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21. PALEOGENE SHALLOW-WATER LARGER FORAMINIFERS FROM HOLES 714A AND 715A, LEG 115, INDIAN OCEAN[1]

Alda Nicora[2] and Isabella Premoli Silva[2]

ABSTRACT

Shallow-water larger foraminifers have been recovered at two drill sites on the eastern Maldive Ridge. Despite the poor recovery in Hole 715A, a rather diversified larger benthic foraminifer assemblage allowed us to date the initiation of a carbonate platform, resting on volcanic basement, as late early Eocene. Several age-diagnostic species belonging to the genera *Alveolina, Nummulites, Orbitolites,* and *Discocyclina* have been identified. The assemblages may be attributable to the upper part of the *Nummulites burdigalensis cantabricus* Zone and/or to the lower part of the *Nummulites campesinus* Zone and to the *Alveolina dainellii* (upper part) and/or to the *A. violae* (lower part) zones. The carbonate platform had a very short life (a few hundred thousand years) and rapidly sank below the euphotic zone, as testified by the occurrence of several species of planktonic foraminifers associated with redeposited reef-derived skeletal debris, especially discocyclinids, in the upper part of the sequence. Among the planktonic foraminifers, the presence of *Planorotalites palmeri,* which has a range confined to the lower portion of the late early Eocene Zone P9, implies that the platform was drowned before the end of the early Eocene.

At Hole 714A, the occurrence of several shallow-water foraminifer genera, such as *Nummulites* (*N. fabianii* gr.), *Discocyclina, Fabiania, Heterostegina,* and *Operculina* (*O. gomezi*), in pebbles derived from turbidite beds interbedded within late Oligocene pelagic sediments, allows us to suggest that a carbonate platform, possibly reduced in size, was still growing in the Maldive Ridge area after the late early Eocene time. The erosional event, responsible for the redeposition of middle to late Eocene reef-derived skeletal debris, is apparently coeval with the global sea-level fall recorded in late Oligocene Zone P22.

INTRODUCTION

Paleogene shallow-water larger benthic foraminifers were recovered at Holes 714A and 715A during Ocean Drilling Program (ODP) Leg 115 in the Indian Ocean, located on the eastern margin of the Maldive Ridge (Fig. 1).

Shallow-water skeletal debris of late Paleocene to early Eocene age was previously found in the Indian Ocean at DSDP Hole 219A from 240 to 411 mbsf, drilled on the Laccadive-Chagos Ridge in 1764 m water depth and located about 4° latitude north of the Maldive Ridge sites discussed here (Whitmarsh, Weser, Ross, et al., 1974). Mamgain et al. (in Whitmarsh et al., 1974, p. 44) identified few representatives of the genera *Operculina* and *Discocyclina* associated with some bryozoans, pelecypods, and red algae. These shallow-water assemblages were never described nor illustrated after the publication of the *Initial Reports.*

Hole 715A

Hole 715A was drilled on the eastern margin of the Maldive Ridge at 05°04.89′N and 73°49.88′E in a water depth of 2262.3 m with a total penetration of 287.8 m (Backman, Duncan, et al., 1988). Hole 715A penetrated basalt at 211.3 mbsf and continued 76.6 m further into basement. Above the basalt was 100 m of early Eocene shallow-water limestones. Pelagic nannofossil oozes of Pleistocene to Miocene age lie above the limestone unit. A total of 31 cores were taken, 12 of which (Cores 115-715A-12R to -23R) belong to the shallow-water limestone unit, with only 7.7% recovery.

The shallow-water limestones, identified as Unit III (Cores 115-715A-12R to -23R), consist of wackestone (Core 115-715A-12R), packstones (Cores 115-715A-13R to -15R and -23R), packstones and grainstones (Cores 115-715A-16R to -21R), and grainstones (Core 115-715A-22R). The recovered material consists of numerous chunks, 1–20 cm in diameter, of very consolidated limestone. Consequently, the study of the fossil content was carried out on thin sections.

Typical shallow-water reefal assemblages, rich in age-diagnostic larger benthic foraminifers, predominate in most of the cores. In the upper part of the interval, they are associated with age-diagnostic planktonic foraminifers.

The faunal distribution is shown on Table 1 and the main bioevents summarized on Figure 2.

Fossil Content

The following four major assemblages may be distinguished from top to bottom:

1. In the interval from Core 115-715A-12R-1, 14–17 cm, to Core 115-715A-14R-1, 33–35 cm, the assemblages are characterized by the occurrence of planktonic foraminifers, the abundance of which decreases downhole. Planktonic foraminifers are limited to a few specimens in the lowermost sample. Conversely, larger foraminifers associated with melobesian algae and rare bryozoans become progressively more abundant downhole. The most frequent planktonic species identified in this interval are *Planorotalites palmeri, Planorotalites pseudoscitulus, "Globigerinatheka" senni, Subbotina pseudoeocaena,* the *Acarinina pentacamerata* group, *Acarinina rohri* group, *Acarinina pseudotopilensis,* and *Pseudohastigerina wilcoxensis* associated with rare *Morozovella aragonensis, Morozovella crassata,* and *Chiloguembelina* sp. Larger foraminifer assemblages are dominated by strongly fragmented discocyclinids associated with small numbers of better preserved nummulitids. Alveolinids are very rare and confined to the lowermost samples of this interval. The following species and genera were identified: *Nummulites pratti, Nummulites* cf. *caupennensis, Nummulites* sp., *Discocyclina sella, Discocyclina douvillei, Asterocyclina* spp., *Operculina* sp., *Alveolina*

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[2] Dipartimento di Scienze della Terra, Università di Milano, via Mangiagalli 34, Milano 20133, Italy.

A

B

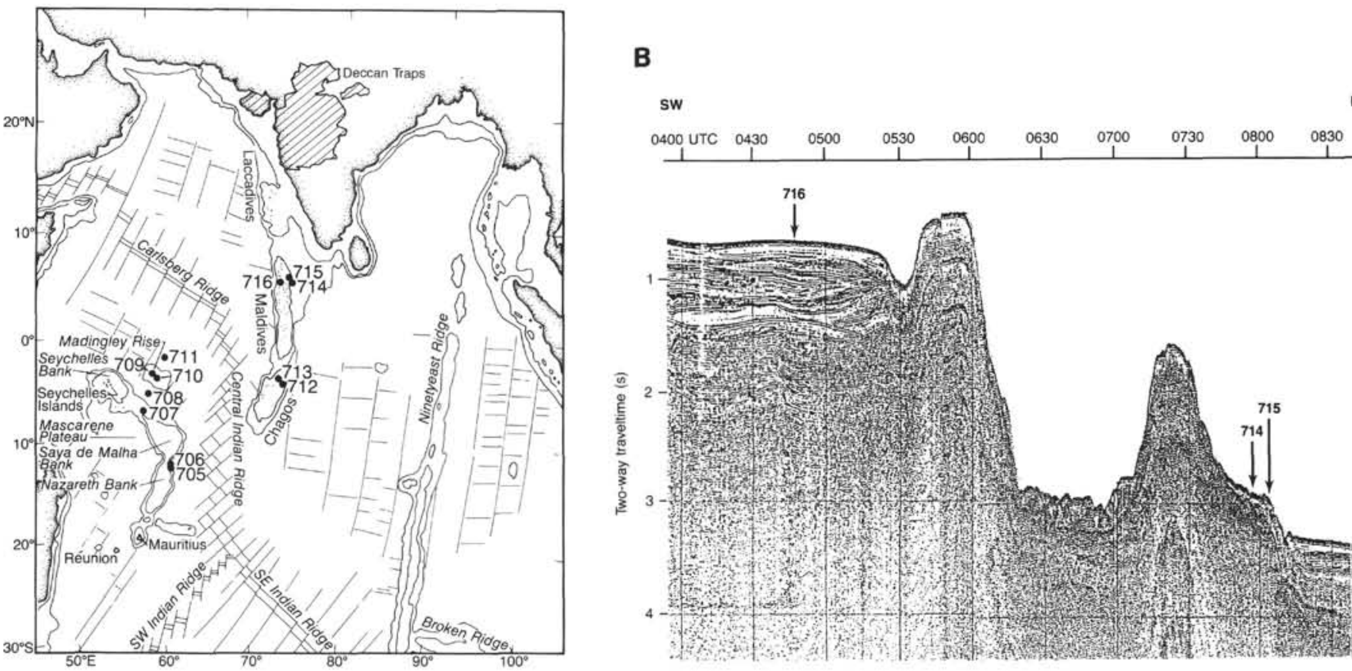


Figure 1. Location of Sites 714 and 715 in the Indian Ocean. **A.** Bathymetric map. **B.** Seismic profile (after Backman, Duncan, et al., 1988).

canavarii group, and small rotaliids. Miliolids and agglutinated foraminifers are rare.

2. From Core 115-715A-14R-1, 40–43 cm, to Core 115-715A-14R-CC, the assemblages are characterized by the occurrence of very abundant granulated (with pillars) *Nummulites* belonging to the *N. burdigalensis* group, several *Alveolina* species (*A. canavarii* group, *A. dainellii* to *A. palermitana* transitional forms), and discocyclinids (occasionally fragmented) associated with *Orbitolites* (*O.* sp. cf. *O. douvillei*) and *Operculina. Rotalia* sp., *Linderina*?, and miliolids are also present. The assemblages also comprise several dasycladacean and melobesian algae, rare gastropods, and corals.

3. From Core 115-715A-15R-1, 41–44 cm, to Core 115-715A-19R-1, 2–5 cm, the assemblages are characterized by several *Alveolina* (*A. canavarii* group, *A.* cf. *dainellii*, transitional forms from *A. dainellii* to *A. palermitana*, individuals of the *A. aragonensis* group, and *A. fornasinii*), granulated *Nummulites* (*N. burdigalensis* group and rare specimens of the *N. partschi* group), *Orbitolites*, and rare discocyclinids, associated with melobesian algae (e.g., *Distichoplax*), *Ethelia*, dasycladaceans, coral fragments, hydrozoans, gastropods, and echinoids. Miliolids and rotaliids are frequent.

4. From Core 115-715A-19R-1, 10–12 cm, to Core 115-715A-23R-1, 34–36 cm, the assemblages are characterized by very abundant small benthic foraminifers (miliolids, rotaliids, rare agglutinated forms) associated with much rarer larger foraminifers, frequent melobesian algae (e.g., *Distichoplax*), rare dasycladaceans, and *Halimeda*. Larger foraminifers belong to *Alveolina* (*A.* cf. *dainellii*, *A. dainellii*/*A. palermitana* transitional forms, *Alveolina* sp. aff. *A. palermitana*, the *A. aragonensis* group, and *A. fornasinii*), the *Nummulites burdigalensis* group (*N. burdigalensis* s. str. and forms close to *N. burdigalensis cantabricus*/*N. campesinus*), *Orbitolites* cf. *O. douvillei*, and *Orbitolites* sp. A few discocyclinids are present in the upper part.

Bio- and Chronostratigraphy

Larger foraminifers are known to have evolved rather rapidly through time. Among them the alveolinids and nummulitids were revealed to be the most useful groups biostratigraphically for constructing zonal schemes for the Paleocene to Eocene interval, especially for the Tethys province (Hottinger, 1960; Schaub, 1951, 1981). Moreover, these zonal schemes recently have been correlated to the calcareous nannofossil zonation (Schaub, 1981) (Fig. 3).

The shallow-water assemblages from the Maldive Ridge contain several specimens attributable to the genera *Alveolina, Nummulites,* and, more rarely, *Orbitolites*. Although the larger foraminifers are abundant throughout the studied interval, only a few could be specifically identified. The recovery of a few chunks of limestone in Hole 715A prevented us from cutting oriented sections of these larger foraminifers, on which reliable identifications might be based. Some thin sections, however, yielded a few cuts, more or less properly oriented, that allowed identification at a specific level. All the identified species have been described from the Tethyan province; thus, the Tethyan zonal schemes could be applied, allowing correlation between Indian Ocean and Tethyan faunas (Hottinger, 1960; Lehmann, 1961; Schaub, 1981). The age of the sequence could be established fairly accurately for the combined occurrence of the few age-diagnostic species of both alveolinids and nummulitids.

The most important occurrences are as follows (from bottom to top) (Fig. 2):

1. The first occurrence (FO) of representatives of the *Alveolina aragonensis* group and *A. fornasinii* in Sample 115-715A-23R-1, 34–36 cm;

2. The FO of representatives of the *Nummulites burdigalensis* group in Sample 115-715A-22R-CC;

Table 1. Distribution of early late Eocene fossil content in Hole 715A.

Core, section, interval (cm)	*Alveolina* sp.	*Alveolina fornasinii*	*Alveolina aragonensis* gr.	*Alveolina* cf. *dainellii*	*Alveolina dainellii*/*A. palermitana*	*Alveolina* aff. *palermitana*	*Alveolina canavarii* gr.	*Orbitolites* sp.	*Orbitolites* cf. *douvellei*	*Rotalia* sp.	*Nummulites* sp.	*Nummulites burdigalensis* gr.	*Nummulites b. cantabricus*/*N. campesinus*	*Nummulites* cf. *caupennensis*	*Nummulites partchi* gr.	*Nummulites pratti*	*Discocyclina* sp.	*Discocyclina douvillei*	*Discocyclina sella*	*Somalina* sp.	*Asterocyclina* sp.	*Linderina*? sp.	*Operculina* sp.	*Gypsina* sp.	*Assilina* sp.	Miliolidae	Rotaliidae	Victoriellidae	Small foraminifers	*Acarinina* sp.	*Planorotalites pseudoscitulus*	*Subbotina* sp.	*Acarinina rohri*	*Morozovella* sp.	*Morozovella aragonensis*	"*Globigerinatheka*" *senni*	*Pseudohastigerina wilcoxensis*	"*Turborotalia*" cf. *praecentralis*	*Acarinina pseudotopilensis*	*Morozovella crassata*	*Planorotalites palmeri*	*Subbotina pseudoeocaena*	*Acarinina pentacamerata*	*Acarinina gravelli*	*Chiloguembelina* sp.	*Acarinina aquiensis*	*Subbotina inequispira*	Melobesiae	*Distichoplax* sp.	*Halimeda* sp.	*Ethelia* sp.	Dasycladaceae	Hydrozoans	Corals	Crinoids	Gastropods	Echinoids	Molluscs	Bryozoans	Ostracods
12R-1, 14–17											A						C				C								P												P	P				P	P	P												
12R-1, 16–18											P						C				C		P								P	P			P													P												
12R-1, 44–46											P					A	A	P	C		A									P	P					A	P			P	P	P		P	P			P											P	
12R-1, 55–57											A					P	A								P	P	P		P																			P											P	
12R-1, 60–62											P						C																																											
12R-1, 74–76											C						C													P	P				P				P				P																	
12R-1, 100–101											C																																					P												
12R-1, 102–105											A			P		P	A	C	C		C									P						P					P							P											P	P
12R-1, 117–120											C													P						P	P	P		P								P			P															
12R-CC, 18–21											C						A	P	C		A									P	P		P		P	P	P	P	P	P	P							A												
12R-CC, 97–99											P						A				A									P				P		P	P	P										A											P	
13R-1, 1–4											P						P				P							P		P		P																P												
13R-1, 8–10											P			P			A		P		A								P	P		P	P	P	P													A											P	
13R-1, 10–11	P						P				P						A				A					C	C		A																			A											P	
13R-1, 14–16											A						A				A					P	P		P																			C												
13R-1, 15–16	P						P										A				A					P	P		C	P			P																											
13R-1, 19–21	P							P		P	A	A				P	A				A					P	C		A																			A												
14R-1, 12–14												A														C	C	P	A	P	P	P																												
14R-1, 33–35											A	A														C	C	P	A	P	P	P																												
14R-1, 40–43	P				P		P	P	P		A	A					P	P			P	P	P			C	C		A																			C	P			C		P						
14R-1, 44–45	P										A	A					P				P					C	C	P	A																															
14R-CC	C			P	P		P	P	P	C	A	A					A	P			A	P	P	P		A	A	P	A																			C	P			A	P			P				
15R-1, 41–44								P														P				C	C	P	A																			P												
15R-1, 61–64	P			P	P					P	P															C	C		A																			P												
15R-1, 106–109	P																P				P					P	P		C																					P										
16R-1, 2–5	A	P		C	C	P		P	P		A						C				A	P				C	C		A																			P			P					P	P	P		
16R-1, 10–12	P			P				P		P	P						P									C	C		A																						P									
16R-1, 18–20	P			P	P			P		P	C														P	A	A		A																															
17R-CC	P		P	P	P			P		P	A						P				P					C	A	P	A	P																		P				A								
18R-1, 1–3	P							P			P															C	C		C																			C				C								
18R-1, 19–20	P				C			P		P	A	P					P	P	P		P					C	C		A																			A				P		P			P			
18R-1, 20–22	C	P		P	P		P	P	P	P	A	C			P		P	P	P	P	P	P	P	P		C	A	P	A																			A				A								
19R-1, 2–5	P	P			P					P	A	C					P					P				C	C		A																			A	C		C			P		P				
19R-1, 10–12	P				P																C					C	C	P	A																			A												
19R-1, 20–21	P				P																C					C		P	C																			A												
19R-1, 22–24	C				P		P				P															C	C	P	A																															
20R-1, 15–17	P										P						C									C	C	P	A																			A												
20R-CC	A	P	P	C	C	P		C	P	P	A						P									C	C		A																			C	C		P	P	P	P						
21R-1, 8–10	C	P	P	P	P	P		C	P	P	A	C	P				P			P			P			C	C	P	A																															
21R-1, 27–28	C	P	P	P	P						P						C									C	C		A																			P												
21R-1, 64–66	P			P	P	P		C																		C	C	P	A																			A		P										
22R-1, 10–12	P											C														C	C	P	A																			P												
22R-2, 90–92	P							C		P	P															C	C	P	A																				C											
22R-CC	P							C	P	P	P															A	A	C	A																			A	A	P										
23R-1, 34–36	P	P	P					C	P																	A	C	P	A																															

Note: A = abundant, C = common, and P = present.

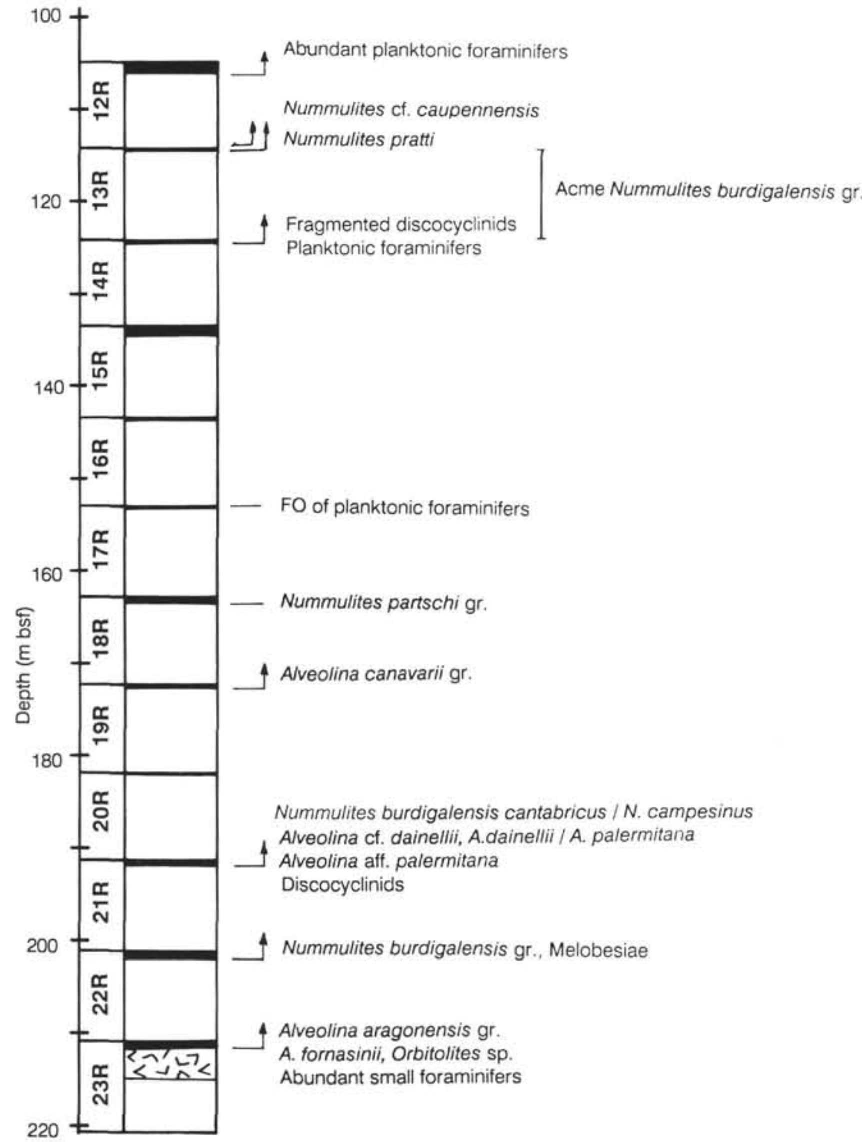


Figure 2. Succession of main bioevents recorded in Hole 715A above basement (late early Eocene). Note the very poor recovery (plain black).

3. The FO of *Alveolina* cf. *dainellii* and transitional forms to *A. palermitana* and *Alveolina* sp. aff. *A. palermitana* in Sample 115-715A-21R-1, 64–66 cm;

4. The FO of forms close to *Nummulites burdigalensis cantabricus/N. campesinus* in Sample 115-715A-21R-1, 8–10 cm;

5. The FO of representatives of the *Alveolina canavarii* group in Sample 115-715A-19R-1, 22–24 cm;

6. The FO of representatives of the *Nummulites partschi* group in Sample 115-715A-18R-1, 20–22 cm;

7. The FO of planktonic foraminifers in Sample 115-715A-17R-CC;

8. The acme of representatives of the *Nummulites burdigalensis* group from Sample 115-715A-14R-CC to Sample 115-715A-13R-1, 19–21 cm;

9. The FO of *Nummulites pratti* in Sample 115-715A-13R-1, 19–21 cm;

10. The FO of *Nummulites* cf. *caupennensis* in Sample 115-715A-13R-1, 8–10 cm; and

11. The FO of *Planorotalites palmeri* in Sample 115-715A-12R-CC, 18–21 cm.

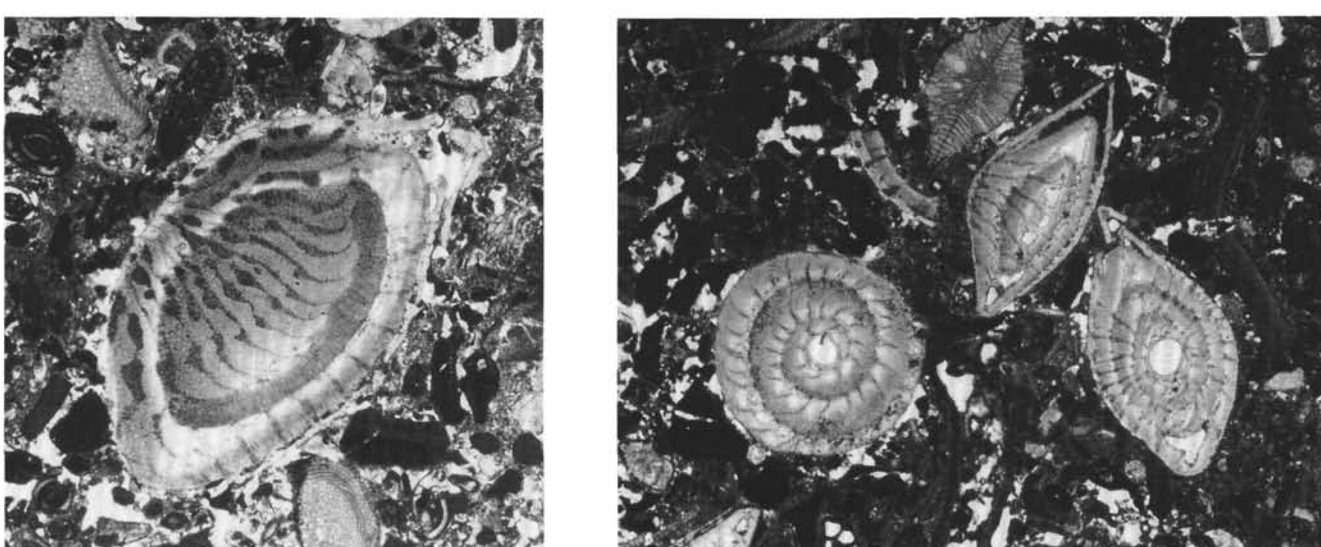
Based on the occurrences listed above, the following age determinations are possible.

The presence of *Alveolina* cf. *dainellii,* several transitional forms from *A. dainellii* to *A. palermitana,* and a few *A.* aff. *palermitana* along with other specimens belonging to the *A. aragonensis* group and to *A. fornasinii* suggests that these assemblages may be from the top of the *Alveolina dainellii* Zone or the base of the *Alveolina violae* Zone (Hottinger, 1960). The presence of representatives of the *Alveolina canavarii* group higher in the sequence is consistent with such an attribution.

The nummulitid assemblage throughout the sequence studied is characterized by the continuous presence of representatives of the *Nummulites burdigalensis* group, which show an acme from Core 115-715A-13R-1, 19–21 cm, to Core 115-715A-14R-CC (Figs. 4 and 5). Beside typical *N. burdigalensis,* in the lower part of the sequence a specimen (Form B) close to *N. burdigalensis cantabricus* and/or *N. campesinus* was identified in Sample 115-715A-21R-1, 8–10 cm. Higher in the sequence, a representative of the *N. partschi* group was recognized, followed in the upper part by the appearance of *N. pratti* along with *N.*

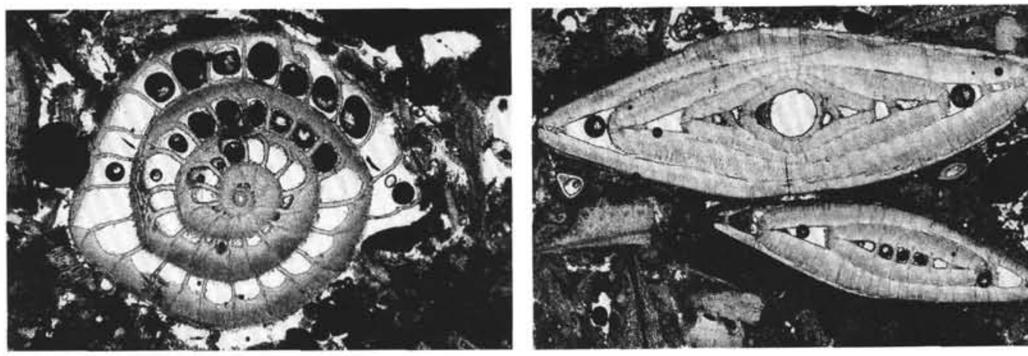
SERIES	STAGES	BIOZONES: *Nummulites* – N.brongniarti gr.	*Nummulites* – N.perforatus gr.	Others	*Assilina*	*Alveolina*	Calcareous nannofossils
OLIGOCENE	lower			*fichteli*			*Er.subdisticha*
EOCENE upper	Priabonian			*fabianii*		*(Neoalveolina)*	*I.pseudoradians* *I.recurvus*
EOCENE middle	Biarritzian	*brongniarti*	*perforatus*	*ptukhiani*		*elongata*	*Ch.oamaruensis*
EOCENE middle	Lutetian upper	*herbi*	*aturicus*	*bullatus*	*gigantea*		*Disc.tani nodifer*
	Lutetian middle 2	*sordensis*	*crassus*		*planospira*	*prorrecta*	*Disc.tani nodifer*
	Lutetian middle 1	*gratus*	*beneharnensis*		*spira spira*	*munieri*	*Chiphr.alatus*
	Lutetian lower 2; lower 1 = basal	*laevigatus*	*obesus* / *gallensis*		*spira abrardi*	*stipes*	*Chiphr.alatus*
EOCENE lower	Cuisian upper	*manfredi*	*campesinus*	*formosus*	*maior*	*violae*	*Disc.sublodoensis*
	Cuisian middle	*praelaevigatus*	*burd.cantabricus*	*nitidus*	*laxispira*	*dainellii*	*Disc.lodoensis*
	Cuisian lower 2; lower 1 = basal	*planulatus*	*burdigalensis* *burdigalensis*	aff.*laxus*	*plana*	*oblonga*	*Disc.lodoensis*; *Marth.tribrachiatus*
(1) upper (1)	Ilerdian upper	*involutus*		*laxus*	*adrianensis*	*trempina*	*Marth.tribrachiatus*
(2)	Ilerdian middle 2	*exilis*	*pernotus*	*globulus*	*leymeriei*	*corbarica*	*Disc.binodosus*
	Ilerdian middle 1	*robustiformis*		*carcasonensis*	aff.*arenensis*	*moussoulensis*	*Disc.binodosus*
	Ilerdian lower 2	*fraasi*	*solitarius*	*minervensis*	*arenensis*	*ellipsoidalis*	*Marth.contortus*
(2)	Ilerdian lower 1			*deserti*	*prisca*	*cucumiformis*	
PALEOCENE middle (1) upper (2)	Thanetian upper				*yvettae*	*levis*	*Disc.multiradiatus*
	Thanetian lower					*primaeva*	*Hel.riedeli* *Disc.gemmeus* *Hel.kleinpelli* *Fasc.tympaniformis*
PALEOCENE lower	Danian						*Ell.macellus* *Chiasm.danicus* *Crucipl.tenuis* *Markal.inversus*

Figure 3. Correlation between Paleogene larger foraminifer and calcareous nannofossil biozones, plotted vs. stages (after Schaub, 1981, modified). (1). Position of Paleocene/Eocene boundary according to Hottinger and Schaub (1960). (2). Position of Paleocene/Eocene boundary according to Special Meeting Soc. Géol. France, Nov. 18, 1974 (Boll. Soc. Géol. France, 1975) (fide Schaub, 1981).



A B

Figure 4. Sample 115-715A-12R-1, 102–105 cm. **A.** *Nummulites* cf. *caupennensis,* Form A, slightly oblique equatorial section (× 12). **B.** *Nummulites pratti,* Form A, axial section (× 13).



A B

Figure 5. Sample 115-715A-18R-1, 20–22 cm. **A.** *Nummulites partschi* group, tangential section. Note the characteristically regular distribution of pillars (×11). **B.** *Nummulites burdigalensis* group, equatorial, oblique and almost axial sections. Specimens with proloculus of the same size as *N. b. cantabricus,* but with more numerous septa per whorl (×11).

cf. *caupennensis*. The occurrence of the aforementioned *Nummulites* characterizes the transition between the *Nummulites burdigalensis cantabricus* and *Nummulites campesinus* Zones, or the lower part of the *N. campesinus* Zone (Schaub, 1981).

Schaub (1981) considers the *Nummulites campesinus* Zone coeval with the *Alveolina violae* Zone of Hottinger (1960) and dates both zones as late Cuisian (i.e., late early Eocene). Schaub (1981) also suggests that those zones are coeval with the *Discoaster sublodoensis* nannofossil Zone, which should straddle the early to middle Eocene boundary according to Berggren et al. (1985) (see Fig. 3).

Among the planktonic foraminifers, especially from Core 115-715A-12R, the most age-diagnostic species is *Planorotalites palmeri,* the nominal species of the youngest zone belonging to the early Eocene according to Bolli (1957). Toumarkine (1983) and Toumarkine and Luterbacher (1985) reported that this taxon ranges from the upper part of Zone P8 through the lower part of Zone P9 (sensu Blow, 1969), which is equated to their *Acarinina pentacamerata* Zone (late early Eocene age).

The occurrence of *Planorotalites palmeri* in the upper part of the studied interval, slightly preceded by that of *N.* cf. *caupennensis* and *N. pratti,* along with the occurrence of specimens close to *N. burdigalensis cantabricus* and/or *N. campesinus* in the lower portion, help to pin down the age attribution of the sequence. According to Proto Decima (1980), *P. palmeri* was found in association with *Discoaster sublodoensis,* although it occurs much more frequently along with a nannofossil assemblage belonging to the underlying *Discoaster lodoensis* Zone. Schaub (1981) correlates the latter zone with the lower portion of the underlying *Nummulites burdigalensis cantabricus* and *Alveolina dainellii* Zones. The co-occurrence of the aforementioned transitional forms among the alveolinids and nummulitids with *Planorotalites palmeri* suggests that the interval studied could actually straddle the boundaries between the *A. dainellii* and *A. violae* Zones or the *N. burdigalensis cantabricus* and *N. campesinus* Zones. Based on this interpretation, we suggest that this sequence can be assigned to the late early Eocene (middle to late Cuisian).

Hole 714A

Hole 714A was drilled on the eastern shoulder of the Maldive Ridge at 05°03.6′N and 73°47.2′E in a water depth of 2038.3 m with a total penetration of 233.0 m (Backman, Duncan, et al., 1988). Hole 714A penetrated 19.55 m of late Pleistocene nannofossil ooze (Unit I); 100.45 m of middle to late Miocene nannofossil ooze down to 120.0 mbsf (Subunit IIA); and 133 m of a lithology similar to Subunit IIA, but more lithified, down to 233.0 mbsf (Subunit II).

Three samples from calcareous pebbles of turbiditic origin included in Subunit II (Core 115-714A-24X-CC, 28–30 cm, 29–30 cm, 37–39 cm) and assigned to the late Oligocene planktonic foraminifer Zone P22 (see Premoli Silva and Spezzaferri, this volume) are rich in reef-derived skeletal debris. Fossils in general are poorly preserved and mainly corroded at their edges. In Sample 115-714A-24X-CC, 29–30 cm, melobesian algae dominate and are associated with rare *Amphistegina, Heterostegina,* and fragments of molluscs (possibly ostreids). Rare planktonic foraminifers also occur, but their walls are micritized, thus preventing identification (Table 2).

In addition to melobesian algae, the other two samples contain numerous large benthic foraminifers that belong to the genera *Nummulites* (*N. fabianii* group), *Fabiania, Discocyclina, Alveolina, Operculina* (*O. gomezi*), *Heterostegina,* and *Amphistegina* (Table 2). Although some of these genera can range as high as the late Oligocene, *Discocyclina* and *Fabiania* are typical of middle to late Eocene assemblages; *O. gomezi* and the representatives of the *N. fabianii* group (here recorded) are confined to the late Eocene. Thus, at least part of the shallow-water skeletal debris must be interpreted as reworked. The occurrence of the latter foraminifer genera and species suggests that a carbonate platform continued to grow in the vicinity of Site 714 in younger time (at least late Eocene) than at Hole 715A.

Table 2. Distribution of middle to late Eocene, shallow-water fossil content in Hole 714A.

Core, section, interval (cm)	*Operculina* sp.	*Operculina gomezi*	*Fabiania* sp.	*Discocyclina* sp.	*Nummulites* sp.	*Nummulites fabianii* gr.	*Orbitolites* sp.	*Amphistegina* sp.	*Heterostegina* sp.	*Alveolina* sp.	Small foraminifers	Melobesiae	Corals	Echinoids
24X-CC, 28–30			P		A		P			C	A	C		
24X-CC, 29–30					P			P	P		P	A	P	P
24X-CC, 37–39	P	P	C	P	A	C			P		A			

Notes: Host sediments are attributed to late Oligocene Zone P22 (see Premoli Silva and Spezzaferri, this volume). A = abundant, C = common, and P = present.

PALEOENVIRONMENTAL REMARKS AND CONCLUSIONS

The succession of shallow-water facies recovered in Hole 715A indicates that by late early Eocene time a carbonate platform developed above the basement. Initially it was characterized by back-reef facies with abundant miliolids, rotaliids, agglutinated foraminifers, and *Orbitolites,* as well as sparse alveolinids and *Nummulites* in association with abundant melobesian algae. The carbonate platform then evolved toward a deeper, more open marine environment, as testified by the appearance of discocyclinids that become progressively more abundant upward along with frequent *Nummulites* (see Ferrer et al., 1973).

In the upper part of the sequence, the occurrence of well-diversified planktonic foraminifer faunas and the presence of strongly fragmented discocyclinids as well as some nummulitids oriented parallel to the bedding show that the carbonate platform stopped growing and sank below the euphotic zone. The time span between the initiation of the platform and its end appears to be very short, a few hundred thousand years only (Berggren et al., 1985). In Hole 715A the sedimentary sequence is truncated by a major hiatus that spans the latest early Eocene through middle Miocene and indicates that erosion predominated over deposition at Site 715 during this time.

At Hole 714A, the occurrence of shallow-water larger foraminifers of middle to late Eocene age, now enclosed in late Oligocene pelagic sediments, suggests that (1) in the Maldive Ridge area a carbonate platform, possibly spatially reduced in size in comparison with that of late early Eocene age, continued to grow later than early Eocene time (till at least the late Eocene); and (2) the presence of reef-derived skeletal debris in beds of turbiditic origin testifies to a major erosional event during the late Oligocene, as the pelagic sediments containing the turbiditic layers can be assigned to Zone P22 (Premoli Silva and Spezzaferri, this volume). This erosional event appears to be coeval with the youngest global sea-level fall of Oligocene age (Haq et al., 1988). Sea level during this event is estimated to be as much as 100 m lower than at present (Schlanger and Premoli Silva, 1986).

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SPECIES LIST

The species identified are listed in alphabetic order. For the alveolinids and nummulitids, the classifications of Hottinger (1960) and Schaub (1981) have been followed. For the planktonic foraminifers, the generic and specific concepts by Premoli Silva and Boersma (1988) are retained whenever possible, with a few changes according to Toumarkine and Luterbacher (1985). References are made to figures of isolated specimens, even if this study was conducted on thin sections. In this case, identification was based in particular on the comparison of axial sections, whereas spiral views were taken into consideration for estimating the number of whorls and for determining how the size of chambers progressively increased in each species.

Larger Foraminifers

Alveolina aragonensis group Hottinger, 1960 (Plate 3, Fig. 1). See Hottinger (1960), Pl. 6, Figs. 5–10; Fig. 60 (b–f); Drobne (1977), Pl. 5, Figs. 1–6. Several specimens mainly not complete and poorly cut. The best specimen is a Form B that displays narrow and high chamberlets; a moderately, rather regularly increasing spire, with a thin basal thickening in the equatorial region and slightly more development at the poles; and a general shape that is a little more fusiform than the typical *A. aragonensis.* Diameter in the most complete specimens: 3 mm; length/width ratio: 1.5. Moreover, several other specimens exhibit transitional characters between this form and *A. fornasinii,* which in general should have a larger size.

Alveolina canavarii group Checchia-Rispoli, 1905 (Plate 2, Fig. 3; Plate 4, Fig. 1). See Hottinger (1960), Pl. 8, Figs. 15–18; Figs. 68 and 69. Small specimens, in unoriented cuts, with important basal thickening up to two-thirds of the spire height, more pronounced in the pole areas. Form more fusiform than *A. canavarii.* Length/width ratio: 1.8 × 1 mm.

Alveolina fornasinii Checchia-Rispoli, 1909 (Plate 1, Fig. 3). See Hottinger (1960), Pl. 6, Figs. 1–4; Fig. 60a. The illustrated specimen, not complete, has a proloculus of 0.45 mm and a length/width ratio: 2, without basal thickening in the outer whorls at the poles. These characters are typical of *A. fornasinii.*

Alveolina sp. cf. *A. dainellii* Hottinger, 1960 (Plate 3, Fig. 5). See Hottinger (1960), Pl. 5, Figs. 12–14; Fig. 53. Common specimens, frequently not complete and not oriented. Diameter in the most complete specimens: 3.5–4 mm. Chamberlets low and wide. Several specimens show basal thickening and coiling rate close to *A. dainellii.* Several other specimens possess higher chamberlets and show transitional characters between typical *A. dainellii* and *A. palermitana* (Plate 1, Figs. 4 and 6; Plate 2, Fig. 1).

Alveolina sp. aff. *A. palermitana* Hottinger, 1960 (Plate 2, Fig. 2; Plate 3, Fig. 3). See Hottinger (1960), Pl. 5, Figs. 17, 18; Fig. 54. Few specimens, poorly oriented. Some of them show very tight inner coils, followed by a few, much looser coils with important basal thickening (up to 10 times the height of the chamberlets) and outer whorls again rather tightly coiled. Although not centered, the described specimens are very close to *A.* aff. *palermitana* illustrated by Hottinger (1961, Pl. 5, Fig. 16). Diameter of the most complete specimens: 3.5 mm.

Discocyclina douvillei (Schlumberger, 1903) (= *Orthophragmina douvillei* Schlumberger). See Schweighauser (1953), Pl. 12, Fig. 3; Figs. 34 and 53.

Discocyclina sella (d'Archiac, 1850) (= *Orbitolites sella* d'Archiac) (Plate 2, Fig. 6; Plate 3, Fig. 6). See Schweighauser (1953), Pl. 11, Figs. 2, 6, 10, 11, and 13; Figs. 22 and 49.

Fabiania sp. (Plate 5, Figs. 2 and 3).

Nummulites burdigalensis de la Harpe, 1926, emend. Schaub, 1951 (Plate 3, Fig. 8). See Schaub (1981), Pl. 4, Figs. 10–12; Pl. 5, Figs. 1–18, 27–31, and 46–51.

Nummulites burdigalensis group (Plate 3, Fig. 2). Specimens belonging to this group are common and show an acme between Samples 115-715A-14R-1R-CC and 115-715A-13R-1, 19–21 cm. They are frequently badly oriented but exhibit the characteristic pillars, dimensions, and coiling rate typical of the group. Among those, in the lower part of the sequence, a few specimens display a large proloculus similar in size to that of *N. burdigalensis cantabricus* Schaub, 1981, but with a number of septa greater than the typical *N. b. cantabricus.* A Form B specimen (Plate 3, Fig. 2) exhibits sizes (8.5 × 5 mm), numbers of coils, and distribution of pillars on the surface, recording characters in between *N. b. cantabricus* and *N. campesinus* (see below).

Nummulites campesinus Schaub, 1966. See Schaub (1981), Pl. 7, Figs. 23–44; Pl. 8, Figs. 1–22; Pl. 9, Figs. 1–20.

Nummulites sp. cf. *N. caupennensis* Schaub, 1962 (Plate 2, Fig. 5; Fig. 4A). See Schaub (1981), Pl. 45, Figs. 1–19, 22–25. In the specimen of Fig. 4A, septa are at a right angle at the base and recurved at the top; on the third whorl septa show the characteristic sharp inflection of *N. caupennensis.* Chambers higher than wider, 7 per sector, marginal cord well developed. Size of proloculus (0.35 mm) as in *N. caupennensis.* The specimen (Form B) in Plate 2, Figure 5, in slightly oblique axial section, is here referred to *N. caupennensis* because of the characteristically irregular shape of the outer whorls (see Schaub, 1981, Pl. 45, Fig. 22). Associated to the forms described above, there are also several specimens, in poorly oriented cuts, that show slightly flexuous septal filaments, gently thickened to form few small pillars. Because of the sizes, they may be related to *N. caupennensis,* but they possess septal filaments similar to *N. formosus* de la Harpe, 1883.

Nummulites fabianii group Prever, 1905 (Plate 5, Fig. 1). See Schaub (1981), Pl. 49, Figs. 57-69; Pl. 50, Figs. 1-4. Few oblique sections characteristic of the *N. fabianii* group.

Nummulites partschi group de la Harpe, 1880 (Fig. 5A). See Schaub (1981), Pl. 28, Figs. 1-20; Pl. 29, Figs. 1-14; Fig. 80. Some specimens, tangentially cut, exhibit a regular distribution of pillars characteristic of the *N. partschi* group.

Nummulites pratti d'Archiac and Haime, 1853 (Plate 3, Fig. 6; Fig. 4B). See Schaub (1981), Pl. 65, Figs. 32-53. We attributed several specimens to this species that displayed a large proloculus (0.5 mm) and a growth rate similar to that of *N. pratti.* The specimen illustrated in Plate 3, Figure 6, is a characteristic axial section of *N. pratti* Form B.

Operculina gomezi Colom and Bauzà, 1950 (= *Operculina canalifera* d'Archiac subsp. *gomezi* Colom and Bauzà) (Plate 5, Fig. 1). See Ellis and Messina (1940); Hottinger (1977), Figs. 38 (A-F).

Orbitolites sp. cf. *Orbitolites douvillei* (Nuttall, 1925) (= *Opertorbitolites douvillei* Nuttall) (Plate 1, Fig. 1). See Lehmann (1961), Pl. 7, Figs. 1-10; Figs. 27 and 28.

Planktonic Foraminifers

"*Acarinina*" *aquiensis* (Loeblich and Tappan, 1957) (= *Globigerina aquiensis* Loeblich and Tappan). See Loeblich and Tappan (1957), Pl. 56, Figs. 4a-6c.

Acarinina gravelli (Brönnimann, 1952) (= *Globigerina gravelli* Brönnimann). See Brönnimann (1952), Pl. 1, Figs. 16-18.

Acarinina pentacamerata Subbotina, 1953. See Subbotina (1953), Pl. XXIV, Figs. 1-6.

Acarinina pseudotopilensis Subbotina, 1953 (Plate 5, Fig. 6). See Subbotina (1953), Pl. XXI, Figs. 8 and 9; Pl. XXII, Figs. 1 and 2.

"*Globigerinatheka*" *senni* (Beckmann, 1953) (= *Sphaeroidinella senni* Beckmann) (Plate 5, Fig. 8). See Toumarkine (1978), Pl. 10, Figs. 10-14.

Morozovella aragonensis (Nuttall, 1930) (= *Globorotalia aragonensis* Nuttall) (Plate 5, Fig. 4). See Blow (1979), Pl. 141, Figs. 4-9.

"*Morozovella*" *convexa* (Subbotina, 1953) (= *Globorotalia convexa* Subbotina). See Subbotina (1953), Pl. XVII, Figs. 2 and 3.

Morozovella crassata (Cushman, 1925) (= *Pulvinulina crassata* Cushman). See Toumarkine and Luterbacher (1985), Fig. 30 (9-10).

Morozovella spinulosa (Cushman, 1927) (= *Globorotalia spinulosa* Cushman). See Toumarkine and Luterbacher (1985), Fig. 30 (1 and 2).

Planorotalites palmeri (Cushman and Bermudez, 1937) (= *Globorotalia palmerae* Cushman and Bermudez). (Plate 4, Fig. 9; Plate 5, Fig. 5). See Toumarkine and Luterbacher (1985), Fig. 20 (14-29).

Planorotalites pseudoscitulus (Glaessner, 1937) (= *Globorotalia pseudoscitula* Glaessner) (Plate 4, Fig. 6). See Blow (1979), Pl. 173, Figs. 1-8.

Pseudohastigerina wilcoxensis (Cushman and Ponton, 1932) (= *Nonion wilcoxensis* Cushman and Ponton) (Plate 5, Fig. 13). See Berggren et al. (1967), Fig. 2.

Subbotina pseudoeocaena (Subbotina, 1953) (= *Globigerina pseudoeocaena* Subbotina) (Plate 5, Fig. 15). See Subbotina (1953), Pl. V, Figs. 1 and 2.

"*Turborotalia*" *praecentralis* (Blow, 1979) (= *Globorotalia praecentralis* Blow). (Plate 5, Fig. 12). See Blow (1979), Pl. 135, Figs. 7-9; Pl. 136, Figs. 1-6.

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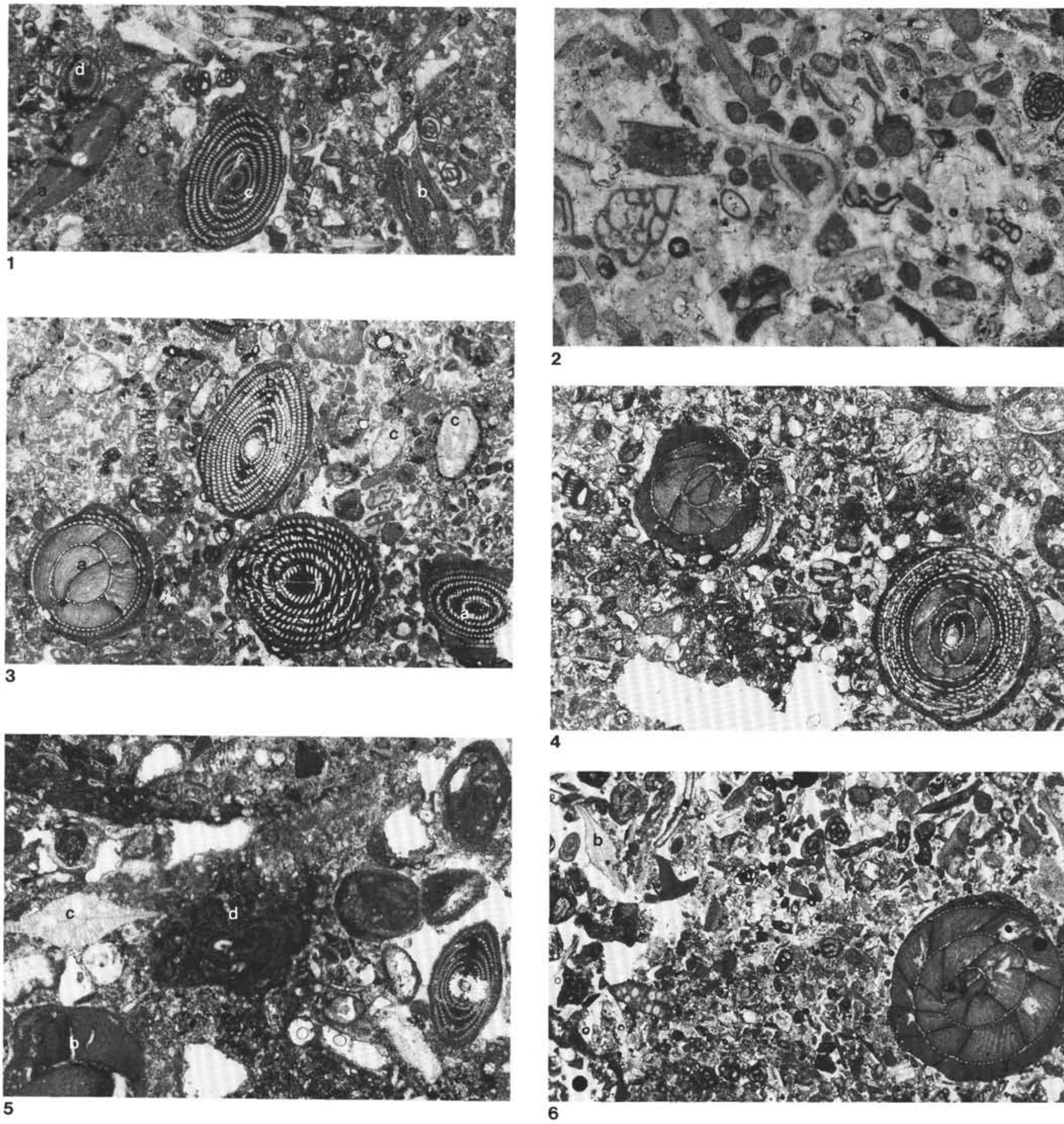

Plate 1. **1.** Bioclastic packstone with abundant small foraminifers. (a) *Orbitolites* cf. *douvillei.* (b) Oblique section of *Orbitolites* sp. (c) *Alveolina* sp. possibly related to the *A. aragonensis* group, oblique axial section. (d) *Alveolina* sp.; Sample 115-715A-23R-1, 34–36 cm (×7.5). **2.** Bioclastic grainstone with abundant small foraminifers, fragments of melobesian algae, and *Alveolina* sp. (inner whorls); Sample 115-715A-22R-CC (×9). **3.** Bioclastic packstone with abundant small foraminifers. (a) *Alveolina* sp., oblique sections. (b) *Alveolina fornasinii,* axial section. (c) *Nummulites* sp.; Sample 115-715A-21R-1, 27–28 cm (×6.5). **4.** Bioclastic packstone with abundant small foraminifers, small *Nummulites* sp., and *Alveolina dainellii/A. palermitana* transitional forms, oblique sections; Sample 115-715A-19R-1, 22–24 cm (×7.5). **5.** Bioclastic packstone with abundant small foraminifers. (a) *Alveolina* sp. possibly related to *A. fornasinii,* axial section. (b) *Alveolina* sp., oblique section. (c) Discocyclinid. (d) Encrusting algae; Sample 115-715A-19R-1, 2–5 cm (×11). **6.** Bioclastic packstone with abundant small foraminifers. (a) *Alveolina* sp. possibly related to *A. dainellii/A. palermitana.* (b) *Discocyclina* sp.; Sample 115-715A-17R-CC (×7.5).

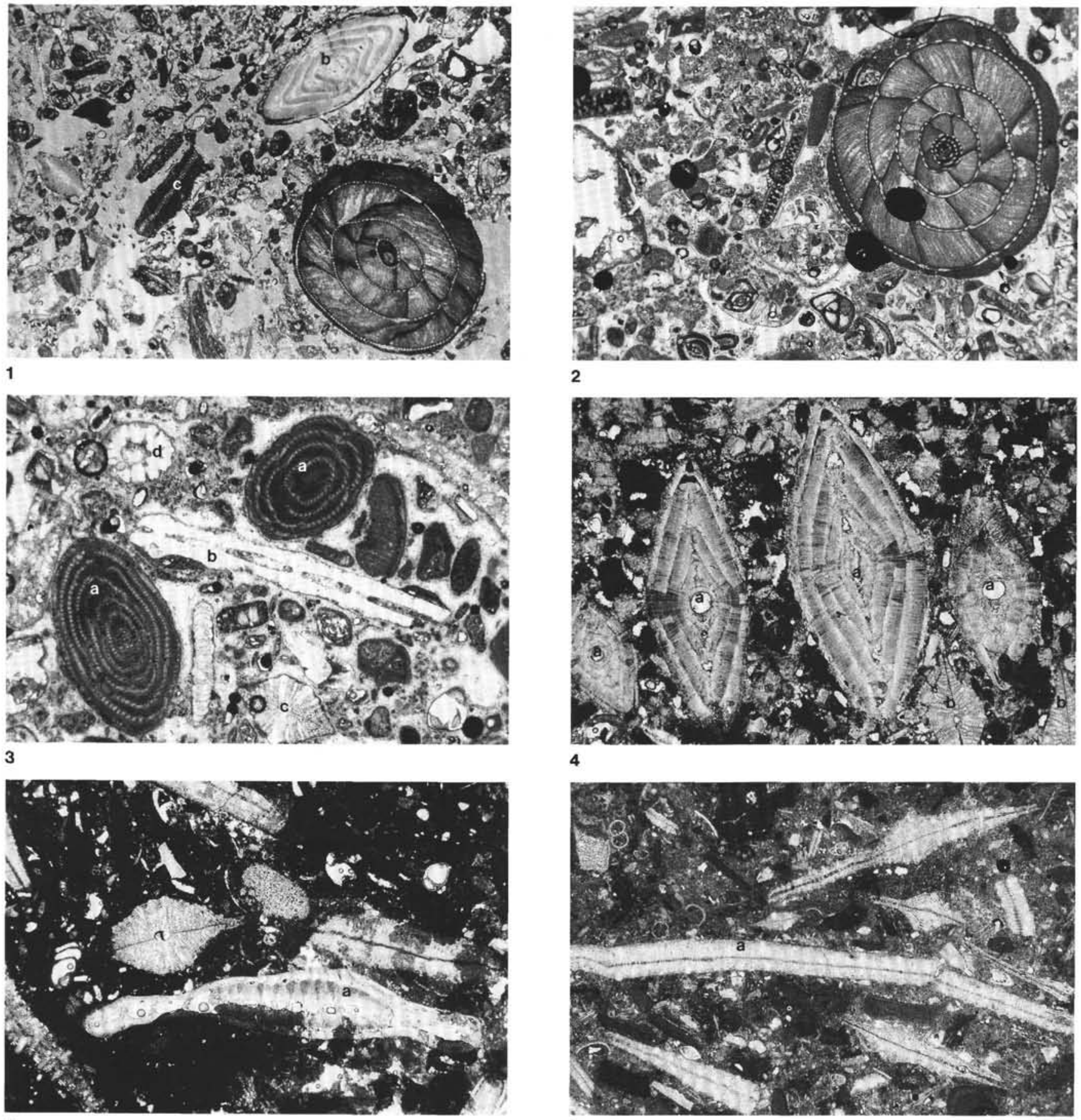

Plate 2. **1.** Bioclastic packstone/grainstone with abundant small foraminifers. (a) *Alveolina dainellii/A. palermitana* transitional forms, oblique section. (b) *Nummulites* sp. (c) Fragments of *Orbitolites* sp.; Sample 115-715A-16R-1, 18–20 cm (×7.5). **2.** Bioclastic packstone with abundant small foraminifers and fragments of *Orbitolites* sp. (a) *Alveolina* sp. related to *A.* aff. *palermitana;* Sample 115-715A-16R-1, 2–5 cm (×11). **3.** Bioclastic packstone. (a) *Alveolina* sp. probably related to *A. canavarii* group, axial and oblique sections. (b) *Operculina* sp. (c) *Discocyclina* sp. (d) Dasycladacean alga associated with small foraminifers; Sample 115-715A-14R-CC (×16.5). **4.** Bioclastic packstone. (a) *Nummulites* sp. (b) Discocyclinids oriented parallel to the bedding plane, associated with abundant, strongly fragmented discocyclinids; Sample 115-715A-13R-1, 19–21 cm (×12). **5.** Bioclastic wackestone. (a) *Nummulites* cf. *caupennensis* associated with discocyclinids. Note rare planktonic foraminifers in the background; Sample 115-715A-13R-1, 8–10 cm (×11). **6.** Bioclastic packstone. (a) *Discocyclina sella* and other discocyclinids, fragments of melobesian algae, and some planktonic foraminifers; Sample 115-715A-12R-CC, 18–21 cm (×12).

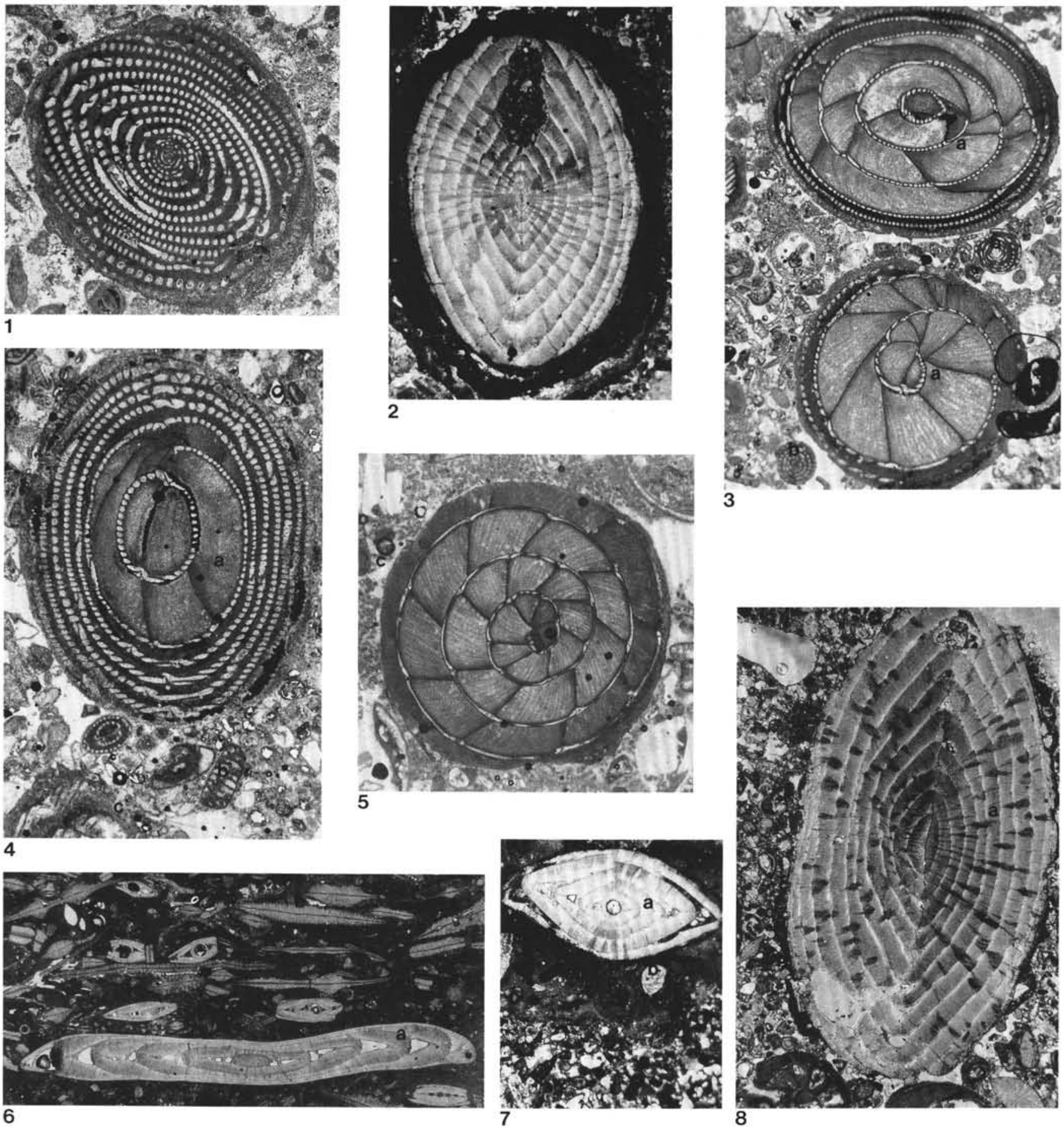

Plate 3. **1.** *Alveolina aragonensis* group, Form B, axial section; Sample 115-715A-21R-1, 8–10 cm (×18). **2.** *Nummulites burdigalensis cantabricus/N. campesinus* transitional form, Form B, axial section; Sample 115-715A-21R-1, 8–10 cm (×8). **3.** Bioclastic packstone with abundant small foraminifers. (a) *Alveolina* aff. *palermitana*, oblique sections. (b) Inner whorls of *Alveolina* sp.; Sample 115-715A-20R-CC (×12). **4.** Bioclastic packstone with abundant small foraminifers. (a) *Alveolina* sp., oblique axial section. (b) Fragment of *Orbitolites* sp. (c) Discocyclinid; Sample 115-715A-14R-1, 40–43 cm (×15). **5.** *Alveolina* sp. possibly related to *A. dainellii;* Sample 115-715A-16R-1, 2–5 cm (×15). **6.** Bioclastic packstone/wackestone. (a) *Nummulites pratti,* Form B, axial section, and several fragmented specimens of *Nummulites,* Forms A and B. (b) *Discocyclina sella.* (c) *Asterocyclina* sp. and several other discocyclinids, associated with planktonic foraminifers; Sample 115-715A-12R-1, 44–46 cm (×10). **7.** Bioclastic packstone. (a) *Nummulites* sp., Form A, axial section. (b) Rotaliid, associated with discocyclinids and small foraminifers; Sample 115-715A-18R-1, 19–20 cm (×18). **8.** Bioclastic packstone with abundant small foraminifers. (a) *Nummulites burdigalensis,* discocyclinids, and fragments of alveolinids; Sample 115-715A-14R-1, 44–45 cm (×12).

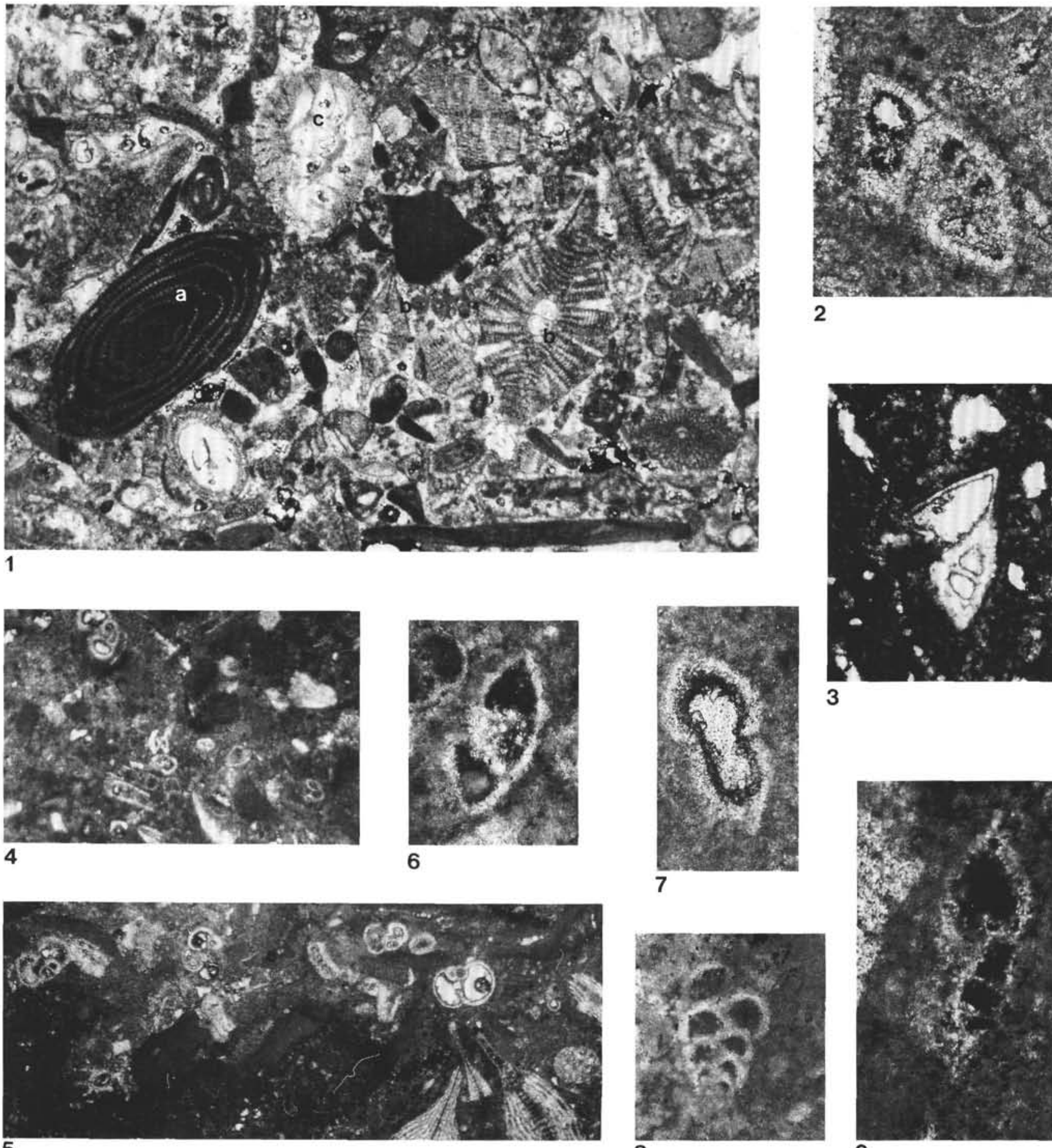

Plate 4. **1.** Bioclastic packstone with abundant small foraminifers. (a) *Alveolina* sp., possibly *A. canavarii* group, oblique axial section. (b) Discocyclinids. (c) *Nummulites* sp.; Sample 115-715A-13R-1, 10–11 cm (×12). **2.** *Planorotalites pseudoscitulus;* Sample 115-715A-12R-1, 18–21 cm (×330). **3.** *Morozovella* sp.; Sample 115-715A-12R-CC, 97–99 cm (×60). **4.** Bioclastic wackestone/packstone with common planktonic foraminifers; Sample 115-715A-12R-1, 44–46 cm (×5). **5.** Bioclastic wackestone/packstone with common planktonic foraminifers, discocyclinids, and melobesian algae; Sample 115-715A-12R-1, 44–46 cm (×5). **6.** *Planorotalites pseudoscitulus;* Sample 115-715A-12R-1, 44–46 cm (×300). **7.** *Pseudohastigerina* sp.; Sample 115-715A-12R-1, 44–46 cm (×300). **8.** *Chiloguembelina* sp.; Sample 115-715A-12R-1, 44–46 cm (×115). **9.** *Planorotalites palmeri;* Sample 115-715A-12R-1, 44–46 cm (×300).

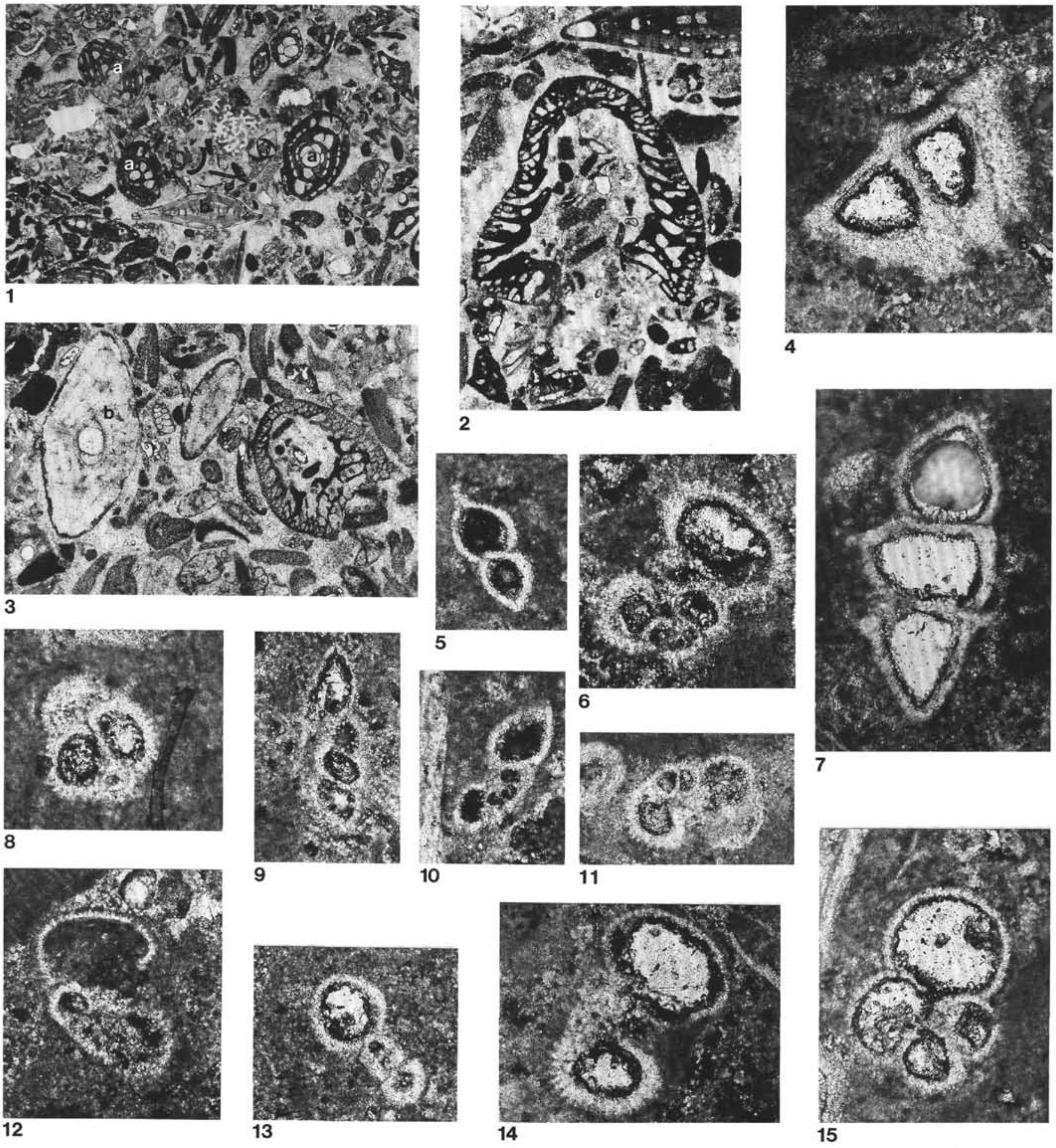

Plate 5. **1.** Bioclastic grainstone. (a) Different cuts of *Nummulites fabianii* group. (b) *Operculina gomezi,* axial section, and small foraminifers; Sample 115-714A-24X-CC, 37–39 cm (×12.5). **2.** Bioclastic grainstone. (a) *Fabiania* sp. (b) *Nummulites* sp.; Sample 115-714A-24X-CC, 37–39 cm (×20). **3.** Bioclastic grainstone. (a) *Fabiania* sp. (b) *Nummulites* sp. and small foraminifers; Sample 115-714A-24X-CC, 28–30 cm (×12.5). **4.** *Morozovella* cf. *aragonensis;* Sample 115-715A-12R-CC, 18–21 cm (×80). **5.** *Planorotalites* cf. *palmeri;* Sample 115-715A-12R-1, 44–46 cm (×125). **6.** *Acarinina pseudotopilensis;* Sample 115-715A-12R-CC, 18–21 cm (×115). **7.** *Morozovella*? sp.; Sample 115-715A-12R-CC, 97–99 cm (×105). **8.** "*Globigerinatheka*" *senni;* Sample 115-715A-12R-1, 44–46 cm (×145). **9.** *Planorotalites* sp.; Sample 115-715A-12R-CC, 18–21 cm (×125). **10.** *Planorotalites* sp.; Sample 115-715A-12R-1, 44–46 cm (×165). **11.** *Acarinina* sp.; Sample 115-715A-12R-1, 44–46 cm (×95). **12.** "*Turborotalia*" cf. *praecentralis;* Sample 115-715A-12R-CC, 18–21 cm (×105). **13.** *Pseudohastigerina wilcoxensis;* Sample 115-715A-12R-CC, 18–21 cm (×105). **14.** *Acarinina* sp.; Sample 115-715A-12R-CC, 18–21 cm (×110). **15.** *Subbotina* cf. *pseudoeocaena;* Sample 115-715A-12R-1, 44–46 cm (×115).