are replaced up-section by Oligocene and early and middle Miocene nannofossil chalk and siliceous nannofossil chalk with intercalations of vitric mudstone and tuff. A hiatus separates these sediments from upper Miocene, Pliocene, and Quaternary siliceous nannofossil, nannofossil, and vitric nannofossil oozes with thin beds of silty or sandy ash.

Although the sediments are calcareous, assemblages of planktonic foraminifers are impoverished. Tests are few to scarce, and only in some samples are they common. Many zonal species are lacking. Therefore, only a rather rough stratigraphic subdivision of the sediments is possible.

The interval from Section 458-1-1, 50–52 cm to Section 458-1-5, 50–52 cm with *Globigerina calida calida, Globorotalia truncatulinoides, G. tumida, G. menardii, G. crassaformis crassaformis, G. crassaformis ronda, G. ungulata, Sphaeroidinella dehiscens, Pulleniatina obliquiloculata, Candeina nitida, Orbulina universa, Globigerinella siphonifera, Globigerinoides conglobatus, G. trilobus, G. ruber,* and *G. sacculifer* is dated as late Quaternary (*Globigerina calida calida* Zone in Blow's sense, N23).

The interval from Section 458-2-1, 50–52 cm to Section 458-2-6, 50–52 cm with more diverse planktonic foraminifers (*Globorotalia truncatulinoides, G. tosaensis, G. puncticulata, G. menardii, G. tumida, G. scitula, G. crassaformis, Orbulina universa, Globigerinoides trilobus, G. ruber, G. sacculifer, G. conglobatus, Pulleniatina obliquiloculata, Sphaeroidinella dehiscens, Candeina nitida, Neogloboquadrina dutertrei, Globigerinella siphonifera, Globorotaloides hexagonus,* and *Globigerinita glutinata*) is dated as early Quaternary (*Globorotalia truncatulinoides* Zone in Blow's sense, N22).

The interval from Section 458-3-1, 50–52 cm to Section 458-4-1, 50–52 cm contains very scarce and badly preserved planktonic foraminifers. A few *Globigerinoides conglobatus, G. ruber, Globorotalia tumida, Sphaeroidinella dehiscens* are indicative of a Pliocene-Quaternary age.

The interval from Section 458-5-1, 50–52 cm to Section 458-5-4, 50–52 cm is characterized by an entirely different microfauna consisting of numerous *Globigerina nepenthes, Sphaeroidinellopsis seminulina,* and scarce specimens of *S. subdehiscens, Orbulina universa, Globigerinoides trilobus,* and *Globorotalia acostaensis.* The age of the sediments can be determined only as late Miocene to early Pliocene.

On the basis of nannofossils and radiolarians (see Ellis and Kling, this volume) the Miocene and Pliocene are separated by a hiatus (between Cores 4 and 5), and uppermost Miocene-lower Pliocene sediments are missing. The sharp change in planktonic foraminiferal assemblages between Cores 4 and 5 indirectly confirms this hiatus, but their diversity is too poor to permit zonation and to define the absence of some foraminiferal zones.

In the interval from Section 458-6-1, 60–62 cm to Section 458-7-3, 50–52 cm, planktonic foraminifers are lacking. Radiolarians and sponge spicules and primitive agglutinated benthonic foraminifers are common.

In the interval where Sample 458-7-4, 50–52 cm was taken, planktonic foraminifers are represented by scarce *Sphaeroidinellopsis seminulina, S. subdehiscens,* and *Globigerina nepenthes.* The last defines the lower age limit of this interval as the *Globigerina nepenthes-Globorotalia siakensis* Zone (the uppermost middle Miocene), but all three of the forementioned species disappear in the early Pliocene. Nannofossils (see Ellis, this volume) and radiolarians (see Kling, this volume) indicate these sediments to be uppermost middle Miocene (the *Discoaster hamatus* Zone and the *Cannartus petterssoni* Zone, respectively).

In the interval from Section 458-9-1, 52–54 cm to Section 458-11-2, 50–52 cm only a few long-ranging species of planktonic foraminifers were identified: *Sphaeroidinellopsis seminulina, Globoquadrina altispira, G. dehiscens,* and *Globigerinoides trilobus.* They cannot precisely determine the age of the sediments (middle Miocene, based on nannofossils and radiolarians) nor confirm a hiatus within the middle Miocene.

The interval from Section 458-14,CC to Section 458-19-2, 32–35 cm is very poor in planktonic foraminifers, with only a few *Globigerinoides trilobus, Globigerina venezuelana, Globigerinita dissimilis, G. unicava, Globorotaloides suteri, Globorotalia nana,* and *Globoquadrina altispira* present (early Miocene).

The interval from Section 458-21-5, 5–7 cm to Section 458-25-1, 53–55 cm is characterized by a scarce microfauna of the late Oligocene: *Globigerina* aff. *ciperoensis, G. venezuelana, G. rohri, G. angustiumbilicata, Globigerinita unicava,* and *Globorotaloides suteri.*

The Oligocene/Miocene boundary cannot be defined at Site 458 with high precision by means of planktonic foraminifers because of an impoverished microfauna.

The lowest specimen from the site (Sample 458-25-2, 44–46 cm) contains a few small *Globorotalia opima opima, Globigerina* sp. aff. *G. ampliapertura, G. rohri, G. praebulloides, G. angustiumbilicata,* and *Globorotaloides suteri;* it can be placed approximately at the base of the *Globorotalia opima* Zone (Oligocene).

Benthonic foraminifers are scarce in Oligocene, Neogene, and Quaternary sediments of Site 458 (*Hyperammina, Rhizammina, Ammodiscus, Pullenia, Melonis, Cassidulina, Bulimina, Virgulina, Nodosaria, Planulina, Cibicides, Eponides,* and *Gyroidina*). Their species composition has certainly changed through time but a continuing deep-water environment is indicated.

Site 459

This site is located on the eastern margin of the Mariana island arc, near the trench-slope break. Hole 459 penetrated a few meters of recent sediments; Hole 459B reached basalts of the basement. The latter are overlain by claystones and silicified claystones of the middle Eocene and siliceous mudstones and vitric tuff

of the early Oligocene. A thick pile (about 475 m) of deep-water turbidites (siltstone, sandstone, sandy and silty vitric tuff, vitric nannofossil chalk) represents the late Oligocene and Miocene. Pliocene and Quaternary sediments are composed of siliceous and nannofossil oozes, vitric mud, and sandy to muddy ash. Poor assemblages of planktonic foraminifers were identified in Quaternary, Miocene, and Oligocene sediments; many samples are barren of planktonic foraminiferal tests.

The interval from Section 459B-1-1, 50–52 cm to Section 459B-2-3, 50–52 cm and also Sample 459-1-1, 44–46 cm contain scarce Quaternary planktonic foraminifers: *Sphaeroidinella dehiscens*, *Globorotalia tumida*, *G. menardii*, *G. crassaformis*, *Globigerinoides conglobatus*, *G. ruber*, and *Pulleniatina obliquiloculata*. Benthonic foraminifers (*Hyperammina*, *Valvulina*, *Pullenia*, *Melonis*, and *Cassidulina*) indicate a deep-water environment.

With the exception of a few specimens of *Globigerina nepenthes* Sample 459B-11-2, 50–52 cm, the interval from Section 459B-2-4, 50–52 cm to Section 59B-19-1, 50–52 cm does not contain foraminifers. The indicated age is latest middle Miocene-early Pliocene.

The interval from Section 459B-20-1, 50–52 cm to Section 459B-24-2, 91–93 cm, including only scarce benthonic foraminifers (*Pullenia, Cassidulina, Bulimina, Cibicides, Anomalina, Nodosaria, Siphonodosaria, Sphaeroidina, Eponides*, and *Cyclammina*) is of deep-water character. Spicules of siliceous sponges are abundant in places.

The interval from Section 459B-25-1, 87–89 cm to Section 459B-29-2, 36–38 cm is barren of foraminifers.

The interval from Section 459B-29-3, 21–23 cm to Section 459B-43-1, 51–53 cm is characterized by few to scarce *Globigerinoides trilobus*, *G. altiaperturus*, *Globigerina bradyi*, *G. juvenilis*, *G. angustiumbilicata*, *G. foliata*, *G. woodi*, *Cassigerinella chipolensis*, and *Globorotalia minutissima*. These sediments belong to the lower part of the early Miocene (within the *Globigerinita dissimilis-Globigerinita stainforthi* zones). It should be noted that in many samples planktonic foraminifers are missing.

The interval from Section 459B-44-1, 64–66 cm to Section 459B-53-4, 43–45 cm does not contain foraminifers, except for some tests of corroded *Siphonodosaria*, *Cibicides*, and *Eponides*.

The interval from Section 459B-54-1, 81–83 cm to Section 459B-54-2, 69–71 cm, with scarce to common *Globigerina ciperoensis*, *G. angulisuturalis*, *G. angustiumbilicata*, *G. praebulloides*, *G. venezuelana*, *G. ouachitaensis*, and *Cassigerinella chipolensis* is late Oligocene (the *Globigerina ciperoensis* Zone).

In the interval from Section 459B-54-3, 86–88 cm to Section 459B-56-2, 64–66 cm, the assemblage of planktonic foraminifers consists of *Globigerina ciperoensis*, *G. angustiumbilicata*, *G. angulisuturalis*, *G. praebulloides*, *G. ouachitaensis*, *Cassigerinella chipolensis*, and *Chiloguembelina cubensis* together with scarce *Globorotalia* sp. aff. *G. opima opima*. Sediments of this interval can be placed in the late Oligocene, within the *Globigerina ciperoensis-Globorotalia opima* zones (probably in the *Globorotalia opima* Zone).

In the interval from Section 459B-56-3, 10–12 cm to Section 459B-59-2, 46–47 cm foraminifers are absent, except for a few benthonics: *Cassidulina*, *Pullenia*, *Gyroidina*, *Cibicides*, *Eponides*, and *Siphonodosaria*. On the basis of radiolarians and nannofossils, the sediments were subdivided into middle Eocene, late Eocene, and early Oligocene.

Site 460

This site (Holes 460 and 460A) was located on the inner (arc-side) wall of the Mariana Trench. The Quaternary diatomaceous ooze and siliceous mud are underlain here by calcareous mud, vitric mud, and conglomerates with middle and late Eocene and Oligocene nannofossils and radiolarians.

In all samples of Hole 460, foraminifers are absent. Most of the samples from Hole 460A are also barren of foraminifers. They were discovered only in three specimens: Sample 460A-4-4, 38–40 cm with few *Globigerinoides ruber*, *G. trilobus*, *G. sacculifer*, *Globigerina* sp.; Sample 460A-4-6, 38–40 cm with few *Globigerinoides ruber* and *Globigerina* sp.; and Sample 460A-5-1, 50–52 cm with scarce *Globorotalia tosaensis*, *G. menardii*, *G. scitula*, *Neogloboquadrina dutertrei*, *Sphaeroidinella dehiscens*, *Globigerinoides ruber*, and *G. trilobus*. If we exclude the possibility of drilling contamination, the sediments cannot be older than late Pliocene (even assuming redeposition of microfauna from the shallower water area of the fore-arc region).

Site 461

Two holes were drilled in the deep area (7034 m) of the inner wall of the Mariana Trench. They penetrated siliceous ooze, vitric and siliceous mud, and zeolitic clay of the Quaternary with redeposited Eocene and Oligocene nannofossils. Foraminifers are absent from all samples.

Site 452

This site (Holes 452 and 452A) was located in the northern Mariana Basin, on the deep, old Pacific plate crust. Quaternary pelagic brown clays unconformably overlie Cretaceous siliceous mudstone, porcellanite, and chert. Although 44 samples were examined, foraminifers are absent.

MAIN FEATURES OF THE CENOZOIC FORAMINIFERAL STRATIGRAPHY OF THE LEG 60 AREA

Oligocene, Neogene, and Quaternary deposits of the Mariana Trough and Mariana Ridge penetrated by Leg 60 holes contain very poor assemblages of planktonic foraminifers. They provide a very vague idea of true tropical Cenozoic assemblages of planktonic foraminifers known after drilling on the Mid-Pacific mountains and Caroline Islands. This impoverishment is certain to be secondary and related to the deep-water character of sediments. The chief mass of species was destroyed by dissolution. As a rule only resistant species, or species with a thickened wall, remain (*Globigerina nepenthes, Globorotaloides suteri, Globigerinita unicava, Pulleniatina obliquiloculata, Globorotalia opima, G. acosta-*

ensis, G. tumida, Neogloboquadrina dutertrei, Sphaerodinella dehiscens, and *Sphaeroidinellopsis* spp.).

A deep-sea environment of sedimentation is also evidenced by the character of benthonic foraminifers. Noteworthy is that ecological peculiarities of planktonic and benthonic foraminifers upward in the section remain practically unchanged; that is, sedimentation in basal layers of the section took place at depths similar to those of the present.

Because of impoverishment of planktonic foraminiferal assemblages, it was not possible to subdivide the Cenozoic deposits of Leg 60 on the basis of the zonal scale successfully applied in the tropical, subtropical, and temperate areas of the Pacific Ocean, as well as in the Atlantic and Indian oceans (Krasheninnikov, 1977, 1978). The *Globorotalia opima* and *Globigerina ciperoensis* zones (Sites 458 and 459) can be very tentatively identified in the Oligocene. In the Neogene, only subseries were practically identified: early, middle, and late Miocene, and early and late Pliocene (Sites 458 and 459). Quaternary deposits are subdivided into the *Globorotalia truncatulinoides* and *Globigerina calida calida* zones, as interpreted by Blow (1969), but the boundary between them is obscure (Sites 455, 456, and 458). It appears more expedient to regard these subdivisions as subzones. This rough stratigraphic subdivision does not allow us to evaluate continuity of sections nor to fix the presence of stratigraphic breaks.

Redeposited Cretaceous foraminifers were not observed in Leg 60 sediments.

Cenozoic deposits penetrated during Leg 60 provide good examples of the greater resistance of calcareous nannofossils to selective dissolution than that of planktonic foraminifers. Although it was not possible to use the foraminiferal zonal scale, as previously mentioned, the nannofossil zonal scale was successfully applied (see Ellis, this volume). Thus, it is necessary to note once again the reliability of the methods adopted for stratigraphic studies by the Deep Sea Drilling Project, where three of four groups of fossils are analyzed simultaneously. This makes the trend of the studies very flexible, and the findings rather reliable.

The results of foraminiferal stratigraphy are in accordance with the data on radiolarians and nannofossils on the change in age of basal layers from the axial part of the Mariana Trough toward its peripheral zones (Figure 2).

At the trough axis the basalts are overlain by Quaternary (Sites 454 and 456). To the west, toward the West Mariana Ridge the basalts are overlain by Pliocene (Site 453). East of the Mariana Trench the basalts are overlapped by Oligocene (Site 458), or middle Eocene (Sites 459 and 460). The symmetrical change in age of the basalt layers testifies to the spreading process in the axial part of the Mariana Trough.

Cenozoic deposits are exposed on some islands of the Mariana archipelago, including Guam and Saipan (Todd, 1957, 1966; Todd et al., 1954). On Guam, above basalts there occur sandstones, clays, and limestones with tuffaceous material. Their basal layers, with *Globorotalia spinulosa* and *G. spinuloinflata*, are assigned to the upper part of the middle Eocene. The upper Eocene contains *Globorotalia centralis, Globigerapsis index, Hantkenina alabamensis*, and *H. inflata*. The Oligocene is very complete: the presence of *Globigerina sellii* and *Globigerina ampliapertura*, together with *G. gortanii*, *G. senilis*, *G. danvillensis*, and *Chiloguembelina cubensis*, testifies to the early Oligocene; the appearance of *Globorotalia opima* points to the late Oligocene. The lower Miocene is characterized by *Globigerinoides trilobus* and *Globigerinita dissimilis*. The undifferentiated Jannum formation contains *Globorotalia fohsi*, *Orbulina suturalis*, *Biorbulina bilobata*, Globigerina nepenthes, *Globoquadrina altispira* Miocene), as well as *Globorotalia tumida*, *Pulleniatina obliquiloculata*, *Globigerinoides conglobatus*, *G. sacculifer*, *Pulleniatina obliquiloculata*, Candeina nitida, and *Sphaeroidinella dehiscens* (Pliocene). On Saipan, the section begins also with middle-upper Eocene with *Globigerapsis index*, *Globorotalia centralis*, *Hantkenina* sp. No Oligocene

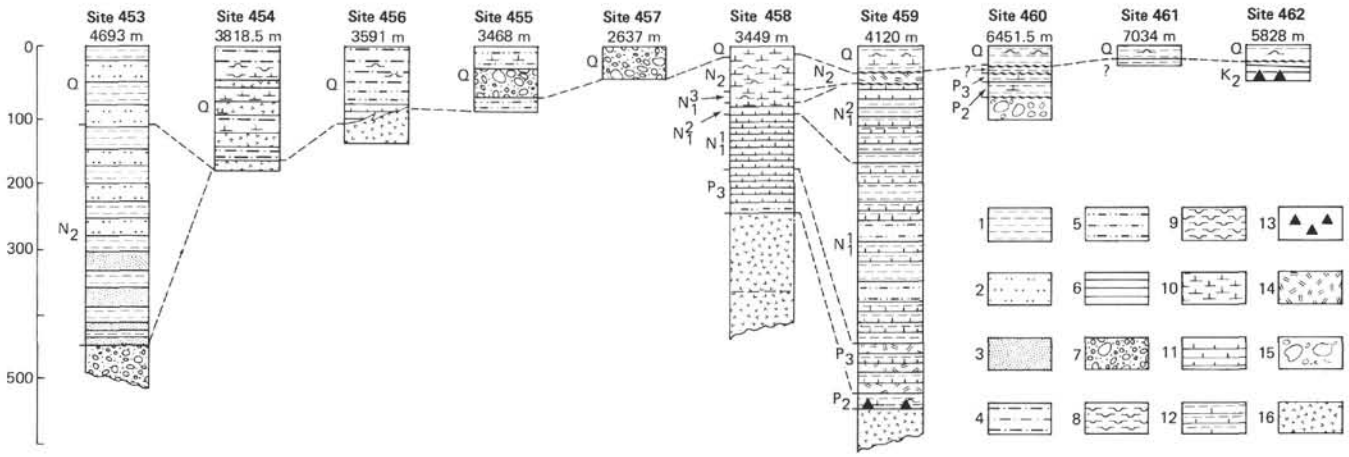

Figure 2. Correlation of sediments penetrated by the Leg 60 holes. Legend: 1 = clay, 2 = silt, 3 = sand, 4 = sandy clay, 5 = silty clay, 6 = mudstone, 7 = breccia and conglomerates, 8 = radiolarian ooze, 9 = diatom ooze, 10 = nannofossil ooze, 11 = nannofossil chalk, 12 = calcareous claystone, 13 = chert, 14 = tuff, 15 = coarse gabbro-metabasalt breccia, 16 = basalts; Q = Quaternary, N_2 = Pliocene, N_1^3 = late Miocene, N_1^2 = middle Miocene, N_1^1 = early Miocene, P_2 = Oligocene, P_2 = Eocene, K_2 = Late Cretaceous.

has been established. The lower Miocene contains *Globigerinatella insueta*, *Globigerinoides trilobus*, *G. bisphaerica*, *Globoquadrina altispira*, and *G. dehiscens*. Middle and upper Miocene have been identified with *Orbulina suturalis*, *O. universa*, *Globorotalia menardii*, Sphaeroidinellopsis seminulina, and Pliocene with *Pulleniatina obliquiloculata*, Sphaeroidinella dehiscens, *Globigerinoides ruber*, and *G. conglobatus*.

Thus, the age of basal layers of the sections on Guam and Saipan is the same as in Sites 459 and 460 on the eastern slope of the Mariana Ridge (middle-upper Eocene).

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