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FORAMINÍFEROS PLANCTÔNICOS E BENTÔNICOS DO INTERVALO
APTIANO-ALBIANO DO DSDP *SITE* 364 (BACIA DE KWANZA):
TAXONOMIA, BIOESTRATIGRAFIA, PALEOECOLOGIA
E IMPLICAÇÕES PALEOCEANOGRÁFICAS

São Leopoldo

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Dissertação apresentada como requisito parcial para a obtenção do título de Mestre, pelo programa de Pós-graduação em Geologia da Universidade do Vale do Rio dos Sinos - UNISINOS

Orientador: Dr. Gerson Fauth

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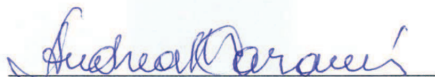
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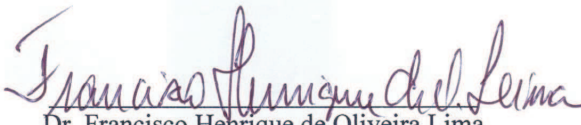
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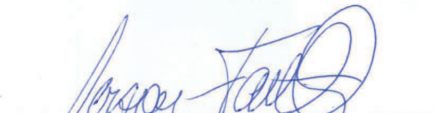
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“We may restore in imagination the appearance of the ancient continents which have passed away.”

(Charles Lyell - Principles of Geology, 1833)

RESUMO

O presente estudo apresenta a taxonomia, bioestratigrafia e paleoecologia dos foraminíferos planctônicos e bentônicos recuperados no intervalo Aptiano superior-Albiano da sucessão predominantemente carbonática do *Deep Sea Drilling Project* (DSDP) *Site* 364, localizado na bacia de Kwanza (costa afora de Angola). Foram identificadas 30 espécies de foraminíferos planctônicos e 42 espécies de foraminíferos bentônicos. Com base nas assembleias de foraminíferos planctônicos, a seção sedimentar estudada foi subdividida em diversas biozonas, abrangendo as idades Aptiano tardio ao Albiano, da Zona *Hedbergella trocoidea* a Zona *Pseudothamminella ticinensis*. Uma conspícua discordância foi identificada no *core* 31, compreendendo do topo do Albiano inferior à base do Albiano superior. A composição específica das assembleias de foraminíferos planctônicos as caracteriza como assembleias marinhas de águas rasas e permite a inferência do domínio de condições mesotróficas a eutróficas ao longo do intervalo estudado. As associações aptianas de foraminíferos planctônicos apresentam afinidade paleobiogeográfica tetiana, suportando um influxo de água superficial tetiana no setor restrito (ao norte da Cadeia de Walvis-Elevação do Rio Grande) do Oceano Atlântico Sul setentrional já no Aptiano tardio. Tendências nos valores isotópicos de $\delta^{13}\text{C}$, que devem ser cuidadosamente interpretadas devido a uma possível alteração diagenética, sugerem uma idade aptiana tardia (Zona *Globigerinelloides algerianus*) para o intervalo estratigráfico do *core* 42 ao *core* 37, no qual fósseis-guia tetianos estão ausentes, além de sugerir que os folhelhos negros da base do testemunho estudado (*cores* 42-39) podem ser correlatos ao evento anóxico do Aptiano tardio. Entre os foraminíferos planctônicos

ocorre uma profunda mudança faunística na passagem Aptiano-Albiano, caracterizada por altas taxas de extinção seguidas por elevadas taxas de surgimento de espécies, além de uma significativa mudança no padrão arquitetural das testas. Foram identificadas três associações de foraminíferos bentônicos, que parecem ser principalmente controladas por variações paleobatimétricas. A fauna de foraminíferos bentônicos pode ser classificada como uma Associação do tipo *Marssonella*, provavelmente relacionada a paleo-profundidades neríticas a batiais superiores, e também exibindo uma marcada afinidade paleobiogeográfica tetiana.

Palavras-chave: Foraminíferos. Aptiano-Albiano. Bioestratigrafia. Paleoecologia. Isótopos de carbono e oxigênio. DSDP Site 364.

ABSTRACT

This work presents a taxonomic, biostratigraphic and paleoecologic study on the planktic and benthic foraminiferal faunas recovered from the late Aptian-late Albian carbonate-dominated succession of Deep Sea Drilling Project (DSDP) Site 364, located in the Kwanza Basin (offshore Angola). Thirty planktic and 42 benthic foraminiferal species were identified herein. Based on planktic foraminiferal assemblages, the studied section was subdivided in a series of biozones, late Aptian to late Albian in age, from the *Hedbergella trocoidea* Zone to the *Pseudothalmanninella ticinensis* Zone. A remarkable unconformity was identified in core 31, spanning the latest early to earliest late Albian. The specific composition of the recovered planktic foraminiferal assemblages characterizes them as open marine epipelagic dwellers, and permits the suggestion of predominant mesotrophic to eutrophic environmental conditions throughout the studied stratigraphic succession. Aptian planktic foraminiferal assemblages present a significant Tethyan paleobiogeographic affinity, supporting a Tethyan surface-water influx into this restricted southeastern sector of the northern South Atlantic Ocean (north to the Walvis Ridge-Rio Grande Rise) back in the late Aptian. $\delta^{13}\text{C}$ trends, which have to be carefully interpreted due to possible diagenetic overprint, suggest a late Aptian age (*Globigerinelloides algerianus* Zone) for the stratigraphic interval from core 42 to about core 37, where Tethyan age-diagnostic foraminiferal species are missing, as well as that the black shale levels in cores 42-39 could be correlated to the “late Aptian anoxic event”. Among planktic foraminifera, a conspicuous faunal turnover occurs at the Aptian/Albian transition, characterized by high rates of extinctions followed by

increasing rates of species originations and changes in tests' architecture. Three benthic foraminiferal associations were identified, which seem to be mainly controlled by changes in paleobathymetry. Also, the studied benthic foraminiferal fauna could be classified as a *Marssonella* Association, probably related to neritic and upper bathyal paleodepths, also exhibiting a Tethyan paleobiogeographic affinity.

Keywords: Foraminifera. Aptian-Albian. Biostratigraphy. Paleoecology. Carbon and oxygen isotopes. DSDP Site 364.

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1 INTRODUÇÃO

O intervalo de tempo Aptiano-Albiano (entre 126,3 Ma e 100,5 Ma antes do presente; GRADSTEIN et al., 2012) é marcado pela ocorrência de depósitos sedimentares ricos em matéria orgânica, comumente atribuídos a eventos anóxicos globais (OAEs – *oceanic anoxic events*) (e.g. ARTHUR; PREMOLI SILVA, 1982; JENKYNS, 1995; JENKYNS; WILSON, 1999). Estes eventos anóxicos são caracterizados pela ocorrência de folhelhos negros com ampla distribuição geográfica e pronunciadas mudanças nos valores isotópicos de carbono (LECKIE et al., 2002), tendo profundas consequências sobre a biota marinha, inclusive entre os foraminíferos planctônicos e bentônicos (e.g. LECKIE, 1984; LECKIE et al., 2002; KOUTSOUKOS et al., 1991B; PREMOLI SILVA et al., 1999). Esse intervalo de tempo apresenta elevadas taxas de geração de crosta oceânica e platôs oceânicos (LARSON, 1991), fato que levou à liberação de massivas quantidades de dióxido de carbono na atmosfera e profundas reorganizações no sistema oceânico-atmosférico. Apesar de diversos esforços na proposição de um estratotipo para a base do Albiano (e.g. KENNEDY et al., 2000; HANCOCK, 2001), nenhum *Global Boundary Stratotype Section and Point* (GSSP) foi aceito até o presente momento, principalmente devido ao elevado grau de endemismo das assembleias de amonóides neste intervalo de tempo, tradicionalmente utilizados na demarcação dos limites entre os andares do Cretáceo (BIRKELUND et al., 1984). Este fato dificulta o estudo dos eventos paleoceanográficos mencionados acima, bem como pode causar diversas discrepâncias entre as idades atribuídas a partir de esquemas bioestratigráficos, baseados em diferentes grupos fósseis, para uma mesma sucessão estratigráfica (e.g. BOLLI et al., 1978). Além disto, a subdivisão do intervalo Aptiano-

Albiano em subandares (*e.g.* PFLAUMANN; KRASHENINNIKOV, 1977; MOULLADE et al., 2005) causa problemas adicionais, também devido ao alto grau de endemismo das assembleias de amonóides que os caracterizam, sendo estes rejeitados pela maioria dos trabalhos recentes (*e.g.*, KENNEDY et al., 2000; SCOTT, 2009) e considerados portanto informais (cf. escala do tempo geológico oficial da Comissão Internacional de Estratigrafia; www.stratigraphy.org).

Huber e Leckie (2011), estudando foraminíferos planctônicos do intervalo Aptiano-Albiano de diversas regiões do globo, identificaram uma mudança faunística significativa coincidente com o limite entre os dois andares. Estes autores apontaram como possíveis causas para este padrão: (1) mudanças no comportamento químico do carbonato de cálcio na água do mar, (2) reduzida estratificação da coluna da água e (3) mudanças no aporte de nutrientes e na produtividade primária. Mudanças na composição faunística e nas tendências dos caracteres morfológicos, semelhantes àquelas apresentadas por Huber e Leckie (2011), foram previamente discutidas por diversos autores (KOUTSOUKOS et al., 1991a,b; KENNEDY et al., 2000; LECKIE et al., 2002). Tendências faunísticas como as descritas acima (*e.g.* surgimentos e extinções de espécies), de maior ou menor intensidade, foram historicamente utilizadas na elaboração dos esquemas bioestratigráficos para o Aptiano-Albiano (Figura 1). Os zoneamentos precursores com base em foraminíferos planctônicos para o intervalo Aptiano-Albiano são apresentados (SIGAL, 1966; MOULLADE, 1974; VAN HINTE, 1976; LONGORIA; GAMPER, 1977; PREMOLI SILVA; BOERSMA, 1977), sendo que a proposição de novos esquemas taxonômicos e bioestratigráficos ainda consiste em um tema bastante atual (HUBER; LECKIE, 2011; PETRIZZO et al., 2012). Esse fato evidencia as

dificuldades inerentes ao estudo do grupo nesse intervalo temporal, principalmente em relação a aspectos taxonômicos e de distribuição estratigráfica e paleobiogeográfica, caracterizando um dos grandes desafios atuais. Dentre os esquemas apresentados na Figura 1, Longoria (1974) propôs um arcabouço bioestratigráfico detalhado para o andar Aptiano de seções estratigráficas no México e na França, composto por sete zonas baseadas em eventos evolutivos de táxons tetianos. Leckie (1984) propôs um esquema bioestratigráfico para o intervalo Aptiano-Cenomaniano da Bacia Central do Marrocos, adicionando uma subzona, *Planomalina cheniourensis*, aos zoneamentos propostos anteriormente. Caron (1985), revisando dados provenientes de diversos estudos anteriores, propôs um esquema bioestratigráfico para todo o Cretáceo com base em foraminíferos planctônicos tetianos. Essa autora definiu 11 zonas para o intervalo Aptiano-Albiano. Huber e Leckie (2011) propuseram um esquema bioestratigráfico baseado na revisão taxonômica dos foraminíferos planctônicos de baixas e altas latitudes, reconhecendo um limite erosivo, com provável distribuição global, coincidente com o limite Aptiano/Albiano. Petrizzo et al. (2012), por conseguinte, adicionaram uma zona de intervalo, *Microhedbergella renilaevis*, ao esquema bioestratigráfico previamente proposto por Huber e Leckie (2011).

Idade	van Hinte, 1976										Leckie, 1984		Caron, 1985	Huber e Leckie, 2011		Petruzzo et al., 2012		
	van Hinte, 1976										Leckie, 1984		Caron, 1985	Tropical	Austral			
Albiano	Sup.	à appenninica (parte)	à Rotalipores (tichensis)	moliensis buxtorfi	Tt. tichensis	R. buxtorfi - R. appenninica	R. appenninica	R. appenninica	R. appenninica	R. appenninica	P. praebuxtorfi	R. appenninica	R. appenninica	Pt. appenninica	Pt. appenninica			
						R. tichensis - P. buxtorfi	P. praebuxtorfi	P. praebuxtorfi	P. praebuxtorfi	B. breggiensis	B. breggiensis	R. tichensis	R. tichensis	Ps. tichensis	Ps. tichensis	Ps. tichensis	Ps. tichensis	Ps. tichensis
Albiano	Méd.	à Rotalipores (tichensis)	breggiensis	tichensis praeticinensis	Tt. breggiensis	B. breggiensis	B. breggiensis	B. breggiensis	B. breggiensis	B. breggiensis	B. breggiensis	B. breggiensis	B. breggiensis	B. breggiensis	B. breggiensis	B. breggiensis	B. breggiensis	
																		à washitensis - roberti, sans Rotalipores
Aptiano	Sup.	à Hebertella, sans	avec roberti	sudnodosa	Tt. bejaouaensis	Tt. bejaouaensis	Tt. bejaouaensis - Gld. gyroldinaeformis	Tt. bejaouaensis - Gld. gyroldinaeformis	Tt. bejaouaensis - Gld. gyroldinaeformis	Tt. bejaouaensis - Gld. gyroldinaeformis	Tt. bejaouaensis - Gld. gyroldinaeformis	Tt. bejaouaensis - Gld. gyroldinaeformis	Tt. bejaouaensis - Gld. gyroldinaeformis	Tt. bejaouaensis - Gld. gyroldinaeformis	Tt. bejaouaensis - Gld. gyroldinaeformis	Tt. bejaouaensis - Gld. gyroldinaeformis	Tt. bejaouaensis - Gld. gyroldinaeformis	Tt. bejaouaensis - Gld. gyroldinaeformis
Aptiano	Méd.	à Schakoines (parte)	sans roberti	trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea	Hd. trocoidea

Figura 1 – Correlação entre os esquemas bioestratigráficos propostos com base em foraminíferos planctônicos para o intervalo Aptiano-Albiano (arcabouço até o ano de 1984 modificado de LECKIE, 1984). Detalhes relacionados a esses zoneamentos podem ser encontrados no texto. Abreviações:

Tt. = *Ticinella*; Hd. = *Hedbergella*; Gld. = *Globigerinelloides*; L. = *Leopoldina*; R. = *Rotalipora*; P. = *Planomalina*; B. = *Biticinella*; Sc. = *Schackoina*; Ps. = *Pseudothamminella*; Pt. = *Parathamminella*; Mi. = *Microhedbergella*; Pa. = *Paraticinella*.

É nesse contexto geoistórico, por sua vez, que se instaurou a abertura de diversos setores do Oceano Atlântico Sul (*rifting seaways*). A ruptura entre as placas africana e sul-americana iniciou-se no Jurássico inicial, no extremo sul do Oceano Atlântico Sul e gradualmente se estendeu para o norte durante o Eocretáceo (UCHUPI et al., 1989; BINKS; FAIRHEAD, 1992; GUIRAUD; MAURIN, 1992). A área ocupada atualmente pelo Golfo da Guiné se rompeu por último, formando um “braço” de mar disóxico-anóxico contínuo [setor setentrional (restrito) do Oceano Atlântico Sul], da Cadeia de Walvis-Elevação do Rio Grande ao norte da África, no intervalo Aptiano tardio-Turoniano (TISSOT et al., 1980) (Figura 2). Conforme o processo de separação entre as duas massas continentais avançava, a importância da Cadeia de Walvis-Elevação do Rio Grande e da zona de transcorrência do Golfo da Guiné como barreiras à circulação oceânica (principalmente de fundo) diminuiu (TISSOT et al., 1980; vide reconstrução do intervalo Campaniano-Maastrichtiano na Figura 2). Modelos propostos para as primeiras incursões marinhas nesse setor restrito do Oceano Atlântico Sul (ao norte da Cadeia de Walvis-Elevação do Rio Grande) propuseram que estas acompanhariam a abertura tectônica, de sul para norte (CONCEIÇÃO et al., 1988). Entretanto, a influência tetiana apresentada por diversos grupos fósseis descritos para o setor norte do Oceano Atlântico Sul (*e.g.* KOUTSOUKOS et al., 1991a; KOUTSOUKOS, 1992) sugere que as primeiras transgressões associadas à subida eustática do Aptiano tardio poderiam advir do Mar de Tétis/proto-Oceano Atlântico Central (para uma revisão, vide ARAI, 2009). Bengtson et al. (2007), com base na análise de amonóides e foraminíferos da Bacia de Sergipe, apresentam evidências em favor do influxo de água superficial tetiana no setor norte do

Oceano Atlântico Sul já no mesoaptiano, ou mesmo no eoaptiano. Essa afinidade tetiana levou Dias-Brito (1995; 2000) a propor, com base no estudo de pitonellídeos, o “Tétis Sul-Atlântico”, caracterizado como um corpo marinho raso de águas quentes e restrito, que se prolongaria do Tétis oeste/proto-Atlântico Central até o complexo Cadeia de Walvis-Elevação do Rio Grande (Figura 3) durante o Aptiano tardio-Albiano.

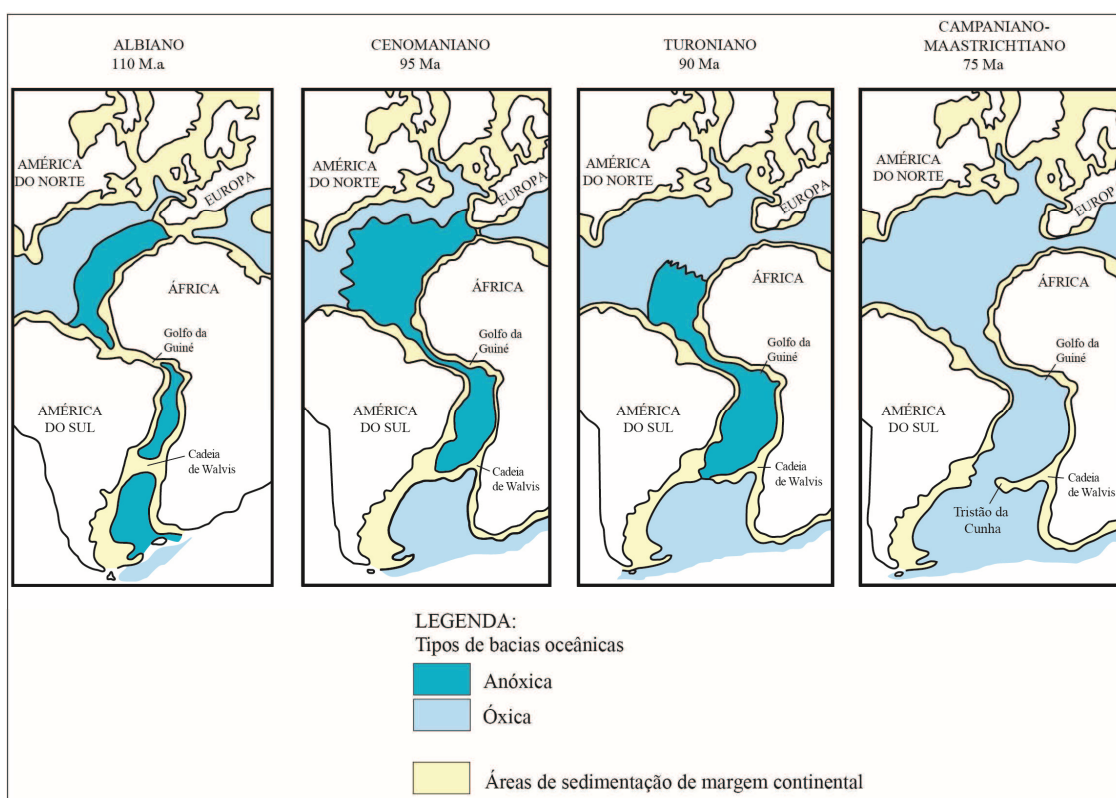


Figura 2 – Reconstituição paleogeográfica da ruptura do Gondwana, mostrando a localização aproximada do *seaway* anóxico (ao norte da Cadeia de Walvis), característico dos estágios iniciais de formação do Oceano Atlântico Sul. Modificado de Tissot et al. (1980).

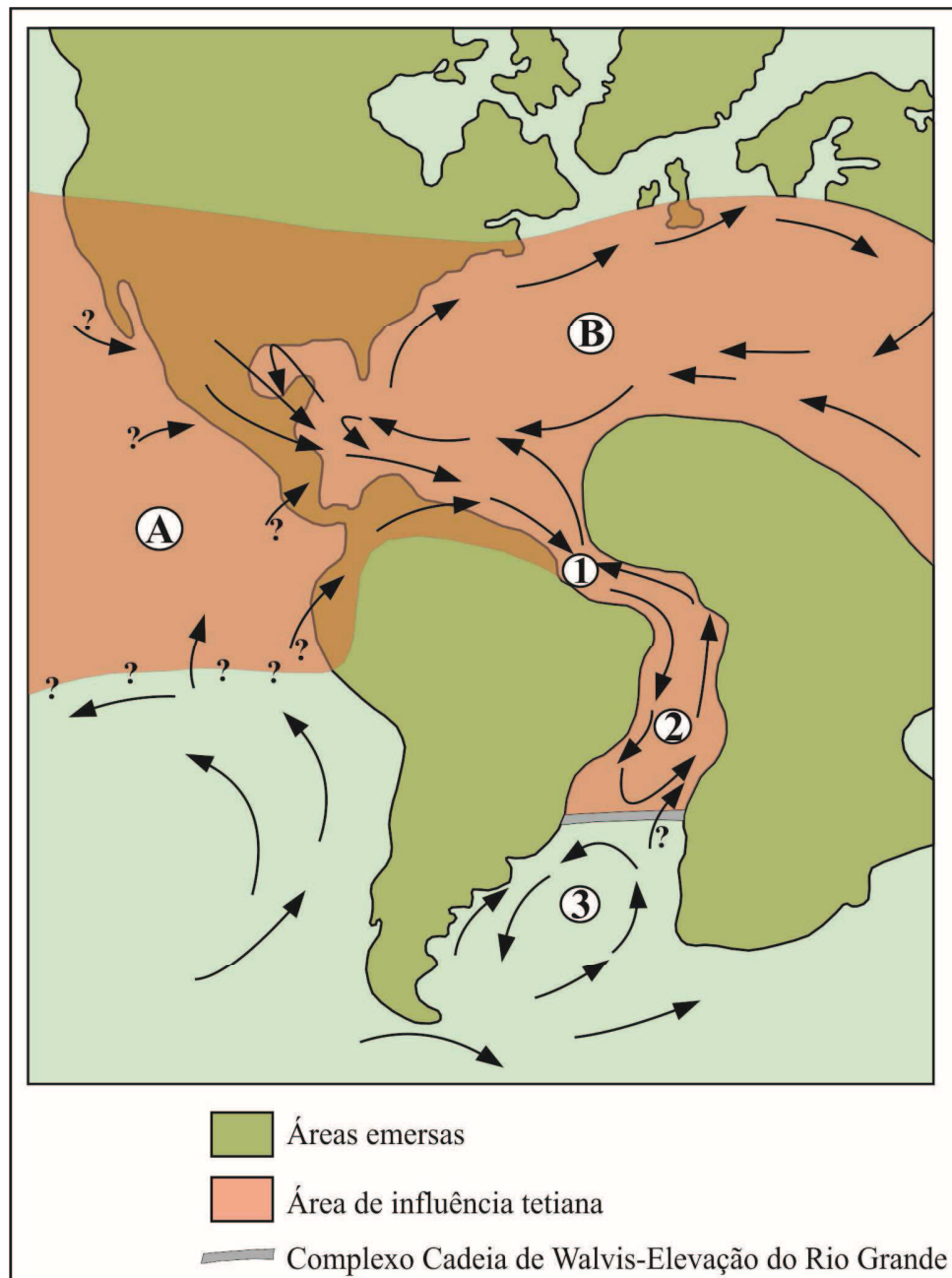


Figura 3 – Modelo especulativo para a circulação de águas superficiais no intervalo Aptiano tardio-Albiano. 1: Atlântico Sul equatorial; 2: Atlântico Sul setentrional [onde se localizava o DSDP Site 364]; 3: Atlântico Sul meridional; A: massa de água pacífica, mais velha e menos salina; B: massa de água atlântica-mediterrânea, mais nova e mais salina. O “Tétis Sul-Atlântico” seria composto pelos segmentos 1 e 2 do Oceano Atlântico Sul. Modificado de Dias-Brito (1995; 2000). Base paleogeográfica de 100 Ma simplificada de Smith et al. (1981).

Neste contexto, o presente estudo analisa os foraminíferos planctônicos e bentônicos contidos nos primeiros estratos tipicamente marinhos do setor restrito do Oceano Atlântico Sul setentrional (ao norte da Cadeia de Walvis), intervalo Aptiano tardio-Albiano tardio do *Deep Sea Drilling Project* (DSDP) *Site* 364 (costa afora de Angola), Bacia de Kwanza (Figura 4). O arcabouço estratigráfico simplificado da Bacia de Kwanza (intervalo Jurássico Superior-Cretáceo Inferior) é apresentado na Figura 5. O estudo tem por objetivos: i) identificar taxonomicamente os foraminíferos planctônicos e bentônicos recuperados nos andares Aptiano e Albiano do DSDP *Site* 364; ii) determinar a distribuição estratigráfica das espécies e realizar um refinamento bioestratigráfico, com base em foraminíferos planctônicos, para a seção estudada; iii) realizar o estudo paleoecológico das associações de foraminíferos planctônicos e bentônicos, procurando relacionar as mudanças faunísticas às condições paleoceanográficas vigentes na bacia durante o intervalo de tempo estudado; iv) utilizar análises isotópicas de carbono e oxigênio em rocha total, visando o refinamento das interpretações sugeridas com base nos dados microfaunísticos.

São apresentados dois artigos (capítulos). O artigo I, intitulado **Aptian-Albian planktic foraminifera from DSDP Site 364 (offshore Angola): Biostratigraphy, paleoecology and paleoceanographic significance**, apresenta o estudo relativo aos foraminíferos planctônicos e isótopos estáveis de carbono e oxigênio no testemunho estudado. O artigo II, intitulado **Aptian-Albian benthic foraminifera from DSDP Site 364 (offshore Angola): A Taxonomic and paleoenvironmental appraisal**, apresenta os

dados relativos aos foraminíferos bentônicos que, embora menos abundantes, corroboram diversas interpretações apresentadas no artigo I.

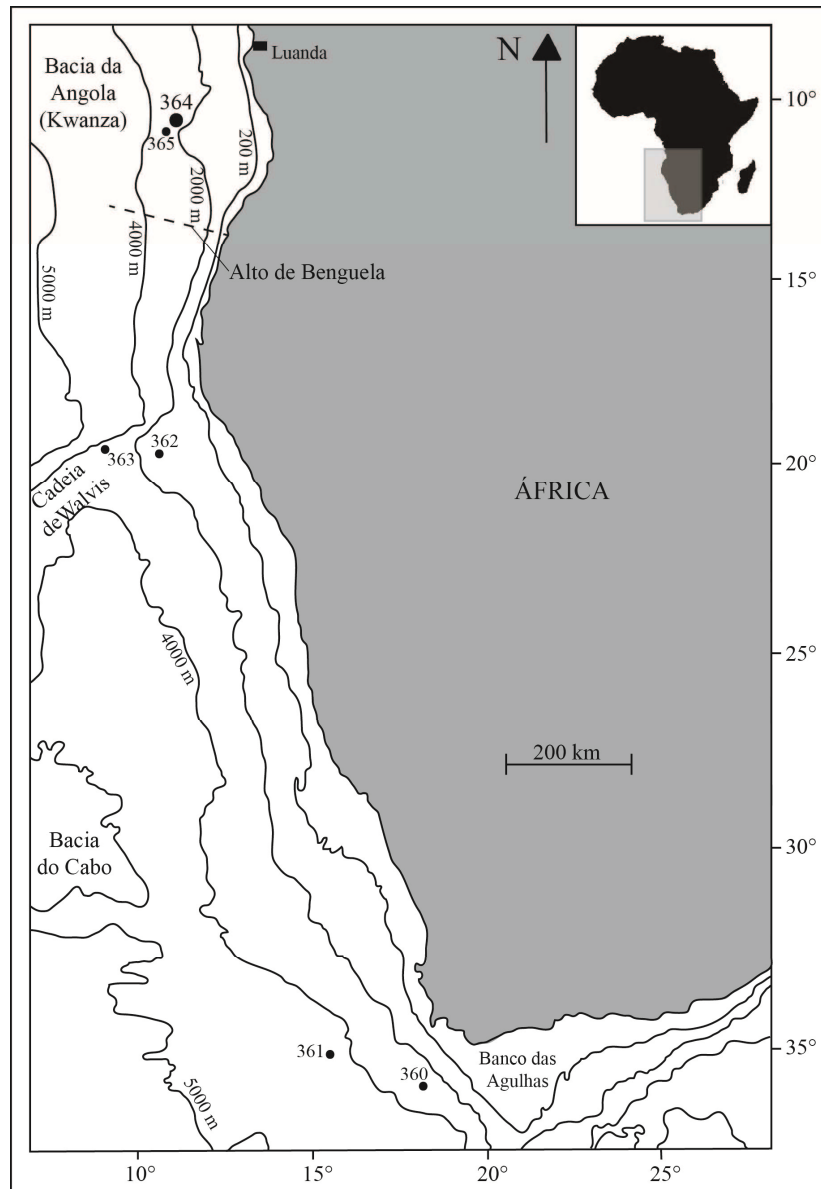


Figura 4 – Mapa de localização do DSDP Site 364, Bacia da Angola, também mostrando a localização dos demais sites perfurados durante o DSDP Leg 40. Modificado de Siesser (1978) e Brownfield e Charpentier (2006).

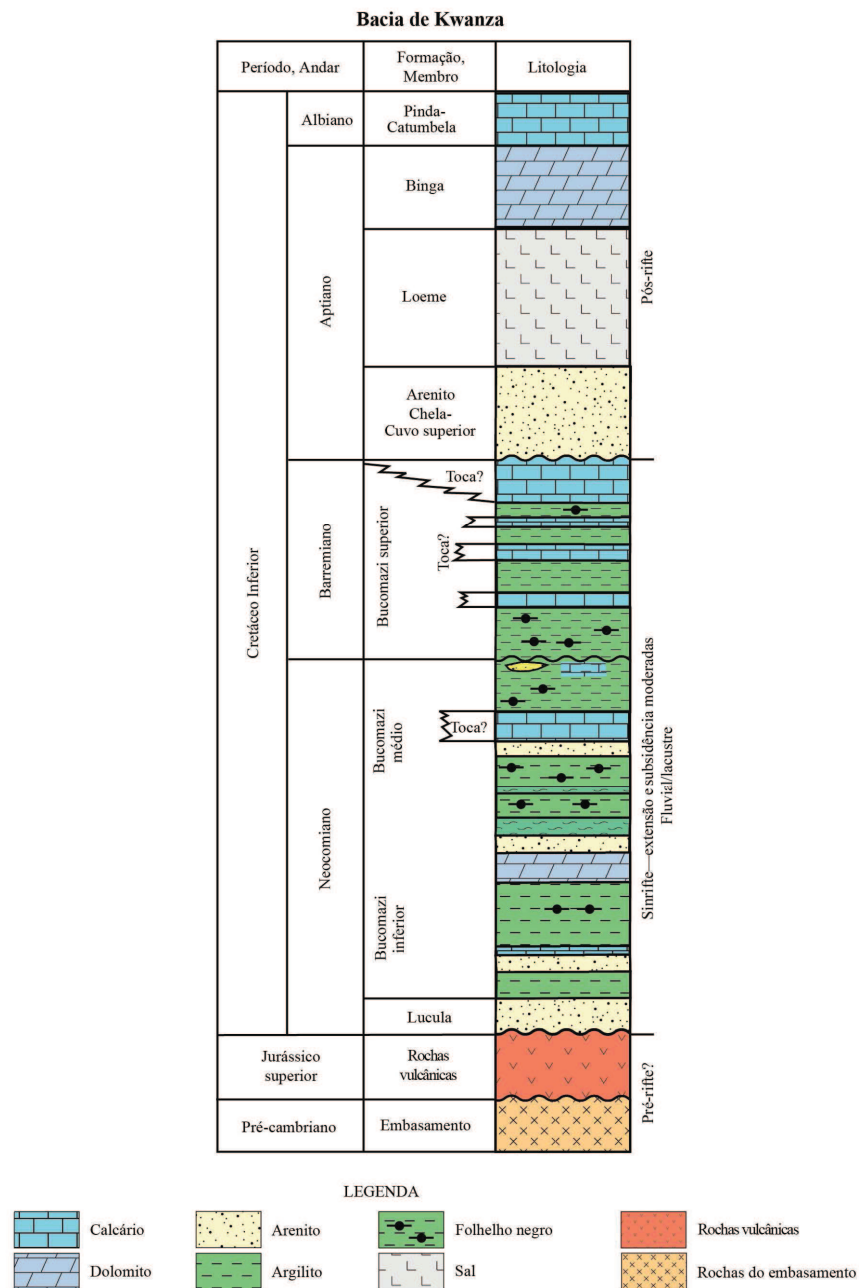


Figura 5 - Arcabouço estratigráfico simplificado da Bacia de Kwanza (intervalo Jurássico Superior-Cretáceo Inferior). Modificado de Brownfield e Charpentier (2006).

Estudos abordando foraminíferos do intervalo Aptiano-Albiano no Oceano Atlântico Sul são raros (SLITER, 1976; PREMOLI SILVA; BOERSMA, 1977; CARON,

1978; KRASHENINNIKOV; BASOV, 1983; VIVIERS, 1987; KOUTSOUKOS et al., 1991a, 1993; CUNHA; KOUTSOUKOS, 1998; HUBER; LECKIE, 2011). Uma das características mais marcantes das faunas recuperadas nesse intervalo de tempo no setor setentrional (restrito) do Oceano Atlântico Sul é a ausência de alguns marcadores bioestratigráficos tetianos em determinadas zonas de foraminíferos planctônicos (PREMOLI SILVA; BOERSMA, 1977; CARON, 1978; VIVIERS, 1987). Esse padrão de distribuição estratigráfica foi historicamente interpretado como um indicativo da afinidade paleobiogeográfica austral dessas faunas (PREMOLI SILVA; BOERSMA, 1977; CARON, 1978). O presente estudo, por sua vez, contribui de forma significativa para a melhor compreensão desse problema, uma vez que reporta a dominância de morfotipos planctônicos que caracterizam associações marinhas de águas rasas (espécies que provavelmente habitavam as camadas superiores da coluna d'água) nos níveis onde os marcadores tetianos (supostamente adaptados a habitar níveis mais profundos da coluna d'água) estão ausentes. Dessa forma, interpreta-se a ausência de algumas espécies tetianas como o resultado de uma restrição ecológica ao ambiente raso e restrito sugerido para o início do processo de abertura do Oceano Atlântico Sul setentrional, fato que não se opõe à afinidade tetiana (principalmente para com o Tétis Oeste/proto-Oceano Atlântico Central) das faunas descritas até o momento (incluindo os foraminíferos planctônicos e bentônicos descritos no presente trabalho). Com base nas tendências dos valores isotópicos de carbono, tornou-se possível inferir idades para intervalos estratigráficos em que fósseis-guia não ocorrem, além de permitir a sugestão de que o evento anóxico do Aptiano tardio, descrito originalmente para estratos aptianos do México (BRALOWER et al., 1999), levou à deposição de folhelhos negros no setor norte

do Oceano Atlântico Sul (ao norte do complexo Cadeia de Walvis-Elevação do Rio Grande). Quanto às interpretações paleoceanográficas, baseadas na análise paleoecológica, sugere-se que toda a sucessão estudada tenha sido depositada sob condições de águas relativamente quentes (província tetiana) e mesotróficas a eutróficas quanto ao conteúdo de nutrientes. A paleobatimetria sugerida varia predominantemente entre ambientes neríticos externos e batiais superiores, sendo que as condições de fundo seriam depletadas em oxigênio, mas com camadas epipelágicas bem oxigenadas.

2 ARTIGO I

Aptian-Albian planktic foraminifera from DSDP Site 364 (offshore Angola):
Biostratigraphy, paleoecology and paleoceanographic significance. *Journal of
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RRH: APTIAN–ALBIAN PLANKTIC FORAMINIFERA

LRH: KOCHHANN AND OTHERS

APTIAN–ALBIAN PLANKTIC FORAMINIFERA FROM DSDP SITE 364
(OFFSHORE ANGOLA): BIOSTRATIGRAPHY, PALEOECOLOGY AND
PALEOCEANOGRAPHIC SIGNIFICANCE

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ABSTRACT

This work presents a taxonomic, biostratigraphic and paleoecological study on the planktic foraminiferal fauna recovered from the Aptian–Albian carbonate-dominated succession of Deep Sea Drilling Project (DSDP) Site 364, located in the Kwanza Basin (offshore Angola). Thirty planktic foraminiferal species were identified, which enabled the identification of a series of biozones, late Aptian to late Albian in age, from the *Hedbergella trocoidea* Zone to the *Pseudothalmaninella ticinensis* Zone. A remarkable unconformity was identified in core 31, spanning the latest early to earliest late Albian, presenting the *Microhedbergella rischi* Zone in direct contact to the *Pseudothalmaninella ticinensis* Zone. The specific composition of the recovered assemblages characterizes them as open marine epipelagic dwellers, and permits the suggestion of predominant mesotrophic to eutrophic environmental conditions throughout the studied stratigraphic succession. Aptian planktic foraminiferal assemblages present a significant Tethyan paleobiogeographic affinity, supporting a Tethyan surface-water influx into this restricted southeastern sector of the northern South Atlantic Ocean (north to the Walvis Ridge–Rio Grande Rise) back in the late Aptian. Trends in isotopic values for $\delta^{13}\text{C}$, which have to be carefully interpreted due to possible diagenetic overprint, suggest a late Aptian age (*Globigerinelloides algerianus* Zone) for the stratigraphic interval from core 42 to about core 37, where Tethyan age-diagnostic foraminiferal species are missing, as well as that the black shale levels in cores 42–39 could be correlated to the “late Aptian anoxic event.” Some taxonomic and biostratigraphic particularities regarding planktic foraminiferal assemblages from this sector of the

northern South Atlantic Ocean are also considered taking into account its unique paleocenographic setting.

INTRODUCTION

The Aptian–Albian is a unique time interval in Earth’s history due to the common occurrence of organic-rich rocks, which are frequently related to oceanic anoxic events (OAEs; e.g., Arthur and Premoli Silva, 1982; Jenkins, 1995; Jenkins and Wilson, 1999). These anoxic events are characterized by the widespread occurrence of black shales and drastic shifts in the carbon isotope ratio record (Leckie and other, 2002), leading to main reorganizations in the marine ecosystem, even among the planktic foraminifera (e.g., Leckie, 1984; Koutsoukos and other, 1991b; Premoli Silva and others, 1999; Leckie and others, 2002). Despite the efforts in proposing several candidates for the stratotype section of the base of the Albian stage (e.g., Kennedy and others, 2000; Hancock, 2001) and the high relevance of this time interval in understanding coupled global paleoceanographic and paleoclimatic changes, there is still no consensus about a Global Boundary Stratotype Section and Point (GSSP), mainly due to the elevated degree of endemism of the ammonoids assemblages, commonly used in the definitions of the boundaries between Cretaceous stages (Birkelund and others, 1984). This fact makes difficult to study the paleoceanographic events mentioned above, as well as commonly 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).

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), as well as to use the dataset 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 also the absence of some Tethyan biostratigraphic markers, the studied fauna reveals a series of particularities regarding Aptian–Albian planktic foraminiferal assemblages from the restricted southernmost portion (north to the Walvis Ridge–Rio Grande Rise) of the northern South Atlantic Ocean.

GEOLOGICAL SETTING

Séranne and Anka (2005) proposed the subdivision of the African margin in equatorial western African margin (with the occurrence of evaporitic and carbonatic units in the Cretaceous) and southwest African margin (dominated by clastic deposition in the Cretaceous). The physical boundary between these provinces was the high standing Walvis Ridge. Historically, the entire basin and continental shelf of the equatorial western African margin has been called the Angola Basin, being the most remarkable depression of the northeastern South Atlantic Ocean. Its degree of isolation, mainly as a consequence of the presence of the Walvis Ridge, was inherited from its very birth (Barremian–Aptian; cf. Séranne and Anka, 2005), allowing the formation of a huge layer of evaporites, exceeding in places 3 km in thickness. In the context of the Angola Basin, recent studies proposed the individualization 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., Clifford, 1986; Brownfield and Charpentier, 2006). The Kwanza Basin is northwardly limited by the Ambriz Arch, southwardly by the Benguela High, eastwardly by the east edge of the sedimentary basins and westwardly by the 4,000 m bathymetric depth.

Séranne and Anka (2005) subdivided the geological history of the equatorial western African margin (including the Kwanza Basin) in four main phases, as follows: rifting, rift–drift transitional, drift and late drift sequence. According to the authors, the rift–drift transitional sequence is characterized by a transgressive clastic sequence, grading upwards from fluvial sandstones and lagoonal shales to thick layers of evaporites. Deposition of evaporites during the mid- to late Aptian makes the distinctive feature of equatorial western African rift–drift transitional sequence. The effective marine transgression started with the deposition of evaporites and followed with the deposition of shallow-water carbonates (dolomites and limestones studied herein) during the late Aptian–Albian (Binga and Pinda formations: Séranne and Anka, 2005; Brownfield and Charpentier, 2006; or Pinda Group: Valle and others, 2001; mentioned herein as units five, six and seven).

The breakup between African and South American plates began in the Early Jurassic in the southernmost part of the Gondwanaland and gradually extended northwards during the Early Cretaceous (Uchupi, 1989; Binks and Fairhead, 1992; Guiraud and Maurin, 1992). In this way, the area of the Gulf of Guinea opened last, forming a continuous dysoxic–anoxic seaway from the Walvis Ridge to North Africa in the late Aptian to Turonian (Tissot and others, 1980). Although earlier paleogeographic

studies stated that the first marine transgressions accompanied the tectonic opening, from south to north (e.g., Conceição and others, 1988), recent paleontological studies, based on paleobiogeographic data, have suggested that the first marine incursions came from the Tethyan/Central Atlantic Ocean province (Koutsoukos and others, 1991b; Koutsoukos, 1992; Dias-Brito, 1995, 2000; Azevedo, 2004; Bengtson and others, 2007; Arai, 2009). Hence, during the late Aptian to early Albian interval, the Kwanza Basin presented stagnant bottom-water conditions that prevented oxidation of organic matter (Bolli and others, 1978).

In DSDP Site 364, Albian marly-chalks and limestones 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 paleophysiography (Bolli and others, 1978). The sedimentary rocks recovered in the deepest cores of DSDP Site 364 suggest outer-shelf or shelf-break depths for the time of deposition of the black shales (Bolli and others, 1978).

MATERIAL AND METHODS

The studied Aptian–Albian section of DSDP Site 364 is mainly composed of limestones, dolomitic limestones, nannofossil chalks, mudstones, claystones and black shales. In a 354.5 m thick sedimentary succession, with several not-recovered intervals (recovery rate of about 61.9%), 74 samples were collected for the micropaleontological survey. Each sample was processed as follows: approximately 20 g of dried rock were crushed and soaked in a 200 ml hydrogen peroxide solution (H_2O_2 , at concentration of

29%) for 24 hours. When samples presented high levels of calcium carbonate and the above procedure was not successful in recovering foraminiferal tests, the acetolysis method (experiment 12) was used in accordance to Rodrigues and others (2012). Finally, residues were washed through a 38 μm mesh sieve and a minimum of 300 planktic specimens were identified from each sample under a stereomicroscope. Scanning electron micrographs of the identified species were taken in order to ensure accurate identifications of wall microstructures. Specific abundances of planktic foraminifera were estimated relatively to the total planktic assemblage. First occurrence datums (FODs) and last occurrence datums (LODs) of marker species were applied in the identification of biostratigraphic events, mainly following the latest propositions of Huber and Leckie (2011) and Petrizzo and others (2012). Average test diameter is based on measurements of at least five specimens of each species per sample. In the statistical analysis of the data it was used the software PAST – Paleontological Statistics (Hammer and others, 2001).

Carbon and oxygen stable isotopic measurements were performed on bulk powdered limestone samples at the NEG-LABISE, Departamento de Geologia, Universidade Federal de Pernambuco. CO_2 was extracted in a high vacuum line after reaction with phosphoric acid (H_3PO_4), at concentration of 100% and 25°C , and cryogenically cleaned as described by Craig (1975). Released CO_2 was analyzed in a double inlet, triple collector SIRA II mass spectrometer, being C and O isotopic values (Appendix 1) reported as δ (‰) deviations with reference to V-PDB (Vienna-Pee Dee belemnite international standard).

BIOSTRATIGRAPHY

Aptian–Albian sedimentary successions from the restricted southernmost sector (north to the Walvis Ridge–Rio Grande Rise) of the northern South Atlantic Ocean have been historically characterized by the absence of several typical Tethyan 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 once 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 remained unzoned (the base and the top of the studied site), due to the complete absence of age-diagnostic forms. The sedimentary succession from core 37 to core 26, late Aptian to late Albian in age, presents the following planktic foraminiferal zones: *Hedbergella trocoidea*, “*Paraticinella eubejaouaensis*,” *Microhedbergella rischi* and *Pseudothalmanninella ticinensis* (Tab. 1; Fig. 2). The definition of each zone, as well as their microfaunal characteristics, is described below.

APTIAN

The basal strata of DSDP Site 364, interval between 1032.37 m (meters below the seafloor) and 932.45 m, remained not zoned in the present study due to the absence of

age-diagnostic species (Fig. 2), although an Aptian age can be suggested to this interval due to the FODs of *Hedbergella praetrocoidea* and *Hd. trocoidea* (see Taxonomic notes section below for their stratigraphic ranges and Fig. 2). These data corroborate the Aptian age suggested by Caron (1978) for this stratigraphic interval. That author subdivided this interval in the “*algeriana*” and “*gorbachikae*” zones, based on faunal associations. However, in face of new knowledge on taxa stratigraphic ranges, there are no age-diagnostic species in the assemblages reported by Caron (1978), and the ones recovered herein, to subdivide it. It is also remarkable that occurrences of *Favusella* sp. aff. *F. washitensis* are restricted from core 42 to core 40 (Fig. 2), and if it is assumed that this species has had the same paleoecological preferences as the closely related *Favusella washitensis* (probably adapted to shallow, warm, hypersaline, carbonate-saturated environments; Koutsoukos and others, 1989), its occurrence would be able to explain the absence of probable deeper-dwelling age-diagnostic forms (e.g., *Globigerinelloides algerianus* Cushman and ten Dam) in this interval of the studied site.

The stratigraphic interval from 932.45 m to 877.42 m was attributed to the *Hedbergella trocoidea* Partial-Range Zone (Fig. 2). According to Huber and Leckie (2011), this zone, the lowest one identified in the studied site, is defined by the partial range of *Hd. trocoidea*, from the LOD of *Globigerinelloides algerianus* (not recovered in the studied samples) to the FOD of *Paraticinella eubejaouaensis*. Since *Globigerinelloides algerianus* is absent in the studied succession, the basal boundary of this zone is tentatively placed at the FOD of *Hedbergella labocaensis*, which first occurs within this zone (see Taxonomic notes section below and Fig. 2; cf. Longoria, 1974). Also, the LOD of *Hedbergella luterbacheri* below this level (which is reported within the

Globigerinelloides algerianus elsewhere; cf. Longoria, 1974) supports this statement. Typical species of this stratigraphic interval are *Hedbergella aptiana*, *Hd. labocaensis*, *Hd. trocoidea* and *Globigerinelloides* sp. cf. *Gld. aptiensis*.

The interval between 877.42 m and 844.57 m was attributed to the “*Paraticinella eubejaouaensis*” Taxon-Range Zone (Fig. 2), defined by the total stratigraphic range of the homonym species. As the specimens of “*Paraticinella eubejaouaensis*” recovered from this restricted southernmost sector (north to the Walvis Ridge–Rio Grande Rise) of the northern South Atlantic Ocean present some morphological peculiarities in relation to forms occurring elsewhere (see Taxonomic notes section below for remarks), the zonal name and the specific designation are presented between quotation marks. Despite the taxonomic uncertainties, the stratigraphic range of the recovered forms (Fig. 2) seems to be identical to that of specimens assigned to *P. eubejaouaensis* elsewhere, preserving the same relative position when compared to other species occurrences [e.g., *Hedbergella trocoidea*, *Globigerinelloides barri*, species of *Microhedbergella*) and to the main extinction level reported by Huber and Leckie (2011)]. The FOD of “*Pa. eubejaouaensis*” reported herein coincides with the FOD described by Caron (1978), while its LOD is herein reported higher in the succession, where specimens become smaller and fewer. There are remarkable extinction levels within this zone, as in sample 364-33-5, 65–69 cm (850.15 m) and at its uppermost boundary. Virtually all the long-ranging Aptian species characteristic of the *Hedbergella trocoidea* Zone become extinct within the upper portion of the “*Paraticinella eubejaouaensis*” Zone (Tab. 1). Besides, *Globigerinelloides paragottisi* and *Microhedbergella* sp. cf. *Mi. miniglobularis* are also typical species. *Globigerinelloides barri* presents an isolated occurrence within the lowermost

“*Paraticinella eubejaouaensis*” Zone at 875.96 m (Tab. 1), being worth mentioning that Verga and Premoli Silva (2003b) also reported the occurrence of some specimens of *Globigerinelloides barri* in the lowermost *Ticinella bejaouaensis* Zone (=“*Paraticinella eubejaouaensis*” Zone herein) in Tethyan sections.

ALBIAN

The *Microhedbergella rischi* Interval Zone was identified between 829.46 m and 807.4 m (Fig. 2), being defined by Huber and Leckie (2011) as the stratigraphic interval between the FOD of *Microhedbergella rischi* and the FOD of *Ticinella madecassiana* Sigal (not recorded herein due to an unconformity). Species characteristic of this zone are *Microhedbergella rischi*, *Microhedbergella pseudoplanispira* and *Microhedbergella* sp. cf. *Mi. miniglobularis*, *Microhedbergella rischi* trans. *madecassiana*, *Muricohedbergella angolae* and *Ticinella?* sp. aff. *Ti. primula*.

Despite the absence of zonal markers [for close comparisons see Premoli Silva and Boersma (1977), Caron (1978) and Viviers (1987)], the stratigraphic interval from 807.4 m to 715.34 m was tentatively assigned to the *Pseudothalmanninella ticinensis* Zone [for a definition see Caron (1985); Fig. 2], based on the known stratigraphic ranges of the occurring species (see Taxonomic notes section below). The base of this tentatively-zoned interval is placed at the FOD of *Muricohedbergella astrepta* (807.4 m), while its top is placed at the LOD of *Muricohedbergella angolae* (715.34 m). The FODs of *Muricohedbergella praelibyca*, *Mu. delrioensis* and *Ticinella raynaudi* within this interval also supports the zonal assignment (for their stratigraphic ranges see the

Taxonomic notes section). The direct contact between the *Microhedbergella rischi* Zone and the *Pseudothalmanninella ticinensis* Zone points to the occurrence of a remarkable unconformity, spanning four planktic foraminiferal zones (latest early to earliest late Albian in age; Huber and Leckie, 2011).

Upper in the section, the stratigraphic interval from 715.34 m to 672.92 m remained not zoned, due to the complete absence of foraminifera in some samples and the lack of age diagnostic species in the remaining ones (Tab. 1). Nannofossil biostratigraphy attributed a late Albian age for this interval (*Eiffellithus turriseiffeli* Zone; cf. Proto Decima and others, 1978).

APTIAN/ALBIAN BOUNDARY AND UNCONFORMITIES

Considering the sampling resolution utilized herein and the poor recovery of cored intervals (see Fig. 2 for their thickness), the Aptian/Albian boundary is spanned by a not cored interval of about 13 m between the “*Paraticinella eubejaouaensis*” and the *Microhedbergella rischi* zones (Fig. 2). Despite the absence of the *Microhedbergella miniglobularis* Zone [in accordance to Huber and Leckie (2011)] and the *Microhedbergella renilaevis* Zone [in accordance to Petrizzo and others (2012)], any statement regarding the occurrence of an unconformity would be overstated due to the poor temporal resolution. In addition, the Aptian/Albian boundary is characterized by a remarkable faunal turnover, distinguished by the extinction of virtually all long-ranging Aptian species (only one species crossed the boundary) and followed by the appearance of few small smooth-walled species (Tab. 1; cf. Huber and Leckie, 2011).

Despite the tentative zonal assignment for the stratigraphic interval from 807.4 m to 715.34 m (*Pseudothalmanninella ticinensis* Zone), the abrupt superposition of early Albian assemblages (*Microhedbergella rischi* Zone) by late Albian ones (*Pseudothalmanninella ticinensis* Zone) is well defined (Fig. 2). This superposition of zones characterizes a remarkable unconformity within core 31, spanning the zones *Ticinella madecassiana*, *Ticinella primula*, *Ticinella praeticinensis* and *Pseudothalmanninella subticinensis* (Huber and Leckie, 2011), latest early to earliest late Albian in age. For comparison, Huber and Leckie (2011) reported even greater 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 the one reported herein is the complete absence of middle Albian assemblages, and the consequent unconformity, reported in the later work (Fig. 2). This difference is believed to be a consequence of problems in the identification of ticinellids. For instance, Caron (1978) identified the *Ticinella primula* Zone (middle Albian in age) by the occurrence of the homonym taxon, however, the specimen figured as *Ti. primula* Luterbacher in that work seems more likely to fit in the description of *Ti. madecassiana*, due to the rapid and non-gradual growth rate of the last forming chamber, or even *Microhedbergella rischi* trans. *madecassiana* (as reported herein). Also, the specimens figured as *Ticinella* cf. *roberti* and *Ticinella praeticinensis* by Caron (1978) do not present a typical “ticinellid wall structure,” being herein considered *Muricohedbergella astrepta* and *Muricohedbergella praelibyca*, respectively (see Taxonomic notes section below).

CARBON AND OXYGEN ISOTOPES

 $\delta^{13}\text{C}$ AND $\delta^{18}\text{O}$ VALUES

$\delta^{13}\text{C}$ values vary between -2.59‰ and 2.94‰ in the late Aptian–late Albian interval of DSDP Site 364 (Appendix 1). There is an increasing trend in $\delta^{13}\text{C}$ values from core 42 to core 36, followed by a more or less variable plateau from core 36 to core 28, and a decreasing trend in $\delta^{13}\text{C}$ values from core 28 to core 24 (Fig. 2). It is remarkable that $\delta^{13}\text{C}$ values drop near to the black-shale levels (e.g., from core 42 to core 39 and within core 25). $\delta^{18}\text{O}$ values vary from -5.47‰ to -2.16‰ within the studied interval of DSDP Site 364 (Appendix 1). There is an increasing trend in $\delta^{18}\text{O}$ values from core 42 to core 36, followed by $\delta^{18}\text{O}$ values more or less scattered around a mean value (about -3.25‰) from core 36 to core 24 (Fig. 2).

Some authors have suggested that significant positive correlation between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values might be an indicative of diagenetic overprint (e.g., Jenkyns, 1995). Stable isotopic measurements performed herein visually seem to display positive correlation (Fig. 2), although no significant graphical correlation is seen in the scatterplot (Fig. 3), with a linear correlation index $r = 0.32$, suggesting minor diagenetic overprint. $\delta^{18}\text{O}$ values presented in Fig. 2 are not further discussed herein, as they display the typical sawtooth pattern (Jenkyns and Wilson, 1999) that may reflect the local effect of early diagenesis [see also Bolli and others (1978) for stratigraphic intervals with preferential dolomitization]. On the other hand, $\delta^{13}\text{C}$ values are believed to be less prone

to display diagenetic overprints (e.g., Jenkyns, 1995; Holser, 1997; Jenkyns and Wilson, 1999; Fisher and others, 2005; Amodio and others, 2008). Hence, tentative interpretations regarding $\delta^{13}\text{C}$ values are made herein, once they can be representative of the environmental conditions during the time of deposition. However, carefulness is needed in order to avoid overstatements and future studies, based on better-preserved material, may test trends and interpretations presented herein.

CARBON ISOTOPES DISCUSSION

General trends in $\delta^{13}\text{C}$ values reported herein (Fig. 2) are comparable to previously published curves for the same time interval (e.g., Jenkyns, 1995; Jenkyns and Wilson, 1999; Bralower and others, 1999; Price, 2003), mainly the increasing trend reported for late Aptian strata. Taking into account previous studies, $\delta^{13}\text{C}$ values present a minimum within the *Globigerinelloides algerianus* Zone, followed by a return to more positive values across the *Hedbergella trocoidea* Zone and the *Paraticinella eubejaouaensis* Zone (e.g., Jenkyns, 1995; Price, 2003). Within Albian, mainly during the late Albian, $\delta^{13}\text{C}$ values are reported to return (decrease) to pre-excursion levels elsewhere (Price, 2003). These trends, reported for a wide range of localities, are quite comparable to the $\delta^{13}\text{C}$ curve presented in Fig. 2. The trend of increasing $\delta^{13}\text{C}$ values from core 42 throughout the *Hedbergella trocoidea* Zone and the “*Paraticinella eubejaouaensis*” Zone is likely to correspond to the isotopic segments C9 and C10 described by Bralower and others (1999). $\delta^{13}\text{C}$ values minima in cores 42, 41 and 40 (1032.37 m to 988.42 m) also support the above statement, suggesting a late Aptian age

(*Globigerinelloides algerianus* Zone) for the stratigraphic interval from core 42 to about core 37 (1032.37 m to about 934.44 m), in which Tethyan age-diagnostic foraminiferal species are missing. Furthermore, the $\delta^{13}\text{C}$ values minima are correlated with the deposition of C_{org} -rich sediments (core 42 to core 39; 1032.37 m to 968.45 m), permitting the suggestion that some, or even all, the black shale levels in these cores could be correlated to the so-called “late Aptian anoxic event,” described by Bralower and others (1999) within the upper *Globigerinelloides algerianus* Zone. Bralower and others (1999) described the “late Aptian anoxic event” as C_{org} -rich strata associated to a decrease in $\delta^{13}\text{C}$ values and a rising relative sea-level trend in the Santa Rosa Canyon section, Mexico. Bralower and others (1999) also identified the isotopic signal associated to the “late Aptian anoxic event” in geographically widespread Tethyan sections, despite the absence of black shales in all those areas. The decrease in $\delta^{13}\text{C}$ values within the *Globigerinelloides algerianus* Zone has been interpreted as a consequence of a cooling event associated to waning of C_{org} cycling in Tethyan limestone successions (Price, 2003); however, no clear cause-effect relation has been pointed out yet (cf. Bralower and others, 1999).

The drop in $\delta^{13}\text{C}$ values close to black shale levels in DSDP site 364 is remarkable, once the expected $\delta^{13}\text{C}$ trend associated to organic-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; Hoef, 2004; Maslin and Swann, 2006). Global $\delta^{13}\text{C}$ negative excursions have been reported from Jurassic to Paleogene (Bralower and others, 1999; Hesselbo and others, 2000; Price, 2003), but there are conflicting arguments when

these are associated to C_{org} -rich horizons. Three hypotheses have been proposed to explain significant negative $\delta^{13}C$ excursions: i) voluminous release of methane from gas hydrates contained in marine continental margin-deposits (e.g., Bralower and others, 1999; Jahren and others, 2001); ii) increasing volcanic activity, mainly during the Aptian (Larson, 1991), leading to enhanced CO_2 emissions (e.g., Bralower and others, 1994; Price, 2003); iii) 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 $\delta^{13}C$ negative excursions, even during Aptian times (e.g., Jahren and others, 2001), when seafloor spreading rates and volcanic activity are believed to have been the highest of the Phanerozoic (Larson, 1991). According to Hesselbo's and others (2000) and Jahren's and others (2001) models, methane hydrate dissociation during the Early Jurassic and the Early Cretaceous could have saturated the deep ocean, perhaps resulting in local anoxia and explaining the $\delta^{13}C$ negative excursions associated with the black shale levels. Moreover, it is worth mentioning that the oceanic (pelagic) $\delta^{13}C$ record is a global signal, while black shales deposition is a local phenomenon (Price, 2003).

PALEOECOLOGY

FAUNAL PATTERNS

The simple species richness, characterized by the number of planktic foraminiferal species in each sample, varies between 1 and 9 within the studied succession of DSDP Site 364, presenting its highest value (9 species) within the lower “*Paraticinella eubejaouaensis*” Zone (Fig. 4). It is also remarkable that species richness falls in stratigraphic intervals dominated by black shales (i.e., from 1,033 m to about 960 m) and in the earliest Albian (lower *Microhedbergella rischi* Zone; Fig. 4). The Shannon-Wiener (H') diversity index, also known as entropy index, is dependent on the number of taxa in an assemblage and their relative abundances (Hammer and Harper, 2006). In the studied succession, the Shannon-Wiener diversity index follows the same trends as the simple species richness (Fig. 4), being both variables correlated (linear correlation: $r = 0.71$). The dominance index takes into account the relative abundances of taxa and the degree in which they dominate the assemblage (Hammer and Harper, 2006). As a general trend, dominance presents opposite trends when compared to the simple species richness ($r = -0.57$) and the Shannon-Wiener diversity index ($r = -0.97$) in 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). Equitability presents a moderate correlation with the Shannon-Wiener diversity index ($r = 0.81$), suggesting a more even distribution of the relative abundances in highly diversified assemblages (Fig. 4).

Regarding the relative abundances of the planktic foraminiferal families (Fig. 4), the Hedbergellidae is the dominant taxon group, presenting elevated relative abundance throughout most of the studied stratigraphic interval. 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 expressive occurrences of the Favusellidae and Schackoinidae (Fig. 4) Most of the species assigned to these families are considered typical taxa from open marine shallow-water assemblages (e.g., *Hedbergella trocoidea*, *Muricohedbergella delrioensis*, *Schackoina cenomana*, “*Globigerinelloides bentonensis*”; cf. Leckie, 1987; Koutsoukos and others, 1989). It is also worth mentioning that the Favusellidae (*Favusella* sp. aff. *F. washitensis*) is restricted to the basal cores of the studied site, occurring even at or near to the black shale levels (Fig. 4).

Main occurrences of species with radially elongated chambers (*Hedbergella labocaensis*, *Hd.* sp. cf. *Hd. maslakovae*, *Hd.* sp. cf. *Hd. similis*, *Schackoina bicornis*, *Sc. cenomana* and *Pseudoschackoina?* sp.) do not correlate with the presence of organic-rich sedimentary rocks (black shales), being their highest abundance values at cores 37 and 38 (Fig. 4). The total relative abundance of rugose species (*Favusella* sp. aff. *F. washitensis*, *Globigerinelloides barri*, *Muricohedbergella angola*, *Mu. delrioensis*, *Mu.* sp. cf. *Mu. planispira*, *Mu. praelybica*, *Mu. astrepta* and “*Paraticinella eubejaouaensis*”) presents its highest values in late Albian strata (Fig. 4). Finally, the Aptian/Albian transition presents a conspicuous faunal turnover (Tab. 1), characterized by high rates of extinctions in the latest Aptian followed by increasing rates of species originations in the earliest Albian (Fig. 4).

PALEOECOLOGICAL AND PALEOECEANOGRAPHIC SIGNIFICANCE

In general aspects, the family Hedbergellidae dominates in relative abundance throughout the studied interval of DSDP Site 364 (Fig. 4). Species of this family are often ecologically considered r-strategists, commonly adapted to eutrophic environments (Cunha and Koutsoukos, 1998), supporting the suggestion of dominating eutrophic environmental conditions in the upper water column throughout the studied stratigraphic succession. According to the proposition of Premoli Silva and Sliter (1999), some of the species recorded herein could possibly be considered r/K-strategists (intermediate forms of a continuous spectrum; e.g., *Hedbergella trocoidea*, *Globigerinelloides barri* and the genus *Globigerinelloides* itself), also suggesting the possible occurrence of even mesotrophic environmental conditions. The consistent occurrences of the genera *Hedbergella*, *Globigerinelloides* and *Ticinella* allow assigning the studied assemblages to open marine shallow-water ones (Leckie, 1987) and also suggest well-oxygenated epipelagic layers (Koutsoukos and others, 1991a). The total relative abundance of planktic vs. benthic foraminifera (Fig. 4) was usually high from core 42 to core 39, in which black shale levels consistently occur, and also in other portions of the studied stratigraphic succession (e.g., within the *Pseudothalmanninella ticinensis* Zone). Such patterns, with rare or no benthic foraminifera and a rich planktic biota, suggest deposition under oxygen-depleted bottom conditions, but with well-oxygenated epipelagic layers.

Paleobiogeographically, the studied Aptian planktic foraminiferal fauna presents strong Tethyan affinity when compared to previously described ones (e.g., Longoria, 1974; Leckie, 1984; Koutsoukos, 1989; Koutsoukos and others, 1991b; Koutsoukos, 1992; Premoli Silva and Sliter, 1999; Moullade and others, 2005; Huber and Leckie, 2011). For instance, BouDagher-Fadel and others (1997) stated that *Blefuscuiana*

praetrocoidea (= *Hedbergella praetrocoidea* herein) was known only for the Aptian interval of the eastern Tethys. *Hedbergella labocaensis* is also believed to be a Tethyan taxon (cf. BouDagher-Fadel and others, 1997). These data support a Tethyan surface-water influx, with open marine shallow-water foraminiferal assemblages (e.g., Leckie and others, 2002), into this southernmost restricted sector (north to the Walvis Ridge–Rio Grande Rise) of the northern South Atlantic Ocean already in the late Aptian. It could possibly be related to the global sea-level rise of that time, and it is in accordance to several previous studies (e.g., Koutsoukos and others, 1991b; Dias-Brito, 1995, 2000; Bengtson and others, 2007; Arai, 2009). The Albian planktic foraminiferal fauna studied herein also presents a characteristic Tethyan affinity when compared to previous described ones (e.g., Longoria and Gamper, 1977; Koutsoukos, 1992; Petrizzo and Huber, 2006). Rugose species mainly of Hedbergellidae, supposed to thrive in shallower environments [mostly middle to deep neritic environments, according to Koutsoukos and Hart (1990), Koutsoukos and others (1991b), Koutsoukos (1992)], dominated late Albian strata, also characterized by the occurrence of open marine shallow-water assemblages (sensu Leckie, 1987) and the absence of keeled taxa (supposed to thrive in deeper environments; e.g., Leckie and others, 2002). These data suggest the occurrence of shallower water conditions in this part of the studied succession (upper *Pseudothalmanninella ticinensis* Zone and the not zoned interval; Fig. 4) and are able, together with the occurrence of *Favusella* sp. aff. *F. washitensis* in late Aptian strata, to explain the absence of some Tethyan deep-dwelling index species in particular intervals of the studied section. Furthermore, data presented here do not contradict Koutsoukos' (1992) and Leckie's and others (2002) interpretations, which suggested an intermediate-

water connection between the North and the South Atlantic Ocean basins by the early Albian. Deep Sea Drilling Project (DSDP) Site 364 could well represent a shallower area, more restricted and closer to the high standing Walvis Ridge, when compared to other sites from the northern South Atlantic Ocean (with a probable well-developed intermediate-water connection to the Central Atlantic). Hence, the absence of some Tethyan biostratigraphic markers in the studied interval of DSDP Site 364 is attributed to their probable deeper-dwelling preferences and not to the influx of colder-water from the southern South Atlantic Ocean, as has been suggested by previous studies (e.g., Premoli Silva and Boersma, 1977; Caron, 1978). The record of keeled Rotaliporidae [*Parathalmanninella appenninica* (Renz)] in late Albian strata from the high latitude DSDP Site 511 (Huber and Leckie, 2011) also supports the inference stated above.

Several authors pointed out that the degree of chambers radial elongation in Early Cretaceous planktic foraminifera was an adaptive response to the low-oxygen content (dysoxic context) of surface waters (e.g., BouDagher-Fadel and others, 1997; Magniez-Jannin, 1998; Premoli Silva and others, 1999; Coccioni and others, 2006). According to Magniez-Jannin (1998), the increasing surface area of the test would allow better gas exchange with the sea water and the intake of sufficient quantities of oxygen for the metabolic needs. In the studied section, main occurrences of species with radially elongated chambers do not correlate with the presence of organic-rich sedimentary rocks (from core 42 to core 39), being their highest abundances at cores 38 and 37 (Fig. 4). This pattern suggests that water oxygenation itself could not have been the single controlling factor affecting the development of this morphological characteristic (cf. Coccioni and others, 2006). Furthermore, it does corroborate the occurrences of a well-oxygenated

epipelagic layer during the deposition of black shales. The low values of simple species richness within or close to the black shale levels, registered herein, are in accordance to previous observations of Premoli Silva and others (1999), suggesting stressing environmental conditions. It is assumed that the species described herein as *Favusella* sp. aff. *F. washitensis* has had similar paleoecological preferences as the closely related *Favusella washitensis* (probably adapted to shallow, warm, hypersaline, carbonate-saturated environments; Koutsoukos and others, 1989; Cunha and Koutsoukos, 1998). Thus, it is possible to infer that the portion of the studied sedimentary succession that presents black shales (probably correlated to the “late Aptian anoxic event”) was also deposited in a relatively shallow-water environment (possible inner to middle neritic biotopes due to the occurrence of probable ephebic to gerontic specimens of *Favusella* sp. aff. *F. washitensis*; cf. Koutsoukos and others, 1989). It is also worth mentioning that this part of the studied succession (core 41 to about core 38), presents generally opposed trends between simple species richness and equitability (Fig. 4). This pattern was identified in the upper Albian of ODP Leg 171 by Petrizzo and Huber (2006), who suggested that it could be the result of mixing of species from adjacent water masses, or seasonal productivity with greater flux of foraminiferal tests during a portion of the year.

Despite the fact that the Aptian/Albian boundary itself is spanned by a not-cored interval in the studied site, the transition is characterized by high rates of extinctions in the latest Aptian followed by increasing rates of species originations in the earliest Albian (Fig. 4). Similar faunal patterns have been pointed out by recent studies (e.g., Koutsoukos and others, 1991b; Koutsoukos and others, 1991a; Kennedy and others, 2000; Leckie and others, 2002; Huber and Leckie, 2011; Petrizzo and others, 2012), being related by Huber

and Leckie (2011) to main reorganizations in the oceanic system, for instance, changes in the carbonate chemistry, vertical stratification of the water column, nutrient supply and/or surface productivity. Leckie and others (2002) stated that the Aptian/Albian boundary is marked by a protracted event of dysoxia with multiple discrete black shale levels across parts of the Tethys (OAE1b; 113–109 Myr), spanning from the *Ticinella bejaouaensis* Zone (=“*Paraticinella eubejaouaensis*” Zone herein) to the *Hedbergella planispira* Zone (comprehending the *Microhedbergella rischi* Zone herein). The recognition of a remarkable faunal turnover in the Aptian/Albian boundary of the studied section seems to be in accordance to the data of Leckie and others (2002) and Huber and Leckie (2011). The Aptian/Albian not-cored interval identified herein is likely to cross the interval characterized by the deposition of discrete black shale layers described by Leckie and others (2002), being only recognized in the studied site the faunal patterns in the foraminiferal assemblages below and above this level. It is also remarkable that there is a drastic change in foraminiferal tests architecture across the Aptian/Albian boundary. In the studied site, latest Aptian species are mainly represented by distinctive large and rugose species, while earliest Albian ones are dominantly small and smooth-walled forms (see the maximum test diameter in Fig. 4). These morphological trends are in accordance with observations presented in previous studies (e.g., Caron, 1978; Leckie and others, 2002; Huber and Leckie, 2011; Petrizzo and others, 2012), whereas 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 earliest Albian taxa.

CONCLUDING REMARKS

The taxonomic study on the Aptian–late Albian interval of DSDP Site 364 enabled the identification of 30 planktic foraminiferal taxa, which evolutionary events (bioevents) permitted the identification of the following biozones: *Hedbergella trocoidea*, “*Paraticinella eubejaouaensis*,” *Microhedbergella rischi* and *Pseudothalmanninella ticinensis*. The Aptian/Albian boundary itself is spanned by a not cored interval between the “*Paraticinella eubejaouaensis*” Zone and the *Microhedbergella rischi* Zone. Within core 31, there is a remarkable unconformity, presenting the *Microhedbergella rischi* Zone in direct contact to the *Pseudothalmanninella ticinensis* Zone.

The specific composition of the studied assemblages characterizes them as open marine shallow-water dwellers, and the dominance in relative abundances of species assigned to the family Hedbergellidae, often ecologically considered r-strategists, suggests eutrophic (perhaps even mesotrophic) environmental conditions throughout the studied stratigraphic succession. The occurrence of a rich planktic biota associated with none or rare benthic foraminifera suggests deposition under oxygen-depleted bottom conditions, but with well-oxygenated epipelagic layers, for the intervals characterized by the deposition of black shales and also for the *Pseudothalmanninella ticinensis* Zone. In addition, the deposition of black shales (core 42 to about core 38) is assumed to have occurred in an oxygen-depleted shallow-water environment.

Paleobiogeographically, the studied Aptian planktic foraminiferal fauna presents a significant Tethyan affinity when compared to previously described ones, supporting a Tethyan surface-water influx into the restricted southernmost sector (north to the Walvis Ridge–Rio Grande Rise) of the northern South Atlantic Ocean already in the late Aptian.

Herein, the absence of some Tethyan biostratigraphic markers is attributed to their deeper-dwelling preferences and not to the influx of colder-water masses from the southern South Atlantic Ocean. Global $\delta^{13}\text{C}$ trends, reported for a wide range of localities, are quite comparable to the $\delta^{13}\text{C}$ trends reported for DSDP Site 364, suggesting a late Aptian age (*Globigerinelloides algerianus* Zone) for the stratigraphic interval from core 42 to about core 37, where Tethyan age-diagnostic foraminiferal species are missing. The above-mentioned trends also permit the suggestion that the black shale levels in cores 42–39 could be correlated to the so-called “late Aptian anoxic event,” described within the upper *Globigerinelloides algerianus* Zone. However, these data have to be carefully interpreted due to possible diagenetic overprint.

The quantitative analysis of these assemblages permitted the identification of a conspicuous faunal turnover at the Aptian/Albian transition, characterized by high rates of extinctions followed by increasing rates of species originations. It is also remarkable that there is a drastic change in foraminiferal tests architecture across the Aptian/Albian boundary.

Some similarities can be seen between the data on planktic foraminifera reported by Caron (1978) for DSDP Site 364 and those presented herein. For instance, that author suggested that the dominance of strongly ornamented species could be related to more neritic environments during the Albian and that the assemblages were Hedbergellidae-dominated throughout the studied section. In addition, Caron (1978) reported the absence of keeled forms and suggested the occurrence of hypersaline conditions in a restricted environment. On the other hand, 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 they take into account microstructural features or not). Also, that author suggested the occurrence of cool environmental conditions during the Albian, while herein the absence of some Tethyan species is attributed to their deeper-dwelling preferences (e.g., keeled morphotypes).

TAXONOMIC NOTES

All species identified in this study are presented and 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 were made under each species in order to clarify the main distinguishing features. Species concepts and stratigraphic ranges are mainly based on the studies of Huber and Leckie (2011) and information given in the Mesozoic Planktonic Foraminiferal Taxonomic Dictionary (http://portal.chronos.org/gridsphere/gridsphere?cid=res_foram), while suprageneric classification follows that of Loeblich and Tappan (1987), as modified by Lee (1989). Concerning detailed descriptions, the reader is referred to the works listed in the synonymies. Occurrences of the identified species in the studied section, even of those left in open nomenclature, and their relative abundances are given in Tab. 1. The specimens figured herein will be deposited in the collections of the Museu de História Geológica do Rio Grande do Sul, Universidade do Vale do Rio dos Sinos (UNISINOS), Brazil, under the curatorial numbers ULVG-8843 to ULVG-8875 (entries given after each species in Figs. 5–8).

Supergroup RHIZARIA Cavalier-Smith, 2002

Class FORAMINIFERA d'Orbigny, 1826

Order GLOBIGERININA Delage and Hérouard, 1896

Family HEDBERGELLIDAE Loeblich and Tappan, 1961

Genus *Hedbergella* Brönnimann and Brown, 1958, emend. Huber and Leckie, 2011

Type species: *Anomalina lorneiiana* d'Orbigny var. *trocoidea* Gandolfi, 1942

Hedbergella aptiana Bartenstein, 1965

Fig. 5.1

Hedbergella aptiana Bartenstein, 1965, p. 347, text-figs. 4–6.

Hedbergella aptiana Bartenstein, 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 growth rate of the chambers in the last whorl.

Stratigraphic range. Barremian to late Aptian (*Hedbergella similis* to *Paraticinella eubejaouaensis* zones — Mesozoic Planktonic Foraminiferal Taxonomic Dictionary; Chronos Portal).

Hedbergella luterbacheri Longoria, 1974

Fig. 5.2

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, increasing gradually and slowly in size. The chambers of the last whorl are globular to sub-globular.

Stratigraphic range. Barremian to Aptian (*Hedbergella similis* to *Globigerinelloides algerianus* zones — Mesozoic Planktonic Foraminiferal Taxonomic Dictionary; Chronos Portal).

Hedbergella sp. cf. *Hd. sigali* Moullade, 1966

Fig. 5.3

Remarks. This species presents a low trochospiral test, with 4.5 chambers in the last whorl. The equatorial outline is cross-shaped, being more or less lobate, and the surface is relatively smooth. Poor preservation does not enable a more precise identification.

Hedbergella sp. cf. *Hd. maslakovae* Longoria, 1974

Fig. 5.4

Remarks. This species is characterized by its oval-shaped outline, and last two chambers that are semi-elongate. It differs from *Hedbergella labocaensis* by having a wider and shallower umbilical area, as well as by its low to flat spiral side.

Hedbergella praetrocoidea Kretzchmar and Gorbachik, 1986

Fig. 5.5

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

Remarks. *Hedbergella praetrocoidea* differs from its descendant, *Hedbergella 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* to *Paraticinella eubejaouaensis* zones — Mesozoic Planktonic Foraminiferal Taxonomic Dictionary; Chronos Portal).

Hedbergella trocoidea (Gandolfi, 1942), emend. Huber and Leckie, 2011

Fig. 5.6

Anomalina lorneiiana var. *trocoidea* Gandolfi, 1942, p. 99, 134, pl. 2, fig. 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 presents 6.5–8 chambers in the final whorl that increase gradually in size; chambers shape is subtriangular to triangular on the umbilical side and subspherical to trapezoidal on the spiral side. There is no apertural lip and the umbilical area is relatively small and deep.

Stratigraphic range. Aptian (*Globigerinelloides ferreolensis* to *Paraticinella eubejaouaensis* zones — Mesozoic Planktonic Foraminiferal Taxonomic Dictionary; Chronos Portal).

Hedbergella labocaensis Longoria, 1974

Fig. 5.7

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

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

Stratigraphic range. Aptian (*Hedbergella trocoidea* to *Paraticinella eubejaouaensis* zones — Longoria, 1974).

Hedbergella sp. cf. *Hd. similis* Longoria, 1974

Fig. 5.8

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

Genus *Muricohedbergella* Huber and Leckie, 2011

Type species: *Muricohedbergella delrioensis* (Carsey, 1926)

Muricohedbergella angolae (Caron, 1978)

Fig. 5.9, 6.1

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

Remarks. *Muricohedbergella angolae* is characterized by having about 5 globular chambers in the last whorl that increase regularly in size (except by the last one or two that increase very rapidly) and by the presence of oriented pustulae on the early chambers.

Stratigraphic range. Albian [*Microhedbergella rischi* (this study) to *Pseudothalmaninella ticinensis* zones (Caron, 1978)].

Muricohedbergella delrioensis (Carsey, 1926), sensu Longoria, 1974

Fig. 6.2

Globigerina cretacea var. *delrioensis* Carsey, 1926, p. 43–44.

Hedbergella delrioensis (Carsey), Caron, 1978, p. 658, pl. 5, figs. 1, 2; pl. 7, figs. 5, 6.

Praeglobotruncana delrioensis (Plummer), Caron, 1978 p. 660, pl. 7, figs. 3, 4.

[Not] *Globorotalia delrioensis* Plummer, 1931, p. 199, pl. 13, figs. 2a–c.

Hedbergella delrioensis (Carsey), Petrizzo and Huber, 2006, p. 185, pl. 7, fig. 4.

Remarks. As suggested by Huber and Leckie (2011) this species is assigned to the genus *Muricohedbergella*, presenting all generic features described by those authors. On the other hand, the revised description of the species (= *Hedbergella delrioensis*; Petrizzo and Huber, 2006) reported the occurrence of a macroperforate wall and a rapid increase in chambers growth rate. Both features were not seen in the material studied herein and are in disagreement to the generic definition proposed by Huber and Leckie (2011). It is important to note that the figured specimen presents the last chamber slightly laterally compressed. Anyhow, it is possible that specimens presenting this small variation should not be identified as an entirely new taxon [for the historical discussion regarding the identity of this taxon see Petrizzo and Huber (2006)]. The presence of an apertural lip/flap in the figured specimen seems to fit well with the description of Longoria (1974) and also one of the specimens figured by Petrizzo and Huber (2006; pl. 7, fig. 4).

Stratigraphic range. Albian to Turonian [*Pseudothalmanninella ticinensis* (Petrizzo and Huber, 2006) to *Helvetoglobotruncana helvetica* zones (Mesozoic Planktonic Foraminiferal Taxonomic Dictionary; Chronos Portal)].

Muricohedbergella sp. cf. *Mu. planispira* (Tappan, 1940), emended Huber and Leckie,

2011

Fig. 6.5

Remarks. This species presents 6–7.5 chambers in the last whorl, increasing slowly in size as added. It has a low to almost flat trochospiral test and an equatorial outline circular and weakly lobate.

Muricohedbergella astrepta (Petrizzo and Huber, 2006)

Fig. 6.3

Ticinella cf. *roberti* (Gandolfi), Caron, 1978, p. 660, pl. 6, figs. 3–4.

Hedbergella astrepta Petrizzo and Huber, 2006, p. 182, pl. 6, figs. 1–4.

Remarks. This species is characterized by its large muricate test. It presents a low trochospiral test, biconvex, with 7–8 globular inflated chambers in the last forming whorl. Chambers are sub-triangular on the umbilical side and rhomboidal on the spiral side; muricae are well developed on the early chambers of the last whorl, and decrease in abundance in the last ones. The aperture is also bordered by a portici.

Stratigraphic range. Late Albian (*Pseudothalmaninella ticinensis* to *Parathalmaninella appenninica* zones — Petrizzo and Huber, 2006).

Muricohedbergella praelibyca (Petrizzo and Huber, 2006)

Fig. 6.4

Ticinella praeticinensis (Sigal), Caron, 1978, p. 660, pl. 7, figs. 1–2.

[Not] *Ticinella praeticinensis* Sigal, 1966, p. 195, pl. 2, figs. 3–8; pl. 3, figs. 1–6.

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

Remarks. This species presents a low trochospiral test, with usually 6 globular chambers, which increase gradually in size, in the last whorl. Surface with scattered pustules, which sometimes become aligned as costalae without a preferential orientation. As in *Muricohedbergella astrepta*, the aperture is bordered by a portici. The tendency to uncoil presented by the figured specimen can be also seen in one of the specimens figured by Petrizzo and Huber (2006; pl. 5, fig. 5).

Stratigraphic range. Albian to Cenomanian (*Pseudothalmaninella ticinensis* to *Thalmaninella globotruncanoides* zones — Petrizzo and Huber, 2006).

Genus *Microhedbergella* Huber and Leckie, 2011

Type species: *Microhedbergella renilaevis* Huber and Leckie, 2011

Microhedbergella sp. cf. *Mi. miniglobularis* Huber and Leckie, 2011

Fig. 6.6

Remarks. Specimens recovered herein are considerable larger 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 in order to confirm the phylogenetic relation between those specimens and the occurrences reported herein.

Microhedbergella rischi (Moullade, 1974), emend. Huber and Leckie, 2011

Fig. 6.7

Hedbergella rischi Moullade, 1974, p. 1816.

Microhedbergella rischi (Moullade), Huber and Leckie, 2011, p. 79, figs. 20.1–20.6, 21.1.

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. pl. 20, fig. 1). It is distinguished from the other species of *Microhedbergella* recorded herein due to the presence of usually six chambers in the last whorl, its subglobular chambers, weakly to moderately lobate in equatorial view, and it never possesses a kummerform final chamber.

Stratigraphic range. Early to late Albian (*Microhedbergella rischi* to *Ticinella primula* zones — Huber and Leckie, 2011).

Microhedbergella rischi trans. *madecassiana* Huber and Leckie, 2011

Fig. 7.8

Microhedbergella rischi trans. *madecassiana* Huber and Leckie, 2011, p. 85, fig. 21.2.

Remarks. This form is characterized by the absence of sutural supplementary apertures, having a densely perforated test and a typical “ticinellid wall texture,” with raised rims that surround the pores (Fig. 7.8d). No typical *Ticinella madecassiana* specimens were recovered in the studied site, once the basis for distinguishing the later species from the transitional form reported herein is the presence of at least one sutural supplementary aperture.

Stratigraphic range. Early Albian (*Microhedbergella rischi* Zone — Huber and Leckie).

Microhedbergella sp.

Fig. 6.8

Hedbergella gorbachikae Longoria, Caron, 1978, p. 658, pl. 3, figs. 9–12.

[Not] *Hedbergella gorbachikae* Longoria, 1974, p. 56, pl. 15, figs. 11–13.

Description. Medium sized test coiled in a low trochospire, with 5–6 chambers in the last forming whorl, rapidly increasing in size. Chambers of the last whorl are globular

to subglobular except by the last one, which tends to be reniform in apertural view and strongly protruded towards the umbilicus. The wall is microperforate to finely perforate. Aperture 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 microperforate wall. Besides, Caron's (1978) Albian specimens and the ones reported herein present apertural lips and relict apertural flaps surrounding the umbilicus. These features are in disagreement to the emended definition of *Hedbergella gorbachikae* (Huber and Leckie, 2011).

Microhedbergella pseudoplanispira Huber and Leckie, 2011

Fig. 6.9

Microhedbergella pseudoplanispira Huber and Leckie, 2011, p. 77, figs. 17.1–17.4.

Remarks. This species is characterized by its small size, smooth test with 6.5–7 chambers in the final whorl, weakly depressed to flush sutures between the early chambers, and the presence of a narrow apertural lip. The test is also low trochospiral, and weakly lobate in equatorial outline.

Stratigraphic range. Early to late Albian (*Microhedbergella rischi* to *Ticinella primula* zones; Huber and Leckie, 2011), although its LOD is reported herein within the *Pseudothalmaninella ticinensis* Zone (also late Albian in age).

Subfamily PARATICINELLINAE Huber and Leckie, 2011

Genus *Paraticinella* Premoli Silva and others, 2009

Type species: *Ticinella eubejaouaensis* Randrianasolo and Anglada, 1998

“*Paraticinella eubejaouaensis*” (Randrianasolo and Anglada, 1998)

Fig. 8.2

Ticinella bejaouaensis Sigal, Caron, 1978, p. 659, pl. 2, figs. 9, 10.

Ticinella bejaouaensis Sigal, Koutsoukos, 1989, p. 240, pl. 28, figs. 16–25.

cf. *Paraticinella eubejaouaensis* (Randrianasolo and Anglada), Premoli Silva and others, 2009, p. 131, text-fig. 2; fig. 3, numbers 3–6; pl. 1, figs. 5–6; pl. 2, figs. 1–6.

Remarks. This species presents 8 subglobular (subtriangular on the umbilical side) chambers in the last whorl, arranged in a flat trochospire, with poor-developed rugosities paralleling the spiral suture, 2 infralaminar accessory apertures, and a broad and shallow umbilicus, partially covered by a large apertural flap protruding from the last two chambers. Once specimens assigned to *P. eubejaouaensis* in Aptian sections from the restricted southernmost sector (north to the Walvis Ridge–Rio Grande Rise) of the northern South Atlantic Ocean typically present a flat spiral side, 8 chambers in the last

forming whorl and the main aperture largely extended towards the periphery (see also the specimens figured by Caron, 1978 and Koutsoukos, 1989), the specific assignment is herein presented between quotation marks. Further studies, on better-preserved material, are needed in order to confirm whether the morphological plasticity described above is an ecophenotypic adaptation to particular paleoenvironmental conditions or these forms should be considered as an entirely new taxon.

Stratigraphic range. Latest Aptian (“*Paraticinella eubejaouaensis*” Zone — Mesozoic Planktonic Foraminiferal Taxonomic Dictionary; Chronos Portal).

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 paragottisi Verga and Premoli Silva, 2003a

Fig. 6.10

Globigerinelloides paragottisi Verga and Premoli Silva, 2003a, p. 332, figs. 6.7–14, 7.1–13.

Remarks. Medium sized planispiral involute test, with 5–5.5 globular chambers increasing relatively rapidly in size in the last whorl; chambers are also slightly inflated in lateral view (mainly the last ones). The equatorial periphery is sub-circular to ovoid

and moderately lobate; umbilical areas are shallow and relatively large. Apertural features are obscured in the studied specimens.

Stratigraphic range. Upper Valanginian to upper Aptian (Verga and Premoli Silva, 2003a).

Globigerinelloides sp. cf. *Gld. blowi* (Bolli, 1959)

Fig. 7.1

Remarks. This species possesses a planispiral involute test, with 5–6 subglobular chambers in the last forming whorl. Sutures are radial and the umbilical area is rather wide. Chambers are slightly reniform in lateral view. The poor preservation of all recovered specimens does not enable a more precise identification.

Globigerinelloides barri (Bolli and others, 1957)

Fig. 7.2

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. The figured specimen presents about 7 chambers in the last whorl (including the paired last one), not fully matching the original diagnosis of the species. Despite this, all specific characteristics described by Verga and Premoli Silva (2003b)

were observed in the studied material, and those authors suggested that 7-chambered individuals should be considered as *Globigerinelloides barri* juveniles. Also, Verga and Premoli Silva (2003b) recorded isolated occurrences of *Gld. barri* within the lower *Ticinella bejaouaensis* Zone (“*Paraticinella eubejaouensis*” Zone herein) as reported in the present study.

Stratigraphic range. Upper Aptian (Verga and Premoli Silva, 2003b).

Globigerinelloides sp. cf. *Gld. aptiensis* Longoria, 1974

Fig. 7.4

Remarks. Medium sized test, planispiral, and with 6–6.5 chambers in the last whorl. Despite the poor preservation of the recovered specimens, the rough hexagonal peripheral outline also supports the tentative specific assignment used herein.

“*Globigerinelloides bentonensis* (Morrow, 1934)

Fig. 7.3

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.

Globigerinelloides bentonensis (Morrow), Caron, 1978, p. 658, pl. 2, figs. 5, 6.

Globigerinelloides caseyi (Bolli and others), Caron, 1978, p. 658, pl. 6, figs. 8–10.

Globigerinelloides bentonensis (Morrow), Leckie, 1984, p. 593, pl. 10, figs. 5–11.

Remarks. Test planispiral, with earlier whorls partly exposed on both sides at the center. The periphery is broadly rounded, chambers inflated, continuously increasing in size as added, numbering 7–9 in last whorl. Herein the genus “*Globigerinelloides*” is used between quotation marks for this species, once it is known that “true” *Globigerinelloides* became extinct at the latest Aptian/earliest Albian.

Stratigraphic range. Albian to Cenomanian (*Ticinella primula* to *Rotalipora cushmani* zones — Mesozoic Planktonic Foraminiferal Taxonomic Dictionary; Chronos Portal), although its FOD is reported herein within the *Microhedbergella rischi* Zone herein.

Family FAVUSELLIDAE Longoria, 1974

Genus *Favusella* Michael, 1973

Type species: *Globigerina washitensis* Carsey, 1926

Favusella sp. aff. *F. washitensis* (Carsey, 1926), emend. Koutsoukos and others, 1989

Fig. 7.5–7.6

Remark. Specimens described and figured herein differ from *Favusella washitensis* by having a deeper umbilicus [see those specimens figured by Koutsoukos and others (1989)]. Apertural lip is also absent in this species. Following Koutsoukos and others (1989), the figured specimens seem to be ephebic (Fig. 7.5) and gerontic (Fig. 7.6)

forms. It is also worth mentioning that this species has its occurrences restricted to Aptian strata.

Family ROTALIPORIDAE Sigal, 1958

Subfamily TICINELLINAE Longoria, 1974

Genus *Ticinella* Reichel, 1950

Type species: *Anomalina roberti* Gandolfi, 1942

Ticinella raynaudi Sigal, 1966

Fig. 7.7

Ticinella raynaudi Sigal, 1966, p. 200, pl. 6, figs. 1–3.

Ticinella raynaudi Sigal, Caron, 1978, p. 660, pl. 9, figs. 8–9.

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

Ticinella raynaudi Sigal, Petrizzo and Huber, 2006, p. 181, pl. 2, figs. 3–4.

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

Stratigraphic range. Late Albian (*Pseudothalmaninella ticinensis* to *Parathalmaninella appenninica* zones — Petrizzo and Huber, 2006).

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

Fig. 8.1

Ticinella sp. cf. *T. primula* Luterbacher (in Renz and others, 1963) of Koutsoukos, 1989, p. 242, pl. 29, figs. 6, 7.

Remarks. This species has a low to almost flat trochospiral test, with 6 chambers in the last whorl, which enlarge relatively slowly and gradually in size; surface smooth. Also, the umbilical area is wide and some specimens present a tendency to uncoil. The spiral side is flat and the aperture extends broadly to the periphery, but still is asymmetrical.

Family SCHACKOINIDAE Pokorny, 1958

Genus *Schackoina* Thalmann, 1932

Type species: *Siderolina cenomana* Schacko, 1897

Schackoina cenomana (Schacko, 1897)

Fig. 8.3

Siderolina cenomana Schacko, 1897, p. 166, pl. 4, figs. 3–5.

Schackoina cenomana (Schacko), Caron, 1978, p. 658, pl. 8, figs. 8, 9.

Schackoina cenomana (Schacko), Leckie, 1984, p. 598, pl. 9, figs. 5, 9.

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

Stratigraphic range. Albian to Cenomanian (*Parathalmaninella appenninica* to *Rotalipora cushmani* zones — Mesozoic Planktonic Foraminiferal Taxonomic Dictionary; Chronos Portal), although its FOD is herein reported within the *Pseudothalmaninella ticinensis* Zone, late Albian in age.

Schackoina bicornis Reichel, 1948

Fig. 8.4

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 in an angle higher than 90°.

Stratigraphic range. Cenomanian (*Thalmaninella globotruncanoides* to *Rotalipora cushmani* zones — Mesozoic Planktonic Foraminiferal Taxonomic Dictionary; Chronos Portal), although its FOD is herein reported within the *Pseudothalmaninella ticinensis* Zone, late Albian in age.

Genus *Pseudoschackoina* Verga and Premoli Silva, 2005

Type species: *Planomalina saundersi* Bolli, 1959

Pseudoschackoina? sp.

Fig. 8.5

Description. Medium sized test, pseudoplanispiral, and stellate in peripheral outline; 5–5.5 chambers in the last forming whorl, increasing rather fast in size as added. Umbilical area wide and shallow. Last 3–4 chambers tend to be radially elongate, pointed ending. Sutures radial, depressed, and straight to slightly curved on both sides.

Remarks. Poor preservation does not enable a more precise identification.

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Depth (m)	$\delta^{13}\text{C}_{\text{VPDB}}$ ‰	$\delta^{18}\text{O}_{\text{V PDB}}$ ‰	$\delta^{18}\text{O}_{\text{VSMOW}}$ ‰
672.92	-1.03	-2.47	28.31
674.96	1.59	-2.16	28.63
702.91	-1.07	-3.27	27.85
706.19	-0.81	-4.23	26.49
707.66	-0.23	-3.59	27.15
714.14	1.04	-3.36	27.40
715.34	0.89	-3.24	27.52
717.23	1.14	-4.17	26.26
719.15	1.06	-3.29	27.46
723.67	1.53	-3.28	27.48
725.24	1.71	-2.89	27.88
752.37	2.57	-2.90	27.88
753.64	2.17	-3.70	27.04
768.19	1.84	-4.49	26.24
769.33	2.14	-3.37	27.29
807.4	1.96	-3.25	27.51
810.94	2.07	-3.58	27.17
825.73	2.11	-4.08	26.65
826.4	2.33	-3.60	27.14
829.46	2.57	-3.62	27.12
844.57	2.21	-4.13	26.60
845.92	2.42	-3.69	27.06
847.43	2.72	-2.78	27.99
850.15	2.25	-3.92	26.82
875.96	2.50	-3.84	26.90
911.25	2.94	-2.69	28.09
931.7	1.99	-3.76	26.98
932.45	2.05	-3.36	27.40
934.44	1.94	-3.77	26.98
950.53	1.37	-2.68	28.10
952.77	1.57	-3.86	26.87
954.53	1.56	-3.98	26.76
975.48	-0.42	-4.58	26.14
987.42	0.15	-3.05	27.71
988.42	1.36	-4.11	26.62
992.63	0.12	-5.07	25.63
1008.41	-0.21	-5.47	25.22
1025.37	-2.59	-4.85	25.86

APPENDIX 1. Carbon and oxygen isotopic measurements discussed herein. Values are reported as δ (‰) deviations with reference to V-PDB (Vienna-Pee Dee belemnite international standard).

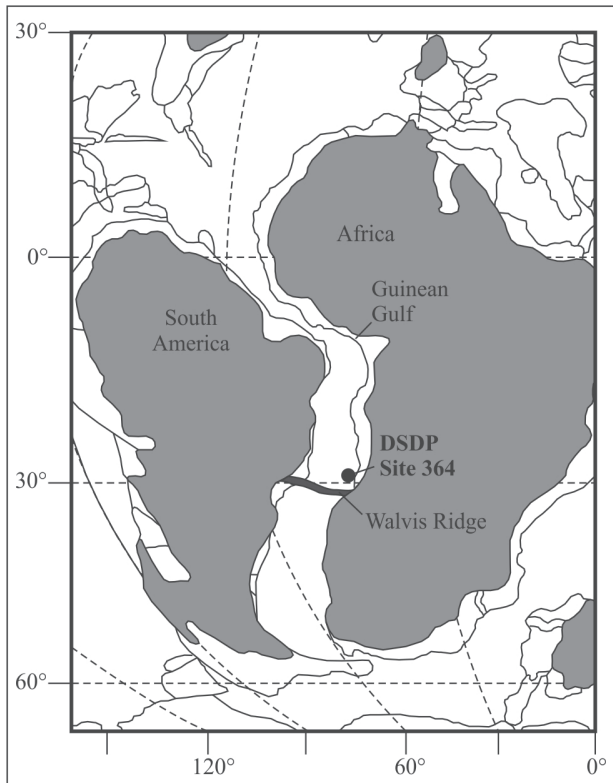
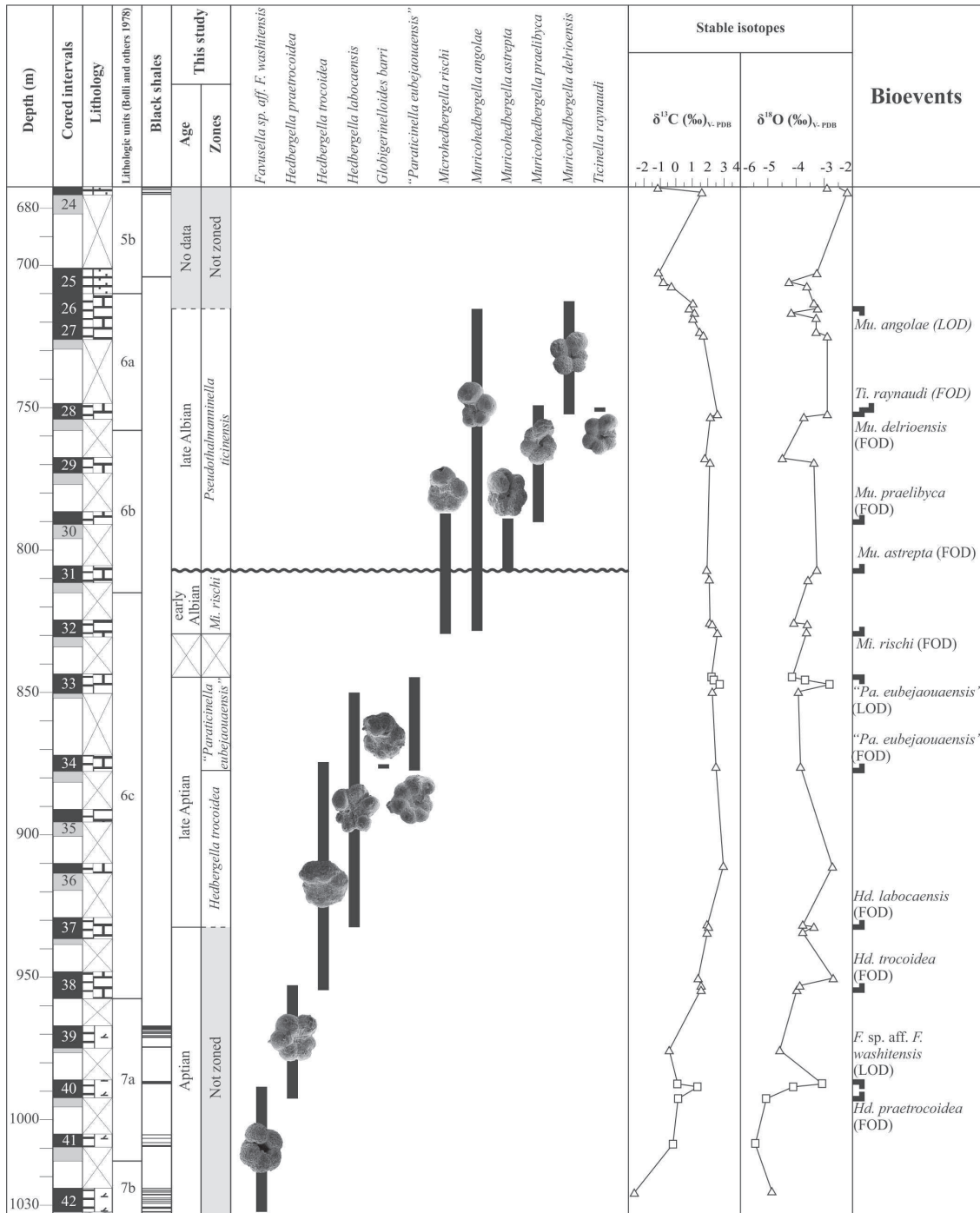


FIGURE 1. Paleogeographic reconstruction for 112 Ma [modified from Hay and others (1999)] presenting the inferred location of DSDP Site 364 ($11^{\circ}34.32'S$; $11^{\circ}58.30'E$), the Walvis Ridge and the Guinean Gulf.



Caption: [Lithology symbols] Limestone [Dolomite symbol] Dolomite [Mudstone symbol] Mudstone [Nannofossil chalk symbol] Nannofossil chalk [Isotopic analysis on micritic limestone symbol] Isotopic analysis on micritic limestone [Isotopic analysis on marls symbol] Isotopic analysis on marls

FIGURE 2. Stratigraphic range of selected planktic foraminiferal species and $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ measurements (reported in per mil values; ‰) from DSDP Site 364. Cored intervals are presented in gray and total core recovery in black; unconformity is represented by a wavy line.

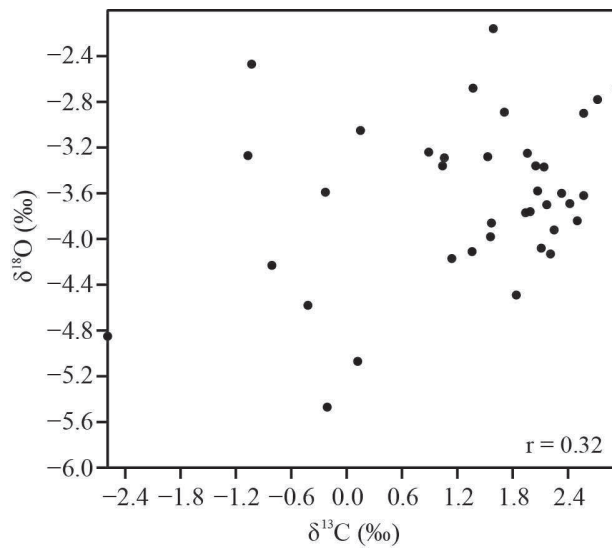


Fig. 3. Scatterplot of $\delta^{18}\text{O}$ (‰) and $\delta^{13}\text{C}$ (‰) values. The linear correlation index (r) between the two variables is also shown.

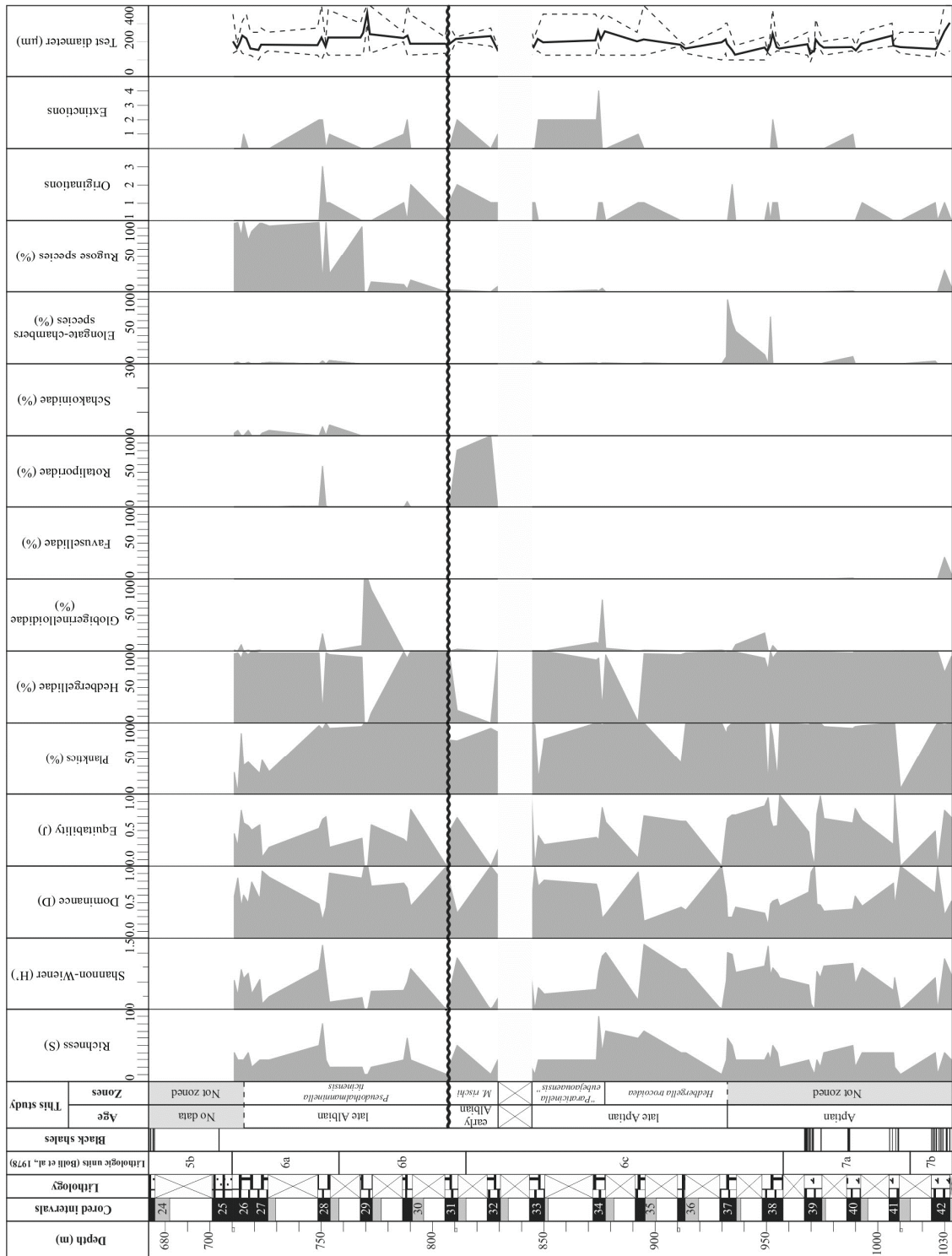


FIGURE 4. Diversity indexes, total relative abundances of planktic over benthic specimens, families, species with radially elongated chambers and rugose species, rates of originations and extinctions and diameter of tests (minimum, average and maximum) for DSDP Site 364. For more information regarding the lithostratigraphic profile, see Figure 2.

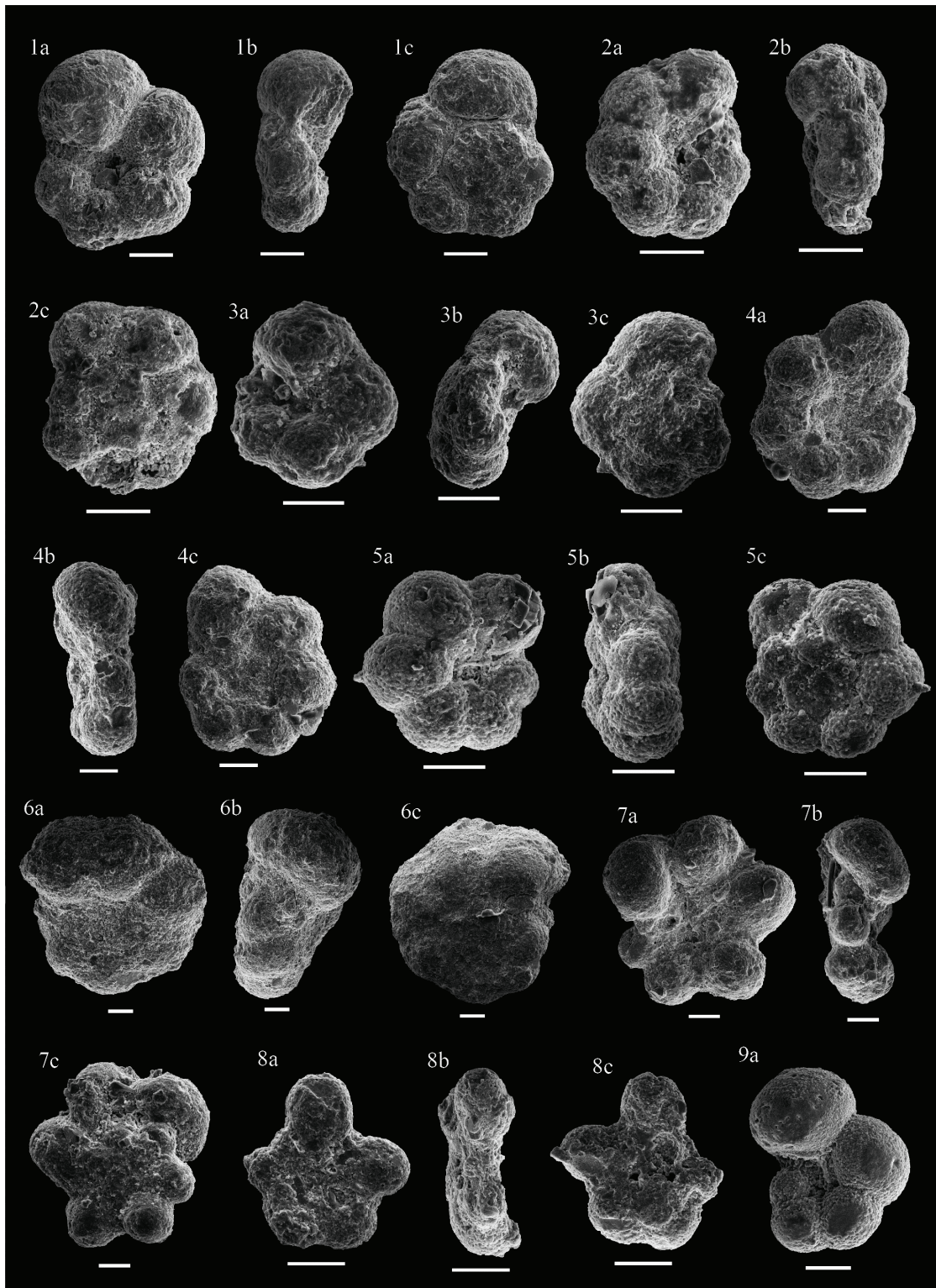


FIGURE 5. Electron scanning micrographs of Aptian–Albian foraminifera from DSDP Site 364. Scale bars = 50 μm . **1** *Hedbergella aptiana*, 364-35-3, 99–101 cm (ULVG-8843); **2** *Hedbergella luterbacheri*, 364-42-2, 92–96 cm (ULVG-8844); **3** *Hedbergella* sp. cf. *Hd. sigali*, 364-34-3, 96–99 cm (ULVG-8845); **4** *Hedbergella* sp. cf. *Hd. maslakovae*, 364-33-3, 93–95 cm (ULVG-8846); **5** *Hedbergella praetrocoidea*, 364-40-2, 92–96 cm (ULVG-8847); **6** *Hedbergella trocoidea*, 364-34-4, 92–96 cm (ULVG-8849); **7** *Hedbergella labocaensis*, 364-37-3, 45–47 cm (ULVG-8850); **8** *Hedbergella* sp. cf. *Hd. similis*, 364-34-4, 92–96 cm (ULVG-8851); **9** *Muricohedbergella angolae*, 364-30-1, 66–70 cm (ULVG-8852).

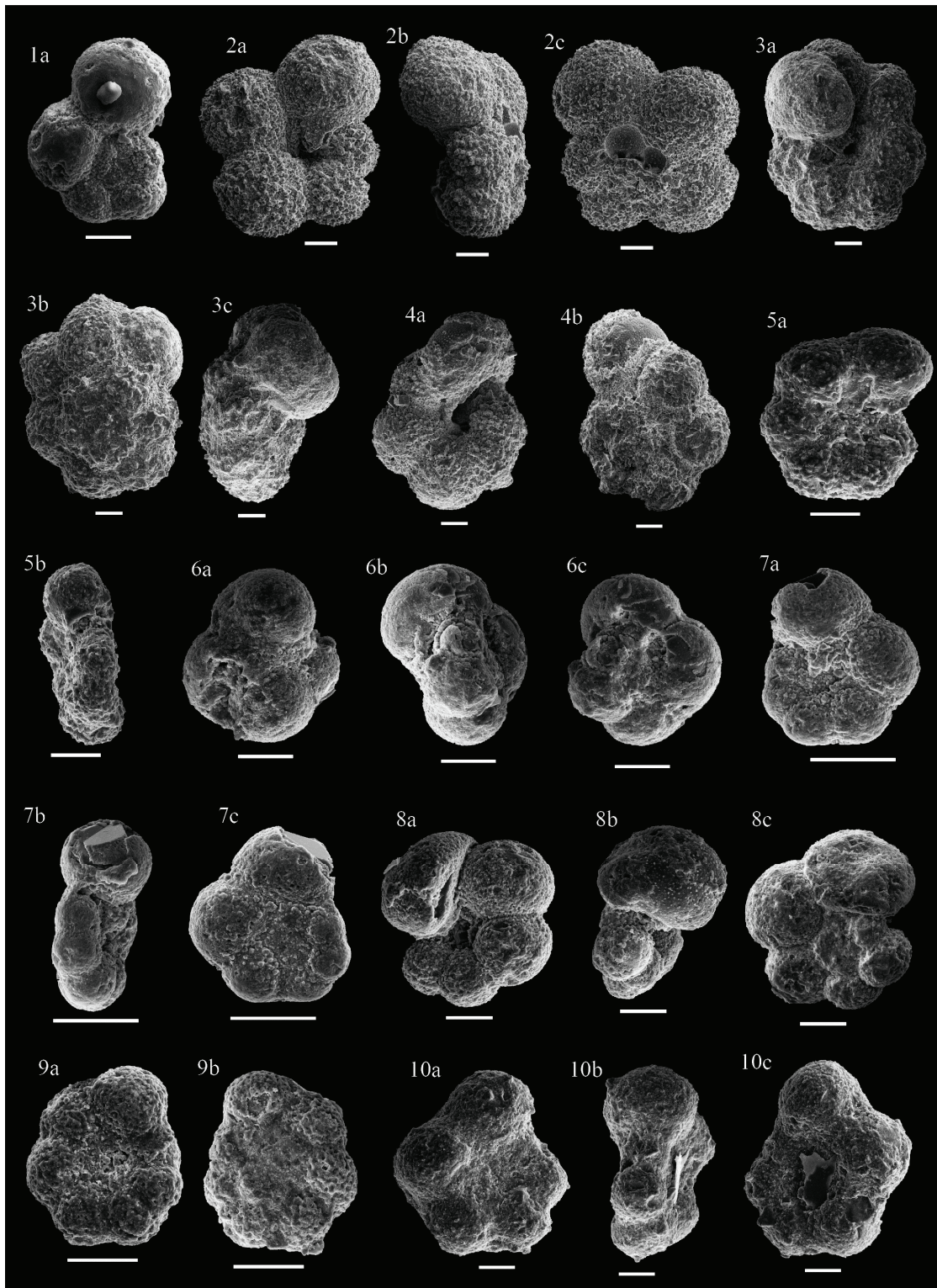


FIGURE 6. Electron scanning micrographs of Aptian–Albian foraminifera from DSDP Site 364. Scale bars = 50 μm . **1** *Muricohedbergella angolae*, 364-30-1, 66–70 cm (ULVG-8852); **2** *Muricohedbergella delrioensis*, 364-28-4, 64–68 cm (ULVG-8853); **3** *Muricohedbergella astrepta*, 364-31-2, 40–42 cm (ULVG-8854); **4** *Muricohedbergella praelibyca*, 364-30-2, 94–98 cm (ULVG-8855); **5** *Muricohedbergella* sp. cf. *Mu. planispira*, 364-28-2, 70–74 cm (ULVG-8856); **6** *Microhedbergella* sp. cf. *Mi. miniglobularis*, 364-32-2, 40–44 cm (ULVG-8857); **7** *Microhedbergella rischi*, 364-32-4, 42–50 cm (ULVG-8858); **8** *Microhedbergella* sp., 364-30-1, 66–70 cm (ULVG-8859); **9** *Microhedbergella pseudoplanispira*, 364-31-1, 79–82 cm (ULVG-8860); **10** *Globigerinelloides paragottisi*, 364-33-3, 93–95 cm (ULVG-8861).

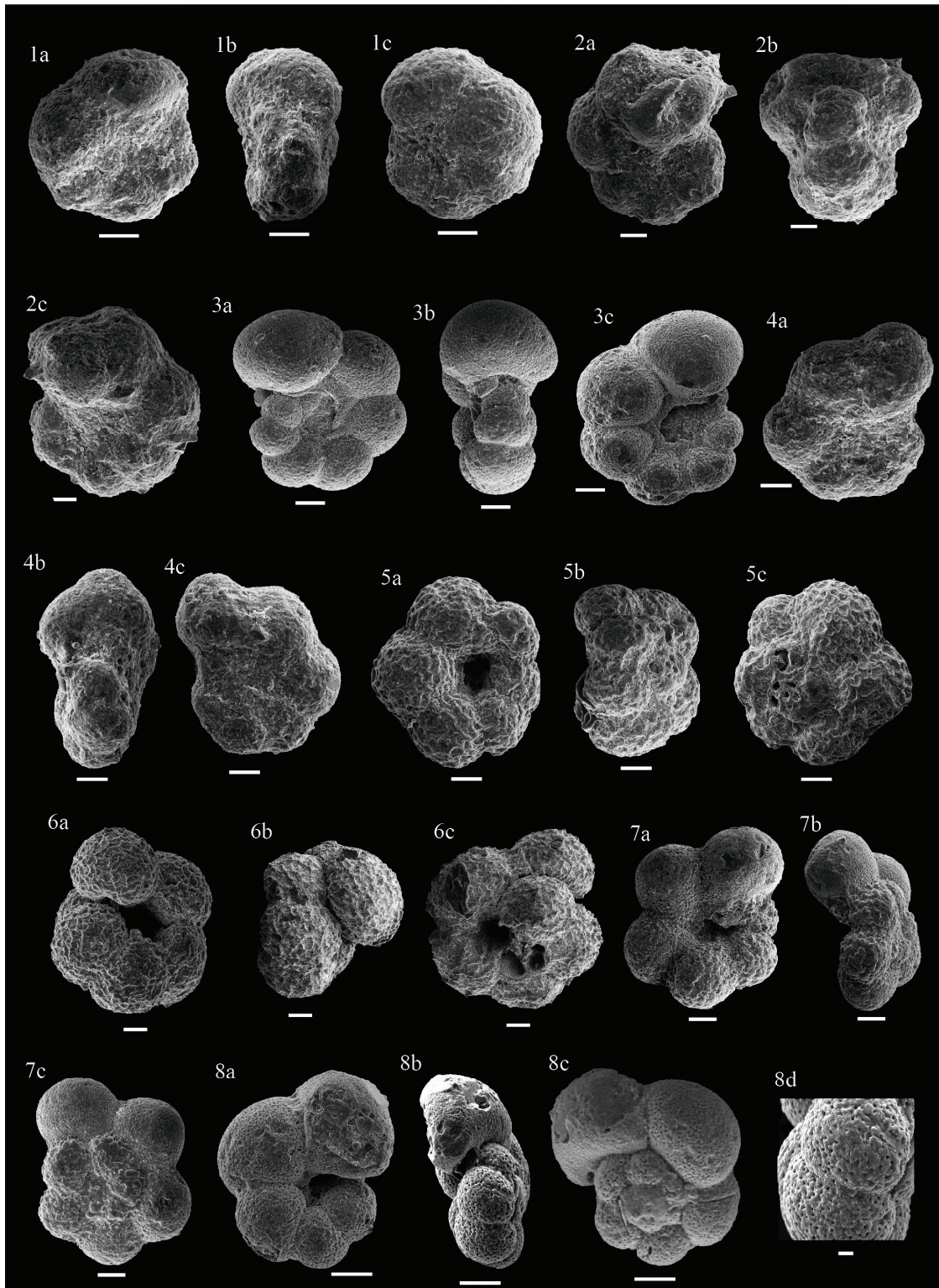


FIGURE 7. Electron scanning micrographs of Aptian–Albian foraminifera from DSDP Site 364. Scale bars = 50 μm , except in 8d (10 μm). **1** *Globigerinelloides* sp. cf. *Gld. blowi*, 364-34-3, 96–99 cm (ULVG-8862); **2** *Globigerinelloides barri*, 364-34-3, 96–99 cm (ULVG-8863); **3** “*Globigerinelloides*” *bentonensis*, 364-29-4, 34–37 cm (ULVG-8864); **4** *Globigerinelloides* sp. cf. *Gld. aptiensis*, 364-34-3, 96–99 cm (ULVG-8865); **5–6** *Favusella* sp. aff. *F. washitensis*, 364-42-6, 87–90 cm (Fig. 7.5: ULVG-8866; Fig. 7.6: ULVG-8867); **7** *Ticinella raynaudi*, 364-28-2, 70–74 cm (ULVG-8868); **8** *Microhedbergella rischi* trans. *madecassiana*, 364-32-1, 123–127 cm (ULVG-8870).

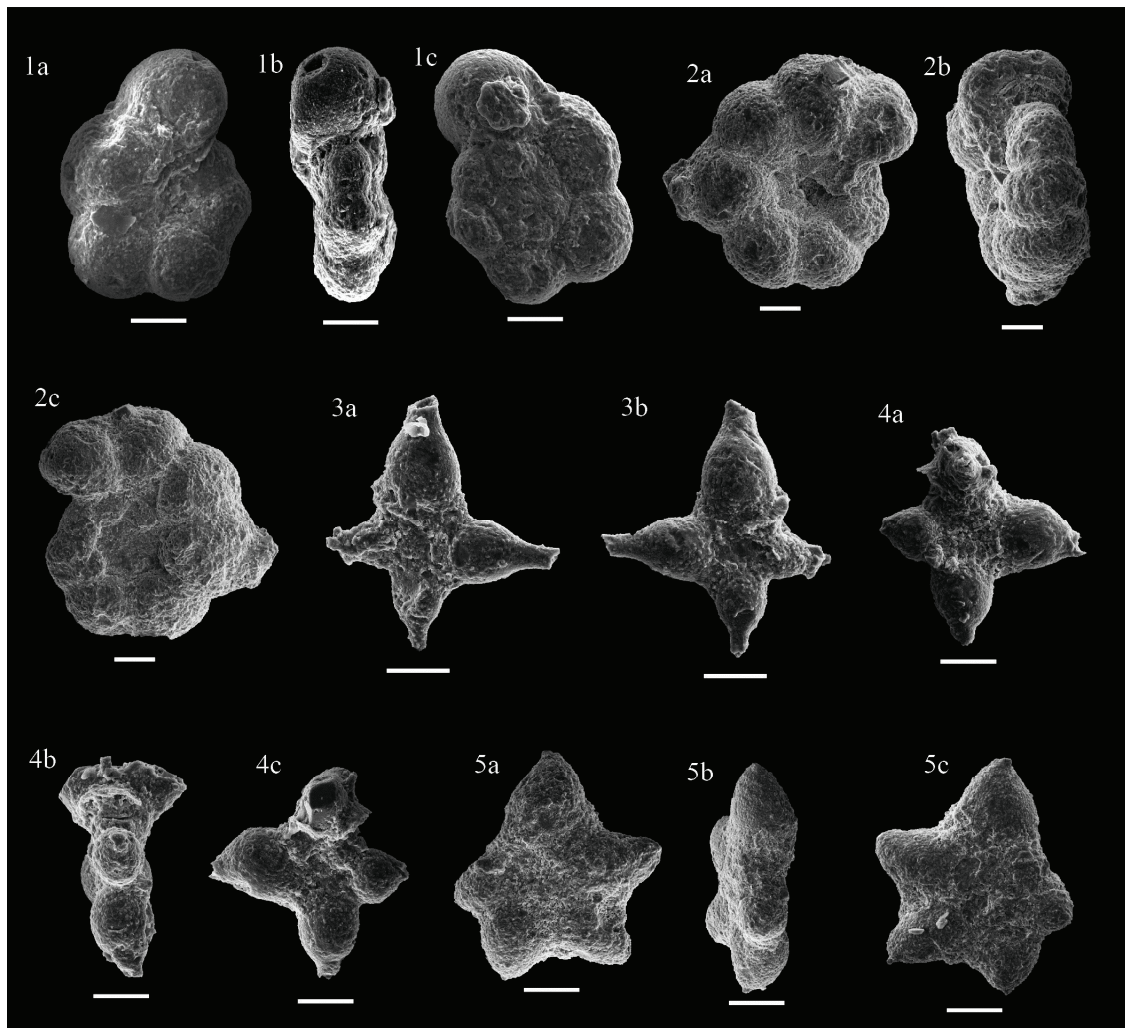


FIGURE 8. Electron scanning micrographs of Aptian–Albian foraminifera from DSDP Site 364. Scale bars = 50 μm . 1 *Ticinella?* sp. aff. *Ti. primula*, 364-28-1, 69–73 cm (ULVG-8871); 2 “*Paraticinella eubejaouaensis*,” 364-34-3, 96–99 cm (ULVG-8872); 3 *Schackoina cenomana*, 364-28-2, 70–74 cm (ULVG-8873); 4 *Schackoina bicornis*, 364-28-2, 70–74 cm (ULVG-8874); 5 *Pseudoschackoina?* sp., 364-28-4, 64–68 cm (ULVG-8875).

Sample	Depth (m)	Lithostratigraphic unit	% Planktonics	Preservation index	Foraminifera	Other microfossils	Zones	Age	
364-24-1, 42-44 cm	672.92	5b	0				Not zoned	No data	
364-24-2, 96-100 cm	674.96		0						
364-25-2, 41-44 cm	702.91		0						
364-25-4, 69-73 cm	706.19		0						
364-25-6, 72-75 cm	709.22	6a	30.4	M			P. icenensis	Late Albanian	
364-26-2, 71-73 cm	712.71		5	G					
364-26-3, 64-67 cm	714.14		85.4	M					
364-26-4, 34-38 cm	715.34		40.4	M					
364-26-5, 73-77 cm	717.23		45.4	M					
364-26-6, 115-117 cm	719.15		41.2	M					
364-27-2, 125-128 cm	722.75		29.8	G					
364-27-3, 67-71 cm	723.67		48.4	M					
364-27-5, 66-70 cm	726.66		31.6	M					
364-28-1, 69-73 cm	749.19		97.1	G					
364-28-2, 70-74 cm	750.7		91.9	G					
364-28-3, 87-91 cm	752.37		100	M					
364-28-4, 64-68 cm	753.64	93.4	M						
364-29-1, 69-71 cm	768.19	95.5	M						
364-29-2, 33-37 cm	769.33	100	M						
364-29-3, 67-71 cm	771.17	100	M						
364-29-4, 34-37 cm	772.34	99	M						
364-30-1, 66-70 cm	787.16	100	M						
364-30-2, 94-98 cm	788.94	100	M						
364-30-3, 91-94 cm	790.41	100	M						
364-31-1, 79-82 cm	806.29	100	M						
364-31-2, 40-42 cm	807.4	76.8	G						
364-31-4, 94-98 cm	810.94	76.2	M						
364-32-1, 123-127 cm	825.73	74	M						
364-32-2, 40-44 cm	826.4	92.6	M						
364-32-3, 90-92 cm	828.4	88.9	M						
364-32-4, 46-50 cm	829.46	87.5	P						
364-33-1, 107-111 cm	844.57	100	M						
364-33-2, 92-95 cm	845.92	98.3	M						
364-33-3, 93-95 cm	847.43	20	M						
364-33-5, 65-69 cm	850.15	78.4	M						
364-34-1, 133-136 cm	873.33	100	P						
364-34-2, 93-96 cm	874.43	100	M						
364-34-3, 96-99 cm	875.96	98.1	G						
364-34-4, 92-96 cm	877.42	100	M						
364-35-1, 114-117 cm	892.14	100	P						
364-35-2W, 46-49 cm	892.96	0							
364-35-3, 99-101 cm	894.99	100	M						
364-36-1, 125-128 cm	911.25	44.5	P						
364-36-2, 52-54 cm	912.02	0							
364-36-3, 75-77 cm	913.75	0							
364-37-1, 66-69 cm	929.66	100	P						
364-37-2, 120-122 cm	931.7	85.5	M						
364-37-3, 45-47 cm	932.45	94.7	M						
364-37-4, 94-97 cm	934.44	100	M						
364-37-5, 98-101 cm	935.98	100	P						
364-38-1, 90-93 cm	948.9	100	P						
364-38-2, 103-105 cm	950.53	0							
364-38-3, 47-49 cm	951.47	99	P						
364-38-4, 27-30 cm	952.77	82.2	M						
364-38-5, 53-55 cm	954.53	21.5	M						
364-38-6, 25-28 cm	955.75	100	P						
364-39-1, 145-148 cm	968.45	98	P						
364-39-2, 114-119 cm	969.64	100	P						
364-39-3, 118-122 cm	971.18	100	P						
364-39-4, 66-69 cm	972.16	100	P						
364-39-5, 89-92 cm	973.89	100	M						
364-39-6, 98-101 cm	975.48	95.2	P						
364-40-2, 92-96 cm	988.42	93.3	M						
364-40-3, 71-75 cm	989.71	95.3	P						
364-40-5, 63-66 cm	992.63	97	P						
364-41-1, 141-145 cm	1006.41	100	P						
364-41-2, 46-50 cm	1006.96	100	P						
364-41-4, 29-32 cm	1009.79	8.7	P						
364-42-1, 137-139 cm	1025.37	95.5	M						
364-42-2, 81-84 cm	1026.31	100	P						
364-42-3, 24-28 cm	1027.24	0							
364-42-4, 100-103 cm	1029.5	97.6	P						
364-42-6, 87-90 cm	1032.37	100	M						

TABLE 1. Relative abundances for planktic foraminiferal species from Aptian to 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 is in accordance to Huber and Leckie's (2011) proposition, where: G = good; M = moderate; P = poor. The red line locates the not-recovered interval of the Aptian–Albian transition.

2.1 DOCUMENTAÇÃO RELATIVA À SUBMISSÃO DO ARTIGO I

De: jforamr@gmail.com

Para: k.kochhann@gmail.com

Data: 18/10/2012

Assunto: Confirmation

Dear Dr. Kochhann,

Your manuscript arrived safely; thank you for submitting it. The paper is assigned number 2251; please use that number in all correspondence about it. I will send it out soon for review.

Best wishes,

Paul Brenckle

Journal of Foraminiferal Research (Editor)

3 ARTIGO II

Aptian-Albian benthic foraminifera from DSDP Site 364 (offshore Angola): A
Taxonomic and paleoenvironmental appraisal

Aptian-Albian benthic foraminifera from DSDP Site 364 (offshore Angola): A taxonomic and paleoenvironmental appraisal

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Abstract

Despite the importance of the Aptian-Albian time interval for the better understanding of coupled climatic and paleoceanographic changes, studies on benthic foraminiferal faunas are patchy in the literature. This work presents a taxonomic and paleoenvironmental appraisal of the benthic foraminiferal fauna recovered from the Aptian-Albian carbonate-dominated succession of Deep Sea Drilling Project (DSDP) Site 364, located in the Kwanza Basin (offshore Angola). Forty-two species were identified within the studied stratigraphic interval, presenting two events of diversification, the first at the latest Aptian and the second at the late Albian. Three benthic foraminiferal associations were identified (*Bathysiphon* sp., *Gyroidinoides infracretaceus* and *Kadriayina gradata*), which seem to be mainly controlled by changes in paleobathymetry. In addition, the studied fauna could

be related to the *Marssonella* association of Haig (1979), inferred to be characteristic of neritic to upper bathyal depths, and exhibiting a Tethyan paleobiogeographic affinity. At and/or close to black shale levels, probably deposited at neritic to upper bathyal depths, low values of benthic foraminiferal abundance and species richness could be indicative of anoxic to dysoxic bottom waters, although the epipelagic layer was supposed to be well-oxygenated due to the high abundances of planktic forms. Shallower paleodepth estimatives (mainly neritic) for the stratigraphic intervals in which Tethyan planktic biostratigraphic markers are missing suggest that the absence of some of these forms in the northern South Atlantic Ocean (north to the Walvis Ridge-Rio Grande Rise) could be a result of their deeper-dwelling preferences and not necessarily due to the influx of colder-water masses from the southern South Atlantic Ocean, as has been historically reported.

Keywords: Benthic foraminifera, Aptian-Albian, Taxonomy, Paleoecology, Offshore Angola, DSDP Site 364

1. Introduction

During Aptian-Albian times the oceanic-atmospheric coupled system underwent a profound reorganization. Besides increased oceanic-crust and oceanic plateaus production (Larson, 1991) that released huge amounts of carbon dioxide in the atmosphere leading to global warming (Jones and Jenkins, 2001), black shales were broadly deposited in several oceanic basins (e.g. Arthur and Premoli Silva, 1982; Jenkins, 1995; Jenkins and Wilson, 1999). These intervals of enhanced organic carbon burial are known as Oceanic Anoxic Events (OAEs), and some are supposed to have had a global

distribution (Schlanger and Jenkyns, 1976). In addition, probable coupled changes in the carbonate chemistry, vertical stratification of the water column, nutrient supply and/or surface productivity led the planktic foraminifera to experience their greatest rates of faunal turnovers across the Aptian-Albian boundary (Leckie et al., 2002; Huber and Leckie, 2011; Kochhann et al., submitted). It also encompasses the very birth of most sectors of the proto-northern South Atlantic Ocean (rifting seaways), when the degree of restriction, sluggish deep-water circulation, and poor oxygenation probably played significant roles (Tissot et al. 1980; Azevedo, 2004; Arai, 2009; Kochhann et al., submitted).

The objectives of this study are to present the taxonomy and general paleoecological inferences regarding the Aptian-Albian benthic foraminifera recovered from Deep Sea Drilling Project (DSDP) Site 364 (Fig. 1), Kwanza Basin (offshore Angola). The studied benthic fauna is highly significant for a better understanding of the environmental evolution of the southernmost portion (north to the Walvis Ridge-Rio Grande Rise) of the northern South Atlantic Ocean, considered to have been restricted concerning deep-water circulation, with poorly oxygenated bottom-waters during that time (e.g. Bolli et al., 1978; Tissot et al., 1980; Azevedo, 2004). For additional information concerning the geological setting in which DSDP Site 364 is located, the reader is referred to Kochhann et al. (submitted).

2. Material and Methods

The studied Aptian-Albian section of DSDP Site 364 is mainly composed by limestones, dolomitic limestones, nannofossil chalks, mudstones, claystones and black

shales. The micropaleontological survey was conducted on 74 samples, however only 32 of them permitted the recovery of benthic foraminifera. Each sample was chemically processed as follows: approximately 20 g of dried rock were crushed and soaked in a 200 ml hydrogen peroxide solution (H₂O₂), at concentration of 29%, for 24 hours. When samples presented high levels of calcium carbonate and the above-described procedure was not successful in recovering the foraminifera tests, the acetolysis method (experiment 12) was used in accordance to Rodrigues et al. (in press). Finally, residues were washed through a 38 µm-mesh sieve and the total amount of benthic foraminiferal specimens hand-picked from each sample under a stereomicroscope (almost never exceeding 90 specimens in a single sample). Due to this scarcity of benthic foraminiferal specimens, quantitative and statistical analyses were not performed herein, except for some simple general indexes (e.g. calcareous/agglutinated forms ratio; epifaunal/infaunal forms ratio). This work presents mainly optical micrographs, with multidimensional acquisition using extended focus (computation from Z-stack in the software AxioVision 4.8) under a Zeiss Discovery V20 stereomicroscope. This technique emphasizes diagnostic features (such as sutures and internal details), while scanning electron micrographs stresses mainly external “noise” due to poor preservation (Fig. 2), hampering accurate identifications. SEM images (Zeiss Evo 40) were used only for figuring small specimens, which could not be accurately identified using optical microphotographs. Biostratigraphic framework and ages mentioned herein are after Kochhann et al. (submitted).

3. Results

In the Aptian-Albian succession of DSDP Site 364, forty-two benthic

foraminiferal species were identified (Tab. 1; Section 6 for taxonomic discussions), presenting two main events of diversification: the first one at the uppermost “*Paraticinella eubejaouaensis*” Zone (latest Aptian in age; 850.15 m – meters below the seafloor) and the second one within the *Pseudothalmanninella ticinensis* Zone (late Albian; 750.7 m). It is also worth mentioning that there is a remarkable gap in benthic foraminiferal occurrences between cores 31 and 28.

Benthic foraminiferal abundances are low throughout the studied section, showing an increasing-upward trend and reaching values of about five benthic specimens per gram of analyzed rock in latest Albian strata (Fig. 3). Simple species richness is constantly low in Aptian strata, rising abruptly at the uppermost part of the “*Paraticinella eubejaouaensis*” Zone (Fig. 3). Species richness also falls across the Aptian/Albian boundary and afterwards follows a recovery trend in the late Albian (Fig. 3). Both variables, benthic foraminiferal abundance and species richness, seem to be highly correlated (Fig. 3). As a general trend, it can be said that infaunal species tend to dominate assemblages when both abundance and simple richness are low or close to black shales, while epifaunal forms increase in relative abundance when both benthic foraminiferal abundance and simple species richness show increasing trends (Fig. 3). Proportions between calcareous and agglutinated forms vary quite randomly throughout the studied section, being the former dominant in the late Aptian-early Albian interval whereas the later tends to dominate assemblages from core 38 to core 36 and in late Albian strata (Fig. 3).

The stratigraphic distribution of the benthic foraminiferal species enabled the identification of three distinct informal associations (Tab. 1). Spanning most of the Aptian

interval, it was identified the *Bathysiphon* sp. association, named after its most typical species. Its base is defined by the basal limit of the studied interval (1,027.24 m), while its top is characterized by the first diversification event identified in the studied section (850.15 m). It is characterized by the remarkable constant and low values of both benthic foraminiferal abundance and species richness (Fig. 3). *Clavulina gabonica* (Tab. 1) is a typical species of the *Bathysiphon* sp. association. Upwards in section, the *Gyroidinoides infracretaceus* association was identified, from 850.15 m (basal limit), coeval with the first occurrences of several species (*Laevidentalina* sp. 2, *Vaginulinopsis?* sp., *Ramulina* sp. and *Gyroidinoides globosus*), to 750.7 m (second diversification event). It spans from the uppermost “*Paraticinella eubejaouaensis*” Zone (latest Aptian) to the middle *Pseudothalmaninella ticinensis* Zone (late Albian). Its base is characterized by a sharp increase in both benthic foraminiferal abundance and species richness followed by a decreasing-upwards trend (Fig. 3). Calcareous forms dominate this association (Fig. 3) and typical species are *Laevidentalina* sp. 2, *Tritaxia* sp., *Gyroidinoides infracretaceus* and *Osangularia* sp. Across the unconformity within core 31 (Fig. 3), a considerable faunal reorganization occurred, with three first occurrence datums at 807.4 (Tab. 1). From 750.7 m (first occurrences of *Aragonia?* sp., *Lenticulina subangulata*, *Kadriayina gradata*, *Spiroplectinella* sp. and *Lenticulinella* sp.) to 672.92 m (upper limit of the studied section), the *Kadriayina gradata* association was identified (late Albian in age). It presents highly variable patterns in all parameters presented in Fig. 3, as well as the highest values of benthic foraminiferal abundance; characteristic species are *Tritaxia gaultina*, *Kadriayina gradata*, *Ammoglobigerina?* sp. and *Lenticulinella* sp.

4. Discussion

In broad terms, the studied Aptian-Albian benthic foraminiferal fauna of DSDP Site 364 could be classified as a *Marssonella* association, as described by Haig (1979). This association is typical of carbonate-rich open continental shelves, having as characteristic genera *Protomarssonella*, *Ramulina*, *Pleurostomella*, with others, and the dominance of calcareous agglutinated taxa. Its latitudinal range is broad, although mainly restricted to the tropical region, having as main factors influencing distribution: i) availability of calcium carbonate, ii) normal-marine or high salinities and iii) depth (cf. Haig, 1979). It is important to note that there is no major benthic foraminiferal extinction across the Aptian/Albian boundary in DSDP Site 364.

Considering the paleobathymetric preferences of several taxa reported by Koutsoukos (1989) for the Brazilian continental margin, some paleobathymetric trends can be suggested (Fig. 3). From core 42 to core 40 the dominance of ephebic and gerontic specimens of *Favusella* sp. aff. *F. washitensis* suggests shallow to middle neritic paleodepths (cf. Koutsoukos et al., 1989; Kochhann et al., submitted). Upper in the section (core 37), the dominance of *Glomospira gordialis* suggests middle to lower bathyal settings, characterizing a deepening trend from core 42 to core 37. Core 33 is dominated by *Gyroidinoides globosus*, supposed to thrive in deep neritic to upper bathyal biotopes, marking a modest shallowing trend from core 37 to core 33. From core 33 to core 27 (dominance of *Lenticulina subangulata* at core 27 – shallow to middle neritic; the shallowest paleobathymetric estimative in the studied section) there is a shallowing trend in, followed by another deepening trend up to core 24 (dominance of *Gyroidinoides globosus* – deep neritic to upper bathyal). In accordance to Basov and Krasheninnikov's

(1983) observations on Albian benthic foraminifera from the southernmost South Atlantic Ocean, the occurrences of *Kadriayina gradata*, *Clavulina gabonica* and *Orithostella indica* could also suggest a deep neritic to upper slope environment, corroborating the interpretations presented herein. Paleobathymetry seems to be the main factor controlling the distribution of the benthic foraminiferal associations, being their boundaries roughly correlated to major shifts in the mean paleobathymetric curve (Fig. 3). For instance, the *Bathysiphon* sp. association correlates to a deepening-upward trend in paleobathymetry, whereas the *Gyroidinoides infracretaceus* association to a shallowing-upward trend, and the *Kadriayina gradata* association to a deepening-upward trend (Fig. 3). Shallower paleobathymetric estimatives for the intervals in which Tethyan biostratigraphic markers of the planktic foraminifera are missing seem to corroborate the hypothesis suggested by Kochhann et al. (submitted), that their absence in this restricted sector (north to the Walvis Ridge-Rio Grande Rise) of the northern South Atlantic Ocean could be a result of their deep-dwelling preferences, and not necessarily related to the influx of colder-water masses from the southern South Atlantic Ocean.

Low values of benthic foraminiferal abundance and species richness at and/or close to black shale levels, and from core 31 to core 28 (where benthic foraminifera are absent), may be indicative of anoxic to dysoxic bottom waters, high organic matter fluxes and a likely position within an oxygen minimum zone (Friedrich and Erbacher, 2006; Holbourn and Kuhnt, 2001). On the other hand, high abundances of planktic forms (Fig. 3) at these same levels suggest a well-oxygenated epipelagic layer (Koutsoukos et al., 1991; Kochhann et al., submitted). The dominance of infaunal forms close to black shale levels can be interpreted as a result of their sensitiveness to changes in dissolved oxygen

content (Coccioni and Galeotti, 1993; Peryt and Lamolda, 1996; Kaminski et al., 1999). Modern and fossil infaunal morphotypes seem able to tolerate poor-oxygenated environmental conditions by vertical migrations within sediments (Kaiho, 1991). Furthermore, taking into account the paleobathymetric estimative presented above (Fig. 3), it is possible to suggest that the black shales deposition in DSDP Site 364, probably including the “late Albian anoxic event” (cf. Kochhann et al., submitted), took place at neritic to upper bathyal paleodepths.

In general terms, when the studied Aptian-Albian benthic foraminiferal fauna is compared to previously described ones (e.g., Neagu, 1965; Sliter, 1977; Koutsoukos, 1989; Koutsoukos and Hart, 1990; Gradstein et al., 1999; Holbourn and Kaminski, 1995), a Tethyan paleobiogeographic affinity can be suggested. This paleobiogeographic affinity is in accordance to the low degree of endemism of neritic to upper bathyal Aptian-Albian benthic foraminiferal assemblages that has been suggested for the Brazilian marginal basins (e.g. Koutsoukos, 1992). Taking into account the Tethyan affinity of the studied assemblages (mainly within Albian strata), it is possible to support previous suggestions of a shallow-water passage (the so-called Equatorial Atlantic Gateway) between the central and South Atlantic Ocean sometime in the Albian (e.g. Foster, 1978; Friedrich and Erbacher, 2006) or even back to mid- or late Aptian (e.g. Bengtson et al., 2007; Koutsoukos and Bengtson, 2007; Kochhann et al., submitted). However, this gateway is not believed to have enabled intermediate to deep water-masses from the Tethys to enter the restricted sector of the northern South Atlantic Ocean (Friedrich and Erbacher, 2006). On the other hand, Scheibnerová (1978), who previously studied Aptian-Albian foraminifera from DSDP Site 364, attributed the studied assemblages to the Austral

Biogeoprovince and suggested a southern marine connection in this sector of the South Atlantic Ocean during that time span. This suggestion would imply in paleocirculation patterns similar to modern ones (Scheibnerová, 1978). Apart from *Orithostella indica*, none of the taxa reported as Austral by Scheibnerová (1978) were identified in the present study, being the identification of the taxa illustrated in that work based on extremely poorly preserved material. The main differences between the present report and the one of Scheibnerová (1978) are the absence of *Discorbis* species, which that author reported as occurring sporadically and for this reason might be absent in the sample resolution applied herein, and species of gavelinellids, which doubtful identifications are based on poorly preserved specimens in Scheibnerová (1978). Furthermore, Scheibnerová (1978) did not exclude the possibility of a northern marine connection through the Benue rift and Sahara region.

5. Concluding remarks

Despite the low abundance and species richness of the studied fauna, the stratigraphic distribution of the forty-two identified benthic foraminiferal species enabled the identification of three informal associations, the *Bathysiphon* sp. (Aptian), *Gyroidinoides infracretaceus* (latest Aptian to late Albian) and *Kadriayina gradata* (late Albian), which seem to be mainly controlled by changes in paleobathymetry. Two diversification events, the first one at the latest Aptian and the second one at the late Albian, were identified.

The studied fauna could be classified as a *Marssonella* association (sensu Haig, 1979), displaying a Tethyan paleobiogeographic affinity, and mostly associated to neritic

to upper bathyal paleodepths. Besides, shallower paleobathymetric estimatives for stratigraphic intervals in which Tethyan planktic biostratigraphic markers are missing help to corroborate the hypothesis suggested by Kochhann et al. (submitted), which stated that the absence of some of these forms in the restricted sector (north to the Walvis Ridge-Rio Grande Rise) of the northern South Atlantic Ocean could be a result of their deep-dwelling preferences, and not necessarily related to the influx of colder-water masses from the southern South Atlantic Ocean.

Low values of benthic foraminiferal abundance and species richness at and/or close to black shale levels might be indicative of anoxic to dysoxic bottom waters, although the epipelagic layer was supposed to be well-oxygenated due to the high abundances of planktic forms. These dark-colored strata were probably deposited at neritic to upper bathyal paleodepths, and the dominance of infaunal forms close or within these levels might be related to their sensitiveness to changes in dissolved oxygen content and their capability to migrate vertically within organic-rich muddy sediments.

6. Taxonomic notes

All species identified in this study are presented and discussed below. Synonymies are restricted to the original description, plus those references relevant to the understanding of the species concept used herein and the stratigraphic ranges. Remarks were made under each species entry in order to clarify the main distinguishing features. Suprageneric classification follows that of Loeblich and Tappan (1987) as modified by Loeblich and Tappan (1992), for calcareous benthic foraminifera, and Kaminski (2004), for the agglutinated taxa. Concerning detailed descriptions, the reader is referred to the

works listed in the synonymies. Stratigraphic ranges are based on the references cited in synonymies. Occurrences of the identified species within the studied section, even of those left in open nomenclature, and their relative abundances are given in Tab. 1. The specimens figured herein will be deposited in the collections of the Museu de História Geológica do Rio Grande do Sul, Universidade do Vale do Rio dos Sinos (UNISINOS), Brazil, under the curatorial numbers ULVG-9578 to ULVG-9619 (entries given after each species in Figs. 4 and 5). Paleobathymetric ranges of some of the identified species are mainly based on those reported by Koutsoukos (1989) for the Brazilian marginal basins or works cited on synonymies. Modes of life of the benthic foraminifera were inferred after Koutsoukos and Hart (1990) and Cetaan et al. (2011), based on foraminiferal morphogroup analysis and the functional morphology concept.

Class: Foraminifera d'Orbigny, 1826

Order: Astrorhizida Lankester, 1885

Suborder: Astrorhizina Lankester, 1885

Superfamily: Astrorhizacea Brady, 1881

Family: Rhabdamminidae Brady, 1884

Genus *Bathysiphon* Sars, 1872

Bathysiphon sp.

Fig. 4.1

Description. elongate, mainly unbranched, tubular test, agglutinated of fine-grained

material; has both ends opened and a slightly flattened inner cavity.

Remarks. the figured specimen presents a slight annular constriction.

Inferred mode of life. erect epifaunal.

Suborder: Hippocrepinina Saidova, 1981

Superfamily: Hippocrepinacea Rhumbler, 1895

Family: Hyperamminidae Eimer and Fickert, 1899

Genus *Hyperammina* Brady, 1878

Hyperammina sp.

Fig. 4.2

Description. globular initial chamber followed by an undivided tubular one, with a rounded terminal aperture. Test agglutinated mainly of medium-grained quartz particles.

Inferred mode of life. shallow infaunal.

Suborder: Ammodiscina Mikhalevich, 1980

Superfamily: Ammodiscacea Reuss, 1862

Family: Ammodiscidae Reuss, 1862

Genus *Glomospira* Rzehak, 1885

Glomospira gordialis (Jones and Parker, 1860)

Fig. 4.3

1860 *Trochammina squamata* var. *gordialis*, Jones and Parker, p. 304; OD(M).

1978 *Ammodiscus* sp.: Scheibnerová, pl. 1, fig. 2.

2005 *Glomospira gordialis* (Jones and Parker): Kaminski and Gradstein, p. 191, fig. 25 and fig. 1.

Remarks. this species is characterized by its proloculus followed by an undivided second tubular chamber that is first coiled in a low trochospire. Wall finely agglutinated; aperture at the open end of the tubular second chamber.

Inferred mode of life. superficial epifaunal.

Range. Aptian (this study) to Recent (Kaminski and Gradstein, 2005).

Paleobathymetry. middle to lower bathyal (Koutsoukos, 1989).

Glomospira sp. cf. *G. charoides* (Jones and Parker, 1860)

Fig. 4.4

Description. test having an undivided tubular chamber almost trochospirally coiled, except by the last one or two whorls that are irregularly coiled. Wall is smooth, of fine-grained calcareous agglutinated particles.

Inferred mode of life. superficial epifaunal.

Order: Lituolida Lankester, 1885

Suborder: Trochamminina Saidova, 1981

Superfamily: Trochamminacea Schwager, 1877

Family: Trochamminidae Schwager, 1877

Genus *Ammoglobigerina* Eimer and Fickert, 1899

Ammoglobigerina? sp.

Fig. 4.5

Description. subglobular trochospiral test with few globular chambers per whorl. The test is finely agglutinated.

Remarks. apertural features are not seen due to the poor preservation of the studied material.

Inferred mode of life. superficial epifaunal.

Suborder: Spiroplectamina Mikhalevich, 1992

Superfamily: Spiroplectamminacea Cushman, 1927

Family: Spiroplectamminidae Cushman, 1927

Genus *Spiroplectinella* Kisel'man, 1972

Spiroplectinella nuda n. comb. (Lalicker, 1935)

Fig. 4.6

1935 *Spiroplectamina nuda* Lalicker, p. 4, pl. 1, figs. 6-7.

1977 *Spiroplectamina nuda* Lalicker: Sliter, p. 675, pl. 2, fig. 1.

Remarks. this species is characterized by its small test, finely-agglutinated, but not

completely smooth. It presents a coiled early stage followed by a longer biserial stage, and raised sutures. Since this species is very small, SEM images were more efficient in the representation of its morphological features. A new combination is proposed here, being this species attributed to the genus *Spiroplectinella*.

Inferred mode of life. superficial epifaunal.

Range. Albian (Sliter, 1977).

Spiroplectinella sp.

Fig. 4.15

Description. test with early microspheric stage planispirally coiled, followed by a biserial stage which increases rapidly in breadth; agglutinated of calcareous particles. Biserial stage a lozenge in cross section; aperture a low arch at the apertural face.

Inferred mode of life. superficial epifaunal.

Suborder: Verneulinina Mikhalevich and Kaminski, 2004

Superfamily: Verneulinacea Cushman, 1911

Family: Prolixoplectidae Loeblich and Tappman, 1985

Genus *Kadriayina* Al-Najdi, 1975

Kadriayina gradata (Berthelin, 1880)

Fig. 4.11

1880 *Gaudryina gradata* Berthelin, p. 24, pl. 1, fig. 6.

1965 *Dorothia gradata* Berthelin: Neagu, p. 8, pl. 2, fig. 23.

1993 *Dorothia gradata* Berthelin: Coccioni and Galeotti, pl. 2, fig. 21.

Remarks. test as described for the genus; early stage trochospiral or triserial, later becoming biserial (with about 10 chambers). Aperture a low arch at the base of the apertural face. The generic assignment presented herein follows the suggestion of Holbourn and Kaminski (1997) (see Kaminski, 2004).

Inferred mode of life. deep infaunal.

Range. Albian (Neagu, 1965; Coccioni and Galeotti, 1993).

Paleobathymetry. middle to deep neritic (Koutsoukos, 1989).

Genus *Protomarssonella* Desai and Banner, 1987

Protomarssonella sp. cf. *P. trochus* (d'Orbigny, 1840)

Fig. 4.13

Description. early stage trochospirally coiled followed by a late biserial stage. Test profile conical, with an extremely rapid increase in chambers breadth, and a concave terminal face. Wall agglutinated of fine-grained calcareous particles, non canaliculate.

Inferred mode of life. deep infaunal.

Family: Tritaxiidae Plotnikova, 1979

Genus *Tritaxia* Reuss, 1960

Tritaxia gaultina Morozova, 1948

Fig. 4.7

1948 *Clavulina gaultina* Morozova, p. 36, pl. 1, fig. 4.

1977 *Tritaxia gaultina* (Morozova): Sliter, p.676, pl. 3, figs. 5-6.

1978 *Clavulina gabonica* (Morozova): Scheinerová, pl. 1, figs. 12-13.

[Non] 1971 *Clavulina gabonica* LeCalvez, de Klasz and Brun, p. 308, pl. 1, figs. 7-9.

1993 *Clavulinoides gaultina* (Morozova): Coccioni and Galeotti, pl. 2, fig. 22.

Remarks. this species possesses an elongated pyramidal, triserial stage, followed by a uniserial stage (with about five chambers), circular in cross-section. Early stage pointed-ending. Moderately deep sutures separate the chambers of the uniserial stage. The last chamber is “onion-shaped” and the aperture is terminal and rounded. The test is of fine-grained agglutinated material.

Inferred mode of life. deep infaunal.

Range. Albian to Cenomanian (Morozova, 1948).

Tritaxia sp.

Fig. 4.8

Description. elongate test, with early triserial stage followed by a longer uniserial stage. Test is practically entirely tri-carinated with concave sides, except by the last-forming

chamber. Most of the uniserial stage presents a triangular cross-section, except by the circular cross-section of the last chamber. Aperture rounded, terminal and central.

Remarks. the generic assignment used herein is justified by the absence of canaliculated walls.

Inferred mode of life. deep infaunal.

Family: Verneuilinidae Cushman, 1911

Genus *Verneuilina* d'Orbigny, 1839

Verneuilina sp.

Fig. 4.9

Description. elongate test, triserial and triangular in cross-section throughout. Margins are carinated and the wall is of fine-grained agglutinated material.

Inferred mode of life. deep infaunal.

Order: Textulariida Delage and Herouard, 1896

Suborder: Textulariina Delage and Herouard, 1896

Superfamily: Eggerellacea Cushman, 1937

Family: Eggerellidae Cushman, 1937

Genus *Dorothia* Plummer, 1931

Dorothia sp. 1

Fig. 4.10

Description. elongate and stout test, mainly of fine-grained calcareous agglutinated particles. Test presents an early trochospiral stage followed by a biserial one. Aperture an open slit on the inner margin of the terminal chamber.

Inferred mode of life. deep infaunal.

Dorothia sp. 2

Fig. 4.12

Description. stout agglutinated test. The test presents an early trochospiral stage followed by a relatively short biserial one. Aperture an open slit on the inner margin of the terminal chamber.

Remarks. it differs from *Dorothia* sp. 1 by having fewer chambers in the biserial stage and being formed by coarser, probably terrigenous, agglutinated particles.

Inferred mode of life. deep infaunal.

Family: Valvulinidae Berthelin, 1880

Genus *Clavulina* d'Orbigny, 1826

Clavulina gabonica LeCalvez, de Klasz and Brun, 1971

Fig. 4.14

1971 *Clavulina gabonica* LeCalvez, de Klasz and Brun, p. 308, pl. 1, figs. 7-9.

1978 *Clavulina gabonica* LeCalvez, de Klasz and Brun: Scheibnerová, pl. 1, figs. 12-13.

Remarks. this species presents an elongate test, of calcareous agglutinated material. Early stage triserial followed by a uniserial one. Sutures are poorly marked externally, and the aperture is terminal, central and rounded.

Inferred mode of life. deep infaunal.

Range. Aptian (this study) to Cenomanian (LeCalvez, de Klasz and Brun, 1971).

Order: Lagenida Lankester, 1885

Superfamily: Nodosariacea Ehrenberg, 1838

Family: Nodosariidae Ehrenberg, 1838

Genus *Laevidentalina* Loeblich and Tappan, 1986

Laevidentalina sp. 1

Fig. 4.16

Description. elongate (slightly arcuate) smooth uniserial test, with three chambers increasing irregularly in breadth and regularly in height as added. Sutures are well-marked externally, and the aperture is terminal, composed of a series of radial slits.

Inferred mode of life. epifaunal to shallow infaunal.

Laevidentalina sp. 2

Fig. 4.17

Description. elongate, arcuate, and big uniserial test, with up to five ovate chambers increasing regularly and slightly in size as added; sutures depressed; aperture terminal, composed of a series of radial slits.

Remarks. it differs from *Laevidentalina* sp. 1 by having a bigger and more elongated test, with more numerous ovate chambers, and by having less depressed sutures.

Inferred mode of life. epifaunal to shallow infaunal.

Genus *Tribrachia* Schubert, 1912

Tribrachia excavata (Reuss, 1863)

Fig. 4.18

1863 *Rhabdgonium excavatum* Reuss, p. 91, pl. 12, fig. 8.

1965 *Tristix excavata* (Reuss): Neagu, pl. 5, figs. 14-15.

1977 *Tribrachia excavata* (Reuss): Sliter, p. 676, pl. 4, fig. 2.

1993 *Tristix excavata* (Reuss): Coccioni and Galeotti, pl. 1, fig. 12.

Remarks. this species is herein assigned to the genus *Tribrachia* due to its rounded terminal aperture.

Inferred mode of life. epifaunal to shallow infaunal.

Range. Albian (Neagu, 1965; Sliter, 1977; Coccioni and Galeotti, 1993).

Paleobathymetry. middle neritic to upper bathyal (Koutsoukos, 1989).

Family: Vaginulinidae Reuss, 1860

Genus *Lenticulina* Lamarck, 1804

Lenticulina subangulata (Reuss, 1863)

Fig. 4.19

1863 *Cristellaria subangulata* Reuss, p. 74, pl. 8, fig. 7.

1965 *Lenticulina subangulata* (Reuss): Neagu, p. 10, pl. 3, figs. 21-22.

Remarks. this species presents an involute lenticular test, with about 11 chambers in the last whorl. Sutures are slightly raised, oblique and curved; the margin is angular, with poorly developed projections at sutural areas.

Inferred mode of life. epifaunal.

Range. Albian (Neagu, 1965).

Paleobathymetry. shallow-middle neritic to upper bathyal (Koutsoukos, 1989).

Lenticulina sp. aff. *L. macrodisca* (Reuss, 1863)

Fig. 4.20

Description. test planispiral, lenticular and biumbonate (with a relatively broad apertural face). Periphery carinate; sutures are curved and undistinguishable externally, with chambers increasing slowly in size.

Remarks. it differs from the holotype described by Reuss (1863) in having more chambers (around 10) in the last whorl.

Inferred mode of life. epifaunal.

Lenticulina? sp. 1

Fig. 4.21

Description. test planispiral, lenticular and biumbonate. Periphery slightly carinate, mostly broadly rounded; sutures are curved and slightly raised, chambers increasing slowly in size as added, with a tendency to uncoil.

Remarks. aperture, at the peripheral angle, is obscured by the poor preservation.

Inferred mode of life. epifaunal.

Lenticulina? sp. 2

Fig. 4.22

Description. test planispiral, lenticular and biumbonate. Periphery is carinate (acute), sutures are curved and slightly raised, chambers increasing slowly in size with a tendency to uncoil.

Remarks. this species differs from *Lenticulina?* sp. 1 by having more carinate margins, and a more compressed profile.

Inferred mode of life. epifaunal.

Genus *Lenticulinella* Samyschkina, 1983

Lenticulinella sp.

Fig. 4.23

Description. semi-involute, planispiral test, with a tendency to uncoil, and 7 chambers in the last-forming whorl. The periphery is subacute, and there is a prominent umbonal boss. Aperture radiate at the dorsal angle.

Inferred mode of life. epifaunal.

Genus *Saracenaria* DeFrance, 1824

Saracenaria sp.

Fig. 5.1

Description. early planispirally coiled portion followed by a flaring stage, tending to become rectilinear. Apertural face broad and flat; margins carinate. Sutures curved and depressed. Aperture radiate at the dorsal angle.

Remarks. this species is herein assigned to the genus *Saracenaria* due to its broad and flat apertural face.

Inferred mode of life. epifaunal to shallow infaunal.

Genus *Astacolus* de Montfort, 1808

Astacolus sp.

Fig. 5.2

Description. test ovate in outline, with broad and low chambers added on a slightly curved axis. Sutures are strongly oblique and sinuate, not marked externally, and the aperture is radial at the dorsal angle.

Inferred mode of life. epifaunal to shallow infaunal.

Genus *Vaginulinopsis* Silvestri, 1904

Vaginulinopsis? sp.

Fig. 5.3

Description. test with planispiral early stage followed by an uncoiled and rectilinear stage. Late stage is slightly laterally compressed and ovate in cross-section; aperture is terminal and radiate at the dorsal angle.

Remarks. sutures are hardly visible, hampering a more precise identification.

Inferred mode of life. epifaunal to shallow infaunal.

Genus *Citharina* d'Orbigny, 1839

Citharina sp. 1

Fig. 5.4

Description. flattened uniserial test, with chambers increasing rapidly in breadth and

strongly angled towards the base of the dorsal margin. A few longitudinal ribs are present on the surface.

Inferred mode of life. epifaunal to shallow infaunal.

Citharina sp. 2

Fig. 5.5

Description. flattened uniserial test, with chambers increasing rapidly in breadth and strongly angled towards the base of the dorsal margin. Test outline subtriangular; numerous longitudinal ribs are present on the surface.

Remarks. differs from *Citharina* sp. 1 by having a bigger test with subtriangular outline and more numerous and symmetrical longitudinal ribs.

Inferred mode of life. epifaunal to shallow infaunal.

Family: Lagenidae Reuss, 1862

Genus *Lagena* Walker and Jacob, 1798

Lagena sp.

Fig. 5.6

Remarks. this species presents a hyaline, unilocular, ovate, and pointed-ending test. Poorly-developed longitudinal striae are present on the surface of the upper portion of the test. Aperture is terminal and rounded, at the extremity of a short neck.

Inferred mode of life. infaunal.

Superfamily: Polymorphinacea d'Orbigny, 1839

Family: Polymorphinidae d'Orbigny, 1839

Genus *Ramulina* Jones, 1875

Ramulina novaculeata Bullard, 1953

Fig. 5.7

1953 *Ramulina novaculeata* Bullard, p. 346, pl. 46, fig. 26.

2008 *Ramulina novaculeata* Bullard: Cetean et al., pl. 1, fig. 11.

Remarks. this species possesses cylindrical branches extending from an inflated proloculum. Thick spines cover the wall, and the apertures are rounded and positioned at the extremities of the branching chambers.

Inferred mode of life. epifaunal to shallow infaunal.

Range. latest Aptian (this study) to late Cenomanian (Cetean et al., 2008).

Ramulina sp.

Fig. 5.8

Description. test possesses cylindrical branches extending from an inflated and globular proloculum. The surface is smooth to slightly hispid.

Inferred mode of life. epifaunal to shallow infaunal.

Order: Buliminida Fursenko, 1958

Superfamily: Bolivinaea Glaessner, 1937

Family: Bolivinoidea Loeblich and Tappan, 1984

Genus *Aragonia* Finlay, 1939

Aragonia? sp.

Fig. 5.9

Description. test biserial throughout, with chambers increasing rapidly in breadth as added. Margins slightly carinate in the early stage of development; test is fusiform in section.

Remarks. the identification remains as tentative due to the test outline (more triangular than rhomboidal).

Inferred mode of life. infaunal.

Superfamily: Pleurostomellacea Reuss, 1860

Family: Pleurostomellidae Reuss, 1860

Genus *Ellipsoglandulina* Silvestri, 1900

Ellipsoglandulina sp.

Fig. 5.10

Description. elongate, uniserial and flaring test, circular in cross-section. It possesses 3 chambers, the third comprising approximately two-thirds of the test length. Sutures are

slightly depressed and the surface is completely smooth. Aperture is terminal and semilunate.

Inferred mode of life. infaunal.

Genus *Pleurostomella* Reuss, 1860

Pleurostomella obtusa Berthelin, 1880

Fig. 5.11

1880 *Pleurostomella obtusa* Berthelin, p. 29, pl. 1, fig. 9.

1965 *Pleurostomella obtusa* Berthelin: Neagu, p. 29, pl. 7, figs. 29-32.

1978 *Pleurostomella obtusa* Berthelin: Scheibnerová, pl. 1, fig. 26.

Remarks. this species differs from all other *Pleurostomella* reported herein by having a bigger globular initial chamber.

Inferred mode of life. infaunal.

Range. Aptian (Scheibnerová, 1978) to Albian (Neagu, 1965).

Pleurostomella reussi Berthelin, 1880

Fig. 5.12

1880 *Pleurostomella reussi* Berthelin, p. 28, pl. 1, figs. 10-12.

1965 *Pleurostomella reussi* Berthelin: Neagu, p. 30, pl. 7, figs. 27-28.

1978 *Pleurostomella obtusa* Berthelin: Scheibnerová, pl. 1, fig. 25.

[Non] 1880 *Pleurostomella obtusa* Berthelin, p. 29, pl. 1, fig. 9.

2001 *Pleurostomella reussi* Berthelin: Holbourn and Kuhnt, fig. 8.5.

Remarks. differs from *P. obtusa* due to the smaller initial chambers.

Inferred mode of life. infaunal.

Range. Aptian to Albian (Holbourn and Kuhnt, 2001).

Pleurostomella subnodosa Reuss, 1860

Fig. 5.13

1860 *Pleurostomella subnodosa* Reuss, p. 204, pl. 8, fig. 2.

1929 *Pleurostomella subnodosa* var. *giganta* White, p. 53, pl. 5, fig. 16.

1977 *Pleurostomella subnodosa* Reuss: Sliter, p. 675, pl. 6, figs. 8-9.

Remarks. differs from all other species of *Pleurostomella* recovered herein by having a stouter test.

Inferred mode of life. infaunal.

Range. Albian (this study) to Maastrichtian (Sliter, 1977).

Order: Rotaliida Lankester, 1885

Superfamily: Chilostomellacea Brady, 1881

Family: Globorotalitidae Loeblich and Tappan, 1984

Genus *Conorotalites* Kaeber, 1958

Conorotalites sp.

Fig. 5.14

1978 *Globorotalites michelinianus* (d'Orbigny): Scheibnerová, p. 747, pl. 4, figs. 2-4.

[Non] 1840 *Rotalina micheliniana* d'Orbigny, p. 31, pl. 3, figs. 1-3.

Description. test has a plano-convex or unequally biconvex profile, an acutely carinate periphery, 6-7 chambers in the last whorl, high umbilical shoulder and raised sutures on the spiral side.

Remarks. regarding the poor preservation of the studied material, the generic assignation is supported by the lobate equatorial outline of the species.

Inferred mode of life. epifaunal.

Family: Osangulariidae Loeblich and Tappan, 1964

Genus *Osangularia* Brotzen, 1940

Osangularia sp.

Fig. 5.15

Description. trochospiral test, lenticular in apertural view, with about 9 chambers in the last-forming whorl. Sutures oblique and curved on the spiral side, radial and slightly

curved on the umbilical side. Test is also hyaline and smooth, and margins are acute. Apertural system as described for the genus.

Inferred mode of life. epifaunal.

Family: Gavelinellidae Hofker, 1956

Genus *Gyroidinoides* Brotzen, 1942

Gyroidinoides infracretaceus (Morozova, 1948)

Fig. 5.16

1948 *Gyroidinoides infracretaceus* Morozova, p. 40, pl. 2, figs. 12-14.

2005 *Gyroidinoides infracretaceus* Morozova: Haig, p. 72, pl. 4, figs. 1-2.

Remarks. this species differs from *G. globosus* (Hagenow) mainly by having a slightly angular test outline, and by the smaller number of chambers.

Inferred mode of life. epifaunal.

Range. late Aptian (Haig, 2005) to late Albian (this study).

Gyroidinoides globosus (Hagenow, 1842) emend. Alegret and Thomas, 2001

Fig. 5.17

1842 *Nonionina globosa* Hagenow, p. 574 (cf. Cushman, 1946 – p. 140).

1989 *Gyroidinoides globosa* (Hagenow): Koutsoukos, p. 175, pl. 16, figs. 12-18.

2001 *Gyroidinoides globosus* (Hagenow): Alegret and Thomas, p. 288, pl. 16, figs. 12-18.

Remarks. differs from *G. infracretaceus* by having a distinctive globular test, and a broadly rounded equatorial periphery without a clearly defined peripheral shoulder. Apertural face is about four times broader than high.

Inferred mode of life. epifaunal.

Range. late Aptian to Maastrichtian (Koutsoukos, 1989).

Paleobathymetry. deep neritic to upper bathyal (Koutsoukos, 1989).

Genus *Berthelina* Malapris, 1965

Berthelina? sp.

Fig. 5.18

Description. test low trochospiral, biconvex, with narrow umbilicus and about 10 chambers in the last forming whorl. Sutures slightly curved; aperture probably an equatorial slit.

Remarks. following the revision of Revets (2001), this form is tentatively assigned to the genus *Berthelina* due to its covered umbilicus and poorly-developed periumbilical ridge. The poor preservation also prevents a more precise identification.

Inferred mode of life. epifaunal.

Genus *Orithostella* Eicher and Worstell, 1970

Orithostella indica Scheibnerová, 1974

Fig. 5.19

1974 *Orithostella indica* Scheibnerová, p. 715, pl. 7, figs. 4, 8-13; pl. 8, figs. 1-9; pl. 11, fig. 9.

1978 *Orithostella indica* Scheibnerová: Scheibnerová, p. 747, pl. 3, figs. 9-11, 14-16.

Remarks. the most remarkable morphological feature regarding this species is that only the chambers of the last-forming whorl are completely visible on both sides of the test. In addition, the umbilical side is less convex (inflated) than in other species of this genus.

Inferred mode of life. epifaunal.

Range. Aptian (this study) to Albian (Scheibnerová, 1978).

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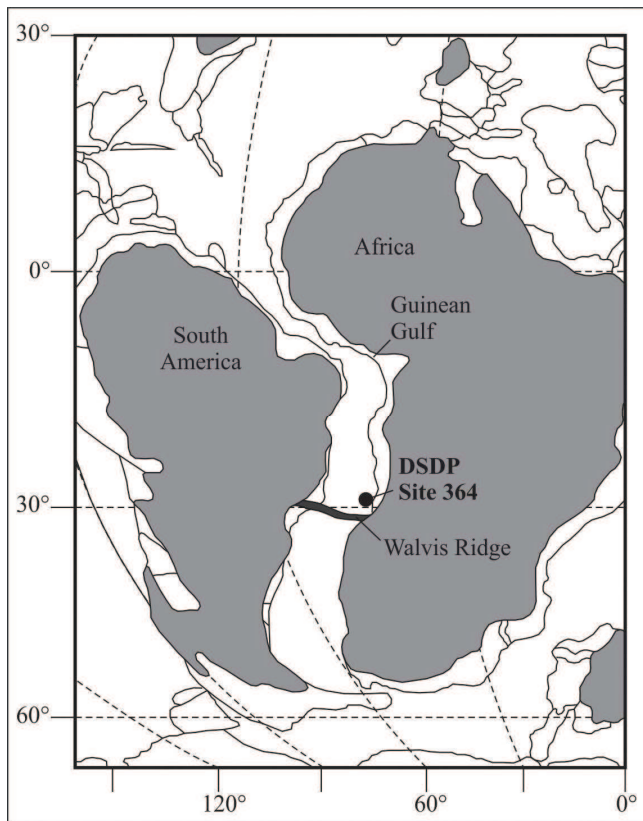


Fig. 1. Paleogeographic reconstruction for 112 Ma (modified from Hay et al., 1999) presenting the inferred location of DSDP Site 364 ($11^{\circ}34.32'S$; $11^{\circ}58.30'E$), the Walvis Ridge and the Guinean Gulf.

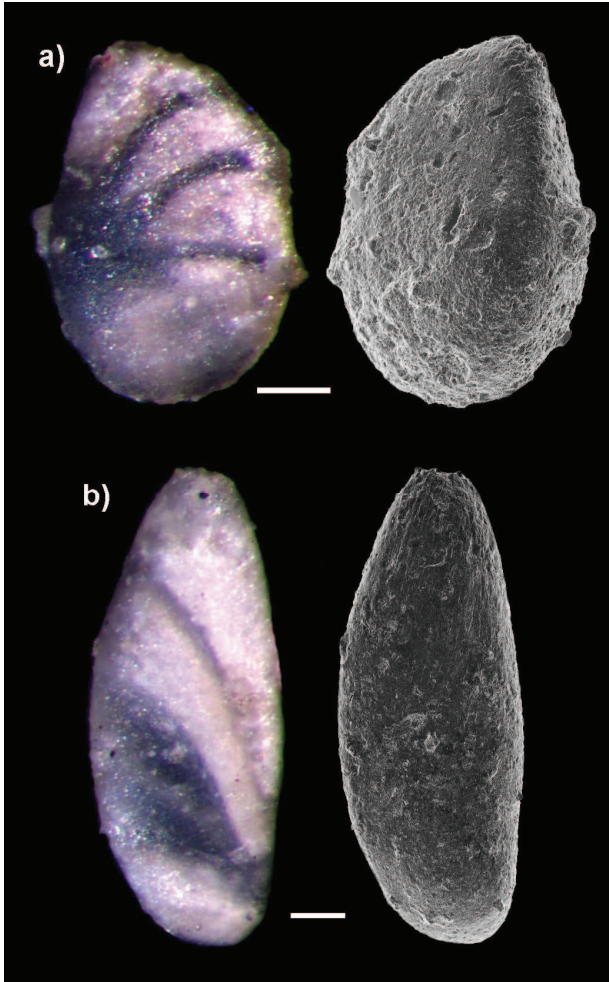
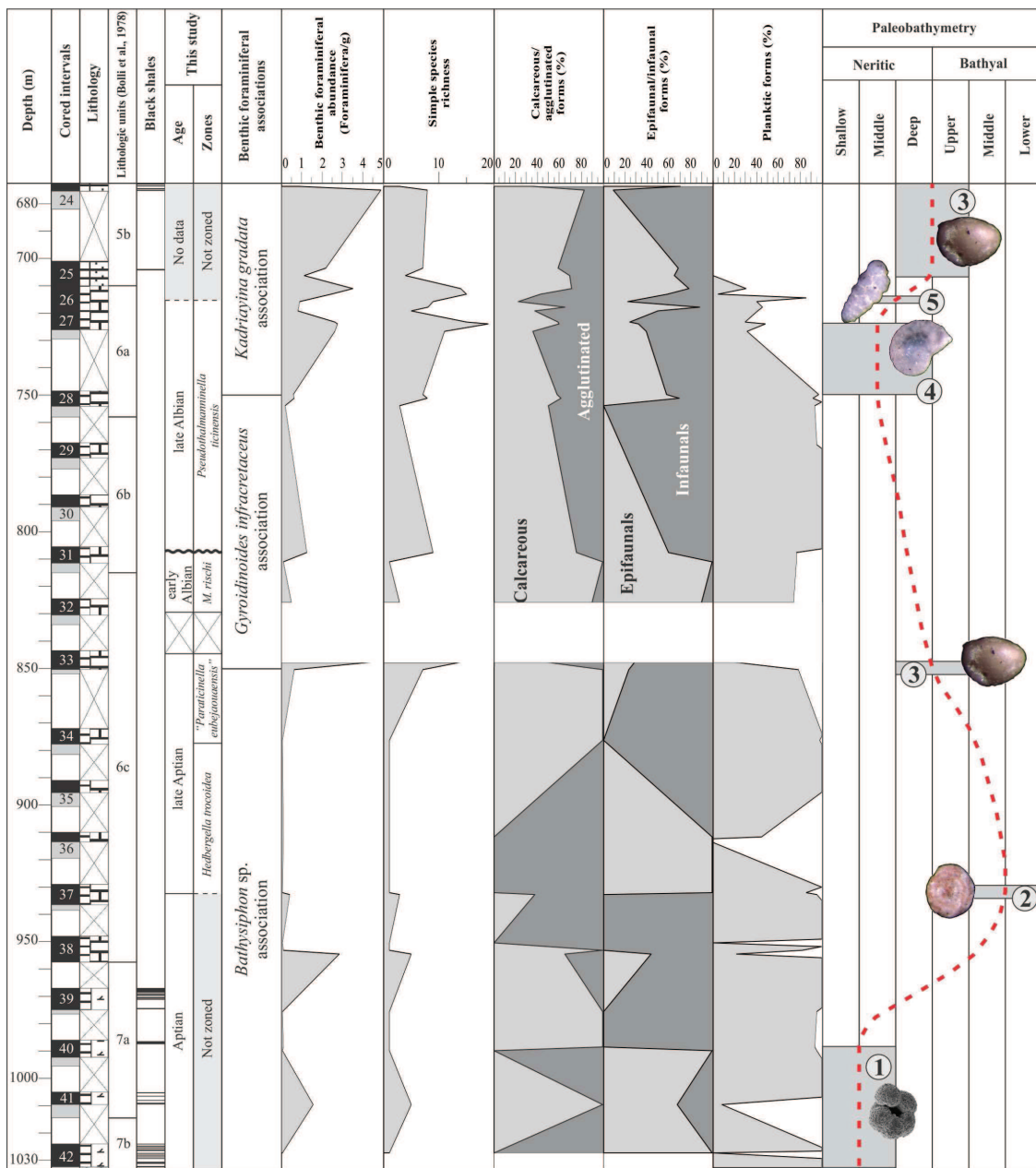


Fig. 2. Comparison between optical and SEM microographies. A) *Lenticulinella* sp., 364-28-2, 70-74 cm; B) *Astacolus* sp., 364-26-2, 71-73 cm. Scale bars = 100 μm .



Caption: Limestone Dolomite Mudstone Nannofossil chalk

Fig. 3. Benthic foraminiferal indexes for DSDP Site 364: Benthic foraminiferal abundance, simple species richness, calcareous/agglutinated forms ratio, epifaunal/infaunal forms ratio and relative abundance of planktic foraminifera. Paleobathymetric estimatives based on *Favusella* sp. aff. *F. washitensis* (1), *Glomospira gordialis* (2), *Gyroidinoides globosus* (3), *Lenticulina subangulata* (4) and *Kadriayina gradata* (5). The biostratigraphic zonation proposed by Kochhann et al. (submitted) is shown. Cored intervals are presented in gray and total core recovery in black; unconformity is represented by a wavy line.

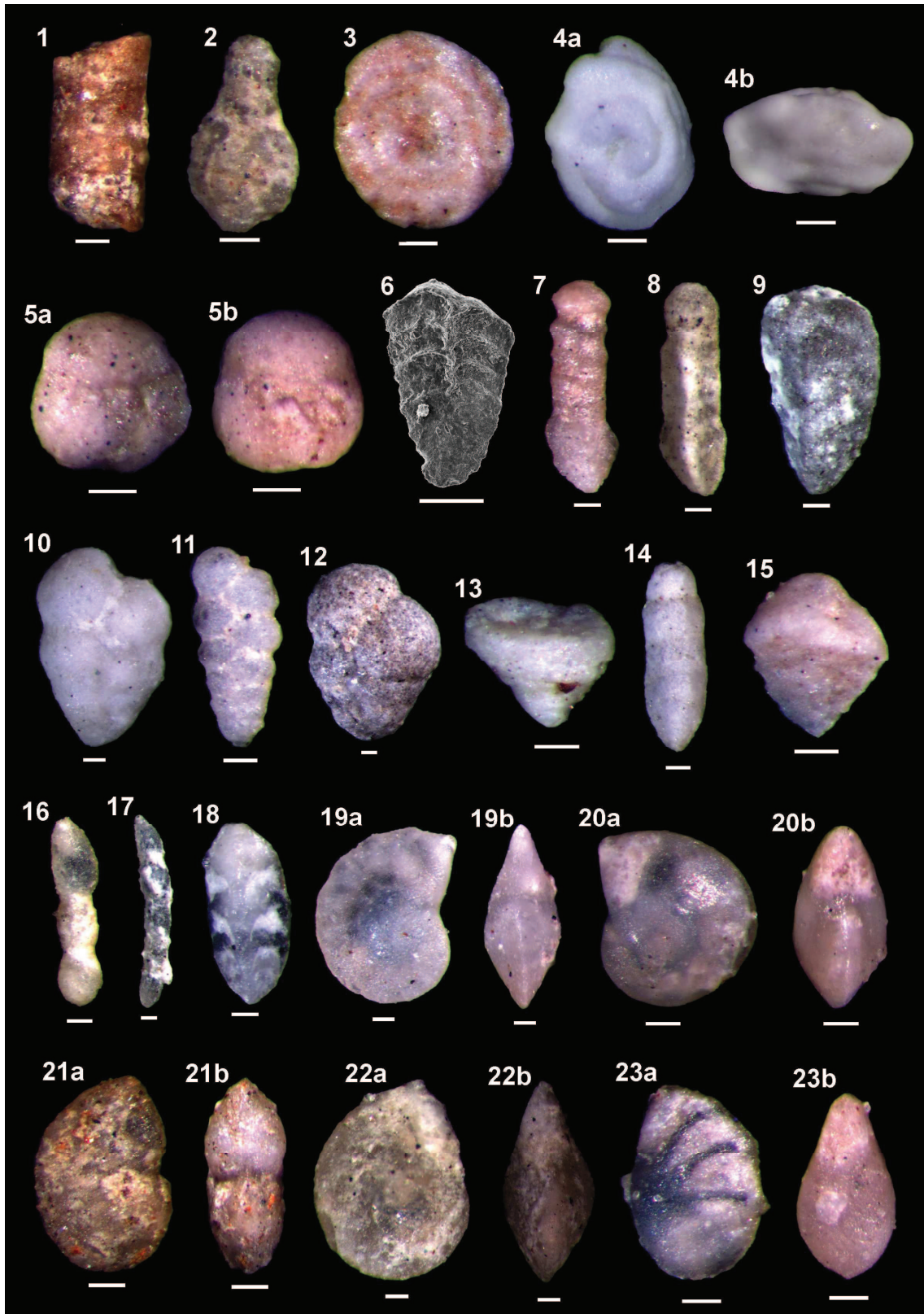


Fig. 4. Optical micrographs of Aptian-Albian benthic foraminifera from DSDP Site 364, except by fig. 4.6 that is an electron scanning micrograph. Scale bars = 100 μm . 1, *Bathysiphon* sp., 364-42-3, 24-28 cm (ULVG-9578); 2, *Hyperammina* sp., 364-33-3, 93-95 cm (ULVG-9579); 3, *Glomospira gordialis*, 364-26-1, 47-50 cm (ULVG-9580); 4, *Glomospira* sp. cf. *G. charoides*, 364-24-2, 99-100 cm (ULVG-9581); 5, *Ammoglobigerina?* sp., 364-27-5, 66-70 cm (ULVG-9582); 6, *Spiroplectinella nuda* n. comb., 364-28-1, 69-73 cm (ULVG-9583); 7, *Tritaxia gaultina*, 364-28-1, 69-73 cm (ULVG-9584); 8, *Tritaxia* sp., 364-33-3, 93-95 cm (ULVG-9585); 9, *Verneuilina* sp., 364-38-2, 103-105 cm (ULVG-9586); 10, *Dorothia* sp. 1, 364-28-4, 64-68 cm (ULVG-9587); 11, *Kadriayina gradata*, 364-28-2, 70-74 cm (ULVG-9588); 12, *Dorothia* sp. 2, 364-26-2, 71-73 cm (ULVG-9589); 13, *Protomarssonella* sp. cf. *P. trochus*, 364-24-2, 99-100 cm (ULVG-9590); 14, *Clavulina gabonica*, 364-31-2, 40-42 cm (ULVG-9591); 15, *Spiroplectinella* sp., 364-28-2, 70-74 cm (ULVG-9592); 16, *Laevidentalina* sp. 1, 364-33-3, 93-95 cm (ULVG-9593); 17, *Laevidentalina* sp. 2, 364-33-5, 65-69 cm (ULVG-9594); 18, *Tribrachia excavata*, 364-27-3, 67-71 cm (ULVG-9595); 19, *Lenticulina subangulata*, 364-28-2, 70-74 cm (ULVG-9596); 20, *Lenticulina* sp. aff. *L. macrodisca*, 364-27-5, 66-70 cm (ULVG-9597); 21, *Lenticulina?* sp. 1, 364-41-4, 29-32 cm (ULVG-9598); 22, *Lenticulina?* sp. 2, 364-33-3, 93-95 cm (ULVG-9599); 23, *Lenticulinella* sp., 364-28-2, 70-74 cm (ULVG-9600).



Fig. 5. Optical micrographs of Aptian-Albian benthic foraminifera from DSDP Site 364. Scale bars = 100 μ m. 1, *Saracenaria* sp., 364-26-5, 73-77 cm (ULVG-9601); 2, *Astacolus* sp., 364-26-2, 71-73 cm (ULVG-9602); 3, *Vaginulinopsis?* sp., 364-33-3, 93-95 cm (ULVG-9603); 4, *Citharina* sp. 1, 364-33-3, 93-95 cm (ULVG-9604); 5, *Citharina* sp. 2, 364-26-2, 71-73 cm (ULVG-9605); 6, *Lagena* sp., 364-34-3, 96-99 cm (ULVG-9606); 7, *Ramulina novaculeata*, 364-33-3, 93-95 cm (ULVG-9607); 8, *Ramulina* sp., 364-28-1, 69-73 cm (ULVG-9608); 9, *Aragonia?* sp., 364-28-2, 70-74 cm (ULVG-9609); 10, *Ellipsoglandulina* sp., 364-31-2, 40-42 cm (ULVG-9610); 11, *Pleurostomella obtusa*, 364-41-4, 29-32 cm (ULVG-9611); 12, *Pleurostomella reussi*, 364-31-2, 40-42 cm (ULVG-9612); 13, *Pleurostomella subnodosa*, 364-27-2, 125-128 cm (ULVG-9613); 14, *Conorotalites* sp., 364-31-2, 40-42 cm (ULVG-9614); 15, *Osangularia* sp., 364-33-3, 93-95 cm (ULVG-9615); 16, *Gyroidinoides infracretaceus*, 364-31-2, 40-42 cm (ULVG-9616); 17, *Gyroidinoides globosus*, 364-24-2, 99-100 cm (ULVG-9617); 18, *Berthelina?* sp., 264-27-3, 67-71 cm (ULVG-9618); 19, *Orithostella indica*, 364-26-6, 115-117 cm (ULVG-9619).

Sample	Depth (m)	Lithostratigraphic unit	Planktic foraminiferal zones	Age	Species
364-24-1, 42-44 cm	672.92	5b	Not zoned	No data	<i>R</i>
364-24-2, 96-100 cm	674.96				<i>R</i>
364-25-2, 41-44 cm	702.91	6a	Not zoned	No data	<i>C</i>
364-25-4, 69-73 cm	706.19				<i>F</i>
364-25-6, 72-75 cm	709.22				<i>F</i>
364-26-1, 47-50 cm	710.97				<i>F</i>
364-26-2, 71-73 cm	712.71				<i>F</i>
364-26-3, 64-67 cm	714.14				<i>F</i>
364-26-4, 34-38 cm	715.34				<i>F</i>
364-26-5, 73-77 cm	717.23				<i>R</i>
364-26-6, 115-117 cm	719.15				<i>F</i>
364-27-2, 125-128 cm	722.75				<i>F</i>
364-27-3, 67-71 cm	723.67	6b	Not zoned	No data	<i>F</i>
364-27-5, 66-70 cm	726.66				<i>F</i>
364-28-1, 69-73 cm	749.19				<i>F</i>
364-28-2, 70-74 cm	750.7				<i>F</i>
364-28-3, 87-91 cm	752.37				<i>F</i>
364-28-4, 64-68 cm	753.64				<i>F</i>
364-29-1, 69-71 cm	768.19				<i>F</i>
364-29-2, 33-37 cm	769.33				<i>F</i>
364-29-3, 67-71 cm	771.17				<i>F</i>
364-29-4, 34-37 cm	772.34				<i>F</i>
364-30-1, 66-70 cm	787.16	6c	Not zoned	Aptian	<i>F</i>
364-30-2, 94-98 cm	788.94				<i>F</i>
364-30-3, 91-94 cm	790.41				<i>F</i>
364-31-1, 79-82 cm	806.29				<i>F</i>
364-31-2, 40-42 cm	807.4				<i>F</i>
364-31-4, 94-98 cm	810.94				<i>F</i>
364-32-1, 123-127 cm	825.73				<i>F</i>
364-32-2, 40-44 cm	826.4				<i>F</i>
364-32-3, 90-92 cm	828.4				<i>F</i>
364-32-4, 46-50 cm	829.46				<i>F</i>
364-33-1, 107-111 cm	844.57	6c	Not zoned	Aptian	<i>F</i>
364-33-2, 92-95 cm	845.92				<i>F</i>
364-33-3, 93-95 cm	847.43				<i>F</i>
364-33-5, 65-69 cm	850.15				<i>F</i>
364-34-1, 133-136 cm	873.33				<i>F</i>
364-34-2, 93-96 cm	874.43				<i>F</i>
364-34-3, 96-99 cm	875.96				<i>F</i>
364-34-4, 92-96 cm	877.42				<i>F</i>
364-35-1, 114-117 cm	892.14				<i>F</i>
364-35-2W, 46-49 cm	892.96				<i>F</i>
364-35-3, 99-101 cm	894.99	7a	Not zoned	Aptian	<i>F</i>
364-36-1, 125-128 cm	911.25				<i>F</i>
364-36-2, 52-54 cm	912.02				<i>F</i>
364-36-3, 75-77 cm	913.75				<i>F</i>
364-37-1, 66-69 cm	929.66				<i>F</i>
364-37-2, 120-122 cm	931.7				<i>F</i>
364-37-3, 45-47 cm	932.45				<i>F</i>
364-37-4, 94-97 cm	934.44				<i>F</i>
364-37-5, 98-101 cm	935.98				<i>F</i>
364-38-1, 90-93 cm	948.9				<i>F</i>
364-38-2, 103-105 cm	950.53	<i>F</i>			
364-38-3, 47-49 cm	951.47	7b	Not zoned	Aptian	<i>F</i>
364-38-4, 27-30 cm	952.77				<i>F</i>
364-38-5, 53-55 cm	954.53				<i>F</i>
364-38-6, 25-28 cm	955.75				<i>F</i>
364-39-1, 145-148 cm	968.45				<i>F</i>
364-39-2, 114-119 cm	969.64				<i>F</i>
364-39-3, 118-122 cm	971.18				<i>F</i>
364-39-4, 66-69 cm	972.16				<i>F</i>
364-39-5, 89-92 cm	973.89				<i>F</i>
364-39-6, 98-101 cm	975.48				<i>F</i>
364-40-2, 92-96 cm	988.42	7b	Not zoned	Aptian	<i>F</i>
364-40-3, 71-75 cm	989.71				<i>F</i>
364-40-5, 63-66 cm	992.63				<i>F</i>
364-41-1, 141-145 cm	1006.41				<i>F</i>
364-41-2, 46-50 cm	1006.96				<i>F</i>
364-41-4, 29-32 cm	1009.79				<i>F</i>
364-42-1, 137-139 cm	1025.37				<i>F</i>
364-42-2, 81-84 cm	1026.31				<i>F</i>
364-42-3, 24-28 cm	1027.24				<i>F</i>
364-42-4, 100-103 cm	1029.5				<i>F</i>
364-42-6, 87-90 cm	1032.37	<i>F</i>			

Tab. 1. Relative abundances for benthic foraminiferal species from Aptian to 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%). The red line locates the not-recovered interval of the Aptian-Albian transition.

4 CONSIDERAÇÕES FINAIS

A sucessão estratigráfica estudada do DSDP Site 364 pode ser atribuída ao intervalo Aptiano superior-Albiano, apresentando as zonas de foraminíferos planctônicos *Hedbergella trocoidea*, “*Paraticinella eubejaouaensis*”, *Microhedbergella rischi* e *Pseudothalmaninella ticinensis*. Uma discordância erosiva, compreendendo todo o Albiano médio, ocorre no *core* 31, sendo caracterizada pela sobreposição direta da Zona *Microhedbergella rischi* pela Zona *Pseudothalmaninella ticinensis*. Tendências nos valores isotópicos de $\delta^{13}\text{C}$, que devem ser cuidadosamente interpretadas devido a uma possível alteração diagenética, sugerem uma idade aptiana tardia (Zona *Globigerinelloides algerianus*) para o intervalo estratigráfico do *core* 42 ao *core* 37, no qual fósseis-guia tetianos estão ausentes, além de sugerir que os folhelhos negros da base do testemunho estudado (*cores* 42-39) possam ser correlatos ao evento anóxico do Aptiano tardio.

A composição taxonômica específica das assembleias de foraminíferos planctônicos permite caracterizá-las como assembleias marinhas de águas rasas. A dominância em abundância relativa de espécies atribuídas à família Hedbergellidae, normalmente consideradas estrategistas-r, permite a inferência do domínio de condições mesotróficas a eutróficas ao longo do intervalo estudado. A ocorrência de uma rica biota planctônica associada com a ausência, ou baixa abundância, de foraminíferos bentônicos, sugere a ocorrência de condições de fundo depletadas em oxigênio, mas com camadas epipelágicas bem oxigenadas, para os intervalos onde ocorrem folhelhos negros e para o intervalo estratigráfico atribuído à Zona *Pseudothalmaninella ticinensis*. Ainda, assume-se que a deposição dos folhelhos negros ocorreu em ambiente relativamente raso

(dominantemente nerítico) e depletado em oxigênio.

As assembleias aptianas de foraminíferos planctônicos apresentam significativa afinidade paleobiogeográfica tetiana, suportando um influxo de água superficial tetiana no setor setentrional (restrito) do Oceano Atlântico Sul (ao norte da Cadeia de Walvis-Elevação do Rio Grande) já no Aptiano tardio. No presente estudo, a ausência de alguns marcadores bioestratigráficos tetianos é interpretada como uma consequência das suas preferências por habitar camadas mais profundas da coluna d'água, que provavelmente não adentravam o setor setentrional do Oceano Atlântico Sul e/ou apresentavam características disóxicas-anóxicas, sem relação necessária com um suposto influxo de massas de águas austrais.

A análise quali-/quantitativa das assembleias de foraminíferos planctônicos permitiu a identificação de uma mudança faunística na passagem Aptiano/Albiano, caracterizada por altas taxas de extinções seguidas por elevadas taxas de surgimentos de espécies, além de uma significativa mudança no padrão arquitetural das testas.

Quanto à fauna aptiana tardia-albiana de foraminíferos bentônicos do DSDP *Site* 364, três associações de foraminíferos bentônicos foram identificadas, cujas distribuições estratigráficas parecem ser principalmente controladas por variações paleobatimétricas. Esta fauna pode ser classificada como uma Associação do tipo *Marssonella*, provavelmente relacionada a paleo-profundidades neríticas a batiais superiores, também exibindo uma marcada afinidade paleobiogeográfica tetiana.

Uma síntese apresentando os dados de foraminíferos planctônicos e bentônicos identificados no presente estudo é apresentada no Apêndice 1.

Estudos futuros nesse mesmo tema têm o potencial de: i) confirmar ou refutar a aplicabilidade bioestratigráfica (bioeventos) de foraminíferos planctônicos de assembleias marinhas de águas rasas no zoneamento de sucessões sedimentares aptianas-albianas do setor setentrional (restrito) do Oceano Atlântico Sul, historicamente caracterizado pela ausência de marcadores bioestratigráficos tetianos; ii) avaliar o modelo paleobatimétrico baseado em foraminíferos bentônicos apresentado no presente estudo; iii) com base em material melhor preservado, corroborar ou refutar as interpretações estratigráficas baseadas em isótopos estáveis de carbono apresentadas nesse trabalho.

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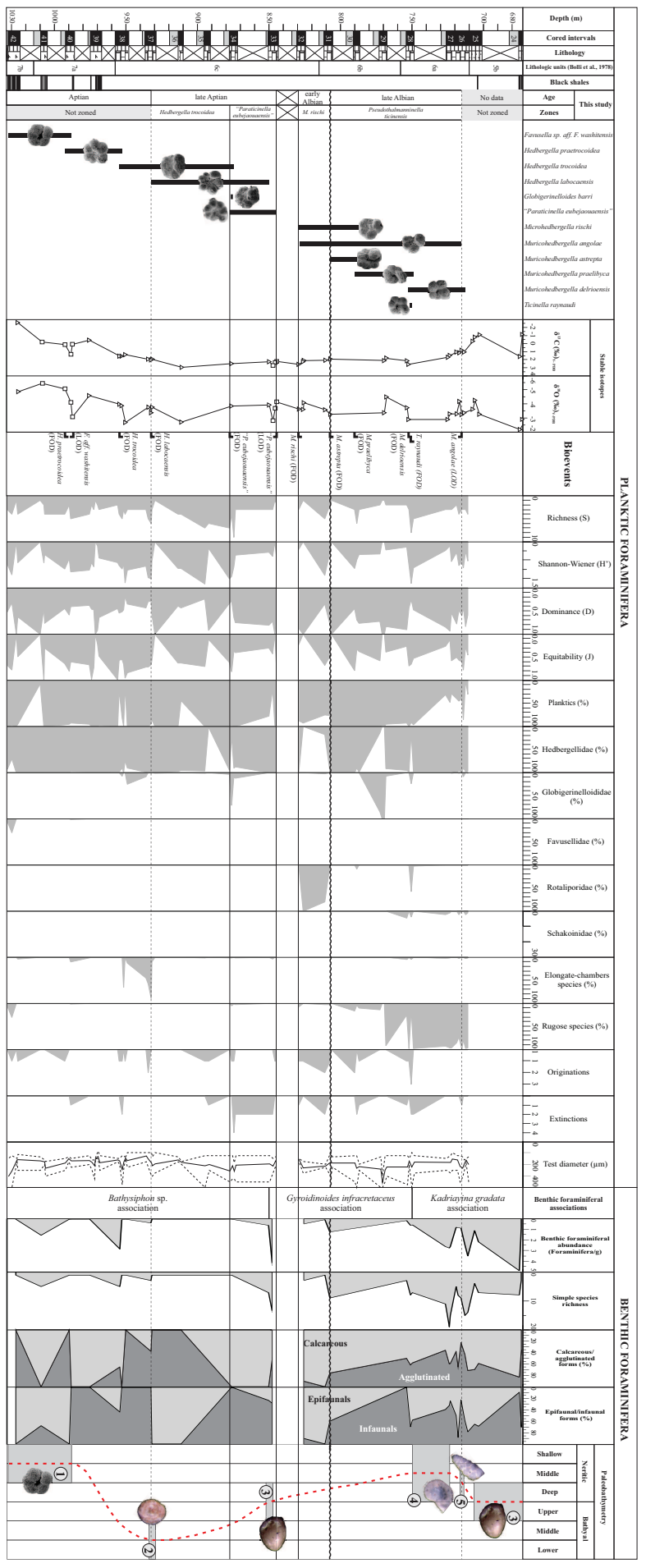
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APÊNDICE 1



Sample	Depth (m)	Stratigraphic unit	Planktic Foraminifera	Benthic Foraminifera
1020	689	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
990	700	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
980	710	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
970	720	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
960	730	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
950	740	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
940	750	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
930	760	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
920	770	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
910	780	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
900	790	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
890	800	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
880	810	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
870	820	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
860	830	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
850	840	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
840	850	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
830	860	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
820	870	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
810	880	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
800	890	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
790	900	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
780	910	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
770	920	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
760	930	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
750	940	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
740	950	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
730	960	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
720	970	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
710	980	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
700	990	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
690	1000	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>
689	1020	Aptian	<i>Hedbergella troscoides</i>	<i>Bathysiphon sp. association</i>

Figura 1 - Figura sempre apresentando os dados de foraminíferos planctônicos e bentônicos identificados no presente estudo. A linha pontilhada representa uma discordância crônica e a linha vermelha o intervalo não-escarpado da passagem Aptiano-Albiano.