28. CRETACEOUS PLANKTONIC FORAMINIFERS—DSDP LEG 39 (SOUTH ATLANTIC)

Isabella Premoli Silva, University of Milano, Milan, Italy,
and
Anne Boersma, Lamont-Doherty Geological Observatory, Palisades, New York

ABSTRACT

Cretaceous sediments were recovered at five sites during Leg 39 in the western Atlantic. Only two sites, Site 356 on the São Paulo Plateau and Site 357 on the Rio Grande Rise, contained rich sequences of planktonic foraminifers allowing the recognition of biostratigraphic zones from the upper Albian through the Maestrichtian.

Late Albian: Site 356 was closed to the North Atlantic, but opened intermittently to bottom and surface waters from the south. Both the planktonic and benthic foraminifer faunas are austral in character; there are no rotaliporids. The bottom depth here is estimated at around 1000 meters at this time. The late Albian north-south communication postulated by Reyment (1969) was not indicated here in the foraminifer faunas. There is a hiatus from the latest Albian through the Cenomanian. However, the presence of reworked rotaliporids higher in this section demonstrates the former presence of open marine deposition during the middle Cenomanian. Rotaliporids, a Tethyan group, indicate either a minor climatic change or free surface connection between the North and South Atlantic in the middle Cenomanian.

Middle-late Turonian: The sediments at Site 356 are sapropelic and are preserved during regressive sea level stands. The early and latest Turonian are times of transgression in the South Atlantic and sediments of that age are missing at this site.

Late Turonian-early Coniacian: There is a hiatus at the Turonian/Coniacian boundary including most of the late Turonian. Coniacian sediments are sapropelic, and the faunas contain Tethyan species evidencing the establishment of a permanent North-South connection by this time. The sapropels terminate at the top of the Coniacian section.

Santonian: This is a period of transgressions and extensive reworking of material both at Site 356 and at the oldest levels recovered at Site 357. *Inoceramus* is found abundantly in the deep sediments of these sites, estimated to represent bathyal depths. There are large amounts of Coniacian material reworked into the Santonian at Site 357; and much early Santonian reworked into later Santonian, making biostratigraphic zonation very difficult.

Santonian-Campanian: This is a major period of dissolution on the Rio Grande Rise (Site 357), which is not, however, found at the nearby Site 356. Faunas at Site 357 look as if they had been deposited near the CCD, although the site is estimated to have lain at bathyal depths. The nearby Leg 3, Site 21, lacks these dissolved faunas, suggesting either different sinking histories for these two segments of the Rio Grande Rise, or unusual bottom conditions at Site 357.

Campanian-Maestrichtian: A major period of dissolution and sometimes reducing conditions is indicated at Sites 354, 355, 356, 357, 358, and at Sites 13 and 144 from Legs 3 and 14, respectively. Site 355 and later Site 358, both deep basinal sites, evolved at this time in a near-ridge position.

Maestrichtian: Site 355 sank permanently below the paleo CCD by the end of the Maestrichtian. Site 358, on the other hand, apparently sank from above the paleo foraminifer lysocline intersecting either the lysocline or the CCD throughout the Maestrichtian. Improved preservation characterizes both the shallower Sites

356 and 357; excellent tropical to subtropical faunas are found including *Globotruncana gansseri* in the mid Maestrichtian. Planktonic faunas including much redeposited shallow water material were found at Site 354 underlying samples barren except for benthic foraminifers.

INTRODUCTION

Cretaceous sediments were recovered at Sites 354 through 358 during Leg 39 in the western Atlantic (Figure 1). Sites 354, 355, and 358 yielded impoverished Cretaceous faunas often containing only benthic foraminifers and calcareous nannofossils. Rich Albian to Maestrichtian and Santonian to Maestrichtian planktonic foraminifer faunas were recovered at Sites 356 and 357, respectively (Table 1).

Cretaceous sediments have been previously recovered from the central and southern Atlantic on Legs 3, 14, 36 (Scientific Staff, 1975a); and more recently on Legs 40 and 41 (Scientific Staff, 1975b, 1975c). Figure 2 summarizes the Cretaceous sediments recovered from these legs as well as from Leg 39.

BIOSTRATIGRAPHY

The zonal scheme used in this paper is presented in Figure 3, which also includes the most important datum levels. This scheme is based mainly on recent works by Moullade (1966, 1974) and Porthault (1969, 1974) on the classical sections of southern France, and on data from Premoli Silva and Bolli (1973) from the Venezuelan Basin, and Van Hinte (1976). We chose to continue to designate zones by fossil names, instead of numbers used by Porthault (1974) and Van Hinte (1976).

We employ here 13 planktonic foraminifer zones spanning the interval from the Albian to the Santonian and refer the reader to the descriptions of Premoli Silva and Bolli (1973) for the zonal succession above the Santonian. The pre-Santonian zones are, from bottom to top:

Ticinella breggiensis Zone

Definition: Range of the zonal marker.

Remarks: According to Moullade (1974) this zone can be split into two subzones, the *Ticinella praeticinensis* (below) and *Rotalipora ticinensis* (above) on the basis of the first appearance of the latter taxon. *Praeglobotruncana delrioensis* overlaps slightly with *T. breggiensis*. Both subzonal markers are lacking in the South Atlantic, thus preventing identification of these subzones.

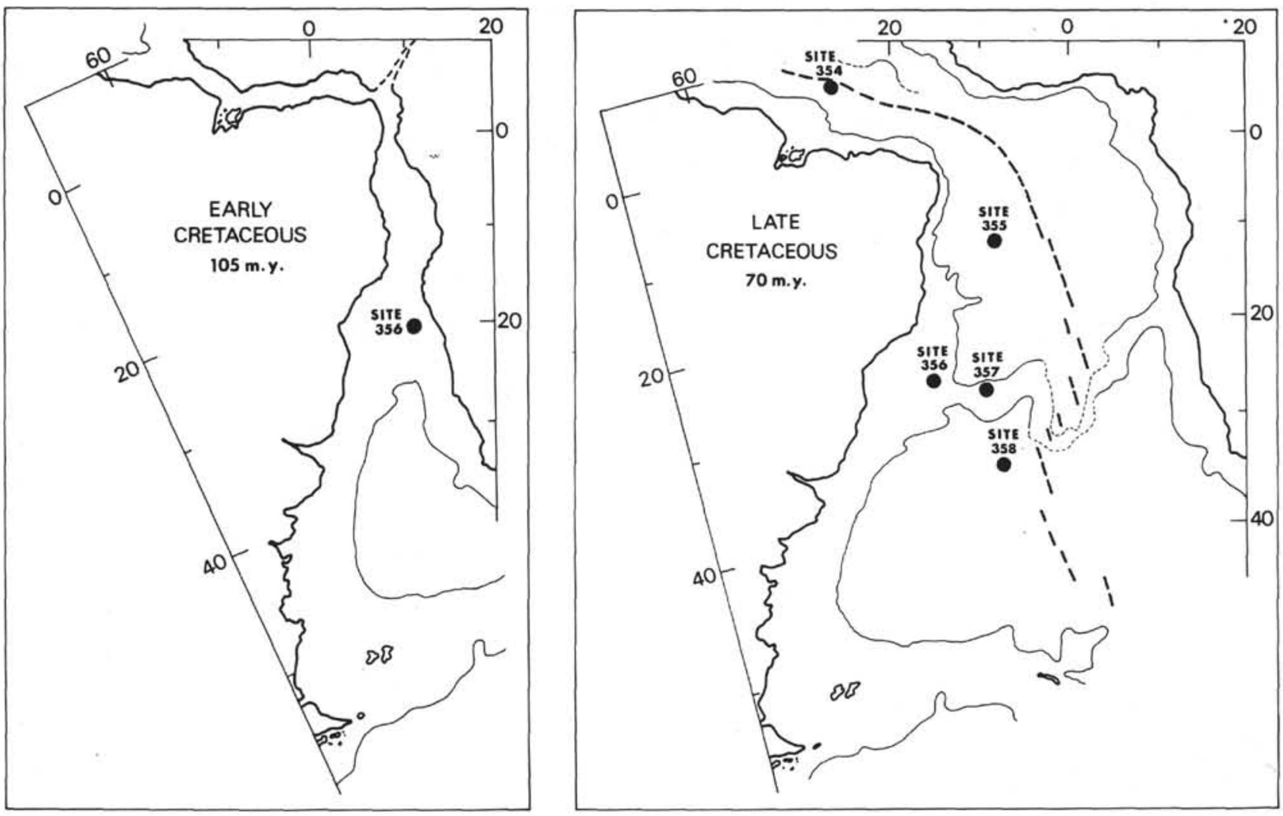

Figure 1. *Locations of sites drilled during Leg 39 in the South Atlantic. Reconstructions by McCoy and Zimmerman (this volume) after Ladd (1974). Only present-day latitudes are shown.*

TABLE 1
Site Data, Leg 39 Sites Which Penetrated Cretaceous Sediments

Site	Present Latitude	Present Longitude	Present Depth (m)	Bottom Age	Cored (m)	Recovery (%)
354	5°53'N	44°11'W	4045	Early Maestrichtian	29	~56
355	15°42'S	30°36'W	4901	Campanian	19	57
356	28°17'S	41°05'W	3175	Late Albian	333	76
357	30°00'S	35°33'W	2086	Santonian	209	73
358	37°39'S	35°57'W	4962	Late Campanian	28	59

Planomalina buxtorfi Zone

Definition: Range of the zonal marker.

Remarks: According to Moullade (1974) *Rotalipora appenninica* appears at the base of the zone and *Praeglobotruncana stephani* in the middle part. *P. delrioensis, T. roberti, Hedbergella planispira*, and *Globigerinelloides caseyi* are the main constituents of the assemblage. Rotaliporids are generally absent in the South Atlantic. *Schackoina cenomana gandolfii* appears at the top of this zone at Site 356.

Schackoina moliniensis Zone

Definition: Interval from the appearance of the zonal marker to the appearance of *Rotalipora brotzeni.*

Remarks: This zone has not yet been recovered in the South Atlantic.

Rotalipora brotzeni Zone

Definition: Interval from the appearance of the zonal marker to the appearance of *Rotalipora montsalvensis.*

Remarks: This zone corresponds to Zone Cn 1 of Porthault (1974) and to the lower part of *Rotalipora gandolfii-Rotalipora greenhornensis* Zone of Van Hinte (1976). It has not been found in the South Atlantic.

Rotalipora montsalvensis Zone

Definition: Interval from the appearance of the zonal marker to the appearance of *Rotalipora cushmani.*

Remarks: This zone corresponds to Zone Cn 2 of Porthault (1974) who distinguished two subzones—(a) and (b)—on the basis of the occurrence of *Rotalipora* aff. *reicheli* in the upper part. According to Van Hinte (1976) this zone corresponds to the upper part of the *Rotalipora gandolfii-Rotalipora greenhornensis* Zone. It is not represented at Site 356.

Rotalipora cushmani Zone

Definition: Interval from the appearance of the zonal marker to the appearance of *Rotalipora greenhornensis* and *R. deeckei.*

Remarks: This zone, not present at Site 356, corresponds to Zone Cn 3 of Porthault (1974) and to the lower portion of the *Rotalipora cushmani* Zone of Van Hinte (1976).

Whiteinella alpina Zone

Definition: Range of the zonal marker.

Remarks: This zone includes Zones Cn 5 and Cn 6 of Porthault (1974) and corresponds to the upper part of the *Rotalipora cushmani* Zone of Van Hinte (1976). It is not represented at Site 356.

Praeglobotruncana lehmanni Zone

Definition: Interval from the last occurrence of *Whiteinella alpina* and *Rotalipora deeckei* to the appearance of *Praeglobotruncana helvetica.*

Remarks: This zone corresponds to Zone Tu 1 of Porthault (1974) and to the lower part of the *Hedbergella lehmanni* Zone of Van Hinte (1976). It is not represented at Site 356.

Praeglobotruncana helvetica Zone

Definition: Range of the zonal marker.

Remarks: This zone corresponds to Zones Tu 2 and Tu 3 of Porthault (1974), to the upper part of the *Hedbergella lehmanni* and the lower part of "*Globotruncana*" *helvetica* zones of Van Hinte (1976). Porthault (1974) defined two zones within the range of *P. helvetica* on the basis of the appearance of so-called marginotruncanids in the upper part. Because of the co-occurrence of "*Globotruncana sigali*" (= *Marginotruncana*) and *Gtr. angusticarenata* with *P. helvetica* only the upper part of the zone is represented at Site 356. *Praeglobotruncana indica, P. imbricata, Hedbergella delrioensis*, and heterohelicids are common components of the *P. helvetica* assemblage when it is present.

Globotruncana schneegansi Zone

Definition: Interval with the zonal marker from the last occurrence of *Praeglobotruncana helvetica* to the appearance of *Globotruncana concavata.*

Remarks: This zone is missing in Leg 39 sites. It corresponds to Zones Tu 4, Tu 5, and to the base of Co 1 of Porthault (1974) and to the *Globotruncana renzi-Globotruncana sigali* Zone of Van Hinte (1976).

Globotruncana concavata concavata Zone

Definition: Interval from the appearance of the zonal marker to the evolutionary appearance of *Globotruncana concavata carinata.*

Remarks: This is a very long zone. Porthault (1974) distinguished four zones (Co 1, Co 2, St 1, and St 2) within this interval. The lack of a continuous record at any of the drill-sites prevents a more sophisticated subdivision of Leg 39 material. It is possible to detect the disappearance of marginotruncanids, such as "*Gtr.*" *sigali*, "*Gtr.*" *sinuosa*, "*Gtr.*" *tarfayaensis* in the

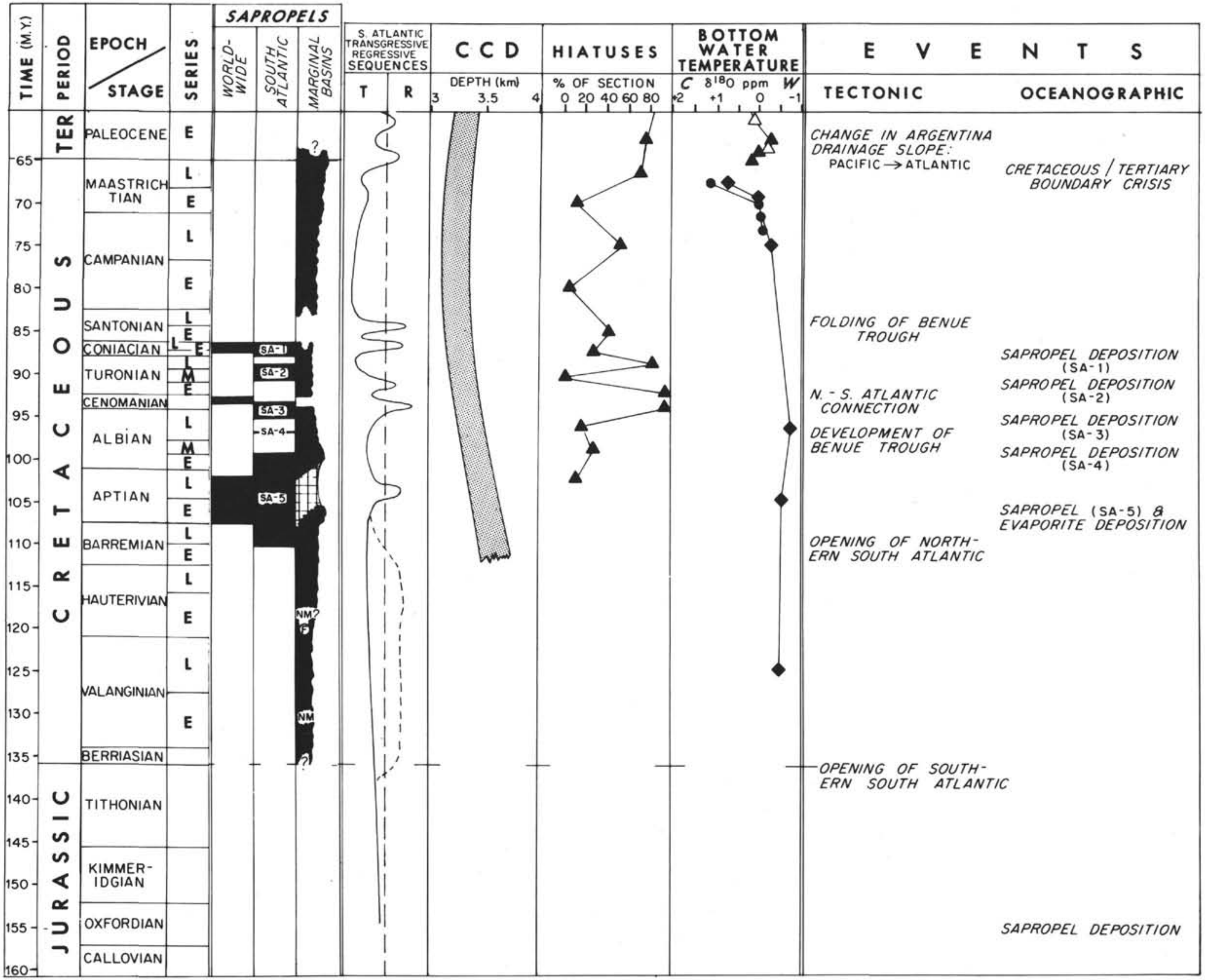

Figure 2. *Mesozoic sediments recovered in Central and South Atlantic during Legs 14, 36, 39, 40, and 41 (Hayes, Pimm, et al, 1972; Scientific Staff Leg 36, Leg 40, and 41). Ages of sediments from Legs 36, 40, and 41 have been reinterpreted. Time-scale after Thierstein, in press. Paleotemperature curves:* ▲ *from Boersma and Shackleton, unpublished, Site 356;* △ *from Boersma and Shackleton, this volume;* ■ *Douglas and Savin, 1973;* ● *Saito and Van Donk, 1974; CCD and transgression-regression curves from McCoy and Zimmerman, this volume.*

lower part and the appearance of *Rugoglobigerina pilula* and *Globotruncana fornicata* in the middle of the zone. It is difficult to correlate this zone with Van Hinte's zonal scheme because of the correlations this author made with the standard Ammonite zonation (see section on Chronostratigraphy).

Globotruncana concavata carinata Zone

Definition: Range of the zonal marker.

Remarks: This zone corresponds to Zone St 3 of Porthault (1974). *Globotruncana arca* has its first occurrence at the base of this zone; "*Gtr.*" *fornicata* is very frequent and many authors used this taxon as the zonal marker (see Bolli, 1957; Pessagno, 1967). *Planoglobulina glabrata* is a normal constituent of the assemblage, as are "*Gtr.*" *lapparenti* and "*Gtr.*" *bulloides*. "*Gtr.*" *concavata*, "*Gtr.*" *angusticarenata*. *Globigerinelloides asper*, and *Heterohelix reussi* disappear at the top of the zone.

SITE 356

The Mesozoic sequence at Site 356 was spot cored at close intervals and extended from Sample 29-3, 40 cm through Core 44, for a total thickness of 333 meters. The ranges of the planktonic foraminifers and their estimated frequencies are plotted in Figures 4 and 5.

The bottom of Core 44 (Section 5 to CC) yielded a foraminifer fauna dominated by *Hedbergella* and small heterohelicids. Rotaliporids are absent; *Praeglobotruncana* is represented only by *P. delrioensis*. *Ticinella* is rare and limited to a few "primitive" species. The presence of *T. breggiensis*, though rare, in the lower part allows us to recognize the *Ticinella breggiensis* Zone. Above Section 44-5 to Sample 41-4, 80 cm the presence of some *Schackoina cenomana gandolfii* is apparently diagnostic of this interval in the South Atlantic.

In Sample 41-4, 70 cm the presence of *Praeglobotruncana helvetica* along with *P. indica, P. imbricata, Whiteinella archaeocretacea*, "*Globotruncana*" *sigali*, and "*Gtr.*" *angusticarenata* indicates the upper part of the *Praeglobotruncana helveltica* Zone.

Apparently seven zones and the lower part of the *P. helvetica* Zone are missing within Core 41, Section 4. The same assemblage seems present up to Sample 40-3, 89 cm; however, throughout this interval sediments are rich in organic carbon and in many levels the foraminifers have been dissolved.

From Core 40, Section 2 to Core 38 the sediments have been attributed to the *Globotruncana concavata concavata* Zone. The presence of "*Gtr.*" *tarfayaensis*, "*Gtr.*" *sigali*, "*Gtr.*" *renzi*, and *Whiteinella archaeocretacea* along with the zonal marker indicates that part of the *Gtr. concavata* Zone corresponding to CO_1 and CO_2 zones of Porthault (1974). There are many barren layers in this interval. The upper part of the *Gtr. concavata* Zone is recorded only in the lower part of Core 37 which is separated from Core 38 by a 38-meter uncored interval.

The faunas become richer higher in the section. It is possible to follow the evolution of (1) *Gtr. concavata* into *Gtr. concavata carinata* which appears rarely in Core 37; (2) of *Gtr. angusticarenata* into *Gtr. arca*, which appears more or less at the same level as *Gtr. carenata*; while transitional forms between *Gtr. angusticarenata* and *Gtr. arca* are common in the upper part of the *Gtr. concavata* Zone. Thus from Core 37, Section 4 to Core 35 the *Gtr. concavata carinata* Zone can be recognized. Double-keeled forms such as *Gtr. fornicata, Gtr. lapparenti, Gtr. linneiana*, and *Gtr. bulloides* are the most common species in this interval along with some small *Heterohelix* and *Globigerinelloides*. The frequency of various taxa varies considerably from level to level due to differential dissolution and recrystallization. Large forms are frequently squeezed and broken (Section 35-4). In some cases large amounts of reworked material were present; for example in Core 35, Section 1, 40-42 cm, a lower *Gtr. concavata* Zone assemblage is mixed with the *Gtr. carinata* Zone assemblage. This is the most obvious example, but minor reworking is detectable throughout the succession.

Core 34 yielded foraminifer faunas belonging to the *Globotruncana elevata* Zone. The co-occurrence of *Rugoglobigerina pilula* and *Globotruncana coronata* with *Rugoglobigerina rugosa, Pseudoguembelina costulata*, and *Pseudotextularia elegans* marks the middle part of the *Gtr. elevata* Zone. The frequency of *Globotruncana rosetta* is consistent with this conclusion. The lower part of the *Gtr. elevata* Zone and the topmost part of the *Gtr. carinata* Zone were not recovered but Cores 35 and 34 are separated by a 19-meter uncored interval.

The rich assemblages of the *Gtr. elevata* Zone are generally poorly preserved. Most of Core 33 belongs to the *Globotruncana calcarata* Zone, but the top of this zone was not recovered. Faunas are very rich, but only moderately well preserved and occasionally badly dissolved. *Gtr. elevata* is particularly sensitive to dissolution. Reworking is common; in particular, a few rotaliporids were recovered from Section 1. Sediments from Core 32 are highly contaminated and contain reworked material, making it difficult to locate zonal boundaries. The base of the *Globotruncana gansseri* Zone is placed at the first occurrence of the zonal marker (Core 32, Section 3, 118-120 cm), while the lower part of Core 32 is attributed to the *Gtr. tricarinata* Zone. Within the *Gtr. gansseri* Zone, *Globotruncana havanensis* and *Pseudoguembelina costulata* evolve into *Abathomphalus intermedius* and *Pseudoguembelina excolata*, respectively. *Globotruncana rosetta, Globigerinelloides prairiehillensis*, and *G. yaucoensis* decrease in abundance and disappear before the end of the zone. The anomalous presence of *Ab. intermedius* and *Psg. excolata* prior to the beginning of the zone is considered downhole contamination. The *Globotruncana contusa* Zone was not recovered at Site 356; however, 10 meters were not cored between Cores 32 and 31. Core 31 belongs to the *Abathomphalus mayaroensis* Zone. This assemblage was recovered up to Sample 29-3, 33 cm where it occurs together with an early Paleocene assemblage belonging to the base of the "*Globigerina*" *eugubina* Zone. The two assemblages show markedly different preservation, as the Cretaceous is recrystallized and the tests of the Paleocene foraminifers are nearly transparent. The

ABSOLUTE AGE (m.y.)	AGE		ZONES	
65	MAESTRICHTIAN	late	*Abathomphalus mayaroensis*	
	MAESTRICHTIAN	middle	*Globotruncana contusa*	
	MAESTRICHTIAN	middle	*Globotruncana gansseri*	
	MAESTRICHTIAN	early	*Globotruncana tricarinata*	
71	CAMPANIAN	late	*Globotruncana calcarata*	
	CAMPANIAN	early	*Globotruncana elevata*	
78	SANTONIAN	late	"*Globotruncana*" *concavata carinata*	
	SANTONIAN	early	"*Globotruncana*" *concavata concavata*	
82	CONIACIAN			
	TURONIAN	late	"*Globotruncana*" *schneegansi*	
	TURONIAN	middle	*Praeglobotruncana helvetica*	
	TURONIAN	early	*Praeglobotruncana lehmanni*	
92	CENOMANIAN	late	*Whiteinekla alpina*	
	CENOMANIAN	middle	*Rotalipora greenhornensis*	
	CENOMANIAN	middle	*Rotalipora cushmani*	
	CENOMANIAN	early	*Rotalipora montsalvensis*	
	CENOMANIAN	early	*Rotalipora brotzeni*	
	ALBIAN	VRACONIAN	*Schackoina moliniensis*	
	ALBIAN	VRACONIAN	*Planomalina buxtorfi*	
	ALBIAN	late s.str.	*Ticinella breggiensis*	*Rotalipora ticinensis*
	ALBIAN	late s.str.	*Ticinella breggiensis*	*Ticinella praeticinensis*

Figure 3. *Late Albian to Maestrichtian foraminifer zonation scheme and datum levels of index species. Foraminifer zones and calibration to ages are after Moullade (1973), Porthault (1974), and Premoli Silva and Bolli (1973). Datum*

SELECTED DATUM LEVELS

⊤ extinction of all Cretaceous planktonic foraminifers

⊥ *Abathomphalus mayaroensis*

⊥ First Occurrence
⊤ Extinction

⊥ *Globotruncana contusa, Racemiguembelina fructicosa*
⊤ *Globigerinelloides praeriehillensis, G. yaucoensis*
⊥ *Abathomphalus intermedius*
⊥ *Pseudoguembelina excolata*
⊥ *Globotruncana gansseri*
⊥ *Globotruncana aegyptiaca*

⊤ *Globotruncana calcarata*
⊥ *Globotruncana havanensis*
⊥ *Globotruncana subcircumnodifer*
⊥ *Globotruncana calcarata*
⊤ *"Globotruncana" coronata, Rugoglobigerina pilula*
⊥ *Planoglobulina glabrata*
⊥ *Globotruncana elevata,* ⊤ *"Globotruncana" concavata* group
⊤ *Heterohelix reussi*

⊥ *"Globotruncana" concavata carinata, Globotruncana arca*

⊥ *Globotruncana fornicata, Rugoglobigerina pilula*
⊤ *"G." sigali, "G." sinuosa, "G." tarfayaensis, Whiteinella archaeocretacea*
⊥ *"Globotruncana" concavata concavata*
⊥ *"Globotruncana" sinuosa, "Globotruncana" tarfayaensis*

⊤ *Praeglobotruncana helvetica*

⊥ *"Globotruncana" sigali, "Globotruncana" angusticarinata, "G." coronata*

⊥ *Praeglobotruncana helvetica*

⊥ *Whiteinella archaeocretacea*
⊤ *Rotalipora deeckei, Whiteinella alpina*

⊥ *Whiteinella alpina*

+ *Rotalipora greenhornensis, R. deeckei* ⊤ *Rotalipora appenninica*

⊥ *Rotalipora cushmani*

⊥ *Rotalipora montsalvensis*

⊤ *Schackoina moliniensis*
⊥ *Rotalipora brotzeni*

⊥ *Schackoina moliniensis*
⊥ *Praeglobotruncana stephani*

⊤ *Planomalina buxtorfi, Ticinella roberti, Rotalipora ticinensis*

⊥ *Planomalina buxtorfi, Rotalipora appenninica, Praeglobotruncana delrioensis*
⊥ *Globigerinelloides caseyi*
⊥ *Rotalipora ticinensis*
⊥ *Ticinella breggiensis, Ticinella roberti*

levels are after Moullade (1973), Porthault (1974), and the present work. Absolute ages modified from Van Hinte (1976). ⊤ *= first occurrence,* ⊥ *= extinction.*

Core	Section	Interval (cm)	PLANKTONIC FORAMINIFERS																					MINERALS	PLANKT. FORAMS		FISH DEBRIS	BENTHICS	RADIOLARIANS	ZONE	AGE
			Hd. planispira	*Hd. rischi*	*T. primula*	*T. roberti*	*Heterohelicidae*	*T. breggiensis*	*T. subticinensis*	*G'lloides caseyi*	*Hast. watersi*	*Pgr. delrioensis*	*Hd. globigeriniformis*	*Pla. buxtorfi*	*Schackoina cen. gandolfi*	*Hd. delrioensis*	*Hd. simplicissima*	*Pgr. indica*	*Pgr. imbricata*	*Whit. archaeocretacea*	*Gtr. augusticarinata*	*Gtr. augusticarenata*	*Gtr. sigali*		ABUNDANCE	PRESERVATION					
40	3	89-91		only benthic foraminifers																				PQ			f	R		?	
	4	72-74		only benthic foraminifers																				GM PQ			C	VR	R/VP		
	5	104-106														A		f	f	f	f	f	f		A	P					
	CC			no foraminifers																					R	P		F	A/P		
41	1	46-48		no foraminifers																							F			*Praeglobotruncana helvetica*	middle TURONIAN
	2	31-33					A			C						A				C	R				A	P					
	3	96-98		no foraminifers																							F				
	4	54-56		no foraminifers																							F				
		67-69								C						C		C	C	C	Cf	C	C		A	M		F			
	CC		A			C	A			R	C	C		R	C	F	F							G	A	P		F			
42	1	52-54	F							F								sorted							C	P			A/P		
	2	60-62	F			F				f								sorted							A	P					
	3	71-73				f																			R	VP					
	5	66-68	f						R	f															C	P		C	f/P		
	6	30-32	C		R	R	R			F		R												GM	R	P	R	f	A/P		
43	1	33-35	F			C	F			C															F	P			C/P	*Planomalina buxtorfi*	
		78-80	F			f				C		C		?	C										F	PM			A/P		
	3	51-53	F			C				C		C												GM	A	P					
	5	59-61	F			C				C		C													F	P			C/P		
	CC		F		?	f				C		f	f												F	P			f/P		
44	2	43-45	R			R				R								sorted							C	VP			A/P		LATE ALBIAN
	4	47-49	F		f	f				f		R													F	PM		F	A/P		
	5	64-66	F			R		R	C	f								sorted							F	P		F	A/P	?	
	6	70-72	F	C	f	f	R	R																	A	VP		f	f/P	*Ticinella breggiensis*	
	CC		F	C	f	f	R	C																	C	VP		f	R/P		
																													R/P		

Hd. = *Hedbergella*
T. = *Ticinella*
G'lloides = *Glodigerinelloides*
Hast. = *Hastigerinoides*
Hx. = *Heterohelix*
Whit. = *Whiteinella*
Pgr. = *Praeglobotruncana*
Pla. = *Planomalina*
Gtr. = *Globotruncana*
Clavih. = *Clavihedbergella*
Plag. = *Planoglobulina*
Arch. = *Archaeoglobigerina*
Loebl. = *Loeblichella*
Rug. = *Rugoglobigerina*
Ptx. = *Pseudotextularia*
Ab. = *Abathomphalus*
Psg. = *Pseudoguembelina*

A = ABUNDANT
F = FREQUENT
C = COMMON
f = FEW
R = RARE
VR = VERY RARE

M = MICAS
G = GLAUCONITE
P = PYRITE
B = BIOTITE
Q = QUARTZ
D = DOLOMITE

P = POOR
M = MODERATE
VP = VERY POOR
PM = POOR TO MODERATE

Figure 4. *Distribution of selected planktonic foraminifers at Site 356, late Albian to middle Turonian.*

older fauna may be reworked; nevertheless the *Ab. mayaroensis* Zone seems complete.

SITE 357

The Mesozoic sequence at Site 357 was spot cored at close intervals from Core 31 through Core 51 for a total thickness of 209 meters. The ranges of the most important planktonic foraminifers are plotted in Figure 6.

Characteristic of the Upper Cretaceous sequence recovered at this site is the high frequency of reworked faunas and displaced layers. As shown in Figure 6, layers with homogeneous faunas alternate with layers yielding younger assemblages and no mixing is apparent. When no mixing has been detected then the level is interpreted as a slump. On the other hand, a melange of faunas of different zones is common throughout and because of the presence of many long-ranging species, the estimated frequency of a single taxon in those levels may be altered. Unfortunately, the preservation, which is generally poor, does not differ between reworked and in situ assemblages. The layers yielding reworked foraminifer faunas also contain abundant fragments of *Inoceramus* and other megafossils.

From Core 47, Section 3 to total depth (Core 51) *Globotruncana concavata concavata* Zone is recognizable. The presence of *Rugoglobigerina* aff. *bulbosa, R. pilula, Globigerinelloides asper*, and true *Globotruncana fornicata* at the bottom locates the oldest material here in the upper part of the zone. The absence of "*Globotruncana*" *tarfayaensis* and *Whiteinella archaeocretacea* is consistent with this attribution. Moreover, "*Gtr.*" *sigali* and "*Gtr.*" *sinuosa* disappear rapidly in the lower cores assigned to this zone (Cores 50 and 51). Reworking in this zone is minimal and the preservation is generally poor. The overlying *Globotruncana concavata carinata* Zone is present from Core 47, Section 2 through Core 40. The zonal marker is rather rare, so that the lower boundary is based on the first appearance of *Gtr. arca* from transitional forms of *Gtr. angusticarenata* which is common in the highest levels of the underlying zone. The upper zonal boundary is placed just below the appearance of *Gtr. elevata* which first occurs in Sample 39-1, 33 cm. The evolution in this fauna is difficult to follow, as slumping and mixing are common throughout this interval. The first reworked faunas belong to the *P. helvetica* Zone or the earliest *Gtr. schneegansi* Zone found in Core 45. Then assemblages of the lower *Gtr. concavata concavata* Zone are found reworked in different amounts throughout most of the overlying cores.

The approximately 105-meter interval from Cores 39 to 36 contains diagnostic species only at its base, above which most of the sediments are barren of planktonic foraminifers. Diagnostic faunas appear again in Core 35 and belong to the *Gtr. tricarinata* Zone. These faunas also contain *Gtr. havanensis*, but lack *Gtr. calcarata*, the index taxon for the underlying zone. Thus the barren interval is considered to correspond to the *Gtr. elevata* and *Gtr. calcarata* zones.

The lower part of the *Gtr. tricarinata* Zone was not recovered, but may be contained in the 19-meter uncored interval between Cores 35 and 36. In Core 35 preservation is sometimes very poor and some reworking is present. Representatives of the *Gtr. fornicata-Gtr. calciformis* lineage are very rare, as are members of the *Gtr. elevata* group.

An uncored interval of 19 meters separates Core 35 from Core 34. On the basis of the evolution of *Gtr. havanensis* to *Abathomphalus intermedius* and *Pseudoguembelina costulata* into *Psg. excolata* we tentatively attribute Core 34 from its bottom to the *Gtr. gansseri* Zone. In this interval the preservation is so poor that the zonal marker is rarely present, as are the species mentioned above.

The absence and/or scarcity of members of the *Gtr. fornicata/Gtr. caliciformis-contusa* lineage, possibly due to solution, prevent recognition of the *Gtr. contusa* Zone. In fact, at Sample 33-4, 30 cm *Ab. mayaroensis*, the zonal marker of the uppermost Cretaceous zone, appears. It is only at this level that the fauna begins to look more complete and not so dissolved; *Gtr. contusa* accompanies the zonal marker. *Racemiguembelina fructicosa*, another species marking the beginning of the underlying *Gtr. contusa* Zone, does not appear until Core 31, several meters higher than *Gtr. contusa*. Reworking and slumping which were insignificant in the *Gtr. tricarinata* Zone become important again. Under such conditions downhole contamination cannot be ruled out and zonal boundaries are only tentatively located.

SITE 358

At Site 358 Cretaceous sediments were recovered in Cores 15 and 16 for a total thickness of 28 meters. According to the calcareous nannofossil zones, this interval spans the *Gtr. tricarinata* through the *Ab. mayaroensis* zones.

Moderately preserved planktonic foraminifers are present in at least one sample from Core 16. *Globotruncana tricarinata, Gtr. arca, Gtr. fornicata*, and *Rugoglobigerina rugosa* are present, but the entire fine fraction was missing. Samples higher in Core 16 and Core 15 contained only benthic foraminifers or are barren. Apparently this site intersected the paleo CCD during most of the Maestrichtian and the planktonic foraminifers were dissolved (see Boersma, this volume).

SITE 354

At Site 354 on the Ceará Rise 29 meters of Cretaceous sediments were recovered in Cores 17 and 18. The nannofossil zones identified in these cores correspond to the *Gtr. tricarinata* planktonic foraminifer zone. The sediments of this site contain only benthic foraminifers in the examined samples. Sediments are stained red, as are the fossils. Displaced shallower water agglutinated foraminifers are present and were also stained red.

SITE 355

No foraminifers were recovered from the sediments of Cretaceous age (Core 21 to Core 16) at Site 355. The nannofossil zones identified in these cores correspond to the *Gtr. elevata* through the *Ab. mayaroensis* zones.

			PLANKTONIC FORAMINIFER																																																								
Core	Section	Interval (cm)	*Whit. archaeocretacea*	*Gtr. concavata*	*Gtr. pseudolinneiana*	*Gtr. angusticarinata*	*Gtr. renzi*	*Gtr. marginata*	*Gtr. tarfayaensis*	*Gtr. sigali*	*Gtr. coronata*	*Gtr. sinuosa*	*Pgr. indica*	*Hd. flandrini*	*Hd. loelterli*	*Hd. delrioensis*	*G'lloides asper*	*G'lloides caseyi*	*Hast. alexanderi*	*Clavih. simplex*	*Clavih. moremani*	*Schakoina cen. gandolfii*	*Schakoina multispina*	*Hx. reussi*	*Hx. globulosa*	*Planoglobulina* sp.	*Gtr. concavata carinata*	*Gtr. fornicata*	*Gtr. lapparenti*	*Plag. glabrata*	*Hast. watersi*	*Arch. bosquensis*	*Arch. blowi*	*G'lloides praeriehillensis*	*Gtr. arca*	*Hx. striata*	*Gtr. bulloides*	*Arch. cretacea*	*Gtr. linneiana*	*Loebl. hessi*	*Rug. pilula*	*Hx. pulchra*	*Gublerina* sp.	*Gtr. elevata*	*Gtr. rosetta*	*Ptx. elegans*	*Psg. costulata*	*G'lloides bollii*	*Rug. rugosa*	*Gtr. leupoldi*	*Gtr. tricarinata*	*Gtr. plummerae*	*G'lloides pauconensis*	*Hx. punctulata*	*Hx. globocarinata*	*G'lloides volutus*	*Gtr. calciformis*	*Gtr. hilli*	*Gtr. subcircumnodifer*	*Gtr. calcarata*	*Gtr. subspinosa*
29	3	31-33																					f		C											C							C			C			F					C		F					
		40-42																							C											C							C	f		C			F	f				C		F					
30	4	119-120	reworking of *G. gansseri* Zone																						C										R	C							F			C			F	f				f		F			R		
	CC																								C										f	C							C	f					F	C						F					
31	4	118-120	reworking																						C										C	C							C	C					F	C						F					
	5	38-40	reworking																						C																		C	C		F			F		f			R		F		f			
		120-122																							C											C							C	f		F			F	C	f			R		F			R		
	6	40-42																							C										f	C			R				A	C		F			F	R	f			R		F	C				
	CC																								C										R				R				A	f					F												
32	1	119-121																							F											C							F	f		C			f		F	A		C			C		f		
	2	40-42																							F			VR						F	f	C	C	C	C				F	f			C			C	f	F	C	C		F	F		f		
		120-124																							F			VR						f	VR	C	f	f	F				F	F	R	R	f		F	C	F	F	VR	f		F	F		C		
	3	118-120																							F											C		f					F	F		R	C		F		F	A		C					f		
	4	46-48																							F			R	f					C	C		R		C			C	F	F	C		f		F	F		C	R	C		F	C	f	f		
		120-122																							F			R						C	C	C	R		C			C	F	F	f	F	f		F	f	F	F		C	f	F	C		f		
	6	39-41	some contamination and reworking																						F			R						VR	f	C	f		R			C	C	F	R	f	F		F	R	A	F		C	f	F	C		F		
		113-115																							A			F	f					VR	F	F	C		F			C	C	F	C	f	F		A	A	A	A		C	f	F	R		A		
	CC		strongly contaminated																				C		A			F	C					F	f	F	C		F			C		f	C	C	F		F	F	F	A	F	C	C	A	C	F	F		
33	1	20-22																					C		A			F	C					F	f	F	C		F			C		f	C	C	F		F	F	F	A	F	C	C	A	C	F	F	R	f
		120-122	reworked rotaliporids																				VR		F			F	F					A	f	F	R		F			R		f	F	R	F		R	F	C	F	A	F	R	A	F	C	C	C	f
	3	40-42																					R		A			A	C					A	f	F	C	F	F			F		R	F	A	F		F	F	F	A	A	R	F	A	C	C	f	VR	f
	6	40-42																					f		F			F	C					F	C	F	C	C	F			F		F	F	R	R		F	F	F	VR	C	F	f	C	C	C	f	R	F
		119-121																					F		A			F	C					F	F	F	C	F	C			F		F	F	C	C		F	F	VR	C	C	C	R	C	F	C	f		
34	1	39-41																							A			F	F					F	C	F	C		F			C			R	R	C	C	C	R	R		f	R		F	f	R			
	2	40-42																							F				F					F	C		R		F			A		C	R	R		F	C	P			VR	R	R	F					
	3	118-120																					VR		A			A	F				R	F	C	F	C	C	A	R		F		A	A	F	R	F	F	C	R	C	VR aff								
	5	40-42									R														A			A	A				C	F	C	R	C		A		F	F	C	A	A	C	R	C	R												
	6	40-42																																																											
	CC																											A	F						f				F			VR		VR	C	VR								VR							
35	1	40-42		f	f	A					A						C	C						C	C		f			F	f			C		C					R	C	C	early concavata zone fauna reworked																	
		120-122			R	R					A						F	F						F	C		R	A	F	A	R			F	F	f	C	F	F		F		F																		
	2	39-41		f		R					F						C	C						C	C		F	A	F	F				C	A	C			C		F		F																		
		120-122			C	R					C						f	f					R	F	R		C	A	A	R	R		R	R	F	VR		R	R	F	F	cfF	C																		
	4	40-42			f	f					F					f	A	A						A	C			C	R	R				C	f	VR			R																						
		120-122		f	f	f		R			F					C	A	C						A	F		R	R	VR	F				f	R	R			VR																						
	5	120-122		C	C	C		f			F					C	A	C						A	F		C	C	f	F				C	f	R			f		f																				
	6	50-52														C	A	C						VR	A			C	C	f			R	C	cf	R		R	C	R	C																				
36	2	40-42		R	R	C		R			F					C	A	A		R			R	F	A		R	F	F	R	R		C	F	F	A	C	VR	C																						
	4	100-103		A	F	C	R	R			R					R	A	A		f			R	A	A		A	C	C	C	R	R	R	C	cf	A																									
	CC			R	f	R	R	R			R					f	A	A	F				R	A	A	F	R	C	C		R																														
37	2	63-66		C	C	f	cf	r			C					C	A	A	F				R	A	A	C	R	F		C				f	f																										
	4	47-49		A	C	F	F	f			F			A	C	C	F	A	C					A	C	F	r	F		f																															
	5	51-53	VR	VR	F	F	A	F	R		C	C	R	A	C	C	C	A	A	R	R	R	R	A	A																																				
38	3	63-66	A	F	A	F	F	C	f	f	F	f		C	C	C	F	F						F	C	C																																			
39	1	103-105	f		f		r			f	f			C	f	C	C							C																																					
40	2	71-72	f	C	F	F	F	C	R	f	F	f	R	C	C	C	F	F		f				C																																					

Figure 5. *Distribution of selected planktonic foraminifers at Site 356, early Coniacian to late Maestrichtian.*

Dissolution below the paleo CCD has apparently removed all the foraminifers.

CORRELATIONS WITH HOLES 20C AND 21 OF LEG 3

The Cretaceous sections drilled in Holes 20C and 21 are shown in Figure 2 (see Maxwell et al., 1970). At Site 20C (Core 6, Sections 5 to 6) the *Ab. mayaroensis* zonal assemblage is recorded in sediments partly interbedded into the Paleocene. The faunas, although displaced, show a definite similarity to those recovered at Site 357. They are very rich in species and moderately well-preserved.

A more complete sequence of about 65 meters thickness was recovered at Site 21 (Cores 3-9). All zones from the *Gtr. elevata* to the *Ab. mayaroensis* Zone are represented as follows:

Gtr. elevata Zone, Cores 9-6,

Gtr. calcarata Zone, Core 5, Section 6 and Sample 5, CC

Gtr. tricarinata Zone, Sections 5-5 to 4-4

Gtr. gansseri Zone, including *Gtr. contusa* Zone, Sections 4-3 to 4-1

Ab. mayaroensis Zone, Core 3.

Fragments of *Inoceramus* are present throughout the section. There is a discrepancy between foraminifer and nannofossil ages which can be accounted for by reworking. It is noteworthy, however, that the *Gtr. elevata* and *Gtr. calcarata* zonal fossils, strongly affected by solution at Site 357, are in place, well-represented, and well preserved at Site 21.

Gtr. ventricosa	Gtr. havanensis	Rug. hexacamerata	Hx. navarroensis	Gtr. andorri	Gtr. falsostuarti	Gtr. subpennyi	G'lloides subcarinatus	Plag. acervulinoides	Plag. multicamerata	Psg. excolata	Ab. intermedius	Gtr. gagnebini	Rug. rotundata	Gtr. aegyptiaca	Gtr. gansseri	Hx. palpebra	Gtr. contusa	Ab. mayaroensis	Pst. deformis	Racemiguembelina fructicosa	Gtr. trinidadensis	Gtr. stuarti	Rug. macrocephala	Guembelitria cretacea	Woodringina sp.	"Globigerina" edita	"Globigerina" eugubina	"Globigerina" fringa	"Globigerina" minutula	Globoconusa aff. daubjergensis	ABUNDANCE (PLANKT. FORAMS)	PRESERVATION (PLANKT. FORAMS)	BENTHIC FORAMS	OSTRACODES	RADIOLARIANS	FISH DEBRIS	MINERALS	ZONE	AGE
	F						F	C	C	F			C	f		C		C			F			f	A	R	R	C	C	C	F	MG						"Globigerina" eugubina	PALEO.
	A						F	C	C	F			F	f			C	f		C	F		f								A	M	f				B	Abathomphalus mayaroensis	MAESTRICHTIAN
	F	R				R	C			C		C	f	C	f		F	F	f	f	f										A	M	f						
	C	C		C			F	VR	VR					R	R		F	F	f	f		R	f								A	M	f						
R	A			C			F	R	R					R	R		f	C	f	C	R										F	P		f			M		
R	A	f	R			R			f	F						f		F	f	C	f		f								F	P							
	F			C	C	f	F			A	f		R	R				A		f	f										A	M					M		
f	F	R	R		C	R	F	F	F	A			F	C		f	A	A	F		C	f									A	MG							
F	A	C			f			F	F		R	R			R		A	f	F	F	R										A	MG							
C		f	f	F	F	F					f					f															A	G	f	f					
f	F	C	f	F		C	F			F	f			C	F																A	MG						Globotruncana gansseri	
F	F	f	f	F?		C	F			F		R	R	R	F																A	M	f	R					
			f	C		F				f				R	R																A	M							
	F		f			F						R		R																	A	MG							
F	A	f	f	C		F	C			f		R	f	VR																	A	MG	f				B	Globotruncana tricarinata	
A	F	f	f	F		F	C			F	f		R																		A	M	f						
A	F	A	f	C	C	C	F	R	R	cf																					A	G	VR						
R	C	C	f																												A	M							
R	VR	C	f																												A	P	C	R				Globotruncana calcarata	CAMPANIAN
R	VR		f																												A	PM	R		VR				
		R	f																												A	M	R				G		
F	VR																														A	MG							
																															A	MG	f				Q	Globotruncana elevata	
																															A	MG	f						
																															A	P	f	R			M		
																															A	P	f			C			
																															A	P	C	C			G		
																															F	VP	R			C			
																															A	M		f			G	Globotruncana concavata carinata	SANTONIAN
																															A	G	f		F/P		G		
																															A	P	f						
																															A	M	f		f/P				
																															F	VP	f						
																															A	P	f		R/VP		G		
																															A	P	f		F/P				
																															A	P	A	f			G		
																															A	P	f						
																															A	M	f						
																															A	M	f	R					
																															A	M	f						
																															A	G	f	f		R		Globotruncana concavata concavata	CONIACIAN
																															A	M	f						
																															A	M	C			R	G		
																															f	P	C						
																															F	M	C			R	MQ		

Hd.	= *Hedbergella*	A	= ABUNDANT
T.	= *Ticinella*	F	= FREQUENT
G'lloides	= *Globigerinelloides*	C	= COMMON
Hast.	= *Hastigerinoides*	f	= FEW
Hx.	= *Heterohelix*	R	= RARE
Whit.	= *Whiteinella*	VR	= VERY RARE
Pgr.	= *Praeglobotruncana*	M	= MICAS
Pla.	= *Planomalina*	G	= GLAUCONITE
Gtr.	= *Globotruncana*	P	= PYRITE
Clavih.	= *Clavihedbergella*	B	= BIOTITE
Plag.	= *Planoglobulina*	Q	= QUARTZ
Arch.	= *Archaeoglobigerina*	D	= DOLOMITE
Loebl.	= *Loeblichella*	P	= POOR
Rug.	= *Rugoglobigerina*	M	= MODERATE
Ptx.	= *Pseudotextularia*	VP	= VERY POOR
Ab.	= *Abathomphalus*	PM	= POOR TO MODERATE
Psg.	= *Pseudoguembelina*		

Figure 5. *(Continued).*

CHRONOSTRATIGRAPHY

Recent studies (Seronie-Vivien, 1972; Moullade, 1966, 1974; Porthault, 1969, 1974; Manivit, 1971; Longoria, 1974; Thierstein, 1973, in press; Van Hinte, 1976) on Cretaceous stratotype sections in the northernmost Aquitaine Basin and in the classical region in southern France have markedly improved the correlation between foraminifer and calcareous nannofossil zonal schemes and the standard zonation based on ammonites. Thus, the foraminifer and nannofossil zonal schemes can be related to the European stages whose boundaries are defined on the basis of the ammonite assemblages.

Figure 7 shows the updated correlations between the foraminifer zonal succession used in this paper and European stages. This correlation is based mainly on the studies of Moullade (1966, 1974) for the Albian to Cenomanian and Donze, Porthault, et al. (1970) and Porthault (1974) for the Turonian to Maestrichtian. The time-scale recently presented by Van Hinte (1976) is consistent with Moullade and Porthault's correlations except for the ranges of the *Globotruncana concavata* group relative to *Globotruncana elevata*.

According to Porthault (1974) the overlap between these two species is short and occurs close to the Campanian-Santonian boundary. Van Hinte (1976), instead, indicates that this overlap is approximately 2 m.y. long and that "*G.*" *elevata* appears in the early Santonian rather than in the latest Santonian. Moreover, "*G.*" *concavata* would appear at the base of the late Coniacian above the Haberfellneri Zone instead of

Core	Section	Interval (cm)	Gtr. sinuosa	Gtr. sigali	Gtr. renzi		Gtr. concavata	Gtr. angusticarinata	Gtr. pseudolinneiana	Gtr. fornicata	Gtr. lapparenti	G'lloides caseyi	Hx. reussi	Hx. globulosa	Arch. cretacea	G'lloides asper	Gtr. coronata	Gtr. bulloides	Hd. flandrini	Hd. delrioensis	Rug. aff. bulbosa	Rug. pilula	Hast. watersi		Hx. striata	Planoglobulina sp.	Gtr. marginata		Loebe. hessi	Plag. glabrata	G.lloide praeriehillensis	Gtr. austinensis	Gublerina sp.	Angusticarenata/arca	Clavih. simplex	Gtr. arca	Schackoina multispina	Arch. blowi	Gtr. limiciana	Gtr. concavata carinata	Gtr. elevata	Pst. elegans	Rug. rugosa	Gtr. havanensis	G'lloides volutus	Gtr. rosetta	Gtr. leupoldi	Rug. hexacamerata	Gublerina sp.	G. lloides yaucoensis
31	1	117-119												C											C											C					F	C	F	C	C		r		F	
	2	37-39	Gtr. tricarinata or Gtr. ganseri zonal assemblage displaced											C											C											f					C	C	F	C	C					C
	3	40-42	Gtr. ganseri assemblage displaced											F											C											C						C	F	F	C				F	
	4	41-43												C											C											R					C	C	F	C	C					
32	3	40-42	little reworking											C	C										C											C	C				F	C	F	F	R			C	F	
33	2	40-42	Gr. ganseri assemblage displaced											R											f											R					C	R	C	F	C				C	
	3	39-41	reworking											f											f											R					F	f	C	f	f				f	
	4	30-32	sorted?											R											R											R		R			F	F	C	C					A	
	5	30-32												F											C											f			C			F	F	F	F				F	F
	CC									f				F				F							C						VR					F		R	R		F	R	A	F	F	f	f		F	R
34	2	40-42									R			F	f			F							F						C					C		R	R		C	R	A	F	F	f	f	C	F	C
	4	40-42								f	F			F				F							F						C					C		R	F			C	C	F	F	F	F	F	F	C
	5	40-42								f	C			F	R			F							F						C					F		R	C			C	C	R	F	F	F		C	C
35	2	37-39									R			F	f			C							F						C					F			C		f	F	C	R	C	F	F		f	C
	3	34-36								VR				F				f							F						C					f			f		R		C	A	C	C	C		A	C
	4	40-42								R				A	f			f							A						F					C		f	f		f		F	A	F	F	F	R	F	F
	5	48-50												F	R			R													f					R		f	R		R	R	F	F	F	C	C	C	F	F
36	1	72-75												R						R																	R								R					
	2	34-38																													f																			
	5	33-37												R						R																														
37			no forams or only benthics																																															
38			no forams or only benthics																																															
39	1	33-35								R	R			f			R	R				R			R				R	f	R					R			R		R									
40	1	33-37						R	C	F	C	A	A	A	f	A	F	C				f			f				R	C						C		f	F											
	2	31-35							C	F	C	A	A	A	f	A	F	C				f			f											C		f	F											
	3	33-37							C	F	C	A	A	A	R	A	F	C				f			f					C	A					C		f	F											
	4	60-62							C	F	C	A	A	A	R	A	F	f				f			f					C	A					C		f	F											
41	1	61-63							C	C	C	R	R	R	r	R	R	R				r			R					C	A					C		f	F											
	4	58-60							C	F	C	C	A	C	f	C	f	C				f			f				R	R	C					C			F											
	5	28-30							C	R	C	A	A	C	R	A	F	f				f			A					R	F					C			C											
42	1	58-60					f	f	R	F	F	f	F	A	f	F	F	R				R			A		f		f	C	F					C	R	R	f	C										
	2	60-62					F	F	R	F	F	F	F	A	R	F	F	R				R	f		C		f		R	C	F					C	R	R	F	A										
	3	35-37						R	C	C	A	f	f	f		f	C	C				VR								f	f					C			F											
	4	59-61								F	f	A	A	A		A	C	R				R								f	C																			
43	1	80-82								A	C	A	A	A	R	A	f	C				R								f	C								R											
	3	74-76								A	R	A	A	A	VR	A	VR					VR			R				VR		f					VR			R											
	4	56-58						R	C	A	C	A	A	A		A	C	f		C		VR			R					f	f					f			R											
	5	55-57						C	R	C	A	A	A	A	f	A	C	F		C		R			f	C	R			C	C	C				C			VR											
	6	50-52							f	C	F	F	A	A	C	F	R	A		C		R			C	f				C	F	C				C			F											

Figure 6. *Distribution of selected planktonic foraminifers at Site 357, early Santonian to late Maestrichtian.*

Hx. navarroensis	Gtr. tricarinata	Gtr. plummerae	Gtr. subcircumnodifer	Gtr. hilli	Rug. macrocephala	Hx. pulchra	Psg. costulata	Gtr. ventricosa	Gtr. calciformis	Hx. punctulata	Gtr. subpenneyi	Plag. multiloculata	Plag. acervulinoides	G'lloides subcarinatus	Gtr. falsostuarti	Rug. rotundata	Psg. excolata	Gtr. gansseri	Gtr. gagnebini	Ab. intermedius	Gtr. aegyptiaca	Gtr. andorri	Gtr. contusa	Ab. mayaroensis	Ptx. deformis	Gtr. trinidadensis	Racemiguembelina fructicosa	Gtr. stuarti		PLANKT FORAMS ABUNDANCE	PLANKT FORAMS PRESERVATION	BENTHIC FORAMS	OSTRACODES	RADIOLARIANS	FISH DEBRIS	MEGAFOSSILS	INOCERAMUS	MINERALS	ZONE	AGE
f	f				R	R								C		f	f				f	F	C	C	C	f	C	f		A	PM	f								MAASTRICHTIAN
f	f				R	R		f	C			C	C	C		C	C			C		C	A	R	f	f	C	f		A	P	f								
f	f					f				f				C		C	C	f					f	C	C	f	C			F	VP	f								
f	f				R	R						F	F	C	f	C	C		C			C	C	C			F			A	P	f								
f	R				R	R		R			R	F	F	f	C	R	C	R				C	A	C	C	f	C			A	M	f							*Abathomphalus mayaroensis*	
f	C	f			R	R	f		f						f	f	f	F		f			f	C	F					A	VP/P	f								
f	R	f				R			R								f			R			R	R	R					A	P	f								
f	R	F			VR	R	R		C	R	C				F		F			f		C	C	R						A	PM	f								
f	F	A				f			C	F	F	f	f	C	F	C	C			f	C									A	MG	C								
f	R	F			R	f	C		R	C	C	f	f	C		f	C			R										A	PM	f							*Globotruncana contusa*	
f	R	f	R		R	f	R		R	C	R	C	C	C	C	C	R	R	R	f										A	PM	f								
f	A	C			R	f	R			C	R	f	f	C																A	P	C	C						*Globotruncana gansseri*	
R	F	F					R	f	R	C	R	f	f	C																A	PM	R								
	C	C				R	C																						little reworking	A	P	f								
R	R	R	f	f		R	R	R																						A	VP	F	f						*Globotruncana tricarinata*	
R	R	R	C	f	R	R	R																							F	VP	A								
C	R					R	R																						few species reworked	A	VP	F				F	C			
																														P	P	A								CAMPANIAN
																														VR	P	C						M		
																														R	P	C							not zoned	
																																R			?				?	
																																R			?				*Globotruncana elevata*	
																														f to A	P	C								
																														A	P	C						r		SANTONIAN
																														A	P	C								
																														A	P	C								
																														A	P	C								
																														A	P	C						Fe_2O_3		
																													partly reworked	A	P	C								
																													strongly reworked	A	P	C								
																													early *G. concavata* displaced assemblage	A	VP	C								
																													partly reworked	A	PM	C	R	R/P				G		
																													reworked	A	VP	C	f				C			
																													reworked	A	VP	C					C		*Globotruncana concavata carinata*	
																													few reworked species	A	P	C								
																													reworked	A	VP	C								
																													reworked	A	P	C	R							
																													reworked	A	P	C	R							
																													reworked	A	PM	C	R							

Figure 6. *(Continued).*

Core	Section	Interval (cm)	Gtr. sinuosa	Gtr. sigali	Gtr. renzi		Gtr. concavata	Gtr. angusticarinata	Gtr. pseudolinneiana	Gtr. formicata	Gtr. lapparenti	G'lloides caseyi	Hx. reussi	Hx. globulosa	Arch. cretacea	G'lloides asper	Gtr. coronata	Gtr. bulloides	Hd. flandrini	Hd. delrioensis	Rug. aff. bulbosa	Rug. pilula	Hast. watersi		Hx. striata	Planoglobulina sp.	Gtr. marginata		Loebe. hessi	Plag. glabrata	G.lloide praeriehillensis	Gtr. austinensis	Gublerina sp.	Angusticarenata/arca	Clavih. simplex	Gtr. arca	Schackoina multispina	Arch. blowi	Gtr. linneiana	Gtr. concavata carinata	Gtr. elevata	Pst. elegans	Rug. rugosa	Gtr. havanensis	G'lloides volutus	Gtr. rosetta	Gtr. leupoldi	Rug. hexacamerata	Gublerina sp.	G. lloides yacoensis
44	3	56-58					R	R		F	F	A	A	F	R	A	C	F	R	C		R					R			f																				
	5	60-62						R		F	F	A	A	F	R	A	F	A	R	C		R					R			f	C			R		C	R	R												
45	1	140-142					F	R	F	C	f	A	A	C	R	C	F	R	R	f		R			R		R							F						f										
46	2	76-78					F	R	f	A	F	A	A	A	R	A	F	R	R	F		R			VR		R		VR	R	f			F						cf										
	4	32-34					R	C	C	C	F	A	A	A	R	A	F	R	R	F		R									f			f																
47	2	66-68					VR	C	C	A	F	A	A	F	R	A	F	C	R	F		R							R		R			F	f	R														
	3	53-55			R					C	f	F	F	F	VR	F	C	R	R			R									f			R																
	4	47-49					R	R	F	A	F	A	A	C		A	F	R		C		R			R		R		R	R	F cf	R	R aff	F																
48	3	61-63			C		F	C	F	F	F	A	A	A		C	F	R		C		F			C	C	R			R																				
	4	13-15			C			F	F	cf	VR	A	A	A	R	A	F	R	R	C		R				C	F																							
	6	52-54						f	f	f	f	f	f	f		f	f			R		R			R	R																								
49	3	64-66			R		f	F	F	f	F	A	A	A	C	A	C		R	C	R	C	R		F	C																								
	4	60-62			f		f	F	F	f	F	A	A	A	C	A	C		R	C	R	C			F	C																								
50	1			too indurated																																															
	CC		R		F		f	F	f	C	C	A	A	A	R	C	C	f	f	f	R																														
51	5	30-32	R	C	F		f	C	f	C	C	A	A	A	R	f	f	f	f	f	R																														

Figure 6. *(Continued).*

just above the base of the early Coniacian, as indicated by Porthault (1974). The nannofossil, *Marthasterites furcatus*, which has almost the same range as the *Gtr. concavata* group, is plotted too high by Van Hinte (see Thierstein, in press). The interpretations of Porthault and Thierstein are followed here. Paleomagnetic stratigraphy further confirms that the age of the *Gtr. elevata* Zone is mainly Campanian. At Site 355, sediments lying on top of the reversed interval between Anomaly 33 and Anomaly 34 yielded the nannofossil *Broinsonia parca*, which marks for most authors including Van Hinte, the beginning of the Campanian. In the Gubbio section, extinction of *Gtr. concavata* s.l. occurs within the same magnetic reversed interval (see Alvarez et al., in press). In this section the latest representatives of *Gtr. concavata* overlap for a short interval with a form related to *Gtr. elevata* with a single keel on the last whorl, but double keeled on the inner whorls. Therefore, we believe that *Gtr. concavata* overlaps for a short interval with forms close to *Gtr. elevata* and becomes extinct when *Broinsonia parca* appears at the beginning of the Campanian; thus, the *Gtr. elevata* Zone is mainly Campanian in age.

HIATUSES

Figure 2 includes a simple and preliminary hiatus curve based on the percent of cored section containing hiatuses for all published southern South Atlantic DSDP sites and deep-sea cores. The three primary hiatuses evident from this curve (see also Figure 8) occur in the: (1) interval from late Albian to middle Turonian, including the entire Cenomanian (longer at Site 356 than at other sites), (2) interval from late Turonian to earliest Coniacian, and (3) interval spanning the Santonian-Campanian boundary.

Comparison of this curve with a preliminary transgression-regression curve (Figure 2) compiled for the South Atlantic and adjacent basins demonstrates a correlation between transgressions and hiatuses in this basin, particularly to the north.

REMARKS ON PALEOENVIRONMENTAL CONDITIONS

Site 356—Boreal Planktonic Foraminifer Faunas

Late Albian planktonic foraminifer faunas at Site 356 are characterized by large numbers of *Hedbergella* and globigeriniform planktonics. *Ticinella* is rare, and the rotaliporids are essentially absent. Such faunas are generally low in diversity relative to more equatorial, Tethyan, faunas.

The genus *Rotalipora* is rarely reported in either the South Atlantic or the Indian Ocean. Sigal (1974) mentions rare *Rotalipora balernaensis* (= *R. appenninica*) from the upper Albian to lower Cenomanian (Sample 23-3, 3 cm) at Site 249 in the western Indian Ocean.

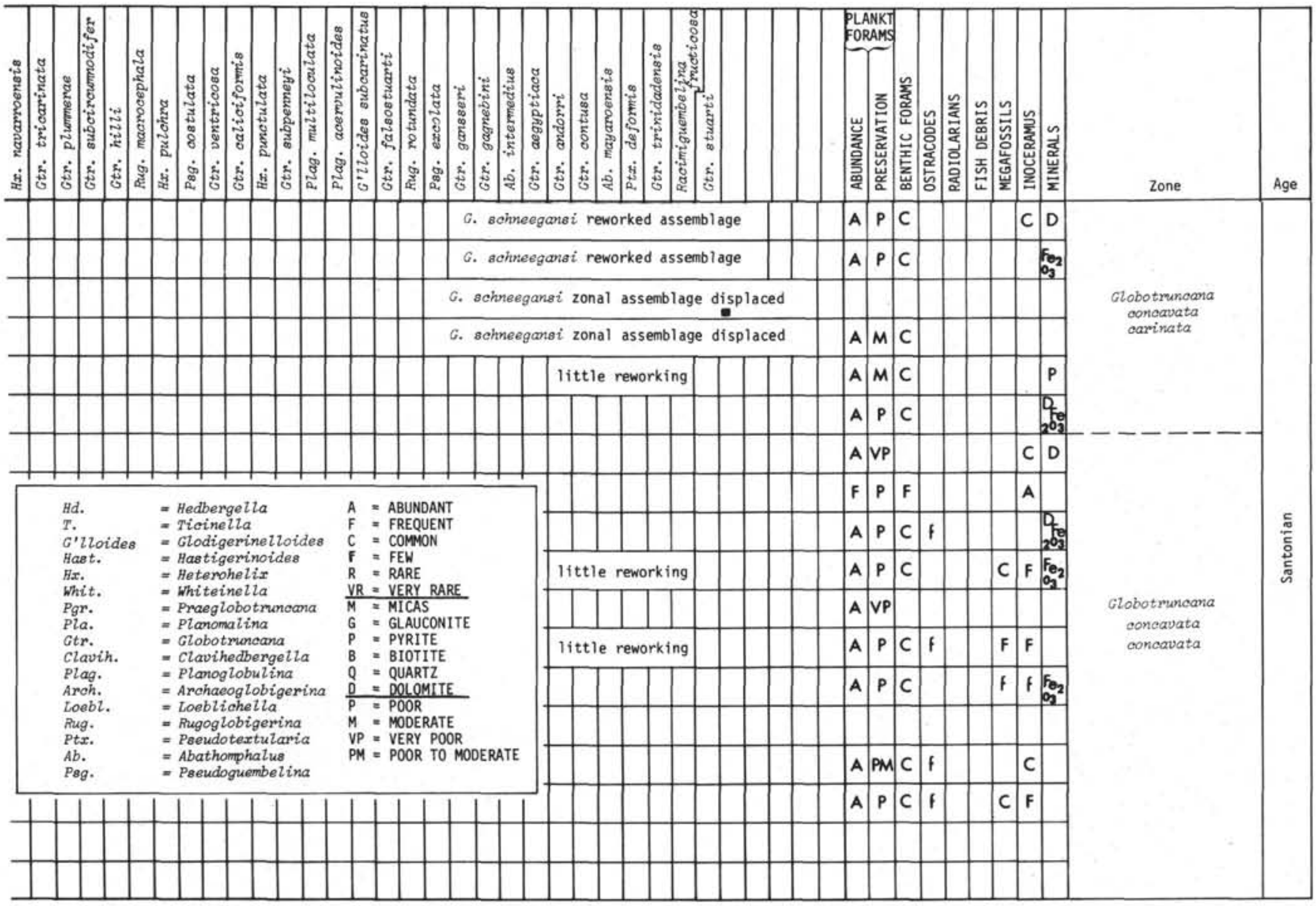

Figure 6. *(Continued).*

Herb (1974) reports one fragment of *Rotalipora reicheli* from Site 258 in the eastern Indian Ocean, and Sliter (in press) has found few specimens of *R. reicheli* from Leg 36 on the Falkland Plateau.

Faunas similar to those at Site 356 are reported from Sites 257 and 258A from the Wharton Basin, eastern Indian Ocean, and have been called "boreal" by Herb (1974). These faunas were interpreted to reflect the presence of cooler, boreal waters in this region. Sliter (personal communication, 1976) confirmed that the austral character of the 356 faunas could explain the absence of the rotaliporids.

The location of Site 356 to the south of the main evaporite bodies in Albian time indicates that the area of the São Paulo Plateau was opened towards the Southern Ocean, but had no connection with the central North Atlantic and its tropical water masses. That such a connection to the north was established sometime in the Cenomanian is suggested by the preservation (although reworked) of rotaliporids belonging to the *Rotalipora greenhornensis* Zone of mid Cenomanian age at Site 356.

There is, however, no indication whether this connection was through the opening Central Atlantic or through the trans-African Benue channel to the Mediterranean Tethys (Reyment, 1969). However, a sea level high and/or a poleward migration of climatic belts could accommodate an invasion of rotaliporids into the South Atlantic at this time.

By middle Turonian time (*P. helvetica* Zone), the central Atlantic was apparently open to free communication between the North and South Atlantic so that Tethyan faunas are recorded at Site 356 for the remainder of the Cretaceous.

DISPLACED AND REWORKED FAUNAL ASSEMBLAGES

Sedimentation at both Sites 356 and 357 was disturbed throughout the Mesozoic sequences; the maximum disturbance and reworking are concentrated in the upper Santonian.

At Site 356 in upper Albian sediments, foraminifers and radiolarians are frequently size sorted in turbiditic layers which are interbedded with unsorted material. Occasionally the coarser turbiditic layers contain displaced shallow-water benthic foraminifers and invertebrate debris.

Sedimentation during the middle Turonian *Praeglobotruncana helvetica* Zone is apparently undisturbed during euxinic conditions. A conglomeratic layer 30 cm thick marks the beginning of sedimentation after the upper Turonian-earliest Coniacian hiatus (Core 40 between Sections 3 and 2). Sediments above this level and throughout Core 39 were very coarse and produced conglomeratic layers. No reworking has been detected in this interval, but many layers are barren. The sedimentary sequence evolves upwards into less coarse sediments in which *Inoceramus* debris is very common.

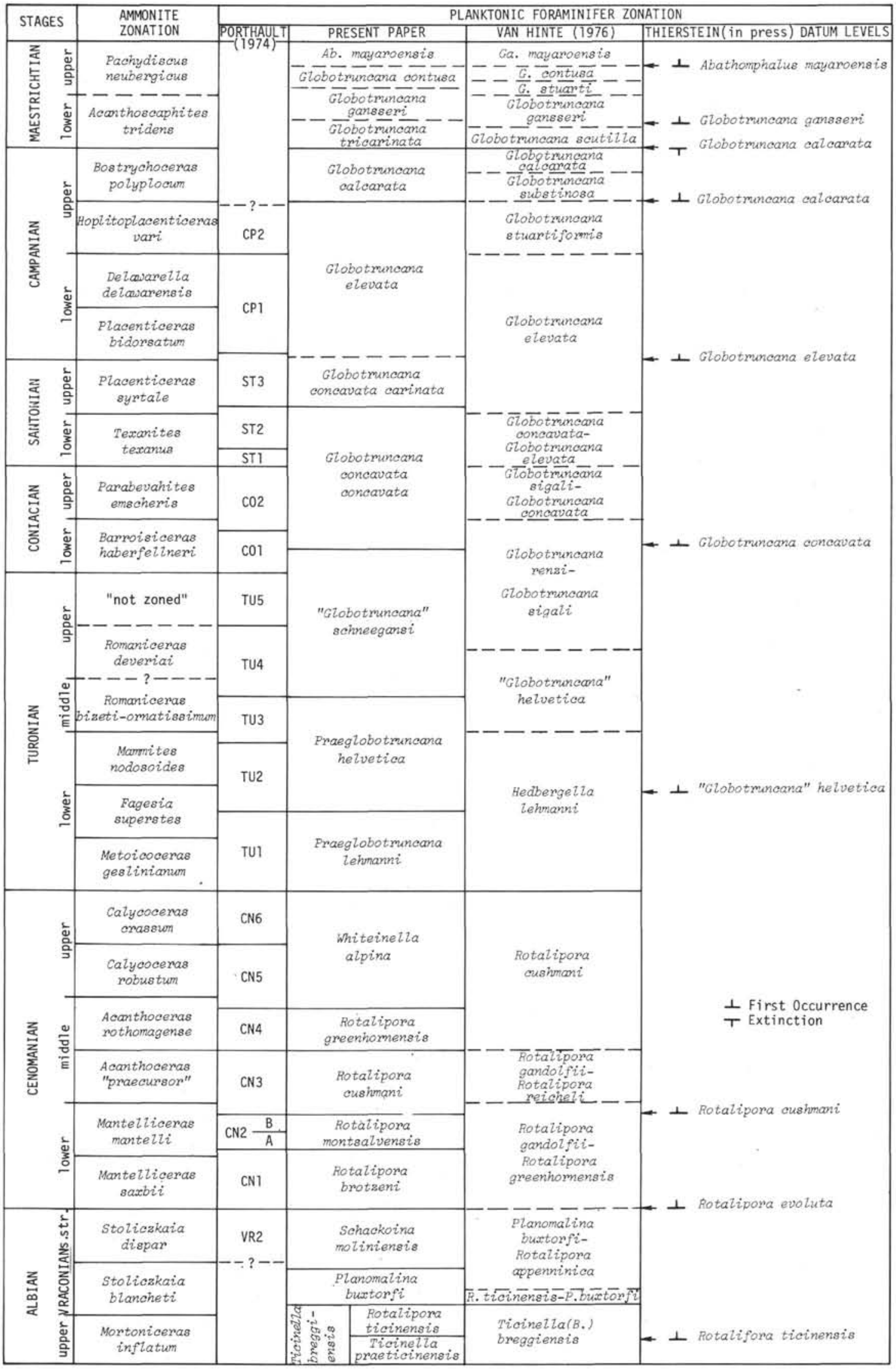

Figure 7. *Standard Ammonite zonation and planktonic foraminifer zonal schemes and their correlations with the late Mesozoic Stages. Correlations between stages and Ammonite zonation is mainly after Porthault (1974).*

AGE		FORAMINIFER ZONES		Site 356	Site 357
MAESTRICHTIAN	L	*Abathomphalus mayaroensis*		29-3-31 thru 31,CC	31-1-33 thru 4-40
	M	*Globotruncana contusa*			33-5 thru 34,CC
		Globotruncana gansseri		32-1 thru 32-3	not zoned
	E	*Globotruncana tricarinata*		32-4 thru 32,CC	35-1 to CC
CAMPANIAN	L	*Globotruncana calcarata*		33-1 thru 33-6-40	36-1 thru 39,CC not zoned
	E	*Globotruncana elevata*		33-6-119 thru 34,CC	
SANT.	L	*"Globotruncana" concavata carinata*		35-1 thru 36,CC	40-1 thru 47-2
	E	*"Globotruncana" concavata concavata*		37-1 thru 40-2	47-3 thru 51,CC
CONIACIAN / TURONIAN	L	*"Globotruncana" schneegansi*			
	M	*Praeglobotruncana helvetica*		40-3-41 thru 4-67	
	E	*Praeglobotruncana lehmanni*			
CENOMANIAN	L	*Whiteinella alpina*			
	M	*Rotalipora greenhornensis*		? few species displaced higher in the section	
		Rotalipora cushmani			
	E	*Rotalipora montsalvensis*			
		Rotalipora brotzeni			
ALBIAN	late VARCONIAN	*Schackoina moliniensis*			
		Planomalina buxtorfi		41,CC thru 44-4	
	s.str.	*Ticinella breggiensis*	*R. ticinensis*	44-5 thru 44,CC	
			T. praeticinensis		

||||||||| not recovered /////// hiatus ~~~~~ hole bottom

Figure 8. *Stratigraphic summary of Mesozoic sediments recovered at Sites 356 and 357. Notice the large hiatuses present at Site 356.*

Inoceramus in most cases is considered reworked from shallower depths. Reworking is common throughout the upper Santonian *Gtr. carinata* Zone (Cores 37-35). Eroded sediments belong mainly to the older (Coniacian) part of the *Gtr. concavata* Zone.

These sediments, mainly marly calcareous chalk, do not show any structures which hint at the presence of reworked material, except for slight color changes. Such color changes within a homogeneous pelagic sequence may reveal abnormal accumulations of fossils and possibly reworking (see Premoli-Silva and Luterbacher, 1966). The nannoflora does not show reworking, but from lower Coniacian to upper Santonian only the *Marthasterites furcatus* Zone is recorded without any differentiation into an earlier or later part. The last episode of reworking of older sediments is recorded in the upper Campanian *Gtr. calcarata* Zone where rare specimens of middle Cenomanian rotaliporids are present. Most of the Campanian sediments are generally undisturbed.

In the Maestrichtian, reworking occurs in minor amounts and mainly from one zone into an adjacent one. The most mixing occurs in Core 32 where silt-size allochthonous material is recorded throughout the later part of the *Gtr. tricarinata* and the earlier part of the *Gtr. gansseri* zones. We conclude that Site 356 since the late Albian has been located at the foot of or adjacent to an eroding area of oceanic origin. Seismic profiles adjacent to this site show a prominent channel nearby, so that discharge from submarine canyons could account for the reworking. Simultaneously, a strong erosional current regime is considered responsible for the hiatuses.

At Site 357 reworking is detectable mainly on the basis of the foraminifer content and color changes. Large amounts of reworking appear in the lower part of the upper Santonian *Gtr. carinata* Zone when a lower upper Turonian foraminiferal assemblage belonging possibly to the "*Globotruncana*" *schneegansi* Zone or to the uppermost part of the *Praeglobotruncana helvetica*

Zone is recorded in Core 45. From Core 45 to Core 40, eroded sediments belong mainly to the Coniacian part of the *Gtr. concavata* Zone.

No reworking has been found in the Campanian and lower and middle Maestrichtian, but recovery was rather poor (~12% in the Campanian and ~23% in the lower and middle Maestrichtian). The sediments show strong evidence of dissolution; however, the thickness of sediments is two to three times that recorded at either Site 356 or Site 21 for the same time interval. With better recovery, reworking becomes more evident in the *Abathomphalus mayaroensis* Zone (upper Maestrichtian). As a general rule, during the Maestrichtian (and lower Paleocene) reworked material is only little older than the autochthonous material; generally faunas of one zone are displaced into the next zone. When the assemblages are different like those from upper Maestrichtian and lower Paleocene, this reworking feature is particularly obvious. In all the other cases the boundaries between zones become obscure. Although both Sites 357 and 21 on the Rio Grande Rise are located adjacent to topographic highs, it is our opinion that in the upper Santonian and possibly Campanian we are observing an erosional phase possibly related to tectonic movements of the Rio Grande Rise blocks.

DISSOLUTION AND THE CARBONATE COMPENSATION DEPTH

Figure 9 characterizes the preservation state of the planktonic foraminifer faunas through the Cretaceous at the Leg 39 sites. High dissolution is continually recorded at the basinal Sites 355 and 358, and at the deep Site 354; all were drilled in waters presently deeper than 4000 meters.

Site 355 bottomed in basalt overlain by sediments containing indices for the nannoplankton *E. eximius* Zone of early Campanian age. These sediments contain no foraminifers and only rare nannofossils, implying intense dissolution of most calcareous material. No autochthonous calcareous material was found above the early Maestrichtian *T. trifidus* Zone. Using the simplest model for the sinking history of this site, we can assume that when contiguous with the ridge the site lay at an average depth of 2700 meters. A simple sinking rate then can be derived from the age-depth relationships inherent in the McKenzie and Sclater (1971) model for sea floor sinking and crustal contraction (Table 2).

Site 358 did not terminate in basement, but in sediments of latest Campanian-earliest Maestrichtian age (*T. trifidus* Zone). Moderately preserved faunas of planktonic foraminifers, including abundant globotruncanids and deep benthonics, occur in the oldest samples at this site. Dissolution is evident in these faunas and increases markedly above Core 16, leaving more or less dissolved faunas through the Cretaceous and into the lower Tertiary when dissolution is so intense that only the most resistant planktonic foraminifers are rarely found and faunas contain more or less dissolved calcareous benthics and significant numbers of abyssal agglutinated foraminifers. Reflection profiles suggest that drilling terminated 50 meters above basement, which is known to lie between magnetic Anomalies 32 and 33 (Ladd, 1974). Extrapolation over that 50-meter interval allows an estimated age designation of late Campanian for basement at this site.

Again taking the simplest method of estimating sinking rates, we assume contiguity with the Mid-Atlantic Ridge at an approximate depth of 2700 meters in the late Campanian. Comparing the strong fluctuations in faunal preservation with the estimated depth of the site through the Cretaceous allows us to make some rough estimates of the paleo CCD and foraminiferal lysocline (Table 2) in the northern Argentine Basin.

Site 354 was located on the Ceará Rise. Dissolution is common, but less intense in the faunas here. Throughout the Cretaceous and parts of the Tertiary both at Site 354 and at the nearby Site 144 on the Demarara Rise, red and green dissolved sediments attest to dissolution supposedly related to reducing conditions, possibly due to their location in a high productivity area with high organic input to the bottom.

From Figure 9 it is clear that in the intermediate depth Sites 356, 357, and 21 (1) dissolution is always more intense at Site 357 than at 356 or 21; (2) maximum dissolution occurs in the Campanian at both sites; (3) high dissolution occurs in middle Maestrichtian; (4) later Maestrichtian is represented by almost undissolved assemblages; (5) the sedimentation rates (Figure 10 and Table 3) at Site 357 are three times greater than those at Site 21, lying some 400 km to the east.

The contrast between the sedimentologic and fossil records at Sites 357 and 21 is significant and renders uncertain the suggestion that these two sites have had analogous sinking histories. Both sites were drilled at depths close to 2000 meters and both lie on pinnacles constituting the eastern flank of the Rio Grande Rise.

It is worthwhile to mention also that the later Maestrichtian is a period of low dissolution at the South Atlantic sites, which according to the reconstruction of Ladd (1974) lay between 40° and 30° south latitude. By contrast, equatorial west Atlantic and Caribbean sites from Legs 14 and 15 show maximum dissolution (and/or erosion) during the same period of time.

Layers of Campanian-Maestrichtian characterized by unusual coloration or dissolution were identified in Leg 39 sites. Coloration ranged from greenish (Site 356), to red (Sites 354 and 358) to alternating green and red layers (Site 355). Analysis of microfaunas showed intense dissolution of planktonic foraminifers, occasionally leaving residues of only benthic forms. Preservation of nannofossils allowed dating of these layers as late Campanian/early Maestrichtian, generally the *T. trifidus* Zone. Similar sediment types were found at several other DSDP sites including Leg 3 Site 13 (Maxwell et al., 1970) and Leg 14 Site 144, both in the equatorial Atlantic, and Leg 24 Site 249 in the Indian Ocean. At this time organic-carbon-rich layers were found in several South Atlantic marginal basins (Reyment and Tait, 1972; Zambrano and Urien, 1974, etc.).

AGE		FORAMINIFER ZONES	SITE 356 (w.d. 3203 m)	SITE 357 (w.d. 2109 m)	SITE 21 (w.d. 2102 m)	SITE 358 (w.d. 4990 m)	SITE 355 (w.d. 4896 m)	SITE 354 (w.d. 4052 m)
MAESTRICHTIAN	late	*Abathomphalus mayaroensis*	Moderately preserved to slightly dissolved	Moderately well preserved	Well preserved			
	middle	*Globotruncana contusa*		Strongly dissolved		Strongly or totally dissolved		
		Globotruncana gansseri						Totally dissolved
	early	*Globotruncana tricarinata*		Partially dissolved		Recrystallized and partially dissolved	Totally dissolved	
CAMPANIAN	late	*Globotruncana calcarata*	Moderately well preserved to strongly dissolved	Almost totally dissolved				
	early	*Globotruncana elevata*	Slightly to partially dissolved					
SANTONIAN	late	*"Globotruncana" concavata carinata*	Recrystallized and slightly dissolved	Partially dissolved				
CONIACIAN	E	*"Globotruncana" concavata concavata*	Strongly dissolved	Poorly to moderately preserved				
TURONIAN	late	*"Globotruncana" schneegansi*						
	M	*Praeglobotruncana helvetica*	Evenly but strongly dissolved					
	early	*Praeglobotruncana lehmanni*						
CENOMANIAN	late	*Whiteinella alpina*						
	middle	*Rotalipora greenhornensis*						
		Rotalipora cushmani						
	early	*Rotalipora montsalvensis*						
		Rotalipora brotzeni						
ALBIAN	VARCONIAN	*Schackoina moliniensis*						
		Planomalina buxtorfi	Recrystallized not dissolved					
	late s.str.	*Ticinella breggiensis* — *R. ticinensis* / *T. praeticinensis*						

Figure 9. *Schematic description of the preservation of the planktonic foraminifer faunas in the Mesozoic sequences recovered at Leg 39 sites and at Site 21 on the Rio Grande Rise (after Maxwell et al., 1970).*

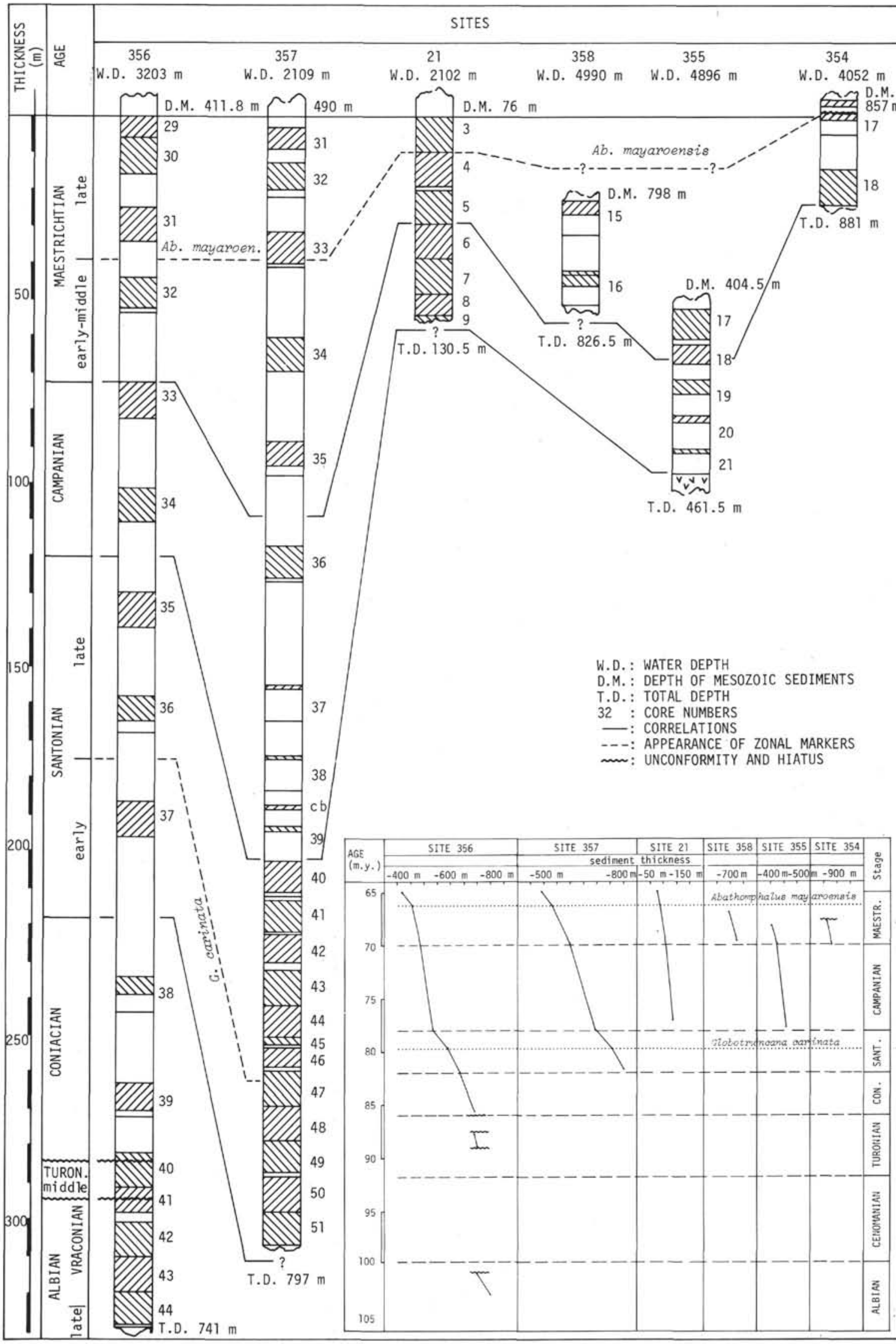

Figure 10. *Thickness of Mesozoic sediments versus age drilled during Leg 39 in the South Atlantic and at Site 21 on the Rio Grande Rise (after Maxwell et al., 1970) and rates of sedimentation. Absolute age scale after Van Hinte; 1976. Shaded areas show the recovery per each core.*

TABLE 2
Estimates of the Paleo CCD and Foraminifer Lysocline Based on a Continuous Sinking Model for Site 358 in the Argentine Basin

Core-Section	Age (m.y.)	Calc. Depth (m)	Type Fauna	Lysocline Level	Appx. CCD
10	49	4100	Below CCD		>4100
11	49	4100	Below CCD	<4100	<4100
11, CC	49	4100	Near CCD	<4100	near 4100
12-2	52	3500	Near lysocline	near 3800	
12, CC	52	3800	Below CCD		<3800
13-1	60	3600	Near CCD		near 3600
13-4	60	3600	Near lysocline	near 3600	
13, CC	60	3600	Near CCD	<3600	near 3600
14-4	60	3600	Below CCD		<3600
14-15	63	3500	Near CCD	<3500	>3500
15	65	3300	Below CCD		<3300
15-16	67	3200	Near lysocline	near 3200	
16, CC	70	2700	Above lysocline	>2700	

TABLE 3
Rate of Sedimentation Values Calculated Using the Van Hinte (1976) Absolute Scale (numbers correspond to cm/1000 a)

	Site					
	356	357	21	358	355	354
Late Maestrichtian	3.3	3.3	0.8	–	–	–
Early-middle Maestrichtian	0.9	1.8	0.5	1.1	0.8	1.1
Campanian	0.6	1.1	0.4	–		–
Late Santonian	2.9	3.1	–	–	–	–
Early Santonian	2.0	2.4	–	–	–	–
Coniacian	1.6	–	–	–	–	–
Middle Turonian	2.0	–	–	–	–	–
Late Albian	1.7	–	–	–	–	–

Maxwell et al. (1970) further related the red layers at Site 13 to the Scaglia Rossa Formation of the Appenines which ranges in age from Santonian through Paleocene. Geochemical analysis of these layers revealed low iron contents ruling out the possibility that high iron content was responsible for the red coloration. This red coloration instead may be interpreted as result of an oxidizing stage of open marine sediments originally deposited in reducing conditions (originally green sediments) (Bonatti, personal communication 1976). The intense dissolution of the planktonic foraminifers detected in the red levels is also explicable by reducing conditions rather than CCD changes.

This reducing interval appears characterizing sites of all depths throughout the Central and South Atlantic. However, further investigations are necessary at this stage.

SAPROPELIC LAYERS AND THEIR FAUNAS, SITE 356

At Site 356 a series of deposits—dark green, brown, to dark gray and black—occurs from Samples 38, CC, to 41-4, 72 cm. The vivid dark color banding as well as elevated organic carbon values mark these deposits as sapropels. In a general way above a basal unconformity deposits grade from jet black at the bottom to greens and browns, reds, and finally to lighter grays in higher levels. There are probably several cycles of these sapropels throughout this sequence.

Residues from these deposits contain characteristic suites of minerals in the coarse fraction, including glauconite, gypsum crystals, other evaporitic minerals, barite, microscopic and macroscopic crystals of pyrite, and abundant mica and clays. The accompanying fossil residues can be:

(1) only fish teeth, pyritized radiolarians, and no foraminifers; (2) only simple agglutinated foraminifers, some fish teeth, and/or pyritized radiolarians; (3) only benthic foraminifers, calcareous and agglutinated forms, with fewer fish teeth and pyritized radiolarians; (4) planktonic and benthic foraminifer open marine oozes.

No foraminifers are found in the bottom jet black to gray-black highly pyritiferous samples. However, foraminifers characteristically occur in light green, green brown, or light gray layers. In the browner samples there is more dissolution of the planktonic foraminifers and a higher ratio of agglutinated foraminifers. The lowest carbonate contents consistently occur in the dark gray to blackish gray bands. In nearly every sample the foraminifers are recrystallized, and in most all cases the radiolarians are pyritized. Planktonic foraminifers, when present, are often miniscule in size.

Ages of the Sapropels

Calcareous open marine oozes occur at Site 356 from the top of the Maestrichtian down to the upper Coniacian in the top of Core 39. Section 39-1 contains an assemblage of the *Globotruncana concavata concavata* Zone, including "*Gtr.*" *tarfayaensis*, "*Gtr.*" *sigali*, "*Gtr.*" *renzi*, and *W. archaeocretacea*. Oozes alternate with more or less reduced layers below Section 39-1. Samples containing foraminifers of Coniacian age continue into Core 40. However, levels below Section 40-3 have been placed in the *Praeglobotruncana helvetica* Zone on the basis of the zonal marker plus *P. indica*, *P. imbricata*, *W. archaeocretacea*, "*Gtr.*" *sigali*, and "*Gtr.*" *angusticarenata*. The nannofossil *M. staurophora* Zone was recognized from

Section 40-3 to Sample 41-4, 72 cm. Both zones correspond to a middle Turonian age. A hiatus spanning the late Turonian thus occurs within Core 40.

Below Section 40-3 foraminifer oozes occur only sporadically. At Sample 41-4, 67 cm the fauna contains *Hedbergella delrioensis, W. archaeocretacea, P. helvetica*, and *Globigerinelloides caseyi*. Just below this level in Sample 41-4, 72 cm there is a sharp break between black sapropel layers above and an underlying blue-gray, uniform limestone containing fossils of the late Albian *Planomalina buxtorfi* Zone. This fauna contains *P. buxtorfi, Schackoina cenomana gandolfii, Ticinella roberti*, and abundant *Hedbergella planispira*. A hiatus spanning the entire Cenomanian to latest Albian is thus encompassed within Core 41, Section 4. However, the presence of reworked *Rotalipora greenhornensis* into Campanian levels at this site (Core 33, Section 1) demonstrates that there was deposition at or near this site during the middle Cenomanian *Rotalipora greenhornensis* Zone.

Depth of Site 356 During Sapropel Deposition

The Albian limestone sequence at the bottom of Site 356 has been interpreted by us and several other workers to represent deposition at close to 1000 meters water depth (Sliter, this volume; Aubert, personal communication). The overlying reducing sediments contain evidence of extensive solution of the calcareous forms and only simple agglutinated foraminifers and fish debris remain. Such faunas are reminiscent of the *Rhabdammina* faunas of Luterbacher (1972) which have been interpreted as indicating abyssal depths. However, the presence of the underlying Albian limestone, of the intercalated Turonian planktonic oozes containing bathyal benthic foraminifers, and of the overlying Santonian open marine oozes also containing bathyal benthic foraminifers (Sliter, this volume) indicate that our sapropel faunas were deposited in a reducing environment at bathyal, not abyssal depths. The faunas containing only simple agglutinated foraminifers are a residual fauna left after the dissolution of the calcareous foraminifers, due to the acidic nature of the interstitial water in the sapropelic sediments, and do not indicate abyssal depths.

Depositional Dynamics

The depositional sequence at Site 356 during the sapropel episodes is visualized as follows:

1) Albian limestone deposited in a quiet basin near some eroding topographic high (São Paulo Ridge) and /or receiving substantial detrital input from nearby land source (Santos Basin); open marine planktonic foraminifer faunas are accompanied by radiolarians and nannofossils; benthic foraminifers in the limestone suggest a bottom depth close to 1000 meters.

2) Hiatus (within Core 41).

3) Deposition of planktonic foraminifer oozes and invasion of equatorial (Tethyan) faunas during the middle Cenomanian (not in situ).

4) Hiatus (within Core 40).

5) Black pyritiferous sapropel sequence is deposited in reducing conditions during the middle Turonian. Several more oxygenated episodes, represented by reds and light gray levels, some containing planktonic oozes, interrupt the generally reducing environment.

6) Hiatus (within Core 40).

7) Re-establishment of reducing conditions and sapropel deposition during the Coniacian.

8) Establishment of open marine conditions by the early Santonian.

South Atlantic Sapropels

Figure 2 contains a summary of the general stratigraphy and lithologies of Cretaceous age sediments cored by DSDP in the South and Central Atlantic on Legs 3, 14, 36, 39, 40, and 41. Sediment ages for Legs 36, 40, and 41 were taken from the Scientific Staff (1975a-c) as well as personal observation by one of us (AB), but are still preliminary. From Figure 2 it can be seen that there are three major episodes of sapropel and black shale deposition: the Jurassic; the Aptian-Albian, and the late Albian through the Coniacian. These three major episodes can be divided into several minor ones.

Lower Cretaceous sapropels have been recovered north of the RGR-Walvis barrier (Sites 363, 364) and to the south (Sites 330 and 327). Lack of adequate stratigraphic resolution in the sections makes comparison between them still tenuous. North of the Walvis Ridge Albian sapropels characterize the deeper Site 364 while limestones cap the shallower Site 363. The southern Site 330 contains the oldest sapropels, perhaps reflecting the earlier spread in the southern South Atlantic. However, the presence of marine sapropels of Jurassic age on the Falkland Plateau, if related to the opening of the southern South Atlantic, then indicates an earlier age of opening than that known from the literature (i.e., Ladd, 1974).

Younger sapropel episodes vary from south to north. Higher latitude areas apparently have major hiatuses from the Campanian into the upper Albian and do not therefore contain a record of the youngest sapropel episode. The age of the sandstones and black shales from Site 361 in the Cape Basin is unclear and therefore, it is impossible to consider this site at this time.

From Figure 2 it is apparent at least in the northern South Atlantic (north of the São Paulo Ridge-Walvis Ridge barrier) that sapropel episodes are preserved during regressions and hiatuses are characteristic of transgressive phases. If the South American-African connection to the north and the Walvis-São Paulo Ridge to the south were operational barriers, then a sill effect may be responsible for stagnation at these northern South Atlantic sites. In the eastern Mediterranean during the Pleistocene, the sill effect caused euxinification of the basin during low sea levels when the sills could not be breached, but oxygenation of the bottom during transgressions (McCoy, personal communication). The post-Turonian sapropels should not be as subject to this barrier effect, however, as the seaway to the north Atlantic was opened and the RGR-Walvis ridges were in theory, sinking from outer shelf depths (363) in the Aptian to closer to 1000 meters in the later Cretaceous.

The Cenomanian sapropels typical of the Central Atlantic (Leg 41) and the North Atlantic (Leg 14) have not been identified in the South Atlantic. The lack of concurrent sedimentation between the northern South Atlantic and the equatorial Atlantic is pronounced before the Turonian and reflects the lack of a permanent, major connection between these areas until this time. The entrance of Tethyan planktonic foraminifer faunas into the South Atlantic after the Turonian demonstrates the presence of a passageway between north and south.

TAXONOMIC NOTES

Most of the taxa encountered at these southwestern Atlantic sites have been exhaustively described by several authors (Pessagno, 1967; Herb, 1974; Caron, 1972; Longoria, 1974; Sigal, 1966; Premoli Silva and Bolli, 1973), to whose papers the reader is referred for descriptions, illustrations, and synonymies.

Schackoina cenomana (Schacko) gandolfii Reichel
(Plate 2, Figure 1)

Schackoina cenomana gandolfii Reichel, 1948, p. 397, pl. 8, fig. 1; text-fig. 3, 6(8), 7(3), 8a, 10,(1, 3, 4, 11).
Schackoina cenomana gandolfii Luterbacher and Premoli Silva, 1962, p. 270, pl. 22, fig. 1, 2.

Several specimens of schackoinids have been found at Site 356 in Samples 41, CC and in 43-1, 78 cm, belonging to the late Albian *Planomalina buxtorfi* Zone. Poor preservation prevents observation of the inner whorls. Three and one half to four chambers are visible in the last whorl. Their arrangement is close to that of the group of *Schackoina cenomana* (Schacko) to which it is surely related; however, the more elongated chambers than in the type species instead resemble the subspecies *Schackoina cenomana gandolfii* Reichel to which these specimens are attributed. The type locality is the Breggia section, level 45, Cenomanian, Canton Ticino, Switzerland. This subspecies was also found in levels attributable to the late Albian from the Gubbio section (Central Italy) (Luterbacher and Premoli Silva, 1962), but it was never recorded from the deep-sea oceans. Only *Schackoina cenomana* has been reported from all oceans.

Planoglobulina browni (Martin)
(Plate 2, Figure 4)

Ventilabrella browni Martin, 1972, p. 85, pl. 1, fig. 3, 4.

Specimens attributable to this taxon have been found in abundance in late Santonian sediments from the South Atlantic sites, along with *Planoglobulina glabrata* (Cushman) from which it can be distinguished by fewer chambers in the multiserial portion, and by the ornamentation: longitudinal costae are very heavy in the biserial portion of *P. browni*.

The type species was first described from the Lower Taylor Formation of Texas.

ACKNOWLEDGMENTS

The writers wish to thank the Deep Sea Drilling Project for inviting one of them (AB) to participate on *Glomar Challenger* Leg 39. They are greatly indebted to Maria Bianca Cita for her stimulating suggestions and criticism and F. McCoy, W.V. Sliter, and H. Zimmerman for discussions and interpretations. Jo Ann Weinrib gave technical assistance and Dee Breger provided SEM photography.

This research was partially funded by Consiglio Nazionale delle Ricerche, Comitato 05, to the Institute of Paleontology, University of Milan and by NSF Grant OCE 74-24110 to Lamont Geological Observatory.

REFERENCES

Alvarez, W., Arthur, M.A., Fischer, A.G., Lowrie, W., Napoleone, G., Premoli Silva, I., and Roggenthen, W.M., in press. Late Cretaceous-Paleocene geomagnetic reversal time scale: type section in the pelagic limestone sequence at Gubbio, Italy: Geol. Soc. Am. Bull.

Beckmann, J.P., 1972. The foraminifera and some associated microfossils of Sites 135 to 144. *In* Hayes, D.E., Pimm, A.C., et al., Initial Reports of the Deep Sea Drilling Project, Volume 14: Washington (U.S. Government Printing Office), p. 389.

Bolli, H.M., 1957. The genera *Praeglobotruncana, Rotalipora, Globotruncana*, and *Abathomphalus* in the Upper Cretaceous of Trinidad, B.W.I.: U.S. Nat. Mus. Bull., v. 215, p. 61.

———, 1966. Zonation of Cretaceous to Pliocene marine sediments based on planktonic foraminifera: Assoc. Venezolana Geol. Mineria Petrol., v. 9, p. 3.

Caron, M., 1972. Planktonic foraminifera from the Upper Cretaceous of Site 98, Leg 11, DSDP. *In* Hollister, C.D., Ewing, J.I., et al., Initial Reports of the Deep Sea Drilling Project, Volume 11: Washington (U.S. Government Printing Office), p. 551.

Delteil, J.-R., et al., 1974. Continental Margin in the Northern Part of the Gulf of Guinea. *In* Burk, C.A., Drake, C.C. (Eds.), The geology of continental margin: New York (Springer-Verlag), p. 297.

Donze, P., Porthault, B., et al., 1970. Le Sénonien inférieur de Puget-Theniers (Alpes Maritimes) et sa microfauna: Geobios., v. 3, p. 41.

Douglas, R.G. and Savin, S., 1971. Isotopic analyses of planktonic foraminifera from the Cenozoic of the Northwest Pacific, Leg 6. *In* Fischer, A.G., Heezen, B.C., et al., Initial Reports of the Deep Sea Drilling Project, Volume 6: Washington (U.S. Government Printing Office), p. 1123.

———, 1973. Oxygen and carbon isotope analysis of Cretaceous and Tertiary foraminifera from the central North Pacific. *In* Winterer, E.L., Ewing, J.I., et al., Initial Reports of the Deep Sea Drilling Project, Volume 17: Washington (U.S. Government Printing Office), p. 591.

———, 1975. Oxygen and carbon isotope analyses of Tertiary and Cretaceous microfossils from Shatsky Rise and other sites in the North Pacific Ocean. *In* Larson, R.L., Moberly, R., et al., Initial Reports of the Deep Sea Drilling Project, Volume 32: Washington (U.S. Government Printing Office), p. 509.

Gandolfi, R., 1942. Ricerche micropaleontologiche e stratigrafiche sulla Scaglia e sul Flysch cretacici dei dintorni di Balerna (Canton Ticino): Mem. Riv. Ital. Paleontol., v. 4.

———, 1955. The genus Globotruncana in northeastern Colombia: Am. Paleontol. Bull., v. 36.

Hayes, D.E., Pimm, A.C., et al., 1972. Initial Reports of the Deep Sea Drilling Project, Volume 14: Washington (U.S. Government Printing Office).

Herb, R., 1974. Cretaceous planktonic foraminifera from the Eastern Indian Ocean. *In* Davies, T.A., Luyendyk, B.P., et al., Initial Reports of the Deep Sea Drilling Project, Volume 26: Washington (U.S. Government Printing Office), p. 745.

Ladd, J.W., 1974. South Atlantic seafloor spreading and Caribbean tectonics: Ph.D. Thesis, Columbia University, New York.

Loeblich, A.R. and Tappan, H., 1961. Cretaceous planktonic foraminifera. Part 1—Cenomanian: Micropaleontology, v. 7, p. 257.

Longoria, J.F., 1974. Stratigraphic, morphologic and taxonomic studies of Aptian planktonic Foraminifera: Rev. Espan. Micropaleontol., Spec. Publ., 107 p.

Luterbacher, H.P., 1972. Foraminifera from the Lower Cretaceous and Upper Jurassic of the Northwestern Atlantic. *In* Hollister, C.D., Ewing, J.I., et al., Initial Reports of the Deep Sea Drilling Project, Volume 11: Washington (U.S. Government Printing Office), p. 561.

———, 1975. Early Cretaceous foraminifera from the Northwestern Pacific: Leg 32 of the Deep Sea Drilling Project. *In* Larson, R.L., Moberly, R., et al., Initial Reports of the Deep Sea Drilling Project, Volume 32: Washington (U.S. Government Printing Office), p. 703.

Luterbacher, H.P. and Premoli Silva, I., 1962. Note préliminaire sur une révision du Profil de Gubbio, Italie: Riv. Ital. Paleontol. Strat., v. 68, p. 253.

Manivit, H., 1971. Les nannofossiles calcaires du Crétacé français (de l'Aptien au Danien). Essai de biozonation appuyée sur les stratotypes: Thèse.

Martin, S.E., 1972. Reexamination of the Upper Cretaceous planktonic foraminiferal genera *Planoglobulina* Cushman and *Ventilabrella*: Cushman J. Foram. Res., v. 2, p. 73.

Maxwell, E.A., et al., 1970. Initial Reports of the Deep Sea Drilling Project, Volume 3: Washington (U.S. Government Printing Office).

McKenzie, D.P. and Sclater, J.G., 1971. The evolution of the Indian Ocean since the late Cretaceous: Geophysics, v. 25, p. 437.

Moullade, M., 1966. Etude stratigraphic et micropaléontologique du Crétacé inférieur de la "Fosse vocontienne": Doc. Lab. Géol. Fac. Sci. Lyon, no. 15.

———, 1974. Zones de Foraminifères du Crétacé inférieur mésogéen. C.R. Acad. Sci. Paris, v. 278, Sér. D-1813.

Pessagno, E.A., 1967. Upper Cretaceous planktonic foraminifera from the western Gulf Coastal Plain: Paleontol. Am., v. 5.

Porthault, B. 1969. Foraminifères planctoniques et biostratigraphie du Cénomanien dans le sud-est de la France: Intern. Conf. Plankt. Microfossils, 1st Proc., v. 2, p. 526.

———, 1974. Le Crétacé supérieur de la "Fosse Vocontienne" et des régions limitrophes (France Sud-Est): Univ. Claude Bernard, Lyon, Thèse, v. 257.

Premoli Silva, I. and Bolli, H.M., 1973. Late Cretaceous to Eocene planktonic foraminifera and stratigraphy of Leg 15 Sites in the Caribbean Sea. *In* Edgar, N.T., Saunders, J.B., et al., Initial Reports of the Deep Sea Drilling Project, Volume 15: Washington (U.S. Government Printing Office), p. 499.

Premoli Silva, I. and Luterbacher, H.P., 1966. The Cretaceous-Tertiary boundary in the Southern Alps: Riv. Ital. Paleontol. Strat., v. 72, p. 1183.

Reichel, M., 1948. Les Hantkéninidés de la Scaglia et des Couches Rouges (Crétacé supérieur): Eclog. Geol. Helv. v. 40, p. 391.

Reyment, R.A., 1969. Ammonite biostratigraphy, continental drift and oscillatory transgressions: Nature, v. 224, p. 137.

———, 1971. Experimental studies of Cretaceous transgressions for Africa: Geol. Soc. Am. Bull., v. 82, p. 1063.

Reyment, R.A. and Tait, E.A., 1972. Biostratigraphical dating of the early history of the South Atlantic Ocean: Phil. Trans. Roy. Soc. London., v. , p.

Saito, T., 1970. Site Reports. *In* Maxwell, E.A., et al., 1970. Initial Reports of the Deep Sea Drilling Project, Volume 3: Washington (U.S. Government Printing Office).

Saito, T. and Van Donk, J., 1974. Oxygen and carbon isotope measurements of Late Cretaceous and early Tertiary foraminifera: Micropaleontology, v. 20, p. 152.

Scientific Staff Leg 36, 1975a. Southwestern Atlantic: Geotimes, v. 19, p. 16.

Scientific Staff Leg 40, 1975b. Basins and margins of the eastern South Atlantic. Geotimes, v. 20, p. 22.

Scientific Staff Leg 41, 1975c. The eastern North Atlantic: Geotimes, v. 20, p. 18.

Séronie-Vivien, M., 1972. Contribution à l'étude du Sénonien en Aquitaine septentrionale, ses stratotypes: Coniacien, Santonien, Campanien: Centre Nat. Rech. Sci. Editions, 195 p.

Sigal, J., 1966. Contribution à une monographie des Rosalines: 1. Le genre Ticinella Reichel, souche des Rotalipores: Eclog. Geol. Helv., v. 59, p. 185.

———, 1967. Essai sur l'état actuel d'une zonation stratigraphique à l'aide des principales éspèces de rosalines (foraminifères): C.R. Soc. Géol. France, v. 2, p. 48.

———, 1974. Comments on Leg 25 sites in relation to the Cretaceous and Paleogene stratigraphy in the eastern and southeastern Africa Coast and Madagascar regional setting. *In* Simpson, E.S.W., Schlich, R., et al., Initial Reports of the Deep Sea Drilling Project, Volume 25: Washington (U.S. Government Printing Office), p. 687.

Sliter, W.V., in press. Cretaceous foraminifers from the southwestern Atlantic Ocean, Leg 36, Deep Sea Drilling Project. *In* Barker, P.F., Dalziel, I.W.D., et al., Initial Reports of the Deep Sea Drilling Project, Volume 36: Washington (U.S. Government Printing Office).

Thierstein, H.R., 1973. Lower Cretaceous calcareous nannoplankton biostratigraphy: Geol. Bundesanst. Abh. Wien, v. 29.

———, in press. Biostratigraphy of marine Mesozoic sediments by calcareous nannoplankton: Marine Micropaleontol.

Van Hinte, J., 1976. A Cretaceous time scale: Am. Assoc. Petrol. Geol. Bull., v. 60, p. 498.

Worsley, T., 1974. The Cretaceous-Tertiary boundary Event in the Ocean. *In* Hay, W.W. (Ed.), Studies in paleo-oceanography, S.E.P.M., Spec. Publ., v. 20, p. 94.

Zambrano, J.J. and Urien, C.M., 1974. Pre-Cretaceous Basins in the Argentine Continental Shelf. *In* Burk, C.A. and Drake, C.C. (Eds.), The geology of continental margins: New York (Springer-Verlag), p. 463.

PLATE 1

Figures 1a, b	*Globotruncana subspinosa* Pessagno, Leg 39, Sample 356-33-6, 40 cm. *Globotruncana calcarata* Zone, late Campanian. (a) Spiral view, ×80; (b) Umbilical view, ×80.
Figure 2	*Abathomphalus mayaroensis* (Bolli). Leg 39, Sample 357-31-1, 40 cm. *Abathomphalus mayaroensis* Zone, late Maestrichtian. Umbilical view, ×90.
Figure 3	*Globotruncana calcarata* Cushman, Leg 39, Sample 356-33-3, 40 cm. *Globotruncana calcarata* Zone, late Campanian. Spiral view, ×125.
Figures 4a-c	*"Globotruncana" havanensis* Voorwijk. Leg 39, Sample 357-37-4, 47 cm. Campanian. (a) Spiral view, ×165; (b) Umbilical view, ×160; (c) Side view, ×135.
Figures 5a, b	*Globotruncana gansseri* Bolli. Leg 39, Sample 356-32-3, 10 cm. *Globotruncana gansseri* Zone, middle Maestrichtian. (a) Spiral view, ×120; (b) Umbilical view, ×125.

(see page 640)

PLATE 2

Figure 1	*Schackoina cenomana gandolfii* Reichel. Leg 39, Sample 356-41-4, 104 cm. *Planomalina buxtorfi* Zone, late Albian, ×365.
Figure 2	*Schackoina cenomana* (Schacko). Leg 39, Sample 356-32, CC *Globotruncana tricarinata* Zone, early Maestrichtian, ×345.
Figures 3a, b	*Pseudoguembelina excolata* (Cushman). Leg 39, Sample 356-32-3, 38 cm. *Globotruncana gansseri* Zone, middle Maestrichtian. (a) Axial view, ×162; (b) Side view, ×160.
Figures 4a, b	*Planoglobulina browni* (Martin). Leg 39, Sample 356-35, CC. *Globotruncana concavata corinata* Zone, late Santonian. (a) Axial view, ×135; (b) Side view, ×110.
Figures 5a, b	*Pseudoguembelina costulata* (Cushman). Leg 39, Sample 356-32, CC. *Globotruncana tricarinata* Zone, early Maestrichtian. (a) Axial view, ×180; (b) Side view, ×185.
Figures 6a, b	*Globotruncana concavata carinata* Dalbiez. Leg 39, Sample 357-47-2, 10 cm. *Globotruncana concavata carinata* Zone, late Santonian. (a) Umbilical view, ×100; (b) Side view, ×90.
Figures 7a, b	*Globotruncana concavata concavata* (Brotzen). Leg 39, Sample 357-49-3, 64 cm. *Globotruncana concavata* Zone, early Santonian. (a) Umbilical view, ×102; (b) Side view, ×90.

(see page 641)

PLATE 1

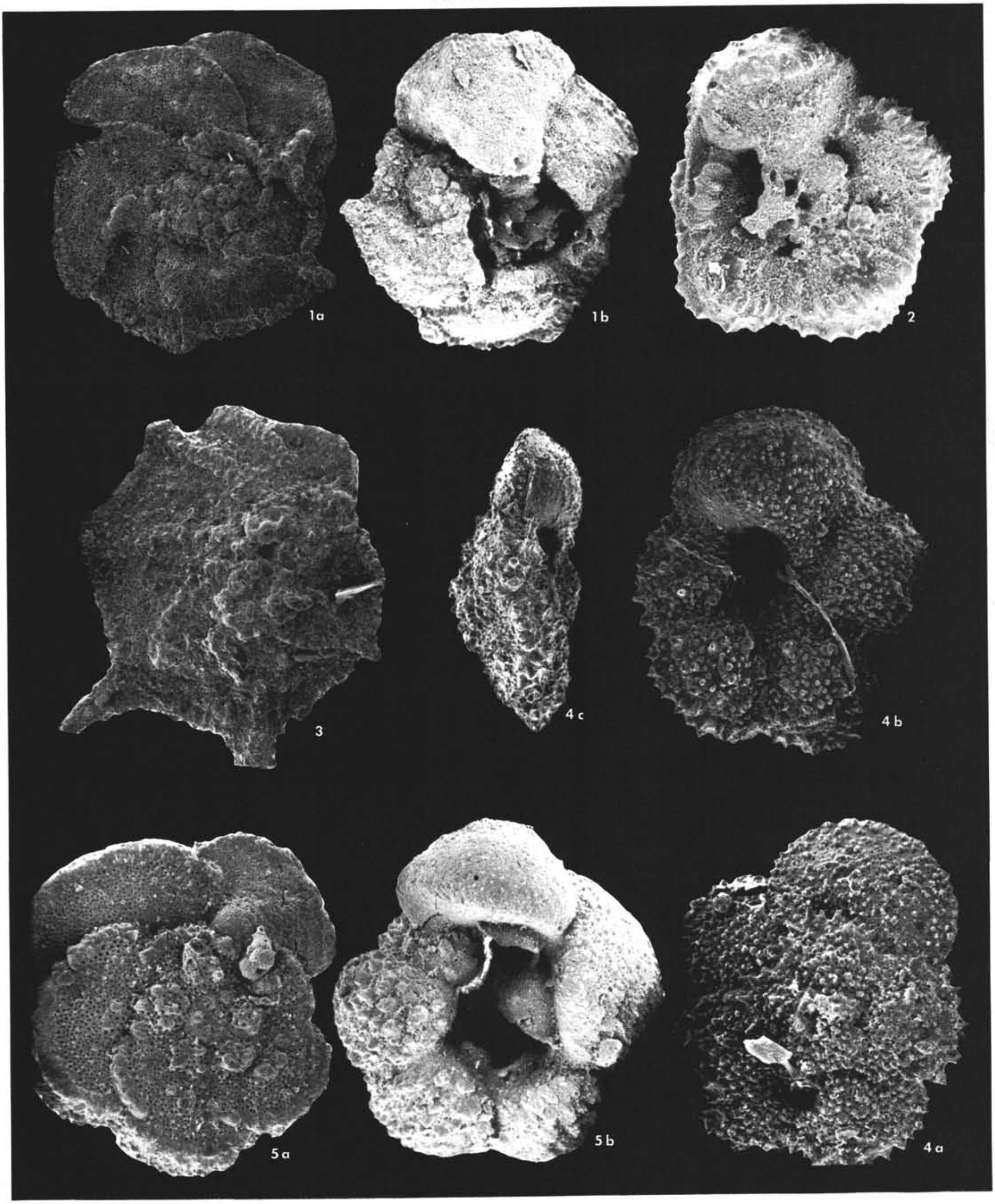

PLATE 2