PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA AMBIENTAL
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CENTRO DE CIÊNCIAS HUMANAS E NATURAIS

PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA AMBIENTAL

FABIANA KARLA DE ALMEIDA

DISTRIBUIÇÃO DOS FORAMINÍFEROS BENTÔNICOS RECENTES E SUA RELAÇÃO COM OS PARÂMETROS SEDIMENTOLÓGICOS E OCEANOGRÁFICOS DA BACIA DO ESPÍRITO SANTO

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Tese apresentada ao Programa de Pós-Graduação em Oceanografia Ambiental da Universidade Federal do Espírito Santo, como requisito parcial para obtenção do título de Doutor em Oceanografia Ambiental.

Orientador: Prof. Dr. Alex Cardoso Bastos

Co-orientadora: Dra. Renata Moura de Mello

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"Toda pessoa sempre é as marcas das lições diárias de outras tantas pessoas.
E é tão bonito quando a gente entende que a gente é tanta gente onde quer que a gente vá.
É tão bonito quando a gente sente que nunca está sozinho por mais que pense estar.
É tão bonito quando a gente pisa firme nessas linhas que estão nas palmas de nossas mãos.
É tão bonito quando a gente vai à vida nos caminhos onde bate, bem mais forte o coração."

(Gonzaguinha)

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RESUMO

O fundo marinho heterogêneo da Margem Continental Brasileira pode resultar em diferenças na composição das associações de foraminíferos bentônicos. Com propósito de compreender os principais fatores ambientais que controlam a distribuição dos foraminíferos bentônicos no talude continental, e corroborar com interpretações paleoambientais do Holoceno Superior, os foraminíferos bentônicos recentes (fauna total > 63 µm), em conjunto com dados sedimentológicos foram investigados e integrados ao longo de seis transectos no talude continental, e dentro de dois cânions submarinos da Bacia do Espírito Santo (BES, 18°20' e 21°20' S). As amostras de sedimentos superficiais (0-2 cm) foram coletadas perpendicularmente à costa, desde o talude superior (400 m) até o inferior (3.000 m), e no interior dos cânions Watu Norte (CANWN) e Doce (CAND), desde a cabeceira até a porção média-inferior (150 a 1.300 m). A densidade, diversidade taxonômica e composição das associações variam com a profundidade e entre os dois cânions. Diferenças entre as preferências ecológicas dos táxons mais abundantes permitiram o reconhecimento de grupos (associações) distintos, distribuídos em cinco setores batimétricos principais: plataforma externa (50 m), talude superior 150-400m), talude médio-inferior (1.000-1.300 m), talude inferior (1.900 m), e a porção mais profunda do talude inferior (2.500-3.000 m). Além disso, dois grupos distintos foram reconhecidos, revelando diferenças entre as associações encontradas em cada cânion submarino. O fator primário que controla a distribuição das associações de foraminíferos bentônicos ao longo da profundidade está associado a quantidade e qualidade do fluxo orgânico que atinge o fundo marinho. Outros fatores secundários incluem as propriedades das massas de água, as correntes de contorno intermediária e profunda, e a granulometria do sedimento de fundo. O aumento no percentual de testas de foraminíferos bentônicos e planctônicos fragmentadas (>125 µm) parece estar relacionado à abrasão devido o transporte das testas de regiões mais rasas para o talude. A porção média-inferior do CANNW indica condições tróficas instáveis, relacionadas ao fluxo de sedimentos terrígenos provocado por correntes de turbidez. No CAND, a ecologia das associações de foraminíferos bentônicos indica que conteúdo de matéria orgânica aprisionado nesse cânion foi suficiente para favorecer a estabilidade e diversidade de espécies, revelando um ambiente mais produtivo e menos instável que no CANWN. Os dados obtidos nesse estudo com poderão servir como análagos na interpretação de sistemas deposicionais marinhos mais antigos, podendo auxiliar em reconstruções paleoambientais e paleobatimétricas mais precisas da Bacia do Espírito Santo.

Palavras-chave: foraminíferos bentônicos, mar profundo, fluxo de matéria orgânica, talude, margem continental brasileira.

ABSTRACT

The heterogeneity of the seafloor at the Brazilian Continental Margin may result in differences in the benthic foraminiferal assemblages composition. To understand the main environmental factors controlling the benthic foraminiferal distribution on the continental slopes, and corroborate paleoenvironmental interpretations in the Late Holocene, the benthic foraminiferal assemblages (total fauna > 63 µm) and sedimentological data were investigated along six transects on the continental slope, and within two submarine canyons of the Espírito Santo Basin (ESB, 18°20' and 21°20' S). Surface sediment samples (0-2 cm) were collected perpendicularly to the coast, from the upper (400 m) to the lower slope (3000 m). Inside the Watu Norte (CANWN) and Doce (CAND) canyons, samples were collected from the canyon head to the middle-lower canyon (150 to 1300 m). The density, taxonomic diversity, and assemblage composition change with depth and between the canyons. The differences in ecological preferences among the most abundant taxa allowed the recognition of distinct benthic foraminiferal groups, distributed in five main bathymetric sectors: outer shelf (50m), upper (150-400 m), middle – lower (1000-1300 m), lower slope (1900 m), and deepest lower slope (2500-3000 m). In addition, two different groups were recognized, revealing differences between individual submarine canyons assemblages. The quantity and quality of food supply is the primary factor controlling the distribution of benthic foraminiferal assemblages along depth. Secondary factors include the properties of water masses, intermediate and deep boundary currents, sediment type and grain size. The increased fragmentation of benthic and planktic foraminifera tests (>125 µm) is related to abrasion during transport from shallower regions to the slope. The middle-lower CANNW indicated unstable trophic conditions, related to terrigenous sediment influx due to turbidity currents. In the CAND, foraminiferal assemblages ecology indicated enough organic matter content that benefits species establishment and diversity, revealing an environment more productive and less unstable than the CANWN. The data obtained in this study could be used as analogues in the interpretation of older marine depositional systems, helping to generate more accurate paleoenvironmental and paleobathymetric models of the Espírito Santo Basin.

Key words: benthic foraminifera, deep sea, organic matter flux, continental slope, Brazilian margin.

LISTA DE ABREVIAÇÕES

Abrolhos Eddy (AE)
Água Central do Atlântico Sul (ACAS)
Água Circumpolar Inferior (ACI)
Água Circumpolar Superior (ACS)
Água Intermediária Antártica (AIA)
Água Profunda do Atlântico Norte (APAN)
Água Tropical (AT)
Projeto de Caracterização Regional da Bacia do Espírito Santo e Porção Norte da Bacia de Campos (PCR-ES/AMBES/PETROBRAS)
Antarctic Intermediate Water (AAIW)
Área de Proteção Ambiental Costa das Algas (APA-CA)
Bacia do Espírito Santo (BES)
Brazil Current (BC)
Cadeia Vitória-Trindade (CVT)
Cânion Doce (CAND)
Cânion Watu Norte (CANWN)
Circumpolar Water (CPW)
Corrente de Contorno Intermediária (CCI)
Corrente de Contorno Profunda (CCP)
Corrente do Brasil (CB)
Deep Western Boundary Current (DWBC)
Doce Canyon (CAND)
Embaiamento de Tubarão (ET)
Espírito Santo Basin (ESB)
Intermediate Western Boundary Current (IWBC)
Lower Circumpolar Water (LCPW)
North Atlantic Deep Water (NADW)
Northern Campos Basin (NCB)
Porção Norte da Bacia de Campos (PNBC)
South Atlantic Central Water (SACW)
Tropical Water (TW)
Tubarão Bight (TB)
Upper Circumpolar Water (UCPW)
Vitória Eddy (VE)
Vitória-Trindade Ridge (VTR)
Vórtice de Abrolhos (VAb)
Vórtice de Vitória (VV)
Watu Norte Canyon (CANWN)

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1.1 INTRODUÇÃO

Os foraminíferos constituem o grupo mais diversificado de organismos unicelulares que são revestidos por uma carapaça (testa) nos oceanos atuais (Sen Gupta, 1999), sendo considerados um dos principais componentes da comunidade bentônica, correspondendo a cerca de 50% da biomassa oceânica (Gooday, 1994). Esses microrganismos sofreram radiação adaptativa, e por isso são amplamente distribuídos por todos os ambientes marinhos, desde as regiões costeiras até a planície abissal (Armstrong e Brasier, 2005).

A existência de uma carapaça resistente, com alto potencial de preservação no sedimento durante o processo de fossilização, e a significativa densidade numérica em diversos sedimentos marinhos, faz com que os foraminíferos sejam considerados excelentes indicadores ambientais em estudos de oceanografia geológica (Sen Gupta, 1999; Murray, 2006). Os fósseis desses microrganismos (microfósseis) são encontrados desde o Cambriano Inferior até o Recente (Holoceno), sendo mais abundantes a partir do Cenozóico (van Morkoven, 1986). A grande maioria dos foraminíferos do Quaternário tem hábito de vida bentônico (> 10.000 espécies), enquanto os planctônicos apresentam cerca de 40 a 50 espécies (Sen Gupta, 1999).

Os primeiros trabalhos publicados utilizando esses microfósseis tinham como principal objetivo a divulgação de uma classificação taxonômica bem detalhada (Cushman, 1927; 1928; 1933, e outros; Loeblich e Tappan, 1988; 1994; Boersma, 1984; van Morkoven, 1986). Com o passar dos anos e com os avanços nas pesquisas exploratórias da indústria petrolífera, os foraminíferos bentônicos assumiram sua importância em estudos bioestratigráficos e paleoecológicos (Boersma, 1977; Tjalsma, 1983; Tjalsma e Lohmann, 1983; Müller-Merz e Oberhänsli, 1991; Bolli et al., 1994), e informações mais precisas sobre os parâmetros ambientais que controlam a distribuição desses organismos passaram a ser mais investigados. A partir da segunda metade do século 20, estudos sobre a ecologia dos foraminíferos tornaram-se mais importantes e as pesquisas nesse campo aumentaram significativamente (Gooday, 1988; 1993; 1994; 1996; Gooday e Turley, 1990), principalmente devido à percepção de que a distribuição de foraminíferos recentes fornecem pistas confiáveis sobre o ambiente que habitam, funcionando como análogos para a compreensão das mudanças ambientais nos oceanos, em diferentes escalas geológicas de tempo (Sen Gupta, 1999).

De acordo com Murray (2006), os fatores que influenciam a distribuição dos foraminíferos podem ser abióticos (ex. temperatura, salinidade, disponibilidade de oxigênio dissolvido, pH, concentração de matéria orgânica, natureza do substrato) ou bióticos (ex. competição intra e inter-específica, predação, bioturbação). Sendo assim, os registros deixados por foraminíferos bentônicos têm sido utilizados para reconstruir uma vasta gama de parâmetros oceanográficos (Jorissen et al., 2007), incluindo a profundidade da coluna d'água (Boersma, 1977; Tjaslma e Lohman, 1983; Müller Merz e Oberhänsli, 1991; Hayward et al., 2004; Barbosa, 2010; Mello et al., 2016), as propriedades das massas d'água (Schnitker, 1974; 1980; Lohman, 1978; Peterson e Lohmann, 1982; Gonzales et al., 2017), o teor de oxigênio da água de fundo (Sen Gupta e Machain-Castillo, 1993; Kaiho, 1994; Bernhard e Sen Gupta, 1999; Venturelli et al., 2018), e a intensidade do fluxo orgânico nos oceanos (Smart et al., 1994; Jorissen et al. 1995; Altenbach et al., 1999; De Rijik et al., 2000; Fontanier et al., 2002, 2005; de Almeida et al., 2015; Rodrigues et al., 2018).

Os padrões de distribuição dos foraminíferos bentônicos geralmente são marcados por zonas que podem coincidir com o aumento da profundidade da coluna d'água, no entanto, a composição taxonômica dessas zonas varia de região para região em diferentes oceanos (Murray, 2006). O conhecimento desses padrões de distribuição, bem como os fatores bióticos e abióticos por eles responsáveis, são essenciais para reconstruções paleoambientais e análises de bacias sedimentares baseadas em foraminíferos fósseis (Hayward et al., 2004).

No oceano Atlântico Sul, a distribuição dos foraminíferos bentônicos recentes tem sido documentada por vários autores (Lohmann, 1978; Peterson e Lohmann, 1982; Mackensen et al., 1995; Fariduddin e Loubere, 1997; Schmiedl et al., 1997; Schmiedl e Mackensen, 1997; Altenbach et al., 1999; Alperin et al., 2011). Os estudos dos padrões de distribuição e as preferências ecológicas de foraminíferos bentônicos recentes realizados em diferentes bacias da margem continental brasileira são de fundamental importância, pois servem como base para estudos paleoecológicos, paleobatimétricos e paleoceanográficos no oceano Atlântico Sul. Entretanto, a grande maioria das pesquisas de foraminíferos bentônicos do Quaternário se concentram nas bacias marginais brasileiras das regiões sul e sudeste, com destaque para a Bacia de Campos (Sousa et al., 2006; 2017; Mello, 2006;

Nagai et al., 2009; 2010; Barbosa, 2002; 2010; Burone et al., 2011; Yamashita, 2011; 2015; Yamashita et al., 2018a; Dissaró et al., 2017; Dias et al., 2018), Bacia de Santos (Barbosa, 2002; Ferreira et al., 2014; de Almeida et al., 2015; Yamashita et al., 2020) e Bacia de Pelotas (Eichler et al., 2008; 2016; 2019; García-Chapori et al., 2014; Rodrigues et al., 2018; Schmitt et al., 2019). Muito pouco se conhece sobre os foraminíferos bentônicos recentes da Bacia do Espírito Santo (Lisboa, 2006; D'Agostini et al., 2019), sendo que não existem trabalhos publicados que abordem a distribuição dessa microfauna ao longo de um gradiente de profundidade.

A Bacia do Espírito Santo (BES) apresenta um diferencial em relação as demais bacias marginais brasileiras por possuir uma plataforma continental caracterizada por uma variação significativa em sua extensão lateral e diferentes regimes de sedimentação (Bastos et al., 2015). Além disso, a morfologia do talude continental dessa bacia é considerada complexa por apresentar cânions, canais e ravinas construídos ao longo do tempo geológico em resposta às variações relativas de nível do mar, remobilização de sedimentos, sistemas turbidíticos associados a sistemas fluviais, e a tectônica salífera (Schreiner et al., 2008; 2009). Devido as suas particularidades, torna-se imprescindível reconhecer os principais fatores que influenciam os padrões de distribuição de foraminíferos bentônicos recentes na BES, bem como investigar se esses parâmetros estão relacionados à profundidade ao longo do talude continental. Quanto mais conhecida essa distribuição, maior a acurácia dos modelos deposicionais. Esses dados poderão proporcionar uma analogia com sistemas deposicionais marinhos mais antigos, podendo auxiliar em reconstruções paleoambientais e paleobatimétricas mais precisas, num contexto da evolução sedimentar da Bacia do Espírito Santo e do atual sistema fluvial associado Rio Doce.

1.2 OBJETIVOS DA TESE

O objetivo geral desse estudo é investigar a relação entre a distribuição das associações de foraminíferos bentônicos recentes e as características morfológicas, sedimentológicas e oceanográficas atuais da Bacia do Espírito Santo, onde o padrão transgressivo atinge o nível relativo de mar alto, bem como compreender quais são os principais fatores ambientais que influenciam essa distribuição. Para atingir o objetivo principal, esse estudo foi compartimentado em três objetivos específicos:

- Analisar as diferenças entre as associações de foraminíferos bentônicos encontradas ao longo de um gradiente de profundidade no talude continental, e verificar se ocorre uma variação lateral na composição dessas associações.
- Analisar os padrões de distribuição das associações de foraminíferos bentônicos nos cânions submarinos Doce e Watu Norte.
- Buscar a relação entre a a distribuição das associações de foraminíferos bentônicos nos cânions e os transectos adjacentes, verificando a influência do padrão de sedimentação no compartilhamento das associações de foraminíferos bentônicos.

1.3 ESTRUTURA DA TESE

O presente estudo apresenta os capítulos principais de forma independente, onde cada capítulo possui sua própria metodologia e base de dados. Dessa forma, a Tese consiste em três capítulos e três subcapítulos. Os subcapítulos 2.1 e 2.2 são apresentados no formato de artigos científicos, seguindo as normas da revista onde foram submetidos e/ou publicados.

O **Capítulo 1** trata-se da introdução ao tema abordado pela tese, com apresentação dos objetivos gerais e específicos, e a estrutura da tese.

O **Capítulo 2** está dividido em três subcapítulos. O **subcapítulo 2.1** aborda a distribuição batimétrica das associações foraminíferos bentônicos no talude continental (400 m a 3.000 m) da Bacia do Espírito Santo e Parte Norte da Bacia de Campos, onde é realizada uma integração entre os dados da microfauna e dados de sedimentologia (provenientes do Projeto AMBES), associados aos possíveis mecanismos oceanográficos que influenciam na distribuição dos foraminíferos ao longo de um gradiente batimétrico. O **subcapítulo 2.1** resultou no **primeiro artigo científico da tese**, que foi publicado on-line em 13 de janeiro de 2022, e na edição de março de 2022 no periódico *Deep-Sea Research: Part I (v.181, 103688)* sob o título: *"Bathymetric and regional benthic foraminiferal distribution on the Espírito Santo Basin slope, Brazil (SW Atlantic)."* O documento que comprova a publicação desse artigo pode ser visualizado no **Anexo A**, juntamente com o material suplementar publicado.

O **subcapítulo 2.2** aborda a distribuição de foraminíferos bentônicos ao longo dos Cânions Watu Norte (CANWN) e Doce (CAND), e seus respectivos transectos adjacentes, desde a plataforma externa até o talude médio-inferior (50 m a 1.300 m de profundidade). Os dados da microfauna também estão integrados aos de sedimentologia e oceanografia atuante na Bacia do Espírito Santo, com a finalidade de reconhecer como os cânions submarinos influenciam no padrão de distribuição dos foraminíferos bentônicos no talude. A análise integrada de dados dos ambientes plataforma externa – cânion – talude possibilita a compreensão da dinâmica de distribuição da microfauna e a interação entre esses ambientes no Holoceno tardio. O **subcapítulo 2.2** representa o **segundo artigo científico da tese**, que foi submetido no periódico *Marine Micropaleontology* em 13 novembro de 2022 sob o título provisório *"Submarine canyons influence in the recent benthic foraminiferal assemblages, Espírito Santo Basin, Southeastern Brazil (SW Atlantic)."* O documento que comprova a submissão desse manuscrito encontra-se no **Anexo B**, juntamente com o material suplementar submetido.

No **subcapítulo 2.3** são ressaltadas algumas das principais semelhanças e diferenças observadas no padrão de distribuição das associações de foraminíferos bentônicos do talude da BES em relação a padrões previamente analisados e publicados nos taludes das bacias de Campos e Santos.

O **Capítulo 3** apresenta as principais conclusões obtidas na tese, destacando os principais fatores ambientais que influenciam a distribuição dos foraminíferos bentônicos recentes na configuração plataforma externa – cânion – talude da Bacia do Espírito Santo. Além disso, sugere a necessidade de estudos futuros.

A autora ressalta que, em virtude de os capítulos serem relativamente independentes, inevitavelmente algumas informações poderão estar presentes em mais de um capítulo.

CAPÍTULO 2. DISTRIBUIÇÃO DE FORAMINÍFEROS BENTÔNICOS NA BACIA DO ESPÍRITO SANTO

2.1 BATHYMETRIC AND REGIONAL BENTHIC FORAMINIFERAL DISTRIBUTION ON THE ESPÍRITO SANTO BASIN SLOPE, BRAZIL (SW ATLANTIC)

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ABSTRACT

To understand the main environmental factors controlling the benthic foraminiferal distribution along continental slopes, and corroborate paleoenvironmental interpretations, we investigated benthic foraminiferal assemblages (total fauna > 63 µm) and sedimentological data along six transects on the continental slope of the Espírito Santo Basin (ESB) between 18°20' and 21°20' S. Surface sediment samples (0-2 cm) were collected perpendicularly to the coast, from the upper (400 m) to the lower slope (3000 m). The density, taxonomic diversity and assemblage composition change with depth. The genus *Globocassidulina* dominates the upper and lower slope, whereas *Bolivina* is the most abundant taxon in the deepest lower slope. The differences in ecological preferences among the most abundant taxa allowed us to recognize five benthic foraminiferal groups, distributed in three main bathymetric sectors: upper, middle – lower, and lower slope. Group I (upper slope, 400 m) is characterized by the highest mean relative abundances of *Globocassidulina rossensis*, *Trifarina* spp. and *Trifarina angulosa*. Group II (middle – lower slope, 1000 to 1300 m) shows the highest mean relative abundances of *Globocassidulina subglobosa*, *Bolivina albatrossi*, *Bulimina aculeata* and *Uvigerina peregrina*. Group III (middle – lower slope, 1000 to 1300 m) is characterized by the highest mean relative abundances of *Globocassidulina crassa*, *Gavelinopsis versiformis*, *Epistominella exigua* and the unilocular group. Group IV (lower slope, 1900 m) shows the highest mean relative abundances of *Alabaminella weddellensis*, *Bolivina inflata* and *E. exigua*. Group V (lower slope, 2500 – 3000 m) is dominated by the genus *Bolivina* (*B. lowmani*, *B. pseudoplicata* and *Bolivina* spp). The most abundant taxa along the ESB slope are ecologically associated to the organic matter flux, bottom water oxygen concentration, and hydrodynamics conditions. The quantity and quality of food supply is the primary factor controlling the distribution of benthic foraminiferal assemblages along depth. Secondary factors include the properties of water masses, and intermediate and deep boundary currents. The increased fragmentation of benthic and planktic foraminifera tests (>125 µm) on the upper and middle – lower slope is related to abrasion during transport from shallower regions to the slope.

Key-words: benthic foraminifera, deep sea, organic matter flux, continental slope, Brazilian margin.

1. INTRODUCTION

The distribution of recent benthic foraminiferal assemblages provides reliable information about organic matter flux (Jorissen et al., 1995; Altenbach et al., 1999; De Rijk et al., 2000; Gooday, 2002), bottom water oxygenation (Kaiho, 1994; Bernhard and Sen Gupta, 1999; Kaminski, 2012), and hydrodynamic conditions (Lohmann, 1978; Mackensen et al., 1995; Schmiedl et al., 1997), serving as analogues for understanding past environmental changes in the oceans (Sen Gupta, 1999). The environmental parameters that determine the distribution of deep-sea benthic foraminifera result from a complex interaction between physical and biological factors (Jorissen et al., 1995; 2007).

According to Mackensen et al. (1995), and Jorissen et al. (2007), the environmental parameters governing the distribution of benthic foraminiferal assemblages in the South Atlantic Ocean are: (i) the amount of organic matter exported to the seafloor and the organic carbon content in the sediments; (ii) the hydrodynamic conditions of the bottom waters and the sediment grain size; (iii) the bottom water oxygen concentration; (iv) the carbonate saturation state of the bottom water.

It is increasingly evident that the quantity and quality of organic matter, along with bottom water oxygenation, are the essential factors that control the abundances and composition of benthic foraminifera (Gooday, 1988; 1993; 1996; 2002; Corliss and Chen, 1988; Corliss, 1991; Fariduddin and Loubere, 1997; Schmiedl and Mackensen, 1997; Altenbach et al., 1999; Fontanier et al., 2002, 2005; Kaminski, 2012; Enge et al., 2014). The trophic oxygen model (TROX), proposed by Jorissen et al. (1995), predicts that the depth of foraminiferal microhabitats results from a combination of oxygen penetration and food availability in the sediment. Therefore, in oligotrophic and well-oxygenated environments, benthic foraminifera distributions are mainly restricted to the sediment surface and assemblages consist largely of epifaunal species. On the other hand, in eutrophic and dysoxic environments, the foraminiferal assemblage is mainly dominated by infaunal taxa. In oligotrophic regions, very little labile organic matter reaches the seafloor and, when it does, it is rapidly consumed at the sediment-water interface (Carney, 1989), promoting a rapid population increase in opportunistic benthic foraminiferal species (Fontanier et al., 2003; 2006).

The benthic foraminiferal distribution patterns are generally zoned, with increasing water depth (Mackensen et al., 1985; Hayward et al., 2002; 2013). Because the taxonomic composition of these zones varies from region to region, they are applicable with accuracy only on a local scale (Murray, 2006). The knowledge of these distribution patterns, as well as the environmental factors and oceanographic mechanisms responsible for such distribution, are essential for paleoenvironmental and paleoceanographic reconstructions, and for the analyzes of sedimentary basins based on fossil foraminifera (Hayward et al., 2004; Mello et al., 2016).

In the Southwest Atlantic, the distribution of recent deep-sea benthic foraminifera has been documented (Lohmann, 1978; Mackensen et al., 1995; Fariduddin and Loubere, 1997). In the Brazilian Continental Margin, the environmental parameters that influence the distribution of benthic foraminiferal assemblages on the slope have been observed using living and total fauna data. The majority of these studies focus on the Campos Basin (Sousa et al., 2006; 2017; Mello, 2006; Nagai et al., 2009; 2010; Barbosa, 2010; Burone et al., 2011; Yamashita et al., 2016; 2018a; 2018b), the Santos Basin (Barbosa, 2002; Ferreira et al., 2014; de Almeida et al., 2015; Gonzales et al., 2017; Yamashita et al., 2016) and the Pelotas Basin (García-Chapori et al., 2014; Rodrigues et al., 2018; Schmitt et al., 2019).

The Espírito Santo Basin (ESB) is an oligotrophic, and geomorphologically diverse basin (Viana et al., 1998; Gaeta and Brandini, 2006). The shelf-slope system in the ESB differs from that of the other Brazilian basins because of a significant variation in the continental shelf width, shifts in sedimentation regimes, changes of the shelf-break orientation (Bastos et al., 2015), and the presence of complex morphological structures on the slope, built in response to relative sea level fluctuations over geological time (Schreiner et al., 2008; 2009). In addition, like the other Brazilian marginal basins, the ESB is considered a region economically important for the oil and fishing industries.

The distribution of recent benthic foraminifera on the continental slope of the ESB remains poorly documented (Lisboa, 2006; D'Agostini et al., 2019). An improved knowledge of the distribution of recent benthic foraminifera in the ESB would provide a basis for paleoceanographic models in the South Atlantic Ocean, especially in the western portion, where paleoceanographic records are particularly scarce. The main goal of this study is to investigate the distribution of recent benthic foraminifera assemblages along depth gradients on the ESB slope, and to unravel the environmental factors that control the microfauna distribution. Because of the high environmental heterogeneity of this basin, we expect to find marked spatial differences among the benthic foraminifera assemblages. The results obtained in this study will contribute to refine paleoenvironmental and paleobathymetric reconstructions in the study area.

2.MATERIALS AND METHODS

2.1 Study area

The ESB is located on the southeastern Brazilian continental margin, between 18°20' and 21°20' S (Figure 1), bordered by the Campos Basin (RJ) to the south, by the Abrolhos Shelf to the north (França and Tokutake, 2004; França et al., 2007), and by the linear sequence of seamounts of the Vitória-Trindade Ridge (VTR) to the east (Motoki et al., 2012).

The shelf width and shelf-break in the ESB vary locally (Bastos et al., 2015). The Abrolhos Shelf, a volcanic complex formed during Paleogene, contributes to the particular ESB physiography, characterized by a wide shelf (> 240 km) to the north of the Doce River (Sobreira and França, 2006), which discharges terrigenous sediments over the shelf (Quaresma et al., 2015; Oliveira and Quaresma, 2017). The shelf morphology was shaped by several Quaternary changes in relative sea level, which controlled sediment distribution (Bastos et al., 2015). The sedimentation is essentially mixed (coeval carbonate and terrigenous deposition), with rhodolith beds located along the outer shelf Bastos et al., 2015; D'Agostini et al., 2015, 2019; Bourguignon et al., 2018; Vieira et al., 2019; Oliveira et al., 2020).

The present-day bottom morphology of the slopes of the ESB and northern Campos Basin (NCB) results from several processes, such as sea level variations, remobilization of bottom sediments through gravity flow, influence of boundary currents, and emplacement of turbiditic systems associated with river discharge, and salt tectonics (Schreiner et al. 2008; 2009). A dense submarine drainage system indents the ESB slope, including the Doce, Watu Norte, and Watu Sul canyons, with their associated turbiditic systems (Schreiner et al., 2009). During the Holocene, the sea level rise interrupted almost all of these deposition processes (Vicalvi and Kowsmann, 2006). The morphological features on the ESB slope can be considered as fossil, inherited from the Upper Pleistocene. A Holocene sediment drape covers the entire seafloor. The Holocene sedimentation rates are relatively low, ranging from ≤ 2.5 to 6 cm kyr $^{-1}$ (Schreiner and Hercos, 2015).

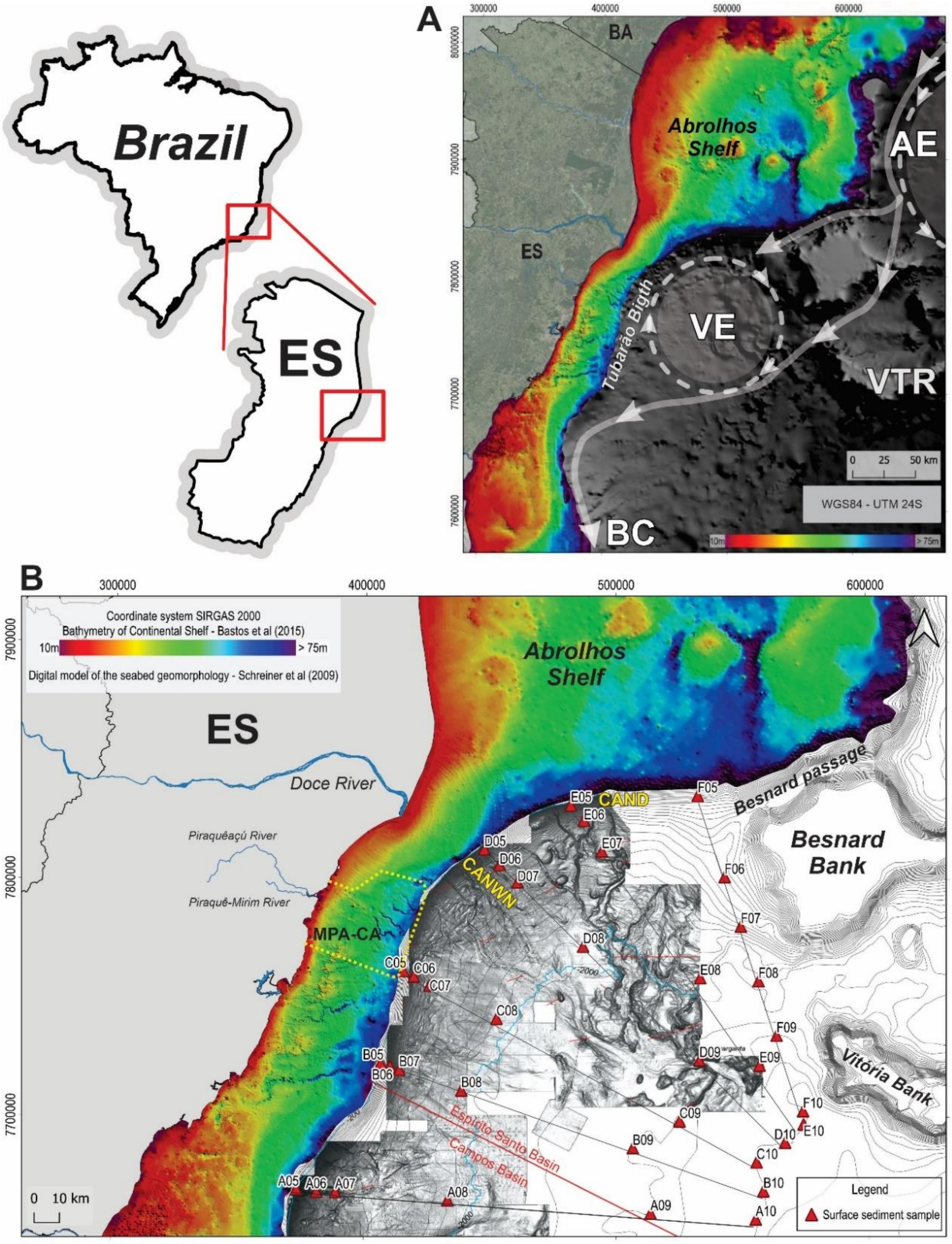

Figure 1: *(A) Schematic surface circulation of the Brazil Current (BC), Abrolhos Eddy (AE), Vitória Eddy (VE) and (B) map of samples distributed on Espírito Santo (Transects B to F) and Campos Basins (transect A). A-F indicate sampling transects and numbers indicate isobaths sampled: 05 (400 m), 06 (1000 m), 07 (1300 m), 08 (1900 m), 09 (2500 m) and 10 (3000 m). The yellow dotted line indicates limits of the Marine Environmental Protection Area Costa das Algas (MPA-CA) (ICMBIO, 2020). Bathymetry of continental shelf adapted from Bastos et al. (2015). Digital model of the seabed geomorphology adapted from Schreiner et al. (2009).*

The complex topography of the study area influences the regional hydrodynamics, with an intricate flow pattern associated with surface and intermediate currents, their meanders and vortical features (Soutelino et al., 2011; 2013; Silveira et al., 2020). Surface waters of the ESB are dominated by the southward-flowing, warm, saline and nutrient-depleted Brazil Current (BC), which is the western boundary current associated with the anticyclonic South Atlantic Subtropical Gyre (Stramma et al., 1990; Stramma and England 1999; Campos et al., 2000). As the BC crosses the VTR, it usually loses bathymetric orientation, bifurcating or trifurcating along the channels to the west of the VTR and Abrolhos Shelf (Ghisolfi et al., 2015; Silveira et al., 2020), resulting in a discontinuous, eddy-dominated flow (Soutelino et al., 2011), which reattaches to the shelf-break at approximately 21°30' S (Arruda and Silveira, 2019).

In terms of primary productivity, the Brazilian Continental Margin has been considered typically oligotrophic (Gaeta and Brandini, 2006). However, episodic intrusions of cold, nutrient-rich South Atlantic Central Water (SACW) on the ESB continental shelf (Palóczy et al., 2016) causes surface waters enrichment, and consequently increases primary production (Martins, 2014), inducing a response of the benthic fauna assemblages (Bernardino et al., 2016). The quasi-stationary and recurrent eddies, such as the Abrolhos Eddy (AE) (Soutelino et al., 2011) and Vitória Eddy (VE) (Schmid et al., 1995), also play an important role in the nutrient enrichment of surface waters. The cyclonic VE (~20°30' S) is generally constrained by the ESB shelf to the west, by the Abrolhos Shelf to the north and by the Besnard Bank to the east (Arruda and Silveira, 2019), with an average radius ~ 50 km (Schmid et al., 1995). The VE was observed in previous studies (Schmid et al., 1995; Gaeta et al., 1999; Campos, 2006; Martins, 2014; Silveira et al., 2020). The anticyclonic AE (~ 19° S) moves southward and interacts with the VE in the vicinity of the ESB (Arruda et al., 2013). According to Gaeta et al. (1999), in the VE mixing layer, chlorophyll-a concentration and primary productivity are up to twice higher than in the surrounding oligotrophic waters. These results suggest that the pumping of nutrient-rich waters by the VE contributes significantly to the local increase in phytoplankton production (Martins, 2014).

The ESB slope is under the influence of four water masses and their distinct current flows directions: (i) South Atlantic Central Water (SACW), flowing southward and transported by the BC, between 200 and 600 m depth; (ii) Antarctic Intermediate Water (AAIW), flowing northward and transported by the Intermediate Western Boundary Current

(IWBC) between 600 and 1300 m depth; (iii) North Atlantic Deep Water (NADW) flowing southward and transported by the Deep Western Boundary Current (DWBC) between 1300 and 3000 m (Stramma e England, 1999; Silveira et al., 2000; 2015; 2020). The Circumpolar water (CPW) contains less oxygen, and has a density comparable to that of the NADW flowing southward. As a result, NADW splits the CPW into an upper (UCPW) and a lower (LCPW) branch (Johnson, 1983; Mérmery et al., 2000). Recent studies suggest that the IWBC develops a strong cyclonic recirculation in the ESB, topographically induced at intermediate depth (Costa et al., 2016; Napolitano et al., 2019).

2.2 Sampling strategy

Surface (0-2 cm) sediment samples were obtained from the archive of the Espírito Santo Basin Assessment Project (AMBES, CENPES/PETROBRAS), that includes samples collected in the ESB and NCB basins in the period 2008 – 2014. Our investigation is based on the analyses of 36 sediment samples collected with a box-corer during an oceanographic cruise in winter 2013, which only allowed a total microfauna census study based on recent benthic foraminifera. Samples are evenly distributed in six transects in the NCB (transect A) and ESB (transect B-F) at water depths of 400, 1000, 1300, 1900, 2500 and 3000 m (Figure 1).

2.3 Sedimentological data

The sedimentological data set used in this study is a compilation by Maia et al. (2015) that include sediment grain size, calcium carbonate ($CaCO_3$) and total organic matter content (TOM). Because these authors performed analyzes in replicates, we chose to use the median values of the parameters measured in each sample. The gravel and sand fractions were quantified by standard wet sieving, whereas the mud fraction was quantified through pipetting (Suguio, 1973; Dias, 2004). The $CaCO_3$ content (%$CaCO_3$) was determined by mass loss after dissolution in HCl (10%), using a modified Bernard Calcimeter (Soares, 2017). The TOM content (%TOM) was determined after combustion at 450 °C, by mass difference between dry and ash free dry sediment samples.

2.4 Foraminiferal analysis

In the laboratory of CENPES/PETROBRAS, samples for foraminiferal study were dried at 60°C. For each sample, aliquots of 20g dry sediment were gently washed through a 63 µm sieve to remove mud. The sand residue was dried, weighed and microsplit to obtain at least 300 specimens of benthic foraminifera per sample. All benthic foraminifera were picked from the split, mounted on faunal slides, identified, and included in the assemblage counts. Specimens were identified following the classification and taxonomy based on Boltovskoy et al. (1980), Loeblich and Tappan (1988; 1994), Boersma (1984), van Morkhoven et al. (1986), Bolli et al. (1994), Jones (1994), Kaminski and Gradstein (2005), and Houlborn (2013). The genera *Fissurina*, *Lagena*, *Oolina* and *Parafissurina* were placed into a single group, herewith referred to as unilocular, because of its large number of species (Patterson and Richardson, 1987).

The number of planktic (whole and broken) and broken benthic foraminiferal tests were determined during the picking of benthic specimens in the > 125 µm size fraction. This size fraction was assumed to include the majority of adult specimens for each planktic foraminiferal species (Peeters et al., 1999). The planktic foraminiferal fauna was used to calculate the Benthic/Planktic (B/P) ratio, which allows a direct observation of increase or decrease of benthic foraminifera density with depth and food availability (Berger and Diester-Hass, 1988). To determine the benthic and planktic foraminiferal fragmentation, the numbers of whole (i.e., four or more chambers together) and broken benthic and planktic tests were counted and converted into percentage. In general, foraminiferal tests < 125 µm were well-preserved.

2.5 Statistical analysis

The benthic foraminifera density (density = total number of tests/gram dry sediment) was calculated for each sample, as well as the percentage of agglutinated, porcelaneous and hyaline tests. The microhabitat preference (epifaunal *versus* infaunal) was based on the morphotypes of the tests as proposed by Corliss (1985), Corliss and Chen (1988), and Kaminski et al. (1995). Species diversity was expressed in two ways, considering the species richness (S) and the Simpson's index (D). The Simpson’s index (Eq. (1)) is weighted by the abundances of the commonest species.

$$D = \sum n_i \, (n_i - 1)/N \, (N - 1) \qquad (1)$$

where n_i = the number of individuals in the ith species; and N = the total number of individuals. The Simpson’s index is usually expressed as (1-D) (Magurran, 2004), and was calculated using the software PAST 2.17c (Hammer et al., 2001).

The relative abundance of species that contribute for 84% to the total population (relative abundances > 1% in at least two samples) was analyzed through Q-mode cluster analysis to define benthic foraminiferal assemblages. The Bray-Curtis distance was used to measure the proximity between samples, and the Ward's Method was used to arrange samples into a hierarchical dendrogram. The distance matrix, generated by foraminifera data, was coordinated by non-metric multidimensional scaling (NMDS) (Gotelli and Ellison, 2011) to emphasize the geometrical aspects of similarity and to enable visualization of complex data in a graphical environment. These multivariate analyzes were performed using the PRIMER v.5 (Clarke and Warwick, 1994) and STATISTICA v.7 (Statsoft, 2001) software packages.

3. RESULTS

3.1 Sediments properties: grain size, calcium carbonate and organic matter content

In general, the sediments from the slope are predominantly composed of mud. However, high sand fraction contents (> 30%) are observed on the lower slope (2500 to 3000 m) and along transect F (400 to 1300 m). The gravel content represents less than 0.1% of bottom sediments (Figure 2).

The $CaCO_3$ in surface sediments is generally > 50%, but it increases with depth, mostly on the lower slope (1900 m to 3000 m). Likewise, high $\%CaCO_3$ are observed along transect F and on the upper slope (B05 and C05). TOM values range from 5 to 21%, and are generally lowest in sandy sediments. TOM values above the average (12%) are more frequent on the middle and lower slope (1000 to 1900 m) (Figure 2).

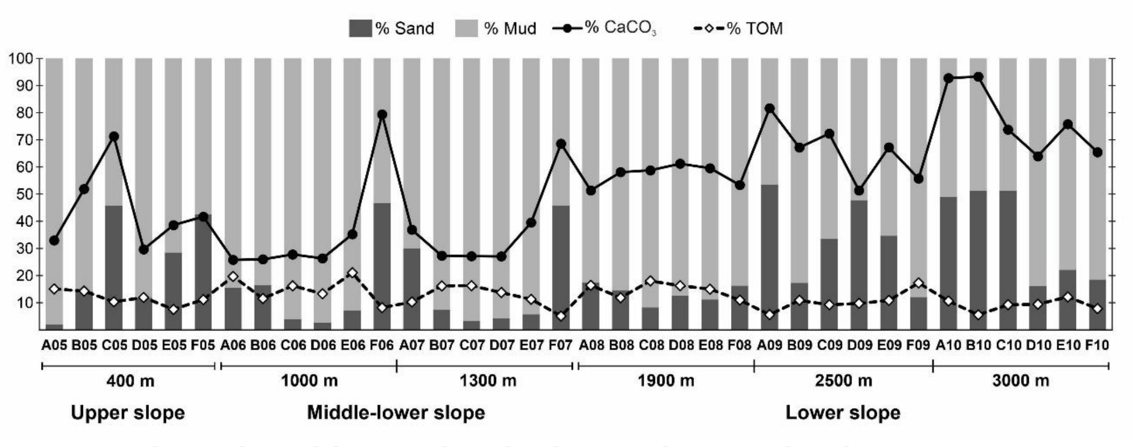

Figure 2: *Sedimentological data (sand, mud, calcium carbonate and total organic matter content) on the ESB slope. Values expressed in percentage.*

3.2 Benthic foraminiferal distribution: abundance, composition and diversity

The density varies between 194 and 28344 tests/g, with a median value of 13435 tests/g on the upper slope (400 m) and a marked decrease with depth (Figure 3). In terms of diversity indexes, richness presents on average 62 species per sample, generally exhibiting high values on the middle – lower slope (1000 to 1300 m). The Simpson's index indicates high species diversity (> 0.85) on the medium (1000 m) and lower slope (1900 to 3000 m) (Figure 3).

The hyaline taxa are dominant (mean 93%) on the slope, followed by the porcelaneous, that are more abundant (mean 5%) on the upper (400 m) and lower slope (1900 and 2500 m). Agglutinated taxa are relatively uncommon (mean 2%), but in general their abundance is high on the middle (1000 to 1300 m) and lower slope (1900 m) (Figure 3). As for microhabitat preference, benthic assemblages include a heterogeneous mixture of shallow infaunal and epifaunal morphogroups (Supplementary Table 1). The infaunal morphogroup dominates (mean 81%) over the epifaunal throughout the ESB (Figure 3). The epifaunal morphogroup reaches values > 20% on the lower slope (1900 to 3000 m). Agglutinated tubular taxa with sessile microhabitat were not taken into account in the infauna vs. epifauna ratio, as a single live individual can break into numerous fragments and thereby bias the specimen counts (Bubik, 2019).

The decrease in B/P ratio (>125 µm) towards the middle and lower slope is remarkable (Figure 3). The highest B/P ratios are observed on the upper slope (400 m), with a slight increase on the middle slope (1000 m). Consequently, the percentage of planktic foraminifera increases with depth.

In terms of tests preservation, the fragmentation of both benthic (mean 22%) and planktic (mean 10%) foraminifera generally shows values above their respective means both on the upper and middle – lower slope (400 to 1300 m). At 3000 m depth, only the percentage of fragmented benthic tests increases again (Figure 4).

Forty-seven species have relative abundance higher than 1% in at least two samples, accounting for 84% of the total population (Supplementary Table 2). The genus *Globocassidulina* dominates on the upper, middle and lower slopes (400 to 1900 m), whereas *Bolivina* is the most abundant taxa on the deepest lower slope (2500 to 3000 m). The relative abundances of *Trifarina* spp., *Trifarina angulosa*, *Gavelinopsis versiformis*, *Epistominella exigua*, *Alabaminella weddellensis* and *Discorbis vilardeboanus* vary along the ESB slope, though these species are more abundant and frequent at certain water depths (Figure 5).

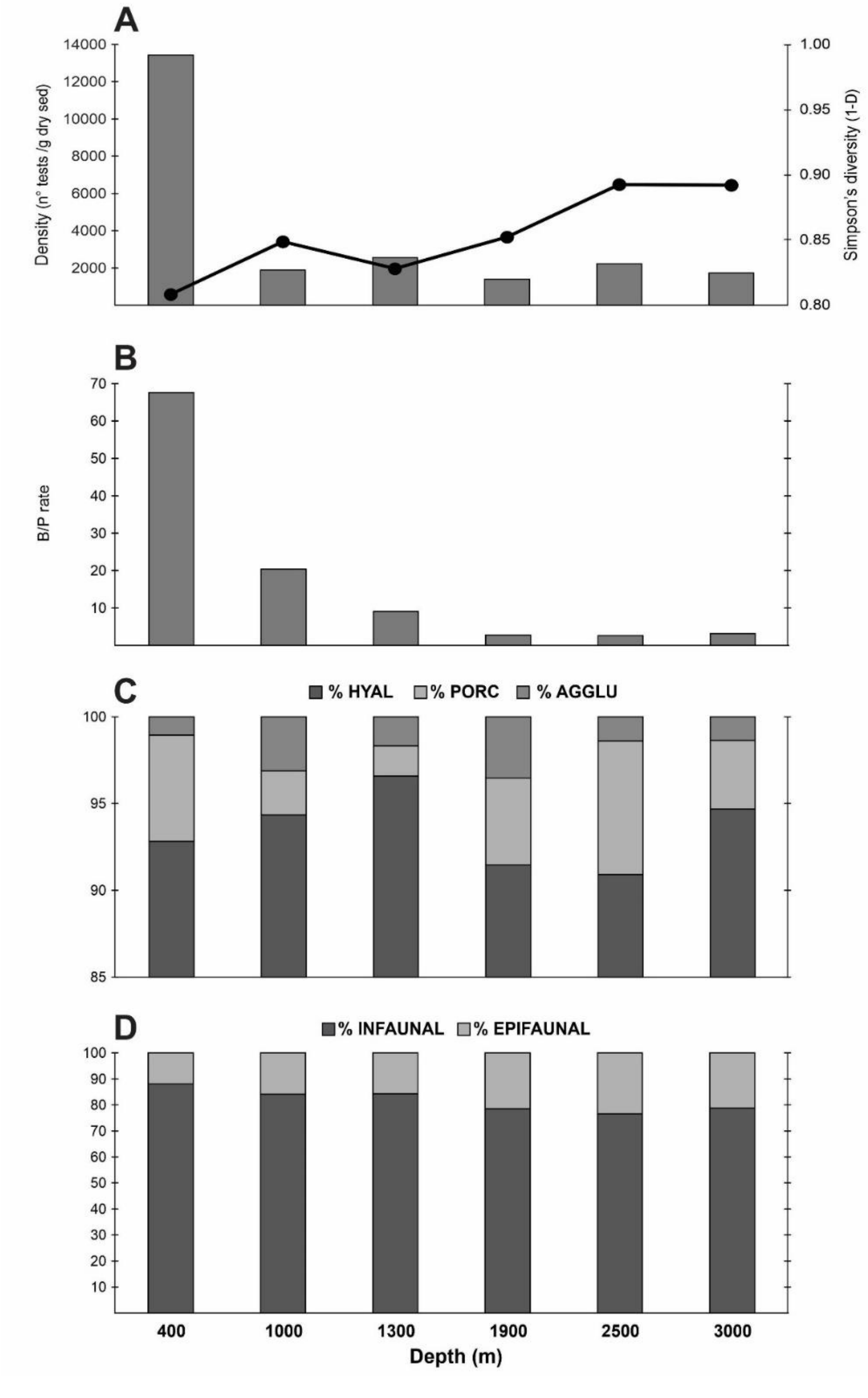

Figure 3: *Mean values of (A) benthic foraminifera density (n° tests/gram dry sediment) versus Simpson's diversity (1-D), (B) B/P ratio (> 125 µm), (C) proportion of hyaline (HYAL), porcelaneous (PORC) and agglutinated (AGGLU) tests, and (D) proportion of epifaunal and infaunal in the analyzed isobaths on the ESB slope. Values expressed in percentage.*

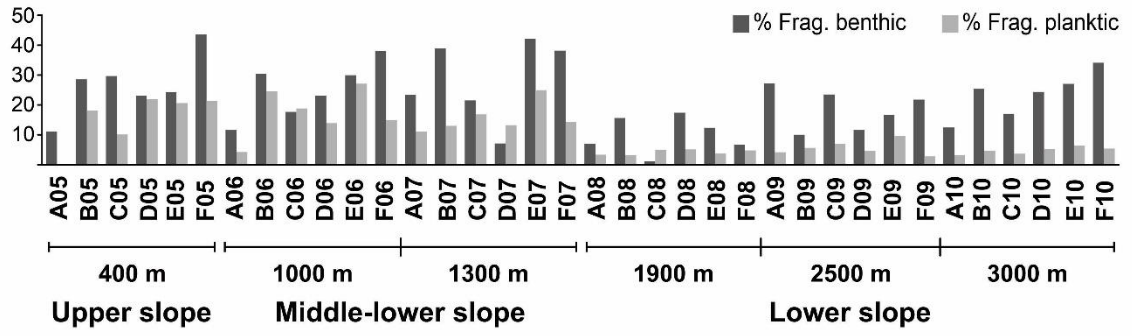

Figure 4: *The benthic and planktic foraminiferal fragmentation (> 125 µm) on the ESB slope. Values expressed in percentage.*

3.3 Benthic foraminiferal assemblages

The dendrogram obtained with Q-mode cluster analysis allowed us to identify five major groups (I, II, III, IV and V) which represent five benthic foraminiferal assemblages distributed on the ESB and NCB (Figure 6). These groups are clearly distinct along bathymetric gradients on the slope. Each group consists of two or more samples that are clustered because of the similarity of their microfaunal content. In order to improve the understanding of the assemblages composition, the mean relative abundances of species in each group were examined, as well as the biological and sedimentological parameters (Table 1). The NMDS analyses performed using microfaunal data proved to be very useful to recognize which environmental parameters are more related to each group (Figures 7 and 8).

Group I includes samples from the upper slope (400 m) and is characterized by the highest mean relative abundances of *Globocassidulina rossensis* (29%), *Trifarina* spp. (4%) and *Trifarina angulosa* (3%). This group is also characterized by an increase in benthic foraminifera density and, consequently, by the highest B/P ratios (mean 68%). A high percentage of porcelaneous (mean 6%) and infaunal taxa (mean 88%) are also observed. The lowest species richness and Simpson`s diversity values indicate high dominance. However, sample C05 shows high diversity and an increase in the relative abundances of the macroforaminiferal species *Amphistegina lessoni* and *Archaias angulatus* (>500 µm). These species show a high degree of fragmentation, indicating transport of tests from shallower settings to the upper slope. The predominantly muddy sediment presents low mean values of %$CaCO_3$ (44%) and TOM content (12%).

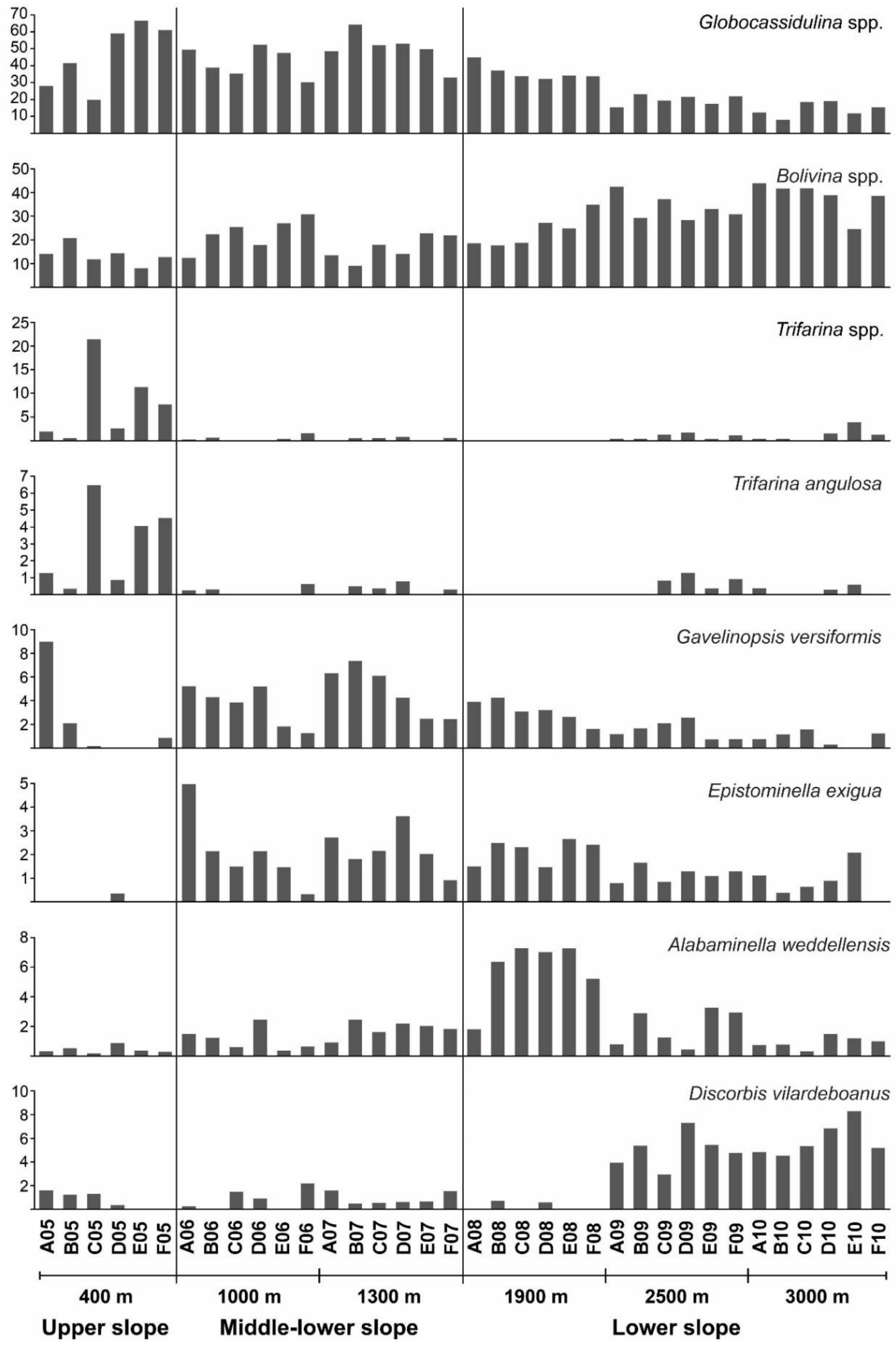

Figure 5: *The relative abundances of the main benthic foraminiferal genus and species distributed on the ESB slope.*

Table 1: *Comparison of mean relative abundance values (%) of the main species, sedimentological and biological data for each group. The highest mean values found in each group are emphasized in bold and underlined.*

	Group I	Group II	Group III	Group IV	Group V
Depth (m)	400	1000-1300	1000-1300	1900	2500-3000
Globocassidulina rossensis	**29.3**	10.7	20.5	24.4	8.2
Globocassidulina crassa	11.0	13.0	**26.2**	9.7	5.7
Bolivina lowmani	5.4	14.8	11.0	14.8	**19.2**
Globocassidulina subglobosa	5.4	**6.6**	1.7	1.4	2.7
Bolivina pseudoplicata	0.6	4.2	0.6	0.9	**9.4**
Bolivina spp.	2.6	1.6	2.4	3.8	**4.2**
Gavelinopsis versiformis	2.0	1.8	**4.7**	3.1	1.2
Unilocular group	1.1	3.1	**3.4**	2.2	1.7
Alabaminella weddellensis	0.4	1.2	1.5	**5.8**	1.4
Discorbis vilardeboanus	0.7	1.9	0.7	0.2	**5.4**
Bolivina inflata	1.2	0.9	1.1	**3.0**	2.3
Epistominella exigua	0.1	0.6	**2.5**	2.1	1.0
Sigmavirgulina tortuosa	0.5	1.1	0.2	0.1	**4.4**
Paracassidulina nipponensis	1.6	0.6	**1.8**	1.4	0.5
Cassidulina curvata	1.7	0.8	0.1	0.0	**2.9**
Bolivina ordinaria	**2.0**	1.4	1.3	0.5	0.4
Trifarina spp.	**4.5**	...	0.1	...	0.0
Trifarina angulosa	**2.9**	0.5	0.2	...	0.4
Nonionoides grateloupii	0.7	...	**1.6**	1.3	0.3
Bolivina albatrossi	0.0	**3.1**	0.8	...	0.0
Bulimina aculeata	0.3	**2.8**	0.0	0.1	0.2
Uvigerina peregrina	0.6	**1.5**	0.4	0.3	0.2
Discorbinella bertheloti	0.3	...	0.9	0.4	**1.3**
Nuttalides umbonifer	...	...	...	**1.9**	0.9
Seabrookia curta	**0.8**	...	0.6	0.8	0.4
Neoeponides antillarum	...	**1.7**	0.2	0.2	0.6
Bolivina fragilis	0.9	...	**1.0**	0.4	0.1
Sigmamiliolinella australis	**1.0**	...	...	0.1	0.2
Cymbaloporetta bradyi	0.1	...	...	...	**1.0**
Juvenile forms	8	7	4	8	**10**
Density (n° tests/ gram dry sediment)	**13435**	3083	2049	1394	1978
Species richness (S)	60	**82**	68	57	57
Simpson's diversity (1-D)	0.81	**0.91**	0.82	0.85	0.89
% Agglutinated	1	1	3	**4**	1
% Porcelaneous	**6**	**6**	1	5	6
% Hyaline	93	93	**96**	91	93
% Epifaunal	12	18	15	**22**	**22**
% Infaunal	**88**	82	85	78	78
B/P ratio (>125 µm)	**68**	9	16	3	3
% Planktic foraminifera (>125 µm)	32	91	84	**97**	**97**
% Frag. benthic foraminifera (>125 µm)	27	**38**	25	10	21
% Frag. planktic foraminifera (>125 µm)	15	15	**17**	4	5
% Sand	24	**46**	10	13	34
% Mud	76	54	**90**	87	66
% $CaCO_3$	44	**74**	30	57	72
% TOM	12	7	**15**	**15**	10

Group II consists only of samples F06 (1000 m) and F07 (1300 m), which are located to the south of the South Abrolhos Shelf and next to the Besnard Bank. This group differs from the others by showing the highest mean relative abundances of *Globocassidulina subglobosa* (7%), *Bolivina albatrossi* (3%), *Bulimina aculeata* (3%) and *Uvigerina peregrina* (2%). It also exhibits the highest values of richness (mean 82 species per sample) and diversity (mean 0.91). The high proportion of porcelaneous species (mean 6%) and fragmented benthic tests (mean 38%) suggest a high energy environment, with a significant transport of tests. Grain size analysis shows an increase in sand content (mean 46%), the highest mean values of %$CaCO_3$ (74%) and the lowest TOM content (7%).

Group III includes samples from the middle – lower slope (1000 to 1300 m) and is characterized by the highest mean relative abundances of *Globocassidulina crassa* (26%), *Gavelinopsis versiformis* (5%), *Epistominella exigua* (2%) and the unilocular group (3%). The mean values of richness and diversity are relatively low, when compared to the other groups. Moreover, the fragmentation values of planktic tests are high in samples E06 and E07, which are very close to the Doce Canyon. Group III presents the lowest mean values of %$CaCO_3$ (30%) and the highest TOM content (15%).

Group IV contains samples that encompass the lower slope (1900 m) and is characterized by the highest mean relative abundances of *Alabaminella weddellensis* (6%), *Bolivina inflata* (3%) and *Epistominella exigua* (2%). The increased abundance of small specimens of *Nuttalides umbonifer* is a peculiarity of this group. It is also characterized by high mean values of agglutinated (4%) and epifaunal (22%) taxa (mostly related to the abundances of *A. weddellensis* and *E. exigua*). There is also an increase in the quantity of planktic foraminifera and well-preserved tests. The muddy sediment shows an increase in TOM mean values (15%), while %$CaCO_3$ reaches 57%.

Group V includes samples from the deepest lower slope (2500 – 3000 m). This group differs from the other groups due to the dominance of the genus *Bolivina*, attributed to the highest mean relative abundances of *Bolivina lowmani* (19%), *Bolivina pseudoplicata* (9%) and *Bolivina* spp. (4%). Moreover, *Discorbis vilardeboanus* (5%), *Sigmavirgulina tortuosa* (4%) and *Cassidulina curvata* (3%) exhibit high mean relative abundances. In this group, the epifaunal morphogroup (22%) is mostly related to the genus *Discorbis*, *Discorbinella* and *Cymbaloporetta*. About a half of the samples that compose this group present high values of fragmented benthic tests. The sediment has higher mean values of %$CaCO_3$ (72%) and a lower TOM content (10%), when compared to the other groups.

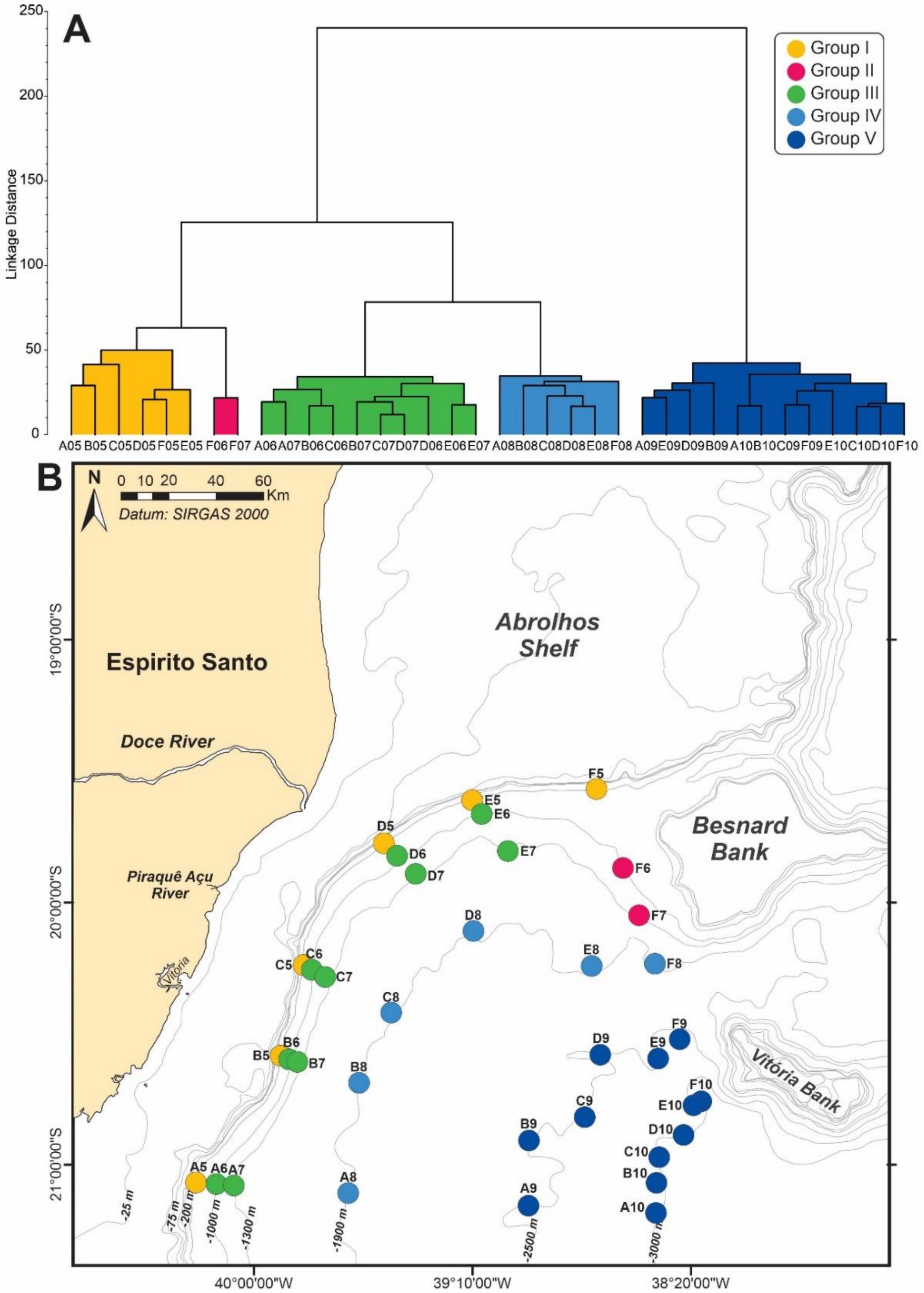

Figure 6: *(A) Cluster analysis (Bray-Curtis distance) based on the benthic foraminiferal relative abundance and (B) map of distribution patterns of groups (assemblages) found on the ESB. Group I (400 m, upper slope), Group II (1000-1300 m, middle-lower slope), Group III (1000-1300 m, middle-lower slope), Group IV (1900 m, lower slope) and Group V (2500-3000 m, lower slope).*

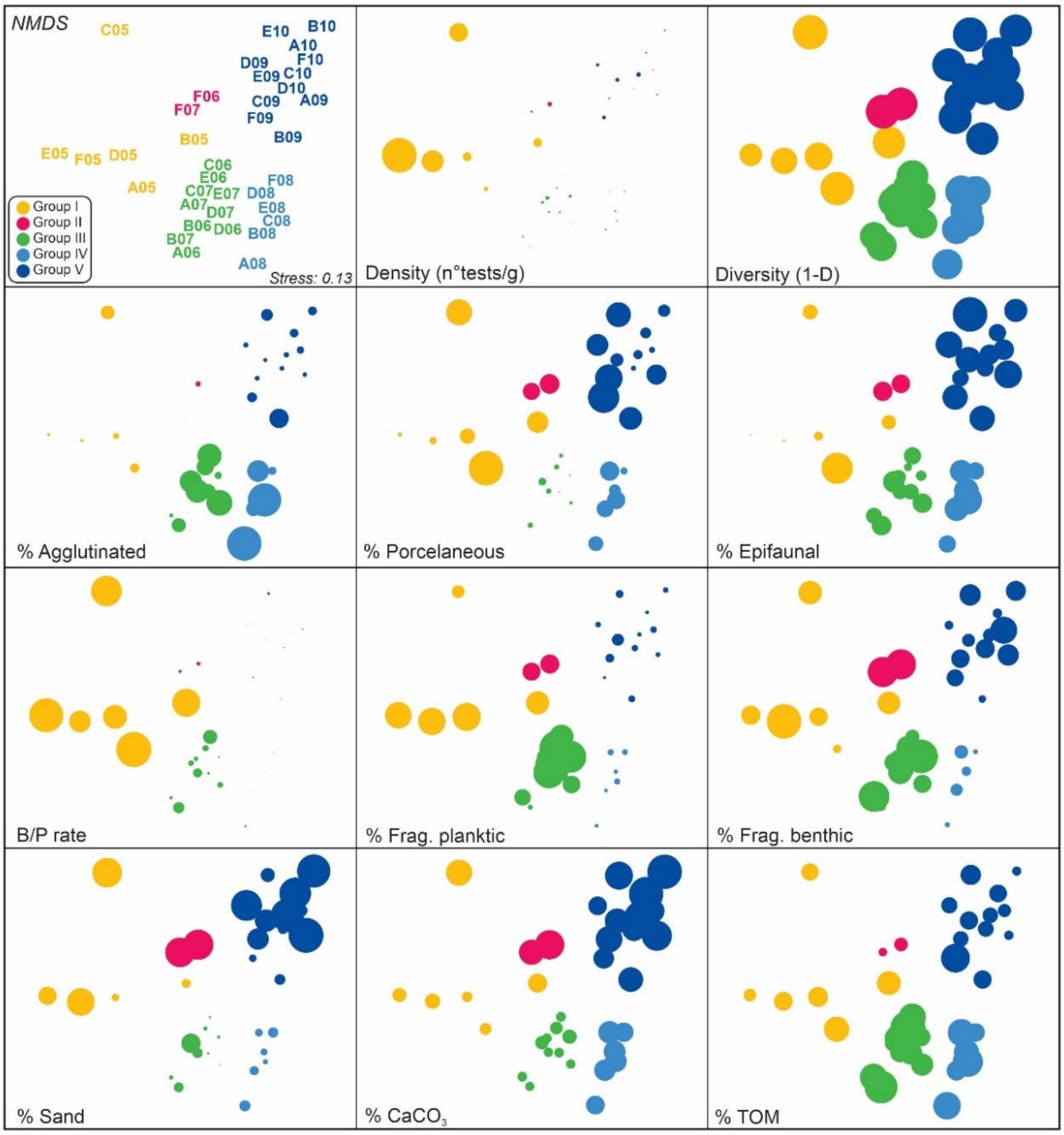

Figure 7: *Ordination analysis diagrams (NMDS) according to foraminiferal clusters analysis. Group I (400 m, upper slope), Group II (1000-1300 m, middle-lower slope), Group III (1000-1300 m, middle-lower slope), Group IV (1900 m, lower slope) and Group V (2500-3000 m, lower slope). The circle's size varies according to the values. The contribution of each parameter for groups can be seen in the graph according to the circle's sizes*

4. DISCUSSION

The deep-sea benthic foraminifera abundance and assemblage composition are mainly controlled by the interplay between organic carbon flux and bottom water oxygenation (Jorissen and Wittling, 1999; van der Zwaan et al., 1999; Kaminski, 2012). In well-oxygenated sediments, the influx of organic matter is considered the principal factor responsible for the areal and bathymetric distribution of benthic foraminiferal assemblages (Jorissen et al., 1995; De Rijk et al., 2000; Jorissen et al., 2007).

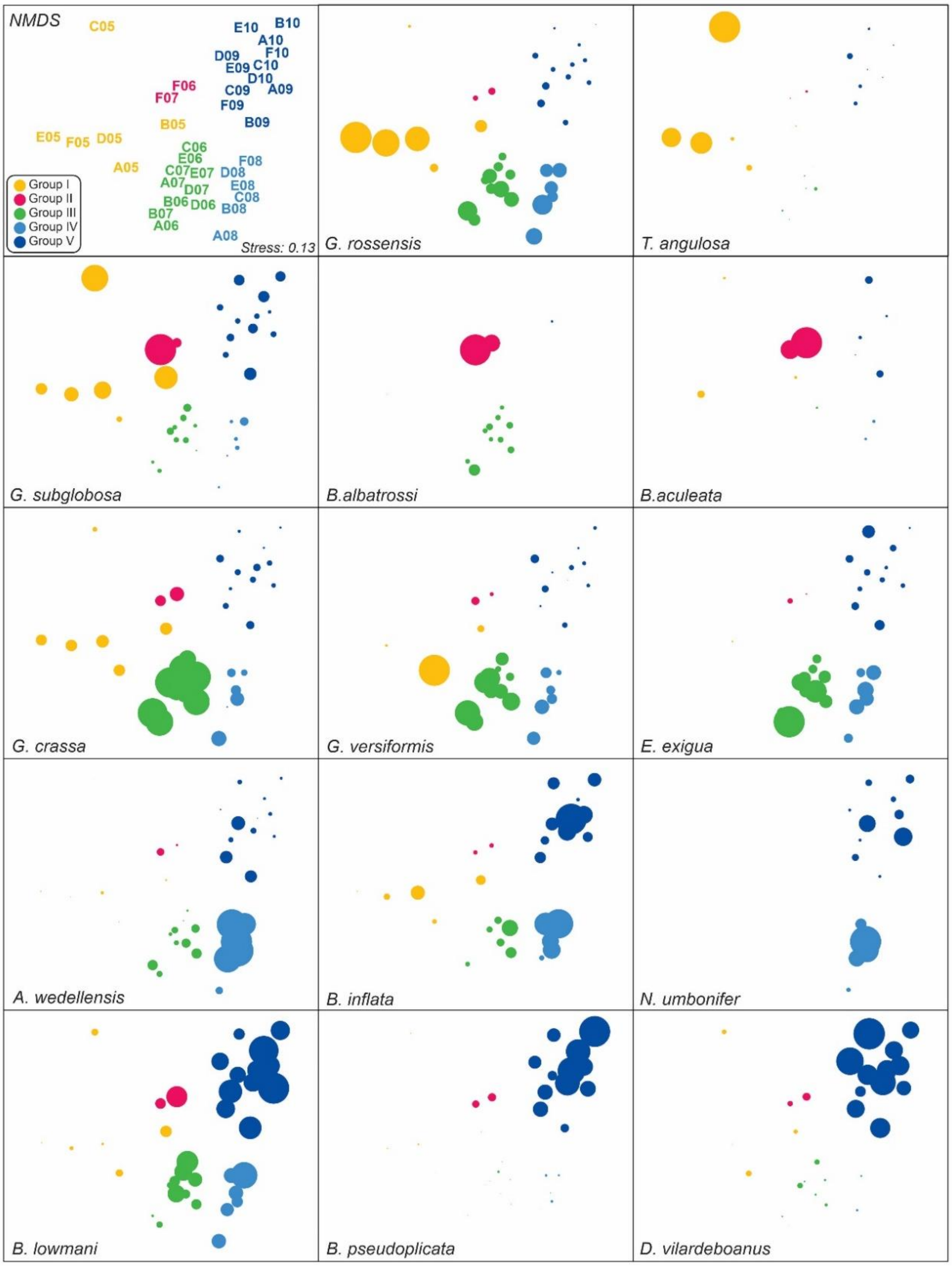

Figure 8: *Ordination analysis diagrams (NMDS) according to foraminiferal clusters analysis. Group I (400 m, upper slope), Group II (1000-1300 m, middle-lower slope), Group III (1000-1300 m, middle-lower slope), Group IV (1900 m, lower slope) and Group V (2500-3000 m, lower slope). The circle's size varies according to the values. The contribution of each taxon for groups can be seen in the graph according to the circle's sizes.*

In the study area, we observed the dominance of hyaline infaunal taxa (mostly shallow infaunal) along the slope, which suggests an enhanced organic matter flux (Corliss and

Chen, 1988; Jorissen et al., 1995). In the oligotrophic regions of the modern oceans, a small part of labile organic matter reaches the seafloor, limiting the depth habitat of benthic foraminifera to the first few centimeters below the sediment-water interfaces (Jorissen et al., 1995). This “fresh” material is unstable and rapidly consumed at the sediment-water interface (Carney, 1989). Only a minor part of this material penetrates into the sediment (e.g., owing to bioturbation), and is then converted into bacterial biomass (Carney, 1989), or, it is partially degraded by anaerobic microbial activity before being consumed by the micro and macrofauna (Jorissen and Wittling, 1999). Hence, the benthic foraminifera typically living in this microhabitat are epifaunal (e.g., *Alabaminella, Epistominella, Discorbis*) (Gooday, 1988; 1993; Smart et al., 1994; Hayward et al., 2007) or shallow infaunal (e.g., *Trifarina, Bolivina, Globocassidulina*) (Corliss and Chen, 1988; Altenbach et al., 1999; Bernhard and Sen Gupta, 1999; Schmiedl et al., 1997).

The dominant taxa distributed on the ESB slope (*Globocassidulina* and *Bolivina)* are ecologically associated with the quantity and quality of organic matter flux that reaches the seafloor (Gooday, 1994, 2003; Smart et al., 1994; Mackensen et al., 1995; Thomas et al., 1995; Schmiedl and Mackensen, 1997; Jorissen et al., 2007; Sun et al., 2006; Smart, 2008; de Almeida et al., 2015; Sousa et al., 2017; Rodrigues et al., 2018; Yamashita et al., 2018a). Benthic foraminiferal assemblages dominated by *Globocassidulina* indicates well-oxygenated environments (Gooday, 1994; Mackensen et al., 1995). The dominance of *Bolivina* is associated with reduced bottom water oxygenation (Gooday, 1994; Mackensen et al., 1995, Bernhard and Sen Gupta, 1999; Schmiedl et al., 1997) or with an increase in the availability of more refractory organic matter (Abu-Zied et al., 2008), metabolized by anaerobic bacteria within the sediment (Jorissen and Wittling, 1999).

4.1 Relationship among assemblages distribution, productivity and organic matter fluxes

4.1.1 Upper slope (400 m)

The characteristics of Group I (Tables 1 and 2) indicate a large supply of organic matter on the ESB and NCB upper slopes. For example, the high-density values, combined with the increased number of infaunal species is in line with the results of Sousa et al. (2017) in the upper slope of the Campos Basin. According to these authors, these observations point out a sustained flux of metabolizable organic matter, indicating that the availability of food is not limited at 400 m depth. Likewise, Rodrigues et al. (2018) found a positive correlation between the relative abundance of *T. angulosa* and the total organic carbon content in a Pleistocene-Holocene core recovered from the Pelotas Basin. The highest B/P ratios observed in Group I indicate an increase in organic matter flux to the seafloor. In the modern oceans, at depths with no significant carbonate dissolution, the B/P ratio can be interpreted as a productivity index (Berger and Diester-Hass, 1988).

A possible oceanographic mechanism linked to this organic enrichment could be shelf-break upwelling. Since Group I occurs close to the shelf-break, this area could remain constantly influenced by the upwelling of nutrient-rich water, enhancing local productivity. The ESB upper slope is bathed by the SACW, a nutrient-rich water mass that, because of the thermocline stability, does not reach the surface (Lopes et al., 2006). Some physical processes (e.g., internal waves) can disrupt the thermocline, bringing the SACW to the surface and eventually fertilizing the photic zone through coastal upwelling (Gaeta and Brandini, 2006). Cyclonic meanders of the BC are responsible for a relatively strong upwelling regime that brings the SACW to the upper slope and continental shelf (Campos et al., 2000; Palóczy et al., 2016).

At the ESB, the BC incursion on the continental shelf results in an episodic intrusion of SACW along a narrower sector of the shelf (Palóczy et al., 2016). The seasonal influence of the SACW on the shelf triggers the nutrient enrichment of surface waters, increasing primary productivity (Martins, 2014), and sustaining the development of rhodolith beds (Rocha et al., 2020), which predominate along the outer shelf in the entire area (Bastos et al., 2015; Bourguignon et al., 2018; Vieira et al., 2019; Rocha et al., 2020; Oliveira et al., 2020).

Additionally, the transport of organic matter from the continent to the slope can be facilitated by morphological features present on the ESB shelf (e.g., channels, paleochannels and paleovalleys) (Bastos et al., 2015) and slope (e.g., gullies, canyons and turbiditic systems) (Schreiner et al., 2008; 2009). A narrow continental shelf in the Tubarão Bight, with high bathymetric gradients, also contributes to this transport (Bastos et al., 2015). On the ESB upper slope (400 m), Bernardino et al. (2016) attributed both the increase in macrobenthic density and the change in benthic assemblage composition to a combination of two factors, namely the short-term primary productivity peaks near the shelf-break, and the continental export of organic matter.

The genera *Globocassidulina* and *Trifarina*, abundant in Group I, may also indicate high energy environments (Mackensen et al., 1985; 1995; Schmiedl et at., 1997; Sousa et al., 2006; Smart, 2008; Di Bella et al., 2017; Martorelli et al., 2021). This is corroborated by the increased fragmentation of benthic and planktic foraminiferal tests on the upper slope, which probably occur due to the high energy conditions (e.g., bottom currents) at the proximity of the shelf-break. The transport of foraminiferal tests could be facilitated by the features present on the shelf and slope (Bastos et al., 2015; Schreiner et al., 2008; 2009). The unfilled paleochannels can act as sediment pathways from the shelf to the slope (Bourguignon et al., 2018). Tests fragmentation was also observed in the macroforaminiferal species (> 500 µm) *A. lessoni* and *A. angulatus*, typical of reefs and carbonate shelves. The genus *Amphistegina* generally inhabits depths below 100 m (Hallock, 1999) and was found at shallower depths in the Abrolhos Shelf (D'Agostini et al., 2019). Therefore, these fragmented tests in Group I indicate the transport of these specimens from shallower regions, such as the Marine Environmental Protection Area Costa das Algas (MPA-CA), located in the southern Espírito Santo shelf, and from the southern Abrolhos Shelf (Figure 1).

4.1.2 Middle – lower slope (1000 to 1300 m)

In contrast with other areas in the middle – lower slope of the ESB, the area of occurrence of Group II (Tables 1 and 2) shows evidence of high influx of organic matter, associated with high hydrodynamic energy. Although the mean TOM values are relatively low, the highest %$CaCO_3$ may be related to increased carbonate productivity in the water column, as indicated by the high deposition of planktic foraminiferal tests, evidenced by very low B/P ratio in this group. *G. sublgobosa*, abundant in Group II, is considered an opportunistic, shallow infaunal species (Corliss and Chen, 1988), that can inhabit sandy sediments, eventually affected by strong bottom currents (Mackensen et al., 1995; Schmiedl et at., 1997; Sousa et al., 2006; Smart, 2008; Di Bella et al., 2017; Martorelli et al., 2021). Along the upper and middle – lower slope of the southeastern Brazilian margin, *G. subglobosa* has been associated to episodic phytodetritus deposition (Burone et al., 2011) and high vertical influx of particulate organic matter (Yamashita et al., 2018a). In addition to the abundance of *G. subglobosa*, Group II is characterized by high relative abundances of *Bulimina* spp. and *Uvigerina* spp., which characterize environments with intermittent organic matter flux (Gooday, 1994; Hayward et al., 2002). The presence of *B. aculeata* was correlated to phytodetritus pulses in the South Atlantic (Mackensen et al., 1995), whereas *U. peregrina* is more related to intermittent carbon organic flux than to low oxygen levels (Rathburn and Corliss, 1994).

The benthic foraminifera test fragmentation is highest in Group II. This group is located near the Besnard Bank, a feature that has ravined slopes and flat summits, with a high bathymetric gradient (Schreiner and Hercos, 2015). We believe that the cause of this fragmentation is the same observed for Group I, that is physical fragmentation due to transport. Possibly, these tests came from the Besnard Bank or, further north, from the Abrolhos Shelf (Figure 1), and have been transported by the BC through the Besnard Passage (Motoki et al., 2012). The BC flows from north to south, intrudes over the Abrolhos Shelf (Silveira et al., 2000; Ghisolfi et al., 2015), and may directly influence the local occurrence of carbonate deposits (Bastos et al., 2015). Thus, the highest species richness and diversity observed in Group II should be carefully evaluated, because there is a partial contribution of fragmented benthic tests from shallower environments, especially porcelaneous species.

The dominance of opportunistic species, such as *G. crassa*, and the increased abundance of *E. exigua* in Group III indicate the influx of labile organic matter to the middle – lower slope. Therefore, the other species associated with this group (such as *G. versiformis*, *P. nipponensis*, the unilocular group and others) may have similar ecological preferences as *G. crassa* and *E. exigua* in the ESB. *G. crassa* is a shallow infaunal, cosmopolitan, opportunistic species that indicates intermittent organic matter flux (Hayward et al., 2002) and well-oxygenated environments (Gooday, 1994). Peaks of relative abundance of *G. versiformis* were associated with periods of higher productivity in the Santos Basin during glacial stages (de Almeida et al., 2015). It is well known that *E. exigua* grows and reproduces during seasonal pulses of labile organic matter input, indicating the seasonality of organic flux resulting from primary productivity, as previously observed in the South Atlantic (Mackensen et al., 1995; de Almeida et al., 2015; Yamashita et al., 2018a; Rodrigues et al., 2018; Smart et al., 2019).

The mechanism that contributes to increased regional primary productivity and, consequently, to the export of organic matter to the seafloor of the middle – lower slope of the ESB, is associated to mesoscale oceanographic features. The occurrence of quasi-stationary and recurrent eddies (Schmid et al., 1995, Soutelino et al., 2011, Arruda et al., 2013; Arruda and Silveira, 2019), and remotely generated eddies (Mill et al., 2015) has been reported in the vicinity of the ESB. The VE commonly occurs at intermediate depth and may be considered a quasi-stationary feature for extended periods (Arruda and Silveira, 2019). In the VE mixing layer, there is an increase in chlorophyll-a concentration and primary productivity (Gaeta et al., 1999). The pumping of nutrient-rich waters by the VE contributes to the fertilization of surface waters, and, consequently, to the local increase in phytoplankton production (Gaeta et al., 1999; Martins, 2014). Recently, Arruda and Silveira (2019) proposed that the coupling of the Abrolhos and the Vitória Eddies (two mesoscale features) around the Besnard Bank results in upwelling of the SACW to the shelf-break, pumping nutrients to the euphotic zone, which are then advected oceanward for more than 250 km from the shelf-break.

Lemos et al. (2018) associated the annual bloom of phytoplankton to the chlorophyll-a concentration in four seamounts of the VTR. The authors suggest that the flat topography of the seamount summits, associated with the heat loss of seawater in winter create favorable conditions for the increase of chlorophyll-a, with a direct impact on primary productivity in the VTR.

Phytodetritus originates in the euphotic zone during seasonal blooms, such as the spring phytoplankton bloom (Smart et al., 1994), and only a small portion of it reaches the seafloor in pulses (Gooday, 2002; Gooday and Turley, 1990). Phytodetritus contains a wide variety of planktonic remains, including live and dead phytoplankton, zooplankton, and fecal pellets bound by a gelatinous and membranous matrix (Gooday and Turley, 1990; Turley, 2002). The deposition of phytodetritus (a labile food source), triggers rapid population increases in opportunistic benthic foraminiferal species (Fontanier et al., 2003; 2006). The dominance of opportunistic species, that reproduce rapidly due to phytodetritus pulses delivered to the sediment, confirms the quasi-stationary and recurrent nature of the VE, as well as the seasonality of primary productivity in the ESB.

4.1.3 Lower slope (1900 m to 3000 m)

The oceanographic mechanisms that influence Group IV (Tables 1 and 2) on the lower slope are probably the same previously discussed in Group III. The reason why *A. weddellensis* is more abundant than *E. exigua* at 1900 m depth may be associated with the subtle differences in their food preference. *A. weddellensis* is also an opportunistic, phytodetritus-dependent epifaunal species, and like *E. exigua*, responds to seasonal pulses of labile organic matter availability with rapid growth and reproduction rates (Gooday, 1988, 1993). However, the opposite abundance trend of these species has been linked to a subtle difference in their environmental preferences (Gooday and Turley, 1990; Gooday, 1993, 1996; Ohkushi et al., 2000; Smart, 2008; Smart et al., 2019). The abundance of *A. weddellensis* was associated with an area of high primary productivity in the North Atlantic whereas *E. exigua* seems to respond to high seasonality (Fariduddin and Loubere, 1997; Sun et al., 2006). Besides, *A. weddellensis* increases during periods of phytodetritus deposition containing a high proportion of needle-shaped diatoms (King et al., 1998).

The dominance of the genus *Bolivina* in Group V (Tables 1 and 2), in the deepest lower slope, can be considered an indicator of continuous high flux of refractory organic matter to the seafloor (Abu-Zied et al., 2008) and/or of reduced bottom water oxygen concentration (Mackensen et al., 1995, Bernhard and Sen Gupta, 1999; Schmiedl et al., 1997). In the Campos Basin, *Bolivina* spp. were associated with low oxygen levels at the seafloor (Sousa et al., 2006). Low oxygenation levels on the slope can be triggered by high organic carbon influx, so the benthic foraminiferal assemblages can reflect the increased availability of food (Hayward et al., 2002). Similar to Group II, Group V is associated with a high %$CaCO_3$ in the sediment, combined with the lowest B/P ratio and the highest percentage of planktic foraminifera. At greater distance from the coast (and from the shelf-break) the turbidity in the water column decreases (van der Zwann et al., 1990), allowing planktic foraminifera to grow and establish viable populations, which normally occur in the uppermost 450 – 600 m (Bé, 1977).

4.2 Influence of water masses and bottom currents

The different currents and water masses distributed along the middle and lower slopes of the ESB and NCB need to be considered when comparing the bathymetric distribution of Groups II, III, IV and V (see Table 2). Although the water masses properties appear to play a minor role in determining the benthic foraminiferal distribution (Jorissen et al., 2007), in oligotrophic oceanic regions, where organic matter fluxes are low and/or highly seasonal, the physical and chemical characteristics of the bottom water masses can influence the microfauna (Schnitker, 1994; Mackensen et al., 1985; Schmiedl et al., 1997; Jorissen et al., 2007).

The fragmentation of benthic and planktic foraminiferal tests in Groups I and II (400 to 1300 m), was possibly not caused by carbonate corrosive water masses, such as the UCPW and LCPW. The reason is because the UCPW is latitudinally limited to 20°S

(Reid, 1989; Mémery et al., 2000; Silveira et al., 2020) and occurs near VTR (Mémery et. al., 2000). A weak signature of UCPW was recorded in the study area diluted at the AAIW-NADW interface (Silveira et al., 2015; 2020). The LCPW is also characterized by lower oxygen concentration and salinity, and high dissolved nutrient and CO_2 concentrations (Stramma and England, 1999; Mémery et al., 2000), which makes it carbonate corrosive. However, in the ESB the LCPW remains at depths below 3000 m (Silveira et al., 2015).

At intermediate depths, the IWBC flows northward transporting AAIW, a nutrient-rich water mass (Silveira et al., 2020) which baths the middle – lower slope of the ESB (where Groups II and III occur). Silveira et al. (2004; 2008) identified a stronger (maximum velocities > 30 cm/s at 800 m), and thicker current, with transport estimates ranging from ~ 4-7 Sv (1 Sv = 10^6 m^3/s). At intermediate depth, a topographically-induced cyclonic recirculation of the IWBC occurs (Costa et al., 2016; Napolitano et al., 2019). Costa et al. (2016) concluded that an intense alongshore flow occurs at intermediate levels on the western side of the Tubarão Bight. Thus, the IWBC could remobilize, transport and deposit sediments in the middle – lower slope of the ESB and NCB, also causing changes in bottom morphology (d'Avila et al., 2008).

On the other hand, at deeper depth, the DWBC transports NADW (Silveira et al., 2020), which bathes the lower slope of the ESB (where Groups IV and V occur). The nutrient-poor NADW, has high oxygen concentration, temperature, and salinity (Lohmann, 1978; Hinrichsen and Tomczak, 1993; Silveira et al., 2020). Silveira et al. (2015) observed a large vertical extension of this water mass near the ESB, ranging from 1300 to 3000 m.

Therefore, the physical and chemical characteristics of the boundary currents and water masses at intermediate and deep depth may have a subordinated impact on the benthic foraminifera assemblage distribution along the ESB slope, and cause the differences observed among Groups III, IV and V (1000 to 3000 m).

Table 2: *Synthesis of the main characteristics observed in each benthic foraminiferal assemblage (group) distributed on the slope of the Espírito Santo and northern Campos basins. Total organic matter content (%TOM), Calcium carbonate content (%$CaCO_3$), Brazil Current (BC), Intermediate Western Boundary Current (IWBC), Deep Western Boundary Current (DWBC), South Atlantic Central Water (SACW), Antarctic Intermediate Water (AAIW) and North Atlantic Deep Water (NADW).*

	GROUP I	**GROUP II**	**GROUP III**	**GROUP IV**	**GROUP V**
Samples	A05, B05, C05, D05, E05, F05	F06, F07	A06, B06, C06, D06, E06 A07, B07, C07, D07, E07	A08, B08, C08, D08, E08, F08	A09, B09, C09, D09, E09, F09, A10, B10, C10, D10, E10, F10
Depth (m)	400	1000 – 1300	1000 – 1300	1900	2500 – 3000
Bathymetric zone	Upper slope	Middle – lower slope	Middle – lower slope	Lower slope	Lower slope
Abundant species	*G. rossensis* *Trifarina* spp. *T. angulosa*	*G. subglobosa* *B. albatrossi* *B. aculeata* *U. peregrina*	*G. crassa* *G. versiformis* *E. exigua* unilocular group	*A. weddellensis* *B. inflata* *E. exigua*	*B. lowmani* *B. pseudoplicata* *Bolivina spp.* *D. vilardeboanus*
Other species	*B. ordinaria, P. nipponensis, S. australis*	*N. antillarum*	*P. nipponensis, N.grateloupii, B. fragilis*	*N. umbonifer*	*S. tortuosa, C. curvata, D.bertheloti, C. bradyi*
Ecological features (Highest mean values)	Density, dominance, B/P rate, % PORC, % infaunal	Species richness, diversity, % PORC, % fragmented benthic foraminifera	% Fragmented planktic foraminifera	% AGGLU, % epifaunal, %planktic foraminifera	% Epifaunal, % juvenile %planktic foraminifera
Sedimentological features	Mud TOM = 12%	Sandy mud TOM < 12% $CaCO_3$ > 70%	Mud TOM > 12%	Mud TOM > 12%	Mud TOM < 12% $CaCO_3$ > 70%
Currents/water masses	BC/SACW	IWBC/AAIW	IWBC/AAIW	DWBC/NADW	DWBC/NADW

5. CONCLUSIONS

1. The distribution of recent benthic foraminiferal assemblages in the ESB is primarily governed by the quantity and quality of organic matter influx in the ESB slope, which varies with depth.

2. The ecology of the taxa that compose Group I (400 m), indicates that the organic flux is higher on the upper slope than on the middle and lower slope. Shelf-break upwelling, along with organic matter transport from the shelf to the slope, result in large availability of food. Organic matter transport can be facilitated by morphological features that indent the ESB shelf and slope.

3. The abundance of opportunistic benthic foraminiferal species of Groups II, III, IV and V (1000 to 3000 m), which feed on phytodetritus pulses, confirms the influence of quasi-stationary mesoscale features like the Vitoria Eddy, as well as the seasonality of primary productivity in the ESB.

4. The physical-chemical properties of water masses (especially AAIW and NADW), and the presence of intermediate (IWBC) and deep (DWBC) boundary currents, play a secondary role in the benthic foraminiferal assemblages distribution, and results in the differences among Groups III, IV and V (1000 to 3000 m).

5. The increased fragmentation of benthic and planktic foraminifera tests (Groups I and II) in the upper and middle – lower slope of the ESB and NCB is related to physical processes, like the transport of tests from shallower regions to the slope.

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REFERENCES

Abu-Zied, R. H., Rohling, E. J., Jorissen, C. F., Casford, J. S. L. Cooke, S., 2008. Benthic foraminiferal response to changes in bottom-water oxygenation and organic carbon flux in the eastern Mediterranean during LGM to Recent times. Mar. Micropaleontol. 67, 46–48. https://doi.org/10.1016/j.marmicro.2007.08.006

Altenbach, A. V., Pflaumann, U., Schiebel, R., Thies, A., Timm, S., Trauth, M., 1999. Scaling percentages and distributional patterns of benthic foraminifera with flux rates of organic carbon. J. Foraminiferal Res. 29, 173–185.

Arruda, W. Z., Campos, E. J. D., Zharkov, V., Soutelino, R. G., Silveira, I. C. A., 2013. Events of equatorward translation of the Vitoria Eddy. Cont. Shelf Res. 70, 61–73. https://doi.org/10.1016/j.csr.2013.05.004

Arruda, W. Z., Silveira, I. C. A., 2019. Dipole-induced Central Water extrusions south of Abrolhos Bank (Brazil, 20.5°S). Cont. Shelf Res. 188. https://doi.org/10.1016/j.csr.2019.103976

Barbosa, V. P., 2002. Sistemática, bioestratigrafia e paleoceanografia de foraminíferos do Quaternário do talude continental das bacias de Santos e Campos. Unpublished thesis. Instituto de Geociências, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil. 455p.

Barbosa, V. P., 2010. Foraminíferos bentônicos como indicadores bioestratigráficos no Quaternário Superior da Bacia de Campos. Rev. Bras. Paleontol. 13, 129–142. http://doi.org/10.4072/rbp.2010.2.06

Bastos, A. C., Quaresma, V. S., Marangoni, M. B., D'Agostini, D. P., Bourguignon, S. N., Cetto, P. H., Silva, A. E., Amado Filho, G. A., Moura, R. L., Collins, M., 2015. Shelf morphology as an indicator of sedimentary regimes: A synthesis from a mixed siliciclastic-carbonate shelf on the eastern Brazilian margin. J. S. Am. Earth Sci. 63, 125–136. https://doi.org/10.1016/j.jsames.2015.07.003

Bé, A. W. H., 1977. An ecological, zoogeographic and taxonomic review of recent planktonic foraminifera. In: Ramsay, A.T.S. (Ed.), Oceanic Micropaleontology. Academic Press, pp. 1–100.

Berger, W. H., Diester-Hass, L., 1988. Paleoproductivity: the benthic/planktonic ratio in foraminifera as a productivity index. Mar. Geol. 81, 15–25. https://doi.org/10.1016/0025-3227(88)90014-X

Bernardino, A. F., Berenguer, V., P. Ribeiro-Ferreira, V. P., 2016. Bathymetric and regional changes in benthic macrofaunal assemblages on the deep Eastern Brazilian margin, SW Atlantic. Deep-Sea Res. Part I Oceanogr. Res. Pap. 111, 110-120. https://dx.doi.org./10.1016/j.dsr.2016.02.016

Bernhard, J. M., Sen Gupta, B. K., 1999. Foraminifera of oxygen depleted environments. In: Sen Gupta, B.K. (Ed.), Modern Foraminifera. Kluwer Academic Publishers, Dordrecht, pp. 201–216.

Boersma, A., 1984. Handbook of common Tertiary Uvigerina. Microclimates Press. Stony Point, New York.

Bolli, H. M., Beckmann, J-P., Saunders, J. B., 1994. Benthic foraminiferal biostratigraphy of South Caribbean region. Cambridge University Press.

Boltovskoy, E., Giussani, G., Watanabe, S., Wright, R., 1980. Atlas of benthic shelf Foraminifera of the Southwest Atlantic. Oxford: Dr. W. Junk B. V. Publishers.

Bourguignon, S. N., Bastos, A. C., Quaresma, V. S., Vieira, F. V., Pinheiro, H., Amado-Filho, G. M., de Moura, R. L., Teixeira, J. B., 2018. Seabed Morphology and Sedimentary Regimes defining Fishing Grounds along the Eastern Brazilian Shelf. Geoscience. 8 , 2–7. https://doi.org/10.3390/geosciences8030091

Bubik, M., 2019. Remarks on the quantitative analysis of deep-sea agglutinated foraminiferal taphocoenoses with special attention to tubular astrorhizids. Micropaleontology. 65, 63–74.

Burone, L. B., Sousa, S. H. M., Mahiques, M. M., Valente, P., Ciotti, A., Yamashita, C., 2011. Benthic foraminiferal distribution on the southeastern Brazilian shelf and upper slope. Mar. Biol. 158, 159–179. http://dx.doi.org/10.1007/s00227-010-1549-7

Campos, E. J. D., Velhote, D., Silveira, I. C. A., 2000. Shelf break upwelling driven by Brazil Current cyclonic meanders. Geophys. Res. Lett. 27, 751–754. https://doi.org/10.1029/1999GL010502

Campos, E. J. D., 2006. The equatorward translation of the Vitoria Eddy in a numerical simulation. Geophys. Res. Lett. 33, L22607. https://doi.org/10.1029/2006GL026997

Carney, R. S., 1989. Examining relationships between organic carbon flux and deep-sea deposit feeding, in: G. Lopez, G. Taghon and J. Levinton (Eds). Ecology of Marine Deposit Feeders, Springer-Verlag, New York, pp. 24–58.

Clarke K. R., Warwick, R. M., 1994. Similarity-based testing for community pattern: The 2-way layout with no replication. Mar. Biol. 118, 167–176. https://doi.org/10.1007/BF00699231

Corliss, B. H., 1985. Microhabitats of benthic foraminifera within deep-sea sediments. Nature 314, 435–438. https://doi.org/10.1038/314435a0

Corliss, B. H., 1991. Morphology and microhabitat preferences of benthic foraminifera from the northwest Atlantic Ocean. Mar. Micropaleontol. 17, 195–236. https://doi.org/10.1016/0377-8398(91)90014-W

Corliss, B. H., Chen, C., 1988. Morphotype patterns of Norwegian deep-sea benthic foraminifera and ecological implications. Geology 16, 716–719. https://doi.org/10.1130/0091-7613(1988)016<0716:MPONSD>2.3.CO;2

Costa, V. S., Mill, G. N., Gabioux, M., Grossmann-Matheson, G. S., Paiva, A. M., 2016. The recirculation of the intermediate western boundary current at the Tubarão Bight – Brazil. Deep-Sea Res. Part I Oceanogr. Res. Pap. 120, 48–60. https://doi.org/10.1016/j.dsr.2016.12.001

D'Agostini, D. P., Bastos, A. C., Reis, A. T., 2015. The modern mixed carbonate-siliciclastic Abrolhos Shelf: implications for a mixed depositional model. J. Sediment. Res. 85, 124–139. https://doi.org/10.2110/jsr.2015.08

D’Agostini, D. P., Bastos, A. C., Amado-Filho, G. M., Vilela, C. G., Thaís, C. S., Oliveira, T. C. S., Webster, J. M., Moura, R. L., 2019. Morphology and sedimentology of the shelf-upper slope transition in the Abrolhos continental shelf (East Brazilian Margin). Geo-Mar. Lett. 39, 117–134. https://doi.org/10.1007/s00367-019-00562-6

d’Ávila, R. S. F., Arienti, L. M., Aragão, M. A. N. F., Veseley, F. F., Santos, S. F., Voelcker, H. E., Viana, A. R., Kowsman, R. O., Moreira, J. L. P., Coura, A. P. P., Paim, P. S. G., Matos, R. S., Machado, L. C., 2008. Ambientes marinhos profundos: sistemas turbidíticos. (In): Ambientes de sedimentação siliciclástica do Brasil, pp. 244-301.

de Almeida, F. K., Mello, R. M., Costa, K. B., Toledo, F. A. L., 2015. The response of deep-water benthic foraminiferal assemblages to changes in paleoproductivity during the Pleistocene (last 769.2 kyr), Western South Atlantic Ocean. Palaeogeogr. Palaeoclimatol. Palaeoecol. 440, 201–212. https://doi.org/10.1016/j.palaeo.2015.09.005

De Rijk, S., Jorissen, F. J., Rohlinga, E. J., Troelstra, S. R. 2000. Organic flux control on bathymetric zonation of Mediterranean benthic foraminifera. Mar. Micropaleontol. 40, 151-166. https://doi.org/10.1016/S0377-8398(00)00037-2

Di Bella, L.; Pierdomenico, M., Porretta, R., Chioccia, F. L., Martorelli, E. 2017. Living and dead foraminiferal assemblages from an active submarine canyon and surrounding sectors: the Gioia Canyon system (Tyrrhenian Sea, Southern Italy). Deep-Sea Res. I: Oceanogr. Res. Pap. 123, 129-146. https://doi.org/10.1016/j.dsr.2017.04.005

Dias, J. A., 2004. A análise sedimentar e o conhecimentos dos sistemas marinhos – Uma Introdução à Oceanografia Geológica. Universidade do Algarve, Faro.

Enge, A. J., Witte, U., Kucera, M., Heinz, P., 2014. Uptake of phytodetritus by benthic foraminifera under oxygen depletion at the Indian margin (Arabian Sea). Biogeosciences 11, 2017–2026. https://doi.org/10.5194/bg-11-2017-2014

Fariduddin, M., Loubere, P., 1997. The surface ocean productivity response of deeper water benthic foraminifera in the Atlantic Ocean. Mar. Micropaleontol. 32, 289–310. https://doi.org/10.1016/S0377-8398(97)00026-1

Ferreira, F., Frontalini, F., Leão, C., Leipnitz, I. I., 2014. Changes in the water column structure and paleoproductivity in the western South Atlantic Ocean since the middle Pleistocene: Evidence from benthic and planktonic foraminifera. Quat. Int. 352, 111–123. https://doi.org/10.1016/j.quaint.2014.07.061

Fontanier, C., Jorissen, F. J., Licari, L., Alexandre, A., Anschutz, P., Carbonel, P., 2002. Live benthic foraminiferal faunas from the Bay of Biscay: faunal density, composition, and microhabitats. Deep-Sea Res. Part I Oceanogr. Res. Pap. 49, 751–785. https://doi.org/10.1016/S0967-0637(01)00078-4

Fontanier, C., Jorissen, F. J., Chaillou, G., David, C., Anschutz, P., Lafon, V., 2003. Seasonal and interannual variability of benthic foraminiferal faunas at 550 m depth in the Bay of Biscay. Deep-Sea Res. Part I Oceanogr. Res. Pap. 50, 457–494. https://doi.org/10.1016/S0967-0637(02)00167-X

Fontanier, C., Jorissen, F. J., G. Chaillou, G., Anschutz, P., Grémare, A., Griveaud, C., 2005. Live foraminiferal faunas from a 2800 m deep lower canyon station from the Bay of Biscay: Faunal response to focusing of refractory organic matter. Deep-Sea Res. Part I Oceanogr. Res. Pap. 52, 1189–1227. https://doi.org/10.1016/j.dsr.2005.01.006

Fontanier, C., Mackensen, A., Jorissen, F. J., Anschutz, P., Licari, L., Griveaud, C., 2006. Stable oxygen and carbon isotopes of live benthic foraminifera from the Bay of Biscay: Microhabitat impact and seasonal variability. Mar. Micropaleontol. 58, 159–183. https://doi.org/10.1016/j.marmicro.2005.09.004

França, R. L., Tokutake, L. R., 2004. Bacias sedimentares brasileiras: Bacia do Espírito Santo. Phoenix 69, 1–6.

França, R. L.; Del Rey, A. C.; Tagliari, C. V.; Brandão, J. R.; Fontanelli, P. R., 2007. Bacia do Espírito Santo. Bol. Geoc. Petrobrás 15, 501–509.

Gaeta, S. A., Lorenzzetti, J. A., Miranda, L. B. d., Susini-Ribeiro, S. M. M., Pompeu, M., Araujo, C. E. S., 1999. The Vitória Eddy and its relation to the phytoplankton biomass and primary productivity during the austral fall of 1995. Arch. Fish. Mar. Res. 47, 253–270.

Gaeta, S. A, Brandini, F. P., 2006. Produção primária do fitoplâncton na região entre Cabo de São Tomé (RJ) e o Chuí (RS), In: Rossi-Wongtschowski, C. L. D. B., Madureira, L. S. (Eds). O ambiente oceanográfico da plataforma continental e do talude na região sudeste-sul do Brasil. Edusp, São Paulo, pp. 219–264.

García-Chapori, N. G., Laprida, C., Watanabe, S., Totah, V., Violante, R. A., 2014. Mid-Late Pleistocene benthic foraminifera from Southwestern South Atlantic: driven by primary productivity or water mass properties? Micropaleontology 60, 195–210.

Ghisolfi, R. D., Pereira da Silva, M., Thomaz dos Santos, F., Servino, R. N., Cirano, M., Thompson, F. L., 2015. Physical Forcing Mechanisms Controlling the Variability of Chlorophyll-a over the Royal-Charlotte and Abrolhos Banks – Eastern Brazilian Shelf. Plos One 10: e0117082. https://doi.org/10.1371/journal.pone.0117082

Gonzales, M. V., de Almeida, F. K., Costa, K. B., Santarosa, A. C. A., Camillo Jr., E., Quadros, J. P., Toledo, F. A. L., 2017. HELP INDEX: Hoeglundina elegans preservation index for marine sediments in the western South Atlantic. J. Foraminiferal Res. 47, 56–69. https://doi.org/10.2113/gsjfr.47.1.56

Gooday, A. J., 1988. A response by benthic foraminifera to the deposition phytodetritus in the deep sea. Nature 332, 70–73. https://doi.org/10.1038/332070a0

Gooday, A. J., 1993. Deep-sea benthic foraminiferal species which exploit phytodetritus: characteristic features and controls on distribution. Mar. Micropaleontol. 22, 197–205. https://doi.org/10.1016/0377-8398(93)90043-W

Gooday, A. J., 1994. The biology of deep-sea foraminifera: a review of some advances and their applications in paleoceanography. PALAIOS 9, 14–31. https://doi.org/10.2307/3515075

Gooday, A. J., 1996. Epifaunal and shallow infaunal foraminiferal communities at three abyssal NE Atlantic sites subject to differing phytodetritus input regimes. Deep-Sea Res. I: Oceanogr. Res. Pap. 43 (9), 1395–1421. https://doi.org/10.1016/S0967-0637(96)00072-6

Gooday, A. J., 2002. Biological responses to seasonally varying fluxes of organic matter to the ocean floor: a review. J. Oceanogr. 58, 305–332. https://doi.org/10.1023/A:1015865826379

Gooday, A. J., 2003. Benthic foraminifera (Protista) as tools in deep-water paleoceanography: a review of environmental influences on faunal characteristics. Adv. Mar. Biol. 46, 1–90. https://doi.org/10.1016/S0065-2881(03)46002-1

Gooday, A. J., Turley, C. M., 1990. Responses by benthic organisms to inputs of organic material to the ocean floor: a review. Philos. Trans. R. Soc. Lond. 331, 119–138. https://doi.org/10.1098/rsta.1990.0060

Gotelli, N. J., Ellison, A. M., 2011. Princípios de Estatística em Ecologia. Artmed, Porto Alegre.

Hallock, P., 1999. Symbiont-bearing Foraminifera. In: Sen Gupta, B. K. (Ed.), Modern Foraminifera. Kluwer Academic Publishers, Dordrecht, pp. 123–139.

Hammer, Ø., Harper, D. A. T., Ryan, P. D., 2001. Past: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontol. Electronica 4, art. 4: 9 pp., 178kb. http://palaeo-electronica.org/2001_1/past/issue1_01.htm.

Hayward, B. W. Neil, H. Carter, R. Grenfell, H. R. Hayward, J. J., 2002. Factors influencing the distribution patterns of Recent deep-sea benthic foraminifera, east of New Zealand, Southwest Pacific Ocean. Mar. Micropaleontol. 46, 139–176. https://doi.org/10.1016/S0377-8398(02)00047-6

Hayward, B. W., Grenfell, H. R., Carter, R., Hayward, J. J., 2004. Benthic foraminiferal proxy evidence for the Neogene palaeoceanographic history of the Southwest Pacific, east of New Zealand. Mar. Geol. 205, 147–184. https://doi.org/10.1016/S0025-3227(04)00022-2

Hayward, B. W. Grenfell, H. R., Sabaa, A. T., Neil., H. L., 2007. Factors influencing the distribution of Subantarctic deep-sea benthic foraminifera, Campbell and Bounty Plateaux, New Zealand. Mar. Micropaleontol. 62, 141–166. https://doi:10.1016/j.marmicro.2006.08.001

Hayward, B. W., Grenfell, H. R., Sabaa, A. T., Hayward, C. M., Neil, H. N., 2013. Ecological distribution of benthic foraminifera, offshore northeast New Zealand. J. Foraminiferal Res. 36, 332–354. https://doi.org/10.2113/gsjfr.36.4.332

Hinrichsen, H. Tomczak, M., 1993. Optimum multiparameter analysis of the water mass structure in the western North Atlantic Ocean. J. Geophys. Res. 98 (C6). https://doi.org/10.1029/93JC00180

Holbourn, A., Henderson, A. S.; Macleod, N., 2013. Atlas of Benthic Foraminifera. Oxford, Natural History Museum. https://doi.org/10.1002/9781118452493

ICMBio, 2020. Marine Environmental Protection Area Costa das Algas (MPA-CA) [WWW Document]. World Wide Web Electronic Publication (URL) <https://www.icmbio.gov.br/apacostadasalgas/>, acceded 06.06.20.

Johnson, D. A., 1983. Paleocirculation of the Southwestern Atlantic. Initial Reports of the Deep-Sea Drilling Project 72, 977–994.

Jones, R. W. 1994. The Challenger Foraminifera. Oxford University Press. 149 p., 115 pls.

Jorissen, F. J., Stigter, H. C., Widmark, J. G. V., 1995. A conceptual model explaining benthic foraminiferal microhabitats. Mar. Micropaleontol. 26, 3–15. https://doi.org/10.1016/0377-8398(95)00047-X

Jorissen, F. J., Wittling, I., 1999. Ecological evidence from live-dead comparisons of benthic foraminiferal faunas off Cape Blanc (NW Africa). Palaeogeogr. Palaeoclimatol. Palaeoecol. 149, 151–70. https://doi.org/10.1016/S0031-0182(98)00198-9

Jorissen, F. J., Fontanier, C., Thomas, E., 2007. Paleoceanographical proxies based on deep-sea benthic foraminiferal assemblage characteristics, In: Hillaire-Marcel C., Vernal, A. (Eds.). Proxies in Late Cenozoic Paleoceanography (Pt. 2): Biological tracers and biomarkers, Elsevier, pp. 263–326. https://doi.org/10.1016/S1572-5480(07)01012-3

Kaiho, K., 1994. Benthic foraminiferal dissolved-oxygen index and dissolved oxygen levels in the modern ocean. Geology. 22, 719-722. https://doi.org/10.1130/0091-7613(1994)022<0719:BFDOIA>2.3.CO;2

Kaminski, M. A., Gradstein, F. M., 2005. Atlas of Paleogene cosmopolitan deep-water agglutinated foraminifera: Grzybowski Foundation Special Publication, 10, 547 p.

Kaminski, M. A., 2012. Calibration of the Benthic Foraminiferal Oxygen Index in the Marmara Sea. Geo. Q. 56, 757–764.

Kaminski, M. A., Boersma, A., Tyszka, J., Holbourn, A. E. L., 1995. Response of deep-water agglutinated foraminifera to dysoxic conditions in the California Borderland basins. In: Kaminski, M. A. Geroch, S., Gasiński, M. A. (Eds.). Proceedings of the Fourth International Workshop on Agglutinated Foraminifera, Kraków Poland, September 12-19, 1993. Grzybowski Foundation Special Publication, 3, pp. 131–140.

King, S. C., Murray, J. W., Kemp, A. E. S., 1998. Palaeoenvironments of deposition of Neogene laminated diatom mat deposits from the eastern equatorial Pacific from studies of benthic foraminifera (Sites 844, 849, 851). Mar. Micropaleontol. 35, 161–177. https://doi.org/10.1016/S0377-8398(98)00020-6

Lemos, A. T., Ghisolfi, R. D. R., Mazzini, P. L. F., 2018. Annual phytoplankton blooming using satellite-derived chlorophyll-a data around the Vitória-Trindade Chain, Southeastern Brazil. Deep-Sea Res. I: Oceanogr. Res. Pap. 136, 62–71. https://doi.org/10.1016/j.dsr.2018.04.005

Loeblich, A. R., Tappan, H., 1988. Foraminiferal Genera and their Classification. New York: Van Nostrand Reinhold Ed., 970 p., 847 pls.

Loeblich, A. R., Tappan, H., 1994. Foraminifera of the Sahul Shelf and Timor Sea. Cushman Foundation for Foraminiferal Research. Special Publication. n. 31, 661 p. 393 pls.

Lohmann, G. P., 1978. Abyssal benthonic foraminifera as hydrographic indicators in the western South Atlantic Ocean. J. Foraminiferal Res. 8, 6–34.

Lisboa, L. P., 2006. Paleoecologia e bioestratigrafia em foraminíferos do talude continental da Bacia do Espírito Santo: Estudo em dois “piston cores”. Unpublished thesis. Departamento de Oceanografia e Ecologia, Universidade Federal do Espírito Santo, Vitória, Brazil. 76 p.

Lopes, R. M., Katsuragawa, M, Dias, J. F., Montú, M. A., Muelbert, J. H., Gorri, C., Brandini, F. P., 2006. Zooplankton and ichthyoplankton distribution on the southern Brazilian shelf: an overview. Science Marine 70, 189–202. https://doi.org/10.3989/scimar.2006.70n2189

Mackensen, A., Sejrup, H. P., Jansen, E., 1985. The distribution of living benthic foraminifera on the continental slope and rise off southwest Norway. Mar. Micropaleontol. 9, 275–306. https://doi.org/10.1016/0377-8398(85)90001-5

Mackensen, A., Schmiedl, G., Harloff, J., Giese, M., 1995. Deep-sea foraminifera in the South Atlantic Ocean: Ecology and assemblage generation. Micropaleontology. 41, 342–358. https://doi.org/10.2307/1485808

Magurran, A. E., 2004. Measuring Biological Diversity. Blackwell Publishing.

Maia, L. P., Castelo-Branco, M. P. N., Soares, R. S., Catunda B. N., Bastos, A. C., Leal, C. A., Marcon, E. H., 2015. Sedimentologia da Margem Continental da Bacia do Espírito Santo e Norte da Bacia de Campos. In: Relatório Final do Projeto de Caracterização Ambiental Regional da Bacia do Espírito Santo e parte norte da Bacia de Campos (PCR-ES), Anexo II, Petrobras, Rio de Janeiro, Brazil.

Martins, T. R., 2014. A Corrente do Brasil no Embaiamento de Tubarão - Oceano Atlântico Sudoeste. Unpublished thesis. Departamento de Oceanografia e Ecologia, Universidade Federal do Espírito Santo. Vitória, Brazil. 57 p.

Martorelli, E., Bosman, A., Casalbore, D., Chiocci, F., Conte, A. M., Di Bella, L., Ercilla, G., Falcini, F., Falco, P., Frezza, V., Gaglianone, G., Giaccio, B., Mancini, M. 2021. Mid-to-late Holocene upper slope contourite deposits off Capo Vaticano (Mediterranean Sea): High-resolution record of contourite cyclicity, bottom current variability and sandy facies. Marine Geology 431, 106372. https://doi.org/10.1016/j.margeo.2020.106372

Mello, R. M. de., 2006. Caracterização da Fauna de Foraminíferos Bentônicos do Talude da Bacia de Campos, RJ, e sua Correlação com os Parâmetros das Massas d´água do Atlântico Sul. Unpublished thesis. Instituto de Geociências, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil. 196 p.

Mello, R. M. M., Leckie, R. M., Frass, A. J., Thomas, E., 2016. Upper Maastrichtian – Eocene benthic foraminiferal biofacies of the Brazilian margin, western South Atlantic. In: Kaminski, M. A., Alegret, L. (Eds.). Proceedings of the Ninth International Workshop on

Agglutinated Foraminifera. Grzybowski Foundation Special Publication 22, 119–161. https://doi.org/10.2307/3515178

Mémery, L., Arthan, M., Alvarez-Salgado, X. A., Messias, M. J., Mercier, H., Castro, C. G., Rios, A. F., 2000. The water masses along the western boundary of the south and equatorial Atlantic. Prog. Oceanogr. 47, 69–98. https://doi.org/10.1016/S0079-6611(00)00032-X

Mill, G. N., Costa, V. S., Lima, N. D., Gabioux, M., Guerra, L. A. A., Paiva, A. M., 2015. Northward migration of Cape São Tomé rings, Brazil. Cont. Shelf Res. 106, 27–37. http://dx.doi.org/10.1016/j.csr.2015.06.010

Motoki, A., Motoki, K. F., Melo, D. P., 2012. Caracterização da morfologia submarina da Cadeia Vitória-Trindade e áreas adjacentes-ES, com base na batimetria predita do topo versão 14.1. Rev. Bras. Geomorfol. 13, 151–170. http://dx.doi.org/10.20502/rbg.v13i2.195

Murray, J. W., 2006. Deep sea. In: Ecology and applications of benthic foraminifera. Cambridge University Press, Cambridge. pp. 180-237.

Nagai, R. H., Sousa, S. H. M., Burone, L., Mahiques, M. M., 2009. Paleoproductivity changes during the Holocene in the inner shelf of Cabo Frio, southeastern Brazilian continental margin: benthic foraminifera and sedimentological proxies. Quat. Int. 206, 62–71. https://doi.org/10.1016/j.quaint.2008.10.014

Nagai, R. H., Sousa, S. H. M., Lourenço, R. A., Bícego, M. C., Mahiques, M. M., 2010. Paleoproductivity changes during the late quaternary in the southeastern Brazilian upper continental margin of the Southwestern Atlantic. Braz. J. Oceanogr. 58, 31–41. https://doi.org/10.1590/S1679-87592010000500004

Napolitano, D. C., Silveira, I. C. A., Rocha, C. B., Flierl, G. R., Calil, P. H. R., Martins, R. P., 2019. On the steadiness and instability of the intermediate western boundary current between 24° and 18°S. J. Phys. Oceanogr. 49, 3127–3143. https://doi.org/10.1175/JPO-D-19-0011.1

Ohkushi, K., Thomas, E., Kawahata, H., 2000. Abyssal benthic foraminifera from the northwestern Pacific (Shatsky Rise) during the last 298 kyr. Mar. Micropaleontol. 38, 119–147. https://doi.org/10.1016/S0377-8398(99)00040-7

Oliveira, K. S. S., Quaresma, V. S., 2017. Temporal variability in the suspended sediment load and streamflow of the Doce River. J. S. Am. Earth Sci. 78, 101–115. https://doi.org/10.1016/j.jsames.2017.06.009

Oliveira, N., Bastos, A. C., Quaresma, V. S., Vieira, F. V., 2020. The use of Benthic Terrain Modeler (BTM) in the characterization of continental shelf habitats. Geo-Mar. Lett. 40, 1087–1097. https://doi.org/10.1007/s00367-020-00642-y

Palóczy, A., Brink, K. H., Silveira, I. C. A., Arruda, W. Z., Martins, R. P., 2016. Pathways and mechanisms of offshore water intrusions on the Espírito Santo Basin shelf (18°S–22°S, Brazil). J. Geophys. Res. Oceans 121, 5134–5163. https://doi.org/10.1002/2015JC011468

Patterson, R. T., Richardson, R. H., 1987. A taxonomic revision of the Unilocular foraminifera. J. Foraminiferal Res. 17, 212–226. https://doi.org/10.2113/gsjfr.17.3.212

Quaresma, V. S., Catabriga, G., Bourguignon, S. N., Godinho, E., Bastos, A. C., 2015. Modern sedimentary processes along the Doce river adjacent continental shelf. Braz. J. Geol. 45, 635–644. https://doi.org/10.1590/2317-488920150030274

Rathburn, A. E., Corliss, B. H., 1994. The ecology of living (stained) deep-sea benthic foraminifera from the Sulu Sea. Paleoceanography 9, 87–150. https://doi.org/10.1029/93PA02327

Reid, J. L., 1989. On the total geostrophic circulation of the South Atlantic Ocean: flow patterns, tracers, and transports. Prog. Oceanogr. 23, 149–244. https://doi.org/10.1016/0079-6611(89)90001-3

Rocha, G. A., Bastos, A. C., Amado-Filho, G. M., Boni, G. C., Moura, R. L., Oliveira, N., 2020. Heterogeneity of rhodolith beds expressed in backscatter data. Mar. Geol. 423. https://doi.org/10.1016/j.margeo.2020.106136

Rodrigues, A. R., Pível, M. A. G., Schmitt, P., de Almeida, F. K., Bonetti, C., 2018. Infaunal and epifaunal benthic foraminifera species as proxies of organic matter paleofluxes in the Pelotas Basin, south-western Atlantic Ocean. Mar. Micropaleontol. 144, 38–49. https://doi.org/10.1016/j.marmicro.2018.05.007

Schmid, C., Schafer, H., Podesta, G., Zenk, W., 1995. The Vitoria Eddy and Its Relation to the Brazil Current, J. Phys. Oceanogr. 25, 2532–2546. https://doi.org/10.1175/1520-0485(1995)025<2532:TVEAIR>2.0.CO;2

Schmiedl, G., Mackensen, A., 1997. Late Quaternary paleoproductivity and deep-water circulation in the eastern South Atlantic Ocean, evidence from benthic foraminifera. Palaeogeogr. Palaeoclimatol. Palaeoecol. 130, 43–80. https://doi.org/10.1016/S0031-0182(96)00137-X

Schmiedl, G., Mackensen, A., Müller, P. J., 1997. Recent benthic foraminifera from the eastern South Atlantic Ocean: dependence on food supply and water masses. Mar. Micropaleontol. 32, 249–287. https://doi.org/10.1016/S0377-8398(97)00023-6

Schmitt, P., Rodrigues, A. R., Bonetti, C., 2019. Sucessão de associações de foraminíferos bentônicos como indicadoras de variações paleoceanográficas no Terraço de Torres (RS - Brasil) durante o Quaternário Tardio. Anu. do Inst. de Geocienc. UFRJ 42, 387–395. http://dx.doi.org/10.11137/2019_4_387_395

Schnitker, D., 1994. Deep-Sea Benthic Foraminifers: Food and Bottom Water Masses. In: Zahn R., Pedersen T.F., Kaminski M.A., Labeyrie L. (Eds.). Carbon Cycling in the Glacial Ocean: Constraints on the Ocean's Role in Global Change. NATO ASI Series (Series I: Global Environmental Change), vol 17. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-78737-9_23

Schreiner, S., Souza, M. B. F. M., Migliorelli, J. P. R., 2008. Modelo digital da geomorfologia do fundo oceânico da Bacia de Campos, Boletim de Geociências da Petrobras 16, 157–160.

Schreiner, S.; Souza, M. B. F. M.; Migliorelli, J. P. R., 2009. Modelo digital da geomorfologia do fundo oceânico do centro-sul da Bacia do Espírito Santo e norte da Bacia de Campos. Boletim de Geociências da Petrobras 17, 365–369.

Schreiner, S., Hercos, C. M., 2015. Geomorfologia do talude continental, platô de São Paulo e sopé continental. In: Relatório Final do Projeto de Caracterização Ambiental Regional da Bacia do Espírito Santo e parte norte da Bacia de Campos (PCR-ES), Anexo II, Petrobras, Rio de Janeiro, Brazil.

Sen Gupta, B. K., 1999. Introduction to modern foraminifera. In: Sen Gupta, B. K. (Ed.), Modern Foraminifera. Kluwer Academic Publishers, Dordrecht, pp. 3–6.

Silveira, I. C. A., Brown, W. S., Flierl, G. R., 2000. Dynamics of the North Brazil Current retroflection from the WESTRAX observations. J. Geophys. Res. 105 (C12), 28559–28583. https://doi.org/10.1029/2000JC900129

Silveira, I. C. A., Calado, L., Castro, B. M., Cirano, M., Lima, J. A. M., Mascarenhas, A. S., 2004. On the baroclinic structure of the Brazil Current-Intermediate Western boundary Current system at 22°–23°S. Geophys. Res. Lett. 31, L14308. https://doi.org/10.1029/2004GL020036

Silveira, I. C. A., Lima, J. A., Schmidt, A. C. K., Ceccopieri, W., Sartori, A., Fontes, R. F. C., 2008. Is the meander growth in the Brazil Current system due to baroclinic stability? Dyn. Atmos. Oceans. 45, 187–207. https://doi.org/10.1016/j.dynatmoce.2008.01.002

Silveira, I. C. A., Napolitano, D. C., Palóczy Filho, A., Watanabe, G. A. O., Baldasso, P., Calixto, P. S., Yamashita, M. K., Castro, B. M., Godoi, S. S., Arruda, W. Z., Paranhos, R. P. R., Martins, R. P., Grossman-Matheson, G. S., Cavalcante, L. M., Ribeiro, E. O., 2015. Massas de água e circulação do talude continental e região oceânica da Bacia de Espírito Santo e norte da Bacia de Campos. In: Relatório Final do Projeto de Caracterização Ambiental Regional da Bacia do Espírito Santo e parte norte da Bacia de Campos (PCR-ES), Anexo II, Petrobras, Rio de Janeiro, Brazil.

Silveira, I. C. A., Napolitano, D.C., Farias, I. U., 2020. Water Masses and Oceanic Circulation of the Brazilian Continental Margin and Adjacent Abyssal Plain. In: Sumida, P. Y. G., Bernardino, A. F., De Léo F. C. (Eds.) Brazilian Deep-Sea Biodiversity. Brazilian Marine Biodiversity. Springer, Cham. https://doi.org/10.1007/978-3-030-53222-2_2

Smart, C. W., King, S. C., Gooday, A. J., Murray, J. W., Thomas, E., 1994. A benthic foraminiferal proxy of pulsed organic matter paleofluxes. Mar. Micropaleontol. 23, 89–99. https://doi.org/10.1016/0377-8398(94)90002-7

Smart, C. W., 2008. Abyssal NE Atlantic benthic foraminifera during the last 15 kyr: relation to variations in seasonality of productivity. Mar. Micropaleontol. 69, 193–211. https://doi.org/10.1016/j.marmicro.2008.07.007

Smart, C. W., Thomas, E., Bracher, C. M., 2019. Holocene variations in North Atlantic export productivity as reflected in bathyal benthic foraminifera. Mar. Micropaleontol. 149, 1–18. https://doi.org/10.1016/j.marmicro.2019.03.004

Soares, R. S., 2017. Novas Proposições Metodológicas Para o Calcímetro de Bernard e Caracterização dos Sedimentos Marinhos do Espírito Santo. Unpublished thesis. Instituto de Ciências do Mar, Universidade Federal do Ceará, Fortaleza, Brazil. 90 p.

Sobreira, J. F. F., França, R. L., 2006. Um modelo tectonomagmático para a região do Complexo Vulcânico de Abrolhos. Boletim de Geociências da Petrobras 14, 143–147.

Sousa, S. H. M., Passos, R. F., Fukumoto, M., da Silveira, I. C. A., Figueira, R. C. L., Koutsoukos, E. A. M., Mahiques, M. M., Rezende, C. E., 2006. Mid-lower bathyal benthic foraminifera of the Campos Basin, Southeastern Brazilian margin: Biotopes and controlling ecological factors. Mar. Micropaleontol. 61, 40–57. https://doi.org/10.1016/j.marmicro.2006.05.003

Sousa, S. H. M., Yamashita, C., Nagai, R. H., Martins, M. V. A., Ito, C., Vicente, T., Taniguchi, N., Burone, L., Fukumoto, M., Aluizio, R., Koutsoukos, E. A. M., 2017. Foraminíferos bentônicos no talude continental, platô de São Paulo e cânions da Bacia de Campos. In: Falcão, A. P. C., Lavrado, H. P. (Eds.). Ambiente Bentônico: caracterização ambiental regional da Bacia de Campos, Atlântico Sudoeste. Rio de Janeiro, Elsevier, Habitats 3, 111–144. https://doi.org/10.1016/B978-85-352-7263-5.50005-9

Soutelino, R. G., Silveira, I. C. A., Gangopadhyay, A., Miranda, J. A., 2011. Is the Brazil Current eddy-dominated to the north of 20° S? Geophys. Res. Lett. 38, L03607. https://doi.org/10.1029/2010GL046276

Soutelino, R. G., Gangopadhyay, A., Silveira, I. C. A., 2013. The roles of vertical shear and topography on the eddy formation near the site of origin of the Brazil Current. Cont. Shelf Res. 70, 46–60. https://doi.org/10.1016/j.csr.2013.10.001

Statsoft, Inc. 2001. STATISTICA Data Analysis Software System. Available on-line: http://www.statsoft.com

Stramma, L., Ikeda, Y., Peterson, R. G., 1990. Geostrophic transport in the Brazil Current region north of 20° S. Deep-Sea Res. Part I Oceanogr. Res. Pap. 37, 1875–1886. https://doi.org/10.1016/0198-0149(90)90083-8

Stramma, L., England, M., 1999. On the water masses and mean circulation of the South Atlantic Ocean. J. Geophys. Res. 104, 20863–20883. https://doi.org/10.1029/1999JC900139

Suguio, K., 1973. Introdução à Sedimentologia. Edgard Blücher Ltda, São Paulo.

Sun, X., Corliss, B. H., Brown, C. W., Showers, W. J., 2006. The effect of primary productivity and seasonality on the distribution of deep-sea benthic foraminifera in the North Atlantic. Deep-Sea Res. Part I Oceanogr. Res. Pap. 53, 28–47. https://doi.org/10.1016/j.dsr.2005.07.003

Thomas, E., Booth, L., Maslin, M., Schackleton, N. J., 1995. Northeastern Altantic benthic foraminifera during the last 45,000 years: Changes in productivity seen from the bottom up. Paleoceanography 10, 545–562. https://doi.org/10.1029/94PA0305

Turley, C., 2002. The importance of “marine snow”. Microbiology Today 29, 177–179.

van der Zwaan, G. J., Jorissen, F. J., Stigter, H. C., 1990. The depth dependency of planktonic/benthic foraminiferal ratios: Constraints and applications. Mar. Geol. 95, 1–16. https://doi.org/10.1016/0025-3227(90)90016-D

van der Zwaan, G. J., Duijnstee, I. A. P., den Dulk, M., Ernst, S. R., Jannink, N. T., Kouwenhoven, T. J., 1999. Benthic foraminifers: proxies or problems?: A review of paleocological concepts. Earth-Science Reviews, 46, 213–236. https://doi.org/10.1016/S0012-8252(99)00011-2

van Morkhoven, F. P. C. M., Berggren, W. A., Edwards, A. S., 1986. Cenozoic cosmopolitan deep-water benthic foraminifera. Bull. Cent. Rech. Explor. Prod. Elf-Aquitaine. Mem.11. 421 p., 126 pls.

Viana, A. R., Faugeres, F. C., Kowsmann, R. O., Lima, J. A. M., Caddah, L. F. G., Rizzo, J. G., 1998. Hydrology: morphology and sedimentology of the Campos continental margin, offshore Brazil. Sediment. Geol. 115, 133–157. https://doi.org/10.1016/S0037-0738(97)00090-0

Vicalvi, M. A., Kowsmann, R. O., 2006. Application of foraminiferal biostratigraphy to the assessment of submarine geohazards. In: International Symposium of Foraminifera – FORAMS, 2006, Natal, Brazil.

Vieira, F. V., Bastos, A. C., Quaresma, V. S., Leite, M. L., Costa Jr., A., Oliveira, K. S. S, Dalvi, C. F., Bahia, R. G., Holz, V. L., Moura, R. L., Amado-Filho, G. M., 2019. Along-shelf changes in mixed carbonate-siliciclastic sedimentation patterns. Cont. Shelf Res. 187, 103964. https://doi.org/10.1016/j.csr.2019.103964

Yamashita, C., Nagai, R. N., Martins, M. V. A., Vicente, T. M., Sousa, S. H. M., Frontalini, F., et al., 2016. On the interplay between hydrodynamics, bottom morphology, sedimentary processes and benthic foraminifera assemblages in the São Paulo Bight (Brazil, SW Atlantic). J. Sediment. Environ. 3, 334–355. https://doi.org/10.12957/jse.2016.25990

Yamashita, C., Martins, M. V. A., Melo e Sousa, S. H., Vicente, T. M., Kaminski, M. A., Frontalini, F., Carreira, R., Godoi, S. S., Taniguchi, N. K., Paranhos, R., Figueira, R. C. L., de Rezende, C. E. 2017. Distribution and ecology of living (Rose Bengal stained) Marsipella elongata Norman, 1878 (Foraminifera) in the Campos Basin, southeastern Brazilian continental margin. Micropaleontology 63, 321–334.

Yamashita, C., Sousa, S. H. M., Vicente, T. M., Martins, M. V., Nagai, R. H., Frontalini, F., Godoi, S. S., Napolitano, D., Burone, L., Carreira, R., Figueira, R. C. L, Taniguchia, N. K., Rezende, C.E., Koutsoukos, E. A. M., 2018a. Environmental controls on the distribution of living (stained) benthic foraminifera on the continental slope in the Campos Basin area (SW Atlantic). J. Mar. Syst. 181, 37–52. https://doi.org/10.1016/j.jmarsys.2018.01.010

Yamashita, C., Sousa, S. H. M., Kaminski, M. A., and de Araujo, B. D., 2018b. Description, distribution and ecology of living (rose Bengal stained) Eggerelloides camaransis n. sp. Micropaleontology 64, 515-525.

2.2 SUBMARINE CANYONS INFLUENCE IN THE RECENT BENTHIC FORAMINIFERAL ASSEMBLAGES, ESPÍRITO SANTO BASIN, SOUTHEASTERN BRAZIL (SW ATLANTIC)

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ABSTRACT

The heterogeneity of the continental margins seafloor may result in differences in the benthic assemblages composition. Submarine canyons are features with higher complex topography than the adjacent slope. To understand the influence of the submarine canyons over benthic foraminiferal assemblages, and to corroborate paleoenvironmental interpretations in the Late Holocene, we investigated benthic foraminiferal assemblages (total fauna > 63 µm) and sedimentological data along two canyons (CANWN and CAND) in the Espírito Santo Basin between 18°20' and 21°20' S. Surface sediment samples (0-2 cm) were collected inside the canyons (150 to 1300 m water depth) and in the nearest shelf-slope adjacent transects (50 to 1300 m water depth). The density, taxonomic diversity, and assemblage composition change with depth and locally. Distinct ecological preferences among the most abundant taxa allowed to recognize five benthic foraminiferal groups. Three groups (V, III, and I) are distributed in three main bathymetric sectors: outer shelf, upper, and middle – lower slope, whereas the other two (II and IV) are related to each canyon. The species that contribute most to Group I (middle – lower open slope, 1000 to 1300 m) are *Globocassidulina crassa*, *Bolivina lowmani*, *Gavelinopsis versiformis*, *Alabaminella weddellensis*, and *Epistominella exigua*. The main species related to Group II (CAND, 150, 1000 to 1300 m) are *Trifarina angulosa*, *Globocassidulina subglobosa*, and *Discorbis vilardeboanus*. In Group III (upper slope, 150 to 400 m), *Globocassidulina rossensis* is dominant, and *Trifarina* spp. is abundant. Agglutinated species contribute most to Group IV (middle-lower CANWN, 1000 to 1300 m), mainly *Glomospira charoides*, *Rhabdammina abyssorum*, and *Psammosphaera fusca*. The main species related to Group V (outer shelf, 50 m) are *Hanzawaia boueana*, *Peneroplis planatus*, and *Quinqueloculina lamarckiana*. Our data corroborates that the quantity (and quality) of food supply, hydrodynamics conditions, and sediment properties are the main environmental factors controlling the distribution of benthic foraminiferal assemblages along water depth and inside the canyons. The middle-lower CANNW revealed unstable trophic conditions, related to terrigenous sediment influx due to turbidity currents. In the CAND, foraminiferal assemblages ecology indicated enough organic matter content that benefits species establishment and diversity, indicating an environment more productive and less unstable than the CANWN.

Key words: *benthic foraminifera, submarine canyon, slope, Brazilian Continental Margin, SW Atlantic.*

1. INTRODUCTION

Submarine canyons are deep incisions particularly common along continental margins (Shepard, 1972; Amblas et al., 2018). They act as important channels, transporting terrigenous sediment from the shelf environments to the deep ocean (Puig et al., 2014; Amblas et al., 2018). The prevailing model for canyon origin is based on evidence of exposure canyon heads during sea level lowstands (Amblas et al., 2018). The downslope transport of material, and the associated turbidity currents erode the seafloor, accumulating sediment over long distances from the canyon head (Koho et al., 2007). Even inactive submarine canyons may still channel offshore any material that is received (Kennet, 1982).

The variability of submarine canyon topography enables distinct benthic ecological niches. Specific biotic and abiotic parameters are noticeably different from those of the open slope (Amblas et al., 2018). Submarine canyons have great ecological importance to continental margins (Harris and Whiteway, 2011; De Leo et al., 2020) because they can be sites of enhanced organic-matter flux and deposition, which makes them potential hotspots of benthic biomass and productivity (De Leo et al., 2010). Therefore, sedimentary dynamics and variable organic matter concentration in the canyons lead to particular ecological conditions compared to open slope settings (Duros et al., 2013), and support distinct benthic assemblages in the deep sea (Bernardino et al., 2019).

Studies carried out in submarine canyons suggest specific ecological conditions in the benthic foraminiferal distribution patterns due to sediment instability and turbidity current activity (Jorissen et al., 1994; Schröder-Adams et al., 2008; Hess and Jorissen, 2009; Duros et al., 2017), or to organic carbon fluxes (Schmiedl et al., 2000; Fontanier et al., 2005; Koho et al., 2007; Sousa et al., 2017; Di Bella et al., 2017). The environmental parameters governing the distribution of benthic foraminiferal assemblages consist of a complex interplay between physical and biological factors (Jorissen et al., 1995; 2007). However, the quantity (and quality) of organic matter, along with bottom water oxygenation, are the essential factors that control benthic foraminiferal density and composition in the deep sea (Gooday, 1988; 1993; 1996; 2002; Corliss and Chen, 1988; Corliss, 1991; Fariduddin and Loubere, 1997; Schmiedl and Mackensen, 1997; Altenbach et al., 1999; Fontanier et al., 2002, 2005; de Almeida et al., 2015; 2022 Rodrigues et al., 2018). The hydrodynamic conditions of the bottom waters and the sediment grain size appear to play a minor role in determining the benthic foraminiferal distribution

(Schnitker, 1974; Mackensen et al.,1985; 1995; Schmiedl et al., 1997; Jorissen et al. 2007).

Although benthic foraminiferal are among the most common organisms found on the ocean floor, their distribution remains poorly documented at the Brazilian Continental Margin, and coincides with areas targeted by the offshore oil and gas industry. The majority of these studies focus on the slope of the Campos Basin (Sousa et al., 2006; 2017; Mello, 2006; Nagai et al., 2009; 2010; Barbosa, 2010; Burone et al., 2011; Yamashita et al., 2016; 2018a; 2018b; Saupe et al., 2022), the Santos Basin (Barbosa, 2002; Ferreira et al., 2014; de Almeida et al., 2015; Yamashita et al., 2016) and the Pelotas Basin (García-Chapori et al., 2014; Rodrigues et al., 2018; Schmitt et al., 2019). Studies focusing on recent benthic foraminifera within submarine canyons are even more scarce. Some research has been recently performed in the Almirante Câmara, Grussaí, and Itapemirim canyons at the Campos Basin (Sousa et al., 2017; Yamashita et al, 2018a), and in the São Francisco Canyon, at Sergipe-Alagoas Basin (Araújo et al., 2018).

The Espírito Santo Basin (ESB) is very distinct from the other Brazilian marginal basins because of a significant variation in the continental shelf width, change in the shelf-break orientation, shifts in sedimentation regimes, and complex morphological structures on the seafloor (Schreiner et al., 2009; Bastos et al., 2015). These unique characteristics make this basin a great opportunity to expand knowledge about variations in the benthic foraminiferal distribution on a heterogeneous seafloor. In a previous study, de Almeida et al. (2022) analyzed the benthic foraminiferal assemblages distribution on the ESB slope and discussed the main environmental factors and mechanisms involved. In the present work, our main goal is to analyze whether and how the environmental factors of the submarine canyons exert influence over benthic foraminiferal composition. In addition, this study attempts to verify: (1) if the benthic foraminiferal assemblages from two submarine canyons differ from each other, and (2) if the assemblages from the ESB outer shelf extend their abundance into the upper slope. To address these goals, we investigate the microfaunal and sedimentological composition inside the canyons and in the nearest shelf-slope transects, sampled in similar water depths. This dataset (shelf-canyon-slope) enables us to contribute to the knowledge of distinct mechanisms controlling the benthic foraminiferal distribution in a heterogeneous seafloor, and the interaction between these environments in the Late Holocene.

2. REGIONAL SETTINGS

The ESB is located in the southeastern Brazilian Continental Margin between 18°20' and 21°20' S. (Fig. 1). The ESB is limited by the Campos Basin (RJ) to the south, by the Abrolhos Shelf to the north (França and Tokutake, 2004; França et al., 2007), and by the linear sequence of seamounts of the Vitória-Trindade Ridge (VTR) to the east (Motoki et al., 2012).

The ESB shelf varies in width and shelf-break depths, presenting nowadays a morphology that was shaped by several changes in relative sea level during the Quaternary, with controlled sediment distribution (Bastos et al., 2015). In front of the Doce River, the shelf width is around 50-60 km, with a shelf break depth of around 60-70 m water depth. The Doce River discharges a large input of terrigenous sediments over the continental shelf (Quaresma et al., 2015; Oliveira and Quaresma, 2017). Towards the north, the Abrolhos Shelf (> 240 km wide), a volcanic complex formed during the Paleogene (Sobreira and França, 2006), break at a water depth of 80-90 m (Bastos et al., 2015; Vieira et al., 2017). Shelf sedimentation is essentially mixed (coeval carbonate/terrigenous deposition), with rhodolith beds along the entire outer shelf (Bastos et al., 2015; D'Agostini et al., 2015, 2019; Bourguignon et al., 2018; Vieira et al., 2019; Oliveira et al., 2020). The Doce River Shelf presents a supply regime (Quaresma et al., 2015; Bastos et al., 2015), whereas the Abrolhos Shelf presents carbonate sedimentation (Leão et al. 2003; Amado-Filho et al., 2012; Moura et al., 2012; Moura et al. al., 2013; Bastos et al. 2015).

The present-day ESB slope morphology results from several processes, such as sea-level variations, remobilization of bottom sediments through gravity flow, the influence of boundary currents, emplacement of turbiditic systems associated with river discharge, and salt tectonic (Schreiner et al. 2008; 2009). A dense submarine drainage system indents the ESB slope, including the Doce and Watu Norte canyons, with their respective turbiditic systems (Schreiner et al., 2009). The Doce Canyon (CAND) is a mature canyon that indents the South Abrolhos Shelf and develops along the slope and São Paulo plateau. The CAND may have its origin associated with the evolution of the Doce River fluvial system during sea level lowstands (Hercos et al., 2015). The Watu Norte Canyon develops from the edge of the present-day Doce River shelf to a distal gutter, where it meets the Doce Turbidite System (Hercos and Schreiner, 2006; Schreiner and Hercos, 2015). During the Holocene, the sea level rise interrupted almost all of these depositional processes (Vicalvi and Kowsmann, 2006). The morphological features on the ESB slope can be considered fossils and inherited from the Upper Pleistocene, prevailing a Holocene sediment drape that covers the entire seafloor (Schreiner and Hercos, 2015). The Holocene sedimentation rates are relatively low, ranging from ≤ 2.5 to 6 cm kyr $^{-1}$ (Schreiner and Hercos, 2015).

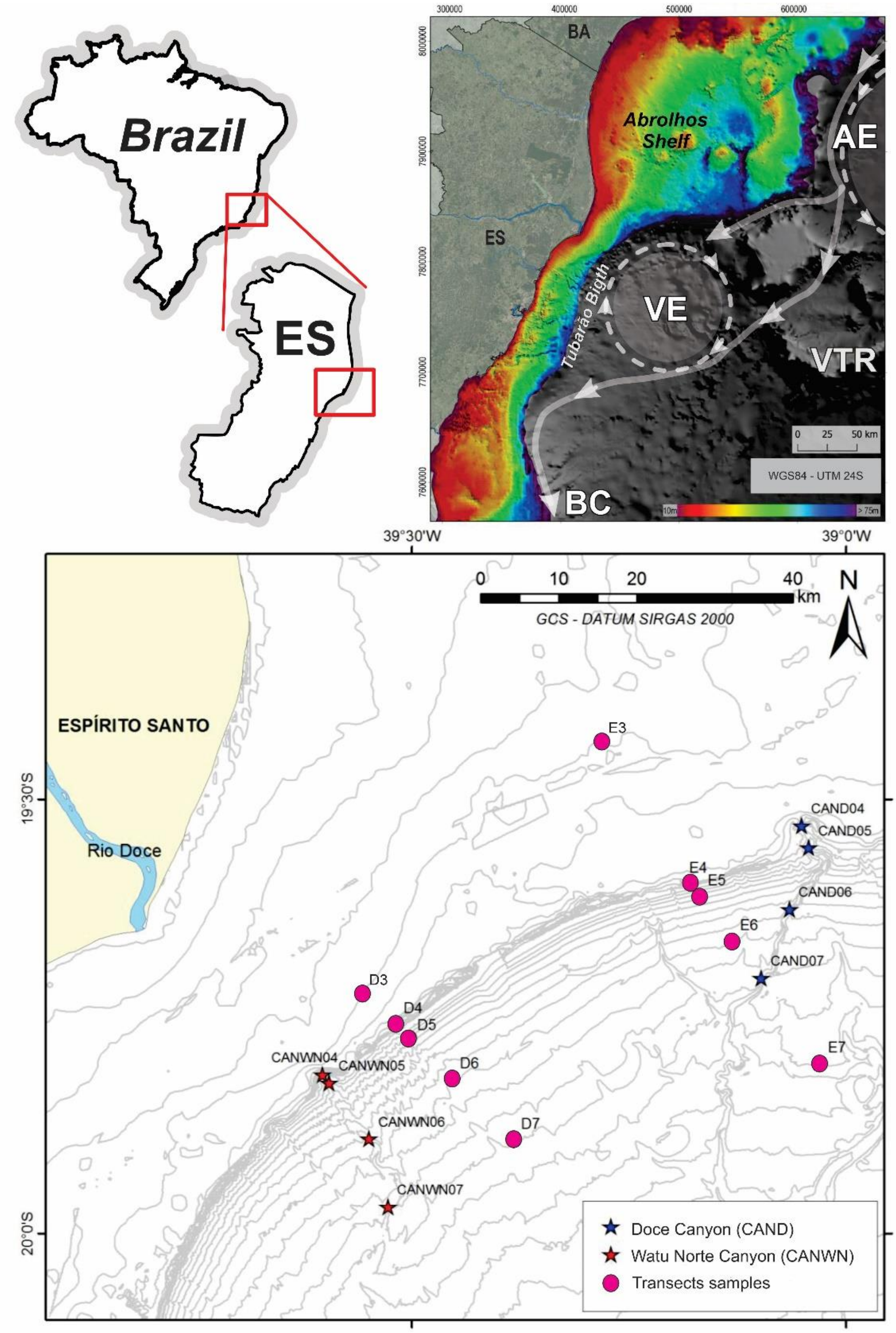

Figure 1: *Samples location distributed in the submarine canyons and adjacent shelf-slope transects from the Espírito Santo Basin. Adapted from Ribeiro-Ferreira et al. (2015). Shelf bathymetric background adapted from Bastos et al. (2015).*

The complex topography of the study area influences regional hydrodynamics, with an intricate flow pattern associated with surface and intermediate currents, current meanders, and vortical features (Soutelino et al., 2011; 2013; Silveira et al., 2020). Surface waters of the ESB are dominated by the southward-flowing Brazil Current (BC), which is the western boundary current associated with the anticyclonic South Atlantic Subtropical Gyre (Stramma et al., 1990; Stramma and England 1999; Campos et al., 2000). The BC brings warm and oligotrophic waters over the shelf (Soutelino et al. 2013; Palóczy et al. 2016). As the BC crosses the Vitória-Trindade Ridge (VTR), this surface current usually loses bathymetric orientation, bifurcating or trifurcating along the channels to the west of the VTR and Abrolhos Shelf (Ghisolfi et al., 2015; Silveira et al., 2020). The ramification of the BC results in an eddy-dominated flow (Soutelino et al., 2011), that reattaches to the shelf break at approximately 21°30' S (Arruda and Silveira, 2019).

The Brazilian Continental Margin has been considered typically oligotrophic (Gaeta and Brandini, 2006). However, episodic intrusions of cold, nutrient-rich South Atlantic Central Water (SACW) on the ESB continental shelf (Palóczy et al., 2016) is responsible for surface waters enrichment, and consequently increases primary production that can be seen on benthic fauna assemblages distribution (Bernardino et al., 2016, de Almeida et al. 2022). Moreover, the quasi-stationary and recurrent eddies also play an important role in the nutrient enrichment of surface waters. The cyclonic Vitória Eddy (VE, ~20°30' S, ~ 50 km average radius) is generally constrained by the ESB shelf to the west, by the Abrolhos Shelf to the north, and by the Besnard Bank to the east (Arruda and Silveira, 2019), and was observed in previous studies (Schmid et al., 1995; Gaeta et al., 1999; Campos, 2006; Silveira et al., 2015; 2020). The anticyclonic Abrolhos Eddy (AE, ~19˚ S) can move southward and interacts with the VE in the vicinity of the ESB, promoting an AE-VE interaction (Arruda et al., 2013; Arruda and Silveira, 2019). In the VE mixing layer, the nutrient concentration and primary productivity are up to twice higher than in the surrounding oligotrophic waters (Gaeta et al., 1999). Therefore, the pumping of nutrient-rich waters by the VE contributes significantly to the local increase in phytoplankton production (Martins, 2014).

Five major water masses compose the stratification of 3000 m of the water column at the ESB (Table 1), with their respective current flow directions: (i) Tropical Water (TW), flowing southward and transported by the Brazil Current (BC) between 0 and 150 m depth; (ii) South Atlantic Central Water (SACW), flowing southward and transported by the BC, between 150 and 500 m depth; (iii) Antarctic Intermediate Water (AAIW), flowing northward and transported by the Intermediate Western Boundary Current (IWBC) between 500 and 1000 m depth; (iv) Upper Circumpolar Water (UCPW), flowing northward also transported by the IWBC between 1000 and 1300 m; (v) North Atlantic Deep Water (NADW) flowing southward and transported by the Deep Western Boundary Current (DWBC) between 1300 and 3000 m (Stramma and England, 1999; Silveira et al., 2020). The UCPW is limited to 20°S (Reid, 1989; Mémery et al., 2000; Silveira et al., 2020), presenting a weak signature, usually found diluted in the AAIW-NADW interface. (Silveira et al., 2020; Perassoli et al., 2020). As the IWBC reaches the ESB, it recirculates cyclonically, forming a stationary eddy at intermediate levels (Costa et al., 2017; Napolitano et al., 2019).

3. MATERIALS AND METHODS

3.1 Sample collection

The present study is based on the sediment samples collected by the Espírito Santo Basin Assessment Project (AMBES, CENPES/PETROBRAS), which sampled the ESB during the years of 2008 – 2014. The 18 sediment samples (0-2 cm) were collected with a box-corer (canyons and adjacent slope) and a modified Van-Veen (shelf) during an oceanographic cruise in 2013, which only allowed a total microfauna census study based on recent benthic foraminifera. Samples are distributed into two submarine canyons, the Watu Norte (CANWN) and Doce (CAND), and two nearby shelf-slope transects (D and E) at waters depths of 50, 150, 400, 1000 and 1300 m (Fig. 1, Table 1).

3.2 Sedimentological data

The sedimentological data set used in our study is a compilation by Maia et al. (2015) that include sediment grain size, calcium carbonate ($CaCO_3$), and total organic matter content (TOM). Because these authors performed analyzes in replicates, we chose to use the median values of the parameters measured in each sample. Gravel and sand fractions were analyzed by standard wet sieving methods and mud fraction through pipetting (Suguio, 1973; Dias, 2004). The Carbonate content (%$CaCO_3$) was determined by calcium carbonate loss by dissolution (HCl 10%), using a modified Bernard Calcimeter (Soares, 2017). The TOM content (%TOM) was determined after combustion at 450 °C, by the mass difference between dry and ash-free dry sediment samples.

Table 1: *Sampling location, water depth, the respective environments, and water masses at the Espírito Santo Basin. TW, Tropical Water; SACW, South Atlantic Central Water; AAIW, Antarctic Intermediate Water; NADW, North Atlantic Deep Water. Environments terminology follows Bastos et al. (2015) and Schreiner and Hercos (2015). Water masses configuration according to Silveira et al. (2020).*

Sample	Isobath (m)	Latitude (S)	Longitude (W)	Environment	Water mass
D03	50	-19.720647	-39.559660	Outer shelf	TW
D04	150	-19.764841	-39.507215	Upper slope	TW-SACW
D05	400	-19.775790	-39.501013	Upper slope	SACW
D06	1000	-19.835003	-39.442950	Middle slope	AAIW
D07	1300	-19.901325	-39.374851	Lower slope	AAIW-NADW
CANWN 04	150	-19.434670	-39.294068	Watu Norte Canyon (head)	TW-SACW
CANWN 05	400	-19.600991	-39.176010	Watu Norte Canyon (upper)	SACW
CANWN 06	1000	-19.608499	-39.172054	Watu Norte Canyon (middle)	AAIW
CANWN 07	1300	-19.667071	-39.122775	Watu Norte Canyon (lower)	AAIW-NADW
E03	50	-19.784011	-39.054062	Outer shelf	TW
E04	150	-19.531017	-39.051121	Upper slope	TW-SACW
E05	400	-19.555831	-39.043388	Upper slope	SACW
E06	1000	-19.629205	-39.066320	Middle slope	AAIW
E07	1300	-19.705117	-39.097893	Lower slope	AAIW-NADW
CAND 04	150	-19.818685	-39.602367	Doce Canyon (head)	TW-SACW
CAND 05	400	-19.827004	-39.594793	Doce Canyon (upper)	SACW
CAND 06	1000	-19.892093	-39.548985	Doce Canyon (middle)	AAIW
CAND 07	1300	-19.969844	-39.527302	Doce Canyon (lower)	AAIW-NADW

3.3 Foraminiferal analysis

In the laboratory of CENPES/PETROBRAS, samples for the foraminiferal study were dried at 60°C. All samples had their dry bulk weight standardized to 20 g, and were gently washed under tap water with a 63 µm sieve. The sand residue was dried, weighed, and dry sieved (63, 125, 500 µm) to improve the observation and species classification in different grain sizes. The benthic foraminifera specimens were entirely picked from 500 µm fraction. The < 500 µm fraction was separated using a microsplitter until it reached at least 300 benthic specimens per sample. All benthic foraminifera tests were picked from the picking tray, organized in plummer slides, and taxonomically identified. The total absolute number of foraminifera for each sample was normalized to 20 g. The tubular agglutinated forms (i.e., *Rhabdammina, Rhizammina, Saccorhiza*) were considered one single individual every five size-standardized fragments (~ 0.30 cm length).

Specimens were identified following the classification and taxonomy based on Boltovskoy et al. (1980), Loeblich and Tappan (1988; 1994), Boersma (1984), van

Morkhoven et al. (1986), Bolli et al. (1994), Jones (1994), Kaminski and Gradstein (2005), and Houlborn (2013). The genera *Fissurina, Lagena, Oolina,* and *Parafissurina* were placed into a single group, referred as unilocular, because of its large number of species (Patterson and Richardson, 1987). The revised names for benthic species are according to the WoRMS (World Register of Marine Species) classification (Hayward et al., 2022).

Additionally, the planktic foraminiferal tests (%planktic foraminifera) were observed and counted during the picking of benthic specimens in the >125 μm size fraction. The >125 μm size fraction was assumed to include the majority of adult specimens for each planktic foraminiferal species (Peeters et al., 1999; Tapia et al., 2022).

3.4 Statistical analysis

The benthic community structure was investigated using density, diversity, test composition, and microhabitat preference. The benthic foraminifera density (density = total number of tests/gram dry sediment), the percentage of agglutinated (%AGGLU), calcareous porcelaneous (%PORC), and calcareous hyaline (%HYAL) tests were calculated for each sample. Epifaunal and infaunal taxa were differentiated from each other based on the morphotypes of the tests, as proposed by Corliss (1985), Corliss and Chen (1988), and Kaminski et al. (1995). Species diversity was expressed in three ways, considering the species richness (S), the Simpson's index (D), and the Shannon-Weaver index (H'). The Simpson's index (usually expressed as 1-D) is weighted by the abundances of the commonest species whereas the Shannon-Weaver index take into consideration rare species that make a smaller contribution to the community (Magurran, 2004). These diversity indexes were calculated using the software PAST 4.10 (Hammer et al., 2001).

The relative abundance of species that contribute more than 80% to the total benthic population (relative abundances >2%) was analyzed through Q-mode cluster analysis (Ward's Method, Bray-Curtis dissimilarity index) to define benthic foraminiferal assemblages. The same distance matrix (Bray-Curtis), generated by foraminifera data, was coordinated by a non-metric multidimensional scaling (NMDS) and Similarity Percentage Breakdown (SIMPER) analyses. The NMDS analysis emphasizes the geometrical aspects of similarity, allowing the visualization of complex environmental data in a graphical environment (Gotelli and Ellison, 2011). The SIMPER analysis was carried out in order to define which benthic foraminiferal species contribute most to the dissimilarity of each group (Clarke, 1993). The multivariate analyzes were performed using the PAST 4.10c (Hammer et al., 2001), PRIMER v.5 (Clarke and Warwick, 1994), and STATISTICA v.7 (Statsoft Inc., 2001) software packages.

4. RESULTS

4.1 Sedimentological composition

In general, sediments from the ESB submarine canyons and adjacent slopes are mainly composed of silt, which increases at depths below 400 m. The lowest clay content values are observed on the outer shelf (50 m) and middle-lower CANWN (1000 to 1300 m). Coarser sediments (varying from very coarse to fine sand) predominate from 50 to 150 m and in the CAND head. Sand content is higher along the CANWN than the CAND, mostly in the middle-lower CANWN. The highest gravel content values are observed at 150 m and in the canyons head. (Table 2, Fig. 2).

The $CaCO_3$ content in surface sediments is generally high along the CAND and adjacent transect E, reaching values > 50% at 150 m and 400 m depths (Table 2, Fig. 2). The %$CaCO_3$ values are higher in the CAND than CANWN, indicating a predominance of carbonate mud. On the other hand, sediments from the CANWN consist of more terrigenous sand. TOM content shows high variability of values, ranging from 4 to 21%. TOM values above the average (>10%) are generally observed at depths greater than 400 m on the open slope. The lowest %TOM values are observed in sandy sediments on the shelf (50 m), canyons head (150 m), and in the middle-lower CANWN (1000 to 1300 m) (Table 2, Fig. 2).

4.2 Benthic foraminiferal composition: density, diversity, and microhabitas

The total benthic foraminiferal density varies between 13 and 28344 tests/g and reaches the highest values at 400 m depth (mean 16433 tests/g) (Fig. 3A). Density values are higher in the CAND and adjacent transect E than CANWN and adjacent transect D. The lowest density values are observed in the middle-lower CANWN (1000 to 1300 m) (Fig.3A). A total of 248 taxa were identified in the analyzed samples. Fifty-four species have relative abundances >2%, accounting for 83% of the total population. The relative abundances of these species vary according to the environments and water depths (see Supplementary Table and Appendix). Species richness (S) presents on average 63 species per sample, generally exhibiting values above the average below 400 m water depth, both in the canyons and open slope. In general, the diversity indexes show values above the average (1-D > 0.84 and H'> 2.66) from 50 to 150 m and within the canyons. The highest indexes values are found within the CAND, indicating high species diversity in this environment (Fig. 3A).

Table 2: *Sediment analyses of surface samples: detailed sediment grain size, calcium carbonate ($CaCO_3$), and total organic matter content (TOM) in the Watu Norte Canyon (CANWN), Doce Canyon (CAND), and adjacent transects D and E. Values are expressed in percentages.*

Sample	Isobath (m)	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay	$CaCO_3$	TOM
D03	50	1.3	3.8	11.3	65.9	13.6	0.0	3.9	13.3	3.5
D04	150	4.8	3.0	5.1	11.4	12.9	26.7	22.8	28.9	11.6
D05	400	0.1	0.3	0.8	4.3	5.4	51.7	36.3	29.7	11.9
D06	1000	0.1	0.1	0.4	0.6	1.5	48.1	49.4	26.3	13.3
D07	1300	0.0	0.3	1.3	1.4	1.6	90.1	5.8	26.4	13.5
CANWN 04	150	0.6	0.8	4.5	28.6	18.9	22.7	20.4	12.6	10.4
CANWN 05	400	0.2	1.8	3.0	6.6	9.7	61.0	16.4	27.4	11.3
CANWN 06	1000	3.2	3.5	7.8	16.6	20.6	38.1	2.3	25.5	3.6
CANWN 07	1300	0.7	3.0	12.5	16.3	20.7	45.3	5.8	27.7	9.1
E03	50	1.5	1.8	4.8	77.4	7.2	0.0	6.8	8.4	4.1
E04	150	11.0	18.3	27.9	15.1	2.1	0.0	18.1	79.0	9.7
E05	400	0.2	0.3	1.0	8.4	19.9	34.5	36.9	38.6	7.5
E06	1000	0.2	0.6	1.9	2.9	2.1	49.3	40.4	35.2	21.1
E07	1300	0.1	0.2	1.5	1.9	2.0	52.7	41.9	39.5	11.3
CAND 04	150	34.2	14.8	6.3	6.0	5.3	19.0	6.4	54.8	5.7
CAND 05	400	0.1	0.3	1.5	7.0	11.3	66.1	13.1	53.4	15.0
CAND 06	1000	0.2	0.4	1.2	6.2	13.3	31.4	32.0	41.5	14.3
CAND 07	1300	0.1	1.1	6.4	10.6	12.7	29.9	39.6	38.2	8.2

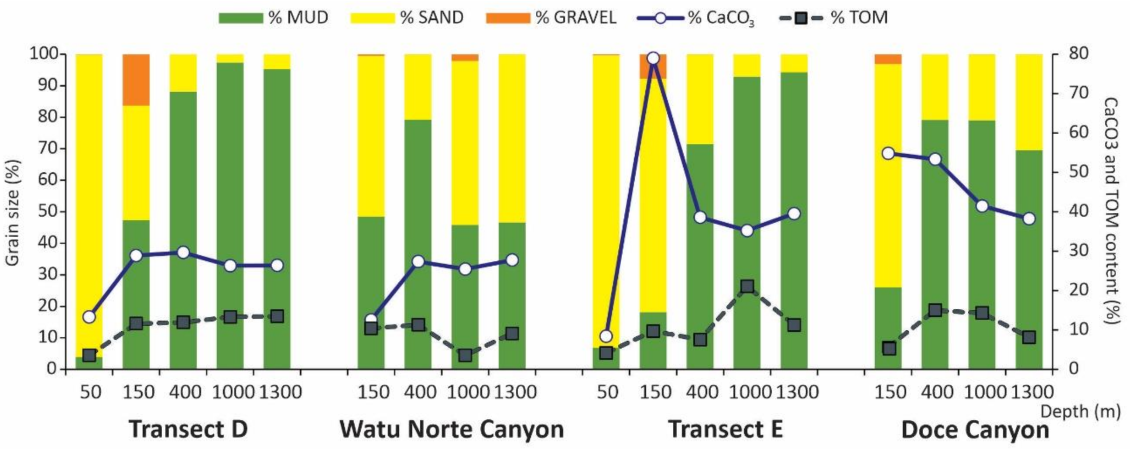

Figure 2: *Sediment composition of surface samples (gravel, sand, mud, calcium carbonate, and total organic matter content) in the Watu Norte Canyon (CANWN), Doce Canyon (CAND), and adjacent transects D and E. Values are expressed in percentages.*

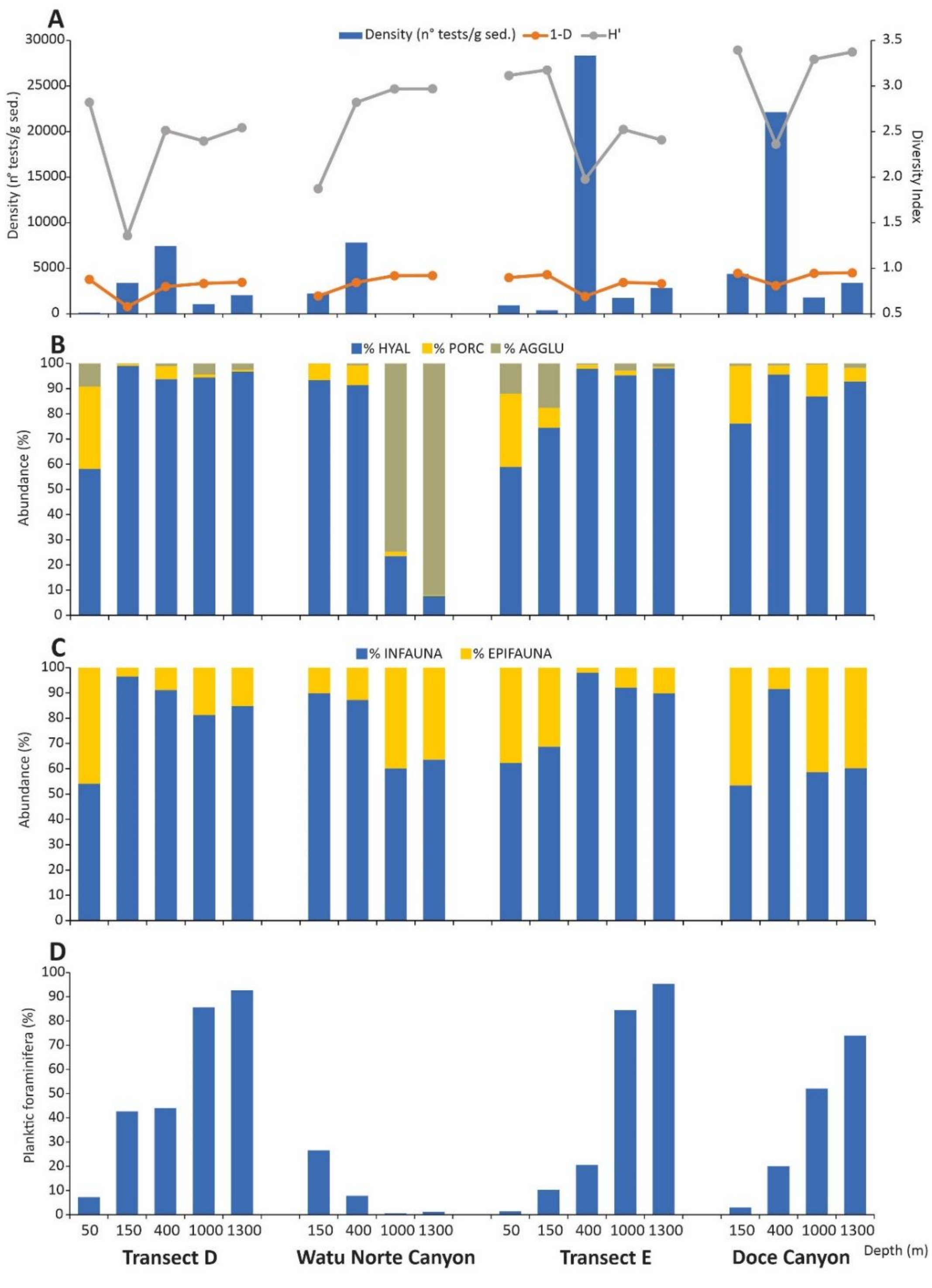

Figure 3: *(A) Benthic foraminiferal density (n° tests/g dry sediment) and diversity indexes (1-D = Simpson; H' = Shannon Weaver); (B) agglutinated (AGGLU), porcelaneous (PORC), and hyaline (HYAL) tests; (C) epifaunal and infaunal microhabitat; (D) planktic foraminiferal tests (>125 mm) in the Espírito Santo Basin.*

The calcareous hyaline taxa are dominant (mean 80%) and frequent in almost all investigated samples (Fig. 3B), followed by the agglutinated taxa (mean 12%). However, in the middle-lower CANWN the hyaline species are almost entirely replaced by agglutinated species, reaching 75% and 92% abundances at 1000 and 1300 m water depth respectively (Fig. 3B). The porcelaneous taxa (mean 8%) are clearly more abundant in the outer shelf and in the CAND head (50 to 150 m).

In terms of microhabitat preference, benthic foraminiferal assemblages include a heterogeneous mixture of shallow infaunal and epifaunal morphogroups. The infaunal morphogroup dominates (mean 77%) over epifaunal (mean 23%) throughout the entire study area (Fig. 3C). The highest epifaunal values are observed from 50 to 150 m, and in the middle-lower canyons (1000 to 1300 m), mainly in the CAND (Fig. 3C).

In general, the planktic foraminiferal tests increase with depth. The highest values (> 50%) are observed from 1000 to 1300 m water depth, except for the middle-lower CANWN, where the lowest % planktic foraminiferal tests were observed (Fig. 3D).

4.3 Benthic foraminiferal assemblages: characteristics and distribution

Based on the Q-mode cluster analysis (Fig.4), benthic foraminiferal assemblages can be differentiated into five main groups (I, II, III, IV, and V). Each group has two or more samples that are clustered because of the similarity of their microfaunal content. These groups represent five benthic foraminiferal assemblages, which reflect a depth gradient and a heterogenous bottom morphology at the ESB. The NMDS (Fig. 5) and SIMPER (Table 3) analyses proved to be very useful to understand the assemblage's composition and recognizing which environmental parameters are more related to each group. Some of the main representative species are illustrated using SEM images (Figures 6 and 7).

According to the SIMPER analysis, the species which showed the highest dissimilarity among all investigated samples include *Globocassidulina rossensis* (19.3%), *G. crassa* (12.5%), *Hanzawaia boueana* (6.1%), *Bolivina lowmani* (4.8%), *Trifarina angulosa* (4.4%) *and Glomospira charoides* (3.1%) (Table 3).

Group I contains samples from the open slope (1000 to 1300 m). The species that contribute most to this group are *G. crassa* (27.8%) and *B. lowmani* (12.1%). Other species that contribute to this group are *Gavelinopsis versiformis*, *Alabaminella weddellensis*, *Epistominella exigua*, *Discorbinela berthelloti*, and the unilocular group (Table 3). The increase of planktic foraminifera tests and muddy sediments organic matter enriched are also related to Group I (Fig. 5).

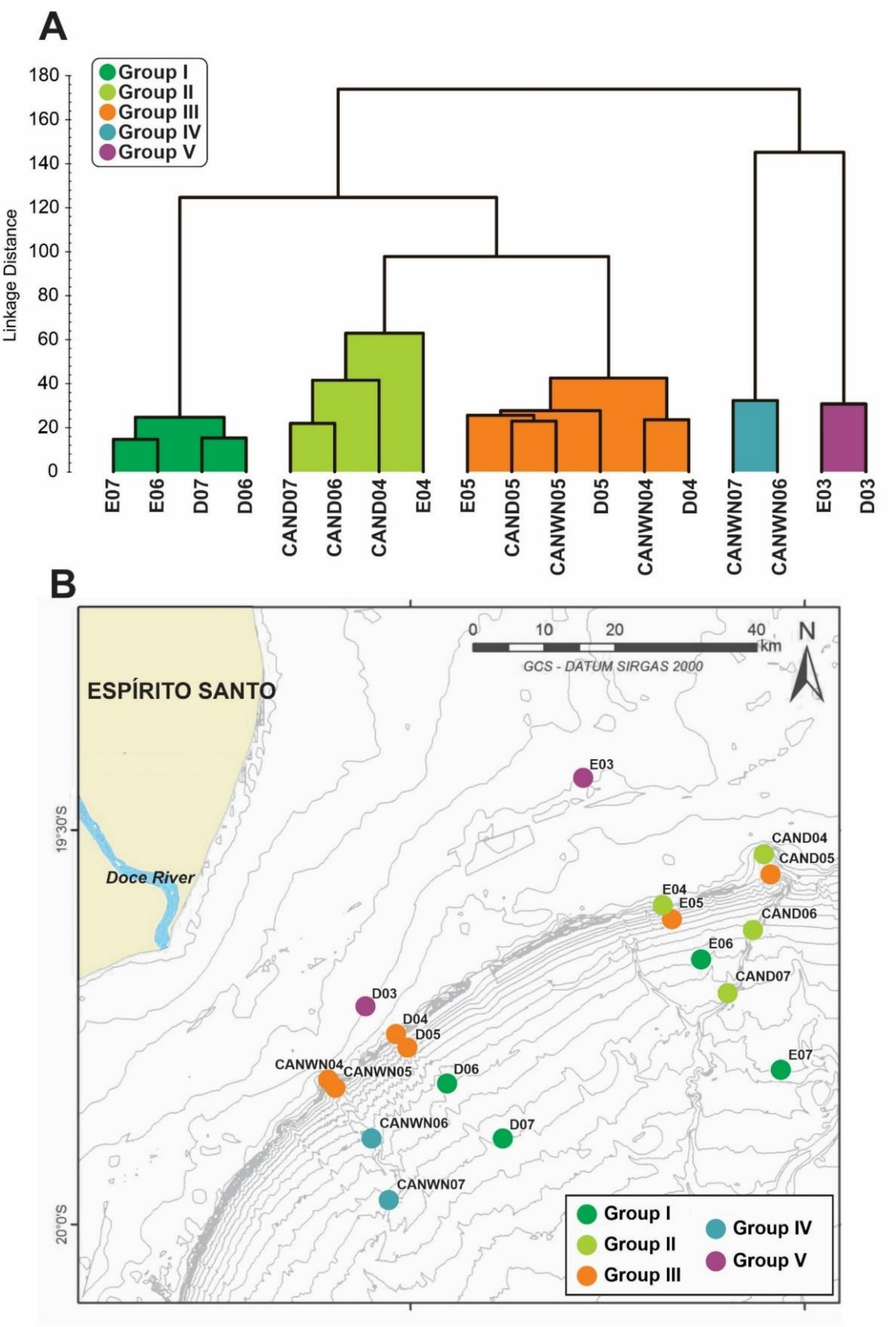

Figure 4: *(A) Cluster analysis (Bray-Curtis distance) based on the benthic foraminiferal relative abundance and (B) map of groups (assemblages) distribution patterns found at the ESB. Group I (1000-1300 m, open middle-lower), Group II (CAND+E04), Group III (150-400 m, upper slope), Group IV (1000-1300 m, middle-lower CANWN) and Group V (50 m, outer shelf).*

Figure 5: *Ordination analysis diagrams (NMDS) according to foraminiferal clusters analysis. Group I (1000-1300 m, open middle-lower), Group II (CAND+E04), Group III (150-400 m, upper slope), Group IV (1000-1300 m, middle-lower CANWN) and Group V (50 m, outer shelf). The circle's size varies according to the values. The contribution of each parameter for groups can be seen in the graph according to the circle's sizes.*

Group II includes most of CAND samples and one from the adjacent transect E (E04, 150 m). The species that contribute most to this group are T. angulosa (8.9%), Discorbis vilardeboanus (6.4%) and Globocassidulina subglobosa (4%). Other related species are *Cibicidoides mundulus, Trifarina* spp., and *Rosalina globularis* (Table 3). The increase in species diversity, epifaunal, juvenile benthic foraminifera species, and very coarse to medium sands enriched of $CaCO_3$ are also observed in Group II (Fig. 5).

Table 3: *Results of SIMPER analysis. The average overall dissimilarity is 71.86. The highest value of a species between the groups is marked in bold and underlined. Av. dissim=average dissimilarity, and Contrib.%=contribution.*

Taxon	**Av. dissim**	**Contrib. %**	**Cumulative %**	**Shelf**	**Upper slope/canyons**	**Middle-lower open slope**	**Middle-lower CANWN**	**CAND/E04***
				5	**3**	**1**	**4**	**2**
Globocassidulina rossensis	13.9	19.3	19.3	3.2	**43.7**	21.0	6.9	8.6
Globocassidulina crassa	9.0	12.5	31.8	0.7	18.6	**27.8**	0.2	5.3
Hanzawaia boueana	4.4	6.1	37.9	**27.2**	0.2	0.0	0.2	0.4
Bolivina lowmani	3.4	4.8	42.7	0.4	1.4	**12.1**	1.1	3,3
Trifarina angulosa	3.1	4.4	47.1	1.2	4.8	0.2	0.0	**8.9**
Glomospira charoides	2.2	3.1	50.2	0.0	0.0	0.0	**14.3**	0.0
Rhabdammina abyssorum	2.0	2.7	52.9	0.0	0.0	0.2	**12.4**	0.1
Discorbis vilardeboanus	1.9	2.6	55.6	1.2	0.4	0.6	0.0	**6.4**
Psammosphaera fusca	1.8	2.5	58.0	0.0	0.0	0,1	**11.3**	0.0
Gavelinopsis versiformis	1.5	2.1	60.1	0.0	0.5	**3.4**	0.2	3.3
Globocassidulina subglobosa	1.5	2.0	62.1	0.3	2.8	1.6	0.2	**4.0**
Cribrostomoides spiculolegus	1.3	1.9	64.0	0.0	0.0	0.0	**8.6**	0.0
Cibicidoides mundulus	1.2	1.7	65.7	0.2	0.6	0.0	0.0	**4.2**
Peneroplis planatus	1.2	1.7	67.4	**7.4**	0.1	0.0	0.0	0.2
unilocular group	1.2	1.6	69.0	0.2	0.6	**4.2**	0.2	0.4
Trifarina spp.	1.0	1.4	70.4	0.9	**2.1**	0.1	0.0	**2.1**
Rosalina globularis	0.8	1.2	71.6	0.2	0.1	0.0	0.0	**2.8**
Glomospira gordialis	0.8	1.2	72.8	0.0	0.0	0.5	**4.9**	0.0
Sigmamiliolinella australis	0.8	1.2	73.9	1.5	1.0	0.0	0.2	**1.7**
Haplophragmoides sandiegoensis	0.8	1.2	75.1	0.0	0.1	0.0	**5.3**	0.0
Bolivina spp.	0.8	1.1	76.2	0.9	1.4	**2.7**	0.4	1.4
Quinqueloculina lamarckiana	0.8	1.1	77.3	**4.9**	0.0	0.0	0.0	0.0
Articulina pacifica	0.8	1.1	78.3	**4.3**	0.1	0.0	0.0	0.5
Paracassidulina nipponensis	0.8	1.1	79.4	0.7	1.3	1,1	0.5	**1.8**
Cibicidoides spp.	0.7	1.0	80.4	1.1	0.3	0.0	0.0	**2.3**
Quinqueloculina spp.	0.7	1.0	81.4	**3.0**	0.4	0.2	0.2	0.7
Bolivina inflata	0.7	0.9	82.3	0.0	0.8	**2.1**	0.2	0.3
Bolivina ordinaria	0.7	0.9	83.3	0.0	**1.4**	1.3	0.9	0.7
Textularia agglutinans	0.7	0.9	84.2	**4.1**	0.0	0.0	0.0	0.2
Epistominella exigua	0.7	0.9	85.1	0.0	0.1	**2.3**	0.2	0.3
Spirotextularia tubulosa	0.65	0.9	86.0	0.4	0.1	0.0	0.0	**2.2**
Bolivina sp. 1	0.6	0.8	86.9	0.0	**1.6**	0.0	0.6	0.3
Quinqueloculina agglutinans	0.6	0.8	87.7	**3.6**	0.0	0.0	0.0	0.2
Planulina foveolata	0.6	0.8	88.5	0.2	0.5	0.0	0.0	**1.7**
Sigmavirgulina tortuosa	0.6	0.8	89.3	0.0	0.1	0.1	0.0	**1.8**
Alabaminella weddellensis	0.5	0.7	90.0	0.0	0.3	**1.8**	0.2	0.4
Ammosphaeroidina grandis	0.5	0.7	90.8	0.0	0.0	0.0	**3.4**	0.0
Discorbinella bertheloti	0.5	0.7	91.5	0.0	0.2	**1.3**	0.2	1.0
Nonionoides grateloupii	0.5	0.7	92.2	**1.9**	0.3	1.0	0.0	0.3
Bolivina fragilis	0.5	0.7	92.9	0.2	**1.5**	0.7	0.2	0.3
Reussella spinulosa	0.5	0.7	93.6	**2.2**	0.1	0.0	0.0	0.7
Uvigerina peregrina	0.5	0.7	94.2	0.0	0.2	0.6	**1.9**	0.6
Bolivina pseudoplicata	0.5	0.6	94.9	0.0	0.4	0.8	0.0	**1.2**
Archaias angulatus	0.4	0.6	95.4	**2.1**	0.0	0.0	0.0	0.4
Discammina compressa	0.4	0.5	96.0	0.0	0.0	0.0	**2.5**	0.0
Pseudoclavulina serventyi	0.4	0.5	96.5	**1.9**	0.0	0.0	0.5	0.3
Cassidulina curvata	0.4	0.5	97.1	0.2	0.6	0.1	0.0	**1.1**
Cribrostomoides subglobulosus	0.4	0.5	97.6	0.0	0.0	0.0	**2.5**	0.0
Cribroelphidium excavatum	0.4	0.5	98.1	**2.1**	0.0	0.0	0.0	0.2
Ammoglobigerina globulosa	0.3	0.4	98.5	0.0	0.0	0.2	**1.6**	0.0
Elphidium discoidale	0.3	0.4	99.0	**1.7**	0.1	0.0	0.0	0.0
Textularia hystrix	0.3	0.4	99.4	0.0	0.0	0.0	**1.9**	0.0
Lenticulina vortex	0.2	0.3	99.7	0.0	0.0	0.0	0.0	**0.9**
Amphistegina lessoni	0.2	0.3	100	0.2	0.0	0.0	0.0	**0.7**

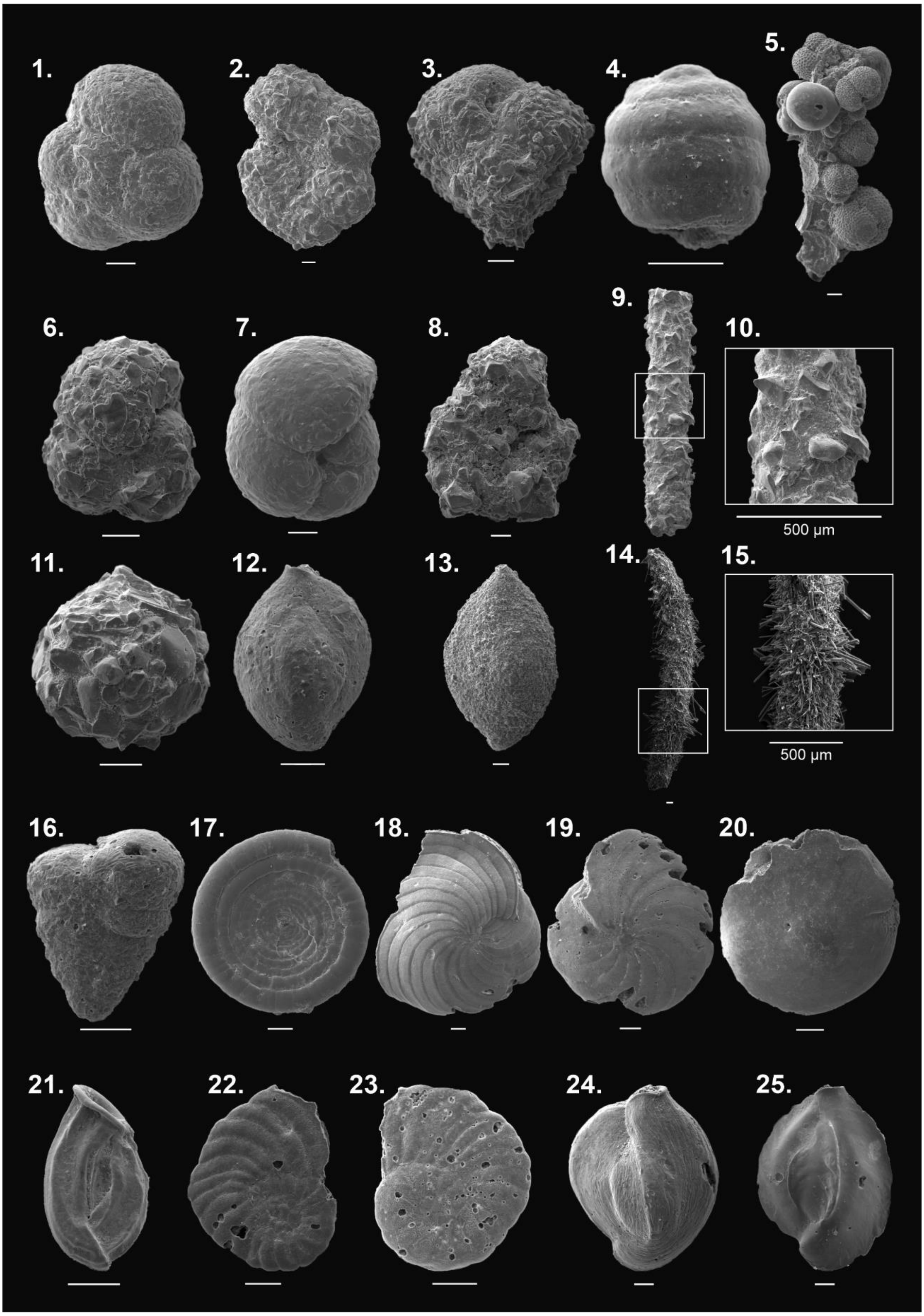

Figure 6: *Ammoglobigerina globulosa, 2. Discammina compressa, 3. Gaudryina pyramidata, 4. Glomospira charoides, 5. Rhizammina algaeformis, 6. Haplophragmoides sandiegoensis, 7. Labrospira nitida, 8. Cribrostomoides spiculolegus, 9-10. Rhabdammina abyssorum, 11. Psammosphaera fusca, 12. Quinqueloculina agglutinans, 13. Sigmoilospsis schlumbergeri. 14-15. Sarccohiza ramosa, 16. Textularia agglutinans, 17. Ammodiscus anguillae, 18-19. Archaias angulatus, 20. Amphistegina lessoni, 21. Articulina pacifica, 22-23. Peneroplis planatus, 24. Quinqueloculina cuvieriana, 25. Quinqueloculina lamackiana. Scale-bar 100 µm*

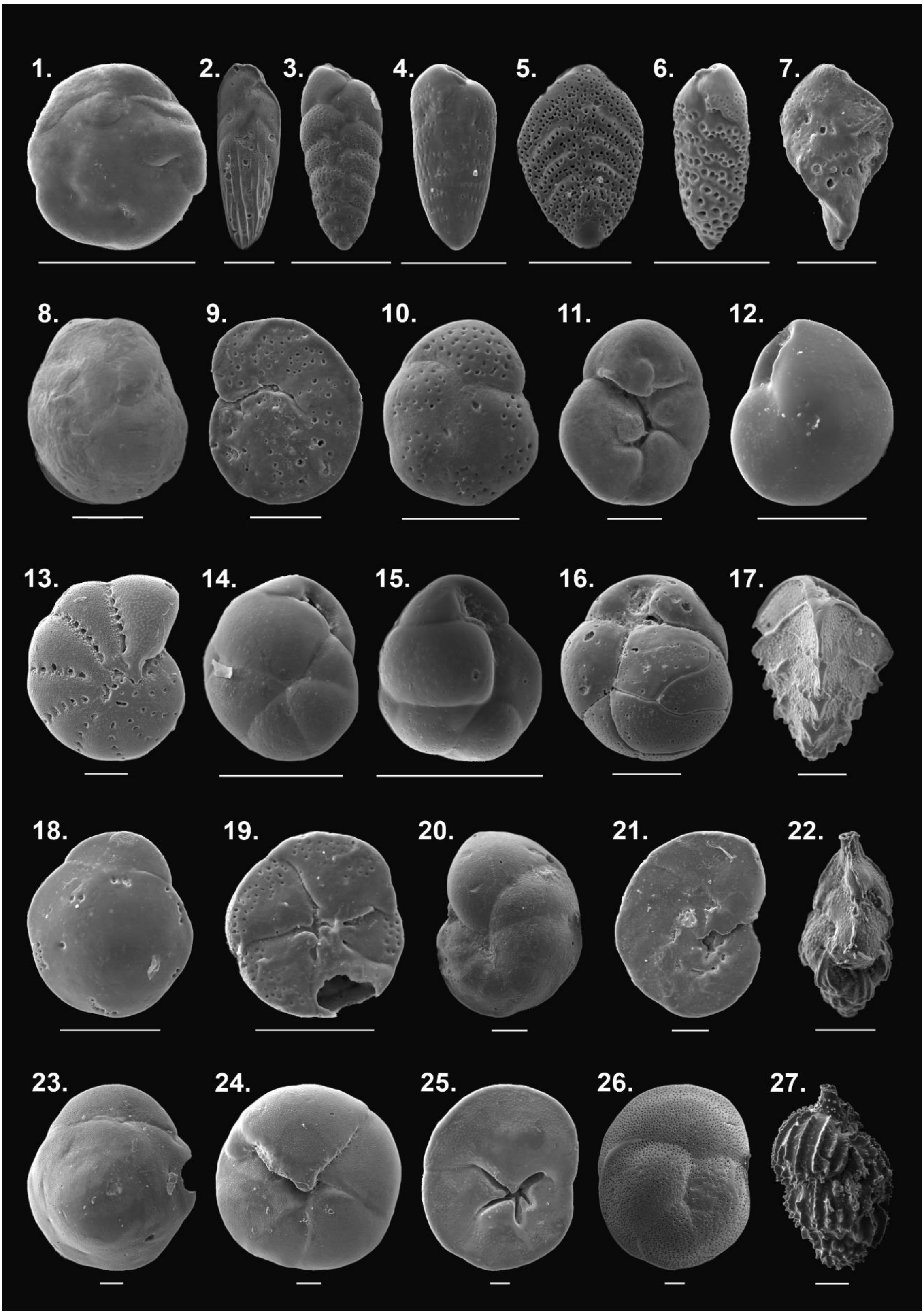

Figure 7: *Alabaminella weddellensis, 2. Bolivina fragilis, 3. Bolivina inflata, 4. Bolivina lowmani, 5. Bolivina ordinaria, 6. Bolivina sp.1, Sigmavirgulina tortuosa, 8-9. Cibicidoides mundulus, 10-11. Discorbis vilardeboanus, 12. Epistominella exigua, 13. Cribroelphidium excavatum, 14. Globocassidulina crassa, 15. Globocassidulina rossensis, 16. Globocassidulina subglobosa, 17. Reussela spinulosa, 18-19. Gavelinopsis versiformis, 20-21. Hanzawaia boueana, 22. Trifarina angulosa, 23-24. Neoeponides antillarum, 25-26. Rosalina globularis, 27. Uvigerina peregrina. Scale-bar 100 µm.*

Group III contains samples from the canyons head and upper slope (150 to 400 m). This group shows low diversity values and the highest density (Fig. 5), with the predominance of *G. rossensis* (43.7%). Other species that contribute to this group are *Trifarina* spp., *Bolivina ordinaria, Bolivina* sp.1, and *Bolivina fragilis* (Table 3).

Group IV consists only of two samples from the middle-lower CANWN (1000 to 1300 m). In this group predominate agglutinated species such as *Glomospira charoides* (14.3%), *Rhabdammina abyssorum* (12.4%), *Psammosphaera fusca* (11.3%), and *Cribrostomoides spiculolegus* (8.6%). A diversity of other agglutinated species composes this group. Only the hyaline species, such as *G. rossensis* and *Uvigerina peregrina* reach values ≥ 2% (Table 3). In this group predominate sediments mainly composed of very fine sand, with low clay, carbonate, and TOM contents (Fig. 5).

Group V also consists only of two samples located on the ESB outer shelf (50 m). The species that contribute most to this group are *Hanzawaia boueana* (27.2%), *Peneroplis planatus* (7.4%), *Quinqueloculina lamarckiana* (4.9%), *Articulina pacifica* (4.3%) and *Textularia agglutinans* (4.1%) (Table 3). Other related species are *Reussella spinulosa*, *Archaias angulatus*, and *Cribroelphidium excavatum*. The increase of porcelaneous taxa along with a sediment dominated by fine sand, low $CaCO_3$ and TOM content are also observed in Group V (Fig. 5).

5. DISCUSSION

The cluster tree in Fig. 4 shows five categories that are characterized by high dissimilarity among the benthic foraminiferal assemblages. The majority of analyzed samples present a bathymetric distribution (groups I, III, and V), while a small number show a local distribution connected to the submarine canyons (groups II and IV).

5.1 Benthic foraminiferal bathymetric distribution: sediments properties and organic matter influx

5.1.1 Outer shelf (50 m) – Group V

The dominant hyaline epifaunal *H. boueana*, and other species related to Group V, are almost restricted to 50 m or decrease considerably in abundance from this water depth. Species of the genus *Hanzawaia* are also abundant on the Campos and Santos continental shelf (SE Brazil). In these basins, *Hanzawaia* was related to sandy sediments with low carbonate content (Disaró et al., 2017) and upwelling events (Disaró et al., 2017;

Yamashita et al., 2020). In the Pelotas Basin (southern Brazil), Eichler et al. (2008) attributed the dominance of *H. boueana* in shallower stations to the freshwater intrusion of the La Plata River plume. In the coral reefs of the Mucuri Basin (NE Brazil), *A. angulatus*, *Q. lamarckiana*, and *Peneroplis* species are more abundant in sandy carbonate to mixed (siliciclastic and carbonate) sediments (Araújo and Machado, 2008). Miliolids, including *Quinqueloculina* species, are abundant in recent sandy sediments from the Argentinean Continental Shelf (Bernasconi et al., 2018). In fact, the relationship between porcelaneous tests abundance and sandy sediments has been documented on several continental shelves worldwide (Murray, 2006).

Our investigation shows the same pattern where fine sand sediments with low $CaCO_3$ and TOM contents on the outer shelf are populated by *Hanzawaia* and *Quinqueloculina* species. In addition, species related to Group V seem to be adapted to an environment ruled by the BC current flows. The BC brings warm and oligotrophic waters, sweeping sediments, and influences the occurrence of carbonate deposits (Bastos et al., 2015; Silveira et al., 2020).

5.1.2 Upper slope and canyons head (150 to 400 m) – Group III

The highest benthic foraminiferal density was observed in Group III, which is associated with the dominance of *G. rossensis* and a high abundance of infaunal species (e.g., *Trifarina* spp. and bolivinids). Benthic foraminiferal assemblages dominated by *Globocassidulina* indicate well-oxygenated environments (Gooday, 1994; Mackensen et al., 1995), and higher organic matter flux (Smart et al., 1994; Thomas et al., 1995; Schmiedl and Mackensen, 1997; Gooday, 2003; Jorissen et al., 2007; de Almeida et al., 2015; Sousa et al., 2017; Yamashita et al., 2018a). The high-density values and infaunal predominance at Campos (Sousa et al., 2017) and Espírito Santo (de Almeida et al., 2022) basins were attributed to a sustained flux of metabolizable organic matter, indicating a large food supply at 400 m depth.

The main food source on the ESB upper slope, which turns available to the benthic assemblages (Bernardino et al., 2016; de Almeida et al., 2022), seems to be organic material derived from primary production. The ESB upper slope is bathed by the SACW, a nutrient-rich water mass (Silveira et al., 2020). The SACW eventually disrupts the thermocline (e.g., physical processes like internal waves), and brings a cold and nutrient-rich water mass to the surface, which fertilizes the photic zone through coastal upwelling

(Gaeta and Brandini, 2006). Cyclonic meanders of the BC are responsible for a relatively strong upwelling regime that brings the SACW from the upper slope to the continental shelf break (Campos et al., 2000; Palóczy et al., 2016; Silveira et al., 2020). Thus, episodic intrusion of SACW along a narrower shelf (Palóczy et al., 2016) triggers the nutrient enrichment of surface waters, increasing local primary productivity and the organic flux that reaches the ESB upper slope.

5.1.3 Open middle-lower slope (1000-1300 m) – Group I

In the Group I, the increased abundance of species *G. crassa*, *G. versiformis*, and the 'phytodetritus-species' (*E. exigua* and *A. wedellensis*) indicates the influx of labile organic matter to the middle-lower slope. Similar to other species from the genus *Globocassidulina*, *G. crassa* is a shallow infaunal, opportunistic, cosmopolitan specie that indicates intermittent organic matter flux and well-oxygenated environments (Hayward et al., 2002; Gooday, 1994). It is well known that the 'phytodetritus-species' grow and reproduce during seasonal pulses of labile organic matter input, resulting from primary productivity, as previously observed in the South Atlantic (Mackensen et al., 1995; de Almeida et al., 2015; Yamashita et al., 2018a; Rodrigues et al., 2018; Smart et al., 2019). The deposition of phytodetritus (labile organic matter), triggers rapid population increases in opportunistic benthic foraminiferal species (Fontanier et al., 2003; 2006).

Group I demonstrated very similar characteristics to that found by de Almeida et al. (2022) on the middle-lower slope of the ESB. According to these authors, a possible oceanographic mechanism responsible for the increased regional primary productivity, that impacts directly the benthic foraminiferal distribution on the middle-lower slope of the ESB, is associated with mesoscale oceanographic features. The occurrence of the quasi-stationary and recurrent VE (Schmid et al., 1995, Soutelino et al., 2011, Arruda et al., 2013; Arruda and Silveira, 2019) has been reported in the vicinity of the ESB. The increase in nutrients concentration in the VE mixing layer (Gaeta et al., 1999), and the capacity of pumping nutrient-rich waters, reinforce that VE contributes to the fertilization of surface waters, and, consequently, to the local increase in phytoplankton production (Gaeta et al., 1999; Silveira et al., 2020). A simple model conducted by Pereira et al (2019) supports the idea that vortical features are capable of sustaining the phytoplankton and zooplankton community inside it. The coupling of VE and AE in the vicinity of the ESB results in the upwelling of the SACW to the shelf-break, pumping nutrients to the euphotic zone (Arruda and Silveira, 2019). According to these authors, the upwelled plume can be tracked for more than 400 km away from the coast by its chlorophyll-a signature. Therefore, the dominance of opportunistic species on the open middle-lower slope confirms the seasonality of primary productivity in the ESB.

Simultaneously, the seafloor sediment can be re-suspended through bottom currents. The re-suspended sediment can be nutrient-rich and, sometimes, be quickly utilized by the benthic microfauna, with the assistance of anaerobic microbial activity (Jorissen and Wittling, 1999; Sousa et al., 2006). The IWBC flows northward transporting AAIW, a nutrient-rich water mass that baths the middle-lower slope of the ESB (Perassoli et al., 2020; Silveira et al., 2020). At intermediate depth, a topographically-induced cyclonic recirculation of the IWBC occurs forming a stationary intermediate eddy (Costa et al., 2017; Napolitano et al., 2019; Silveira et al., 2020). The IWBC recirculation possibly promotes sediment remobilization, transport, and deposition on the seafloor (d'Avila et al., 2008), causing changes in bottom morphology on the ESB middle-lower slope. The strength of IWBC (Silveira et al., 2004) and the benthic foraminiferal response to the intensity of this boundary current have been more investigated in the Campos Basin (Sousa et al., 2006; Yamashita et al., 2018; Saupe et al., 2022).

5.2 Submarine canyon's influence supports different assemblages – Groups II and IV

This study allowed a rare opportunity for a comparison between benthic foraminiferal composition from two distinct submarine canyons localized in the same sedimentary basin. Despite having many species in common, differences between individual CANWN and CAND assemblages are evident. Distinct macrofaunal assemblages were also reported by Bernardino et al. (2019) for these canyons, with notable variations in the species composition and dominance patterns.

The predominance of sandy sediments, and the relatively low $CaCO_3$ content, within the CANWN suggest that sediments from the Doce River Shelf are transported to this canyon. The Doce River Shelf is a supply regime environment associated with riverine input and characterized by a narrow shelf (Bastos et al., 2015). Sediment bottom samples taken from the upper thalweg of the CANWN revealed the presence of mixed and bioclastic sands, descendent from the adjacent outer shelf (Hercos et al., 2015). Maia et al. (2015) classified surface sediments from the CANWN region as litoclastic, due to the influence of the Doce River, which is the main source of terrigenous sediment to the ESB shelf

(Quaresma et al., 2015; Oliveira and Quaresma, 2017). Thus, this terrigenous material deposited on the shelf may be carried to the ESB slope via the CANWN.

Although sandy sediments are found in most of the CANWN depths, only on the middle-lower CANWN (Group IV) sandy sediments (very fine sand) coincide with low TOM content and an abrupt change in hyaline species dominance. At these depths, benthic foraminiferal assemblages become dominated by agglutinated taxa, such as *G. charoides*, *R. abyssorum,* and *P. fusca*. The specie *G. charoides* is cosmopolitan in the modern ocean and abundant in oligotrophic regions, flourishing under conditions of very low carbon flux (De Rijik et al., 2000). In the North Atlantic, high proportions of *Glomospira* was correlated to an interval marked by a rapid change in productivity (Ortiz, 1995; Kaminski and Gradstein, 2005). *P. fusca* was related to sandy, organic carbon-poor substrate and strong deep bottom currents in the Argentine continental slope (Harloff and Mackensen, 1997). In the Panama Basin, *P. fusca* was associated with an opportunistic fauna that is able to colonize quickly habitats after sediment disturbance triggered by counter currents (Kaminski, 1985; Kaminski and Gradstein, 2005). The specie *R. abyssorum* developed the ability to accumulate detrital material with its pseudopodia, which makes it possible to inhabit rough sediment surfaces and turbulent conditions (Murray, 2006). The genus *Rhabdammina* occurs constantly in Recent deep-sea samples and has been observed in the Upper Cretaceous to Paleogene flysch-type benthic foraminiferal biofacies (Kaminski and Gradstein, 2005). A flysch-type biofacies consists of benthic foraminiferal assemblages dominated by single-chambered and uniserial, multi-chambered agglutinated taxa (Bouwer, 1965; Kaminski and Gradstein, 2005). In a study encompassing several Brazilian marginal basins, Mello et al. (2016) found a biofacies from the middle Paleocene composed of coarse-grain agglutinated flysch-type taxa. Successfully establishing of a flysch-type benthic foraminifera assemblage depends on the continuous delivery of siliciclastic sediments and terrestrial organic matter (Kaminski et al., 1988; Mello et al., 2016).

In addition, the lowest %planktic foraminiferal tests in Group IV are also remarkable. Generally, the percentage of planktic foraminifera increases with water depth. At a greater distance from the coast the turbidity in the water column decreases (van der Zwaan et al., 1990), allowing planktic foraminifera to grow and establish viable populations (Bé, 1977). However, the anomalously low relative abundances of planktic tests at bathyal depths may indicate downslope transport of sediment and/or local stronger bottom currents (Hayward et al., 2013; Mello et al., 2016; Tapia et al., 2022).

These unstable trophic conditions on the middle-lower CANWN limited the occurrence of normal deep-sea taxa and favors the development and preservation of agglutinated forms. This condition could have its origin linked to several reasons, such as sediment disturbance by contour and/or turbidity currents (Kaminski and Gradstein, 2005). Despite the IWBC strength in the ESB lead to bottom sediment remobilization, local occurrence of slope contourites (Hercos et al., 2015), and promotes microhabitat instability (Sousa et al., 2006; Yamashita et al., 2018; Saupe et al., 2022), this seems not to be the only explanation for the agglutinated taxa dominance on the middle-lower CANWN. Supposing the increased bottom currents in this area was primarily responsible for agglutinated dominance, as observed by Sousa et al. (2006) at Campos Basin, these taxa should be greatly abundant and frequent along the entire 1000 to 1300 m isobaths. However, as recently shown by de Almeida et al. (2022), this pattern is not observed on along the middle-lower ESB slope.

On the other hand, turbidity currents could transport terrigenous sediments from the Doce River outer shelf to the slope through the CANWN. This process would lead to an increase the availability of siliciclastic grains, commonly used by agglutinated benthic foraminifera to build their tests (Kaminski et al., 1988; Kaminski and Gradstein, 2005). Nevertheless, the reason why this condition is evident only on the middle-lower CANWN remains uncertain. We believe that a mass transport movement in the CANWN may have exposed an older deposit. This agrees with Hercos et al. (2015), who identified some small scars on the walls of the canyons that cross the slope. According to these authors, the scars are associated with the mobilization of small volumes of sediment. Another possibility is that only the shallowest environments of the CANWN have already been covered by a Holocene hemipelagic drape.

Terrigenous input into the ESB slope seems to decrease northward, since sedimentological data and benthic foraminifera composition in the CAND (Group II) are relatively different from those observed in the CANWN system. Species diversity indexes, the percentage of juvenile species, and the $CaCO_3$ and TOM contents in the CAND sediments are higher, indicating an environment more productive and less unstable than the CANWN.

According to the TOM content, CAND does not consistently accumulate higher organic matter in the sediment if compared to the adjacent slope (Transect E). A similar pattern was observed by Bernardino et al. (2019), who found that mean COT values are higher on the open slope sediment than in the ESB submarine canyons. These authors concluded that the submarine canyons of the ESB did not trap significant amounts of organic material.

The shallow infaunal taxa *T. angulosa* and *G. subglobosa* are more abundant in the CAND samples. These species have been associated with a variable food supply and a high vertical influx of particulate organic matter (Burone et al., 2011; Yamashita et al., 2018a; Saupe et al., 2020). Rodrigues et al. (2018) found a positive correlation between the relative abundance of *T. angulosa* and the total organic carbon content in a Pleistocene-Holocene core recovered from the Pelotas Basin. The genera *Globocassidulina* and *Trifarina* may also indicate high-energy environments, suggesting they take advantage of the increased bottom current activity (Mackensen et al., 1985; 1995; Schmiedl et at., 1997; Sousa et al., 2006; Smart, 2008; Di Bella et al., 2017; Martorelli et al., 2021). In the Almirante Câmara and Grussaí canyons (Campos Basin, SE Brazil), benthic foraminiferal density and biomass were reported to be comparatively higher than adjacent open slope areas, suggesting a relatively more eutrophic condition inside the canyons (Sousa et al., 2017).

Therefore, despite the sedimentological data, the ecology of the main taxa suggests a localized organic enrichment within the CAND, which seems to benefit the establishment and species diversity, indicating an environment more productive and less unstable than the CANWN.

6. CONCLUSIONS

1. Microfaunal and sedimentological data indicated that the environmental factors related to the submarine canyons (CANWN and CAND) have an influence in the benthic foraminiferal distribution on the ESB slope.
2. The new data set show distinct benthic foraminiferal assemblages composition between the CANWN and CAND, mostly from 1000 to 1300 m water depth, confirming that these topographic features enable different ecological niches on the slope.

3. The influx of terrigenous sediment within the CANWN, due to turbidity currents, promotes microhabitat instability. The agglutinated assemblage recorded only on the middle-lower CANWN probably reflects a mass transport movement inside this canyon, whereas the shallowest environments remains covered by a Holocene drape.
4. The abundance of opportunistic, shallow infaunal benthic foraminiferal species in the CAND indicated that this submarine canyon could trapped enough organic matter to benefit species establishment and diversity.
5. The benthic foraminifera assemblage found on the outer ESB shelf does not extend into the upper slope, corroborating the differences between these two physiographic provinces.

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APPENDIX: Taxonomic reference list for all species from the Espírito Santo Basin (Southeastern Brazil) cited in this paper.

Alabaminella weddellensis (Earland, 1936) = *Eponides weddellensis* Earland, 1936

Ammodiscus anguillae Höglund, 1947

Ammoglobigerina globulosa (Cushman, 1920) = *Trochammina globulosa* Cushman, 1920

Ammosphaeroidina grandis Cushman, 1910

Amphistegina lessoni d'Orbigny in Guérin-Méneville, 1832

Archaias angulatus (Fichtel & Moll, 1798) = *Nautilus angulatus* Fichtel & Moll, 1798

Articulina pacifica Cushman, 1944

Bolivina fragilis Phleger & Parker, 1951

Bolivina inflata Heron-Allen & Earland, 1913

Bolivina lowmani Phleger & Parker, 1951

Bolivina ordinaria Phleger & Parker, 1952

Bolivina pseudoplicata Heron-Allen & Earland, 1930

Cassidulina curvata Phleger & Parker, 1951

Cibicidoides mundulus (Brady, Parker & Jones, 1888) = *Truncatulina mundula* Brady, Parker & Jones, 1888

Cribroelphidium excavatum (Terquem, 1875) = *Polystomella excavata* Terquem, 1875

Cribrostomoides spiculolegus (Parr, 1950) = *Labrospira spiculotesta* (Zheng, 1979) = *Cribrostomoides spiculotesta* Zheng, 1979

Cribrostomoides subglobosus (Cushman, 1910) = *Haplophragmoides subglobosum* Cushman, 1910

Discammina compressa (Goës, 1882) = *Lituola irregularis var. compressa* Goës, 1882

Discorbinella bertheloti (d'Orbigny, 1839) = *Rosalina bertheloti* d'Orbigny, 1839

Discorbis vilardeboanus (d'Orbigny, 1839) = *Rosalina vilardeboana* d'Orbigny, 1839

Elphidium discoidale (d'Orbigny, 1839) = *Polystomella discoidalis* d'Orbigny, 1839

Epistominella exigua (Brady, 1884) = *Pulvinulina exigua* Brady, 1884

Gaudryina (Pseudogaudryina) pyramidata subsp. tumeyensis Israelsky, 1951 = Gaudryina pyramidata Cushman, 1926

Gavelinopsis versiformis Bandy, 1953 = *Rotalia versiformis* Bandy, 1953

Globocassidulina crassa (d'Orbigny, 1839) = *Cassidulina crassa* d'Orbigny, 1839

Globocassidulina rossensis Kennett, 1967 = *Globocassidulina crassa subsp. rossensis* Kennett, 1967

Globocassidulina subglobosa (Brady, 1881) = *Cassidulina subglobosa* Brady, 1881

Glomospira charoides (Jones & Parker, 1860) = *Trochammina squamata var. charoides* Jones & Parker, 1860

Glomospira gordialis (Jones & Parker, 1860) = *Trochammina squamata var. gordialis* Jones & Parker, 1860

Hanzawaia boueana (d'Orbigny, 1846) = *Truncatulina boueana* d'Orbigny, 1846

Haplophragmoides sandiegoensis Uchio, 1961 = *Haplophragmoides quadratus* Uchio, 1960

Polystomammina nitida (Brady, 1881*) = Labrospira nitida Brady, 1881*

Lenticulina vortex (Fichtel & Moll, 1798) = *Nautilus vortex* Fichtel & Moll, 1798

Nonionoides grateloupii (d'Orbigny, 1839) = *Nonionina grateloupii* d'Orbigny, 1839

Neoeponides antillarum (d'Orbigny, 1839) = *Rotalina (Rotalina) antillarum* d'Orbigny, 1839

Paracassidulina nipponensis (Eade, 1969) = *Globocassidulina nipponensis* Eade, 1969

Peneroplis planatus (Fichtel & Moll, 1798) = *Nautilus planatus* Fichtel & Moll, 1798

Planulina foveolata (Brady, 1884) = *Anomalina foveolata* Brady, 1884

Psammosphaera fusca Schulze, 1875

Pseudoclavulina serventyi (Chapman & Parr, 1935) = *Clavulina serventyi* Chapman & Parr, 1935

Quinqueloculina agglutinans d'Orbigny, 1839

Quinqueloculina cuvieriana d'Orbigny, 1839

Quinqueloculina lamarckiana d'Orbigny, 1839

Reussella spinulosa (Reuss, 1850) = *Verneuilina spinulosa* Reuss, 1850

Rhabdammina abyssorum Sars in Carpenter, 1869

Rhizammina algaeformis Brady, 1879

Rosalina globularis d'Orbigny, 1826

Saccorhiza ramosa (Brady, 1879) = *Hyperammina ramosa* Brady, 1879

Sigmamiliolinella australis (Parr, 1932) = *Quinqueloculina australis* Parr, 1932

Sigmavirgulina tortuosa (Brady, 1881) = *Bulimina (Bolivina) tortuosa* Brady, 1881

Sigmoilopsis schlumbergeri (Silvestri, 1904) = *Sigmoilina schlumbergeri* Silvestri, 1904

Spirotextularia tubulosa (Zheng, 1980) = *Textularia tubulosa* Zheng, 1980

Textularia agglutinans d'Orbigny, 1839

Textularia hystrix Jones, 1994

Trifarina angulosa (Williamson, 1858) = *Uvigerina angulosa* Williamson, 1858

Uvigerina peregrina Cushman, 1923

REFERENCES

Altenbach, A. V., Pflaumann, U., Schiebel, R., Thies, A., Timm, S., Trauth, M., 1999. Scaling percentages and distributional patterns of benthic foraminifera with flux rates of organic carbon. Journal of Foraminiferal Research 29 (3), 173–185.

Amblas, D., Ceramicola, S., Gerber, T. P., Canals, M. Chiocci, F. L., Dowdeswell, J. A., Harris, P. T., Huvenne, V. A. I., Lai, S. Y. J., Lastras, G., Lo Iacono, C., Micallef, A., Mountjoy, J. J., Paull, C. K., Puig, P., Sanchez-Vidal, A. 2018. Submarine Canyons and Gullies. In: Micallef, A., Krastel, S., Savini, A. (eds) Submarine Geomorphology. Springer Geology. Springer, Cham. https://doi.org/10.1007/978-3-319-57852-1_14

Araújo, H.A.B., Machado, A.J. 2008. Benthic foraminifera associated with the South Bahia coral reefs, Brazil. Journal of Foraminiferal Research 38 (1), 23–38.

Araújo, H.A.B., Dominguez, J.M.L., Machado, A.J., Rangel., A.G.A. 2018. Benthic foraminifera distribution in a deltaic clinoform (São Francisco Delta, eastern Brazil): A reference study. Journal of Marine Systems 186, 1-6.

Arruda, W. Z., Campos, E. J. D., Zharkov, V., Soutelino, R. G., Silveira, I. C. A., 2013. Events of equatorward translation of the Vitoria Eddy. Continental Shelf Research 70, 61–73. https://doi.org/10.1016/j.csr.2013.05.004

Arruda, W. Z., Silveira, I. C. A., 2019. Dipole-induced Central Water extrusions south of Abrolhos Bank (Brazil, 20.5o S). Continental Shelf Research, 188. https://doi.org/10.1016/j.csr.2019.103976

Barbosa, V. P., 2002. Sistemática, bioestratigrafia e paleoceanografia de foraminíferos do Quaternário do talude continental das bacias de Santos e Campos. Unpublished thesis. Instituto de Geociências, Universidade Federal do Rio de Janeiro, RJ, Brasil.

Barbosa, V. P., 2010. Foraminíferos bentônicos como indicadores bioestratigráficos no Quaternário Superior da Bacia de Campos. Revista Brasileira de Paleontologia. 13 (2), 129–142. http://doi.org/10.4072/rbp.2010.2.06

Bastos, A. C., Quaresma, V. S., Marangoni, M. B., D'Agostini, D. P., Bourguignon, S. N., Cetto, P. H., Silva, A. E., Amado Filho, G. A., Moura, R. L., Collins, M., 2015. Shelf morphology as an indicator of sedimentary regimes: A synthesis from a mixed siliciclastic-carbonate shelf on the eastern Brazilian margin. Journal of South American Earth Sciences 63, 125–136. https://doi.org/10.1016/j.jsames.2015.07.003

Bé, A. W. H., 1977. An ecological, zoogeographic and taxonomic review of recent planktonic foraminifera. In: Ramsay, A.T.S. (Ed.), Oceanic Micropaleontology. Academic Press, pp. 1–100.

Bernardino, A. F., Berenguer, V., P. Ribeiro-Ferreira, V. P., 2016. Bathymetric and regional changes in benthic macrofaunal assemblages on the deep Eastern Brazilian margin, SW Atlantic. Deep-Sea Research I 111, 110-120. https://dx.doi.org./10.1016/j.dsr.2016.02.016

Bernardino, A.F., Gama, R.N., Mazzuco, A.C.A., Omena, E.P., Lavrado, H.P. 2019. Submarine canyons support distinct macrofaunal assemblages on the deep SE Brazil margin. Deep-Sea Research Part I 149, 103052. https://doi.org/10.1016/j.dsr.2019.05.012

Bernasconi, E., Mansilla, M., Cusminsky, G. 2018. Recent benthic foraminifers from the South Atlantic Shelf of Argentina. Journal of Foraminiferal Research 48 (3), 210–222.

Boersma, A., 1984. Handbook of common Tertiary Uvigerina. Microclimates Press. Stony Point, New York.

Bolli, H. M., Beckmann, J-P., Saunders, J. B., 1994. Benthic foraminiferal biostratigraphy of South Caribbean region. Cambridge University Press.

Boltovskoy, E., Giussani, G., Watanabe, S., Wright, R., 1980. Atlas of benthic shelf Foraminifera of the Southwest Atlantic. Oxford: Dr. W. Junk B. V. Publishers.

Bourguignon, S. N., Bastos, A. C., Quaresma, V. S., Vieira, F. V., Pinheiro, H., Amado-Filho, G. M., de Moura, R. L., Teixeira, J. B., 2018. Seabed Morphology and Sedimentary Regimes defining Fishing Grounds along the Eastern Brazilian Shelf. Geosciences 8 (3), 2-7. https://doi.org/10.3390/geosciences8030091

Bouwer, J. 1965. Agglutinated foraminiferal from some turbiditic sequences. I. Koninklijke Nederlandse Akademie Van Weteschappen - Proceedings Series B-Physical Sciences 68 (5), 309.

Burone, L. B., Sousa, S. H. M., Mahiques, M. M., Valente, P., Ciotti, A., Yamashita, C., 2011. Benthic foraminiferal distribution on the southeastern Brazilian shelf and upper slope. Marine Biology. 158, 159–179. http://dx.doi.org/10.1007/s00227-010-1549-7

Campos, E. J. D., Velhote, D., Silveira, I. C. A., 2000. Shelf break upwelling driven by Brazil Current cyclonic meanders. Geophysical Research Letters. 27 (6), 751–754. https://doi.org/10.1029/1999GL010502

Campos, E. J. D., 2006. The equatorward translation of the Vitoria Eddy in a numerical simulation. Geophysical Research Letters. 33, L22607. https://doi.org/10.1029/2006GL026997

Clarke, K. R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology 18 (1), 117-143. https://doi.org/10.1111/j.1442-9993.1993.tb00438.x

Clarke K. R., Warwick, R. M., 1994. Similarity-based testing for community pattern: The 2-way layout with no replication. Mar. Biol. 118, 167–176. https://doi.org/10.1007/BF00699231

Corliss, B. H., 1985. Microhabitats of benthic foraminifera within deep-sea sediments. Nature 314, 435–438. https://doi.org/10.1038/314435a0

Corliss, B. H., 1991. Morphology and microhabitat preferences of benthic foraminifera from the northwest Atlantic Ocean. Marine Micropaleontology 17, 195–236. https://doi.org/10.1016/0377-8398(91)90014-W

Corliss, B. H., Chen, C., 1988. Morphotype patterns of Norwegian deep-sea benthic foraminifera and ecological implications. Geology 16, 716–719. https://doi.org/10.1130/0091-7613(1988)016<0716: MPONSD>2.3.CO;2

Costa, V. S., Mill, G. N., Gabioux, M., Grossmann-Matheson, G. S., Paiva, A. M., 2017. The recirculation of the intermediate western boundary current at the Tubarão Bight – Brazil. Deep-Sea Research I 120, 48–60. https://doi.org/10.1016/j.dsr.2016.12.001

D'Agostini, D. P., Bastos, A. C., Reis, A. T., 2015. The modern mixed carbonate-siliciclastic Abrolhos Shelf: implications for a mixed depositional model. Journal Sedimentary Research 85, 124–139. https://doi.org/10.2110/jsr.2015.08

D’Agostini, D. P., Bastos, A. C., Amado-Filho, G. M., Vilela, C. G., Thaís, C. S., Oliveira, T. C. S., Webster, J. M., Moura, R. L., 2019. Morphology and sedimentology of the shelf-upper slope transition in the Abrolhos continental shelf (East Brazilian Margin). Geo-Marine Letters 39, 117–134. https://doi.org/10.1007/s00367-019-00562-6

d’Ávila, R. S. F., Arienti, L. M., Aragão, M. A. N. F., Veseley, F. F., Santos, S. F., Voelcker, H. E., Viana, A. R., Kowsman, R. O., Moreira, J. L. P., Coura, A. P. P., Paim, P. S. G., Matos, R. S., Machado, L. C., 2008. Ambientes marinhos profundos: sistemas turbidíticos. (In): Ambientes de sedimentação siliciclástica do Brasil, pp. 244-301.

de Almeida, F. K., Mello, R. M., Costa, K. B., Toledo, F. A. L., 2015. The response of deep-water benthic foraminiferal assemblages to changes in paleoproductivity during the Pleistocene (last 769.2 kyr), Western South Atlantic Ocean. Palaeogeography, Palaeoclimatology and Palaeoecology 440, 201–212. https://doi.org/10.1016/j.palaeo.2015.09.005

de Almeida, F.K.; Mello, R.M.; Rodrigues, A.R.; Bastos, A.C. 2022. Bathymetric and regional benthic foraminiferal distribution on the Espírito Santo Basin slope, Brazil (SW Atlantic). Deep-Sea Research Part I 181, 103688. https://doi: 10.1016/j.dsr.2022.103688

De Leo, F.C., Smith, C.R., Rowden, A.A., Bowden, D.A., Clark, M.R. 2010. Submarine canyons: hotspots of benthic biomass and productivity in the deep sea. Proceedings of the Royal Society 277, 2783–2792. https://doi:10.1098/rspb.2010.0462

De Leo F.C., Bernardino A.F., Sumida P.Y.G. 2020. Continental Slope and Submarine Canyons: Benthic Biodiversity and Human Impacts. In: Sumida P.Y.G., Bernardino A.F., De Leo F.C. (Eds) Brazilian Deep-Sea Biodiversity. Brazilian Marine Biodiversity. Springer, Cham. https://doi.org/10.1007/978-3-030-53222-2_3

De Rijk, Jorissen, F.J., Rohlinga, E.J., Troelstra, S.R. 2000. Organic flux control on bathymetric zonation of Mediterranean benthic foraminifera. Marine Micropaleontology 40, 151-166. https://doi.org/10.1016/S0377-8398(00)00037-2

Di Bella, L.; Pierdomenico, M., Porretta, R., Chioccia, F. L., Martorelli, E. 2017. Living and dead foraminiferal assemblages from an active submarine canyon and surrounding sectors: the Gioia Canyon system (Tyrrhenian Sea, Southern Italy). Deep-Sea Res. I: Oceanogr. Res. Pap. 123, 129-146. https://doi.org/10.1016/j.dsr.2017.04.005

Dias, J. A., 2004. A análise sedimentar e o conhecimentos dos sistemas marinhos – Uma Introdução à Oceanografia Geológica. Universidade do Algarve, Faro

Dissaró, S. T., Aluizio, R., Ribas, E. R., Pupo, D. V., Tellez, I. R., Watanabe, S., Totah, V. I., Koutsoukos, E. A. M., 2017. Foraminíferos bentônicos na plataforma continental da Bacia de Campos. In A. P. C. Falcão e H. P. Lavrado (Eds.), Ambiente Bentônico: Caracterização ambiental regional da Bacia de Campos, Atlântico Sudoeste, 3, 65–110. Rio de Janeiro. Elsevier. https://doi.org/10.1016/B978-85-35-7263-5.50004-7

Duros, P., Fontanier, C., Metzger, E., Cesbron, F., Deflandre, B., Scmidt, S., Buscail, R., Zaragosi, S., Kerhervé, P., Rigaud, S., Delgard, M.L., Jorissen, F.J. 2013. Live (stained) benthic foraminifera from the Cap-Ferret Canyon (Bay of Biscay, NE Atlantic): A comparison between the canyon axis and the surrounding areas. Deep-Sea Research Part I 74, 98–114. http://dx.doi.org/10.1016/j.dsr.2013.01.004

Duros, P., Silva Jacinto, R., Dennielou, B., Schmidt, S., Martinez Lamas, R., Gautier, E., Roubi, A., Gayet, N. 2017. Benthic foraminiferal response to sedimentary disturbance in the Capbreton canyon (Bay of Biscay, NE Atlantic). Deep-Sea Research Part I 120, 61–75. http://dx.doi.org/10.1016/j.dsr.2016.11.012

Eichler, P. P. B., Sen Gupta, B. K., Eichler, B. B., Braga, E. S., Campos, E. J., 2008. Benthic foraminiferal assemblages of the South Brazil: relationship to water masses and nutrient distributions. Continental Shelf Research. 28 (13), 1674–1686. https://doi.org/10.1016/j.csr.2007.10.012

Fariduddin, M., Loubere, P., 1997. The surface ocean productivity response of deeper water benthic foraminifera in the Atlantic Ocean. Marine Micropaleontology 32, 289–310. https://doi.org/10.1016/S0377-8398(97)00026-1

Ferreira, F., Frontalini, F., Leão, C., Leipnitz, I. I., 2014. Changes in the water column structure and paleoproductivity in the western South Atlantic Ocean since the middle Pleistocene: Evidence from benthic and planktonic foraminifera. Quaternary International. 352, 111–123. https://doi.org/10.1016/j.quaint.2014.07.061

Fontanier, C., Jorissen, F. J., Licari, L., Alexandre, A., Anschutz, P., Carbonel, P., 2002. Live benthic foraminiferal faunas from the Bay of Biscay: faunal density, composition, and microhabitats. Deep-Sea Research I 49, 751–785. https://doi.org/10.1016/S0967-0637(01)00078-4

Fontanier, C., Jorissen, F. J., Chaillou, G., David, C., Anschutz, P., Lafon, V., 2003. Seasonal and interannual variability of benthic foraminiferal faunas at 550 m depth in the Bay of Biscay. Deep-Sea Res. Part I Oceanogr. Res. Pap. 50, 457–494. https://doi.org/10.1016/S0967-0637(02)00167-X

Fontanier, C., Jorissen, F. J., G. Chaillou, G., Anschutz, P., Grémare, A., Griveaud, C., 2005. Live foraminiferal faunas from a 2800 m deep lower canyon station from the Bay of Biscay: Faunal response to focusing of refractory organic matter. Deep-Sea Research Part I 52, 1189–1227. https://doi.org/10.1016/j.dsr.2005.01.006

Fontanier, C., Mackensen, A., Jorissen, F. J., Anschutz, P., Licari, L., Griveaud, C., 2006. Stable oxygen and carbon isotopes of live benthic foraminifera from the Bay of Biscay: Microhabitat impact and seasonal variability. Mar. Micropaleontol. 58, 159–183. https://doi.org/10.1016/j.marmicro.2005.09.004

França, R. L., Tokutake, L. R., 2004. Bacias sedimentares brasileiras: Bacia do Espírito Santo. Phoenix 69 (6), 1–6.

França, R. L.; Del Rey, A. C.; Tagliari, C. V.; Brandão, J. R.; Fontanelli, P. R., 2007. Bacia do Espírito Santo. Boletim Geociências da Petrobras 15 (2), 501–509.

Gaeta, S. A., Lorenzzetti, J. A., Miranda, L. B. d., Susini-Ribeiro, S. M. M., Pompeu, M., Araujo, C. E. S., 1999. The Vitória Eddy and its relation to the phytoplankton biomass and primary productivity during the austral fall of 1995. Archive of Fishery and Marine Research 47 (2/3), 253–270.

Gaeta, S. A, Brandini, F. P., 2006. Produção primária do fitoplâncton na região entre Cabo de São Tomé (RJ) e o Chuí (RS), In: Rossi-Wongtschowski, C. L. D. B., Madureira, L. S. (Eds). O ambiente oceanográfico da plataforma continental e do talude na região sudeste-sul do Brasil. Edusp, São Paulo, pp. 219–264.

García-Chapori, N. G., Laprida, C., Watanabe, S., Violeta Totah, V., Violante, R. A., 2014. Mid-Late Pleistocene benthic foraminifera from Southwestern South Atlantic: driven by primary productivity or water mass properties? Micropaleontology. 60 (2), 195–210.

Ghisolfi, R. D., Pereira da Silva, M., Thomaz dos Santos, F., Servino, R. N., Cirano, M., Thompson, F. L., 2015. Physical Forcing Mechanisms Controlling the Variability of Chlorophyll-a over the Royal-Charlotte and Abrolhos Banks – Eastern Brazilian Shelf. Plos One 10 (2): e0117082. https://doi.org/10.1371/journal.pone.0117082

Gooday, A. J., 1988. A response by benthic foraminifera to the deposition phytodetritus in the deep sea. Nature 332, 70–73. https://doi.org/10.1038/332070a0

Gooday, A. J., 1993. Deep-sea benthic foraminiferal species which exploit phytodetritus: characteristic features and controls on distribution. Marine Micropaleontology 22, 197–205. https://doi.org/10.1016/0377-8398(93)90043-W

Gooday, A. J., 1994. The biology of deep-sea foraminifera: a review of some advances and their applications in paleoceanography. PALAIOS 9, 14–31.

Gooday, A. J., 1996. Epifaunal and shallow infaunal foraminiferal communities at three abyssal NE Atlantic sites subject to differing phytodetritus input regimes. Deep-Sea Research I 43 (9), 1395–1421. https://doi.org/10.1016/S0967-0637(96)00072-6

Gooday, A. J., 2002. Biological responses to seasonally varying fluxes of organic matter to the ocean floor: a review. Journal of Oceanography 58, 305–332. https://doi.org/10.1023/A:1015865826379

Gooday, A. J., 2003. Benthic foraminifera (Protista) as tools in deep-water paleoceanography: a review of environmental influences on faunal characteristics. Advances in Marine Biology 46, 1–90. https://doi.org/10.1016/S0065-2881(03)46002-1

Gotelli, N. J., Ellison, A. M., 2011. Princípios de Estatística em Ecologia. Artmed, Porto Alegre.

Hammer, Ø., Harper, D. A. T., Ryan, P. D., 2001. Past: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontol. Electronica 4, art. 4: 9 pp., 178kb. http://palaeo-electronica.org/2001_1/past/issue1_01.htm.

Harloff, J.; Mackensen, A. 1997. Recent benthic foraminiferal associations and ecology of the Scotia Sea and Argentine Basin. Marine Micropaleontology 31, 1-29. https://doi.org/10.1016/S0377-8398(96)00059-X

Harris, P., Whiteway, T. 2011. Global distribution of large submarine canyons: Geomorphic differences between active and passive continental margins. Marine Geology 285, 69–86. https://doi.org/10.1016/j.margeo.2011.05.008

Hayward, B. W. Neil, H. Carter, R. Grenfell, H. R. Hayward, J. J., 2002. Factors influencing the distribution patterns of Recent deep-sea benthic foraminifera, east of New Zealand, Southwest Pacific Ocean. Mar. Micropaleontol. 46, 139–176. https://doi.org/10.1016/S0377-8398(02)00047-6

Hayward, B. W., Grenfell, H. R., Sabaa, A. T., Hayward, C. M., Neil, H. N., 2013. Ecological distribution of benthic foraminifera, offshore northeast New Zealand. Journal of Foraminiferal Research 36 (4), 332–354. https://doi.org/10.2113/gsjfr.36.4.332

Hercos, C. M., Schreiner, S. 2006. Sedimentação, estratigrafia e morfologia de uma porção do talude continental da Bacia do Espírito Santo In: CONGRESSO BRASILEIRO DE GEOLOGIA, 43., 2006, Aracaju. Expanded abstracs Sergipe: Sociedade Brasileira de Geologia.

Hercos, C.M., Schreiner, S., Sousa, M. B. F. M. 2015. Sedimentação e feições de instabilidade do talude submarino das bacias do Espirito Santo e norte de Campos. In: Relatório Final do Projeto de Caracterização Ambiental Regional da Bacia do Espírito Santo e parte norte da Bacia de Campos (PCR-ES), Anexo II, Petrobras, Rio de Janeiro, Brazil.

Hess, S., Jorissen, F. J. 2009. Distribution patterns of living benthic foraminifera from Cape Breton canyon, Bay of Biscay: Faunal response to sediment instability. Deep-Sea Research Part I 56, 555–1578. https://doi.org/10.1016/j.dsr.2009.04.003

Holbourn, A., Henderson, A. S.; Macleod, N., 2013. Atlas of Benthic Foraminifera. Oxford, Natural History Museum. https://doi.org/10.1002/9781118452493

Jones, R. W. 1994. The Challenger Foraminifera. Oxford University Press. 149 p., 115 pls.

Jorissen, F. J., Buzas, M., Culver, S. J., Kuehl, S. A. 1994. Vertical distribution of living benthic foraminifera in submarine canyons off New Jersey. Journal of Foraminiferal Research 24 (I), 28-36.

Jorissen, F. J., Stigter, H. C., Widmark, J. G. V., 1995. A conceptual model explaining benthic foraminiferal microhabitats. Marine Micropaleontology 26, 3–15. https://doi.org/10.1016/0377-8398(95)00047-X

Jorissen, F. J., Wittling, I., 1999. Ecological evidence from live-dead comparisons of benthic foraminiferal faunas off Cape Blanc (NW Africa). Palaeogeography, Palaeoclimatology and Palaeoecology 149, 151–70. https://doi.org/10.1016/S0031-0182(98)00198-9

Jorissen, F. J., Fontanier, C., Thomas, E., 2007. Paleoceanographical proxies based on deep-sea benthic foraminiferal assemblage characteristics, In: Hillaire-Marcel C., Vernal, A. (Eds.). Proxies in Late Cenozoic Paleoceanography (Pt. 2): Biological tracers and biomarkers, Elsevier, pp. 263–326.

Kaminski, M.A. 1985. Evidence for control of abyssal agglutinated foraminiferal community structure by substrate disturbance: Results from the HEBBLE Area. Marine Geology, 66, 113-131.

Kaminski, M.A., Gradstein, F.M., Berggren, W. Geroch, S., Beckmann, J.P. 1988. Agglutinated foraminiferal assemblages Trinidad: Taxonomy, Stratigraphy, and Paleobathymetry. In: Gradstein, F.M. and Rölg, F. (eds), Second International Workshop on Agglutinated Foraminifera, Vienna 1986, Ab-handlungen der Geologishen Bundesanstalt 41, 155-228.

Kaminski, M. A., Boersma, A., Tyszka, J., Holbourn, A. E. L., 1995. Response of deep-water agglutinated foraminifera to dysoxic conditions in the California Borderland basins. In: Kaminski, M. A. Geroch, S., Gasiƒski, M. A. (Eds.). Proceedings of the Fourth International Workshop on Agglutinated Foraminifera, Kraków Poland, September 12-19, 1993. Grzybowski Foundation Special Publication, 3, pp. 131–140.

Kaminski, M. A., Gradstein, F. M., 2005. Atlas of Paleogene cosmopolitan deep-water agglutinated foraminifera: Grzybowski Foundation Special Publication, 10, 547 p.

Kennet, J. P. 1982. Marine Geology. Prentice-Hall. Englewood Cliffs, N.J. pp. 752.

Koho, K.A., Kouwenhoven, T.J., de Stigter, H.C., van der Zwaan, G.J. 2007. Benthic foraminifera in the Nazaré Canyon, Portuguese continental margin: Sedimentary environments and disturbance. Marine Micropaleontology 66, 27–51. https://doi.org/10.1016/j.marmicro.2007.07.005

Loeblich, A. R., Tappan, H., 1988. Foraminiferal Genera and their Classification. New York: Van Nostrand Reinhold Ed., 970 p., 847 pls.

Loeblich, A. R., Tappan, H., 1994. Foraminifera of the Sahul Shelf and Timor Sea. Cushman Foundation for Foraminiferal Research. Special Publication. n. 31, 661 p. 393 pls.

Mackensen, A., Sejrup, H. P., Jansen, E., 1985. The distribution of living benthic foraminifera on the continental slope and rise off southwest Norway. Marine Micropaleontology 9, 275–306. https://doi.org/10.1016/0377-8398(85)90001-5

Mackensen, A., Schmiedl, G., Harloff, J., Giese, M., 1995. Deep-sea foraminifera in the South Atlantic Ocean: Ecology and assemblage generation. Micropaleontology. 41 (4), 342–358. https://doi.org/10.2307/1485808

Magurran, A. E., 2004. Measuring Biological Diversity. Blackwell Publishing.

Maia, L. P., Castelo-Branco, M. P. N., Soares, R. S., Catunda B. N., Bastos, A. C., Leal, C. A., Marcon, E. H., 2015. Sedimentologia da Margem Continental da Bacia do Espírito Santo e Norte da Bacia de Campos. In: Relatório Final do Projeto de Caracterização Ambiental Regional da Bacia do Espírito Santo e parte norte da Bacia de Campos (PCR-ES), Anexo II, Petrobras, Rio de Janeiro, Brazil.

Martins, T. R., 2014. A Corrente do Brasil no Embaiamento de Tubarão - Oceano Atlântico Sudoeste. Unpublished thesis. Departamento de Oceanografia e Ecologia, Universidade Federal do Espírito Santo. Vitória, Brazil. 57 p.

Martorelli, E., Bosman, A., Casalbore, D., Chiocci, F., Conte, A. M., Di Bella, L., Ercilla, G., Falcini, F., Falco, P., Frezza, V., Gaglianone, G., Giaccio, B., Mancini, M. 2021. Mid-to-late Holocene upper slope contourite deposits off Capo Vaticano (Mediterranean Sea): High-resolution record of contourite cyclicity, bottom current variability and sandy facies. Marine Geology 431, 106372. https://doi.org/10.1016/j.margeo.2020.106372

Mello, R. M. de., 2006. Caracterização da Fauna de Foraminíferos Bentônicos do Talude da Bacia de Campos, RJ, e sua Correlação com os Parâmetros das Massas d´água do Atlântico Sul. Unpublished thesis. Instituto de Geociências, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil. 196 p.

Mello, R. M. M., Leckie, R. M., Frass, A. J., Thomas, E., 2016. Upper Maastrichtian – Eocene benthic foraminiferal biofacies of the Brazilian margin, western South Atlantic. In: Kaminski, M. A., Alegret, L. (Eds.). Proceedings of the Ninth International Workshop on Agglutinated Foraminifera. Grzybowski Foundation Special Publication 22, 119–161. https://doi.org/10.2307/3515178

Mémery, L., Arthan, M., Alvarez-Salgado, X. A., Messias, M. J., Mercier, H., Castro, C. G., Rios, A. F., 2000. The water masses along the western boundary of the south and equatorial Atlantic. Progress in Oceanography 47, 69–98. https://doi.org/10.1016/S0079-6611(00)00032-X

Motoki, A., Motoki, K. F., Melo, D. P., 2012. Caracterização da morfologia submarina da Cadeia Vitória-Trindade e áreas adjacentes-ES, com base na batimetria predita do topo versão 14.1. Rev. Bras. Geomorfol. 13, 151–170. http://dx.doi.org/10.20502/rbg.v13i2.195

Murray, J. W., 2006. Deep sea. In: Ecology and applications of benthic foraminifera. Cambridge University Press, Cambridge. pp. 180-237.

Nagai, R. H., Sousa, S. H. M., Burone, L., Mahiques, M. M., 2009. Paleoproductivity changes during the Holocene in the inner shelf of Cabo Frio, southeastern Brazilian continental margin: benthic foraminifera and sedimentological proxies. Quaternary International. 206 (1/2), 62–71. https://doi.org/10.1016/j.quaint.2008.10.014

Nagai, R. H., Sousa, S. H. M., Lourenço, R. A., Bícego, M. C., Mahiques, M. M., 2010. Paleoproductivity changes during the late quaternary in the southeastern Brazilian upper continental margin of the Southwestern Atlantic. Brazilian Journal of Oceanography. 58, 31–41. https://doi.org/10.1590/S1679-87592010000500004

Napolitano, D. C., Silveira, I. C. A., Rocha, C. B., Flierl, G. R., Calil, P. H. R., Martins, R. P., 2019. On the steadiness and instability of the intermediate western boundary current between 24° and 18°S. Journal Physical Oceanography 49 (12), 3127–3143. https://doi.org/10.1175/JPO-D-19-0011.1

Oliveira, K. S. S., Quaresma, V. S., 2017. Temporal variability in the suspended sediment load and streamflow of the Doce River. Journal of South America Earth Science 78, 101–115. https://doi.org/10.1016/j.jsames.2017.06.009

Oliveira, N., Bastos, A. C., Quaresma, V. S., Vieira, F. V., 2020. The use of Benthic Terrain Modeler (BTM) in the characterization of continental shelf habitats. Geo-Marine Letters 40, 1087–1097. https://doi.org/10.1007/s00367-020-00642-y

Ortiz, N. 1995. Differential patterns of benthic foraminiferal extinctions near the Paleocene/Eocene boundary in the North Atlantic and the western Tethys. Marine Micropalontology 26, 341-359.

Palóczy, A., Brink, K. H., Silveira, I. C. A., Arruda, W. Z., Martins, R. P., 2016. Pathways and mechanisms of offshore water intrusions on the Espírito Santo Basin shelf (18°S–22°S, Brazil). Journal of Geophysical Research: Oceans 121 (7), 5134–5163. https://doi.org/10.1002/2015JC011468

Patterson, R. T., Richardson, R. H. 1987. A taxonomic revision of the Unilocular foraminifera. Journal of Foraminiferal Research 17 (3), 212-226. https://doi.org/10.2113/gsjfr.17.3.212

Peeters, F., Ivanova, E., Conan S., Brummer, G-J., Ganssen, G., Troelstra, S., Hinte, J. v. 1999. A size analysis of planktic foraminifera from the Arabian Sea. Marine Micropaleontology 36, 31–63. https://doi.org/10.1016/S0377-8398(98)00026-7

Perassoli, F., Ghisolfi, R. D., Lemos, A. T. 2020. Spatial distribution of nutrients associated with water masses in the Tubarão Bight (20°S–22°S), Brazil. Journal of Marine Systems, 212, 103425, https://doi.org/10.1016/j.jmarsys.2020.103425

Pereira, F., Silveira, I. C. A., Flierl, G. R., Tandon, A. 2019. NPZ response to eddy-induced upwelling in a Brazil Current ring: A theoretical approach. Dynamics of Atmospheres and Oceans, 87, 101096. https://doi.org/10.1016/j.dynatmoce.2019.101096

Puig, P. Palanques, A., Martín, J. 2014. Contemporary Sediment-Transport Processes in Submarine Canyons. Annual Review of Marine Science 6, 53–77. https://doi.org/10.1146/annurev-marine-010213-135037

Quaresma, V. S., Catabriga, G., Bourguignon, S. N., Godinho, E., Bastos, A. C., 2015. Modern sedimentary processes along the Doce river adjacent continental shelf. Brazilian Journal of Geology 45 (4), 635–644. https://doi.org 10.1590/2317-488920150030274

Reid, J. L., 1989. On the total geostrophic circulation of the South Atlantic Ocean: flow patterns, tracers, and transports. Prog. Oceanogr. 23, 149–244. https://doi.org/10.1016/0079-6611(89)90001-3

Ribeiro-Ferreira, V. P., Marcon, E. H., Berenguer, V., Falcão, A. P. C. 2015. Metodologia de Campo do Compartimento de Sedimento na Bacia do Espírito Santo e Porção Norte da Bacia de Campos. In: Relatório Final do Projeto de Caracterização Ambiental Regional da Bacia do Espírito Santo e parte norte da Bacia de Campos (PCR-ES), Anexo II, Petrobras, Rio de Janeiro, Brazil.

Rodrigues, A. R., Pível, M. A. G., Schmitt, P., de Almeida, F. K., Bonetti, C., 2018. Infaunal and epifaunal benthic foraminifera species as proxies of organic matter paleofluxes in the Pelotas Basin, south-western Atlantic Ocean. Marine Micropaleontology 144, 38–49. https://doi.org/10.1016/j.marmicro.2018.05.007

Saupe, A., Schmidt, J., Petersen, J., Bahr, A., Dias, B. B., Albuquerque, A. L. S., Ramos, R. A. D., Grunert, P. 2022. Controlling Parameters of Benthic Deep-Sea Foraminiferal Biogeography at the Brazilian Continental Margin (11-22°S). Frontiers in Marine Science (9), 901224. https://doi.org/10.3389/fmars.2022.901224

Schmid, C., Schafer, H., Podesta, G., Zenk, W., 1995. The Vitoria Eddy and Its Relation to the Brazil Current, Journal of Physical Oceanography 25, 2532–2546. https://doi.org/10.1175/1520-0485(1995)025<2532:TVEAIR>2.0.CO;2

Schmiedl, G., Mackensen, A., 1997. Late Quaternary paleoproductivity and deep-water circulation in the eastern South Atlantic Ocean, evidence from benthic foraminifera. Palaeogeography, Palaeoclimatology, Palaeoecology 130, 43–80. https://doi.org/10.1016/S0031-0182(96)00137-X

Schmiedl, G., Mackensen, A., Müller, P. J., 1997. Recent benthic foraminifera from the eastern South Atlantic Ocean: dependence on food supply and water masses. Marine Micropaleontology. 32, 249–287. https://doi.org/10.1016/S0377-8398(97)00023-6

Schmiedl, G., de Bove, F., Buscail, R., Charrière, B., Hemleben, C., Medernach, L., Picon, P. 2000. Trophic control of benthic foraminiferal abundance and microhabitat in the bathyal Gulf of Lions, western Mediterranean Sea. Marine Micropaleontology 40, 167–188.

Schmitt, P., Rodrigues, A. R., Bonetti, C., 2019. Sucessão de associações de foraminíferos bentônicos como indicadoras de variações paleoceanográficas no Terraço de Torres

(RS - Brasil) durante o Quaternário Tardio. Anu. do Inst. de Geocienc. UFRJ 42, 387–395. http://dx.doi.org/10.11137/2019_4_387_395

Schnitker, D., 1974. West Atlantic abyssal circulation during the past 120,000 years. Nature. 247, 385–387.

Schreiner, S.; Souza, M. B. F. M.; Migliorelli, J. P. R. 2009. Modelo digital da geomorfologia do fundo oceânico do centro-sul da Bacia do Espírito Santo e norte da Bacia de Campos. Boletim de Geociências da Petrobras 17 (2), 365–369.

Schreiner, S., Hercos, C. M., 2015. Geomorfologia do talude continental, platô de São Paulo e sopé continental. In: Relatório Final do Projeto de Caracterização Ambiental Regional da Bacia do Espírito Santo e parte norte da Bacia de Campos (PCR-ES), Anexo II, Petrobras, Rio de Janeiro, Brazil.

Schröder-Adams, C.J., Boyd, R., Ruming, K., Sandstrom, M. 2008. Influence of sediment transport dynamics and ocean floor morphology on benthic foraminifera, offshore Fraser Island, Australia. Marine Geology 254, 47–61. https://doi.org/10.1016/j.margeo.2008.05.002

Shepard, F.P. 1972. Submarine canyons. Earth-Sciences Review 8, 1-12.

Silveira, I. C. A., Napolitano, D. C., Palóczy Filho, A., Watanabe, G. A. O., Baldasso, P., Calixto, P. S., Yamashita, M. K., Castro, B. M., Godoi, S. S., Arruda, W. Z., Paranhos, R. P. R., Martins, R. P., Grossman-Matheson, G. S., Cavalcante, L. M., Ribeiro, E. O., 2015. Massas de água e circulação do talude continental e região oceânica da Bacia de Espírito Santo e norte da Bacia de Campos. In: Relatório Final do Projeto de Caracterização Ambiental Regional da Bacia do Espírito Santo e parte norte da Bacia de Campos (PCR-ES), Anexo II, Petrobras, Rio de Janeiro, Brazil.

Silveira, I. C. A., Napolitano, D.C., Farias, I. U. 2020. Water Masses and Oceanic Circulation of the Brazilian Continental Margin and Adjacent Abyssal Plain. In: Sumida, P. Y. G., Bernardino, A. F., De Léo F. C. (Eds.) Brazilian Deep-Sea Biodiversity. Brazilian Marine Biodiversity. Springer, Cham. https://doi.org/10.1007/978-3-030-53222-2_2

Smart, C. W., King, S. C., Gooday, A. J., Murray, J. W., Thomas, E., 1994. A benthic foraminiferal proxy of pulsed organic matter paleofluxes. Marine Micropaleontology 23, 89–99. https://doi.org/10.1016/0377-8398(94)90002-7

Smart, C. W., 2008. Abyssal NE Atlantic benthic foraminifera during the last 15 kyr: relation to variations in seasonality of productivity. Marine Micropaleontology 69, 193–211. https://doi.org/10.1016/j.marmicro.2008.07.007 7

Smart, C. W., Thomas, E., Bracher, C. M., 2019. Holocene variations in North Atlantic export productivity as reflected in bathyal benthic foraminifera. Mar. Micropaleontol. 149, 1–18. https://doi.org/10.1016/j.marmicro.2019.03.004

Soares, R. S., 2017. Novas Proposições Metodológicas Para o Calcímetro de Bernard e Caracterização dos Sedimentos Marinhos do Espírito Santo. Unpublished thesis. Instituto de Ciências do Mar, Universidade Federal do Ceará, Fortaleza, Brazil. 90 p.

Sobreira, J. F. F., França, R. L., 2006. Um modelo tectonomagmático para a região do Complexo Vulcânico de Abrolhos. Boletim de Geociências da Petrobras 14 (1), 143–147.

Sousa, S. H. M., Passos, R. F., Fukumoto, M., da Silveira, I. C. A., Figueira, R. C. L., Koutsoukos, E. A. M., Mahiques, M. M., Rezende, C. E., 2006. Mid-lower bathyal benthic foraminifera of the Campos Basin, Southeastern Brazilian margin: Biotopes and controlling ecological factors. Mar. Micropaleontol. 61, 40–57. https://doi.org/10.1016/j.marmicro.2006.05.003

Sousa, S. H. M., Yamashita, C., Nagai, R. H., Martins, M. V. A., Ito, C., Vicente, T., Taniguchi, N., Burone, L., Fukumoto, M., Aluizio, R., Koutsoukos, E. A. M., 2017. Foraminíferos bentônicos no talude continental, platô de São Paulo e cânions da Bacia de Campos. In: Falcão, A.P.C., Lavrado, H.P. (Eds.). Ambiente Bentônico: caracterização ambiental regional da Bacia de Campos, Atlântico Sudoeste. Rio de Janeiro, Elsevier, Habitats 3, 111–144. https://doi.org/10.1016/B978-85-352-7263-5.50005-9

Soutelino, R. G., Silveira, I. C. A., Gangopadhyay, A., Miranda, J. A., 2011. Is the Brazil Current eddy-dominated to the north of 20° S? Geophysical Research Letters 38 (3), L03607. https://doi.org/10.1029/2010GL046276

Soutelino, R. G., Gangopadhyay, A., Silveira, I. C. A., 2013. The roles of vertical shear and topography on the eddy formation near the site of origin of the Brazil Current. Continental Shelf Research 70, 46–60. https://doi.org/10.1016/j.csr.2013.10.001

Stramma, L., Ikeda, Y., Peterson, R. G., 1990. Geostrophic transport in the Brazil Current region north of 20° S. Deep-Sea Res. Part I Oceanogr. Res. Pap. 37, 1875–1886. https://doi.org/10.1016/0198-0149(90)90083-8

Stramma, L., England, M., 1999. On the water masses and mean circulation of the South Atlantic Ocean. J. Geophys. Res. 104, 20863–20883. https://doi.org/10.1029/1999JC900139

Suguio, K. 1973. Introdução à Sedimentologia. Edgard Blücher Ltda, São Paulo. pp. 317

Tapia, R., Le, S. Ling Ho, S., Bassetti, M-A., Lin, I-T. Lin, H-L., Chang, Y-P., Jiann, K-T., Wang, P-L., Lin, J-K., Babonneau, N., Ratzov, G., Hsu, S-K., Su, C-C. 2022. Planktic-benthic foraminifera ratio (%P) as a tool for the reconstruction of paleobathymetry and geohazard: A case study from Taiwan. Marine Geology 453, 106922. https://doi.org/10.1016/j.margeo.2022.106922.

Thomas, E., Booth, L., Maslin, M., Schackleton, N. J., 1995. Northeastern Altantic benthic foraminifera during the last 45,000 years: Changes in productivity seen from the bottom up. Paleoceanography 10, 545–562. https://doi.org/10.1029/94PA0305

van der Zwaan, G. J., Jorissen, F. J., Stigter, H. C., 1990. The depth dependency of planktonic/benthic foraminiferal ratios: Constraints and applications. Marine Geology 95, 1–16. https://doi.org/10.1016/0025-3227(90)90016-D

van Morkhoven, F. P. C. M., Berggren, W. A., Edwards, A. S., 1986. Cenozoic cosmopolitan deep-water benthic foraminifera. Bull. Cent. Rech. Explor. Prod. Elf-Aquitaine. Mem.11. 421 p., 126 pls.

Vicalvi, M. A., Kowsmann, R. O., 2006. Application of foraminiferal biostratigraphy to the assessment of submarine geohazards. In: International Symposium of Foraminifera – FORAMS, 2006, Natal, Brazil.

Vieira, F. V., Bastos, A. C., Quaresma, V. S., Leite, M. L., Costa Jr., A., Oliveira, K. S. S, Dalvi, C. F., Bahia, R. G., Holz, V. L., Moura, R. L., Amado-Filho, G. M., 2019. Along-shelf changes in mixed carbonate-siliciclastic sedimentation patterns. Continental Shelf Research. 187, 103964. https://doi.org/10.1016/j.csr.2019.103964

WoRMS (World Register of Marine Species). Foraminifera. Accessed at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=1410 on 2022-10-27

Yamashita, C., Nagai, R. N., Martins, M. V. A., Vicente, T. M., Sousa, S. H. M., Frontalini, F., et al., 2016. On the interplay between hydrodynamics, bottom morphology, sedimentary processes and benthic foraminifera assemblages in the São Paulo Bight (Brazil, SW Atlantic). J. Sediment. Environ. 3, 334–355. https://doi.org/10.12957/jse.2016.25990

Yamashita, C., Martins, M. V. A., Melo e Sousa, S. H., Vicente, T. M., Kaminski, M. A., Frontalini, F., Carreira, R., Godoi, S. S., Taniguchi, N. K., Paranhos, R., Figueira, R. C. L., de Rezende, C. E. 2017. Distribution and ecology of living (Rose Bengal stained) Marsipella elongata Norman, 1878 (Foraminifera) in the Campos Basin, southeastern Brazilian continental margin. Micropaleontology 63, 321–334.

Yamashita, C., Sousa, S. H. M., Vicente, T. M., Martins, M. V., Nagai, R. H., Frontalini, F., Godoi, S. S., Napolitano, D., Burone, L., Carreira, R., Figueira, R. C. L, Taniguchia, N. K., Rezende, C.E., Koutsoukos, E. A. M., 2018a. Environmental controls on the distribution of living (stained) benthic foraminifera on the continental slope in the Campos Basin area (SW Atlantic). J. Mar. Syst. 181, 37–52. https://doi.org/10.1016/j.jmarsys.2018.01.010

Yamashita, C., Sousa, S. H. M., Kaminski, M. A., and de Araujo, B. D., 2018b. Description, distribution and ecology of living (rose Bengal stained) Eggerelloides camaransis n. sp. Micropaleontology 64, 515-525.

Yamashita, C., Omachi, C., Santarosa, A. C. A., Iwai, F. S., Araujo, B. D., Disaró, S. T., Martins, M. V. A., Vicente, T. M., Taniguchi, N., Burone, L., Mahiques, M. M., Bícego, M. C., Figueira, R. C. L., Sousa, S. H. M. 2020. Living benthic foraminifera of Santos continental shelf, southeastern Brazilian continental margin (SW Atlantic): chlorophyll a and particulate organic matter approach. Journal of Sedimentary Environments. https://doi.org/10.1007/s43217-019-00001-7

2.3 COMPARAÇÃO ENTRE AS ASSOCIAÇÕES DE FORAMINÍFEROS BENTÔNICOS DO TALUDE DA BACIA DO ESPÍRITO SANTO E DEMAIS BACIAS MARGINAIS BRASILEIRAS

A partir de uma análise integrada, pode-se constatar que a densidade, diversidade e composição das associações de foraminíferos bentônicos recentes do talude continental da BES são influenciadas por uma complexa interação dos seguintes fatores ambientais: tipo e intensidade do fluxo orgânico (quantidade e qualidade da matéria orgânica), características físico-químicas das massas d’água (ACAS, AIA e APAN) e das correntes superficiais (CB), intermediárias (CCI) e profundas (CCP), granulometria e composição dos sedimentos. Esses fatores corroboram com o que tem sido relatado para os foraminíferos bentônicos de mar profundo das bacias marginais brasileiras Sul e Sudeste.

Estudos preliminares no talude das bacias de Campos, Santos indicaram que os principais fatores responsáveis pelas diferentes respostas das associações de foraminíferos recentes estão relacionadas com as variações na produtividade primária, o fluxo orgânico na coluna de água, e, consequentemente, no fluxo estimado de carbono orgânico para o fundo marinho. Outros fatores como a intensidade das correntes de fundo, massa d’água, tipo de substrato e a profundidade da coluna d’água também foram considerados como fatores importantes nessas bacias (Mello, 2006; Sousa et al., 2006; 2017; Burone et al., 2011; Yamashita, 2011; 2015; Yamashita et al., 2018a; 2020; Saupe et al., 2022).

A seguir, serão ressaltadas as principais semelhanças e diferenças observadas quanto a estrutura da comunidade (densidade, composição das testas, hábito de vida) e preservação das testas de de foraminíferos bentônicos no talude continental das bacias de Campos, Espírito Santo, e Santos.

- Densidade

A primeira semelhança observada entre os dados obtidos na BES e na Bacia de Campos está relacionada a densidade de foraminíferos bentônicos. Em ambas bacias, a densidade diminui com o aumento da profundidade ao longo do talude continental (Yamashita, 2015; Sousa et al., 2006; 2017; Yamashita et al., 2018a). Os maiores valores de densidade foram observados no talude superior (isóbata de 400 m) das bacias de Campos, principalmente na região norte dessa bacia, (Yamashita, 2015; Sousa et al., 2017) e Espírito Santo (de Almeida et al., 2022).

Na Bacia de Campos, a densidade apresentou uma correlação positiva com a diversidade e riqueza de espécies de foraminíferos bentônicos, representada, principalmente por espécies infaunais detritívoras (i.e., *Globocassidulina subglobosa*) (Yamashita, 2015) e características de ambiente com fluxo elevado e sustentável de matéria orgânica metabolizável (i.e., bolivinídeos, buliminídeos, *Uvigerina peregrina*) (Souza et al., 2017). Esse padrão difere da BES, pois com o aumento na densidade de foraminíferos foi observada a diminuição da riqueza e diversidade de espécies. Além disso, as espécies que mais contribuem para o aumento nos valores de densidade também são diferentes, entretanto, também são calcárias hialinas infaunais, tais como *Globocassidulina rossensis*, *Trifarina angulosa* e *Trifarina* spp. (de Almeida et al., 2022).

Os autores dos estudos realizados em ambas bacias concordam que o aumento na densidade de foraminíferos bentônicos está relacionado à disponibilidade de alimento no talude superior. Nesses casos, o aumento da quantidade de matéria orgânica se deve à influência das feições de mesoescala predominante em cada bacia, relacionadas à CB e seus meandros (que geram os vórtices de Cabo Frio, Cabo de São Tomé, e Vórtice de Vitória), a intensidade da CCI, ao fenômeno de ressurgência da ACAS próximo a quebra da plataforma, e a própria presença da ACAS, uma massa d'água rica em nutrientes, em 400 m de profundidade.

- Composição das testas e microhabitat

Outra semelhança observada em amostras superficiais no talude das bacias do Espírito Santo e Campos é que no talude superior e médio predominam espécies com carapaça calcária hialina, e, na maioria das amostras analisadas, com hábito de vida infaunal Yamashita, 2015; Sousa et al., 2017; de Almeida et al., 2022; Saupe et al., 2022). Isso também ocorreu no talude inferior da Bacia de Santos durante o Pleistoceno (de Almeida et al., 2015; Rodrigues et al., 2018; Schmitt et al., 2019). O predomínio de espécies calcárias hialinas infaunais do gênero *Globocassidulina* nas associações distribuídas no talude superior, médio – inferior das bacias de Campos, Espírito Santo, e Santos indica elevada concentração de oxigênio no sedimento de fundo (Gooday, 1994; Mackensen et al., 1995).

Em relação à composição das testas, a principal diferença observada ocorre a partir do talude inferior das bacias de Campos e Espírito Santo. Na BES, a microfauna calcária hialina continua predominante entre 1.300 a 3.000 de profundidade (com exceção do

CANWN). Embora ocorra um aumento no percentual de aglutinantes em 1.900 m de profundidade, os foraminíferos calcário hialinos dominam ao longo de todo talude (de Almeida et al., 2022). Na Bacia de Campos, Mello (2006) reconheceu uma área dominada por táxons aglutinantes abaixo de 1.600 m de profundidade, relacionada ao domínio da APAN, uma massa de água rica em oxigênio e pobre em nutrientes. De acordo com Souza et al. (2017), o domínio de espécies aglutinantes, menores valores de densidade e diversidade no talude inferior (1.900 a 3.000 m) da Bacia de Campos refletem condições ambientais mais restritivas quanto à disponibilidade de alimento, sugerindo um ambiente mais oligotrófico.

Ainda no talude inferior (1.350 a 1.950 m) da Bacia de Campos, Yamashita et al. (2018a) identificou associações de foraminíferos caracterizadas por menor densidade, riqueza e diversidade, dominadas por Bolivina spp. Esses autores sugeriram que a região do talude inferior é menos afetada pelo fluxo sazonal de fitodetritos (provenientes da produtividade primária), e que o sedimento lamoso alto teor de matéria orgânica, mas com menor qualidade para serem utilizados como alimento. Na região mais profunda do talude inferior (2.000 a 3.000) da BES o táxon Bolivina spp. também é dominante, e foi relacionada ao predomínio da APAN e sugere um aumento de matéria orgânica mais refratária no sedimento (de Almeida et al., 2022).

- *Preservação das testas*

Em um estudo utilizando sedimentos superficiais do talude da Bacia de Campos, Mello (2006) reconheceu duas associações de foraminíferos bentônicos distribuída em cotas batimétricas sob a influência da Água Circumpolar (AC), uma massa de água mais corrosiva ao carbonato. Essa autora analisou diferentes graus de dissolução em testas de foraminíferos calários hialinos e calcários porcelanosos, e ressaltou que o caráter corrosivo da ACP é capaz de promover um aumento efetivo na dissolução de testas calcárias dos foraminíferos bentônicos, justificado pelo aumento na alcalinidade e no CO2 total no intervalo entre 1.000 a 1.700 m de profundidade da Bacia de Campos.

Um método semelhante foi aplicado em um testemunho recuperado no talude inferior (2.200 m de profundidade) da Bacia de Santos por Gonzales et al. (2017). Esses autores propuseram um índice de preservação de *Hoeglundina elegans* (> 150 µm), uma espécie de foraminífero bentônico composta por aragonita e muito sensível à dissolução do carbonato. Nesse estudo, constatou-se que a dissolução foi mais efetiva durante os intervalos glaciais do Pleistoceno (762 kyrs), quando a baixa preservação das testas de *H. elegans* indicaram maior influência da massa d'água AC na camada de mistura entre AC-APAN.

No talude superior e médio-inferior (400 a 1.300 m) da BES foi observado um aumento na fragmentação das testas de foraminíferos bentônicos e planctônicos (> 125 µm). Entretanto, de Almeida et al. (2022) atribuiu esse aumento à processos físicos, como transporte de testas de regiões mais rasas para mais profundas no talude e/ou a ressuspensão dos sedimentos devido a intensidade da CCI. Por hora, esses autores acreditam que a fragmentação das testas não esteja relacionada à influencia da ACS no talude médio-inferior, já que na BES o núcleo dessa massa d'água é indefinido e, quando observada, encontra-se diluído na interface AIA-APAN, limitada a latitude de 21° S (Silveira et al., 2015; 2020).

CAPÍTULO 3. CONSIDERAÇÕES FINAIS

O presente trabalho permitiu uma oportunidade rara de integração de dados da microfauna de foraminíferos bentônicos com dados sedimentológicos previamente analisados no sedimento superficial, associados a morfologia de fundo e as condições oceanográficas atuais na BES. Essa bacia possui características morfológicas, sedimentares e oceanográficas muito singulares, o que a torna uma oportunidade única, e desafiadora, para reconhecer a distribuição de foraminíferos bentônicos em um fundo marinho heterogêneo, e indicar os principais fatores ambientais que influenciam tal distribuição.

O fator primário que influencia a distribuição de foraminíferos no talude da BES está associado a quantidade e qualidade do fluxo orgânico que chega até o fundo marinho. Esse fluxo pode ter sua origem associada aos mecanismos oceanográficos atuantes na região, tais como: (i) a produtividade primária local, que, por sua vez, é controlada pela dinâmica das feições de mesoescala associadas a CB, seus meandros e vórtices, resultando no fluxo vertical de fitodetritos (matéria orgânica lábil); (ii) a atividade das correntes de fundo (como a CCI), que podem remobilizar o sedimento de fundo, e transferir lateralmente a matéria orgânica para determinadas profundidades, resultando no fluxo de matéria orgânica refratária, e (iii) a chegada de material orgânico proveniente da plataforma continental, que pode ser viabilizado através de cânions, canais e ravinas.

Através da microfauna bentônica analisada pode-se constatar que o fluxo orgânico varia conforme a profundidade da coluna d’água, caracterizando assim padrões de distribuição definidos por zonas batimétricas, que são compostas por associações de foraminíferos bentônicos distintas.

Dessa maneira, foi possível observar que as associações de foraminíferos presentes no talude superior (150 a 400 m), onde foram observados os maiores valores de densidade de foraminíferos associados a espécies infaunais oportunistas (i.e., *Globocassidulina rossensis, Trifarina angulosa,* e *Trifarina* spp.), indicam um maior e contínuo fluxo orgânico. Provavelmente, esse fluxo ocorre em reposta a intrusão da ACAS na plataforma continental, provocando o fenômeno de ressurgência de quebra da plataforma. Outro mecanismo possível está relacionado ao transporte de matéria orgânica da plataforma para o talude superior. Esse transporte poderia ser facilitado pelos cânions, canais e ravinas que recortam a plataforma e a talude da BES.

A dominância de espécies oportunistas (i.e., espécies do gênero *Globocassidulina* e *Bolivina*), e a abundância de espécies fitodetritívoras (ex. *Alabaminella weddellensis* e *Epistominella exigua*) no talude médio e inferior (1.000 a 3.000 m) confirmam a influência das feições de mesoescala quase-estacionárias e recorrentes na BES, como VV. O bombeamento de águas ricas em nutrientes pelo VV contribui significativamente para o aumento da produtividade primária local, eleva o fluxo de matéria orgânica lábil, e beneficia as espécies de foraminíferos bentônicos que se alimentam de pulsos de fitodetritos.

Um outro fator que influencia a distribuição de foraminíferos no talude da BES está associado as propriedades físico-químicas das massas de água (principalmente ACAS, AAI e APAN) e das correntes de contorno intermediárias (CCI) e profundas (CCP). Aparentemente, elas correspondem a um fator mais secundário na distribuição dos foraminíferos bentônicos, porém, resulta nas diferentes associações encontradas ao longo do talude. Além disso, a abundância e frequência da espécie *Globocassidulina subglobosa*, e o aumento na deposição de testas de foraminíferos bentônicos e planctônicos fragmentadas no talude médio-inferior (1.000 a 1300 m) pode estar relacionado a remobilização e transporte de sedimento de fundo causado pela CCI. Outra hipótese para que testas de foraminíferos bentônicos fragmentadas tenham sido redepositadas, principalmente na região próxima ao Banco Besnard, é que tenham sido transportadas pela CB de regiões mais rasas, como a Plataforma Sul de Abrolhos, para o talude.

A influência dos diferentes tipos de sedimentos na distribuição dos foraminíferos bentônicos foi mais efetiva ao analisar a microfauna em dois cânions submarinos (CANWN e CAND) distintos. Foi possível constatar que as características morfológicas desses cânions influenciam, de maneira mais localizada, a distribuição dos foraminíferos bentônicos no talude, e que os cânions diferem entre si quanto à composição e diversidade de espécies. No CANWN foi observado que, a menos que ocorra o transporte de sedimentos terrígenos arenosos dentro do cânion, provocado por correntes de contorno e/ou turbidez, a distribuição dos foraminíferos bentônicos continua variando conforme a profundidade da coluna d’água. No CAND, de acordo com a ecologia dos foraminíferos bentônicos abundantes, esse cânion parece aprisionar matéria orgânica suficiente para beneficiar o estabelecimento e a diversidade de espécies, indicando assim um ambiente mais produtivo e menos instável que o CANWN

Apesar das poucas amostras analisadas na plataforma da BES, ficou evidente que a associação de foraminíferos bentônicos encontrada na plataforma externa não se estende até o talude superior. Isso corrobora as diferenças batimétricas entre essas duas províncias fisiográficas. Entretanto, são necessários mais estudos com maior resolução espacial para confirmar esse padrão de distribuição na plataforma.

Por fim, a distribuição das associações de foraminíferos bentônicos recentes encontradas nesse estudo reflete uma imagem mais integrada da dinâmica populacional e das condições ambientais predominantes durante o Holoceno Tardio (Biozona Z) na BES. A complexa morfologia da BES já é conhecida por influenciar os padrões de sedimentação e hidrodinâmicos. Aparentemente, essa complexidade também influencia a distribuição de foraminíferos bentônicos de forma mais local, como nos casos das associações encontradas dentro dos cânions submarinos e próximo ao Banco Besnard.

Os dados adquiridos através do presente trabalho podem servir como base para estudos futuros em sedimentos superficiais e de testemunhos no talude das bacias marginais brasileira como, por exemplo: (i) verificar se as associações de foraminíferos bentônicos vivos (corados com Rosa de Bengala) nos sedimentos superficiais também indicam os mesmos resultados discutidos nessa tese; (ii) verificar se as associações encontradas no presente trabalho também ocorrem em períodos interglaciais durante o Quaternário; (iii) testemunhos coletados no talvergue dos cânions submarinos, que recebem alto aporte de sedimentos terrígenos, podem elucidar qual mecanismo (i.e., correntes de contorno ou de turbidez) tem maior influência no aumento de foraminíferos aglutinantes e diminuição de foraminíferos planctônicos no talude médio – inferior da BES.

6. REFERÊNCIAS

Alperin, M. I., Cusminsky, G. C., Bernasconi, E., 2011. Benthic foraminiferal morphogroups on the Argentine continental shelf. Journal of Foraminiferal Research. 41 (2), 155–166. https://doi.org/10.2113/gsjfr.41.2.155

Altenbach, A. V., Pflaumann, U., Schiebel, R., Thies, A., Timm, S., Trauth, M., 1999. Scaling percentages and distributional patterns of benthic foraminifera with flux rates of organic carbon. Journal of Foraminiferal Research. 29 (3), 173–185.

Armstrong, H. A., Brasier, M. D., 2005. Microfossils. 2a edição. Blackwell Publishing. 296 p.

Barbosa, V. P., 2010. Foraminíferos bentônicos como indicadores bioestratigráficos no Quaternário Superior da Bacia de Campos. Revista Brasileira de Paleontologia. 13 (2), 129–142. http://doi.org/10.4072/rbp.2010.2.06

Barbosa, V. P., 2002. Sistemática, bioestratigrafia e paleoceanografia de foraminíferos do Quaternário do talude continental das bacias de Santos e Campos (Tese – Doutorado). Instituto de Geociências, Universidade Federal do Rio de Janeiro, RJ, Brasil.

Bastos, A. C., Quaresma, V. S., Marangoni, M. B., D'Agostini, D. P., Bourguignon, S. N., Cetto, P. H., Silva, A. E., Amado Filho, G. A., Moura, R. L., Collins, M., 2015. Shelf morphology as an indicator of sedimentary regimes: A synthesis from a mixed siliciclastic-carbonate shelf on the eastern Brazilian margin. Journal of South American Earth Sciences, 63, 125–136. https://doi.org/10.1016/j.jsames.2015.07.003

Bernhard, J. M., Sen Gupta, B. K., 1999. Foraminifera of oxygen depleted environments. In: Sen Gupta, B.K. (Ed.), Modern Foraminifera. Kluwer. Academic Publishers, The Netherlands, pp. 201–216.

Boersma A., 1977. Eocene to Early Miocene benthic foraminifera DSDP LEG 39, South Atlantic. In: Supko, P. R., et al. (Eds) Initial Reports of the Deep-Sea Drilling Project. Washington, D.C.: U.S. Government Printing Office, 39, 643–656.

Boersma, A., 1984. Handbook of common Tertiary Uvigerina. Microclimates Press. Stony Point, New York.

Bolli, H. M., Beckmann, J-P., Saunders, J. B., 1994. Benthic foraminiferal biostratigraphy of South Caribbean region. Cambridge University Press.

Burone, L. B., Sousa, S. H. M., Mahiques, M. M., Valente, P., Ciotti, A., Yamashita, C., 2011. Benthic foraminiferal distribution on the southeastern Brazilian shelf and upper slope. Marine Biology. 158, 159–179. http://dx.doi.org/10.1007/s00227-010-1549-7

Cushman, J. A., 1927. The generic revision of five families of Rotaliine. Cushman Foundation for Foraminiferal Research. Special Publication, 34.

Cushman, J. A., 1928. Foraminifera: Their Classification and Economic Use. Cushman Laboratory for Foraminiferal Research Special Publication, 1, 1–401.

Cushman, J. A., 1933. An illustrated key to the genera of the foraminifera. Cushman Laboratory for Foraminiferal Research Special Publication, 5.

D'Agostini, D. P., Bastos, A. C., Amado-Filho, G. M., Vilela, C. G., Thaís, C. S., Oliveira, T. C. S., Webster, J. M., Moura, R. L., 2019. Morphology and sedimentology of the shelf-upper slope transition in the Abrolhos continental shelf (East Brazilian Margin). Geo-Marine Letters. 39, 117–134. https://doi.org/10.1007/s00367-019-00562-6

de Almeida, F. K., Mello, R. M., Costa, K. B., Toledo, F. A. L., 2015. The response of deep-water benthic foraminiferal assemblages to changes in paleoproductivity during the

Pleistocene (last 769.2 kyr), Western South Atlantic Ocean. Palaeogeography, Palaeoclimatology and Palaeoecology. 440, 201–212. https://doi.org/10.1016/j.palaeo.2015.09.005

De Rijk, Jorissen, F.J., Rohlinga, E.J., Troelstra, S.R. 2000. Organic flux control on bathymetric zonation of Mediterranean benthic foraminifera. Marine Micropaleontology. 40, 151-166.

Dias, B. B., Barbosa, C. F., Faria, G. R., Seoane, J. C. S., Albuquerque, A. L. S., 2018. The effects of multidecadal-scale phytodetritus disturbances on the benthic foraminiferal community of a Western Boundary Upwelling System, Brazil. Marine Micropaleontology. 139, 102–112. https://doi.org/10.1016/j.marmicro.2017.12.003

Dissaró, S. T., Aluizio, R., Ribas, E. R., Pupo, D. V., Tellez, I. R., Watanabe, S., Totah, V. I., Koutsoukos, E. A. M., 2017. Foraminíferos bentônicos na plataforma continental da Bacia de Campos. In A. P. C. Falcão e H. P. Lavrado (Eds.), Ambiente Bentônico: Caracterização ambiental regional da Bacia de Campos, Atlântico Sudoeste, 3, 65–110. Rio de Janeiro. Elsevier. https://doi.org/10.1016/B978-85-35-7263-5.50004-7

Eichler, P. P. B., Sen Gupta, B. K., Eichler, B. B., Braga, E. S., Campos, E. J., 2008. Benthic foraminiferal assemblages of the South Brazil: relationship to water masses and nutrient distributions. Continental Shelf Research. 28 (13), 1674–1686. https://doi.org/10.1016/j.csr.2007.10.012

Eichler, P. P. B., Pimenta, F. M., Eichler, B. B., Vital, H., 2016. Living benthic foraminiferal species as indicators of cold-warm water masses interaction and upwelling areas. Continental Shelf Research, 116, 116–121. https://doi.org/10.1016/j.csr.2016.01.006

Eichler, P. P. B., Rodrigues, A. R., Gomes, M. P., Vital, H., 2019. Benthic foraminifera as indicators of river discharge in the Western South Atlantic continental shelf. Marine Geology. 415. https://doi.org/10.1016/j.margeo.2019.105973

Fariduddin, M., Loubere, P., 1997. The surface ocean productivity response of deeper water benthic foraminifera in the Atlantic Ocean. Marine Micropaleontology. 32, 289–310. https://doi.org/10.1016/S0377-8398(97)00026-1

Ferreira, F., Frontalini, F., Leão, C., Leipnitz, I. I., 2014. Changes in the water column structure and paleoproductivity in the western South Atlantic Ocean since the middle Pleistocene: Evidence from benthic and planktonic foraminifera. Quaternary International. 352, 111–123. https://doi.org/10.1016/j.quaint.2014.07.061

Fontanier, C., Jorissen, F. J., Licari, L., Alexandre, A., Anschutz, P., Carbonel, P., 2002. Live benthic foraminiferal faunas from the Bay of Biscay: faunal density, composition, and microhabitats. Deep-Sea Research I. 49, 751–785. https://doi.org/10.1016/S0967-0637(01)00078-4

Fontanier, C., Jorissen, F. J., G. Chaillou, G., Anschutz, P., Grémare, A., Griveaud, C., 2005. Live foraminiferal faunas from a 2800 m deep lower canyon station from the Bay of Biscay: Faunal response to focusing of refractory organic matter. Deep-Sea Research I. 52, 1189–1227. https://doi.org/10.1016/j.dsr.2005.01.006

García-Chapori, N. G., Laprida, C., Watanabe, S., Violeta Totah, V., Violante, R. A., 2014. Mid-Late Pleistocene benthic foraminifera from Southwestern South Atlantic: driven by primary productivity or water mass properties? Micropaleontology. 60 (2), 195–210.

Gonzales, M. V., de Almeida, F. K., Costa, K. B., Santarosa, A. C. A., Camillo Jr., E., Quadros, J. P., Toledo, F. A. L., 2017. HELP INDEX: Hoeglundina elegans preservation index for marine sediments in the western South Atlantic. Journal of Foraminiferal Research. 47 (1), 56–69. https://doi.org/10.2113/gsjfr.47.1.56

Gooday, A. J., 1988. A response by benthic foraminifera to the deposition phytodetritus in the deep sea. Nature 332, 70–73. https://doi.org/10.1038/332070a0

Gooday, A. J., 1993. Deep-sea benthic foraminiferal species which exploit phytodetritus: characteristic features and controls on distribution. Marine Micropaleontology. 22, 197–205. https://doi.org/10.1016/0377-8398(93)90043-W

Gooday, A. J., 1994. The biology of deep-sea foraminifera: a review of some advances and their applications in paleoceanography. PALAIOS, 9, 14–31.

Gooday, A. J., 1996. Epifaunal and shallow infaunal foraminiferal communities at three abyssal NE Atlantic sites subject to differing phytodetritus input regimes. Deep-Sea Research. I 43 (9), 1395–1421. https://doi.org/10.1016/S0967-0637(96)00072-6

Gooday, A. J., Turley, C. M., 1990. Responses by benthic organisms to inputs of organic material to the ocean floor: a review. Philosophical Transactions of the Royal Society of London. 331, 119–138.

Hayward, B. W., Grenfell, H. R., Carter, R., Hayward, J. J., 2004. Benthic foraminiferal proxy evidence for the Neogene palaeoceanographic history of the Southwest Pacific, east of New Zealand. Mar. Geol. 205, 147–184. https://doi.org/10.1016/S0025-3227(04)00022-2

Jorissen, F. J., Stigter, H. C., Widmark, J. G. V., 1995. A conceptual model explaining benthic foraminiferal microhabitats. Marine Micropaleontology. 26, 3–15. https://doi.org/10.1016/0377-8398(95)00047-X

Jorissen, F. J., Fontanier, C., Thomas, E., 2007. Paleoceanographical proxies based on deep-sea benthic foraminiferal assemblage characteristics, In: Hillaire-Marcel C., Vernal, A., Proxies in Late Cenozoic Paleoceanography (Pt. 2): Biological tracers and biomarkers, Elsevier, pp. 263–326.

Kaiho, K. 1994. Benthic foraminiferal dissolved-oxygen index and dissolved oxygen levels in the modern ocean. Geology. 22, 719-722.

Lisboa, L. P., 2006. Paleoecologia e bioestratigrafia em foraminíferos do talude continental da Bacia do Espírito Santo: Estudo em dois “piston cores” (Monografia). Departamento de Oceanografia e Ecologia, Universidade Federal do Espírito Santo, Vitória, Brasil.

Loeblich, A. R., Tappan, H., 1988. Foraminiferal Genera and their Classification. New York: Van Nostrand Reinhold Ed., 970 p., 847 pls.

Loeblich, A. R., Tappan, H., 1994. Foraminifera of the Sahul Shelf and Timor Sea. Cushman Foundation for Foraminiferal Research. Special Publication. n. 31, 661 p. 393 pls.

Lohmann, G. P., 1978. Abyssal benthonic foraminifera as hydrographic indicators in the western South Atlantic Ocean. Journal of Foraminiferal Research. 8, 6–34. https://doi.org/10.2113/gsjfr.8.1.6

Mackensen, A., Schmiedl, G., Harloff, J., Giese, M., 1995. Deep-sea foraminifera in the South Atlantic Ocean: Ecology and assemblage generation. Micropaleontology. 41 (4), 342–358.

Mello, R. M. de., 2006. Caracterização da Fauna de Foraminíferos Bentônicos do Talude da Bacia de Campos, RJ, e sua Correlação com os Parâmetros das Massas d´água do Atlântico Sul (Dissertação – Mestrado). Instituto de Geociências, Universidade Federal do Rio de Janeiro, RJ, Brasil. 182 p.

Mello, R. M. M., Leckie, R. M., Frass, A. J., Thomas, E., 2016. Upper Maastrichtian – Eocene benthic foraminiferal biofacies of the Brazilian margin, western South Atlantic. In: Kaminski, M. A., Alegret, L., (Eds), Proceedings of the Ninth International Workshop on Agglutinated Foraminifera. Grzybowski Foundation Special Publication. 22, 119–161. https://doi.org/10.2307/3515178

Müller-Merz, E., Oberhänsli, H., 1991. Eocene bathyal and abyssal benthic foraminifera from a South Atlantic transect at 20-30°S. Palaeogeography. Palaeoclimatology, Palaeoecology. 83, 117–171.

Murray, J. W., 2006. Ecology and applications of benthic foraminifera. Cambridge. Cambridge University Press.

Nagai, R. H., Sousa, S. H. M., Burone, L., Mahiques, M. M., 2009. Paleoproductivity changes during the Holocene in the inner shelf of Cabo Frio, southeastern Brazilian continental margin: benthic foraminifera and sedimentological proxies. Quaternary International. 206 (1/2), 62–71. https://doi.org/10.1016/j.quaint.2008.10.014

Nagai, R. H., Sousa, S. H. M., Lourenço, R. A., Bícego, M. C., Mahiques, M. M., 2010. Paleoproductivity changes during the late quaternary in the southeastern Brazilian upper continental margin of the Southwestern Atlantic. Brazilian Journal of Oceanography. 58, 31–41. https://doi.org/10.1590/S1679-87592010000500004

Peterson, L. C., Lohmann, G. P., 1982. Major change in Atlantic deep and bottom waters 700,000 yr ago: Benthonic foraminiferal evidence from the South Atlantic. Quaternary Research. 17, 26–38.

Rodrigues, A. R., Pível, M. A. G., Schmitt, P., de Almeida, F. K., Bonetti, C., 2018. Infaunal and epifaunal benthic foraminifera species as proxies of organic matter paleofluxes in the Pelotas Basin, south-western Atlantic Ocean. Marine Micropaleontology. 144, 38–49. https://doi.org/10.1016/j.marmicro.2018.05.007

Saupe, A., Schmidt, J., Petersen, J., Bahr, A., Dias, B. B., Albuquerque, A. L. S., Ramos, R. A. D., Grunert, P. 2022. Controlling Parameters of Benthic Deep-Sea Foraminiferal Biogeography at the Brazilian Continental Margin (11-22°S). Frontiers in Marine Science (9), 901224. https://doi.org/10.3389/fmars.2022.901224

Schmitt, P., Rodrigues, A. R., Bonetti, C., 2019. Sucessão de associações de foraminíferos bentônicos como indicadoras de variações paleoceanográficas no Terraço de Torres (RS - Brasil) durante o Quaternário Tardio. Anuário do Instituto de Geociências – UFRJ. 42 (4), 387–395. http://dx.doi.org/10.11137/2019_4_387_395

Schmiedl, G., Mackensen, A., 1997. Late Quaternary paleoproductivity and deep-water circulation in the eastern South Atlantic Ocean, evidence from benthic foraminifera. Palaeogeography, Palaeoclimatology, Palaeoecology. 130, 43–80.

Schmiedl, G., Mackensen, A., Müller, P. J., 1997. Recent benthic foraminifera from the eastern South Atlantic Ocean: dependence on food supply and water masses. Marine Micropaleontology. 32, 249–287. https://doi.org/10.1016/S0377-8398(97)00023-6

Schnitker, D., 1974. West Atlantic abyssal circulation during the past 120,000 years. Nature. 247, 385–387.

Schnitker, D., 1980. Quaternary deep-sea benthic foraminifers and bottom water masses. In: Donath, F.E. (Ed) Annual Review of Earth and Planetary Sciences 8, 343–370.

Schreiner, S., Souza, M. B. F. M., Migliorelli, J. P. R., 2008. Modelo digital da geomorfologia do fundo oceânico da Bacia de Campos, Boletim de Geociências da Petrobras.16 (1), 157–160.

Schreiner, S.; Souza, M. B. F. M.; Migliorelli, J. P. R. 2009. Modelo digital da geomorfologia do fundo oceânico do centro-sul da Bacia do Espírito Santo e norte da Bacia de Campos. Boletim de Geociências da Petrobras. 17 (2), 365–369.

Sen Gupta, B.K., Machain-Castillo, M.L. 1993. Benthic foraminifera in oxygen-poor habitats. Marine Micropaleontology. 20, 183-201.

Sen Gupta, B. K., 1999. Introduction to modern foraminifera. In: Sen Gupta, B. K. (Ed.), Modern Foraminifera. Kluwer Academic Publishers, Dordrecht, pp. 3–6.

Sen Gupta, B.K., 1999. Systematics of modern foraminifera. In: Sen Gupta, B.K. (Ed.), Modern Foraminifera. Kluwer Academic Publishers, Dordrecht, pp. 7–36.

Smart, C. W., King, S. C., Gooday, A. J., Murray, J. W., Thomas, E., 1994. A benthic foraminiferal proxy of pulsed organic matter paleofluxes. Marine Micropaleontology. 23, 89–99. https://doi.org/10.1016/0377-8398(94)90002-7

Sousa, S. H. M., Passos, R. F., Fukumoto, M., da Silveira, I. C. A., Figueira, R. C. L., Koutsoukos, E. A. M., Mahiques, M. M., Rezende, C. E. 2006. Mid-lower bathyal benthic foraminifera of the Campos Basin, Southeastern Brazilian margin: Biotopes and controlling ecological factors. Marine Micropaleontology. 61, 40–57. https://doi.org/10.1016/j.marmicro.2006.05.003

Sousa, S. H. M., Yamashita, C., Nagai, R. H., Martins, M. V. A., Ito, C., Vicente, T., Taniguchi, N., Burone, L., Fukumoto, M., Aluizio, R., Koutsoukos, E. A. M., 2017. Foraminíferos bentônicos no talude continental, platô de São Paulo e cânions da Bacia de Campos. In: Falcão, A.P.C., Lavrado, H.P. (eds). Ambiente Bentônico: caracterização ambiental regional da Bacia de Campos, Atlântico Sudoeste. Rio de Janeiro: Elsevier. Habitats. 3, 111–144. https://doi.org/10.1016/B978-85-352-7263-5.50005-9

Tjalsma R. C., 1983. Eocene to Miocene benthic foraminifers from Deep Sea Drilling Project SITE 516, Rio Grande Rise, South Atlantic. In: Barker, P. F.; Carlson, R. L.; Johnson, D. A. et al (Eds). Initial Reports os the Deep-Sea Drilling Project. Washington, D.C.: U. S. Government Printing Office. 72, 731–755.

Tjalsma, R. C., Lohmann, G. P., 1983. Paleocene-Eocene bathyal and abyssal benthic foraminifera from the Atlantic Ocean. Micropaleontology Special Publication. (4).

van Morkhoven, F. P. C. M., Berggren, W. A., Edwards, A. S., 1986. Cenozoic cosmopolitan deep-water benthic foraminifera. Bulletin des Centres de Recherches Exploration-Production Elf-Aquitaine. Mem.11. 421 p., 126 pls.

Venturelli, R.A., Rathburn, A.E., Burkett, A.M., Ziebis, W. 2018. Epifaunal foraminifera in an infaunal world: insights into the influence of heterogeneity on the benthic ecology of oxygen-poor, deep-sea habitats. Frontiers in Marine Science. 17. https://doi.org/10.3389/fmars.2018.00344

Yamashita, C., 2011. Distribuição dos foraminíferos bentônicos vivos no talude continental e Platô de São Paulo, Bacia de Campos (23° 12'-24° 30' e 39° 59'-41° 20'): fatores ambientais condicionantes (Dissertação – Mestrado). Instituto Oceanográfico, Universidade de São Paulo, USP, São Paulo.

Yamashita, C., 2015. Foraminíferos bentônicos vivos na margem sudoeste do Atlântico Sul, Bacia de Campos: processos oceanográficos condicionantes. Instituto Oceanográfico, Universidade de São Paulo, USP, São Paulo.

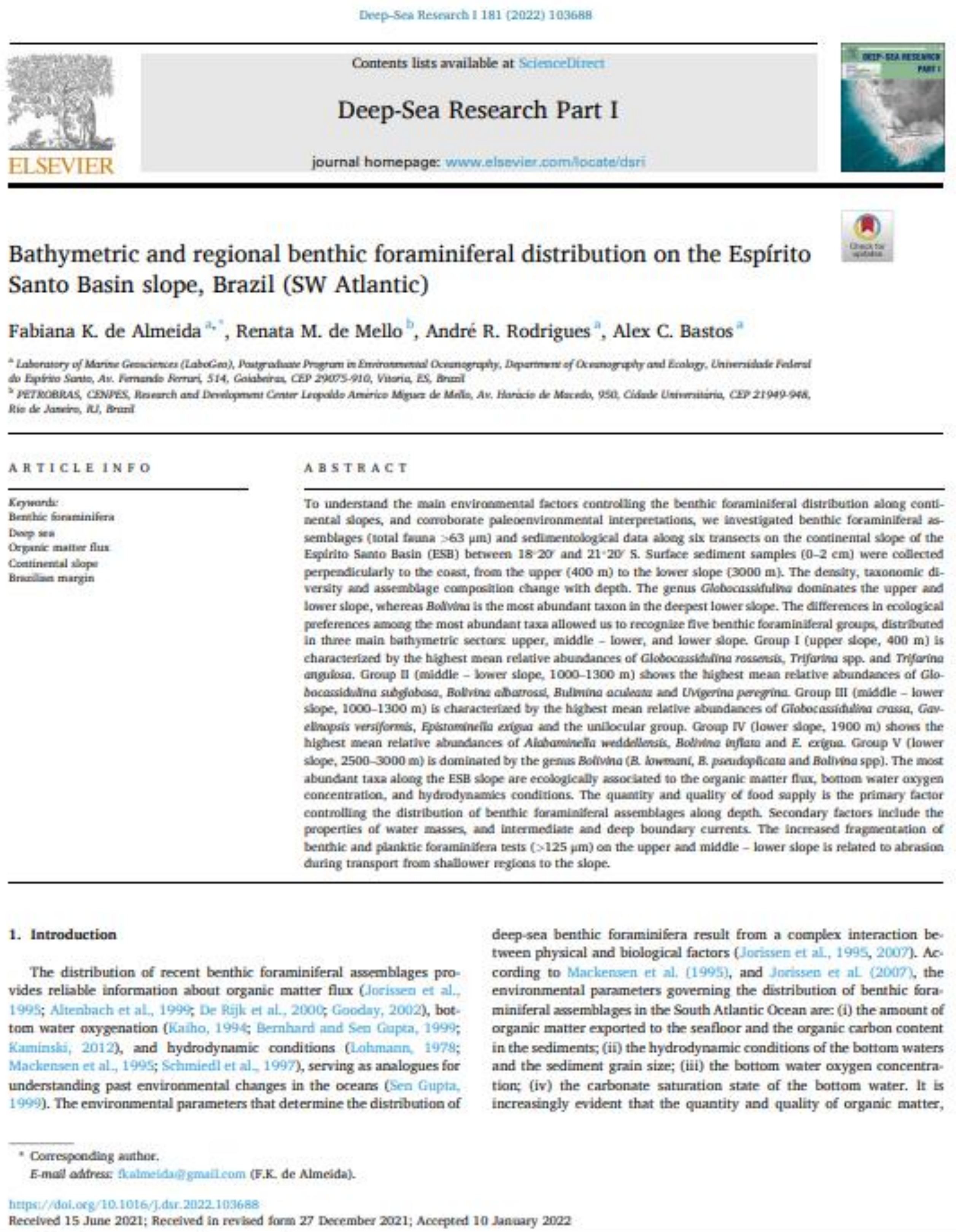
Yamashita, C., Nagai, R. N., Martins, M. V. A., Vicente, T. M., Sousa, S. H. M., Frontalini, F., et al., 2016. On the interplay between hydrodynamics, bottom morphology, sedimentary processes and benthic foraminifera assemblages in the São Paulo Bight (Brazil, SW Atlantic). Journal of Soils and Sediments. 1 (3), 334–355. https://doi.org/10.12957/jse.2016.25990

Yamashita, C., Sousa, S. H .M., Vicente, T. M., Martins, M. V., Nagai, R. H., Frontalini, F., Godoi, S. S., Napolitano, D., Burone, L., Carreira, R., Figueira, R. C. L, Taniguchia, N. K., Rezende, C.E., Koutsoukos, E. A. M., 2018. Environmental controls on the distribution of living (stained) benthic foraminifera on the continental slope in the Campos Basin area (SW Atlantic). Journal of Marine Systems. 181, 37–52. https://doi.org/10.1016/j.jmarsys.2018.01.010

Yamashita, C., Omachi, C., Santarosa, A. C. A., Iwai, F. S., Araujo, B. D., Disaró, S. T., Martins, M. V. A., Vicente, T. M., Taniguchi, N., Burone, L., Mahiques, M. M., Bícego, M. C., Figueira, R. C. L., Sousa, S. H. M. 2020. Living benthic foraminifera of Santos continental shelf, southeastern Brazilian continental margin (SW Atlantic): chlorophyll a and particulate organic matter approach. Journal of Sedimentary Environments. https://doi.org/10.1007/s43217-019-00001-7

ANEXOS

ANEXO A – Documento comprobatório do primeiro artigo (publicado).



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Bathymetric and regional benthic foraminiferal distribution on the Espírito Santo Basin slope, Brazil (SW Atlantic)

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Brazilian margin

ABSTRACT

To understand the main environmental factors controlling the benthic foraminiferal distribution along continental slopes, and corroborate paleoenvironmental interpretations, we investigated benthic foraminiferal assemblages (total fauna >63 μm) and sedimentological data along six transects on the continental slope of the Espírito Santo Basin (ESB) between 18°20′ and 21°20′ S. Surface sediment samples (0–2 cm) were collected perpendicularly to the coast, from the upper (400 m) to the lower slope (3000 m). The density, taxonomic diversity and assemblage composition change with depth. The genus *Globocassidulina* dominates the upper and lower slope, whereas *Bolivina* is the most abundant taxon in the deepest lower slope. The differences in ecological preferences among the most abundant taxa allowed us to recognize five benthic foraminiferal groups, distributed in three main bathymetric sectors: upper, middle – lower, and lower slope. Group I (upper slope, 400 m) is characterized by the highest mean relative abundances of *Globocassidulina rossensis*, *Trifarina* spp. and *Trifarina angulosa*. Group II (middle – lower slope, 1000–1300 m) shows the highest mean relative abundances of *Globocassidulina subglobosa*, *Bolivina albatrossi*, *Bulimina aculeata* and *Uvigerina peregrina*. Group III (middle – lower slope, 1000–1300 m) is characterized by the highest mean relative abundances of *Globocassidulina crassa*, *Gavelinopsis versiformis*, *Epistominella exigua* and the unilocular group. Group IV (lower slope, 1900 m) shows the highest mean relative abundances of *Alabaminella weddellensis*, *Bolivina inflata* and *E. exigua*. Group V (lower slope, 2500–3000 m) is dominated by the genus *Bolivina* (*B. lowmani*, *B. pseudoplicata* and *Bolivina* spp). The most abundant taxa along the ESB slope are ecologically associated to the organic matter flux, bottom water oxygen concentration, and hydrodynamics conditions. The quantity and quality of food supply is the primary factor controlling the distribution of benthic foraminiferal assemblages along depth. Secondary factors include the properties of water masses, and intermediate and deep boundary currents. The increased fragmentation of benthic and planktic foraminifera tests (>125 μm) on the upper and middle – lower slope is related to abrasion during transport from shallower regions to the slope.

1. Introduction

The distribution of recent benthic foraminiferal assemblages provides reliable information about organic matter flux (Jorissen et al., 1995; Altenbach et al., 1999; De Rijk et al., 2000; Gooday, 2002), bottom water oxygenation (Kaiho, 1994; Bernhard and Sen Gupta, 1999; Kaminski, 2012), and hydrodynamic conditions (Lohmann, 1978; Mackensen et al., 1995; Schmiedl et al., 1997), serving as analogues for understanding past environmental changes in the oceans (Sen Gupta, 1999). The environmental parameters that determine the distribution of deep-sea benthic foraminifera result from a complex interaction between physical and biological factors (Jorissen et al., 1995, 2007). According to Mackensen et al. (1995), and Jorissen et al. (2007), the environmental parameters governing the distribution of benthic foraminiferal assemblages in the South Atlantic Ocean are: (i) the amount of organic matter exported to the seafloor and the organic carbon content in the sediments; (ii) the hydrodynamic conditions of the bottom waters and the sediment grain size; (iii) the bottom water oxygen concentration; (iv) the carbonate saturation state of the bottom water. It is increasingly evident that the quantity and quality of organic matter,

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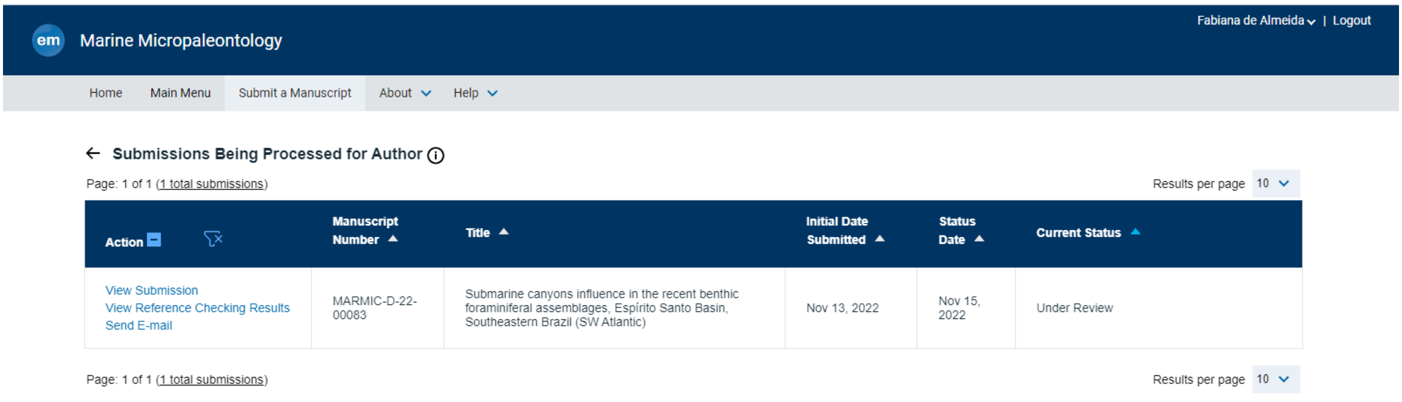
Supplementary material – Table S1: List of benthic foraminiferal species and their respective microhabitats.

SESSILE	EPIFAUNAL			INFAUNAL			
Bathysiphon sp.	*Adelosina granulocostata*	*Glomospira charoides*	*Pyrgoella sphaera*	*Alassoida schlumbergeri*	*Cassidulina curvata*	*Karrerrulina conversa*	*Sagrinella* sp.
Hormosina spp.	*Adercotryma glomeratum*	*Glomospira gordialis*	*Quinqueloculina bosciana*	*Ammobaculites agglutinans*	*Cassidulina laevigata*	*Labrospira crassimargo*	*Sahulia conica*
Hormosinella carpenteri	*Alabaminella weddellensis*	*Gyroidina orbicularis*	*Quinqueloculina oblonga*	*Ammobaculites calcareus*	*Clavulina mexicana*	*Labrospira nitida*	*Saidovina karreriana*
Hormosinella distans	*Ammodiscus anguillae*	*Gyroidina soldanii*	*Quinqueloculina porterensis*	*Ammobaculites* sp.1	*Clavulina multicamerata*	*Labrospira spiculotesta*	*Seabrookia curta*
Hormosinella globulifera	*Ammodiscus* sp.	*Haplophragmoides quadratus*	*Quinqueloculina seminulum*	*Ammobaculites* sp.2	*Cribrostomoides subglobulosus*	*Labrospira wiesneri*	*Sigmavirgulina tortuosa*
Hormosinella spp.	*Ammodiscus tenuis*	*Laticarinina pauperata*	*Quinqueloculina venusta*	*Ammosphaeroidina grandis*	*Cyclammina cancelatta*	*Laevidentalina* sp.	*Siphotextularia* sp.
Hyperammina sp.	*Ammoglobigerina globulosa*	*Lituoba lituiformis*	*Quinqueloculina weaveri*	*Ammosphaeroidina* sp.	*Cyclammina pusilla*	*Lagenammina* sp.	*Siphouvigerina* sp.
Marsipella cylindrica	*Ammoglobigerina* sp.	*Lobatula lobatula*	*Sigmamiliolinella australis*	*Ammosphaeroidina sphaeroidiniformis*	*Cyclammina* sp.	*Lenticulina atlantica*	*Sphaeroidina bulloides*
Marsipella elongata	*Ammolagena clavata*	*Miliolinella subrotunda*	*Sigmoilina obesa*	*Amphicoryna scalaris*	*Dorothia scabra*	*Lenticulina gibba*	*Subreophax aduncus*
Pelosina cylindrica	*Amphistegina lessoni*	*Neoeponides antillarum*	*Sigmoilopsis schlumbergeri*	*Amphycorina* sp.	*Dorothia* sp.	*Lenticulina iota*	*Textularia atlantica*
Pelosina rotundata	*Amphistegina radiata*	*Neoeponides* sp.1	*Siphonaperta ammophila*	*Anomalinoides globulosus*	*Eggerella afixa*	*Loxostomum truncatum*	*Textularia candeiana*
Rhabdammina abyssorum	*Archaias angulatus*	*Nummoloculina contraria*	*Siphonina bradyiana*	*Astacolus crepidulus*	*Eggerella bradyi*	*Marsonella* sp.	*Textularia hystrix*
Rhabdammina discreta	*Cancris oblongus*	*Nuttalides umbonifer*	*Spirillina* spp.	*Bolivina albatrossi*	*Ehrenbergina spinea*	*Melonis barleeanum*	*Textularia mexicana*
Rhabdammina linearis	*Cibicidoides bradyi*	*Oridorsalis umbonatus*	*Spiroloculina bradyi*	*Bolivina fragilis*	*Ehrenbergina trigona*	*Melonis pompilioides*	*Textularia porrecta*
Rhabdammina sp.	*Cibicidoides cicatricosus*	*Oridorsalis variapertura*	*Spiroloculina depressa*	*Bolivina inflata*	*Elphidium discoidale*	*Morulaeplecta bulbosa*	*Trifarina angulosa*
Rhizammina algaeformis	*Cibicidoides incrassatus*	*Oridorsalis westi*	*Spiroloculina* sp.	*Bolivina lowmani*	*Eratidus foliaceous*	*Nodosaria lamnulifera*	*Trifarina asperrima*
Saccorhiza ramosa	*Cibicidoides mundulus*	*Osangularia bengalensis*	*Spirophitalmidium* sp.	*Bolivina ordinaria*	*Evolutinella rotulata*	*Nonionella auris*	*Trifarina bradyi*
	Cibicidoides pachyderma	*Pararotalia* sp.	*Spirosigmoilina tenuis*	*Bolivina pseudoplicata*	*Fursenkoina complanata*	*Nonionella* sp.	*Trifarina cojimarensis*
	Cibicidoides robertisonianus	*Paratrochammina globorotaliformis*	*Tolypammina vagans*	*Bolivina quadrilatera*	*Fursenkoina* sp.	*Nonionoides grateloupii*	*Trifarina pauperata*
	Cibicidoides wuellerstorfi	*Patellina corrugata*	*Triloculina tricarinata*	*Bolivina* sp. 1	*Gaudryina flintii*	*Paracassidulina nipponensis*	*Trifarina semitrigona*
	Cornuloculina inconstans	*Peneroplis* sp.	*Triloculina trigonula*	*Bolivina subaenariensis*	*Gaudryina pyramidata*	*Pleurostomella* sp.	*Uvigerina ampullacea*
	Cornuspira involvens	*Planorbulina mediterranensis*	*Triloculinella lucernula*	*Bolivinellina transluscens*	*Globobulimina* sp.	*Psammosphaera fusca*	*Uvigerina auberiana*
	Cornuspira planorbis	*Planorbulina* sp.	*Triloculinella pseudooblonga*	*Brizalina subaenariensis* var. *mexicana*	*Globocassidulina crassa*	*Pseudobrizalina lobata*	*Uvigerina hispido-costata*
	Cymbaloporreta bradyi	*Planulina ariminensis*	*Trochammina lomonosovensis*	*Brizalina subspinescens*	*Globocassidulina moluccensis*	*Pseudogaudryina atlantica*	*Uvigerina mediterranea*
	Discammina compressa	*Planulina foveolata*	*Trochammina* sp.	*Bulimina aculeata*	*Globocassidulina oblonga*	*Pullenia bulloides*	*Uvigerina peregrina*
	Discorbinella bertheloti	*Pyrgo comata*	*Trochamminoides challengeri*	*Bulimina alazanensis*	*Globocassidulina rossensis*	*Pullenia quinqueloba*	*Uvigerina pigmea*
	Discorbis sp.1	*Pyrgo depressa*	*Wisnerella auriculata*	*Bulimina marginata*	*Globocassidulina subglobosa*	*Recurvoides contortus*	*Vaginulinopsis* sp.
	Discorbis vilardeboeanus	*Pyrgo elongata*		*Bulimina mexicana*	*Hanzawaia* sp.	*Reophax subfusiformis*	*Valvulineria javana*
	Epistominella exigua	*Pyrgo inornata*		*Bulimina striata*	*Haynesina germanica*	*Robertina bradyi*	*Valvulineria laevigata*
	Eponides sp. 1	*Pyrgo lucernula*		*Buliminella elegantissima*	*Hoeglundina elegans*	*Robertinoides* sp.	*Veleroninoides scitulus*
	Gavelinopsis translucens	*Pyrgo murrhina*		*Cassidulina angulosa*	*Hopinkisina pacifica*	*Sacammina* sp.	*Vertebralina striata*
	Gavelinopsis versiformis	*Pyrgo serrata*		*Cassidulina carinata*	*Islandiella norcrossi*	*Sagrina pulchella*	*Vulvulina pennatula*

Supplementary material – Table S2: Relative abundance of the main benthic foraminiferal species found along the Espírito Santo Basin slope. Values expressed in percentage.

	UPPER SLOPE						MIDDLE - LOWER SLOPE												LOWER SLOPE																	
Species relative abundances (> 1%)	**A05**	**B05**	**C05**	**D05**	**E05**	**F05**	**A06**	**B06**	**C06**	**D06**	**E06**	**F06**	**A07**	**B07**	**C07**	**D07**	**E07**	**F07**	**A08**	**B08**	**C08**	**D08**	**E08**	**F08**	**A09**	**B09**	**C09**	**D09**	**E09**	**F09**	**A10**	**B10**	**C10**	**D10**	**E10**	**F10**
Globocassidulina rossensis	14.1	20.4	5.5	40.3	51.0	44.5	19.9	17.8	13.3	24.5	15.7	12.3	14.7	31.9	23.8	27.0	16.7	9.1	27.3	32.9	18.0	21.7	22.2	24.1	8.3	9.5	12.6	10.3	8.3	12.9	6.0	1.9	7.9	9.2	4.4	7.4
Bolivina lowmani	7.1	10.8	6.6	2.8	1.4	4.0	6.2	16.2	20.2	9.8	16.8	19.5	6.5	2.8	10.0	8.5	13.3	10.1	13.5	12.4	10.7	14.1	13.6	24.5	28.7	21.1	21.8	16.3	15.2	17.3	27.2	17.8	17.9	17.2	10.7	19.3
Globocassidulina crassa	11.9	12.6	5.1	13.1	11.5	11.9	28.1	18.7	17.8	27.3	29.2	14.8	30.9	30.4	24.6	22.9	31.8	11.3	15.6	2.1	14.2	9.1	10.6	6.8	5.1	8.7	3.8	8.2	6.5	6.4	2.6	2.7	7.9	6.5	3.6	5.9
Bolivina pseudoplicata	0.3	0.7	0.8	1.0	0.1	0.8	0.0	0.3	0.6	0.6	1.5	4.4	0.5	0.5	0.5	0.5	0.7	4.0	0.0	0.4	1.5	1.5	0.7	1.2	8.3	4.5	8.0	6.9	5.1	7.9	12.7	15.9	14.1	12.8	7.1	9.4
Bolivina spp.	3.2	5.2	1.5	2.8	1.7	1.0	2.0	2.5	1.2	2.8	3.7	1.9	3.2	1.1	3.8	2.0	2.3	1.2	3.9	2.5	1.9	6.1	5.6	2.8	2.8	2.5	4.6	4.7	9.1	2.0	3.0	5.3	2.8	4.2	3.9	5.7
Globocassidulina subglobosa	1.9	7.5	8.6	5.7	3.8	4.7	1.5	1.8	2.7	0.6	2.2	3.1	2.5	1.1	1.6	2.0	1.4	10.1	0.9	0.7	1.6	1.2	1.4	2.8	2.0	4.1	2.6	2.2	1.8	2.0	3.7	3.4	1.9	3.3	3.6	1.3
Gavelinopsis versiformis	9.0	2.1	0.2	0.0	0.0	0.8	5.2	4.3	3.9	5.2	1.8	1.3	6.3	7.4	6.1	4.2	2.5	2.4	3.9	4.2	3.1	3.2	2.6	1.6	1.2	1.7	2.1	2.6	0.7	0.7	0.7	1.1	1.6	0.3	0.0	1.2
Unilocular group	1.0	2.8	0.7	1.7	0.4	0.1	3.0	4.3	2.4	1.8	4.4	1.3	2.5	0.7	4.7	4.4	6.3	4.9	1.2	3.5	1.5	3.2	2.3	1.6	0.8	3.3	1.7	0.0	0.7	2.8	2.6	2.3	1.3	1.5	1.8	1.7
Discorbis vilardeboanus	1.6	1.2	1.3	0.3	0.0	0.0	0.2	0.0	1.5	0.9	0.0	2.2	1.6	0.5	0.5	0.6	0.7	1.5	0.0	0.7	0.0	0.6	0.0	0.0	3.9	5.4	2.9	7.3	5.4	4.8	4.8	4.6	5.3	6.8	8.3	5.2
Alabaminella weddellensis	0.3	0.5	0.2	0.9	0.4	0.3	1.5	1.2	0.6	2.5	0.4	0.6	0.9	2.5	1.6	2.2	2.0	1.8	1.8	6.4	7.3	7.0	7.3	5.2	0.8	2.9	1.3	0.4	3.3	2.9	0.7	0.8	0.3	1.5	1.2	1.0
Bolivina inflata	1.0	1.9	0.0	2.8	0.3	1.3	0.0	0.0	0.0	2.1	1.5	0.9	0.0	1.0	1.3	1.6	3.2	0.9	0.0	1.1	3.5	4.4	3.3	5.6	2.0	0.0	1.7	0.0	2.5	2.2	0.7	2.7	6.0	3.6	2.4	3.5
Sigmavirgulina tortuosa	0.0	0.3	2.3	0.2	0.0	0.3	0.0	0.6	0.3	0.0	0.4	1.6	0.2	0.0	0.0	0.0	0.0	0.6	0.0	0.4	0.0	0.0	0.0	0.0	3.5	1.2	3.4	2.1	7.3	2.2	7.5	10.6	4.7	4.5	3.0	3.2
Epistominella exigua	0.0	0.0	0.0	0.3	0.0	0.0	5.0	2.1	1.5	2.1	1.5	0.3	2.7	1.8	2.2	3.6	2.0	0.9	1.5	2.5	2.3	1.5	2.6	2.4	0.8	1.7	0.8	1.3	1.1	1.3	1.1	0.4	0.6	0.9	2.1	0.0
Cassidulina curvata	0.0	3.3	4.8	0.9	0.5	0.6	0.0	0.0	0.3	0.0	0.0	0.6	0.0	0.0	0.4	0.0	0.5	0.9	0.0	0.0	0.0	0.3	0.0	0.0	1.2	0.0	2.5	3.4	4.7	0.7	1.9	4.9	3.5	3.6	3.6	5.2
Paracassidulina nipponensis	2.2	0.7	0.0	3.1	1.1	2.7	3.7	3.4	1.2	0.9	1.1	0.3	1.6	2.8	1.1	1.7	0.7	0.9	2.4	1.8	0.4	1.5	1.3	0.8	1.6	1.2	0.4	0.9	0.7	0.6	0.7	0.4	0.0	0.0	0.0	0.0
Bolivina ordinaria	1.9	1.9	1.5	1.9	1.5	3.0	1.2	1.5	0.9	0.6	2.6	1.6	2.0	1.3	0.9	0.6	1.4	1.2	0.0	1.4	0.4	0.6	0.7	0.0	0.8	1.2	0.4	0.4	0.7	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Nonionoides grateloupii	2.2	1.7	0.3	0.0	0.0	0.0	1.0	3.1	4.4	0.0	1.5	0.0	1.1	1.0	1.8	1.6	0.9	0.0	0.3	2.5	1.9	1.2	0.7	1.2	0.0	0.0	0.4	0.0	0.4	0.6	0.0	0.0	0.0	1.8	0.9	0.0
Discorbinella bertheloti	0.0	0.5	0.5	0.7	0.0	0.0	0.0	0.6	1.8	3.1	0.7	0.0	0.7	0.8	0.2	0.8	0.7	0.0	0.0	0.7	1.2	0.0	0.3	0.0	2.0	2.1	1.3	0.0	2.9	1.3	0.4	0.0	0.9	0.9	0.6	3.5
Trifarina spp.	0.6	0.2	14.4	1.7	7.2	2.7	0.0	0.3	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
Trifarina angulosa	1.3	0.3	6.5	0.9	4.1	4.5	0.2	0.3	0.0	0.0	0.0	0.6	0.0	0.5	0.4	0.8	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.3	0.4	0.9	0.4	0.0	0.0	0.3	0.6	0.0
Nuttalides umbonifer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	2.1	3.1	1.5	4.0	0.0	2.4	0.4	0.4	0.4	2.2	0.9	0.7	1.1	0.0	0.0	0.9	1.2
Seabrookia curta	1.6	1.2	0.2	1.9	0.2	0.0	1.0	0.3	1.2	1.2	0.0	0.0	0.0	0.0	0.7	1.3	0.7	0.0	0.0	0.7	0.4	1.8	1.3	0.8	0.4	0.4	0.8	0.0	0.4	0.7	0.0	0.0	0.6	0.6	0.6	0.5
Bolivina fragilis	0.3	0.2	1.3	0.5	2.2	0.8	1.5	1.2	2.1	0.9	0.4	0.0	0.7	1.6	0.5	0.2	1.1	0.0	1.2	0.0	0.8	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.9	0.3	0.0	0.0
Globocassidulina oblonga	0.0	0.9	0.5	0.0	0.4	0.0	0.0	0.6	1.5	0.0	0.4	0.0	0.5	0.8	2.0	0.9	0.0	0.3	1.2	1.4	0.0	0.3	0.0	0.0	0.0	0.8	0.4	0.4	0.7	0.6	0.0	0.0	0.9	0.0	0.3	0.7
Bolivina albatrossi	0.0	0.0	0.0	0.0	0.0	0.1	1.5	0.6	0.6	0.9	0.7	2.2	0.7	0.7	0.9	0.8	0.9	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Uvigerina peregrina	0.6	0.0	2.2	0.0	0.6	0.3	0.0	0.0	0.0	0.0	1.1	0.3	1.1	0.0	0.5	0.3	1.1	2.7	0.0	0.0	0.4	0.6	0.0	0.8	0.0	0.0	0.0	1.3	0.0	0.4	0.0	0.0	0.0	0.0	0.3	0.0
Neoeponides antillarum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	2.2	0.5	0.2	0.0	0.3	0.2	1.2	0.6	0.0	0.4	0.0	0.0	0.0	2.0	0.0	0.4	1.3	0.7	0.9	0.4	0.0	0.6	0.6	0.0	0.5
Cymbaloporetta bradyi	0.0	0.5	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.4	1.8	1.1	0.8	2.5	0.9	2.1	1.2
Bolivina sp. 1	0.3	0.0	0.0	2.8	0.8	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.7	0.8	0.0	0.0	0.8	0.0	0.0	0.4	0.4	0.0	0.0	0.9	0.6	0.7
Bulimina aculeata	0.0	0.3	0.3	0.0	0.0	0.8	0.0	0.0	0.3	0.0	0.0	3.5	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.8	0.4	0.0	0.0	0.2	0.0	0.0	0.3	0.0	0.9	0.0
Sigmamiliolinella australis	2.6	0.0	1.3	2.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.3	0.0	0.6	0.0
Cibicidoides wuellerstorfi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.2	0.0	0.0	0.4	0.0	0.4	0.6	0.0	0.0	1.3	0.0	0.0	0.9	0.8	0.2	0.7	1.2	0.0	0.3	0.9	0.3
Nonionoides spp.	0.3	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.8	1.2	0.8	0.9	0.4	0.2	0.4	0.0	0.0	0.0	0.0	0.0
Uvigerina auberiana	0.3	0.2	2.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.4	0.4	1.5	0.4	0.0	0.0	0.0	0.0	0.9	0.5
Pullenia quinqueloba	0.0	0.5	0.5	0.2	0.0	0.3	0.2	0.0	0.0	0.0	0.4	0.0	0.2	0.2	0.4	0.3	0.0	1.5	0.0	0.7	1.5	0.3	0.0	0.0	0.0	0.0	0.8	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quinqueloculina weaveri	0.0	0.0	0.7	0.0	0.0	0.0	0.5	0.3	0.3	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.4	0.0	1.1	0.0	0.8	0.8	0.6	0.0	0.6	0.0
Quinqueloculina seminulum	1.3	1.9	0.2	0.2	0.0	0.1	0.2	0.3	0.3	0.3	0.0	0.6	0.2	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Quinqueloculina spp.	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.3	0.0	0.0	0.0	0.0	0.2	0.0	0.0	1.1	0.0	1.8	0.0	0.0	0.0	0.0	0.8	0.9	0.4	0.0	0.0	0.8	0.0	0.0	0.0	0.0
Sigmoilina obesa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.4	0.3	0.3	0.0	1.6	1.3	0.0	0.4	0.4	0.9	0.8	0.0	0.0	0.0	0.6	0.0
Ammoglobigerina globulosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.2	0.0	0.0	0.9	0.0	0.0	1.0	1.4	1.2	0.3	0.3	0.0	0.4	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.1
Cibicidoides spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.4	1.1	0.0	0.0	0.4	0.6	0.0	3.3	0.2
Pullenia bulloides	0.0	0.3	1.0	0.0	0.1	0.1	0.0	0.3	0.3	0.0	1.1	0.6	0.2	0.2	0.0	0.0	0.2	0.0	1.8	0.4	0.0	0.0	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glomospira gordialis	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	1.5	0.0	1.2	0.3	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.2	0.0	0.0	0.3	0.3	0.0	0.0
Bolivinellina transluscens	1.3	0.0	0.2	0.5	0.0	0.6	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.3	0.4	0.3	0.0	0.6	0.6	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cibicidoides mundulus	0.0	0.5	1.5	0.0	0.5	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.3	0.3	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Morulaeplecta bulbosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	1.2	0.0	0.8	1.2	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Islandiella norcrossi	1.3	1.0	0.5	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.3	0.0	0.0	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ANEXO B – Documento comprobatórios do segundo artigo (submetido).

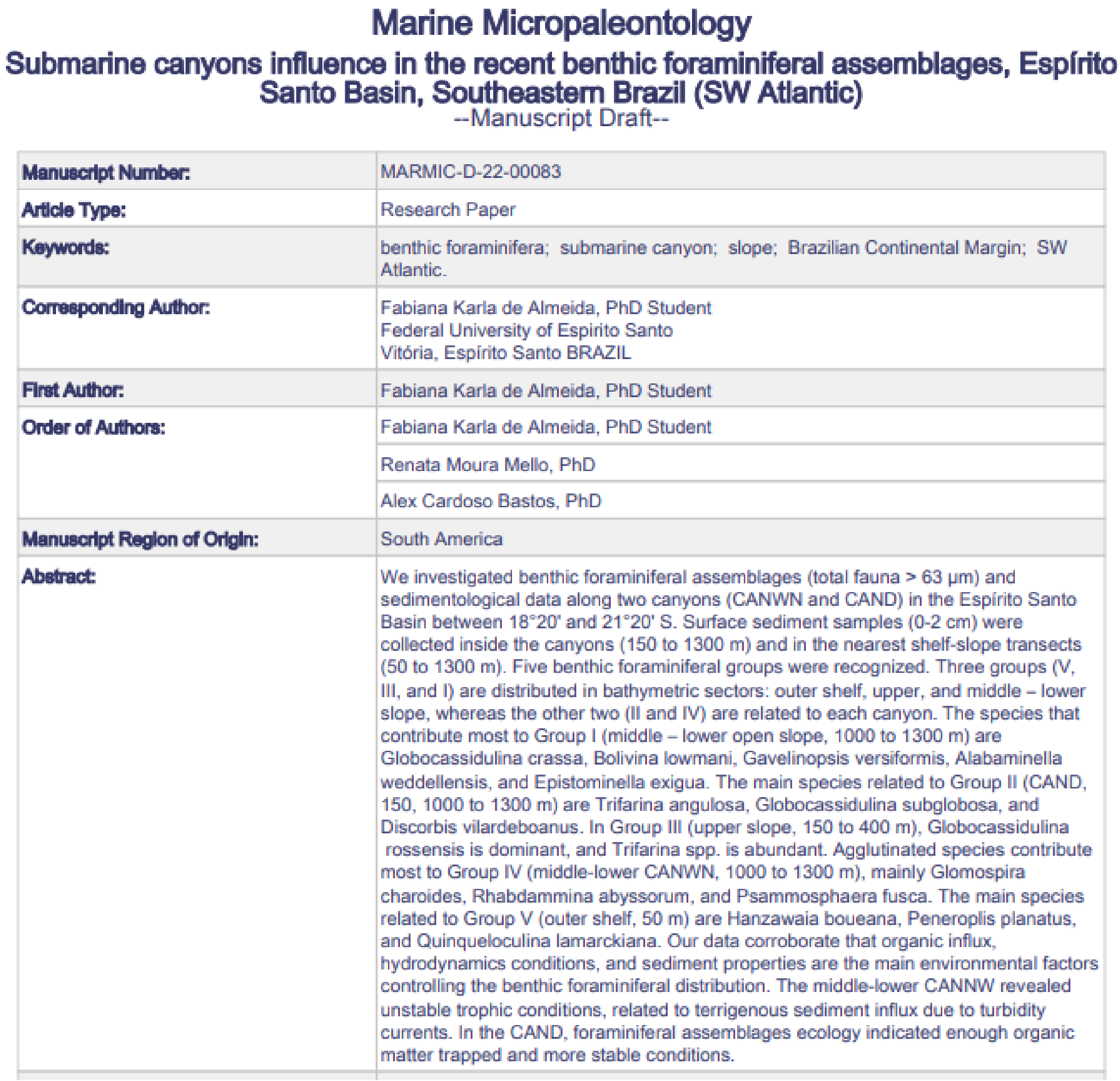


Submissions Being Processed for Author

Page: 1 of 1 (1 total submissions)

Action	Manuscript Number	Title	Initial Date Submitted	Status Date	Current Status
View Submission View Reference Checking Results Send E-mail	MARMIC-D-22-00083	Submarine canyons influence in the recent benthic foraminiferal assemblages, Espírito Santo Basin, Southeastern Brazil (SW Atlantic)	Nov 13, 2022	Nov 15, 2022	Under Review

Page: 1 of 1 (1 total submissions)



Marine Micropaleontology

Submarine canyons influence in the recent benthic foraminiferal assemblages, Espírito Santo Basin, Southeastern Brazil (SW Atlantic)

--Manuscript Draft--

Manuscript Number:	MARMIC-D-22-00083
Article Type:	Research Paper
Keywords:	benthic foraminifera; submarine canyon; slope; Brazilian Continental Margin; SW Atlantic.
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	Renata Moura Mello, PhD
	Alex Cardoso Bastos, PhD
Manuscript Region of Origin:	South America
Abstract:	We investigated benthic foraminiferal assemblages (total fauna > 63 µm) and sedimentological data along two canyons (CANWN and CAND) in the Espírito Santo Basin between 18°20' and 21°20' S. Surface sediment samples (0-2 cm) were collected inside the canyons (150 to 1300 m) and in the nearest shelf-slope transects (50 to 1300 m). Five benthic foraminiferal groups were recognized. Three groups (V, III, and I) are distributed in bathymetric sectors: outer shelf, upper, and middle – lower slope, whereas the other two (II and IV) are related to each canyon. The species that contribute most to Group I (middle – lower open slope, 1000 to 1300 m) are Globocassidulina crassa, Bolivina lowmani, Gavelinopsis versiformis, Alabaminella weddellensis, and Epistominella exigua. The main species related to Group II (CAND, 150, 1000 to 1300 m) are Trifarina angulosa, Globocassidulina subglobosa, and Discorbis vilardeboanus. In Group III (upper slope, 150 to 400 m), Globocassidulina rossensis is dominant, and Trifarina spp. is abundant. Agglutinated species contribute most to Group IV (middle-lower CANWN, 1000 to 1300 m), mainly Glomospira charoides, Rhabdammina abyssorum, and Psammosphaera fusca. The main species related to Group V (outer shelf, 50 m) are Hanzawaia boueana, Peneroplis planatus, and Quinqueloculina lamarckiana. Our data corroborate that organic influx, hydrodynamics conditions, and sediment properties are the main environmental factors controlling the benthic foraminiferal distribution. The middle-lower CANNW revealed unstable trophic conditions, related to terrigenous sediment influx due to turbidity currents. In the CAND, foraminiferal assemblages ecology indicated enough organic matter trapped and more stable conditions.

Supplementary material – Table S1: Relative abundances of the main species (> 2%) identified in the submarine canyons and adjacent transects in the Espirito Santo Basin.

	Transect D					**Transect E**					**Watu Norte Canyon**				**Doce Canyon**			
Specie relative abundance (> 2%)	**50**	**150**	**400**	**1000**	**1300**	**50**	**150**	**400**	**1000**	**1300**	**150**	**400**	**1000**	**1300**	**150**	**400**	**1000**	**1300**
Alabaminella weddellensis	0.0	0.0	0.9	2.5	2.2	0.0	0.0	0.4	0.4	2.0	0.0	0.7	0.4	0.0	0.0	0.0	1.1	0.4
Ammoglobigerina globulosa	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	2.8	0.0	0.0	0.0	0.0
Ammosphaeroidina grandis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	5.6	0.0	0.0	0.0	0.0
Amphistegina lessoni	0.4	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Archaias angulatus	3.5	0.0	0.0	0.0	0.0	0.7	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.1
Articulina pacifica	6.2	0.0	0.0	0.0	0.0	2.4	0.4	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.3	0.1	0.7	0.4
Bolivina fragilis	0.0	0.9	0.5	0.9	0.2	0.3	0.4	2.2	0.4	1.1	1.2	2.1	0.0	0.4	0.9	1.8	0.0	0.0
Bolivina inflata	0.0	0.2	2.8	2.1	1.6	0.0	0.0	0.3	1.5	3.2	0.3	1.5	0.4	0.0	0.7	0.2	0.4	0.0
Bolivina lowmani	0.0	0.6	2.8	9.8	8.5	0.7	0.0	1.4	16.8	13.3	0.3	2.0	1.3	0.8	1.2	1.3	6.4	5.6
Bolivina ordinaria	0.0	0.2	1.9	0.6	0.6	0.0	0.0	1.5	2.6	1.4	0.3	3.6	1.7	0.0	0.0	1.0	1.8	0.8
Bolivina pseudoplicata	0.0	0.2	1.0	0.6	0.5	0.0	0.0	0.1	1.5	0.7	0.0	0.3	0.0	0.0	1.6	0.5	0.7	2.3
Bolivina sp. 1	0.0	1.3	2.8	0.0	0.0	0.0	0.0	0.8	0.0	0.0	1.7	2.8	0.0	1.2	0.4	0.3	0.7	0.0
Bolivina spp.	0.0	0.6	2.8	2.8	2.0	1.7	0.0	1.7	3.7	2.3	0.0	2.3	0.0	0.8	2.5	0.9	1.4	1.5
Cassidulina curvata	0.3	0.0	0.9	0.0	0.0	0.0	2.4	0.5	0.0	0.5	0.0	0.9	0.0	0.0	0.7	1.0	1.1	0.0
Cibicidoides mundulus	0.3	0.6	0.0	0.0	0.0	0.0	3.2	0.5	0.0	0.0	0.9	0.9	0.0	0.0	2.2	0.5	5.7	5.6
Cibicidoides spp.	0.7	0.0	0.0	0.0	0.0	1.4	2.8	0.0	0.0	0.0	0.6	0.1	0.0	0.0	1.3	0.9	2.8	2.3
Cribroelphidium excavatum	2.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0
Cribrostomoides spiculolegus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	8.8	0.0	0.0	0.0	0.0
Cribrostomoides subglobulosus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	4.4	0.0	0.0	0.0	0.0
Discammina compressa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.8	3.2	0.0	0.0	0.0	0.0
Discorbinella bertheloti	0.0	0.0	0.7	3.1	0.8	0.0	0.0	0.0	0.7	0.7	0.3	0.1	0.4	0.0	1.8	0.2	0.7	1.5
Discorbis vilardeboanus	0.3	0.6	0.3	0.9	0.6	2.1	1.2	0.0	0.0	0.7	0.0	0.7	0.0	0.0	6.7	0.9	8.5	9.0
Elphidium discoidale	0.0	0.0	0.2	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.1	0.0	0.0	0.0
Epistominella exigua	0.0	0.0	0.3	2.1	3.6	0.0	0.0	0.0	1.5	2.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.8
Gavelinopsis versiformis	0.0	0.8	0.0	5.2	4.2	0.0	0.0	0.0	1.8	2.5	0.9	0.5	0.4	0.0	1.0	0.7	5.0	7.2
Globocassidulina crassa	0.0	27.2	13.1	27.3	22.9	1.4	5.2	11.5	29.2	31.8	20.2	16.7	0.4	0.0	7.3	23.1	4.6	4.1
Globocassidulina rossensis	2.3	56.8	40.3	24.5	27.0	4.1	9.6	51.0	15.7	16.7	48.7	32.8	13.0	0.8	8.6	32.8	9.6	6.4
Globocassidulina subglobosa	0.3	0.4	5.7	0.6	2.0	0.3	5.6	3.8	2.2	1.4	0.9	0.9	0.4	0.0	0.7	4.9	3.2	6.4
Glomospira charoides	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.6	16.0	0.0	0.0	0.0	0.0
Glomospira gordialis	0.0	0.0	0.0	1.5	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	7.8	2.0	0.0	0.0	0.0	0.0
Hanzawaia boueana	27.2	0.4	0.0	0.0	0.0	27.1	0.8	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.1	0.4	0.4
Haplophragmoides sandiegoensis	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	6.1	4.4	0.0	0.0	0.0	0.0
Lenticulina vortex	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nonionoides grateloupii	1.6	0.0	0.0	0.0	1.6	2.1	0.0	0.0	1.5	0.9	0.9	0.7	0.0	0.0	0.3	0.0	0.7	0.0
Paracassidulina nipponensis	0.3	0.6	3.1	0.9	1.7	1.0	0.0	1.1	1.1	0.7	1.4	1.4	0.9	0.0	0.0	0.3	3.2	4.1
Peneroplis planatus	13.1	0.0	0.0	0.0	0.0	1.7	0.4	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.4	0.0
Planulina foveolata	0.0	0.6	0.0	0.0	0.0	0.3	6.4	0.2	0.0	0.0	1.2	0.3	0.0	0.0	0.4	0.5	0.0	0.0
Psammosphaera fusca	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	9.8	12.8	0.0	0.0	0.0	0.0
Pseudoclavulina serventyi	1.0	0.0	0.0	0.0	0.0	2.7	1.2	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0
Quinqueloculina agglutinans	3.3	0.0	0.0	0.0	0.0	3.8	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quinqueloculina lamarckiana	5.3	0.0	0.0	0.0	0.0	4.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quinqueloculina spp.	0.0	0.0	0.0	0.0	0.0	5.9	2.0	0.0	0.4	0.2	0.9	0.6	0.4	0.0	0.5	0.6	0.0	0.4
Reussella spinulosa	3.6	0.2	0.0	0.0	0.0	0.7	1.6	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.1	0.0	0.4	0.8
Rhabdammina abyssorum	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.2	11.6	0.0	0.0	0.0	0.4
Rosalina globularis	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.3	0.0	0.0	0.0	9.5	0.0	1.4	0.0
Sigmamiliolinella australis	0.3	0.0	2.1	0.0	0.0	2.7	0.0	0.2	0.0	0.0	0.0	2.9	0.4	0.0	4.5	0.8	2.1	0.0
Sigmavirgulina tortuosa	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.3	0.0	0.0	0.0	3.9	0.1	0.4	3.0
Spirotextularia tubulosa	0.7	0.0	0.0	0.0	0.0	0.0	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Textularia agglutinans	3.6	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
Textularia hystrix	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	2.4	0.0	0.1	0.0	0.0
Trifarina angulosa	1.3	2.1	0.9	0.0	0.8	1.0	18.0	4.1	0.0	0.0	8.6	2.3	0.0	0.0	2.3	10.9	8.9	6.4
Trifarina spp.	0.7	0.6	1.7	0.0	0.0	1.0	3.6	7.2	0.4	0.0	0.6	0.7	0.0	0.0	2.0	2.0	2.1	0.8
Unilocular group	0.3	0.2	1.7	1.8	4.4	0.0	0.0	0.4	4.4	6.3	0.3	0.4	0.0	0.4	0.6	0.3	0.0	0.8
Uvigerina peregrina	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.6	1.1	1.1	0.0	0.7	1.7	2.0	0.0	0.1	0.4	1.9