

BIOSTRATIGRAPHY AND TAXONOMY OF LATE ALBIAN PLANKTONIC FORAMINIFERA FROM ODP LEG 171B (WESTERN NORTH ATLANTIC OCEAN)

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ABSTRACT

A detailed taxonomic and biostratigraphic analysis of upper Albian planktonic foraminifera is presented for Ocean Drilling Program sites 1050 and 1052, which were deposited at ~23°N paleolatitude and ~1300 m and 300 m paleodepths, respectively, on the Blake Nose escarpment (subtropical western North Atlantic Ocean). The generally excellent preservation of the material, especially in the clay-rich layers, permits recognition of new bioevents within the uppermost Albian, in addition to most of the standard bioevents that have been previously defined in the Tethyan Realm. The taxonomic assignments and the stratigraphic range of some species that are often overlooked or misidentified in the stratigraphic record have also been clarified, and three species are formally described as new (*Hedbergella astrepta*, *H. praelibyca* and *H. blakensis*). Graphic correlation and age-depth curves constructed from integrated planktonic foraminifera and calcareous nannofossils datum events enable reliable estimation of the relative timing of species first and last occurrences and relative abundance variations, as well as determination of the timing and extent of an unconformity at Site 1050. While most of the species datum events are well correlated, several are found to be diachronous and/or unreliable probably as a result of different surface water conditions along the depth transect.

INTRODUCTION

Ocean Drilling Program (ODP) Leg 171B was drilled on the flank of Blake Nose, a prominent bulge on the margin of Blake Plateau off northeastern Florida (Fig. 1). The thick section of the upper Albian-lower Cenomanian continental slope and rise sediments recovered at Sites 1050 (2296 m water depth) and 1052 (1345 m water depth) provides an unique opportunity to compare overlapping stratigraphies of these two closely spaced sites using remarkably well-preserved material. The paleolatitude of both sites is estimated as 23°N and their paleodepths were about 1000 m shallower during the late Albian and Cenomanian compared to their present day depths (Norris and others, 1998). At both sites the sediments are represented by black and green, laminated claystone that cyclically alternates with minor amounts of chalk, limestone and sandstone.

The rhythmically bedded, organic-rich “black shale” sequences found at both sites correspond to Oceanic Anoxic Event 1d (OAE1d) as their age and high organic carbon content are remarkably similar to black shale beds described from the Vocontian Basin in southeastern France

(Breistroffer event; Breheret, 1994). This OAE1d interval falls in the upper part of the planktonic foraminiferal *Rotalipora appenninica* Zone, and is totally comprised within the stratigraphic interval identified by the total range of the distinctive biomarker *Planomalina buxtoni*. This event is widely preserved as black shale of latest Albian age across the eastern and western Tethys (Erbacher and Thuro, 1997; Erbacher and others, 1999; Coccioni, 2001; Strasser and others, 2001), with sporadic occurrences also in the South Atlantic, southern Indian, and eastern Pacific Ocean basins (Leckie and others, 2002).

The primary aim of this paper is to present results of a high-resolution planktonic foraminifera biostratigraphic study of the uppermost Albian sections in order to obtain a detailed bio- and chronostratigraphic framework. Previous biostratigraphic analysis of planktonic foraminifera from the upper Albian interval on Blake Nose is confined to low resolution biostratigraphic study by Bellier and others (2000). Several calcareous nannofossil biostratigraphic datums from the Leg 171B Initial Results volume (Norris and others, 1998) and the taxonomic study of Watkins and Bergen (2003) are used to help constrain the age model interpretations for sites 1050 and 1052.

The generally excellent preservation of the material, especially in the clay-rich layers, has permitted recognition of new bioevents within the uppermost Albian in addition to most of the standard bioevents that have been previously defined in the Tethyan Realm. Graphic correlation of the two sites enables assessment of the reliability of species first and last occurrences of the two Blake Nose sites, which are separated by 30 km along the continental margin. The taxonomic assignments and the stratigraphic range of some species that are often overlooked or misidentified in the stratigraphic record have also been clarified, and three species are formally described as new.

MATERIAL AND METHODS

At Hole 1050C our study focuses on the uppermost Albian sediments from Sample 26R-5, 18–20 cm to Sample 28R-1, 70–73 cm (Fig. 2). This 13.72-m-thick interval was assigned to Subunit VIA (Norris and others, 1998) and consists of olive-gray, nannofossil claystone alternating with laminated, dark claystone (“black shales”). The claystone contains variable proportions of calcareous microfossils, neritic shell debris and siliciclastic components. The laminated black shales are rich in pyrite and contain clay with varying proportions of calcareous microfossils, silt-sized quartz and feldspar, fish remains, and organic debris with up to 1.40% wt% total organic carbon (TOC; Barker and others, 2001). At Hole 1052E we have analyzed a 38.38 m stratigraphic interval from Sample 40R-1, 20–23 cm to 44R-1, 8–10.5 cm in detail (Fig. 2). The upper two samples studied in Section 40R-1 belong to the

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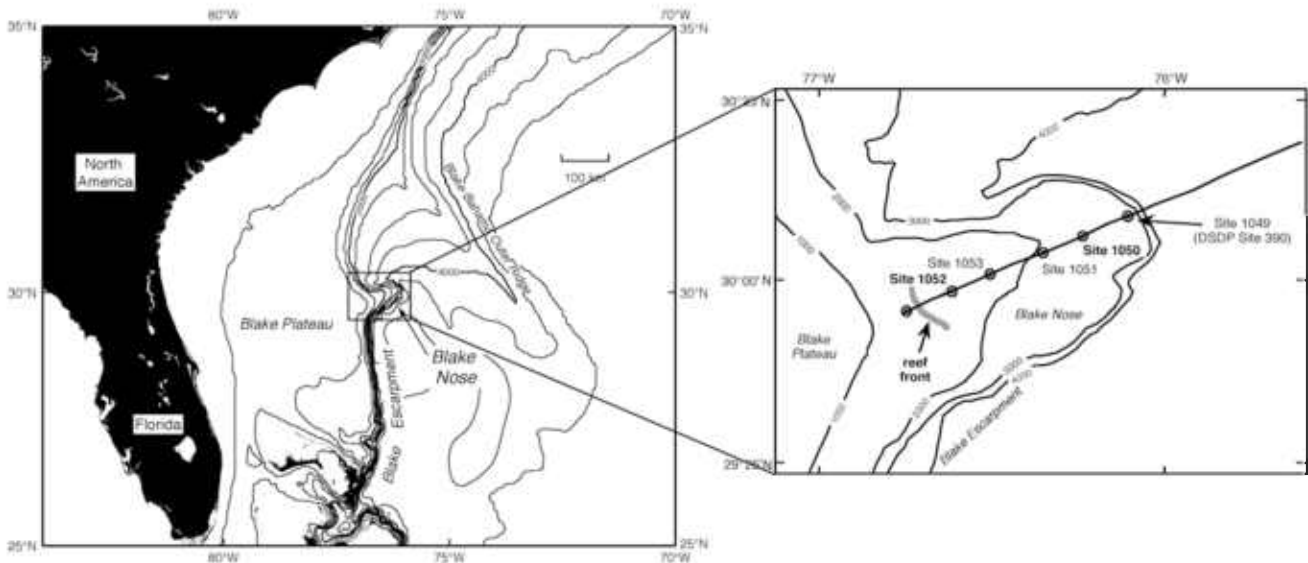


FIGURE 1. Location of the ODP Leg 171B Blake Nose area showing drilling sites.

base of Subunit VA, which mainly consists of calcareous claystone and quartz silt claystone. Sample 1052E-40R-1, 124 cm occurs at the top of the sedimentary sequence assigned to Subunit VB and consists of claystone alternating with laminated dark claystone (black shales) with up to 1.06 wt% TOC (Barker and others, 2001) and minor, lighter colored limestone. The color varies from light olive gray in the limestones to very dark olive gray in the black shale (Norris and others, 1998).

A total of two hundred samples with a 20- to 30-cm sampling resolution (three to seven samples per section) were analyzed for planktonic foraminifera in the uppermost Albian sediments (totaling 60 samples from Hole 1050C and 140 from Hole 1052E). In addition, one sample per section or one every two sections below the studied interval (see Fig. 2) at both holes were also analyzed for the presence of biostratigraphic marker species.

Samples of about 10 cm³ from un lithified mudstone and chalk were soaked in a 3% solution of hydrogen peroxide with a small amount of Calgon added, washed under running water over a 63- μ m sieve, and then dried on a hot plate. Semilithified ooze and chalk were first partially fragmented by hand and then soaked in hydrogen peroxide and Calgon before washing.

Planktonic foraminifera were counted in all samples (60) from Hole 1050C, whereas two to four samples per section (a total of 68 samples) were counted in Hole 1052E. To perform the counting, the >125 μ m fractions were split with a microsplitter until an equal quantity containing approximately 300–500 foraminifera remained. Samples were further scanned for the presence of biostratigraphic marker species. Where residues were small, counts of all specimens were performed; in very small residues less than 200 specimens were counted. Where counting was not performed (72 samples from Hole 1052E), the number of specimens within species was calculated for the total residues through semiquantitative analysis from several fields of view using relative abundance values as follows:

very abundant (VA), >40%; (A) abundant, 26–39%; (C) common, 16–25%; (F) few, 6–15%; (R) rare, 2–5%; (VR) very rare, <2%. Numerical and relative abundance counts of planktonic foraminifera are shown in Tables 1, 2, and 3, together with the foraminiferal preservation rating. Foraminifera whose preservation was judged to be very good (VG) show no evidence of diagenetic alteration in transmitted light and their test walls are optically translucent. A good (G) preservation rating is given for foraminifera that have little diagenetic alteration, minimal test fragmentation and their test walls are optically opaque. Foraminifera judged as having moderate (M) preservation show minor to moderate test fragmentation, and are overgrown with secondary calcite; poor (P) preservation is denoted for specimens that are fragmented and difficult to identify at species level. The numerical counts and relative abundance ranking for benthic foraminifera are also included (Tables 1, 2 and 3). Core sample notation follows the standard ODP format, with designation for site, hole, core number, section number and centimeter interval.

Diversity indices were calculated for both holes and the abundance of the various taxa were used to estimate simple species diversity (S), Shannon diversity [H (S)], and equitability (E). Simple species diversity or species richness (S) is the number of species within the counted aliquot without normalizing for sample size. Shannon diversity takes into account the proportion of each species within the sample using the Information Function $H(S) = -\sum p_i \ln p_i$, in which $i = 1$ to the number of species observed and where p_i is the proportion of the total sample represented by the i th species (Shannon, 1949). Equitability $E = e^{H(S)}/S$ is a measure of the evenness of the species distribution within a sample.

Species richness could reflect the diversity of available habitat (e.g., water column stratification) as well as evolution, including speciation, or immigration. Shannon diversity varies with species richness, but, for any given number of species (S), it has a maximum value when all taxa

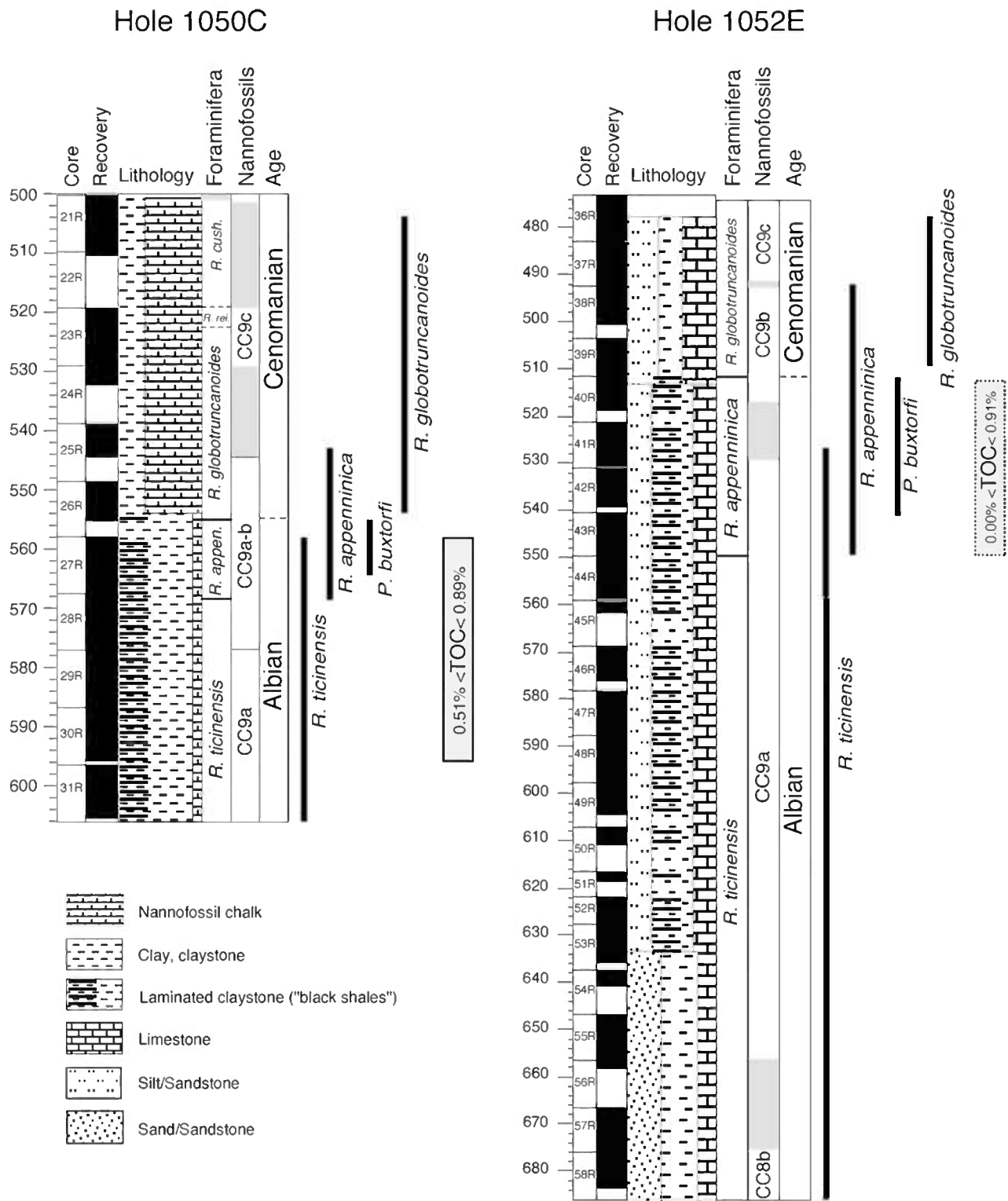


FIGURE 2. Summary of lithology, core recovery, biostratigraphy and age assignments from sediment recovered from holes 1050C and 1052E.

are equally abundant and a minimum value when most of the individuals in a sample are represented by a single taxon. Equitability equals one if all species are present in the same proportion, and it approaches zero if one species dominates the assemblages; it is not dependent on the number of species in a sample.

These diversity indices can be used for environmental interpretation if variation in assemblage composition is representative of the original populations. For example, low diversity and low equitability are expected for assemblages from extreme or eutrophic conditions and reflect high-productivity conditions (Ottens and Nederbragt, 1992).

TABLE 4. Planktonic foraminifera occurrences at holes 1050C and 1052E.

SPECIES DATUMS	1050C - Core-section, interval (cm)	DEPTH (mbsf)	1052E - Core-section, interval (cm)	DEPTH (mbsf)
LO <i>Costellagerina libyca</i>	26R-2, 56-59	550.46	39R-4, 32-34	506.32
FO <i>Rotalipora globotruncanoides</i>	26R-5, 83-86	555.23	40R-1, 20-23	510.80
LO <i>Planomalina buxtorfi</i>	26R-CC, 9-10	555.57	40R-1, 127-130	511.31
FO <i>Rotalipora gandolfii</i>	26R-CC, 9-10	555.57	40R-2, 8-10	512.18
FO <i>Praeglobotruncana stephani</i>	26R-CC, 9-10	555.57	41R-4, 3-4	524.83
LO <i>Ticinella madecassiana</i>	27R-1, 10-12	558.10	40R-5, 50-51	516.60
LO <i>Rotalipora ticinensis</i>	27R-1, 10-12	558.10	41R-6, 28-30	528.13
LO <i>Ticinella primula</i>	27R-1, 10-12	558.10	42R-1, 43-46	530.33
LO <i>Biticinella breggiensis</i>	27R-1, 10-12	558.10	42R-1, 141.5-143	531.32
LO <i>Planomalina praebuxtorfi</i>	27R-1, 10-12	558.10	42R-2, 47-50	531.87
LO <i>Globigerinelloides pulchellus</i>	27R-1, 10-12	558.10	42R-3, 25-27	533.15
LO <i>Ticinella raynaudi</i> gr.	27R-1, 10-12	558.10	42R-3, 48-50	533.38
LO <i>Ticinella praebalernaensis</i>	27R-1, 42-44	558.42	42R-3, 48-50	533.38
FO <i>Costellagerina libyca</i>	27R-2, 54-56	560.04	42R-1, 43-46	530.33
LO <i>Hedbergella astrepta</i>	27R-2, 54-56	560.04	42R-1, 43-46	530.33
FO <i>Praeglobotruncana delrioensis</i>	27R-3, 8-10	561.08	42R-3, 101-103	533.91
FO <i>Planomalina buxtorfi</i>	27R-5, 4.5-6.5	564.05	43R-2, 9-11	541.03
FO <i>Rotalipora appenninica</i>	28R-1, 70-73	568.30	44R-1, 80-81.5	549.90
LO <i>Rotalipora subticinensis</i>	28R-4, 66-69	572.76	44R-4, 50-53	554.10
LO <i>Ticinella praeticinensis</i>	29R-2, 60-62	579.30	44R-6, 50-53	557.10
FO <i>Hedbergella praelibyca</i>	29R-5, 72-75	583.92	46R-4, 43-47	572.69
FO <i>Hedbergella astrepta</i>	30R-4, 78-81	592.08	47R-7, 22-25	587.22

The stratigraphic interval between the FO and the LO of *P. buxtorfi* (*P. buxtorfi* Subzone) is marked at both sites by several appearances and extinctions which reflect a major change in the planktonic foraminiferal composition (Premoli Silva and Sliter, 1999; Leckie and others, 2002). Within this subzone the most distinct and useful datums for biostratigraphic purposes are the FO of *Praeglobotruncana delrioensis*, which occurs in the lower third of the *R. appenninica* Zone at 561.08 mbsf in Hole 1050C and 533.91 mbsf in Hole 1052E, followed by the FO of *Costellagerina libyca* in the upper half of the *R. appenninica* Zone 560.04 and 530.33 mbsf at sites 1050 and 1052, respectively. This latter datum also coincides with the LO of *H. astrepta* at both holes.

The sequence of extinctions is slightly different between the two holes. At Hole 1052E the extinctions of *Ticinella praebalernaensis* and *Ticinella raynaudi* (Sample 42R-3, 48–50 cm), *Globigerinelloides pulchellus* (Sample 42R-3, 25–27 cm), *Planomalina praebuxtorfi* (Sample 42R-2, 47–50 cm) and *Biticinella breggiensis* (Sample 42R-1, 141.5–143 cm) all fall in a narrow stratigraphic interval slightly below the FO of *C. libyca* (Sample 42R-1, 43–46 cm). The LO of *Ticinella primula* (Sample 42R-1, 43–46 cm) coincides with the FO of *C. libyca*, whereas *R. ticinensis* (Sample 41R-6, 28–30 cm) and *Ticinella madecassiana* (Sample 40R-5, 50–51 cm) disappear above the FO of *C. libyca*. However, in Hole 1050C all these taxa disappear in Sample 27R-1, 10–12 cm (558.10 mbsf), above the FO of *C. libyca* (Sample 27R-2, 54–56 cm).

This extinction trend is interrupted at both sites by the FO of *Praeglobotruncana stephani*, which at Hole 1052E is

first recorded in Sample 41R-4, 3–4 cm (524.83 mbsf), and is followed by the FO of *Rotalipora gandolfii* (Sample 40R-2, 8–10 cm), the LO of *P. buxtorfi* (Sample 40R-1, 127–130 cm) and the FO of *R. globotruncanoides* (Sample 40R-1, 20–23). At Hole 1050C the FO's of *P. stephani* and *R. gandolfii* and the LO of *P. buxtorfi* fall in Sample 26R-CC, 9–10 cm, whereas *R. globotruncanoides* first occurs slightly above in Sample 26R-5, 85–86 cm. The last occurrence of *C. libyca* is recorded 4.77 m and 4.48 m above the base of the *R. globotruncanoides* Zone in holes 1050C and 1052E, respectively.

REGIONAL AND GLOBAL CORRELATIONS

Comparison between the two holes (Fig. 3) highlights good correlation of the first occurrence datums, whereas almost all of the last occurrences plot off the correlation line. This discrepancy partially results from less complete recovery at Site 1050, and may also reflect the presence of a stratigraphic gap that was not previously identified. At Hole 1050C the LO's of several taxa at the top of Core 27R and the simultaneous FO's of *P. stephani* and *R. gandolfii* together with the LO of *P. buxtorfi* in the sample immediately above (26R-CC, 9–10 cm), are related to a 2.43-m recovery gap between Core 27R and the overlying Core 26R, and to the presence of a hiatus spanning the upper part of the *R. appenninica* Zone at this site (at ~258 mbsf). Discrepancies in the composition of the planktonic foraminiferal assemblages were also observed between the two sites, such as (1) the complete absence of *Favusella washitensis* at Site 1050, probably because of its

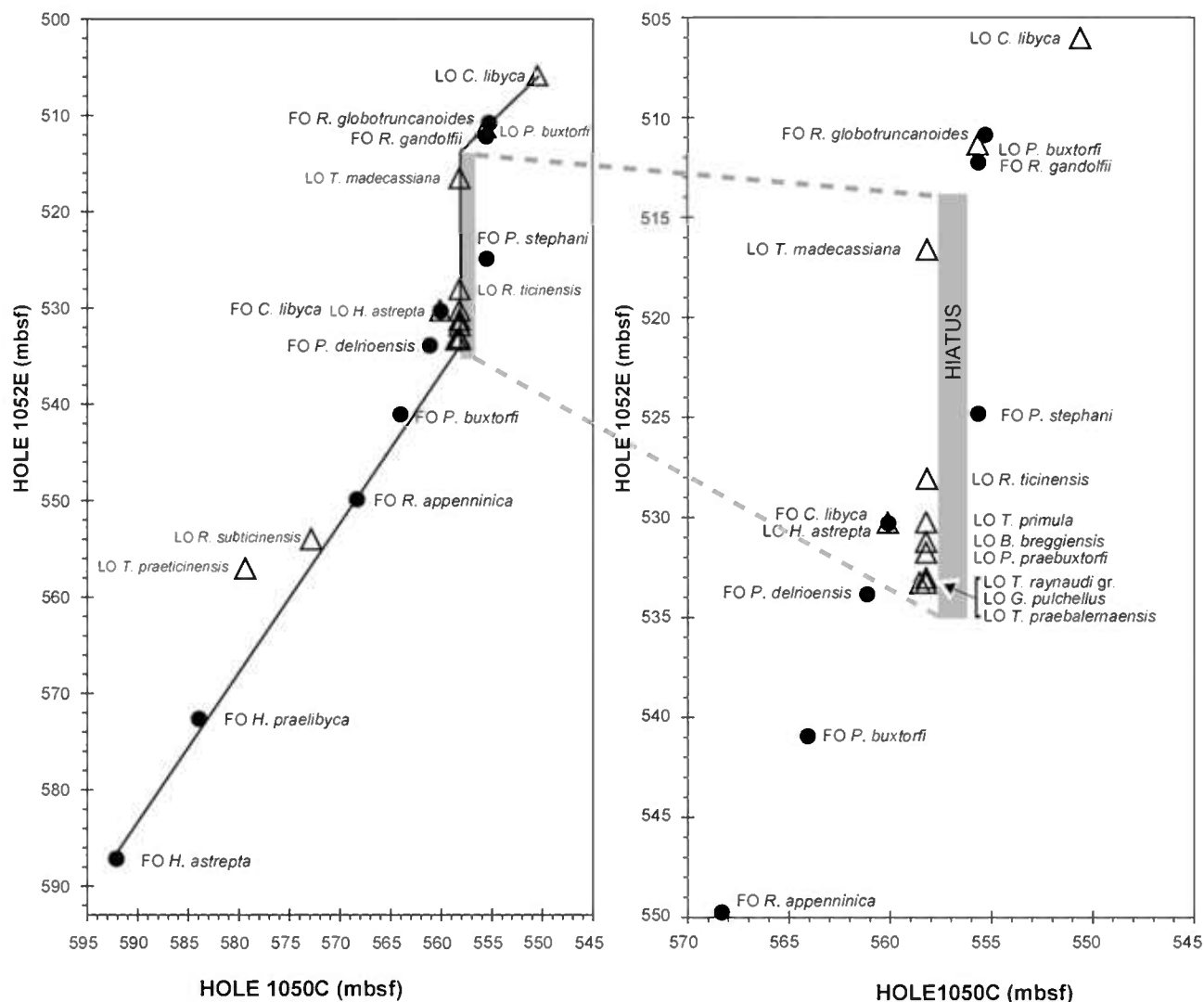


FIGURE 3. Graphic correlation of sites 1050 and 1052 showing the reliability of species first and last occurrence datums along a ~1000-m depth transect of the Blake Nose.

preference for shallow-water environments as observed by Koutsoukos and others (1989); (2) the consistent occurrences of *B. breggiensis* and the *T. raynaudi* group, as well as of all the ticinellids in Hole 1050C, whereas they are sporadic and more rare in Hole 1052E; and (3) the less sporadic occurrence of *Schackoina* at Hole 1050C.

The biostratigraphic framework developed for both Blake Nose sites correlates well with the standard low-latitude planktonic foraminiferal biozonation and the planktonic foraminifera stratigraphic ranges compiled by Leckie and others (2002). However, some of the secondary events recorded in the North Atlantic display different stratigraphic distributions in the Tethyan region. The main differences concern the first occurrence of the genus *Praeglobotruncana*. At Blake Nose as well as at Site 547 (Leckie, 1984), both the late Albian *Praeglobotruncana* species (*P. delrioensis* and *P. stephani*) first appear within the *R. appenninica* Zone above the FO's of *P. buxtorfi* and *C. libyca*, respectively. In contrast, the FO's of *P. delrioensis* and *P. stephani* in the Umbria Marche Basin (Bottaccione

section, Central Italy) are reported by Premoli Silva and Sliter (1995) in the middle-upper part of the *R. ticinensis* Zone and close to the base of the *R. appenninica* Zone, respectively. The same levels of first occurrence seen in Central Italy were observed at the Cismon section in Northern Italy (Bellanca and others, 1996). In the pelagic succession of the Gargano Promontory in Southern Italy the first occurrence of both *Praeglobotruncana* species is reported at even lower stratigraphic levels. *Praeglobotruncana delrioensis* is first recorded below the FO of *B. breggiensis* (upper part of the *T. primula* Zone; middle Albian), and *P. stephani* first occurs below the FO of *R. subticinensis* in the middle part of the *B. breggiensis* Zone (Luciani and others, 2004). Determination of the reason for this apparent diachroneity will require further study.

At Blake Nose the Albian/Cenomanian boundary is placed at the FO of *Rotalipora globotruncanoides*, in agreement with the recommendations of the accepted Global Standard Section and Point (GSSP) for the base of the Cenomanian Stage at Mont Risou, Hautes-Alpes,

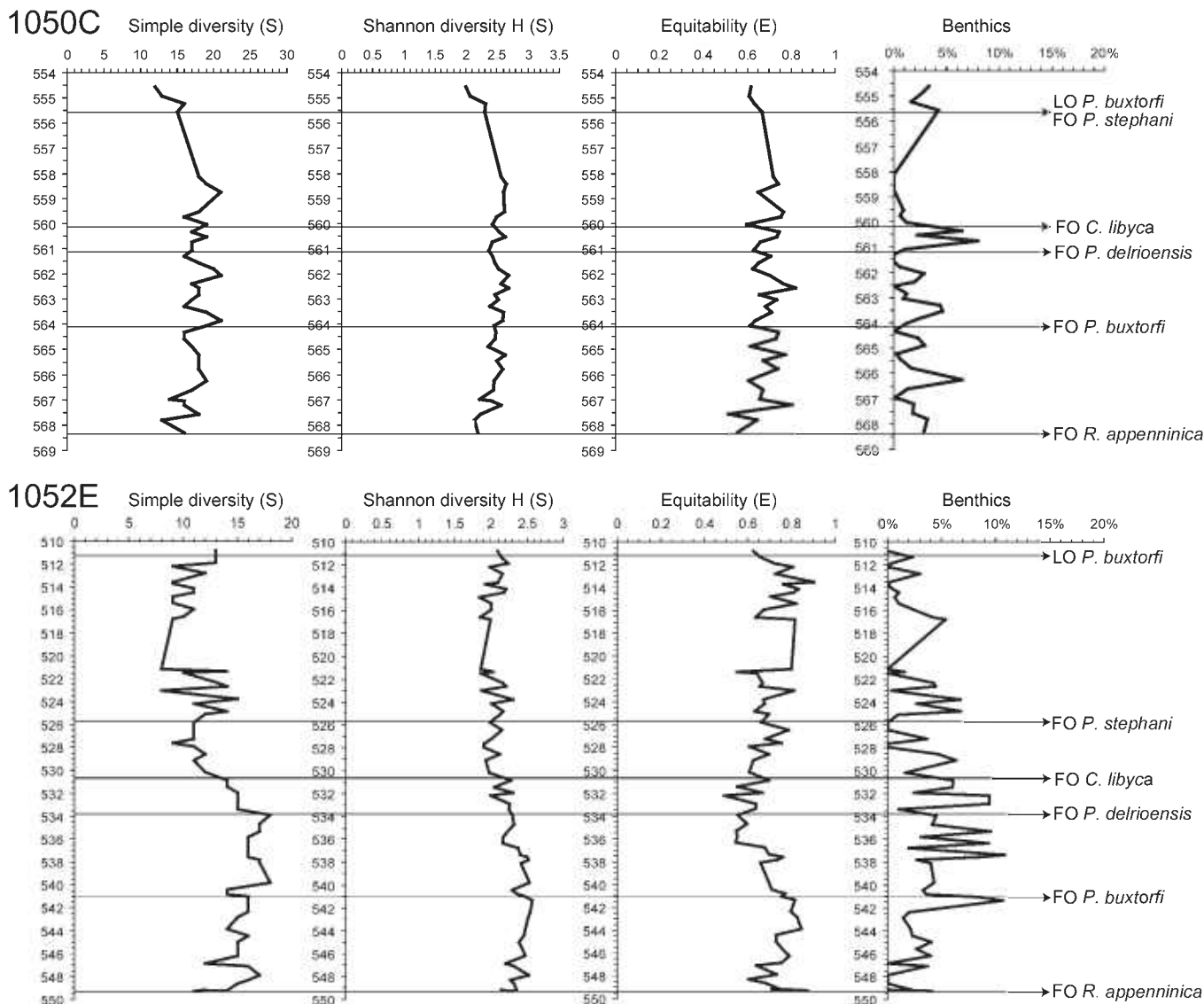


FIGURE 4. Diversity indices. Simple species diversity (S), Shannon diversity [H (S)], and equitability (E), based on the abundance of the various taxa, are calculated for holes 1050C and 1052E.

France (Kennedy and others, 2004). However, we observed that *R. globotruncanoides* is very rare at the beginning of its stratigraphic range; its first occurrence is difficult to find due to the presence in the same assemblages of both transitional specimens close to *R. globotruncanoides* (e.g., *Rotalipora* aff. *globotruncanoides* of Moullade and Bellier, 2002) and very rare specimens of true *R. globotruncanoides*. In addition, the 20- to 30-cm sampling resolution used in this study reveals that at both sites the LO of *P. buxtorfi* precedes the FO of *R. globotruncanoides*, and only 34 cm at Hole 1050C and 51 cm at Hole 1052E separate the two datums. For this reason, we believe that the LO of *P. buxtorfi* is a useful marker that well approximates the Albian/Cenomanian boundary.

QUANTITATIVE ANALYSIS RESULTS

The gaps in core recovery and the hiatus inferred at Hole 1050C do not overprint the major turnover in the planktonic

foraminiferal assemblages, although the turnover is better documented at Hole 1052E. This faunal change mainly consists of the progressive disappearance of the late Albian tinnellids and *B. breggiensis* as well as the contemporary appearance of a new fauna, including the praeglobotruncanids and *C. libyca*. Quantitative analysis documents that the major turnover occurred in the latest Albian, and it also highlights differences in composition of the planktonic foraminiferal assemblages between the two sites.

The planktonic foraminiferal diversity and equitability plots show relatively minor change through the studied interval at Site 1050, whereas several changes are observed at Site 1052 (Fig. 4). Species diversity varies between 12 and 21 species at the deeper Site 1050, and from 8 to 18 at the shallower Site 1052, with the maximum diversity occurring in the interval between the FO's of *P. buxtorfi* and *C. libyca* at both sites. This diversity maximum is followed by a general decrease in the number of species, reflecting the progressive disappearance of the tinnellids. The generally

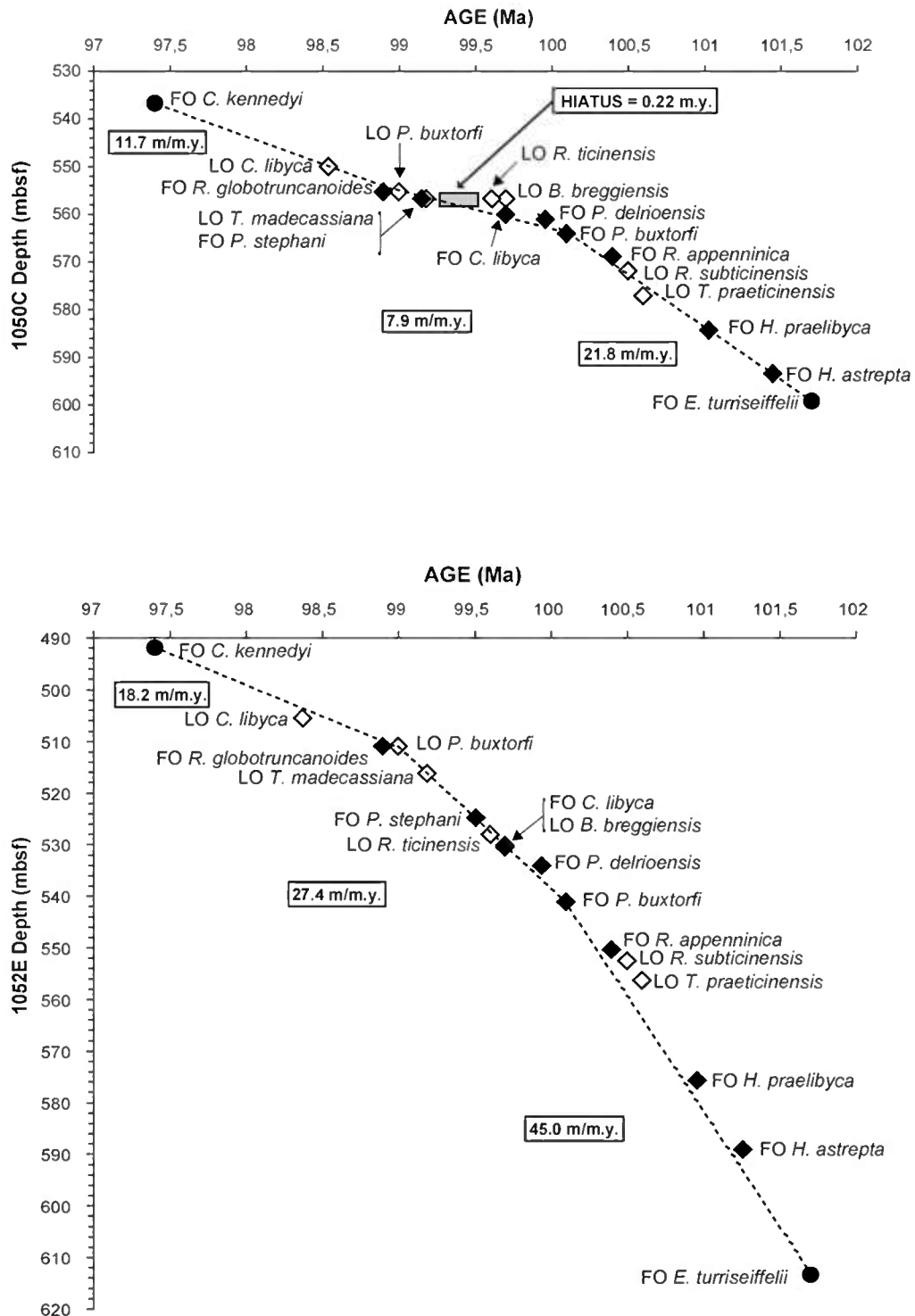


FIGURE 5. Sediment accumulation rates based on the calcareous plankton datums listed in Table 5.

higher number of species at the deeper site throughout the studied interval mainly results from the consistent occurrences of *B. breggiensis* and the *T. raynaudi* group, as well as of all the ticinellids in Hole 1050C, but sporadic or rare occurrence of these species in Hole 1052E. Shannon diversity values show a similar trend at both sites.

Equitability is relatively high at Site 1050 with average values of 0.65, but there is no significant stratigraphic trend

at this site, although a slight increase to a maximum value of 0.80 is observed in the interval between the FO's of *R. appenninica* and *P. buxtorfi*. This increase in equitability in the lower part of the studied interval reflects only minor changes in composition, as most of the species are present in the same proportion. However, at the shallower Site 1052 the equitability trend is more cyclic, as its values range from 0.52 to 0.82 with the maximum value occurring twice,

TABLE 5. Planktonic foraminifera and calcareous nannofossils datums for holes 1050C and 1052E. Age assignments according to Erba and others (1995), Leckie and others (2002), and Robaszynski and Caron (1995).

DATUMS	HOLE 1050C				HOLE 1052E			
	Top depth (mbsf)	Bottom depth (mbsf)	Midpoint depth (mbsf)	Age (Ma)	Top depth (mbsf)	Bottom depth (mbsf)	Midpoint depth (mbsf)	Age (Ma)
FO <i>Corollithion kennedyi</i>	529.30	544.10	536.70	97.4 ^a	491.40	492.50	491.95	97.4 ^a
LO <i>Costellagerina libyca</i>	549.69	550.46	550.08	98.54 ^c	506.08	506.32	506.20	98.38 ^c
FO <i>Rotalipora globotruncanoides</i>	555.23	555.57	555.40	98.9 ^b	510.80	511.31	511.06	98.9 ^b
LO <i>Planomalina buxtorfi</i>	555.23	555.57	555.40	99.0 ^b	510.80	511.31	511.06	99.0 ^b
LO <i>Ticinella madecassiana</i>	555.57	558.10	556.84	99.18 ^c	516.01	516.60	516.31	99.19 ^c
FO <i>Praeglobotruncana stephani</i>	555.57	558.10	556.84	99.18 ^c	524.83	525.00	524.92	99.51 ^c
LO <i>Rotalipora ticinensis</i>	555.57	558.10	556.84	99.6 ^b	527.93	528.13	528.03	99.6 ^b
LO <i>Biticinella breggiensis</i>	555.57	558.10	556.84	99.7 ^b	530.87	531.32	531.10	99.7 ^b
FO <i>Costellagerina libyca</i>	560.04	560.35	560.20	99.7 ^d	530.33	530.87	530.60	99.7 ^d
FO <i>Praeglobotruncana delrioensis</i>	561.08	561.30	561.19	99.96 ^c	533.91	534.49	534.20	99.94 ^c
FO <i>Planomalina buxtorfi</i>	564.05	564.32	564.18	100.1 ^b	541.03	541.35	541.19	100.1 ^b
FO <i>Rotalipora appenninica</i>	568.30	569.71	569.01	100.4 ^e	549.90	551.10	550.50	100.4 ^e
LO <i>Rotalipora subticinensis</i>	571.20	572.78	571.99	100.5 ^b	551.10	554.10	552.60	100.5 ^b
LO <i>Ticinella praeticinensis</i>	575.10	579.30	577.20	100.6 ^b	555.78	557.10	556.44	100.6 ^b
FO <i>Hedbergella praelibyca</i>	583.92	584.91	584.41	101.03 ^c	572.69	578.90	575.80	100.96 ^c
FO <i>Hedbergella astrepta</i>	592.08	595.10	593.59	101.45 ^c	587.22	591.20	589.21	101.26 ^c
FO <i>Eiffellithus turriseiffelii</i>	598.66	599.59	599.13	101.7 ^a	608.63	618.03	613.33	101.7 ^a

^a Depth from Watkins and Bergen (2003); Age from Erba and others, 1995)
^b Robaszynski and Caron (1995)
^c Estimated this study
^d After Leckie and others (2002)
^e Erba and others (1995)

preceding the FO and the LO of *P. buxtorfi*. The first maximum can be correlated with the analogous value at Site 1050, whereas the second is not recorded at Site 1050 as it falls in the interval of poor recovery and/or stratigraphic gap. The low equitability value observed at the shallower Hole 1052E between the FO's of *P. buxtorfi* and *C. libyca* indicates that one or several species dominate the assemblages, and is associated with high diversity as mentioned above.

In general, high diversity corresponds to a high number of available ecological niches, such that an increase in simple diversity can be interpreted as a shift to warmer, more stratified waters. However, when high diversity is associated with relatively low equitability the high species diversity may be the result of mixing of species from adjacent water masses, or alternatively, seasonal productivity with the greatest flux of foraminiferal tests during a portion of the year. The diversity indices at Site 1052 reflect dominance in the assemblage of hedbergellids.

Benthic foraminifera are characterized by cyclic fluctuations throughout the uppermost Albian at both sites. Percent benthics relative to the total foraminifer population ranges between 0 and 8% at Site 1050 and 0–10% at Site 1052 (Fig. 4). Therefore, comparison of diversity indices between sites suggests mixing along water mass boundaries at the shallower Site 1052.

ACCUMULATION RATES

Sedimentation rate curves for holes 1050C and 1052E, shown plotted on Figure 5, are based on the stratigraphic position of planktonic foraminifera and nannofossil datums

and their correlation with the Gradstein and others (1994) time scale. Age assignments and references for calcareous plankton first and last appearance datums used to constrain the age-depth curve for both sites are listed in Table 5.

Average rates of sedimentation are calculated for three intervals at both sites (see Fig. 5): (1) between the FO of *E. turriseiffelii* and the FO of *P. buxtorfi*, (2) between the FO and LO of *P. buxtorfi*, and (3) between the LO of *P. buxtorfi* and the FO of *C. kennedyi*. Results indicate higher sedimentation rates at the shallower Site 1052 for all three intervals. The average sedimentation rates in the first interval are calculated as 21.8 m/m.y. at Site 1050 and 45.0 m/m.y. at Site 1052, rates decrease at both sites in the second interval (7.9 m/m.y. at Site 1050 and 27.4 m/m.y. at Site 1052), and they increase at Site 1050 (11.7 m/m.y.) and decrease at Site 1052 (18.2 m/m.y.) in the third interval.

The low (7.9 m/m.y.) sedimentation rate estimated at Hole 1050C in the stratigraphic interval yielding *P. buxtorfi* is interpreted as the result of a hiatus at the top of the zone (Fig. 5). The average sedimentation rate between the FO's of *P. buxtorfi* and *C. libyca* is calculated as 9.97 m/m.y., whereas it is 6.85 m/m.y. between the FO of *C. libyca* and the LO of *P. buxtorfi*. Such a difference in the same interval allows us to estimate that at least 2.18 m of sediment is missing in the upper part of the *R. appenninica* Zone, corresponding to a hiatus of 0.22 m.y. length (Fig. 5).

Age estimates for the FO's of *H. astrepta*, *H. praelibyca*, *P. delrioensis* and *P. stephani*, and for the LO of *T. madecassiana* listed in Table 5 and shown in Figure 5, were determined by plotting the stratigraphic position of their first or last appearances extrapolated beyond the sedimentation rate curves for both Blake Nose sites. Between the

TABLE 6. List of planktonic foraminifera recorded in the range chart but not discussed in the Systematic Taxonomy section.

<i>Biticinella breggiensis</i> (Gandolfi, 1942)
<i>Costellagerina libyca</i> (Barr, 1972)
<i>Favusella washitensis</i> (Carsey, 1926)
<i>Globigerinelloides bentonensis</i> (Morrow, 1934)
<i>Globigerinelloides ultramicrus</i> (Subbotina, 1949)
<i>Guembeltria cenomana</i> (Keller, 1935)
<i>Hedbergella simplex</i> (Morrow, 1934)
<i>Heterohelix moremani</i> (Cushman, 1938)
<i>Rotalipora gandolfii</i> Luterbacher and Premoli Silva, 1962
<i>Rotalipora globotruncanoides</i> Sigal, 1948
<i>Rotalipora subticinensis</i> (Gandolfi, 1957)
<i>Rotalipora tehamensis</i> Marianos and Zingula, 1966
<i>Rotalipora ticinensis</i> (Gandolfi, 1942)
<i>Schackoina cenomana</i> (Schacko, 1897)
<i>Schackoina leckiei</i> Bellier, Moullade and Tronchetti, 2003
<i>Ticinella madecassiana</i> Sigal, 1966
<i>Ticinella praeticinensis</i> Sigal, 1966
<i>Ticinella primula</i> Luterbacher 1963
<i>Ticinella roberti</i> (Gandolfi, 1952)

two sites, agreement of these age assignments is very good and very promising for global correlations.

CONCLUSIONS

Our high-resolution planktonic foraminiferal study has permitted development of a detailed bio- and chronostratigraphic framework for the North Atlantic region that shows good agreement with species distributions at Site 547 (Leckie, 1984), on the opposite side of the North Atlantic Ocean, as well as with the Tethyan planktonic foraminiferal biozonation. Graphic correlation and age-depth curves constructed from integrated planktonic foraminifer and calcareous nannofossil datums enable reliable estimation of the relative timing of species first and last occurrences, identification of some secondary biostratigraphic datum levels that are potentially very useful for global correlation, and determination of the timing and extent of an unconformity at Site 1050.

Constrained by the primary zonal events (FO of *R. appenninica*, FO and LO of *P. buxtorfi*, and FO of *R. globotruncanoides*), the most distinct and useful datums for biostratigraphic purpose detected at both sites are: the FO's of *H. astrepta*, *H. praelibyca*, *P. delrioensis* and *P. stephani*, and the LO's of *T. praeticinensis*, *R. subticinensis* and *T. madecassiana*.

However, some of the secondary bioevents recorded in the North Atlantic display different stratigraphic distributions in the Tethyan region. The main difference concerns

the appearance of both species of *Praeglobotruncana* (*P. delrioensis* and *P. stephani*) that first occur well within the *R. appenninica* Zone at both Blake Nose and Site 547, whereas in the Tethyan region they are reported to first occur at lower stratigraphic levels either well below or close to the first appearance of *R. appenninica* (Premoli Silva and Sliter, 1995; Luciani and others, 2004).

Among the datum events recorded at Blake Nose, those considered less reliable are the last occurrence of *B. breggiensis* and the extinction levels of most of the *Ticinella* species. Comparison between sites 1050 and 1052 highlights a discrepancy in species composition with consistent occurrences of *B. breggiensis*, the *T. raynaudi* group, and all the ticinellids in Hole 1050C, but sporadic or rare occurrences of these taxa with last occurrences at lower stratigraphic levels in Hole 1052E.

The graphic correlation and the age-depth curves of sites 1050 and 1052 document well the main differences between the two sites, such as (1) the consistently higher sedimentation rates at the shallower Site 1052, and (2) the presence of a hiatus at ~258 mbsf in Hole 1050C. In fact, the LO's of several taxa (e.g., *T. madecassiana* and *R. ticinensis*) at the top of Core 27R and the simultaneous FO's of *P. stephani* and *R. gandolfii* together with the LO of *P. buxtorfi* in the sample immediately above (at the bottom of Core 26R) are related to a 2.43-m recovery gap between the two cores, and to the presence of an unconformity restricted to within the upper part of the *R. appenninica* Zone at this site. The timing and extent of the unconformity, extrapolated beyond the sedimentation rate curve, are estimated as 0.22 m.y. in duration and 2.18 m of missing sediment.

Finally, results indicate that most of the species datum events are well correlated on a global scale, whereas some are found to be diachronous and/or unreliable, probably as a result of different surface water conditions along the depth transect.

SYSTEMATIC TAXONOMY

The stratigraphic distribution of selected species is given in Tables 1, 2, and 3. Short comments are included for previously overlooked or misidentified species in order to clarify the taxonomic concepts followed in this study and to note significant morphological features. Synonymies are limited to the original descriptions; additional references are included when needed to support our species concept. Three species are formally described as new.

Planktonic foraminifera that have been recorded in the range chart but not discussed in this section are listed in Table 6. We adopted the taxonomic concepts for these species that are presented in the *CHRONOS* online taxonomic dictionary located at: http://portal.chronos.org/gridsphere/gridsphere?cid=data_taxondb&JavaScript=enabled

Globigerinelloides bentonensis (Morrow, 1934)
Pl. 1, Figs. 8 and 9a-c (holotype)

Anomalina bentonensis Morrow, 1934, p. 201, pl. 30, figs. 4a-b [Cenomanian, Hartland member of the Greenhorn Limestone of Kansas]
Planomalina caseyi Bolli, Loeblich and Tappan 1957, p. 24, pl. 1, figs. 4-5 [Albian, Gault Clay at Arleseay, England]
Globigerinelloides bentonensis (Morrow), Leckie 1984, p. 593, pl. 10, figs. 9-11 [Albian, off central Morocco, DSDP Site 547]

'*Blowiella*'? *caseyi* (Bolli, Loeblich & Tappan), Moullade and others 2002, p. 141, figs. 6D–G [topotype from the Gault of England]

Diagnosis. Test planispiral and involute, wall macroperforate and smooth, periphery broadly rounded to subrounded, aperture equatorial, sutures strongly depressed, radial to curving slightly backward as on either side of the periphery, 7–9 inflated chambers in the last whorl rapidly increasing in size as added.

Distinguishing features. Differs from *G. ultramicrus* in being larger in size and smooth rather than pustulose, and in having more inflated and rapidly increasing chambers.

Stratigraphic range. *Globigerinelloides bentonensis* consistently occurs in low abundance from the upper part of the *R. ticinensis* Zone to the top of the *R. appenninica* Zone.

Remarks. Re-examination of the primary type specimens of *P. caseyi* (USNM 4869) and *A. bentonensis* (USNM 65381, see Pl. 1, Figs. 9a–c) deposited at the Smithsonian Museum of Natural History, Washington, D.C., reveal that both species have a smooth surface texture and an identical external morphology (e.g., weakly lobate test outline, moderately gradual rate of chamber size increase, and low arched aperture at the base of the final chamber). For this reason and contrary to the conclusion of Moullade and others (2002) the two species are considered synonymous, and *G. bentonensis* is designated as the senior synonym because of priority, as was pointed out by Leckie (1984).

Globigerinelloides pulchellus (Todd and Low, 1964)
Pl. 1, Figs. 5a–b and 10a–c (holotype)

Planomalina pulchella Todd and Low, 1964, p. 409, pl. 1, figs. 9a–b [Cenomanian?, dredge haul taken at a depth between 3200 and 3500 fathoms on the north slope of the Puerto Rico Trench].

Globigerinelloides cf. *G. bentonensis* (Morrow), Leckie 1984, p. 593, pl. 10, figs. 5–6 [Albian, off central Morocco, DSDP Site 547].

Globigerinelloides bentonensis (Morrow), Leckie 1984, p. 593, pl. 10, figs. 7–8 (non figs. 9–11) [Albian, off central Morocco, DSDP Site 547].

Globigerinelloides praebuxtorfi (Wonders), Randrianasolo and Anglada, 1989, p. 807, pl. 2, figs. 1–5 [upper Albian, Antsiranana (ex Diego-Suarez), northern Madagascar]

Planohedbergella? *bentonensis* (Morrow), Moullade and others, 2002, p. 141–142, figs. 5F–M [upper Albian, ODP leg 171B, Site 1050, Blake Nose, western north Atlantic]

Diagnosis. Test planispiral, involute, wall macroperforate and heavily muricate on the early part becoming smooth on the final 2 or 3 chambers, periphery subrounded, chambers inflated, increasing gradually in size, aperture equatorial, sutures strongly depressed, radial to curving slightly backward.

Distinguishing features. Distinguished from *G. bentonensis* by having a peripheral margin that is ornamented by coarse muricae on the early chambers of the final whorl. Differs from *P. praebuxtorfi* in having more globular chambers, a more rounded peripheral margin, depressed sutures between final chambers, and lacking the peripheral keel on the earlier chambers.

Stratigraphic range. It first occurs in the middle part of the *R. ticinensis* Zone and disappears in the middle part of the *R. appenninica* Zone.

Remarks. Re-examination of the holotype and paratypes of *P. pulchella* at the Smithsonian Museum of Natural History (USNM 641522; Pl. 1, Figs. 10a–b) reveals the presence of randomly distributed muricae and fused muricae on the first chambers of the final whorl but these do not coalesce to form a peripheral keel as occurs in *P. praebuxtorfi*. Based on the rounded periphery, absence of a keel, and presence of fused muricae aligned on the peripheral margin, we assign this species to the genus *Globigerinelloides*. Therefore, we reject the hypothesis that *G. pulchellus* (= *P. pulchella*) is a senior synonym of *P. praebuxtorfi* as was proposed by Moullade and others (2002).

Planomalina buxtorfi (Gandolfi, 1942)
Pl. 1, Figs. 7a–b

Planulina buxtorfi Gandolfi, 1942, p. 103, pl. 3, figs. 7a–c [lower Cenomanian, Breggia River, near Chiasso, Canton Ticino, Switzerland]

Planomalina buxtorfi (Gandolfi), Loeblich and Tappan 1961, p. 269, pl. 2, figs. 1–2 [Albian, Main Street formation, Texas, holotype and

hypotype of *Planomalina apsidostroba* (=junior synonym of *P. buxtorfi*)

Planomalina buxtorfi bicarinata Randrianasolo and Anglada, 1989, p. 809, pl. 3, figs. 4–9 [upper Albian, Antsiranana (ex Diego-Suarez), northern Madagascar]

Diagnosis. Test planispiral compressed, wall macroperforate, involute, periphery acute, aperture equatorial, sutures raised, strongly curved backwards, peripheral keel distinct.

Stratigraphic range. Its stratigraphic distribution is restricted to the upper part of the *R. appenninica* Zone.

Remarks. Two additional morphotypes are recognized, one with a tendency to uncoil (Lipson-Benitah and Almogi Labin, 2000) and a second with a double keel, named *P. buxtorfi bicarinata* by Randrianasolo and Anglada (1989). The latter form occurs sporadically in the Blake Nose sediments among assemblages yielding common and large-sized *P. buxtorfi*. In our opinion both morphotypes are within the morphologic variability of the species.

Planomalina praebuxtorfi Wonders, 1975
Pl. 1, Figs. 6a–b

Planomalina praebuxtorfi Wonders, 1975, p. 90, pl. 1, figs. 1a–c [upper Albian, El Burrueco, southern Spain]

Planomalina praebuxtorfi Wonders, Leckie 1984, p. 613, pl. 10, figs. 1–2 [upper Albian, off Central Morocco, DSDP Site 547]

Planomalina pulchella Todd and Low, Randrianasolo and Anglada, 1989, p. 808, pl. 2, figs. 6–9 [upper Albian, Antsiranana (ex Diego-Suarez), northern Madagascar]

Diagnosis. Test planispiral compressed, wall macroperforate, involute, periphery subacute to acute, aperture equatorial, sutures depressed and slightly curved with those between the earlier chambers bordered by moderately developed muricae giving the impression of raised sutures; peripheral keel on the earlier chambers results from concentration of muricae.

Distinguishing features. This species differs from *P. buxtorfi* in having a more rounded periphery on the last chambers, and in having raised sutures and a peripheral keel only on earlier chambers.

Stratigraphic range. Its stratigraphic distribution is restricted to the lower part of the *R. appenninica* Zone.

Remarks. Following strictly Wonders' original description of *P. praebuxtorfi* (1975): "equatorial periphery subangular to angular, with either a keel or irregular rugosities or both, which only occur on the earlier part of the last whorl", we easily differentiated this species from *G. pulchellus*, and we also noted the sporadic occurrence of an intermediate form between the two species.

Ticinella praebalernaensis (Sigal, 1969)
Pl. 2, Figs. 5 a–c

Rotalipora praebalernaensis Sigal 1969, p. 635–637, pl. 1, figs. 1–3 [upper Albian, forage de Diego-Suarez, Madagascar]

Diagnosis. Test trochospiral, wall macroperforate, outline lobulate, peripheral margin subrounded to subacute; primary aperture umbilical-extraumbilical, supplementary apertures occur within the umbilical area, sutures curved and bordered by variably developed pustules on the earliest chambers, then depressed and straight on the final chambers, imperforate peripheral margin with fused pustules sometimes aligned on the earliest chambers.

Distinguishing features. Distinguished from *T. raynaudi* by having a poreless margin with distinctive, fused muricae, and a smaller and deeper umbilicus, and by possessing curved and slightly raised spiral sutures on the earlier chambers. Resembles *P. delrioensis* but differs in having a supplementary aperture within the umbilical area.

Stratigraphic range. From the *R. ticinensis* Zone to the middle part of the *R. appenninica* Zone.

Remarks. Based on the absence of a true well-developed keel and the supplementary aperture, we assign this species to the genus *Ticinella*. As already pointed out by Sigal in his original description *T. praebalernaensis* was derived from *T. raynaudi* through acquisition of a peripheral keel and a more compressed margin bordered by variably developed muricae, as shown by the occurrences of common intermediate forms between these two species mainly at Site 1050.

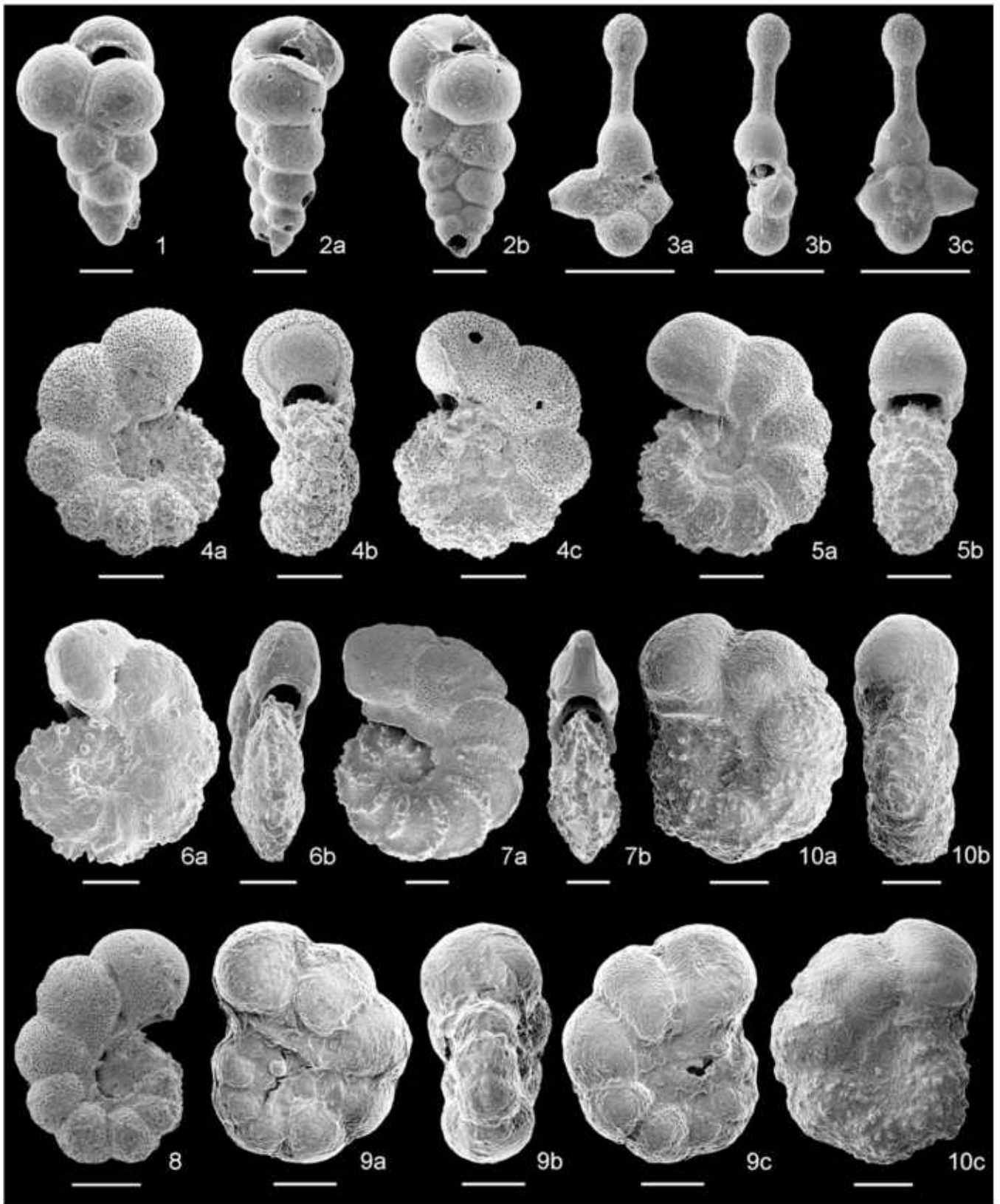


PLATE 1

(Scale bars 100 μ m except where otherwise stated) **1** *Guembelitria cenomana*, Sample 1050C-27R-1, 73–76 cm, scale bar 20 μ m. **2a–b** *Laeviheterohelix* sp., Sample 1050C-27R-1, 73–76 cm, scale bar 20 μ m. **3a–c** *Schackoina leckiei*, Sample 1050C-27R-1, 73–76 cm. **4a–c** *Hedbergella wondersi*, Sample 1050C-31R-6, 88–91 cm. **5a–b** *Globigerinelloides pulchellus*, Sample 1050C-27R-4, 134–136 cm. **6a–b** *Planomalina praebuxtorfi*, Sample 1052E-42R-5, 146.5–148.5 cm. **7a–b** *Planomalina buxtorfi*, Sample 1052E-40R-1, 127–130 cm. **8** *Globigerinelloides bentonensis* Sample 1052E-44R-6, 50–53 cm. **9a–c** *Globigerinelloides bentonensis*, holotype USNM 65381. **10a–c** *Globigerinelloides pulchellus*, holotype USNM 641522.

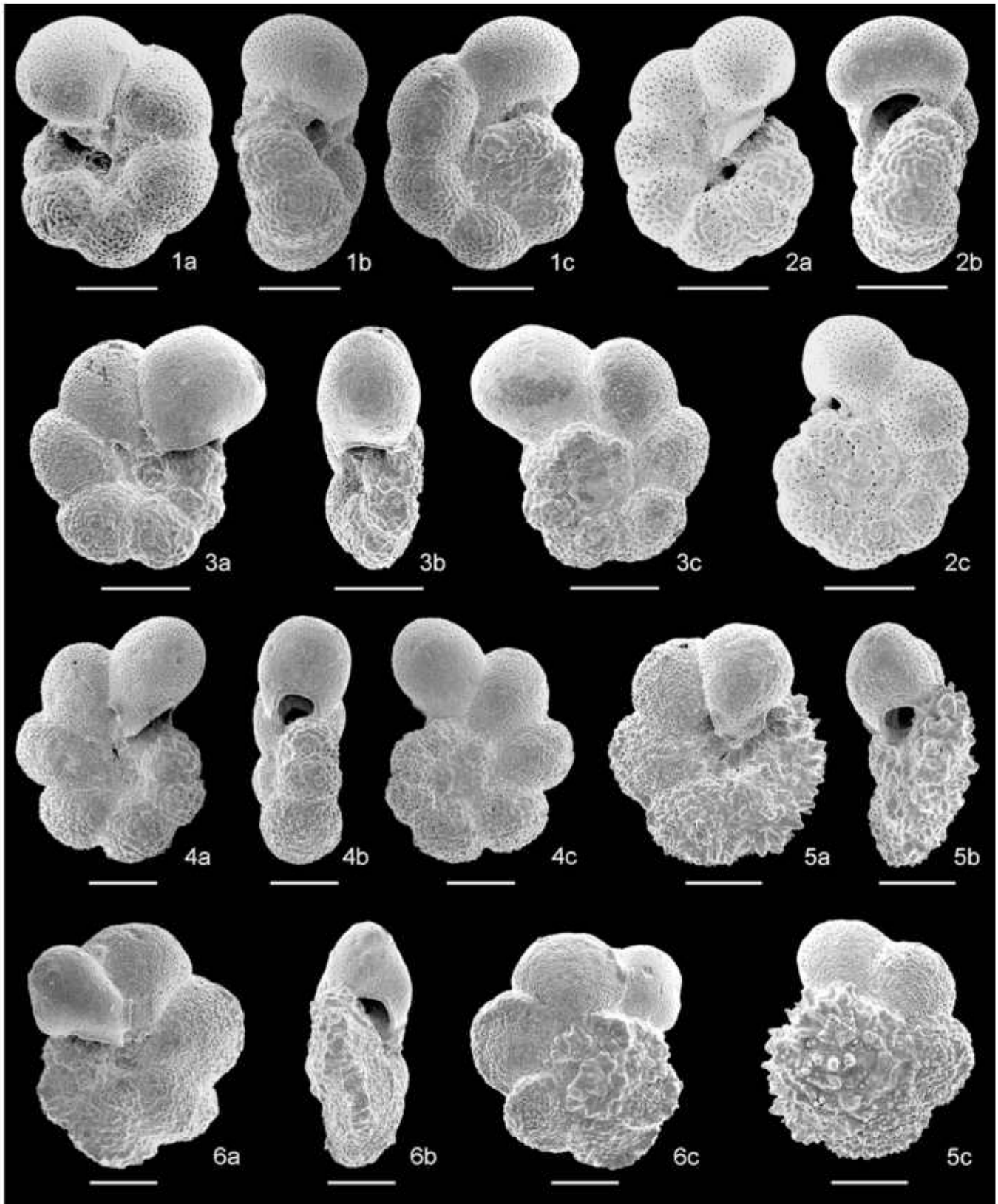


PLATE 2

(Scale bars 100 μ m) **1a–c** *Ticinella madecassiana*, Sample 1050C-27R-3, 79–82 cm. **2a–c** *Ticinella primula*, Sample 1050C-29R-6, 21–24 cm. **3a–c** *Ticinella raynaudi*, Sample 1050C-27R-2, 25–26 cm. **4a–c** *Ticinella raynaudi*, Sample 1050C-27R-4, 134–136 cm. **5a–c** *Ticinella praebalernaensis*, Sample 1052E-43R-1, 68–70 cm. **6a–c** *Rotalipora evoluta*, Sample 1050C-27R-4, 34–36 cm.

Ticinella raynaudi Sigal, 1966
Pl. 2, Figs. 3a–c and 4a–c

- Ticinella raynaudi* Sigal 1966, p. 200–201, pl. 6, figs. 1ab–3ab [upper Albian, forage de Diego-Suarez, Madagascar]
Ticinella raynaudi s.l. Sigal, Leckie 1984, p. 600, pl. 7, figs. 1–4 [upper Albian, off Central Morocco, DSDP Site 547]
Ticinella raynaudi Sigal, Lipson-Benitah and Almogi-Labin 2000, p. 16, pl. 3, figs. 1a, 1b, 2 [upper Albian, offshore Israel, Yam boreholes]

Diagnosis. Test low trochospiral, wall thick and macroperforate, chambers elongate tangential to the axis of coiling (reniform), peripheral margin rounded, primary aperture umbilical-extraumbilical, supplementary apertures occur within the umbilical area, sutures depressed and straight on both sides, pustules randomly distributed on the earlier chambers of the last whorl.

Distinguishing features. Differs from *T. madecassiana* and *T. primula* in having a more lobate outline and more elongate (reniform), subtriangular chambers.

Stratigraphic range. From the *R. ticinensis* Zone to the middle part of the *R. appenninica* Zone.

Remarks. The three subspecies described by Sigal 1966, including *T. raynaudi raynaudi*, *T. raynaudi aperta*, *T. raynaudi digitalis*, and two varieties (*T. raynaudi* var. 1 and *T. raynaudi* var. 2) occur in the studied assemblage, but they are extremely transitional from one to another, such that it is difficult to choose a demarcation line within the lineage. Even the morphotype with more elongate chambers, named *T. raynaudi digitalis* by Sigal (1966), appears to be an extreme form. Further studies are in progress to evaluate if *T. raynaudi raynaudi* and *T. raynaudi digitalis* possess significant differences and distinct morphological features at the species level. For the time being we consider all three subspecies and the two varieties to fall within the morphologic variability of the same species.

Rotalipora appenninica (Renz, 1936)
Pl. 3, Figs. 7a–c

- Globotruncana appenninica* Renz 1936, p. 14, fig. 2 [lower Cenomanian ?, Gubbio, Umbria, Italy]
Rotalipora appenninica appenninica (Renz), Luterbacher and Premoli Silva, 1966, p. 266–268, pl. 19, figs. 1, 2 [upper Albian, Gubbio, Umbria, Italy]
Rotalipora appenninica (Renz), Robaszynski, Caron, and others, 1979, p. 60, pl. 4, figs. 1a–c [topotype]

Diagnosis. Test trochospiral, wall macroperforate and smooth, oblate outline, peripheral margin angular with one keel, primary aperture umbilical-extraumbilical, supplementary apertures occur within the umbilical area, sutures depressed and straight, becoming curved on the last chambers of the umbilical side, raised and curved sutures on the spiral side.

Distinguishing features. Differs from *R. balernaensis* in having a more elongate (oblate) outline and crescentic chambers that increase rapidly in size as added, and in having depressed and curved sutures on the last chambers of the umbilical side. Distinguished from *R. ticinensis* in being smaller in size, and in having a more elongate outline with fewer chambers that increase rapidly in size as added.

Stratigraphic range. Its first occurrence is used to identify the base of the *R. appenninica* Zone. *Rotalipora appenninica* disappears in the upper part of the *R. globotruncanoides* Zone.

Remarks. The identification of this species is still problematic although it has been revised several times (Luterbacher and Premoli Silva, 1962; Sigal, 1969; Wonders, 1978; Robaszynski, Caron, and others, 1979) since the first description by Renz (1936), who erected this species from thin section only. Although Renz did not identify a holotype, Marie (1948) designated a specimen from one of his sections (p. 14, fig. 2, left specimen) as a lectotype. Since then, several similar forms have been identified. Among them *R. balernaensis* has been considered a junior synonym (Wonders, 1978; Robaszynski, Caron, and others, 1979). In our identification of *R. appenninica* we have followed the concept of Luterbacher and Premoli Silva (1962) and the topotype of Gubbio illustrated in Robaszynski, Caron, and others (1979) by the European Working Group on Planktonic Foraminifera. Following strictly this concept we identified the first occurrence of *R. appenninica* in the upper part of the *R. ticinensis* stratigraphic range. Moreover, just prior the appearance of *R. appenninica*, we observed the occurrence of rare specimens regarded by us as transitional forms between *T. raynaudi* and *R. appenninica*. In their study of the Bottaccione section,

Premoli Silva and Sliter (1995) also reported the presence of rare specimens that they identified as *R. praeappenninica* near the FO of *R. appenninica*, which they interpreted as the *R. appenninica* predecessor. The latter authors attributed *R. praeappenninica* to Sigal without giving a reference. We informally use the name *R. praeappenninica* to accommodate these specimens, as, for the time being, we cannot find any reference or citation in Sigal's published papers. It is worth mentioning that, although at Blake Nose *R. appenninica* is very rare, its first occurrence is relatively easy to find, as this species is clearly different from *R. ticinensis* within the same interval.

Rotalipora balernaensis (Gandolfi, 1957)
Pl. 3, Figs. 5 a–c

- Globotruncana appenninica* Renz 1936, var. alpha Gandolfi 1942, p. 118–119, text fig. 40 [lower Cenomanian, Breggia River, Switzerland]
Globotruncana appenninica balernaensis Gandolfi 1957, p. 60, pl. 8, figs. 3a–c [lower Cenomanian, Breggia River, Switzerland]
Rotalipora balernaensis (Gandolfi), Sigal 1969, p. 635, pl. 2, figs. 2, 4, 5–8 [lower Cenomanian, Breggia River, Switzerland]

Diagnosis. Test trochospiral, wall macroperforate and smooth, circular outline, peripheral margin angular with one keel, primary aperture umbilical-extraumbilical, supplementary apertures occur within the umbilical area in the earlier chambers and then become sutural; sutures depressed and straight on the umbilical side, raised and curved on the spiral side.

Distinguishing features. Distinguished from *R. evoluta* in being entirely keeled. Differs from *R. appenninica* in having a more circular outline with semicircular chambers on the spiral side that increase gradually in size, and presence of a larger umbilicus, straighter umbilical sutures, and a more developed periumbilical ridge.

Stratigraphic range. *Rotalipora balernaensis* first occurs slightly above the FO of *R. appenninica*.

Remarks. At Blake Nose this species is common and more abundant than *R. appenninica* after its first occurrence.

Rotalipora evoluta (Sigal, 1969)
Pl. 2, Figs. 6 a–c

- Rotalipora praebalernaensis* forma *evoluta* Sigal 1969, p. 637–638, pl. 1, figs. 10–12 [upper Albian, forage de Diego-Suarez, Madagascar]
Rotalipora praebalernaensis Sigal, Lipson-Benitah and Almogi-Labin 2000, p. 30, pl. 8, figs. 4–6 [upper Albian, offshore Israel, Yam boreholes]

Diagnosis. Test trochospiral, wall macroperforate, outline lobulate, primary aperture umbilical-extraumbilical, supplementary apertures at the base of the sutures bordered by a rim, raised and curved sutures on the earliest chambers of the spiral side, sutures depressed and straight on the umbilical side, peripheral keel present in the earlier chambers.

Distinguishing features. Differs from *T. praebalernaensis* in having a peripheral keel and raised sutures on the earlier chambers of the last whorl.

Stratigraphic range. From the *R. ticinensis* Zone to the middle part of the *R. appenninica* Zone.

Remarks. Between *T. praebalernaensis* and *R. balernaensis* Sigal (1969) recognized the subspecies *R. praebalernaensis* forma *evoluta*, which represents a slightly more advanced evolutionary stage than that of *T. praebalernaensis*, being characterized by a more rapid increase in size of the chambers in the last whorl and by the progressive acquisition of the peripheral keel. In agreement with Sigal (1969), all the specimens showing aligned pustules forming a peripheral keel and raised sutures on the earlier chambers are assigned to *R. evoluta*.

Rotalipora sp. 1
Pl. 3, Figs. 6a–c

Description. Test trochospiral, planoconvex, spiral side flat, wall smooth; equatorial periphery subcircular, peripheral margin trapezoidal with one keel less pronounced on the last chamber; chambers uniformly and slowly increasing in size, 6–8 in final whorl, triangular and inflated on the umbilical side, circular on the spiral side; sutures curved and raised on the spiral side, depressed and straight on the umbilical side; umbilicus moderately narrow and deep; supplementary apertures within the umbilical area of the earlier chambers, then becoming sutural; primary aperture umbilical-extraumbilical bordered by a thick lip.

Distinguishing features. Differs from the other *Rotalipora* species occurring in the same stratigraphic interval in having a planoconvex profile, more inflated chambers on the umbilical side and in possessing smaller supplementary apertures.

Stratigraphic range. Its range is restricted to within the *R. appenninica* Zone.

Remarks. This distinctive taxon is rare and co-occurs with *R. appenninica*.

Praeglobotruncana delrioensis (Plummer, 1931)

Pl. 4, Figs. 2a–c

Globorotalia delrioensis Plummer, 1931, p. 199, pl. 13, figs. 2a–c [lower Cretaceous, Del Rio Formation, on right bank of Shoal Creek, Austin, Travis County, TX]

Praeglobotruncana delrioensis (Plummer), Robaszynski, Caron, and others, 1979, p. 29, pl. 43, figs. 1a–c [topotype, Grayson Formation, TX]

Diagnosis. Test trochospiral, outline biconvex and lobulate, peripheral margin subrounded to subacute, imperforate and marked by an aligned concentration of pustules best developed on the early chambers of the last whorl; primary aperture umbilical-extraumbilical, bordered by a narrow flap; sutures straight and depressed on the umbilical side, curved and marked by pustules on the earliest chambers of the spiral side.

Distinguishing features. Distinguished from *Hedbergella* by possessing an imperforate peripheral margin.

Stratigraphic range. *Praeglobotruncana delrioensis* first occurs in the upper part of the *R. appenninica* Zone above the FO of *P. buxtorfi*. Its disappearance, not recorded in the present study of the Blake Nose section, falls in the upper part of the *R. cushmani* Zone (Premoli Silva and Sliter, 1995; Leckie and others, 2002).

Remarks. At Blake Nose this species displays wide morphological variability mainly regarding the number of chambers of the last whorl, the shape of the chambers, and degree of keel development (e.g., Leckie, 1984). In fact, besides specimens very close to the holotype, we also found (1) specimens with 6–7 chambers in the final whorl, with the six-chamber morphotypes more common than the five and seven-chambered forms, and (2) specimens with more globular and less compressed chambers compared to the holotype.

Praeglobotruncana stephani (Gandolfi, 1942)

Pl. 4, Figs. 4a–c

Globotruncana stephani Gandolfi, 1942, p. 130, pl. 3, figs. 4a–c [Cenomanian, Gorge of the Breggia River, near Chiasso, south-eastern Switzerland]

Praeglobotruncana stephani (Gandolfi), Robaszynski, Caron, and others, 1979, p. 47, pl. 48, figs. 1a–c [topotype, Breggia southeastern Switzerland]

Diagnosis. Test medium-high trochospiral, outline biconvex and lobulate, peripheral margin imperforate and marked by an aligned concentration of pustules; primary aperture umbilical-extraumbilical bordered by a narrow flap; sutures straight and depressed on the umbilical side, curved and marked by pustules on the earliest chambers of the spiral side.

Distinguishing features. Differs from *P. delrioensis* in having a more convex spiral side and a higher trochospire, in possessing a more regular and better developed alignment of pustules on the peripheral margin forming a keel, and presence of curved and raised sutures on the earlier chambers of the spiral side.

Stratigraphic range. *Praeglobotruncana stephani* first occurs in the upper part of the *R. appenninica* Zone above the first appearance of *C. libyca*. Its disappearance, not recorded in the Blake Nose section, falls in the middle part of the *H. helvetica* Zone (Premoli Silva and Sliter, 1995; Leckie and others, 2002).

Hedbergella astrepta nov. sp.

Pl. 6, Figs. 1a–c, 2a–c, 3a–c, and 4a–c

Hedbergella almadensis (Cushman and Todd), Bellier and Moullade, 2002, p. 20, pl. 1, figs. 16–18 [upper Albian, North Atlantic, Blake Nose ODP Site 1050]

Etymology. Named for the presence of straight (from the Greek “astreptos”) and depressed sutures on both sides.

Description. Wall macroperforate, muricae irregularly scattered on test surface, very abundant on the early outer chambers and gradually decreasing on the last ones; test low trochospiral, biconvex, equatorial periphery subcircular and lobulate, peripheral margin rounded; chambers globular and inflated, 7–8 in final whorl, uniformly and slowly increasing in size, triangular on the umbilical side, rhomboidal on the spiral side; sutures depressed, straight and radial; umbilicus narrow and deep; aperture an interiomarginal, extraumbilical-umbilical, low arch bordered by portici.

Distinguishing features. Differs from the other *Hedbergella* species in having more depressed and straight sutures on both sides. Distinguished from *T. roberti* by the absence of the supplementary apertures in the umbilical area. Importantly, *H. astrepta* differs from *T. roberti* in having a distinctively muricate wall, which is very different from the thick and encrusted wall with large perforations found in *T. roberti*.

Stratigraphic range. From the upper part of the *R. ticinensis* Zone to the upper part of the *R. appenninica* Zone.

Remarks. Bellier and Moullade (2002) and Moullade and others (2002), in their study of the upper Albian material from Leg 171B, attributed this upper Albian form to *Globigerina almadensis* Cushman and Todd (1948). Based on the similarity with one of the paratypes these authors preferred to use the name of *Hedbergella almadensis* rather than erecting a new name. Re-examination of the type material deposited at the Smithsonian Museum of Natural History, Washington, D.C. (USNM 58502; see Plate 6, Figs. 6a–c), showed that, besides the very poor preservation of the holotype, the paratypes do not belong to the same species. For this reason we erect a new name.

Size. Holotype maximum diameter 364 μ m, thickness 174 μ m; paratype 1 maximum diameter 375 μ m, thickness 182 μ m; paratype 2 maximum diameter 383 μ m, thickness 190 μ m.

Repository. Holotype (USNM 527794; Pl. 6, Figs. 1a–c), paratype 1 (USNM 527795; Pl. 6, Figs. 2a–c), and paratype 2 (USNM 527796; Pl. 6, Figs. 4a–c) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Type locality. Blake Nose, western North Atlantic, holotype from Sample 1050C-27R-1, 73–76 cm, paratype 1 from Sample 1050C-28R-3, 60–63 cm, and paratype 2 from Sample 1052E-46R-2, 50–53 cm.

Hedbergella blakensis nov. sp.

Pl. 4, Figs. 5a–c, and 6a–c

Etymology. Named for the type locality (Blake Nose) where it is found.

Description. Wall with dense pustules, irregularly distributed and more developed on the earliest chambers of the last whorl, last chamber smooth. Test low trochospiral, biconvex, equatorial periphery lobate, peripheral margin rounded, perforate and marked by pustules irregularly scattered on the first chambers of the last whorl. Chambers inflated, 6, rarely 7 in final whorl, uniformly and slowly increasing in size, triangular on the umbilical side, circular on the spiral side; sutures depressed and straight on both sides; umbilicus moderately narrow; primary aperture umbilical-extraumbilical, bordered by a thin lip.

Distinguishing features. Distinguished from *H. simplex* by having more but less lobate chambers that increase more uniformly and gradually in size in the last whorl. Differs from *H. delrioensis* in having a more lobate outline, and by possessing smaller and less inflated chambers that increase gradually in size in the last whorl. Resembles *P. delrioensis* but differs in having a more evenly scattered distribution of pustules on the test surface, and in not possessing an imperforate peripheral margin.

Phylogenetic relationships. This form probably evolved from *H. simplex* by increasing the number of chambers that become less lobate in the final whorl, and developing a low rate of chamber enlargement, and gave rise to *P. delrioensis* through the acquisition of an imperforate peripheral margin with fused pustules. However, although *H. blakensis* is likely the ancestor species of *P. delrioensis*, it was not found in the stratigraphic interval below the FO of *P. delrioensis*.

Stratigraphic range. *Hedbergella blakensis*'s stratigraphic distribution is very short and restricted to the uppermost part of the *R. appenninica* Zone at both Blake Nose sites. Its first appearance follows the FO of *P. delrioensis* and precedes the FO of *P. stephani*.

Remarks. This short-lived species commonly occurs together with *P. delrioensis* and *P. stephani* in the stratigraphic interval immediately below the extinction level of *P. buxtorfi*.

Size. Holotype maximum diameter 364 μ m, thickness 164 μ m; paratype maximum diameter 352 μ m, thickness 161 μ m.

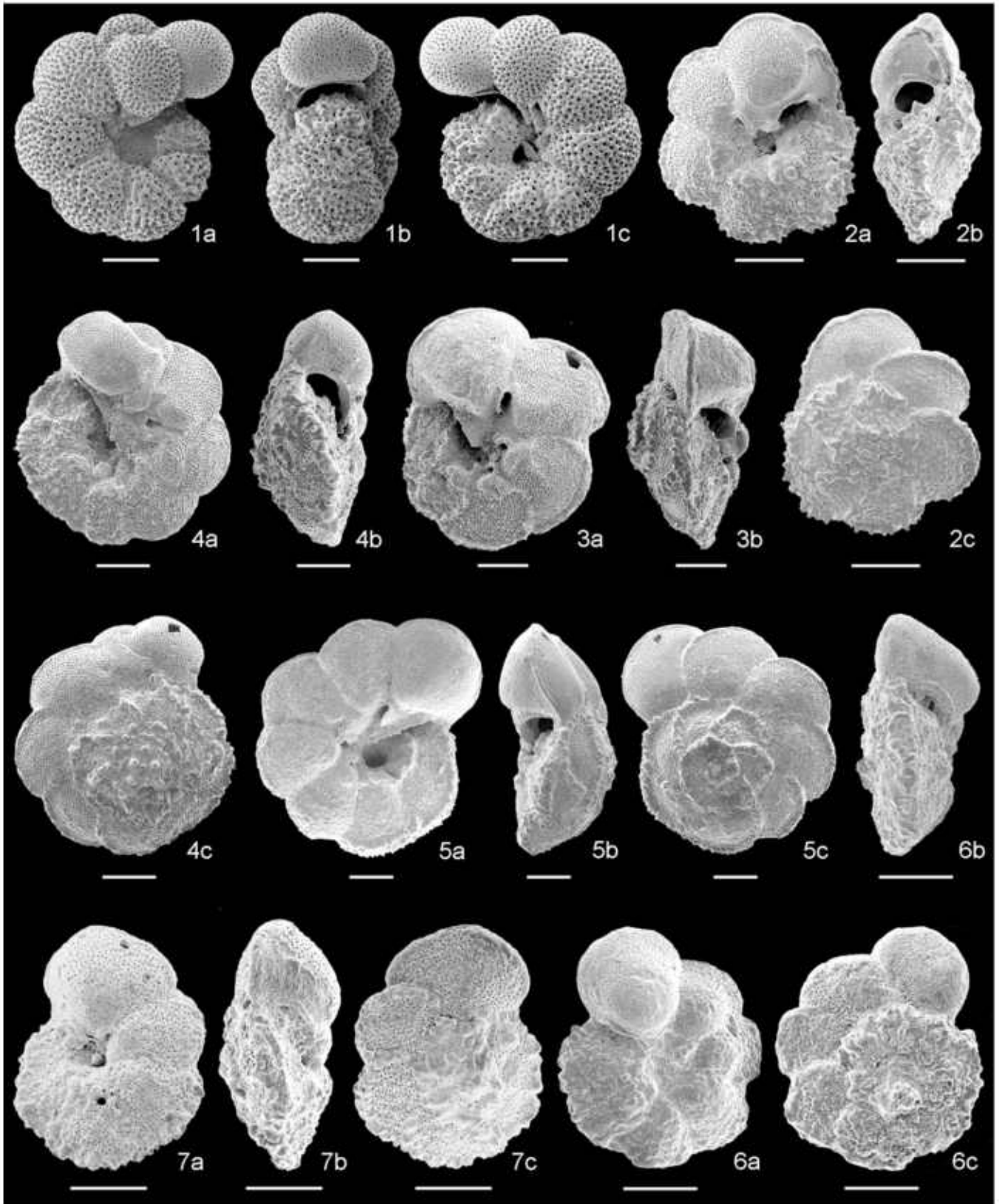


PLATE 3

(Scale bars 100 μ m) **1a-c** *Biticinella breggiensis*, Sample 1050C-27R-CC. **2a-c** *Rotalipora gandolfii*, Sample 1052E-40R-2, 118-121 cm. **3a-b** *Rotalipora globotruncanoides*, Sample 1050C-24R-1, 32-35 cm. **4a-c** *Rotalipora ticinensis*, Sample 1050C-27R-1, 73-76 cm. **5a-c** *Rotalipora balernaensis*, Sample 1052E-40R-2, 20-23 cm. **6a-c** *Rotalipora* sp. 1, Sample 1050C-27R-4, 134-136 cm. **7a-c** *Rotalipora appenninica*, Sample 1052-43R-3, 143-145 cm.

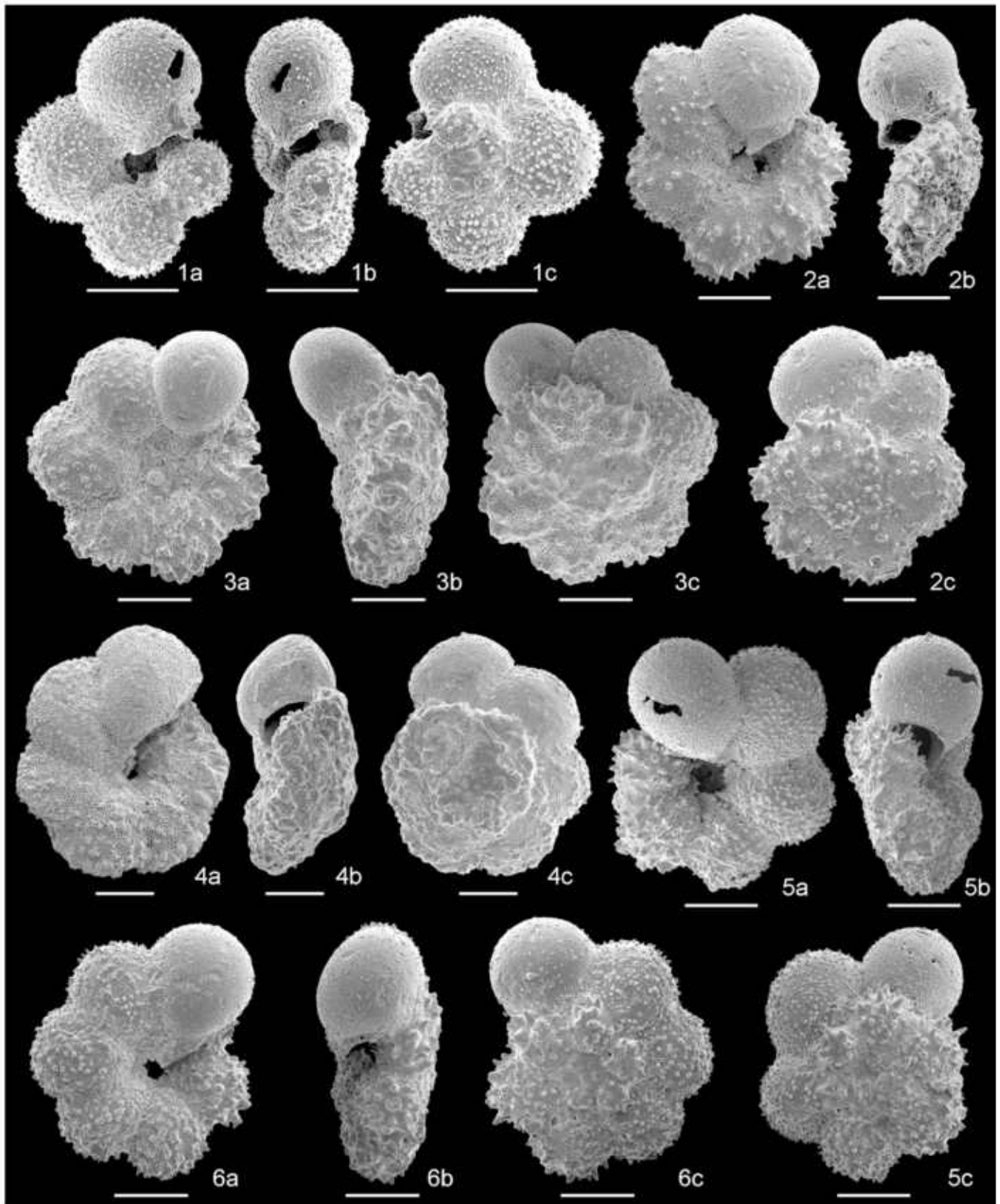


PLATE 4

(Scale bars 100 μm) **1a–c** *Hedbergella simplex*, Sample 1052E-42R-3, 64–66 cm. **2a–c** *Praeglobotruncana delrioensis*, Sample 1052E-40R-5, 65–66 cm. **3a–c** *Praeglobotruncana* cf. *stephani*, Sample 1052E-41R-4, 3–4 cm. **4a–c** *Praeglobotruncana stephani*, Sample 1052E-40R-2, 98–99 cm. **5a–c** *Hedbergella blakensis*, Sample 1052E-41R-4, 29–31 cm, holotype USNM 527788. **6a–c** *Hedbergella blakensis*, Sample 1052E-41R-4, 29–31 cm, paratype USNM 527789.

Repository. Holotype (USNM 527788; Pl. 4, Figs. 5a–c), paratype (USNM 527789; Pl. 4, Figs. 6a–c) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Type locality. Blake Nose, western north Atlantic, holotype and paratype from Sample 1052E-41R-4, 29–31 cm.

Hedbergella delrioensis (Carsey, 1926)

Pl. 7, Figs. 3a–c (Master's neotype) and Figs. 4a–c

Globigerina cretacea var. *del rioensis* Carsey, 1926, p. 43, 44 [lower Cenomanian, Del Rio Clay, Grayson Formation, Austin, TX]

Hedbergella delrioensis (Carsey), Longoria, 1974, p. 54, pl. 10, figs. 1–3 [neotype, Del Rio Clay, Grayson Formation, Austin, TX]

Hedbergella delrioensis (Carsey), Masters, 1976, p. 328, pl. 3, fig. 2 [neotype, Del Rio Clay on Shoal Creek, Austin, TX]

Diagnosis. Test low trochospiral, equatorial outline lobulate, peripheral margin rounded and slightly convex, wall macroperforate, test surface with irregularly distributed pustules more developed on the earlier chambers of the last whorl; chambers globular, 4 1/2 to 5 1/2 (rarely 6) increasing rapidly in size as added, last chamber often slightly offset towards the umbilical side; primary aperture a low umbilical-extraumbilical arch that extends on to the periphery, bordered by a flap; sutures radial and depressed on both sides.

Distinguishing features. Differs from *H. planispira* by having fewer chambers per whorl, larger and more inflated chambers, and a more strongly pustulose surface.

Remarks. The identity of *H. delrioensis* was the subject of many discussions as Carsey (1926) originally described this species from the Grayson Formation (Del Rio Clay), but failed to figure it and to designate the repository of the type specimens (Pessagno, 1967). In 1931, Plummer searched through the Carsey collection at the University of Texas and refigured some of Carsey's types but reported *H. delrioensis* missing. The lack of a type figure and type specimens to be referred to for comparison made the identification of *H. delrioensis* difficult. As a result, this species has been misidentified several times. A neotype for *H. delrioensis* was erected first by Longoria in 1974 and later by Masters in 1976. Both neotypes are deposited at the Smithsonian Museum of Natural History, Washington, D.C. with Longoria's neotype (USNM 184997) having priority, as was pointed out by Masters (1977). However, our re-examination of both type specimens revealed that Longoria's neotype has been lost and only the invalid neotype of Master (USNM 184813, see Plate 7, Figs. 3a–c) remains deposited in the repository.

At both Blake Nose sites we consistently found (1) common specimens of *H. delrioensis* very similar to the Master's neotype together with (2) very rare specimens that closely match Longoria's (1974) species concept (see Plate 7, Figs. 4a–c). For this reason, and despite the problems arising from the loss of the valid neotype, we consider both neotypes to fall within the morphologic variability of the same species.

Hedbergella planispira (Tappan, 1940)

Pl. 7, Figs. 1a–c (holotype) and Figs. 2a–c

Globigerina planispira Tappan, 1940, p. 12, pl. 19, fig. 12 [Cenomanian, Grayson Formation, Denton County, TX]

Hedbergella planispira (Tappan), Robaszynski, Caron, and others, 1979, p. 139, pl. 27, figs. 1a–c [topotype, Grayson Formation, TX]

Diagnosis. Test low trochospiral, equatorial outline circular and slightly lobulate, peripheral margin rounded; wall macroperforate with irregularly distributed pustules more developed on the earlier chambers of the last whorl; last chamber smooth; chambers globular, 6–8 increasing slowly in size as added; primary aperture umbilical-extraumbilical extended to the periphery and bordered by a narrow lip; sutures straight and depressed on both sides.

Distinguishing features. Distinguished from the other *Hedbergella* species in having a higher number of chambers in the last whorl increasing uniformly and gradually in size, and in having a wall surface with irregularly distributed pustule.

Stratigraphic range. Previous reports of *H. planispira* found in the early Albian *Hedbergella planispira* Zone are based on incorrect identification, as no hedbergellid forms with a pustulose surface texture have been documented in that interval. *Hedbergella planispira* is present in the lowermost upper Albian samples recovered at sites 1050 and 1052 and, thus, the level of its evolutionary appearance was not recorded. The species is known to range throughout the Cenomanian, but determination of its extinction level will also require further study.

Remarks. Re-examination of the type material deposited at the Smithsonian Museum of Natural History, Washington, D.C. (USNM 25113; see Plate 7, Figs. 1a–c) showed that the test surface of *H. planispira* is not entirely smooth as stated in the original description (Tappan, 1940), and common pustules are irregularly scattered on the early outer surface chambers, then gradually decrease on the last ones. Small, smooth-walled hedbergellids from within the so-called *Hedbergella planispira* Zone of the early Albian that have previously been attributed to *H. planispira* should no longer be included in this species.

Hedbergella praelibyca nov. sp.

Pl. 5, Figs. 1a–c, 2a–c, 3a–c, 4a–c and 5a–c

Etymology. Ancestor of *C. libyca*.

Description. Wall macroperforate, surface with pustules irregularly scattered on test surface, sometimes becoming aligned as costellae without a preferential alignment direction. Test low trochospiral, biconvex, equatorial periphery subcircular, moderately lobulate, peripheral margin rounded. Chambers inflated and globular, 5–7 (usually 6) in final whorl, uniformly and gradually increasing in size. Sutures depressed, straight and radial. Umbilicus moderately narrow and deep. Aperture an interiomarginal, extraumbilical-umbilical with a low arch bordered by portici.

Distinguishing features. *Hedbergella praelibyca* differs from *C. libyca* in lacking meridionally aligned costellae. Distinguished from *H. astrepta* in having fewer chambers in the last whorl. *Hedbergella praelibyca* resembles *Hedbergella portsdownensis* (Williams-Mitchell, 1948) and *Hedbergella brittonensis* (Loeblich and Tappan, 1961, probably junior synonym of *H. portsdownensis*) but differs in having a lower trochospiral coiling mode, and by possessing a wall surface with more irregularly scattered pustules sometimes becoming aligned as costellae.

Phylogenetic relationships. This species probably evolved from *H. delrioensis* in the upper part of the *R. ticinensis* Zone by increasing the number of chambers in the final whorl and developing a dense, muricate ornament. It gave rise to *C. libyca* in the upper part of the *R. appenninica* Zone.

Stratigraphic range. From the upper part of the *R. ticinensis* Zone to the lower part of the *R. globotruncanoides* Zone.

Size. Holotype maximum diameter 329 µm, thickness 170 µm; paratype 1 maximum diameter 333 µm, thickness 162 µm; paratype 2 maximum diameter 301 µm, thickness 160 µm.

Repository. Holotype (USNM 527791; Pl. 5, Figs. 1a–c), paratype 1 (USNM 527792; Pl. 5, Figs. 4a–c), and paratype 2 (USNM 527793; Pl. 5, Figs. 3a–c) deposited at the Smithsonian Museum of Natural History, Washington, D.C.

Type locality. Blake Nose, western north Atlantic, holotype from Sample 1050-27R-6, 74–78 cm, paratype 1 from Sample 1052E-38R-4, 44–46 cm, and paratype 2 from Sample 1052E-43R-6, 139.5–141.5 cm.

Hedbergella wondersi Randrianasolo and Anglada, 1989

Pl. 1, Figs. 4a–b

Hedbergella wondersi Randrianasolo and Anglada, 1989, p. 806, pl. 1, figs. 1–3 [upper Albian, Antsiranana (ex Diego-Suarez), northern Madagascar]

Diagnosis. Test low trochospiral, equatorial outline oblate, peripheral margin rounded; wall macroperforate; chambers inflated subtriangular, 7–9 increasing slowly in size as added, muricae on the first chambers of the last whorl; primary aperture from umbilical-extraumbilical to slightly equatorial, sutures straight and depressed on both sides.

Distinguishing features. Differs from *Hedbergella planispira* in having more developed muricae on the first chambers of the last whorl and in attaining a larger size. Distinguished from *G. pulchellus* by its trochospiral coiling mode.

Stratigraphic range. It commonly occurs in the *R. ticinensis* Zone and disappears in the second half of the zone, close to the FO of *H. astrepta*.

Remarks. Although this species was considered a junior synonym of *Hedbergella almadenensis* by Moullade and others (2002), this attribution is not followed in the present study.

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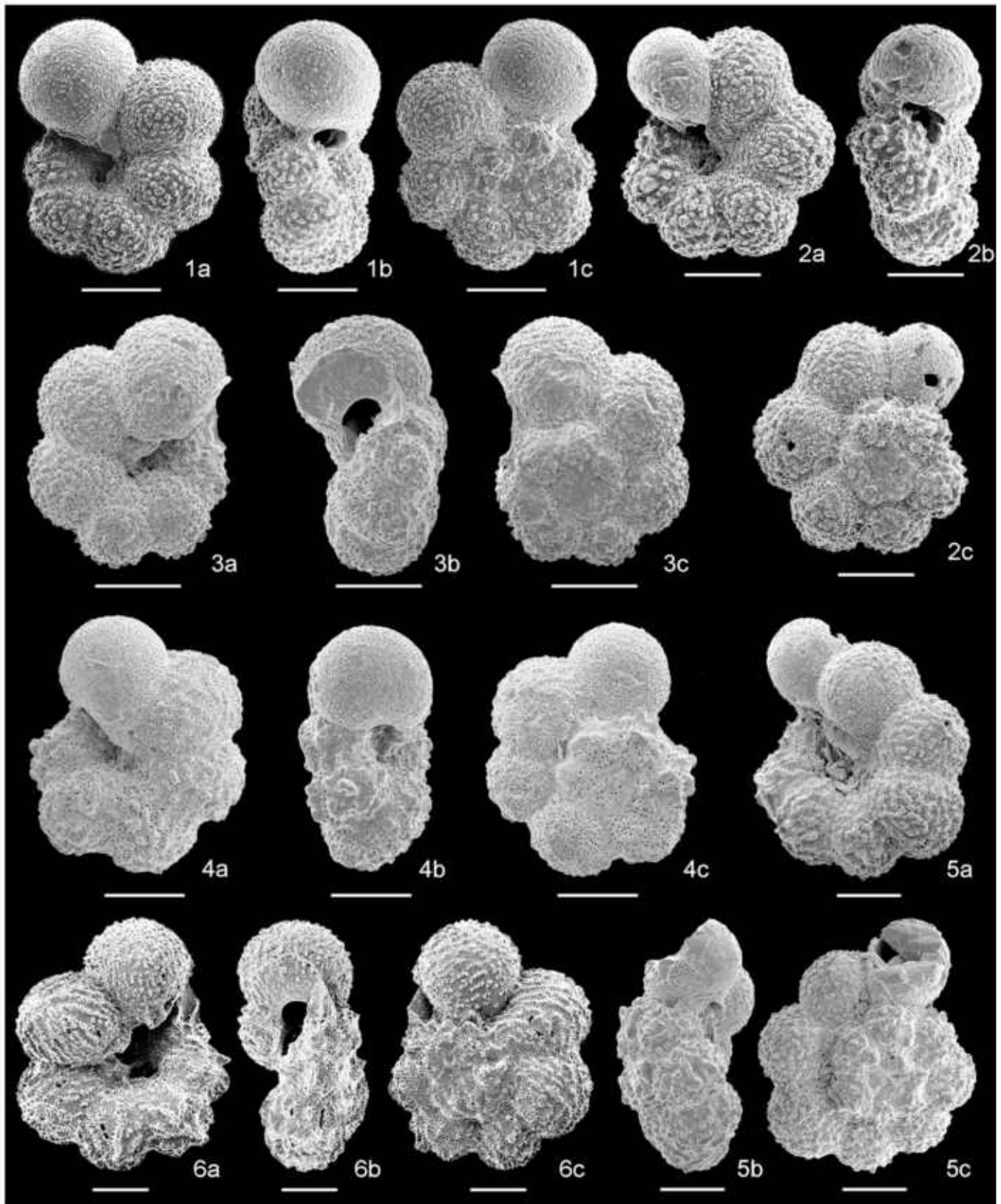


PLATE 5

(Scale bars 100 μ m) **1a–c** *Hedbergella praelibyca*, Sample 1050-27R-6, 74–78 cm, holotype USMN 527791. **2a–c** *Hedbergella praelibyca*, Sample 1052E-38R-4, 44–46 cm. **3a–c** *Hedbergella praelibyca*, Sample 1052E-43R-6, 139.5–141.5 cm, paratype 1 USMN 527793 **4a–c** *Hedbergella praelibyca*, Sample 1052E-42R-1, 28–30 cm, paratype 2 USMN 527792. **5a–c** *Hedbergella praelibyca*, Sample 1052E-41R-3, 124–126 cm. **6a–c** *Costellagerina libyca*, Sample 1050E-26R-4, 83–86 cm.

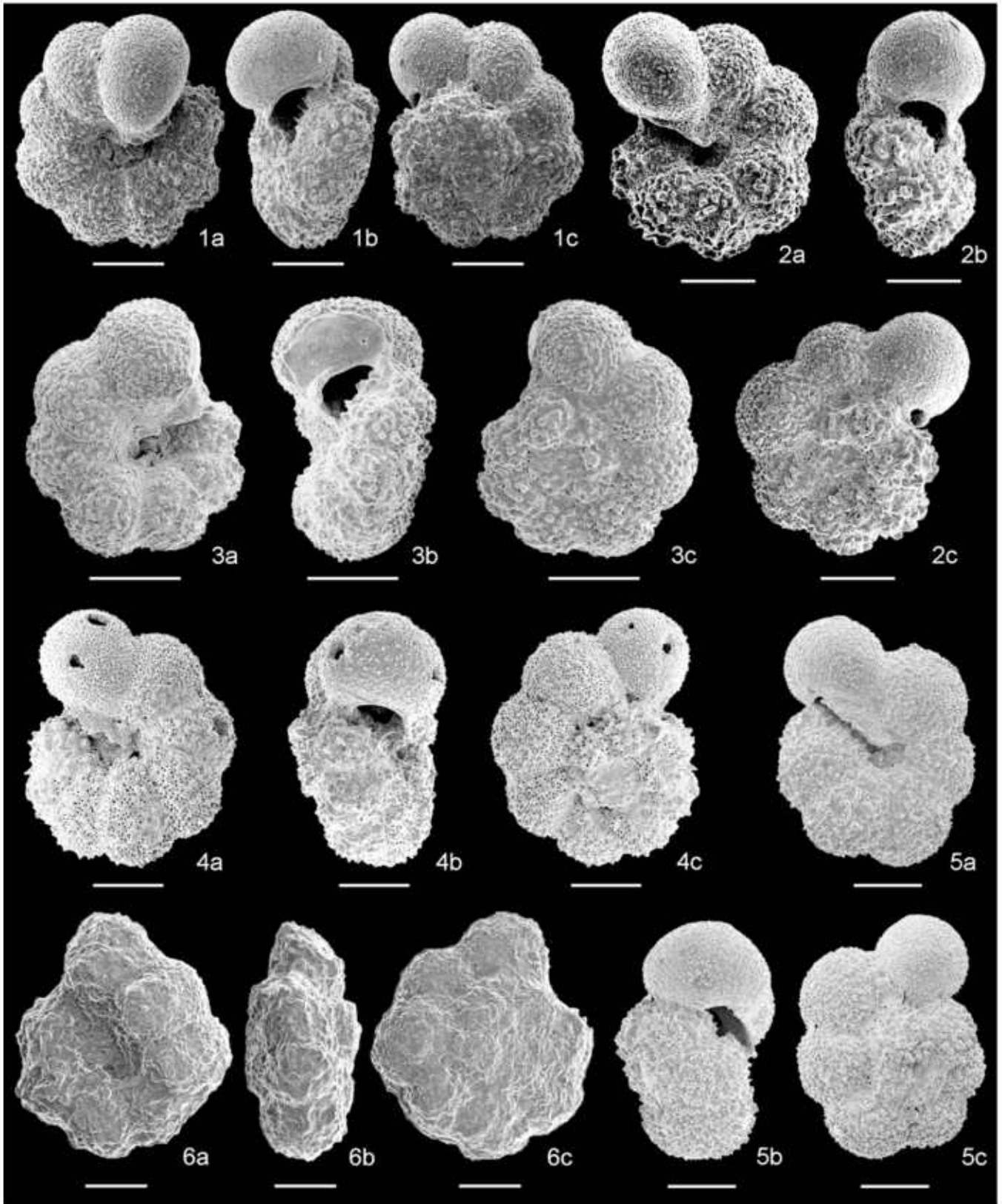


PLATE 6

(Scale bars 100 μm) **1a–c** *Hedbergella astrepta*, Sample 1050C-27R-1, 73–76 cm, holotype USMN 527794. **2a–c** *Hedbergella astrepta*, Sample 1050C-28R-3, 60–63 cm, paratype 1 USMN 527795. **3a–c** *Hedbergella astrepta*, Sample 1050C-29R-6, 21–24 cm. **4a–c** *Hedbergella astrepta*, Sample 1052E-46R-2, 50–53 cm, paratype 2 USMN 527796. **5a–c** *Hedbergella* aff. *astrepta*, Sample 1050C-27R-2, 25–26 cm. **6a–c** *Globigerina almadenensis*, holotype USMN 58502.

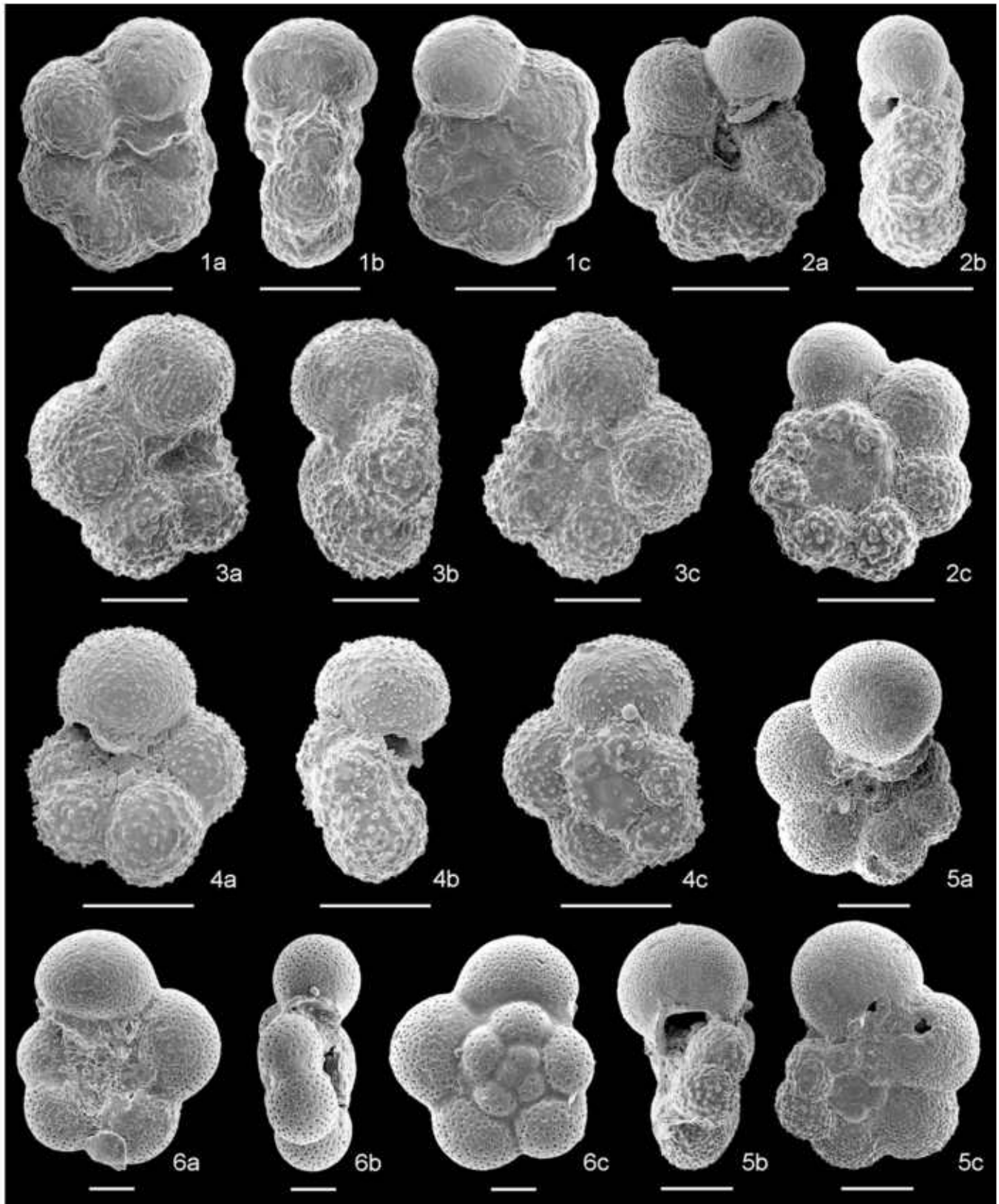


PLATE 7

(Scale bars 100 μm except where otherwise stated) **1a-c** *Hedbergella planispira*, holotype USNM 25113. **2a-c** *Hedbergella planispira*, Sample 1050C-27R-CC. **3a-c** *Hedbergella delrioensis*, Master's neotype USMN 184813. **4a-c** *Hedbergella delrioensis*, Sample 1052E-41R-1, 19-120 cm. **5a-c** *Hedbergella* aff. *delrioensis*, Sample 1050C-27R-1, 73-76 cm. **6a-c** *Hedbergella* sp., Sample 1050C-27R-1, 73-76 cm, scale bar 20 μm .

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