UNIVERSIDADE DO ALGARVE

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Resumo

Esta tese apresenta uma investigação sobre os foraminíferos bentónicos como indicadores paleo-ambientais na plataforma continental do Norte do Golfo de Cádis, nordeste do Oceano Atlântico. O principal objectivo foi determinar o valor dos foraminíferos bentónicos vivos como indicadores ambientais e sua aplicação em reconstruções paleoambientais durante o Holocénico.

As relações entre as faunas de foraminíferos bentónicos vivos e os parâmetros físico-químicos associados foram analisados em amostras de sedimentos superficiais, colhidos na plataforma continental entre as desembocaduras dos Rios Guadiana e Guadalquivir. As faunas de foraminíferos bentónicos vivos foram caracterizadas em detalhe e as associações das espécies mais abundantes classificadas em quatro grupos. Estes grupos permitiram caracterizar do ambiente actual e os parâmetros físico-químicos que lhe estão associados.

O estudo sedimentológico e dos foraminíferos bentónicos, enquadrado numa janela cronológica, foi realizado em três sequências sedimentares Holocénicas, colhidas em ambientes sedimentares contrastantes. A comparação entre as faunas vivas e as associações de foraminíferos bentónicos mais abundantes que ocorrem na plataforma foi também realizada. Uma abordagem integradora, usando toda a informação disponível, permitiu clarificar as alterações peloambientais, revelando cinco cenários evolutivos. Cada cenário representa as alterações ambientais ocorridas em cada ambiente estudado, durante diferentes períodos do Holocénico, influenciado por diversos factores, tais como as alterações do nível médio do mar, as descargas do rio e as propriedades do sedimento, que são reflectidas pelas diferentes associações de foraminíferos bentónicos.

Esta tese demonstra que as preferências ecológicas das espécies actuais de foraminíferos bentónicos mais abundantes, tem aplicação directa na interpretação do registo paleoambiental.

Palavras-chave: Golfo de Cádis; plataforma continental; foraminíferos bentónicos; ecologia; Holocénico

Abstract

This thesis is an investigation of benthic foraminifera as palaeo-environmental indicators on the Northern Gulf of Cadiz continental shelf, northeast Atlantic Ocean. The main objective was to determine the environmental indicator value of living benthic foraminifera and their application to Holocene palaeoenvironmental reconstruction.

Relationships between living benthic foraminiferal fauna and both physical and chemical parameters were analysed in surficial samples collected from the continental shelf between the Guadiana and Guadalquivir Rivers. Living benthic foraminiferal faunas were characterised in detail and associations of the most abundant species classified into four groups. These groups allowed the characterisation of the modern environment and associated physical and chemical parameters.

Sedimentological and benthic foraminiferal analyses, combined with a chronological framework, were performed on three Holocene sequences from contrasting sedimentary environments. A comparison between the most abundant species in living faunas and those occurring in Holocene shelf sediments was also made. An integrated approach using all the available information sheds light on paleoenvironmental changes, which were distilled into five evolutionary scenarios. Each scenario is a representation of the environmental changes that characterised the three studied environments at different times during the Holocene. They indicate the influence of various factors, including sea-level changes, river discharge and substrate properties, that are mirrored by different benthic foraminiferal assemblages.

The thesis demonstrates that the modern ecological preferences of common benthic foraminiferal species have direct applicability to interpreting the palaeoenvironmental record.

Keywords: Gulf of Cadiz; continental shelf; benthic foraminifera, ecology; Holocene

Resumo alargado

Esta tese apresenta uma investigação sobre os foraminíferos bentónicos como indicadores paleo-ambientais na plataforma continental do Norte do Golfo de Cádis, nordeste do Oceano Atlântico.

Os foraminíferos bentónicos constituem um dos grupos da meio-fauna protista mais abundantes. A sua distribuição e abundância são influenciadas por parâmetros físicos, químicos e biológicos, o que os torna excelentes ferramentas para interpretações ecológicas e ambientais. A sua carapaça biomineralisada possui a capacidade de ser preservada no registo fóssil, podendo fornecer informações credíveis para compreender as alterações em ambientes marinhos, ocorridas no passado histórico e geológico. Nas últimas décadas o seu estudo tem sido aplicado nas áreas da ecologia, biogeografia, monitorização ambiental, paleoecologia, paleoceanografia e reconstruções bioestratigráficas. No entanto, interpretações exactas do registo fóssil estão dependentes do conhecimento sobre a ecologia das espécies, preferencialmente das que vivem na mesma área. Assim, é essencial obter novas informações sobre a distribuição no espaço e tempo das espécies de foraminíferos bentónicos e avaliar a sua relação com os parâmetros ambientais. Isto com o intuito de inferir o seu habitat passado, compreender as alterações ambientais ocorridas e melhorar a calibração destas espécies como indicadores (“proxies”) de parâmetros que não podem ser medidos directamente. Este conhecimento é importante não só para compreender o passado, mas também para prever futuras tendências das alterações climáticas e oceanográficas.

As plataformas continentais são zonas de transferência entre os ambientes terrestres e o oceano. As sequências sedimentares destas áreas são importantes arquivos ambientais, onde ficam registados os processos naturais, tais como variações do nível médio do mar, alterações climáticas e oceanográficas, e o impacto antrópico ocorrido durante o Holocénico. A plataforma continental do norte do Golfo de Cádis (SW da Península Ibérica) é uma área com

elevado potencial para o estudo e compreensão destes processos. Esta área recebe as descargas do Rio Guadiana, que é a principal fonte sedimentar da região. A bacia hidrográfica do Rio Guadiana é ainda altamente susceptível a mudanças climáticas, influenciada por fortes variações inter-anuais e variações em larga escala, nomeadamente a Oscilação do Atlântico Norte. As variações climáticas e o aumento da actividade antrópica nesta área alteraram significativamente o sistema durante o Holocénico, modificando o tipo e a quantidade de sedimentos exportados para a plataforma continental. Na área da plataforma a evolução pós-glacial dos sistemas deposicionais foi fortemente influenciada pela rápida elevação do nível médio do mar que levou à formação de depósitos transgressivos e de alto nível do mar ("highstand system tracts").

Na plataforma norte do Golfo de Cádis, a maioria dos estudos sobre foraminíferos bentónicos tem-se focado nas associações totais de foraminíferos bentónicos em amostras de sedimentos superficiais, que incluem as faunas vivas e as associações subfósseis. Em oposição, existem ainda poucos estudos sobre a distribuição das associações de foraminíferos bentónicos durante o Holocénico. Além disso, a realização de estudos em ambientes de plataforma que compare os padrões de distribuição entre faunas vivas e ocorridas durante o Holocénico, essenciais para a verificação de foraminíferos bentónicos como "proxies", são ainda escassos na Europa e inexistentes na plataforma continental do norte do Golfo de Cádis.

Para atingir o objectivo principal deste trabalho - investigar os foraminíferos bentónicos como indicadores ambientais e sua aplicação em reconstruções paleoambientais durante o Holocénico, na plataforma continental do norte do Golfo de Cádis - vários objectivos específicos foram formulados: 1) ampliar o conhecimento sobre a ecologia das faunas vivas de foraminíferos bentónicos em amostras de sedimentos superficiais, através do reconhecimento das associações de espécies, o seu habitat e sua relação com os parâmetros físico-químicos; 2) compreender as alterações paleoambientais decorridas durante o

Holocénico com base no estudo sedimentológico e na caracterização das associações de foraminíferos bentónicos, em três ambientes distintos de deposição sedimentar na plataforma continental; 3) Comparar as associações de foraminíferos bentónicos vivos (amostras de sedimentos superficiais) com as associações fósseis (testemunhos verticais), a fim de: a) analisar os efeitos tafonómicos; b) analisar as relações entre as associações fósseis e os sedimentos em que estas ocorrem, de forma a compreender as relações entre as espécies e o seu habitat; c) reconstruir as condições ambientais ocorridas no passado, usando os foraminíferos bentónicos como "proxies"; d) compreender as alterações paleoambientais ocorridas durante o Holocénico, relacionadas com as alterações do nível médio do mar, as alterações climáticas e o impacto antrópico.

Quarenta e sete amostras de sedimentos superficiais foram analisadas para o estudo das faunas de foraminíferos bentónicos vivos, colhidas na plataforma continental entre as desembocaduras dos Rios Guadiana e Guadalquivir, usando uma draga Smyth McIntyre. Foram ainda analisadas 14 amostras, provenientes dos primeiros centímetros do topo dos testemunhos verticais, colhidos pelo método de vibração. A amostragem estendeu-se entre os 10,7 e os 115,5 m de profundidade. Em ambas as amostragens, a camada superficial foi amostrada, e guardada num frasco contendo uma solução de etanol a 95% e corante Rosa de Bengal (1 g/l). Após a lavagem das amostras, a fracção >63 µm foi analisada à lupa binocular. Sempre que possível, um número mínimo de 300 indivíduos corados foram retirados de cada amostra, colados em porta-foraminíferos, identificados e contados. Foram calculadas as abundâncias relativas das espécies, calculada a densidade populacional (número de indivíduos por 10 cm^3 de sedimento), a riqueza específica, e os índices de diversidade de Shannon, equitabilidade e alfa Fisher. Foram ainda efectuadas análises de estatística multivariada, usando as espécies com abundância relativa superior a 5%, nomeadamente a Análise de Clusters (CA) e a Análise das Componentes Principais (PCA). A distribuição das espécies mais abundantes foi ainda relacionada com dados colhidos na área de estudo, relativos à temperatura, salinidade, matéria particulada em suspensão e dados relativos à produção primária provenientes da literatura.

Os três testemunhos verticais analisados foram colhidos na plataforma continental adjacente ao Rio Guadiana. O testemunho vertical 5, com 353 cm de comprimento foi colhido na zona central do corpo lodoso, a 72 m de profundidade. O testemunho vertical 7, com 71,5 cm de comprimento, foi colhido a 36 m de profundidade, na proximidade de um depósito arenoso transgressivo. O testemunho vertical 8, com 376 cm de comprimento, foi extraído do prodelta do Guadiana a 22 m de profundidade. Ao longo dos 3 testemunhos foram efectuadas 11 datações de radiocarbono (^{14}C) pelo método de AMS (Accelerated Mass Spectrometry). As idades obtidas foram calibradas usando a correcção do efeito de reservatório global dos oceanos e o efeito reservatório local. No testemunho vertical 5 foram ainda realizadas duas datações pelo método da racemisação de aminoácidos (AAR). Análises sedimentológicas foram efectuadas ao longo dos 3 testemunhos estudados, nomeadamente análises granulométricas realizadas sequencialmente e análises à lupa binocular dos componentes da fracção arenosa. As associações de foraminíferos bentónicos fósseis foram analisadas e realizadas análises de clusters usando as espécies com abundância superior a 5%.

Foi efectuada a caracterização detalhada das faunas de foraminíferos bentónicos vivos, na plataforma continental entre as desembocaduras dos Rios Guadiana e Guadalquivir. Os resultados demonstraram que a densidade populacional é geralmente influenciada pelas descargas dos rios, particularmente associada a maiores concentrações de matéria particulada em suspensão e sedimentos finos. A riqueza específica revelou ser influenciada pelo tipo de sedimento. As associações de foraminíferos bentónicos obtidas a partir das espécies mais abundantes revelaram uma clara relação com os parâmetros físico-químicos do meio. Foi assim possível a obtenção de quatro grupos de espécies, que caracterizam o seu ambiente actual:

O grupo 1, é representado pelas espécies *Bolivina ordinaria* e *Hopkinsina atlantica*, consideradas as mais oportunistas da associação. A sua abundância está associada às descargas dos rios, ao elevado fornecimento de matéria orgânica, a sedimentos finos e aos limites de distribuição da produtividade primária. A abundância de *Hopkinsina atlantica* foi também associada com a elevada produção, resultante das descargas do Rio Guadalquivir.

O grupo 2 é dominado por *Ammonia beccarii*, *Eggerelloides scaber*, *Elphidium gerthi*, *Quinqueloculina laevigata* e *Quinqueloculina stelligera*, que apresentaram maiores abundâncias em águas pouco profundas. Estas espécies foram ainda associadas a diferentes tipos de sedimento e a sua distribuição influenciada pelas descargas dos rios de diferente forma.

O grupo 3 é dominado por *Bulimina aculeata*, *Elphidium excavatum*, *Bulimina elongata*, *Epistominella vitrea, Rectuvigerina phlegeri* e *Elphidium culvilliere*. Estas espécies apresentaram maiores abundâncias entre os 30 e os 100 m de profundidade. Ocorrem principalmente em sedimentos lodosos, associados a reduzidos níveis de hidrodinâmica, a baixos níveis de oxigénio e altos teores de matéria orgânica.

O grupo 4 inclui as espécies que ocorrem com maior abundância a profundidades superiores. Este grupo foi dividido no Sub-grupo 4A (*Bolivina catanensis*, *Cassidulina laevigata*, *Stainforthia* sp., *Nouria polymorphinoides, Bolivina italica*, *Bolivina striatula*, e *Nouria* sp.) que apresentou maiores abundâncias em amostras seleccionadas e o Sub-grupo 4B (*Brizalina dilatata*, *Brizalina spathulata*, *Bulimina marginata, Nonionella iridea*, *Nonionella stella* e *Nonionella turgida*) em que as espécies apresentaram uma distribuição irregular em áreas distintas da plataforma. A maior abundância de espécies do género

Nonionella foi também relacionada com valores inferiores de temperatura e salinidade. A abundância da espécie *N. iridea* foi ainda associada a filamentos de "upwelling".

As alterações paleoambientais ocorridas durante o Holocénico foram investigadas em três ambientes marinhos distintos da plataforma continental adjacente ao Rio Guadiana: o corpo lodoso localizado na plataforma média (core 5), que registou os últimos ca. 11.500 Cal anos BP; o depósito transgressivo localizado na plataforma média superior (core 7), registando os últimos ca. 10.400 Cal anos BP; e o prodelta do Guadiana (core 8) localizado na plataforma interna que registou os últimos ca. 5.000 Cal anos BP. Estes ambientes diferem em termos de profundidade, regime sedimentar e associações de foraminíferos bentónicos. No entanto, foi observado nos três ambientes que a fracção arenosa era predominantemente de origem fluvial. As análises sedimentológicas e dos foraminíferos bentónicos foram efectuadas em cada registo sedimentar e integradas num quadro cronológico. Foram identificados quatro estágios evolutivos (descritos posteriormente), que fornecem informações sobre os padrões de deposição sedimentar ocorridos durante o Holocénico, em resposta às alterações do nível médio do mar, às descargas do Rio Guadiana, às alterações climáticas e ao impacto antrópico.

As análises efectuadas no testemunho vertical 7 colhido junto ao depósito arenoso transgressivo, indicam que este é um ambiente complexo e requer a realização de mais estudos, no sentido de melhor compreender a sua formação e evolução.

A comparação entre as faunas de foraminíferos bentónicos vivos e associações de mortos/fósseis, na plataforma continental adjacente ao Rio Guadiana, revelaram que, em média, 95% das faunas vivas foram preservadas no registo fóssil. A comparação entre as associações de foraminíferos vivos e as totais, revelaram maior abundância de indivíduos vivos das espécies *B. ordinaria* e *E. excavatum* em Fevereiro, indicando um período reprodutivo coincidente com o período de amostragem. No entanto, dependendo do ambiente da plataforma analisado, para além dos períodos reprodutivos, outros factores como a profundidade, o tipo de sedimento e a quantidade e qualidade de alimento disponível, revelaram ter um papel importante na abundância das espécies *R. phlegeri*, *B. dilatata*, *N. iridea, N. stella* e *N. turgida*. No corpo lodoso situado na plataforma média, a abundância destas espécies foi principalmente influenciada por fenómenos de "upwelling" local. No entanto, para validar estas conclusões, mais estudos usando amostras sem perturbação dos sedimentos superficiais para a comparação entre as associações de organismos vivos e totais são requeridos.

Os processos que ocorrem após a morte do organismo (*post-mortem*), tais como a destruição e dissolução das carapaças, parecem ser responsáveis pelas diferenças encontradas entre as associações de organismos vivos e mortos/fósseis. Estes processos parecem justificar a maior abundância das espécies *B. ordinaria*, *R. phlegeri*, *B. dilatata*, *N. iridea* e *N. stella* nas associações de foraminíferos vivos comparativamente às associações de mortos ou fósseis. Além disso, estas espécies apresentaram menores abundâncias nos testemunhos verticais do que nas amostras de sedimentos superficiais. No entanto, estas espécies foram também as mais abundantes em pelo menos um dos três ambientes estudados durante o Holocénico, indicando que estas espécies podem ser usadas como indicadores paleoambientais. As variações das espécies de foraminíferos bentónicos mais abundantes podem ser consideradas indicadores úteis das alterações ambientais ocorridas durante o Holocénico em ambientes de plataforma.

A abundância das espécies *E. scaber*, *E. gerthi* and *Q. stelligera* é controlada pela profundidade, preferindo águas pouco profundas, e pelas propriedades do substrato. A espécie *A. beccarii* ocorreu em todos os ambientes com abundância reduzida. A espécie *E. scaber* pode ser usada como indicadora do aumento da matéria orgânica na plataforma, devido à sua associação com sedimentos finos, baixos níveis hidrodinâmicos e tolerância a elevadas concentração de metais pesados. As maiores abundâncias de *E. gerthi* and *Q. stelligera* parecem estar associadas a ambientes de águas pouco profundas e sedimentos grosseiros.

As abundâncias das espécies *Bulimina aculeata*, *B. elongata*, *C. laevigata* e *B. spathulata* são controladas pela profundidade da coluna de água, por baixos níveis de hidrodinâmica e por sedimentos finos. A abundância de *Bulimina aculeata* foi ainda controlada pela ocorrência de sedimentos finos e reduzidos níveis de oxigénio, em águas pouco profundas. As espécies *C. laevigata* e *B. spathulata* apresentaram o seu nicho ecológico em zonas mais profundas da plataforma. Durante o Holocénico a sua distribuição foi possivelmente controlada pela subida do nível médio do mar e aumento do teor de silte e argila nos sedimentos.

A abundância das espécies *A. mamilla* e *P. mediterranensis*, associada a sedimentos grosseiros, pode ser considerada um indicador do nível médio do mar mais baixo, isto é, localizado numa posição inferior à actual. A combinação entre a subida do nível médio do mar e a competição entre espécies parecem controlar a abundância da *S. fusiformis*, a qual desapareceu após o nível médio do mar ter atingido a sua posição actual. A abundância de *Q. rugosa* foi também controlada pela subida do nível médio do mar, e pode ser indicativa de um ambiente arenoso restrito a zonas pouco profundas.

Uma abordagem integradora, usando toda a informação disponível, permitiu clarificar as alterações peloambientais ocorridas na plataforma continental adjacente ao Rio Guadiana durante o Holocénico, apresentando cinco cenários evolutivos. Esta integração revelou um cenário evolutivo adicional, que se seguiu à estabilização do nível médio do mar (entre ca. 5.000 e 4.500 Cal anos BP), detalhando assim os estágios evolutivos definidos anteriormente.

O primeiro cenário evolutivo, entre ca. 11.500 e ca. 10.000 Cal anos BP, corresponde a um período de subida do nível médio do mar, resultando na deposição de sedimentos finos e na redução dos níveis de hidrodinâmica em áreas mais profundas da plataforma. O aumento na abundância das espécies *B. ordinaria* e *R. phlegeri* indica ainda um aumento de matéria orgânica de origem terrestre. As abundâncias relativamente elevadas de *N. iridea* e *N. stella* indicam também produtividade elevada durante este período.

Entre ca. 10.000 e ca. 5.000 Cal anos BP, as descargas do rio e o fornecimento de sedimentos terrígenos para a plataforma diminuíram, facto relacionado com a subida do nível médio do mar para uma posição próxima da actual e consequente aumento da distância à foz do rio.

Após a estabilização do nível do mar que terá ocorrido entre ca. 5.000 e 4.500 Cal anos BP, a maior abundância de *E. vitrea*, *B. dilatata* e *B. marginata* indica o estabelecimento de novos nichos ecológicos em áreas de maior profundidade e menor influência das descargas do rio. A maior abundância de *B. dilatata*, *C. laevigata* e *R. phlegeri* indica ainda um curto período de forte "upwelling".

As abundâncias relativamente constante das espécies de foraminíferos entre os ca. 5.000 - 4.500 e os ca. 1.000 Cal anos BP, indicam condições ambientais relativamente estáveis, que se seguiram após o estabelecimento dos nichos ecológicos a maiores profundidades, de acordo com a estabilização do nível médio do mar, os reduzidos níveis de hidrodinâmica e o elevado teor de matéria orgânica de origem marinha e terrestre.

Os últimos ca. 1.000 anos reflectem as condições actuais de deposição, que se estabeleceram após a formação do prodelta na plataforma interna e a formação do corpo lodoso na plataforma média. Ocorrem eventos de "upwelling" sazonal na plataforma média com consequente aumento da produção primária. Este período reflecte ainda o impacto antrópico na bacia hidrográfica do Guadiana através da intensificação do uso do solo, da actividade mineira, da construção de barragens e da desflorestação, e as alterações climáticas, como o inicio da Pequena Idade do gelo e a relação com a fase negativa da Oscilação do Atlântico Norte.

Esta tese demonstra portanto que as preferências ecológicas das espécies actuais de foraminíferos bentónicos mais abundantes, têm aplicação directa na interpretação do registo paleoambiental na plataforma continental adjacente ao Rio Guadiana.

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Chapter 1

Introduction

1.1. Motivation for this study

Foraminifera constitute the most abundant group of shelled microorganisms in modern marine environments. They are generally small (<1 mm) although some can exceed few centimetres and most have a test which may be preserved in the fossil record (Murray, 2006). There are 45 living planktonic species recognised (Hemleben et al., 1989). The overwhelming majority of modern Foraminifera are benthic. They have greater diversity and a much longer geological record than planktonic foraminifera. The oldest fossil species are of Cambrian age, whereas the planktonic foraminifera originated in the mid Jurassic (e.g. Sen Gupta, 1999a).

The first biological investigations of foraminifers began in the 19th century, however, only in the second half of the 20th century the ecology of Foraminifera became a major area of study. Increasing interest in this field was driven by the realization that the distribution of Foraminifera in the present-day environment can provide reliable clues for understanding marine environmental changes in the historical past and geological record (e.g. Sen Gupta, 1999a). Benthic foraminifera are highly dependent on environmental conditions, and even subtle changes are mirrored by shifts in species composition and abundance (e.g. Murray, 2001).

Over the last decades, benthic foraminifera have found wide application in ecology, biogeographic, environmental monitoring, palaeoecological and palaeoceangraphic reconstructions, biostratigraphy and correlation. However, accurate interpretations of the fossil record depend largely on our knowledge of the ecology of living benthic foraminiferal species, preferably from the same area (e.g. Alve, 2003; Murray, 2006). Thus it is essencial to gather new information on the spatial and temporal distribution of living benthic foraminiferal species and their relationship with environmental parameters in order to infer past habitats, understand environmental changes and improve proxy calibration. This knowledge is important not only to understand the past, but likewise to predict future trends in climatic and oceanographic change.

Continental shelves are areas of transfer of terrestrial material to the ocean. Sedimentary sequences from these areas are important environmental archives, registering a number of natural processes such as sea-level, oceanographic and climatic changes, as well as recent anthropogenic impacts during the Holocene (e.g. Lesueur et al., 1996; Bauch et al., 2001; Evans et al., 2002; Oldfield et al., 2003). The northern Gulf of Cadiz continental shelf (SW Iberian Peninsula) is an area with considerable potential for studying and understanding these processes. The area receives discharge from Guadiana and Guadalquivir Rivers, the main regional sediment sources. Guadiana River basin itself is highly susceptible to climatic changes, influenced by strong seasonal variations and larger-scale annual and decadal signals, such as the North Atlantic Oscillation (Dias et al., 2004; Trigo et al., 2004). Climatic variations and the increase in human activity in the Guadiana catchment area have significantly altered the system (Fletcher et al., 2007), changing both the type and quantity of sediment exported to the continental shelf (Gonzalez et al., 2001). The postglacial evolution of depositional systems in this area was strongly influenced by rapid sea-level rise, leading to the formation of transgressive and highstand system tracts (Lobo et al., 2001, 2004).

The sediments on the continental shelf off the Guadiana River possess a relatively clear signature and origin (e.g. Gonzalez et al., 2004; 2007; Lobo et al., 2004). This facilitates the establishment of a relationship between environmental factors, sedimentary influx, and variations in benthic foraminiferal assemblages.

In the northern Gulf of Cadiz, most of the literature concerning benthic foraminifera has focused on total benthic foraminiferal assemblages, including living fauna and subfossil assemblages of empty tests (e.g. Galhano, 1963; Ubaldo and Otero, 1958; Levy et al., 1993; 1995; Villanueva, 2000; 2001; Villanueva and Canudo, 1998; 1999; 2008; Villanueva and

Cervera, 1998; 1999a; 1999b; Villanueva et al., 1999a; 1999b; González-Regalado et al., 2001; Mendes et al., 2004). In contrast, only a few attempts were made in this area to reconstruct the distribution of benthic foraminifera during the Holocene (e.g. Mendes et al., 2006; 2010). Furthermore, the comparison between living and Holocene distribution patterns, essential for verifying benthic foraminiferal proxies, is generally scarce in European shelf environments and has not yet been done on the Gulf of Cadiz continental shelf.

1.2. Aims and objectives

The main objective of this thesis is to determine the environmental indicator value of benthic foraminifera living on the northern Gulf of Cadiz continental shelf and apply this to Holocene palaeoenvironmental reconstruction. In order to achieve this overarching goal, several specific objectives were formulated, namely:

1. Increasing ecological information about living benthic foraminiferal faunas in surficial samples, through establishing of their species associations and their relationship to physical and chemical parameters in their habitats.
2. Understanding the Holocene paleoenvironmental changes based on sedimentological and benthic foraminiferal characterisation in three different sedimentary depositional environments on the continental shelf.
3. Compare living benthic foraminiferal assemblages with fossil assemblages in sediment cores, in order to:
    a) evaluate taphonomic effects;
    b) analyse associations between fossil assemblages and the sediments in which they occur to better understand species-environment relationships;
    c) reconstruct past environmental conditions using benthic foraminifera as a proxy;

d) understand the Holocene paleoenvironmental changes associated with sea-level changes, climatic variations and anthropogenic impact.

1.3. Structure of the thesis

This thesis is organised into six main chapters, followed by a taxonomic compilation. Each of the chapters introducing new data includes its own introduction, material and methods, results, discussion and conclusions.

- **Chapter 1** is a general introduction, where this sub-chapter is included, describes the motivation to study benthic foraminifera on the northern Gulf of Cadiz continental shelf and the main objectives of this study.
- **Chapter 2** provides general information concerning the study area.
- **Chapter 3** presents an investigation of the distribution and ecology of living benthic foraminiferal faunas, in the study area as a mean of accurately determining their value as proxies (addressing objective 1).
- **Chapter 4** presents an integrated approach that links sedimentology, fossil foraminiferal assemblages and radiocarbon dating to reveal Holocene paleoenvironmental changes in three distinct sedimentary environments on the continental shelf off the Guadiana River (objectives 2 and 3c).
- **Chapter 5** integrates assemblages of the most abundant species from recent (Chapter 3) and Holocene (Chapter 4) shelf sediments to evaluate taphonomic effects, reconstruct palaeoenvironmental changes and propose an integrated model for the evolution of the Guadiana shelf area during the Holocene (addressing objective 3);
- **Chapter 6** provides a summary of the general conclusions of the thesis.

- **Chapter 7** presents the taxonomy of foraminiferal taxa recorded on the northern Gulf of Cadiz continental shelf, illustrated with scanning electron microscope and direct light microscope photographs.
- **Chapter 8** provides a list of the bibliographic references cited in this thesis.
- **Chapter 9** presents the appendices (A, B, C and D), which include tables with the relative abundance of the total assemblages (taxa with more than one specimen), for all analysed samples.

Chapter 2

Study area

2.1. Location

The Gulf of Cadiz is a wide basin located west of the Strait of Gibraltar, in the northeast Atlantic Ocean, between the Iberian Peninsula and northwest African coasts. The study area is located in the middle part of the northern Gulf of Cadiz continental shelf (south-western Iberian Peninsula) between the mouths of the Guadiana and Guadalquivir Rivers. In this area, the Guadiana River is a natural border between Portugal and Spain (Fig. 2.1).

The Gulf of Cadiz is a basin of relatively warm and oligotrophic waters that interrupts the fringe of cold and nutrient-rich upwelled water, during the upwelling season, dividing the North Atlantic Coastal province into the European and African sectors (e.g. Garcia-Lafuente and Ruiz, 2007).

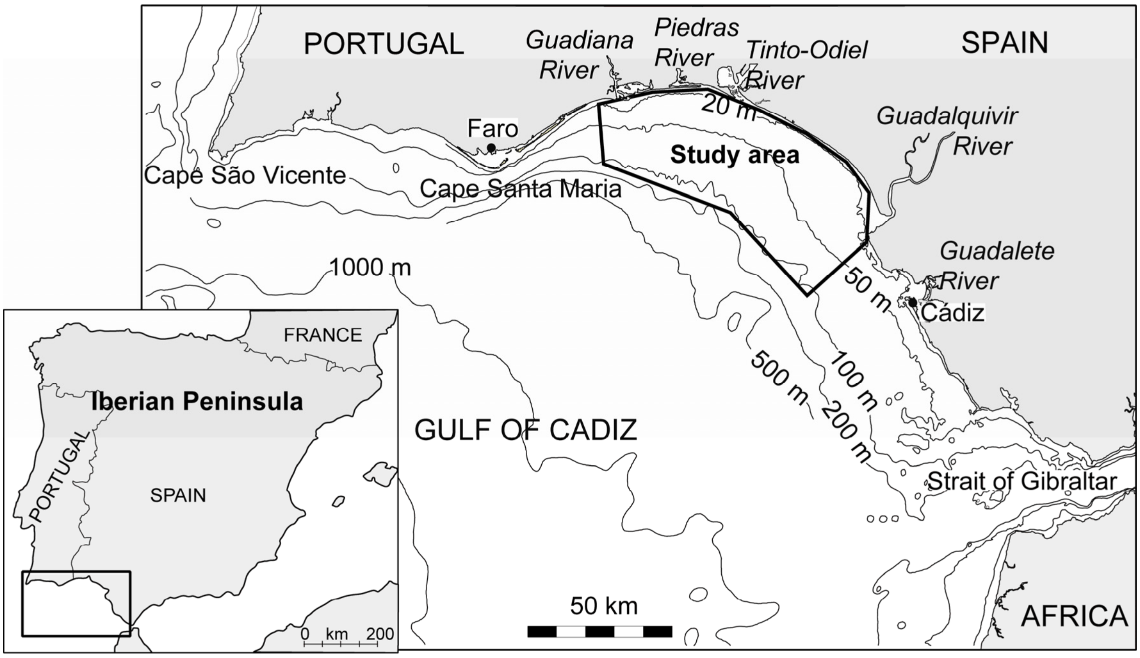

Figure 2.1 – Location map of the study area in the Gulf of Cadiz.

2.2. Climatic characteristics

The study area is characterised by a Mediterranean climate, with hot, dry summers with at least two months of drought after the summer solstice, and mild winters during which the majority of the rain falls. The regional climate of the Guadiana River basin is classify as semi-arid (Morales, 1995). As a consequence, the Guadiana run-off volume is subjected to high seasonal and inter-annual variations (e.g. Loureiro et al., 1986). Episodic floods play a major role in the supply of sediment from the river basin to the continental shelf (Morales, 1997; Portela, 2006).

These situations can be further aggravated by the influence of the North Atlantic Oscillation (NAO), which is the leading pattern of weather and climate variability over the Northern Hemisphere (e.g. Hurrell, 1995; Luterbacher et al., 2001). The NAO refers to a redistribution of atmospheric mass between the Arctic and the subtropical Atlantic, and swings from one phase to another producing large change in surface air temperature, winds, storminess and precipitation over the Atlantic, as well as the adjacent continents. The NAO also affects the ocean through changes in heat content, gyre circulations, mixed layer depth, salinity, high latitude deep water formation and sea ice cover (e.g. Hurrell and Deser, 2010).

A positive phase of the NAO reflects a below-normal pressure in the northern North Atlantic and an above-normal pressure over the central North Atlantic, leading to strong westerly winds associated with warm and moist air masses across the northern Europe during winter. On the western Iberian margin, this phase enhances upwelling conditions (e.g. Abrantes et al., 2005; Lebreiro et al., 2006; Bartels-Jónsdóttir et al., 2009). During a negative phase of the NAO, the atmospheric system changes, resulting in dry conditions at northern latitudes, and increases precipitation at the southern latitudes of Europe (Hurrell, 1995). Consequently on the Iberian Peninsula this phase results in more rainfall, and subsequent flooding in the river basin during winter mouths, also confirmed for the Guadiana River basin (Trigo et al., 2002; 2004; Dias et al., 2004).

The reconstruction of the climate history in the Guadiana valley based on pollen spectra indicates a warm, dry early Holocene phase between ca. 11790 and ca. 9000 Cal yr BP; a generally warm, humid phase, with prevalence of oceanic conditions from ca. 9000 to ca. 5000 Cal yr BP; and a return to warm, dry conditions after ca. 5000 Cal yr BP (Fletcher et al., 2007).

2.3. Oceanographic setting

2.3.1. Shelf current patterns

The North Atlantic Central Water (NACW) is a representative water mass of the upper 1000 m of the water column. Criado-Aldeanueva et al. (2006) based on data from spring 2001, identified two surface coastal variations of the NACW, not considered as water mass: the Atlantic Water (SAW) and the Warm Shelf Waters (SW). SAW has it origin in the shallow NACW modified by air-sea interactions, and it was found between the surface and a depth of approximately 100 m over the entire region, except for the continental shelf. The SW has been detected mainly over the continental shelf, comes from the noticeably SAW influence by continental processes, including heating and fresh water inputs from land. To the northern part of the Gulf of Cadiz, the lower part of the NACW layer is entrained by Mediterranean Water towards the open ocean, while the upper layer forms part of the anticyclonic surface circulation of the Gulf of Cadiz (Criado-Aldeanueva et al., 2006).

In the Gulf of Cadiz the general surface circulation is anticyclonic with short-term, meteorologically induced variations (Criado-Aldeanueva et al., 2006). Recently studies showed a permanent anticyclonic circulation in the open sea during spring-summer and a more or less complex circulation on the continental shelf. Two cells of cyclonic circulation were located over the northern Gulf of Cadiz: the western shelf linked with open-sea processes and the eastern shelf linked to coastal processes (Garcia-Lafuente et al., 2006 and Garcia-Lafuente and Ruiz, 2007).

The northern continental shelf of Gulf of Cadiz is divided by the Cape Santa Maria (off Faro) in two shelves (Fig. 2.1) of different shape that hold different oceanographic processes. The western shelf is narrow, under the influence of the almost-permanent upwelling off Cape São Vicente, related with wind-stress curl (e.g. Fiúza, 1983; Vargas et al., 2003; Criado-Aldeanueva et al., 2006; Garcia-Lafuente and Ruiz, 2007). To the east of Cape Santa Maria, the eastern shelf is wider, receiving sediment and energy inputs from land as well as tidally-driven processes, making this shelf more productive (e.g. Navarro and Ruiz, 2006; Garcia-Lafuente and Ruiz, 2007; Prieto et al., 2009).

The dynamics in this area is also strongly dependent on wind regime. Westerly winds enhance the upwelling off Cape São Vicente, creating a second intense core of upwelling off Cape Santa Maria and generalize the upwelling along the southern Portuguese coast (e.g. Vargas et al., 2003; Garcia-Lafuente and Ruiz, 2007). The upwelling off Cape Santa Maria is a more likely coastal process with a short time response to changes in the wind regime: it is enhanced under westerlies, and it weakens, and even fades out, under easterlies. Off Cape Santa Maria the upwelled water can form a filament extended southward, which reaches its maximum signature at about 40-50 m depth, becoming almost indistinguishable at around 200 m depth (Criado-Aldeanueva et al., 2006). These upwelling events could induce new production resulting from vertical advection of nitrogen, two orders of magnitude greater than the maintained by vertical diffusion (Ruiz and Navarro, 2006). Easterly winds favour a warm coastal countercurrent that is observed in the eastern shelf and may invade the western shelf connecting both shelves in an east to west direction, often turning poleward around Cape São Vicente (e.g. Relvas and Barton, 2002; 2005; Lobo et al., 2004; Garcia-Lafuente et al., 2006; Garcia-Lafuente and Ruiz, 2007; Relvas et al., 2007).

The coastal zone between Guadiana and Guadalquivir River mouths showed the highest chlorophyll concentrations values of northern Gulf of Cadiz, based on remote sensing data from the Sea-viewing Wide Field-of-view Sensor recorded between 1998 and 2000 (Navarro and Ruiz, 2006). In the open sea, the surface chlorophyll maxima occur in winter and in coastal areas in spring followed by a second bloom either in summer or fall. In coastal areas these blooms are mainly due to the presence of several processes that favour the nutrient entrance, such as upwelling events, rainfall and river discharges. Local winds also influence the biological production, westerlies cause an increase in chlorophyll concentrations and easterlies a decrease in phytoplankton biomass (Navarro and Ruiz, 2006; Prieto et al., 2009).

2.3.2. Tide and wave regime

The coast between the Guadiana and Guadalquivir Rivers is considered mesotidal, with mean tidal range of 2 m. Off the Guadiana River mean spring tide is of 2.82 m (e.g. Morales, 1997) and in the north of the Cadiz Bay can reaches a maximum tidal range of 3.7 m (e.g. Benavente et al., 2000).

The offshore wave climate is dominated by west-southwest waves (71% of the occurrences; Costa et al., 2001). Southeastern waves that consist of short-period waves generated by regional winds are also frequent (23% of the occurrences; Costa et al., 2001). Wave energy is moderate with an average annual significant offshore wave height of 1.0 m and average peak period of 8.2 s (Costa et al., 2001). Storm events in the region were defined as events with significant offshore wave height greater than 3 m (Pessanha and Pires, 1981). Between 1986 and 1993, storm conditions corresponded to 1% of the offshore wave climate (Costa, 1994).

2.4. Shelf bathymetry

On the northern Gulf of Cadiz shelf, the maximum width occur on the middle part, and decreases both towards Cape São Vicente and the Strait of Gibraltar. The shelf has a minimum width of 5 km off Faro (Portugal), increases to 20-25 km off the Guadiana River and attains a width of more than 30 km close to the Guadalquivir River mouth. Accordingly, the mean slope of the Portuguese shelf is 0.5°, decreasing to slopes of less than 0.3° on the Spanish shelf. The mean Guadiana shelf slope is 0.32° (Roque, 1998; Lobo et al., 2001).

The shelf break lies at varying water depths in concordance with width and sea floor gradients changes. Between the mouths of the Guadiana and Guadalquivir Rivers it is located at 120 to 150 m water depth (Baldy, 1977).

2.5. Fluvial and sediment supply

The study area receives fluvial supply from the Guadiana, Piedras, Tinto-Odiel and Guadalquivir Rivers (Fig. 2.1). The annual mean water discharge of Guadalquivir River (160 m^3s^{-1}) is about twice the Guadiana River (80 m^3s^{-1}) discharge. The contributions of the Tinto-Odiel system are small, with mean discharges of 20 m^3s^{-1} (van Geen et al., 1997).

The Guadalquivir River is the main fluvial input of the Gulf of Cadiz northern margin, however its associated mud sedimentary wedge is deflected south-eastward of the study area, mainly dominated by the North Atlantic Central Water current (e.g. Gutiérrez-Mas et al., 1996; Nelson et al., 1999; Lobo et al., 2004, as North Atlantic Surface Water). The Guadiana River is, therefore, the main sediment source to the study area. The estimated sediment supply from the river basin to the shelf between 1946 and 1990 was 57.90×10^4 m^3yr^{-1} for the average suspended load and 43.96×10^4 m^3yr^{-1} for bedload (Morales, 1995; 1997). For the winter of 2000/2001, an exceptionally rainy year compared to the previous 10 years, the estimated sand onto the inner shelf was about $7.5\text{-}9.5 \times 10^5$ m^3 (Gonzalez et al., 2007). These numbers are about twice the average ones estimated by Morales (1995; 1997). However after the closure of the Alqueva dam in February 2002, the sediment supply decreased drastically. Estimates excluding occasional discharges related with flood events, indicated around 10×10^3 m^3yr^{-1} of sand is today exported (as bedload) to the inner shore (Garel et al., submitted).

The second regional sediment source is the littoral drift. Prevailing onshore wave conditions along the coastline produce an eastward net annual littoral drift estimated to be around 180 x 10^3 m^3yr^{-1} of mostly sandy sediment, carrying sediments from the southern Portuguese coast towards the eastern portion of the Gulf of Cadiz (Gonzalez et al., 2001).

2.6. Modern surficial sediment distribution

Sandy deposits dominate the inner shelf down to a depth of approximately 25 m, particularly in nearshore zones (Fig. 2.2) (Moita, 1985; Fernández-Salas et al., 1999; Nelson et al., 1999; Gonzalez et al., 2004; 2007). This deposits are interrupted by a prodeltaic wedge off the Guadiana Estuary, consisting of sandy muds and muds forming an oblong mud patch with an area of about 60 km^2 (Fernández-Salas et al., 1999; Gonzalez et al., 2004; 2007) and by a prodelta off Guadalquivir mouth, consisting of muds (Nelson et al., 1999; Gonzalez et al., 2004; 2007).

The transition between the inner and middle shelf (or outer infralittoral for other authors) located between 25 and 30 m depth consists of sands and sandy mud. Additionally, this area features a series of rocky outcrops of reduced extent, and probably of Holocene age (e.g. Fernández-Salas et al., 1999; Gonzalez et al., 2004), containing varying amounts of terrigenous gravel.

The middle shelf is characterised by an extensive mud belt, consisting of very fine-grained material. Crossing from north to south through the surface of the outer infralittoral ridge and the middle shelf mud deposits lie a series of transgressive deposits composed of muddy gravelly sands and muddy sands (Fig. 2.2) (Gonzalez et al., 2004; 2007).

On the outer shelf below 100 m depth, sediments are generally dominated by sands and silty clay. They are locally interrupted by large patches of sand and gravelly sand in the vicinity of the shelf edge (Gonzalez et al., 2004; 2007).

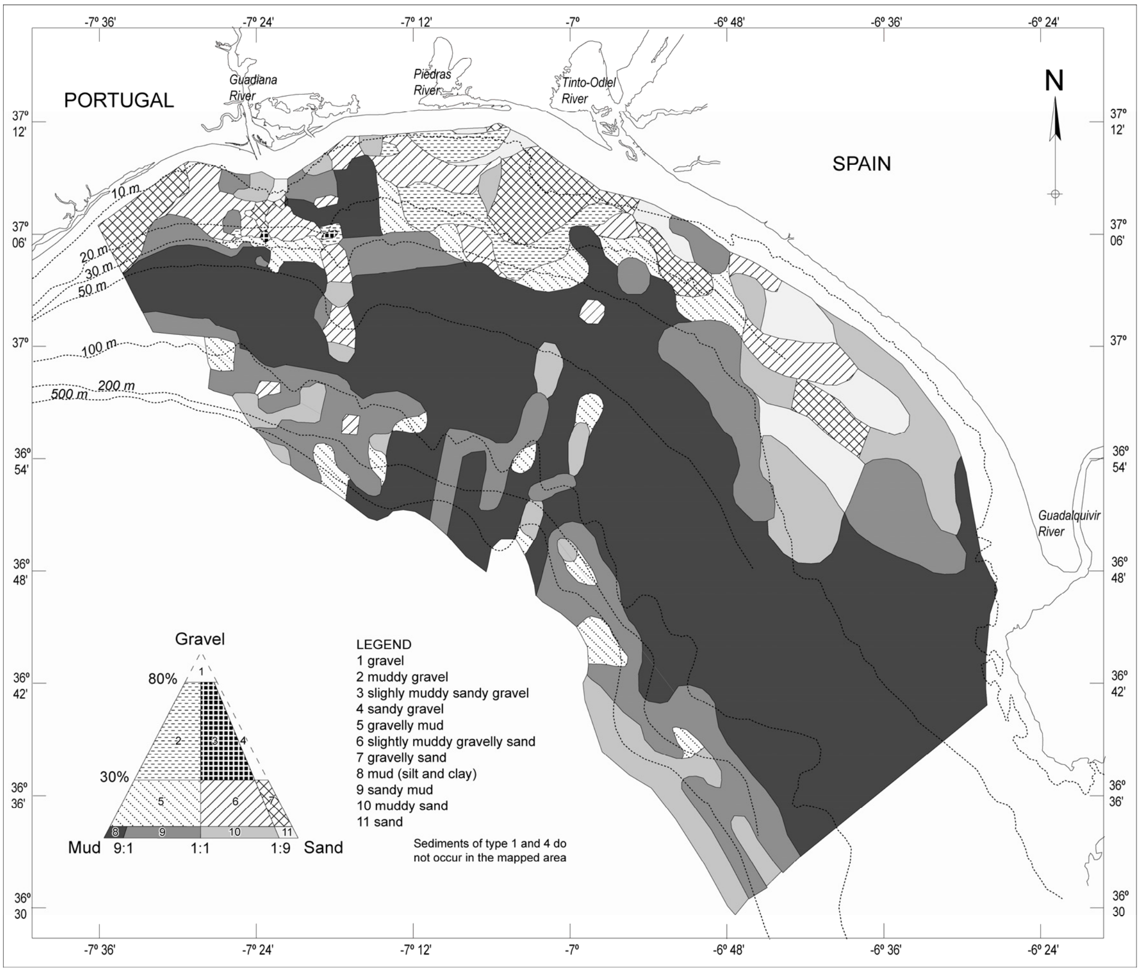

Figure 2.2 – Modern surficial sediment distribution of the northern Gulf of Cadiz continental shelf, between the Guadiana and Guadalquivir Rivers (adapted from Gonzalez et al., 2004).

2.7. Holocene evolution

2.7.1. Continental shelf

The postglacial evolution of depositional systems on the northern Gulf of Cadiz shelf was strongly influenced by rapid sea-level changes, leading to the formation of transgressive and highstand system tracts (Nelson et al., 1999; Lobo et al., 2001; 2002; 2004). Seismic profiles show four transgressive parasequences exposed from the outer to middle shelf (Lobo et al., 2001). Highstand deposits occur on the inner shelf as a prodeltaic wedge and on the middle shelf as an extensive mud belt (Nelson et al., 1999; Gonzalez et al., 2004; 2007; Lobo et al., 2004). The thickest part of the Holocene layer off the Guadiana river mouth is offset to the southeast of the river mouth has an elongate taper to the southeast. All the mud belt margins except the southeast are interrupted by non depositional areas. At its thickest point is localised in the central shelf, the apparent Guadiana-derived Holocene layer is about 15 m thick and 25 km wide (Nelson et al., 1999).

The sediment distribution patterns in the northern Gulf of Cadiz shelf indicate that, since the Late Quaternary, depositional dynamics express the interaction of several factors dominated by the south-eastward transport of sediments under the influence of North Atlantic Central Water, across the Cadiz shelf toward the Strait of Gibraltar (Nelson et al., 1999). Sediment dispersal during the Holocene highstand period is also controlled by an intermittent counter current system, which seems to be intimately linked with the wind regime (Lobo et al., 2004).

2.7.2. Estuary infilling

Several studies deal with estuarine valley infilling during the Holocene in the northern Gulf of Cadiz. On the Spanish coast these studies have been focused in the Tinto-Odiel, Guadalquivir and Guadalete estuaries (e.g. Dabrio et al., 2000; Lario et al., 2002) and on the Portuguese coast in the Guadiana and Gilão-Almargem estuaries (Boski et al., 2002; 2008; Lobo et al., 2003). More recently Zazo et al. (2008) elaborated an integrated approach from previous papers, including information from both Spanish and Portuguese coastal sectors.

The sequence of events that led to the formation of the Guadiana River estuary in its present form indicated that at the beginning of the Holocene, around 9800 Cal yr BP, the Guadiana estuary started to be rapidly filled with clay sediments. Between 7500-7000 Cal yr BP the central part of the estuary began to accommodate coarser sediments partly derived from the adjacent shelf, whilst clay continued to deposit in the marginal lagoons. Since that time, sea-level rise decelerated, leading to the enclosure of lagoons behind sand spits, and to the deposition of predominantly sandy sediment inside the estuary. This occurred until sea level stabilisation at a level close to the present one which took place around 5000 Cal yr BP (Boski et al., 2002).

2.8. Anthropogenic impact

Palynological evidences in the lower Guadiana valley indicate an important increase in human influence on the landscape after ca. 4000 Cal yr BP (Fletcher et al., 2007). An archaeological approach to regional environmental pollution indicates that in the beginning of Third millennium BC, a sudden territorial occupation in the Iberian Pyrite Belt structured on the cooper metallurgy. This occupation was of such magnitude that provoked an unprecedented impact on the environment, increased deforestation, increase on the rate of erosion processes and contamination with heavy metals, at a regional scale, the waters of the Gulf of Cadiz, specifically the area corresponding to the mouth of Tinto-Odiel River (Nocete et al., 2005).

In the southern Portugal, between ca. 3000 and ca. 300 yr BP, and equating to late pre-Roman, Roman, Moorish and early Portuguese stages of settlement, exploitation of the region for timber and other agricultural products caused widespread erosion, sediment movement, deposition of extensive valley fills and siltation of estuaries (Chester and James, 1999). A more recent survey in southern Portugal in the region of Mértola (a village near the upper Guadiana estuary, approximately 70 km from the mouth), by Boone and Worman (2007), revealed that after cessation of the Roman administration of Iberia in the 5th century A.D. (ca. 1500 Cal yr BP) and over the next 500 years, particularly after the Muslim invasion of A.D. 711 (ca. 1200 Cal yr BP), settlement density increased six fold relative to the number of inhabitants during the Roman period. These authors also verified that during the mid-12th century, the majority of rural villages were abandoned. The region remained largely depopulated until the mid-late 1400s, and settlement density in the region was never again as high as it was during the later Medieval Islamic period (800 to 900 Cal yr BP). Geoarchaeological evidence of widespread erosion and soil loss suggests that overuse of land may have been a factor in the abandonment (Boone and Worman, 2007).

The anthropogenic influences on the Guadiana River basin have increased significantly during the last 150 years through the construction of dams, mining, and deforestation with consequent increase of soil erosion, which affected the amount of sediment supply to the shelf (Gonzalez et al., 2001; Dias et al., 2004; Gonzalez and Dias, 2006).

Chapter 3

Distribution of living benthic foraminifera

3.1. Introduction

All applications of benthic foraminifera as environmental indicators are based upon an understanding of their ecology. Any analysis of distribution patterns and abundances of organisms needs to take into account the interaction between individuals, different species, and the chemical and physical environment (e.g. Murray, 1991a; 2006). Only studies of living (stained) fauna can be used for ecological interpretations, to ensure that benthic foraminifera are closely linked to their surrounding environment. Even subtle changes in environmental parameters are mirrored by faunal changes (e.g. Murray, 2001). Because benthic foraminifera are highly dependent on environmental conditions, they have been used extensively for ecological and palaeoecological studies. In the future, foraminiferal ecology will continue to play an important role in the interpretation of the geological record, not only to understand the past but to help predict future trends as well (e.g. Murray, 2006).

Continental shelves are areas of high primary productivity and relatively high environmental variability (Sen Gupta, 1999b). These environments receive nutrients and organic carbon compounds from fluvial supply, as well as from decomposition of organic material in surface sediment and by benthic primary production from seaweed and benthic diatoms. Water movement through wave and tidal circulation distributes nutrients through the water column and promotes enhanced primary production (Murray, 2006). These sources also supply dissolved organic matter, which feeds bacteria and thus supplies the food chain (Loubere and Fariduddin, 1999). Except for species that feed on live food or have endosymbiontes, labile organic matter and the bacteria feeding on it are primary food sources for benthic foraminiferal assemblages (e.g. Murray, 2006).

Dissolved oxygen and organic carbon flux are considered as the main factors controlling depth distribution of benthic foraminifera in sediments (van der Zwaan et al., 1999). In deeper waters, where some environmental factors have little or no spatial or temporal variability, it is sometimes possible to isolate one main factor. In that case, oxygen and the flux of organic matter appear to be the main factors (Murray, 2001). However, not all distributions can be explained in terms of just a few factors, as this would be an oversimplification (Murray, 2001). In marginal marine environments, living benthic foraminifera are distributed according to a complex set of physical, chemical and biological parameters, including temperature, salinity, water depth, sediment type, oxygen concentration, food availability, water currents, and biological interactions (Murray, 2001; 2006; Loubere and Fariduddin, 1999). For species living in dynamic environments, it is probable that various factors or a combination of factors limit their temporal and spatial distribution (Murray, 2006).

Many studies have demonstrated that diverse and/or different parameters influence the distribution of benthic foraminifera in shallow marine environments. In the northwestern Mediterranean coast of Egypt, lateral changes in faunal distribution were most strongly influenced by water depth, substrate type, light intensity, turbidity, nutrients availability, and salinity (Samir et al., 2003). In the Mediterranean Sea, bathymetric distribution of dominant benthic foraminifera is controlled by labile organic matter inputs to the sea floor (de Rijk et al., 2000). In the Rhône prodelta, the data obtained by Mojtahid et al. (2009) suggest a strong link between the density, diversity and composition of the benthic foraminiferal assemblages on one hand, and the quantity and quality of the organic matter inputs on the other. In the Ría de Vigo (NW Spain), spatial distribution of major benthic foraminiferal species is controlled by salinity variations, food availability and oxygen concentrations in muddy sediments (Diz and Francés, 2008), whilst in coarse sediments, their distribution is mainly related to food availability and bottom current strength (Diz et al., 2004). On the French Atlantic continental shelf, water oxygen concentration, oxygen penetration into the sediment and organic carbon content are all important controlling factors. The composition and density of the benthic foraminiferal faunas seems to be correlated with the presence of coastal blooms, in front of river outlets (Duchemin et al., 2008).

Few data on the distribution of living benthic foraminifera are available from the northern Gulf of Cadiz, especially on the continental shelf between the Guadiana and Guadalquivir Rivers. The complexity of environments in this area required a detailed study of the distribution and ecology of living benthic foraminiferal faunas. Such a study is presented in this chapter. Benthic foraminiferal assemblages will be described and the distribution and abundance of the most abundant species will be related to: water depth, sediment type, influence of rivers outflow, temperature, salinity, suspended particulate matter concentrations and primary productivity. This investigation was necessary to increase knowledge of the ecology of benthic foraminifera, which in turn was essential for understanding the present environment and to constrain analogues for interpretation of past ecological and oceanographic conditions.

3.2. Material and methods

3.2.1. Analyses of benthic foraminifera

A total of 120 surface sediment samples were collected between 1st and 5th February 2001 using a Smyth McIntyre grab sampler from the Portuguese oceanographic research vessel *N.R.P Andrómeda*. The surficial layer was sampled and the individual samples were stored in a solution of 95% ethanol containing Rose Bengal (1g/l). This staining method was chosen because it is widely used and allows the study of abundant foraminiferal faunas in an acceptable period of time (e.g. Murray and Bowser, 2000). Other methods were either under developed (e.g. de Nooijer et al., 2006), require a large technological effort, or must be used instantaneously (e.g. CellTracker Green).

In the laboratory, each vial was marked with a line to delimit total sediment volume. Samples were washed with tap water for 10 to 15 minutes, through 63 and 2000 µm sieves, which had previously been placed in a tub of Methylene Blue. The 63 µm sieve content were placed in a Petri dish and examined under a binocular microscope for a first estimate of stained benthic foraminiferal abundance. This fraction was then placed in a test-tube and sediment volume measured. Water was added to the sample vial until the line of total sediment was reached. This volume was measured and the process repeated three times to obtain the mean wet volume of >63 µm fraction and the total sediment volume, respectively. The ratio between volumes is to be used as measure of the sand content of the near-surface sediment. Total sediment volume is used to calculate population density as number of living benthic foraminifera per 10 cm^3 of sediment. Fractions greater than 63 and 2000 µm were dried at 50ºC and weighed. Based on the initial microscopic assessment, samples with more than 50 living specimens were selected for the study of living benthic foraminiferal assemblages. A total of 47 samples were obtained, spread across three distinct areas of the continental shelf near the Guadiana (11 samples), Tinto-Odiel (15 samples) and Guadalquivir (21 samples) Rivers, respectively (Fig. 3.1).

Fourteen additional samples were analysed for living benthic foraminiferal associations near the Guadiana River mouth. The samples were obtained from the first centimetres of sediment cores, collected by vibration method in June 2002 and April 2005 (Fig 3.1). After their opening in the laboratory, the first centimetre of each was kept in vials and stained with a solution of 95% ethanol containing Rose Bengal (1g/l). The previously described methods of washing, volume measurements processes and weighting for surficial samples were followed likewise.

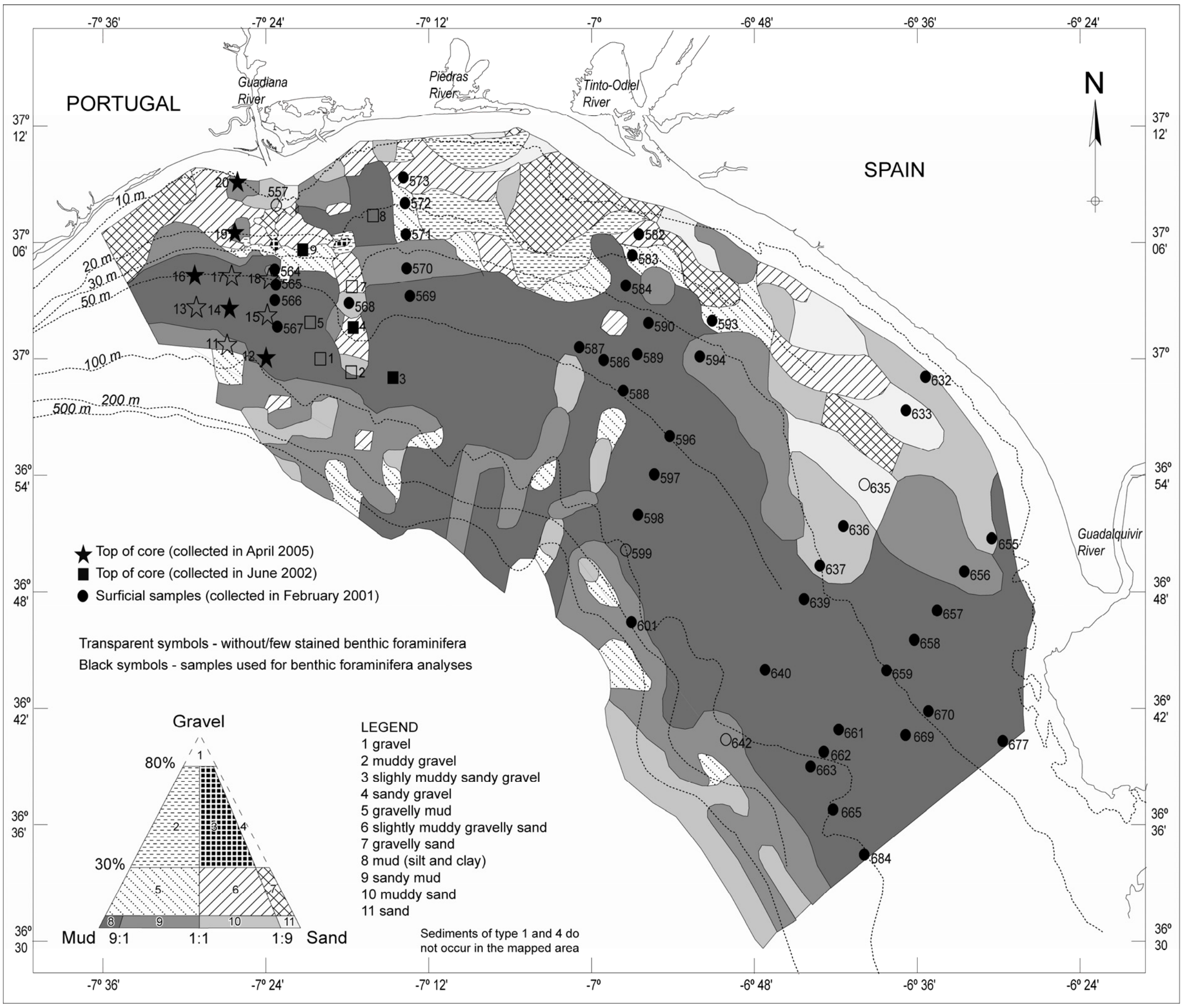

Figure 3.1 – Location of the samples studied, including the collection method and characteristics of surface sediments on the continental shelf of the study area (adapted from Gonzalez et al., 2004).

Grab samples and core tops studied for living benthic foraminiferal assemblages cover a water depth range from 10.7 to 115.5 m. Size fractions >63 µm were reduced to aliquots of a practical size using an Otto micro-splitter, spread on a picking tray and analysed using a binocular microscope with a maximum zoom magnification of 110x (Olympus SZ1145TR). Whenever possible, at least 300 stained individuals were collected from each sample, mounted on lightly glued cardboard slides, identified and counted. According to Fatela and Taborda (2002), 100 foraminifera constitute a statistically representative sample when each species represents at least 5% of the assemblage. From the 61 samples studied, 2 samples did not yield any living benthic foraminifera and 8 samples had less than 50 individuals. These samples were not studied further (Fig. 3.1). Four samples with 63 to 90 living individuals were studied because their faunal composition was consistent with the prevailing species distribution pattern. Only species with abundance greater than 5%, in at least in one sample, were considered for statistical analyses and species distribution.

Benthic foraminifers were classified according to the proposed generic classification of Loeblich and Tappan (1987), and identified by using Ellis and Messina (1942-2009), Jones (1994), Levy et al., (1995), Martins and Gomes (2004), and other studies. Further detail about the taxonomic classification is given in Chapter 7. Dominant foraminifera were documented using scanning electron microscope (SEM) photographs, taken with a JEOL, JSM-5200 LV microscope at the Faculdade de Ciências da Universidade de Lisboa and by microscope photographs taken with an Olympus Camedia C-7070 camera.

The number of living benthic foraminifera per total sediment volume was obtained by the ratio between the number of living benthic foraminifera and the analysed split. This value was used to calculate the number of living benthic foraminifera in 10 cm^3 of sediment.

Diversity statistics indexes were calculated using PAST (Palaeontological Statistics, version 1.81) program (Hammer et al., 2008). The number of species in each sample, termed as species richness (S) and the number of individuals (n), was used. It was calculated the diversity Shannon index (H), Equitability and diversity Fisher's alpha diversity index.

The expected number of species after 100 counted specimens and the expected number of species counted in each sample were obtained from a logarithmic trend-line created after plotting the number of species against counted specimens. Species richness after 100 counted specimens, E100, it's equal to the addition between expected number of species after 100 counted specimens (obtained by logarithmic trend line) and the number of species minus the expected number of species counted in each sample.

Cluster Analyses (CA) and Principal Components Analyses (PCA) were also performed using PAST software (Hammer et al., 2008) on a data matrix of species with abundances >5% in at least one sample. Hierarchical clustering produced a dendrogram indicating relationships between individual data point. Species for R-mode cluster analyses were grouped using the correlation method and Q-mode cluster analyses grouped samples according to their similarity using a Bray-Curtis distance measure. Results were joined using an unweighted pair-group average (UPGMA), which joins clusters based on the average distance between all members of the two groups. The same dataset was analysed using Principal Components Analysis, from which two factors explaining most of the total variance were for plotting. CA and PCA were also performed in a matrix of reduced dataset, considering only species that occurred at least, in half of the analysed samples. Q- and R-mode clusters were produced using Ward's method and joined such that the increase in intra-group variance was minimized.

Distribution maps for individual species with >5% abundance were drawn manually and values between sample locations were interpolated within the limits of the study area. Surfer software (version 8.05) kriging interpolation was tried, but, for species with low abundances, unrealistic distributions were obtained.

3.2.2. Temperature, salinity and suspended particulate matter near sea floor

During surface sediment sampling, hydrological data was gathered at 148 locations throughout the study area, at water depths between 9 and 764 m, on board the Portuguese oceanographic vessel *N.R.P. D. Carlos I.* At each location, vertical profiles of the water column were made using a CTD (Conductivity, Temperature, Depth) profiler *Neil Brown IS MkIIIC (WOCE)*, coupled with a *Rosette* equipped with twelve 1.7 litre *Niskin* water bottles.

For this study, only measurements and water samples collected near the bottom, i.e. <10 m above the seabed, were considered.

Water samples were filtered through weighed 0.45 μm membrane filters until clogged and subsequently oven dried at 40ºC. Suspended Particulate Matter (SPM) content was calculated by dividing the concentration of material retained in each membrane filter by the total volume of filtered water and expressed in milligrams per litre (mg/l).

Contour maps for temperature, salinity and suspended particulate matter were interpolated by kriging, using Surfer software (version 8.05).

3.3. Results

3.3.1. Benthic foraminiferal community

A total of 106 benthic foraminiferal species were determined. Fifty species were assigned to genera only and they were left in open nomenclature. Twenty-six species showed relative abundances >5% in at least one analysed sample (Appendix A).

Benthic foraminiferal population density (specimens/10 cm^3) on the continental shelf between the Guadiana and Guadalquivir Rivers has no evident relationship with bathymetry or sediment type. However, it seems to be influenced by rivers outflow in a non-linear mode (Fig. 3.2A). The highest value (1173 specimens/10 cm^3) was obtained in the area off the Tinto-Odiel mouth, in muddy sediments at 27.5 m depth. The lowest value was observed (14 specimens/10 cm^3) in the same area at 87 m depth, also in muddy sediments. Population density averaged 225 specimens/10 cm^3. Near the Guadiana mouth, two peaks of density were observed in muddy sediments, with 512 and 657 specimens/10 cm^3 in 85 and 100.6 m water depth, respectively. Off the Tinto-Odiel and Guadalquivir Rivers, high density was detected in relatively shallow water (between 14 to 28 m depth), associated with muddy sand and muddy sediments. However, quite low population densities were recorded in the same area (Fig. 3.2A).

Species richness (S), with the exception of one deep-water sample (100.6 m depth), generally decreases with water depth (Fig. 3.2B). The maximum value obtained was 68 and the minimum 13 species. Most of the analysed samples contained 20 to 30 species, with an average of 31.6. Higher values were obtained in shallow waters in samples under the direct influence of rivers outflow, except for two samples with more than 60 species, located between the mouths of the Guadiana and Piedras Rivers (Fig. 3.2B) and associated with muddy gravelly sand and gravelly mud sediments.

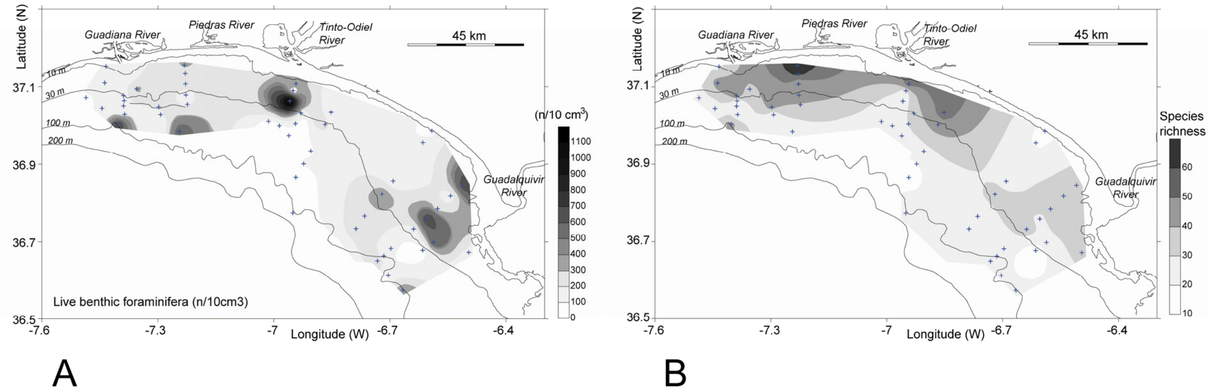

Figure 3.2 – Distribution of: A - living benthic foraminifera, in number of specimens (n) per 10 cm^3, and B- species richness in the study area.

The abundance of living benthic foraminifera per 10 cm^3 and species richness does not correlate (Fig. 3.3). But in both cases, the high abundances were observed off Tinto-Odiel and Guadalquivir Rivers mouths though in different samples (Fig. 3.2). The type of sediment seems to play an important role in the abundance of living benthic foraminiferal population and species richness.

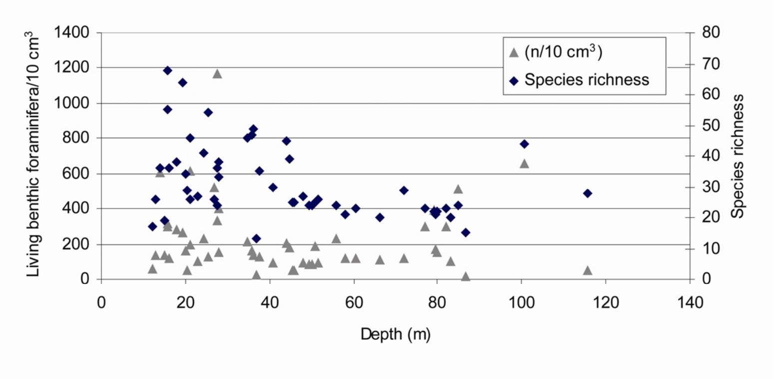

Figure 3.3 – Variation of the number of living benthic foraminifera per 10 cm^3 and species richness with water depth.

The Shannon index (H) ranges between 1.1 and 3.2, with an average value of 2.3 and no evident relationship to water depth (Fig. 3.4a). Equitability (J) ranges from 0.36 and 0.9, with an average value of 0.7 (Fig. 3.4b). The Alpha-Fisher index ranges from 4.2 to 25.1, with a higher concentration of points between 5 and 10 and an average value of 9.6 (Fig. 3.4c). As with species richness, the alpha index also tends to decline with water depth.

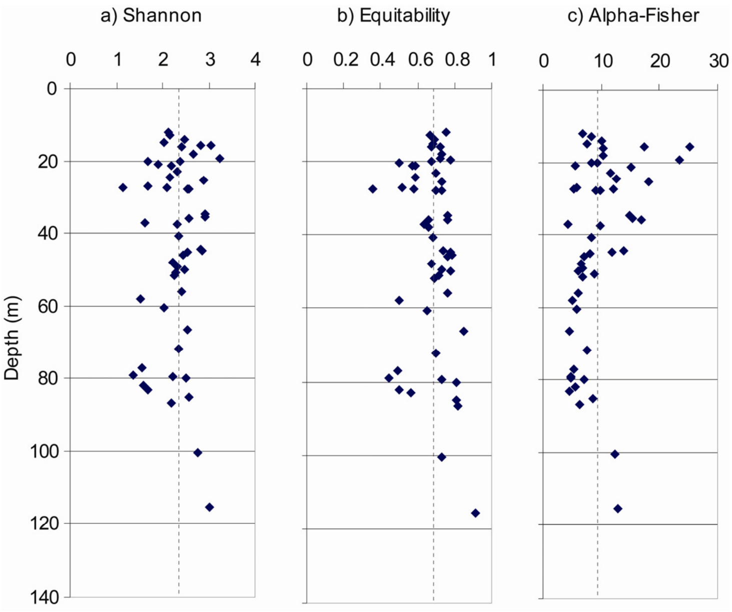

Figure 3.4 – Variation in diversity indices with water depth: a) Shannon index; b) Equitability index; c) Alpha-Fisher index. Average values are represented by a dashed line.

A logarithmic trend-line was fitted to the relationship between species richness and counted specimens, yielding the formula $y = 7.6457*\mathrm{Ln}(x) - 11.149$ (Fig. 3.5A). This included all analysed samples, including those with less than 63 stained individuals. There were some samples in which the observed number of species was approximately double the estimated number of species, even though 300 to 400 specimens were counted. For instance, the expected number of species after 100 specimens was 24, but 40 to 68 species were actually found. Considering only samples used for statistical analyses and individual distributions of benthic foraminifera, a logarithmic trend-line yields formula y = 9.2073*Ln(x) – 19.942 (Fig. 3.5B). Although the trends in figures 3.5A and 3.5B were similar, the latter has a weaker correlation (R^2). The estimated number of species after 100 specimens counted was 23. Samples above the trend line contained more than 35 species for 300 specimens counted and more than 27 species for 100 specimens counted. The samples with unexpectedly high species richness were located in shallow areas with river outflow influence (Fig. 3.2B) and were associated with sandy mud, muddy sand, gravelly mud, mud and slightly muddy gravelly sand sediments.

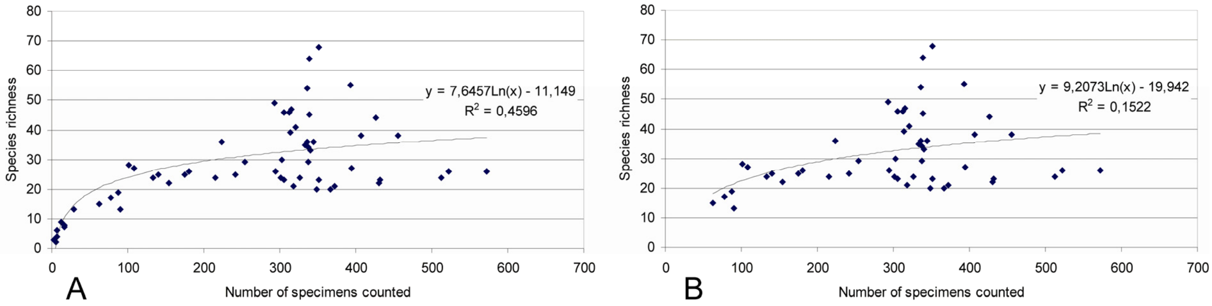

Figure 3.5 – Variation of species richness with the number of specimens counted in each analysed sample and the respective logarithmic trend lines: A – dataset including all the analysed samples; B – dataset including only the samples used in statistical analyses.

Variation in species richness after 100 specimens counted (E100) versus water depth was similar between all the analysed samples (Fig. 3.6A) and samples with more than 5% in at least one sample (Fig. 3.6B). In both cases, minimum species richness was observed between 50 and 80 m water depth. As different intervals have a different number of samples, the average and standard deviation for each 10 m interval was calculated, to get an idea if this tendency was induced by points with higher dispersion (Fig. 3.6). Variation in species richness, considering only samples used in statistical analyses, was robust even though samples were missing around 100 m water depth (Fig. 3.6B).

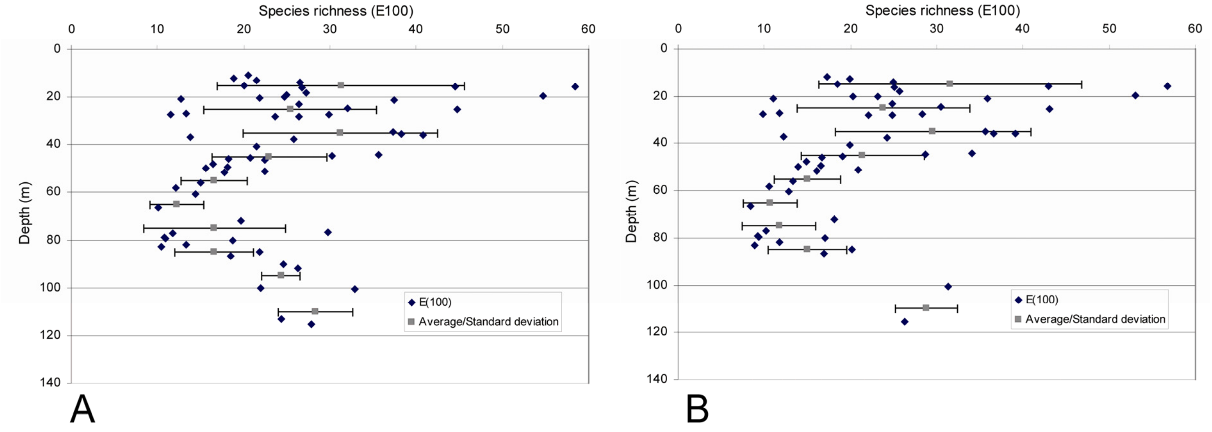

Figure 3.6 – Variation of species richness (E100) with water depth. Average and standard deviation obtained for 10 m water-depth intervals: A – dataset including all the analysed samples; B – dataset including only the samples used for statistical analyses.

If only the samples used for statistical analyses were considered (Fig. 3.6B), there were twelve points with dispersion out of the range of standard deviation: 4 points from shallow waters and muddy sediments with a low number of species; 4 points from shallow waters and gravelly mud, sandy mud and slightly muddy gravelly sand with higher number of species; and another 4 points with a higher number of species in depths ranging from 44 to 85 m, associated with sand, mud and slightly muddy gravelly sand sediments.

3.3.1.1. Multivariate analyses

The multivariate analyses considered 26 species with relative abundances higher than 5% in at least in one sample. These species represent between 59 to 97% of all living specimens (average of 86%).

R-mode cluster analyses, using a correlation similarity measure, paired group algorithm and cophenetic correlation of 0.8231, produced a dendrogram that allowed the differentiation of four assemblages or clusters (Fig. 3.7): Cluster I with the species *Bolivina ordinaria* and *Hopkinsina atlantica*; Cluster II with *Elphidium gerthi*, *Ammonia beccarii*, *Quinqueloculina stelligera*, *Quinqueloculina laevigata* and *Eggerelloides scaber*; Cluster III with *Rectuvigerina phlegeri*, *Elphidium cuvillieri*, *Epistominella vitrea*, *Bulimina elongata*, *Elphidium excavatum* and *Bulimina aculeata*; and Cluster IV with *Cassidulina laevigata*, *Stainforthia* sp., *Bolivina catanensis*, *Nouria polymorphinoides*, *Brizalina spathulata*, *Nonionella stella*, *Nonionella iridea*, *Brizalina dilatata*, *Nonionella turgida*, *Bulimina marginata*, *Brizalina striatula*, *Nouria* sp. and *Bolivina italica*.

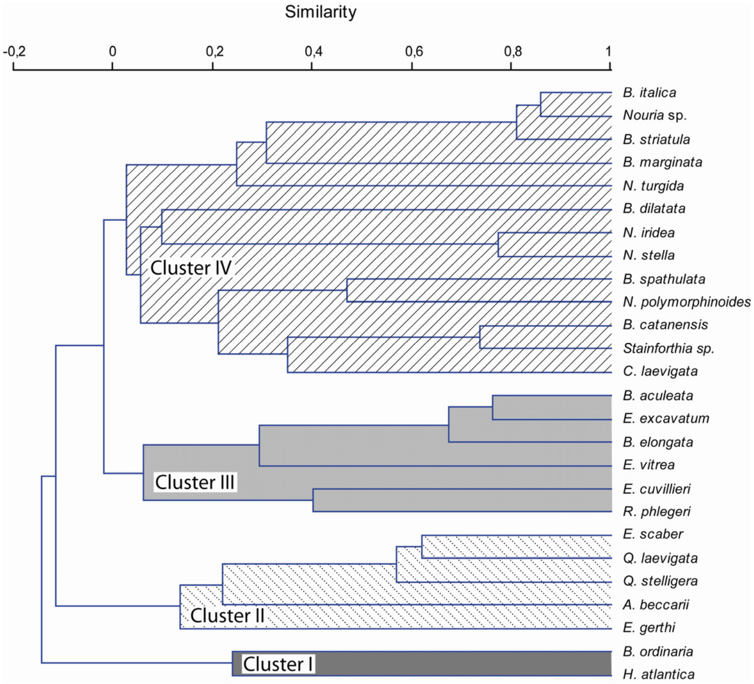

Figure 3.7 – Dendrogram resulting from R-mode cluster analyses (correlation method joined by UPGMA) based on the 26 species with total abundance >5%.

The spatial distribution of the four clusters (Fig. 3.8) showed that each cluster corresponds to a distinct biofacies. Biofacies I (Cluster I) appeared in the vicinity of rivers outflow from the inner to the outer shelf (Fig. 3.8a). Biofacies II (Cluster II) occurred in shallow waters and was mainly associated with river discharge (Fig 3.8b). Biofacies III (Cluster III) was distributed mostly between 40 and 100 m water depth (Fig. 3.8c). Biofacies IV (Cluster IV) occurred in the deepest parts of the study area (Fig. 3.8d).

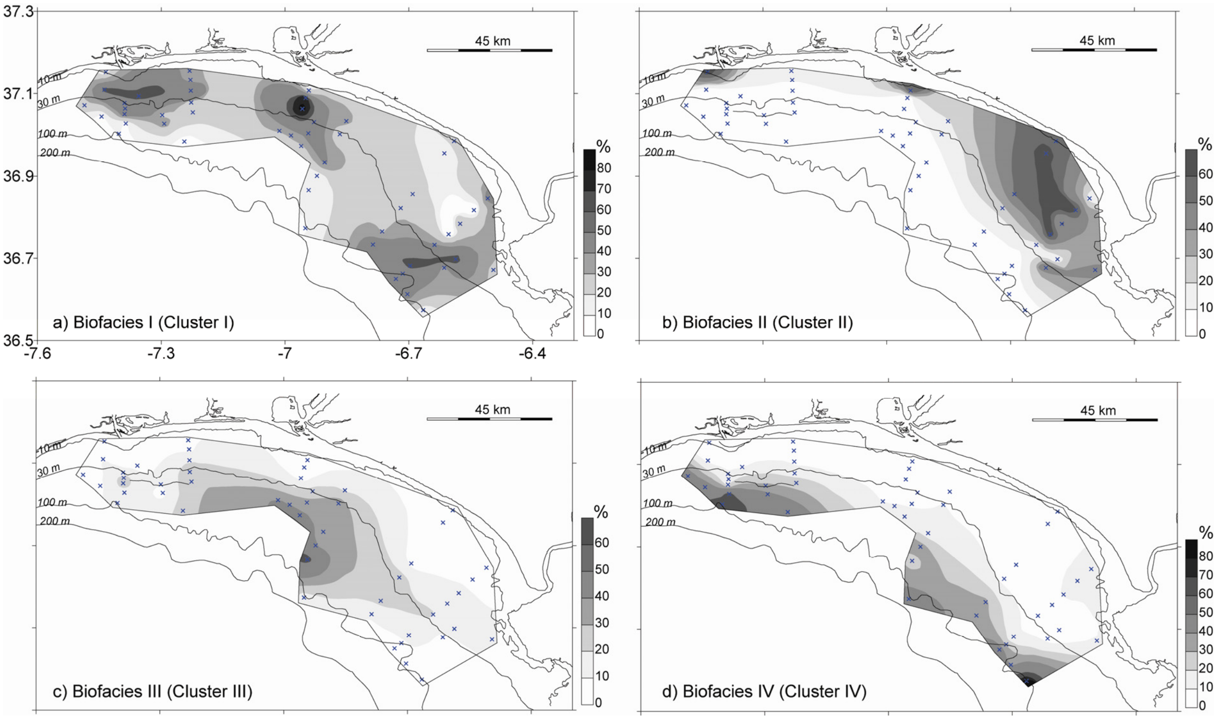

Figure 3.8 – Spatial distribution of the four biofacies recognised by R-mode cluster analyses, based on the 26 species with total abundance >5%.

The Q-mode cluster analysis, using a paired group algorithm, Bray-Curtis similarity measure and cophenetic correlation of 0.8225, produced the most consistent results. With a cut-off at a similarity of 0.38, four clusters or assemblages are recognised (Fig. 3.9A). The shallow-water Cluster A comprises ten samples, located near the Guadiana and Tinto-Odiel mouths and more extensively near Guadalquivir mouth (Fig. 3.9B). *Eggerelloides scaber* was the most abundant specie in seven samples, ranging from 1.5 to 46.4%, *A. beccarii* (1-32%) in two samples and *H. atlantica* (1-29%) in one sample. Cluster B (Fig. 3.9A) occurs in a total of thirty three samples between 25 and 100 m in the southeast part of the study area and from 20 to 60 m in the northwest (Fig. 3.9B). *Bolivina ordinaria* was the dominant species in all analysed samples, ranging from 16 to 75%. Cluster C (Fig. 3.9A), an intermediate group with four samples, was present with 3 samples off the Tinto-Odiel mouth below 60 m water depth, and one sample at 79.5 m depth off the Guadiana mouth (Fig. 3.9B). *Nonionella stella* (0-36%), *B. aculeata* (2-29%) and *Nouria* sp. (0-11%) were the dominant species in this cluster.

Cluster D, from the deepest water (Fig. 3.9A), occurs in the southeast with one deeper sample and northwest with three samples, all below 80 m water depth (Fig 3.9B). *Brizalina dilatata* (4-64%) and *Stainforthia* sp. (0-24%) were its dominant species.

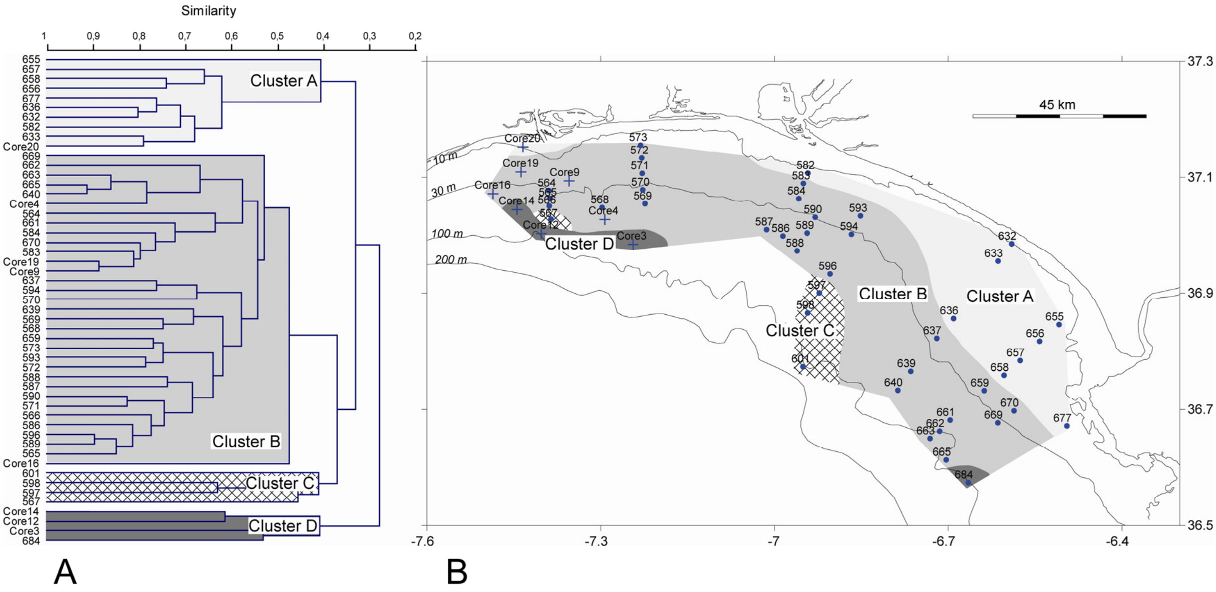

Figure 3.9 – Q-mode cluster analysis (Bray-Curtis measure joined by UPGMA) of the samples based on a total abundance >5%. A- Dendrogram with four clusters recognised. B- Spatial distribution of the four clusters across the continental shelf.

Principal Components Analyses (PCA) of species with abundance >5% weighted most species negatively on both Component 1 and 2 (Fig. 3.10). Only *A. beccarii* and *E. scaber* were positively weighted on Component 2, while *B. ordinaria* was positively weighted on Component 1, and *B. dilatata* was negatively weighted on Component 2. Components 1 and 2 represent 62% and 16% variance, respectively, together explaining 79% of total variance. Component 2 seems to mirror water depth, as indicated by the higher abundance of *B. dilatata* at deeper locations (Fig. 3.8d) and *E. scaber* and *A. beccarii* at the shallowest sites (Fig. 3.8b). Component 1 relates to the influence of rivers outflow, as shown by the higher abundance of *B. ordinaria* in these areas (Fig. 3.8a). The average proportion of these 4 species is 29% of *B. ordinaria*, 9% of *E. scaber*, 6.6% of *B. dilatata* and 4.9% of *A. beccarii*.

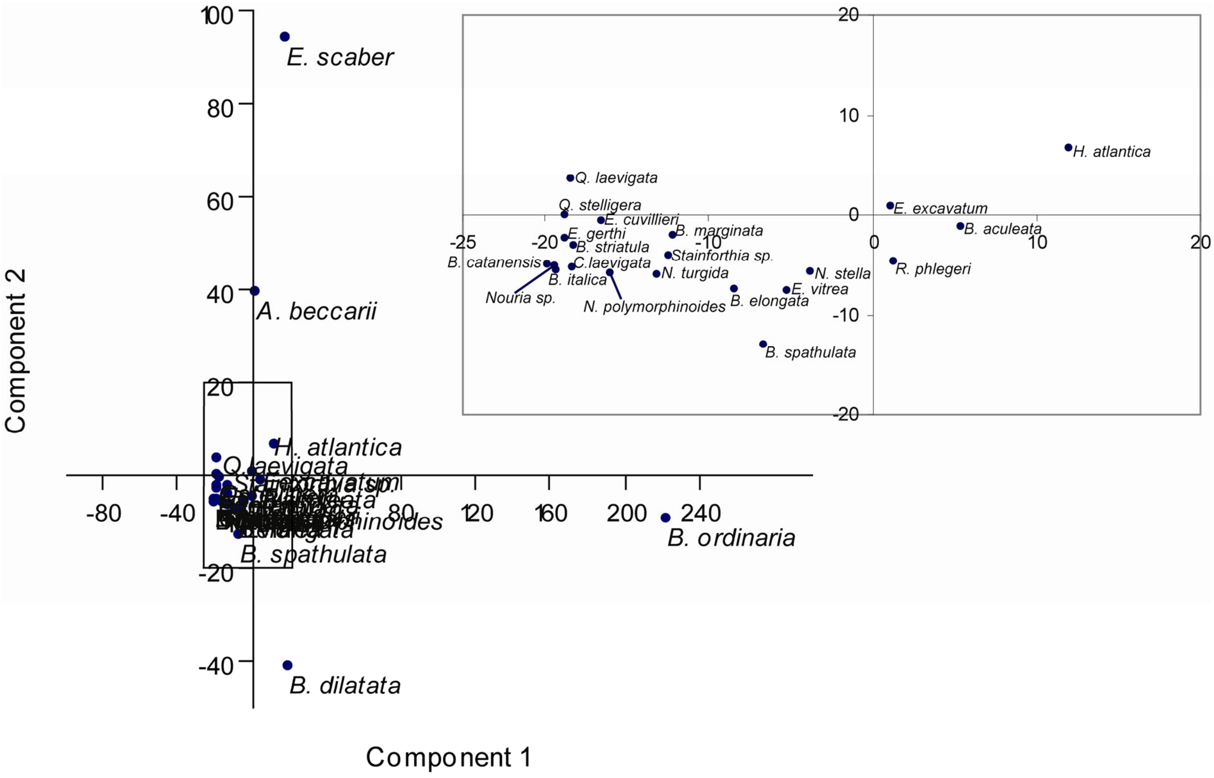

Figure 3.10 – Principal Components Analysis result (components 1 and 2) based on species with total abundance >5%.

A further reduction of the dataset, considering only species occurring in at least half of the samples (26) with abundances >5%, produced a set of 16 species. R-mode cluster analyses by Ward's method and a high cophenetic correlation of 0.9625, separated four species from two distinct clusters (Fig. 3.11). The four individual species were *B. ordinaria*, *E. scaber*, *B. dilatata*, *A. beccarii*. They were the 4 ranked species found in all analysed samples. These species merge with other clusters at very low similarity levels (lower than -90). Cluster Ia, with *B. elongata*, *E. excavatum*, *B. aculeata*, *R. phlegeri* and *H. atlantica,* includes species that show surficial distributions and higher abundances between 30 and 100 m water depth or close to river mouths. This cluster resembles Cluster III of the extended dataset (Fig. 3.7). Cluster IIa, with *N. stella*, *B. marginata*, *E. vitrea*, *N. iridea*, *N. turgida*, *B. spathulata* and *Stainforthia* sp., included species that show a very patchy distribution and resembles Cluster IV of the extended dataset (Fig. 3.7). Although *E. vitrea* was more abundant between 30 and 100 m water, it was also included in this cluster.

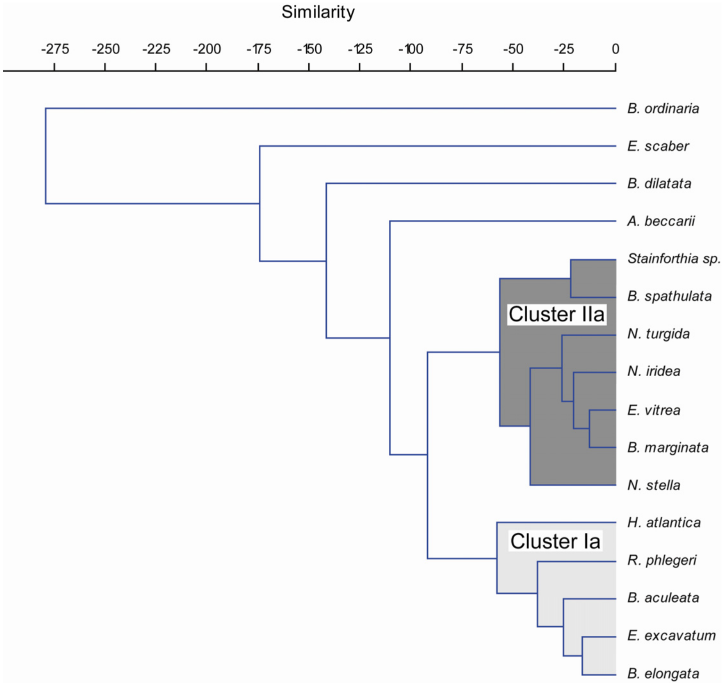

Figure 3.11 - Dendrogram resulting from R-mode cluster analyses (Ward's method) based on 16 species that occurred in at least half of the analysed samples (26).

The application of the same method (Ward's) for Q-mode cluster analysis, with cophenetic correlation of 0.6142, produced 6 clusters with a similarity of -70 (Fig. 3.12A). These clusters have a patchy distribution in the study area (Fig. 3.12B). Cluster A1 occurred at shallow depths and, with exception of sample 655, was similar to Cluster A in the extended data (Fig. 3.9). The remaining clusters were not so distinct. Only limited information can be obtained from a further reduction in information. However it is clear that shallow- and deep-water assemblages were consistently separated.

PCA produced similar results using reduced dataset as for the extended data.

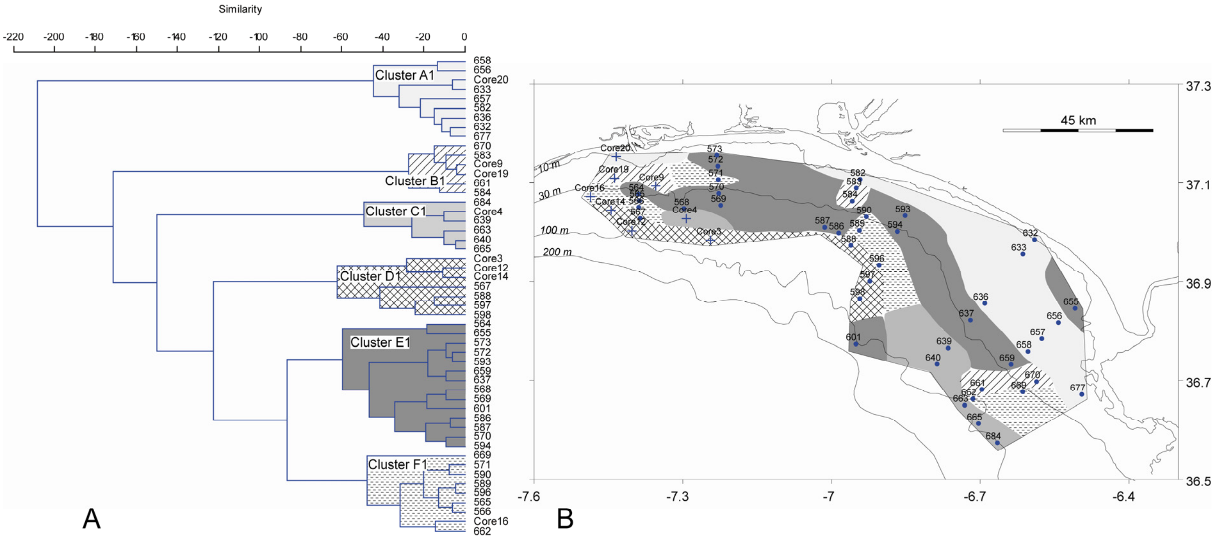

Figure 3.12 – Q-mode cluster analysis (Ward's method) of the samples based on 16 species that occurred in at least half of the analysed samples (26). A- Dendrogram with six clusters recognised. B- Distribution of the six clusters across the continental shelf.

3.3.2. *Individual distribution of benthic foraminifera*

Distribution patterns for each of the 26 common species on the northern Gulf of Cadiz continental shelf between Guadiana and Guadalquivir Rivers, infers the separation of 4 general groups, according to their different patterns of distribution. These groups were closely linked to those obtained by cluster analyses and their spatial distribution (Figs. 3.7, 3.8). Group 1 corresponds to Cluster I (Fig. 3.7), with *Bolivina ordinaria* and *Hopkinsina atlantica* occurring in higher abundances in areas under the direct influence of the Guadiana, Tinto-Odiel and Guadalquivir Rivers discharge. They extend from shallow to deeper areas (Fig. 3.13a, b). *Bolivina ordinaria* was the only species that occurred in all analysed samples and was also the most abundant (2 to 75%). The highest abundances of this species were found in mud, sandy mud and gravelly mud. *Hopkinsina atlantica* occurred in areas of sand, gravelly mud and sandy mud.

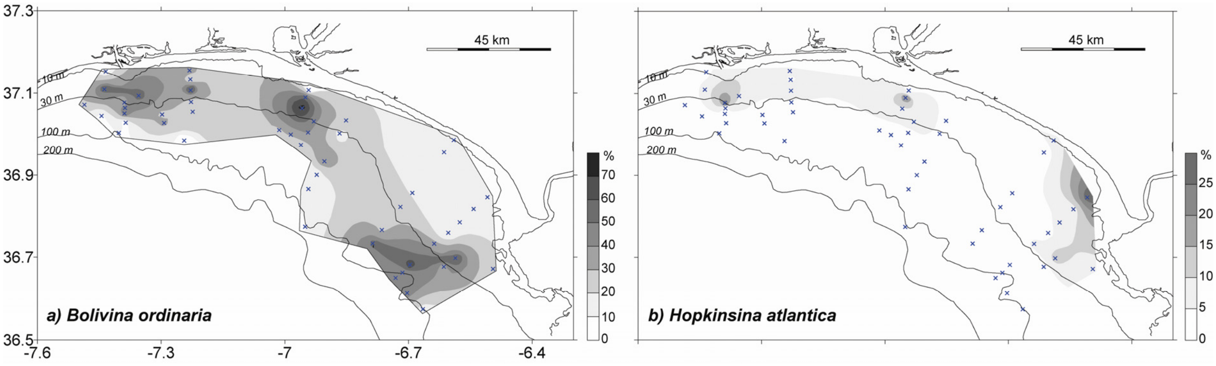

Figure 3.13 – Distribution of species most abundant in areas under the direct influence of rivers outflow. a) *Bolivina ordinaria*; b) *Hopkinsina atlantica*.

Group 2 corresponds to Cluster II (Fig. 3.7), which is characterised by species that were most abundant in shallow waters and associated with rivers outflow. However, different species seem to be associated with different rivers (Fig. 3.14a – e). *Ammonia beccarii* was most abundant (37%) in the vicinity of the Guadalquivir River at 37 m depth (Fig. 3.14a). *Eggerelloides scaber* showed abundances above 40% in the west part of the Guadiana and Guadalquivir River mouths at depths below 21 m (Fig. 3.14b). These species displayed higher abundances in mud, muddy sand and slightly muddy gravelly sand. *Elphidium gerthi* was only frequent in the vicinity of Tinto-Odiel River at 15.6 m (Fig. 3.14c), in slightly muddy gravelly sand. *Quinqueloculina laevigata* and *Q. stelligera* showed higher abundances at 15 and 12 m water depth, where sand and muddy sand prevailed. The samples with *Q. stelligera* occurred in two distinct areas of the inner shelf at similar water depths (Fig. 3.14d, e), also associated with sand and sandy mud.

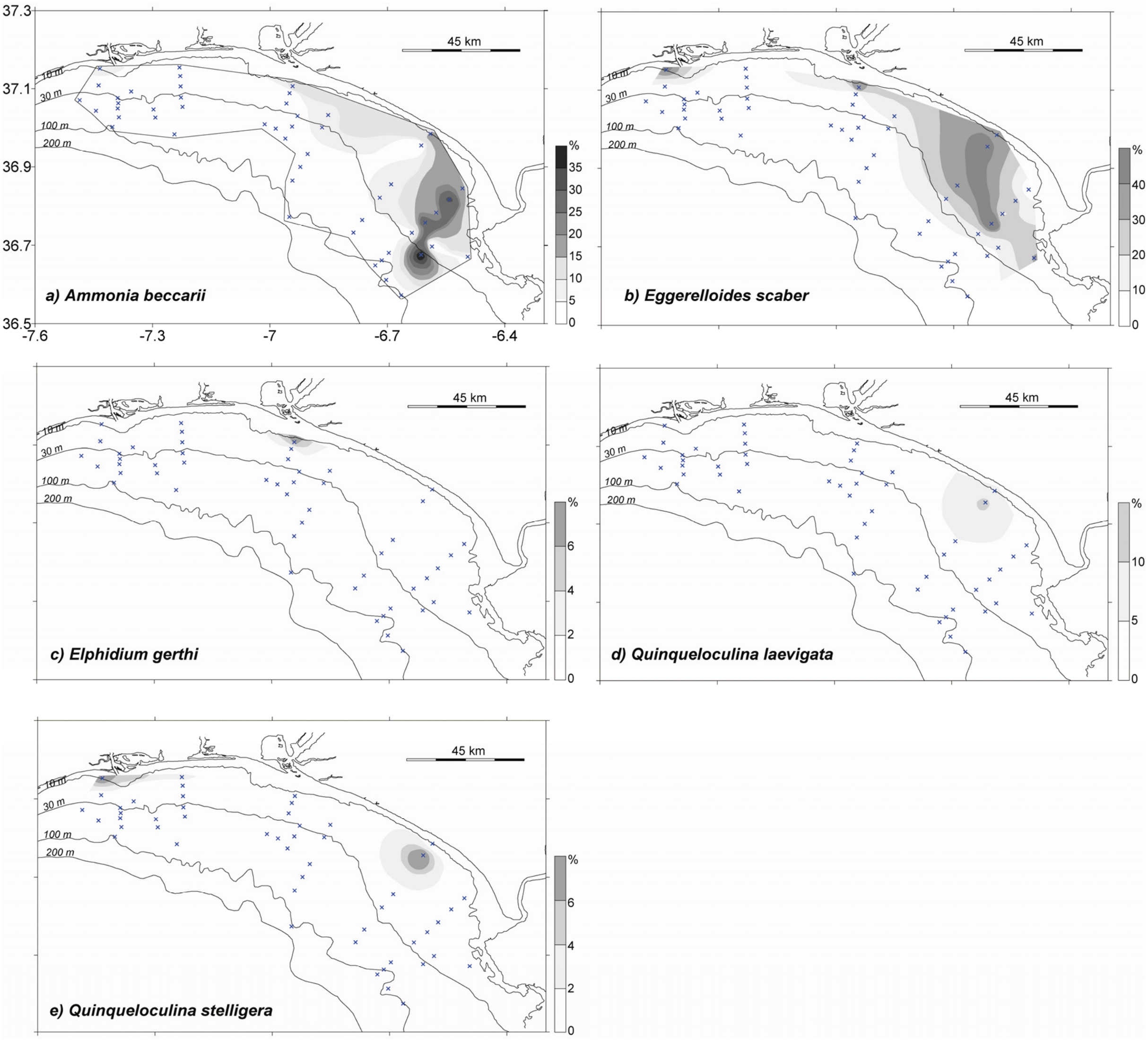

Figure 3.14 – Distribution of species most abundant in shallow waters. a) *Ammonia beccarii*; b) *Eggerelloides scaber*; c) *Elphidium gerthi*; d) *Quinqueloculina laevigata*; e) *Quinqueloculina stelligera*.

Bulimina aculeata (29%), *Elphidium excavatum* (14%), *Bulimina elongata* (16%), *Epistominella vitrea* (7%) and *Rectuvigerina phlegeri* (20%), form Group 3 that corresponds to Cluster III (Fig. 3.7). These species were most abundant in mud and sandy mud at depths of 30 to 100 m off Tinto-Odiel River in the central part of the study area (Fig. 3.15a - e). Abundance decreased in a landward direction for all species. Because no samples were available from greater depths off the Tinto-Odiel mouth, it was not clear whether some species also declined in seaward direction. Only *Elphidium cuvillieri* showed a clear tendency to decrease in both landward and seaward directions (Fig. 3.15f).

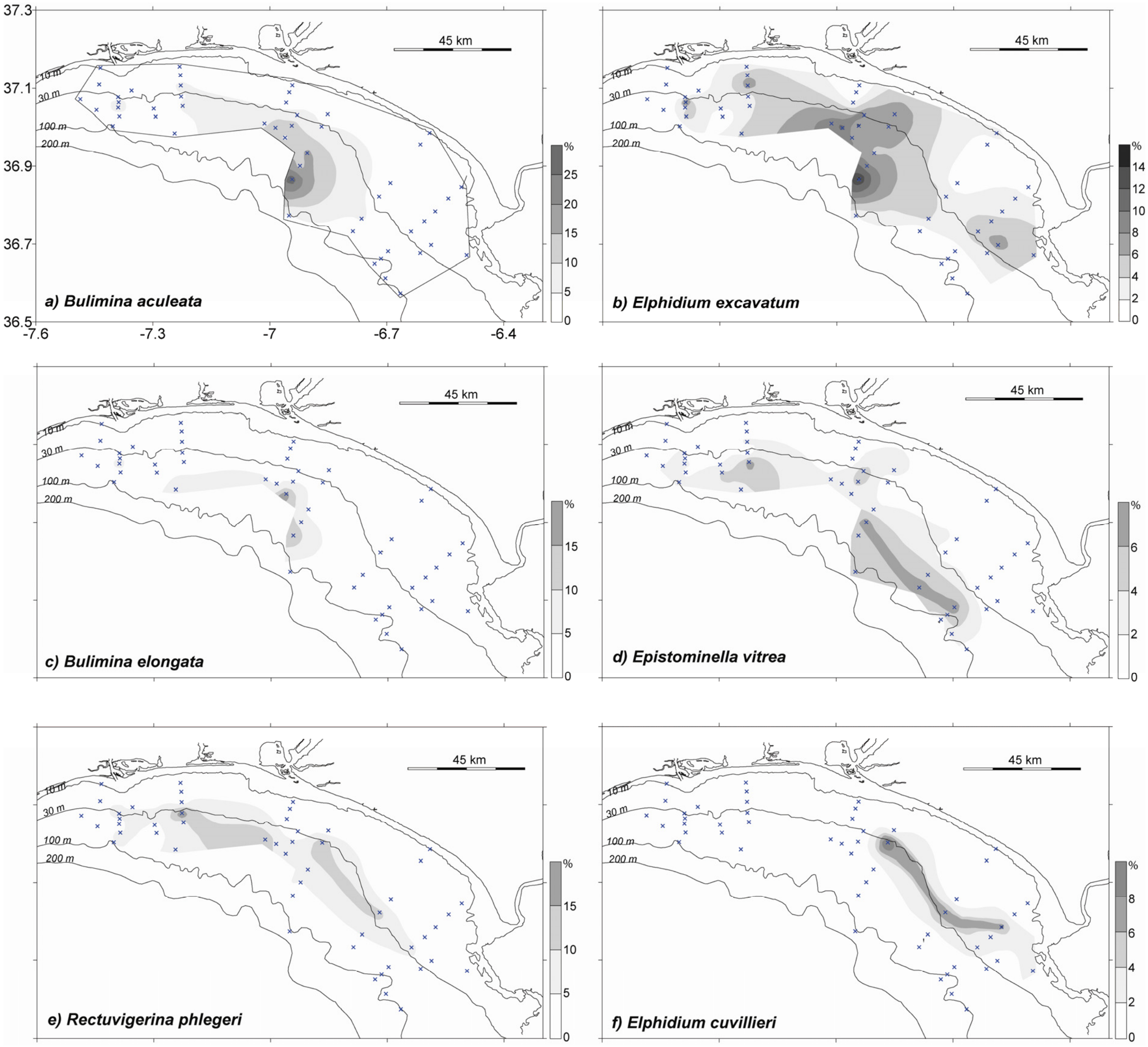

Figure 3.15 – Distribution of species most abundant between 30 and 100 m water depth. a) *Bulimina aculeata*; b) *Elphidium excavatum*; c) *Bulimina elongata*; d) *Epistominella vitrea*; e) *Rectuvigerina phlegeri*; f) *Elphidium cuvillieri*.

The Group 4 corresponds to Cluster IV and is characterised by species that showed isolated occurrences with high abundances in one or two samples, as well as species with a patchy distribution. In both cases, higher abundances were observed in the deeper samples. Although all samples from this group were included in the same cluster (Fig. 3.7). However, after the spatial distribution of each species it was possible to visually sub-divide Group 4 into two sub-groups A and B. The species from sub-group 4A generally occurred at water depths around 100 m (Fig. 3.16). The maximum abundance of *Bolivina catanensis* (7%), *Cassidulina laevigata* (5%), *Stainforthia* sp. (24%) and *Nouria polymorphinoides* (24%) were recorded in the western part of the study area, off the Guadiana River (Fig. 3.16a – d), in muddy sediments. On the other hand, *Bolivina italica*, *Bolivina striatula* and *Nouria* sp. (maximum abundance of 8%, 8% and 11%, respectively) were most abundant off the Tinto-Odiel River (Fig. 3.16e – g) in muddy sand.

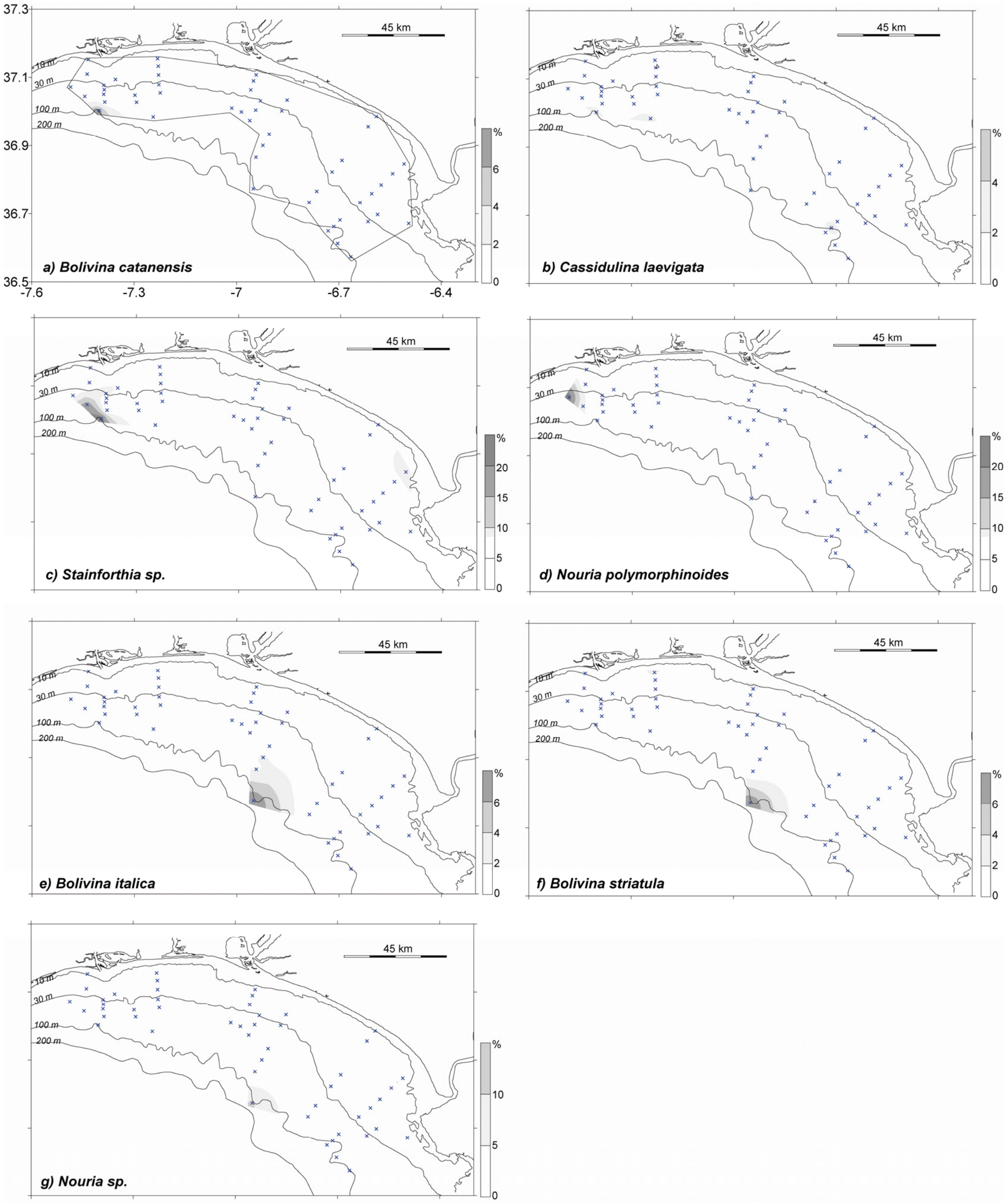

Figure 3.16 – Species with isolated high abundances in a few samples. a) *Bolivina catanensis*; b) *Cassidulina laevigata*; c) *Stainforthia sp.*; d) *Nouria polymorphinoides*; e) *Bolivina italica*; f) *Bolivina striatula*; g) *Nouria sp.*.

The Sub-group 4B includes species with a patchy distribution and high abundances in distinct areas of the continental shelf (Fig. 3.17). Maximum abundances of *Brizalina dilatata* (64%), *Brizalina spathulata* (15%), *Nonionella turgida* (16%), *Nonionella iridea* (15%) and *Nonionella stella* (36%) occurred below 30 m depth (Fig. 3.17a – e). *Nonionella* species and *B. spathulata* display higher abundances off the Guadiana River. *Bulimina marginata* shows a ubiquitous distribution, with a maximum abundance of 6% (Fig. 3.17f). Each of these species was associated with different types of sediments.

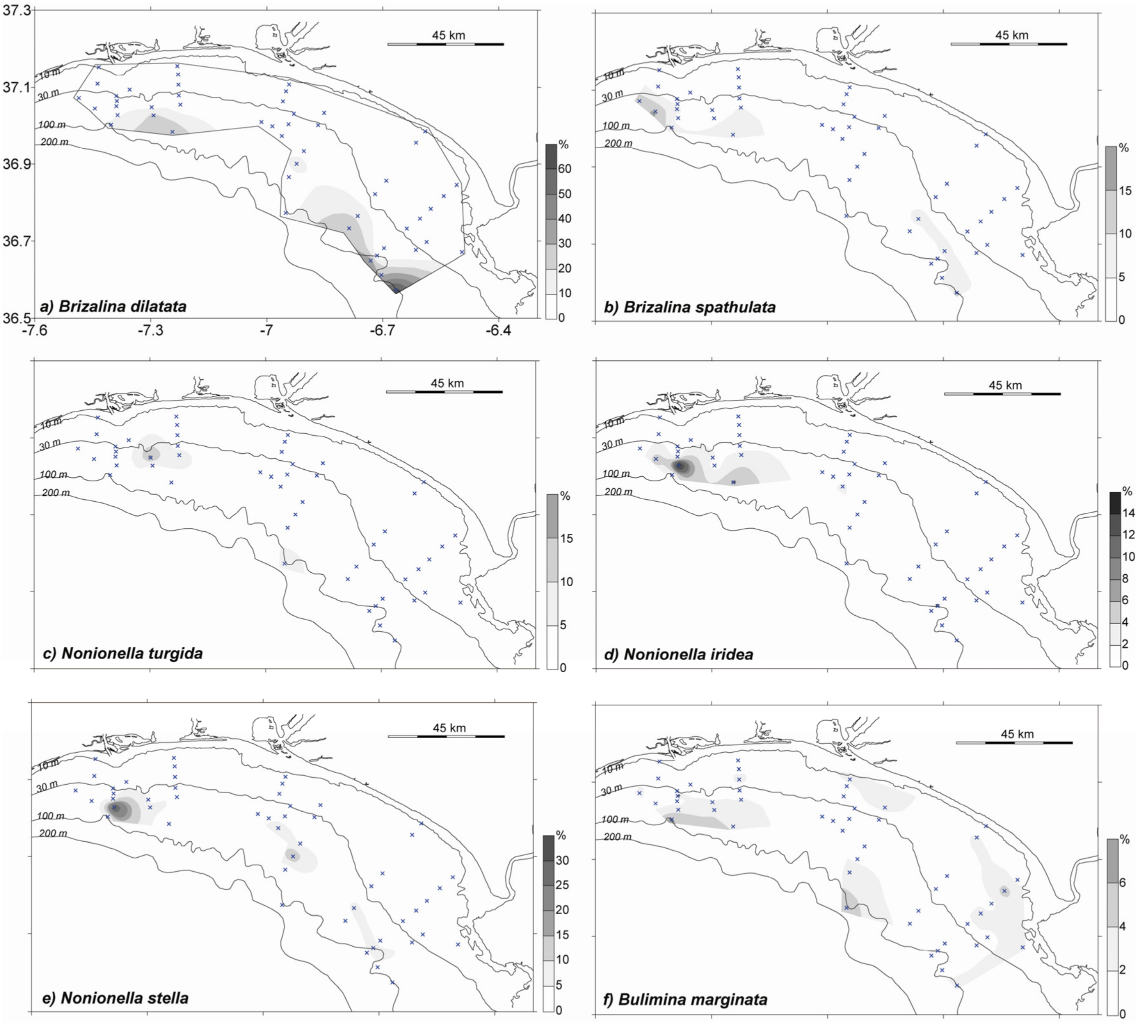

Figure 3.17 – Species with a patchy distribution. a) *Brizalina dilatata*; b) *Brizalina spathulata*; c) *Nonionella iridea*; d) *Nonionella stella*; e) *Nonionella turgida*; f) *Bulimina marginata*.

3.3.3. Hydrological parameters

3.3.3.1. Water temperature and salinity

The near-bottom water temperatures in the study area were up to 2ºC cooler near the Guadiana mouth between 50 and 100 water depth (13.3 to 13.8ºC) compared to the area near the Guadalquivir River mouth (14.8 to 15.38ºC) (Fig. 3.18).

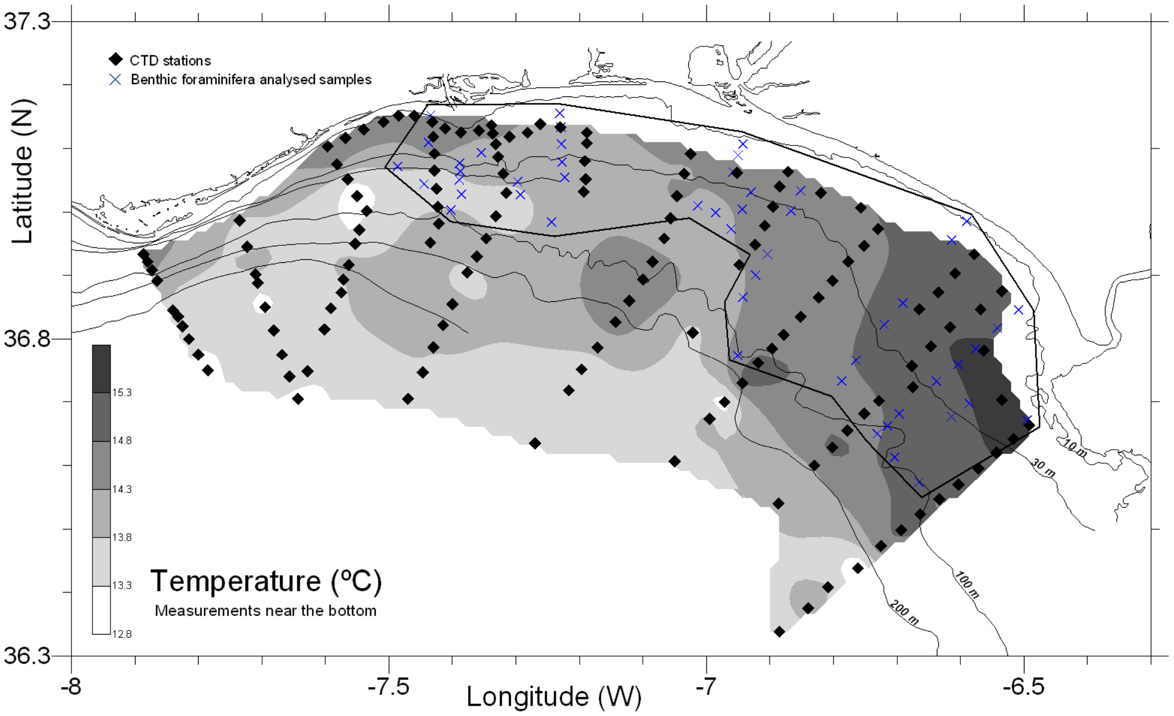

Figure 3.18 – Temperature distribution near sea floor, measured during the period of surficial sediment sampling.

Near-bottom salinities were rather uniform, varying from 36 to 36.25 PSU. Off the Guadiana River below 45-50 m, salinity was lower than 36 PSU (Fig. 3.19).

3.3.3.2. Suspended particulate matter concentration

High concentrations of suspended particulate matter (up to 30.5 mg/l) were obtained near the Guadalquivir River mouth and decreased seaward (Fig. 3.20). Lower values, ranging from 2 to 4 mg/l, were observed near the Piedras and Tinto-Odiel mouths, in water up to 100 m deep. Near the Guadiana River mouth the concentrations were mostly below to 2 mg/l.

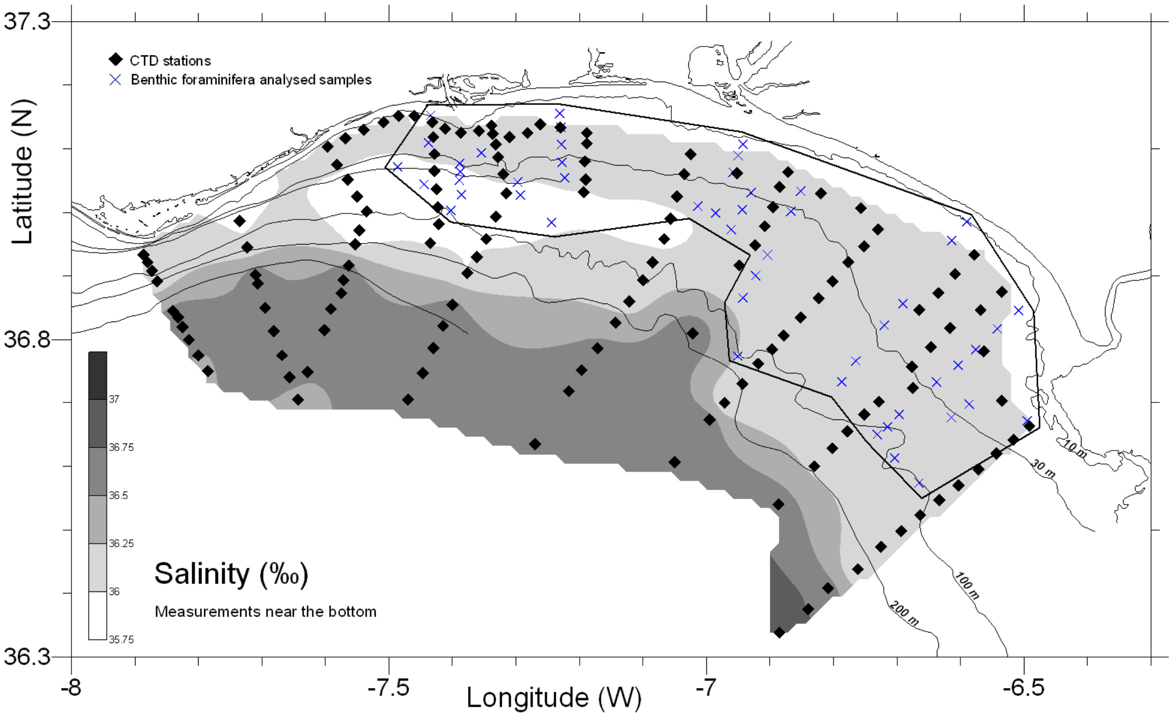

Figure 3.19 - Salinity distribution near the sea floor, measured during the same period of surficial sediment collection.

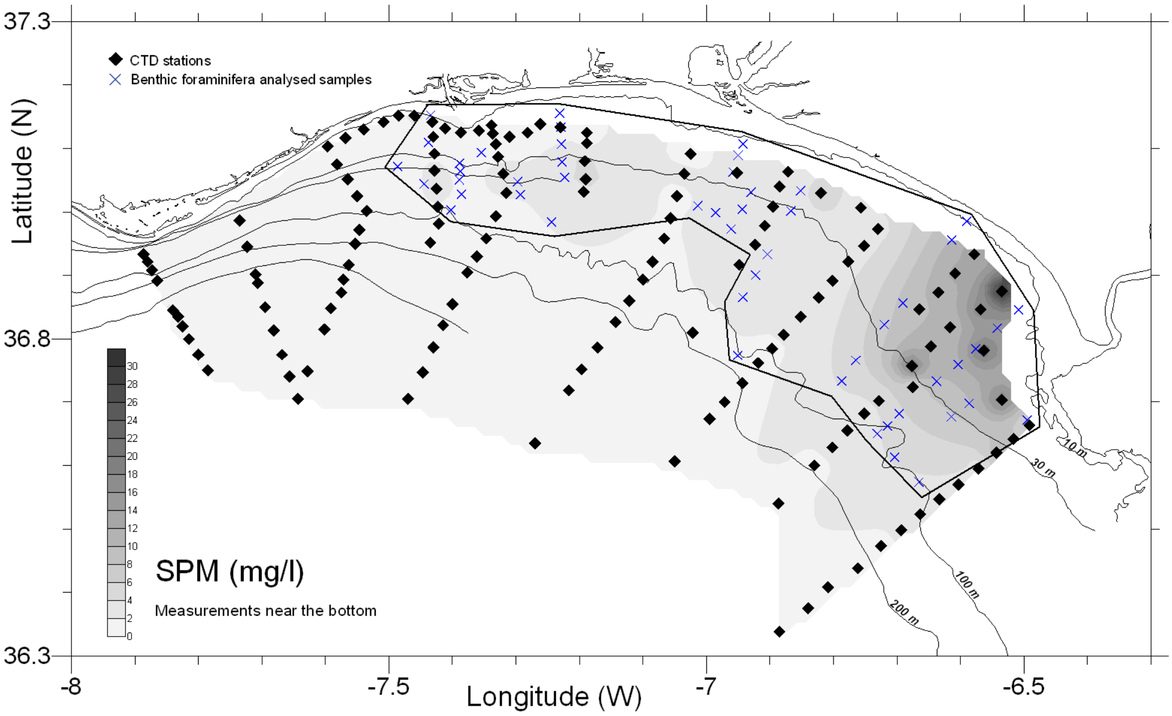

Figure 3.20 – Suspended particulate matter concentrations (mg/l) distributed near the sea floor, calculated for water samples collected during the same period of surficial sediment collection.

3.3.4. Primary productivity

Primary productivity patterns in the study area were obtained from the literature (Fig. 3.21). A map from Navarro and Ruiz (2006) showed the temporal and spatial distribution of chlorophyll concentrations obtained by remote sensing data from the Sea-Viewing Wide Field-of-View Sensor between 1998 and 2000. The data delimit an area of high productivity related to nutrients inputs from the Guadalquivir River. This pattern was confirmed by modes obtained by an Empirical Orthogonal Function decomposition of weekly chlorophyll composite images. In a different approach, Ruiz and Navarro (2006) described nitrogen advection to the photic zone by local upwelling through images analysis of daily nitrogen fluxes from April to September 1998.

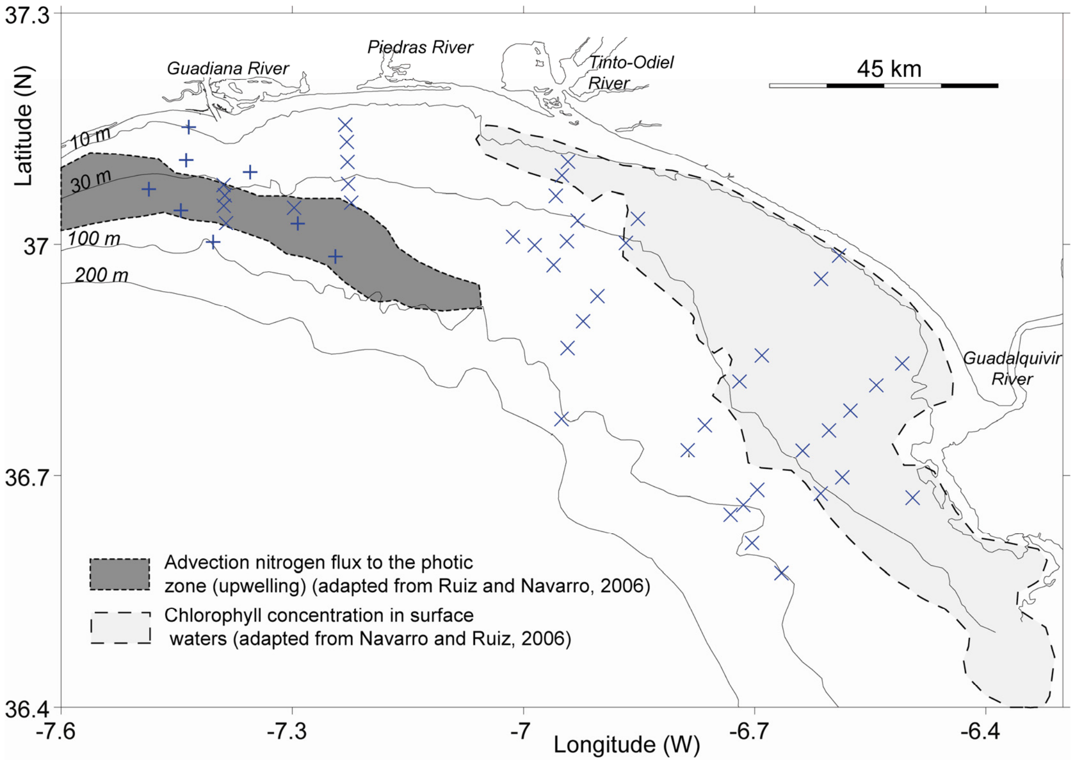

Figure 3.21 - Primary productivity in the study area, obtained from the advection nitrogen flux to the photic zone (Ruiz and Navarro, 2006) and chlorophyll concentrations in surface waters (Navarro and Ruiz, 2006).

If the areas with high primary productivity are compared to the surficial distribution of all benthic foraminiferal species, a congruent pattern emerges for six species. The distribution of *E. scaber* and *A. beccarii* coincided with high production close to the Guadalquivir River mouth (Fig. 3.22a, b). *Bolivina ordinaria* and *R. phlegeri* were most prevalent near the 50 m depth contour at the limits of the high productivity area (Fig. 23.2c, d). *Hopkinsina atlantica* displayed higher abundances within the high productivity areas off the Guadiana, Tinto-Odiel and Guadalquivir Rivers (Fig. 3.22e). *Nonionella iridea* was the only species whose distribution coincided with advective nitrogen flux to the photic zone (Fig. 3.22f).

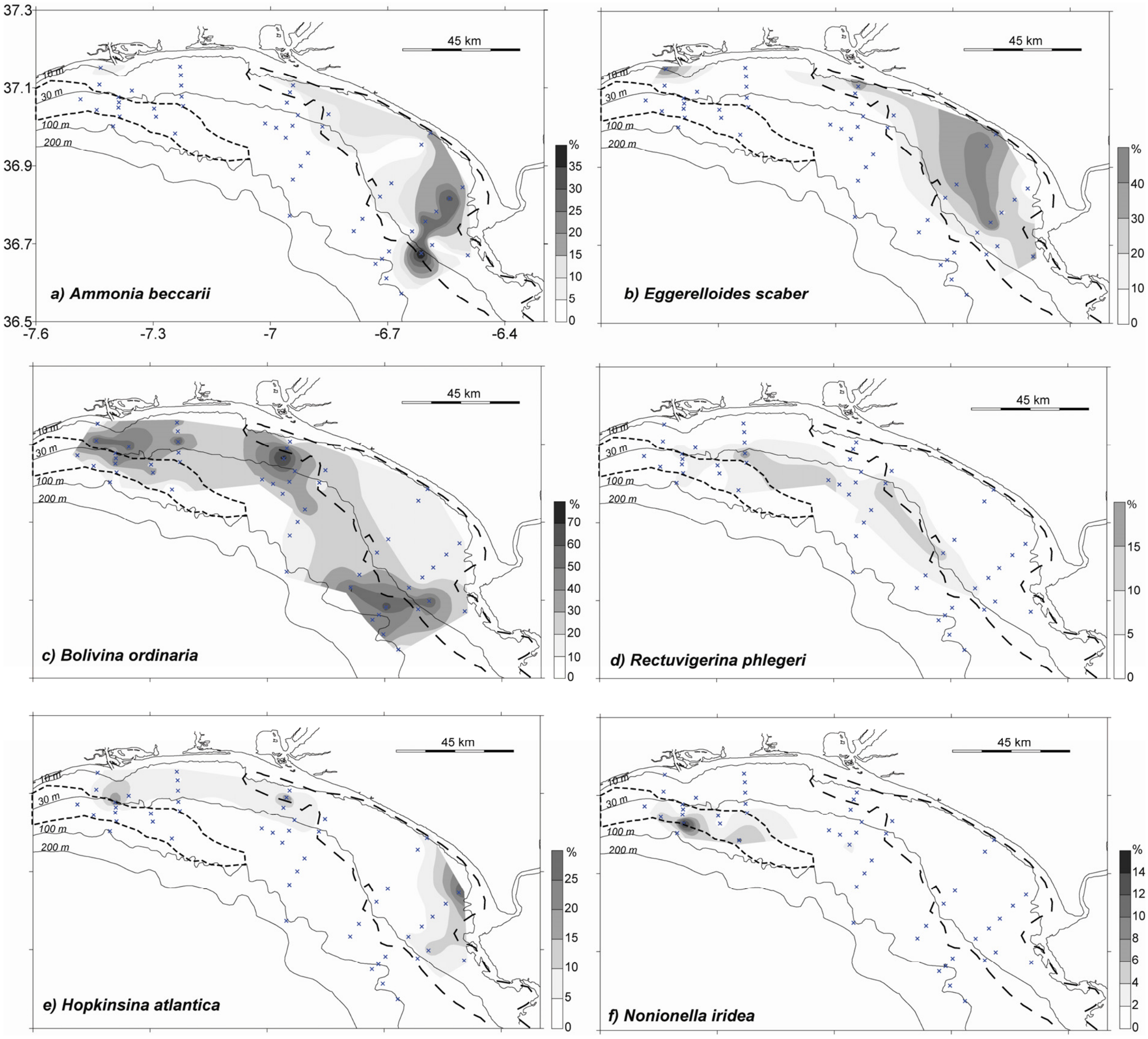

Figure 3.22 – Comparison of areas of high primary productivity in the study area with the surficial distribution of individual benthic foraminiferal species: a) *A. beccarii*, b) *E. scaber*, c) *B. ordinaria*, d) *R. phlegeri*, e) *H. atlantica*, f) *N. iridea*.

3.4. Discussion

The living benthic foraminiferal fauna on the northern Gulf of Cadiz continental shelf between the Guadiana and Guadalquivir Rivers is very diverse. The living assemblages are similar to those described in areas such as the French Atlantic continental shelf (e.g. Duchemin et al., 2005; 2007; 2008), the French Mediterranean shelf in the Rhône prodelta (Mojtahid et al., 2009), NW Spain in the Ría de Vigo (e.g. Diz, 2004; Diz et al., 2004; 2006; Diz and Francés, 2008), and the western coast of Portugal (e.g. Martins, 1997). The living faunas are also similar to total assemblages (living and dead) described from neighbouring shelf areas of the eastern Atlantic, such as the Guadiana Shelf (e.g. Mendes et al., 2004), the northeast Gulf of Cadiz (e.g. Villanueva, 2000; 2001; Villanueva and Sanchez, 1996; Villanueva and Cervera, 1999a; 1999b; Villanueva and Canudo, 1999; 2008; Villanueva et al., 1999a; 1999b), the coast of Morocco (Mathieu, 1986) and the western coast of Portugal (e.g. Martins and Gomes, 2004; Levy et al., 1993; 1995; Ubaldo and Otero, 1978).

The population density of living benthic foraminifera in the northeastern Gulf of Cadiz ranged from 14 to 1173, averaging 225 specimens/10 cm^3. These values were higher than in the Ría de Vigo (NW of Spain), where Diz and Francés (2008) obtained 20 to 80 specimens/10 cm^3. The Gulf of Cadiz standing stock values are nonetheless similar to those described by Duchemin et al. (2005) from the French Atlantic continental shelf in water 90 and 130 m deep (280 to 760 specimens/10 cm^3) and by Schumacher et al. (2007) on the Pakistan continental shelf at 136 and 150 m depth (up to 950 specimens/10 cm^3). Lower abundances of stained benthic foraminifera were reported by Frezza and Carboni (2009) on the continental shelf of from the Northern Tyrrhenian Sea (Italy), and by Szarek et al. (2006) on the Sunda Shelf (South China Sea), although these authors only studied the >150 μm sediment fraction.

On the continental shelf between Guadiana and Guadalquivir Rivers, the density of living benthic foraminifera (Fig. 3.2A) seems to be influenced by rivers outflow. Maximum density was observed in muds. The two peaks observed in deep water off the Guadiana River could be related to a transgressive bulge composed of muddy gravelly sands and muddy sands (Gonzalez et al., 2004; 2007). This bulge does not extend to shallower zones, and represents a different hydrodynamic process. Foraminiferal density peaks observed off the Tinto-Odiel and Guadalquivir Rivers in shallow water seem to be influenced by rivers outflow and suspended particulate matter (namely off Guadalquivir River). However, samples collected in the same area and same sediment type had lower population densities. This infers that not only the river input, but also suspended particulate matter, depth and sediment type, influenced the density of living benthic foraminifera in this area.

Shannon diversity indices (Fig. 3.4a) were higher than those obtained by Diz and Francés (2008) (between 0.82 and 2.8) in the Ría de Vigo and similar to those obtained by Schumacher et al. (2007) on the Pakistan continental shelf. The Shannon index values in the Guadiana-Guadalquivir shelf are typical of those found in normal marine shelf environments (Murray 1991a; 2006).

The higher species richness observed in shallow-water samples (Fig. 3.2B) and the higher-than-estimated richness found for approximately the same number of specimens counted (Figs. 3.3, 3.5), could be related to a different type of sediment, collected at different water depths that permits the existence of additional species with a relatively low number of individuals. The lower number of species found between 50 and 80 m water depth, on the other hand (Figs. 3.3, 3.6), is related to a very specific sediment type (mud belt), which could limit the number of ecological niches available. This could explain the scatter observed when species richness after 100 specimens counted was plotted against water depth (Fig. 3.6). The higher number of species at shallow positions under the influence of rivers discharges, in sandy mud, gravelly mud and slightly muddy gravelly sand, indicates stable conditions that allow accumulation of fine suspended material and more abundant niche space compared to the surrounding areas. The low number of species in muds in shallow areas near the Tinto-Odiel and Guadalquivir Rivers mouths indicates stable conditions that allow only a restricted number of specialized species to inhabit this area. The higher number of species in samples from sands and slightly muddy sandy gravels in 44 and 51 m of depth relates to the presence of transgressive sediments (Gonzalez et al., 2004; 2007). These varied substrates allow several species to cohabit in the same area. However, the large number of species found in muds at 72 and 85 m depth (Fig. 3.6) seem to be unrelated to depth, sediment type or river suspension.

Four major groups could be observed in the distribution of the most abundant living species on the northern Gulf of Cadiz continental shelf (Figs. 3.7 and 3.8).

Species directly linked with river discharge, from the inner to the outer shelf correspond to Cluster I (Fig. 3.7), Biofacies I (Fig. 3.8a) and Group 1 (Fig. 3.13). This group is represented by *Bolivina ordinaria* and *Hopkinsina atlantica*. The most abundant living species and the only one present in all samples was *B. ordinaria*. This species has a ubiquitous distribution, is highly adaptable and has a wide tolerance to a range of different factors or combination of factors. However, this species reached its highest abundance in areas under the direct influence of rivers discharges (Fig. 3.13a) and in samples belonging to Cluster B for Q-mode analyses (Fig. 3.9), which grouped all samples between 25 and 100 m in the southeast and 20 to 60 m depth in the northwest of the study area. These samples are mostly composed of mud in the south and of sandy mud, gravelly mud, slightly muddy gravelly sand and mud in the northwest. Maximum abundance of *B. ordinaria* was also observed close to the 50 m water depth contour (Fig. 3.22e), possibly related to higher values of total chlorophyll >20 µm (large algae or diatoms) known to occur at this depth in this area

(Navarro et al., 2006). Fresh phytoplankton input is higher at 50 m depth than in deeper or shallower areas (Navarro et al., 2006). This could indicate that *B. ordinaria* is one of the most opportunistic species in the study area. Comparison of *B. ordinaria* with the literature is difficult, because of insufficient taxonomic documentation. Furthermore, there is no consensus on the identification of *B. ordinaria.* In the European literature, various names have been used by different authors to describe similar specimens, as for example: *Bolivina dilatata* by Duijnstee et al. (2004); Ernst et al. (2005); Mojtahid et al. (2009); as *Brizalina spathulata* by Diz et al. (2004); Diz and Francés (2008); as *Bolivina variabilis* by Schiebel (1992); Debenay et al. (2001); Duchemin et al. (2005) and as *Bolivina* ex. gr. *dilatata* by Duchemin et al. (2007). This taxon is generally considered to be an indicator of high organic matter input, often in combination with dysoxic conditions. Only a few studies mention *B. ordinaria* in neighbouring areas. This small (63-125 µm) species may have been overlooked if only the fraction >125 µm was analysed (e.g. Villanueva, 2000) or if identified differently as *Bolivina spathulata* (cf. Levy et al., 1993; 1995), or as *Brizalina catanensis* (cf. Ubaldo and Otero, 1978). *Bolivina ordinaria* was described from the NW Iberian continental shelf in a sedimentary sequence (collected at 115 m water depth) associated with mud sediments, a high and sustainable flux of organic matter and low oxygen levels (Martins et al., 2006a; 2007). On the Guadiana shelf, *B. ordinaria* was described in the total assemblage between 40 and 90 m water depth, associated with low hydrodynamic levels and muds (Mendes et al., 2004).

Hopkinsina atlantica is less abundant, but its maximum abundance was directly linked with rivers outflow (Fig. 3.13b) and the limits of productivity (Fig. 3.22e), suggesting an opportunistic behaviour. This was confirmed by their great abundance near the Guadalquivir river-mouth, in muddy sands, as well as being included in the Q-mode cluster A, again characteristic of shallow waters (Fig. 3.9). According to García-Lafuente and Ruiz (2007) and Navarro and Ruiz (2006), the area associated with the Guadalquivir discharge is characterised by high primary production. This interpretation agrees with other authors that consider *H. atlantica* as a low opportunistic taxon (Ernst et al., 2002 as *H. pacifica*) with a preference for fresh food supply (e.g. Diz and Francés, 2008; Ernst et al., 2005). On the Guadiana shelf, *H. atlantica* (identified as *Spriroloxostoma croarae*) was described in the total assemblage between 40 and 95 m depth in fine sediments with low hydrodynamic levels (Mendes et al., 2004).

Species with a high abundance in shallow waters, generally influenced by river discharges, correspond to Cluster II (Fig. 3.7), Biofacies II (Fig. 3.8b) and Group 2 (Fig. 3.14). This ensemble is represented by *Ammonia beccarii*, *Eggerelloides scaber*, *Elphidium gerthi*, *Quinqueloculina laevigata* and *Quinqueloculina stelligera*. The highest abundances of *A. beccarii* in shallow waters near the Guadalquivir mouth seem to be related to high concentrations of suspended particulate matter and muddy sediments characteristic of this area (Fig. 3.20). These results agree with those obtained by Donnici and Barbero (2002), who described this species from a shallow and nutrient-rich belt at depths of about 15 m near the Po Delta (northern Adriatic continental shelf). *Ammonia beccarii* is a typical estuarine species from the Guadiana, Piedras and Tinto-Odiel estuaries (Ruiz et al., 2005), which could explain its lower abundance found on the continental shelf around these rivers. *Eggerelloides scaber* occurred in shallow waters associated with sand, mud and mixed sediments and alongside *A. beccarii*, dominates the benthic assemblage in samples grouped by Q-mode in the shallowest Cluster A (Fig. 3.9). The distribution of these species coincides with the higher water temperatures (Fig. 3.18), and the highest chlorophyll concentrations in surface waters close to the Guadalquivir River mouth (Fig. 3.22a, b). According to García-Lafuente and Ruiz (2007), this area has a higher primary production associated with the Guadalquivir's discharge. These results confirmed the results of Duijnstee et al. (2004), that the abundance of *E. scaber/advena* is directly affected by temperature but a positive response to increased productivity could not be excluded. In the southern North Sea, *Eggerella scaber* is an indicator of seasonal stratification north of the Frisian Front (around 50 m water depth), with higher abundances during winter and lower abundances during spring and summer mouths (de Nooijer et al., 2008). The highest abundance of *E. gerthi* in a sample from shallow waters seems to be linked to Tinto-Odiel River discharge. The occurrence of *Q. laevigata* and *Q. stelligera* in shallow waters associated with pure sand, muddy sand and sandy mud, indicates a restricted habitat for these species. All the species from Group 2 were characteristic for the Guadiana shelf in water depths up to 12 m. These settings are mainly influenced by fair-weather conditions, and the bottom sediments are sand-rich. However, with exception of *E. gerthi* (identified as *Cribrononion gerthi*) occurring between 12 and 40 m water depth, the seabed is mainly influenced by storm waves (Mendes et al., 2004).

Species most abundant between 30 and 100 m water depth in the central study area correspond to R-mode Cluster III (Fig. 3.7), Biofacies III (Fig. 3.8) and Group 3 (Fig. 3.15). This group is represented by *Bulimina aculeata*, *Elphidium excavatum*, *Bulimina elongata*, *Epistominella vitrea, Rectuvigerina phlegeri* and *Elphidium cuvillieri*. Most of the samples from cluster B grouped by Q-mode cluster analyses (Fig. 3.9) are located in an area of the continental shelf covered by fine-grained sediments that form an oblong mud patch (e.g. Gonzalez et al., 2004). This relationship corroborates the results of Murray (1991a, 2006), who designated these genera as living in muddy sediment with low hydrodynamic levels. In addition, *B. aculeata* was associated with low oxygen levels (e.g. Murray, 2006). *Epistominella vitrea* was not strongly affected by anoxic conditions but changes habitat when labile organic matter is provided under oxygenated laboratory conditions (Ernst at al., 2005). These two species were described from the Guadiana shelf with higher abundances in muddy sediments and low hydrodynamic levels (Mendes et al., 2004). *Bulimina elongata* was described from the Portuguese shelf between 0 and 150 m (Levy et al., 1995) and on the

Guadiana shelf at depths between 12 and 40 m (Mendes et al., 2004). In the Rhône prodelta, *B. aculeata* forma *elongata* is more abundant in samples collected close to the river mouth and associated with high organic carbon content, organic matter of terrestrial signature and low sediment oxygenation (Mojtahid et al., 2009). *Rectuvigerina phlegeri* was observed on muddy sea-floors characterised by high organic matter content inputs from a river plume (Villanueva and Cervera, 1999b; Frezza and Carboni, 2009) and high oxygen demand leading to a poor oxygen penetration into the sediment (Mojtahid et al., 2009). This species, like *B. ordinaria*, was most abundant close to the 50 m isobath (Fig. 3.22d). Since higher chlorophyll concentrations were observed in this area (Navarro et al., 2006), this indicates that these species are the most opportunistic found in the assemblages. The settings infer that they follow the horizontal input of fresh organic matter along an isopycnic surface rather than the pelagic vertical flux.

Elphidium excavatum was described by de Nooijer et al. (2008) across the Frisian Front (southern North Sea) in areas where the input of labile organic matter is high and resuspension of fine-grained material is relatively frequent. Thus this species may be a proxy for eutrophic environments with relatively high physical disturbance. Low abundances of *E. cuvillieri* were found in Port Joinville Harbor (France) associated with silty clay sediments (Debenay et al., 2001) and on the south Portuguese shelf between 19 and 74 m water depth in silty clay and silty sands (Levy et al., 1995). The distribution of species from Group 3 is mainly controlled by depth in middle to outer shelf environments. The assemblage settles in fine sediments associated with low levels of water energy, low levels of oxygen and high organic matter content.

Species generally more abundant in deep waters, or with higher abundances in a few samples and a patchy distribution, correspond to R-mode cluster IV (Fig. 3.7), Bioficies IV (Fig. 3.8) and Groups 4A and 4B (Figs. 3.16, 3.17). Their representatives are *Bolivina* *catanensis*, *Cassidulina laevigata*, *Stainforthia* sp., *Nouria polymorphinoides, Bolivina italica*, *Bolivina striatula*, *Nouria* sp., *Brizalina dilatata*, *Brizalina spathulata*, *Bulimina marginata, Nonionella iridea*, *Nonionella stella* and *Nonionella turgida*. The species *Nouria* sp., *N. stella, Stainforthia* sp. and *B. dilatata* are the most abundant species from cluster C and D, from Q-mode cluster analyses, and are characteristic of the deeper areas (Fig. 3.9). *Bolivina catanensis* is more common in the western Mediterranean than in the eastern part (Kaminski et al., 2002; Wright et al., 2007). On the Portuguese shelf, it was described on the northern margin with abundances lower than 3% occurring between 60 and 100 m water depth in sand and silty sand (Levy et al., 1995). *Cassidulina laevigata var. carinata* is one of the best represented species on the Portuguese continental shelf down to 130 m water depth (Levy et al., 1995). On the Guadiana shelf, analyses of total assemblages showed *C. laevigata* to be abundant (18%) around 100 m water depth (Mendes et al., 2004). In the Mediterranean, *Cassidulina laevigata/carinata* is one of the most opportunistic taxa. Its abundance is dependent on a pulsed supply of fresh organic matter with high nutrition value (de Rijk et al., 2000), preferentially marine organic detritus (Mojtahid et al., 2009). Abundance of some *Stainforthia* species is often associated with low oxygen conditions and high concentrations of organic matter (e.g. Alve, 1995; Gooday and Alve, 2001). In the Galicia Mud Deposit (NW Iberian continental shelf) higher abundances of *Fursenkoina/Stainforthia* were observed in a sedimentary sequence associated with mud, high organic matter flux and low oxygen levels (Martins et al., 2006a; 2007). In the Gulf of Guinea (West Africa), *Nouria polymorphynoides* is attributed to high organic carbon concentrations at depths between 27 and 75 m (Altenbach et al., 2003). This species responded immediately to anoxic conditions in laboratory experiments, migrating to the sediment water interface (Ernst et al., 2005). *Bolivina italica*, *B. striatula*, *Nouria* sp. all show their maximum abundance in the same sample of sandy mud (the deepest sample analysed, at 115.5 m). Their abundances were lower than 5% in the remaining samples. On the western Portuguese shelf, *B. striatula* is common down to 100 m water depth and below 60 m in the south (Levy et al., 1995). *Bolivina italica* was identified by these authors at 160 m water depth on the Northern Portuguese margin. On the Guadiana shelf, *B. italica* and *B. striatula* were relatively infrequent (1.6 and 2.6%, respectively) in samples collected between 22 and 103 m depth (Mendes et al., 2004).

Brizalina dilatata and *Brizalina spathulata* are sometimes difficult to distinguish in different growth phases, and this could explain why Levy et al. (1995) only identified *Brizalina spathulata* as one of the most abundant species down to 100 m depth on the Portuguese west coast and 60 m on the south coast. On the Pakistan continental margin, *Bolivina dilatata* was described down to 500 m depth, adapted to very low bottom-water oxygen content and an extremely high input of organic carbon (Schumacher et al., 2007). In the northern Adriatic, *Brizalina spathulata* was reported in areas where currents concentrate food particles from the Po River in a clayey belt, and where periodic anoxia prevails (Donnici and Barbero, 2002). Due to the divergent classification of these species, and because they were often lumped together, only a limited comparison could be made with the literature. *Bolivina* and *Brizalina* genera are frequent in muds and where organic carbon content is high. Some species tolerate dysoxia, and have a wide distribution from marginal marine environments to the bathyal (Murray, 1991b; 2006). In this study, the distributions of *B. dilatata* and *B. spathulata* were relatively coincident. They showed higher abundances in deep locations associated generally with muds, for instance off the Guadiana and Guadalquivir Rivers.

The genus *Nonionella* is normally associated with muds and some species tolerate dysoxia (Murray, 2006). In the northern Adriatic, *Nonionella turgida* (identified as *Nonionella opima*) was associated with clayey sediments from the Po River, which are nutrient-rich and subjected to periodic anoxia (Donnici and Barbero, 2002; Duijnstee et al., 2004). In the Rhône prodelta, *N. turgida* was associated with large proportions of marine organic carbon (Mojtahid et al., 2009). Gustafsson and Nordberg (2001) showed that the main food resource for *N. turgida* is the deposited phytoplankton. A closely related species, *Nonionella stella*, is tolerant of anoxia (Bernhard and Sen Gupta, 1999). In the Ria de Vigo (NE Spain), *N. turgida* and *N. stella* were described as highly opportunistic species that react to the deposition of fresh organic carbon, particularly that associated with upwelling events (Diz et al., 2006). In the northern Bay of Biscay, *N. iridea* is highly related to pulsed deposition of phytodetritus and dominates assemblages between 110 to 140 m depth (Duchemin et al., 2005; 2007). *Nonionella iridea* is considered an opportunistic species reactive to phytoplankton blooms in late winter-early spring (Duchemin et al., 2008). Applied to the northern Gulf of Cadiz, higher abundances of *Nonionella* species off the Guadiana River, namely *N. iridea*, could be related to the deposition of marine organic matter, especially during higher productivity phases between April and September (Ruiz and Navarro, 2006). The lower temperature and salinity observed near the bottom during sample collection in February (Fig. 3.18, 3.19), could indicate that the distribution of these species are also influenced by these parameters or that cold-water filaments prevailed during the winter months in this area.

Bulimina marginata was reported from muddy sea-floors with high organic matter content (e.g. Donnici and Barbero, 2002; Frezza and Carboni, 2009). In the Mediterranean, this species is opportunistic and dependent on a large supply of fresh organic matter with a high nutrition value (de Rijk et al., 2000). On the Portuguese coast, *B. marginata* is common below 100 m depth in the western part and 60 m in the southern part (Levy et al., 1995). On the Guadiana shelf, it was described below 95 m depth, associated with bioclastic sandy mud and gravelly mud (Mendes et al., 2004). In the study area, this species has a ubiquitous distribution with low abundances, occurring in shallow areas off the Tinto-Odiel and

Guadalquivir Rivers and also distinct deeper areas of the continental shelf (Fig. 3.17f). It exhibits no evident relationship with sediment type, water temperature, salinity, suspended particulate matter or productivity.

3.5. Conclusions

Living benthic foraminiferal assemblages from the northern Gulf of Cadiz continental shelf between the Guadiana and Guadalquivir Rivers are very diverse and similar to those described from other parts of the European continental shelf. The living fauna is also comparable with total assemblages described from the continental shelf of the Gulf of Cadiz and the western coast of Portugal.

The population density of living benthic foraminifera (specimens/10 cm^3) is generally influenced by river outflow and clearly associated with muddy sediments and suspended particulate matter around the Guadalquivir river-mouth. Close to the Guadiana River, different hydrodynamic processes and the existence of a transgressive bulge promote deeper patches of high population density when compared to shallow areas around the Tinto-Odiel and Guadalquivir rivers-mouths. Low population densities observed in the same areas, however, indicate that other parameters play an important role in determining the density of living benthic foraminifera in the study area.

Sediment types exert a major influence on species richness. Samples composed of a mixture of mud with sand or gravel in shallow waters, and under the influence of river discharges, provide additional niches for diverse species when compared with surrounding areas. In contrast, muddy sediments have restricted ecological niches and tend to be inhabited only by specialized and dominant species.

Hierarchical classification of the most abundant living benthic foraminiferal species, using R- and Q-mode analyses and the individual distribution of these taxa, allowed grouping the species into four general groups:

Group 1 is represented by *Bolivina ordinaria* and *Hopkinsina atlantica*. *Bolivina ordinaria* is the most abundant species in the assemblage with a high adaptability and tolerance to a range of different factors or combinations of factors. Both species are, however, directly linked to river discharge and its consequent high input of organic matter. Group 1 species are generally associated with sediments with a high mud content and low oxygen levels. These species are considered the most opportunistic of all those identified. They are associated with the limits of productivity and, in the case of *H. atlantica*, also with high primary production from Guadalquivir River discharge.

In Group 2, the dominant taxa are *Ammonia beccarii*, *Eggerelloides scaber*, *Elphidium gerthi*, *Quinqueloculina laevigata* and *Quinqueloculina stelligera*. These species are more abundant in shallow waters. They are associated with various sediment types and their distribution is influenced differently by the discharges of different rivers. Off the Guadalquivir, the highest abundances of *A. beccarii* and *E. scaber* in mud, sandy mud and muddy sand suggest an affinity to higher concentrations of suspended particulate matter and higher productivity at depths less than 40 m. The discharges of the Tinto-Odiel only seem to influence the distribution of *E. gerthi* in slightly muddy gravelly sand to a depth of 16 m. *Quinqueloculina laevigata* and *Q. stelligera* are associated with pure sand, muddy sand and sandy mud, indicating a restricted habitat above 15 m depth without the influence of river discharge.

In Group 3 assemblages are dominated by *Bulimina aculeata*, *Elphidium excavatum*, *Bulimina elongata*, *Epistominella vitrea, Rectuvigerina phlegeri* and *Elphidium cuvillieri*. These species are most abundant between 30 and 100 m water depth. They mostly prevail in muddy sediments associated with low levels of water energy, low levels of oxygen and high organic matter content. *Rectuvigerina phlegeri*, like species from Group 1, was considered an opportunistic species in the assemblage.

Group 4 includes species that are generally more abundant in the deeper parts of the study area. This group was divided into sub-group 4A, with higher abundances in selected samples, and sub-group 4B, with a patchy distribution and higher abundances in distinct areas of the continental shelf. Species from sub-group 4A, i.e. *Bolivina catanensis*, *Cassidulina laevigata*, *Stainforthia* sp. and *Nouria polymorphinoides,* occur in the western part, off the Guadiana River. They were associated with mud and depths below 50 m. *Bolivina italica*, *Bolivina striatula* and *Nouria* sp., from the same sub-group, occurred off the Tinto-Odiel river mouth at 115 m depth in sandy mud. *Brizalina dilatata*, *Brizalina spathulata*, *Bulimina marginata, Nonionella iridea*, *Nonionella stella* and *Nonionella turgida* were the dominant taxa in sub-group 4B. High abundances of *Nonionella* species off the Guadiana River could be related to the lower temperature and salinity near the sea-floor in this area. The abundance of *N. iridea* could also be related to cold-water filaments.

Chapter 4

Holocene palaeoenvironmental changes on the continental shelf off the Guadiana River[1]

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[1] A part of this results has already been published: Mendes, I., Rosa, F., Dias, J. A., Schönfeld, J., Ferreira, Ó., and Pinheiro, J. (2010). Inner shelf paleoenvironmental evolution as a function of land-ocean interactions in the vicinity of the Guadiana River, SW Iberia. *Quaternary International* **221,** 58-67.

4.1. Introduction

The Holocene period is defined as the last 10000 radiocarbon years, which correspond to an age of 11500 calibrated years (Gulliksen et al., 1998; Roberts, 1998). The beginning of this period was characterised by a fast sea-level rise, until ca. 5000 yr BP, when the rate of rise decreased substantially (e.g. Fairbanks, 1989; Stanley, 1995, Bard et al., 1996). Short-term climate variability with different periodicities has been identified during the Holocene, with the most typical pattern characterised by the alternate of warm and cold climate events, the most recent of them exemplified by the Medieval Warm Period and the Little Ice Age (Lamb, 1977; Bond et al., 1997; 2001).

Continental shelf sediment sequences are recognized to be important environmental archives, as they respond to a number of natural processes such as sea level, oceanographic and climatic changes, as well as to the most recent anthropogenic impacts (e.g. Lesueur et al., 1996; Bauch et al., 2001; Evans et al., 2002; Oldfield et al., 2003). The drastic change of the sea level observed within the Holocene combined with local factors, resulted in the generation of both transgressive and highstand sediment bodies. Additionally, the combined influence of climatic and oceanographic changes promoted significant changes in sediment supply in the drainage basins. Offshore shelf depositional systems responded to these changes, as evidenced by shifting depositional and erosional areas. Those processes have been additionally imprinted during the last centuries by a series of human interventions, both in the river basins and in the coastal domain.

Benthic foraminifera are the principal microfossils used in the reconstruction of past sea-floor conditions, because of their wide distribution in space and geologic time and also their rapid response to ecological changes (Murray, 2006). It has long been accepted that benthic foraminiferal assemblages are driven by the ecological demands of their constituting species. The assemblage limits are defined by a faunal change that is directly linked to a change in the immediate environment (Murray, 2006). Besides, the study of benthic foraminifera has different applications in the interpretation of a sedimentary record. In biostratigraphical studies, they can be used to dating the sediments where they lived, providing a relative timescale (e.g. Evans et al., 2002; Scourse et al., 2002; Oldfield et al., 2003; Xiang et al., 2008). Also, they can play a key role in the interpretation of depositional patterns (e.g. Hald et al., 1999; Kaminski et al., 2002; Martins et al., 2007; Wollenburg et al., 2007). In palaeoecology, they can be used to recognise different environments (e.g. Jiang et al., 1997; Jorissen, 1999; Diz et al., 2002; Oldfield et al., 2003; Schmiedl et al., 2003; Morigi et al., 2005; Martins et al., 2006a; Laprida et al., 2007; Wollenburg et al., 2007; Cearreta et al., 2007; Abu-Zied et al., 2008; Rossi and Vaiani, 2008). In palaeoceanography, they can be used as proxies of several parameters (e.g. Jorissen et al., 2007) such as dissolved oxygen (e.g. Kaiho, 1999; Baas et al., 1998; Bernhard and Sen Gupta, 1999; den Dulk et al., 2000; Abu-Zied et al., 2008; Kuhnt et al., 2008), organic production (e.g. Altenbach and Sarnthein, 1989; Kuhnt et al., 1999, Loubere, 1999; 2000; 2002; Martinez at al., 1999; Herguera 2000; Wollenburg et al., 2004; Abrantes et al., 2005; Schönfeld and Altenbach, 2005; Lebreiro et al., 2006; Martins et al., 2006b), salinity and temperature (e.g. Diz et al., 2002; Abrantes et al., 2005; Bartels-Jónsdóttir et al., 2006; Eiríksson et al., 2006). Assemblages can also be used to deduce past currents and transport paths (e.g. Schönfeld, 1997; 2002; Schönfeld and Zahn, 2000; Andrews and Dunhill, 2004).

The northern Gulf of Cadiz continental shelf (SW Iberian Peninsula) has been an area that has received much attention in the recent past. This region receives the discharges from Guadiana River, which is the main regional sediment source. Its river basin is highly susceptible to climatic variability, showing strong intra-annual variations in rainfall with dry, arid summers alternating with wet, temperate winters (Loureiro et al., 1986). Furthermore, the area is also subject to a strong influence of larger-scale annual and decadal climatic signals such as the North Atlantic Oscillation (NAO), verified for example, in data for rainfall and river discharge (Dias et al., 2004; Trigo et al., 2004). These strongly contrasting climatic conditions can result in episodic floods that play a major role in the supply of sediment from the river basin to the continental shelf (Morales, 1997; Portela, 2006).

The postglacial evolution of depositional systems on the northern Gulf of Cadiz shelf was strongly influenced by rapid sea-level changes, leading to the formation of transgressive and highstand system tracts (Lobo et al., 2001; 2004). Seismic profiles show three transgressive parasequences exposed across the inner or middle shelf (Lobo et al., 2001). Highstand deposits occur on the inner shelf as a prodeltaic wedge and on the middle shelf as an extensive mud belt (Nelson et al., 1999; Gonzalez et al., 2004; Lobo et al., 2004). Some recent studies have characterised the geochemistry, micropalaeontological and sedimentological properties of those highstand deposits (e.g. Mendes et al., 2006; 2008; 2010; Burdloff et al., 2008; Corredeira et al., 2008; Rosa et al., 2008).

The reconstruction of the climate history in the Guadiana valley based on pollen spectra indicates a warm, dry early Holocene phase between ca. 11790 and ca. 9000 Cal yr BP; a generally warm, moist phase, with prevalence of oceanic conditions from ca. 9000 to ca. 5000 Cal yr BP; and a return to warm, dry conditions after ca. 5000 Cal yr BP (Fletcher et al., 2007).

Together with climate variations, human activities after ca. 4000 Cal yr BP also initiated environmental changes on the Guadiana basin (Fletcher et al., 2007). These human influences have increased significantly during the last 150 years through deforestation, mining, and the construction of dams in the river basin, and have affected the amount of sediment supply to the shelf (Gonzalez et al., 2001; Dias et al., 2004; Gonzalez and Dias, 2006).

Despite of all these studies, integrated approaches concerning the Holocene palaeoenvironmental changes in shelf environments are scarce. Thus, the main goals of this study are to understand the Holocene palaeoenvironmental changes, associated with evolving sediment depositional patterns in response to sea-level changes, climatic variations and anthropogenic impact. For this purpose three different sedimentary depositional environments from the continental shelf off the Guadiana River were investigated. Sedimentological and benthic foraminiferal analyses, integrated in a temporal framework, were performed on cores retrieved from the mud body (or mud patch) on the middle shelf, the proximal zone of a transgressive sandy bulge on the upper middle shelf and from the prodeltaic wedge on the inner shelf.

4.2. Material and methods

4.2.1. Sediment cores

The cores were collected on the continental shelf off the Guadiana River in July 2002 (Fig. 4.1) during the campaign CRIDA 0702, in the vessel *Aguayo*. A light-weighted vibrocorer with water injection, with a core barrel of 4 m length and an inner diameter of 9 cm was used.

Core 5 with 353 cm length was collected from a central position in the mud patch at 72 m water depth (latitude 37º1’54’’N and longitude 7º20’44’’W) (Fig. 4.1). Core 7 with 71.5 cm long was taken at 36 m water depth (37º3’44’’N, 7º17’40’’W) within the proximal zone of a transgressive sandy deposit (Fig 4.1). Core 8 with 376 cm length was extracted from the present Guadiana prodeltaic wedge, at 22 m water depth, (37º7’24’’N, 7º16’6’’W) (Fig. 4.1).

In the laboratory the cores were split lengthwise into two halves. An archive half was frozen, whereas the working half was immediately sampled. Mud sediment cores (5 and 8) were sampled sequentially in intervals of 1-cm thick slices from the top down to 50 cm (corresponding approximately to the last 1000 to 1500 years of sedimentation record) and in intervals of 2-cm slices from there to the base. Core 7, was sampled in intervals of 1-cm thick slices from the top to 4 cm and from 26 to 50 cm, and in intervals of 2-cm thick slices in the remaining intervals of the core, which consisted of coarser sediments.

Each level of cores 7 and 8 was sampled for geochemical, grain size and benthic foraminiferal analyses. Core 5 was sampled at each level for grain size, and on alternating levels for geochemistry and benthic foraminifera, in order to obtain more material for each analysis.

4.2.2. AMS radiocarbon dates

A total of eleven accelerated mass spectrometry (AMS) radiocarbon (^{14}C) dates were carried out by Beta Analytic (USA), using between 20 and 40 mg benthic foraminiferal tests mixture (Table 4.1). The calibration of radiocarbon ages to calendar years was made with the program Calib 5.1 (Stuiver et al., 2005), using the MARINE 04 curve with global ocean reservoir correction of about 400 years (Stuiver and Reimer, 1993). Local reservoir effect (delta R) was applied according to Soares and Dias (2006) and Soares and Martins (2010). A correction of 0±100 years was considered for dates older than 2000 radiocarbon years, with exception of the period between 4400 and 4000 radiocarbon years where a correction of 100±100 years was applied, and -135±20 years for dates younger than 2000 radiocarbon years (Table 4.1).

Two additional amino acid racemisation (AAR) datings were performed on samples from core 5 (Table 4.1). The analyses were performed by the Amino Lab of the University of Arizona, USA. For each analysis, 50 tests of benthic foraminiferal species *Cassidulina laevigata* were used. AAR is a chemical dating method that measures the relative abundance of amino acid isomers (L- and D-forms) preserved within organic materials expressed as D/L ratio. With some exceptions, living organisms keep all their amino acids in the L configuration. However, as soon as the organism dies, the L-amino acids start to spontaneously convert to the D-form. The conversion of D/L to numeric time scale is a calibrated approach in which D/L values are used to interpolate between, or extrapolate beyond, the known ages of independently dated samples within a restricted geographic/oceanographic area, where temperature histories are similar (Kaufman, 2006). In this case, the calibrated ages obtained by AMS radiocarbon dating in core 5 were applied.

4.2.2.1. Age model

The age model was created based on ^{14}C and AAR calibrated ages (2 sigma), depth and sedimentation rates. The sedimentation rates are expressed in centimetres per thousand of years and reflect the velocity of sediment build-up (van Andel et al., 1975). The calculation of linear sedimentation rates assumed a stable accumulation between the dated levels and was not corrected for compaction and dehydration. The zero validation for the age model was applied. Where the top was considered as recent (cores 5 and 7), all datings were used to create the age model. For core 8, where the age of the top was older than 100 years, the dating below the core top was excluded from the age model.

4.2.3. Grain size

Grain size analyses were performed sequentially along the cores. When available material was not enough, two or more adjacent samples were combined for one grain size analysis. The samples were washed with hydrogen peroxide for elimination of the organic matter. Fine (silt and clay) and coarse (sand and gravel) fractions were wet separated using a 63 µm (4 phi) sieve. The fine fraction was analysed using the pipette method and the coarse fraction was subdivided by dry sieving using a sieve rack. Both fractions were graded in phi intervals. The textural classification of Folk (1954) was followed.

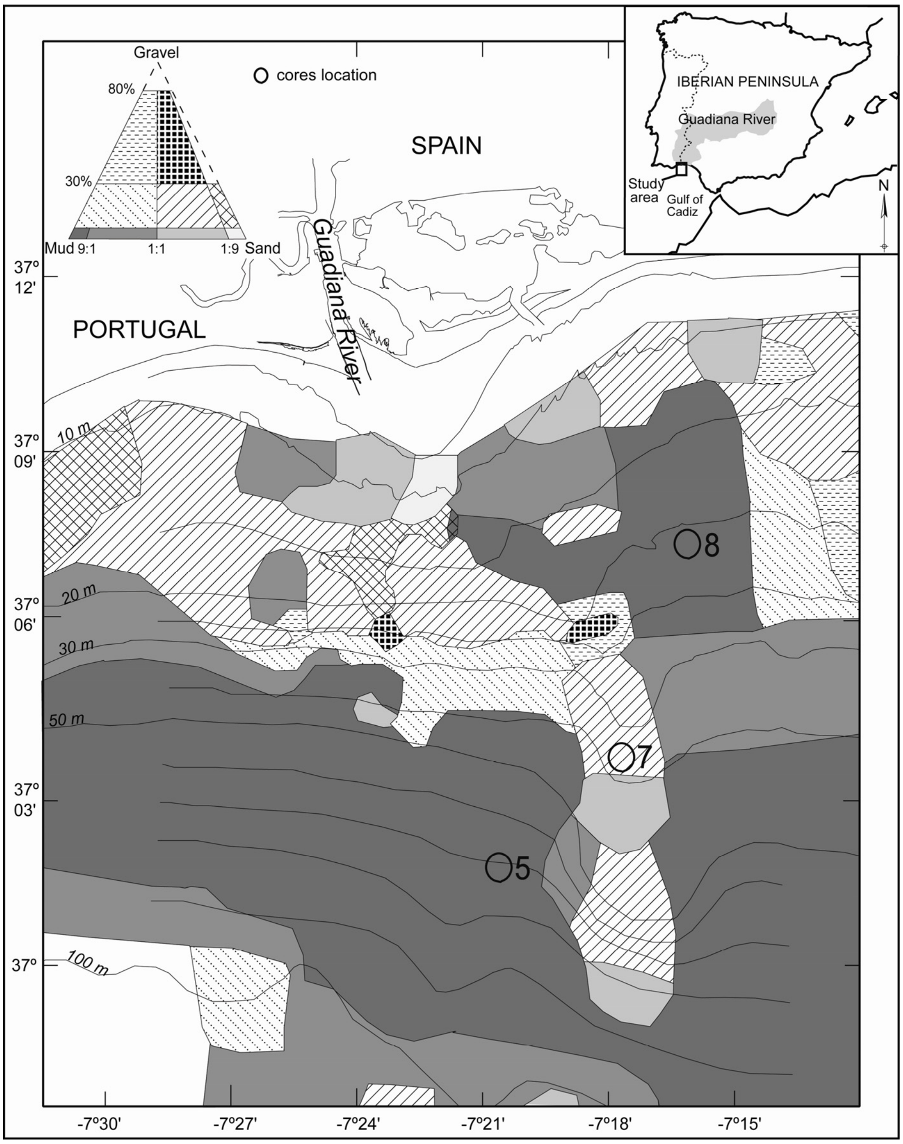


Figure 4.1 – Location of the studied cores (5, 7 and 8) and distribution of surface sediments on the continental shelf off the Guadiana River (adapted from Gonzalez et al., 2004).

2.2.4. Components of sand fraction

Components of the sand fraction were analysed along the three cores by different ways:

Core 5: 71 samples were analysed in intervals of 1 to 6 cm, in slices of 3 to 6 cm;

Core 7: 27 samples were analysed sequentially, in slices varying from 1 to 4 cm;

Core 8: data used here was adapted from Pinheiro et al. (2006) who considered 38 samples, collected in 10 cm intervals in 2-cm slices, except for the top, which was a 1-cm slice.

In each phi grade of the sand fraction, 100 grains were counted and identified under a binocular microscope to determine main terrigenous and biogenic components. Grains were classified visually as quartz, mica, schists and greywackes, other terrigenous, glauconite, foraminifera, molluscs and other bioclasts. For each sample the weighted mean was calculated after Sarnthein (1971), as the total sum of grains number in each phi class multiplied by their weigh, and divided by the total weight of the sand fraction.

4.2.5. Benthic foraminifera

Benthic foraminifera were analysed in core 5 on 41 samples, collected from the core at irregular intervals varying from 2 to 12 cm. In core 8, 38 samples were collected from the core at 10 cm intervals. For both cores, 1-cm sediment slices from the top to 50 cm depth and 2-cm slices from this depth to the core base were considered. In core 7, a total of 15 samples were analysed, collected from the core at irregular intervals of 4 to 6 cm, in slices of 1 and 2-cm along the core. Each sample was washed with tap water for 10 to 15 minutes, through 63 and 2000 µm sieves, previously placed in a tub with Methylene Blue. The fractions 63-2000 µm and >2000 µm were dried in an oven at 50ºC and weighted. The material >63 µm was divided in aliquots by using an Otto micro-splitter, placed in a picking tray and afterwards analysed under a binocular microscope. All benthic foraminiferal tests were picked from each aliquot. The size of the split was chosen according to the number of expected specimens. Whenever possible, at least 300 well preserved benthic foraminiferal tests were collected from each sample, mounted on lightly glued cardboard slides, identified and counted.

Benthic foraminifera were classified according to the proposed generic classification of Loeblich and Tappan (1987), and determined after Ellis and Messina (1942-2009), Murray (1971), Jones (1994), Levy et al. (1995), Martins and Gomes (2004), and other studies (for further details on Taxonomy see the Chapter 7). The relative abundance of each species and the population density (as total number of benthic foraminifera per gram of dry sediment) was calculated. The gravel fraction was excluded. The Diversity Shannon Index was calculated by using the PAST software (PAlaeontological STatistics, ver. 1.81; Hammer et al., 2008). The number of species in each sample, termed as species richness (*S*) and the number of individuals (*n*), were used as data entry. Zonation areas were constructed by using the Psimpoll 4.25 program (Bennett, 2005). The method of binary splitting by information content was used. Only species with an average abundance >5% were considered.

Cluster analyses were also performed using PAST software (Hammer et al., 2008). For each core, a matrix of data was built using species with more than 5% abundance in at least one sample. The R-mode cluster analyses grouped species by using the correlation method and joined the groups by using the unweighted pair-group average (UPGMA). In this method, clusters are joined by the average distance between all members in the two groups. The Q-mode cluster analyses grouped samples by using Ward's method. The clusters are joined in such a way that an increase of the within-group variance is minimized.

4.3. Results

4.3.1. Age models

The complete data of AMS ^{14}C and AAR datings, used to create the age models, are presented in Table 4.1. The ^{14}C dating of ca. 11500 Cal yr BP obtained at the base of core 5 (350-352 cm) indicated that this core covers the largest time period (Table 4.1). The zero validation for the age model gives an age of 84 years for the top of the core (i.e. Recent).

Two periods of high sedimentation rates can be observed (Fig. 4.2a). The first lasted from ca. 11500 to ca. 10100 Cal yr BP (207 cm) with a sedimentation rate of 100 cm/ka. The second lasted from ca. 890 Cal yr BP (95 cm) to Recent times, with sedimentation rates of 117.5 cm/ka and 95.1 cm/ka. An approximately 10 times lower sedimentation rate of 9.3 cm/ka prevailed between ca. 10100 and ca. 4100 Cal yr BP (Fig. 4.2a).

Table 4.1 - AMS Radiocarbon data from cores 5, 7 and 8. AAR ages data from core 5 (*Asp* aspartic acid, *Glu* glutamic acid).

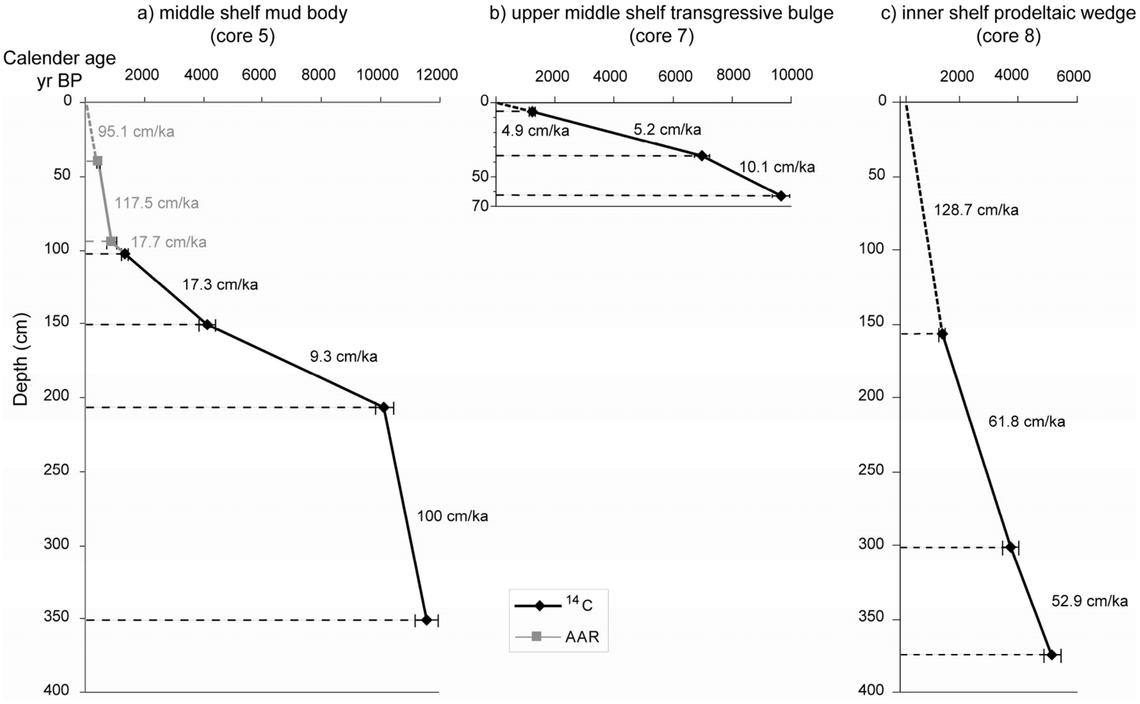
Core	Depth (cm)	Lab. no.	**^{14}C dating**				**AAR dating**
			Conventional radiocarbon age B.P.	Local reservoir effect	2σ calibrated age B.C./A.D.	Cal. Age B.P.	Cal. age B.P. (Asp–Glu)
5	40-41	UAL-6781	-	-	-	-	366-486
5	94-96	UAL-6782	-	-	-	-	719-1061
5	102-104	Beta-211322	1650±40	-135±20	513-705 A.D.	1245-1437	-
5	150-152	Beta-204306	4170±40	100±100	2456-1877 B.C.	3827-4406	-
5	206-208	Beta-211324	9320±50	0±100	8494-7846 B.C.	9796-10444	-
5	350-352	Beta-194504	10400±70	0±100	9987-9233 B.C.	11183-11937	-
7	4-8	Beta-248644	1540±40	-135±20	632-820 A.D.	1130-1318	-
7	35-37	Beta-211325	6480±40	0±100	5281-4775 B.C.	6725-7231	-
7	62-64	Beta-248643	8920±40	0±100	7998-7424 B.C.	9373-9947	-
8	76-78	Beta-204308	1120±40	-135±20	1048-1252 A.D.	698-902	-
8	156-158	Beta-204309	1750±40	-135±20	417-631 A.C.	1319-1533	-
8	300-302	Beta-204310	3800±40	0±100	2091-1518 B.C.	3468-4041	-
8	374-376	Beta-194506	4870±40	0±100	3487-2920 B.C.	4870-5437	-

Extracted from the upper middle shelf transgressive bulge, core 7 showed the lowest sedimentation rates (Fig. 4.2b). These showed a decreased from the core base to the top, ranging from 10.1 to 4.9 cm/ka (Fig. 4.2b). It was not possible to obtain enough benthic foraminiferal tests to carry out a dating at the base of the core (71.5 cm). The ^{14}C dating obtained at level 62-64 cm indicates an age of ca. 9660 Cal yr BP (Table 4.1). The zero validation of the age model gives an age of 73 years for the top of the core (i.e. Recent).

Core 8, collected on the inner shelf prodeltaic wedge, covered only the most recent depositional periods, from ca. 5150 Cal yr BP onwards (Table 4.1). The zero validation for the age model gives an age of 206 years for the top of the core. For this reason, the dating obtained at level 76-78 cm was not used to create the age model.

Core 8 showed the highest sedimentation rates (Fig. 4.2c). The lower sedimentation rate of 52.9 cm/ka was observed between ca. 5150 and ca. 3750 Cal yr BP (375 to 301 cm) and the higher of 128.7 cm/ka between ca. 1420 to 200 Cal yr BP (157 to 0 cm) (Fig. 4.2c).

In cores 7 and 8 the sedimentation rates were approximately gradual during time. On the other hand, in core 5, periods of high and low sedimentation alternated (Fig. 4.2).


a) middle shelf mud body (core 5)

b) upper middle shelf transgressive bulge (core 7)

c) inner shelf prodeltaic wedge (core 8)

Figure 4.2 – Age model for cores 5, 7 and 8, based on calibrated ages with error bars, and sedimentation rates between age control points.

4.3.2. Sediment characteristics

Core 5: The grain size variation showed that 61 to 100% (average 83%), of the core was made up of fines (silt+clay) (Fig. 4.3a-A). The silt fraction was the most abundant, with percentages varying between 43 and 66% (average 50%). The coarse fraction was essentially sand, with percentages varying between 0 and 39% (average 16%). The maximum value was observed near the core base. From ca. 11100 to ca 4000 Cal yr BP the sediment composition showed only small variation. The sand fraction varied between 7 and 27% and the silt fraction from 45 to 66%. From ca. 4000 Cal yr BP to Recent times, the percentage of sand decreased progressively, with values lower than 1.2% in the last ca. 500 Cal yr BP. Simultaneously an increase of the clay fraction to values of more than 50% could be observed for the same period (Fig. 4.3a-A).

When core 5 was opened in the laboratory, a semi-liquid horizon was noted between 44 and 47 cm (ca. 460 to 480 Cal yr BP). However, this level did not stand out as a change in sediment type. The mean grain size showed a fining upward trend from 5.13 to 8.34 phi (average 6.66 phi) (Fig. 4.3a-B).

Core 7: This core was mainly constituted by coarse sediments (Fig. 4.3b-A). Sand was the most abundant fraction along the entire core, varying between a maximum of 95%, in the core base, and a minimum of 54% in the core top (average 79%). The gravel percentage varied from 0.6 to 18% (average 5%). The fine fraction varied between 5 and 45% (average 16%). However, two periods of increased fine fraction were observed. The first was characterised by a silt-clay maximum of 23%, between ca. 7500 and ca. 7000 Cal yr BP. The second from ca. 2500 Cal yr BP to the Recent times, where the maximum of 45% was attained (Fig. 4.3b-A). The mean grain size varied from 1.24 phi (around ca. 2500 cal yr BP) to 4.36 phi (top of the core) and averaged of 2.51 phi (Fig. 4.3b-B).

Core 8: Grain size analyses allowed the identification of two distinct units along core 8 (Fig. 4.3c-A). The lower unit from ca. 5150 to ca. 1500-1400 Cal yr BP, generally presented similar percentages of fine and coarse fractions. This section was only interrupted by a clayey silt unit between ca. 4050 to 3600 Cal yr BP. The upper unit, from ca. 1500-1400 Cal yr BP to the core top, ca. 200 Cal yr BP, was characterised by a higher content of the silt-clay fraction, with exception of sporadic levels of coarser material. The fine fraction reaches more than 90% of total sediment. The last ca. 40 Cal yr BP were characterised by a fast increase of the gravel fraction (Fig. 4.3c-A). Along core 8 the mean grain size varied between -2.72 phi, in the top of the core, and 8 phi at ca. 1200 Cal yr BP, with an average of 5.82 phi (Fig. 4.3c-B).

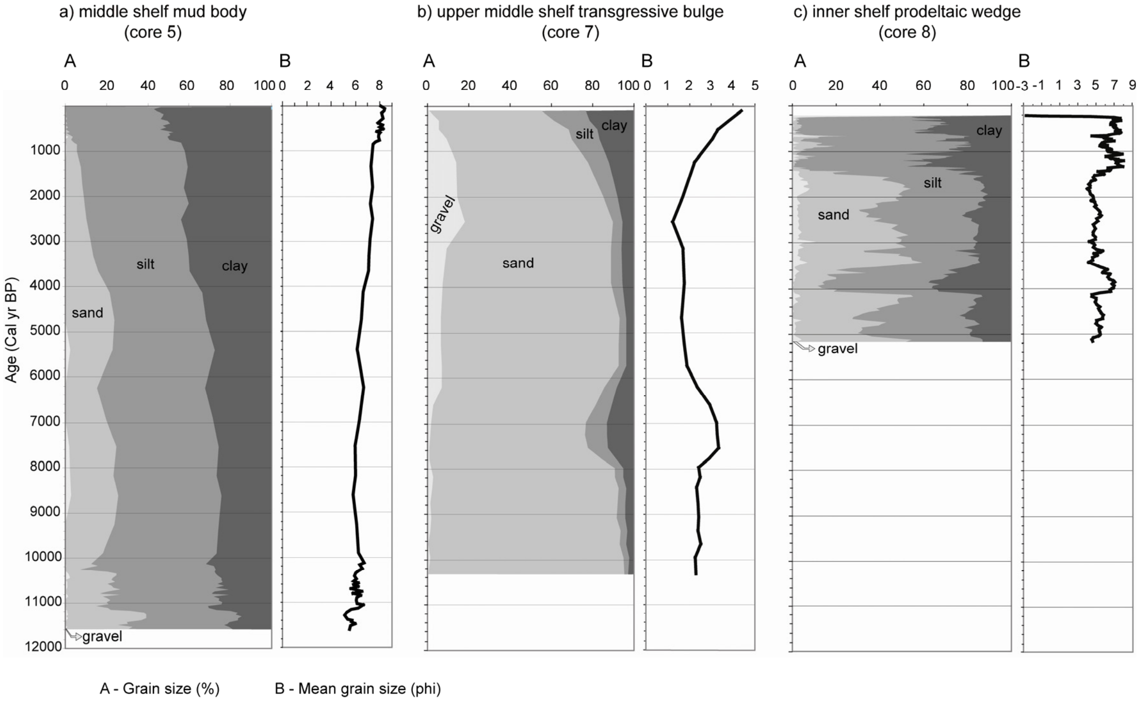


Figure 4.3 – Grain size (A) and mean grain size (B) variations with age (Cal yr BP) for the three environments analysed on the Guadiana continental shelf: a) middle shelf mud body; b) upper middle shelf transgressive bulge; c) inner shelf prodeltaic wedge.

Sand fraction analyses showed that terrigenous dominates core 5 from ca. 11500 to ca. 400 Cal yr BP and the bioclasts from this age to Recent times (Fig. 4.4a). However fluctuations in the terrigenous and bioclasts components allowed the identification of three distinct units. The lower unit from the core base to ca. 5000 Cal yr BP, dominated by terrigenous, namely quartz (56 to 88%), mica (0.7 to 23%) and other terrigenous (0.4 to 12%). During this period glauconite reached values of 3%. The second unit from around ca. 5000 to ca. 400 Cal yr BP showed a decrease of mica and other terrigenous, and the increase of glauconite (3 to 16%), foraminifera (6 to 21%) and other bioclasts (0.4 to 13%). The last ca.

400 Cal yr BP to Recent times showed an increase of bioclasts, namely foraminifera and other bioclasts with a consequent decreasing of the terrigenous fraction, namely quartz (Fig. 4.4a).

Quartz was the principal component founded along core 7, varying between 71 and 90%. The bioclastic component increased from ca. 8500 Cal yr BP to a maximum of 24% attained ca. 1200 Cal yr BP (Fig. 4.4b).

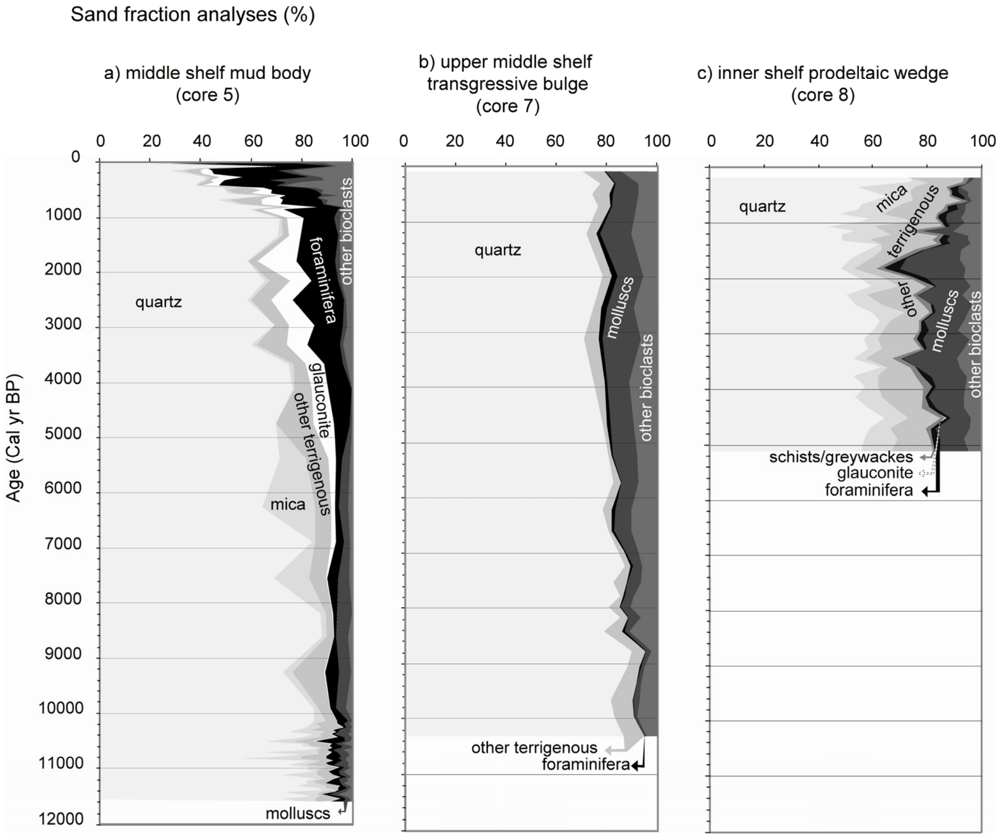


Figure 4.4 – Variation of the components of sand fraction with age (Cal yr BP) for the three environments analysed on the Guadiana continental shelf: a) middle shelf mud body; b) upper middle shelf transgressive bulge; c) inner shelf prodeltaic wedge.

The sand fraction analyses in core 8 showed a dominance of terrigenous components throughout the core (Fig. 4.4c). Quartz (46 to 75%) was the main component, but other terrigenous and mica also showed significant percentages (Fig. 4.4c). Two distinct units could be identified. The lower unit, from ca. 5150 to 1500-1400 Cal yr BP, presented relatively constant percentages of all sand fraction components, with terrigenous varying from 63 to 83% and biogenic with 17% to 37%. The higher abundances of biogenic components, namely molluscs, corresponded to two peaks in the sand fraction (~ 35%) at 3400 and 1800 Cal yr BP, respectively (Fig. 4.4c). The upper unit showed an increased of the terrigenous components, from ca. 1650-1400 Cal yr BP to a maximum abundance of 95% attained in the core top (ca. 200 Cal yr BP). The biogenic components showed a consequent decreasing trend from 30 to 5%, namely the foraminifera and the molluscs. The transition between both units occurred ca. 1500-1400 Cal yr BP, when the silt-clay fraction increased (Fig. 4.3c-A).

Quartz was always the most abundant component in the sand fraction on the upper middle shelf transgressive bulge and on the inner shelf prodeltaic wedge. It also dominated sandy sediments on the middle shelf mud body from ca. 11500 to ca. 400 Cal yr BP (Fig. 4.4).

4.3.3. Benthic foraminifera

4.3.3.1. Core 5: Middle shelf mud body

The population density (the number of benthic foraminifera per gram of dry sediment) varied between 4543 (ca. 10440 Cal yr BP) and 755 (ca. 500 Cal yr BP), with an average of 2474 specimens/g (Fig. 4.5). From the core base to approximately ca. 10000 Cal yr BP the population density showed strong variations (2183 to 4543 specimens/g). From this age to ca. 7000 Cal yr BP values higher than 3800 specimens/g were observed. Relatively constants densities of 2000 to 3000 specimens/g were recorded between ca. 7000 and ca 800 Cal yr BP. After a peak of density at ca. 820 Cal yr BP with 3670 specimens/g, the values dropped to the lowest observed values, remaining approximately constant to the top of the core, with a slight increase in the last ca. 100 Cal yr BP (Fig. 4.5).

The average value of species richness along the core 5 was 54 species, with a maximum of 74 near the base at ca. 11440 Cal yr BP and a minimum of 46 at ca. 500 Cal yr BP. The minimum corresponds to the semi-liquid horizon at 44 to 47 cm, observed when the core was opened (Fig. 4.5).

The Shannon diversity index ranged from 2.6 to 3.3, with an average 3, showing small variations along the entire core (Fig. 4.5).

Along core 5, 17 benthic foraminiferal species showed relative abundance >5%, in at least one sample (Appendix B). Two general trends of species abundance could be identified (Fig. 4.5):

1) Higher abundance or gradual decrease from ca. 11500 Cal yr BP (core base) to ca. 4500 Cal yr BP (155 cm core depth). Then a further decrease in abundance from this level to the top of the core, with abundance <1% or even a complete disappearance of certain species (e.g. *A. mamilla*, *B. pseudoplicata*, *N. stella* and *S. fusiformis*) (Fig. 4.5). Typical examples for this type of species were *Asterigerinata mamilla* with abundances varying from 0 to 22.8%, *Bolivina ordinaria* from 3.8 to 36.5%, *Bolivina pseudoplicata* from 0 to 5.4%, *Elphidium excavatum* from 0.2 to 9.3%, *Nonionella* sp. 0.3 to 5.4%, *Nonionella iridea* from 0.5 to 6%, *Nonionella stella* from 0 to 11%, *Rectuvigerina phlegeri* from 0.9 to 7% and *Stainforthia fusiformis* from 0 to 10.9%.

2) Lower abundances from the core base to ca. 4500 Cal yr BP and an increase from this level to the top of the core. Typical examples for this species were *Brizalina dilatata* with abundances varying from 0.3 to 10.7%, *Brizalina spathulata* from 0 to 17.2%, *Bulimina aculeata* from 0.3 to 9.6%, *Bulimina elongata* from 0 to 5.2%, *Bulimina marginata* from 0 to 6.1%, *Cassidulina laevigata* from 0 to 21.9%, *Cassidulina minuta* from 0 to 5.3% and *Epistominella vitrea* from 0.9 to 17.3%. An exception to this pattern was *C. laevigata*, showing an increase of abundance earlier, at ca. 7000 Cal yr BP (180 cm core depth) (Fig. 4.5).

Bolivina ordinaria was the most abundant species in the lower unit (ca. 11500 to 4500 Cal yr BP) and *C. laevigata* and *E. vitrea* the most abundant in the upper unit (4500 Cal yr BP to Recent times) (Fig. 4.5). Eight species were identified in all the analysed samples (*B.*

ordinaria, *Nonionella* sp., *N. iridea*, *R. phlegeri*, *B. dilatata*, *B. aculeata*, *E. excavatum*, *E. vitrea*). The remaining species were present in more than 75% of the samples, with the exception of *S. fusiformis*, which was only present in 56% of the samples. In the total assemblage it was observed that *Nonion fabum* with abundance <5% (0.47 to 4.31%) was present in all analysed samples (Appendix B).

The zonation based on the species with abundance >5%, produced two zones along core 5. The first zone C-1 stretching from ca. 11500 to ca. 4500 Cal yr BP, and the second zone C-2 from this age to Recent times (Fig. 4.5).

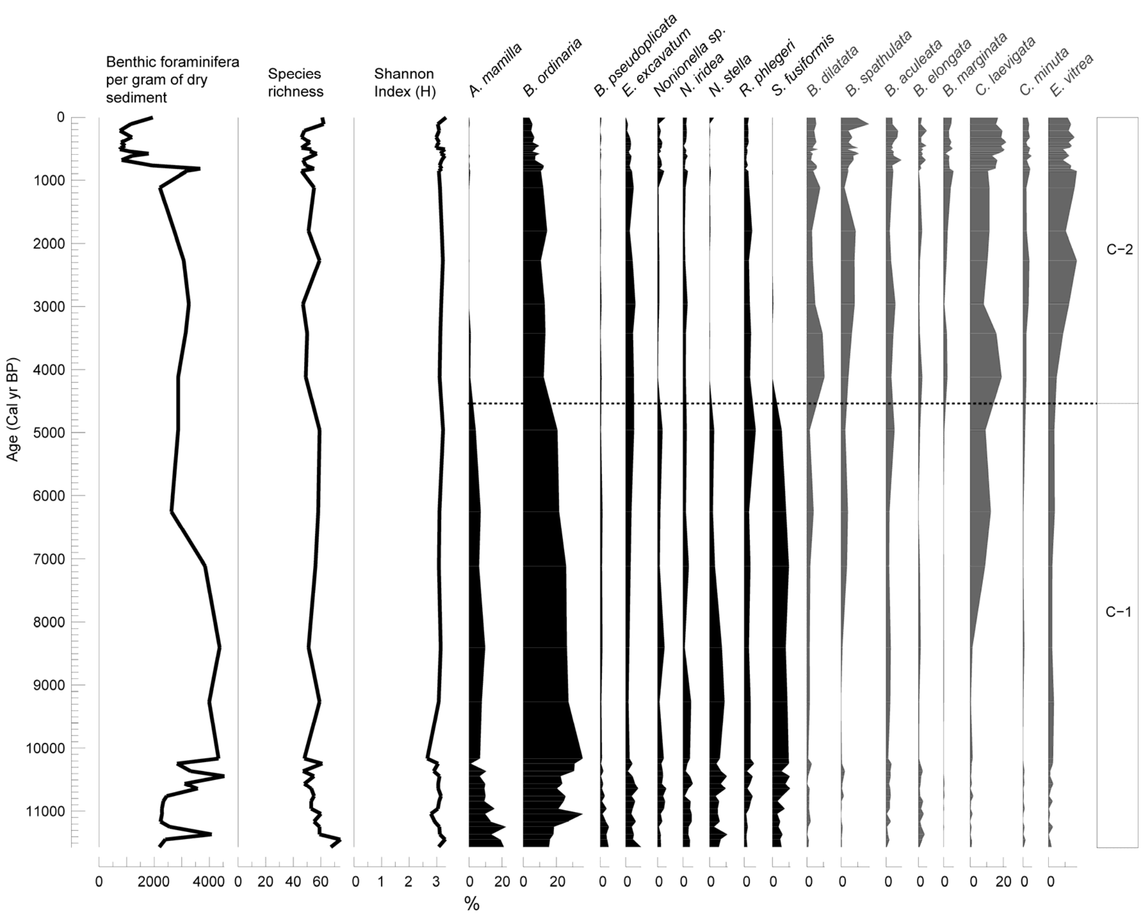


Figure 4.5 – Variation with age in core 5 of: number of benthic foraminifera per gram of dry sediment, species richess, Shannon index diversity, relative abundances of benthic foraminiferal species, with abundance >5% in at least one sample and proposed faunal assemblages zonation.

Cluster analyses were performed using the 17 species that showed an abundance >5%, in at least one sample. These species comprised between 68 and 82% (average 75%), of all species founded in the 41 samples analysed along core 5.

R-mode cluster analyses produced a dendrogram with a cophenetic correlation of 0.9394, which discriminated two assemblages or clusters (Fig. 4.6a). These clusters are closely correlated with the individual distribution of the most abundant species (Fig. 4.5). Cluster I corresponds to the type of trend 1) described above, while Cluster II included the species showing trend 2) (Fig. 4.5).

Q-mode cluster analyses, with cophenetic correlation 0.9127, produced a dendrogram which distinguished two clusters (Fig. 4.6b). Cluster A grouped all the samples with ages comprised between ca. 11560 and ca. 4959 Cal yr BP, in a total of 20 samples. Cluster B, with 21 samples, grouped all the samples from ca. 4117 Cal yr BP to Recent times. Cluster A and B were directly related with the obtained zonation C-1 and C-2, respectively (Fig. 4.5).

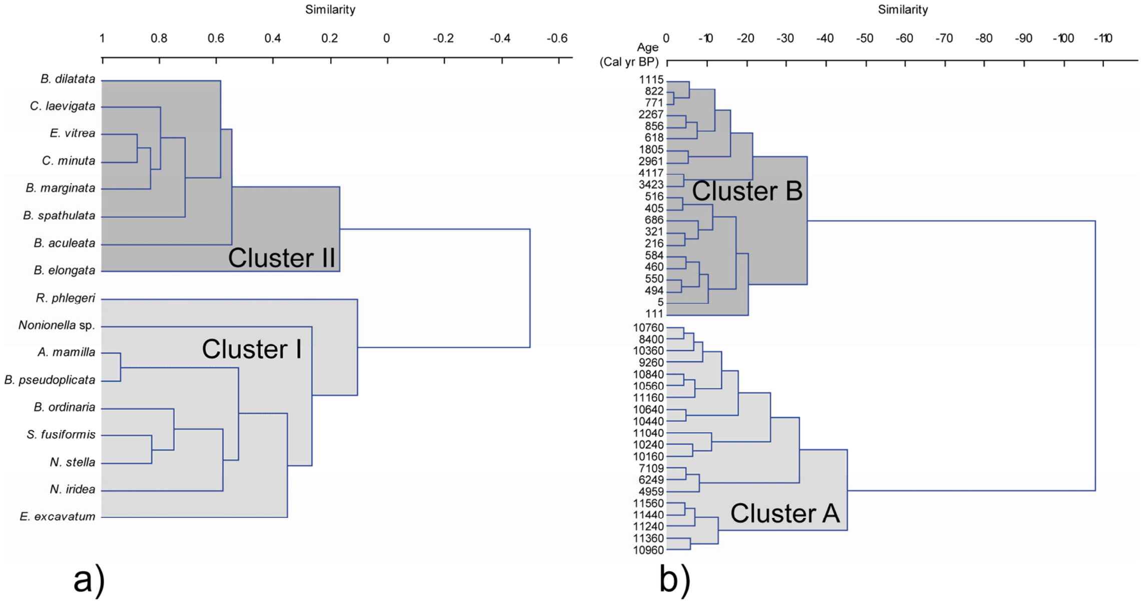


Figure 4.6 - Dendrogram classification resulting from cluster analyses based on 17 species with relative abundance >5% in at least one sample: a) Foraminiferal assemblages produced by R-mode analysis (correlation method joined by UPGMA); b) Samples associated produced by Q-mode analysis (Ward's method).

4.3.3.2. Core 7: Upper middle shelf transgressive bulge

The population density along core 7 varied from 16 to 320 specimens/g, with an average of 106 specimens/g (Fig. 4.7). The minimum value was attained in the core base (ca. 10400 Cal yr BP) and the maximum in a peak at ca. 7300 Cal yr BP. Thereafter this peak dropped to close than 40 specimens/g, observed between ca. 6000 and 5000 Cal yr BP. The last ca. 3000 Cal yr BP were characterised by low and relative constant population density values of around 65 to 100 specimens/g (Fig. 4.7).

The species richness varied from 45 to 96 species (average 75). The lowest value was obtained in the core base, followed by a slight increase (88 species) until ca. 8000 Cal yr BP. After this period the number of species decreased, and only began to increase again at ca. 6000 Cal yr BP, attaining the maximum values between 2000 to 1000 Cal yr BP (Fig. 4.7).

The Shannon diversity index presented low variations, with minimum of 3.17 and maximum of 3.84 (average 3.56). While variations were observed from the base to ca. 5000 Cal yr BP, the diversity index remained relatively constant from there to the top (Fig. 4.7).

Ten species with a relative abundance >5%, in at least one sample were observed along core 7 (Appendix C). Again, two general trends could be identified (Fig. 4.7):

1) Species with higher or decreasing abundance between ca. 10400 and ca. 5400 Cal yr BP (core base to 26 cm core depth): *Asterigerinata mamilla* with abundance of 0 to 6.3%, *Bolivina ordinaria* from 8.9 to 32.8%, *Epistominella vitrea* from 1.9 to 7.9%, *Miliolinella subrotunda* from 0.9 to 6.1%, *Quinqueloculina rugosa* from 0 to 13.3%. From these species, only *Q. rugosa* showed higher abundance in the core base. However, this abundance dropped abruptly to values <2% in the subsequently analysed level. From ca. 5400 Cal yr BP to the core top, the mentioned species decreased in abundance.

2) Species displaying increasing abundance from ca. 5400 Cal yr BP to the top: *Bulimina aculeata* with abundances of 1.2 to 5.6%, *Bulimina elongata* with 0 to 6.9%,

Cassidulina laevigata with 2.2 to 5.7%, *Elphidium crispum* with 0 to 7.3%, *Nonion fabum* with 0.8 to 5.6% and *Textularia deltoidea* with 0 to 5.5%.

Bolivina ordinaria was the species showing the highest abundance along the entire core. The only exception was the core base where *Q. rugosa* showed its maximum and *B. ordinaria* the minimum abundance (Fig. 4.7).

All the species with abundance >5% in this core were presented in more than 85% of the samples, with the exception of *Q. rugosa*, presented in 46% of the samples. Species such as *B. ordinaria*, *E. vitrea*, *M. subrotunda, B. aculeata*, *C. laevigata* and *N. fabum* were present in all the analysed samples along this core. *Brizalina dilatata* and *P. mediterranensis*, showed abundances <5% (0.55 to 3.46% and 1.38 to 3.5%, respectively), but were also present in all samples (Appendix C).

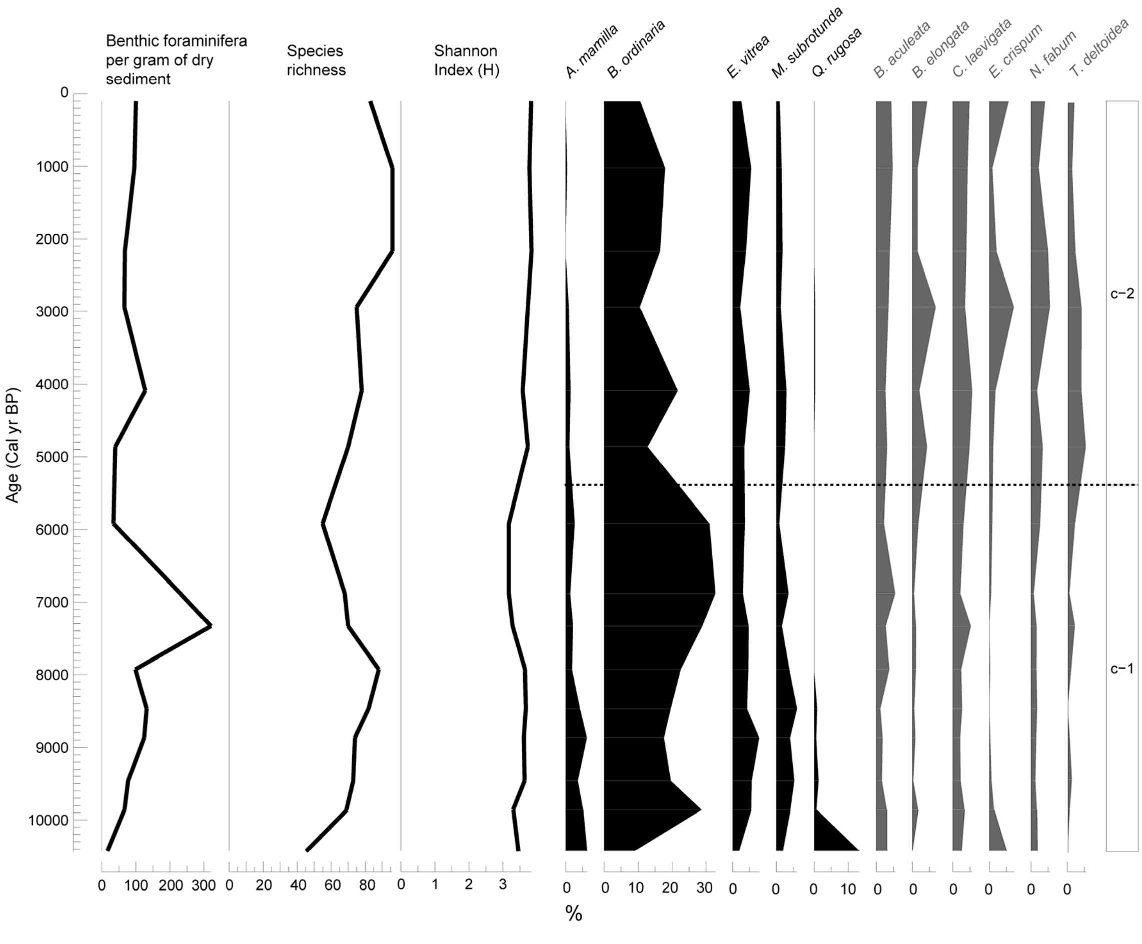


Figure 4.7 – Variation with age (Cal yr BP) in core 7 of: number of benthic foraminifera per gram of dry sediment, species richess, Shannon index diversity, relative abundances of benthic foraminiferal species, with abundance >5% in at least one sample and proposed faunal assemblages zonation.

The zonation based on the species with abundance >5%, produced two zones. The first zone C-1 from ca. 10400 to ca. 5400 Cal yr BP (core base to 26 cm core depth), and the second zone C-2 from this level to Recent times (Fig. 4.7).

Cluster analyses were performed using the 11 species with abundance >5%, in at least one sample. These species only comprised between 40 and 56% (average 46%), of all species found in the 15 samples analysed along core 7.

R-mode cluster analyses with a cophenetic correlation of 0.8545, produced a dendrogram which differentiated two clusters (Fig. 4.8a). These clusters can be closely related to distribution trends shown by individual species (Fig. 4.7). Cluster I corresponds to the type of trend 1), while Cluster II corresponded to trend 2 (Fig. 4.8a).

Q-mode cluster analyses, with cophenetic correlation of 0.6254, also produced two distinct clusters (Fig. 4.8b). Clusters A grouped generally samples from the lower unit (ca. 10400 to 5400 Cal yr BP) of the core and cluster B from the upper unit (ca. 5400 to Recent times). The separation between both clusters occurred between ca. 5920 and 4860 Cal yr BP. However, the sample collected at the core base, ca. 10400 Cal yr BP, was included in cluster B and the sample collected at ca. 4090 Cal yr BP in cluster A (Fig. 4.8b). On the other hand, the obtained zonation indicated two distinct zones. C-1 from the core base to ca. 5400 Cal yr BP and C-2 from this depth to Recent times (Fig. 4.7).

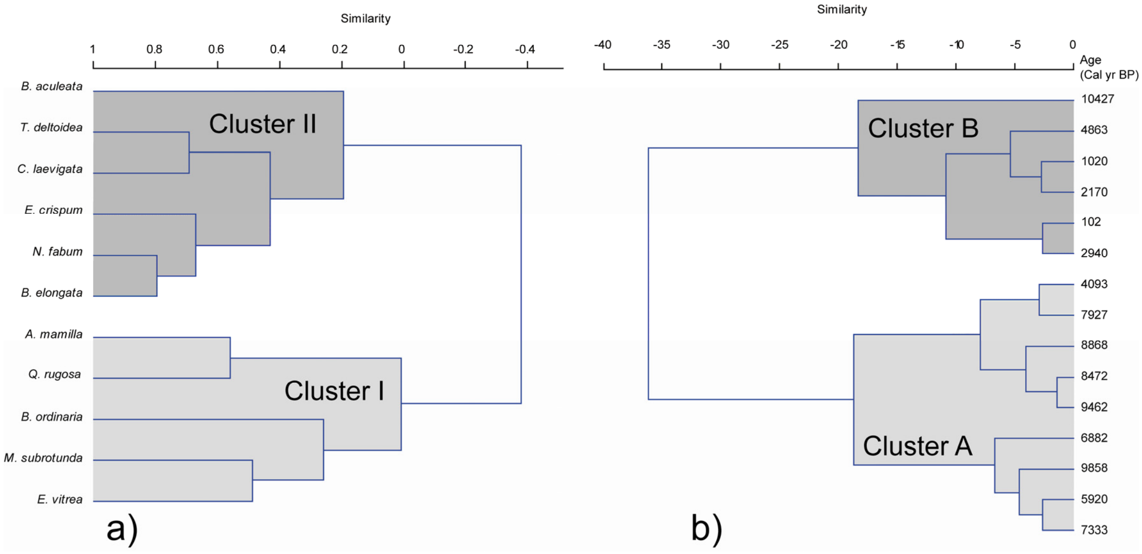


Figure 4.8 - Dendrogram classification resulting from cluster analyses based on 11 species with relative abundance >5% in at least one sample: a) Foraminiferal assemblages produced by R-mode analysis (correlation method joined by UPGMA); b) Samples associated produced by Q-mode analysis (Ward's method).

4.3.3.3. Core 8: Inner shelf prodeltaic wedge

The population density in core 8 varied between 17 and 3090 specimens/g (average 1120 specimens/g). The maximum value was observed in the core base and the minimum ca. 600 Cal yr BP (Fig. 4.9). From the core base until ca. 1400-1200 Cal yr BP higher numbers of benthic foraminiferal tests occurred (average 1500 specimens/g). From this level to the top core (ca. 200 Cal yr BP) a lower and relatively constant number of specimens/g, with an average value of 600 specimens/g were observed (Fig. 4.9).

The species richness varied between 115 and 30 species (average 78). The maximum species richness was observed at ca. 1400 Cal yr BP and the minimum at ca. 600 Cal yr BP (Fig. 4.9). The maximum value coincided with the level of transition between the two general units previously described, and the minimum with the middle of the upper unit (Fig. 4.9).

The Shannon diversity index ranged from 3.11 to 4.05 (average 3.56). The index showed small variations along the core, with the most abrupt change at ca. 1400 to 1200 Cal yr BP (Fig. 4.9).

Twelve benthic foraminiferal species showed relative abundances >5%, at least in one sample (Appendix D). As in the previous cores, two trends of abundance could be observed (Fig. 4.9):

1) A relatively high and constant abundance from the core base to ca. 1400-1200 Cal yr BP, followed by a decrease (Fig. 4.9). Typical species were: *Asterigerinata mamilla* with abundances from 0 to 12%, *Elphidium gerthi* with 1 to 10%, *Nonionella stella* with 0 to 6%, *Planorbulina mediterranensis* with 0 to 23% and *Quinqueloculina stelligera* with 0 to 6%. An exception was *N. stella* which showed two peaks of abundance at ca. 1100 and 900 Cal yr BP (Fig. 4.9).

2) Species with a lower abundance from the core base to ca. 1400 Cal yr BP, and increased abundance from this level to the core top (ca. 200 Cal yr BP) (Fig. 4.9). Examples are *Ammonia beccarii* with abundances from 2 to 10%, *Bolivina ordinaria* with 5 to 29% (with different trend than previous cores), *Bulimina aculeata* with 0 to 9%, *Bulimina marginata* with 0 to 6%, *Eggerelloides scaber* with 0 to 14%, *Elphidium excavatum* with 0 to 6% and *Hopkinsina atlantica* with 0 to 27%. *Eggerelloides scaber* and *A. beccarii* presented a peak of abundance with 14 and 10% respectively, around ca. 600 Cal yr BP.

All species were present in more than 50% of the samples, with the exception of *B. marginata*, *H. atlantica* and *E. scaber*, which appeared only in 30 to 50% of the samples, and particularly with small expression in the lower unit of the core. *Bolivina ordinaria*, *A. beccarii* and *E. gerthi* were present in all analysed samples. In the total assemblage it was not observed species whit abundance <5% present in all analysed samples (Appendix D).

The zonation based on the species with abundance >5%, produced two zones along core 8. The first zone C-2a, from ca. 5000 Cal yr BP (core base) to ca. 1350 Cal yr BP, and the second zone C-2b from this level to ca. 200 Cal yr BP (core top) (Fig. 4.9).

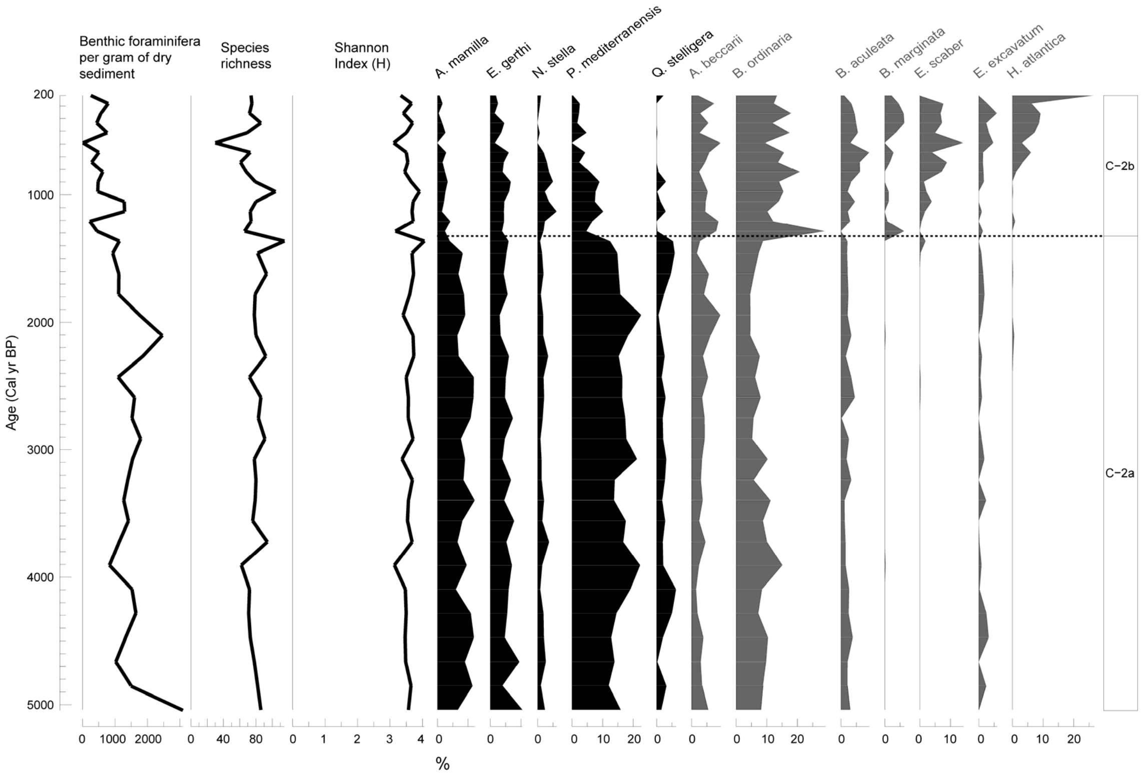


Figure 4.9 – Variation with age (Cal yr BP) in core 8 of: number of benthic foraminifera per gram of dry sediment, species richess, Shannon index diversity, relative abundances of benthic foraminiferal species, with abundance >5% in at least one sample and proposed faunal assemblages zonation.

The cluster analyses were performed using the 12 species with abundance >5% in at least one sample. These species comprised between 44 to 63% (average 52%) of all species found in the 38 analysed samples.

R-mode cluster analyses, with a cophenetic correlation of 0.9128, produced a dendrogram which distinguished two clusters (Fig. 4.10a). These clusters are closely linked with the groups formed by the individual distribution of most abundant species. Cluster I corresponded to abundance trend 1), Cluster II to trend 2), both described above (Fig. 4.9).

Q-mode cluster analyses with cophenetic correlation of 0.7483, also produced two distinct clusters (Fig. 4.10b). Cluster A, with 23 samples, grouped all the samples from ca. 5000 to ca. 1360 Cal yr BP. Cluster B, with 15 samples, grouped samples from ca. 1300 to ca. 200 Cal yr BP (top core). Cluster A and B corresponded to zone C-2a and C-2b, respectively (Fig. 4.9).

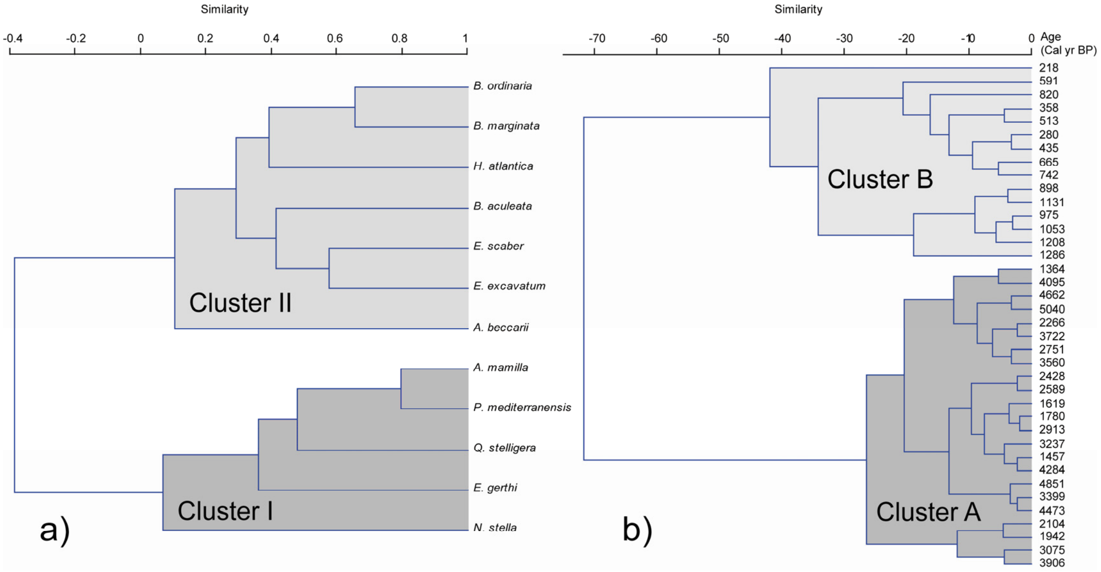


Figure 4.10 - Dendrogram classification resulting from cluster analyses based on 12 species with relative abundance >5% in at least one sample: a) Foraminiferal assemblages produced by R-mode analysis (correlation method joined by UPGMA); b) Samples associated produced by Q-mode analysis (Ward's method).

4.3.3.4. Comparison between environments

The highest values of foraminiferal population density were obtained on the middle shelf mud body (755 to 4543 specimens/g) and the lowest on the upper middle shelf transgressive bulge (16 to 320 specimens/g) (Fig. 4.11a).

The highest variations and values of species richness were observed on the inner shelf prodeltaic wedge (30 to 115 species) and on the upper middle shelf transgressive bulge (45 to 96 species). In contrast, the lower and more stable values were observed on the middle shelf mud body (46 to 74 species) (Fig. 4.11b). These results indicate that higher numbers of specimens are not related to higher number of species. The Shannon index diversity remained relatively constant in all three studied environments (Fig. 4.11c).

The middle shelf mud body environment contained the highest number of species with abundance >5% (17 species), representing 68 to 82% of all species found. In contrast, the middle shelf transgressive bulge environment presented the lowest number of species (11 species), representing only 40 to 56% of all identified species. On the inner shelf prodeltaic wedge environment, 12 species were identified with abundance >5%, which represent 44 to 63% of all species.

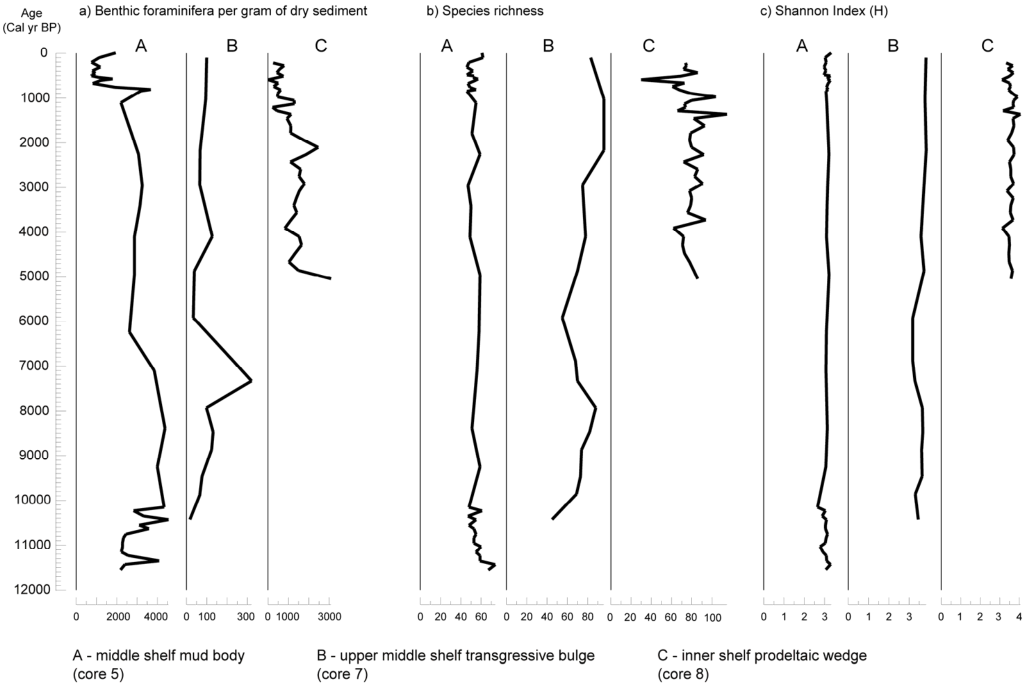


Figure 4.11 – Variation with age (Cal yr BP) of: a) benthic foraminifera per gram of dry sediment; b) species richness, c) Shannon Index. A, B and C represent the three environments analysed on the Guadiana continental shelf as: A- middle shelf mud body; B- upper middle shelf transgressive bulge and C- inner shelf prodeltaic wedge.

Asterigerinata mamilla, *B. ordinaria* and *B. aculeata* were the only species with abundance >5%, in all three analysed environments. However, they showed different abundances and behaviours in each environment (Fig. 4.12). *Bulimina elongata*, *C. laevigata* and *E. vitrea* were observed on the middle shelf mud body and on the middle shelf transgressive bulge. Only *E. vitrea* showed a different behaviour in both environments (Fig. 4.12). *Elphidium excavatum*, *N. stella* and *B. marginata* were the common species on the middle shelf mud body and on the inner shelf prodeltaic wedge environments. Only *E. excavatum* showed different trend in both environments. The remaining species with abundances >5 % were observed in each specific environment (Fig. 4.12).

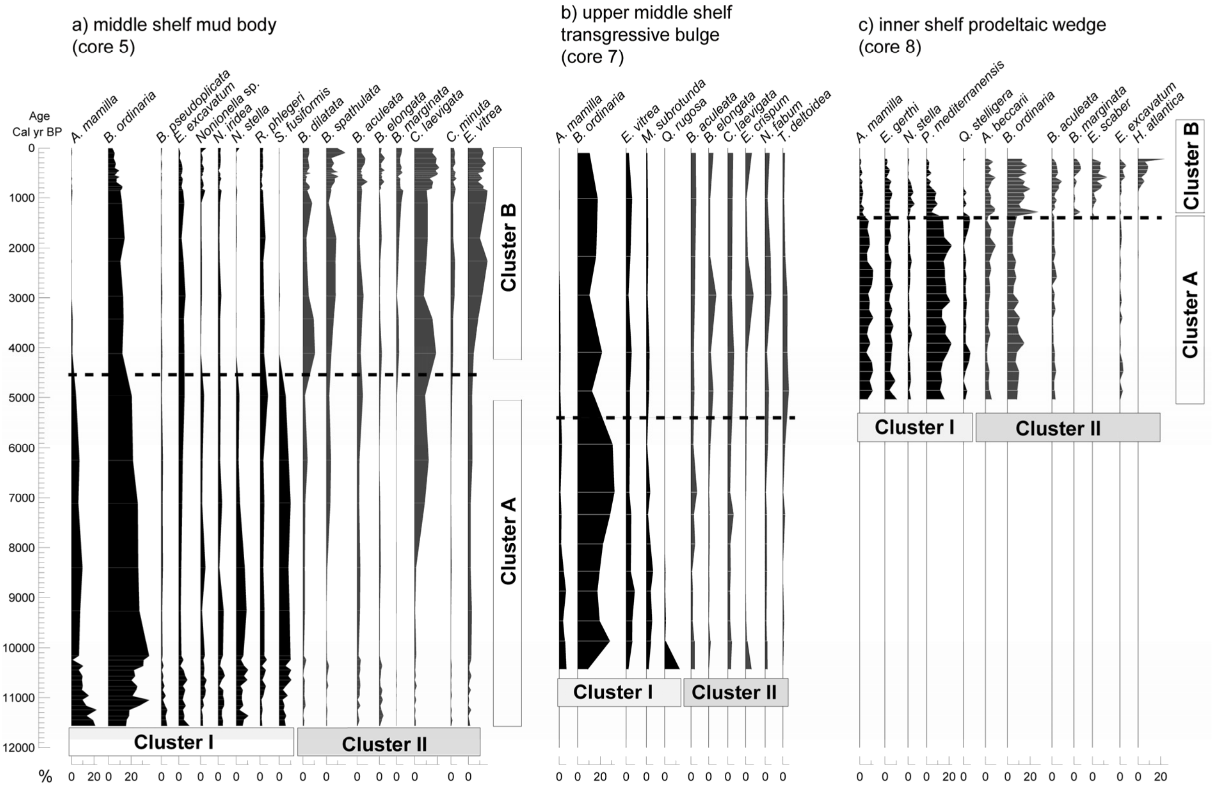


Figure 4.12 – Variation with age (Cal yr BP) of relative abundances of benthic foraminiferal species, with abundance >5% in at least one sample, for the three environments analysed on the Guadiana continental shelf: a) middle shelf mud body; b) upper middle shelf transgressive bulge, c) inner shelf prodeltaic wedge. The results obtained by R-mode (Cluster I and II) and by Q-mode (Cluster A and B) cluster analyses, when consistent, are also represented. The dash lines indicate the results obtained by zonation in each environment.

Bolivina ordinaria was the most abundant species throughout time on the upper middle shelf transgressive bulge. This species dominated the assemblage on the middle shelf mud body from ca. 11500 to ca. 4500 Cal yr BP (lower unit) and on the inner shelf prodeltaic wedge from ca. 1300 to ca. 200 Cal yr BP (upper unit) (Fig. 4.12). On the middle shelf mud body, *C. laevigata* replaced *B. ordinaria* from ca. 4500 Cal yr BP to Recent times (upper unit). On the inner shelf prodeltaic wedge *B. ordinaria* replaced *P. mediterranensis*, most abundant from ca. 5150 to 1400 Cal yr BP (lower unit) (Fig. 4.12).

R-mode cluster analyses (Cluster I and II) were closely correlated with the individual distribution of most abundant species, in the three studied environments of the Guadiana continental shelf (Fig. 4.12). The Q-mode cluster analyses (Cluster A and B) were closely linked with units obtained by zonation of the middle shelf mud body and on the inner shelf prodeltaic wedge (Fig. 4.12). On the upper middle shelf transgressive bulge the Q-mode cluster analysis results were not as distinct as those obtained by zonation, with samples from the lower unit being clustered in the upper unit and vice-versa.

4.4. Discussion

Three sediment cores from the continental shelf off the Guadiana River were analysed in order to better understand a set of characteristic environments on this shelf. Core 5 was extracted from the middle shelf mud body, core 8 from the inner shelf prodeltaic wedge, and core 7 from sands occurring on the upper middle shelf as transgressive bulge (Lobo et al., 2001; Gonzalez et al., 2004). These environments on the continental shelf differed in terms of depths (Fig. 4.1), sedimentary regime (Figs. 4.3 and 4.4) and benthic foraminiferal assemblages (Fig. 4.12). These environments also distinguish themselves by a nonexistence correlation between the population density and species richness (Fig. 4.11a, b). A normal marine shelf environment was also confirmed by the relatively constant values of Shannon index diversity (Murray, 2006) in all three environments (Fig. 4.11c).

A dominant fluvial origin of the sand fraction was observed in all three analysed environments through the abundance of quartz and the significant amount of mica and other terrigenous components (Fig. 4.4). An evolutionary description of the continental shelf in function of the age and the interpretation of each studied environment will be discussed.

4.4.1 Evolutionary stages

In the literature, ages are presented as calibrate or uncalibrated dates. In order to simplify the comparison of results in this study with the literature, a conversion table from radiocarbon years (yr BP) to calendar ages (Cal yr BP) (and vice versa) will be used, according to Roberts (1998).

4.4.1.1. From ca. 11500 to ca. 10000 Cal yr BP

The beginning of the Holocene was characterised by a fast sea-level rise, until ca. 7000-5700 Cal yr BP, when the rate of rise decreased substantially (e.g. Fairbanks, 1989; Stanley, 1995; Dias et al., 2000; Teixeira et al., 2005; Vis et al., 2008) (Fig. 4.13).

The global sea-level curve proposed by Stanley (1995) and the sea-level curve for the north Portuguese shelf (Dias et al., 2000) indicate a variation of 15 to 25 m water depth in the period between ca. 11500 to ca. 10000 Cal yr BP (ca. 10000 to ca. 9040 yr BP) (Fig. 4.13a). At the beginning of this period the mean sea levels were approximately 55 to 60 m below present and 40 to 35 m below present at ca. 10000 Cal yr BP (Fig. 4.13a). In contrast, the relative sea-level curve for the Lower Tagus Valley (west Portugal) points to mean sea level depths 40 and 22 m below present, around ca. 11500 and ca. 10000 Cal yr BP, respectively (Vis et al., 2008) (Fig. 4.13b).

At present fine-grained sediments occur on the continental shelf study area between 35 and 100 m water depth (Gonzalez et al., 2004). If similar conditions existed in the past, the base of core 5 would have been located in an area corresponding to the shallowest limit of fine-grained sedimentation. Core 7 would probably be located near the vicinity of the palaeo-mouth of the Guadiana River in a shallow marine environment. The obtained results seem to be more in accordance with the proposed sea-level curve of Vis et al. (2008) and Teixeira et al. (2005), in which the mean sea level would be located at shallower position in this region (Fig. 4.13b).

During this period, high sedimentation rates were recorded, in agreement with the observed by Nelson et al. (1999) near the study area. On the middle shelf mud body this period was characterised by the highest percentages of sand (Fig. 4.3a) and by the largest sedimentation rates, resulting in an accumulation of about 1.5 m of sediment (Fig. 4.2a). An increasing abundance of *B. ordinaria*, normally associated with high content of organic matter (Martins et al., 2006a) can be observed (Fig. 4.5). This is very likely to be associated with Guadiana River discharges at this time. Simultaneously, *A. mamilla* shows a decrease in abundance (Fig. 4.5) indicating a deepening sedimentary environment and a reduction in hydrodynamic levels. This is in accordance with Mendes et al. (2004) which described this species on the inner shelf off the Guadiana River up to 12 m water depth, and associated with a mixture of mud and sands.

At the upper middle shelf transgressive bulge (core 7) only the period between ca. 10420 and ca. 10000 Cal yr BP is represented. This was characterised by the lowest benthic foraminiferal population density (Fig. 4.11a-B), the lowest abundance of *B. ordinaria* and the highest of *Q. rugosa* through the core (Fig. 4.12b). *Quinqueloculina rugosa* (as *Cycloforina rugosa*) was described on the northeast margin of Gulf of Cadiz, with abundance of 4%, at 32 m water depth, associated with sands and high content of organic matter (Villanueva et al., 1999a). It seems that during this period *Q. rugosa* was the more opportunistic species of the assemblage.

4.4.1.2. From ca. 10000 to ca. 5000 Cal yr BP

The period from ca. 10000 to ca. 5000 Cal yr BP was characterised by the continuous fast sea-level rise, until ca. 7000-5700 Cal yr BP. Afterwards, the rate of rise decreased significantly (Fig. 4.13).

In the studied area, the fast sea-level rise led to an accelerated phase of infilling of the Guadiana Estuary, in the period between 9800 and 6500 yr BP (Boski et al., 2002) (ca. 10700 to ca. 7380 Cal yr BP). This accelerated phase began mainly with clays. Between 7500 and 7000 yr BP (ca. 8220 to ca. 7787 Cal yr BP) the central part of the estuary started to accommodate coarser sediments, partially introduced from the continental shelf (Boski et al., 2002).

The period of estuary infilling resulted in a reduction of sediments exported to the continental shelf. The consequent decrease of sedimentation coincides with the lowest sedimentation rates observed on the middle shelf mud patch (Fig. 4.2a). Furthermore, the progressive decrease of mean grain size (Fig. 4.3a-B), indicated that the fine-grained sediment were mainly exported to the shelf, while high retention of coarse-grained sediments remained inside the estuary.

Sediments were interpreted to reflect a deepening environment, with consequent increased water column, resulting in low hydrodynamic levels, although the influence of Guadiana River discharges was also detected. This was confirmed by the high abundance of opportunistic and/or highly adapted benthic foraminiferal species observed during this period (Fig. 4.12a).

The most abundant species found coexisting in this part of the core have different ecological requirements. Some of the species characterising this period are highly adapted to a specific environment, such as *A. mamilla*, that was described in shallow waters, associated with mixture of mud and sandy or sandy sediments (e.g. Jorissen, 1987; Samir and El-Din, 2001; Mendes et al., 2004). Other species are opportunistic and have been associated with high content of organic matter as *B. ordinaria* (Martins et al., 2006a) and *E. excavatum* also related with frequent resuspention of fine-grained sediments (de Nooijer et al., 2008). The abundance of *R. phlegeri* was also influenced by river discharges (Mojtahid et al., 2009) and described on muddy bottoms characterised by high organic matter content (Villanueva and Cervera, 1999b; Frezza and Carboni, 2009). Other species such as *S. fusiformis*, considered as an opportunistic life-strategy, highly adapted to environmental stress, predominated in areas subject to rapidly changing environmental conditions (Alve, 2003). This period could be interpreted as an environment in disequilibrium under the influence of a series of changing parameters, reflecting shifts in water depth, sediment supply and hydrodynamic levels.

On the upper middle shelf transgressive bulge, the impact of the Guadiana Estuary infilling only seems to show a visible influence in the period between ca. 7500 and ca. 7000 Cal yr BP. During this period, while sands still remain the dominant textural, an increase in fines was observed (Fig. 4.3b), probably as consequence of the retaining of most coarse sediments inside the estuary (Boski et al., 2002). However a temporal discrepancy of approximately 700 years exists between the estuary infilling period reported by Boski et al. (2002) and the one observed for this area of the continental shelf. This temporal difference could be indicative of the existence of a lag time for fine-grained sediments since leaving the estuary and after successive periods of deposition and remobilization, the sediments were deposited in the middle to outer shelf generating the mud body.

The formation of the 4 to 5 km wide and 4 km long transgressive bulge on the continental shelf, elevated 10 m in relation to adjacent areas and composed by muddy gravelly sands and muddy sands (Gonzalez et al., 2004), continues to be a interesting matter of discussion. Lobo et al. (2001) attribute its formation to a combination of reduced rates of sea-level rise and increased sediment yields to the shelf, probably associated with the cold event centred at 8.2 ka BP. Gonzalez et al. (2004) interpret this body as a result of a period of rapid sediment accumulation related to floods in the Guadiana River basin, probably associated with a transition from a dry cold period to a warmer more humid period.

On the Northern Hemisphere, particularly in Northern Europe, the 8.2 ka cooling event was recorded in many areas (e.g. Alley and Ágústsdóttira, 2005; Hald and Korsun, 2008; Kendall et al., 2008), however has not been widely observed in Southern Europe (Davis and Stevenson, 2007). On the Iberian Margin during the 8.2 ka event, a more pronounced cooling was observed on the northern margin, inferring evidence for a different response of the northern and southern Iberian Margin (Eynaud et al., 2009). In the lower Guadiana valley, palynological evidence points to generally warm, humid, oceanic conditions from ca. 9000 to ca. 5000 Cal yr BP, interrupted by a short-lived event associated with aridity conditions of wider regional significance with beginning at ca. 8000 Cal yr BP (Fletcher et al., 2007).

In the study area, from ca. 10000 to 5000 Cal yr BP relatively constant sedimentation rates (Fig. 4.2b), small variations in grain size (Fig. 4.3b), components of sand fraction dominated by terrigenous (Fig. 4.4b) and a low benthic foraminiferal population density were observed (Fig. 4.11a-B), indicating that the 8.2 ka event was not clearly recorded. Similar to what was observed on the middle shelf mud body the more abundant species in this environment were reported in the literature as being highly adapted or opportunistic. *Asterigerinata mamilla* and *B. ordinaria* presented a similar trend as on the middle shelf mud body. On the other hand, *E. vitrea* showed an opposite behaviour, being more abundant during this period in sandy sediments (Fig. 4.12b), indicating an opportunistic behaviour. This species was described in the Bay of Biscay middle shelf (80 m water depth), where river discharge was enhanced (Duchemin et al., 2007), and on the Guadiana shelf between 40 and 90 m water depth, in muddy sediments associated with low levels of water energy (Mendes et al., 2004). *Miliolinella subrotunda*, which is more abundant only in this environment, decreased in abundance during this period, pointing to environmental changes. This species was described on the west Portuguese shelf with abundances <2%, between 55 and 105 m water depth, associated with sediments having more than 75% of sand (Levy et al., 1995).

The high abundances of these species associated with sands, could indicate a shallower environment influenced by the Guadiana River discharges. The low population density observed during the beginning of this period (Fig. 4.11a-B), indicated that this area of the continental shelf was probably located on a shallower position. This area would correspond to a sedimentary environment similar to the present river mouth, where sands mainly composed by terrigenous components can be observed (Gonzalez et al., 2004).

These transgressive sediments seem to have a limited distribution and their environment is very complex. Their formation is probably related with a palaeodelta formation in the area of the bulge, which was possibly formed during different phases of lowstand. During sea-level rise, the palaeodelta would have migrated in landward direction. Furthermore and as consequence of coastline changes, the formation of terraces and coastal erosion would result in a possible input of coarse sediments to this area. The bulge constituted by coarser sediments would resist to erosion until present times and the fine-grained sediments would have been remobilised and accumulated in deeper areas with low hydrodynamic levels.

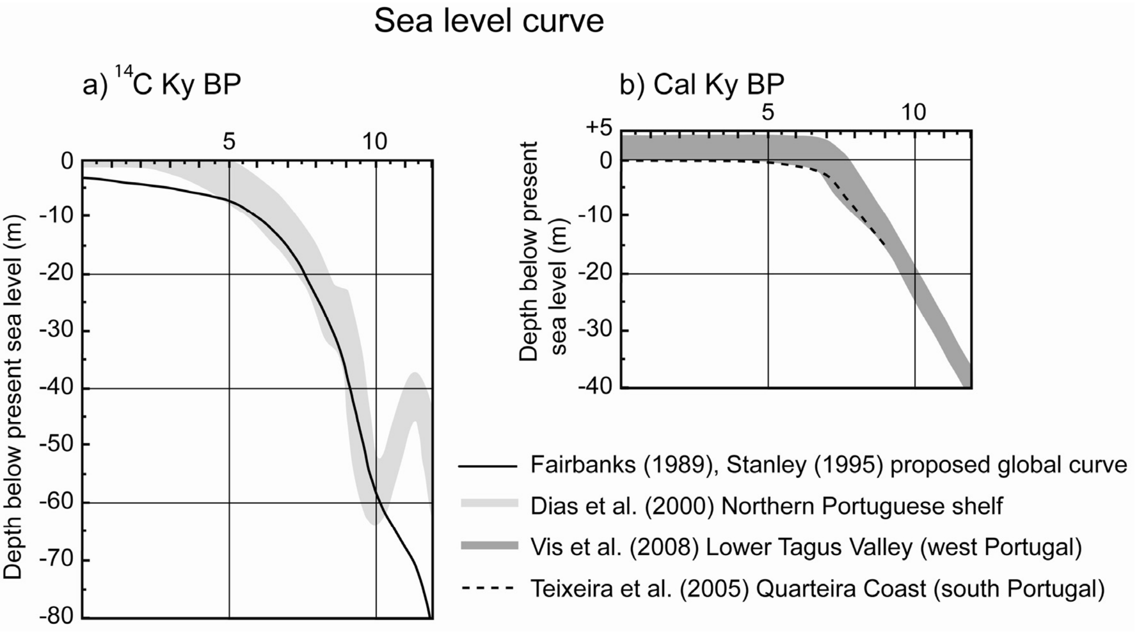


Figure 4.13 – Sea-level curves, proposed by different authors with respective location. Variation of depth below present sea level with: a) radiocarbon ages (Ky BP); b) calibrated age (Cal Ky BP).

4.4.1.3. From ca. 5000 to ca. 1500-1000 Cal yr BP

There is no worldwide or even regional consensus for the time at which the present day sea level was reached. Most of sea level studies indicated that it might have occurred at around 5700-5000 Cal yr BP (e.g. Fairbainks, 1989; Stanley, 1995; Peltier and Fairbanks, 2006; Dias et al., 2000; Zazo et al., 2008). On the other hand, local studies in the Lower Tagus Valley (Vis et al., 2008) and at the Quarteira coast (Teixeira et al., 2005) indicate that present day mean sea levels might have reached as early as 7000 Cal yr BP (Fig. 4.13b). However, these studies generally agreed that a fast sea-level rise occurred until approximately ca. 7000 Cal yr BP.

In this study, variations observed in components of the sand fraction and benthic foraminiferal assemblages indicate that important changes occurred in the study area at around 5000 Cal yr BP (Figs. 4.4 and 4.12). These results are in agreement with those obtained by Zazo et al. (2008) in southern Spain, and by Boski et al. (2002) in the Guadiana Estuary, where dates of ca. 5700-5000 Cal yr BP were calculated for the reaching of present day sea levels, in agreement with the results cited above. These authors observed however a phase of slower rise between 7000-6500 and 7380-5700 Cal yr BP, respectively.

The obtained results in the three environments of the continental shelf off the Guadiana River in the period between ca. 5000 to 1500-1000 Cal yr BP, indicate relatively stable climate and environmental conditions, after the reaching of the present mean sea level.

On the middle shelf mud body, this period reflects the depositional conditions that established the mud body, after the stabilisation of mean sea level. A decreasing trend of sand and mean grain size (Fig. 4.3a) could indicate the progressive disequilibrium of the estuary, with their progressive silted up, until reaching the equilibrium with the new base level (hysteresis of estuarine sedimentation). This process led to a decrease in the sedimentation rates on the shelf (Fig. 4.2a). This was reinforced by an increase of glauconite sediments observed during this period (Fig. 4.4a), normally associated with periods of no or little active sedimentation (e.g. Odin and Matter, 1981). Faunal changes occurred in the beginning of this period, with decreasing abundance of species more adapted to shallow environments and increased abundance of species adapted to deep environments, fine sediments with high organic matter content and low levels of water energy, although influenced by Guadiana River discharges. With exception of *B. elongata*, the other species that showed increase abundance during this period (Fig. 4.5) were described on the middle continental shelf off the Guadiana River at depths >40 m, associated with fine sediments and low levels of water energy (Mendes et al., 2004). Furthermore, species such as *B. spathulata*, *B. aculeata*, *B. marginata*, were reported in areas influenced by river discharges, in mud sediments characterised by high organic matter content (e.g. Donnici and Barbero, 2002; Frezza and Carboni, 2009; Mojtahid et al., 2009). *Cassidulina laevigata* and *B. marginata* were also associated with fresh organic matter with high nutritious value (de Rijk et al., 2000). This indicates that the abundance of these species were not only affected by the establishment of a new deep environment after reaching the present-day mean sea level, but also by increasing contribution of organic matter, that could be related with high river discharges or with productivity changes. This interpretation is in accordance with Burdloff et al. (2008) which observed in core 5, during the postglacial transgression an increasing contribution of fine-sized marine organic matter and the enhancement of terrestrial supplies during the upper Holocene.

On the upper middle shelf transgressive bulge, low benthic foraminiferal population density, high species richness (Fig. 4.11) and only eight species with abundance >5% were observed. This area of the continental shelf is more elevated than the surrounding shelf, and is mainly composed by sands and influenced by Guadiana River discharges.

Despite the decreased abundance, *B. ordinaria* remains as the most abundant species (Fig. 4.12b), indicating this to be the most opportunistic species of the assemblage. However, six more species with different ecological requirements presented increased abundance during this period. These species were *B. aculeata* normally associated with low levels of oxygen (e.g. Murray, 2006). *B. elongata* and *N. fabum* related with sediments with high content on mud (Mendes et al., 2004). Or species as *C. laevigata* associated with fresh organic matter with high nutritious value (de Rijk et al., 2000), preferentially marine organic detritus (Mojtahid et al., 2009). With the exception of *Textularia deltoidea* described on the Portuguese shelf, in all regions at different water depths (Levy et al., 1995), all the remaining species were described on the continental shelf off the Guadiana River with abundances >5% by Mendes et al. (2004). However, these authors observed these species at different water depths and in different environments. For instance *E. crispum* was described at depths <12 m and *C. laevigata* at depths >95 m and associated with different types of sediments (Mendes et al., 2004). The occurrence of these species, with different ecological requirements, indicates that the sandy substratum was the most important factor controlling their abundance.

Apparently relatively low constant sedimentation rates were observed from ca. 5000 to 1500-1000 Cal yr BP (Fig. 4.2b). However, the datings were based on benthic foraminifera and old sediments from the core top could have been colonised by most recent benthic foraminiferal species, given the idea of modern sedimentation.

The obtained results left open questions and further investigation must be developed in this area of the continental shelf, in order to better understand the formation of this complex environment.

The sedimentary sequence retrieved from the inner shelf prodeltaic wedge reflects the environmental conditions achieved after the attainment of the present mean sea level. Here, the sediments belonging to this environment were interpreted as representative of a depositional unit formed under the direct influence of the Guadiana River. The description by Strabo (Geographica, III, 1, 9) of the southern Iberian Peninsula reports the existence of two distributaries of the Guadiana Delta around 2000 Cal yr BP. This description, together with geomorphologic evidence, indicated that the easternmost distributary of the Guadiana estuary (probably in the present day area of Isla Cristina) may have been responsible for direct river discharge into the location of the present-day prodeltaic wedge. This interpretation was supported by the similar percentages of the fine and coarse fractions (Fig. 4.3c), by relatively constant percentages of all components of the sand fraction (Fig. 4.4c) and by high abundance of benthic foraminiferal species characteristic from shallow and sandy environments (Figs. 4.9 and 4.12c). Species such as *A. mamilla* and *P. mediterranensis* were described with the highest abundances on the Guadiana shelf, in shallow waters up to 12 m, influenced by fair-weather waves (Mendes et al., 2004). *Elphidium gerthi* (identified as *Cribrononion gerthi*) was described from 12 to 40 m water depths, in areas only influenced by storm waves (Mendes et al., 2004). These species were also described in sediments with high content on sand (Pujos, 1976; Villanueva and Cervera, 1999a; Mendes et al., 2004).

4.4.1.4. From ca. 1500-1000 Cal yr BP to Recent times

On the middle shelf mud body the period between ca. 1000 and ca. 800 Cal yr BP was interpreted as a transitional stage. This transitional stage was evidenced by the beginning of a gradual increased of bioclastic components (Fig. 4.4a), strong variations in benthic foraminiferal population density and the variations in benthic foraminiferal assemblages (Figs. 4.5, 4.11a and 4.12a).

On the upper middle shelf transgressive bulge the transitional period seemed to have been one of non-sedimentation, because no evident changes were observed on the sand components and benthic foraminiferal assemblages.

On the inner shelf prodeltaic wedge a transitional stage was observed between 1500 and 1200 Cal yr BP. This transitional period was more distinct and evidenced by a rapid increase of the fine fraction (Fig. 4.3c), a smooth increase in the terrigenous component (Fig. 4.4c) and important shifts in benthic foraminiferal assemblages (Figs. 4.9 and 4.12c). The highest species richness occurred during this period (Figs. 4.9 and 4.11b-C) indicating that during this transitional stage, species from the lower and upper units coexisted, until the establishment of the new environmental conditions. Furthermore, a higher abundance of species normally associated with high amounts of organic carbon was recorded, such as *B. ordinaria* (Martins et al., 2006a) and *B. marginata* (Donnici and Barbero, 2002), pointing also to environmental changes (Figs. 4.9 and 4.12c).

Palynological evidence in the lower Guadiana valley (Fletcher et al., 2007) indicates human influence on the landscape after ca. 4000 Cal yr BP, with intensification of human impact on woodland resources and a considerable anthropogenic influence on the landscape during the protohistoric periods (Iron age, Roman). During the Roman occupation of the Iberian Peninsula, between 218 BC and 411 AD (ca. 2168 to 1539 Cal yr BP), the Guadiana River was used to transport agricultural products such as wine (Alarcão, 1988), and copper from the exploration of São Domingos mines (Fabião, 1992). Between 1500 and 1000 Cal yr BP, climatic deterioration occurred in northern Europe characterised by a rapid cooling, defined as Dark Ages (Lamb, 1977). On the Tagus prodelta the period between ca. 400 to 700 AD (ca. 1550 to 1250 Cal yr BP - Dark Ages), could have been as warm as the Medieval Warm Period (MWP) (Lebreiro et al., 2006). Dryer continental conditions and increased coastal upwelling conditions occurred during the MWP on the Tagus prodelta (Abrantes et al., 2005; Lebreiro et al., 2006). However, on the inner shelf prodeltaic wedge the results for the period between 1500 and 1200 Cal yr BP (Figs. 4.3c and 4.9) seem to indicate an opposite sign to the Tagus prodelta. The occurrence of humid conditions allowed the transportation of large volumes of sediment to the continental shelf and consequent changes in the foraminiferal assemblages. It is unlikely that humid climate conditions were related with the suspended load of spring meltwater from snowy mountains or with a negative phase of the NAO, since the Tagus basin adjacent to Guadiana basin would be influenced in the same way.

A humid phases took place (between 1.7 and 1.0 ka BP) off the Israeli coast (Schilman et al., 2001), during the same period that probably occurred on inner shelf prodeltaic wedge. However, this relation is also unlikely, because the SE Mediterranean is mainly influenced by Indian Ocean monsoonal dynamics.

On the middle shelf mud body, the period between ca. 800 Cal yr BP and Recent times would be characterised by the reaching of the estuary equilibrium and the new base level on the continental shelf, reflecting the recent depositional conditions. This equilibrium was revealed by the deposition of fine sediments and relatively constant mean grain size (Fig. 4.3a), increase in sedimentation rates (Fig. 4.2a), and an increase of bioclastic components of the sand fraction (mainly foraminifera and other bioclasts) (Fig. 4.4a). Furthermore, this interval coincides with a lower number of benthic foraminifera per gram of sediment (Figs. 4.5 and 4.11a) and the relatively constant abundance of species characteristics for middle shelf environments. On the other hand, the semi-liquid horizon observed, the small variations in the sediment characteristics and the benthic foraminiferal assemblages could indicate minor climate changes and/or antrophic impact.

On the upper middle shelf transgressive bulge, the last ca. 1000 years were characterised by a relatively stable environment. The increasing of the fine fraction could be interpreted as recent fluvial derived sediments, representing the environment after reaching the estuary equilibrium and the actual environment on the middle continental shelf.

On the inner shelf prodeltaic wedge, after 1200 Cal yr BP and up to the core top, new climatic and environmental conditions were established. These new conditions were evidenced by higher percentages of the fine fraction (Fig. 4.3c), increased terrigenous components (Fig. 4.4c), lower number of benthic foraminifera per gram of dry sediment (Figs. 4.9 and 4.11a) and variations in benthic foraminiferal assemblages (Figs. 4.9 and 4.12c). A more stable environment, with increased deposition of fines and large availability of organic matter seemed to have occurred, evidenced by the higher abundance of *B. ordinaria* and *H. atlantica*, indicating that these species were the most opportunistic of the assemblage. *Hopkinsina atlantica* was described as a low opportunistic taxon (Ernst et al., 2002, as *H. pacifica*) with a preference for fresh food (e.g. Ernst et al., 2005; Diz and Francés, 2008) and *B. ordinaria* related with high content of organic matter (Martins et al., 2006a). On the Guadiana shelf these species were also associated with low levels of water energy and fine-grained sediments (Mendes et al., 2004).

Around ca. 600 Cal yr BP a change seems to have occurred, when the number of benthic foraminifera reached a minimum and some species such as *A. beccarii* and *E. scaber* presented their peaks of abundance. *Ammonia beccarii* is a typical estuarine species form from the Guadiana estuary (Ruiz et al., 2005) and *E. scaber* showed the higher abundance near the Guadiana River mouth (Mendes at al., 2004). Their highest abundance, associated with a smooth peak of gravel and sand (ca. 650 Cal yr BP), could be related to a wetter phase such as that identified by Abrantes et al. (2005) and Lebreiro et al. (2006) in the Tagus prodelta (western Iberian margin) and interpreted as the beginning of the Little Ice Age (LIA). In these studies negative NAO were correlated with precipitation-river input during cold periods and more persistent negative state or frequent extreme NAO minima occurred during the LIA. According to Dias et al. (2004), discharges from the Guadiana River in the last 50 years show a strong link with the NAO index, with negative values usually resulting in more rainfall and subsequent flooding in the river basin during winter months. Furthermore, large inter-annual variability in the flows of Tagus and Guadiana Rivers is largely modulated by the NAO phenomenon (Trigo et al., 2004). Deterioration of climate and intensification of rains would generate transportation of both coarser sediments and related foraminiferal species which are more abundant near the river mouth, to more distal areas of the inner shelf, where core 8 is located. These results are in agreement with those obtained by Bartels-Jónsdóttir et al. (2006) in the Tagus prodelta, where shifts in the benthic foraminiferal assemblages around 550 Cal yr BP were associated with increased river discharges.

On the inner shelf prodeltaic wedge upward 1400 Cal yr BP and the period between ca. 900 and ca. 420 Cal yr BP on the middle shelf mud body, followed the stabilisation of the fine fraction in these environments, showing the highest sedimentation rates (Fig. 4.2a, c). According to Boone and Worman (2007), after the dissolution of the Roman control of Iberia in the 5th century A.D. (ca. 1500 Cal yr BP) and over the next 500 years, particularly after the Muslim invasion of A.D. 711 (ca. 1200 Cal yr BP), settlement density increased six fold regarding the number of inhabitants during the Roman period.

Geoarchaeological evidence in the region of Mértola (approximately 70 km upriver from the estuary mouth) points to widespread erosion and soil loss after the later Medieval Islamic period (800-900 Cal yr BP), caused by the overuse of land (Boone and Worman, 2007). This probably led to the increase in the sediment exportation to the shelf and to the possible silting-up of the Guadiana eastern distributary. The reinforcement of the western distributary, with the transportation of greater amounts of sediments to the shelf, led to the formation of the present prodeltaic wedge. On the middle shelf, the establishment of the mud body where the higher rates of sedimentation were observed seems only to have occurred after the prodeltaic wedge formation. An estimated age of ca. 200 Cal yr BP at the core top on the inner shelf prodeltaic wedge was characterised by the high abundance of gravel material resulted from the lack of deposition of fine sediments. The presence of this material in an area of generally fine particle deposition is not fully understood but was considered as a lag deposit.

4.5. Conclusions

Three marine shelf environments were identified on the continental shelf off the Guadiana River during the Holocene: the middle shelf mud body (last ca. 11500 Cal yr BP); the upper middle shelf transgressive bulge (last ca. 10400 Cal yr BP) and the inner shelf prodeltaic wedge (last ca. 5000 Cal yr BP). These environments differed in terms of depth, sedimentary regime, benthic foraminiferal assemblages and inexistent correlation between benthic foraminiferal population density and species richness. However, a dominant fluvial origin of the sand fraction was observed in all three environments.

Four evolutionary stages were identified on the continental shelf:

1) From ca. 11500 to ca. 10000 Cal yr BP

On the middle shelf mud body (Core 5) this period was characterised by a deepening sedimentary environment, related with fast sea-level rise, and consequent reduction in hydrodynamic levels. This interpretation was confirmed by the largest sedimentation rates, the highest percentages of sand, increased abundance of the opportunistic species such as *B. ordinaria* and decreased of *A. mamilla* related with shallow sandy environments.

The upper middle shelf transgressive bulge (Core 7) was probably located in the vicinity of the palaeo-mouth of the Guadiana River, in a shallow marine environment, during the period between ca. 10420 and ca. 10000 Cal yr BP. This was showed by the high percentage of sand and the lowest benthic foraminiferal population density. During this period *Q. rugosa* was the most opportunistic species of the assemblage.

2) From ca. 10000 to ca. 5000 Cal yr BP

The middle shelf mud body reflected the reduction of sediments exported to the shelf, with low sedimentation rates and a mean grain size decrease. This reduction occurred as a result of the continuous and rapid sea-level rise and consequent accelerated phase of estuary infilling. The high abundance of opportunistic and/or highly adapted benthic foraminiferal specie, such as: *A. mamilla*, *B. ordinaria*, *E. excavatum*, *R. phlegeri* and *S. fusiformis* indicated an environment in disequilibrium under the influence of a series of changing parameters, reflecting shifts in water depth, sediment supply and hydrodynamic levels.

On the upper middle shelf transgressive bulge this period reflected a shallower environment, mainly constituted by sands and influenced by Guadiana River discharges. This interpretation was confirmed by the high abundance of species related with shallow sandy environments, such as *A. mamilla* and *M. subrotunda* and the opportunistic species *B. ordinaria* and *E. vitrea*. The beginning of this period corresponds probably an environment similar to the present river mouth. The formation of this transgressive bulge could be related to the palaeodelta of Guadiana River, formed during different phases of lowstand. However further research is needed to confirm this interpretation.

3) From ca. 5000 to ca. 1500-1000 Cal yr BP

On the continental shelf off the Guadiana River the present day sea level was reached around 5000 Cal yr BP, when drastic changes where observed in components of the sand fraction and benthic foraminiferal assemblages. During this period relatively stable climate and environmental conditions occurred in all studied environments.

On the middle shelf mud body this period reflects depositional conditions that established the mud body, after reaching the present mean sea level and the attainment of estuary equilibrium. This interpretation was confirmed by the decreased percentage of sand, decreased mean grain size and increase of glauconite sediments. Furthermore, increased abundance of *B. dilatata*, *B. spathulata*, *B. aculeata*, *B. marginata*, *C. laevigata*, *C. minuta* and *E. vitrea*, normally associated to middle shelf environments (depths >40 m), fine-grained sediments and low hydrodynamic levels, also confirmed this interpretation.

On the upper middle shelf transgressive bulge the high content in sands and the Guadiana River discharges, seem to be the most important factors controlling the benthic foraminiferal abundance. High number of species occurred during this period, but with low population density. *B. ordinaria* remains the most opportunistic species of the assemblage, despite the decreasing abundance. However species such as *B. aculeata*, *C. laevigata*, *E. crispum*, *N. fabum* and *Textularia deltoidea*, with different ecological requirements and associated to distinct environments, co-existed during the same period. These indicates that this is a complex environment of the continental shelf, and further investigation need to be developed, in order to better understand their formation and evolution.

The inner shelf prodeltaic wedge reflects the environmental conditions achieved after the mean sea level reached its present position. The sediments from this environment were interpreted as representative of a depositional unit formed under the direct influence of the easternmost distributary of the Guadiana River. Similar percentages of fine and coarse fractions and relatively constant percentages of all components of the sand fraction supported this interpretation. This was corroborated by the higher abundance of species characteristics from shallow environments, such as: *A. mamilla*, *E. gerthi* and *P. mediterranensis*.

4) From ca. 1500-1000 Cal yr BP to Recent times

On the middle shelf mud body, after a transitional period between ca. 1000 and 800 Cal yr BP, this environment reached an equilibrium and new base levels were established on the continental shelf, reflecting the mud body formation and the recent depositional conditions. This interpretation was supported by the deposition of fine sediments, relatively constant mean grain size, increase in sedimentation rates and increase of bioclastic components. Furthermore, this period coincides with a lower population density and the relatively constant abundance of species characteristics for middle shelf environments such as *B. dilatata*, *B. spathulata*, *B. aculeata*, *B. elongata*, *B. marginata*, *C. laevigata*, *C. minuta* and *E. vitrea*.

On the upper middle shelf transgressive bulge, the last ca. 1000 years were characterised by a relatively stable environment. The increasing of the fine fraction was interpreted as recent fluvial derived sediments, representing the environment after the reaching of the estuary equilibrium and the recent environment on the middle continental shelf.

On the inner shelf prodeltaic wedge, after 1200 Cal yr BP and extended up to the core top, new climatic and environmental conditions were established. These new conditions were evidenced by the higher percentages of the fine fraction, increased terrigenous components, lower benthic foraminiferal population density and variations in benthic foraminiferal assemblages. A more stable environment, with increased deposition of fine-grained sediments and large availability of organic matter seemed to have occurred, evidenced by the higher abundance of *B. ordinaria* and *H. atlantica*, the most opportunistic species of the assemblage.

Around ca. 600 Cal yr BP, on the prodeltaic wedge, a wetter phase, related with the beginning of the Little Ice Age may have been registered. This phase could also be associated with negative NAO values, which resulted in more rainfall and subsequent flooding in the river basin during winter months.

The intensification of human impact on the Guadiana River basin occurred during this period, with the intensification on the use of woodland resources, landscape exploitation, and the use of Guadiana River to transport agricultural and mining products. Also, the increased settlement density, widespread erosion and soil loss caused by the overuse of land, were responsible for the higher sedimentation rates of the Holocene. These factors associated with possible more humid climate conditions, led to an increase in sediment exportation to the continental shelf and to the possible silting-up of the Guadiana eastern distributary. The reinforcement of the western distributary, with the transportation of greater amounts of sediments to the shelf, led to the formation of the present prodeltaic wedge. On the middle shelf, the establishment of the mud body seems only to have occurred after the prodeltaic wedge formation.

Chapter 5

Comparison between recent (living) and Holocene distribution of benthic foraminifera

5.1. Introduction

The distribution of benthic foraminifera in modern and ancient sediments provides the basis for numerous studies documenting environmental changes over a range of temporal and spatial scales. Living benthic foraminifera are highly dependent on environmental conditions. They were used for studies in ecology and to monitor modern-day environmental change in shelf environments (e.g. Schmiedl et al., 1997; de Stigter et al., 1998; de Rijk et al., 2000; Fontanier et al; 2002; Samir et al., 2003; Duijnstee et al., 2004; Duchemin et al., 2005; 2007; de Nooijer et al., 2008; Mojtahid et al., 2009). In sedimentary records, the fossil assemblages were studied in order to reconstruct palaeoecological and palaeoceanographic conditions, and they were used for biostratigraphic correlation and age determination (e.g. Jiang et al., 1997; Evans et al., 2002; Oldfield et al., 2003; Abrantes et al., 2005; Morigi et al., 2005; Bartels-Jónsdóttir et al., 2006; Eiríksson et al., 2006; Martins et al., 2006a; Rossi and Vaiani, 2008). However, interpretations of the fossil record depend largely on the comparison with modern ecological relationships in a particular area (Murray, 2006).

Several studies have focused on the comparison between living and dead foraminiferal assemblages accumulating at the same site. General differences were reported between the living and dead fauna. These differences are controlled by taphonomic processes, with several stages of transition that include live and *post-mortem* processes and diagenetic effects (Martin et al., 1995; Murray, 2006). Life processes affect the contribution of tests to the sediment, which depend on rates of reproduction and rates and modes of death for each species (e.g. de Stigter et al., 1999; Jorissen and Wittling, 1999; Gooday and Hughes, 2002). *Post-mortem* processes alter the proportions of tests of different species in the sediment over a period of time. These processes include destruction of tests (e.g. loss of agglutinated and dissolution of calcareous tests), transport (e.g. bed and suspended load), bioturbation and time-averaging (dependent on the sedimentation rate) (e.g. Murray, 1986; Alve and Murray, 1997; Murray and Pudsey, 2004; Diz and Francés, 2009). Diagenetic effects may further alter the faunal composition beneath the taphonomically active zone (TAZ) in which the material is effectively fossilised.

A review of the distribution of living and dead foraminifera within cores revealed that the upper 10 cm are the most important taphonomically active zone for foraminifera. Foraminiferal preservation, however, depended on microhabitat, biogeochemical conditions within the sediments, and test composition (Walker and Goldstein, 1999). As long as the effects of taphonomic processes are taken into account, it is possible to make palaeoecological and other interpretations of fossil assemblages (Murray, 2006). However, the level of detail and accuracy of environmental reconstruction will inevitably decrease with progressively older fossil examples (Murray, 1991a; 2006).

In the Quaternary, a higher-resolution timescale can be established, when most of the species have modern representatives. Nevertheless, there are associations of species that do not occur in modern environments. This occurs in response to a range of factors including climatic and glacio-eustatic sea-level changes (Murray, 2006).

In the northern Gulf of Cadiz continental shelf (SW Iberian Peninsula), several studies have been focused on total (living+dead) benthic foraminiferal assemblages distributions (e.g. Galhano, 1963; Ubaldo and Otero, 1978; Levy et al., 1993; 1995; Villanueva, 2000; 2001; Villanueva and Canudo, 1998; 1999; 2008; Villanueva and Cervera, 1998; 1999; Villanueva et al., 1999a; 1999b; González-Regalado et al., 2001; Mendes et al., 2004). In contrast, only a few studies reported the distribution of benthic foraminifera in this area during the Holocene (e.g. Mendes et al., 2006; 2010). Furthermore, the comparison between living (stained) and Holocene distribution patterns, which is essential to validate the use of benthic foraminifera as proxies, is generally scarce in shelf environments and yet missing from the Gulf of Cadiz continental shelf.

The most abundant living benthic foraminiferal species (>5%) were compared with the faunas from sediment cores, collected off the Guadiana River in three different shelf environments: middle shelf mud body; upper middle shelf transgressive bulge and inner shelf prodeltaic wedge. Consequently, the main aims of the present study were: a) to evaluate taphonomic effects; b) to validate the most abundant benthic foraminiferal species as proxies of environmental factors in shelf environments and; c) to understand the Holocene palaeoenvironmental changes associated with sea-level changes, climatic variations and the anthropogenic impact at the study area.

5.2. Material and methods

5.2.1. Surficial benthic foraminiferal distribution

The distribution study of living (stained) benthic foraminiferal species was based on the analyses of surficial samples collected on the northern Gulf of Cadiz continental shelf between the Guadiana and Guadalquivir Rivers. The material and methods used to collect, process, and analyse those samples were previously described in Chapter 3, as well as the method used to create distribution maps for individual species.

5.2.2. Benthic foraminiferal distribution in sediment cores

Three sediment cores extracted from distinct Holocene environments on the continental shelf off the Guadiana River were investigated: core 5 from the middle shelf mud belt was collected at 72 m water depth and comprises the last ca. 11500 Cal yr BP; core 7 was retrieved from the proximal zone of a transgressive sandy bulge (Lobo et al., 2001; Gonzalez et al., 2004) on the upper middle shelf at 36 m water depth, and comprises the last ca. 10400

Cal yr BP; core 8 was taken on the inner shelf prodeltaic wedge, at 22 m water depth and comprises the last ca. 5000 Cal yr BP.

The material and methods used to collect, treat and subsample the selected cores were previously described in Chapter 4. Information on the age control points, the age models, and the distribution of most abundant species is also presented in Chapter 4.

5.2.3. Comparison between the distribution of benthic foraminifera in surficial samples and sediment cores

The distribution of living benthic foraminifera species, obtained in 18 surficial samples collected on the continental shelf off the Guadiana River, was considered for comparison with the sediment cores. These samples were collected in the same area, in the vicinity of the cores location, being representative of the different environments that were intended to be analysed and compared (Fig. 5.1). According to Ruiz and Navarro (2006), this area of the continental shelf is also influenced by upwelling, according to daily maps of nitrogen fluxes composition to the photic zone from April to September 1998 (Fig. 5.1).

The relative abundance of most abundant species (>5%) was calculated based on counting of at least 300 tests of benthic foraminifera. Only the species with relative abundance higher than 5% were used to compare between living (surficial samples) and dead/fossil assemblages (sediment cores). According to van der Plas and Tobi (1965), when counting of 300 specimens in a sample, the absolute error associated with a species that has an abundance of 5%, is 3%. This means that the true proportion of this species lies between 2 and 8% with 95% confidence, indicating that fluctuations included in the statistical error can occur when low percentages are considered.

The comparison between the relative abundance of benthic foraminiferal species in the three studied cores was made by using the psimpoll 4.25 and pscomb 1.03 programs (Bennett, 2005).

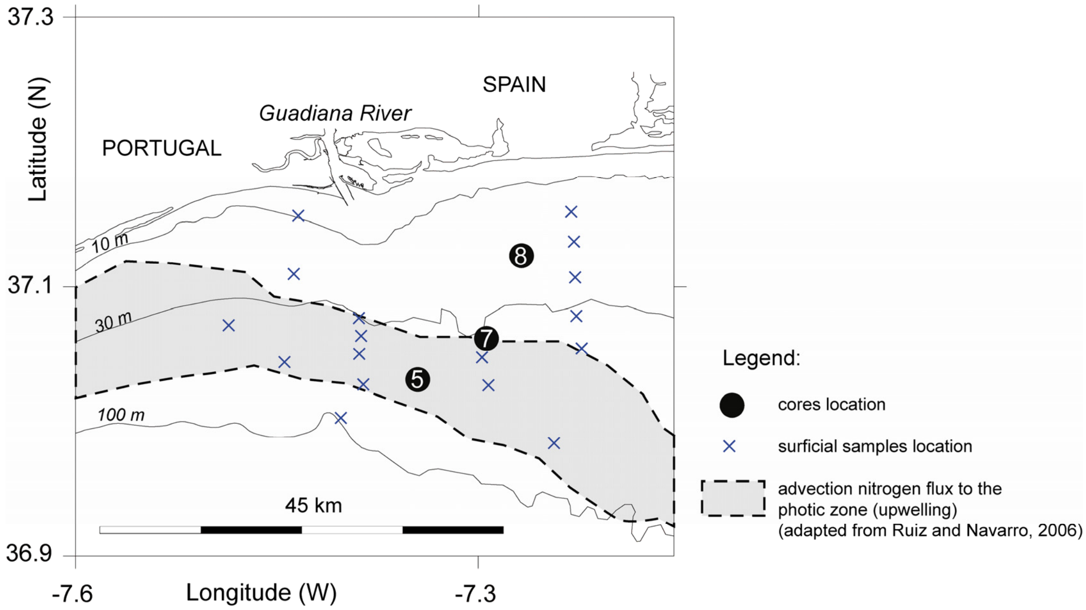


Figure 5.1 – Location of the surface samples and sediment cores on the continental shelf off the Guadiana River. The grey area limited by the dashed line indicates nitrogen flux to the photic zone (adapted from Ruiz and Navarro, 2006).

5.3. Results

Comparison between benthic foraminiferal species in the surficial samples and in the three sediment cores on the continental shelf off the Guadiana River, showed that the average number of species in the surficial samples was lower (106 species and 50 genera left in open classification) than in the sediment cores (153 species and 75 genera left in open classification). On the other hand, each sediment core represented a distinct situation: core 5 showed a lower average number of species (89 species and 54 genera left in open classification; Appendix B); core 7 had a similar average species number (104 species and 54 general left in open classification; Appendix C), and core 8 exhibited a higher number of species (136 species and 60 genera left in open classification; Appendix D).

However, 8 species and 2 genera left in open classification were only observed in the surficial samples and absent from the sediment cores (Appendix A, for taxa with more than one specimen). Within them, 7 taxa were agglutinated and 3 were calcareous and represented an average abundance of 4.52%. Furthermore, *Nouria polymorphinoides*, which is absent from the sediment cores, was the more abundant species among the surficial samples.

The variations of individual benthic foraminiferal species with relative abundance >5% in surficial samples and in sediment cores, were also compared. According with the variations in relative abundance, three different situations were considered:

1) Living species with abundance >5% that showed significant variation in surface samples close to the vicinity of core locations.
2) Living species with abundance >5% that didn't show variation in the vicinity of core locations, but showed significant variations within the cores.
3) Species with abundance >5% in sediment cores and low abundance in surficial samples.

5.3.1. Living species that showed different abundance in the vicinity of core locations

Ten species from the living assemblages on the Guadiana shelf showed relevant regional abundance gradients in the vicinity of core locations. Based on their abundance, these species were grouped by cluster analyses in distinct groups (Chapter 3, Fig. 3.7):

1) Species with higher abundance in the vicinity of river outflows.
2) Species with higher abundance between 30 and 100 m water depth.
3) Species with higher abundance generally in deep areas.

5.3.1.1. Species with higher abundance in the vicinity of river outflow

Bolivina ordinaria and *Hopkinsina atlantica* correlated their maximum abundances with river discharges, the limits of productivity areas, and were considered the most opportunistic in the assemblage. They were the only two species included in group 1 of the living assemblage (Chapter 3, Fig. 3.7).

The abundance of *B. ordinaria* in the top of the cores (total assemblages) was lower than in surficial sediments (living fauna). However the proportions of relative abundance observed in the total assemblages were coincident with the distribution patterns of the living fauna, with lower abundances in the top of core 5 (4%) than in the top of cores 7 (11%) and 8 (13%) (Fig. 5.2a).

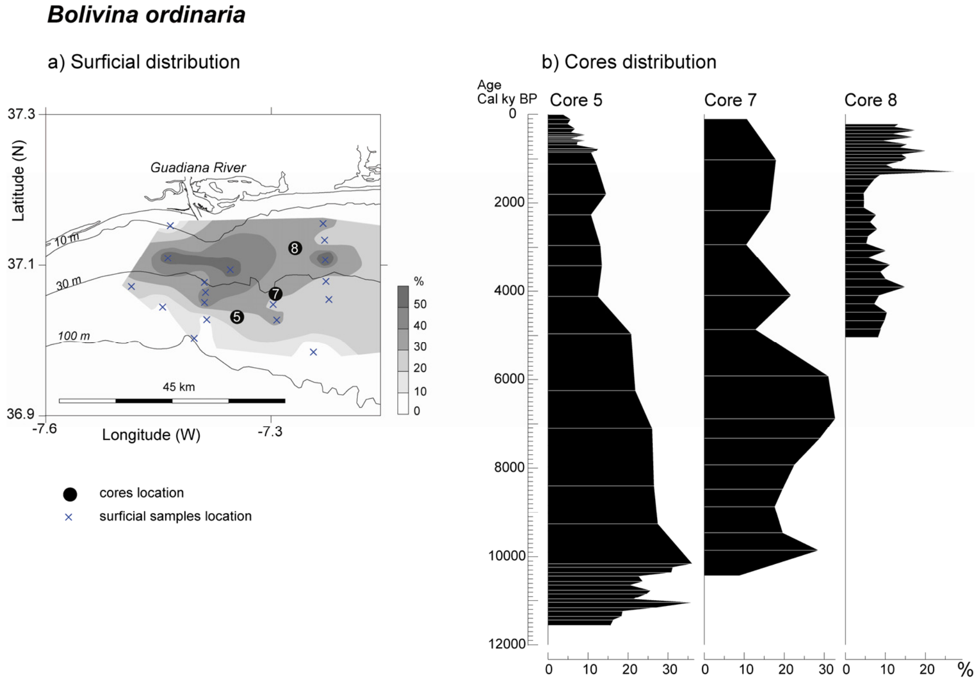


Figure 5.2 – Relative abundance of *Bolivina ordinaria*: a) surficial distribution; b) record in sediment cores.

As for the distribution patterns of living fauna, *B. ordinaria* was the most abundant species of the dead/fossil assemblages, found in sediment cores. Maximum (36.5%) and minimum (3.82%) abundances (average 16.8%) were obtained in core 5 at ca. 11000 Cal yr BP and in the core top, respectively (Fig. 5.2b). In general, cores 5 and 7, presented the same tendency of *B. ordinaria* abundance during the Holocene. The abundance of *B. ordinaria* generally increased from the cores base to ca. 10000 Cal yr BP. From this age to Recent times, it decreased progressively in both cores, with the highest decrease observed between 5000 and 4500 Cal yr BP. The only exception to this trend was observed on core 7, between ca. 8000 and 6000 Cal yr BP, when the abundance increased to more than 20% (Fig. 5.2b). The abundance of *B. ordinaria* in core 8 between ca. 5000 and ca. 1800 Cal yr BP, showed the same tendency as in cores 5 and 7, with low and relatively constant abundances. However, after a peak of 29.3% around ca. 1300 Cal yr BP, an inverse tendency of upwards increasing abundance was observed (Fig. 5.2b).

The abundances of *H. atlantica* in the top of the cores were in agreement with their surficial distribution. However, higher abundance (26.7%) was observed in the top of core 8 than in the surface sediments (5 to 10%) (Fig. 5.3a).

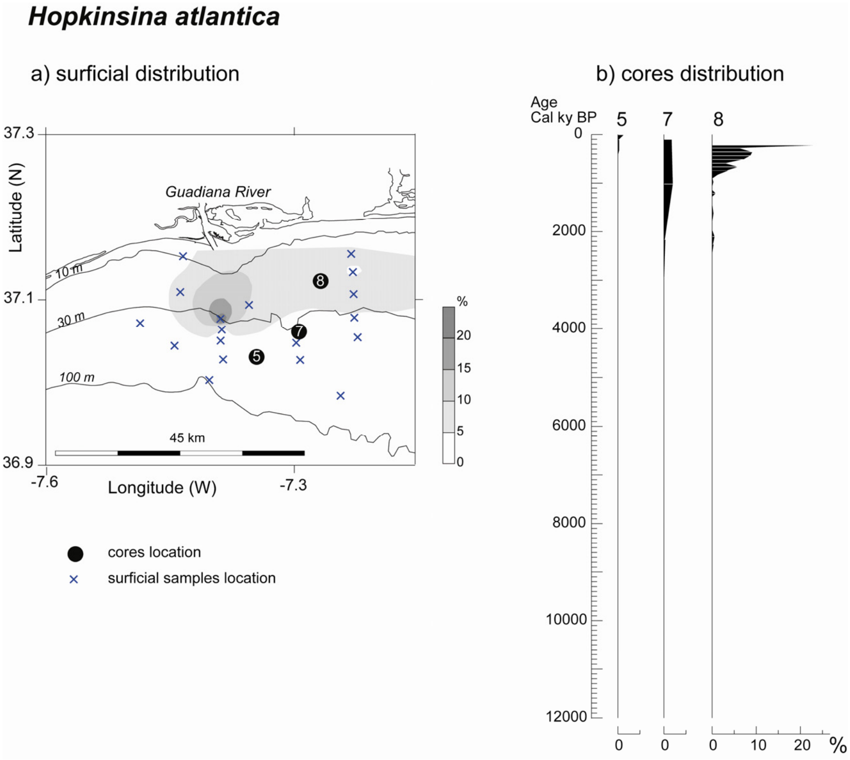


Figure 5.3 – Relative abundance of *Hopkinsina atlantica*: a) surficial distribution; b) record in sediment cores.

In the sediment cores, *H. atlantica* was observed only in cores 7 and 8 during the last ca. 2300 Cal yr BP, and in core 5 during the last ca. 320 Cal yr BP (Fig. 5.3b). Along cores 5 and 7 the abundance was less than 2%. In core 8, abundances lower than 1.3% were observed until ca. 700 Cal yr BP, and afterwards they increased towards the core top (ca. 200 Cal yr BP).

5.3.1.2. Species with higher abundance between 30 and 100 m water depth

Elphidium excavatum, *Epistominella vitrea* and *Rectuvigerina phlegeri* (Chapter 3, Fig. 3.15) showed their maximum abundance between 30 and 100 m water depth in the living assemblage, associated with fine-grained sediments.

The abundance of *E. excavatum* in the total assemblages (<2%) was lower than in the living fauna (Fig. 5.4a). Furthermore, no significant variation was observed in the abundance of total assemblages. In the earlier part of the records, the highest abundance (9.27%) was observed at the base of core 5 around ca. 11500 Cal yr BP, followed by a decrease to ca. 10000 Cal yr BP. Upward abundance variations were observed in all cores, without any consistent trend. An inverse trend was observed only for the last ca. 1000 Cal yr BP, when abundance decreased in core 5 and increased in core 8 until ca. 350 Cal yr BP (Fig. 5.4b).

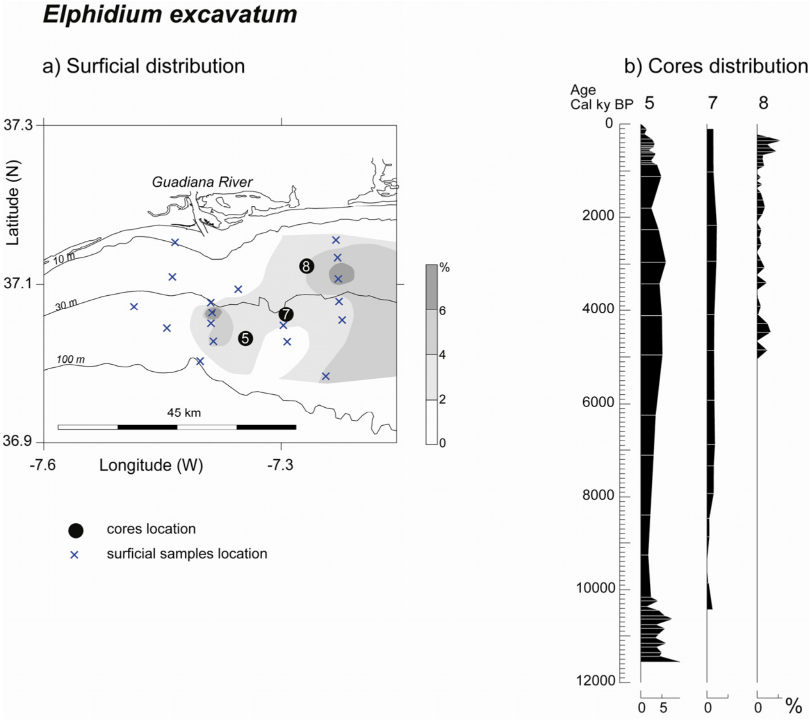


Figure 5.4 – Relative abundance of *Elphidium excavatum*: a) surficial distribution; b) record in sediment cores.

The abundance of *E. vitrea* in the top of the cores was in agreement with the surficial distribution. However, a higher abundance (12%) was observed on top of core 5 as compared to the ambient surficial sediments (2 to 4%) (Fig. 5.5). During the Holocene, *E. vitrea* showed distinct trends in each core. In core 5, low and relative constant abundances were observed between the core base and ca. 4000 Cal yr BP (Fig. 5.5b). From ca. 4200 Cal yr BP to Recent times, occurred the highest abundances but with fluctuations that followed a general increasing trend. In core 7, the abundance increased to a first maximum (4.3%) at ca. 9000 Cal yr BP. Upward, relatively constant values were observed. Core 8 showed abundances lower than 2.2% during this time interval, with slightly higher values over the last ca. 1300 Cal yr BP (Fig. 5.5b).

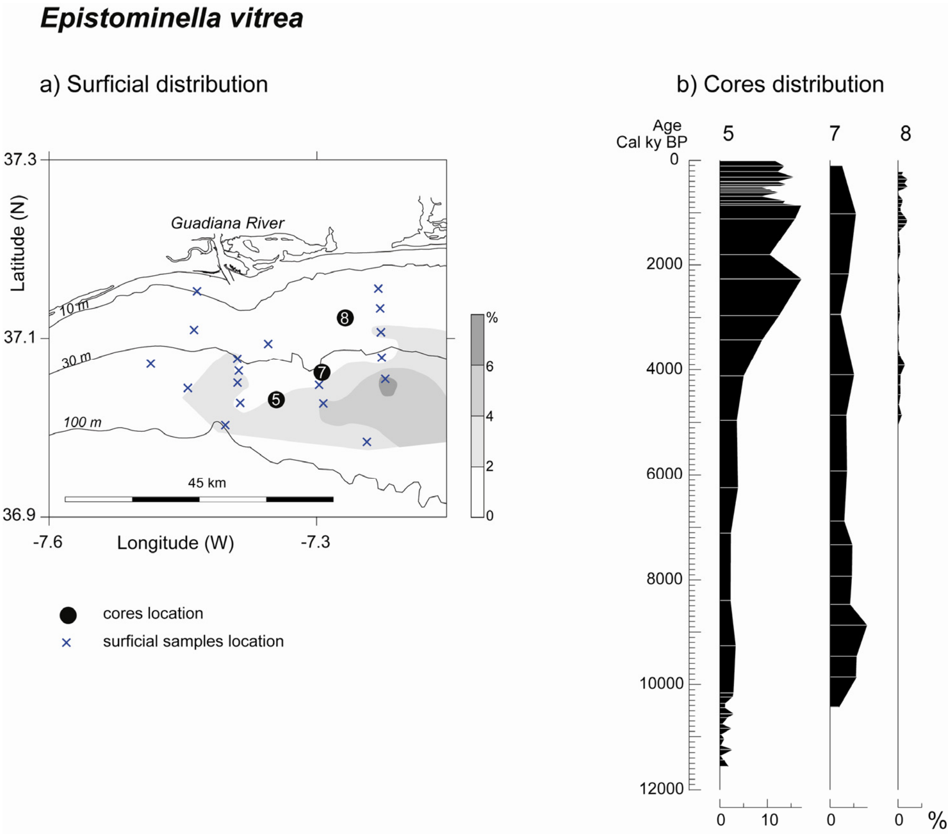


Figure 5.5 – Relative abundance of *Epistominella vitrea*: a) surficial distribution; b) record in sediment cores.

The abundance of *R. phlegeri*, as observed in the top of core 8, was in agreement with abundances in surface sediments. On the other hand, the abundances observed in top of cores 5 and 7 were lower than in the vicinity (Fig. 5.6). In core 5, a slight increase was observed from the core base to ca. 10000 Cal yr BP. From this age to ca. 5000 Cal yr BP, relatively low and constant abundances were observed in cores 5 and 7. The exception was around 5000 Cal yr BP in core 5, where the abundance reached a maximum value (7.0%). From this age to ca. 1000 Cal yr BP, cores 5 and 7 showed opposite trends, with a slight decrease in core 5 and increase in core 7. In core 8, relatively low variations were observed from ca. 5000 to ca. 1000 cal yr BP. In the last 1000 Cal yr BP, cores 5 and 7 showed increasing abundances, while core 8 showed irregular fluctuations (Fig. 5.6b).

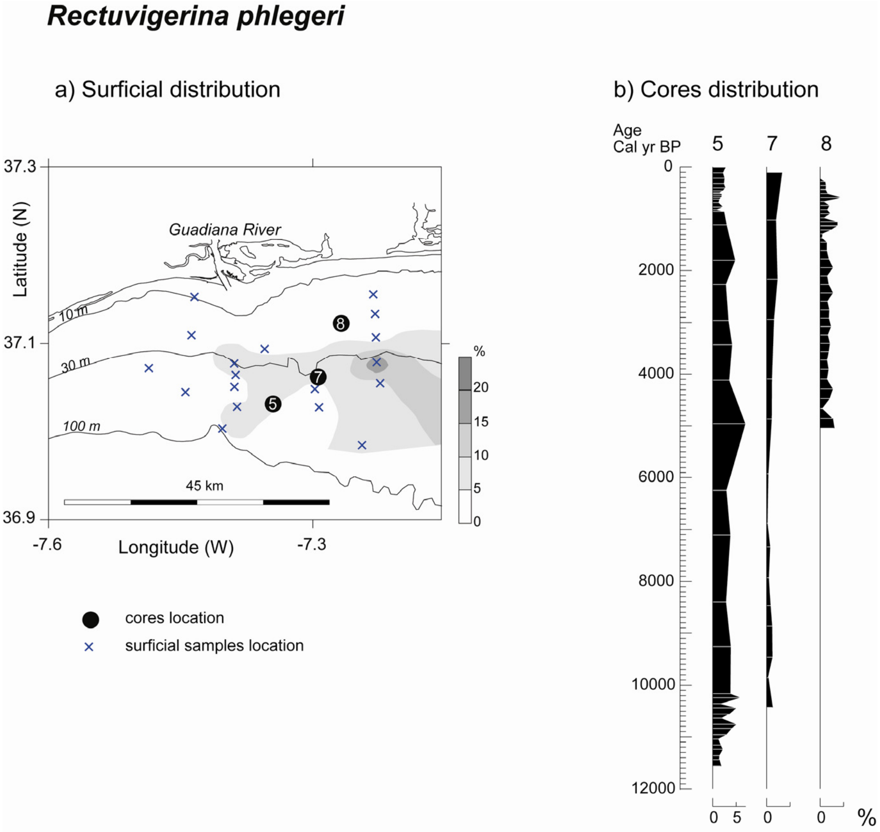


Figure 5.6 – Relative abundance of *Rectuvigerina phlegeri*: a) surficial distribution; b) record in sediment cores.

5.3.1.3. Species with higher abundance in deep areas

Brizalina dilatata, *Bulimina marginata*, *Nonionella iridea*, *Nonionella stella* and *Nonionella turgida* generally presented higher abundances in deeper parts of the continental shelf. In the study area, *Nonionella* species were related to generally lower temperatures and salinities. Furthermore, the abundance of *N. iridea* was also related to cold-water filaments (Chapter 3).

The abundance of *B. dilatata* in the top of the cores was in agreement with surficial abundances (Fig. 5.7a). However, a lower abundance was observed in the top of core 5 (5.25%) as compared to values from ambient surface samples (10 to 20%). In core 5, low and relatively constant abundances were observed up to ca. 5000 Cal yr BP (Fig. 5.7b). After this period, a higher abundance was observed until ca. 3400 Cal yr BP. Upward variations were observed, with a slight increase over the last ca. 600 Cal yr BP. In cores 7 and 8, low abundances (<3.5 and <2%, respectively) were observed throughout the core (Fig. 5.7b).

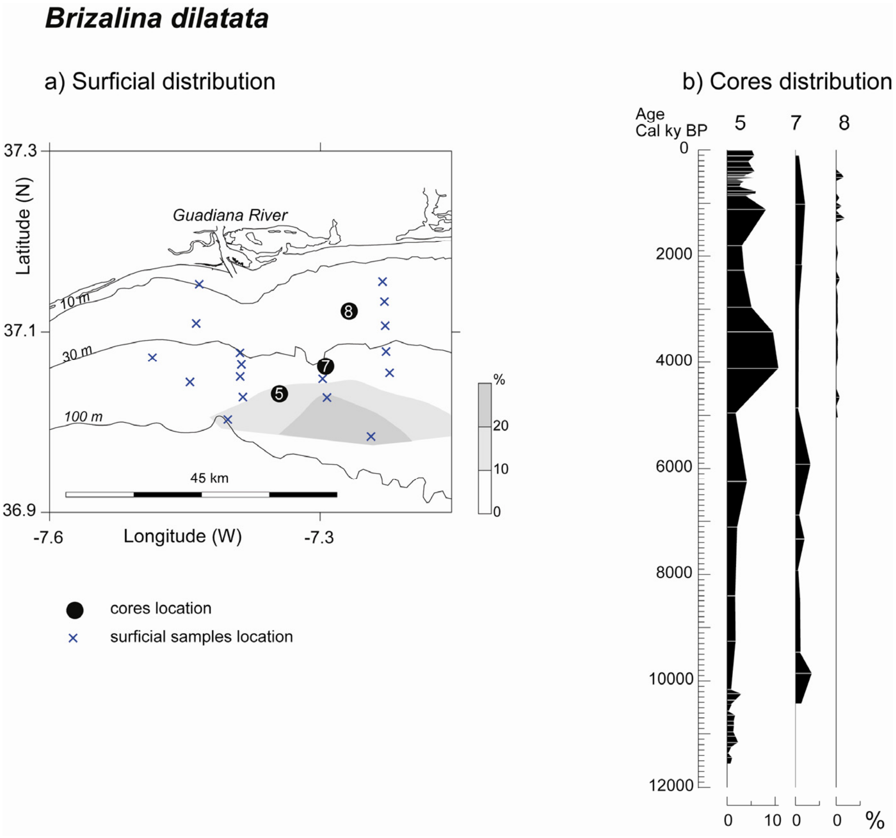


Figure 5.7 – Relative abundance of *Brizalina dilatata*: a) surficial distribution; b) record in sediment cores.

The abundance of *B. marginata* in the top of core 7 was in agreement with the ambient surficial abundances. However, the abundances in the top of cores 5 (5%) and 8 (2.35%) were higher than in the surrounding surface (Fig. 5.8a). *Bulimina marginata* was almost absent in core 5 until ca. 5000 Cal yr BP, throughout core 7 (<1.4%) and in core 8 (<0.3%) until ca. 1300 Cal yr BP (Fig. 5.8b). From these ages upward the abundances of *B. marginata* generally increased in cores 5 and 8. However, strong variations were observed during those intervals.

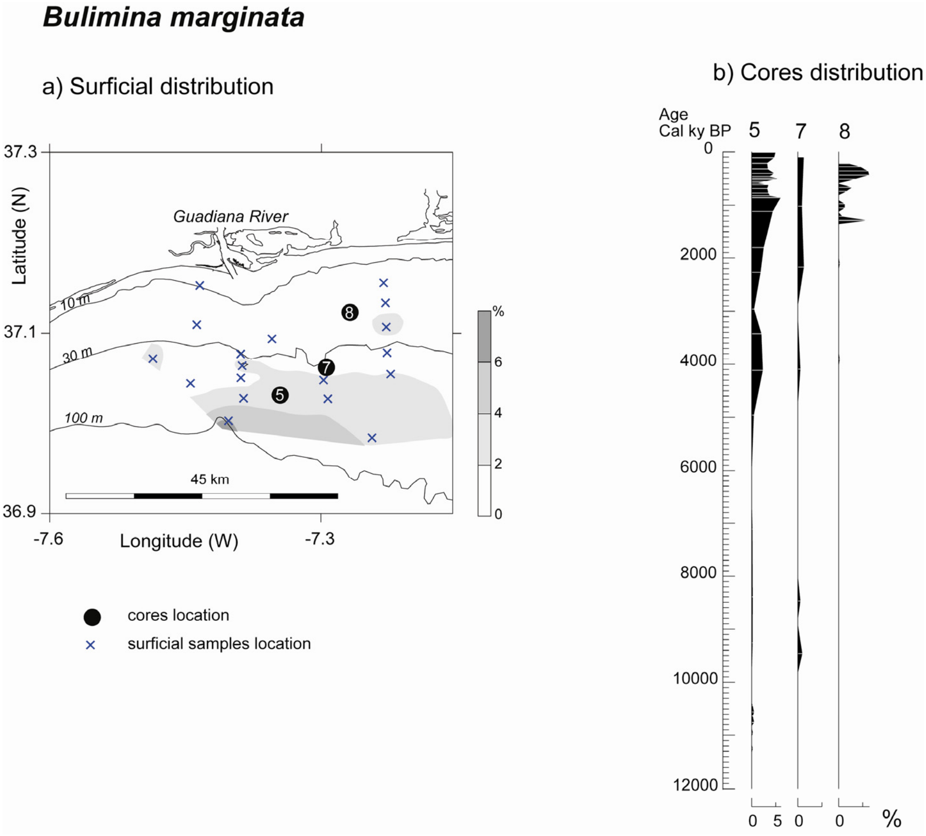


Figure 5.8 – Relative abundance of *Bulimina marginata*: a) surficial distribution; b) record in sediment cores.

The abundances of *N. iridea* in the top of cores 7 and 8 were similar to the surrounding surface. Nevertheless, the top of core 5 (2.4%) showed lower abundances than in the surface samples (Fig. 5.9). During the late Holocene, the abundance of *N. iridea* was relatively low in all cores. Higher abundances were observed in core 5 from ca. 11500 to ca. 9000 cal yr BP, with values around 5%. A general upward decrease in abundance was observed, with a slight increase in the last ca. 400 Cal yr BP (Fig. 5.9b). Core 7 showed an opposite trend, with the higher abundances from ca. 8000 to 6000 Cal yr BP. Core 8 showed abundances lower than 1.8% during this period, with the exception of an abundance peak of 4.8% at ca. 600 Cal yr BP (Fig. 5.9b).

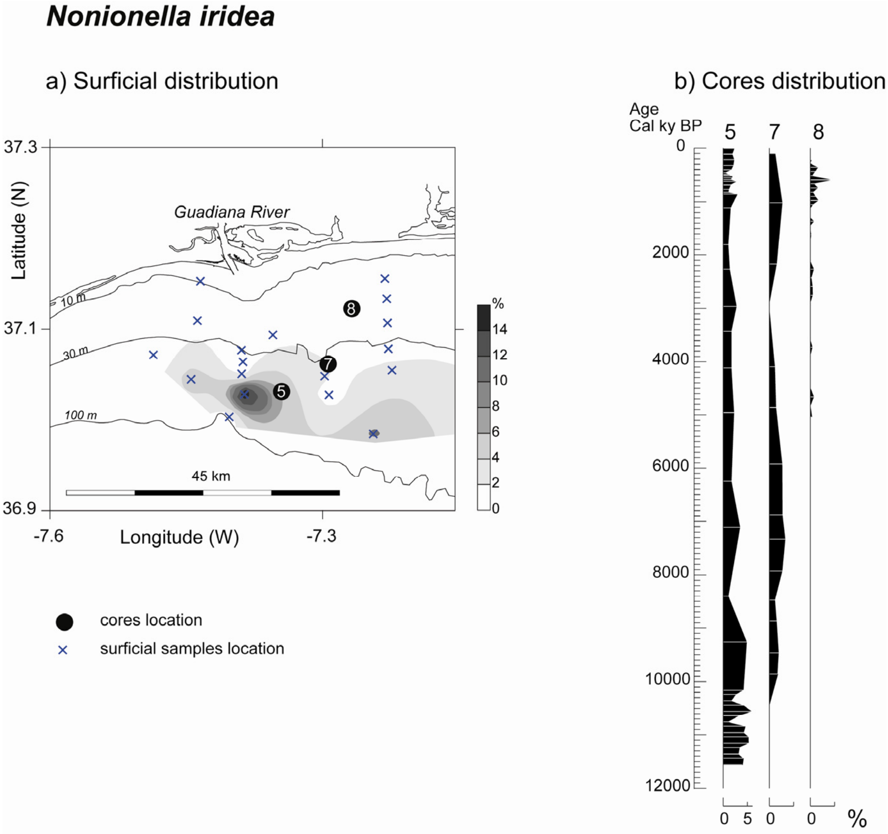


Figure 5.9 – Relative abundance of *Nonionella iridea*: a) surficial distribution; b) record in sediment cores.

The abundances of *N. stella* in the top of cores 7 and 8 were in agreement with the ambient surficial abundances. This species showed lower abundances in the top of core 5 (2.7%), as compared to the abundances in surface sediments (Fig. 5.10). The three analysed cores showed distinct variations of *N. stella* during the Holocene (Fig. 5.10b). A higher abundance was observed in core 5 from ca. 11500 to 8400 Cal yr BP, when a maximum value of 11% was attained. From this age on, the abundance decreased, and the species occurred just sporadically during the last ca. 5000 Cal yr BP. The only exception was a slight increase in the top of the core. In core 7, the abundance ranged from 0 to 2.8% (average 1.59%), without any well-defined trend. Core 8 showed low and relatively constant abundances (0.9 to 3.8%), from ca. 5000 to ca. 1400 Cal yr BP. From this age to the top of the core strong variations were observed, with two peaks of abundance at ca. 1100 and 900 Cal yr BP, with 6.25 and 5%, respectively.

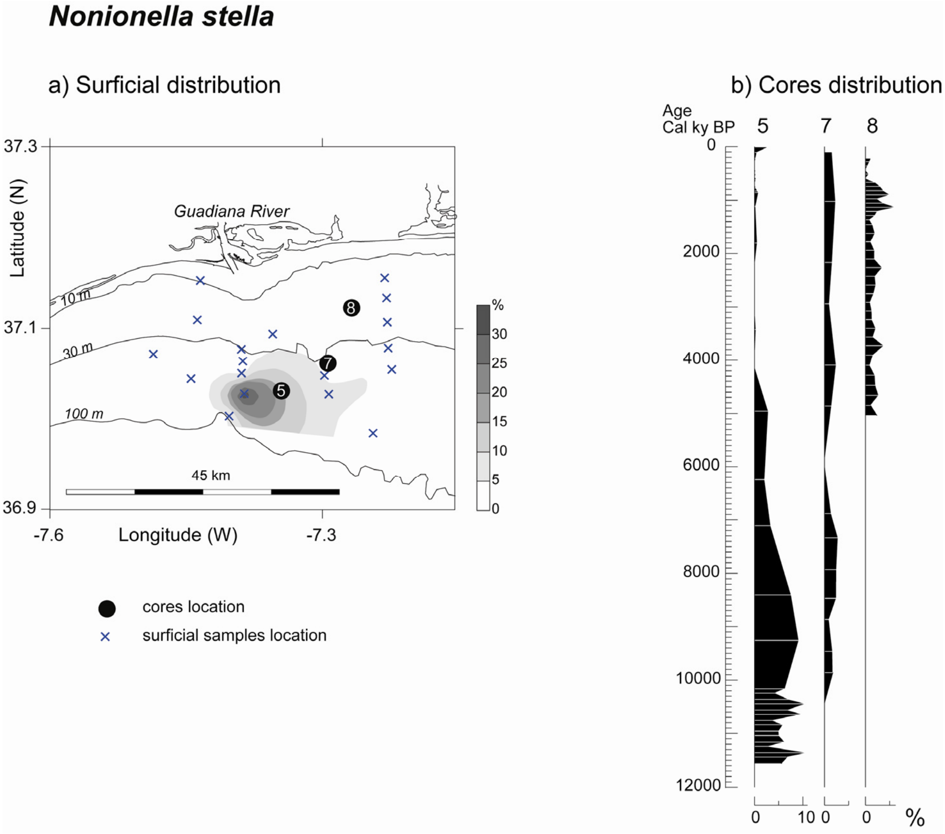


Figure 5.10 – Relative abundance of *Nonionella stella*: a) surficial distribution; b) record in sediment cores.

The abundances of *N. turgida* in the top of cores 5 and 8 were in agreement with the surface samples abundance. On the other hand, a lower abundance (0.52%) was observed in the top of core 7, in comparison with the 10% in a sample close by (Fig. 5.11). Along the three cores, this species showed low abundances (<2.9%) with irregular fluctuations during the Holocene (Fig. 5.11b).

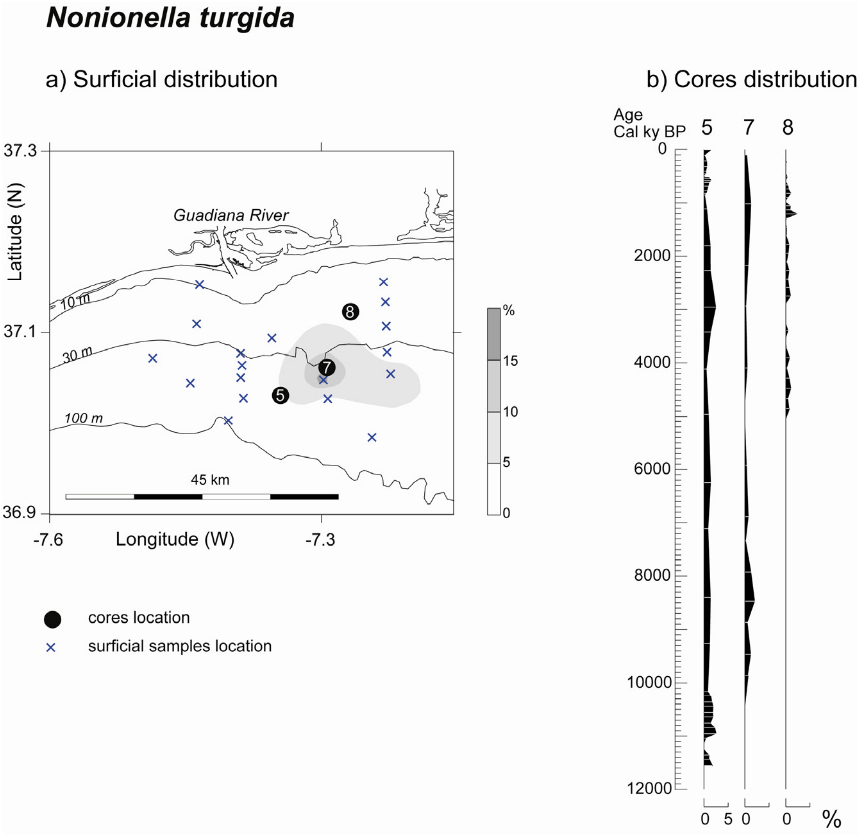


Figure 5.11 – Relative abundance of *Nonionella turgida*: a) surficial distribution; b) record in sediment cores.

5.3.2. Living species without variation in the vicinity of core locations

Sixteen living species with abundances >5% did not show variations in the vicinity of core locations. However, within these species, eight showed significant vertical variations in the sediment cores during the Holocene (Fig. 5.12, 5.13). Furthermore, these species were also grouped by cluster analyses in different groups, according with their surficial distribution (Chapter 3, Fig. 3.7):

1) Species with high abundance in shallow waters

2) Species with high abundance below 30 m water depth

5.3.2.1. Species with high abundance in shallow waters

Ammonia beccarii, *Eggerelloides scaber*, *Elphidium gerthi* and *Quinqueloculina stelligera* showed the higher abundances in shallow waters and their distribution was influenced differently by river discharges (Chapter 3). Generally these four species presented higher abundances in core 8, collected at a lower depth. However, distinct trends were observed through time (Fig. 5.12).

The abundance of *A. beccarii* in cores 5 and 7 showed a decreasing trend from the core base to ca. 10000 Cal yr BP (Fig. 5.12a). From this age to ca. 2000 Cal yr BP, low and relative constant abundances were observed in both cores. Upward opposite trends were observed, as core 5 showed strong variations with a general decreasing trend, whereas in core 7 an increasing trend was recognised. Core 8 showed higher abundances (1.5 to 9.5%) and strong variations during the last ca. 5000 Cal yr BP. Despite the lower abundance, this species was always present along the three cores (Fig. 5.12a).

The abundance of *E. scaber* was very low (<1%) in cores 5 and 7, and in core 8 until ca. 1400 Cal yr BP. It increased towards ca. 600 Cal yr BP, where a peak of 14% was attained. Further upwards, the abundance decreased again (Fig. 5.12b).

A lower abundance of *E. gerthi* was observed in core 5 (maximum 2.6%). Higher abundances were recorded from the core bases to ca. 6500 Cal yr BP in core 5 and ca. 7500 Cal yr BP in core 7 (Fig. 5.12c). Low abundances (<1%) were recorded in the younger sections of both cores. The exception was a slight abundance increase in core 5 during the last ca. 200 Cal yr BP, and in core 7 at ca. 5000 Cal yr BP. Core 8 showed higher abundances (1.5 to 10.5%), with variations along time. A general decreasing trend towards the top was observed (Fig. 5.12c).

Quinqueloculina stelligera was almost absent from the entire record of core 5 (Fig. 5.12d). In core 7, higher abundances (maximum 2.5%) were observed until ca. 6500 Cal yr BP. Afterwards, the abundance decreased to values <1%. In core 8 higher and strong variations were observed until ca. 1300 Cal yr BP. From this age onwards, the abundance decreased significantly (Fig. 5.12d).

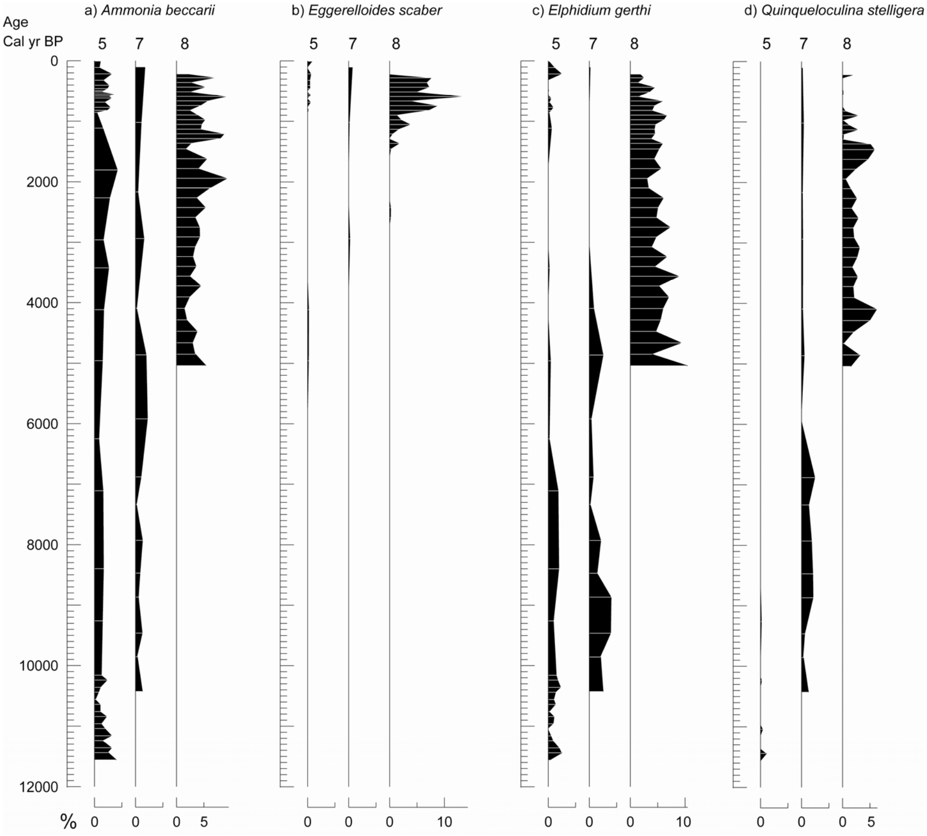


Figure 5.12 – Relative abundance variation with age (Cal yr BP) along cores 5, 7 and 8 from species with high abundance in shallow waters.

5.3.2.2. Species with high abundance below 30 m water depth

Bulimina aculeata, *Bulimina elongata*, *Cassidulina laevigata* and *Brizalina spathulata* were included in different groups of the living assemblages. However, they showed higher abundances below 30 m water depth (Chapter 3, Figs. 3.15a and c, 3.16b and 3.17b).

The average abundance of *B. aculeata* in each sediment core was around 3%, however, different trends were observed (Fig. 5.13a). In core 5 low and relatively constant abundances prevailed until ca. 5000 Cal yr BP. In core 7, a higher abundance was observed between ca. 8000 and ca. 6000 Cal yr BP. In core 8, the abundance showed significant variations without marked trends until ca. 1300 Cal yr BP, and afterwards an increase was observed reaching its maximum (9.6%). In core 5, from ca. 1800 Cal yr BP until ca. 650 Cal yr BP, an increase was also observed, and abundances reached their maximum value (9.3%).

In both cores, strong variations were superimposed on a general decrease thereafter (Fig. 5.13a).

The abundance of *B. elongata* showed distinct trends in each sediment core (Fig. 5.13b). In core 5, a general decrease trend was observed until ca. 10200 Cal yr BP. From this age to ca. 850 Cal yr BP, low variations were observed. High variations followed with a maximum (5.2%) attained at ca. 200 Cal yr BP. Along core 7, low and relatively constant abundances were observed, with intercepting maxima at ca. 5000, ca. 3000 and Recent times. Core 8 showed lower abundances of *B. elongata* (maximum 3.5%). However a general decreasing trend was observed until ca. 1300 Cal yr BP (Fig. 5.13b).

Along core 5, it was also possible to observe alternating fluctuations of *B. aculeata* and *B. elongata*. This means that when the abundance of *B. aculeata* increased the abundance of *B. elongata* decreased and vice-versa (Fig. 5.13a, b).

In contrast to the regional distribution pattern in the living assemblage, *C. laevigata* and *B. spathulata* showed higher abundances in the top of the cores than in adjacent samples. The abundance of these species showed similar trends in the three sediment cores. However, a higher abundance of *C. laevigata* was observed in core 5. These species were almost absent from core 8, with the exception of a slight increase of *B. spathulata* during the last ca. 1000 Cal yr BP (Fig. 5.13c, d).

In core 5, the abundance of both species generally increased after ca. 8000 Cal yr BP. Nevertheless, *C. laevigata* showed higher abundances at ca. 4500 to ca. 3500 and ca. 500 Cal yr BP (19 and 22%, respectively) (Fig. 5.13c). The abundance of *B. spathulata* reached a minimum (2.1%) at ca. 1100 Cal yr BP and a maximum (17.2%) at ca. 100 Cal yr BP (Fig. 5.13d).

In core 7 both species showed the same trends, with increased abundance at ca. 7300 Cal yr BP, ca. 4000 Cal yr BP and in the top of the core (Fig. 5.13c, d).

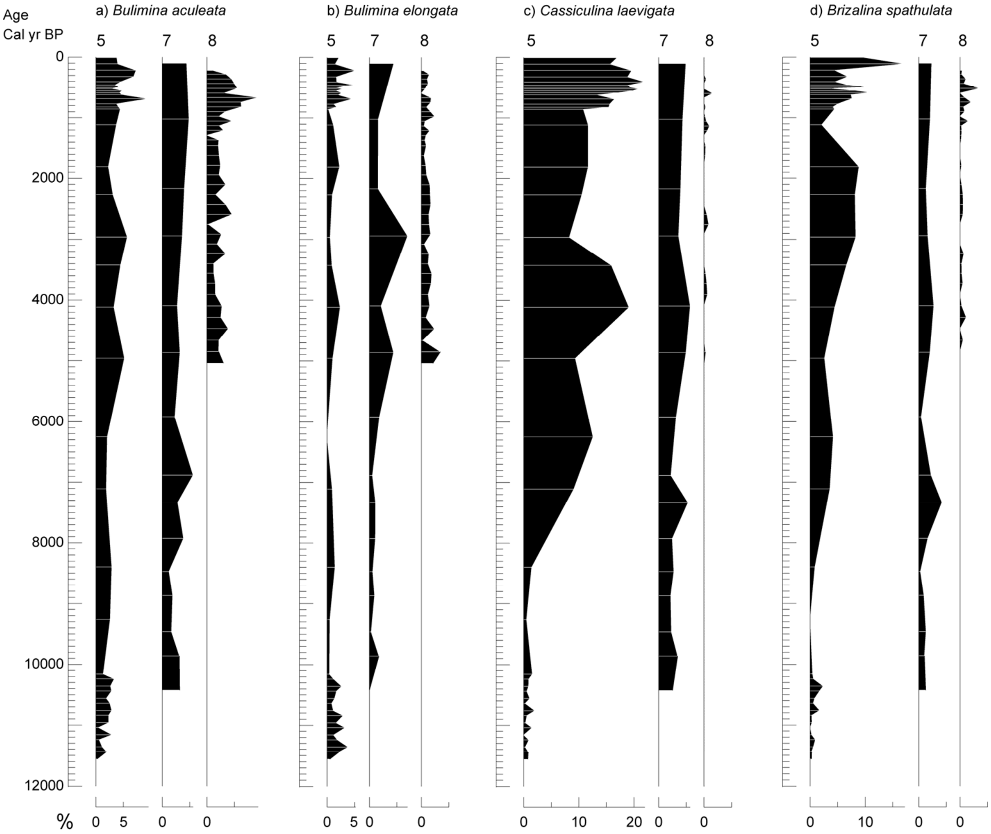


Figure 5.13 – Relative abundance variation with age (Cal yr BP) along cores 5, 7 and 8 from species with high abundance below 30 m water depth.

5.3.3. Species abundant only in sediment cores

Eleven species with low proportions of the living fauna (Appendix A) showed abundances >5% in the sediment cores during the Holocene (Fig. 5.14). In each core, these species showed different abundances and trends. For instance, *Asterigerinata mamilla* was the only species that showed abundance >5% in the three sediment cores (Fig. 5.14a). In contrast, four species were more abundant only in core 5 (Fig. 5.14b-e), five species in core 7 (Fig. 5.14f-j), and only one species in core 8 (Fig. 5.14k).

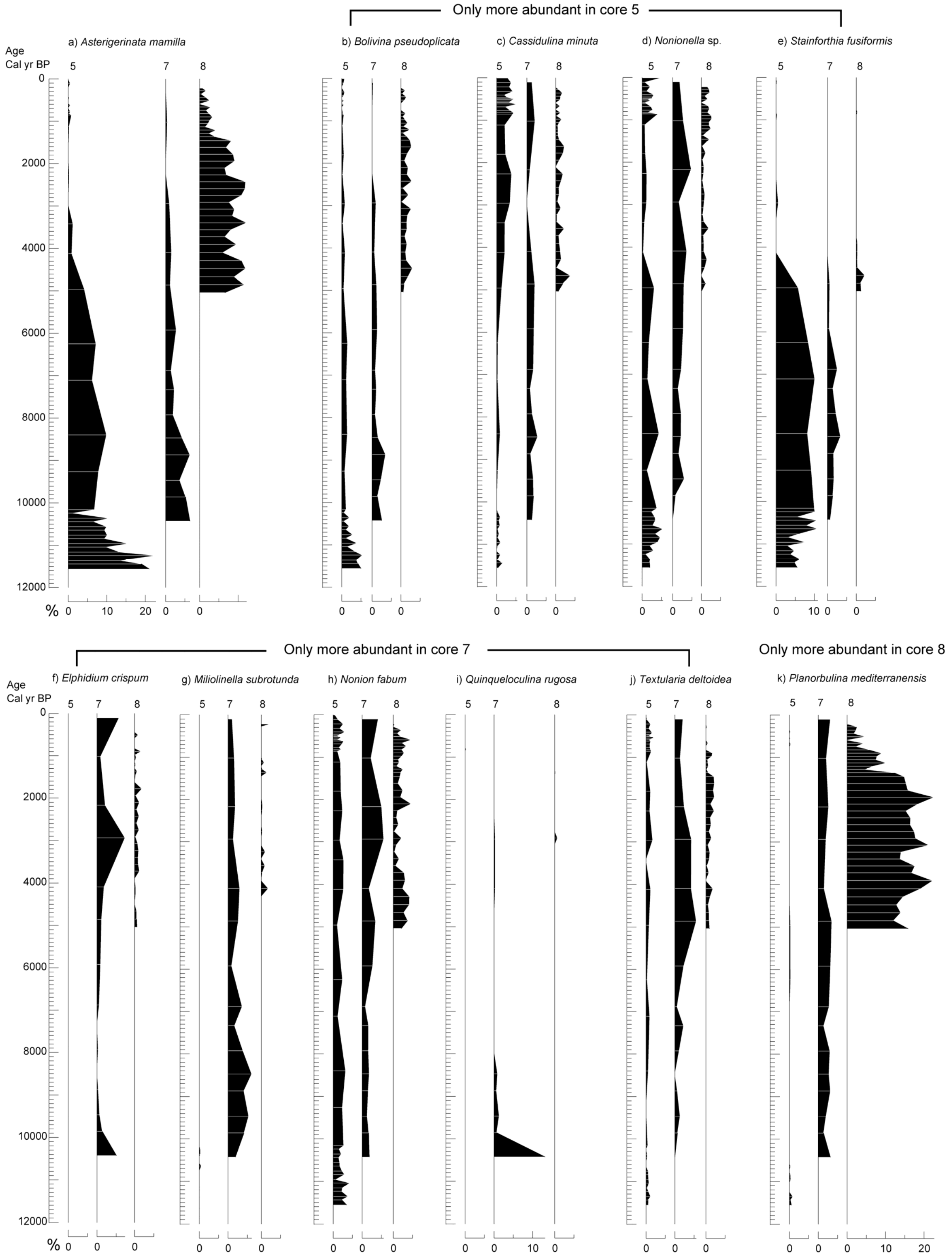


Figure 5.14 – Relative abundance variation with age (Cal yr BP) along cores 5, 7 and 8 from species more abundant only in sediment cores.

In general terms, the abundance of *A. mamilla* decreased from the core base to the top, however, each core showed a distinctive trend (Fig. 5.14a). In core 5, the higher decreased (21 to 1.2%) was observed between 11500 and 10200 Cal yr BP. From this age to ca. 8200 Cal yr BP a slight increase occurred, but afterwards the abundance decreased gradually. The same tendency was observed in core 7, with abundance decreasing gradually from ca. 10300 Cal yr BP (core base), onwards. The species almost disappeared around ca. 3000 Cal yr BP. In core 8, higher and relatively constant abundances were observed from ca. 5000 to ca. 1200 Cal yr BP. From this age to the core top, abundance decreased gradually (Fig. 5.14a).

Bolivina pseudoplicata, *Cassidulina minuta*, *Nonionella* sp. and *Stainforthia fusiformis* were the more abundant species in core 5. However, each species showed a different trend along the core (Fig. 5.14b-e). The highest abundance of *B. pseudoplicata* was observed near the core base and to the top it decreased gradually. The species almost disappeared around ca. 5000 Cal yr BP (Fig. 5.14c). *Cassidulina minuta* showed an opposite trend, it was less abundant until ca. 5000 Cal yr BP and increased upward thereafter (Fig. 5.14d). *Nonionella* sp. showed higher abundances until ca. 4500 cal yr BP and from ca. 900 Cal yr BP upwards (Fig. 5.14e). *Stainforthia fusiformis* showed increasing abundances (maximum 10%) until ca. 10000 Cal yr BP. From this age to ca. 5000 Cal yr BP, considerably high and constant abundances were observed. At 5000 Cal yr BP, the abundance decreased abruptly up to the core top, where it was very low (Fig. 5.14e).

In core 7 only *B. pseudoplicata* showed abundance decrease to the top. *Cassidulina minuta*, *Nonionella* sp. and *S. fusiformis* showed low abundances without well-defined trends. In core 8, *S. fusiformis* showed low abundances (<2.2%) around 5000 Cal yr BP, being absent upward (Fig. 5.14e). In this core and until ca. 1300 Cal yr BP, low relatively constant abundances were observed for the remaining three species. Towards the core top, *B. pseudoplicata* and *C. minuta* decreased, in contrast to the pattern showed by *Nonionella* sp. (Fig. 5.14b-d).

Elphidium crispum, *Miliolinella subrotunda*, *Nonion fabum*, *Quinqueliculina rugosa* and *Textularia deltoidea* were more abundant only in core 7 (Fig. 5.14f-j). *Elphidium crispum*, *N. fabum* and *T. deltoidea* showed similar trends, with lower abundances until ca. 5000 Cal yr BP and higher abundances upward. Furthermore, *M. subrotunda* showed an opposite trend. The higher abundance of *Q. rugosa* was limited to the base of the core. With the exception of *N. fabum*, the remaining species were absent or showed relatively low abundances (<2.2%) in cores 5 and 8.

Planorbulina mediterranensis was more abundant in core 8 from ca. 5000 to ca. 1300 Cal yr BP (12 to 22.6%). To the top of the core the abundance decreased (Fig. 5.14k). This species was almost absent along core 5 (<1%). In contrast, it showed low and relatively constant abundances in core 7 (1.4 to 3.5%).

5.4. Discussion

5.4.1. Species richness

On the continental shelf off the Guadiana River the comparison between species richness in modern (living faunas) and Holocene benthic foraminiferal assemblages, revealed different patterns according to the analysed shelf environment.

The differences between the living and dead assemblages have been reported by several authors in near-coastal environments (e.g. Murray, 1991a; Alve and Murray, 1997; Jorrissen and Wittling, 1999; de Stigter et al., 1999; Horton and Murray, 2006; Schumacher et al., 2007; Diz and Francés, 2009). These differences exist because living assemblages represent only the sampling time, whereas dead assemblages represent many generations added over a longer period of time (Murray, 1991a). This difference was evident when living assemblages were compared with the assemblages found in sediment cores, and a higher average number of species was observed in the cores.

However, the lower average number of species found in core 5, extracted from the present middle shelf mud body, indicate a relatively restricted environment which only allowed the existence of more adapted species. On the other hand, the higher average number of species found in core 8, from the inner shelf prodeltaic wedge, reflects the environmental changes occurred during the last ca. 5000 Cal yr BP, where species that are indicative of several environments occurred during different periods.

The majority of the fossil assemblages preserve a good record of the original environment (Murray, 2006). In this study, species comprising on average 95% of the living fauna, were more or less preserved in the fossil record. The remaining 5% were mainly fragile agglutinated species, for instance *N. polymorphinoides*, which have low fossilization potential. The differences between the living and dead assemblages start to occur in the first shallow centimetres and are attributed mainly to taphonomic effects, mainly dissolution of calcareous tests and loss of fragile agglutinated forms (e.g. Murray and Pudsay, 2004). These effects result in a reduction of the relative abundance and the number of species with low fossilization potential, in dead and fossil assemblages. However in the study area, the higher average number of species in the sediment cores indicates that the addition of dead assemblages represented by many generations over a longer period of time was the main factor controlling species richness.

5.4.2. Living versus total assemblages in the top of the cores

The living assemblages are ephemeral, change with time and are dependent on the environmental conditions. Dead assemblages in the same sample have the potential to provide information both of the long-term contribution of foraminiferal tests to the sediment and of the effects of taphonomic alteration (e.g. Murray, 1991a; 2006). These effects were observed in the top of sediment cores, where the percentages of living and dead assemblages were considered (total assemblages), and higher or similar relative abundances were observed for the same species in comparison with the living assemblages. This was showed by species, such as *H. atlantica* (Fig. 5.3), *E. vitrea* (Fig. 5.5) and *B. marginata* (Fig. 5.8), in different locations on the continental shelf.

In contrast, *B. ordinaria* (Fig. 5.2) and *E. excavatum* (Fig. 5.4) were the only species that showed higher abundances in surficial samples (living assemblages) than in the top of the three cores (total assemblages). This difference could be related with the vibrocore sampling method, that cause disturbance in the uppermost millimetres of surface sediments. In consequence of this disturbance, the comparison could have been made with a mixed fossil assemblage instead of total assemblages. Nevertheless, if it is assumed that the comparison was made between living and total assemblages, the higher abundance in the living assemblages could be related with the different sampling timing, February 2001 for surficial samples and June 2002 for sediment cores. In the case of *B. ordinaria* and *E. excavatum* the sampling could have coincided with a reproductive period, which could lead to higher abundances of live specimens recorded in February. Another possible explanation for the observed differences between living and dead fauna could be related with significant seasonal changes in the flux of organic matter. This differences were also reported by Jorissen and Wittling (1999) off Cape Blanc (northwest Africa), related with seasonal coastal upwelling. In the study area, *B. ordinaria* was considered the most opportunistic specie in the living assemblage, with a high adaptability and tolerance to a range or combination of different factors. Its abundance was also directly related with river discharges and consequent high input of organic matter, and with the limits of productivity (Chapter 3). High abundances of *E. excavatum* were also described in areas where the input of labile organic matter was high (de Nooijer et al., 2008). In the study area the higher discharges from the Guadiana River occur during winter months (Loureiro et al., 1986; Dias et al., 2004). Furthermore, average concentration of chlorophyll higher than normal was observed in February by Ruiz and Navarro (2006) in a zone east Cape Santa Maria which extended to the study area. These could represent favourable conditions for reproductive periods. This interpretation agrees with Schönfeld and Numberger (2007) who related higher abundances of living *Elphidium excavatum clavatum* with reproduction events, coincident with increase chlorophyll concentrations. This interpretation was also reinforced by the fact that comparative lower abundances of *B. ordinaria* (maximum of 25%) were found in the total assemblage (living+dead), from samples collected in November 2000 in the study area (Mendes et al., 2004).

On the other hand, species such as *R. phlegeri* (Fig. 5.6), *B. dilatata* (Fig. 5.7), *N. iridea* (Fig. 5.9), *N. stella* (Fig. 5.10) and *N. turgida* (Fig. 5.11) showed higher or similar abundances in the core tops in different areas of the continental shelf. This evidence could indicate that beyond reproductive periods, other factors such as depth, sediment type, input of organic matter or increased primary productivity could play an important role in controlling species abundance. With the exception of *N. turgida* that showed similar abundances, the remaining species displayed higher abundances in the living faunas in the vicinity of core 5. This area of the continental shelf, according to Ruiz and Navarro (2006) was influenced by local seasonal upwelling (Fig. 5.1), based on a composition of daily maps of nitrogen fluxes from April to September 1998 (Chapter 3). The upwelling of cold waters leads to the entrance of nutrients in surface waters, favouring phytoplankton growth and therefore a rise in chlorophyll concentrations (Navarro and Ruiz, 2006). Species as *R. phlegeri* and *B. dilatata* were generally associated, in different continental shelves, with fine sediments and high input of organic matter (e.g. Villanueva and Cervera, 1999; Frezza and Carboni, 2009; Schumacher et al., 2007). Species such as *N. iridea*, *N. stella* and *N. turgida* were regarded as opportunistic species that react to the deposition of fresh organic carbon (e.g. Diz et al., 2006; Duchemin et al., 2008; Mojtahid et al., 2009; Diz and Francés, 2008). Namely in the northern Bay of Biscay, *N. iridea* was related with phytoplankton blooms occurring in late winter-early spring (Duchemin et al., 2008). In the Ria de Vigo (NE Spain), *N. stella* and *N. turgida* were associated with upwelling events (Diz et al., 2006; Diz and Francés, 2008). These evidences seem to indicate that local upwelling, with increased input of fresh organic matter, could be the main factor influencing the abundance of the living fauna in the present-day middle continental shelf. However, because these species have small thin-walled shells, with low fossilization potential mainly due to dissolution, easily broken tests by physical means or transported due their small-sized (e.g. Diz et al., 2006; Duchemin et al., 2007; 2008), their abundance decreased in the dead assemblage.

5.4.3. Living versus dead/fossil assemblages

The patchiness of the living taxa and time averaging may cause the species rank to differ between the living and dead assemblages, although the abundant species should be the same in both (Murray, 2006). This could explain why *B. ordinaria*, *R. phlegeri*, *B. dilatata*, *N. iridea*, *N. stella* and *N. turgida*, the opportunistic species of the assemblage, showed higher abundances in the living than in the dead/fossil assemblages. However for these species, the same proportions of relative abundance were observed in the living and dead/fossil assemblages. This was clear in the case of *B. ordinaria*, which was the most abundant species in the living (from 3.76 to 54.7%) and in the dead/fossil assemblages (from 3.82 to 36.5%) (Fig. 5.2). The only exception was *N. turgida*, which showed lower abundance (<2.81%) in the cores (Fig. 5.11), indicating that their patchy distribution may have moved irregularly in space and time. Even with lower relative abundances, these species were also the most abundant in the sediment cores during some periods of the Holocene, indicating that they can be used as palaeoceanographic proxies. Similar results were also obtained by Duchemin et al.

(2007), in sedimentary archives along a composite bathymetric transect from the middle shelf to middle slope in the Bay of Biscay. These authors observed that high percentages of the dominant, most opportunistic species, such as *N. iridea* and *Bolivina ordinaria* (as *B.* ex. gr. *dilatata*), could be indicators of strong palaeoseasonality in a range of bathymetric zones with strongly variation of organic flux levels.

The three analysed sediment cores extracted from the continental shelf off the Guadiana River represented distinct environments and periods during the Holocene. These normal marine environments differ in terms of depth (cores 5, 7 and 8, collected at 72, 36 and 22 m water depth, respectively), sedimentary regime and benthic foraminiferal assemblages (Chapter 4). Core 7 was collected in a peculiar environment in a proximal zone of a transgressive sand deposit, with only 71.5 cm long, comprising ca. 10400 Cal yr BP. This core was mainly constituted by sands with low components variations through time, with low benthic foraminifera density (maximum 320 specimens/gram of dry sediment) and 11 species with abundances >5%, but only two species with abundance >10% (Chapter 4). Due to these peculiarities, the comparison between the living and dead/fossil most abundant species will be made predominantly with cores 5 and 8.

In the living assemblage, *Bolivina ordinaria* showed maximum abundances in relation with river discharges and at the limits higher productivity areas (Chapter 3). It seems that in the area of core 5 during the early Holocene, from ca. 11500 to ca. 10000 Cal yr BP, an increased influence of river discharges with a higher influx of terrestrial organic matter probably occurred. During this period the sea-level rise and a deepening of the sedimentary environment was observed (e.g. curves Fairbanks, 1989; Stanley, 1995; Vis et al, 2008) with consequent increase of the deposition of fine sediments and a reduction of hydrodynamic levels (Chapter 4). According to Burdloff et al. (2008) intense supplies to the Guadiana shelf of fine terrigenous particles occurred in the beginning of the Holocene. These authors observed in core 5 variations between 95 and 50% of continental fine size organic carbon from ca. 11500 to ca. 10000 Cal yr BP, respectively. During this period, the increasing abundance of *B. ordinaria* and *R. phlegeri* (Figs. 5.2 and 5.6), the most opportunistic species of the assemblage (Chapter 3), also pointed to increasing organic carbon content from terrestrial sources. Furthermore, other small thin-walled shell opportunistic species such as *N. iridea* and *N. stella*, normally associated with fresh organic matter (e.g. Diz et al., 2006; Duchemin et al., 2008) also showed relatively high abundances during this period (Figs. 5.9 and 5.10), indicating primary productivity. The decreasing abundance of *E. excavatum* (Fig. 5.4), that can stand frequent re-deposition and substrate mobility (de Nooijer et al., 2008), also pointed to the reduction in the hydrodynamic levels.

A reduction in the influence of river discharges and/or changes in the limits of productivity seem to have occurred in the areas of cores 5 and 7, from ca. 10000 to ca. 5000 Cal yr BP. The reduction of river discharge influence was linked with the continuous sea-level rise observed during this period (e.g. curves from Fairbanks, 1989; Stanley, 1995; Vis et al, 2008) and consequent increasing distance from the river mouth. These changes resulted in the decreasing abundance of *B. ordinaria*, *N. stella* and *N. iridea*. In core 7, however, the contrasting higher abundance of *B. ordinaria* between ca. 8000 and 6000 Cal yr BP, seems to be related with a change in depositional environments with increase percentage of fine sediment that occurred during this period, which was probably related to the estuary infilling (Chapter 4, Fig. 4.3b). This indicates that the abundance of *B. ordinaria* was not only affected by the influence of river discharges, but also related with sand sediments with mud content. This interpretation is in agreement with their present distribution in the study area, where the higher abundances were recorded in coarse sediments with high content on mud located in areas influenced by river discharges (Chapter 3).

The present day sea-level on the continental shelf off the Guadiana River was reached around 5000 Cal yr BP, when drastic changes were observed in components of the sand fraction and in benthic foraminiferal assemblages (Chapter 4, Figs. 4.4 and 4.12). In the area of core 5 (72 m water depth), the establishment of present day sea-level conditions was evidenced by drastic changes in the abundances of several species. The strongest decrease in abundance of *B. ordinaria* and the almost disappearance of *N. stella* indicate that this area of the middle shelf started to be less influenced by the Guadiana River discharges. This interpretation was reinforced by the relatively higher and constant abundance of *B. ordinaria* in core 7. The lower unit of core 8 (Fig. 5.10), located at a shallow water depth in an area influenced by river discharges and composed by a mixture of coarse and fine sediments (Chapter 4) showed however lower abundances, indicating that the abundance of *B. ordinaria* is also influenced by low hydrodynamic levels. In contrast, *B. ordinaria* and *N. stella* showed higher abundances in the living assemblage for the same area, indicating that the established environmental conditions could have led to accelerated *post-mortem* and diagenetic processes which caused the drastic abundance decrease in the first centimetres of the core top. Noticeable under-representation of *N. stella* in the dead assemblages was also observed by Diz and Francés (2009) in the Ria de Vigo, due to shells destruction soon after the death of individuals.

An opposite tendency was followed by *E. vitrea*, *B. dilatata* and *B. marginata* with an abundance increases between ca. 5000 to 4500 Cal yr BP. These increased abundances seem to indicate the establishment of new ecological niches in deeper environments in consonance with the sea level stabilisation. However, in the living assemblage these species were included in different groups (Chapter 3) and upward the core they also showed different trends.

In the living assemblage, *E. vitrea* (included in the group 3) showed higher abundances between 30 and 100 water depths, in relation with the following conditions:

muddy substrate, low hydrodynamic levels, low levels of oxygen and high content of organic matter (Chapter 3). This could indicate that at 72 m water depth, these conditions began to be established after ca. 4000 Cal yr BP and remaining with small variations until ca. 1000 Cal yr BP (Fig. 5.5). This interpretation agrees with the results obtained in core 8, at shallow waters (22 m water depth) where low abundances of *E. vitrea* were recorded (Fig. 5.5). Furthermore, *E. excavatum* and *R. phlegeri* were included in the same group of the living assemblage, with higher abundances between 30 and 100 m water depth, associated with mud and sandy mud (Chapter 3). However in core 5 they showed relatively constant abundances until ca. 1000 Cal yr BP and opposite tendencies until Recent times (Fig. 5.4 and 5.6). Those trends would indicate that from ca. 5000 - 4500 to ca. 1000 Cal yr BP the environmental conditions remained relatively stable and changed afterwards. These changes were also confirmed by further decreasing of *B. ordinaria* and *E. excavatum* and increasing of *E. vitrea*, *R. phlegeri*, *B. dilatata* and *B. marginata*. Those changes indicated that during the last ca. 1000 Cal yr BP, the ecological niches have been established in this area of the middle shelf in relation with the establishment of the mud body, reflecting the climate changes and the anthropogenic impact. During this period climate changes occurred, such as the beginning of the Little Ice Age and the link with negative phase of the North Atlantic Oscillation (Chapter 4). Also as the human impact, that increased significantly during the last 150 years through the construction of dams, mining, and deforestation (e.g. Gonzalez et al., 2001; Dias et al., 2004). However, the overuse of land during the later Medieval Islamic period (800-900 Cal yr BP), had already resulted in widespread erosion and soil loss (Boone and Worman, 2007), with increase sediment supply to the shelf.

In the living assemblages, *B. dilatata* showed higher abundance in surficial samples located in deeper areas, associated with muds off the Guadiana River (Chapter 3). The Holocene evolution of this species, with increasing abundance from shallow to intermediate water depth, was in agreement with their surficial distribution. This was displayed by the high abundance in core 5 and low abundance in cores 7 and 8, after the present mean sea-level was attained (Fig. 5.7). On the other hand, it seems that between ca. 4500 and ca. 3400 Cal yr BP the surficial patch of *B. dilatata* was larger, once the abundances observed during this period were similar to the living assemblage, although, higher than the total assemblage (Fig. 5.7), indicating higher abundance during this period. The increased abundance of *B. dilatata* during this period, also observed for *C. laevigata* (Fig. 5.13c) and for *R. phlegeri*, but only around ca. 5000 Cal yr BP (Fig. 5.6), could be related with strong upwelling which would have occurred in the entire region of the Gulf of Cadiz (Soares and Martins, 2010). According to these authors, the high reservoir effect (ΔR) in radiocarbon values determined for this area between 4400 and 4000 BP (ca. 5000 to 4500 Cal yr BP) was consistent with strong upwelling conditions. In several settings, the abundance of those species were related with different environmental conditions: *Brizalina dilatata* was described on the Pakistan continental margin, adapted to an extremely high input of organic carbon (Schumacher et al., 2007); *Cassidulina laevigata* related with a pulsed supply of fresh organic matter with high nutritious value (de Rijk et al., 2000), preferentially marine organic detritus (Mojtahid et al., 2009); and *R. phlegeri*, one of the most opportunistic species in the studied assemblages (Chapter 3), related with higher proportions of marine organic carbon (Mojtahid et al., 2009). In contrast with the living assemblage, when the abundance of *N. iridea* was related with cold-water filaments (Chapter 3), in core 5 from ca. 9000 Cal yr BP to Recent times, low abundance was recorded (Fig. 5.9).

In the living assemblage *B. marginata* showed a ubiquitous distribution with low abundances, occurring at shallow areas off the Tinto-Odiel and Guadalquivir Rivers and at deeper areas on the continental shelf. Off the Guadiana River this species showed higher abundances in deep samples where fine-grained sediments occurred (Chapter 3). In the study area, the abundance of this species seems to be linked with depth, fine sediments, low hydrodynamic levels and high inputs of terrestrial organic carbon. In the Adriatic Sea *B. marginata* showed preference for clay substrata with high content of organic matter (Jorissen, 1987; Donnici and Barbero, 2002). During the Holocene, the abundance of *B. marginata* in core 5 was closely related with an increased rate of organic carbon mass accumulation observed between ca. 2000 to ca. 1000 Cal yr BP, with enhanced terrestrial supplies. It was followed by a general decrease until ca. 600 Cal yr BP with return to marine production and a further increase during medieval times (Burdloff et al., 2008). The increased abundance observed in core 8 after ca. 1200 Cal yr BP could also be related to the increased influx of terrestrial material associated with changes in the deposition from coarser to finer sediments, established after the formation of the present prodeltaic wedge (Chapter 4). This interpretation is in agreement with the increased abundances of *B. ordinaria* (Fig. 5.2), *H. atlantica* (Fig. 5.3) and *R. phlegeri* (Fig. 5.6) which are the most opportunistic species of the assemblage (Chapter 3).

In the living assemblage the maximum abundance of *H. atlantica* was directly linked with river discharges, associated with sediments with high content on mud, and with the limits of productivity. This species showed the same preferences as *B. ordinaria* and both were considered the most opportunistic of the assemblage. Furthermore, *H. atlantica* was also associated with high primary production in the area, influenced by the Guadalquivir discharges (Chapter 3). This interpretation agrees with other authors that consider *H. atlantica* as low opportunistic taxa (Ernst et al., 2002 as *H. pacifica*) with preference for fresh food supply (e.g. Ernst et al., 2005; Diz and Francés, 2008). On the Guadiana shelf, this species was also associated with fine sediments and low hydrodynamic levels (Mendes et al., 2004). In the Holocene record, the occurrence of this species in cores 7 and 8 was observed only upward ca. 2300 Cal yr BP, and seemed to be related with increased abundance of fine sediments (Chapter 4) and high content of organic matter. A shallow and more stable environment in the area of core 8, influenced by Guadiana River discharges, could also enable high primary production during some periods, similar to what was observed on the shelf off Guadalquivir River (García-Lafuente and Ruiz, 2007; Navarro and Ruiz, 2006). Furthermore, the relatively recent occurrence of *H. atlantica* could also be related to increased organic matter supply, related with human influence on the river basin, as increased settlement density after the Muslim invasion A.D. 711 (ca. 1200 Cal yr BP) reposted by Boone and Worman, (2007). An alternative explanation could be related with the heavy metal enrichment that was observed at the upper sections of cores 5 and 8 (Corredeira et al., 2008). Probably related with mining activity that occurred in this area since the Roman occupation (ca. 2168 to 1539 Cal yr BP) (Alarcão, 1988; Fabião, 1992). Corredeira et al. (2008) observed that the enrichment of Cu and Pb in core 5 slightly decreased below the core top and becomes nearly constant below 25 to 30 cm of core depth. Core 8 was an exception to this trend, as Cu and Pb concentrations become nearly constant below 80 cm of core depth. The Zn concentrations were higher in the upper sections and reached constant values at the same core depths than Cu and Pb, in both cores. The mentioned depths (Chapter 4, Fig. 4.2a, c) correspond approximately to the age from which *H. atlantica* started to be observed, in core 5 with low abundances (last ca. 320 Cal yr BP) and in core 8 with a increased abundance (Fig. 5.3). This could indicate that *H. atlantica* is tolerant, or even present increase abundances, in environments with high heavy metal concentrations. However, this is only a hypothesis, and comparison of this species distribution with other shelf areas is required.

5.4.4. Dead/fossil versus living assemblages without variation in the vicinity of core locations

On the northern margin of the Gulf of Cadiz, eight benthic foraminiferal species were recorded in the living assemblage, but they do not showed relative abundance variations in the vicinity of cores location. This fact could be related with: a) the epoch of sampling; b) the transport of empty shells; c) species absent from the present environment. However, high abundances of these species were recorded during the Holocene in distinct shelf environments, indicating that these species belong to fossil benthic foraminiferal assemblages.

Off the Guadiana River, *Ammonia beccarii*, *Eggerelloides scaber* and *Quinqueloculina stelligera* were identified at shallow waters, influenced differently by river discharges (Chapter 3, Fig. 3.14). The higher abundances of these species in the living fauna, together with *Elphidium gerthi* that was observed only off the Tinto-Odiel River, occurred in core 8 during the last ca. 5000 Cal yr BP (Fig. 5.12). This would indicate that these species belong to the shallow assemblage and occurred until Recent times, with exception of *Q. stelligera* which was absent from the top of the cores. In the hypothesis of transported species being considered, the relatively constant abundances of *A. beccarii* and *E. gerthi* observed in core 8, with exception of some peaks related with climatic changes (Chapter 4), would indicated the same general pattern of transport during the last ca. 5000 Cal yr BP (Fig. 5.12).

Ammonia beccarii is a typical species from shallow waters (e.g. Alve and Murray, 1994; 1999; 2001; Albani et al., 1998; Ruiz et al., 2005; Donnici and Barbero, 2002; Mendes et al., 2004 Diz and Francés, 2008). On the continental shelf off the Guadalquivir River, high abundances in the living assemblage were related with high concentrations of suspended particulate matter associated with fine sediments (Chapter 3). Off the Guadiana River, however, the relatively constant abundance of *A. beccarii* observed in the three shelf environments during the Holocene (Fig. 5.12a), would indicate that this species has a ubiquitous distribution and that its distribution was not influenced by depth, sediment type or inputs of organic matter.

The higher abundances of *E. scaber* recorded in core 8 were in agreement with the surficial distribution. The increased abundance of *E. scaber* upward ca. 1400 Cal yr BP (Fig. 5.12b), was in agreement with the observations of Diz et al. (2002) in the Ria de Vigo and Evans et al. (2002) on the northeast shelf of England. Diz et al. (2002) associated the increase abundance of *E. scaber* (as *E. scabrus*) with an organic enrichment caused by the intensification of aquaculture. Evans et al. (2002) related it with an increasing supply of organic matter to the sea floor at this time. In the north of the Frisian Front (southern North Sea) *Eggerella scaber* (as *E. scabra*) was indicator of seasonal stratification, with higher abundances during winter months, and their abundance was independent on the availability of labile organic material (de Nooijer et al., 2008). In the study area the increased abundance of this species could be related with the formation of the prodeltaic wedge (Chapter 4), with consequent increase of fine-grained sediments and increased abundance of organic matter from terrestrial origin. Another alternative explanation could be related with the heavy metal (Cu, Zn and Pb) enrichment observed in the upper sections of cores 5 and 8 (Corredeira et al., 2008), indicating that this species is tolerant to environments with high heavy metal concentrations. This interpretation is in agreement with Alve (1991) that described *E. scaber* (as *E. scabrus*) in an extremely polluted environment by heavy metals in Sorfjord (western Norway). Furthermore, Frontalini and Coccioni (2008) also related the increased abundance of *E. scaber* (as *E. scabra*) with high heavy metal contents in the central Adriatic Sea.

The abundances of *E. gerthi* and *Q. stelligera* during the Holocene seemed to be related with shallow depths, as a consequence of a continuous sea-level rise and the presence of coarser-grained sediments (Fig. 5.12c, d). This was supported by: a) their very low abundances in core 5, recorded only in early Holocene; b) the almost inexistence in core 7, after reaching the present mean sea-level; and c) the relatively high abundance in core 8 (between ca. 5000 and ca. 1200 Cal yr BP), after sea-level stabilisation, in sediments with higher content on sand (Chapter 4, Fig. 4.3). However, it seems that the abundance of *Q. stelligera* was more restricted, as evidenced by its low representation in core 5 and limited occurrence in shallow areas associated with sandy sediments.

Off the Guadiana River *Bulimina aculeata*, *Bulimina elongata*, *Cassidulina laevigata* and *Brizalina spathulata* were recorded in the living fauna, but they did not show variations in the vicinity of cores location. These species were included in different groups and showed higher abundances below 30 m water depth (Chapter 3, Figs. 3.15a and c, 3.16b and 3.17b).

On the Guadiana shelf *B. aculeata* and *B. elongata* were described in the total assemblage, occurring at different depths. *Bulimina elongata* occurred at depths between 12 and 40 m in areas influenced by storm waves, and *B. aculeata* between 40 and 95 m water depth associated with low hydrodynamic levels (Mendes et al., 2004). These species showed an opposite trend in core 5 during the Holocene (Fig. 5.13a, b), which probably indicate changes in their ecological niche. Until ca. 5000 Cal yr BP these changes could be related with the sea-level rise. However, after this age the changes are most likely to indicate alternating periods of storm waves and low hydrodynamic levels. Furthermore, the low levels of water energy could also be linked with low levels of oxygen, normally associated with high abundances of *B. aculeata* (e.g. Murray, 2006). The high abundance of *B. aculeata* observed in core 8 upward ca. 1300 Cal yr BP, and in core 7 from ca. 8000 to ca 6000 Cal yr BP, in contrast with *B. elongata* trends, also pointed to the relation of this species with increased fine sediments at shallower depths (Chapter 4, Fig. 4.3).

Cassidulina laevigata and *B. spathulata* were the best represented species on the Portuguese shelf below 95 m water depth (Levy et al., 1995, Mendes et al., 2004). The increased abundance after ca. 8000 Cal yr BP in cores 5 and 7, and their almost inexistence in core 8 (Fig. 5.13c, d), is indicative of a deep-water ecological niche, which was in agreement with their living distribution (Chapter 3). The further abundance increase of *C. laevigata* observed in core 5 during the last ca. 1000 Cal yr BP could be related with the increased content on silt and clay (>95%). The restricted abundance of this species in fine-grained sediments, deposited under the low-energy regime of the southwestern Mallorca shelf (Milker et al., 2009), also supported this interpretation. In the case of *B. spathulata* the increased abundance was evident near the core top, where silt and clay constitute nearly 100% of the sediments (Chapter 4, Fig. 4.3a).

5.4.5. Dead/fossil assemblages with low representation in the living fauna

Several species showed high abundances during the Holocene with low or absent representation in the living assemblage. This would indicate that those species do not belong to the current assemblage or presented ubiquitous distributions, such as the case of *N. fabum* (Fig. 5.14h). Several factors such as sea-level rise, sediment type, and competition between species, or a combination between some of them, can be invoked to explain the abundance of those species during the last ca. 11500 Cal yr BP.

The high abundances of *A. mamilla* recorded during the early Holocene in cores 5 and 7, under shallow-water conditions and sandy sea floor (Chapter 4, Fig. 4.3) indicate a clear relation to coarse-grained sediments and shallow depths. This relation was also observed in the shallower located core 8 between ca. 5000 and ca. 1300 Cal yr BP, when mean sea level reached its present-day position and coarse-grained sediments dominated shelf deposition (Fig. 5.14a). The abundance of *P. mediterranensis* also seemed to be controlled by this relation, as it is more abundant in core 8 during the same interval, although more restricted to shallower water depths, as evidenced by its almost absence in core 5 (Fig. 5.14k). This interpretation agrees with other explanations that described *A. beccarii* and *P. mediterranensis* in shallow areas associated with sandy sediments (e.g. Murray, 2006; Pujos, 1976; Villanueva and Cervera, 1999; Mendes et al., 2004; Milker et al., 2009).

The different trends showed by the species that are more abundant only in core 5 (middle shelf mud body) (Fig. 5.14b-e), would indicate that these species were restricted to this environment and/or that these species compete directly with more abundant species. This seem to be the case of *S. fusiformis*, an opportunistic life-strategy species, highly adapted to environmental stress, abundant in areas subjected to rapidly environmental changes (Alve, 2003) and low oxygen conditions (e.g. Alve, 1995; Gustafsson and Nordberg, 2000; Nordberg et al, 2009). *Stainforthia fusiformis* disappeared from the continental shelf off the Guadiana River, after the present-day mean sea level was reached (Fig. 5.14e).

The species that were more abundant on the upper middle shelf transgressive bulge (core 7) have been usually described from shallower, sandy environments (e.g. Levy et al., 1995; Villanueva et al., 1999a; Mendes et al; 2004). During the last ca. 10000 Cal yr BP these species showed different trends, indicating changes in this environment. For example, the limited abundance of *Q. rugosa* to the base of the core, would indicate a restricted shallow environment with sand contents >95% (Chapter 4, Fig. 4.3b) and high hydrodynamic levels. However, this is a complex environment not fully understood and further investigation needs to be developed (Chapter 4).

5.4.6. Shelf evolutionary scenarios

Five evolutionary scenarios were identified on the continental shelf off the Guadiana River, during the Holocene (Fig. 5.15A-E). These scenarios differ in terms of mean sea level position, influence of river discharges and sediment type. In each scenario, the location of each sediment core represents a different environment, affected differently by several parameters, namely productivity (related with upwelling), hydrodynamic level and sedimentary influx (also related with terrestrial organic matter). The relative abundance of one representative benthic foraminiferal species was associated to an analysed parameter.

Concerning the periods from 5000 to 4500 Cal yr BP (a transitional period after the present mean sea level was reached; Fig. 5.15C), and from 4500 to 1000 Cal yr BP (Fig. 5.15D), it was impossible to use only one species as representative of the sedimentary influx, since the species abundance was related with more than one parameter. This situation occurs for example with *B. ordinaria*, related with high sedimentary influx and low hydrodynamic levels. The peculiarity of core 7, previously described, also difficult the comparison between environments.

Each evolutionary scenario reflects the environmental changes occurred during the Holocene. From 11500 to 10000 Cal yr BP mean sea level was rising from a shallower position, and higher river discharges occurred, with consequent reduction of the hydrodynamic levels and high sediment influx on the mud body area (Fig. 5.15A). After 10000 Cal yr BP, the terrigenous influx decreased, related with estuary infilling and the sea level rose to a position a few metres below present, attained around ca. 5000 Cal yr BP (Fig. 5.15B). After reaching the present mean sea-level, a transitional period was observed between 5000 and 4500 Cal yr BP (Fig. 5.15C), characterised in deeper areas of the shelf by strong upwelling events, low hydrodynamic levels and deposition of fine-grained sediments supplied by river discharges. After ca. 4500 to 1000 Cal yr BP new ecological niches were established in deeper environments in consonance with sea level stabilisation, low hydrodynamic levels and high content of marine and terrestrial organic matter (Fig. 5.15D). The last ca. 1000 Cal yr BP (Fig. 5.15E) reflect the actual depositional conditions, after the prodeltaic wedge formation on the inner shelf, and the establishment of the mud body on the middle shelf under low hydrodynamic levels. During this period seasonal upwelling occurred on the middle shelf with increase primary productivity.

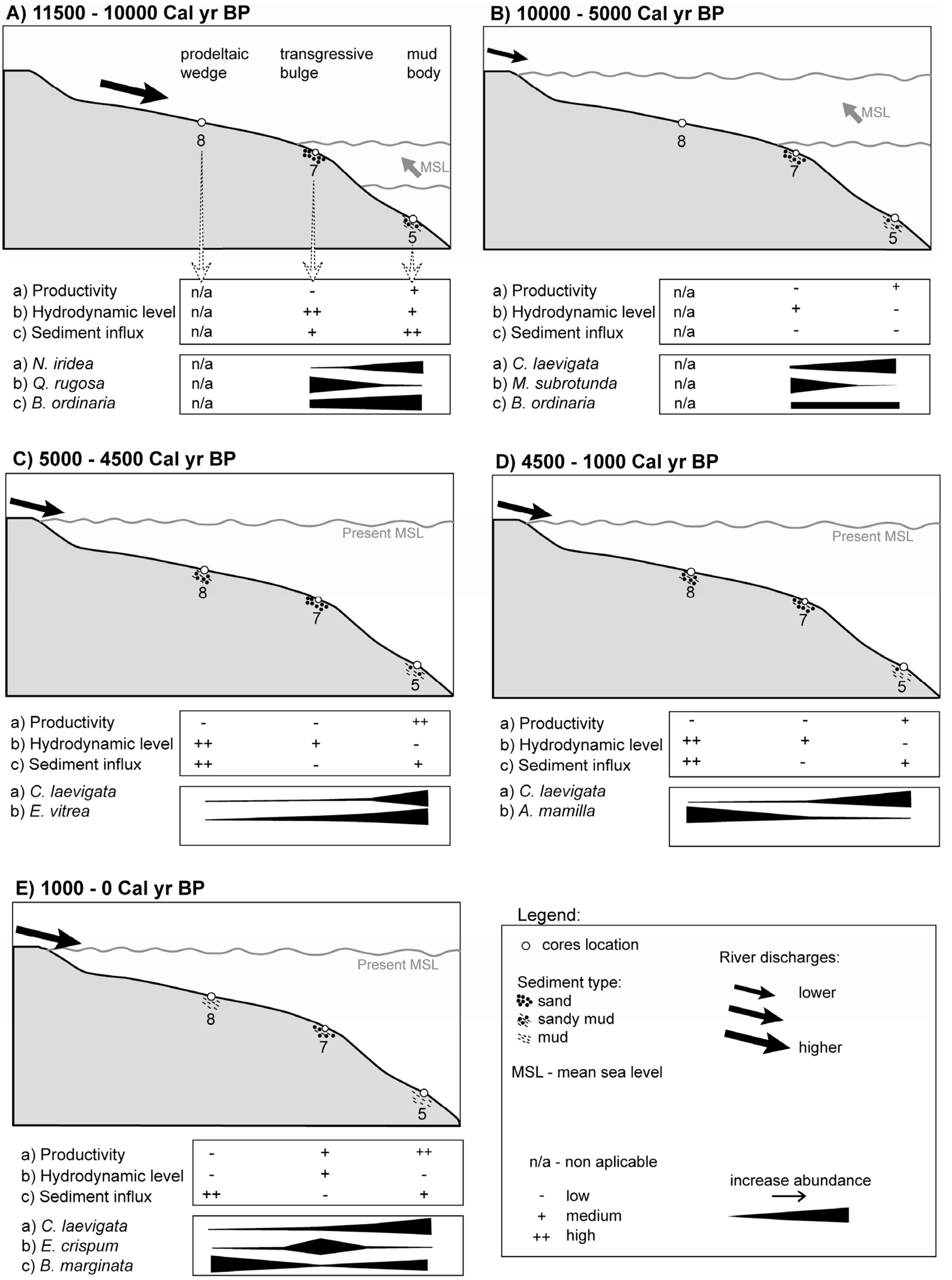


Figure 5.15 – Schematic representation of the five shelf evolutionary scenarios (A to E) identified off the Guadiana River, during the Holocene.

5.5. Conclusions

On the continental shelf off the Guadiana River, the comparison between benthic foraminifera in surface samples and in Holocene sediment cores from three different environments, showed diverse patterns in each of those environments.

Differences between living and dead/fossil assemblages were observed, however on average 95% of the living benthic foraminiferal fauna were preserved in the fossil record. The differences were attributed to loss of fragile agglutinated forms and dissolution of thin calcareous tests. However, in the study area the species richness in sediment cores was controlled by the addition of dead assemblages, represented by many generations over a longer period of time.

Among the most abundant species with variations in the vicinity of the core locations, the differences between living and total (living+dead) assemblages appear to be mainly controlled by seasonal differences in reproductive periods. These periods can occur favourable by changes in the flux of organic matter, which is related with increased river discharges and increase chlorophyll concentrations. The higher abundances of living species *B. ordinaria* and *E. excavatum* in February seem to indicate a reproductive period coincident with the sampling period.

However, depending on the analysed environment beyond reproductive periods, other factors as depth, sediment type, quality and quantity of food available (input of organic matter from river discharges or increase primary productivity), seem to have an important role in the abundance of *R. phlegeri*, *B. dilatata*, *N. iridea, N. stella* and *N. turgida*. On the middle shelf mud body, the abundance of these species seemed to be mainly influenced by local upwelling.

Post-mortem processes, such as destruction and dissolution of tests, appear to be the principal process associated with the differences found between living and dead or fossil assemblages. This is evidenced by the higher abundances in the living than in the dead or fossil assemblages of *B. ordinaria*, *R. phlegeri*, *B. dilatata*, *N. iridea* and *N. stella*. Furthermore these species, with lower abundances in sediment cores as compared to surficial abundances, were also the most abundant, in at least, one of the three studied environments during the Holocene. Therefore, they can be used as palaeoceanographic proxies.

High abundances of the opportunistic species *B. ordinaria*, *R. phlegeri*, *N. iridea* and *N. stella* during the Holocene indicate strong influence of river discharges and great supplies of terrestrial organic matter, related with sea-level rise and changes in the limits of a high productivity zone. Dependent on the environment, the abundance of *B. ordinaria* could also be influenced by increased proportions of fine sediments, related with reduction in the hydrodynamic levels.

During the Holocene, five evolutionary scenarios were identified on the continental shelf off the Guadiana River (Fig. 5.15). Each scenario represents the three shelf environments, influenced by different parameters, in association with sea-level changes, river discharges and substrate properties.

From ca. 11500 to ca. 10000 Cal yr BP average sea-level rose and a deepening of the sedimentary environment occurred, with consequent increase deposition of fine sediments and a reduction of hydrodynamic levels in deeper areas (Fig. 5.15A). The increasing abundance of *B. ordinaria* and *R. phlegeri* indicates increasing organic carbon content from terrestrial sources. The relatively high abundances of *N. iridea* and *N. stella* also indicates enhanced primary productivity during this period.

After ca. 10000 to ca. 5000 Cal yr BP, a reduction of river discharges and terrigenous influx occurred, linked with continuous sea-level rise, and consequent increasing distance from the river mouth, to a position a few metres below present (Fig. 5.15B).

The increased abundance of *E. vitrea*, *B. dilatata* and *B. marginata* after the sea level stabilisation (ca. 5000 to 4500 Cal yr BP) indicates the establishment of new ecological niches in deep-water areas, which were less influenced by river discharges. The increased abundance of *B. dilatata*, *C. laevigata* and *R. phlegeri* around ca. 5000 to 4500 Cal yr BP also indicate a short period of strong upwelling. This high-productivity event has been reported from the entire Gulf of Cadiz region (Fig. 5.15C).

The relatively constant abundances of frequent species from ca. 5000 - 4500 to ca. 1000 Cal yr BP, indicate relatively stable environmental conditions, after the establishment of new ecological niches in deeper environments, in consonance with sea-level stabilisation, low hydrodynamic levels and high content of marine and terrestrial organic matter (Fig. 5.15D).

The last ca. 1000 Cal yr BP (Fig. 5.15E) reflect the actual depositional conditions, after the prodeltaic wedge formation on the inner shelf and the establishment of the mud body on the middle shelf, with low hydrodynamic levels. Seasonal upwelling occurs on the middle shelf leading to increased primary productivity. This period reflects also the impact of human activities in the region, such as overuse of land, construction of dams, mining, and deforestation, and of specific climate changes, such as the beginning of the Little Ice Age and the link with a negative phase of the North Atlantic Oscillation. The increased abundance of *B. marginata* during this period, which was associated with an extended deposition of fine-grained sediments and thus an increased influx of terrestrial material, also reflects the anthropogenic impact in the study area during early medieval times. This interpretation is supported by the increased abundances of opportunistic species such as *B. ordinaria* and *H. atlantica* at shallow water depths at this time. These species were proven to be associated with fine sediments in an area influenced today by Guadiana River discharges. Furthermore, the abundance of *H. atlantica* co-varies with non-redox sensitive heavy metal concentrations in the sediment cores. In particular, the lead enrichment since historical times was most likely related with increased human influence, i.e. mining activity in the river catchment areas.

The living assemblages without variations in the vicinity of cores location, but with high abundance (>5%) in sediment cores, reveal important variations during the Holocene.

The abundance of *E. scaber*, *E. gerthi* and *Q. stelligera* during the Holocene was controlled by shallow waters and substrate properties. *Ammonia beccarii* was normally associated with coastal environments. *Eggerelloides scaber* can be used as an indicator of increased organic matter supply to the shelf, associated with fine-grained sediments, low hydrodynamic levels, and tolerant to heavy metal concentrations. Higher abundances of *E. gerthi* and *Q. stelligera* are indicators of shallow water environments associated with coarse-grained sediments.

With higher abundances below 30 m water depth, *B. aculeata*, *B. elongata*, *C. laevigata* and *B. spathulata* were controlled by depth, low hydrodynamic levels and fine-grained sediments. The abundance of *B. aculeata* was also related with fine-grained sediments and low levels of oxygen at shallow waters. The ecological niche of *C. laevigata* and *B. spathulata* was established in deep-water areas. During the Holocene, their distribution was controlled by sea-level rise and increased content of silt and clay in the sediments.

Only a few species from the fossil assemblages, rare in the living assemblages, displayed abundances higher than 10% and showed significant variations, which were used for past environmental interpretations. In the study area, the abundance of *A. mamilla* was proven to be an indicator of mean sea level located at shallow position, associated with coarse-grained sediments. The abundance of *P. mediterranensis* was also controlled by the same relation, although today this species is more restricted to shallower areas. The combination between sea-level rise and competition between species controlled the abundance of *S. fusiformis*, which disappeared after mean sea level reached its present-day position. The abundance of *Q. rugosa* was also controlled by the sea-level rise, indicating restricted shallow-water environments with high content on sand.

Chapter 6

General conclusions

The specific conclusions of this thesis are presented in Chapters 3, 4 and 5. This chapter provides more general conclusions and suggestions for future work.

A detailed characterisation of the living benthic foraminiferal faunas was performed on the northern Gulf of Cadiz continental shelf, between the Guadiana and Guadalquivir Rivers. The results demonstrate that population density is generally influenced by river outflow, particularly associated with muds and suspended particulate matter. Species richness, on the other hand, is controlled by sediment type. Associations of most abundant species show clear relationship to physical and chemical parameters. From this, four general groups emerge, characterising their modern environment:

a) Group 1 is represented by *Bolivina ordinaria* and *Hopkinsina atlantica*, the most opportunistic species in the assemblage. Their abundance is linked to river discharge with large inputs of organic matter, sediments with high mud content and the limits of higher marine productivity. *Hopkinsina atlantica* is also associated with high primary production from the Guadalquivir discharge;

b) Group 2 is dominated by *Ammonia beccarii*, *Eggerelloides scaber*, *Elphidium gerthi*, *Quinqueloculina laevigata* and *Quinqueloculina stelligera*, with high abundance in shallow waters. They were associated with different sediment types and their distribution was influenced in different ways by inputs of different rivers;

c) Group 3 is were dominated by *Bulimina aculeata*, *Elphidium excavatum*, *Bulimina elongata*, *Epistominella vitrea, Rectuvigerina phlegeri* and *Elphidium culvilliere*. These species are most abundant between 30 and 100 m water depth. They prevailed, mostly, in muddy sediments associated with low levels of water energy, low levels of oxygen and high organic matter contents;

d) Group 4 includes species more abundant in deeper waters. This group was divided into Sub-group 4A (with *Bolivina catanensis*, *Cassidulina laevigata*, *Stainforthia* sp., *Nouria* *polymorphinoides, Bolivina italica*, *Bolivina striatula*, and *Nouria* sp.), which is more abundant in selected samples and Sub-group 4B (with *Brizalina dilatata*, *Brizalina spathulata*, *Bulimina marginata, Nonionella iridea*, *Nonionella stella* and *Nonionella turgida*) which is patchy distributed and more abundant in distinct areas of the continental shelf. In addition, higher abundances of *Nonionella* species off the Guadiana River are related to low temperature and salinity. The abundance of *N. iridea* is associated with cold-water filaments.

The Holocene palaeoenvironmental changes were investigated in three marine shelf environments on the continental shelf off the Guadiana River: the middle shelf mud body (core 5), recording the last ca. 11500 Cal yr BP; the upper middle shelf transgressive bulge (core 7), covering the last ca. 10400 Cal yr BP, and the inner shelf prodeltaic wedge (core 8) over the last ca. 5000 Cal yr BP. These environments differed in terms of depth, sedimentary regime and benthic foraminiferal assemblages. However, the predominantly fluvial origin of the sand fraction is observed in all three environments. Each record was characterised through sedimentological and benthic foraminiferal analyses and integrated into a chronological framework. Four evolutionary stages have been identified (described below), providing information about sediment depositional patterns in response to sea-level changes, Guadiana River discharges, climatic variations and anthropogenic impact during the Holocene. Analyses performed on core 7 collected near the transgressive bulge on the upper middle shelf, indicate that this it is a complex environment and further investigation is needed to better understand its formation and evolution.

Comparison between living and dead or fossil foraminiferal assemblages on the continental shelf off the Guadiana River show that, on average, 95% of the living benthic foraminiferal fauna were preserved in the fossil record. The comparison between living and total assemblages shows more living individuals of *B. ordinaria* and *E. excavatum* in February, indicating a reproductive period coincident with the sampling period. However, depending on the analysed environment beyond reproductive periods, other factors, such as depth, sediment type and quality and quantity of food available, have an important role in the abundance of *R. phlegeri*, *B. dilatata*, *N. iridea, N. stella* and *N. turgida*. On the middle shelf mud body, the abundance of these species is mainly influenced by local upwelling. Despite these conclusions, further research is required to compare living and total assemblages in samples collected without disturbance of the sediments surface.

Post-mortem processes, such as destruction and dissolution of tests, appear to be responsible for differences between living and dead or fossil assemblages. This is evident in the higher abundances of *B. ordinaria*, *R. phlegeri*, *B. dilatata*, *N. iridea* and *N. stella* in the living versus dead or fossil assemblages. Furthermore, with lower abundances in sediment cores compared to surficial abundances, these species were also the most abundant in at least one of the three studied environments during the Holocene. This indicates they can be used as palaeoceanographic proxies. The variations in abundance of most abundant benthic foraminiferal species are useful indicators of Holocene environmental change in shelf environments.

The abundance of *E. scaber*, *E. gerthi* and *Q. stelligera* is controlled by shallow waters and substrate properties. *Ammonia beccarii* occur with low abundance in all environments. *Eggerelloides scaber* may used as an indicator of increased supply of organic matter to the shelf, because of its association with fine-grained sediments, low hydrodynamic levels and tolerance of heavy-metal concentrations. Higher abundances of *E. gerthi* and *Q. stelligera* may indicate shallow-water environments associated with coarse-grained sediments.

Bulimina aculeata, *B. elongata*, *C. laevigata* and *B. spathulata* are controlled by depth, low hydrodynamic levels and fine-grained sediments. The abundance of *B. aculeata* is also modulated by fine-grained sediments and low levels of oxygen in shallow waters. *Cassidulina laevigata* and *B. spathulata* find their ecological niche in deep-water areas.

During the Holocene, their distribution was probably controlled by sea-level rise and increased silt and clay content in the sediments.

The abundance of *A. mamilla* and *P. mediterranensis* is an indicator of a low mean sea level and is associated with coarse-grained sediments. A combination of sea-level rise and competition between species controlled the abundance of *S. fusiformis*, which disappeared after mean sea-level reached the present-day position. The abundance of *Q. rugosa* was also controlled by sea-level rise, indicating sandy, restricted shallow-water environments.

An integrated approach using all the information available sheds light on palaeoenvironmental changes, which are combined in five evolutionary scenarios for the continental shelf off the Guadiana River. This integration revealed an additional evolutionary scenario following sea-level stabilisation (ca. 5000 to 4500 Cal yr BP), augmenting the four stages defined in Chapter 4.

From ca. 11500 to ca. 10000 Cal yr BP average sea-level rose, resulting in an increase in the deposition of fine sediments and a reduction of hydrodynamic levels in deeper areas. The increasing abundance of *B. ordinaria* and *R. phlegeri* indicates increasing organic carbon input from terrestrial sources. Relatively high abundances of *N. iridea* and *N. stella* also indicates high primary productivity during this period.

After ca. 10000 to ca. 5000 Cal yr BP, a reduction of river discharge and terrigenous influx occurred, linked with continuous sea-level rise to a few metres below its present level and the consequent increase in distance from the river mouth.

After sea-level stabilisation between ca. 5000 to 4500 Cal yr BP, the increased abundance of *E. vitrea*, *B. dilatata* and *B. marginata* indicates the establishment of new ecological niches in deep-water areas, less influenced by river discharges. The increased abundance of *B. dilatata*, *C. laevigata* and *R. phlegeri* during this period also indicates a short-lived period of strong upwelling.

The relatively constant abundances of common species from ca. 5000 - 4500 to ca. 1000 Cal yr BP indicate relatively stable environmental conditions followed the establishment of new ecological niches in deeper environments, in agreement with sea-level stabilisation, low hydrodynamic levels and the high content of marine and terrestrial organic matter.

The last ca. 1000 Cal yr BP reflect current depositional conditions, after the formation of a prodeltaic wedge on the inner shelf and the establishment of the mud patch on the middle shelf. Seasonal upwelling occurs on the middle shelf with an increase in primary productivity. This period also reflects human impact through intensification of land-use, mining activity in the river catchment areas, construction of dams, deforestation, and the climate changes, such as the beginning of the Little Ice Age and negative phase of the North Atlantic Oscillation.

Chapter 7

Taxonomy

This chapter presents the taxonomy of all taxa, recorded on the northern continental shelf of Gulf of Cadiz, with two or more specimens in at least one sample (Appendix A to D). All the genera and their higher classification (subfamilies, families, superfamilies and suborders) followed Loeblich and Tappan (1987). However, the separation followed by Loeblich and Tappan (1987) for the genera *Textularia*, *Quinqueloculina* and *Elphidium*, was not applied in this study. The original names obtained by Ellis and Messina (1942-2009) catalogue of Foraminifera were kept.

Since the publications of Loeblich and Tappan during the 1960 decade, most of the systematists placed the foraminifers in the Kingdom Prostista, the same as the current Protoctista (eukaryotic unicellular organisms) rather than in the sub-kingdom or phylum Protozoa (under the Kingdom Animalia) (Sen Gupta, 1999c). The taxonomic rank of foraminifers was raised from order to class by Loeblich and Tappan (1992) according to the following characteristics of the organisms: 1) granuloreticulose pseudopodia, 2) outer cover (usually a test), 3) alternation of haploid and diploid generations, and 4) some of these organisms constructed their test of non-oriented calcareous or siliceous crystals, a characteristic unknown elsewhere in the animal kingdom (in Sen Gupta, 1999c). The more recent classification of Sen Gupta (1999c) considered the foraminifers as belonging to Phylum Granuloreticulosa and Class Foraminifera. In this classification all suborders and consequently the lower taxonomic categories were elevated a degree in the taxonomic classification, when compared with the classification of Loeblich and Tappan (1987). Because the inexistence of an adaption between compatible criteria in the classifications, this study follows the systematic hierarchy established by Loeblich and Tappan (1987), where foraminifers were classified in the Order Foraminiferida Eichwald, 1830.

For each species, after the supra-generic classification, the taxonomic references were organised as follow: 1) species name used in this work, the author and date of the first identification; 2) for species with abundance >5%, it was mentioned the plate and figure number of photographed species. These species were documented by scanning electron microscope (SEM) photographs, taken with a JEOL, JSM-5200 LV microscope and by binocular microscope (BM) photographs taken with a digital compact camera, Olympus Camedia C-7070 (Plates 1 to 5); 3) original generic designation and reference obtained by Ellis and Messina (1942-2009); 4) when existed, synonymy list; 5) examples obtained in the literature (the most used: Murray (1971), Jones (1994), Levy et al., (1995), Martins and Gomes (2004)).

ORDER FORAMINIFERIDA Eichwald, 1830

SUBORDER TEXTULARIINA Delage and Hérouard, 1896

Superfamily HORMOSINACEA Haeckel, 1894

Family HORMOSINIDAE Haeckel, 1894

Subfamily REOPHACINAE Cushman, 1910

Genus *Leptohalysis* Loeblich and Tappan, 1984

Leptohalysis scottii **(Chaster 1892)**

Reophax scottii Chaster, 1892, Southport Soc. Nat. Sci., Rept., Southport, England, 1st Rept. (1890-91), p. 27, pl. 1, fig. 1.

Reophax scottii Chaster, Murray, 1971, p. 17, pl. 1, figs. 6-9 and Levy et al., 1995, p. 18, pl. 1, fig. 15.

Leptohalysis scotti (Chaster), Diz and Francés, 2008, p. 182, pl. 1, fig. 4.

Genus *Reophax* de Montfort, 1808

Reophax curtus **Cushman 1920**

Reophax curtus Cushman, 1920, U.S. Nat. Mus., Bull., Washington, D. C., U.S.A., no. 104, p. 8, pl. 2, figs. 2-3.

Reophax curtus Cushman, Boltovskoy et al., 1980, p.48, pl. 30, figs. 5-7; Villanueva et al., 1999b, p. 245, pl. 1, figs. 2 a-b and Martins and Gomes, 2004, p. 14-15, fig. 2.3.

Reophax dentaliniformis **(Brady 1881)**

Lituola (Reophax) dentaliniformis Brady, 1881, Quart. Jour. Micr. Sci., London, vol. 21, p. 49.

Reophax dentaliniformis (Brady), Jones, 1994, p. 37, pl. 30, figs. 21-22 and Martins and Gomes, 2004, p. 16-17, fig. 2.4.

***Reophax nodolosus* (Brady 1879)**

Reophax nodulosa Brady, 1879, Quart. Jour. Micr. Sci., London, England, vol. 19, p. 52, pl. 4, figs. 7-8.

Reophax nodolosus Brady, Jones, 1994, p. 38, pl. 31, figs. 6-9 and Levy et al., 1995, p. 17, pl. 1, fig. 10.

Superfamily HAPLOPHRAGMIACEA Eimer and Fickert, 1899

Family AMMOSPHAEROIDINIDAE Cushman, 1927

Subfamily AMMOSPHAEROIDININAE Cushman, 1927

Genus *Abercotryma* Loeblich and Tappan, 1950

***Adercotryma glomeratum* (Brady 1878)**

Lituola glomerata Brady, 1878, Ann. Mag. Nat. Hist., London, England, p. 433, pl. 20, fig. 1a-c.

Adercotryma glomeratum (Brady), Jones, 1994, p. 41, pl. 34, figs. 15-18.

Superfamily SPIROPLECTAMMINACEA Cushman, 1927

Family PSEUDOBOLIVINIDAE Wiesner, 1931

Genus *Pseudobolivina* Wiesner, 1931

***Pseudobolivina fusiformis* (Chaster 1892)**

Textularia fusiformis Chaster, 1892, Southport Soc. Nat. Sci., Rept., Southport, England, 1st Rept. (1890-91), append., p. 58, pl. 1, fig. 3.

Pseudobolivina fusiformis (Chaster), Schiebel, 1992, pl. 6, fig. 11 and Martins and Gomes, 2004, p. 24-25, fig. 2.9.

Family NOURIIDAE Chapman and Parr, 1936

Genus *Nouria* Heron-Allen y Earland, 1914

***Nouria polymorphinoides* Heron-Allen and Earland 1914**

Plate 1, fig. 1 a-c

Nouria polymorphinoides Heron-Allen and Earland, 1914, Zool. Soc. London, Trans., London, England, vol. 20, pt. 12, p. 376, pl.37, figs. 1-15.

Nouria polymorphinoides Heron-Allen and Earland, Schiebel, 1992, pl. 8, figs. 14-16.

***Nouria* sp.**

Plate 1, fig. 2 a-b

Family TROCHAMMINIDAE Schwager, 1877

Subfamily TROCHAMMININAE Schwager, 1877

Genus *Trochammina* Parker y Jones, 1859

***Trochammina inflata* (Montagu 1808)**

Nautilus inflatus Montagu, 1808, Exeter, England, Printed by S. Woolmer, p. 81, pl. 18, fig. 3.

Trochammina inflata (Montagu), Murray, 1971, p. 35, pl. 10, figs. 3-6 and Jones, 1994, p. 46, pl. 41, fig. 4.

Subfamily POLYSTOMAMMININAE Brönnimann and Beurlen, 1981

Genus *Lepidodeuterammina* Brönnimann and Whittaker, 1983

Lepidodeuterammina ochracea **(Williamson 1858)**

Rotalina ochracea Williamson, 1858, Ray Soc., London, England, p. 55, pl. 4, fig. 113.

Trochammina ochracea (Williamson), Murray, 1971, p. 37, pl. 11 figs. 1-5.

Lepidodeuterammina ochracea (Williamson), Loeblich and Tappan, 1987, p. 127, pl. 135, figs. 10-14 and Martins and Gomes, 2004, p. 29, fig. 2.12.

Superfamily TEXTULARIACEA Ehrenberg, 1838

Family EGGERELLIDAE Cushman, 1937

Subfamily EGGERELLINAE Cushman, 1937

Genus *Eggerella* Cushman, 1935

Eggerella advena **(Loeblich and Tappan 1958)**

Verneuilina advena Cushman, 1922, Biol. Board, Contr. Canadian Biol., Toronto, Canada, no. 9., p. 9, pl. 1, fig. 5.

Eggerella advena (Loeblich and Tappan), Levy et al., 1995, p. 19, pl. 2, fig. 7.

Genus *Eggerelloides* Haynes, 1973

Eggerelloides scaber **(Williamson 1858)**

Plate 1, fig. 3 a-c

Bulimina scabra Williamson, 1858, Ray Soc., London, England, p. 65, pl. 5, figs. 136-137.

Eggerella scabra (Williamson), Murray, 1971, p. 45, pl. 15, figs. 1-6 and Levy et al., 1995, p. 19, pl. 2, fig. 9.

Eggerelloides scabrus (Williamson), Loeblich and Tappan, 1987, p. 170, pl. 189, figs. 5-7.

Eggerelloides scaber (Williamson), Jones, 1994, p. 52, pl. 47, figs. 15-17 and Martins and Gomes, 2004, p. 36-39, fig. 2.17.

Family TEXTULARIIDAE Ehrenberg, 1838

Subfamily TEXTULARIINAE Ehrenberg, 1838

Genus *Textularia* Defrance, 1824

***Textularia conica* d' Orbigny 1839**

Textularia conica d' Orbigny, 1839, A. Bertrand, Paris, France, p. 143 (plates published separately), vol. 8, pl. 1, figs. 19-20.

Sahulia conica d' Orbigny, Jones, 1994, p. 48, pl. 43, figs. 13-14.

Textularia conica d' Orbigny, Levy et al., 1995, p. 29, pl. 3, fig. 5 and Martins and Gomes, 2004, p. 44-45, fig. 2.20.

***Textularia deltoidea* Reuss 1850**

Plate 1, fig. 4 a-c

Textularia deltoidea Reuss, 1850, K. Akad. Wiss. Wien, Math.-Nat. Cl., Denksch., Wien, Österreich, Bd. 1, p. 381, pl. 49, fig. 4a.

Textularia deltoidea Reuss, Levy et al., 1995, p. 20, pl. 3, fig. 6 and Martins and Gomes, 2004, p. 45-465, fig. 2.21.

***Textularia earlandi* Parker 1952**

Textularia earlandi Parker, 1952, new name, Harvard Coll., Mus. Comp. Zoöl., Bull., vol. 106 (1951-1952), no. 10, p. 458.

Spiroplectinella earlandi (Parker), Martins and Gomes, 2004, p. 21-22, fig. 2.7.

Textularia earlandi Parker, Murray, 1971, p. 33, pl. 9, figs. 1-5 and Levy et al., 1995, p. 20, pl. 3, fig. 4.

***Textularia gramen* d'Orbigny 1846**

Textularia gramen d'Orbigny, 1846, Paris: Gide et Comp., p. 248, pl. 15, figs. 4-6.

Textularia gramen d'Orbigny, Levy et al., 1995, p. 20, pl. 3, fig. 7 and 9.

Textularia sagittula **Deflandre 1824**

Textularia sagittula Deflandre, 1824, in: Blainville, H. M. D. de, Paris: F. G. Levrault, 1824, tome 32 (mollus-morf), p. 177, pl. 13, fig. 5.

Spiroplectinella sagittula (Deflandre), Martins and Gomes, 2004, p. 23-24, fig. 2.8.

Textularia sagittula Deflandre, Murray, 1971, p. 31, pl. 8, figs. 1-9.

SUBORDER SPIRILLININA Hohenegger and Piller, 1975

Family PATELLINIDAE Rhumbler, 1906

Subfamily PATELLININAE Rhumbler, 1906

Genus *Patellina* Williamson, 1858

Patellina corrugata **Williamson 1858**

Patellina corrugata Williamson, 1858, Ray Soc., London, England, p. 1858, pl. 3, figs. 86-89.

Patellina corrugata Williamson, Murray, 1971, p. 147, pl. 61, figs. 2-5; Jones, 1994, p. 93, pl. 86, figs. 1-7 and Martins and Gomes, 2004, p. 47-48, fig. 2.22.

SUBORDER MILIOLINA Delage and Hérouard, 1896

Superfamily CORNUSPIRACEA Schultze, 1854

Family CORNUSPIRIDAE Schultze, 1854

Subfamily CORNUSPIRINAE Schultze, 1854

Genus *Cornuspira* Schultze, 1854

***Cornuspira involvens* (Reuss 1850)**

Operculina involvens Reuss, 1850, K. Akad. Wiss. Wien, Math.-Nat. Cl., Denkschr., Wien, Österreich, Bd. 1, p. 370, pl. 46, fig. 20.

Cyclogyra involvens (Reuss), Murray, 1971, p. 53, pl. 18, figs. 1-3.

Cornuspira involvens (Reuss), Jones, 1994, p. 26, pl. 11, figs. 1-3.

Superfamily MILIOLACEA Ehrenberg, 1839

Family SPIROLOCULINIDAE Wiesner, 1920

Genus *Adelosina* d´Orbigny, 1826

***Adelosina* sp.**

Genus *Spiroloculina* d´Orbigny, 1826

***Spiroloculina* sp.**

Subfamily HAUERININAE Schwager, 1876

Genus *Quinqueloculina* d'Orbigny, 1826

***Quinqueloculina agglutinans* d'Orbigny 1839**

Quinqueloculina agglutinans d'Orbigny, 1839, A. Bertrand, Paris, France, p. 195 (plates published separately), vol, 8, pl. 12, figs. 11-13.

Quinqueloculina agglutinans d'Orbigny, Colom, 1974, p. 188, fig. 60, l-q.

***Quinqueloculina akneriana* d' Orbigny 1846**

Quinqueloculina akneriana d' Orbigny, 1846, Paris: Gide et Comp., p. 290, pl. 18, figs. 16-21.

Quinqueloculina akneriana d' Orbigny, Levy et al., 1995, p. 23, pl. 4, fig. 1 and Martins and Gomes, 2004, p. 50-51, fig. 2.24.

Quinqueloculina aspera **d'Orbigny 1826**

Quinqueloculina aspera d'Orbigny, 1826, Ann. Sci. Nat., Paris, france, ser. 1, tome 7, p. 301.

Siphonaperta aspera (d'Orbigny), Debenay et al., 2001, pl. 1, figs. 25 and 29 and Frezza and Carboni, 2009, pl. 1, fig. 21.

Quinqueloculina aspera d'Orbigny, Jorissen, 1987, p. 46, pl. 3, fig. 2.

Quinqueloculina colomi **Le Calvez and Le Calvez 1958**

Quinqueloculina colomi Le Calvez and Le Calvez, 1958, Mónaco, Inst. Océanogr., Ann., Paris, France, vol. 35, fasc. 3, p. 176, pl. 3, figs. 15-16, pl. 4, figs. 17-19.

Quinqueloculina colomi Le Calvez and Le Calvez, Colom, 1974, p. 187, fig. 57, a-d.

Quinqueloculina laevigata **d'Orbigny 1839**

Plate 1, fig. 5 a-c

Quinqueloculina laevigata d'Orbigny, 1839, Paris: Béthume, tome 2, pt. 2, Zool., p. 143, pl. 3, figs. 31-33.

Quinqueloculina laevigata d'Orbigny, Mendes et al., 2004, pl. 1, fig. 7.

Quinqueloculina rugosa **d'Orbigny 1852**

Plate 1, fig. 6 a-c

Quinqueloculina rugosa d'Orbigny, 1852, V. Masson, Paris, France, vol. 3, p. 195, fig. 13 a-b.

Cycloforina rugosa (d'Orbigny 1826), Villanueva et al., 1999a, p. 104, pl. 3, fig. 5a-b and Debenay et al., 2005, pl. 1, fig. 17.

Quinqueloculina seminulum **(Linnaeus 1758)**

Serpula seminulum Linnaeus, 1758, Holmiae, Suécia, impensis L. Salvii, tomus 1, p. 786.

Quinqueloculina seminulum (Linnaeus), Murray, 1971, p. 65, pl. 24, figs. 1-6; Jones, 1994, p. 21. pl. 5, fig. 6; Levy et al., 1995, p. 23, pl. 4, fig. 3 and Martins and Gomes, 2004, p. 53-54, fig. 2.26.

Quinqueloculina stalkeri **Loeblich and Tappan 1953**

Quinqueloculina stalkeri Loeblich and Tappan, 1953, Smithsonian Inst., Misc. Coll., Washington, D.C., vol. 121, no. 7 (publ. 4105), p. 40, pl. 5, figs. 5-9.

Quinqueloculina stalkeri Loeblich and Tappan, 1953, Boltovskoy et al., 1980, p. 47, pl. 29, figs. 14-16 and Martins and Gomes, 2004, p. 55, fig. 2.27.

Quinqueloculina stelligera **Schlumberger 1893**

Plate 1, fig. 7 a-f

Quinqueloculina stelligera Schlumberger, 1893, Soc. Zool. France, Mém., Paris, tome 6, p. 68, pl. 2, figs. 58-59.

Quinqueloculina stelligera Schlumberger, Debenay et al., 2001, pl. 2, figs. 3-4.

Quinqueloculina striata **d'Orbigny 1843**

Quinqueloculina striata d'Orbigny, 1843, J. B. Baillière, Paris, France, Mollusques, p. 10, pl. 3, fig. 10.

Quinqueloculina striata d'Orbigny, Colom, 1974, p. 188, fig. 52 k-r.

Subfamily MILIOLINELLINAE Vella, 1957

Genus *Biloculinella* Wiesner, 1931

Biloculinella depressa **(d'Orbigny 1826)**

Biloculina depressa d'Orbigny 1826, Ann. Sci. Nat., Paris, France, ser. 1, tome 7, p. 298.

Pyrgo depressa (d'Orbigny), Murray, 1971, p. 71, pl. 27, figs. 1-4 and Jones, 1994, p. 19, figs. 12, 16-17.

Biloculinella depressa (d'Orbigny), Levy et al., 1995, p. 24, pl. 4, fig. 4.

Genus *Miliolinella* Wiesner, 1931

Miliolinella subrotunda **(Montagu 1803)**

Plate 1, fig. 8 a-c

Vermiculum subrotundum Montagu, 1803, J. S. Hollis, Romsey, England, p. 521, pl. 1, fig. 4.

Miliolinella subrotunda (Montagu), Murray, 1971, p. 73, pl. 28, figs. 5-6, Jones, 1994, p. 22, pl. 5, figs. 13-14 and Levy et al., 1995, p. 24, pl. 4, fig. 7.

Genus *Triloculina* d'Orbigny, 1826

Triloculina affinis **d'Orbigny 1852**

Triloculina affinis d'Orbigny, 1852, V. Masson, Paris, France, vol. 3, p. 161.

Triloculina affinis d'Orbigny, Colom, 1974, p. 203, fig. 56, m-q.

Subfamily SIGMOILINITINAE Luczkowska, 1974

Genus *Sigmoilopsis* Finlay, 1947

Sigmolopsis **sp.**

SUBORDER LAGENINA Delage and Hérouard, 1896

Superfamily NODOSARIACEA Ehrenberg, 1838

Family NODOSARIIDAE Ehrenberg, 1838

Subfamily NODOSARIINAE Ehrenberg, 1838

Genus *Dentalina* Risso, 1826

***Dentalina advena* (Cushman 1923)**

Nodosaria advena Cushman, 1923, U.s. Nat. Mus., Bull., Washington, D.C., U.S.A., no. 104, p. 79, pl. 14, fig. 12.

Dentalina advena (Cushman), Jones, 1994, p. 74, pl. 63, fig. 1.

Family VAGINULINIDAE Reuss, 1860

Subfamily LENTICULININAE Chapman, Parr and Collins, 1934

Genus *Lenticulina* Lamarck, 1804

***Lenticulina* sp.**

Subfamily MARGINULININAE Wedekind, 1937

Genus *Amphicoryna* Schlumberger, 1881

***Amphicoryna candei* (d'Orbigny 1839)**

Nodosaria candei d'Orbigny, 1839, A. Bertrand, Paris, France, p. 15, vol. 8, pl. 1, figs. 6-7.

Amphicoryna candei (d'Orbigny), Levy et al., 1995, p. 27, pl. 5, fig. 8.

***Amphycorina scalaris* (Batsch 1791)**

Nautilus (Orthoceras) scalaris Batsch, 1791, Jena: University Press, pp. 1, 4, pl. 2, fig. 4a-b.

Amphycorina scalaris (Batsch), Murray, 1971, p. 77, pl. 29, figs. 1-4; Jones, 1994, p. 75, pl. 63, figs. 28-31; Levy et al., 1995, p. 27, pl. 5, fig. 10 and Martins and Gomes, 2004, p. 65-66, fig. 2.34.

Family LAGENIDAE Reuss, 1862

Genus *Lagena* Walker y Jacob, 1798

***Lagena setigera* Milletti 1901**

Lagena clavata (d'Orbigny) var. *setigera* Millett, 1901, Roy. Micr. Soc. London, Jour., London, England, p. 491, pl. 8, fig. 8 a-b.

Lagena setigera Milletti, Martins and Gomes, 2004, p. 67, fig. 2.35.

***Lagena striata* (d'Orbigny 1839)**

Oolina striata d'Orbigny, 1839, Levrault, Stasbourg, France, tome 5, pt. 5, p. 21, pl. 5, fig. 12.

Lagena striata (d'Orbigny), Jones, 1994, p. 64, pl. 57, figs. 22, 24 and Levy et al., 1995, p. 28, pl. 5, fig. 13.

***Lagena sulcata* (Walker and Jacob) var. *spicata* Cushman and McCulloch 1950**

Lagena sulcata (Walker and Jacob) var. *spicata* Cushman and McCulloch 1950, new name, Southern California, Univ., Publ., Allan Hancock Pacific Exped., Los Angeles, Calif., vol. 6, no. 6, p. 360.

Family ELLIPSOLAGRNIDAE Silvestri, 1923

Subfamily ELLIPSOLAGENINAE Silvestre, 1923

Genus *Fissurina* Reuss, 1850

***Fissurina densifasciata* McCulloch 1977**

Fissurina densifasciata McCulloch, 1977, Los Angeles: University of Southern California, p. 101, pl. 61, fig. 8a-b.

Fissurina fimbriatiformis McCulloch 1977

Fissurina fimbriatiformis McCulloch, 1977, Los Angeles, California: University of Southern California, p. 107, pl. 57, fig. 4a-c.

Fissurina globosa Bornemann 1855

Fissurina globosa Bornemann, 1855, Deutsch. Geol. Ges., Zeitschr., Berlin. Deutschland, Bd. 7, Heft 2, p. 317, pl. 12, fig. 4.

Fissurina laevigata Reuss 1850

Fissurina laevigata Reuss, 1850, K. Akad. Wiss. Wien, Math.-Nat. Cl., Denkschr., Wien, Österreich, Bd. 1, p. 366, pl. 46, fig. 1.

Fissurina laevigata Reuss, Jones, 1994, p. 113, pl. 114, fig. 8 and Martins and Gomes, 2004, p. 74, fig. 2.42.

Fissurina lucida (Williamson 1848)

Entosolenia marginata (Montagu) var. *lucida* Williamson, 1848, Ann. Mag. Hist., London, England, p. 17, pl. 2, fig. 7.

Fissurina lucida (Williamson 1848), Murray, 1971, p. 97, pl. 39, fig. 1-3 and Martins and Gomes, 2004, p. 75, fig. 2.43.

Fissurina marginata (Montagu 1803)

Vermiculum marginatum Montagu, 1803, J.S. Hollis, Romsey, England, p. 524.

Fissurina marginata (Montagu), Murray, 2003, p. 17, fig. 5.3-5.4 and Martins and Gomes, 2004, p. 76-77, fig. 2.44.

Fissurina orbignyana **Seguenza 1862**

Fissurina orbignyana Seguenza, 1862, Messina, Itália, T. Capra, p. 66, pl. 2, figs. 25-26.

Fissurina orbignyana Seguenza, Murray, 1971, p. 99, pl. 40, fig 18; Levy et al., 1995, p. 29, pl. 6, fig. 7 and Martins and Gomes, 2004, p. 78, fig. 2.45.

SUBORDER ROBERTININA Loeblich and Tappan, 1984

Superfamily CERATOBULIMINACEA Cushman, 1927

Family CERATOBULIMINIDAE Cushman, 1927

Subfamily CERATOBULIMININAE Cushman, 1927

Genus *Lamarckina* Berthelin, 1881

Lamarckina haliotidea **(Heron-Allen and Earland 1911)**

Pulvinulina haliotidea Heron-Allen and Earland, 1911, Roy. Micr. Soc., Jour., London, England, p. 338, pl. 11, figs. 6-11.

Lamarckina haliotidea (Heron-Allen and Earland), Murray, 1971, p. 205, pl. 86, figs. 1-6 and Martins and Gomes, 2004, p. 80-81, fig. 2.47.

SUBORDER ROTALIINA Delage and Hérouard, 1896

Superfamily BOLIVINACEA Glaessner, 1937

Family BOLIVINIDAE, Glaessner, 1937

Genus *Bolivina* d´Orbigny, 1839

Bolivina albatrossi **Cushman 1922**

Bolivina albatrossi Cushman 1922, U.S. Nat. Mus., Bull., Washington, D.C., no. 104, p. 31.

Bolivina albatrossi Cushman, Martins and Gomes, 2004, p. 85, fig. 2.49.

Bolivina catanensis Seguenza 1862

Plate 2, fig. 1 a-b

Bolivina catanensis Seguenza, 1862, Accad. Gioenai Sci. Nat. Catania, Atti, Catania, Itália, ser. 2, tomo 18, pp. 113, 125, pl. 2, fig. 3.

Brizalina catanensis (Seguenza), Kaminski et al., 2002, p. 188, pl. 2, fig. 11.

Bolivina catanensis Seguenza, Levy et al., 1995, p. 30, pl. 6, fig. 10.

Bolivina italica Cushman 1936

Plate 2, fig. 2 a-b

Bolivina italica Cushman, 1936, Cushman Lab. Foram. Res., Sharon, Mass., U.S.A., no. 6, p. 56, pl. 8, fig. 6.

Bolivina ordinaria Pheleger and Parker 1952, new name

Plate 2, fig. 3 a-g

Bolivina ordinaria Pheleger and Parker, 1952, Cushman Found. Foram. Res., Contr., Washington, D.C., vol. 3, pt. 1, p. 14.

Bolivina variabilis (Williamson 1858), Debenay et al., 2001, pl. 4, figs 3-4; Duchemin et al., 2005, pl. 1, fig. 12.

Bolivina ex. gr. dilatata; Duchemin et al, 2007, pl. 1, figs. 14-16.

Bolivina ordinaria Pheleger and Parker; Boltovskoy et al., 1980, p. 18, pl. 3, figs. 1-3 and Martins and Gomes, 2004, p. 90-91, fig. 2.53.

Bolivina pseudogoesii Hofker 1956

Bolivina pseudogoesii Hofker, 1956, Univ., Zool. Mus., Spolia (Skrifter), Copenhagen, vol. 15, p. 69, pl. 7, figs. 35-42.

Bolivina pseudoplicata **Heron-Allen and Earland 1930**

Plate 2, fig. 4 a-b

Bolivina pseudoplicata Heron-Allen and Earland, 1930, Roy. Micr. Soc., Jour., London, England, ser. 3, vol. 50, p.81, pl. 3, figs. 36-38.

Bolivina pseudoplicata Heron-Allen and Earland, Murray, 1971, p. 107, pl. 43, figs. 1-7; Levy et al., 1995, p. 31, pl. 6, fig. 14 and Martins and Gomes, 2004, p. 92-94, fig. 2.54.

Bolivina striatula **Cushman 1922**

Plate 2, fig. 5 a-d

Bolivina striatula Cushman, 1922, Carnegie Inst. Washington, Publ. no. 311, Washington, D.C., U.S.A., p. 27, pl. 3, fig. 10.

Bolivina striatula Cushman, Levy et al., 1995, p. 32, pl. 7, fig. 3 and Martins and Gomes, 2004, p. 100-101, fig. 2.57.

Bolivina variabilis **(Williamson 1858)**

Textularia variabilis Williamson, 1858, On the Recent foraminifera of Great Britain. Ray Soc., London, England, p. 76, pl. 6, figs. 162-163.

Brizalina variabilis (Williamson), Murray, 1971, p- 113, pl. 46, figs. 1-3.

Bolivina variabilis (Williamson), Martins and Gomes, 2004, p. 102, fig. 2.58.

Genus *Bolivinellina* Saidova, 1975

Bolivinellina pseudopunctata **(Höglund 1947)**

Bolivina pseudopunctata Höglung, 1947, Uppsala, Univ., Zool. Bidrag, Uppsala, Bd. 26, p. 273, pl. 24, fig. 5 a-b.

Genus *Brizalina* Costa, 1856

***Brizalina alata* (Seguenza 1862)**

Vulvulina alata Seguenza, 1862, Prime ricerche intorno ai rizopodi fossili della argille Pleistoceniche dei dintorni di Catania. Accad. Gioenia Sci. Nat. Catania, Atti, Catania, Itália, ser. 2, tomo 18, p. 115, pl. 2, fig. 5.

Brizalina alata (Seguenza), Jones, 1994, p. 58, pl. 53, figs. 2-4 and Martins and Gomes, 2004, p. 104-105, fig. 2.59.

***Brizalina dilatata* (Reuss 1850)**

Plate 2, fig. 6 a-d

Bolivina dilatata Reuss, 1850, Akad. Wiss. Wienm Math.-Nat. Cl., Denkschr., Wien. Österreich, p. 381, pl. 48, fig. 15.

Bolivina dilatata Reuss; Colom, 1974, p. 129, fig. 18, j-n; Schiebel, 1992, pl. 1, fig. 4a and Martins and Gomes, 2004, p. 88, fig. 2.51.

***Brizalina nitida* (Brady 1884)**

Bolivina nitida Brady, 1884, new name, Rept. Challenger Expedition, London, England, Zool., pt. 22, vol. 9, p. 420, pl. 52, fig. 30a, b.

Brizalina nitida (Brady), Jones, 1994, p. 58, pl. 52, fig. 30.

***Brizalina spathulata* (Williamson 1858)**

Plate 2, fig. 7 a-b

Textularia variabilis Williamson var. *spathulata* Williamson 1858, Ray Sociaty, London, England, p. 76, pl. 6, figs. 164-165.

Brizalina spathulata (Williamson); Murray, 1971, p. 111, pl. 45, figs. 1-4; Schiebel, 1992, pl. 1, fig. 4d; Jones, 1994, p. 57, pl. 52, figs. 20-21; Martins and Gomes, 2004, p. 108-110, figs. 2.61 and 2.62.

***Brizalina subaenariensis* (Cushman 1922)**

Bolivina subaenariensis Cushman, 1922, U.S. Nat. Mus., Bull., Washington, D.C., U.S.A., no. 104, p. 46, pl. 7, fig. 6.

Brizalina subaenariensis (Cushman), Murray, 1971, p. 111, pl. 45, figs. 5-7 and Martins and Gomes, 2004, p. 111-112, fig. 2.63.

Superfamily CASSIDULINIDAE d´Orbigny, 1839

Family CASSIDULINIDAE d´Orbigny, 1839

Genus *Cassidulina* d´Orbigny, 1826

***Cassidulina crassa* d'Orbigny 1839**

Cassidulina crassa d'Orbigny, 1839, Strasbourg, France, Levrault, tome 5, pt. 5, p. 56, pl. 7, figs. 18-20.

Cassidulina crassa d'Orbigny, Jones, 1994, p. 60, pl. 54, fig. 4 and Martins and Gomes, 2004, p. 118-119, fig. 2.67.

***Cassidulina laevigata* d'Orbigny, 1826**

Plate 2, fig. 8 a-c

Cassidulina laevigata d'Orbigny, 1826, Ann. Sci. Nat., Paris, France, ser. 1, tome 7, p. 282, pl. 15, figs. 4-5.

Cassidulina laevigata d'Orbigny, Murray, 2003, p. 21, figs. 6.8-6.10 and Debenay et al., 2001, pl. 4, fig. 19.

***Cassidulina minuta* Cushman 1933**

Plate 2, fig. 9 a-c

Cassidulina minuta Cushman, 1933, Cushman Lab. Forams. Res., Sharon, Mass., U.S.A., vol. 9, pt. 4, no. 137, p. 92, pl. 10, fig. 3.

Cassidulina minuta Cushman, Martins and Gomes, 2004, p. 123, fig. 2.69.

***Cassidulina teretis* Tappan 1951**

Cassidulina teretis Tappan, 1951, Cushman Found. Foram. Res., Contr., Washington, D.C., vol. 2, pt. 1, p. 7, pl. 1, fig. 30.

Cassidulina teretis Tappan, Jones, 1994, p. 59, pl. 54, fig. 1 and Martins and Gomes, 2004, p. 124-125, fig. 2.70.

Genus *Globocassidulina* Volloshiva, 1960

***Globocassidulina rossensis* (Kennett 1967)**

Globocassidulina crassa (d'Orbigny) subsp. *rossensis* Kennett, 1967, Cushman Found. Foram. Res., Contr., Ithaca, N.Y., vol. 18, pt. 3, p. 134, pl. 11, figs. 4 a-c, 5, 6a-b.

Globocassidulina rossensis (Kennett), Martins and Gomes, 2004, p. 127, fig. 2.72.

***Globocassidulina subglobosa* (Brady 1881)**

Cassidulina subglubosa Brady, 1881, Quart. Jour. Micr. Sci., London, vol. 21, p. 60.

Globocassidulina subglobosa (Brady), Jones, 1994, p. 60, pl. 54, fig. 17; Levy et al., 1995, p. 33, pl. 7, fig. 7 and Martins and Gomes, 2004, p. 128-130, fig. 2.73.

Superfamily TURRILINACEA Cushman, 1927

Family STAINFORTHIIDAE Reiss, 1963

Genus *Hopkinsina* Howe and Wallace, 1932

***Hopkinsina atlantica* (Cushman 1944)**

Plate 3, fig. 1 a-c

Hopkinsina pacifica Cushman var. *atlantica* Cushman, 1944, Cushman Lab. Forams. Res., Sharon, Mass., U.S.A., no. 12, p. 30, pl. 4, fig. 1.

Hopkinsina atlantica Cushman, Debenay et al., 2001, pl. 4, fig. 14.

Genus *Stainforthia* Hofker, 1965

***Stainforthia loeblichi* (Feyling-Hanssen 1954)**

Virgulina loeblichi Feyling-Hanssen, 1954, Norsk Geol. Tidsskr., Bergen, vol. 33, no. 3-4, p. 191, pl. 1, figs. 14-18.

Fursenkoina loeblichi (Feyling-Hanssen), Martins and Gomes, 2004, p. 173, fig. 2.100.

***Stainforthia feylingi* Knudsen and Seidenkrantz 1993**

Virgulina schreibersiana Czjzek, 1848, Naturw. Abh., Wien, Österreich, Bd. 2, Abth. 1, p. 147, pl. 13, figs. 18-21.

Stainforthia feylingi Knudsen and Seidenkrantz, 1994, *Stainforthia feylingi:* New species from Arctic to subarctic environments, previously recorded as *Fursenkoina schreibersiana* (Czjzek). Contributions from the Cushman Foundation of Foraminiferal Research, Special Publication, no. 32, p. 5-13.

Stainforthia feylingi Knudsen and Seidenkrantz, 1993, Martins and Gomes, 2004, p. 133-134, fig. 2.75.

Stainforthia fusiformis **(Williamson 1858)**

Plate 3, fig. 2 a-c

Bulimina pupoides d'Orbigny var. *fusiformis* Williamson, 1858, Ray Soc., London, England, p. 63, pl. 5, figs. 129-130.

Stainforthia fusiformis (Williamson), Murray, 1971, p. 185, pl. 77, figs. 1-5; Gooday and Alve, 2001, p. 279, pl. 3-4 and Martins and Gomes, 2004, p. 135-137, fig. 2.76.

Stainforthia **sp.**

Plate 3, fig. 3 a-c

Superfamily BULIMINACEA Jones, 1875

Family SIPHOGENERINOIDIDAE Saidova, 1981

Subfamily SIPHOGENERINOIDINAE Saidova, 1981

Genus *Saidovina* Haman, 1984

Saidovina karreriana **(Brady 1881)**

Bulimina (*Bolivina*) *karreriana* Brady, 1881, Quart. Jour. Micr. Sci., London, vol. 21, p. 58.

Saidovina karreriana (Brady), Jones, 1994, p. 59, pl. 53, figs. 19-21.

Subfamily TUBULOGENERININAE Saidova, 1981

Genus *Rectuvigerina* Mathews, 1945

Rectuvigerina phlegeri **Le Calvez 1959**

Plate 3, fig. 4 a-d

Rectuvigerina phlegeri Le Calvez, 1959, Rev. Trav. Inst. Pêches Marit., Paris, vol.23, nº 3, p. 363, pl. 1, fig. 11.

Rectuvigerina phlegeri Le Calvez, Schiebel, 1992, pl. 3, fig. 10, a-d; Levy et al., 1995, p. 34, pl. 7, fig. 8; Villanueva and Cervera, 1999, p. 196, pl. 5, fig. 5 a-c and Martins and Gomes, 2004, p. 138-139, fig. 2.77.

Family BULIMINIDAE Jones, 1875

Genus *Bulimina* d´Orbigny, 1826

Bulimina acanthia Costa 1856

Bulimina acanthia Costa, 1856, Accad. Pontaniana Napoli, Atti, Napoli, Itália, vol. 7, fasc. 2, p. 335, pl. 13, figs. 35-36.

Bulimina acanthia Costa, Colom, 1974, p. 115, fig. 16, o-u.

Bulimina aculeata d'Orbigny 1826

Plate 3, fig. 5 a-d

Bulimina aculeata d'Orbigny, 1826, Ann. Sci. Nat., Paris, France, sér. 1, tome 7, p. 269.

Bulimina aculeata d'Orbigny, Jones, 1994, p. 56, pl. 51, figs. 7-9; Levy et al., 1995, p. 35, pl. 7, fig. 9 and Martins and Gomes, 2004, p. 140-141, fig. 2.78.

Bulimina buchiana d' Orbigny 1846

Bulimina buchiana d' Orbigny, 1846, Paris: Gide et Comp., p. 186, pl. 11, figs. 15-18.

Bulimina buchiana d' Orbigny, Colom, 1974, p. 116, fig. 16, b'-c'.

Bulimina elongata d'Orbigny 1846

Plate 3, fig. 6 a-c

Bulimina elongata d'Orbigny, 1846, Paris: Gide et Comp., p. 187, pl. 11, figs. 19-20.

Bulimina elongata d'Orbigny, Jones, 1994, p. 54, pl. 50, figs. 3-4 and Levy et al., 1995, p. 35, pl. 7, fig. 10.

***Bulimina exilis* (Brady 1884)**

Bulimina elegans d'Orbigny var. *exilis* Brady, 1884, Rept. Challenger Expedition, London, England, Zool., pt. 22, vol. 9, p. 399, pl. 50, figs. 5-6.

Eubuliminella exilis (Brady), Jones, 1994, p. 54, pl. 50, figs. 5-6.

Bulimina exilis (Brady), Levy et al., 1995, p. 35, pl. 7, fig. 11 and Martins and Gomes, 2004, p. 147-148, fig. 2.82.

***Bulimina marginata* d'Orbigny 1826**

Plate 3, fig. 7 a-d

Bulimina marginata d'Orbigny, 1826, Ann. Sci. Nat., Paris, France, ser. 1, tome 7, p. 269, pl. 12, figs. 10-12.

Bulimina marginata d'Orbigny, Murray, 1971, p. 119, pl. 49, figs. 1-7; Jones, 1994, p. 55, pl. 51, figs. 3-5; Levy et al., 1995, p. 35, pl. 7, fig. 12 and Martins and Gomes, 2004, p. 148-150, fig. 2.83.

Genus *Globobulimina* Cushman, 1927

***Globobulimina auriculata* (Bailey 1851)**

Bulimina auriculata Bailey, 1851, Smithsonian Inst., Contr. Knowledge, Washington D.C., U.S.A., vol. 2, art. 3, p. 12, pl. 67, figs. 25-27.

Globobulimina auriculata (Bailey), Levy et al., 1995, p. 36, pl. 8, fig. 3 and Martins and Gomes, 2004, p. 153-155, figs. 2.85-2.87.

Family BULIMINELLIDAE Hofker, 1951

Genus *Buliminella* Cushman, 1911

***Buliminella elegantissima* (d' Orbigny 1839)**

Bulimina elegantissima d'Orbigny, 1839, Strasbourg, France, Levrault, tome 5, pt. 5, p. 51, pl. 7, figs. 13-14.

Buliminella elegantissima (d' Orbigny), Murray, 1971, p. 105, pl. 42, figs. 1-4; Jones, 1994, p. 55, pl. 50, figs. 20-22 and Martins and Gomes, 2004, p. 157-158, fig. 2.89.

***Buliminella tenuata* (Cushman 1927)**

Buliminella subfusiformis Cushman var. *tenuata* Cushman, 1927, California Univ. Scripps Inst. Oceanogr., Bull., Berkeley, Calif., U.S.A., Tech. Ser., vol. 1. p. 149, pl. 2, fig. 9.

Buliminella tenuata (Cushman), Martins and Gomes, 2004, p. 156-157, fig. 2.88.

Family UVIGERINIDAE Haeckel, 1894

Subfamily UVIGERININAE Haeckel, 1894

Genus *Uvigerina* d´Orbigny, 1826

***Uvigerina peregrina* Cushman 1923**

Uvigerina peregrina Cushman, 1923, U.S. Nat. Mus., Bull., Washington, D.C., U.S.A., no. 104, p. 166, pl. 42, figs. 7-10.

Uvigerina peregrina Cushman, Murray, 1971, p. 121, pl. 50, figs. 1-7; Levy et al., 1995, p. 38, pl. 8, fig. 11; and Martins and Gomes, 2004, p. 162-163, fig. 2.93-2.94.

Subfamily ANGULOGERININAE Galloway, 1933

Genus *Trifarina* Cushman, 1923

Trifarina angulosa **(Williamson 1858)**

Uvigerina angulosa Williamson, 1858, Ray Society, London, England, p. 67, pl. 5, fig. 140.

Trifarina angulosa (Williamson), Murray, 1971, p. 123, pl. 51, figs. 1-6; Jones, 1994, p. 86, pl. 74, figs. 15-16; Levy et al., 1995, p. 38-39, pl. 9, fig. 1 and Martins and Gomes, 2004, p. 166-198, fig. 2.96.

Family REUSSELLIDAE Cushman, 1933

Genus *Reussella* Galloway, 1933

Reussella spinulosa **(Reuss 1850)**

Verneuilina spinulosa Reuss, 1850, K, Akad. Wiss. Wien, Math.-Nat. Cl. Denkschr., Wien, Österreich, Bd. 1, p. 374, pl. 47, fig. 12.

Reussella spinulosa (Reuss), Jones, 1994, p. 51, pl. 47, figs. 1-3.

Superfamily FURSERKOINACEA Loeblich and Tappan, 1961

Family FURSENKOINIDAE Loeblich and Tappan, 1961

Genus *Fursenkoina* Loeblich and Tappan, 1961

Fursenkoina complanata **(Egger 1895)**

Virgulina schreibersiana Cziczek var. *complanata* Egger, 1895, K. bayer. Akad. Wiss., math.-physik. Cl., Abh., München, Deutschland, bd. 18, abth. 2, (1893), p. 292, pl. 8, figs. 91-92.

Stainforthia complanata (Egger), Martins and Gomes, 2004, p. 131-132, fig. 2.74.

Fursenkoina complanata (Egger), Jones, 1994, p. 56, pl. 52, figs. 1-3.

Superfamily DISCORBACEA Ehrenberg, 1838

Family BAGGINIDAE Cushman, 1927

Subfamily BAGGININAE Cushman, 1927

Genus *Cancris* de Monfort, 1808

***Cancris auriculus* (Fichtel and Moll 1798)**

Nautilus auricula Fichtel and Moll, 1798, Vienna: Aton Pichler, p. 108.

Cancris auricula (Fichtel and Moll), Murray, 1971, p. 137, pl. 57, figs. 1-7; Jones, 1994, p. 105, pl. 106, fig. 4 and Martins and Gomes, 2004, p. 175-176, fig. 2.101.

Cancris auriculus (Fichtel and Moll), Jones, 1994, p. 105, pl. 106, fig. 4.

***Cancris oblongus* (Williamson 1858)**

Rotalina oblonga Williamson, 1858, Ray Soc., London, England, p. 51, pl. 4, figs. 98-100.

Cancris oblongus (Williamson), Jones, 1994, p. 105, pl. 106, fig. 5.

Genus *Valvulineria Cushman, 1926*

***Valvulineria bradyana* (Fornasini 1900)**

Discorbina bradyana Fornasini, 1900, R. Accad. Sci. Ist. Bologna, Mem., Bologn, Itália, ser.5, tomo 8 (1899-1900), p. 393, tf. 43.

Valvulineria bradyana (Fornasini), Martins and Gomes, 2004, p. 177-178, fig. 2.102.

Family ROSALINIDAE Reiss, 1963

Genus *Gavelinopsis* Hofker, 1951

***Gavelinopsis praegeri* (Heron-Allen and Earland 1913)**

Discorbina praegeri Heron-Allen and Earland, 1913, Roy. Irish Acad., Proc., Dublin, Ireland, vol. 31, sect. 3 (1911-15), p. 122, pl. 10, figs. 8-10.

Gavelinopsis praegeri (Heron-Allen and Earland), Murray, 1971, p. 133, pl. 55, figs. 1-5; Martins and Gomes, 2004, 185-186, fig. 2.108.

Genus *Neoconorbina* Hofker, 1951

***Neoconorbina williamsoni* (Chapman and Parr 1932)**

Discorbis williamsoni Chapman and Parr, 1932, Roy. Soc. Victoria, Proc. Melbourne, Australia, vol. 44, p. 226, pl. 21, fig. 25.

Discorbis williamsoni Chapman and Parr 1932, Martins and Gomes, 2004, p. 183-184, fig. 2.107.

Neoconorbina nitida (Williamson), Debenay et al., 2001, pl. 5, figs. 9 and 12 and Diz et al., 2004, p. 275, pl. 2, fig. 10.

***Neoconorbina parkerae* (Natland 1950)**

Discorbis parkeri Natland, 1950, Geol. Soc. Amer., Mem., new York, no. 43, pt. 4, p. 27, pl. 6, fig. 11.

Neoconorbina parkerae (Natland), Martins and Gomes, 2004, p. 189, fig. 2.111.

Genus *Rosalina* d´Orbigny, 1826

***Rosalina anomala* Terquem 1875**

Rosalina anomala Terquem, 1875, Soc. Dunkerquoise, Mém., Dunkerque, France, vol. 19, p. 438, pl. 5, fig. 1a-b.

Rosalina anomala Terquem, Murray, 2003, p. 26, fig. 9.9-9.10 and Diz et al., 2004, p. 275, pl. 2, figs. 11 a-b.

***Rosalina bradyi* (Cushman 1915)**

Discorbis globularis (d'Orbigny) var. *bradyi* Cushman, 1915, U. S. Nat. Mus., Bull., Washington, D.C., U.S.A., no. 71, p. 12, pl. 8, fig. 1.

Rosalina bradyi (Cushman), Jones, 1994, p. 93, pl. 86, fig. 8 and Debenay and Redois, 1997, pl. 3, fig. 36.

Superfamily GLABRATELLACEA Loeblich and Tappan, 1964

Family GLABRATELLIDAE Loeblich and Tappan, 1964

Genus *Glabratellina* Seiglie and Bermúdez, 1965

***Glabratellina tabernacularis* (Brady 1881)**

Discorbina tabernacularis Brady, 1881, Quart. Jour. Sci., London, vol. 21, p. 65.

Glabratella tabernacularis (Brady), Jones, 1994, p. 95, pl. 89, figs. 5-7.

Superfamily DISCORBINELLACEA Sigal, 1952

Family PARRELLOIDIDAE Hofker, 1956

Genus *Cibicidoides* Thamann, 1939

***Cibicidoides pachyderma* (Rzehak 1886)**

Truncalina pachyderma Rzehak, 1886, Naturf. Ver. Brünn, Verh., Brünn, Bd. 24, p. 87, pl. 1, fig. 5 a-c.

Cibicidoides pachyderma (Rzehak), Jones, 1994, p. 98, pl. 94, fig. 9 and Martins and Gomes, 2004, p. 196, fig. 2.116.

Family PSEUDOPARRELLIDAE Voloshinova, 1952

Subfamily PSEUDOPARRELLINAE Voloshinova, 1952

Genus *Epistominella* Husezima y Maruhasi, 1944

***Epistominella exigua* (Brady 1884)**

Pulvinulina exigua Brady, 1884, Rept. Challenger Expedition, London, England, Zool., pt. 22, vol. 9, p. 696, pl. 103, figs. 13-14.

Epistominella exigua (Brady), Martins and Gomes, 2004, p. 197-199, fig. 2.117.

***Epistominella vitrea* Parker 1953**

Plate 3, fig. 8 a-d

Epistominella vitrea Parker, Cushman Found. Foram. Res., Washington, D.C., no. 2, p. 9, pl. 4, figs. 34-36, 40-41.

Epistominella vitrea Parker, Murray, 1971, p. 131, pl. 54, figs. 1-6; Martins and Gomes, 2004, p. 199-200, fig. 2.118.

Superfamily PLANORBULINACEA Schwager, 1877

Family PLANULINIDAE Bermúdez, 1952

Genus *Hyalinea* Hofker, 1951

***Hyalinea balthica* (Schröter 1783)**

Nautilus balthicus Schröter, 1783, Einleitung in die Conchylienkenntniss nach Linné, vol. 1, p. 20, pl. 1, fig. 2.

Hyalinea balthica (Schröter), Murray, 1971, p. 173, pl. 72, figs. 5-8; Levy et al., 1995, p. 43, pl. 10, fig. 3 and Martins and Gomes, 2004, p. 204-206, fig. 2.122.

Family CIBICIDIDAE Cushman, 1927

Genus *Cibicides* de Monfort, 1808

***Cibicides lobatulus* (Walker and Jacob 1798)**

Nautilus lobatulus Walker and Jacob, 1798, Dillon and Keating, London, England, p. 642, pl. 14, fig. 36.

Lobatula lobatula (Walker and Jacob), Martins and Gomes, 2004, p. 211-213, fig. 2.126 and Loeblich and Tappan, 1987, p. 583, pl. 637, figs. 10-13.

Cibicides lobatulus (Walker and Jacob), Murray, 1971, p. 175, pl. 73, figs. 1-7 and Levy et al., 1995, p. 44, pl. 10, fig. 4.

Genus *Lobatula* Fleming, 1828

***Lobatula* sp.**

Family PLANORBULINIDAE Schwager, 1877

Subfamily PLANORBULININAE Schwager, 1877

Genus *Planorbulina* d´Orbigny, 1826

***Planorbulina mediterranensis* d'Orbigny 1826**

Plate 4, fig. 1 a-j

Planorbulina mediterranensis d'Orbigny, 1826, Ann. Sci. Nat., Paris, France, ser. 1, tome 7, p. 280, pl. 14, figs. 4-6.

Planorbulina mediterranensis d'Orbigny, Murray, 1971, p. 179, pl. 75, figs. 1-6; Jones, 1994, p. 96, pl. 92, fig. 1, Levy et al., 1995, p. 44-45, pl. 10, fig. 6 and Martins and Gomes, 2004, p. 214-215, fig. 2.127.

Superfamily ASTERIGERINACEA d´Orbigny, 1839

Family ASTERIGERINATIDAE Reiss, 1963

Genus *Asterigerinata* Bermúdez, 1949

***Asterigerinata mamilla* (Williamson 1858)**

Plate 4, fig. 2 a-h

Rotalina mamilla Williamson, 1858, Ray Society, London, England, p. 54, pl. 4, figs. 109-111

Asterigerinata mamilla (Williamson), Murray, 1971, p. 141, pl. 59, figs. 1-6; Levy et al., 1995, p. 46, pl. 10, fig. 10 and Martins and Gomes, 2004, p. 218-219, fig. 2.129.

Genus *Eoeponidella* Wickenden, 1949

***Eoeponidella pulchella* (Parker 1952)**

Pninaella? pulchella Parker, 1952, Harvard Coll., Mus. Comp. Zoöl., Bull., Cambridge, Mass., vol. 106 (1951-1952), no. 9, p. 420, pl. 6, figs. 18-20.

Eoeponidella pulchella (Parker), Martins and Gomes, 2004, p. 219-220, fig. 2.130.

Superfamily NONIONACEA Schultze, 1854

Family NONIONIDAE Shultze, 1854

Subfamily NONIONINAE Schultze, 1854

Genus *Haynesina* Banner y Culver, 1978

***Haynesina germanica* (Ehrenberg 1840)**

Nonionina germanica Ehrenberg, 1840, K. Preuss. Akad. Wiss. Berlin, Ber., Berlin, Deutschland, p. 23.

Haynesina germanica (Ehrenberg), Loeblich and Tappan, 1987, p. 616, pl. 689, figs. 1-4; Jones, 1994, p. 107, pl. 109, figs. 6-7 and Martins and Gomes, 2004, p. 221-222, fig. 2.131.

Genus *Nonion* de Monfort, 1808

***Nonion fabum* (Fichtel and Moll 1798)**

Plate 4, fig. 3 a-e

Nautilus faba Fichtel and Moll, 1798, Vienna: Anton Pichler, p. 103, pl. 19, figs. a-c.

Florilus asterizans (Fichtel and Moll); Ubaldo and Otero, 1978, p. 116, pl. 5, figs. 14, 15.

Nonion commune (d’Orbigny); Levy et al., 1995, p. 46, pl. 11, fig. 1.

Nonion fabum (Fichtel and Moll), Jones, 1994, p. 108, pl. 109, figs. 12-13 and Martins and Gomes, 2004, p. 223-224, fig. 2.132.

Genus *Nonionella* Cushman, 1926

Nonionella iridea **Heron-Allen and Earland 1932**

Plate 4, fig. 4 a-c

Nonionella iridea Heron-Allen and Earland, 1932, University press, Cambridge, England, vol. 4, p. 438, pl. 16, figs. 14-16.

Nonionella iridea Heron-Allen and Earland, Martins and Gomes, 2004, p. 227-228, fig. 2.135 and Duchemin et al., 2005, pl. 2, fig. 18-19.

Nonionella stella **Cushman and Moyer 1930**

Plate 4, fig. 5 a-c

Nonionella miocenica Cushman var. *stella* Cushman and Moyer, 1930, Contr. Cushman Lab. Foram. Res., Sharon, Mass., U.S.A., vol. 6, pt. 3, no. 93, p. 56, pl. 7, fig. 17.

Nonionella stella (Cushman and Moyer); Martins and Gomes, 2004, p. 229-230, fig. 2.136.

Nonionella **sp.**

Plate 4, fig. 6 a-d

Nonionella turgida **(Williamson 1858)**

Plate 4, fig. 7 a-e

Rotalina turgida Williamson, 1858, Ray Soc., London, England, p. 50, pl. 4, figs. 95-97.

Nonionella turgida (Williamson), Murray, 1971, p. 193, pl. 81, figs. 1-5; Jones, 1994, p.108, pl. 109, figs. 17-19; Levy et al., 1995, p. 46, pl. 10, fig. 11 and Martins and Gomes, 2004, p. 231- 232, fig. 2.137.

Subfamily PULLENIINAE Schwager, 1877

Genus *Melonis* de Montfort, 1808

***Melonis* sp.**

Superfamily CHILOSTOMELLACEA Brady, 1881

Family CHILOSTOMELLIDAE Brady, 1881

Subfamily CHILOSTOMELLINAE Brady, 1881

Genus *Chilostomella* Reuss, 1849

***Chilostomella* sp.**

Family GAVELINELLIDAE Hofker, 1956

Subfamily GAVELINELLINAE Hofker, 1956

Genus *Gyroidina* d'Orbigny, 1826

***Gyroidina umbonata* (Silvestri 1898)**

Rotalia soldanii d'Orbigny var. *umbonata* Silvestri, 1898, Accad. Pont. Nuovi Lincei, Mem., Roma, Itália, vol. 15, p. 329, pl. 6, fig. 14a-c.

Gyroidina umbonata (Silvestri), Levy et al., 1995, p. 50, pl. 11, fig. 10 and Martins and Gomes, 2004, p. 247-248, fig. 2.147.

Genus *Hanzawaia* Asano, 1944

***Hanzawaia concentrica* (Cushman 1918)**

Truncatulina concentrica Cushman, 1918, U.S. Geol. Surv., Bull., Washington, D.C., no. 676, p. 64, pl. 21, fig. 3 a-c.

Hanzawaia concentrica (Cushman), Schiebel, 1992, pl. 1, fig. 11, a-d and Schönfeld, 1997, pl. 1, figs. 14-15.

***Hanzawaia rhodiensis* (Terquem 1878)**

Truncatulina rhodiensis Terquem, 1878, Soc. Géol. France, Mém., Paris, France, ser. 3, tome 1, no. 3, p. 21, pl. 1, fig. 26 a-c.

Hanzawaia rhodiensis (Terquem), Schiebel, 1992, pl. 1, fig. 13, a-b.

Superfamily ROTALIACEA Ehrenberg, 1839

Family ROTALIIDAE Ehrenberg, 1839

Subfamily AMMONIINAE Saidova, 1981

Genus *Ammonia* Brünnich, 1772

***Ammonia beccarii* (Linnaeus 1758)**

Plate 5, fig. 1 a-f

Nautilus beccarri Linnaeus, 1758, impensis L. Salvii, Holmiae, Suecia, tomus 1, p. 710, pl. 1, fig. 1a – c.

Ammonia beccarii (Linnaeus), Murray, 1971, p. 151, pl. 62, figs. 1-7; Levy et al., 1995, p. 51, pl. 12 fig. 1 and Martins and Gomes, 2004, p. 253-256, fig. 2.150.

Family ELPHIDIIDAE Galloway, 1933

Subfamily ELPHIDIINAE Galloway, 1933

Genus *Elphidium* de Monfort, 1808

***Elphidium complanatum* (d' Orbigny 1839)**

Polystomella complanata d'Orbigny, 1839, Paris: Béthune, tome 2, pt. 2, Zool., p. 129, pl. 2, figs, 35-36.

Elphidium complanatum (d' Orbigny), Martins and Gomes, 2004, p. 259-260, fig. 2.153.

Elphidium crispum **(Linnaeus 1758)**

Plate 5, fig. 2 a-d

Nautilus crispus Linnaeus, 1758, Impensis L. Salvii, Holmiae, Suécia, tomus 1, p. 709

Elphidium crispum (Linnaeus), Murray, 1971, p. 155, pl. 64, figs. 1-6; Jones, 1994, p. 109, pl. 110, figs. 6-7; Levy et al., 1995, p. 51, pl. 12, fig. 5 and Martins and Gomes, 2004, p. 261-262, fig. 2.154.

Elphidium cuvillieri **Levy 1966**

Plate 5, fig. 3 a-e

Elphidium cuvillieri Levy, 1966, Vie et Milieu, Paris, t. 17, fasc. 1a, p. 5-6, pl. 1, fig.6, pl. 2.

Cribroelphidium cuvillieri (Levy), Debenay et al., 2001, pl. 6, fig. 18 and Villanueva and Canudo, 1999, p. 213-214, pl. 2, fig. 4, a-b.

Elphidium excavatum **(Terquem 1875)**

Plate 5, fig. 4 a-d

Polystomella excavata Terquem, 1875, Soc. Dunkerquoise, Mén., Dunkerque, France, vol. 19, p. 429, pl. 2, figs. 2a-b.

Elphidium excavatum (Terquem), Murray, 1971, p. 159, pl. 66, figs. 1-7.

Elphidium gerthi **Van Voorthuysen 1957**

Plate 5, fig. 5 a-e

Elphidium gerthi Van Voorthuysen, 1957, Geol. Stichting, Meded, Haarlem, Netherlands, no. 11, p. 32, pl. 23, fig. 12a-b

Cribrononion gerthi (Van Voorthuysen); Levy et al., 1995, p. 51, pl. 12, fig. 2 and Martins and Gomes, 2004, p. 257-258, fig. 2.152.

***Elphidium granosum* (d'Orbigny 1846)**

Nonionina granosa d'Orbigny, 1846, Paris: Gide et Comp., p. 110, pl. 5, figs. 19-20.

Porosononion granosum (d'Orbigny), Poignant et al., 2000, p. 400, pl. 1, figs. 13-15.

Elphidium granosum (d'Orbigny), Jorissen, 1987, p. 47, pl. 2, figs. 1-2.

Plate 1

1 - *Nouria polymorphinoides* Heron-Allen and Earland 1914, scale bar = 50 µm; surface sample/Core 16

a - scanning electron microscope (SEM) photograph, side view
b - binocular microscope (BM) photograph, side view
c - SEM photograph, aperture detail

2 - *Nouria sp.*; surface sample/601

a and b - BM photograph, side view

3 - *Eggerelloides scaber* (Williamson 1858), scale bar = 50 µm; surface sample/658

a and b - SEM photograph, side view
c - BM photograph, side view

4 - *Textularia deltoidea* Reuss 1850, scale bar = 50 µm; surface sample/594

a - SEM photograph, side view
b - BM photograph, side view
c - SEM photograph, side view, juvenile

5 - *Quinqueloculina laevigata* d'Orbigny 1839, scale bar = 50 µm, surface sample/632

a - SEM photograph, side view
b - BM photograph, side view
c - SEM photograph, aperture detail

6 - *Quinqueloculina rugosa* d'Orbigny 1852, Core 7/70-71.5

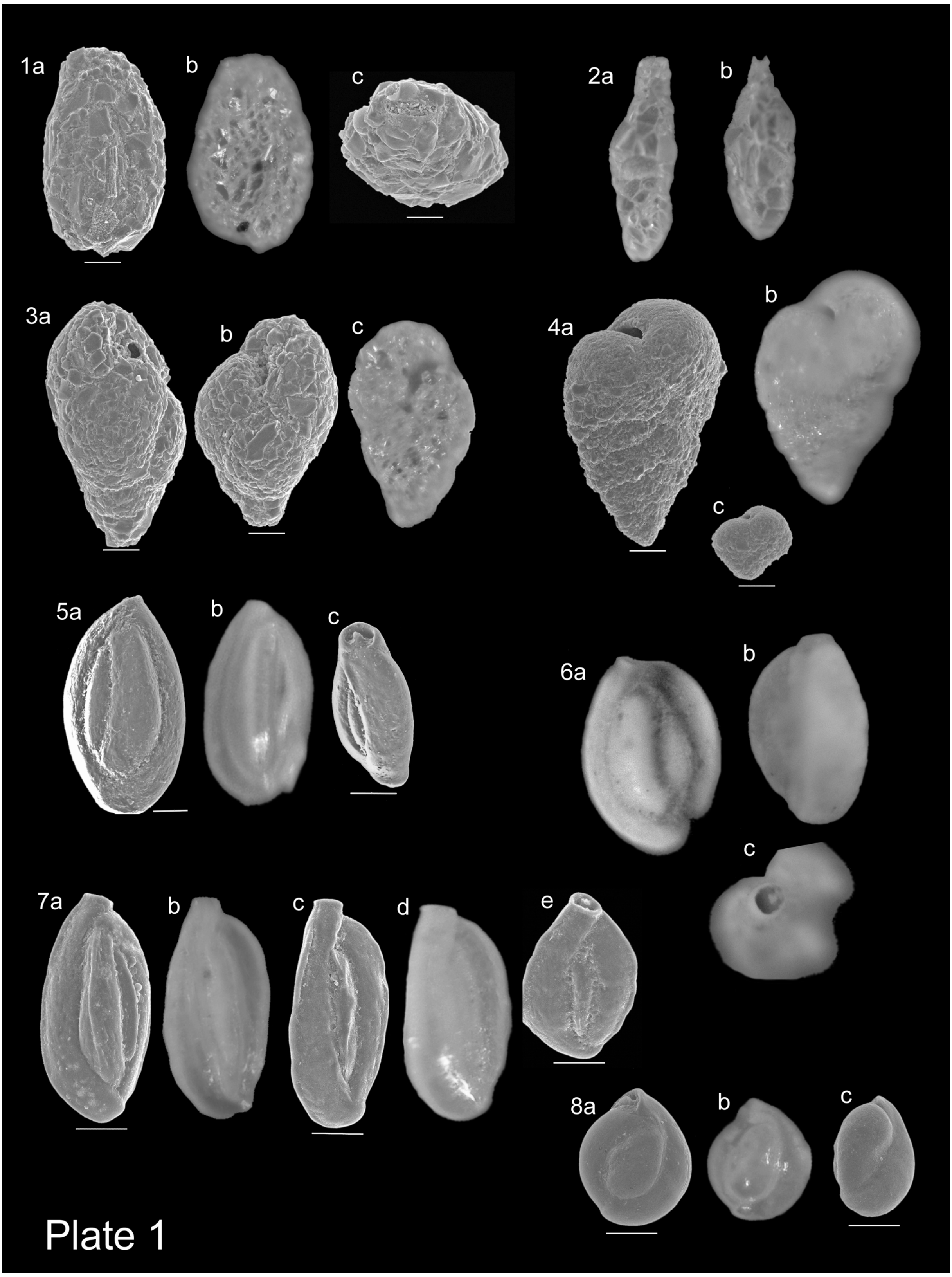
a - BM photograph, side view
b - BM photograph, side view
c - BM photograph, aperture detail

7 - *Quinqueloculina stelligera* Schlumberger 1893, scale bar = 50 µm; Core 8/158-160

a and c - SEM photograph, side view
b and d - BM photograph, side view
e - SEM photograph, aperture detail

8 - *Miliolinella subrotunda* (Montagu 1803), scale bar = 50 µm; Core 8/118-120

a and c - SEM photograph, side view
b - BM photograph, side view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7a
b
c
d
e
8a
b
c
Plate 1

Plate 2

1 - *Bolivina catanensis* Seguenza 1862, scale bar = 50 µm; surface sample/Core 12

a - scanning electron microscope (SEM) photograph, side view

b - binocular microscope (BM) photograph, side view

2 - *Bolivina italica* Cushman 1936; surface sample/601

a - BM photograph, side view

b - BM photograph, profile view and aperture detail

3 - *Bolivina ordinaria* Pheleger and Parker 1952, new name, scale bar = 50 µm; surface sample/584

a and d - SEM photograph, side view

b and e - BM photograph, side view

c - SEM photograph, profile view

f - SEM photograph, view from aperture extremity to apical end

g - SEM photograph, view from apical end to aperture extremity

4 - *Bolivina pseudoplicata* Heron-Allen and Earland 1930, scale bar = 50 µm; Core 8/218-220

a - SEM photograph, side view

b - BM photograph, side view

5 - *Bolivina striatula* Cushman 1922, scale bar = 50 µm; surface sample/657

a and c - SEM photograph, side view, different grow phases

b and d - BM photograph, side view, different grow phases

6 - *Brizalina dilatata* (Reuss 1850), scale bar = 50 µm; surface sample/684

a and c - SEM photograph, side view, different grow phases

b and d - BM photograph, side view, different grow phases

7 - *Brizalina spathulata* (Williamson 1858), scale bar = 50 µm; surface sample/684

a - SEM photograph, side view

b - BM photograph, side view

8 - *Cassidulina laevigata* d'Orbigny, 1826, scale bar = 50 µm; surface sample/684

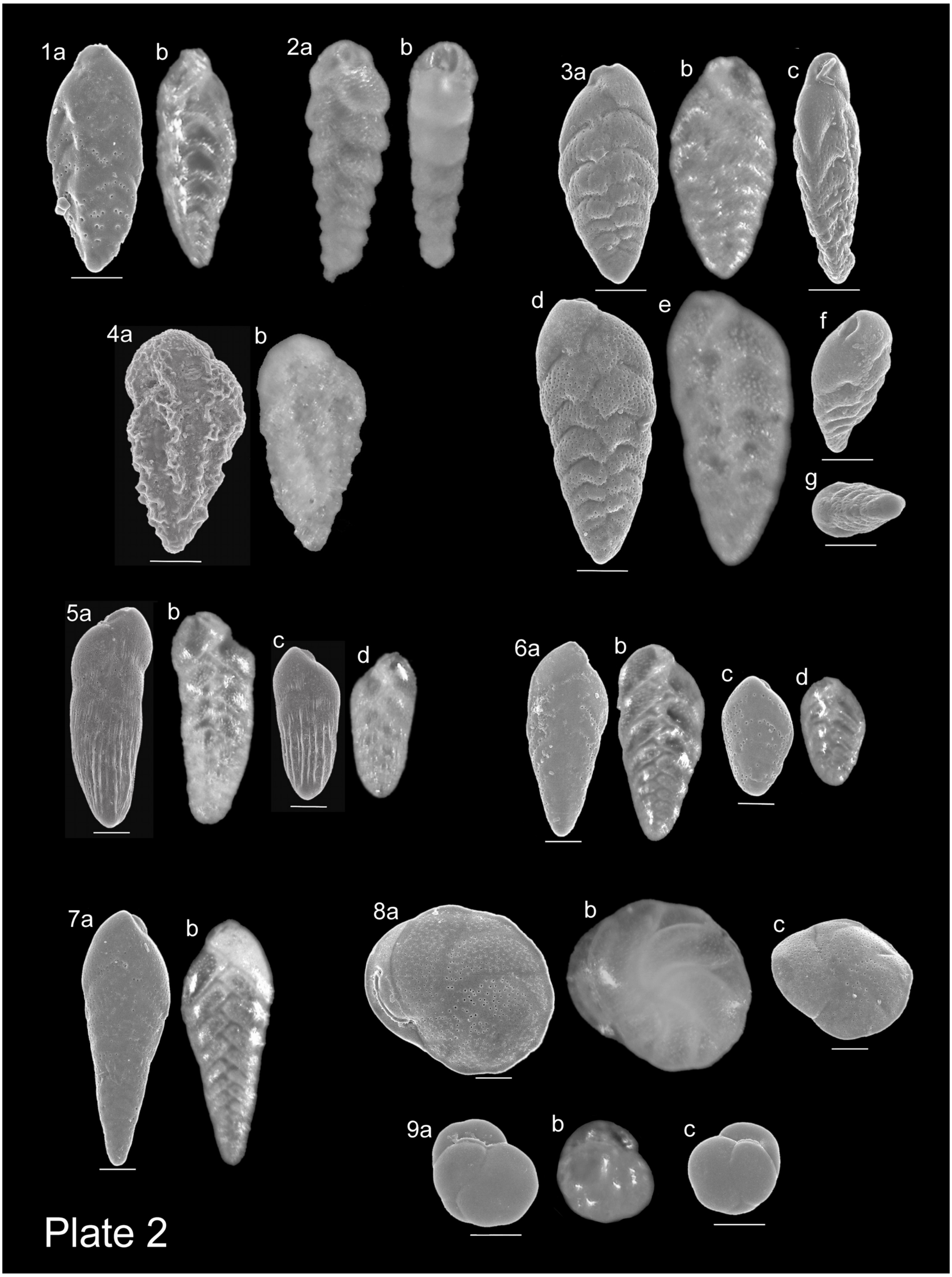
a and c - SEM photograph, side view

b - BM photograph, side view

9 - *Cassidulina minuta* Cushman 1933, scale bar = 50 µm; Core 8/218/220

a and c - SEM photograph, side view

b - BM photograph, side view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b
8a
b
c
9a
b
c
Plate 2

Plate 3

1 - *Hopkinsina atlantica* (Cushman 1944), scale bar = 50 µm; surface sample/670
  a - scanning electron microscope (SEM) photograph, side view
  b - binocular microscope (BM) photograph, side view
  c - SEM photograph, view from aperture extremity to apical end

2 - *Stainforthia fusiformis* (Williamson 1858), scale bar = 50 µm; Core 5/250-252
  a and c - SEM photograph, side view
  b - BM photograph, side view

3 - *Stainforthia* sp., scale bar = 50 µm; surface sample/Core 12 and Core 8/88-90
  a and c - SEM photograph, side view
  b - BM photograph, side view

4 - *Rectuvigerina phlegeri* Le Calvez 1959, scale bar = 50 µm; surface sample/570
  a and c - SEM photograph, side view, different grow phases
  b and d - BM photograph, side view, different grow phases

5 - *Bulimina aculeata* d'Orbigny 1826, scale bar = 50 µm; surface sample/596
  a and c - SEM photograph, side view
  b and d - BM photograph, side view

6 - *Bulimina elongata* d'Orbigny 1846, scale bar = 50 µm; surface sample/597
  a and c - SEM photograph, side view
  b - BM photograph, side view

7 - *Bulimina marginata* d'Orbigny 1826, scale bar = 50 µm; surface sample/Core 12
  a and c - SEM photograph, side view
  b and d - BM photograph, side view

8 - *Epistominella vitrea* Parker 1953, scale bar = 50 µm; surface sample/596 and Core 5/10-11
  a - SEM photograph, dorsal side
  b - BM photograph, dorsal side
  c - SEM photograph, ventral side
  d - BM photograph, ventral side

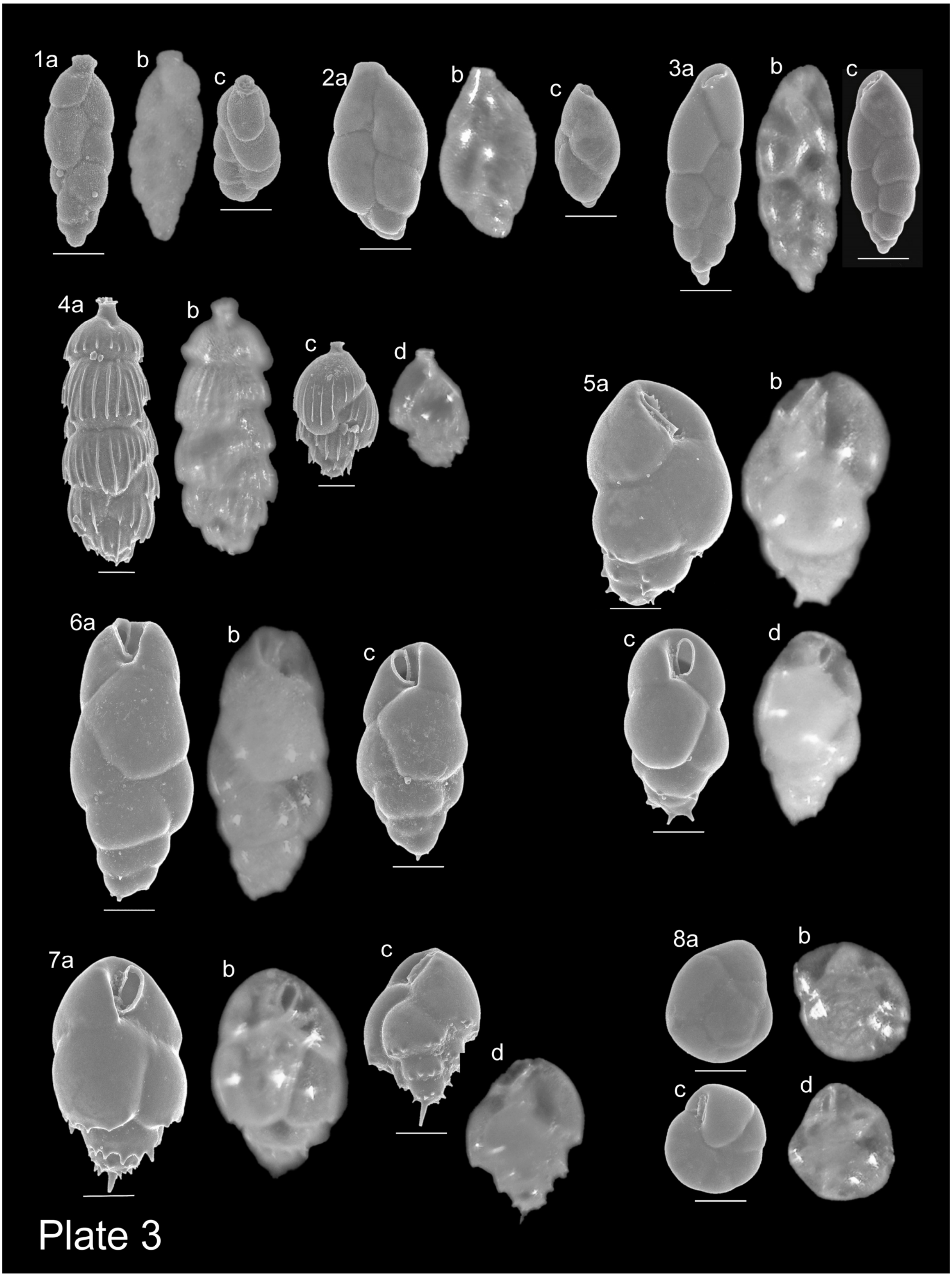

Plate 3

Plate 4

1 - *Planorbulina mediterranensis* d'Orbigny 1826, different grow phases, from a to e scale bar = 50 µm and from g to i scale bar = 100 µm; Core 8/188-190 and Core 8/288-290

a and g - scanning electron microscope (SEM) photograph, ventral side (a - juvenile, g - adult)

b and h - binocular microscope (BM) photograph, ventral side (b - juvenile, h - adult)

c, e and i - SEM photograph, dorsal side (c - juvenile, i - adult)

d, f and j - BM photograph, dorsal side (d - juvenile, j - adult)

2 - *Asterigerinata mamilla* (Williamson 1858), scale bar = 50 µm; Core 8/218-220 and Core 8/228-230

a and e - SEM photograph, dorsal side

b and f - BM photograph, dorsal side

c and g - SEM photograph, ventral side

d and h - BM photograph, ventral side

3- *Nonion fabum* (Fichtel and Moll 1798), scale bar = 100 µm; surface sample/568

a and d - SEM photograph, side view (a - adult, d - juvenile)

b and e - BM photograph, side view (b - adult, e - juvenile)

c - SEM photograph, profile view

4 - *Nonionella iridea* Heron-Allen and Earland 1932, scale bar = 50 µm; surface sample/567 and Core 7/64-66

a - SEM photograph, dorsal side

b - BM photograph, dorsal side

c - SEM photograph, profile view

5 - *Nonionella stella* Cushman and Moyer 1930, scale bar = 50 µm; surface sample/567

a - SEM photograph, ventral side

b - BM photograph, ventral side

c - SEM photograph, dorsal view

6 - *Nonionella* sp., scale bar = 50 µm; Core 8/108/110

a - SEM photograph, dorsal side

b - BM photograph, dorsal side

c - SEM photograph, ventral view

d - SEM photograph, profile view

7 - *Nonionella turgida* (Williamson 1858), scale bar = 50 µm; surface sample/568

a and d - SEM photograph, ventral side, different grow phases

b - SEM photograph, dorsal side

c - BM photograph, dorsal side

e - BM photograph, ventral side, juvenile

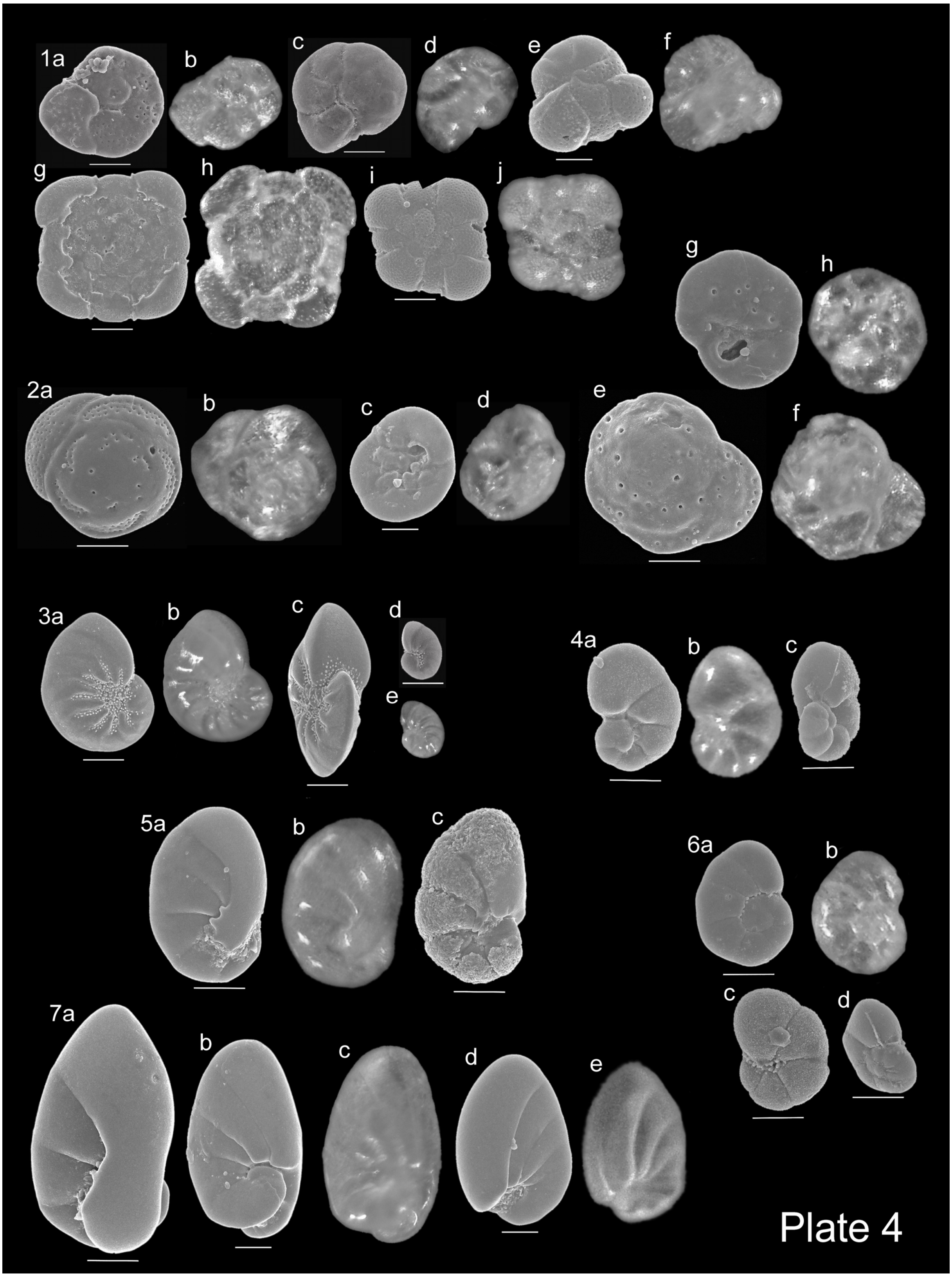

Plate 4

Plate 5

1 - *Ammonia beccarii* (Linnaeus 1758), scale bar = 100 µm; surface sample/657

a and e - scanning electron microscope (SEM) photograph, dorsal side (a - adult, e - juvenile)

b - binocular microscope (BM) photograph, dorsal side

c and f – SEM photographs, ventral side (c - adult, f - juvenile)

d - BM photograph, ventral side

2 - *Elphidium crispum* (Linnaeus 1758), scale bar = 100 µm, Core 7/0-1

a - SEM photographs, side view

b - d - BM photographs, side view

3 - *Elphidium cuvillieri* Levy 1966, scale bar = 50 µm, surface sample/594

a and d - SEM photograph, side view (a - adult, d - juvenile)

b and e - BM photograph, side view (b - adult, e - juvenile)

c - SEM photograph, profile view

4 - *Elphidium excavatum* (Terquem 1875), scale bar = 50 µm, surface sample/593

a and c - SEM photograph, side view

b and d - BM photograph, side view

5 - *Elphidium gerthi* Van Voorthuysen 1957, scale bar = 50 µm, surface sample/593

a - SEM photograph, side view

b, d and e - BM photograph, side view

c - SEM photograph, profile view

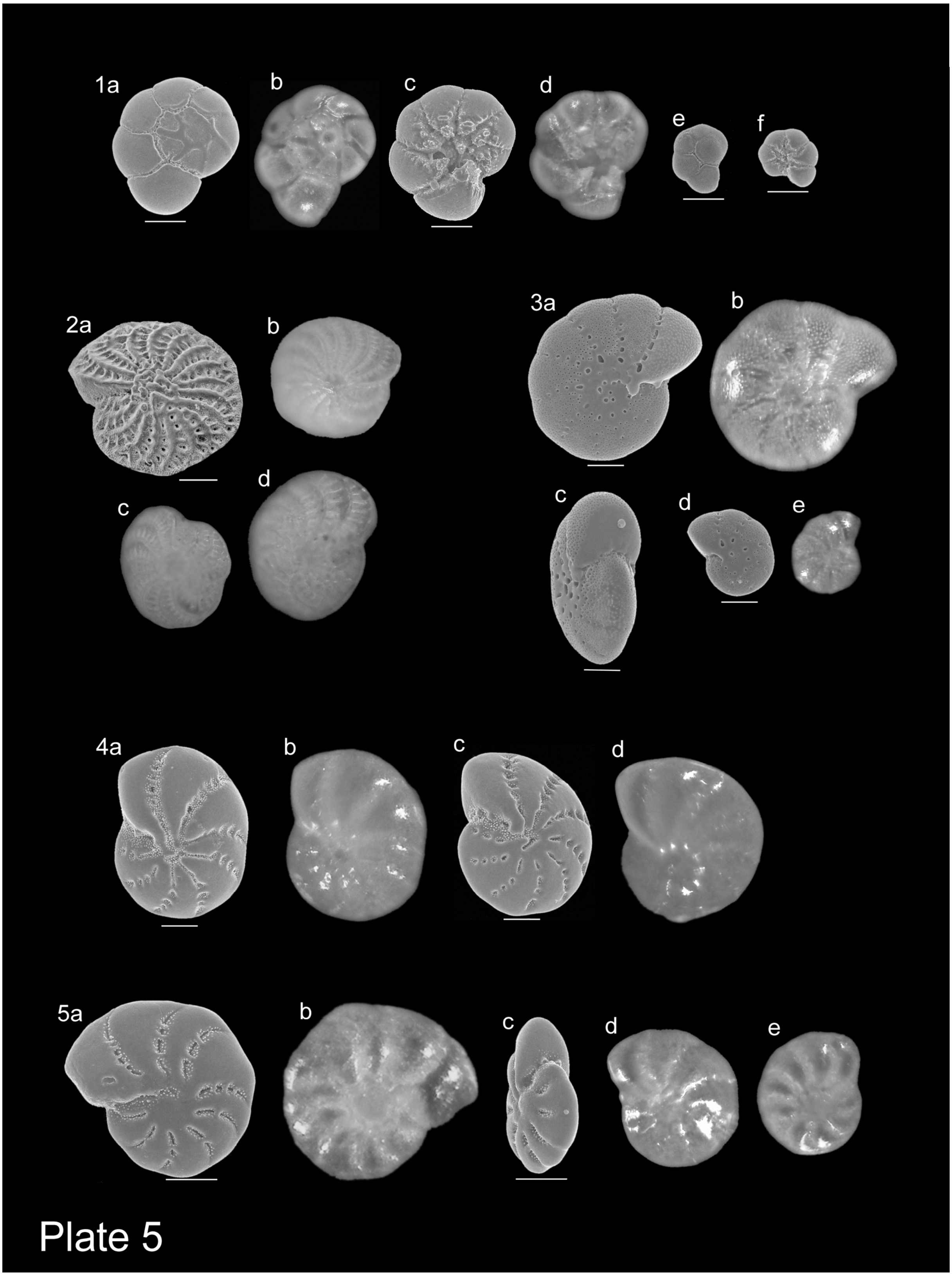

Plate 5

Chapter 8

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Chapter 9

Appendices

Appendix A

Appendix A

Relative abundance of the total assemblage for taxa with more than one specimen for all stations; sampling depth (m) and number of taxa with one specimen.

* species only observed in surficial samples

Stations	**Core3**	**Core4**	**Core9**	**Core12**	**Core14**	**Core16**	**Core19**	**Core20**	**564**	**565**	**566**	**567**	**568**	**569**	**570**	**571**	**572**
Depth (m)	85	51	27.5	100.6	80	49.4	21.2	12.8	36	47.9	60.5	79.5	44.2	44.6	35.7	24.5	19.5
Total of specimens counted	133	140	223	427	154	215	305	181	293	395	306	372	339	314	315	321	339
Number of *taxa* with one specimen	9	11	17	15	6	6	25	9	23	6	8	3	15	14	16	16	20
Taxa																	
Adercotryma glomeratum														1.6			
Agluninate cf. *Alveolopharagmium**																	
Agglutinate form *				0.5													
Alliatina sp.													1.8				
Ammonia beccarii			1.8				1.6	8.3	1.0	1.5	0.7	0.8	0.9	1.9	1.3	1.6	2.4
Ammoscalaria sp.1															1.0		
Ammoscalaria sp.2																	
Asterigerinata mamila								5.0									4.4
Bolivina albatrossi														0.6			
Bolivina catanensis				6.6													
Bolivina italica				0.5								0.5					
Bolivina ordinaria	3.8	34.3	54.7	11.0	5.8	28.4	54.4	8.8	34.5	43.8	45.4	7.0	27.1	24.8	21.9	50.8	26.0
Bolivina pseudogoesii																	0.9
Bolivina pseudoplicata			0.9				2.0		1.0					0.6	1.3	0.6	4.1
Bolivina sp.1		1.4	0.9														
Bolivina sp.2																	
Bolivina sp.3																	
Bolivina sp.4																	
Bolivina spp.													0.6		1.9	0.9	2.1
Bolivina variabilis									0.7							0.6	1.2
Bolivina striatula				0.7		0.9	0.7										0.6
Bolivinellina pseudopuntata		2.9	1.8	0.7	3.9	0.9							0.6				
Brizalina dilatata	29.3	23.6	0.9	11.5	3.9	2.3	1.0		1.4	6.3	6.9	8.9	5.0	1.6	1.0		
Brizalina nitida																	
Brizalina sp.											1.0						
Brizalina spathulata	8.3	3.6	0.9	8.2	14.9	13.0			1.7	3.5	8.8	1.9	1.8	5.1		0.9	

Cont.

Stations	**Core3**	**Core4**	**Core9**	**Core12**	**Core14**	**Core16**	**Core19**	**Core20**	**564**	**565**	**566**	**567**	**568**	**569**	**570**	**571**	**572**
Depth (m)	85	51	27.5	100.6	80	49.4	21.2	12.8	36	47.9	60.5	79.5	44.2	44.6	35.7	24.5	19.47
Total of specimens counted	133	140	223	427	154	215	305	181	293	395	306	372	339	314	315	321	339
Number of *taxa* with one specimen	9	11	17	15	6	6	25	9	23	6	8	3	15	14	16	16	20
Taxa																	
Brizalina spp.																	
Brizalina subaenariensis		1.4	1.3	0.7	1.9	1.4			3.4					1.0	1.3		3.2
Bulimina acanthia														0.6			
Bulimina aculeata	1.5			1.9		3.3	3.0	3.9	1.4	8.1	8.5	1.9	2.1	5.7	4.1	6.5	1.8
Bulimina elongata	9.0			1.4	1.9	1.4	0.7			5.3	8.2	0.5		1.6			
Bulimina exilis																	
Bulimina marginata	3.8	3.6	0.9	6.1		2.3	1.3			2.5	0.7	3.2	2.1	2.2		3.1	1.2
Bulimina sp.							0.7										
Bulimina spp.																	
Buliminella elegantissima							2.6	1.7		0.8							1.2
Buliminella tenuata												0.5	0.9				
Cancris auriculus *													1.8				
Cassidulina crassa																	0.6
Cassidulina laevigata	2.3	1.4		2.6	1.3	0.9											
Cassidulina minuta				0.5													
Cassidulina spp.																	
Cassidulina teretis																	0.6
Cibicides lobatulus			0.9												0.6	1.2	1.2
Cornuspira involvens									1.0								
Cornuspira spp.																	0.9
Deuterammina spp.									0.7								
Eggerella advena								3.3									
Eggerella sp. *																	
Eggerella spp.																	
Eggerelloides sp.2																	
Eggerelloides scaber			0.9		1.3			46.4		1.0	3.3	6.2	0.9	2.5	2.5	0.9	8.6
Elphidium cuvillieri									0.7						1.6		
Elphidium excavatum	4.5		1.3	0.5					0.7	7.1	3.6	4.8	2.4	3.5	2.9	7.5	5.6
Elphidium gerthi							2.0	1.1									
Elphidium granosum								1.1								0.6	

Cont.

Stations	**Core3**	**Core4**	**Core9**	**Core12**	**Core14**	**Core16**	**Core19**	**Core20**	**564**	**565**	**566**	**567**	**568**	**569**	**570**	**571**	**572**
Depth (m)	85	51	27.5	100.6	80	49.4	21.2	12.8	36	47.9	60.5	79.5	44.2	44.6	35.7	24.5	19.47
Total of specimens counted	133	140	223	427	154	215	305	181	293	395	306	372	339	314	315	321	339
Number of *taxa* with one specimen	9	11	17	15	6	6	25	9	23	6	8	3	15	14	16	16	20
Taxa																	
Elphidium sp.																	
Epistominella exigua										1.0							
Epistominella sp.									0.7						1.0		0.9
Epistominella spp.				0.7													
Epistominella vitrea	3.0	4.3		3.5	1.9		1.0		2.4	1.5	2.9	1.3	1.8	7.0		2.2	
Fursenkoina pontoni																	
Gavelinopsis praegeri																	0.6
Globobulimina auriculata *													0.6				
Globobulimina sp.																	
Globocassidulina subglobosa																	
Hanzawaia sp.													0.9				
Haynesina germanica																	
Hopkinsina atlantica		1.4	9.9				6.9	2.8	20.5	3.3	4.2		1.2	3.2	4.4	8.4	3.8
Hopkinsina sp.							1.0		0.7								
Hopkinsina spp.																	
Hyalinea balthica				0.5													
Lagena setigera																	
Lepidodeuterammina ochracea			1.3														
Leptohalysis scottii						4.7		2.2	1.0						0.6		1.8
Melonis sp.																	
Melonis spp.																	0.9
Nonion fabum	3.8			0.5						0.5			7.7	1.3	4.4		
Nonionella sp.	4.5		2.2	0.5													
Nonionella iridea	6.0		1.3		5.2		1.6		0.7	0.8		14.8	2.4	3.2			1.5
Nonionella stella		5.7	1.8	4.2	20.8	2.8	3.6	1.7	1.0	3.0	1.0	36.0	4.7	4.8	2.9	0.6	1.5
Nonionella turgida		2.9		0.5						1.3		2.2	16.2	8.6	2.2		
Nonionnoides sp.										0.5			2.1				
Nouria polymorphinoides				1.4	5.2	23.7									5.7	0.6	
Nouria sp. *																	
Patellina corrugata																	0.9

Cont.

Stations	**Core3**	**Core4**	**Core9**	**Core12**	**Core14**	**Core16**	**Core19**	**Core20**	**564**	**565**	**566**	**567**	**568**	**569**	**570**	**571**	**572**
Depth (m)	85	51	27.5	100.6	80	49.4	21.2	12.8	36	47.9	60.5	79.5	44.2	44.6	35.7	24.5	19.47
Total of specimens counted	133	140	223	427	154	215	305	181	293	395	306	372	339	314	315	321	339
Number of *taxa* with one specimen	9	11	17	15	6	6	25	9	23	6	8	3	15	14	16	16	20
Taxa																	
Planorbulina mediterranensis							1.3										1.8
Planorbulina sp.																	
Pseudobolivina fusiformis *						2.8									0.6		
Pseudobolivina sp.													0.6				
Quinqueloculina laevigata																	1.2
Quinqueloculina seminulum															0.6		
Quinqueloculina sp. 1																	
Quinqueloculina spp.								1.1									
Quinqueloculina stelligera							0.7	5.5								0.6	2.7
Rosalina bradyi			0.9						0.7							0.6	2.9
Rectuvigerina phlegeri	7.5	2.1	4.0	4.9	3.9	1.9	3.9		6.5	5.1	1.6	5.9	4.4	9.9	20.3	0.6	
Reophax curtus																	0.6
Reophax dentaliniformis																	
Reophax nodolosus																	
Rosalina sp.																	
Saidovina karreriana														1.6	0.6		
Sigmoilopsis sp.																	0.9
Spiroplectinella earlandi				0.9	1.3	1.9			3.8			1.1	0.6		2.5	1.6	1.2
Stainforthia loeblichi					4.5	1.9			0.7	0.8	0.7		2.4	0.6	1.6		
Stainforthia sp.			3.6	24.1	18.2	2.8		1.1	5.5	0.8				0.6	3.2	1.2	1.2
Textularia conica																	0.6
Textularia deltoidea	1.5												0.6	1.3	1.3		
Trifarina angulosa		2.1					1.3					1.6	0.9			1.6	1.5
Trifarina sp.							0.7										
Trochammina inflata															0.6	0.9	
Trochammina sp.								1.1									1.5
Uvigerina peregrina	4.5	1.4		1.6													
Valvulineria bradyana													0.9		1.0	0.6	
Indeterminate																	

Appendix A

Relative abundance of the total assemblage for taxa with more than one specimen for all stations; sampling depth (m) and number of taxa with one specimen.
* species only observed in surficial samples

Stations	**573**	**582**	**583**	**584**	**586**	**587**	**588**	**589**	**590**	**593**	**594**	**596**	**597**	**598**	**601**	**632**	**633**
Depth (m)	15.8	15.6	20.3	27.5	46	45.3	50	40.8	37.7	25.34	34.82	51.71	66.37	86.57	115.5	12	15
Total of specimens counted	351	393	254	513	241	175	301	303	333	336	313	295	367	63	102	78	87
Number of *taxa* with one specimen	28	15	18	9	8	9	7	10	13	22	23	7	3	6	9	9	10
Taxa																	
Adercotryma glomeratum																	
Agluninate cf. *Alveolopharagmium**																	
Agglutinate form *		1.3															
Alliatina sp.															2.0		
Ammonia beccarii	4.0	11.2		2.1	2.5			1.3	2.7	6.5	8.3	1.4	1.4	3.2		15.4	
Ammoscalaria sp.1										0.9						5.1	
Ammoscalaria sp.2																	
Asterigerinata mamila	0.6	0.8	1.2														
Bolivina albatrossi																	
Bolivina catanensis																	
Bolivina italica													2.5		7.8		
Bolivina ordinaria	32.5	9.2	58.3	75.4	31.1	27.4	24.3	40.3	42.0	29.2	18.2	39.0	11.2	14.3	8.8	15.4	11.5
Bolivina pseudogoesii																	
Bolivina pseudoplicata	1.1	3.6							0.9	2.1							
Bolivina sp.1		1.0	0.8														
Bolivina sp.2																	
Bolivina sp.3		0.5															
Bolivina sp.4		0.5								0.9							
Bolivina spp.	2.0								0.9								
Bolivina variabilis										1.2							
Bolivina striatula	2.3	2.3	0.8			1.1				0.6					7.8		
Bolivinellina pseudopuntata																	
Brizalina dilatata		0.3			4.1		4.3	3.3	0.6	0.9	1.9	4.7	14.4	4.8	6.9		2.3
Brizalina nitida										0.9							
Brizalina sp.																	
Brizalina spathulata		0.5			1.7	5.7	1.0	1.3			1.6	1.0	2.7		4.9		

Cont.

Stations	**573**	**582**	**583**	**584**	**586**	**587**	**588**	**589**	**590**	**593**	**594**	**596**	**597**	**598**	**601**	**632**	**633**
Depth (m)	15.8	15.6	20.3	27.5	46	45.3	50	40.8	37.7	25.34	34.82	51.71	66.37	86.57	115.5	12	15
Total of specimens counted	351	393	254	513	241	175	301	303	333	336	313	295	367	63	102	78	87
Number of *taxa* with one specimen	28	15	18	9	8	9	7	10	13	22	23	7	3	6	9	9	10
Taxa																	
Brizalina spp.	1.4	0.5															
Brizalina subaenariensis	3.4									0.9	0.6						
Bulimina acanthia												0.7					
Bulimina aculeata	2.3	2.5		1.2	13.7	8.6	9.0	12.2	7.2	3.9	4.8	15.6	12.5	28.6	3.9		2.3
Bulimina elongata	0.6			1.4	3.7	5.7	15.6	4.0	3.9	2.4	2.2	3.7	7.6	14.3			
Bulimina exilis																	
Bulimina marginata	0.6	3.6		0.6			0.7	1.0	1.8	2.7		1.7	1.6	3.2	4.9		2.3
Bulimina sp.																	
Bulimina spp.																	
Buliminella elegantissima	3.1	2.3	2.8	1.6				1.0	2.7	1.8		0.7					4.6
Buliminella tenuata					2.1				0.6								
Cancris auriculus *																	
Cassidulina crassa		1.0															
Cassidulina laevigata																	
Cassidulina minuta															2.0		
Cassidulina spp.										0.6							
Cassidulina teretis																	
Cibicides lobatulus																	
Cornuspira involvens																	
Cornuspira spp.																	
Deuterammina spp.																	
Eggerella advena																2.6	
Eggerella sp. *										0.9							
Eggerella spp.										0.9							
Eggerelloides sp.2		2.3															
Eggerelloides scaber	6.0	31.0		1.6	4.1	4.0	5.3	4.3	5.7	12.5	7.3	1.4	4.1			34.6	46.0
Elphidium cuvillieri										0.9	8.3						
Elphidium excavatum	2.6	0.0		1.8	10.4	9.1	7.6	5.6	8.1	7.7	7.0	5.8	8.4	14.3	2.0	2.6	
Elphidium gerthi		7.4		0.6	1.2												
Elphidium granosum	0.6	1.8															

Cont.

Stations	**573**	**582**	**583**	**584**	**586**	**587**	**588**	**589**	**590**	**593**	**594**	**596**	**597**	**598**	**601**	**632**	**633**
Depth (m)	15.8	15.6	20.3	27.5	46	45.3	50	40.8	37.7	25.34	34.82	51.71	66.37	86.57	115.5	12	15
Total of specimens counted	351	393	254	513	241	175	301	303	333	336	313	295	367	63	102	78	87
Number of *taxa* with one specimen	28	15	18	9	8	9	7	10	13	22	23	7	3	6	9	9	10
Taxa																	
Elphidium sp.								0.7									
Epistominella exigua									0.6			0.7					
Epistominella sp.																	
Epistominella spp.																	
Epistominella vitrea		0.5	1.6		3.3	2.3	2.7	4.6	5.1	3.0		2.4	7.1	4.8	4.9		
Fursenkoina pontoni																	
Gavelinopsis praegeri																	
Globobulimina auriculata *																	
Globobulimina sp.															3.9		
Globocassidulina subglobosa	0.6																
Hanzawaia sp.															4.9		
Haynesina germanica		0.5															
Hopkinsina atlantica	6.8	2.3	16.5	8.8	1.7	2.9	4.0	3.6	7.2	3.9	4.2	3.4				7.7	
Hopkinsina sp.																	
Hopkinsina spp.			1.2														
Hyalinea balthica																	
Lagena setigera								1.0									
Lepidodeuterammina ochracea	1.7																
Leptohalysis scottii		0.8	4.7														
Melonis sp.				0.4													
Melonis spp.											1.0						
Nonion fabum	1.1					3.4	0.7		0.6		1.0				2.0		
Nonionella sp.																	
Nonionella iridea	0.9						2.7						0.8				
Nonionella stella			2.0	0.4	3.7	1.7	8.3	1.0	1.8		0.6	3.4	15.0				
Nonionella turgida						2.3					1.9	0.7			7.8		
Nonionnoides sp.	0.6					1.1											
Nouria polymorphinoides						4.0				2.1	2.2						
Nouria sp. *															10.8		
Patellina corrugata																	

Cont.

Stations	**573**	**582**	**583**	**584**	**586**	**587**	**588**	**589**	**590**	**593**	**594**	**596**	**597**	**598**	**601**	**632**	**633**
Depth (m)	15.8	15.6	20.3	27.5	46	45.3	50	40.8	37.7	25.34	34.82	51.71	66.37	86.57	115.5	12	15
Total of specimens counted	351	393	254	513	241	175	301	303	333	336	313	295	367	63	102	78	87
Number of *taxa* with one specimen	28	15	18	9	8	9	7	10	13	22	23	7	3	6	9	9	10
Taxa																	
Planorbulina mediterranensis	2.8																
Planorbulina sp.										0.6							
Pseudobolivina fusiformis *																	
Pseudobolivina sp.																	
Quinqueloculina laevigata		0.8														5.1	11.5
Quinqueloculina seminulum																	
Quinqueloculina sp. 1																	
Quinqueloculina spp.	0.6	0.8															
Quinqueloculina stelligera	2.8	1.5															5.7
Rosalina bradyi	3.7	0.5								0.6							
Rectuvigerina phlegeri	2.3				8.7	13.7	8.3	6.3		0.9	13.4	8.1	4.9	3.2	2.0		
Reophax curtus																	
Reophax dentaliniformis																	2.3
Reophax nodolosus		0.8															
Rosalina sp.		0.5								0.6	0.6						
Saidovina karreriana																	
Sigmoilopsis sp.																	
Spiroplectinella earlandi				0.4	1.2			0.7	0.6	0.9	1.0	0.0	1.1				
Stainforthia loeblichi	1.4		0.0														
Stainforthia sp.			3.1	0.4			1.0	0.7	1.8		0.6						
Textularia conica	0.6																
Textularia deltoidea					2.1	1.7	1.0	2.6		0.6	3.8	2.4	1.9				
Trifarina angulosa	0.9	1.8		1.8	1.2		1.3	1.3	1.2	2.1	1.9	1.0	1.9				
Trifarina sp.		0.5															
Trochammina inflata		0.8															
Trochammina sp.	1.4																
Uvigerina peregrina															2.0		
Valvulineria bradyana															2.0		
Indeterminate	0.9	1.0															

Appendix A
Relative abundance of the total assemblage for taxa with more than one specimen for all stations; sampling depth (m) and number of taxa with one specimen.
* species only observed in surficial samples

Stations	**636**	**637**	**639**	**640**	**655**	**656**	**657**	**658**	**659**	**661**	**662**	**663**	**665**	**669**	**670**	**677**	**684**
Depth (m)	23	28	56	77	14	16	18	21	28	58	72	82	83	37	27	20	79
Total of specimens counted	108	340	327	432	344	336	407	572	455	318	338	352	349	90	522	337	431
Number of *taxa* with one specimen	14	10	6	8	11	8	11	9	10	6	8	8	4	6	8	11	10
Taxa																	
Adercotryma glomeratum										0.9	2.4						
Agluninate cf. *Alveolopharagmium**						0.6											
Agglutinate form *						0.6											
Alliatina sp.																	
Ammonia beccarii	6.5	6.8	1.5		16.3	32.1	19.4	27.1	2.2	0.6		0.9	1.1	37.8	1.3	9.8	
Ammoscalaria sp.1						2.1	0.5										
Ammoscalaria sp.2						0.9											
Asterigerinata mamila																	
Bolivina albatrossi																	
Bolivina catanensis																	
Bolivina italica				0.7									0.6				0.5
Bolivina ordinaria	19.4	24.7	27.5	50.9	16.3	2.1	15.7	5.1	34.1	64.8	41.4	42.9	46.1	37.8	54.8	20.5	13.5
Bolivina pseudogoesii																	
Bolivina pseudoplicata																	
Bolivina sp.1						0.6	0.7			0.6			0.6				
Bolivina sp.2					1.2												
Bolivina sp.3					0.9												
Bolivina sp.4																	
Bolivina spp.					0.9				0.7						0.4		
Bolivina variabilis							0.5										
Bolivina striatula					1.2	1.2	1.7		0.9								
Bolivinellina pseudopuntata					0.9				0.7	1.6	4.1					0.6	
Brizalina dilatata			18.3	28.2					0.4		4.4	37.2	29.2		1.3	0.3	63.6
Brizalina nitida					0.6	0.6											
Brizalina sp.							0.5										
Brizalina spathulata		0.9	7.0	1.6					1.1	6.9	2.4	4.0	4.9				10.2

Cont.

Stations	**636**	**637**	**639**	**640**	**655**	**656**	**657**	**658**	**659**	**661**	**662**	**663**	**665**	**669**	**670**	**677**	**684**
Depth (m)	23	28	56	77	14	16	18	21	28	58	72	82	83	37	27	20	79
Total of specimens counted	108	340	327	432	344	336	407	572	455	318	338	352	349	90	522	337	431
Number of *taxa* with one specimen	14	10	6	8	11	8	11	9	10	6	8	8	4	6	8	11	10
Taxa																	
Brizalina spp.																	
Brizalina subaenariensis		1.5			0.6	0.9	3.4	0.3	5.5		2.4	0.9			0.4	0.6	
Bulimina acanthia			0.6														
Bulimina aculeata	3.7	2.9	5.5	1.6		1.5	2.2	4.4	2.6	3.1		1.7	1.1	2.2	1.9	0.9	
Bulimina elongata			3.4	0.9					0.7			0.9	0.6		0.8		
Bulimina exilis									2.2								
Bulimina marginata				1.4	1.2	5.1	1.5	2.4	1.8			0.9	1.4	0.0	1.0	4.2	2.6
Bulimina sp.									0.7								
Bulimina spp.								1.6									
Buliminella elegantissima		0.9	0.9		0.6	1.2	2.0	0.5	0.7								
Buliminella tenuata																	
Cancris auriculus *																	
Cassidulina crassa																	
Cassidulina laevigata		1.2									5.0						
Cassidulina minuta											0.9						
Cassidulina spp.																	
Cassidulina teretis																	
Cibicides lobatulus																	
Cornuspira involvens																	
Cornuspira spp.																	
Deuterammina spp.																	
Eggerella advena	1.9	2.1				0.6	0.5	0.5								0.9	
Eggerella sp. *																	
Eggerella spp.																	
Eggerelloides sp.2																	
Eggerelloides scaber	38.0	19.1	6.7	0.7	1.5	24.1	18.7	41.3	14.3	1.9	4.1	0.6	1.4	4.4	11.7	31.2	0.5
Elphidium cuvillieri		7.1					6.4	0.9	3.7							3.0	
Elphidium excavatum		3.2	4.0	0.7	0.9	3.0	3.2	4.5	5.5	0.9	0.6	0.0	0.9	3.3	6.9	4.7	
Elphidium gerthi																	
Elphidium granosum		0.6				0.6											

Cont.

Stations	**636**	**637**	**639**	**640**	**655**	**656**	**657**	**658**	**659**	**661**	**662**	**663**	**665**	**669**	**670**	**677**	**684**
Depth (m)	23	28	56	77	14	16	18	21	28	58	72	82	83	37	27	20	79
Total of specimens counted	108	340	327	432	344	336	407	572	455	318	338	352	349	90	522	337	431
Number of *taxa* with one specimen	14	10	6	8	11	8	11	9	10	6	8	8	4	6	8	11	10
Taxa																	
Elphidium sp.							0.5										
Epistominella exigua																	
Epistominella sp.																	
Epistominella spp.																	
Epistominella vitrea	1.9	0.6	5.5	6.5		0.6		0.9	0.4	7.2	5.6	1.7	3.7		0.8	0.9	1.2
Fursenkoina pontoni							0.5									0.6	
Gavelinopsis praegeri																	
Globobulimina auriculata *																	
Globobulimina sp.																	
Globocassidulina subglobosa																	
Hanzawaia sp.																	
Haynesina germanica																	
Hopkinsina atlantica	2.8	3.2	1.5		28.5	6.0	7.1	2.6	5.7	0.9	0.6				12.6	6.5	0.7
Hopkinsina sp.					1.5												
Hopkinsina spp.																	
Hyalinea balthica																	
Lagena setigera																	
Lepidodeuterammina ochracea																	
Leptohalysis scottii		1.8			0.6	0.6										0.6	
Melonis sp.		0.6															
Melonis spp.																0.9	
Nonion fabum		2.4															
Nonionella sp.																	
Nonionella iridea			1.2	0.5	2.3		1.0				2.4	0.6					
Nonionella stella		1.8	5.8	1.9	3.8	3.0	2.9	0.9	0.9	2.8	8.6	3.4	3.2	4.4		2.7	2.1
Nonionella turgida		0.9			2.3		0.5			2.5	4.4	1.1				0.6	0.5
Nonionnoides sp.																	
Nouria polymorphinoides		0.9										0.6					
Nouria sp. *																	
Patellina corrugata																	

Cont.

Stations	**636**	**637**	**639**	**640**	**655**	**656**	**657**	**658**	**659**	**661**	**662**	**663**	**665**	**669**	**670**	**677**	**684**
Depth (m)	23	28	56	77	14	16	18	21	28	58	72	82	83	37	27	20	79
Total of specimens counted	108	340	327	432	344	336	407	572	455	318	338	352	349	90	522	337	431
Number of *taxa* with one specimen	14	10	6	8	11	8	11	9	10	6	8	8	4	6	8	11	10
Taxa																	
Planorbulina mediterranensis																	
Planorbulina sp.																	
Pseudobolivina fusiformis *											3.3						
Pseudobolivina sp.			0.6														
Quinqueloculina laevigata	4.6				0.9	4.2	0.7		0.4								
Quinqueloculina seminulum																	
Quinqueloculina sp. 1																0.6	
Quinqueloculina spp.	2.8					1.2											
Quinqueloculina stelligera																	
Rosalina bradyi																	
Rectuvigerina phlegeri		11.8	5.2	1.2	1.7	0.6	1.7		6.6	2.2	0.9		1.4		2.5	3.0	
Reophax curtus	1.9							0.9							1.0		
Reophax dentaliniformis	3.7				0.6	1.2	0.7	3.7							0.4		
Reophax nodolosus																	
Rosalina sp.						0.6	0.5										
Saidovina karreriana		0.9									0.6		0.6				
Sigmoilopsis sp.						0.6	0.5										
Spiroplectinella earlandi				0.0	2.9			0.9	2.9		0.9			3.3	0.4	0.6	
Stainforthia loeblichi											0.6						
Stainforthia sp.					9.0	1.5	3.7		1.1			0.6			0.4	2.7	
Textularia conica																	
Textularia deltoidea		1.5	1.8	0.7						0.9	2.1		2.0				1.6
Trifarina angulosa			0.9	0.7					0.4							0.9	0.9
Trifarina sp.																	
Trochammina inflata																	
Trochammina sp.																	
Uvigerina peregrina																	
Valvulineria bradyana									1.8								
Indeterminate																	

Appendix B

Appendix B

Relative abundance of the total assemblage for taxa with more than one specimen for all sampled levels in core 5 and number of taxa with one specimen.

Sampled levels	**0-1**	**10-11**	**20-21**	**30-31**	**38-39**	**44-45**	**48-49**	**50-52**	**54-56**	**58-60**	**62-64**	**70-72**	**82-84**	**86-88**
Total of specimens counted	419	401	424	408	396	371	400	462	353	369	337	303	397	337
Number of *taxa* with one specimen	22	27	12	15	13	16	11	10	13	19	10	12	12	20
Taxa														
Ammonia beccarii	1.2	1.0	3.3	1.7	2.8	2.4	1.8	1.5	4.0	2.7	3.3	2.0	3.0	2.4
Ammoscalaria sp.														
Amphicoryna candei					0.8									
Amphycorina scalaris								0.4		0.5				
Amphycorina spp.			0.5			0.5								
Asterigerinata mamilla		0.5									0.6		0.5	
Asterigerinata sp.				0.5										
Bolivina catanensis	1.2	0.7	0.7	5.1	0.5	0.5	0.5	0.4	0.8		0.9	2.3	1.0	
Bolivina italica		0.5										1.0		
Bolivina ordinaria	3.8	5.7	5.0	6.9	5.8	10.0	7.5	7.4	5.7	10.3	7.4	7.3	12.6	12.2
Bolivina pseudoplicata	0.7	0.5		0.7	0.5			0.6			0.6			
Bolivina sp.														0.6
Bolivina sp. 1														
Bolivina spp.		1.0												
Bolivina striatula														
Bolivina variabilis												0.7	0.8	
Bolivinellina pseudopuntata	0.5		0.5	0.7						0.5	0.6		0.5	0.6
Bolivinellina sp.														
Bolivinellina sp.														
Brizalina alata	0.5	0.5					0.5							
Brizalina dilatata	5.3	5.7	4.5		5.8	4.3	3.5	7.4	2.0	3.8	3.0	2.6	6.0	5.9
Brizalina spathulata	9.8	17.2	4.5	6.9	4.5	7.0	10.8	3.9	8.2	11.1	7.4	7.6	5.0	4.2
Brizalina subaenariensis	0.7	0.5		0.7	0.8	0.8	0.5	1.1	2.0	0.5	1.2	1.3	1.0	1.5
Bulimina acanthia					0.5				0.6		0.9		0.8	
Bulimina aculeata	3.8	4.0	7.3	6.9	4.5	3.5	4.3	3.0	4.8	4.3	4.7	9.6	3.8	4.2
Bulimina buchiana														
Bulimina elongata	2.1	1.5	5.2	1.7	1.8	5.1	1.8	3.0	1.7	2.7	2.1	4.6	1.3	1.8
Bulimina exilis														

Cont.

Sampled levels	**0-1**	**10-11**	**20-21**	**30-31**	**38-39**	**44-45**	**48-49**	**50-52**	**54-56**	**58-60**	**62-64**	**70-72**	**82-84**	**86-88**
Total of specimens counted	419	401	424	408	396	371	400	462	353	369	337	303	397	337
Number of *taxa* with one specimen	22	27	12	15	13	16	11	10	13	19	10	12	12	20
Taxa														
Bulimina marginata	5.0	4.7	3.3	3.4	4.8	3.8	5.5	5.2	3.1	1.4	3.6	3.3	3.5	3.9
Bulimina sp.	0.5													
Buliminella tenuata			0.5	1.2		1.3		0.9			1.8		0.8	0.9
Cancris sp.														
Cassidulina crassa	0.5			0.5						0.5	0.6			
Cassidulina laevigata	16.9	15.7	19.6	18.9	22.0	18.9	19.5	21.0	19.8	17.1	13.4	16.5	15.6	15.4
Cassidulina minuta	2.9	3.7	3.3	4.2	2.0	2.7	4.5	4.1	3.7	3.3	5.3	2.3	3.5	4.5
Cassidulina sp.														
Cassidulina spp.											0.6			
Cassidulina teretis		0.5	0.5	0.7	1.0		1.5	0.4	3.1	2.7	0.9	0.7	1.0	0.6
Cibicides lobatulus		0.5												
Cibicides sp.														
Cibicides spp.														
Cornuspira sp.														
Deuterammina sp.								0.4	1.1					0.6
Deuterammina spp.						0.8							1.0	
Discorbis spp.									0.6					
Eggerelloides scaber	0.7		0.7	0.5	0.5	0.5			0.6	0.5		0.7		
Eggerelloides sp.		0.7						0.6						
Elphidium complanatum														
Elphidium cuvillieri			1.2								0.6			1.2
Elphidium excavatum		1.5	0.9	2.7	3.3	3.2	3.0	3.0	2.0	2.4	3.6	3.3	2.5	3.0
Elphidium gerthi		1.2	2.6								0.6		1.0	0.6
Elphidium granosum														
Elphidium sp.														
Eoeponidella sp.														
Epistominella vitrea	11.7	13.7	12.3	15.9	12.4	14.3	12.8	8.9	10.5	11.4	12.8	8.9	13.9	13.4
Fissurina fimbriatiformis				1.5	0.5		1.0	0.9			0.9			
Fissurina sp.				1.5				0.4						

Cont.

Sampled levels	**0-1**	**10-11**	**20-21**	**30-31**	**38-39**	**44-45**	**48-49**	**50-52**	**54-56**	**58-60**	**62-64**	**70-72**	**82-84**	**86-88**
Total of specimens counted	419	401	424	408	396	371	400	462	353	369	337	303	397	337
Number of *taxa* with one specimen	22	27	12	15	13	16	11	10	13	19	10	12	12	20
Taxa														
Fissurina spp.		0.5	0.9		1.0	1.1	1.0		0.8	0.8	0.9	0.7	0.8	1.5
Fursenkoina complanata	2.1	1.0	2.1	1.2	1.0	1.3	1.0	1.9	2.8	1.9	1.8	1.3	1.3	2.1
Fursenkoina pontoni														
Fursenkoina sp.														
Gavelinopsis praegeri														
Globobulimina sp.														
Globocassidulina sp.														
Globocassidulina subglobosa											0.6			0.6
Gyroidina umbonata	0.7		0.7	2.0		1.6	1.3	2.4	0.8	0.8		0.7	0.5	
Hanzawaia sp.										0.5				
Haynesina germanica														
Haynesina sp.														
Hopkinsina atlantica	1.4													
Hyalinea balthica	0.7				1.3		1.8	1.1	1.1	1.1		2.3	2.0	1.5
Lagena sp.											0.6	0.7		
Lagena spp.					0.8					1.4				
Lagena sulcata	0.5													
Lenticulina sp.													0.8	
Melonis sp.										0.5				
Miliolinella subrotunda														
Neoconorbina williamsoni	0.5							0.4						0.6
Neocornobina sp.										0.8				
Nonion fabum	0.5	1.2	2.6	1.7	3.0	1.9	1.0	1.7	2.0	1.1	2.7	2.3	1.5	2.1
Nonionella sp.	5.0	0.7	2.1	1.2	3.0	2.7	2.5	1.5	2.3	0.8	1.2	2.3	2.8	1.5
Nonionella iridea	2.4	2.0	2.4	2.2	1.8	0.5	1.3	1.9	2.0	1.6	3.0	1.7	1.3	1.2
Nonionella stella	2.9		0.5					0.4						0.6
Nonionella turgida	1.7		0.7	0.7	0.5	0.5		1.1	1.4	1.6	1.2	1.0	0.8	0.6
Nonionnoides sp.														
Planorbulina mediterranensis														

Cont.

Sampled levels	**0-1**	**10-11**	**20-21**	**30-31**	**38-39**	**44-45**	**48-49**	**50-52**	**54-56**	**58-60**	**62-64**	**70-72**	**82-84**	**86-88**
Total of specimens counted	419	401	424	408	396	371	400	462	353	369	337	303	397	337
Number of *taxa* with one specimen	22	27	12	15	13	16	11	10	13	19	10	12	12	20
Taxa														
Quinqueloculina sp.									0.6					
Quinqueloculina spp.					0.8		0.8	1.5			0.6			
Quinqueloculina stalkeri	0.5				1.5		1.3		0.6		0.6			0.6
Quinqueloculina stelligera														
Quinquloculina spp.														
Rectuvigerina phlegeri	2.9	2.2	2.6	2.5	2.8	2.2	1.5	1.9	2.0	1.9	1.5	1.3	2.3	0.9
Rosalina anomala														
Rosalina sp.														
Rosalina spp.								0.4						
Saidovina karreriana	0.7													
Stainforthia feylingi	1.7	0.7	0.7		0.8		1.5	1.1	0.6	0.8	1.2	1.0	0.8	
Stainforthia fusiformis														
Stainforthia loeblichi				0.7										
Stainforthia sp.														
Textularia deltoidea			1.2	0.7	1.5	1.3	0.8	1.7	2.0	0.8	1.2	1.0	1.0	1.2
Textularia sp.														
Trifarina angulosa		0.5	0.7			0.8		1.5	0.6	0.8	0.6	1.3		
Trifarina sp.	1.0													
Uvigerina peregrina		1.5	1.7		0.8	0.8	1.0	0.6	0.6		0.6	1.3	1.5	0.6
Valvulineria bradyana	1.2	1.0	2.1	0.5	1.5	1.1	1.5	1.1	0.8	1.6	1.8	2.0	0.8	1.5
Indeterminate	0.7						0.5	0.6	1.1			0.7		

Appendix B

Relative abundance of the total assemblage for taxa with more than one specimen for all sampled levels in core 5 and number of taxa with one specimen.

Sampled levels	**90-92**	**98-100**	**110-112**	**118-120**	**130-132**	**138-140**	**150-152**	**158-160**	**170-172**	**178-180**	**190-192**	**198-200**	**210-212**	**218-220**
Total of specimens counted	360	427	350	417	350	333	335	384	334	418	343	382	443	327
Number of *taxa* with one specimen	17	21	14	14	9	16	12	18	20	14	11	14	13	16
Taxa														
Ammonia beccarii	0.6	1.6	4.3	2.9	1.7	2.7	1.8	1.6	0.9	1.7	1.7	1.6	1.4	2.4
Ammoscalaria sp.	0.6													
Amphicoryna candei														
Amphycorina scalaris														
Amphycorina spp.														
Asterigerinata mamilla	0.8					1.2	0.9	4.2	7.2	6.2	9.9	7.9	6.8	1.2
Asterigerinata sp.														
Bolivina catanensis			2.6	0.5	2.0	1.2	0.9		0.6					
Bolivina italica				0.5	0.9			0.8						
Bolivina ordinaria	10.8	12.2	14.6	10.8	13.1	13.5	12.5	20.8	21.9	26.1	26.5	27.5	36.1	31.2
Bolivina pseudoplicata	0.6		0.6		0.9		0.9	0.5	1.5	1.2	1.5	0.8	1.1	0.6
Bolivina sp.	0.6						0.9							
Bolivina sp. 1		0.7												
Bolivina spp.								1.0			0.6	1.3		2.4
Bolivina striatula		0.7										0.5		
Bolivina variabilis		0.7		0.7				0.8		0.5	0.9	1.0	0.5	
Bolivinellina pseudopuntata		1.2	1.7		0.9	0.6	1.2	1.0		1.2	0.6	1.3		0.9
Bolivinellina sp.														
Bolivinellina sp.														
Brizalina alata							0.6							
Brizalina dilatata	3.9	8.2	3.1	3.6	5.1	9.6	10.7	1.8	4.2	2.2	1.7	1.8	0.9	3.1
Brizalina spathulata	4.4	2.1	8.9	8.2	8.3	6.6	4.5	2.6	4.2	3.6	0.9		0.5	0.6
Brizalina subaenariensis	2.5	1.4	3.4	1.2	1.7	0.9	2.4	0.8		0.5	1.2	0.5		0.9
Bulimina acanthia														
Bulimina aculeata	4.4	3.7	2.3	3.1	5.7	4.5	3.3	5.2	2.1	1.9	2.9	2.6	1.4	3.4
Bulimina buchiana				0.5	0.6	0.9								
Bulimina elongata		1.2	2.3	1.0	0.6	0.9	2.4	1.0		1.0	1.5	0.5	0.5	1.2
Bulimina exilis			0.6							0.5				

Cont.

Sampled levels	**90-92**	**98-100**	**110-112**	**118-120**	**130-132**	**138-140**	**150-152**	**158-160**	**170-172**	**178-180**	**190-192**	**198-200**	**210-212**	**218-220**
Total of specimens counted	360	427	350	417	350	333	335	384	334	418	343	382	443	327
Number of *taxa* with one specimen	17	21	14	14	9	16	12	18	20	14	11	14	13	16
Taxa														
Bulimina marginata	6.1	4.4	2.6	1.9	0.6	2.1	2.4	0.5						
Bulimina sp.														
Buliminella tenuata	1.7	3.7	2.0	1.2	1.1	0.6	1.2	1.0		0.5	1.2	2.4	1.1	2.1
Cancris sp.								0.5						
Cassidulina crassa												0.5	0.5	
Cassidulina laevigata	10.8	11.7	11.7	10.6	8.3	15.9	19.1	9.4	12.6	9.1	1.5	0.5	1.6	0.9
Cassidulina minuta	4.2	2.1	2.3	3.8	3.4	2.1	2.1	1.3			0.9			
Cassidulina sp.											0.9			
Cassidulina spp.				2.2										
Cassidulina teretis	2.5		0.6	1.2	2.3	1.5			0.6	0.5				
Cibicides lobatulus														
Cibicides sp.														
Cibicides spp.														
Cornuspira sp.														
Deuterammina sp.							0.6							
Deuterammina spp.														
Discorbis spp.														
Eggerelloides scaber														
Eggerelloides sp.														
Elphidium complanatum														0.6
Elphidium cuvillieri				0.5			0.6			0.7	0.6		0.7	
Elphidium excavatum	3.9	4.9	2.6	4.3	6.0	4.5	5.1	5.2	3.6	3.1	2.3	1.8	2.5	4.3
Elphidium gerthi		0.7						0.5		1.9	2.0	1.0	1.6	1.8
Elphidium granosum	0.8													
Elphidium sp.									0.6			0.5		
Eoeponidella sp.														
Epistominella vitrea	17.2	15.9	10.6	17.3	12.6	9.0	5.1	3.6	3.9	2.4	2.3	3.4	2.9	2.8
Fissurina fimbriatiformis	0.6	0.5	0.6				0.6							
Fissurina sp.		0.5			0.6									

Cont.

Sampled levels	**90-92**	**98-100**	**110-112**	**118-120**	**130-132**	**138-140**	**150-152**	**158-160**	**170-172**	**178-180**	**190-192**	**198-200**	**210-212**	**218-220**
Total of specimens counted	360	427	350	417	350	333	335	384	334	418	343	382	443	327
Number of *taxa* with one specimen	17	21	14	14	9	16	12	18	20	14	11	14	13	16
Taxa														
Fissurina spp.			1.1	1.7			0.9	1.6	1.5	0.5		0.8	0.7	0.9
Fursenkoina complanata	2.2	1.4		1.0	1.1	0.6	0.6	1.3	2.1	1.7	1.2	1.3	1.4	
Fursenkoina pontoni														
Fursenkoina sp.														0.6
Gavelinopsis praegeri														
Globobulimina sp.		0.5	0.6				0.6							
Globocassidulina sp.						0.6								
Globocassidulina subglobosa														
Gyroidina umbonata	0.6	0.5	0.6											
Hanzawaia sp.				1.2										
Haynesina germanica										1.0	0.9	0.8	0.7	
Haynesina sp.				0.5				0.5						
Hopkinsina atlantica														
Hyalinea balthica		1.6	1.1	1.2	0.9	1.5	1.5	0.8						
Lagena sp.														
Lagena spp.		0.5							0.6					
Lagena sulcata														
Lenticulina sp.					0.6	0.6								
Melonis sp.									0.6					
Miliolinella subrotunda														
Neoconorbina williamsoni														
Neocornobina sp.														
Nonion fabum	1.1	1.9	2.0	2.4	1.7	2.7	2.7	1.0	2.4	1.2	3.2	2.4	2.7	1.5
Nonionella sp.	4.2	0.7	0.9	1.2	1.1	0.6		3.1	1.8	1.4	4.4	1.3	3.8	2.4
Nonionella iridea	3.1	1.6	1.1	1.4	2.9	1.8	1.8	2.3	1.8	3.6	1.2	5.0	4.3	2.8
Nonionella stella	0.8		0.6					2.9	2.1	3.3	7.6	9.2	6.3	4.3
Nonionella turgida		0.7	1.4	1.4	2.6	1.5	0.6	1.0	1.5	1.0	1.5	1.3	0.9	1.5
Nonionnoides sp.								0.5						0.6
Planorbulina mediterranensis														

Cont.

Sampled levels	**90-92**	**98-100**	**110-112**	**118-120**	**130-132**	**138-140**	**150-152**	**158-160**	**170-172**	**178-180**	**190-192**	**198-200**	**210-212**	**218-220**
Total of specimens counted	360	427	350	417	350	333	335	384	334	418	343	382	443	327
Number of *taxa* with one specimen	17	21	14	14	9	16	12	18	20	14	11	14	13	16
Taxa														
Quinqueloculina sp.													0.5	
Quinqueloculina spp.			0.6		0.6						0.6			
Quinqueloculina stalkeri														
Quinqueloculina stelligera														
Quinquloculina spp.									0.6					
Rectuvigerina phlegeri	2.5	3.0	4.9	2.9	3.4	4.2	3.6	7.0	3.0	3.8	2.9	3.9	3.8	6.1
Rosalina anomala									0.9		0.9	1.0	0.7	
Rosalina sp.														0.6
Rosalina spp.														
Saidovina karreriana														
Stainforthia feylingi	1.4	3.3	1.4	1.0	0.6	0.6	1.2	0.5						
Stainforthia fusiformis					0.6			5.7	8.4	10.0	8.2	9.2	9.9	10.1
Stainforthia loeblichi			0.9											
Stainforthia sp.										0.7	0.6	0.8	0.5	0.9
Textularia deltoidea	1.4		1.1	1.0	1.7		1.2	0.8		1.0	0.6		0.5	
Textularia sp.			0.6											
Trifarina angulosa		0.7		1.0	0.6	0.6		0.8	1.5	0.7	0.9			
Trifarina sp.														
Uvigerina peregrina	1.1	0.5		1.2	2.0	0.6	1.5	1.0		0.5				
Valvulineria bradyana				0.7										
Indeterminate				1.2	0.9	0.9	0.6		1.5	1.7	0.9	1.8	0.7	2.1

Appendix B

Relative abundance of the total assemblage for taxa with more than one specimen for all sampled levels in core 5 and number of taxa with one specimen.

Sampled levels	**230-232**	**238-240**	**250-252**	**258-260**	**270-272**	**278-280**	**290-292**	**298-300**	**310-312**	**318-320**	**330-332**	**338-340**	**350-352**
Total of specimens counted	337	348	362	350	346	340	299	394	336	316	337	358	399
Number of *taxa* with one specimen	12	14	10	15	11	15	12	16	17	12	17	18	13
Taxa													
Ammonia beccarii	1.2	0.9		1.1	1.2	2.4	1.3	2.0	3.3	1.6	3.3	2.5	4.0
Ammoscalaria sp.													
Amphicoryna candei													
Amphycorina scalaris													
Amphycorina spp.									0.6				
Asterigerinata mamilla	10.7	6.6	9.9	9.4	10.1	9.4	15.7	9.9	13.4	22.8	13.6	19.0	21.1
Asterigerinata sp.										0.6			
Bolivina catanensis													
Bolivina italica													
Bolivina ordinaria	30.9	22.7	23.8	20.6	25.7	24.7	21.4	36.5	27.1	18.7	18.4	16.2	15.5
Bolivina pseudoplicata	2.1	0.6	1.9	1.1	2.9	1.2	4.0	1.5	3.6	5.4	3.9	4.2	5.0
Bolivina sp.										0.6			
Bolivina sp. 1													
Bolivina spp.	0.9	1.7	0.6	1.7	1.4	0.9		1.3			0.6	1.7	1.8
Bolivina striatula			0.6										
Bolivina variabilis					0.9	0.6				1.9	0.6		
Bolivinellina pseudopuntata	1.2		1.1	0.6	1.2	1.2		0.5	1.2		0.9		
Bolivinellina sp.			0.6				0.7						
Bolivinellina sp.													
Brizalina alata													
Brizalina dilatata	1.8	0.9		1.7	1.4	1.5	1.3	1.8	2.4	0.9		1.1	0.8
Brizalina spathulata	2.4	1.7	0.8	0.6	1.7					0.9	0.6		
Brizalina subaenariensis		0.6	0.6		0.9	0.6	0.7		0.6		0.6		
Bulimina acanthia													
Bulimina aculeata	2.7	2.9	1.9	2.6	2.9	2.4	2.3	0.5	3.0	0.6	1.2	2.0	
Bulimina buchiana													
Bulimina elongata	2.7	1.7	1.4	0.9	1.2	2.9	1.7	3.3	1.2	1.9	3.9	2.2	0.5
Bulimina exilis					0.6			0.5					

Cont.

Sampled levels	**230-232**	**238-240**	**250-252**	**258-260**	**270-272**	**278-280**	**290-292**	**298-300**	**310-312**	**318-320**	**330-332**	**338-340**	**350-352**
Total of specimens counted	337	348	362	350	346	340	299	394	336	316	337	358	399
Number of *taxa* with one specimen	12	14	10	15	11	15	12	16	17	12	17	18	13
Taxa													
Bulimina marginata			0.6		0.6								
Bulimina sp.													
Buliminella tenuata	2.7	1.4	1.9		1.7	1.8	1.7	0.5	0.6	0.9			
Cancris sp.													
Cassidulina crassa					0.9	0.6			0.6				0.5
Cassidulina laevigata	0.9	0.6	1.1		2.0	0.6		1.5		0.9		0.8	0.8
Cassidulina minuta	0.9	0.6	0.8		0.6		1.0			0.9		1.4	
Cassidulina sp.													
Cassidulina spp.													
Cassidulina teretis							0.7						
Cibicides lobatulus													
Cibicides sp.										0.6			
Cibicides spp.												1.4	0.5
Cornuspira sp.													0.5
Deuterammina sp.													
Deuterammina spp.													
Discorbis spp.													
Eggerelloides scaber													
Eggerelloides sp.													
Elphidium complanatum													
Elphidium cuvillieri	0.6		0.6		1.4					0.9	0.6	0.8	1.0
Elphidium excavatum	1.5	4.3	5.8	7.7	3.8	5.9	4.3	3.6	6.3	3.8	5.0	4.5	9.3
Elphidium gerthi	2.4	1.4	1.1	1.4		1.2	1.0		0.6	0.9	2.1	2.5	
Elphidium granosum		1.4	0.6					0.5					0.5
Elphidium sp.													
Eoeponidella sp.			0.8										
Epistominella vitrea	1.2	1.1	3.0	1.7	0.6	2.6		1.0		2.8		0.8	1.8
Fissurina fimbriatiformis													
Fissurina sp.	0.6		0.8										

Cont.

Sampled levels	**230-232**	**238-240**	**250-252**	**258-260**	**270-272**	**278-280**	**290-292**	**298-300**	**310-312**	**318-320**	**330-332**	**338-340**	**350-352**
Total of specimens counted	337	348	362	350	346	340	299	394	336	316	337	358	399
Number of *taxa* with one specimen	12	14	10	15	11	15	12	16	17	12	17	18	13
Taxa													
Fissurina spp.				1.4	0.6	0.9	1.3	1.5			0.6		
Fursenkoina complanata			1.9	1.1	1.4	0.6	0.7	0.5		1.3	1.2		0.5
Fursenkoina pontoni	0.9												
Fursenkoina sp.													
Gavelinopsis praegeri										0.9	0.6	0.6	
Globobulimina sp.													
Globocassidulina sp.													
Globocassidulina subglobosa													
Gyroidina umbonata													
Hanzawaia sp.													
Haynesina germanica		0.6	0.6		0.6		1.0		0.6	1.6			
Haynesina sp.													
Hopkinsina atlantica													
Hyalinea balthica													
Lagena sp.													
Lagena spp.						0.6							
Lagena sulcata													
Lenticulina sp.													
Melonis sp.			1.1										
Miliolinella subrotunda				0.6									
Neoconorbina williamsoni												0.6	
Neocornobina sp.													
Nonion fabum	2.1	1.4	1.7	1.7	2.3	2.9	0.7	4.3	2.4	2.2	3.9	2.2	3.5
Nonionella sp.	3.3	3.4	2.8	5.4	3.5	4.7	4.0	2.0	3.0	0.9	2.1	2.0	2.0
Nonionella iridea	1.8	4.3	6.1	3.4	1.2	4.7	4.3	5.3	5.4	3.5	3.3	4.2	4.0
Nonionella stella	7.1	10.6	6.9	10.0	3.8	5.9	5.0	5.1	6.3	2.8	11.0	6.7	5.5
Nonionella turgida	1.8	2.0	1.9	2.0	1.4	2.4	2.7	0.5			1.2	1.1	1.8
Nonionnoides sp.													
Planorbulina mediterranensis											0.9		0.5

Cont.

Sampled levels	**230-232**	**238-240**	**250-252**	**258-260**	**270-272**	**278-280**	**290-292**	**298-300**	**310-312**	**318-320**	**330-332**	**338-340**	**350-352**
Total of specimens counted	337	348	362	350	346	340	299	394	336	316	337	358	399
Number of *taxa* with one specimen	12	14	10	15	11	15	12	16	17	12	17	18	13
Taxa													
Quinqueloculina sp.													
Quinqueloculina spp.		1.1	0.6	2.0	1.4	1.5			2.7	3.2	2.4	2.2	
Quinqueloculina stalkeri													
Quinqueloculina stelligera								0.5				1.1	
Quinquloculina spp.	0.9						3.0	1.5					4.0
Rectuvigerina phlegeri	1.8	5.2	3.6	2.0	5.2	4.1	3.0	1.3	1.8	2.2	1.5	1.4	1.8
Rosalina anomala	1.2	0.6	0.6	0.6									
Rosalina sp.		1.1							0.6				1.3
Rosalina spp.							0.7	1.5		0.6	0.9	1.7	
Saidovina karreriana													
Stainforthia feylingi							0.7						
Stainforthia fusiformis	5.6	10.6	8.0	10.9	6.1	3.2	7.7	3.0	4.8	3.8	6.2	4.7	5.5
Stainforthia loeblichi								0.5			0.6		0.8
Stainforthia sp.	1.2	1.1	1.4	1.7	1.7	1.5	1.7	0.5	0.9	0.9	1.2	0.6	
Textularia deltoidea					0.6	0.6	0.7	0.8		0.6	1.2	0.6	0.5
Textularia sp.													
Trifarina angulosa	0.9	0.9		0.9	0.9	0.6			0.9	0.9		0.6	0.8
Trifarina sp.												0.6	
Uvigerina peregrina													
Valvulineria bradyana													
Indeterminate	0.9	1.7		0.9	2.6	1.2	1.0	2.0	1.5	2.5	1.2	2.2	1.0

Appendix C

Appendix C

Relative abundance of the total assemblage for taxa with more than one specimen for all sampled levels in core 7 and number of taxa with one specimen.

Sampled levels	**0-1**	**4-6**	**10-12**	**14-16**	**20-22**	**24-26**	**30-31**	**35-36**	**39-40**	**45-46**	**50-52**	**54-56**	**60-62**	**64-66**	**70-71,5**
Total of specimens counted	384	434	375	303	331	342	219	357	356	363	326	317	300	289	158
Number of *taxa* with one specimen	28	33	30	21	20	14	24	19	18	20	17	14	20	20	12
Taxa															
Adelosina sp.												1.3	0.7		
Agglutinella sp.	1.3	1.2	0.5		0.6	0.9						0.9			
Ammonia beccarii	1.8	1.2	0.5	1.7		2.0	2.3	1.1		1.4	0.9	0.6	1.3		1.3
Amphicoryna candei		0.7													
Amphycorina scalaris	1.3	0.7	1.6												
Asterigerinata mamila		0.5		1.0	1.5	0.9	2.7	1.1	2.0	1.7	4.0	6.3	3.7	5.2	5.7
Asterigerinata sp.												0.6		0.7	
Biloculinella depressa	0.5		0.5												
Bolivina catanensis											0.6	0.6			
Bolivina ordinaria	10.7	18.0	16.5	10.6	21.8	12.9	31.1	32.8	28.9	22.6	19.6	17.7	19.7	28.7	8.9
Bolivina pseudoplicata				1.0	0.6	1.2	1.4	0.8	1.1	0.8	1.5	3.5	2.3	1.4	2.5
Bolivina sp.				1.0											
Bolivina sp. 1		0.7			1.5					0.6					
Bolivina spp.	1.3		0.5		0.9	0.9		1.1	0.6		1.2	0.6	0.7	1.0	
Bolivina striatula	0.5				0.6									0.7	
Bolivina variabilis						0.9		0.6	1.1	0.8		0.6	0.7		
Bolivinellina pseudopuntata		0.5							0.8						
Brizalina sp.							0.9								
Brizalina dilatata	0.8	2.1	1.3	0.7	0.6	0.6	3.2	0.8	2.0	0.6	0.9	0.9	1.0	3.5	1.3
Brizalina spathulata	2.3	2.1	1.3	1.7	2.7	2.0		2.2	4.2	1.7		0.9	1.3	1.0	1.3
Brizalina subaenariensis	0.8	1.8	0.8		0.6	0.9			0.6		0.9	0.6		0.7	
Bulimina aculeata	4.4	4.8	4.0	3.6	2.7	3.2	2.3	5.6	2.8	3.9	1.2	1.9	1.7	3.1	3.2

Cont.

Sampled levels	**0-1**	**4-6**	**10-12**	**14-16**	**20-22**	**24-26**	**30-31**	**35-36**	**39-40**	**45-46**	**50-52**	**54-56**	**60-62**	**64-66**	**70-71,5**
Total of specimens counted	384	434	375	303	331	342	219	357	356	363	326	317	300	289	158
Number of *taxa* with one specimen	28	33	30	21	20	14	24	19	18	20	17	14	20	20	12
Taxa															
Bulimina elongata	4.4	1.6	1.6	6.9	2.1	4.4	1.8	0.6	1.1	1.1	0.6	0.9		1.7	
Bulimina marginata	1.3	0.9	1.3		0.6						0.6		1.0		
Buliminella tenuata	1.3	0.5			0.9			1.1	1.1						
Cancris oblongus						1.8									
Cancris sp.				0.7	0.9										
Cassidulina crassa										0.8	1.8	0.6		1.0	
Cassidulina laevigata	4.9	4.4	4.0	3.6	5.7	5.0	3.2	2.2	5.3	2.5	2.8	2.2	2.3	3.5	2.5
Cassidulina minuta	1.3	2.1	0.8		1.2	2.0	1.8	1.7	0.8	1.4	2.8	0.9	1.7	1.7	1.3
Cassidulina sp.	0.5														
Cibicides lobatulus	2.6			2.6	1.2	0.9	2.3		0.6						1.3
Cibicides sp.	0.5		0.8												
Cibicides spp.						1.5				0.6					
Cibicides lobatulus		1.4	1.3	1.3	0.9	2.0	0.9	0.6			0.9	0.6	1.0	1.4	2.5
Cornuspira spp.		0.5	0.5									0.6			
Dentalina advena				0.7											
Deuterammina sp.	0.5		0.5		0.6										
Eggerelloides scaber	0.8														
Eggerelloides sp.			0.5												
Elphidium crispum	5.7	0.9	2.1	7.3	1.8	1.2	0.9	0.6					0.7	1.4	5.1
Elphidium cuvillieri		0.9	1.1	1.7	1.5	0.9				1.1	0.9	2.5	1.7		2.5
Elphidium excavatum	1.6	1.6	2.4	2.3	1.8	1.8	1.8	2.0	1.7	1.7	0.6	0.6			1.3
Elphidium gerthi					0.9	2.6		0.8		2.2	1.5	4.1	4.0	2.1	2.5
Elphidium granosum															1.9
Eoeponidella pulchella		0.5										1.6	1.7		
Epistominella vitrea	2.6	5.5	4.0	2.3	5.1	3.5	3.7	3.1	4.8	4.7	4.3	7.9	5.7	5.5	1.9

Cont.

Sampled levels	**0-1**	**4-6**	**10-12**	**14-16**	**20-22**	**24-26**	**30-31**	**35-36**	**39-40**	**45-46**	**50-52**	**54-56**	**60-62**	**64-66**	**70-71,5**
Total of specimens counted	384	434	375	303	331	342	219	357	356	363	326	317	300	289	158
Number of *taxa* with one specimen	28	33	30	21	20	14	24	19	18	20	17	14	20	20	12
Taxa															
Fissurina densifasciata									0.8						
Fissurina globosa		0.7	1.1												
Fissurina laevigata	0.5		0.8		0.6										
Fissurina lucidiformis				1.0		0.6				0.6					2.5
Fissurina marginata							1.4	0.6							
Fissurina sp.									0.6					1.0	
Fissurina spp.		0.5	0.8	1.3						1.1	0.9	0.9	2.0		
Fursenkoina complanata	2.1	0.7			0.9	0.6		0.6	1.4		1.2	0.9	1.0		
Gavelinopsis praegeri			0.5	1.7		1.2	2.3	1.7	2.5	2.2	2.1	1.3	1.3	0.7	
Gavelinopsis sp.											0.6				
Glabratella sp.								0.6							
Glabratellina tabernacularis															3.8
Globobulimina sp.						0.6									
Globocassidulina rossensis	0.5					0.6		1.4	0.6				1.7		
Globocassidulina sp.															1.9
Hanzawaia concentrica	2.6	2.3	1.9	4.6	0.9	2.9	2.7	2.5	1.7	1.4	2.1			1.4	1.9
Haynesina germanica									0.6	0.6	0.6			2.1	
Haynesina sp.												2.2			
Hopkinsina atlantica	1.8	2.1													
Hyalinea balthica					0.6		0.9								
Lagena spp.				1.3					0.8						
Miliolinella subrotunda	1.0	1.6	1.9	1.3	3.0	2.6	0.9	3.6	1.7	3.9	6.1	4.1	5.3	4.2	1.9
Neoconorbina parkerae											0.9				
Neoconorbina williamsoni						0.9	1.4	0.8							
Neoconorbina sp.												0.9			

Cont.

Sampled levels	**0-1**	**4-6**	**10-12**	**14-16**	**20-22**	**24-26**	**30-31**	**35-36**	**39-40**	**45-46**	**50-52**	**54-56**	**60-62**	**64-66**	**70-71,5**
Total of specimens counted	384	434	375	303	331	342	219	357	356	363	326	317	300	289	158
Number of *taxa* with one specimen	28	33	30	21	20	14	24	19	18	20	17	14	20	20	12
Taxa															
Neocornobina spp.													1.0		
Nonion fabum	4.2	2.3	5.1	5.6	1.8	3.5	2.7	0.8	1.7	1.7	1.8	1.6	1.3	1.7	1.9
Nonionella sp.	1.8	2.8	4.8	1.7	3.6	2.9	2.7	2.2	1.4	2.2	2.1	1.6	3.0	0.7	
Nonionella iridea	1.3	2.8	1.6		1.2	1.5	2.7	2.8	3.4	2.8	1.2	1.6	2.0	1.7	
Nonionella stella	1.6	2.1	1.6	1.0	2.4	1.5		1.4	2.8	2.5	2.5	0.9	1.7	1.7	
Nonionella turgida	0.5	1.4	0.8		0.6			0.8		1.4	2.1	0.6	1.3	0.7	
Nonionoides sp.										0.6		0.6	0.7		
Patellina corrugata										0.6		0.6			
Planorbulina mediterranensis	3.1	2.1	2.7	2.0	1.5	3.5	3.2	2.8	1.4	3.0	2.8	3.2	2.0	1.4	3.2
Quinqueloculina laevigata		0.7	0.5			0.9					0.6	0.9		2.4	
Quinqueloculina rugosa											0.9	0.6	1.3	0.7	13.3
Quinqueloculina sp.			0.8	0.7				1.1							
Quinqueloculina spp.	2.6	2.1	2.4	2.6	2.7	1.2	0.9	2.0	1.7	4.7	3.4	1.6	2.3	1.7	
Quinqueloculina stalkeri	1.3	0.9	1.3	1.0				1.1					1.0		
Quinqueloculina stelligera		0.5				0.6		2.5	1.4	1.9	2.1	2.2	0.7		1.3
Quinqueloculina striata			0.5	0.7	0.6										
Rectuvigerina phlegeri	3.4	1.8	2.4	1.7	1.2	1.2			0.8	0.6	0.9	1.3	1.3		1.3
Reophax spp.		0.7													
Rosalina anomala				1.0	0.6					0.6					
Rosalina bradyi	0.5			1.0	0.6					1.4	0.9	0.6	1.0		4.4
Rosalina spp.	0.8	0.5	1.1	0.7		0.6			2.0		0.6			1.0	
Saidovina karreriana	1.6	0.5													
Spiroloculina sp.		0.5	0.5			0.6									
Spiroplectinella sagittula				0.7	0.6										1.3
Stainforthia feylingi		0.9		0.7	0.6								0.7		

Cont.

Sampled levels	**0-1**	**4-6**	**10-12**	**14-16**	**20-22**	**24-26**	**30-31**	**35-36**	**39-40**	**45-46**	**50-52**	**54-56**	**60-62**	**64-66**	**70-71,5**
Total of specimens counted	384	434	375	303	331	342	219	357	356	363	326	317	300	289	158
Number of *taxa* with one specimen	28	33	30	21	20	14	24	19	18	20	17	14	20	20	12
Taxa															
Stainforthia fusiformis						0.6		2.2	1.4	2.2	3.4	1.6	1.7	1.4	
Stainforthia loeblichi						0.6		0.8							
Stainforthia sp.					0.6										
Textularia conica	3.1	1.6	1.6	2.6	3.6	2.9	2.3	2.8	2.5	1.7	2.8		1.0		
Textularia deltoidea	2.1	1.4	2.4	4.3	4.2	5.6	2.3	0.6	2.2	1.1		0.6	1.3	0.7	
Textularia gramen						1.2									1.3
Trifarina angulosa		0.9	1.3	1.0	1.2	0.6	1.4			1.4	0.9	2.8	2.0	1.0	
Triloculina affinis	0.5			1.7	0.6	2.0	0.9					0.6			1.3
Triloculina sp.			0.5												2.5
Valvulineria bradyana	1.8	3.0	2.4	1.0		0.9									
Indeterminate		0.5	1.9						2.0	5.0	3.1	1.6	2.0	2.4	1.9

Appendix D

Appendix D

Relative abundance of the total assemblage for taxa with more than one specimen for all sampled levels in core 8 and number of taxa with one specimen.

Sampled levels	**1-2**	**9-10**	**19-20**	**29-30**	**39-40**	**49-50**	**58-60**	**68-70**	**78-80**	**88-90**	**98-100**	**108-110**	**118-120**
Total of specimens counted	262	348	468	561	415	63	344	291	320	355	452	453	400
Number of *taxa* with one specimen	30	18	13	15	15	15	15	11	15	18	35	11	11
Taxa													
Adelosina sp.													
Adelosina spp.													
Ammonia beccarii	2.3	7.5	2.8	5.5	2.7	9.5	5.8	4.5	2.5	3.9	5.3	4.6	4.5
Ammoscalaria sp.		0.6											
Asterigerinata mamila	0.8	1.7	0.4	1.6	2.7		2.9	1.7	2.5	3.4	2.7	2.2	1.5
Asterigerinata sp.													
Bolivina ordinaria	13.4	12.4	18.2	11.9	17.6	9.5	15.7	13.7	20.9	14.1	15.5	13.9	10.3
Bolivina pseudogoesii											0.4		
Bolivina pseudoplicata		1.1	0.4	1.4	1.0				1.3	0.6	1.1	1.8	0.8
Bolivina sp.								1.0					
Bolivina sp. 1													0.5
Bolivina spp.	3.4	3.2	1.7	4.8	1.7		1.2		1.3		0.7		0.5
Bolivina striatula		0.6	0.9	0.5	0.5		0.6				0.4		0.5
Bolivina variabilis	0.8				0.7						0.9		
Bolivinellina pseudopuntata			0.6	0.4							1.1	1.1	1.0
Brizalina sp.													
Brizalina dilatata				1.1	1.7					0.6		1.3	
Brizalina spathulata			1.1	0.7	3.6		0.9	2.1	0.6	0.8		1.5	
Brizalina spp.													
Brizalina subaenariensis	1.9	1.7	2.4	2.5	1.2		2.3	0.7	0.9		1.5	0.4	1.5
Bulimina acanthia				0.7									
Bulimina aculeata	1.1	3.4	4.5	5.0	5.5	3.2	9.3	6.2	6.3	3.4	2.2	4.6	2.3
Bulimina elongata		1.4	1.1	1.2	0.7		1.7	1.7	0.9	1.7	2.4	0.7	0.5
Bulimina exilis				0.4								0.4	
Bulimina marginata	2.3	4.6	6.2	6.4	3.6		2.9	1.7			1.3	1.3	
Bulimina sp.											0.4		0.5
Bulimina sp.1		0.6											
Bulimina sp.2		2.3											
Buliminella elegantissima		2.3	0.9		0.5								0.5

Sampled levels	**1-2**	**9-10**	**19-20**	**29-30**	**39-40**	**49-50**	**58-60**	**68-70**	**78-80**	**88-90**	**98-100**	**108-110**	**118-120**
Total of specimens counted	262	348	468	561	415	63	344	291	320	355	452	453	400
Number of *taxa* with one specimen	30	18	13	15	15	15	15	11	15	18	35	11	11
Taxa													
Buliminella tenuata		0.9	0.9	0.7	2.2		0.6	2.4		0.8	3.3	2.0	4.8
Cancris spp.							1.2						
Cassidulina crassa		1.7	1.3	2.3	1.2		1.5		1.3	1.1	0.7	1.3	0.5
Cassidulina laevigata			0.4									0.4	1.0
Cassidulina minuta		0.9	1.7	1.2	1.2		1.2		1.3		1.5	0.9	0.5
Cassidulina teretis			0.4	1.2					0.6	0.6			
Cibicides lobatulus										0.6			
Cibicides sp.													0.5
Cibicides spp.				0.4							0.4		
Cibicides lobatulus						3.2							
Cibicides sp.													
Cibicidoides pachyderma													
Cibicidoides sp.													
Cornuspira involvens	2.7												
Cornuspira spp.													
Deuterammina sp.						3.2							
Deuterammina spp.		1.4	1.3										
Eggerella advena								1.0					
Eggerelloides scaber		7.8	6.8	7.3	5.1	14.3	4.1	8.9	7.2	1.4	2.2	4.0	1.8
Elphidium complanatum										0.8			
Elphidium crispum					1.0					1.7		0.4	
Elphidium cuvillieri					1.4		1.2	1.4	0.9	1.1	0.9	0.7	1.5
Elphidium excavatum		2.9	6.0	2.5	3.4	4.8	1.5	1.4	1.6	1.7			1.0
Elphidium gerthi	1.9	2.6	1.5	4.6	3.6		6.1	4.5	4.1	6.8	6.2	4.6	4.5
Elphidium granosum	2.7	1.4	3.2	1.6	0.7		2.6	1.7	1.3			2.0	2.5
Elphidium sp.	0.8												
Elphidium spp.								1.7					
Eoeponidella pulchella								1.0			0.9	0.7	1.0
Eoeponidella sp.													
Eoeponidella spp.													
Epistominella sp.													
Epistominella vitrea	1.1	0.9	2.1	1.4	2.2			1.0	0.9	0.6	0.7	1.3	2.0

Sampled levels	**1-2**	**9-10**	**19-20**	**29-30**	**39-40**	**49-50**	**58-60**	**68-70**	**78-80**	**88-90**	**98-100**	**108-110**	**118-120**
Total of specimens counted	262	348	468	561	415	63	344	291	320	355	452	453	400
Number of *taxa* with one specimen	30	18	13	15	15	15	15	11	15	18	35	11	11
Taxa													
Fissurina densifasciata	1.1												
Fissurina globosa											0.7		
Fissurina laevigata	1.1										0.4		
Fissurina lucidiformis													
Fissurina marginata	1.1										0.4		
Fissurina orbignyana												0.4	
Fissurina spp.		2.0	1.3	1.8	0.7		2.0	3.1	0.6	2.5	1.1	1.8	4.0
Florilus pauperatus					0.5	3.2			0.9	0.8			
Florilus sp.												0.4	
Fursenkoina complanata	1.5	1.7	0.9	1.1	2.2		1.7	1.4	1.6	1.1	1.3	1.3	0.5
Fursenkoina pontoni		0.6											
Fursenkoina spp.	0.8		0.4										
Gavelinopsis praegeri									0.6	0.6	0.4	0.7	
Gavelinopsis sp.													
Glabratella sp.							0.6		0.6	0.6	0.9	0.4	
Globocassidulina rossensis													
Globocassidulina sp.													
Globocassidulina subglobosa											0.4		
Hanzawaia concentrica													
Hanzawaia rhodiensis													
Hanzawaia sp.													
Hanzawaia sp.				0.4									
Hanzawaia spp.													
Haynesina germanica		2.0	0.9	0.9	0.5			0.7		1.1			1.0
Hopkinsina atlantica	26.7	6.3	9.2	8.7	7.2	3.2	6.1	3.4	1.3				
Hopkinsina sp.		0.9		0.5			0.6						
Jadammina sp.		0.6											
Lagena setigera											0.4		
Lagena sp.													
Lagena spp.			0.6		0.5		0.9	0.7					
Lagena striata	0.8										0.4		

Sampled levels	**1-2**	**9-10**	**19-20**	**29-30**	**39-40**	**49-50**	**58-60**	**68-70**	**78-80**	**88-90**	**98-100**	**108-110**	**118-120**
Total of specimens counted	262	348	468	561	415	63	344	291	320	355	452	453	400
Number of *taxa* with one specimen	30	18	13	15	15	15	15	11	15	18	35	11	11
Taxa													
Lamarckina haliotidea		0.9	0.4		0.7		1.2			0.6		0.7	
Lenticulina sp.												0.4	
Lepidodeuterammina ochracea	0.8							1.4	1.6			0.7	
Lepidodeuterammina sp.													
Lepidodeuterammina spp.	4.6			1.4							0.4	0.7	2.5
Melonis sp.								1.4					
Melonis spp.									1.6				
Miliolinella sp.													
Miliolinella spp.													
Miliolinella subrotunda	2.3												0.8
Neoconorbina parkerae											0.7		0.5
Neoconorbina williamsoni		0.6	1.1	1.1	1.0		0.6	2.7	3.4	3.4	2.0	4.0	1.3
Neoconorbina sp.	0.8			0.5					0.6		2.0		0.8
Neocornobina spp.		0.6											
Neolenticulina sp.				1.1	0.5								
Nonion fabum			2.1	1.1	1.9	4.8	2.3	3.4	2.2	2.8	2.2	1.3	1.5
Nonion sp.						4.8							
Nonionella sp.	1.5	2.0	2.1	0.9	1.7		1.7	2.1	1.6	2.5	2.7	2.0	2.0
Nonionella iridea			1.7	1.1	0.5	4.8	0.9	1.7	0.6	1.1	1.8	0.7	
Nonionella stella	1.1	0.9	0.4		0.7		2.0	3.1	3.8	5.1	2.4	3.8	6.3
Nonionella turgida					0.5		0.6	0.7	1.3	0.6		1.1	1.0
Nonionoides spp.													
Nonoinoides pauperatus													
Oolina sp.													
Parafissurina spp.													
Patellina corrugata												0.7	0.5
Planorbulina mediterranensis		2.6	2.4	1.8	4.8		4.4	2.4	5.9	9.0	7.7	7.5	10.3
Pseudobolivina spp.					0.5								
Quinqueloculina agglutinans													
Quinquelocula aspera													
Quinqueloculina akneriana										0.8		0.7	
Quinqueloculina colomi													

Sampled levels	**1-2**	**9-10**	**19-20**	**29-30**	**39-40**	**49-50**	**58-60**	**68-70**	**78-80**	**88-90**	**98-100**	**108-110**	**118-120**
Total of specimens counted	262	348	468	561	415	63	344	291	320	355	452	453	400
Number of *taxa* with one specimen	30	18	13	15	15	15	15	11	15	18	35	11	11
Taxa													
Quinqueloculina laevigata		0.6											
Quinqueloculina seminulum											0.4		
Quinqueloculina sp.													
Quinqueloculina spp.	1.9						1.5			2.3		0.7	2.3
Quinqueloculina stalkeri										0.8		0.7	
Quinqueloculina stelligera	2.3								0.6	3.1		1.3	3.0
Rectuvigerina phlegeri		1.1	1.3	1.2	1.7	4.8	0.9	2.1	1.6	2.3	0.9	3.8	3.8
Remaneica sp.													
Reophax curtus													
Reophax nodolosus													
Reophax sp.												1.1	
Reussella spinosa													
Rosalina anomala									0.9				1.0
Rosalina bradyi								0.7	0.9	1.1	1.1		1.3
Rosalina sp.													
Rosalina spp.													
Saidovina karreriana				0.9									
Spiroplectinella earlandi	1.5		0.4				0.6						
Stainforthia fusiformis													
Stainforthia loeblichi	1.1							1.0	1.3		0.4	1.3	
Stainforthia sp.	1.9		1.3	1.4	1.0			0.7		2.0	0.7	0.7	1.0
Textularia conica							0.9		0.6	0.6	1.8	1.1	1.3
Textularia deltoidea							0.6			1.7	1.5	0.4	0.5
Trifarina angulosa		1.1	1.1	1.6	1.0		1.2		1.6	0.8	0.9	0.9	1.3
Triloculina affinis													
Triloculina sp.													
Triloculina spp.													
Trochammina sp.		2.0			0.5			0.7					
Valvulineria bradyana				0.4	1.2			3.8	1.6	0.8	1.1	0.9	1.0
Indeterminate	0.8	4.6	3.0	2.0	1.2	3.2	1.5	0.7	1.9	1.1	1.5	3.3	2.0

Appendix D

Relative abundance of the total assemblage for taxa with more than one specimen for all sampled levels in core 8 and number of taxa with one specimen.

Sampled levels	**128-130**	**138-140**	**148-150**	**158-160**	**168-170**	**178-180**	**188-190**	**198-200**	**208-210**	**218-220**	**228-230**	**238-240**	**248-250**
Total of specimens counted	329	359	465	337	405	367	318	321	373	352	372	350	416
Number of *taxa* with one specimen	7	15	22	19	16	13	15	36	16	13	19	19	20
Taxa													
Adelosina sp.													
Adelosina spp.													
Ammonia beccarii	8.8	8.1	2.8	1.8	5.7	4.1	9.4	6.2	3.8	5.4	3.5	4.3	4.3
Ammoscalaria sp.													
Asterigerinata mamila	4.3	2.5	4.1	8.3	6.9	8.7	9.1	6.5	7.0	11.9	11.8	10.9	7.7
Asterigerinata sp.			0.6										
Bolivina ordinaria	12.2	29.2	8.8	7.4	5.9	4.6	4.7	4.7	7.8	6.3	8.1	5.7	5.3
Bolivina pseudogoesii													0.5
Bolivina pseudoplicata	2.4	0.6	1.3	2.4	2.7	1.6	0.9	1.9	1.6	2.8	0.5	2.0	
Bolivina sp.								0.6					
Bolivina sp. 1													
Bolivina spp.	0.9		1.7		1.0	0.8	0.9		2.1	1.4	2.2		0.5
Bolivina striatula													
Bolivina variabilis			0.4		0.7							0.6	1.2
Bolivinellina pseudopuntata	0.9	0.6							0.5	0.9			
Brizalina sp.									0.5		0.5		
Brizalina dilatata	0.9	1.9								0.9			
Brizalina spathulata									0.5	0.6	0.5		
Brizalina spp.					1.0								
Brizalina subaenariensis	0.9	1.4		0.6	0.7						0.8	0.6	
Bulimina acanthia													
Bulimina aculeata	3.0		2.2	2.1	2.2	2.5	2.2	3.4	1.6	3.4	4.6		2.6
Bulimina elongata	1.5	0.8	0.6	0.9	0.5	0.8	0.9	1.6	1.6	1.7	1.3	1.4	1.7
Bulimina exilis													
Bulimina marginata	0.9	6.1											
Bulimina sp.	0.6												
Bulimina sp.1													
Bulimina sp.2													
Buliminella elegantissima													

Sampled levels	**128-130**	**138-140**	**148-150**	**158-160**	**168-170**	**178-180**	**188-190**	**198-200**	**208-210**	**218-220**	**228-230**	**238-240**	**248-250**
Total of specimens counted	329	359	465	337	405	367	318	321	373	352	372	350	416
Number of *taxa* with one specimen	7	15	22	19	16	13	15	36	16	13	19	19	20
Taxa													
Buliminella tenuata	2.4	1.7	1.5	1.5	1.0				0.5	1.1			0.7
Cancris spp.													
Cassidulina crassa	0.9	1.1	0.4	0.9	0.5		0.6	1.6	0.8		0.8		
Cassidulina laevigata	0.6										0.5	0.9	
Cassidulina minuta	0.6	0.6	0.6	0.9	2.2	1.9	0.9		1.9	1.4	0.8	0.9	0.5
Cassidulina teretis													
Cibicides lobatulus						1.9							
Cibicides sp.		0.8	0.4				0.6	3.1	0.5	0.9		1.1	
Cibicides spp.				2.7	0.7								
Cibicides lobatulus			0.9					1.6	0.5	2.0	1.3	1.1	2.4
Cibicides sp.													
Cibicidoides pachyderma													2.2
Cibicidoides sp.						0.8							
Cornuspira involvens													
Cornuspira spp.			0.6		0.5	0.5							
Deuterammina sp.													
Deuterammina spp.													
Eggerella advena													
Eggerelloides scaber	0.6		1.9										
Elphidium complanatum			0.4		0.5	0.5		0.9	0.5	0.6	1.3	1.1	1.0
Elphidium crispum			0.6			1.9		1.2	0.5	1.1	0.5	1.1	
Elphidium cuvillieri	1.8	2.5	0.9	0.9	0.7	1.6	0.9	1.2		0.9		1.1	0.5
Elphidium excavatum		1.4		0.9	1.5	1.9	1.3		1.1	0.6	1.1		1.0
Elphidium gerthi	4.6	3.9	6.0	5.3	4.4	5.7	3.1	3.4	6.2	5.1	4.8	7.4	4.8
Elphidium granosum	0.6	2.2	1.1	0.6	1.0	0.5	0.9		0.8		0.8		
Elphidium sp.													
Elphidium spp.			1.5										
Eoeponidella pulchella			0.6	0.9		0.8	0.6			0.9	0.5	1.4	1.0
Eoeponidella sp.					1.7								
Eoeponidella spp.								1.2					
Epistominella sp.			0.4										
Epistominella vitrea	1.8	1.1			0.5	0.5			0.5				0.5

Sampled levels	**128-130**	**138-140**	**148-150**	**158-160**	**168-170**	**178-180**	**188-190**	**198-200**	**208-210**	**218-220**	**228-230**	**238-240**	**248-250**
Total of specimens counted	329	359	465	337	405	367	318	321	373	352	372	350	416
Number of *taxa* with one specimen	7	15	22	19	16	13	15	36	16	13	19	19	20
Taxa													
Fissurina densifasciata			0.4										
Fissurina globosa													
Fissurina laevigata													
Fissurina lucidiformis			0.6										0.7
Fissurina marginata													0.7
Fissurina orbignyana			0.4			0.8			1.3		0.8	0.6	
Fissurina spp.	5.8	2.5	1.1	2.1	2.7	1.1	0.9		3.2	1.4	1.6	1.4	1.2
Florilus pauperatus		0.6		0.6	0.5	0.8	0.6		0.5			0.9	
Florilus sp.													
Fursenkoina complanata	0.9	1.1	0.6	0.6					0.8		0.5		
Fursenkoina pontoni													
Fursenkoina spp.													
Gavelinopsis praegeri			0.4	0.9			1.3	1.9		0.9		1.1	1.0
Gavelinopsis sp.	0.6				0.5				0.5				
Glabratella sp.					0.7								
Globocassidulina rossensis													
Globocassidulina sp.										0.6			
Globocassidulina subglobosa													
Hanzawaia concentrica				1.2	1.5								
Hanzawaia rhodiensis													
Hanzawaia sp.						0.5	0.6		0.5	0.9		0.9	
Hanzawaia sp.													
Hanzawaia spp.													1.0
Haynesina germanica	0.9	2.5						0.6			0.5		
Hopkinsina atlantica	0.9							0.6					
Hopkinsina sp.													
Jadammina sp.													
Lagena setigera													
Lagena sp.												0.6	
Lagena spp.	0.6	0.6											
Lagena striata													

Sampled levels	**128-130**	**138-140**	**148-150**	**158-160**	**168-170**	**178-180**	**188-190**	**198-200**	**208-210**	**218-220**	**228-230**	**238-240**	**248-250**
Total of specimens counted	329	359	465	337	405	367	318	321	373	352	372	350	416
Number of *taxa* with one specimen	7	15	22	19	16	13	15	36	16	13	19	19	20
Taxa													
Lamarckina haliotidea			0.6				0.6		0.5	0.6		1.1	1.9
Lenticulina sp.					0.5			0.6					
Lepidodeuterammina ochracea			0.4										
Lepidodeuterammina sp.					0.7		1.3						
Lepidodeuterammina spp.	3.6	0.8	1.5	0.9		1.4			0.8	0.9			
Melonis sp.									1.1				0.5
Melonis spp.													
Miliolinella sp.													
Miliolinella spp.													
Miliolinella subrotunda			1.5										
Neoconorbina parkerae	2.1	1.4									0.5		1.7
Neoconorbina williamsoni	1.5	1.1	4.3	2.1	3.2	4.4	4.7	2.8	2.9	2.6	3.2	3.1	1.2
Neoconorbina sp.											0.5		
Neocornobina spp.	0.6		1.3	2.4	2.0		0.9						2.2
Neolenticulina sp.													
Nonion fabum	0.9	2.5	1.9	1.8	1.2	2.5	1.9	4.7	1.1	0.9	1.3		2.2
Nonion sp.													
Nonionella sp.	2.4	1.4	0.4	2.1		1.1		0.6	0.5		0.5	0.9	0.7
Nonionella iridea			0.9						0.8		0.5	0.6	
Nonionella stella	2.4	1.9	0.9	1.5	2.0	1.1	1.9	1.9	3.5	2.0	2.2	1.7	1.0
Nonionella turgida	2.7					0.8	0.6		0.8	0.6	0.8	1.1	
Nonionoides spp.								0.6					
Nonoinoides pauperatus													0.5
Oolina sp.													
Parafissurina spp.													
Patellina corrugata			0.6	0.6	0.7		0.6				0.8		1.0
Planorbulina mediterranensis	6.7	4.7	12.5	14.8	15.3	15.8	22.6	18.4	15.3	16.5	16.4	17.4	17.8
Pseudobolivina spp.													
Quinqueloculina agglutinans													0.5
Quinquelocula aspera													0.7
Quinqueloculina akneriana													
Quinqueloculina colomi													

Sampled levels	**128-130**	**138-140**	**148-150**	**158-160**	**168-170**	**178-180**	**188-190**	**198-200**	**208-210**	**218-220**	**228-230**	**238-240**	**248-250**
Total of specimens counted	329	359	465	337	405	367	318	321	373	352	372	350	416
Number of *taxa* with one specimen	7	15	22	19	16	13	15	36	16	13	19	19	20
Taxa													
Quinqueloculina laevigata			1.1			0.8							
Quinqueloculina seminulum						0.5						0.6	0.5
Quinqueloculina sp.			0.4										
Quinqueloculina spp.	1.8	0.8	2.6	5.6	4.9	3.8	4.7	1.5	4.3	3.4	3.5	4.6	4.3
Quinqueloculina stalkeri													
Quinqueloculina stelligera			5.2	5.9	4.7	2.5	0.6	1.6	2.7	1.7	3.0	2.0	2.2
Rectuvigerina phlegeri	2.4	0.6	0.4	1.5	1.5	1.9	2.8	1.6	1.9	2.8	1.6	2.0	1.9
Remaneica sp.			0.4										
Reophax curtus			0.4										
Reophax nodolosus			0.4										
Reophax sp.													
Reussella spinosa							0.6						
Rosalina anomala			3.9		1.7		0.9	1.9	1.9		1.3	1.7	2.2
Rosalina bradyi	0.9		1.3	1.8	2.7	4.4	1.9	3.4	2.1	1.1	1.6	3.1	2.4
Rosalina sp.				1.8		1.1				1.1			
Rosalina spp.			0.6										
Saidovina karreriana													
Spiroplectinella earlandi			0.4										
Stainforthia fusiformis													
Stainforthia loeblichi	1.8	0.8	0.9	1.2			0.9			1.1		0.6	
Stainforthia sp.	1.2	1.7					0.6					0.9	
Textularia conica	0.6	0.6	1.5	2.1	1.7	3.8	0.9	1.6	2.1	1.4		1.7	1.7
Textularia deltoidea	0.6			2.1	2.2	1.9	2.2	1.2	2.1	1.1	1.3	0.9	1.4
Trifarina angulosa	0.9	1.1	0.6	1.8	1.2	0.8	0.9	2.2	2.1	2.0	3.2	1.1	1.4
Triloculina affinis													0.7
Triloculina sp.			0.4										
Triloculina spp.													
Trochammina sp.													
Valvulineria bradyana	1.5	0.6											0.7
Indeterminate	1.8	1.9	3.4	1.2	1.0	2.7	1.9	1.8	1.1	3.1	2.4	2.3	1.2

Appendix D

Relative abundance of the total assemblage for taxa with more than one specimen for all sampled levels in core 8 and number of taxa with one specimen.

Sampled levels	**258-260**	**268-270**	**278-280**	**288-290**	**298-300**	**308-310**	**318-320**	**328-330**	**338-340**	**348-350**	**358-360**	**368-370**
Total of specimens counted	376	293	327	318	394	323	330	357	335	366	375	334
Number of *taxa* with one specimen	17	18	20	21	26	14	11	15	21	20	14	26
Taxa												
Adelosina sp.												0.6
Adelosina spp.					0.5							
Ammonia beccarii	3.5	3.1	3.7	2.5	4.6	2.5	1.5	2.0	3.9	3.0	3.5	5.4
Ammoscalaria sp.												
Asterigerinata mamila	9.0	8.5	12.2	8.2	6.6	9.6	6.1	10.9	11.9	9.0	11.5	6.6
Asterigerinata sp.									0.9			
Bolivina ordinaria	10.4	5.8	11.3	8.8	10.2	15.2	8.5	7.3	10.4	9.8	8.8	8.1
Bolivina pseudogoesii					0.5							
Bolivina pseudoplicata	2.7	1.7	1.5	1.6	1.0	1.5	1.2	1.4	2.7	1.9	0.8	0.6
Bolivina sp.			1.2									
Bolivina sp. 1												
Bolivina spp.	0.5	1.4	0.9	0.9	2.3	0.9	1.2	1.1		1.6	1.9	1.2
Bolivina striatula				0.6						0.5		
Bolivina variabilis	0.5						0.9	0.6				0.6
Bolivinellina pseudopuntata					1.3							
Brizalina sp.									0.6			
Brizalina dilatata										0.8		
Brizalina spathulata		0.7			0.5			1.1		0.5		
Brizalina spp.		0.7	0.6									
Brizalina subaenariensis	0.5	0.7	0.6		0.5			0.6			0.8	
Bulimina acanthia												
Bulimina aculeata	1.9	3.4	1.2	1.3	1.5	1.5	2.7	2.5	3.9	2.2	2.1	3.0
Bulimina elongata	0.5	1.4	1.2	1.9	1.8	1.2	1.5	0.8	2.4	0.5	3.5	2.1
Bulimina exilis												
Bulimina marginata												
Bulimina sp.		0.7				0.6		0.6				
Bulimina sp.1												
Bulimina sp.2												
Buliminella elegantissima												

Sampled levels	**258-260**	**268-270**	**278-280**	**288-290**	**298-300**	**308-310**	**318-320**	**328-330**	**338-340**	**348-350**	**358-360**	**368-370**
Total of specimens counted	376	293	327	318	394	323	330	357	335	366	375	334
Number of *taxa* with one specimen	17	18	20	21	26	14	11	15	21	20	14	26
Taxa												
Buliminella tenuata			0.9	1.3	0.5	0.6	1.2		0.9	0.5	1.3	0.6
Cancris spp.												
Cassidulina crassa				0.9	0.8	0.9	0.9	2.0	0.6	1.1	0.5	
Cassidulina laevigata					0.5	0.6						
Cassidulina minuta	1.3			2.2	0.8	0.9	1.2	1.4		3.8	1.9	0.6
Cassidulina teretis												
Cibicides lobatulus												
Cibicides sp.		1.0				0.6		1.1	0.6		0.5	
Cibicides spp.										1.4		0.6
Cibicides lobatulus	1.6	2.4	0.9	0.9	1.5		1.8	1.1	1.2	3.6	1.9	3.3
Cibicides sp.								0.6				
Cibicidoides pachyderma												
Cibicidoides sp.												
Cornuspira involvens												
Cornuspira spp.								0.6				
Deuterammina sp.												
Deuterammina spp.												
Eggerella advena												
Eggerelloides scaber												
Elphidium complanatum	1.3	0.7	0.9	1.6	1.5	0.6		0.8		0.5	0.5	0.9
Elphidium crispum	0.8	1.0	0.9	0.9	1.3						0.5	0.6
Elphidium cuvillieri	0.5	0.7	0.6		0.5	0.9	0.6	0.8	0.6		1.1	0.6
Elphidium excavatum	1.9		2.4			0.9		2.5	3.3		2.4	
Elphidium gerthi	4.0	6.8	4.6	9.1	5.3	7.1	6.1	5.6	4.8	9.6	4.0	10.5
Elphidium granosum					1.0			1.7	1.5	1.9	0.8	1.2
Elphidium sp.		0.7			0.5							
Elphidium spp.					0.5							
Eoeponidella pulchella	0.5	1.4	0.6	0.9	0.5	1.2	0.9		0.9	1.4	0.5	
Eoeponidella sp.												
Eoeponidella spp.										0.5		
Epistominella sp.												0.6
Epistominella vitrea					0.5	1.5	0.6	0.6	0.6		0.8	

Sampled levels	**258-260**	**268-270**	**278-280**	**288-290**	**298-300**	**308-310**	**318-320**	**328-330**	**338-340**	**348-350**	**358-360**	**368-370**
Total of specimens counted	376	293	327	318	394	323	330	357	335	366	375	334
Number of *taxa* with one specimen	17	18	20	21	26	14	11	15	21	20	14	26
Taxa												
Fissurina densifasciata					0.5					0.5		
Fissurina globosa					1.0							
Fissurina laevigata					0.5							
Fissurina lucidiformis					1.0							
Fissurina marginata					1.0							
Fissurina orbignyana	1.9			0.9					0.6			
Fissurina spp.	1.3	2.0	3.1	0.9		1.5	3.9	1.4	3.0	0.5	2.9	0.9
Florilus pauperatus		1.0	1.2	0.9		0.6	0.6		0.6			
Florilus sp.								0.6				
Fursenkoina complanata			0.6	0.9		0.9					0.5	
Fursenkoina pontoni							0.6					
Fursenkoina spp.												
Gavelinopsis praegeri	1.3	1.0	0.6				0.6			0.5	0.8	0.9
Gavelinopsis sp.									0.6			
Glabratella sp.	0.5		0.6			0.6						
Globocassidulina rossensis										0.8		0.6
Globocassidulina sp.	0.5							0.6			0.5	0.6
Globocassidulina subglobosa					0.5							
Hanzawaia concentrica			1.2			0.9						
Hanzawaia rhodiensis		0.7										
Hanzawaia sp.							0.6	0.6				
Hanzawaia sp.												
Hanzawaia spp.												
Haynesina germanica			0.6	0.6		0.9					1.1	
Hopkinsina atlantica												
Hopkinsina sp.												
Jadammina sp.												
Lagena setigera												
Lagena sp.												
Lagena spp.					0.8							
Lagena striata												

Sampled levels	**258-260**	**268-270**	**278-280**	**288-290**	**298-300**	**308-310**	**318-320**	**328-330**	**338-340**	**348-350**	**358-360**	**368-370**
Total of specimens counted	376	293	327	318	394	323	330	357	335	366	375	334
Number of *taxa* with one specimen	17	18	20	21	26	14	11	15	21	20	14	26
Taxa												
Lamarckina haliotidea		1.0			1.0	0.9	0.9		0.9	0.8		
Lenticulina sp.												
Lepidodeuterammina ochracea												
Lepidodeuterammina sp.					0.5							
Lepidodeuterammina spp.												
Melonis sp.				0.6			0.9				0.8	
Melonis spp.												
Miliolinella sp.			0.9									
Miliolinella spp.											0.8	
Miliolinella subrotunda		1.0		0.9			1.8					
Neoconorbina parkerae		2.4			1.3	0.6			0.9			
Neoconorbina williamsoni	2.7	2.7	2.8	3.1	1.3	1.9	4.2	2.5	2.4	3.6	3.2	2.4
Neoconorbina sp.	0.5	0.7	0.6			0.9				0.5		
Neocornobina spp.	1.1			1.6			1.8	0.6			0.8	0.6
Neolenticulina sp.												
Nonion fabum	0.8		1.5	0.6	2.8	3.1	2.4	4.2	4.2	2.7	3.7	2.1
Nonion sp.												
Nonionella sp.	0.5		0.6	1.9	0.5	0.6	0.6	1.4	0.9		1.1	
Nonionella iridea					0.5					0.8		
Nonionella stella	1.3	1.4	2.1	1.6	3.8	1.5	0.9	2.0	2.1	2.7	1.1	2.4
Nonionella turgida			0.6			0.9		0.8	1.2	0.5	0.8	
Nonionoides spp.												
Nonoinoides pauperatus					0.8							0.6
Oolina sp.				0.6								
Parafissurina spp.					0.5							
Patellina corrugata	0.5		0.9	0.6							0.5	
Planorbulina mediterranensis	21.3	14.0	13.8	17.6	16.8	22.3	19.1	14.6	12.8	13.9	12.0	15.9
Pseudobolivina spp.												
Quinqueloculina agglutinans												
Quinquelocula aspera												
Quinqueloculina akneriana				0.6			0.6					
Quinqueloculina colomi				0.6								

Sampled levels	**258-260**	**268-270**	**278-280**	**288-290**	**298-300**	**308-310**	**318-320**	**328-330**	**338-340**	**348-350**	**358-360**	**368-370**
Total of specimens counted	376	293	327	318	394	323	330	357	335	366	375	334
Number of *taxa* with one specimen	17	18	20	21	26	14	11	15	21	20	14	26
Taxa												
Quinqueloculina laevigata							1.8	0.6				
Quinqueloculina seminulum	1.1		0.6							1.1		
Quinqueloculina sp.												
Quinqueloculina spp.	2.4	4.1	2.4	2.5	1.3		1.5	1.7	0.9	1.6	0.8	3.9
Quinqueloculina stalkeri												
Quinqueloculina stelligera	3.2	2.7	1.8	2.8	2.0	2.2	6.4	5.0	2.1		3.2	1.5
Rectuvigerina phlegeri	2.4	1.7	2.1	1.9	1.5	1.9	1.5	2.8	2.1	0.5	2.7	3.0
Remaneica sp.												
Reophax curtus												
Reophax nodolosus												
Reophax sp.												
Reussella spinosa												0.6
Rosalina anomala		3.4	1.2	1.9	0.5	1.5	1.8		0.6		1.3	
Rosalina bradyi	2.7	3.1	2.1	0.9	2.0		1.5	2.0	0.6	1.1	1.6	1.2
Rosalina sp.										0.5		
Rosalina spp.												
Saidovina karreriana												
Spiroplectinella earlandi												
Stainforthia fusiformis										2.2	1.1	1.2
Stainforthia loeblichi		0.7			1.0							
Stainforthia sp.											0.5	0.6
Textularia conica	1.6	0.7	1.2	1.6	1.0		0.9	1.4		0.8	0.5	0.9
Textularia deltoidea	0.5	1.0	0.9		0.8		1.8	1.1	0.6	0.8	0.8	0.9
Trifarina angulosa	3.2	2.7	1.5	1.6		0.9	2.1	3.4	3.6	1.6	1.3	1.2
Triloculina affinis												
Triloculina sp.	0.5		0.6	0.6		0.6						
Triloculina spp.		1.7						1.1			0.5	
Trochammina sp.												
Valvulineria bradyana												
Indeterminate	2.1	1.4	0.9	0.9	1.3	0.9			1.5	1.6	1.6	2.7