

32. CRETACEOUS FORAMINIFERA FROM THE NORTHWESTERN PACIFIC OCEAN: LEG 6, DEEP SEA DRILLING PROJECT

Robert G. Douglas, Department of Geology, Case Western Reserve University, Cleveland, Ohio

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INTRODUCTION

Mesozoic foraminifera and ostracods are present in samples from six of the seventeen sites drilled during Leg 6. All of the sites are located in the northwest Pacific Basin, within an area that apparently delimits the occurrence of pre-Cenozoic sediments and which may be the remnant of the oldest part of the Pacific. The area is bounded to the west by the Mariana-Japan trench systems and to the east approximately by the meridian of the Hawaiian Islands. The other boundaries are less clear although Cretaceous sediments are known to extend south to latitude 10°N in the northwestern part of the Pacific. All Mesozoic fossils recovered from the North Pacific Ocean to date have been collected from within this area (Hamilton, 1956, 1953; Riedel and Funnel, 1964; Ewing, *et al.*, 1966) (Figure 1).

Chert or hard silicified layers, which could not be penetrated by the drill, were encountered at all of the Cretaceous sites (Sites 45, 47, 48, 49, 50 and 51). The amount of core recovery was, therefore, controlled by the depth of the chert layers. For example, at Sites 49 and 50, the chert is interbedded with chalk ooze, and underlies a thin layer of Tertiary brown clay. Recovery at these sites was limited to partial or incomplete cores. At Sites 45 and 51, samples were recovered from the core-catcher. Continuous cores were obtained on the crest of the Shatsky Rise at Sites 47 and 48, where the upper Maestrichtian was drilled beneath a thick (110 meters at Site 47) cover of Cenozoic chalk oozes.

Samples from the incomplete cores and core-catcher samples yield mixed assemblages, usually with "re-worked" younger fossils. Except for the Scan III cores,

the mixing can be attributed to contamination by down-hole cave-in, flow-in, or composite residues resulting from wash-out of the core. The recovered cores represent much of the Cretaceous, although there are no autochthonous samples of the Albian, Turonian, Campanian, or the uppermost Jurassic. A summary of the number and types of samples examined for this report is given in Table 1.

Sample numbers noted in the text and Hole Summaries, such as, 6-47.0-1-4, 7-9 cm, should be read as follows: Leg 6, Hole 47.0 (i.e., the first hole drilled at Site 47), Core 1 (i.e., the first core drilled), Section 4 (of Core 1; the cores being divided into six sections, each 1.5 meter in length), and interval sampled, 7 to 9 centimeters (as measured from the top of that section).

The typical lithology of the Cretaceous samples which contain foraminifera and ostracods is a white or light, cream-colored ooze, predominantly a coccolith ooze, interbedded with brown or amber colored chert in places (see discussion elsewhere in this volume). Planktonic foraminifera are embedded in chert fragments at 50.0-2 and foraminifera are partly replaced by silica at Sites 49, 50 and 51. The sediment, except for differences in consolidation, resembles the flint bearing chalk of northwest Europe. *Inoceramus* fragments were found in samples at 48.2-2-4, 130-135 centimeters, and 50.0-2-3, top; and, isolated prisms occasionally occur in samples from Holes 47.2, 48.2, 49.0 and 51.0.

There is a sharp decrease in calcareous microfossils in Tertiary and modern sediments located below the present calcium carbonate compensation depth (about

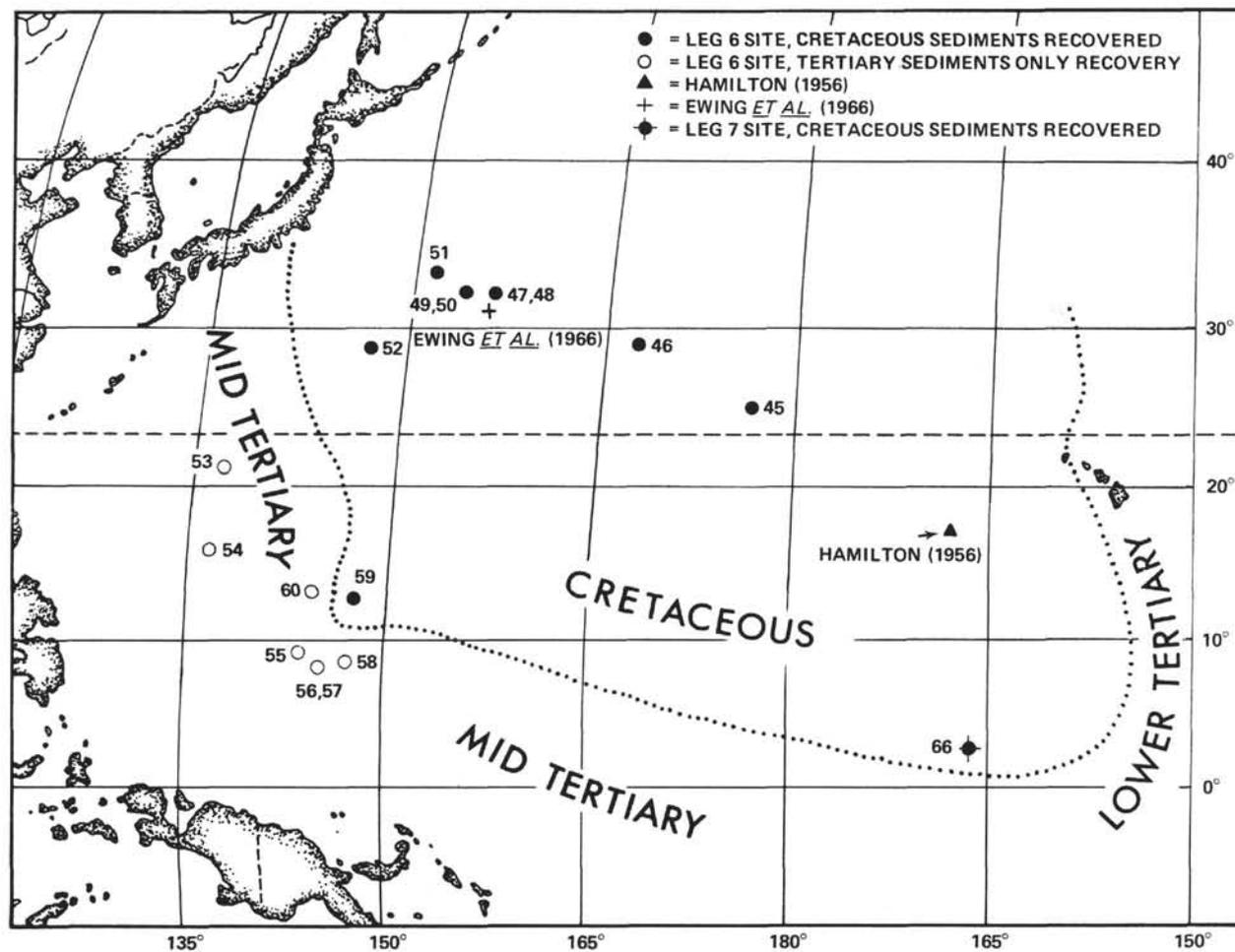


Figure 1. Index map of the northwest Pacific indicating location of Leg 6 sites which recovered Cretaceous microfossils. Location of previously recovered Mesozoic fossils referred to in text.

TABLE 1
Stratigraphic Distribution, Age and Type of Cretaceous Cores
Recovered by Leg 6 and the Number of Samples Examined for this Report

Age	Site		Type of Core Recovered	Total Thickness (m)	Number of Samples Examined	Zones Present
	Hole	Core				
Late Maestrichtian	47.2	12	1	29	11	<i>Abathomphalus mayaroensis</i> <i>Globo truncana gansseri</i>
	(2689 m)	13				
		14			8	
	48.2	1	1	12	11	<i>A. mayaroensis</i> <i>G. gansseri</i>
	(2619 m)	2	1 [‡]	10		
	3	7				
Campanian	*		3	—	4	<i>Globo truncana calcarata</i>
Early Santonian-Coniacian	51.0 (5980 m)	3	2 [‡]	CC	1	<i>Marginotruncana concavata</i>
Turonian	51.0	3	2 [‡]	CC	2	<i>Marginotruncana helvetica</i>
	*		3			
Cenomanian	51.0 (5980 m)	3	2 [‡]	CC	1	<i>Rotalipora evoluta</i>
	45.1 (5507 m)	3	2 [‡]	CC	1	
Albian	51.0 50.0	3	2 [‡]	CC	2	" <i>Ticinella roberti</i> "
Early Neocomian	49.0 (4282 m)	2	2	1.5	3	Nodosariid foraminifera and cytherellid ostracods; no planktonic foraminifera
	49.1 (4282 m)	1	1	1.5	4	
	50.0 (4487 m)	2		4.5	6	
		1	1	CC	1	
		2		9	10	

*Argo core
‡core disturbed

4000 meters in the Pacific; Arrhenius, 1963; Peterson, 1966). Foraminifera are absent in the Cenozoic reddish-brown clays at Sites 45, 46, 51, 52 and 59, and only a few, solution-resistant foraminifers remain in the brown clays at Sites 49 and 50. All of these sites are located in abyssal depths (see Core Hole Summaries). Well-preserved Cretaceous calcareous foraminifera and ostracods occur, however, at Sites 45, 51, 49 and 50. At the other sites Radiolaria indicate a Cretaceous age for the deeper sediments, but there are no calcareous microfossils in the cores. The benthonic and planktonic foraminifera from Sites 45 and 51—at the resolution available with the scanning-electron microscope—show some trace of dissolution, but their state of preservation is comparable to samples in the lower cores at Sites 47 and 48 (present water depth about 2500 meters). However, the microfossils from the flanks of the Shatsky Rise (Sites 49 and 50) are typically recrystallized and exhibit evidences of dissolution, and contemporaneous pelagic groups, such as, foraminifera and nannoconids, are absent. Some of the shells have been replaced by silica. Chert interbedded with chalk ooze was encountered at some abyssal sites (Sites 45, 49, 50 and 51) where Cretaceous calcareous microfossils were recovered. The Holocene and late Tertiary sediment at these sites is a non-calcareous reddish-brown clay. Chert was also encountered at two abyssal sites (Sites 52 and 59) which lacked Cretaceous calcareous remains. Reddish-brown clay with a few Radiolaria was the predominant lithology. The relationship between the occurrence of chert and preserved Cretaceous calcareous sediments in modern abyssal depths suggests that either the presence of the chert, and/or the conditions conducive to its formation, permits the preservation of the calcareous fraction of the microfauna or that post-depositional changes in depth relation to the calcium carbonate compensation level have occurred at Sites 45, 51 and possibly 49 and 50.

The Leg 6 cores are pelagic oozes, essentially the Mesozoic equivalent of modern "globigerine ooze", in these cores, the numbers of coccoliths and planktonic foraminifera greatly exceed the numbers of benthonic foraminifera and ostracods, both in diversity and individuals. Typically, planktonic-benthonic ratios are greater than 100: 1, except for cores at Sites 49 and 50, where planktonic foraminifera are absent. In the upper part of Core 47.2-12 the foraminifera exhibit traces of dissolution, and the decrease in the planktonic-benthonic ratio is assumed to be a result of selective solution.

BIOSTRATIGRAPHY

The late Cretaceous (Albian to Maestrichtian) planktonic foraminifera present in the core samples provide precise correlations with adjacent parts of the Pacific Basin, Australia, North America and Europe. Compositionally, the assemblages from Leg 6 contain the same

species as reported from other Tethyan regions and can be readily integrated into the zonal scheme established by Bolli (1957, 1966) and Pessagno (1967) for the Caribbean and Gulf Coast of North America, respectively. There are differences, however, between the Cretaceous faunas of the northwest Pacific and those reported from California (Takayanagi, 1965; Douglas and Sliter, 1966; Marianos and Zingula, 1966; Douglas, 1969a, 1969b) and Japan (Takayanagi and Iwamoto, 1962; Asano and Takayanagi, 1965; Yoshida, 1961). These differences are considered in detail in the discussion of Cretaceous correlations in the Pacific Basin. For the moment, it is sufficient to point out that the planktonic foraminifera of California and Japan are less diverse. In fact, genera such as the *Rugoglobigerina* and the larger heterohelicids are poorly represented, and most diagnostic Tethyan species are missing.

Benthonic foraminifera and, to a lesser extent, ostracods provide the basis for Lower Cretaceous correlations. These correlations are less precise than those for the Upper Cretaceous because of the few stratigraphically diagnostic species, the lack of information concerning the ranges of Neocomian-Tithonian foraminifera in the Pacific, and the ecologic-environmental differences between the Pacific assemblages and the benthonic assemblages described from the stratotypes of northwest Europe.

Planktonic Foraminifera

Cretaceous samples yielding planktonic species recovered by Leg 6 or from the pre-site survey cores raised by the *R/V Argo* are discussed below. Certain species are known only as reworked or admixed fossils, but they are included in the discussion because they have not been found previously in the Pacific.

Site 45 (lat 24° 15.9'N, long 178° 30.5'W;
Archipelagic Apron Southwest of Midway Island;
Depth 5507 Meters)

Sample 6-45.1-3, core-catcher:

Rotalipora evoluta (Sigal), *R. greenhornensis* (Morrow), *R. cushmani* (Morrow), *Ticinella* sp., *Praeglobotruncana delrioensis* (Plummer), *Planomalina buxtorfi* (Gandolfi), *Globigerinelloides caseyi* (Bolli, Loeblich and Tappan), *G. sp.*, *Schackoia cenoma* (Schacko), *Hedbergella portsdownensis* (Mitchell-Williams), *H. delrioensis* (Carsey), *H. amabilis* (Loeblich and Tappan), *H. planispira* (Tappan), *Heterohelix washitensis* (Tappan).

Recovery at this site was limited to a sandy residue containing free specimens of foraminifera, and chips and fragments of limestone and chert. The foraminifera apparently were washed from marl layers which were not recovered. The most abundant species are *Rotalipora evoluta* and *R. greenhornensis*; in comparison, *R. cushmani* is rare. A few benthonic foraminifera together with rare specimens of late Upper Cretaceous

Globotruncana and Eocene *Globigerina* also occur in the sample. The dominant assemblage, listed above, is considered to belong to the middle Cenomanian *Rotalipora evoluta* Zone.

Site 47 (lat 32° 26.9'N, long 157° 42.7'E;
Western Part of the Shatsky Rise,
Near the Crest; Depth 2689 Meters)

Sample 6-47.2-11, core catcher:
Abathomphalus mayaroensis (Bolli), *A. intermedia* (Bolli), *Globotruncana aegyptiaca* (Nakkady), *G. stuartiformis* Dalbiez, *Heterohelix* spp., *Pseudotextularia elegans* (Rzehak).

The lower part of Core 11 and the core-catcher contain an admixture of Paleocene species from three different zones and a few specimens of the above Cretaceous species from the *Abathomphalus mayaroensis* Zone. Based upon coccolith evidence, the Tertiary-Cretaceous (predominantly Maestrichtian) boundary is placed in Section 3 of Core 11, but a foraminiferal fauna does not occur until the top of Core 12. (See discussion below under Tertiary-Cretaceous Boundary.) The Cretaceous species in Core 11 are poorly preserved and mostly broken.

Samples from Core 12 were as follows:

Sample 47.2-12-1, top:
Sample 47.2-12-1, 145-150 cm:
Sample 47.2-12-2, 7-9 cm:
Sample 47.2-12-3, top:
Sample 47.2-12-3, 145-150 cm:
Sample 47.2-12-4, top:
Sample 47.2-12-4, 145-150 cm:
Sample 47.2-12, core-catcher:

An assemblage of planktonic foraminifera representative of the upper Maestrichtian *Abathomphalus mayaroensis* Zone occurs in all four sections of the core. Included in the assemblage are: *Abathomphalus mayaroensis* (Bolli), *A. intermedia* (Bolli), *Globotruncanella havanensis* (Voorwijk), *Globotruncana stuarti* (Lapparent), *G. aegyptiaca* (Nakkady), *G. contusa* (Cushman), *G. arabica* El-Naggar, *G. stuartiformis* (Dalbiez), *Rugoglobigerina hexacamerata* Bronnimann, *Pseudotextularia deformis* de Klasz, *Racemiguembelina fructicosa* (Egger), *Pseudoguembelina excolata* (Cushman), *Gublerina cuvillieri* Kikoine, *Globigerinelloides subcarinatus* (White).

Foraminifera in the upper part of the core are more poorly preserved than in the core-catcher, or in Cores 13 and 14, and the samples from these levels yielded low planktonic-benthonic ratios (less than 100: 1) relative to Cretaceous samples from other cores. The upper range of species in Sections 1, 2 and 3 in the core is difficult to determine because they are probably absent for reasons of preservation rather than extinction.

Reworked Lower Paleocene species occur in Sections 1, 2 and the core-catcher, but they are rare.

The following samples from Core 13 were examined:

Sample 47.2-13-1, 145-150 cm:
Sample 47.2-13-2, 145-150 cm:
Sample 47.2-13-3, 6-8 cm:
Sample 47.2-13-3, 145-150 cm:
Sample 47.2-13-4, 145-150 cm:
Sample 47.2-13-5, 145-150 cm:
Sample 47.2-13-6, 145-150 cm:
Sample 47.2-13, core-catcher:

The planktonic assemblage in samples from the upper four sections of the core is the same as that in Core 12 (that is, *Abathomphalus mayaroensis* Zone). In Sections 5 and 6 and the core-catcher sample, *Abathomphalus mayaroensis*, *A. intermedia* and *Globotruncana stuarti* are very rare and *Globotruncana gansseri* occurs with *G. subcircumnodifer*, low-spined forms of *G. contusa* and other species characteristic of the *G. gansseri* Zone. *Globotruncana gansseri* in small numbers is present in Samples 47.2-13-1, 145-150 cm and 47.2-13-3, 6-8 cm, but was not found in the samples from Sections 2 or 4. The assemblage in Sections 5 and 6 is either a transition between the two late Maestrichtian zones or the younger species are reworked via down-hole cave-in, in which case, the base of the *Abathomphalus mayaroensis* Zone should be placed in Section 5.

Among the species present in Sections 5, 6 and the core-catcher of Core 13 are: *Globotruncanella havanensis* (Voorwijk), *Globotruncana gansseri* Bolli, *G. arca* (Cushman), *G. contusa* (Cushman) (both low and high spined varieties), *G. stuartiformis* (Dalbiez), *G. subcircumnodifer* (Gandolfi), *G. linneiana* (d'Orbigny) (rare), *Tritinella scotti* (Bronnimann), *Rugoglobigerina rugosa* (Plummer), *R. hexacamerata* Bronnimann, *Globigerinelloides multispinata* Lalicker, *Planoglobulina multicamerata* de Klasz, *Pseudotextularia elegans* (Rzehak), *P. intermedia* (de Klasz), *Racemiguembelina fructicosa* (Egger), *Pseudoguembelina excolata* (Cushman), *P. costulata* (Cushman).

Approximately one meter was drilled for Core 14, but a complete barrel of sediment was recovered; presumably the other eight meters are a result of flow-in. The following sample intervals were examined:

Sample 47.2-14-1, 145-150 cm:
Sample 47.2-14-4, 145-150 cm:
Sample 47.2-14, core-catcher:

The Core 14 contains a mixture of species, mostly of the *Globotruncana gansseri* Zone. *Abathomphalus mayaroensis* and *G. stuarti* are absent, but rare specimens of *Abathomphalus intermedia* are present in the examined samples. *Globotruncana linneiana*, *G. rosetta*

and *G. fornicata* do not range into the *G. gansseri* Zone in the Gulf Coast-Caribbean region (Pessagno, 1967), and their presence in the samples suggests that sediments from the subadjacent zone are incorporated in the core. Among the species present are: *Globotruncana gansseri* Bolli, *G. arca* (Cushman), *G. subcircumnodifer* Gandolfi, *G. linneiana* (d'Orbigny), *G. contusa* (Cushman), *G. fornicata* (Plummer), *G. rosetta* (Plummer), *G. stuartiformis* Dalbiez, *G. elevata* (Brotzen), *Rugoglobigerina rugosa* (Plummer), *R. hexacamerata* Bronnimann, *Pseudotextularia elegans* (Rzehak).

Site 48 (lat 32° 24.5'N, long 158° 01.3'E;
Western Part of Shatsky Rise, in Moat of Knoll,
Near Crest; Depth 2619 Meters)

Samples were examined from the following intervals in Core 1:

Sample 48.2-1-1, 104-106 cm: Miocene with reworked
Sample 48.2-1-2, 8-10 cm: Cretaceous
Sample 48.2-1-3, 100-102 cm:
Sample 48.2-1-5, 104-106 cm: Mixed Cretaceous and
Sample 48.2-1-5, 100-102 cm: Miocene
Sample 48.2-1-6, 26-28 cm:
Sample 48.2-2-1, core-catcher: Cretaceous

Sections 1, 2 and 3 of Core 1 contain Miocene foraminifera and Radiolaria mixed with a few poorly preserved late Upper Cretaceous foraminifera. Sections 4 and 5 are mixed assemblages of Miocene and Cretaceous (upper Maestrichtian) species. The more abundant Cretaceous species include: *Abathomphalus intermedia* (Bolli), *Globotruncana stuarti* (Lapparent), *Racemiguembelina fructifera* (Egger), *Pseudotextularia intermedia* de Klasz, *P. elegans* (Rzehak), *Heterohelix* spp.

The bottom of Core 1 is Upper Maestrichtian with rare reworked Miocene and Pleistocene planktonic foraminifera. The occurrence of *Abathomphalus intermedia*, *Planoglobulina acervulinoides* and *Globotruncana stuarti* with *Globotruncana stuarti* in Section 6 and the core-catcher suggests that the assemblage belongs to the upper part of the *G. gansseri* Zone or is transitional to the overlying *A. mayaroensis* Zone. Species present in the lower section include: *Globotruncanella havanensis* (Voorwijk), *G. arca* (Cushman), *G. aegyptiaca* Nakkady, *G. contusa* (Cushman), *G. elevata* (Brotzen), *G. stuartiformis* Dalbiez, *Rugoglobigerina hexacamerata* Bronnimann, *Trinitella scotti* (Bronnimann), *Planoglobulina multicamerata* de Klasz, *Gublerina cuvillieri* Kikoine.

Planktonic foraminifera were examined from the following samples in Core 2:

48.2-2-2, 5-7 cm:
48.2-2-4, 115-117 cm:

48.2-2-5, 5-7 cm:
48.2-2-6, 31-33 cm:
48.2-2, core catcher:

These samples belong to the *Globotruncana gansseri* Zone, Middle Maestrichtian in age. *G. stuarti* and *Globotruncanella havanensis* are absent from Sections 5 and 6 (though *G. havanensis* occurs in Core 3), and the high-spined, strongly crenulated variety of *G. contusa* is rare.

In Core 3, approximately 1.5 meters were drilled, but a nearly complete core barrel was recovered (similar to the situation at 47.2-12-14). Five samples were examined from the core:

Sample 48.2-3-1, 138-140 cm:
Sample 48.2-3-2, 38-40 cm:
Sample 48.2-3-3, 67-69 cm:
Sample 48.2-3-5, 76-78 cm:
Sample 48.2-3, core-catcher:

Globotruncana gansseri and *G. aegyptiaca* are rare, and *G. linneiana*, *G. subcircumnodifer* and the low-spined, *G. fornicata*-*G. contusa* intermediates are more abundant than in the upper part of the core. This suggests that the assemblage is from the lower part of the *G. gansseri* Zone. Among the more abundant species are: *Globotruncana stuartiformis* Dalbiez, *G. arca* (Cushman), *G. elevata* (Brotzen), *G. rosetta* (Plummer).

Site 50 (lat 32° 24.2'N, long 156° 36.0'E;
Western Flank of the Shatsky Rise;
Depth 4487 Meters)

From Hole 50.0, small, poorly preserved, sometimes partly silicified specimens (mostly of: *Hedbergella* cf. *H. trocoidea* (Gandolfi), *H. spp.* (very small), *Ticinella primula* Luterbacher, *T. cf. T. roberti* (Gandolfi), *Biticinella* sp. are admixed in the Neocomian Samples 50.0-2-3, 50.0-2-5 and the core-catcher samples of Cores 1 and 2, either as isolated individuals or embedded in chert. *Ticinella primula* and *T. sp. cf. T. roberti* indicate an Albian age. It is possible that the small species of *Hedbergella* and *Biticinella* are pre-Albian, but the poor state of preservation prevents more precise identification. The Albian species are apparently derived from down-hole cave-in, and suggest that younger Cretaceous sediments overlie the chalk and chert recovered at the site.

Site 51 (lat 33° 28.5'N, long 153° 24.3'E;
Small Basin at the Base and to the West of the
Shatsky Rise; Depth 5980 Meters)

Sample 6-51.0-3, core catcher:
A composite sample containing species from the Albian, Cenomanian, Turonian and Coniacian-early Santonian was recovered from the residue in the

core-liner and core-catcher. The core apparently washed out during retrieval and the total recovery was less than 100 grams of material.

Albian species recovered here include: *Biticinella breggiensis* (Gandolfi), *Ticinella primula* Luterbacher, *T. roberti* (Gandolfi), *T. sp. cf. T. practinenensis* Sigal, *Hedbergella sp. cf. H. trocoidea* (Gandolfi), *Schackoia primitiva*, *S. sp.*, *Planomalina cheniourensis* Sigal. Based on the occurrence of *Ticinella roberti* and *T. primula* the assemblage is Albian.

Cenomanian species recovered include: *Rotalipora evoluta* Sigal, *Hedbergella delrioensis* (Carsey), *Praeglobotruncana delrioensis* (Plummer), *Clavihedbergella moremani* (Cushman), *Schackoia cenomana* (Schacko). In addition to the above Cenomanian species, *Hedbergella amabilis*, *Clavihedbergella simplex* and *Hedbergella portdownensis*, which range into the Turonian, are also present. *Rotalipora evoluta* and *Praeglobotruncana delrioensis* indicate the middle Cenomanian and suggest correlation with the assemblage at Sample 6-45.1-3, core-catcher.

Turonian species from this sample include: *Marginotruncana helvetica* (Bolli), *M. sigali* (Mornod), *M. roddai* (Marianos and Zingula). Turonian microfossils have not been previously reported from the Pacific Ocean. The above taxa are indicative of the lower part of the stage, *Marginotruncana helvetica* Zone. Several taxa in the list given below also range into the upper Turonian, notably *Marginotruncana coronata*, *M. pseudolinneiana* and *Whiteinella inornata*.

Coniacian-early Santonian species include: *Marginotruncana concavata* (Brotzen), *M. coronata* (Bolli), *M. pseudolinneiana* Pessagno, *M. "renzi"* of Bolli (1957), *Globotruncana fornicata* (Plummer), *Whiteinella inornata* (Bolli), *W. sp. cf. W. archaeocretacea* Pessagno, *W. sp. cf. W. bornholmensis* Douglas, *Archaeoglobigerina sp.*, *Heterohelix reussi* (Cushman), *H. sp.*, *Sigalia deflaensis* (Sigal). The dominant assemblage in the core-catcher sample is the *Marginotruncana concavata* association; it accounts for over 95 per cent of the total population.

The *M. concavata* Zone has not been previously identified in the North Pacific region. Coeval faunas, that is, Coniacian-lower Santonian, in California (Douglas and Sliter, 1965; Douglas, 1969) and Japan (Asano and Takayanagi, 1965) are less diverse than the Site 51 fauna and have few species in common. The excellent preservation of the Pacific microfossils substantiates that the tegilla structures of early Senonian keeled taxa, such as, *Marginotruncana concavata*, are composed of simple, solid plates (Plate 2) and can be distinguished from *Globotruncana s.s.* (see Pessagno, 1967).

Presite Survey: Scan III-20P
(lat 24° 0.86'N, long 178° 30.2'W; Archipelagic Apron
Southwest of Midway Island, Scan Site 12A Near
Leg 6, Site 45; Depth 5606 Meters)

Sample Scan III-20P, 739 cm and 951 cm:
Reworked Cenomanian, Turonian and Campanian species are present in the Miocene portion of the core. Among the species recovered are Cenomanian species: *Rotalipora evoluta*, *Planomalina buxtorfi* (Gandolfi), *Hedbergella delrioensis* (Carsey), *Praeglobotruncana delrioensis* (Plummer); Turonian species: *Marginotruncana helvetica* (Bolli), *M. sigali* (Mornod); Campanian species: *Globotruncana calcarata* (Cushman), *G. stuartiformis* Dalbiez, *Rugoglobigerina rugosa* Plummer.

Summary of Planktonic Foraminiferal Biostratigraphy

Albian

As judged by their excellent state of preservation, the species of *Ticinella* and *Biticinella* at Sites 50 and 51, though displaced, do not appear to be reworked. This is taken to indicate the presence of calcareous Albian sediments in depths at or below the present calcium carbonate compensation level. The occurrence of *T. roberti* and *Planomalina cheniourensis* at Site 51 may indicate upper Aptian (Sigal, 1966) was penetrated. If so, it suggests that the total thickness of the lower Senonian to upper Aptian sequence is probably less than three meters.

Ewing *et al.* (1966) reported *Ticinella roberti*, *T. primula*, *Hedbergella planispira* and *Biglobigerinella cushmani* from a core raised near the crest of the Shatsky Rise, in the vicinity of Leg 6 Sites 47 and 48. Examination of material from the core (Lamont-Doherty V21-143, 45 centimeters) confirms that the assemblage is the same as that at 6-50.0 and 6-51.0-3. Roughly the same Albian horizon can be traced from the crest of the rise, to the lower part of the western flank and to the abyssal sea floor.

In the Albian samples from Leg 1, in the Atlantic, Pessagno (1969) noted that the common Tethyan species *Hedbergella washitensis* was absent, and this also, would appear to be the case in the Pacific. The reason for the absence of this species in oceanic sediments is unclear because it occurs in cores from the Blake Plateau in the Atlantic (Loeblich and Tappan, 1961), and in the Albian of Hokkaido (Japan) (Asano and Takayanagi, 1965).

Cenomanian

Most of all of the Cenomanian species recovered from the northwest Pacific are common to a single foraminiferal zone, the *Rotalipora evoluta* Zone which is correlated with the middle or the late part of the lower Cenomanian (Renz, *et al.*, 1963; Pessagno, 1967; Porthault,

1969). The existence of the upper part of the stage in the Pacific Ocean has yet to be documented.

Turonian

Undisturbed Turonian samples were not recovered during Leg 6 although it is fairly clear that such sediments were drilled at Site 51. The available samples are inadequate for stratigraphic purposes except to identify the *Marginotruncana helvetica* Zone in separate areas of the northwest Pacific.

Coniacian-early Santonian

The occurrence of the *Marginotruncana concavata* Zone at Site 51 documents the presence of an important zonal fauna which was previously unknown in the Pacific Basin. The zone contains the same species reported in other Tethyan regions of the Americas (Bolli, 1957; Esker, 1969) and Europe (Caron, 1967; Herb, 1966; Scheibnerna, 1968). However, the equivalent biostratigraphic units in the North Pacific contain few and, in some cases, different species and illustrate the difficulty in comparing planktonic foraminifera between flysch and Tethyan pelagic environments. Several of the characteristic species in the Pacific assemblage, including: *Globotruncana fornicata*, *Marginotruncana concavata*, *M. sp. cf. M. renzi* and *Sigalia deflaensis*, are absent in the thick clastic sections in northern California. They are partly replaced by *M. pseudolinneiana*, *M. coronata* and species of *Hedbergella* (Douglas, 1969). Heterohelicids are rare and represented by only *Heterohelix reussi*. The situation in Japan is similar. The Coniacian *Globotruncana japonica* Zone and the Santonian *G. hanzawae* Zone contain *Heterohelix globulosa*, "*Rugoglobigerina rugosa*" (? = *Hedbergella sp.*), *Globotruncana fornicata*, *G. lapparenti lapparenti* and *G. japonica* (Asano and Takayanagi, 1965).

Campanian

Reworked *G. calcarata*, *G. stuartiformis*, *G. fornicata* and *R. rugosa* in Scan III can be compared with the same species in admixed samples from the mid-Pacific (Hamilton, 1953). The *G. calcarata* Zone coincides with the Upper Campanian and is an important stratigraphic horizon. Except for a single report (Bandy, 1967), the species is not found in outcropping strata in the North Pacific.

Maestrichtian

The *Globotruncana gansseri* Zone and *Abathomphalus mayaroensis* Zone, Middle and Upper Maestrichtian, respectively, (Bolli, 1957; 1966) in the cores from the Shatsky Rise represent previously unrecorded biostratigraphic units in the North Pacific. It is apparently only the second time these faunas are reported from the Indo-Pacific region (McGowran, 1968). Edgell (1957) identified *Abathomphalus mayaroensis* and

several key species of the zone in the Miria Marl in northwestern Australia, and Hamilton (1953) described most of the key species of the *Globotruncana gansseri* Zone from a mixed Cretaceous-Tertiary assemblage recovered from the Mid-Pacific Mountains (latitude 20° N, longitude 172°W).

The zones in the Pacific contain the diagnostic species described by Bolli (1957) from Trinidad and recognized throughout the Tethyan region of the Americas (Hay, 1960; Ayala, 1954, 1959; Pessagno, 1967, 1962; Bronnimann and Rigassi, 1963), Europe (Herm, 1962; Corminboeuf, 1961; Berggren, 1962) and elsewhere. Thus, in addition to establishing the presence of important biostratigraphic horizons in the northwestern Pacific, the assemblage sets a minimum northern limit for Tethyan foraminifera in the latest Cretaceous. It has been speculated that the absence of Upper Maestrichtian zonal species in the North Pacific was due to a biogeographic restriction, but this does not appear to be the case (Douglas and Sliter, 1965).

The occurrence of *Globotruncana fornicata* with *G. linneiana*, *G. rosetta* and *G. subcircumnodifer* in mixed Cores 47.2-14 and 48.2-3 suggests that the next underlying zone was penetrated, the *G. tricarinata* Zone (= *Rugotruncana subcircumnodifer* Subzone of Pessagno).

Benthonic Foraminifera

Benthonic foraminifera and ostracods occur in many of the Cretaceous samples examined but they are neither abundant nor diverse, except in the Lower Cretaceous cores at Sites 49 and 50. Generally planktonic-benthonic ratios exceed 100:1 in the examined samples (some 500:1) and, with the small sample size normally used (8 to 10 cc), it is impossible to obtain more than a few specimens per sample. Pooling of samples over several sections or the length of a core is necessary to obtain a representative benthonic population. Distinct features characterize the benthonic microfossils in the several assemblages and may be useful in recognizing Mesozoic oceanic biofacies.

1. Few agglutinated foraminifera occur in the examined samples. In the Neocomian cores, *Dorothia* is the only abundant taxa although *Bathysiphon*, *Ammodiscus* and *Gandyrina* are present. In addition, the genera are monospecific; there are perhaps two species of *Dorothia*. The same genera also occur in the Upper Cretaceous samples but abundant species belong to *Clavinuloides*, *Spiroplectammia* and *Gaudryina*, particularly the latter.

2. The major group of benthonic foraminifera are the Rotalina (hyaline calcareous types), there are virtually no miliolids. However, there are distinct differences in the calcareous taxa between the lower and upper Cretaceous assemblages. *Nodosarids* dominate

the Neocomian samples, just as they do in shallow water deposits of Europe (Bartenstein and Brand, 1951) but nearly to the exclusion of all other taxa. *Espistomina*, *Conorboides* and other common trochospiral genera in the chalks of northern Europe are missing. *Lenticulina* and *Dentalia* are most abundant, with large, highly variable populations, followed by *Marginulina*, *Vaginulina*, *Nodosaria*, *Astracolus*, *Lingulina* and smaller numbers of *Lagena*, *Globulina*, *Ramulina* and other genera.

Nodosarids are well represented in Upper Cretaceous samples but trochospiral taxa are much more numerous. Particularly important are *Gyroidinoids*, *Gavinella*, *Osa ngularia*, *Praebulimina*, *Stensioina* and *Plaulina*, *Pullenia*, *Nodosaria*, *Dentalina*, *Lenticulina* and smaller numbers of *Plymorphina*, *Glandulina* and *Bolivinoidea*. In all about 25 genera and perhaps 50 species are present in the four Maestrichtian cores at Holes 47.2 and 48.2, a lower diversity than similar age faunas from the Gulf Coast (Cushman, 1946).

Ostracods are very rare but a seemingly consistent element in the Cretaceous samples. Regardless of age, their general morphology is the same: smooth, non-ornamented, a few with simple, very low relief ornamentation; oval or quadrate outlines with rounded margins. Hinges are simple or lacking and muscle scars are frequently obliterated by recrystallization. Most valves are single, though a few occur together in samples from Holes 49.1 and 50.0.

Systematic descriptions and further discussion of the benthonic foraminifera and ostracods is planned in a forthcoming study and comments here will be restricted to the species identified in samples at Sites 49 and 50.

**Site 49 (lat 32°24.1'N, long 156°35.0'E;
Western Flank of Shatsky Rise; Depth 4882 Meters)**

Core 1 from Hole 49.0 cut about 9 meters of brown clay barren of foraminifera. Core 2 recovered a partial core with white, coccolith ooze. Samples from Core 2 were examined from two horizons:

Sample 49.0-2-1, 63-65 cm:

Sample 49.0-2, core catcher:

The assemblage contains Lower Cretaceous (or uppermost Jurassic) foraminifera and a few smooth, thin-shelled ostracods. No planktonic foraminifera are present. Specimens of *Lenticulina* are corroded or pitted at the axial boss and other species frequently have holes or other traces of dissolution. Ostracod valves are recrystallized and no muscle scars could be detected. Among the species present are: *Dorothyia oxycona* (Reuss), *Lenticulina muensteri* (Roemer), *Citharina acuminata* (Reuss); *Tristix actuangulata* (Reuss). A Neocomian correlation is suggested by the species.

Two partial cores were recovered from Hole 49.1, containing chert fragments and coccolith ooze similar to Hole 49.0. The following samples were examined:

Sample 49.1-1-4, 131-135 cm:

Sample 49.1-1-5, 38-40 cm:

Sample 49.1-2-2, top:

Sample 49.1-2-2, bottom:

Sample 49.1-2-3, top:

Sample 49.1-2-3, bottom:

Sample 49.1-2, core catcher:

These samples yielded a Lower Cretaceous assemblage of benthonic foraminifera and ostracods almost identical to Core 49.0-2. In addition to the species listed above, the following taxa were identified: *Dentalina communis* Orbigny, *D. varians* Terquem, *D. soluta* Reuss, *D. cylindroides* Reuss, *Fronicularia* sp. cf. *F. dichotomiana* Bartenstein and Brand, *Nodosaria* sp. cf. *N. linearis* Romer, *N. hortensis* Terquem, *Pseudonodosaria vulgata* (Boremann), *Globulina prisca* Reuss, *Lenticulina nodosa* (Reuss), *L. subalata* (Reuss), *Dorothyia* sp. cf. *D. subtrochus* Bartenstein, *Ammodiscus* sp., *Bathysiphon* sp.; and the ostracods: *Paracypris*, *Cytherelloidea*, *Cytherella*, *Bairdia*, *Bythocypris*.

**Site 50 (lat 32°24.2'N, long 156°36.0'E;
Western Flank of the Shatsky Rise; Depth 4487 Meters)**

Two cores were drilled at Hole 50.0. Only the core-catcher was recovered of Core 1, and flown-in filled the core barrel of Core 2 in cutting the 4 meters of hole. Samples examined were:

Sample 50.0-1, core catcher

Sample 50.0-2-1, bottom:

Sample 50.0-2-2, bottom:

Sample 50.0-2-3, top:

Sample 50.0-2-3, bottom:

Sample 50.0-2-4, bottom:

Sample 50.0-2-5, top:

Sample 50.0-2-6, top:

Sample 50.0-2-6, bottom:

Sample 50.0-2, core catcher:

The foraminiferal assemblage is very similar to Holes 49.0 and 49.1, and most of the more abundant taxa are common to both sites, despite the fact that Hole 50.0 was drilled approximately 200 meters lower, stratigraphically, than the other two holes. However, species which range into the younger Lower Cretaceous are absent and species, such as, *L. supjurassica*, characteristic of the Upper Jurassic - lowermost Cretaceous are present and suggest an age near the boundary of the two periods. Foraminifera present in the samples include: *Dorothyia oxycona* (Reuss), *D.* sp. cf. *D. subtrochus* Bartenstein, *Gandryina* sp., *Ammodiscus* sp., *Lenticulina muensteri* (Roemer), *L. subgaultina* Bartenstein, *L.* sp. cf. *L. lituola* (Reuss), *L. calliopsis* (Reuss), *L. incurvata* (Reuss), *L.* sp. cf. *L. ouachensis* (Sigal), *Vaginulinopsis praecursoria* Bartenstein and

Brand, *Astacolus* sp. cf. *A. gladius* (Phillippi), *Nodosaria chapmani* Tappan, *N.* sp. cf. *N. linearis* Roemer, *Fronicularia hastata* Roemer, *F.* sp. cf. *F. pseudoconcinna* Bartenstein and Brand, *Dentalina communis* Orbigny, *Lingulina praelonga* Dam, *Globulina prisca* Reuss; ostracods include: *Pontocyprilla*, *Bairdia*, *Monoceratina*, *Cytherella*, *Cytherelloidea*.

TERTIARY-CRETACEOUS BOUNDARY

An important stratigraphic accomplishment of Leg 6 was coring the Mesozoic-Cenozoic boundary at Hole 47.2 on the Shatsky Rise. The boundary was penetrated at about 106 meters below the mudline and beneath a nearly complete sequence of Cenozoic chalk oozes. This was only the second time the boundary has been reached and cored in the ocean (Leg 3, Site 20), and it is one of the few complete Upper Cretaceous boundary sequences known in the northwest Pacific region (McGowan, 1968; Asano and Takayanagi, 1965).

Throughout much of the area surrounding the Pacific, the top of the Cretaceous is marked by an unconformity involving loss of parts of the adjacent stages. Where complete sections are known as in eastern Hokkaido (Yoshida, 1961) and California (Martin, 1964), the strata are of a non-calcareous facies. Thus, in either case the foraminiferal biostratigraphy of the Cretaceous-Tertiary transition is poorly known. The widely accepted planktonic foraminiferal zones of Bolli (1957, 1967) for the later Upper Cretaceous, the *Globotruncana gansseri* Zone and the *Abathomphalus mayaroensis* Zone, have not previously been reported in autochthonous sediments from the Pacific Basin. (Hamilton (1953) has described species belonging to the *G. gansseri* Zone from admixed Cretaceous and Tertiary sediment cored on the Johnston Seamount.) Therefore, cores which span the Cretaceous-Tertiary boundary in the Pacific Ocean provide information about: a) the nature of the contact in an ocean environment with pelagic sedimentation, b) the zonal stratigraphy in the Pacific, and c) the relationship of planktonic microfossil extinctions at the end of the Cretaceous.

The stratigraphy of cored sediments adjacent to the boundary and the distribution and preservation of some of the microfossil groups is summarized in Table 2. The basic lithology of the four cores (11, 12, 13 and 14) is a monotonous light-colored nannoplankton chalk ooze. Core 11 contains a larger fraction of foraminifera and Cores 12, 13 and 14 contain an increasing number of chert layers with depth. (See Core Summary.) The pelagic nature of the sediments indicates accumulation in an oceanic environment for time interval spanned by the cores. An environment then, as now, removed from continentated sedimentation.

Examination of the larger microfossil content in the Cretaceous cores suggests that sedimentation, though probably continuous, was not uniform and that the preferential diagenesis suffered by the foraminifera in Cores 13 and, especially, 12 reflects long exposure on the sea floor before burial. Planktonic foraminifera in Core 11 are well-preserved, fresh appearing, and essentially none contain holes or other traces of dissolution. The most common damage is loss of the last-formed chamber which is thin-walled and therefore fragile. Approximately 6 to 8 per cent of the species from the upper part of Core 11 have broken chambers, probably as a result of various kinds of mechanical abrasion. The assemblages containing an admixture of Paleocene zones from Sections 3, 4, 5 and 6 of Core 11 have nearly twice as many broken specimens. In contrast, the Cretaceous planktonic species from Cores 12, 13 and 14 are chalky appearing, and many exhibit traces of dissolution. About 40 per cent of the fauna in Core 12 and 15 to 25 per cent in Core 13 are lacking the initial chamber and/or are broken; and, in the upper sections of Core 12, there are specimens in which only a "skeleton" composed of the inner septa and outer chamber rims remain. The effects of the dissolution, which acts preferentially between and within major groups of foraminifera, is most obvious in the planktonic/benthonic ratios. It is clear from an examination of the faunas that Cretaceous planktonic species are less resistant to solution than benthonic species, just as in modern sediments (Phleger, 1964). The quantitative loss of planktonic species relative to benthonic forms can be gauged by estimating the number of planktonic specimens necessary to restore the P/B values in Core 12 to those in Core 13 or Core 14. Fortunately for biostratigraphers, keeled species (*Globotruncana*, *Globotruncanella* and *Abathomphalus*) are relatively resistant to solution, and key associations in the *Abathomphalus mayaroensis* Zone survive in Core 12 and as reworked elements in Core 11 and in Core 10, Section 5. Globigerina-shaped taxa do not fare as well, and the low number of *Rugoglobigerina*, *Globigerinelloides* and "*Hedbergella*" in Core 12 (about 7 per cent) as compared to Core 13 (12 per cent) is probably due to preservation. This fact is unfortunate as it obscures the evolutionary relationship between Upper Maestrichtian species, such as, *H. holmdelensis* and earliest Danian globigerines, that might be preserved in oceanic deposits. Cretaceous microfossils have undergone diagenic changes that progressively increase towards the top of Core 12, but the changes do not affect the microfossils in the Lower Paleocene. The zonal stratigraphy of the Cretaceous is continuous and, within the limits of the fauna, the *Abathomphalus mayaroensis* appears to be complete. Assuming the zone spans 3 million years—a reasonable although maximal value if the length of the Maestrichtian is 6 million years (Casey, 1964)—and the total section is 19 meters thick, a sedimentation rate of about 6 meters per million years is indicated. In the modern

TABLE 2
Stratigraphic Distribution of Cores and Nature of the Microfossils
Across the Tertiary-Cretaceous Boundary at Hole 47.2

Core	Section	Sample ^a	P/B Ratio ^b	% Keel-taxa ^c with tegilla	% Tests with Holes ^d		% Tests Broken ^e	Ostracods ^f	Reworked Taxa ^g	Boundary Determination ^h		
					Adult Chambers	Initial Chambers				Coccoliths		Planktonic Foraminifera
10	100.6									Mixed Paleocene and Cretaceous	<i>C. tenuis</i> Zone	Paleocene
	1	*	> 100		0	0	7	+	C b			
11	2	*							C p,b			<i>G.</i> <i>taurica</i> Zone
	3	*	> 100		< 1	0	13		C p,b ⁺			
	4	*						+	C p,b ⁺		Mixed Paleocene and Cretaceous	
	5	*						+	C p,b ⁺⁺			
	6	*						+	C p,b ⁺			
	cc	*	> 100		< 1	0	14	++	C p,b ⁺⁺			
12	cc	< top	15	22	11	39	42	+	p	Cretaceous	<i>Tetralithus murus</i> Zone	Cretaceous
	1											
	2		24	32	15	46	36	+	p			
	3	*						+				
	4	*										
	cc		17	39	18	42	39	+	P,N			
	cc	< CC	40	45	18	44	39		P,N			<i>Abathomphalus mayaroensis</i> Zone

TABLE 2—Continued

Core	Section	Sample ^a	P/B Ratio ^b	% Keel-taxa with tegilla ^c	% Tests with Holes ^d		% Tests Broken ^e	Ostracods ^f	Reworked Taxa ^g	Boundary Determination ^h					
					Adult Chambers	Initial Chambers				Coccoliths	Planktonic Foraminifera				
13	1	* top **	200	66	6	30	19			Cretaceous	<i>Tetralithus murus</i>				
	2											69	4	26	15
	3														
	4														
	5														
	6														
		< CC	300	63	8	17	13	+							
14	129.2	< CC	400	42	9	22	17		N		<i>L. quad-ratus</i>	<i>G. gansseri</i>			

^aQuantitative counts to determine planktonic-benthonic foraminiferal (P/B) ratios and state of preservation were made on 300 or more random specimens taken from microsplit aliquots. Up to 600 specimens were counted in Samples 47.2-11-3, 145-150 cm, 47.2-13-3, 6-8 cm, and 47.2-14-4, 145-150 cm, to test the affect of increased sample size. Individual values changed somewhat (up to 4 per cent), but the relative ranking between categories remained the same.

^bPlanktonic-benthonic ratios were measured by the standard method. Ratios for the Tertiary could only be estimated because of the significant numbers of benthonic species which could not be identified as reworked or indigenous. Some Cretaceous species range into the Paleocene.

^cKeel taxa include species of *Globotruncana*, *Globotruncanella* and *Abathomphalus*. Damaged tegilla which still covered the umbilical opening were scored as present.

^d"Tests with holes" refers to planktonic species which possessed holes anywhere in the shell except in the initial 4 or 5 chambers, which were included in the next category.

^eBroken tests were divided into two classes, based on a preliminary examination of the fauna. A frequent condition is for the dorsal (spiral) wall of the initial 4 or 5 chambers to be broken or missing entirely, exposing the inner septa. With progressive dissolution, the test becomes fragile and tends to break along suture lines. Some broken specimens are undoubtedly due to causes other than dissolution, including biological ingestion and mechanical abrasion during sample processing. All samples were prepared in the same manner and therefore the damages incurred should be roughly the same in all, and can be considered as a constant, though, unknown value.

^fOstracods and reworked foraminifera were scored as absent, present (+) or abundant (++)

^gReworked species were termed abundant when their numbers were equal to or greater than the indigenous fauna. In the column, N = Neogene, P = Paleocene, C = Cretaceous, p = planktonic foraminifera, and b = benthonic foraminifera. Thus, the symbols for 47.2-11, core-catcher, read, Cretaceous planktonic foraminifera and abundant benthonic species.

^hThe Cretaceous/Tertiary as boundary determined by coccoliths and planktonic foraminifera is shown here; for further details see Core Summaries.

ocean, pelagic carbonate sedimentation rates of about this magnitude are characteristic of the low productivity areas in mid-oceans (Blackman, 1966; Ericson, *et al.*, 1961). Thus the evidence suggests that the rate of accumulation on the Shatsky Rise at the end of the Cretaceous was sufficiently slow to allow partial chemical destruction of the foraminifera.

The exact nature of the original contact at the Tertiary boundary is lost in the disturbed sediments in the lower sections of Core 11. Sections 1, 2 and 3 contain a continuous section of foraminiferal and coccolith zones through the lowest Paleocene; the *Globorotalia trinidadensis* Zone occurs in Sections 1 and 2 and the *Globigerina taurica* (= *G. eobulloides*) Zone in the top and bottom of Section 3. However, the lower sections contain a mixed foraminifera assemblage from the middle and lower Paleocene plus numerous microfossils from the underlying Cretaceous. The coccolith assemblage in the lower half of Core 11 is Cretaceous without Tertiary contamination (Bukry, this volume). Thus, the Cretaceous-Tertiary boundary based on the microflora is placed within Section 3. Based on the occurrence of foraminifera, the boundary should be placed lower but the precise position of the contact cannot be determined from the cores. The boundary must occur lower than the lowest occurrence of the *Globigerina taurica* Zone (= *G. eobulloides* Zone), that is, the bottom of Section 3, but above the top of Core 12, which is definitely Cretaceous. Thus, the boundary is bracketed within an interval of about 4 meters.

Although the precise stratigraphic level of the contact cannot be determined by the cores, they do provide information about the type of contact representing the boundary. Large numbers of reworked Cretaceous foraminifera and ostracods in the Paleocene cores are evidence of erosion of Upper Maestrichtian strata beginning in earliest Danian time. To the east, at nearby Hole 48.2, the Miocene rests directly upon the lower part of the *Abathompholus mayaroensis* Zone, and the stratigraphic equivalence of Cores 7 through 12 at Hole 47.2 are missing, presumably removed by erosion.

Thus, the end of the Cretaceous in the Pacific area that is now the Shatsky Rise was marked by declining sedimentation and, beginning in the Paleocene or earlier, erosion at least locally of Maestrichtian strata that continued until the Miocene. The sequence of planktonic foraminifera and coccolith zones across the boundary is the same as in the Caribbean and Southern Europe and is complete despite a 4.5-meter thick section of disturbed sediments, which probably includes the actual boundary. Within the undisturbed portions of the cored sediments there is good agreement between the calcareous microfossils as to age and position of the boundary, and it indicates the same faunal discontinuity at the contact known elsewhere.

PALEOECOLOGY: PLANKTONIC FORAMINIFERA

Planktonic foraminifera provide valuable ecologic-environmental data. For the samples obtained during Leg 6, the insight provided on the nature and preservation of Cretaceous oceanic assemblages is probably more significant than their stratigraphic value.

Recent planktonic foraminifera are oceanic organisms and their numbers and kind decrease rapidly at the margins of the oceanic biotope, a fact recognized by Murray (1897) and abundantly verified in the last 70 years. It is a reasonable assumption that Cretaceous species had a similar affinity for oceanic conditions, and it follows that some of the time-space variation in Cretaceous faunas is ecologic, especially the faunal variations in deposits which represent sedimentation within seaways or on the margins of the Mesozoic continent. However, partitioning the variation in fossil assemblages due to short-term ecologic effects from long-term ecologic-evolutionary changes, which is critical for precise regional correlation, requires data on the nature of demographic and taxonomic changes across environmental gradients. For Cretaceous planktonic foraminifera data are available for assemblages from shallow water, near-shore environments, but data are generally lacking for oceanic assemblages. In this respect, the Leg 6 cores from Sites 45, 47, 48 and 51 help to fill an important information gap.

Samples examined from these four sites have a predominance of planktonic foraminifera and, with the exception of Core 47.2-12, typical planktonic-benthonic ratios are greater than 100:1. Such values suggest deep-water (bathyal) pelagic sedimentation (Smith, 1955; Grimsdale and Morkhoven, 1955), an interpretation that is consistent with the mineralogy and the other microfossils present in the sediments. Ewing *et al.* (1966) have interpreted the lithology, seismic results and Albian fauna of the Shatsky Rise as indicating: 1) an uplifted basin which received shallow-water organisms from nearby atolls or islands of the Darwin Rise, or 2) that the basement arch forming the rise is older than the sediments, and the greater thickness of the sediments on the top of the rise is due to greater depositional rate in lesser depths. *Inoceramus* fragments and juvenile pelecypods recovered with the foraminifera in the Albian fauna were interpreted by the investigators as shallow-water shells, hence, the postulated nearby atolls or islands. An equally forceful argument can be made that some Cretaceous pelecypods, including *Inoceramus*, were bathyal in distribution. The results from Leg 7 (Geotimes, 1969) strain the concept of a great mid-Pacific region of shallow water, the Darwin Rise, and thus the idea of nearby shallow-water to the Shatsky Rise. Evidence from the Leg 6 cores drilled on the Shatsky Rise and adjacent area of the northwest

Pacific support the second model of Ewing *et al.* that the Rise pre-dates the Cretaceous sediments and the differences in sediment thickness is a result of a differential accumulation rates with depth.

Keeled species, namely: *Rotalipora* and *Praeglobotruncana* in the Cenomanian, *Marginotruncana* in the Turonian and early Senonian, and *Globotruncana* in the late Senonian, dominate assemblages in the Pacific samples. In Sample 45.1-3, core-catcher, *Rotalipora evoluta* accounts for 40 per cent of the total population, and the keeled species *R. evoluta*, *R. greenhornensis* and *Praeglobotruncana delroensis* make up about 80 per cent of the individuals, though only 20 per cent of the total diversity. There are four species of *Hedbergella* and two species of *Globigerinelloides* in the same sample, but only *H. delroensis* and *Globigerinelloides* are numerous. In the Coniacian-early Santonian foraminifera of the *Marginotruncana concavata* Zone, *Globotruncana fornicata* is dominate, followed by *M. concavata* and then by *M. coronata*. *Marginotruncana pseudolinneiana* and *M. sp. cf. M. renzi*, a nearly single-keeled species with narrow crescentic-shaped chambers on the spiral side, are distinctly less common. They occur in about equal numbers with the globigerine-shaped taxa, mainly *Whiteinella inornata*, and *Archaeoglobigerina* sp. Maestrichtian assemblages from Cores 47.2-13 and 47.2-14 are twice to three times as diverse as the older Cretaceous faunas, the additional species occurring in *Globotruncana* and the heterohelid genera, *Heterohelix*, *Pseudotextularia*, *Pseudoguembelina* and *Planoglobulina*. For populations of individuals greater than 125 microns in size the relative proportion of the three major groups are approximately: keeled species (*Globotruncana*, *Globotruncanella*, *Abathomphalus*) 60 per cent; heterohelid species 30 per cent; globigerine-shaped taxa (*Rugoglobigerina*, *Trinitella*, *Globigerinelloides*, *Archaeoglobigerina* and "*Hedbergella*") 10 per cent (Table 3). *Globotruncana* accounts for over 95 per cent of the keeled population and *Heterohelix* for the majority of the heterohelids so that the samples can be characterized as a *Globotruncana-Heterohelix* association.

Despite differences in age and taxonomic composition, the predominance of keeled species within the planktonic foraminiferal assemblages, as preserved in the sediments, remains a constant. The relative proportion of the globigerine-shaped taxa and heterohelids however shifts in time. In the Pacific samples, which by chance occur approximately at the beginning, middle and end of the Upper Cretaceous, globigerine-shaped species progressively give way to the heterohelids so that by the end of the period, in the *Abathomphalus mayaroensis* Zone, they contributed 10 per cent, or less, of the total microfauna. Comparison of the northwest Pacific assemblages to the same age assemblages from North America and northwest Europe reveals differences in

both the taxonomic composition and species-abundance of the microfaunas to 1) assemblages from similar latitudes but different environments, and 2) assemblages from different latitudes but similar environments. Analysis of the shallow water, nearshore plankton, though incomplete and based largely on qualitative data, suggests for the moment that the relative contribution of keeled species in fossil assemblages is directly related to the slope of the gradient from oceanic to nearshore environments, with the greatest number and diversity associated with open, oceanic conditions. Globigerine-shaped species tend to be inversely related to the gradient and are better represented in interior seaways and continental shelf deposits (Douglas and Rankin, 1969). The impression is that the globigerine-shaped species are more eurytopic and fill the biospace vacated by the keeled species. For example, in the Middle Austin Chalk of Texas, which outcrop at about the latitude of Site 51 and which is approximately the same age (*Marginotruncana concavata* Zone), the pelagic microfauna contains about 45 per cent globigerines (*Archaeoglobigerina*, *Hedbergella* and *Globigerinelloides*) 30 per cent *Marginotruncana* and 25 per cent heterohelids. If *Marginotruncana marginata*, which has strongly inflated chambers but a keel, is included with the globigerines, the value increases to nearly 60 per cent. Further to the north, within the Western Interior seaway, the only keeled species is *M. marginata* and the microfauna is dominated by globigerine taxa and *Heterohelix* (Kent, 1969; 1967; Wall, 1967).

Pessagno (1969) reported that in samples from Leg 1, heterohelids are less common and several species are absent compared to near-shore Gulf Coast sections. He suggested that the group might be neritopelagic or less abundant in abyssal pelagic deposits. The abundance and diversity of the heterohelids in the northwest Pacific suggests the opposite and favors an interpretation of the group as part of the Cretaceous ocean plankton. *Heterohelix washitensis*, one of the earliest species (Brown, 1969) is numerous in Sample 45.1-3, core-catcher, and, as noted above, heterohelids are particularly important in Maestrichtian samples. Seven genera (*Heterohelix*, *Planoglobulina*, *Pseudotextularia*, *Pseudoguembelina*, *Gublerina* and *Guembelitra*) and over 18 species occur in the cores from Holes 47.2 and 48.2; the heterohelid assemblage is as robust as any reported from outcropping Cretaceous strata. *Planoglobulina multicamerata*, for example, which occurs frequently in Gulf Coast deposits (Pessagno, 1969) is also a common species in the Pacific. The reason for the low diversity of heterohelids in the Leg 1 samples is unclear, but the apparent increase in abundance in nearshore sections may be due to the decrease in keeled species that are present in oceanic assemblages.

PRESERVATION

The potential of planktonic foraminifera for ecologic interpretation (or for correlation) is impaired if the original species-abundance distribution or the taxonomic composition of the assemblage is altered. In the present ocean, an important phenomenon which hinders information retrieval from calcareous microfossils is selective solution (Berger, 1967; Ruddimann and Heezen, 1967). Examination of the foraminiferal faunas from Leg 6 reveals: 1) clear evidence of dissolution of the Cretaceous fossils, 2) that the effects are selective (or preferential), and 3) that solution has altered the original composition of certain fossil assemblages. Without attempting to identify the basic mechanisms involved in solution, the following observations—based primarily upon samples from 45.1, 47.2, 48.2, 49 and 50—are offered as a preliminary step in identifying the problem in Mesozoic deposits and providing information on the relative susceptibility of different Cretaceous species to solution. In the following discussion the term “keeled species” refers to planktonic foraminifera with truncated or acute margins, and that have projections formed by the thickening or reinforcement of the outer edge of the chamber. Species with this feature are placed in the genera *Globotruncana* (including *Rugotruncana*), *Globotruncanella* and *Abathomphalus*. “Globigerine-shaped taxa,” or simply “globigerines” are trochospiral or planispiral species with rounded, non-keeled margins. In this category are *Rugoglobigerina*, *Globigerinelloides*, *Archaeoglobigerina* and *Hedbergella*. *Trinitella*, which has an early globigerine stage but develops a keel of the last chamber, is somewhat intermediate between the two categories. It is here included with the globigerines. The three categories: keeled species, globigerines and heterohelics (the biserial planktonic foraminifera), are useful because they represent fairly distinct taxonomic, and to some degree phylogenetic, ecologic and preservation groupings. Values in Table 3 are based on microsplit cuts and statistical counts of the washed residue greater than 125 microns in size. Specimens smaller than 125 microns are mostly juveniles for which species labels cannot be unequivocally applied (and small species of *Hedbergella*, *Schackoia*, *Guembeltria* and *Heterohelix*). Based on trial and error, the exclusion of this size fraction does not seem to significantly alter the results. Nevertheless, the absolute numbers for the various preservation classes within a sample probably have less meaning, because of the size bias and sampling, than the relative changes between samples. All samples used in the study were processed in the same manner, and any damage to the microfossils is assumed to be constant for all samples.

Solution acts preferentially on Cretaceous species; certain species and morphologic groups are more resistant to dissolution than other, sometimes similar appearing fossils. As a general rule the globigerine-shaped taxa

are less resistant than the majority of heterohelics, and the heterohelics are less resistant than the keeled species. There are exceptions to the rule, however, and the precise position any taxon holds in the solution ranking seems to be dependent upon a number of variables, including size (age), degree of ornamentation, wall structure, shell chemistry and probably exposure time.

The proportion of globigerines in the samples nearly doubles from Core 12 to Core 13, and the increase is uniform for all horizons (Table 3). The change occurs within the *Abathomphalus mayaroensis* Zone, and there is no change in the taxonomic composition between the two cores. In the same 17-meter interval the percentage of globigerines (mainly, *Rugoglobigerina* and *Trinitella*) with broken tests decreases by approximately one-half. It is difficult to evaluate the ranking of the genera or species within the group because of the small number of specimens present. If relative abundance in the samples is indicative of a greater resistance to solution, then *Trinitella* and *Globigerinelloides* are the high and low end members, respectively, with *Rugoglobigerina* holding an intermediate position. Increased ornamentation of the larger *Rugoglobigerina rugosa* and *R. hexacamerata* appears to enhance their resistance to solution. Specimens of globigerines preserved in the upper samples of Core 12 are very chalky and they break under slight pressure. One reason this group may suffer greater destruction, in addition to the more porous test, is that the shells tend to break along sutures. Isolated chambers or tests lacking the last 2 to 3 chambers are common. However, overall the percentage of broken globigerines tests is less than the number of broken shells in the other two categories, suggesting that once damaged, the weakened test rapidly disintegrates.

Partial destruction of heterohelical fossils is apparently not as important a factor in the ultimate preservation of the fossil as in the globigerines. The first noticeable effect of solution is loss of the initial chamber or pair of chambers. All of the specimens in the upper part of Core 12 and a large percentage in Cores 13 and 14 are in this state. The first complete specimen of *Heterohelix* was found in Sample 47.2-12, core-catcher, and the number increases downwards. The majority of the intact specimens have the initial chambers coiled. Some heterohelics, especially the larger *Pseudotextularia*, *Planoglobulina* and *Racemiguelina*, have a tendency to develop holes in the adult chambers. However, the larger last pair of chambers are also the most abundant biserial remains found in samples which have undergone intense solution (Sample 47.2-12-1, top). Once biserial fossils lose the initial chambers, which the author terms “state 1,” the tests exhibit little apparent change, though they are probably undergoing progressive solution, until the test breaks (stage 2). In Core 12, the

TABLE 3
Preservation of Planktonic Foraminifera in Cores 12, 13 and 14 at Hole 47.2—Upper Maestrichtian
Abathomphalus mayaroensis Zone and *Globotruncana gansseri* Zone^a

Sample	Total Count	Holes in Test		Tegilla Complete	Test Broken	Chalky Appearance to Test	Rims Only
		Initial Chambers	Adult Chambers				
47.2-12-1, top	(n = 378)						
Keel	46.00	49	11	22	34	++	+
Globigerine	7.00	7	4	19	19	++	
Heteroheliced	40.00	39	—	—	59	++	
Benthonic	0.60	+	—	—	12	++	
47.2-12-2, 7-9	(n = 445)						
Keel	38.00	50	18	32	31	++	+
Globigerine	10.00	7	2	42	33	++	+
Heteroheliced	46.00	56	2	—	41	++	
Benthonic	0.40	+	5	—	28		
47.2-12-4, 145-150	(n = 419)						
Keel	31.00	44	20	39	33	++	
Globigerine	7.00	10	7	31	17	++	
Heteroheliced	54.00	50	2	—	48	++	
Benthonic	0.60	—	11	—	29		
47.2-12, core catcher	(n = 404)						
Keel	54.00	51	18	45	29	++	
Globigerine	6.00	4	—	50	22	++	
*Heteroheliced	36.00	44	—	—	56	++	
Benthonic	0.25	+	—	—	33		
47.2-13-1, 145-150	(n = 510)						
Keel	45.00	8	6	66	20	++	
Globigerine	11.00	2	1	50	12	++	
Heteroheliced	43.00	61	—	—	20	++	
Benthonic	0.04	—	—	—	—		
47.2-13-3, 6-8	(n = 597)						
Keel	55.00	2	7	58	15	+	
Globigerine	9.00	—	—	32	7		
Heteroheliced	35.00	48	1	—	41		
Benthonic	0.05	—	—	—	—		
47.2-13-4, top	(n = 372)						
Keel	52.00	4	4	69	11	+	
Globigerine	12.00	—	6	63	15		
Heteroheliced	36.00	67	3	—	20		
Benthonic	0.03	—	—	—	—		
47.2-13-5, 145-150	(n = 542)						
Keel	57.00	6	8	61	14	+	
Globigerine	12.00	2	9	56	14		
Heteroheliced	31.00	61	2	—	22		
Benthonic	0.03	—	—	—	+		

TABLE 3 – Continued

Holes in Test							
Sample	Total Count	Initial Chambers	Adult Chambers	Tegilla Complete	Test Broken	Chalky Appearance to Test	Rims Only
47.2-13, core catcher	(n = 380)						
Keel	61.00	5	10	63	10	+	
Globigerine	13.00	2	5	47	7		
Heterohelcid	26.00	55	3	—	26		
Benthonic	0.02	—	+	—	—		
47.2-14-4, 145-150	(n = 548)						
Keel	61.00	2	6	42	18		
Globigerine	11.00	—	3	38	5		
Heterohelcid	28.00	55	5	—	33		
Benthonic	0.01	—	—	—	—		
47.2-14, core catcher	(n = 393)						
Keel	62.00	5	9	62	15		
Globigerine	7.00	—	—	7	7		
Heterohelcid	31.00	60	2	31	20		
Benthonic	0.02	—	—	—	—		

^aAll values given in percentage; n is the number of specimens counted. The six categories approximate progressive steps in the solution destruction of the test. Ordered in terms of increasing destruction, they are: chalky test, holes in test, destruction of tegilla, broken test, loss of shell surface so only marginal suture rims and internal septa remain ("rims only").

number of specimens exhibiting loss of the initial chamber is about equal to the number of broken tests (some shells occur in both classes), but in Core 13 the ratio is about 2:1, respectively. This suggests that a greater number of tests are preserved which have already sustained some damage. It is clear from an examination of the biserial population in Core 12 that large, robust species are most likely to be preserved and presumably the opposite morphologic type is at the other end of the preservation spectrum.

Keeled species show a rather complex pattern of solution preservation, but generally they are the most resistant endmember of Cretaceous planktonic foraminifera, just as *Globorotalia* is in modern sediments (Berger, 1967). Four stages can be recognized in the progressive dissolution of *Globotruncana* species; similar stages occur in *Globotruncanella* and *Abathomphalus*. The first traces (stage 1) of solution are a chalky appearance to the test and destruction of the initial chambers on the spiral side. Small holes appear in the first 4 to 5 chambers which grow in size until the entire spiral surface is destroyed, exposing the inner septa. Holes begin appearing in other parts of the test in the next phase (stage 2), particularly in the center of the chambers on the spiral and umbilical sides and at points which project above the general surface of the

test. The weakened test appears to break easily and frequently, the last chamber or several chambers are separated from the shell (stage 3). During this stage the tegilla, i.e., umbilical cover plates, which are less porous than the test walls, are destroyed. In the final stage 4 only a "skeleton," composed of the keel or marginal rim and the inner septa remain. Species in this stage occurred only in the upper part of Core 12. An unexpected relationship was that the fragile appearing tegilla structures are more resistant to solution than portions of the shell wall. Specimens were repeatedly observed in which most of the spiral surface was gone and holes had appeared in the umbilical surface, but the tegilla was intact and well-preserved. It suggests that destruction of the tegilla in well-preserved deposits is a result of mechanical abrasion rather than solution. This is a possible explanation for the low percentage of complete tegilla in Cores 47.2-14 and 48.2-3, which in other respects have well-preserved fossils. Both cores were largely obtained by flow-in during drilling.

Within the keeled taxa, the pattern of susceptibility to solution cuts across similar species. Thus among the single keeled taxa, *Globotruncana stuarti* almost universally had traces of stage 1 or 2 dissolution in samples from Core 12 and upper part of Core 13, but *G. stuartiformis* in the same samples was frequently in

TABLE 4
Model for the Relative Susceptibility of
Maestrichtian Planktonic Foraminifera to Solution.

Solution	Globigerine-shaped Species	Heteroheliced Species	Keeled Species
Least Resistant	1. Juveniles and small, thin-walled species: <i>Hedbergella</i> , <i>Globigerinelloides</i> 2. Adults medium to large size species with little or no ornamentation: <i>Rugoglobigerina</i> , <i>Hedbergella</i> , <i>Archaeoglobigerina</i> ; rare <i>Globigerinelloides</i> 3. Adults and large, thick-walled species and/or heavy ornamentation: <i>Rugoglobigerina</i> , <i>Trinitella</i>	1. Juveniles and fragile, thin-walled species of <i>Heterohelix</i> , <i>Guembeltria</i> , <i>Pseudoguembelina</i> 2. Adults and medium-sized species with little or no ornamentation; <i>Heterohelix</i> , <i>Pseudoguembelina</i> , <i>Pseudotextularia</i> 3. Large, thick-walled species with coarse ribbing or coalasced spines, thickened sutures: <i>Racemiguembelina</i> , <i>Pseudotextularia</i> , <i>Gublerina</i>	1. Juveniles without keels or marginal thickenings 2. Adults with weak keels and little or no ornamentation (spines) on spiral or umbilical surface: <i>Globotruncana</i> , e.g. <i>G. subcircumnodifer</i> and <i>G. arca</i> . 2a. Smooth, single keeled species, e.g. <i>G. stuarti</i> 3. Large species with thick walls and species with heavy ornamentation and beaded sutures: <i>Globotruncana</i> , <i>Abathomphalus</i> e.g. <i>A. intermedia</i> , <i>G. contusa</i> , <i>G. arabica</i>
Decreasing Susceptibility ↓ Increasing Solution	No globigerines	Few heteroheliceds	
	No planktonic foraminifera, benthonic foraminifera and coccoliths		
Most Resistant			

early stage 1, and better preserved. Among the most resistant species, somewhat surprisingly, are *Globotruncanella havanensis* and *Abathomphalus intermedia*; well-preserved specimens of these species exist in Samples 47.2-12-2, 47.2-12-3 and 47.2-12-4 where roughly 80 per cent of the keeled specimens are damaged. Small, delicate specimens of *G. havanensis* are present without holes and complete tegilla in samples in which large, robust species, such as, *Globotruncana contusa* and *G. arca*, are in stage 2 dissolution. *Abathomphalus mayaroensis*, which is thought to be closely related to the two above species (Pessagno, 1967) ranks below them and occupies a position closer to that of other double-keeled types.

Benthonic foraminifera and ostracods occur in Cores 12, 13 and 14 at Hole 47.2 and in the cores from Hole 48.2. In general, they are better preserved than the planktonic foraminifera, but examination of the shells at high magnification (>1000X) reveals subtle evidence of solution and recrystallization. In the top of Core 12, *Lenticulina* exhibits pits or holes in the umbilical boss and *Nodosaria*, *Dentalina*, *Lagena* and other uniserial species have small holes in the chambers. Similar but more pronounced textures occur in the benthonic foraminifera and ostracods in cores at Sites 49 and 50. Many, perhaps a majority of the specimens, are recrystallized. The absence of *Nannoconus* (Bukry, this volume) and planktonic foraminifera in the samples may be the result of solution rather than age or ecology.

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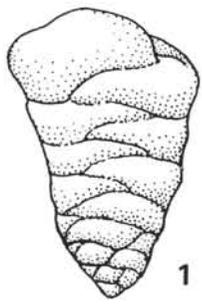
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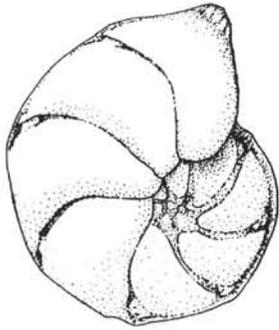
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PLATE 1

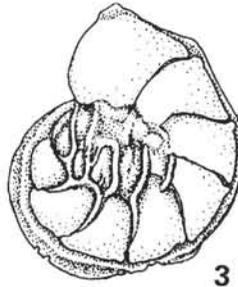
- Figure 1 *Dorothia oxycona* (Reuss); 49.1-2, core-catcher (DSDP 60033), X 65.
- Figure 2 *Lenticulina acuta* (Reuss); 49.1-2, core-catcher (DSDP 60008), X 65.
- Figure 3 *Lenticulina* sp.; 49.1-2, core-catcher (DSDP 60010), X 33.
- Figure 4 *Lenticulina muensteric* (Roemer); 49.1-2, core-catcher (DSDP 60001), X 23.
- Figure 5 *Lenticulina cultrata* (Monfort); 49.1-2, core-catcher (DSDP 60035), X 47.
- Figure 6 *Lenticulina* sp., 50.0-2-1, 145-150 cm (DSDP 60069), X 47.
- Figure 7 *Lenticulina* sp.; 49.1-2, core-catcher (DSDP 60003), X 65.
- Figure 8 *Lenticulina subalata* (Reuss); 49.1-2, core-catcher (DSDP 60006), X 44.
- Figure 9 *Ramulina aculeata* Wright; 49.1-2, top (DSDP 60179), X 47.
- Figure 10 *Lingulina praelonga* Dam; 50.0-2-1, 145-150 cm (DSDP 60070), X 65.
- Figure 11 *Lingulina* sp., 50.0-2-6, 145-150 cm (DSDP 60058), X 47.
- Figure 12 *Lingulina semiornata* Reuss; 50.0-2, core-catcher (DSDP 60056), X 65.
- Figure 13 *Ramulina* sp.; 49.0-2, core-catcher (DSDP 60048), X 47.
- Figure 14 *Frondicularia hastata* Roemer; 50.0-2-6, 145-150 cm (DSDP 60059), X 33.
- Figure 15 *Frondicularia inversa* Reuss; 49.0-2, core-catcher (DSDP 60176), X 47.
- Figure 16 *Frondicularia* sp. cf. *F. dichotomania* Bartenstein and Brand; 49.1-2, core-catcher (DSDP 60016), X 47.
- Figure 17 *Nodosaria* sp.; 49.1-2-2, 145-150 cm. (DSDP 60178), X 65.
- Figure 18 *Ammodiscus gaultinus* Berthelin; 50.0-2-1, 145-150 cm. (DSDP 60066), X 86.



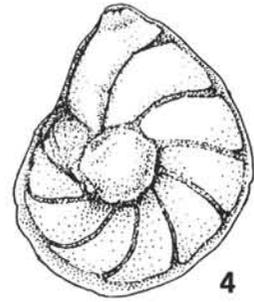
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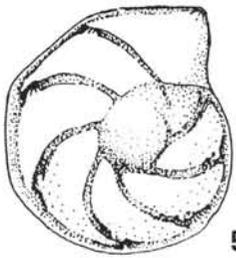
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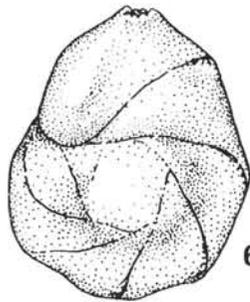
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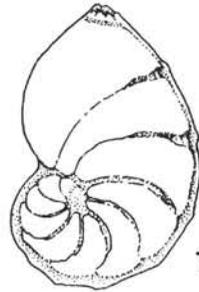
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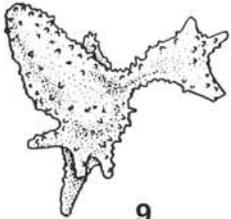
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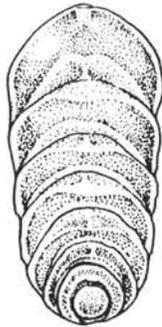
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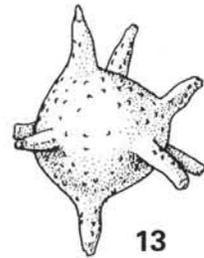
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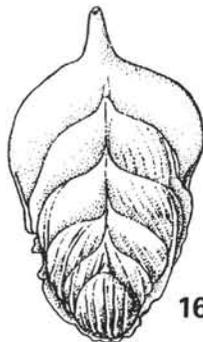
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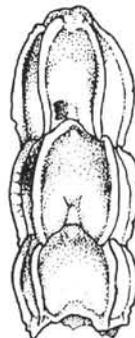
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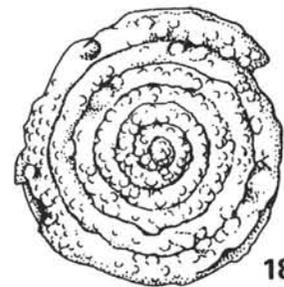
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PLATE 2

- Figure 1 *Marginotruncana coronata* (Bolli); 51.0-3, core-catcher (DSDP 60202), X 50.
Umbilical view illustrating one type of apertural cover plate arrangement in which individual apertural flap or plate is small and more than one flap per chamber may occur. Note that the flaps are solid and not pierced as in *Globotruncana* s.s. (Pessagno, 1967).
- Figure 2 *Marginotruncana coronata* (Bolli); X 450. Same specimen as in Figure 1.
- Figure 3 *Ticinella roberti* (Gandolfi); 51.0-3, core-catcher (DSDP 60205), X 350.
Note sutural supplementary apertures in umbilical cavity and coarse pore structure of shell.
- Figure 4 *Globigerinelloides caseyi* Bolli, Loeblich and Tappan 51.0-3, core-catcher (DSDP 60203), X 350.
- Figure 5 Detail of surface texture on fifth from last chamber of specimen in Figure 4. Note: "spines" are single crystals with few overgrowths.
- Figure 6 Detail of surface texture, center of second from last chamber in Figure 4. "Spines" are compound structures with overgrowths. Pore can be observed in interarea between "spines".

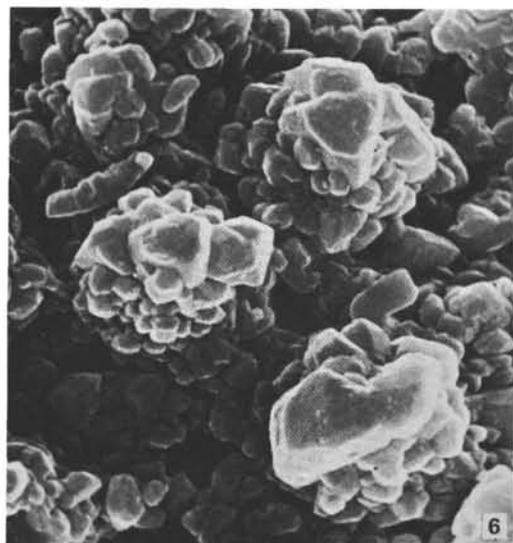
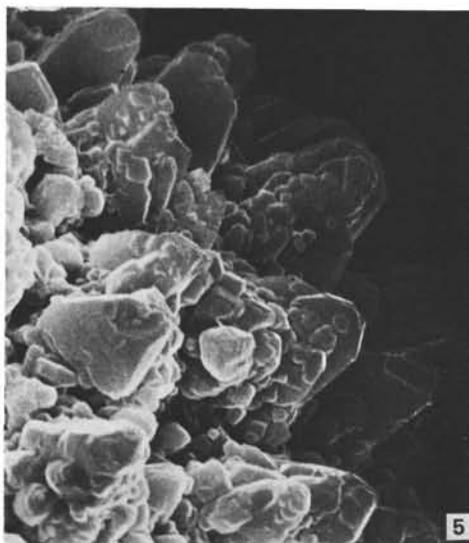
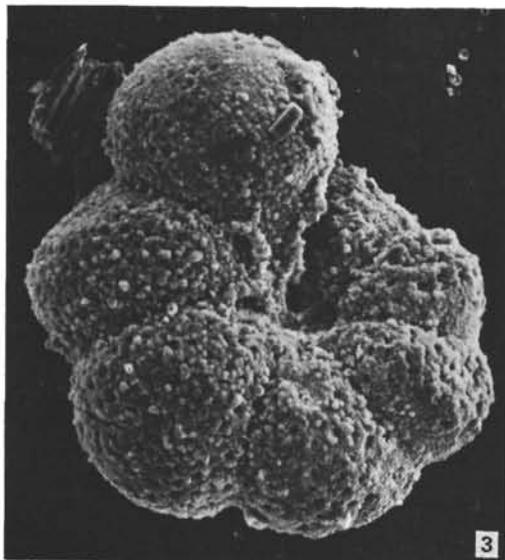


PLATE 3

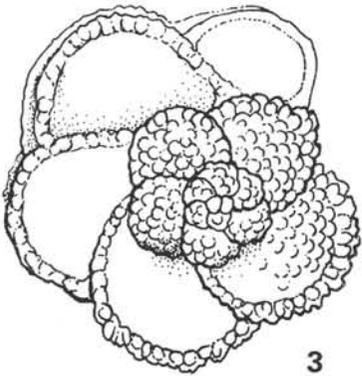
- Figure 1 *Marginotruncana concavata* (Brotzen); 51.0-3, core-catcher (DSDP 60201), $\times 150$.
Note: Solid apertural flaps.
- Figure 2 *Marginotruncana concavata* (Brotzen); 51.0-3, core-catcher (DSDP 60204), $\times 250$.
Juvenile specimen with kummerform last chamber. Apertural flaps are absent on the earlier formed chambers.
- Figures 3, 4 and 5 *Marginotruncana concavata* (Brotzen); 51.0-3, core-catcher (DSDP 60095), all $\times 140$.
Typical morphology of the species in oceanic sediments:
Fig. 3 – spiral view.
Fig. 4 – side view.
Fig. 5 – umbilical view.
- Figures 6, 7 and 8 *Ticinella primula* Luterbacher; 51.0-3, core-catcher (DSDP 60072), all $\times 140$.
Sutural supplementarily apertures in umbilical cavity obscured by matrix.
Fig. 6 – umbilical view.
Fig. 7 – side view.
Fig. 8 – spiral view.
- Figures 9, 10 and 11 *Ticinella roberti* (Gandolfi); 51.0-3, core-catcher (DSDP 60073), all $\times 140$.
Fig. 9 – umbilical view.
Fig. 10 – side view.
Fig. 11 – spiral view.



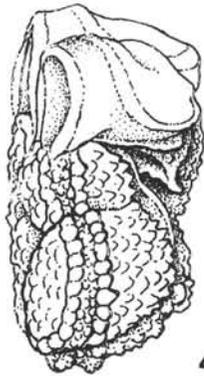
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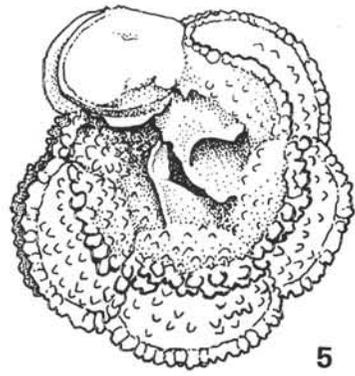
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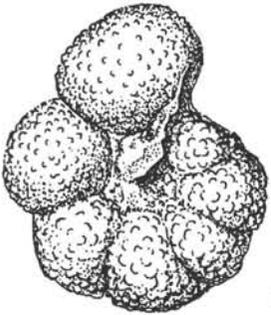
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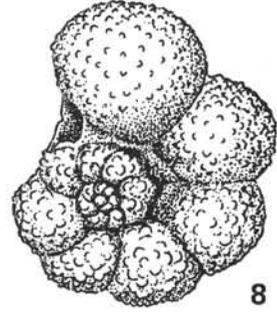
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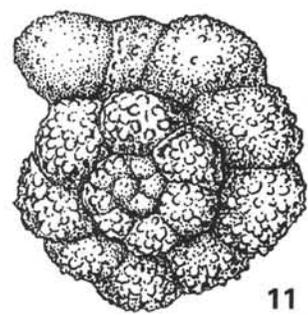
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