INTRODUCTION

The Aptian–Albian is a unique time interval in Earth’s history due to the common occurrence of organic-rich sedimentary rocks, which are frequently related to oceanic anoxic events (OAEs; e.g., Arthur and Premoli Silva, 1982; Jenkyns, 1995; Jenkyns and Wilson, 1999). These anoxic events are characterized by the widespread occurrence of black shales and drastic shifts in the carbon isotope ratio (Leckie and others, 2002), leading to major reorganizations in the marine ecosystem, including planktic foraminifera (e.g., Leckie, 1984; Koutsoukos and others, 1991b; Premoli Silva and others, 1999; Leckie and others, 2002). Although events in this time interval are highly relevant for understanding coupled global paleoceanographic and paleoclimatic changes, stratigraphic problems may hamper their accurate investigation. For instance, no section has been chosen yet for a Global Boundary Stratotype Section (GBS) at the base of the Albian stage, although several candidates have been proposed (e.g., Kennedy and others, 2000; Hancock, 2001), including a promising sequence at Prè-Guitard (Vocontian Basin, SE France; Petrizzo and others, 2012). The main reason for this indefiniteness is the elevated degree of endemism of the ammonoid assemblages, commonly used to define Cretaceous stages boundaries (Birkelund and others, 1984). This problem causes several discrepancies between age assignments when biostratigraphic schemes based on different fossil groups are applied to the same sedimentary succession (e.g., Bolli and others, 1978), making it difficult to study the paleoceanographic events mentioned above (e.g., OAEs).

The objectives of this study are to present the taxonomy and biostratigraphy of the Aptian–Albian planktic foraminifera recovered from Deep Sea Drilling Project (DSDP) Site 364 (Fig. 1), Kwanza Basin (offshore Angola), and use their distributions to infer paleoecological aspects of the studied fauna and their paleoceanographic significance. Despite the generally poor preservation of the studied material, poor core recovery and absence of some tropical/subtropical biostratigraphic markers, the studied fauna remains relevant for a better understanding of the Aptian–Albian interval and associated environmental conditions of the northern South Atlantic Ocean (north of the Walvis Ridge-Rio Grande Rise).

GEOLOGICAL SETTING

Séranne and Anka (2005) proposed the physiographic subdivision of the African margin into the equatorial western African margin (with the occurrence of evaporitic and carbonate units in the Cretaceous) and the southwest African margin (dominated by clastic deposition in the Cretaceous), which are divided by the high-standing Walvis Ridge (Fig. 1). Historically, the entire basin and continental shelf of the equatorial western African margin has been called the Angola Basin, as it is the largest depression in the northeastern South Atlantic Ocean. Its physical isolation by the Walvis Ridge was inherited from its origin in the Barremian–Aptian (cf. Séranne and Anka, 2005), allowing the formation of a thick layer of evaporites that exceeds 3 km in some locations. In the context of the Angola Basin, recent studies proposed the recognition of the Kwanza Basin, in which DSDP Site 364 is located (cf. Brownfield and Charpentier, 2006), classified as an Atlantic-type marginal sag basin with the deposition of evaporitic units during the Aptian (e.g., Clifftord, 1986; Brownfield and Charpentier, 2006). The Kwanza Basin is bordered to the north by the Ambriz Arch, to the south by the Benguela High, to the east by the edge of the sedimentary basins and to the west by the 4-km bathymetric depth.
Séranne and Anka (2005) subdivided the geological record of the equatorial western African margin (including the Kwanza Basin) into four main phases: rifting, rift–drift transitional, drift, and late drift. According to these authors, the rift–drift transitional phase is characterized by a transgressive clastic sequence, grading upwards from fluvial sandstones and lagoonal shales to thick evaporites, whose deposition during the mid- to late Aptian is a distinctive feature of this phase. The marine transgression, initiated by evaporite formation, was followed by deposition of shallow-water carbonates (dolomites and limestones studied herein) during the late Aptian–Albian (Binga and Pinda formations of Séranne and Anka, 2005, and Brownfield and Charpentier, 2006; or Pinda Group of Valle and others, 2001; mentioned herein as units 5–7).

The breakup of the African and South American plates began in the Early Jurassic in the southernmost part of Gondwana and gradually extended northward during the Early Cretaceous (Uchupi, 1989; Binks and Fairhead, 1992; Guiraud and Maurin, 1992). In this way, the Gulf of Guinea opened last, forming a continuous dysoxic–anoxic seaway from Walvis Ridge to North Africa in the late Aptian–Turonian (Tissot and others, 1980). Although earlier paleogeographic studies stated that the first marine incursions came from the central Atlantic Ocean (Koutsoukos and others, 1991b; Koutsoukos, 1992; Dias-Brito, 1995, 2000; Azevedo, 2004; Bengtson and others, 2007; Arai, 2009). During the late Aptian–early Albian, the Kwanza Basin had stagnant bottom-water conditions that prevented oxidation of organic matter (Bolli and others, 1978).

Albian marly-chalks and limestones at DSDP Site 364 contain pressure-solution stylolites, steeply dipping bedding contacts, overturned folds, and interformational breccias, probably linked to salt diapirism and/or gravitational flows due to a slope paleophysiology (Bolli and others, 1978). The sedimentary rocks recovered in the deepest cores from this site suggest outer-shelf or shelf-break depths during black shale deposition (Bolli and others, 1978).

MATERIAL AND METHODS

DSDP Site 364 is located offshore of Angola, southwest of Luanda (11°34.32’S; 11°58.30’E), at a water depth of 2448 m. The studied Aptian–Albian section comprises the interval from cores 42–24 [1033.5–672.5 mbsf (meters below the seafloor)] that were spot-cored at an average spacing of 10 m with 61% average recovery (Bolli and others, 1978). Three lithologic units (Bolli and others, 1978) occur in the studied stratigraphic interval (units 7–5 from bottom to top; Fig. 2). Unit 7 is composed of marly dolomitic limestones and black shales, divided into two subunits based on the greater proportion of black shales intervals in subunit 7b than in 7a. Unit 6 contains intercalations of limestones and mudstones, which was divided into subunits a, b, and c based on changes of color and induration. Unit 5 (subunit 5b) is a marly chalk with black shales.

Seventy-four samples were collected for the micropaleontological survey, one sample per section with an average spacing of 1.5 m within cored intervals. Approximately 20 g of each sample were crushed and soaked in a 200-ml hydrogen peroxide solution (29% H₂O₂) for 24 hours. For indurated limestones the acetylsyrin method of Rodrigues and others (2012, experiment 12) was used to extract foraminiferal tests. The remaining residues were washed through a 38-μm sieve, and at least 300 planktic specimens were identified from each sample under a stereomicroscope. After an ultrasonic bath, scanning electron micrographs of the specimens were taken to ensure accurate identifications using wall microstructures. Abundances of planktic foraminiferal species were estimated relative to the total planktic assemblage. First occurrences (FOs) and last occurrences (LOs) of marker species were used to identify biostratigraphic events, mainly following Petrizzo and Huber (2006), Huber and Leckie (2011), and Petrizzo and others (2012). Average test diameter was based on measurements of at least five specimens of each species/sample. The software PAST—Paleontological Statistics was used for statistical analysis (Hammer and others, 2001).

Stable carbon and oxygen isotopic measurements were performed on 38 bulk, powdered limestone and marlstone samples at the NEG-LABISE, Departamento de Geologia, Universidade Federal de Pernambuco. Carbon dioxide was extracted in a high vacuum line after reaction with phosphoric acid (H₃PO₄) at 100% concentration and 25°C, and cryogenically cleaned as described by Craig (1975). Released CO₂ was analyzed in a double inlet, triple collector SIRA II mass spectrometer, with C and O
Figure 2. Stratigraphic range of selected planktic foraminiferal species and δ¹⁸O and δ¹³C measurements reported as per mil (‰) with reference to V-PDB (Vienna-Pee Dee belemnite international standard); continuous segments between points represent cored intervals, while dashed segments represent uncored intervals in DSDP Site 364. Black shales are identified from the description presented in Bolli and others (1978). Cored intervals are presented in gray and total core recovery in black; unconformity is represented by a wavy line; mbsf = meters below the seafloor.
isotopic values reported as δ (‰) deviations with reference to V-PDB (Vienna-Pee Dee belemnite international standard).

**BIOSTRATIGRAPHY**

**INTRODUCTION**

Aptian–Albian sedimentary successions from the southernmost sector of the northern South Atlantic Ocean (north to the Walvis Ridge–Rio Grande Rise) lack several typical tropical/subtropical planktic foraminiferal index species (e.g., Premoli Silva and Boersma, 1977; Caron, 1978; Viviers, 1987; Bralower and others, 1993). As a consequence, several authors have made tentative zonal assignments based on the occurring assemblages, and have interpreted this pattern as an effect of a possible Austral paleobiogeographic affinity (e.g., Premoli Silva and Boersma, 1977; Caron, 1978).

The biostratigraphic scheme proposed by Huber and Leckie (2011) was applied in the present study when age-diagnostic taxa were recovered; otherwise, assemblages were tentatively assigned to foraminiferal zones based on the known stratigraphic ranges of the occurring species. Two intervals remain unzoned (the base and the top of the studied site), due to the absence of age-diagnostic forms. The sedimentary succession from cores 37–26, late Aptian–late Albian in age, contains the following planktic foraminiferal zones (identified from bottom to top): *Hedbergella trocoidea*, *Pararicinaella eubejaouensis*, *Microhedbergella rischi*, and *Pseudothalmanninella ticinensis* (Table 1; Fig. 2). The definition of each zone and their microfaunal characteristics are described below.

**APTIAN**

The basal strata of DSDP Site 364 from 1032.37–932.45 mbsf (cores 42–37) remain unzoned in the present study due to the absence of age-diagnostic species (Fig. 2), although the occurrences of *Hedbergella praetrocoidea* and *Hd. trocoidea* (see systematics below for their stratigraphic ranges and Fig. 2) suggest an Aptian age for this interval. These data support the Aptian age suggested by Caron (1978), who subdivided this interval into the “algeriana” and “gorbachikae” zones, based on the faunal associations. However, Caron (1978) reported no age-diagnostic species in the assemblages from this interval, and the ones recovered herein are insufficient to subdivide it. It is also significant that *Favusella washtensis*, a species probably adapted to shallow, warm, hypersaline, carbonate-saturated environments (Koutsoukos and others, 1989), is restricted to cores 42–40 (Fig. 2). Its presence may explain the absence of open-marine forms that may have lived deeper to cores 42–40 (Fig. 2). Its presence may explain the absence of open-marine forms that may have lived deeper.

The stratigraphic interval from 932.45–877.42 mbsf was assigned to the *Hedbergella trocoidea* Partial-Range Zone (Fig. 2). According to Huber and Leckie (2011), this zone, which is the lowest identified in the studied site, is defined by the partial range of *Hd. trocoidea*, from the LO of *Gld. algerianus* to the FO of *Pa. eubejaouensis*. Since *Gld. algerianus* does not occur in the studied succession, the basal boundary of this zone is tentatively placed at the FO of *Hedbergella labocaensis* (see systematics below and Fig. 2). Typical species of this stratigraphic interval include *Hd. aptiana*, *Hd. labocaensis*, *Hd. trocoidea*, and *Gld. barri*.

The interval between 877.42–844.57 mbsf was assigned to the *Pararicinaella eubejaouensis* Taxon-Range Zone (Fig. 2), which is defined by the stratigraphic range of the nominal species. The FO of *Pa. eubejaouensis* herein coincides with the FO reported by Caron (1978), while its LO is higher in the succession than reported by Caron (1978). Typical species within the zone include *Gld. aptiensis*, *Microhedbergella* sp. aff. *Mi. miniglobularis*, and *Gld. barri*, the last of which Verga and Premoli Silva (2003b) also reported in the lowermost *Ticinella bejaouensis* Zone (= *Pararicinaella eubejaouensis* Zone herein) in Tethyan sections. There are remarkable extinction levels within this zone, as in sample 364-33-5, 65–69 cm (850.15 mbsf), and at its uppermost boundary (Table 1), where virtually all the long-ranging Aptian species characteristic of the *Hedbergella trocoidea* Zone become extinct.

**ALBIAN**

The *Microhedbergella rischi* Interval Zone was identified between 829.46–807.4 mbsf (Fig. 2), being defined by Huber and Leckie (2011) as the stratigraphic interval between the FO of *Mi. rischi* and the FO of *Ticinella madecassians* (absent herein due to a unconformity). Species characteristic of this zone are *Mi. rischi*, *Mi. pseudoplanispira*, *Microhedbergella* sp. aff. *Mi. miniglobularis*, *Microhedbergella rischi* trans. madecassiana, *M. angolae* and *Ticinella* sp. aff. *Ti. primula*.

Despite the absence of zonal markers [as previously reported for sections in the South Atlantic Ocean (Premoli Silva and Boersma, 1977; Caron, 1978; Viviers, 1987)], the stratigraphic interval from 807.4–715.34 mbsf was tentatively assigned to the *Pseudothalmanninella ticinensis* Zone [as defined by Caron (1985); Fig. 2], based on the stratigraphic ranges of the co-occurring species (see systematics below). The base of this tentatively zoned interval is placed at the FO of *Muricohedbergella astrept* (807.4 mbsf), while its top is placed at the LO of *Mu. angolae* (715.34 mbsf). The FOs of *Muricohedbergella praetlybyca* and *Ticinella raynada* within this interval also support the zonal assignment. Petrizzo and Huber (2006) previously recognized the reliability of the FOs of *Mu. astrept* and *Mu. praetlybyca* as secondary markers within this zone in the Atlantic Ocean. The direct contact between the *Microhedbergella rischi* and the *Pseudothalmanninella ticinensis* zones indicates a major unconformity, spanning four planktic foraminiferal zones (latest early–earliest late Albian in age; Huber and Leckie, 2011).

Higher in the section, the stratigraphic interval from 715.34–672.92 mbsf remains unzoned due to the absence of foraminifera or lack of age-diagnostic species (Table 1). Proto Decima and others (1978) attributed a late Albian age to this interval, based on the presence of the nannofossil *Eiffellithus turrisieffeli* (Deflandre) that probably first
<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth (cm)</th>
<th>Location</th>
<th>Preservation index</th>
<th>Relative Abundance</th>
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<td>710</td>
<td>5</td>
<td>B</td>
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<td>1070</td>
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</table>

**Notes:**
- A: Abundant (>25%), C: Common (10-25%), F: Few (1-10%), R: Rare (<1%).
- Preservation index follows Huber and Leckie (2011), where G = good, M = moderate, and P = poor; mbsf = meters below the seafloor.

**Table 1:** Relative abundances of planktic foraminiferal species from the Aptian–late Albian of DSDP Site 364. Abundances are represented as follows: A = abundant (>25%), C = common (10-25%), F = few (1-10%), R = rare (<1%). Preservation index follows Huber and Leckie (2011), where G = good, M = moderate, and P = poor; mbsf = meters below the seafloor.
occurs within the *Pseudothalmanninella ticinensis* Zone (Gale and others, 2011).

**DISCUSSION**

As described by Huber and Leckie (2011) and Pettrizzo and others (2012), the Aptian/Albian boundary, equated to the Niveau Kilian from the Vocontian Basin (Pettrizzo and others, 2012), is characterized by a remarkable faunal turnover in DSDP Site 364 that is marked by the extinction of virtually all long-ranging Aptian species (only *Microhedbergella* sp. aff. *Mi. miniglobularis* crossed the boundary) and followed by the appearance of a few small smooth-walled species (Table 1; cf. Huber and Leckie, 2011). Considering the sampling resolution utilized herein and the poor core recovery (see Fig. 2 for core thicknesses), the Aptian/Albian boundary is spanned by an uncored interval of ~13 m between the *Paraticinella eubejaouensis* and the *Microhedbergella rischi* zones (Fig. 2). Despite the absence of the intervening *Microhedbergella miniglobularis* (see Huber and Leckie, 2011) and *Microhedbergella renilaevis* (Pettrizzo and others, 2012) zones, the existence and duration of a boundary unconformity cannot be reliably estimated due to the low sampling resolution. However, the presence of *Microhedbergella* sp. aff. *Mi. miniglobularis* (Table 1; cf. Huber and Leckie, 2011) suggests that the *Paraticinella eubejaouensis* Zone is almost complete and the Aptian/Albian boundary should fall in the lower part of the uncored interval between cores 33 and 32.

Despite the tentative assignment of interval 807.4–715.34 mbsf to the *Pseudothalmanninella ticinensis* Zone, the change from early Albian (*Microhedbergella rischi* Zone) to late Albian (*Pseudothalmanninella ticinensis* Zone) assemblages is abrupt and distinct (Fig. 2). This juxtaposition of zones signifies a major unconformity within core 31, spanning the latest early–earliest late Albian *Ticinella madecassiana, Ticinella primula, Ticinella praeticinensis* and *Pseudothalmanninella subticinensis* zones (Huber and Leckie, 2011). Furthermore, planktic foraminiferal tests are poorly preserved, and even corroded in some samples below this unconformity, and moderately to well-preserved above it (Table 1). For comparison, Huber and Leckie (2011) reported even larger unconformities above the *Microhedbergella rischi* Zone in ODP Holes 1049A and 1049B and DSDP Site 390 (Blake Plateau, North Atlantic Ocean).

The most conspicuous difference between the biostratigraphic zonation reported by Caron (1978) for DSDP Site 364 and this one is the unconformity signified by the absence of middle Albian assemblages (Fig. 2). This difference is believed to result from problems with the identification of ticinellids. For instance, Caron (1978) identified the middle Albian *Ticinella primula* Zone on the occurrence of the nominal taxon. However, Caron's figured specimen of *Ti. primula* Luterbacher seems more likely to fit the description of *Tt. madecassiana* (*Microhedbergella rischi* trans. *madecassiana* herein) due to the rapid growth of the last chambers. Also, Caron’s figures of *Ti. cf. Ti. roberti* (Gandolfi) and *Ti. praeticinensis* Sigal do not yield a typical “ticinellid wall structure,” being herein considered *Mu. astrepta* and *Mu. praetibyca*, respectively (see systematics below).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth (mbsf)</th>
<th>(\delta^{13}C_{V-PDB}) (%)</th>
<th>(\delta^{18}O_{V-PDB}) (%)</th>
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</tr>
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<td>364-40-5, 63–66 cm</td>
<td>992.63</td>
<td>0.12</td>
<td>-5.07</td>
</tr>
<tr>
<td>364-41-3, 41–44 cm</td>
<td>1008.41</td>
<td>-0.21</td>
<td>-5.47</td>
</tr>
<tr>
<td>364-42-1, 137–139 cm</td>
<td>1025.37</td>
<td>-2.59</td>
<td>-4.85</td>
</tr>
</tbody>
</table>

**CARBON AND OXYGEN ISOTOPES**

\(\delta^{13}C\) and \(\delta^{18}O\) Values

The \(\delta^{13}C\) values vary between −2.59 and 2.94% in the Aptian–late Albian interval at Site 364 (Table 2), with an increase from cores 42–36, a more or less variable plateau from cores 36–28, and a decrease from cores 28–24 (Fig. 2). It is remarkable that these values decrease near the black shale levels (e.g., from cores 42–39 and within core 25). The \(\delta^{18}O\) values vary from −5.47 to −2.16%, with an increase from cores 42–36 followed by fluctuations scattered around a mean value of about −3.23% from cores 36–24 (Fig. 2).

Some authors have suggested that significant positive correlation between \(\delta^{13}C\) and \(\delta^{18}O\) values may indicate a diagenetic overprint (e.g., Jenkyns, 1995), but our stable isotopic measurements display no such correlation (Fig. 3), with a linear correlation index of \(r = 0.32\), suggesting only a minor diagenetic overprint. The \(\delta^{18}O\) values (Fig. 2), however, are not discussed further, as they display the typical sawtooth pattern (Jenkyns and Wilson, 1999) that
General trends in $\delta^{13}$C values (Fig. 2) are comparable to previously published curves for the Aptian–Albian, particularly the increasing trend in the late Aptian (e.g., Jenkyns, 1995; Bralower and others, 1999; Jenkyns and Wilson, 1999; Price, 2003; Herrle and others, 2004; Huber and others, 2011). These values are at a minimum within the Globigerinelloides algerianus Zone, followed by a return to more positive values across the Hedbergella trocoidea and Paraticinella eubejaouaensis zones (e.g., Jenkyns, 1995; Price, 2003; Herrle and others, 2004). Values decrease at the Aptian/Albian boundary (Herrle and others, 2004), increase to positive levels during the late Albian, and then return to pre-excursion levels (Price, 2003). These trends, reported for a wide range of localities, are quite comparable to our $\delta^{13}$C curve (Fig. 2). The increasing $\delta^{13}$C values from core 42 through the Hedbergella trocoidea and Paraticinella eubejaouaensis zones likely correspond to the isotopic segments C9 and C10 described by Bralower and others (1999) and Ap11–Ap15 described by Herrle and others (2004). The $\delta^{13}$C minima in cores 42–40 and the deposition of $C_{\text{org}}$-rich sediments in cores 42–39, suggesting that some, or even all, the black shale levels in these cores [marked in Figs. 2 and 4 as originally described by Bolli and others (1978)] could be correlated to the so-called “late Aptian anoxic event,” described by Bralower and others (1999) within the upper Globigerinelloides algerianus Zone. These authors related that event to the deposition of $C_{\text{org}}$-rich strata associated with a decrease in $\delta^{13}$C values and rising relative sea-level in the Santa Rosa Canyon section, Mexico. They also identified the isotopic signal associated with the same event in geographically widespread Tethyan sections, despite the absence of black shales in those areas. The decrease in $\delta^{13}$C values within the Globigerinelloides algerianus Zone has been interpreted as a consequence of a cooling event associated with the waning of $C_{\text{org}}$ cycling in Tethyan limestone successions (Price, 2003); however, no clear cause-effect relationship has yet been identified (cf. Bralower and others, 1999).

At the Aptian/Albian boundary and within the early Albian, the standard trend is a decrease in $\delta^{13}$C values mainly across the Hedbergella planispire Zone (= Microhedbergella rischi Zone herein; Herrle and others, 2004). Therefore, $\delta^{13}$C values in the Microhedbergella rischi Zone should be about 1% lower than in the Paraticinella eubejaouaensis Zone (cf. Herrle and others, 2004), a fact not seen in Fig. 2. We suggest that this difference in trends may be the result of regional control on the $\delta^{13}$C values.

The decrease in $\delta^{13}$C values near black shales is remarkable, since the expected trend associated with $C_{\text{org}}$-rich sediments is characterized by positive excursions, as a consequence of the preferential removal of isotopically lighter $^{12}$C from surface water by photosynthesis during periods of enhanced primary productivity (Holser, 1997; Hoefs, 2004; Maslin and Swann, 2006). Global $\delta^{13}$C negative excursions have been reported from the Jurassic–Paleogene (Bralower and others, 1999; Hesselbo and others, 2000; Price, 2003), but there are conflicting arguments why these are associated with $C_{\text{org}}$-rich horizons. Possible explanations include: 1) voluminous release of methane from gas hydrates contained in marine continental-margin deposits (e.g., Bralower and others, 1999; Jahren and others, 2001); 2) increasing volcanic activity, mainly during the Aptian (Larson, 1991), leading to enhanced CO$_2$ emissions (e.g., Bralower and others, 1994; Price, 2003); and 3) intensified recycling and upwelling of intermediate waters (e.g., Bralower and others, 1994; Price, 2003). Due to volume calculations (amount of carbon required to drive an excursion), the first hypothesis has been usually preferred for explaining drastic $\delta^{13}$C excursions, even during the Aptian (e.g., Jahren and others, 2001), when seafloor spreading rates and volcanic activity are believed to have been the highest in the Phanerozoic (Larson, 1991). According to the models of Hesselbo and others (2000) and Jahren and others (2001), methane hydrate dissociation during the Early Jurassic and the Early Cretaceous could have saturated the deep ocean, perhaps resulting in local anoxia leading to the $\delta^{13}$C negative excursions associated with the black shale levels. Moreover, the oceanic (pelagic) $\delta^{13}$C record tends to be a global signal, while black shales deposition is a local phenomenon (Price, 2003).
Simple species richness, the number of planktic foraminiferal species in each sample, varies between 1–9 within the studied succession, with maximum number (9) in the lower Paraticinella eubejaouaensis Zone (Fig. 4). The Shannon-Wiener ($H$) diversity index, also known as an entropy index, is dependent on the number of taxa in an assemblage and their relative abundances (Hammer and Harper, 2006). This diversity index in our study follows the same trend as species richness ($r = 0.73$), with a high correlation of both variables. The dominance index takes into account the relative abundances of taxa and the degree to which they dominate the assemblage (Hammer and Harper, 2006). As a general trend, dominance presents opposite trends when compared to the simple species richness ($r = -0.59$) and the Shannon-Wiener diversity index ($r = -0.97$) at the studied site (Fig. 4). The equitability ($J$) is a distribution index that applies normalized values of the Shannon-Wiener diversity index (Hammer and Harper, 2006). It presents a moderate correlation with the Shannon-Wiener diversity index ($r = 0.82$), suggesting a more even distribution of the relative abundances in highly diversified assemblages (Fig. 4).

The Hedbergellidae is the dominant planktic foraminiferal family with high relative abundance throughout most of the studied stratigraphic interval (Fig. 4). Also, there are stratigraphic intervals with consistent occurrences of the families Globigerinelloididae and Rotaliporidae (including Microhedbergella rischi trans. madecassiana due to the occurrence of a typical “ticinellid wall structure”) and less

**Figure 4.** Diversity indexes, % planktics relative to total (benthic + planktic) specimens, relative abundance of families, rates of originations and extinctions, and test diameters [minimum (left dashed line), average (continuous line), and maximum (right dashed line)] for DSDP Site 364. For all curves, except test diameters, continuous segments represent cored intervals, while dashed segments represent uncored intervals. For more information regarding the lithostratigraphic profile, see Figure 2.
abundant occurrences of the Favusellidae and Schackoinidae (Fig. 4). Most of the species in these families are considered characteristic of open-marine shallow-water assemblages (e.g., Hedbergella trocoidea, Globigerinelloides blowi, Schackoina cenomana, “Globigerinelloides” bentonensis; cf. Leckie, 1987; Koutsoukos and others, 1989). The Favusellidae (Favusella wasnhitenis) is restricted to the basal cores, occurring at or near black shale levels (Fig. 4). Finally, the Aptian/Albian transition presents a conspicuous faunal turnover (Table 1), characterized by high rates of extinctions in the latest Aptian and followed by increasing rates of species originations in the early Albian (Fig. 4).

**Paleoecological and Paleoceanographic Significance**

Species of the family Hedbergellidae (which dominate in the studied site; Fig. 4) are often ecologically considered r-strategists (Cunha and Koutsoukos, 1998). According to Premoli Silva and Sliter (1999), some of the species recorded herein could be considered r/K-strategists (intermediate forms of a continuous spectrum; e.g., *Hd. trocoidea*, *Gld. barri*, and *Globigerinelloides* itself). These observations suggest mesotrophic environmental conditions in the upper water column throughout the studied stratigraphic succession. The consistent occurrences of *Hedbergella*, *Microhedbergella*, *Murichoedbergella*, *Globigerinelloides*, and *Tinicella* suggest open-marine shallow-water conditions (Leckie, 1987) and well-oxygenated epipelagic layers (Koutsoukos and others, 1991a).

The relative abundance of planktic vs. benthic foraminifera is very high in most of the samples (Fig. 4). Levels of diminished planktic foraminiferal abundance are more prevalent above core 28, although large amplitude fluctuations are also observed in deeper cores. Below the unconformity in core 31, preservation is generally poor, and the relative planktic/benthic abundance shows greater fluctuations than would be expected in open-oceanic environments (cf. Huber and Leckie, 2011). Samples with close to no planktics are also usually devoid of benthics (Table 1; % benthics column), which, when present, are composed exclusively of agglutinated forms (species of *Bathylysiphon* and *Verneuilina*). These observations suggest that the large amplitude fluctuations in relative planktic/benthic abundance of foraminifera below the core 31 unconformity more likely reflect a preservational bias caused by dissolution rather than a primary environmental signal. Above the unconformity, preservation improves and the fluctuations in relative planktic/benthic abundance are dampened. Planktic foraminifera (≈100%) dominate assemblages from cores 31–28, decrease in abundance from cores 28–26, and are absent in cores 25 and 24, where they are replaced by more diverse benthic foraminiferal assemblages typical of neritic biotopes [composed of *Kadiyavinia gradata* (Berthelin), *Lenticulina subangulata* (Reuss), and *Gyroildionoides globosus* (Hagenow) among others]. Thus, the relative planktic/benthic abundance may be interpreted as a primary environmental signal above the unconformity, with the decrease in planktic abundance probably related to the onset of shallower (neritic) environmental settings.

In this study, the Aptian planktic foraminiferal fauna has a tropical/subtropical affinity when compared to previously described ones (e.g., Longoria, 1974, Sabinas Basin, Mexico; Leckie, 1984, DSDP Leg 79, offshore central Morroco; Koutsoukos, 1989, 1992, Sergipe Basin, Brazil; Koutsoukos and others, 1991b; Premoli Silva and Sliter, 1999; Moullade and others, 2005, Cassis-La Bédoule, France). For instance, BouDagher-Fadel and others (1997) stated that *Blefuscuiana praetrocoidea (=Hedbergella praetrocoidea* herein) was known only from the Aptian interval of the peri-Tethyan region (SW Crimea) and *Hedbergella labocaensis* might also be considered a tropical/subtropical taxon. Koutsoukos (1992), comparing foraminiferal assemblages from the Sergipe Basin (Brazil) to assemblages described elsewhere, also suggested a tropical/subtropical affinity for several species reported herein (e.g., *Gld. barri*, *Gld. blowi*, *Hd. labocaensis*). Moreover, Aptian planktic foraminiferal assemblages of DSDP Site 364 are more diversified than high-latitude ones described from DSDP Site 511 (Falkland Plateau; Krasheninnikov and Basov, 1983; Huber and Leckie, 2011). Thus, data presented herein support a surface-water marine connection, with open-marine shallow-water foraminiferal assemblages (e.g., Leckie and others, 2002), between the central Atlantic Ocean and the northern South Atlantic Ocean (north of the Walvis Ridge-Rio Grande Rise) by the late Aptian. This connection could be related to the global sea-level rise reported at that time, and it is in accordance with several previous studies (e.g., Koutsoukos and others, 1991b; Koutsoukos, 1992; Dias-Brito, 1995, 2000; Bengtson and others, 2007; Arai, 2009).

In contrast, the Albian planktic foraminiferal fauna in our cores seems more depauperate of tropical/subtropical elements, although some similarities can be seen when comparing it with assemblages from the Sabinas Basin (Mexico; Longoria and Gamper, 1977), Sergipe Basin (Brazil; Koutsoukos, 1992), and ODP Leg 171 (western North Atlantic Ocean; Petrizzo and Huber, 2006). Albian assemblages recovered from high-latitude DSDP sites 327, 330, and 511 (Falkland Plateau; Sliter, 1976; Krasheninnikov and Basov, 1983; Huber and Leckie, 2011) seem less diversified than ours, although also dominated by hedbergellids. Open-marine shallow-water assemblages (sensu Leckie, 1987), mainly characterized by rugose species of *Murichoedbergella*, also occur in late Albian strata at Site 364 (Table 1), but keeled taxa, which are thought to have been deep-water dwellers (e.g., Leckie, 1987; Leckie and others, 2002; Petrizzo and others, 2008), are absent. These data suggest that shallower-water conditions predominated in the late Albian part of the studied succession (upper *Pseudothalaminella ticenensis* Zone and the uppermost unzoned interval; Fig. 4), accounting for the absence of some tropical/subtropical deep-dwelling species commonly used as biostratigraphic markers. The co-occurrence of the neritic benthic foraminiferal associations cited above with these open-marine shallow-water planktic assemblages (cf. Leckie, 1987) also supports this interpretation. Furthermore, data presented here do not contradict interpretations by Koutsoukos (1992) and Leckie and others (2002), which suggested an intermediate-water connection between the North and the South Atlantic Ocean basins by the early
Albian. Deep Sea Drilling Program Site 364 could represent a more restricted area, closer to the high relief Walvis Ridge, than other sites from the northern South Atlantic Ocean (e.g., Sergipe Basin; Koutsoukos, 1992) that likely had a well-developed intermediate-water connection to the central Atlantic Ocean. The record of keeled Rotaliporidae \textit{[Parathalmanninella appenninica (Renz)]} in late Albian strata from the high-latitude DSDP Site 511 (Huber and Leckie, 2011) also supports the inference that the absence of some tropical/supertropical deep dwellers from Site 364 may be related to the occurrence of shallow-water conditions, although the low abundance of \textit{P. appenninica} in Site 511 may reflect a significant paleobiogeographic exclusion. Scheibnerová (1978) suggested an Austral affinity for the shallow-water benthic assemblages at Site 364, mainly those assigned to the late Albian. According to that author, the occurrences of \textit{Oritostela indica} Scheibnerová and \textit{Discorbis} spp. in upper Albian strata support a marine connection between the Indian and South Atlantic oceans at that time (the “Austral Biogeoprovine”). Wiedmann and Neugebauer (1978), on the other hand, suggested a tropical/subtropical affinity (with North Atlantic and Tethyan faunas) for the late Albian ammonite fauna recovered from Site 364, implying a well-developed connection between the North and South Atlantic oceans. Thus, further studies will be necessary to resolve these conflicting paleobiogeographic interpretations based on different late Albian fossil organisms collected from the same site.

Since \textit{F. washitensis} was probably adapted to shallow, warm, hypersaline, carbonate-saturated waters (Koutsoukos and others, 1989; Cunha and Koutsoukos, 1998), the black shales where the species was found (mainly within core 42; probably the local expression of the “late Aptian anoxic event”) most likely were also deposited in a relatively shallow-water environment (possibly an inner-midle-neritic setting due to the occurrence of epehic to gerontic specimens of \textit{F. washitensis}; cf. Koutsoukos and others, 1989). This part of the succession (from cores 41 to ~38) also presents generally opposing trends between species richness and equitability (Fig. 4). The same pattern was identified in upper Albian strata of ODP Leg 171 by Petrizzo and Huber (2006), who suggested that it could be the result of species mixing from adjacent water masses or differing seasonal productivity.

Recent studies (e.g., Koutsoukos and others, 1991a, b; Kennedy and others, 2000; Leckie and others, 2002; Huber and Leckie, 2011; Petrizzo and others, 2012) have recognized a faunal turnover at the Aptian/Albian boundary, being in agreement with the high rates of extinctions in the latest Aptian followed by increasing rates of species origination in the early Albian at Site 364 (Fig. 4). Huber and Leckie (2011) related these changes to a major reorganization in the oceanic system, such as modifications in carbonate chemistry, vertical stratification of the water column, nutrient supply, and/or surface productivity. Our study recognized drastic changes in foraminiferal test architecture across the Aptian/Albian boundary. Latest Aptian species are mainly represented by distinctive large and rugose species, while early Albian ones are dominantly small and smooth-walled forms (see the maximum test diameter in Fig. 4). These morphological trends agree with previous studies (e.g., Caron, 1978; Leckie and others, 2002; Huber and Leckie, 2011; Petrizzo and others, 2012), and Leckie and others (2002) related them to limited trophic strategies and availability of food resources, with bacterivory as a likely feeding strategy in the smaller early Albian taxa.

**CONCLUDING REMARKS**

This taxonomic study of the Aptian–late Albian interval at DSDP Site 364 identified 29 planktic foraminiferal taxa belonging to the followingbiozones: \textit{Hedbergella trocoidea}, \textit{Paraticinella eubejaouensis}, Microhedbergella rischi, and \textit{Pseudothalmanninella ticinensis}. The stratigraphic interval containing the Aptian/Albian boundary was not cored between the \textit{Paraticinella eubejaouensis} and \textit{Microhedbergella rischi} zones, and an unconformity representing a significant time gap separates the \textit{Microhedbergella rischi} Zone from the \textit{Pseudothalmanninella ticinensis} Zone within core 31.

The planktic species are open-marine shallow-water dwellers, dominated by the Hedbergellidae. Members of this family are often considered r-strategists for their ecological preferences, suggesting mesotrophic environmental conditions throughout the studied stratigraphic succession. Paleobiogeographically, the studied Aptian planktic foraminiferal fauna have a tropical/subtropical affinity, supporting the theory of a surface-water connection between the proto-central Atlantic Ocean and the southernmost sector of the northern South Atlantic Ocean (north of the Walvis Ridge-Rio Grande Rise) in the late Aptian. The absence of some tropical/subtropical biostratigraphic markers is attributed to their probable deeper-water dwelling preferences and not necessarily to an influx of colder-water masses from the southern South Atlantic Ocean, as previously suggested (e.g., Premoli Silva and Boersma, 1977; Caron, 1978).

Global δ13C trends are quite comparable to the δ13C trends reported for DSDP Site 364, suggesting a late Aptian age (\textit{Globigerinelloides algerianus} Zone) for the stratigraphic interval from cores 42 to ~37, where age-diagnostic foraminiferal species do not occur. The above-mentioned trends also suggest that the black shale levels in cores 42–39 could be considered the local expression of the so-called “late Aptian anoxic event,” described within the upper \textit{Globigerinelloides algerianus} Zone.

Quantitative analyses of the assemblages revealed a conspicuous faunal turnover at the Aptian/Albian transition, characterized by high rates of extinctions followed by increasing rates of species originations. There is also a drastic change in foraminiferal test architecture across the boundary interval.

Some similarities can be seen between the planktic foraminiferal data reported by Caron (1978) for DSDP Site 364 and those presented herein. For instance, that author collected assemblages that were devoid of keeled forms and Hedbergellidae-dominated, and suggested the occurrence of hypersaline conditions in a restricted environment. However, Caron (1978) reported much longer stratigraphic ranges for several species, which are herein interpreted as a result of the species concepts adopted (e.g., whether or not they take into account microstructural features). Also, Caron (1978) suggested cool environmental
conditions during the Albian, while we attributed the absence of some tropical/subtropical species (e.g., keeled morphotypes) to their deeper-dwelling preferences.

**SYSTEMATICS**

All species identified in this study are discussed below. Synonymies are restricted to the original description, plus those references relevant to the understanding of the species concept used herein and the specific assignments made by Caron (1978). Remarks within descriptions clarify the main distinguishing features of each species. Stratigraphic ranges are mainly based on the information given in the Mesozoic Planktonic Foraminiferal Taxonomic Dictionary (http://portal.chronos.org/gridsphere/gridsphere?cid=res_foram) and cited works. Suprageneric classification follows that of Loeblich and Tappan (1987), as modified by Lee (1989). For detailed descriptions, the reader is referred to the publications listed in the synonymies. Species occurrences and their relative abundances are given in Table 1. Figured specimens are reposited in the collections of the Museu de História Geológica do Rio Grande do Sul, Universidade do Vale do Rio dos Sinos (UNISNOS), Brazil, under the curatorial numbers ULVG-8843–ULVG-8875 (entries given after each species in Figs. 5–8).

Superfamily RHIZARIA Cavalier-Smith, 2002

Class FORAMINIFERA d'Orbigny, 1826

Order GLOBIGERININA Delage and Hérouard, 1896

Family GLOBIGERINELLOIDIDAE Longoria, 1974

Subfamily GLOBIGERINELLOIDINAE Longoria, 1974

Genus Globigerinelloides Cushman and ten Dam, 1948

Type species: Globigerinelloides algerianus Cushman and ten Dam, 1948

Globigerinelloides barri (Bolli and others, 1957)

Figs. 5.1, 5.2

Biglobigerinella barri Bolli and others, 1957, p. 25, pl. 1, figs. 13–18b. Globigerinelloides barri (Bolli and others). Longoria, 1974, p. 80, pl. 4, figs. 1–3, 8, 14, pl. 5, figs. 9–16, pl. 27, fig. 19.

Remarks. This species has a medium to large planispiral test, usually with 7 subspherical chambers in the last whorl that increase rather slowly in size. Last chambers are reniform in edge view or paired. Possible 6-chambered juvenile forms, with final chambers subtriangular in spiral view and slightly reniform in edge view, are shown in Fig. 5.2.


Globigerinelloides blowi (Bolli, 1959)

Fig. 5.3


Remarks. This species possesses an involute planispiral test, with 5–6 subglobular chambers in the last whorl. Sutures are radial and the umbilical area is rather wide. Chambers are slightly reniform in lateral view. Considering the wide morphological variability reported by Verga and Premoli Silva (2003a) for this species, this identification is possible in spite of the poor preservation.


Globigerinelloides aptiense Longoria, 1974

Fig. 5.4

Globigerinelloides apichi Longoria, 1974, p. 79, pl. 4, figs. 9, 10, pl. 8, figs. 4–6, 17, 18.

Remarks. This species has a small subcircular test, with 5–6 subspherical chambers in the last whorl that increase gradually and slowly in size as added. It differs from Globigerinelloides paragottisi Verga and Premoli Silva, 2003a, by having a slower growth rate, subspherical chambers in edge view, and a subcircular equatorial periphery.


“Globigerinelloides” bentonensis (Morrow, 1934)

Fig. 5.5

Anomalina bentonensis Morrow, 1934, p. 201, pl. 30, fig. 4. Globigerinelloides bentonensis (Morrow). Eicher and Worstell, 1970, p. 297, pl. 8, figs. 17, 19, pl. 9, fig. 3; Caron, 1978, p. 658, pl. 2, figs. 5, 6; Leckie, 1984, p. 593, pl. 10, figs. 5–11. Globigerinelloides caseyi (Bolli and others). Caron, 1978, p. 658, pl. 6, figs. 8–10.

Remarks. Test planispiral, with earlier whorls partly exposed on both sides. The periphery is broadly rounded, chambers inflated, continuously increasing in size as added, numbering 7–9 in last whorl. Herein, the genus name of this species is placed in quotation marks since true Globigerinelloides became extinct before the Aptian/Albian boundary.

Stratigraphic range. Albian to Cenomanian (Ticinella primula–Rotalipora cushmani zones; Mesozoic Planktonic Foraminiferal Taxonomic Dictionary), although specimens that can be assigned to “Gld.” bentonensis were herein identified within the Microhedbergella rischi Zone.

Family SCHACKOINIDAE Pokorny, 1958

Genus Schackoina Thalmann, 1932

Type species: Siderolina cenomana Schacko, 1897

Schackoina cenomana (Schacko, 1897)

Fig. 5.6

Siderolina cenomana Schacko, 1897, p. 166, pl. 4, figs. 3–5. Schackoina cenomana (Schacko). Caron, 1978, p. 658, pl. 8, figs. 8, 9; Leckie, 1984, p. 598, pl. 9, figs. 5, 9.

Remarks. Test as described for the genus, with an equatorially aligned, tubular spine at the extremity of each of the 4 elongate chambers that compose the last whorl.

Stratigraphic range. Albian–Cenomanian (Parathalmanninella appendinica–Rotalipora cushmani zones; Mesozoic Planktonic Foraminiferal Taxonomic Dictionary), although its FO is herein reported within the Pseudothaumalinellina ticinensis Zone.

Schackoina bicornis Reichel, 1948

Fig. 5.7

Schackoina cenomana bicornis Reichel, 1948, p. 401, text-figs. 4a–g, 6 (4), 7 (4), 8b, 9a–g, 10 (6, 8). Schackoina bicornis Reichel. Leckie, 1984, p. 598, pl. 9, figs. 10, 11.

Remarks. Differs from Schackoina cenomana by having 2 tubular spines at the top of the last chamber, oriented more or less exactly in a plane perpendicular to the equatorial (coiling) plane, but obliquely directed, usually meeting each other at an angle >90°.
FIGURE 7. Electron scanning micrographs of Aptian–Albian foraminifera from DSDP Site 364. Scale bars = 50 μm, except in 3d (= 10 μm).
1 Microhedbergella rischi, 364-32-4, 42–50 cm (ULVG-8858).
2 Microhedbergella pseudoplanispira, 364-31-1, 79–82 cm (ULVG-8860).
4 Microhedbergella sp., 364-30-1, 66–70 cm (ULVG-8859).
5 Muricohedbergella angolae, 364-30-1, 66–70 cm (ULVG-8852).
6 Muricohedbergella astrepta, 364-31-1, 40–42 cm (ULVG-8854).
7 Muricohedbergella praellivexa, 364-30-2, 94–98 cm (ULVG-8855).
8 Muricohedbergella cf. Mu. planispira, 364-28-2, 70–74 cm (ULVG-8856).
9 Muricohedbergella sp. aff. Mu. delrioensis, 364-28-4, 64–68 cm (ULVG-8853).

For trochospiral species: a, b, and c usually refer to umbilical, edge, and spiral views, respectively; d refers to detailed view.
Stratigraphic range. Cenomanian (\textit{Thalmanninella} globo-
truncanoides–\textit{Rotalipora} cushmani zones; Mesozoic Plank-
tonic Foraminiferal Taxonomic Dictionary), although its FO is herein reported within the upper Albian \textit{Pseudothal-
manninella ticinensis} Zone.

Family \textbf{PRAEHEDBERGELLIDAE} Banner and Desai, 1988

Genus \textit{Lilliputianella} Banner and Desai, 1988

Type species: \textit{Lilliputianella longorii} Banner and Desai, 1988

\textit{Lilliputianella bizonae} (Chevalier, 1961)

\textit{Hastigerinella bizonae} Chevalier, 1961, p. 34, pl. 1, figs. 24–28.


Remarks. This species differs from \textit{Lilliputianella kuhryi} (Longoria, 1974) by having a faster growth rate and a radially elongate initial chamber in the last whorl. Since this species has a stratigraphic range restricted to the Barre-
mian–Aptian interval, its occurrence within the \textit{Pseudothal-
manninella ticinensis} Zone in DSDP Site 364 is interpreted as possible evidence of reworking and not discussed further.

Stratigraphic range. Barremian–Aptian (\textit{Globigerinelloides} blowi–\textit{Gld. algerianus} zones; Mesozoic Planktonic Foraminiferal Taxonomic Dictionary).

Figure 8. Electron scanning micrographs of Aptian–Albian foraminifera from DSDP Site 364. Scale bars = 50 \(\mu\)m, except in 1d and 1e (= 10 \(\mu\)m). 1 \textit{Paraticinella eubejaouensis}, 364-34-3, 96–99 cm (ULVG-8872). 2, 3 \textit{Favusella washitensis}, 364-42-6, 87–90 cm; 2 (ULVG-8866), 3 (ULVG-
8867). 4 \textit{Ticinella} sp. aff. \textit{T. primula}, 364-28-1, 69–73 cm (ULVG-8871). 5 \textit{Ticinella raynaudi}, 364-28-2, 70–74 cm (ULVG-8868). For trochospiral species: a, b, and c usually refer to umbilical, edge, and spiral views, respectively; d and e refer to detailed views.
Family HEDBERGELLIDAE Loeblich and Tappan, 1961

Genus Hedbergella Brönnimann and Brown, 1958, emend.

Hedbergella aptiana Bartenstein, 1965

Fig. 5.9

Hedbergella aptiana Bartenstein, 1965, p. 347, text-figs. 4–6; Huber and Leckie, 2011, p. 65, figs. 5.6, 5.7 (and synonymy therein).

Remarks. Hedbergella aptiana is characterized by its mostly smooth surface, 5–5.5 globular to subglobular chambers in the final whorl, and a moderate chamber growth rate in the last whorl.

Stratigraphic range. Barremian–upper Aptian (Globigerinelloides ferreolensis–Paraticinella eubejaouaensis zones; Mesozoic Planktonic Foraminiferal Taxonomic Dictionary).

Hedbergella luterbacheri Longoria, 1974

Fig. 6.1

Hedbergella luterbacheri Longoria, 1974, p. 61, pl. 19, figs. 21–26, pl. 26, figs. 15–17.

Remarks. This species possesses a subcircular to ovoid equatorial outline, a flat spiral side, and 6.5–7.5 chambers in the last whorl that increase gradually in size. The chambers of the last whorl are globular to subglobular.

Stratigraphic range. Barremian–Aptian (Hedbergella similis–Paraticinella eubejaouaensis zones; Mesozoic Planktonic Foraminiferal Taxonomic Dictionary).

Hedbergella sp. aff. Hd. sigali Moullade, 1966

Fig. 6.2

Remarks. This species differs from Hedbergella sigali Moullade, 1966, by having a longer inner spire.

Hedbergella cf. Hd. maslakovae Longoria, 1974

Fig. 6.3

Remarks. This species is characterized by its oval-shaped outline with the last two chambers semi-elongate. It differs from Hedbergella labocaensis by having a wider and shallower umbilical area and a low–flat spiral side. Poor preservation hampers more precise identification.

Hedbergella praetrocoida Kretzchmar and Gorbachik, 1986

Fig. 6.4

Hedbergella praetrocoida Kretzchmar and Gorbachik in Gorbachik, 1986, p. 95, pl. 16, figs. 3–5.

Remarks. Hedbergella praetrocoida differs from its descendant, Hd. trocoidea, in having 6–6.5 chambers in the last whorl, a wider and shallower umbilical area, and, normally, a less convex spiral side.

Stratigraphic range. Aptian (Globigerinelloides blowi–Paraticinella eubejaouaensis zones; Mesozoic Planktonic Foraminiferal Taxonomic Dictionary).

Hedbergella trocoidea (Gandolfi, 1942) emend.

Huber and Leckie, 2011

Fig. 6.5

Anomalina lorneiana var. trocoidea Gandolfi, 1942, p. 99, 134, pl. 2, figs. 1a–c, pl. 4, figs. 2, 3, pl. 13, figs. 2, 5.

Hedbergella trocoidea (Gandolfi). Huber and Leckie, 2011, p. 72, figs. 10.1, 10.3 (and synonymy therein).

Remarks. This species has 6.5–8 chambers in the final whorl that increase gradually in size; chamber shape is subtriangular–triangular on the umbilical side and sub-spherical–trapezoidal on the spiral side. There is no apertural lip and the umbilical area is relatively small and deep. Poor preservation prevents accurate identification of wall microstructure, although it seems to be finely perforate at high magnification.

Stratigraphic range. Aptian (Globigerinelloides ferreolensis–Paraticinella eubejaouaensis zones; Mesozoic Planktonic Foraminiferal Taxonomic Dictionary).

Hedbergella cf. Hd. similis Longoria, 1974

Fig. 6.6

Remarks. Hedbergella cf. Hd. similis differs from Hd. labocaensis in having a depressed spiral side and more radially elongate chambers. It differs from Hd. cf. Hd. maslakovae by having a faster growth rate and more elongate last two chambers. Poor preservation does not allow more precise identification.

Hedbergella labocaensis Longoria, 1974

Fig. 6.7

Hedbergella labocaensis Longoria, 1974, p. 60, pl. 16, figs. 7–9, 22–24.

Remarks. The first whorls of Hedbergella labocaensis are coiled in a higher plane than the last and the peripheral margin is lobate, with 6–7 chambers in the last whorl and an extrambilical-spiroumbilical primary aperture that is bordered by an imperforate cap. The specimen figured by Caron (1978, pl. 2, figs. 3, 4) seems more likely to fit the definition of Hd. similis Longoria.

Stratigraphic range. Aptian (Hedbergella trocoidea–Paraticinella eubejaouaensis zones; Longoria, 1974).

Genus Microhedbergella Huber and Leckie, 2011

Type species: Microhedbergella renlaesis

Huber and Leckie, 2011

Microhedbergella sp. aff. Mi. miniglobularis

Huber and Leckie, 2011

Fig. 6.8

Remarks. Specimens recovered from Site 364 are considerably larger and broader in edge view than those originally described by Huber and Leckie (2011). Although those authors discussed that their specimens could represent a juvenile morphology of a larger form, further studies are needed to determine the taxonomic relationship between those specimens and the specimens reported herein.

Microhedbergella rischi (Moullade, 1974) emend.

Huber and Leckie, 2011

Fig. 7.1

Microhedbergella rischi Moullade, 1974, p. 1816.


Remarks. Despite the fact that the figured specimen presents a flat spiral side, it is believed to fall within the morphological plasticity reported by Huber and Leckie (2011, cf. fig. 20.1). This species differs from other species of Microhedbergella recorded herein in the usual presence of six subglobular chambers in the last whorl that increase moderately in size as added, absence of a kummerform final
chamber, and an outline that is weakly to moderately lobate in equatorial view. Despite the poor preservation of the studied material, relict apertural lips can be seen surrounding the umbilicus in some specimens.

**Stratigraphic range.** Albian (Microhedbergella rischi–Ticinella primula zones; Huber and Leckie, 2011).

*Microhedbergella pseudoplanispira* Huber and Leckie, 2011

Fig. 7.2


**Remarks.** This species is characterized by its small size, smooth test with 6.5–7.0 chambers in the final whorl, weakly depressed to flush sutures between the early chambers, and the presence of a narrow apertural lip. The test also has a low coiling axis, and weakly lobate equatorial outline.

**Stratigraphic range.** Albian (Microhedbergella rischi–Ticinella primula zones; Huber and Leckie, 2011), although its LO is reported herein within the *Pseudothallassmanninella ticinensis* Zone.


Fig. 7.3


**Remarks.** This form is characterized by the absence of supplementary sutural apertures and having a densely perforated test and a typical “ticinellid wall texture,” with raised rims that surround the pores (Fig. 7.3d). No typical *Ticinella madecassiana* specimens were recovered, using the presence of at least one supplementary sutural aperture as the basis for distinguishing the latter species from the transitional form reported herein.

**Stratigraphic range.** Lower Albian (Microhedbergella rischi Zone; Huber and Leckie, 2011).

*Microhedbergella sp.*

Fig. 7.4


**Description.** Medium-sized test coiled in a low trochospire, with 5–6 chambers that increase rapidly in size in the last whorl. Chambers of the last whorl are subglobular–subglobular except for the last one, which tends to be reniform in apertural view and is strongly protruded towards the umbilicus. The wall is microperforate–finely perforate. Aperture is a low interiomarginal, umbilical-extraumbilical arch bordered by a poorly developed lip. Umbilicus quite narrow and deep, bordered by relict apertural lips.

**Remarks.** This species was attributed to *Hedbergella gorbachikae* Longoria by Caron (1978); however, as suggested by Huber and Leckie (2011), this assignment is not correct due to the absence of perforation cones and the occurrence of a probable microperforate wall. Furthermore, Caron’s (1978) Albian specimens and the ones reported herein have apertural lips and relict apertural flaps surrounding the umbilicus. These features are not included in the emended definition of *Hd. gorbachikae* (Huber and Leckie, 2011).

Genus *Muricohedbergella* Huber and Leckie, 2011

Type species: *Globigerina cretacea var. del rioensis* Carsey, 1926

*Muricohedbergella angolae* (Caron, 1978)

Fig. 7.5

*Hedbergella angolae* Caron, 1978, p. 658, pl. 10, figs. 5–7. text-figs. 6a–c.

**Remarks.** *Muricohedbergella angolae* has about 5 globular chambers in the last whorl that increase regularly in size except for the last one or two that increase very rapidly, and has pustules on the early chambers.

**Stratigraphic range.** Albian [Microhedbergella rischi (herein)–Pseudothallassmanninella ticinensis zones (Caron, 1978)].

*Muricohedbergella sp.*

Fig. 7.6

*Hedbergella praelibyca* Petrizzo and Huber, 2006, p. 185, pl. 5, figs. 1–5.

**Remarks.** This species has a low trochospiral test usually with 6 globular chambers that increase gradually in size in the last whorl. Surface with scattered pustules, which sometimes become aligned without preferential orientation. As in *Mu. delrioensis*, the aperture is bordered by a porticus. The figured specimen tends to uncoil, a feature also seen in one of the specimens figured by Petrizzo and Huber (2006, pl. 5, fig. 5).

**Stratigraphic range.** Upper Albian (Pseudothallassmanninella ticinensis–Parathalmanninella appenninica zones; Petrizzo and Huber, 2006).

*Muricothedbergella praelibyca* (Petrizzo and Huber, 2006)

Fig. 7.7

*Hedbergella praeticinensis* (Sigal). Caron, 1978, p. 660, pl. 7, figs. 1, 2.

**Remarks.** This species presents a coarser pustulose surface and more equidimensional and more axially compressed chambers than the neotype and typical forms of *Mu. delrioensis* (see Petrizzo and Huber, 2006).
Subfamily PARATICINELLINAE Huber and Leckie, 2011
Genus Paraticinella Premoli Silva and others, 2009
Type species: Ticinella eubejaouaensis Randriasolo and Anglada, 1998

Paraticinella eubejaouaensis (Randriasolo and Anglada, 1998)

Fig. 8.1


Paraticinella eubejaouensis (Randriasolo and Anglada). Premoli Silva and others, 2009, p. 131, text-figs. 2, 3.3–23.6, pl. 1, figs. 5, 6, pl. 2, figs. 1–6.

Remarks. This species has 8 subglobular (subtriangular on the umbilical side) chambers in the last whorl, arranged in a flat trochospire, with poorly developed rugosities paralleling the spiral suture (Fig. 8.1e), two or three infralaminar accessory apertures (Fig. 8.1d), and a broad and shallow umbilicus that is partially covered by a large apertural flap protruding from the last two chambers. The flat spiral side falls within the morphologic variability reported by Premoli Silva and others (2009).

Stratigraphic range. Uppermost Aptian (Paraticinella eubejaouensis Zone; Premoli Silva and others, 2009).

Family FAVUSELLIDAE Longoria, 1974
Genus Favusella Michael, 1972
Type species: Globigerina washtensis Carsey, 1926

Favusella washtensis (Carsey, 1926) emend. Koutsoukos and others, 1989

Figs. 8.2, 8.3

Globigerina washtensis Carsey, 1926, p. 44, pl. 7, fig. 10, pl. 8, fig. 2.

Hedbergella (Favusella) washtensis (Carsey). Koutsoukos and others, 1989, p. 335, pl. 1, figs. 1–15, pl. 2, figs. 1–14.

Remark. This highly variable trochospiral species is characterized mainly by having a coarse reticulate surface ornamentation with a honeycomb pattern in adult specimens. Following Koutsoukos and others (1989), the figured specimens seem to be ephebic (Fig. 8.2) and gerontic (Fig. 8.3) forms.

Stratigraphic range. Upper Barremian–middle Cenomanian (Koutsoukos and others, 1989).

Family ROTALIPORIDAE Sigal, 1958
Subfamily TICINELLINAE Longoria, 1974
Genus Ticinella Reichel, 1950
Type species: Anomalina roberti Gandolfi, 1942

Ticinella? sp. aff. Ti. primula Luterbacher, 1963

Fig. 8.4


Remarks. This species has a low to almost flat trochospiral test, a smooth surface, and 6 chambers in the last whorl, which enlarge relatively slowly and gradually in size. Also, the umbilical area is wide and some specimens tend to uncoil. The spiral side is flat and the aperture extends broadly to the periphery, but still is asymmetrical. Supplementary apertures have not been observed probably because of poor preservation; the figured specimen is also somewhat deformed.

Ticinella raynaudi Sigal, 1966

Fig. 8.5

Ticinella raynaudi Sigal, 1966, p. 200, pl. 6, figs. 1–3; Caron, 1978, p. 660, pl. 9, figs. 8, 9; Petrizzo and Huber, 2006, p. 181, pl. 2, figs. 3, 4.

Ticinella raynaudi aperta Sigal, 1978, p. 660, pl. 9, figs. 3, 4.

Remarks. This species differs from other Ticinella by having a more lobate outline and a rugose wall surface; the last chambers on the umbilical side are also slightly subtriangular in shape.

Stratigraphic range. Upper Albian (Pseudothalmanninella ticinensis–Paralthalmanninella appenninica zones; Petrizzo and Huber, 2006).

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