Universidade do Estado do Rio de Janeiro

Centro de Tecnologia e Ciências

Faculdade de Geologia

Missilene Yhasnara Rodrigues Silva

Assinaturas microtexturais em grãos de quartzo e foraminíferos de depósitos de tsunamis da plataforma portuguesa

Rio de Janeiro

2022

Missilene Yhasnara Rodrigues Silva

Assinaturas microtexturais em grãos de quartzo e foraminíferos de depósitos de tsunamis da plataforma portuguesa

Dissertação apresentada como requisito parcial para obtenção do título de Mestre, ao programa de Pós-Graduação em Geociências, da Universidade do Estado do Rio de Janeiro. Área de concentração: Geociências.

Orientador: Prof. Dr. Francisco de Assis Dourado da Silva

Coorientador: Prof. Dr. Pedro José Miranda da Costa

Rio de Janeiro

2022

CATALOGAÇÃO NA FONTE
UERJ / REDE SIRIUS / BIBLIOTECA CTC/C

S586a Silva, Missilene Yhasnara Rodrigues.

Assinaturas microtexturais em grãos de quartzo e foraminíferos de depósitos de tsunamis da plataforma portuguesa. / Missilene Yhasnara Rodrigues Silva. – 2022.

69 f. : il.

Orientador: Francisco de Assis Dourado da Silva.

Coorientador: Pedro José Miranda da Costa.

Dissertação (Mestrado) - Universidade do Estado do Rio de Janeiro, Faculdade de Geologia.

1. Geologia estratigráfica – Teses. 2. Tafonomia – Teses. 3. Conformação de alta energia. – Teses. 4. Análise de sedimentação – Teses. I. Silva, Francisco de Assis Dourado da. II. Costa, Pedro José Miranda da. III. Universidade do Estado do Rio de Janeiro. IV. Faculdade de Geologia. V. Título.

CDU 551.243

Bibliotecária responsável: Fernanda Lobo CRB7/5265

Assinatura | Data

Missilene Yhasnara Rodrigues Silva

Assinaturas microtexturais em grãos de quartzo e foraminíferos depósitos de tsunami da plataforma portuguesa.

Dissertação apresentada, como requisito parcial para obtenção do título de Mestre, ao Programa de Pós-Graduação em Geociências da Universidade do Estado do Rio de Janeiro. Área de concentração: Geociências.

Aprovada em 03 de novembro de 2022.

Orientador: Prof. Dr. Francisco de Assis Dourado da Silva
Faculdade de Geologia – UERJ

Coorientador: Prof. Dr. Pedro José Miranda da Costa
Faculdade de Ciências – Universidade de Coimbra

Banca Examinadora:

____

Prof. Dr. Sergio Bergamaschi
Faculdade de Geologia – UERJ

____

Prof.ª Dra. Maria Virgínia Alves Martins
Faculdade de Geologia – UERJ

____

Prof. Dr. Pedro Alexandre Henriques Dias Morgado Dinis
Universidade de Coimbra

Rio de Janeiro

2022

AGRADECIMENTOS

Em primeiro lugar, agradeço a Deus pelo seu imensurável amor.

Sou grata ao meu orientador Francisco Dourado pelo acompanhamento permanente desde a graduação, por sua generosidade e sugestões ao longo deste trabalho. Da mesma forma, estimo meus agradecimentos ao professor Pedro Costa, por sua coorientação, motivação e confiança em meu trabalho, estando sempre bem disposto em atender quando precisei, além de fornecer os dados para que a concretização deste trabalho fosse possível.

Aos mestres que contribuíram diretamente para o avanço deste estudo: Sergio Bergamaschi pelo fornecimento dos materiais utilizados na preparação dos grãos; Maria Virgínia Martins pelo acesso ao Laboratório de Micropaleontologia, auxílio nas análises e identificação dos foraminíferos, pelas revisões e sugestões desde o início; ao professor : Luiz Carlos Bertolino pelo apoio na utilização do MEV, nas instalações do CETEM; Ao time do projeto de pesquisa OnOff pelo apoio em conceder dados indispensáveis à realização do meu trabalho. Reforço minha gratidão a todos os membros da banca, tanto da defesa como nos seminários de acompanhamento, pelas críticas construtivas e correções.

Expresso agradecimentos à Marianni, secretária da pós, por ser tão atenciosa e competente. Também à CAPES, pelo apoio financeiro com a concessão da bolsa.

Aos meus pais e irmã, à quem tudo devo. Não é possível listar todos os nomes de amigos e colegas que me encorajaram em momentos difíceis.

Muito obrigada a todos!

O que sabemos é uma gota, o que ignoramos é um oceano.

Isaac Newton

RESUMO

SILVA, Missilene Yhasnara Rodrigues. *Assinaturas microtexturais em grãos de quartzo e foraminíferos de depósitos de tsunamis da plataforma portuguesa.* 2022. 69 f. Dissertação (Mestrado em Geociências) – Faculdade de Geologia, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, 2022.

Este estudo apresenta resultados de dois testemunhos sedimentares recolhidos na plataforma sul portuguesa, tentando, parcialmente, preencher a lacuna no conhecimento do registro *offshore* de eventos de alta energia. Os resultados foram obtidos com base na litoestratigrafia, análise microtextural de grãos de quartzo e tafonomia de foraminíferos. A litoestratigrafia correspondente à sedimentação do Holoceno Superior, consiste de silte a areia muito fina, com intercalações de areia rica em fragmentos bioclásticos. Dentro desta sequência, uma unidade foi associada à sedimentação por *backwash*, com base em um conjunto de critérios sedimentológicos (tamanho do grão, contato basal erosivo, composição, etc.). Em termos de microtexturas, um alto grau e presença de marcas mecânicas nos grãos associadas à deposição de tsunami foi observada nas amostras deste estudo e reflete os processos hidrodinâmicos de alta energia. Em termos composicionais observou-se uma maior presença de grãos de quartzo nestas unidades, quando comparadas às camadas sobre e subjacente. Isso também favorece o aumento das marcas mecânicas, pois o contato grão a grão é mais intenso comparado ao impacto com bioclastos. Além disso, a configuração batimétrica e geomorfológica dos locais de testemunhagem determinaram o grau e o tipo de microtexturas mecânicas observadas. Isto deve-se à presença do *canyon* de Portimão. O fluxo de *backwash* ao longo do *canyon* de Portimão favorece colisões mais violentas, como foi observado na sondagem GeoB23512-02, localizada contígua a esta estrutura geomórfica. Além disso, mudanças pós-deposicionais e características da fonte sedimentar original contribuem para explicar a ocorrência de dissolução em unidades ricas em silte da GeoB23513-02. A tafonomia dos foraminíferos apresentou predominância de alteração de dissolução nas superfícies das testas, que foi mais evidente nas camadas siltosas. Por outro lado, à semelhança da assinatura microtextural dos grãos de quartzo, as unidades arenosas de alta energia exibem uma ligeira predominância de processos físicos (abrasão) apesar da presença ainda forte de dissolução derivada quer das feições originais da fonte sedimentar quer relacionadas com processos pós-deposicionais. Além disso, a presença única de espécies (plataforma média a externa) em algumas unidades é um indicativo de que houve pouco retrabalhamento desses indivíduos. Finalmente, os resultados obtidos neste estudo mostram potencial para reconhecer a assinatura microtextural de eventos de tsunami do Holoceno em ambientes *offshore*.

Palavras-chave: *Offshore*. *Backwash*. Tafonomia. Eventos de alta energia. MEV.

ABSTRACT

SILVA, Missilene Yhasnara Rodrigues. *Microtextural signatures in quartz grains and foraminifera from tsunami deposits of the Portuguese shelf.* 2022. 69 f. Dissertação (Mestrado em Geociências) – Faculdade de Geologia, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, 2022.

This study presents results from two sediment cores collected on the southern Portuguese shelf attempting to, partially, fill the knowledge gap of the offshore record of high-energy events. The results were obtained based on lithostratigraphy, microtextural analysis of quartz grains and foraminiferal taphonomy. The lithostratigraphy, corresponding to late Holocene sedimentation, consist of silt to very fine sand, with intercalations of sand-rich in bioclastic fragments. Within this sequence a unit has been associated with backwash sedimentation based on a group of sedimentological criteria (grain-size, erosive basal contact, composition, etc.). In terms of microtextures, a high degree and presence of mechanical marks on the grains associated with tsunami deposition was observed in samples from this study and reflects the high-energy hydrodynamic processes. In compositional terms it was observed a higher presence of quartz grains in these units, when compared to over and underlying layers. This, also favours the increase of mechanical marks, because grain-to-grain contact is more intense compared to the impact with bioclasts. Additionally, the bathymetric and geomorphological setting of the coring sites determined the degree and type of mechanical microtextures observed. This is due to the presence of the Portimão canyon. The backwash flow along the Portimão canyon favours more violent collisions, as it was observed on core GeoB23512-02, located contiguous to this geomorphic structure. Furthermore, post-depositional changes and characteristics of the original sediment source contribute to explain the occurrence of dissolution in silt-rich units of GeoB23513-02. The foraminiferal taphonomy displayed a predominance of dissolution alteration in the tests surfaces that was more evident in the silty layers. On the other hand, similarly to quartz grains microtextural signature, the sandy high-energy units exhibit a slight predominance of physical processes (abrasion) despite the still strong presence of dissolution derived either from the original sedimentary source features or related with post-depositional processes. Furthermore, the sole presence of species (middle to outer shelf) in some units is an indication that there was little reworking of these specimens. Finally, the results obtained in this study show potential to recognize the microtextural signature of Holocene tsunami events in offshore environments.

Keywords: Offshore. Backwash. Taphonomy. High-energy events. SEM.

LISTA DE ILUSTRAÇÕES

LISTA DE ABREVIATURAS E SIGLAS

CETEM	Centro de Tecnologia Mineral
ENACW	*Eastern North Atlantic Central Water*
E	*East*
Hs	*Significant Wave Height*
M	Magnitude
m	metros
MEV	Microscópio Electrônico de Varredura
MOW	*Mediterranean Outflow Water*
N	*North*
NCCS	*Northern Canary Current System*
NE	*Northeast*
OnOff	*Coupling onshore and offshore record of tsunamis*
S	*South*
s	segundos
SW	*Southweast*
UERJ	Universidade do Estado do Rio de Janeiro
W	*West*
ZFAG	Zona de Fraturamento Açores-Gibraltar

SUMÁRIO

INTRODUÇÃO

A restrição de dados sobre a frequência e magnitude dos tsunamis no passado, limitam os estudos sobre os riscos desses fenômenos no presente. No entanto, os aspectos geológicos são as chaves disponíveis para reconstituir o alcance e a magnitude dessas inundações. Nesse sentido, as evidências na estratigrafia costeira deixadas pelos tsunamis permitem correlacionar o tipo de ondas e suas características com o transporte e deposição de sedimentos durante estes eventos (COSTA et al. 2012a).

As tragédias do tsunami no Oceano Índico em 2004 (CHAGUÉ-GOFF et al. 2011; HORI et al. 2007; SZCZUCINSKI et al. 2006; 2012), chileno em 2010 (MORTON et al. 2011; YAMAKAKI e CHEUNG, 2011) e do Japão de em 2011 (FUJIWARA et al., 2012; 2014; KUWATANI et al. 2014; TAMURA et al. 2015), despertaram o mundo para os perigos inerentes a essas catástrofes naturais. Por esta razão, compreensivelmente os estudos sobre estes eventos extremos cresceram nas últimas duas décadas.

Na bacia atlântica, os tsunamis são relativamente raros à escala de vida humana. Utilizando dados geológicos, COSTA et al. (2021) efetuaram uma compilação dos principais depósitos de tsunamis documentados ao longo das costas atlânticas. No caso do Brasil, apesar destas catástrofes naturais serem atípicas, há relatos indicativos de que o tsunami de 1755 CE que afetou de forma dramática a costa portuguesa, também atingiu a costa nordeste brasileira (VELOSO, 2015). Também foram detectados registros do tsunami de Sumatra em 2004 no sudeste brasileiro, (CANDELA et al. 2008) e do evento de 2011 no Japão, em Arraial do Cabo, Rio de Janeiro (CANDELA, 2014), em dados de marégrafos e bóias ondógrafo.

Em Portugal, os trabalhos iniciados por ANDRADE (1990, 1992) em várias áreas da costa Algarvia, permitiram encontrar depósitos arenosos associados às ondas do tsunami de 1 de Novembro de 1755 CE. Vários locais também foram investigados na costa portuguesa como o estuário da Boca do Rio (DAWSON et al. 1995; HINDSON et al. 1996; HINDSON e ANDRADE, 1999), Lagoa dos Salgados (COSTA et al. 2009; 2012a; 2012b) e Martinhal (KORTEKAAS e DAWSON, 2007). Esses trabalhos apoiam-se em análises multiparamétricas para o reconhecimento de depósitos de tsunamis, nomeadamente, nas suas características peculiares sedimentares e micropaleontológicas que forneceram importantes indícios da ocorrência do tsunami de 1755 CE.

Na sedimentologia, a aplicação da análise microtextural em grãos de quartzo através de imagens obtidas no microscópio eletrônico de varredura (MEV) foi iniciada na década de 1970 (DOORNKAMP e KRISLEY, 1971) e mais recentemente com finalidades diferentes os trabalhos de MAHANEY (2002) e VOS et al. (2014) merecem destaque pelo progresso e revisão realizados sobre esta técnica. Esta técnica também foi aplicada a depósitos de inundação marinha extrema, onde o aumento relativo das marcas de impacto mecânico na superfície do grão foi, geralmente, observado e que pode refletir a dinâmica do evento de alta energia, como em BELLANOVA et al. 2016; COSTA et al. 2012a; 2012b; 2014; MAHANEY e DOHM, 2011; TUDOR et al. 2020.

Outra abordagem regularmente utilizada como *proxy* em investigações de depósitos de tsunamis é o estudo de assembléias de foraminíferos. Mudanças na composição da assembléia quando comparadas com as camadas sob e sobrejacente, correspondendo ao período antes e após o evento do tsunami, podem permitir inferências sobre a distância de transporte do fluxo de inundação e retorno (*backwash*) (BAHLBURG e WEISS 2007; HAWKES et al. 2007; UCHIDA et al. 2007). Aspectos tafonômicos de conchas de foraminíferos também podem apontar para informações sobre hidrodinâmica do fluxo e sobre processos pós-deposicionais (KORTEKAAS e DAWSON, 2007; PILARCZYK e REINHARDT, 2012; QUINTELA et al., 2016). Em MAMO et al. (2009) encontra-se uma revisão sobre a geologia dos tsunamis que aborda o uso dos foraminíferos, descrevendo os procedimentos, características e recomendações dessa ferramenta no reconhecimento destes depósitos.

A evidência de *backwash* na plataforma ainda é pouco explorada em comparação com os depósitos *onshore*. de tsunami. A fim de contribuir com informações sobre depósitos de tsunamis *offshore*, foram realizados levantamentos na plataforma do Algarve (sul de Portugal), que revelaram não só o registro do tsunami de 1755 C.E, mas também de outro evento, que ocorreu cerca de 3400 anos BP (REICHERTER et al. 2019). Este evento não foi arquivado no registro geológico *onshore* e leva a uma alteração na definição dos períodos de recorrência destes fenômenos para o setor SW da Península Ibérica.

Neste trabalho investiga-se o registro de tsunami na plataforma continental do sul do Algarve aplicando a análise microtextural de grãos de quartzo (fração 125-500 µm) e aspectos tafonômicos da assembleia de foraminíferos como principais ferramentas discriminantes. Para tanto, foram estudados dois testemunhos de sedimentos *offshore* (GeoB23512-01 e GeoB23513-02 – Figura 1). Com este estudo, pretende-se compreender a dinâmica durante os eventos de alta energia do Holoceno e caracterizar as suas fases de *backwash* através das diferentes marcas deixadas no registo sedimentar *offshore* da plataforma portuguesa do Algarve.

1 OBJETIVOS

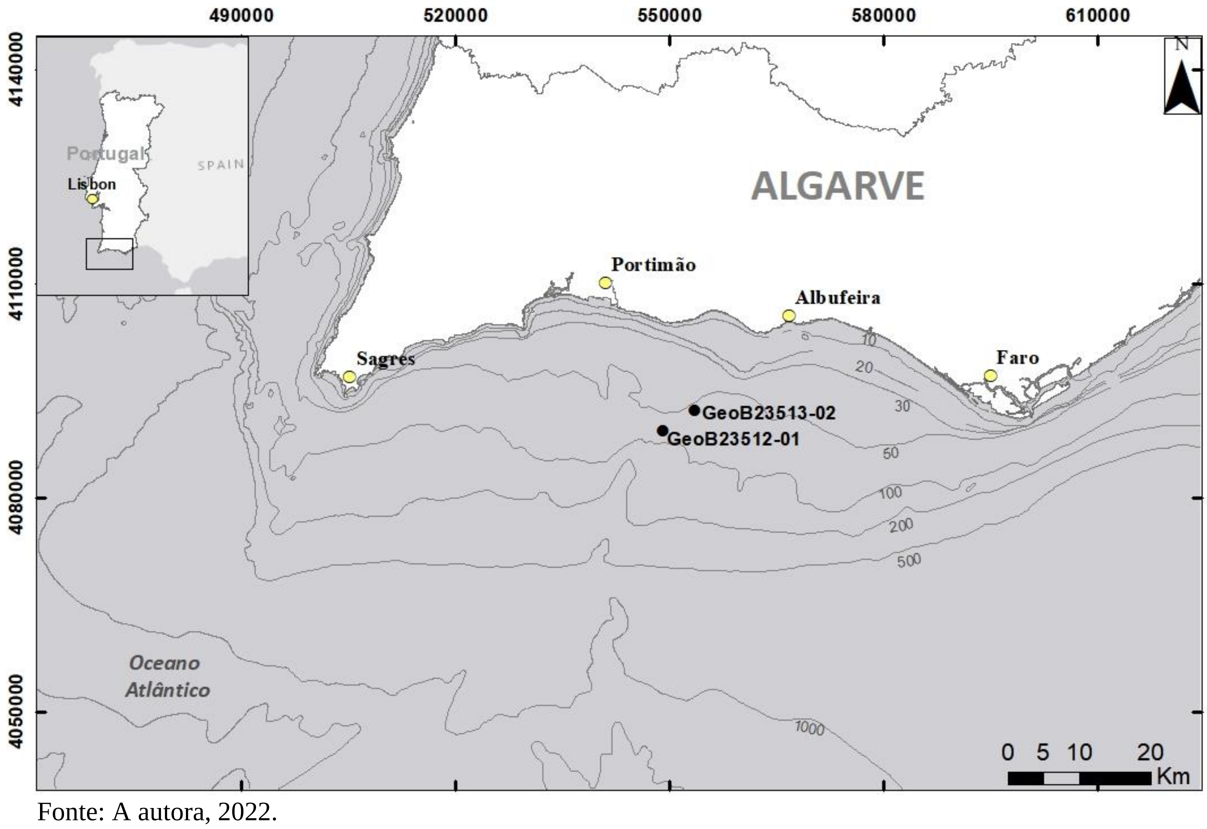
O objetivo fundamental do trabalho é reconhecer assinaturas microtexturais em grãos de quartzo e em foraminíferos provenientes da plataforma sul portuguesa, como *proxy* para identificação de eventos de alta energia, que afetaram a região durante o Holoceno. De modo a atingir esse objetivo, estabelece-se os seguintes objetivos específicos:

a) Distinguir depósito(s) de tsunami recorrendo a descrição litoestratigráfica de duas sondagens;
b) Estabelecer a composição dos sedimentos;
c) Identificar microtexturas em grãos de quartzo na fração areia (125-500 μm) através de imagens MEV;
d) Classificar e descrever as características microtexturais dos grãos de quartzo de forma qualitativa e quantitativa;
e) Avaliar o caráter tafonômico dos foraminíferos em termos de alteração física e química e correlacioná-los com processos de *backwash*.

2 LOCALIZAÇÃO DA ÁREA DE ESTUDO

Na zona de convergência das Placas Africana e Ibérica situa-se a plataforma continental sul portuguesa, também denominada plataforma sul algarvia, na qual está inserida a área de estudo do presente trabalho (Figura 01). Com particularidades que a caracterizam, sua largura é variável (entre 7km em frente ao Cabo de Santa Maria, alargando para oeste e leste até um máximo de 28km), possui declive suave e uma borda bem definida entre os 110-150 m de profundidade (DIAS, 1987). De acordo com LOPES e CUNHA (2010) este setor é composto pela plataforma interna (até aos 40 m de profundidade), plataforma média (dos 40 m aos 90 m) e pela plataforma externa (dos 90 m até ao bordo da plataforma).

Figura 01 – Localização da área de estudo.



Fonte: A autora, 2022.

3 **CARACTERIZAÇÃO DA PLATAFORMA CONTINENTAL ALGARVIA**

3.1 **Batimetria**

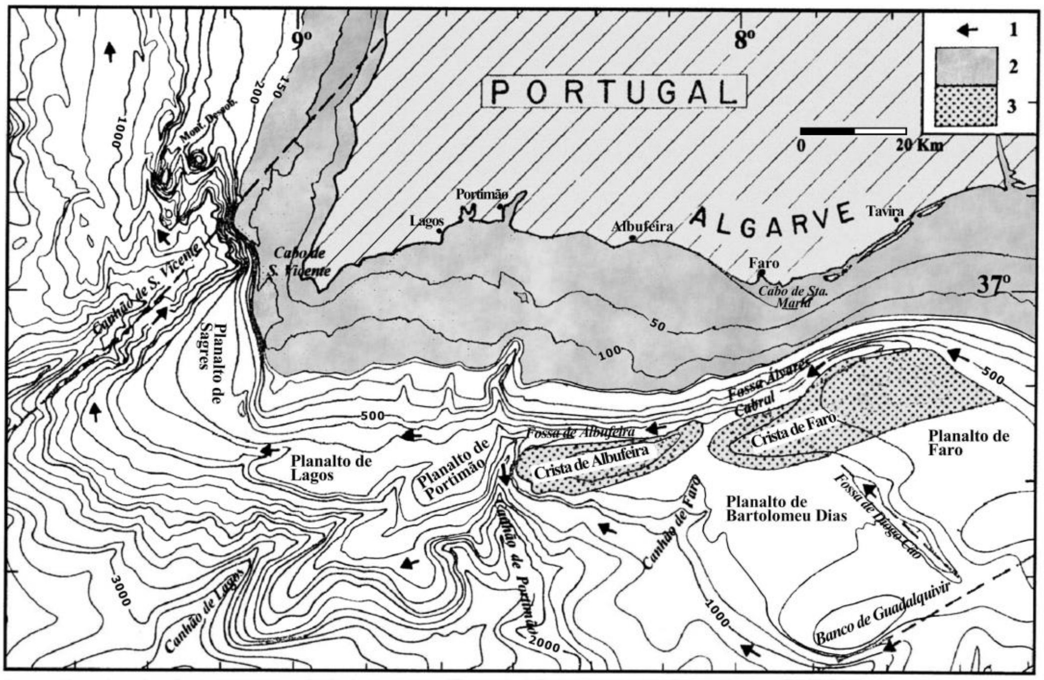
O conhecimento da geologia, estrutura e morfologia do setor imerso da Margem Algarvia está condicionado pela quantidade e qualidade dos dados geofísicos existentes (reflexão sísmica multicanal, gravimétricos e de sismicidade), e sua comparação com a informação sobre o setor emerso (*onshore*) (TERRINHA, 1998; TERRINHA et al. 2006). Embora a plataforma continental algarvia se caracterize por formas simples, adjacente a ela existe uma série de planaltos marginais. Estas estruturas, construídas e modeladas pela circulação de massas de água provenientes do Mediterrâneo, apresentam cerca de l0 Km a 40 Km de largura e atingem entre 600m-800m de profundidade, (LOPES e CUNHA, 2010).

O planalto de Sagres situa-se imediatamente a sudoeste do Cabo de São Vicente e está relacionado com a diminuição da corrente para jusante. Os planaltos de Lagos e de Portimão situam-se no Algarve Ocidental, entre Sagres e Portimão, estão separados entre si pelo canhão de Lagos. A sul e a sudeste de Faro, respectivamente, situam-se os planaltos de Bartolomeu Dias e de Faro, separados entre si pela Fossa de Diogo Cão. Estas acumulações distais ocupam antigos depocentros com orientação geral N60ºE (LOPES et al. 2006).

De acordo com GONTHIER et al. (1984) as cristas de contornitos de Albufeira e de Faro são formadas por depósitos monticulares que se desenvolvem paralelamente à margem e às correntes, em resultado da acreção vertical e lateral dos sedimentos. Sua formação está ligada à carga sedimentar relacionada com a ação da massa de água profunda e densa proveniente do Mediterrâneo.

Além do alinhamento de planaltos, a plataforma sul algarvia apresenta-se sulcada por *canyons* e fossas submarinas que individualizam os planaltos (Figura 03). O *canyon* de Lagos fica situado no Algarve ocidental, encaixado entre os planaltos submarinos de Lagos e de Portimão e possui uma orientação geral NE-SW.

Figura 02 – Aspectos morfológicos da Plataforma Continental Algarvia



Legenda: 1 – Corrente de água proveniente do Mediterrâneo; 2 – Zonas de plataforma; 3 – Cristas de contornitos.
Fonte: Adaptado de Mougenot e Vanney , 1982.

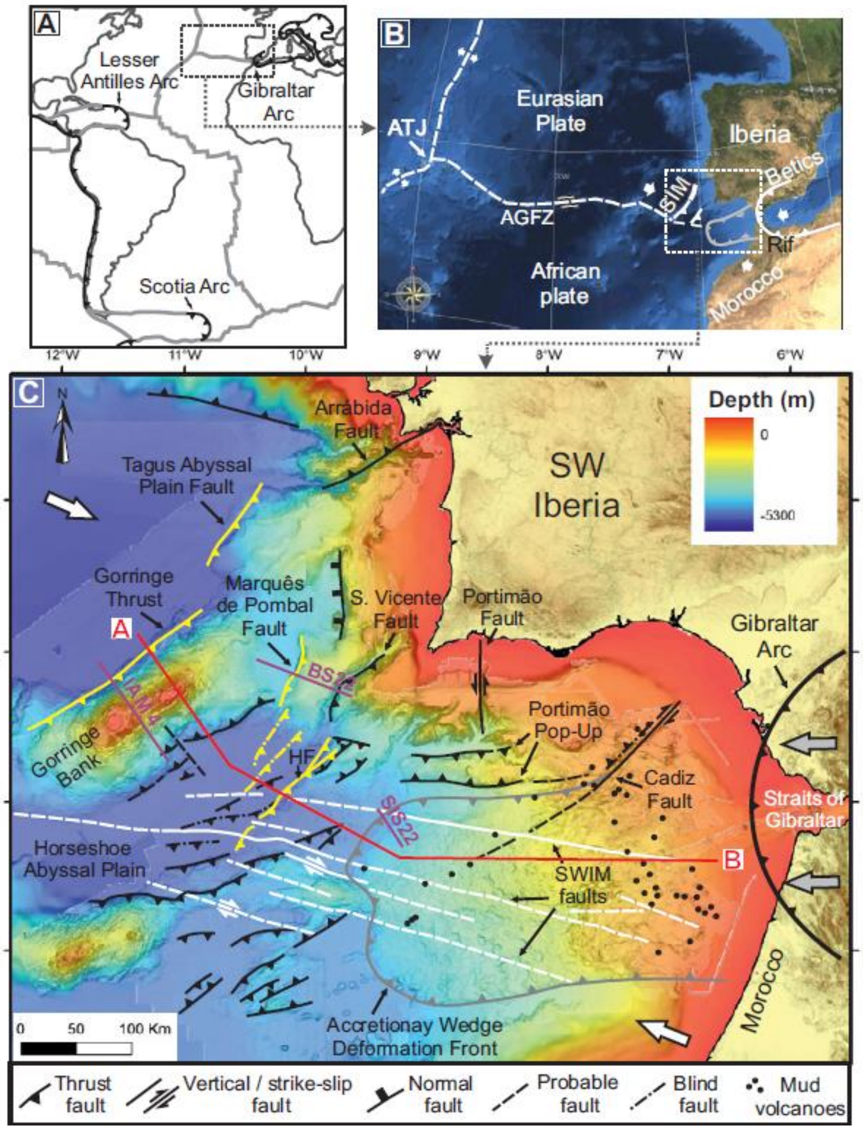
O *canyon* de Portimão é uma estrutura de grande expressão, de orientação geral N-S, que atravessa os planaltos marginais de Portimão e de Albufeira e provoca pequena incisão na plataforma (com cerca de 8Km de comprimento) (LOPES e CUNHA, 2010). As amostras analisadas neste trabalham foram recolhidas imediatamente a norte deste canhão.

O *canyon* de Faro é bastante mal definido, situa-se entre as cristas de contornitos de Faro e Albufeira, possui uma orientação geral NNE-SSW e está ligado a montante à Fossa de Álvares. O *canyon* de Albufeira é uma depressão alongada E-W, localizada a sul de Albufeira, e ligada na sua extremidade ocidental ao canhão de Portimão. Finalmente, o *canyon* de S. Vicente separa a margem alentejana da algarvia e acompanha a falha da Messejana (PEREIRA, 1991).

3.2 **Geotectônica**

No contexto geotectônico global o território continental português situa-se na placa litosférica eurasiática, junto à margem continental ibérica a oeste de direção aproximada N-S. Ao Sul, faz fronteira entre a placa eurasiática e a placa africana, disposta segundo uma direção E-W, materializada pela Zona de Fraturamento Açores-Gibraltar (ZFAG) (Figura 04) (DUARTE et al. 2013).

Figura 03 – Enquadramento geodinâmico do setor SW da Ibéria.



Legenda: A Mapa tectônico simplificado do Oceano Atlântico. B: Localização da área de estudo (retângulo tracejado). ATJ — Azores Triple Junction; AGFZ— Azores-Gibraltar Fracture Zone; SIM – Southwest Iberia Margin. C: Mapa tectônico do sudoeste da Península Ibérica: Setas cinza mostram o movimento do Arco de Gibraltar para oeste; setas brancas mostram convergência África-Eurásia WNW-ESE (~ 4 mm ano – 1), sistema de falha SWIM (em branco). Segmento A – B e perfis sísmicos BS22 e SIS22, em vermelho e roxo; HF — Horseshoe Fault.

Fonte: Duarte et al. (2013).

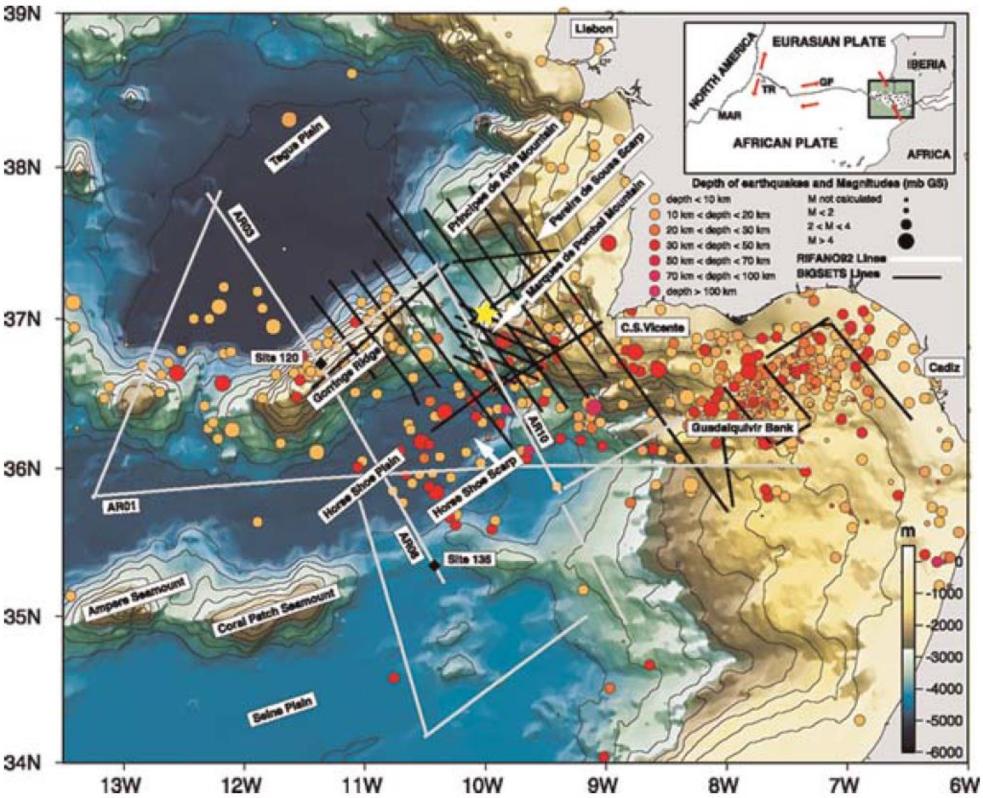
Atualmente, considera-se que a margem continental oeste ibérica esteja em transição de passiva para margem ativa convergente, com lenta colisão intracontinental das placas Eurasiática e Africana através de uma zona de subducção incipiente a sul, em processo de propagação para norte (CABRAL e RIBEIRO, 1989; CABRAL, 1995; RIBEIRO et al.1996; TERRINHA, 1998).

A ZFAG, de direção geral W-E, estende-se entre o ponto tríplice dos Açores até a zona de colisão continental do Mediterrâneo Ocidental (RIBEIRO et al. 1996). Nesta estrutura, define-se três segmentos caracterizados por regimes sismotectônicos distintos ao longo da sua extensão (SARTORI et al. 1994). No seguimento mais ocidental ocorre um regime divergente, a leste do arquipélago dos Açores, passando para um regime transtensivo dextral no setor central (materializada pela falha de Glória), e a convergente oblíquo para leste da crista Tore-Madeira, até à região do Golfo de Cádis, onde a placa africana (sub placa Núbia) é empurrada em direção NW-SE contra a placa Ibérica a uma taxa aproximada de 4mm/ano (GUTSCHER, 2004; ZITELLINI et al. 2004).

A convergência no setor oriental é distribuída por uma ampla área de deformação e é acomodada por cavalgamentos oblíquos vertentes para oeste, de direção NNE-SSW, como a falha da Ferradura, falha de Marquês de Pombal e pela reativação de falhas pré-existentes WNW-ESE (ROSAS et al. 2009; TERRINHA et al. 2009; ZITELLINI et al. 2001). Segundo BUFORN et al. (2004), a atividade sísmica neste segmento oriental é significativa.

Decorrente de sua proximidade com o seguimento oriental da ZFAG, na região a sudoeste do Cabo de S. Vicente, entre o Banco de Gorringe até o Banco de Guadalquivir, se encontra uma das zonas sísmicas mais ativas, associadas a um movimento de compressão horizontal (BEZZEGHOUD et al. 2013). Os sismos que ocorrem nesta zona têm geralmente foco superficial ($h < 40$km) e magnitude (M) moderada, em geral $M < 5.0$ (Figura 05).

Figura 04 – Mapa batimétrico da área de estudo com localização de hipocentros de terremotos registrados durante 1973 – 2004.



Nota: A estrela amarela indica a posição do evento de 1755 CE. MAR – *Mid Atlantic Ridge*; TR – Terceira Ridge; GF: Gloria Fault. Setas sólidas vermelhas exibem a cinemática relativa da placa.
Fonte: Zitellini et al. (2004).

A margem SW Ibérica foi abalada em tempos históricos por fortes sismos M >7, alguns deles associados a tsunamis, dentre os quais merecem particular destaque pela destruição que causaram, os sismos de Lisboa em 1755 CE com magnitude M=7.7± 0.5, segundo FONSECA (2020). Considera-se também o de Tavira em 1722 com magnitude estimada de M=7.5 (BORGES et al. 2001; BORGES e CALDEIRA, 2012) e o evento de 1531, que teve efeito na zona interna do estuário de Lisboa (ZITELLINI et al. 2004).

Segundo DIAS e CABRAL (1995; 2002 e DIAS, 2001) a sismicidade não se propaga significativamente para o interior do território continental, o que sugere a existência de estruturas geológicas submarinas que absorvem importante parte da deformação interplacas e reduzem a atividade intraplaca.

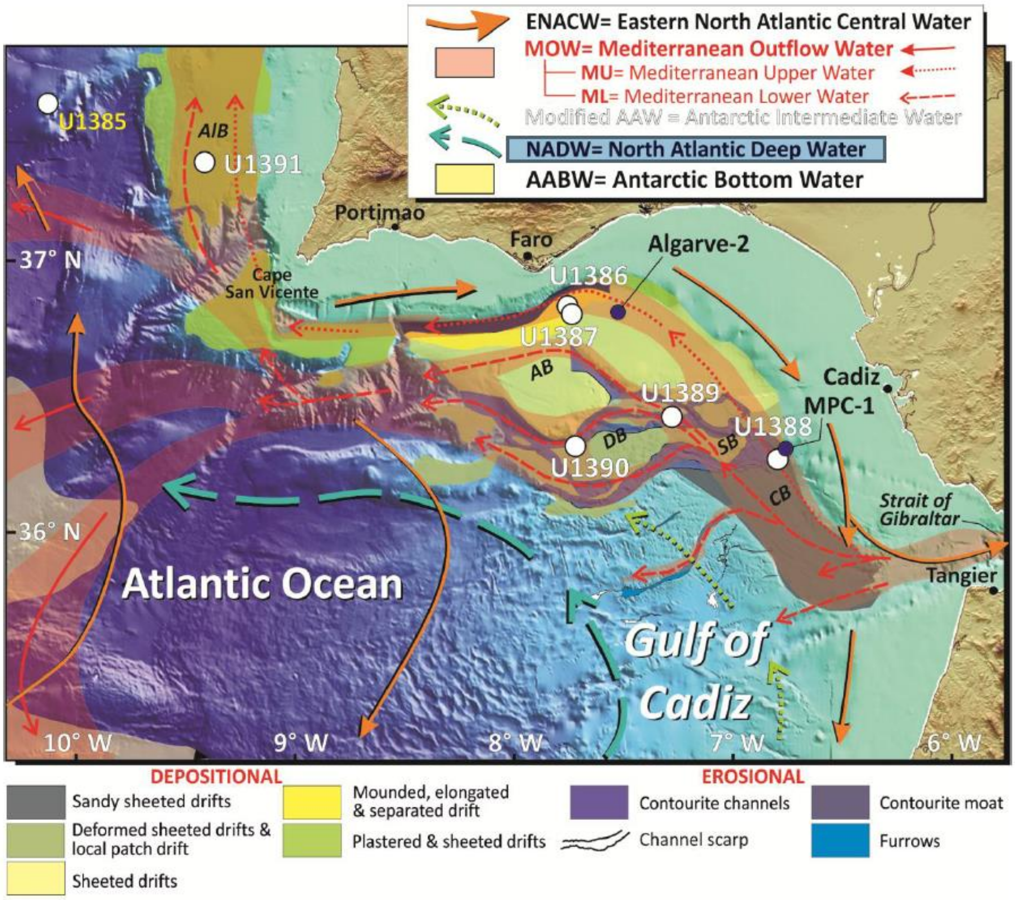
3.3 **Características oceanográficas**

No contexto de inundações marinhas provocadas por eventos extremos, é importante avaliar a morfodinâmica costeira bem como as características oceanográficas predominantes, pois estes fatores são fundamentais nos processos de distribuição e de acumulação dos sedimentos. No oceano ocorrem fenômenos físicos, como as correntes, provocadas normalmente pela mudança do regime de ventos, o afloramento costeiro (*upwelling*) ou ainda as contracorrentes (RELVAS e BARTON, 2005). Em Portugal, uma das áreas mais estudadas associadas a estes fenômenos é a do cabo de São Vicente, onde ocorrem recorrentemente alterações de correntes em função do regime de ventos. Os trabalhos de oceanografia de RELVAS e BARTON (2002); SÁNCHEZ (2006); SÁNCHEZ e RELVAS (2003), são alguns desses estudos realizados próximos desta região.

A região da costa oeste da Península Ibérica está inserida no Sistema Norte da Corrente das Canárias (NCCS - *Northern Canary Current System*), uma corrente de superfície conduzida pelo vento, que faz parte do giro subtropical do Atlântico Norte e transporta águas de norte mais frias em direção ao equador (WOOSTER et al. 1976). O regime de circulação costeira neste setor é caracterizado por eventos sazonais e intermitentes impulsionados por ventos persistentes do Norte (nortada). Na primavera e no verão, a prevalência destes ventos sobre a superfície costeira oceânica resulta em um deslocamento das águas para o mar aberto pelo Efeito Coriolis, que força as águas mais profundas a subirem gerando eventos de ressurgência (*upwelling*) (WOOSTER et al. 1976). Através do Cabo de São Vicente, onde as costas sul e oeste se intersectam (MOITA. 2001) a água aflorada na costa oeste ocasionalmente estende-se a leste ao longo da Plataforma Sul do Algarve, sob ventos vindos de Oeste (FIÚZA. 1983; RELVAS e BARTON. 2002).

Na região do Golfo de Cádiz ocorre o encontro entre o Oceano Atlântico, à superfície, com a água mais salina de *Mediterranean Outflow Water* (MOW) em profundidade (Figura 06) (GARCIA-LAFUENTE et al. 2006; SÁNCHEZ et al. 2006). A *Eastern North Atlantic Central Water* (ENACW) é uma das principais massas de água que circula na região do Oceano Atlântico norte. É uma massa de água com salinidade relativamente baixa, que ocupa as camadas mais superiores (LIU e TANHUA, 2019) que vai progressivamente entrando Mediterrâneo, através do Estreito de Gibraltar (HERNÁNDEZ e MOLINA et al. 2016).

Figura 05 – Circulação das correntes no Golfo de Cádiz.



Nota: Locais mostrados como círculos brancos e círculos azuis são poços perfurados por empresas de exploração de petróleo. Legenda das bacias sedimentares ao longo da margem sul ibérica: AB = bacia do Algarve; AlB= bacia do Alentejo; CB = bacia de Cádiz; DB = bacia de Doñana; RB = bacia de Rota; SB = bacia Sanlucar.
Fonte: Hernández-Molina et al., 2016.

A massa de água do MOW transporta água mais quente, salina e densa que circula em profundidades intermediárias, no sentido contrário a ENACW (HERNÁNDEZ e MOLINA et al. 2016). No Golfo de Cádiz, o MOW é responsável pela formação dos contornitos do Algarve e seu fluxo é influenciado pela complexa batimetria do talude continental que divide essa corrente em dois ramos distintos: *Mediterranean Upper Water* e *Mediterranean Lower Water* (DIAS, 1987).

A costa sul do Algarve está sujeita a uma contracorrente costeira proveniente do Golfo de Cádiz, que transporta água mais quente do que a água oceânica. Isto acontece normalmente durante o regime de ventos de sudeste ou em períodos de relaxamento do regime de nortada, provocando o movimento das correntes no sentido Vila Real de Santo Antônio até Sagres (RELVAS, 1999; RELVAS e BARTON, 2002; SÁNCHEZ e RELVAS, 2003).

3.3.1 **Regime de ondas**

A região da costa sul algarvia é caracterizada por um regime de ondas de baixa energia, com média anual de alturas significativas de onda (Hs) inferiores a 1 m (PIRES, 1989). Os valores de Hs > 3 m ocorrem de SW, associados a grandes tempestades nos meses de Inverno (COSTA et al. 1994). Os rumos predominantes da agitação marítima são SW e SE, sendo o primeiro dominante. Os valores mais frequentes de período médio situam-se entre 3 e 5s (63%) e apenas cerca de 4% são superiores a 7s (COSTA et al. 2001).

De acordo com MOITA (1986), as marés na costa algarvia são do tipo semidiurno regular. A amplitude média das marés é de cerca de 2,1 m podendo atingir 3 m durante as marés vivas e as elevações máximas alcançadas pelo nível do mar na maré alta durante as tempestades intensas refletem pouca contribuição da maré de tempestade para os níveis extremos relatados, de aproximadamente 2,15 m acima do nível médio do mar. TABORDA e DIAS (1992), baseados no estudo de duas grandes tempestades (14 de Fevereiro a 3 de Março de 1978; 25 a 31 de Dezembro de 1981) relataram que a contribuição da maré de tempestade é relativamente pequena, com um aumento médio da elevação da superfície do mar de 0,42 m em Lagos.

4 **MATERIAIS E MÉTODOS**

4.1 **Materiais**

Os testemunhos que serviram de base para este trabalho foram coletados em 2018 na campanha de amostragem M152, a bordo do navio oceanográfico alemão *FS Meteor*, na plataforma meridional algarvia (REICHERTER et al. 2019). As sondagens foram recolhidas utilizando-se um sistema de *vibrocoring*, com recuperação máxima de 6 m. A sondagem GeoB23512-01 dista em torno de 14 km da linha de costa e foi recuperada aos 88 metros de profundidade de coluna d'água. Por sua vez, a sondagem GeoB23513-02 fica a aproximadamente 12 km da costa e foi coletada aproximadamente em 50 metros de profundidade de coluna d'água, a distância entre os dois testemunhos equivale a 5,3 Km.

Após abertos os testemunhos, estes foram descritos macroscopicamente. Por terem sido identificados camadas arenosas intercaladas entre níveis de sedimentos hemipelágicos mais finos, os níveis de amostragem que conduziram este estudo foram focados nos intervalos arenosos das colunas sedimentares. Para este estudo, foram obtidas 39 amostras da primeira sondagem e 19 da última (Tabela 01).

Tabela 01 – Dados das sondagens e relação de amostragem.

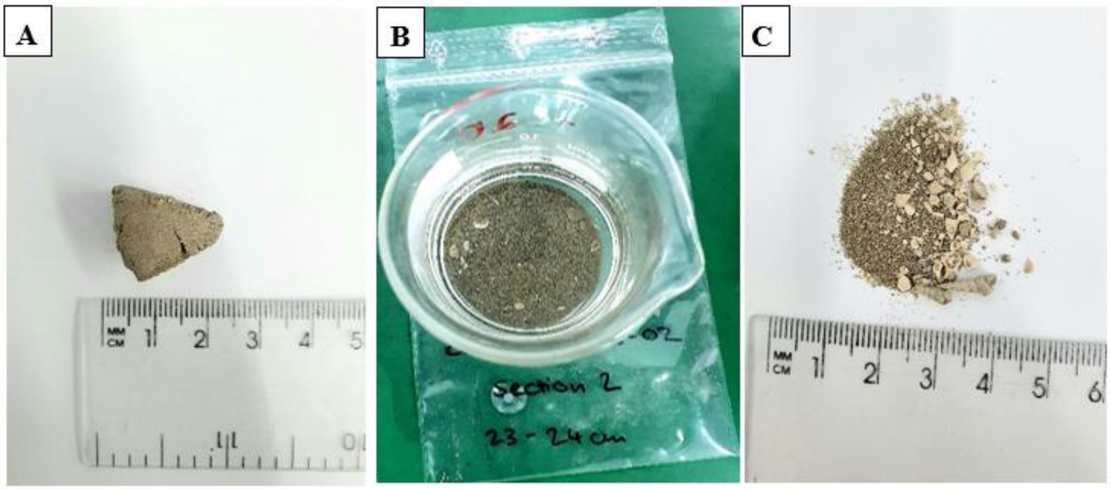
SONDAGEM	COORDENADAS (E,N)	COMPRIMENTO da SONDAGEM (cm)	NÍVEIS de AMOSTRAGEM (cm)	TOTAL
GeoB23512-01	548084,685m E; 4089698,08m N	434	33-38; 81-82; 127-138; 141-142; 145-146; 149-150; 153-154; 157-158; 217- 218; 221-222; 227-228; 231-233.	39
GeoB23513-02	553721,943m E; 4.092394,269m N	531	21-25; 48-49; 52-53; 56-57; 62-63; 68-69; 74-75; 78-79.	19
TOTAL DE AMOSTRAS				**58**

Fonte: A autora, 2022.

4.2 **Procedimento laboratorial**

Os procedimentos laboratoriais aplicados às amostras, tiveram como finalidade a separação e tratamento da fração superior a 63µm (Figura 02). Inicialmente foi necessário desagregar os sedimentos, utilizando uma solução de hidróxido de sódio (NaOH) diluído a 10% em água por 24h, posteriormente as amostras foram lavadas com água destilada sob uma peneira de < 63µm. A fração mais grossa (> 0,63 mm) é recuperada e levada para a estufa por 60 ^{o}C, uma vez seca, as amostras foram peneiradas em intervalos de 0,5 ϕ. Estes procedimentos foram realizados no Laboratório de Micropaleontologia da Faculdade de Geologia, Universidade do Estado do Rio de Janeiro (UERJ).

Figura 06 – Tratamento inicial das amostras.



Legenda: A) Exemplo de amostra em estado inicial; B) Sedimentos em solução de NaOH diluído em água; C) Fração > 63 µm, após lavada e seca.
Fonte: A autora, (2022).

4.3 **Análise composicional**

A análise composicional dos sedimentos foi efetuada na fração de 250-500 µm. Com o auxílio de uma espátula, foi retirado cuidadosamente uma subamostragem desta fração, pesou-se e então colocou-se num tabuleiro de triagem de foraminíferos (placa preta quadriculada), sendo por fim analisada no microscópio binocular Zeiss – Stemi 2000C, do

Laboratório de Micropaleontologia da UERJ. Os elementos contados foram agrupados em bioclastos (fragmentos de conchas, moluscos, foraminíferos e de outros organismos), quartzo, feldspato, opacos e micas (muscovita e biotita).

4.4 **Análise microtextural dos grãos de quartzo**

Para a análise micromorfológica dos grãos (exoscopia) seguiu-se as recomendações de COSTA et al. (2012a; 2014). COSTA et al. (2012a) sugerem pelo menos cinco características de microtexturas diferentes para obter resultados válidos, posto que uma única microtextura não é determinante de um certo ambiente sedimentar. Além disso, essas associações de microtexturas devem envolver o contraste entre marcas por ação mecânica (marcas de percussão e superfícies frescas, fraturas) formadas em contexto de elevada energia e por ação química (dissolução e partículas aderentes) discriminantes de ambientes de baixa energia, bem como características de longo prazo (arredondamento), na superfície dos grãos.

Essa etapa foi reservada para grãos de quartzo da fração granulométrica de 125–500 µm, esses grãos foram selecionados sob o microscópio binocular Zeiss – Stemi 2000C, preparados para observação ao MEV. MAHANEY (2002) e COSTA et al. (2012a) investigaram a representatividade estatística desta análise e concluíram que o número mínimo de grãos para que os dados sejam viáveis é entre 15 e 20 por amostragem. A análise dos grãos de quartzo selecionados foi efetuada em dois laboratórios: no Laboratório do Centro de Tecnologia Mineral (CETEM), utilizando o MEV TM3030 Plus – HITACHI e no Departamento de Estratigrafia e Paleontologia da Faculdade de Geologia da UERJ utilizando o MEV ZEISS modelo EVO MA 10. Na tabela Tabela 02 encontra-se a relação da quantidade de grãos analisados em cada nível de amostragem (abaixo da superfície do mar) neste estudo.

Tabela 02 – Relação de amostras observadas no MEV e quantidade de grãos.

GeoB23512-01		**GeoB23513-02**	
Nível (cm)	Nº de grãos	Nível (cm)	Nº de grãos
33	17	21	32
35	21	22	33
37	20	23	29
38	22	24	28
81	20	25	29
127	21	48	17
129	20	49	18
131	23	52	19
135	20	56	20
142	20	62	19
146	21	63	18
153	21	68	19
157	25		
158	20		
218	24		
TOTAL	**315**		**281**

Fonte: A autora, 2022.

A classificação e quantificação das microtexturas detectadas foram baseadas nas definições de MAHANEY (2002) e COSTA et al. (2012a; 2014a). Cada grão foi descrito de acordo com as características microtexturais reveladas em sua superfície, por exemplo:

a) marcas de percussão – microtexturas que resultam do impacto mecânico entre os grãos, são caracterizadas pela presença de marcas e depressões em forma de “v”;
b) superfícies frescas – são microtexturas sem qualquer marca de ação química (precipitação e/ou dissolução) ou mecânica posterior;
c) fraturas – podem ser paralelas ou conchoidais, produzidas por ação mecânica;
d) dissolução – são originadas por processos químicos e seus efeitos mais visíveis são a destruição de marcas preexistentes, formando uma rede de cavidades;
e) partículas aderentes – caracterizada pela presença de micropartículas protuberantes na superfície do grão.

Após a identificação, aplica-se uma abordagem semiquantitativa em cada grão, com base na proporção da microtextura presente em sua superfície. Para isso, adotou-se a escala de 0-5 onde: 0 (ausente); 1 (até 10% da superfície do grão); 2 (10–25% da superfície do grão); 3 (25–50% da superfície do grão); 4 (50-75% de superfície do grão); e 5 (>75% da superfície do grão). O arredondamento também foi avaliado como um atributo complementar, usando a classificação de POWERS (1953), adotando-se uma escala de 0 a 5: 0 (muito arredondado); 1 (arredondado); 2 (sub arredondado); 3 (sub angular); 4 (angular) e 5 (muito angular).

4.5 **Tafonomia de foraminíferos**

O foco da análise de foraminíferos neste estudo foram as marcas de superfície impressas nas carapaças de foraminíferos. Uma análise simplificada de foraminíferos foi realizada nos foraminíferos de tamanho médio, portanto, resultados paleoecológicos devem ser interpretados com cautela devido ao tamanho limitado das frações analisadas. A preparação, triagem e microscopia eletrônica dos foraminíferos foram conduzidas no *Institute of Neotectonics and Natural Hazards – Aachen University*, no âmbito do projeto *OnOff*. As amostras foram peneiradas e a fração >63 µm foi seca a 40°C. Em seguida, as amostras secas foram homogeneizadas e subdivididas em tamanhos de aproximadamente 0,01g. Os foraminíferos em cada amostra foram contados utilizando um microscópio Zeiss Stemi 200C com aumento de 80x. Destes, pelo menos 300 indivíduos foram coletados, identificados e armazenados em células Krantz para futuras investigações.

De acordo com FATELA e TABORDA (2002) 300 indivíduos nas amostras são representativos para assembleias de alta diversidade de amostras *offshore*. A identificação taxonômica foi baseada em várias publicações de referência (por exemplo, ARMSTRONG e BRASIER, 2005; BOLTOVSKOY et al. 1980; KENNETT e SRINIVASAN, 1983; LOEBLICH e TAPPAN, 1988; MENDES et al. 2012; MILKER e SCHMIEDL, 2012 MURRAY, 1971 e 2006). Posteriormente, imagens dos indivíduos foram tiradas por um FE-SEM (Zeiss Supra 55) com o elétron secundário na voltagem de 3 kV e analisadas a fim de avaliar o estado de conservação das carapaças.

Para o efeito, foram efetuadas e analisadas as imagens MEV. As testas foram classificadas de acordo com o grau de alteração física, quando apresentavam fragmentação ou abrasão, enquanto as marcas de dissolução foram usadas para identificar alterações químicas. Foram estabelecidos alguns critérios de análise, com base nos trabalhos de PILARCZYK et al. (2011; 2012; 2019). Dessa forma, considerou-se: (0) quando as carapaças se apresentavam inalteradas, sendo consideradas bem preservadas; (1) pouco alterada; (2) moderada alteração e (3) muito alterada.

5 **RESULTADOS**

O detalhamento dos resultados e discussões deste trabalho estão apresentados no APÊNDICE (p.41), em formato de manuscrito intitulado "*Microtextural signatures in quartz grains and foraminifera from tsunami deposits of the Portuguese shelf*" submetido ao periódico Marine Geology.

CONSIDERAÇÕES FINAIS

Neste trabalho foram estudadas duas sondagens obtidas na plataforma sul portuguesa. Com base nas características litoestratigráficas, foram identificadas pelo menos duas camadas arenosas significativas (C e A1) contrastantes na litoestratigrafia e com abundantes fragmentos bioclásticos. Essas camadas, cujo contato basal é erosivo e abrupto com a camada subjacente, foram interpretadas como resultado de um alto fluxo hidrodinâmico da costa em direção ao mar causado pelo *backwash* do tsunami.

A partir da análise microtextural, foi estabelecido que um dos testemunhos (GeoB23512-01) registrou maior frequência e grau de marcas mecânicas nas camadas de depósito de tsunami. Esta abundância, também anteriormente observada em outros depósitos de tsunami ao longo da costa algarvia, indica que estas feições foram esculpidas num ambiente hidrodinâmico de alta energia, capaz de imprimir novas microtexturas nos grãos. Por outro lado, a sondagem GeoB23513-02, apesar de apresentar valores elevados de ação mecânica na base do depósito de tsunami (unidade A1), apresenta pouco contraste microtextural com a unidade inferior (B1) especialmente, devido à presença mais forte de dissolução nos grãos depositados pelo tsunami. É muito provável que a configuração geomórfica desempenhem um papel importante na impressão das microtexturas, uma vez que o fluxo turbulento de *backwash* foi canalizado de forma mais intensa através do *canyon* de Portimão, o que elevou a velocidade do fluxo, promovendo assim a geração de marcas mecânicas. Este cenário justifica as diferenças microtexturais entre os dois testemunhos sedimentares, uma vez que o GeoB23512-01 está localizado mais adjacente ao *canyon* de Portimão. Além disso, as alterações pós-deposicionais e as características da fonte original do sedimento podem ajudar a explicar a ocorrência de dissolução nas unidades A1 e B1, portanto, a falta de heterogeneidade microtextural em GeoB23513-02.

A composição do sedimento também desempenhou um papel na geração de microtexturas. Isso provavelmente ocorre porque, antes da deposição, camadas mais ricas em quartzo foram erodidas e enriqueceram as camadas do tsunami com uma leve adição de grãos de quartzo. Isso se mostra suficiente para intensificar o choque mecânico entre os grãos, uma vez que esses elementos possuem a mesma densidade que contrasta nas unidades ricas em bioclastos que imprimem menos marcas mecânicas nos grãos de quartzo.

O uso da tafonomia de foraminíferos, através de sua análise em imagens MEV, evidenciou que na camada siltosa as carapaças foraminíferas parecem essencialmente alteradas pela dissolução. Por outro lado, nas unidades arenosas há um ligeiro aumento na abrasão nas testas, apesar de ainda ser notada a ocorrência de dissolução. A presença apenas de espécies marinhas (plataforma média a externa) nas unidades arenosas atesta que houve pouco tempo para retrabalhar. Portanto, as assinaturas microtexturais de foraminíferos parecem ser parcialmente controladas por tamanhos de grãos mais grossos que podem aumentar o estresse por abrasão nos foraminíferos.

Finalmente, para uma melhor compreensão da dinâmica de processos de tsunami na plataforma meridional portuguesa, ainda pouco explorada, recomenda-se a continuação de estudos com abordagem *multiproxy*, em sondagens de transectos perpendiculares à linha de costa. O uso de datações neste tipo de investigação pode contribuir para a identificação dos eventos de alta energia, bem como fornecer as taxas de sedimentação. Além disso, seria importante em trabalhos futuros conhecer a resposta dos foraminíferos (taxonomia, tafonomia) com maior resolução vertical nas sondagens. Assim, será possível obter uma representação estatística e espacial dos registros de origem tsunâmica arquivados neste setor.

REFERÊNCIAS

ANDRADE, C. O Ambiente de barreira da Ria Formosa (Algarve, Portugal). 1990. 345 p. Tese (Doutorado em Geologia), Departamento de Geologia, Universidade de Lisboa, Lisboa, 1990.

ANDRADE, C. Tsunami generated forms in the Algarve barrier island (South Portugal). In: Dawson, A.G. (Ed.), European Geophysical Society, 1992 Tsunami Meeting. *Science of Tsunami Hazards*, v.10, n.1, p. 21 – 34, 1992.

ARMSTRONG, H. A., e BRASIER, M. D. (2009). Microfossils. Blackwell.

BAHLBURG, H., WEISS, R. Sedimentology of the December 26, 2004, Sumatra tsunami deposits in eastern India (Tamil Nadu) and Kenya. *International Journal of Earth Sciences,* v.96, p. 1195-1209, 2007.

BELLANOVA, P.; BAHLBURG, H.; NENTWIG, V. SPISKE, M. Microtextural analysis of quartz grains of tsunami and non-tsunami deposits – A case study from Tirúa (Chile). *Sedimentary Geology*, n. 343, p. 72–84, 2016.

BEZZEGHOUD M.; J.F. BORGES, B. CALDEIRA, 2013. Sismotectónica ao longo da fronteira de placas tectónicas Núbia e Euro- asiática. In Geodinâmica e Tectónica global; a Importância da Cartografia Geológica Livro de actas da 9a Conferência Anual do GGET-SGP, Eds. N. Moreira, R. Dias, A. Araújo, 63-66, ISBN: 978-989-95398-3-9

BOLTOVSKOY, E.; AL, E. Atlas of benthic shelf foraminifera of the southwest Atlantic. The Hague; London: Junk; Brentford, 1980.

BORGES, J.F.; CALDEIRA, B. Fontes sísmicas ao longo da fronteira de placas tectónicas entre os Açores e a Argélia: um modelo sismotectónico. In: R. Dias, A. Araújo, P. Terrinha, J.C. Kullberg (Eds), Geologia de Portugal, Escolar Editora, vol. 2, p. 747-790, 2012.

BORGES, J.F.; FITAS, A.J.S.; BEZZEGHOUD, M.; TEVES-COSTA, P. Seismotectonics of Portugal and its adjacent Atlantic area. *Tectonophysics*, v. 337, p. 373-387, 2001.

BUFORN, E.; BEZZEGHOUD.M.; UDÁS, A.; PRO, C. Seismic Sources on the Iberia-African Plate Boundary and their Tectonic Implications. *Pure and Applied Geophysics*, v. 161, n. 3, p. 623–646, 2004.

CABRAL, J.; RIBEIRO, A. Incipient subduction along the West-Iberia continental margin. In: Abstracts, 28th International Geological Congress, Washington, D. C., USA, v. 1/3, p. 223, 1989.

CANDELLA, R. N. Statistical and spectral characteristics of the 2011 east japan tsunami signal in Arraial do Cabo, RJ, Brazil. *Revista Brasileira de Geofísica*, v. 32, n. 2, p. 235, 2014.

CANDELLA, R. N.; RABINOVICH, A. B.; THOMSON, R. E. The 2004 Sumatra tsunami as recorded on the Atlantic coast of South America. *Advances in Geosciences*, v.14, p.117–128, 2008.

CHAGUÉ-GOFF, C.; SCHNEIDER, J.; GOFF, J. R.; DOMINEY-HOWES, D.; STROTZ, L. Expanding the proxy toolkit to help identify past events: Lessons from the 2004 Indian Ocean Tsunami and the 2009 South Pacific Tsunami. *Earth-Science Reviews*, v. 107, n. 1–2, p. 107–122, 2011.

CONSULMAR, *Hidroprojecto e Hidroquatro. Regularização da zona estuarina de transição entre o porto de Figueira da Foz e o troço terminal de regularização do baixo Mondego*. Estudo de impacto ambiental, Direção Geral de Portos, Tech. Report, p. 145, 1991.

COSTA, M.; SILVA, R.; VITORINO, J. Contribuição para o estudo do clima de agitação marítima na costa portuguesa. 2ª Jornadas Portuguesas de Engenharia Costeira e Portuária, p. 20, 2001.

COSTA, P. J. M., ANRADE, C.; FREITAS, M.C. Preliminary Results of Exoscopic Analysis of Quartz Grains Deposited by a Palaeotsunami in Salgados Lowland (Algarve, Portugal). *Journal of Coastal Research*, p.39-43, 2009.

COSTA, P. J. M.; ANDRADE, C.; DAWSON, A. G.; MAHANEY, W. C.; FREITAS, M. C.; PARIS, R.; TABORDA, R. A tsunami record in the sedimentary archive of the central Algarve coast, Portugal: Characterizing sediment, reconstructing sources and inundation path. *The Holocene*, v. 22, n. 8, p. 899–914, 2012b.

COSTA, P. J. M.; ANDRADE, C.; FREITAS, M. D. C. Análise microtextural: princípios, procedimentos e caracterização micromorfológica de grãos de quartzo. Proveniência de materiais geológicos: *abordagens sobre o Quaternário de Portugal*, p. 19-36, 2014.

COSTA, P. J. M.; ANDRADE, C.; FREITAS, M.; OLIVEIRA, M.; LOPES, V.; DAWSON, A.;… JOUANNEAU, J-M. Microtextural characteristics of quartz grains transported and deposited by tsunamis and storms. *Sedimentary Geology*, v. 275, p. 55-69, 2012a.

COSTA, P. J. M.; DAWSON, S.; RAMALHO, R. S.; ENGEL, M.; DOURADO, F.; BOSNIC, I.; ANDRADE, C. A review on onshore tsunami deposits along the Atlantic coasts. *Earth-Science Reviews*, v. 212, p. 103441, 2021.

DAWSON, A. G.; HINDSON, R.; ANDRADE, C.; FREITAS, C.; PARISH, R.; BATEMAN, M.Tsunami sedimentation associated with the Lisbon earthquake of 1 November AD 1755: Boca do Rio, Algarve, Portugal. *The Holocene*, v. 5, n. 2, p. 209-215, 1995.

DIAS, J. M. A. Dinâmica sedimentar e evolução recente da plataforma continental portuguesa setentrional. 1987, p.384, Dissertação de doutorado, Faculdade de Ciências, Lisboa, 1987.

DIAS, R. P.; CABRAL, J. Actividade Neotectónica na região do Algarve. IV Congresso Nacionalde Geologia, Resumos alargados, Universidade do Porto - Faculdade de Ciências Museu e Laboratório Mineralógico e Geológico, n. 4, p. 241-245, 1995.

DIAS, R.P. Neotectónica da Região do Algarve. 2001. p. 369. Dissertação de doutorado, Faculdade de Ciências, Univ. Lisboa, 2001.

DIAS, R.P.; CABRAL, J. Neotectonic activity of the Algarve region (S of Portugal). *Comunicações do Instituto Geológico e Mineiro*, v. 89, p. 193-208, 2002.

DOORNKAMP, J. C.; KRINSLEY, D. Electron Microscopy Applied to Quartz Grainz from a Tropical Environment. *Sedimentology*, v.17, p. 89-101, 1971.

DUARTE, J. C.; ROSAS, F. M.; TERRINHA, P.; SCHELLART, W. P.; BOUTELIER, D.; GUTSCHER, M.A.; RIBEIRO, A. Are subduction zones invading the Atlantic? Evidence from the southwest Iberia margin, *Geology*, v. 41 n. 8, p. 839–842, 2013.

FATELA, F.; TABORDA, R. Confidence limits of species proportions in microfossil assemblages. Marine Micropaleontology, v. 45, n. 2, p. 169–174, jun. 2002.

FIÚZA, A.F.G. Upwelling patterns off Portugal. In: Suess, E., Thiede, J. (Eds.), Coastal Upwelling Its Sediment Record. *Springer US, Boston*, MA, pp. 85–98, 1983.

FONSECA, J. F. B. D. A Reassessment of the Magnitude of the 1755 Lisbon Earthquake. *Bulletin of the Seismological Society of America*, 2020.

FUJIWARA, O.; SAWAI, Y.; SHISHIKURA, M.; NAMEGAYA, Y. Sedimentary features of the 2011 Tohoku earthquake tsunami deposit, on the central Kujukuri coast, east Japan. *The Quaternary Research (Daiyonki-Kenkyu)*, v. 51, n. 2, p. 117–126, 2012.

FUJIWARA, O.; TANIGAWA, K. Bedforms record the flow conditions of the 2011 Tohoku-Oki tsunami on the Sendai Plain, northeast Japan. *Marine Geology*, v. 358, p. 79–88, 2014.

GARCÍA-LAFUENTE, J., DELGADO, J., CRIADO-ALDEANUEVA, F., BRUNO, M., DEL RÍO, J., MIGUEL VARGAS, J. Water mass circulation on the continental shelf of the Gulf of Cádiz. *Deep Sea Research Part II: Topical Studies in Oceanography*, v. 53, n. 11-13, p. 1182–1197, 2006.

GOFF, J. R.; CROZIER, M.; SUTHERLAND, V.; COCHRAN, U.; SHANE, P. Possible tsunami deposits of the 1855 earthquake, North Island, New Zealand. *Coastal Tectonics, Geological Society, London, Special Publications*, v. 146, n. 1, p. 353-374, 1999.

GOFF, J. R.; ROUSE, H. L.; JONES, S. L.; HAYWARD, B. W.; COCHRAN, U.; MCLEA, W.; … MORLEY, M. S. Evidence for an earthquake and tsunami about 3100–3400 yr ago, and other catastrophic saltwater inundations recorded in a coastal lagoon, New Zealand. *Marine Geology*, v. 170, p. 231–249, 2000.

GOFF, J.; PEARCE, S.; NICHOL, S. L.; CHAGUÉ-GOFF, C.; HORROCKS, M.; STROTZ, L. Multi-proxy records of regionally-sourced tsunamis, NewZealand. *Geomorphology*, v. 118, p. 369–382, 2010.

GONTHIER, E.; FAUGÈRES, J.; STOW, D. Contourite facies of the Faro Drift, Gulf of Cadiz. In: Stow, D.A.V. and Piper, D.J.W. (Eds.). (1984). Fine grained sediments: deep-water processes and facies. Geol. Soc. London, v.15, 1984.

GUTSCHER, M. A. What Caused the Great Lisbon Earthquake?. *Science*, v. 305, p. 1247-1248, 2004.

HAWKES, A. D.; BIRD, M.; COWIE, S.; GRUNDY-WARR, C.; HORTON, B. P.; SHAU HWAI, A. T.; … AIK, L. W. Sediments deposited by the 2004 Indian Ocean Tsunami along the Malaysia–Thailand Peninsula. *Marine Geology*, v. 242, n. 1-3, p.169–190, 2007.

HERNÁNDEZ-MOLINA, F.J.; SIERRO, F.J.; LLAVE, E.; ROQUE, C.; STOW, D.A.V.; WILLIAMS, T.; LOFI, J.; VAN der SCHEE, M.; ... BRACKENRIDGE, R.E.; Evolution of the gulf of Cadiz margin and southwest Portugal contourite depositional system: Tectonic, sedimentary and paleoceanographic implications from IODP expedition 339. *Marine Geology*, v. 377, p. 7–39, 2016.

HINDSON, R.; ANDRADE, C.; DAWSON, A. Sedimentary processes associated with the tsunami generated by the 1755 Lisbon Earthquake on the Algarve coast, Portugal. *Physics and Chemistry of the Earth*, v.21, p. 57-63, 1996.

HINDSON, R.A.; ANDRADE, C. Sedimentation and hydrodynamic processes associated with the tsunami generated by the 1755 Lisbon earthquake. *Quaternary International*, v. 56, n. 1, p. 27-38, 1999.

HORI, K.; KUZUMOTO, R.; HIROUCHI, D.; UMITSU, M.; JANJIRAWUTTIKUL, N.; PATANAKANOG, B. Horizontal and vertical variation of 2004 Indian tsunami deposits: An example of two transects along the western coast of Thailand. *Marine Geology*, v. 239, n. 3-4, p. 163–172, 2007.

KENNETT, J. P.; SRINIVASAN, M. S. Neogene planktonic Foraminifera: a phylogenetic atlas. Stroudsburg Penn: Hutchinson Ross, 1983.

KORTEKAAS, S.; DAWSON, A.G. Distinguishing tsunami and storm deposits: An example from Martinhal, SW Portugal. *Sedimentary Geology*, v. 200, n. 3-4, p. 208-221, 2007.

KUWATANI, T.; NAGATA, K; OKADA, M.; WATANABE, T.; OGAWA, Y.; KOMAI, T.; TSUCHIYA, N. Machine-learning techniques for geochemical discrimination of 2011 Tohoku tsunami deposits. *Scientific Reports*, v. 4, n. 1, 2014.

LOEBLICH JR.; A.R.; Tappan, H. 1988. Foraminiferal Genera and Their Classification. Van Nostrand Reinhold, New York, 970 pp.

LIU, M.; TANHUA, T. Characteristics of water masses in the Atlantic Ocean based on GLODAPv2 data. *Ocean Science Discussions*, p. 1-43, 2019.

LOPES, F. C.; CUNHA, P. A plataforma continental algarvia e províncias adjacentes: Uma análise geomorfológica. In: Ciências Geológicas – Ensino e Investigação e sua História, Geologia Clássica, v. 1, p. 479- 489, 2010.

LOPES, F. C.; CUNHA, P. P.; LE GALL, B. Cenozoic seismic stratigraphy and tectonic evolution of the Algarve margin (offshore Portugal, southwestern Iberian Peninsula). *Marine Geology*, v. 231, n. 1-4, p. 1–36, 2006.

MAHANEY, W.C. Atlas of sand grain surface textures and applications. Oxford University Press, Oxford, United Kingdom, 237p. 2002.

MAMO, B., STROTZ, L., DOMINEY-HOWES, D. Tsunami sediments and their foraminiferal assemblages. *Earth-Science Reviews*, v. 96, p. 263-278, 2009.

MENDES, I.; DIAS, J. A., SCHÖNFELD, J.; FERREIRA, Ó.; ROSA, F.; LOBO, F. J. Living, dead and fossil benthic foraminifera on a river dominated shelf (northern Gulf of Cadiz) and their use for paleoenvironmental reconstruction. *Continental Shelf Research*, v. 68, p. 91–111, out. 2013.

MILKER, Y.; SCHMIEDL, G. A taxonomic guide to modern benthic shelf foraminifera of the western Mediterranean Sea. *Palaeontologia Electronica*, 2012

MOITA, I. (1986) Carta dos Sedimentos Superficiais. Notícia Explicativa da Folha SED 7 e 8. Cabo de S- Vicente ao Rio Guadiana. Instituto Hidrográfico, Lisboa, Portugal.
MORTON, R. A.; GELFENBAUM, G.; BUCKLEY, M. L.; RICHMOND, B. M. Geological effects and implications of the 2010 tsunami along the central coast of Chile. *Sedimentary Geology*, v. 242, n. 1-4, p. 34–51, 2011.

MURRAY, J.M. (1971). An Atlas of British Recent Foraminifererids. Heinemann Educational Books Ltd, London, p. 244.

MURRAY, J. M. (2006). Ecology and Applications of Benthic Foraminifera. Cambridge University Press, p. 426.

PEREIRA, A. R. A margem continental portuguesa. Breve síntese do conhecimento actual. *Finisterra*, v. 26, n. 51, 1991.

PILARCZYK, J. E.; HORTON, B. P.; WITTER, R. C.; VANE, C. H.; CHAGUÉ-GOFF, C.; GOFF, J. Sedimentary and foraminiferal evidence of the 2011 Tōhoku-oki tsunami on the Sendai coastal plain, Japan. *Sedimentary Geology*, v. 282, p. 78–89, 2012.

PILARCZYK, J. E.; REINHARDT, E. G.; BOYCE, J. I.; SCHWARCZ, H. P.; DONATO, S. V. Assessing surficial foraminiferal distributions as an overwash indicator in Sur Lagoon, Sultanate of Oman. *Marine Micropaleontology*, v. 80, n. 3-4, p. 62–73, 2011.

PILARCZYK, J. E.; SAWAI, Y.; MATSUMOTO, D.; NAMEGAYA, Y.; NISHIDA, N.; IKEHARA, K.; … HORTON, B. P. Constraining sediment provenance for tsunami deposits using distributions of grain size and foraminifera from the Kujukuri coastline and shelf, Japan. *Sedimentology*, v. 67, n. 3, p. 1373–1392, 2020.

PIRES, H.O. Alguns aspectos do clima de agitação marítima de interesse para a navegação na costa de Portugal. *O Clima de Portugal*, fasc. XXXVII, vol. II, INMG, Lisboa, 34 p.

POWERS. A New Roundness Scale for Sedimentary Particles. *SEPM Journal of Sedimentary Research*, v. 23, 1953.

QUINTELA, M.; COSTA, P. J. M.; FATELA, F.; DRAGO, T.; HOSKA, N.; ANDRADE, C.; FREITAS, M. C. The AD 1755 tsunami deposits onshore and offshore of Algarve (south Portugal): Sediment transport interpretations based on the study of Foraminifera assemblages. *Quaternary International,* v. 408, p. 123–138, 2016.

RELVAS, P. The physical oceanography of the Cape São Vicente upwelling region observed from sea, land and space, Ph.D. thesis, Univ. of Wales, Bangor, 1999.

RELVAS, P.; BARTON, E. D. A separated jet and coastal counterflow during upwelling relaxation off Cape São Vicente (Iberian Peninsula). *Continental Shelf Research*, v. 25, n. 1, p. 29–49, 2005.

RELVAS, P; BARTON, E.D. RELVAS, P. Mesoscale patterns in the Cape São Vicente (Iberian Peninsula) upwelling region. *Journal of Geophysical Research*, v. 107, n. C10, 2002.

REICHERTER, K., VÖTT, A., FEIST, L., COSTA, PJM, SCHWARZBAUER, J., SCHÜTTRUMPF, H., JENS, H., RAEKE, A., HUHN-FREHERS, K.). Lisboa 1755, Cruzeiro nº M152/1, 02.11. - 14.11.2018, Funchal (Portugal) - Hamburgo (Alemanha). Em METEOR-Berichte, vol. M152, p. 1-36, 2019.

RIBEIRO, A.; CABRAL, J.; BAPTISTA, R.; MATIAS, L. Stress pattern in Portugal mainland and the adjacent Atlantic region, West Iberia. *Tectonics*, v. 15, n. 3, p. 641–659, 1996.

ROSAS, FM, DUARTE, JC, TERRINHA, P., VALADARES, V., MATIAS, L. Morphotectonic characterization of major bathymetric lineaments in Gulf of Cadiz (Africa–Iberia plate boundary): Insights from analogue modelling experiments. *Marine Geology*, v. 261, n. 1-4, p. 33–47, 2009.

SÁNCHEZ, R.F.; MASON, E.; RELVAS, P.; DA SILVA, A. J.; PELIZ, Á. On the inner-shelf circulation in the northern Gulf of Cádiz, southern Portuguese shelf. *Deep Sea Research Part II: Topical Studies in Oceanography*, v. 53, n. 11-13, p. 1198–1218, 2006.

SÁNCHEZ, R.F; RELVAS, P. Spring–summer climatological circulation in the upper layer in the region of Cape St. Vincent, Southwest Portugal. *ICES Journal of Marine Science*, v. 60, n. 6, p. 1232-1250, 2003.

SARTORI, R.; TORELLI, L.; ZITELLINI, N.; PEIS, D.; LODOLO, E. Eastern Segment of the Azores- Gibraltar Line (Central-eastern Atlantic): An Oceanic Plate Boundary with Diffuse Compressional Deformation, *Geology*, v. 22, p. 555–558, 1994.

SZCZUCIŃSKI, W.; CHAIMANEE, N.; NIEDZIELSKI, P.; RACHLEWICZ, G.; SAISUTTICHAI, D.; TEPSUWAN, T.; ... SIEPAK, J. Environmental and geological impacts of the 26 December 2004 tsunami in coastal zone of Thailand — overview of short and long-term effects. *Polish Journal of Environmental Studies*, v. 15, p. 793–810, 2006.

SZCZUCIŃSKI, W.; NIEDZIELSKI, P.; RACHLEWICZ, G.; SOBCZYŃSKI, T.; ZIOŁA, A.; KOWALSKI, A.; LORENC, S.; SIEPAK, J. Contamination of tsunami sediments in a coastal zone inundated by the 26 December 2004 tsunami in Thailand. *Environmental Geology*, v. 49, n. 2, p. 321–331, 26, 2005.

TABORDA, R.; DIAS, J. Análise da sobreelevação do mar de origem meteorológica durante os temporais de Fevereiro/Março de 1978 e Dezembro de 1981. *Geonovas*, v. 1, 1992.

TAMURA, T.; SAWAI, Y.; IKEHARA, K.; NAKASHIMA, R.; HARA, J; KANAI, Y. Shallow-marine deposits associated with the 2011 Tohoku-oki tsunami in Sendai Bay, Japan. *Journal of Quaternary Science*, v. 30, n. 4, p. 293–297, 2015.

TERRINHA, P.; MATIAS, L.; VICENTE, J.; DUARTE, J.; LUÍS, J.; PINHEIRO, L.; … VÍCTOR, L. M. Morphotectonics and strain partitioning at the Iberia–Africa plate boundary from multibeam and seismic reflection data. *Marine Geology*, v. 267, n. 3-4, p. 156–174, 2009.

TERRINHA, P.; ROCHA, R.; REY, J.; CACHÃO, M.; MOURA, D.; ROQUE, C.; ... BENSALAH, M. K. A Bacia do Algarve: Estratigrafia, paleogeografia e tectónica. *Geologia de Portugal no contexto da Ibéria*, p. 1-138, 2006.

TERRINHA, P.A. Structural geology and tectonic evolution of the Algarve Basin, South Portugal. 1998. p. 430. Tese de Doutorado. Imperial College London (University of London), Londres, 1998.

TUDOR, M.; RAMOS-PEREIRA, A.; COSTA, P. J. M. A Possible Tsunami Deposit Associated to the CE 1755 Lisbon Earthquake on the Western Coast of Portugal. *Geosciences*, v. 10, n. 7, p. 257, 2020.

UCHIDA, J.; ABE, K.; HASEGAWA, S.; FUJIWARA, O. Studies on the Source of Run-up Tsunami Deposits Based on Foraminiferal Tests and Their Hydrodynamic Verification. *The Quaternary Research (Daiyonki-Kenkyu)*, v. 46, n. 6, p. 533–540, 2007.

VELOSO, J. A. V. 2015. Tremeu a Europa e o Brasil também. 1ª Edição, Chiado Editora, p. 412.

VOS, K.; VANDENBERGHE, N.; ELSEN, J. Surface textural analysis of quartz grains by scanning electron microscopy (SEM): From sample preparation to environmental interpretation. *Earth-Science Reviews*, v. 128, p. 93–104, jan. 2014.

WOOSTER, W. S.; BAKUN, A.; MCLAIN, D. R. Seasonal upwelling cycle along the eastern boundary of the North Atlantic. *Journal of Marine Research*, v. 34, n. 2, p. 131-141, 1976.

YAMAZAKI, Y.; CHEUNG, K. F. Shelf resonance and impact of near-field tsunami generated by the 2010 Chile earthquake. *Geophysical Research Letters*, v. 38, n. 12, 2011.

ZITELINI, N.; ROVERE, M.; TERRINHA, P.; CHIERICI, F.; MATIAS, L; BIGSETS Team. Neogene Through Quaternary Tectonic Reactivation of SW Iberian Passive Margin. *Pure and Applied Geophysics,* v. 161, n. 3, p. 565–587, 1. 2004.

ZITELLINI, N.; MENDES, L. A.; CORDOBA, D.; DANOBEITIA, J.; NICOLICH, R.; PELLIS, G.; ... RUIZ, A. Z. Source of 1755 Lisbon earthquake and tsunami investigated. Eos, *Transactions American Geophysical Union*, v. 82, n. 26, p. 285-291, 2001.

APÊNDICE – Microtextural signatures in quartz grains and foraminifera from tsunami deposits of the Portuguese shelf (Artigo científico)

Microtextural signatures in quartz grains and foraminifera from tsunami deposits of the Portuguese shelf

Missilene Yhasnara Rodrigues Silva[1], Pedro JM Costa[2,3], Francisco Dourado[1], Maria Virginia Alves Martins[1], Lisa Feist[5,] Piero Bellanova[5], Klaus Reicherter[5]

[1]Departamento de Geologia Aplicada, Faculdade de Geologia, Universidade do Estado do Rio de Janeiro, Brazil

[2]Departamento de Ciências da Terra, Faculdade de Ciências e Tecnologia, Universidade de Coimbra, Rua Sílvio Lima, Univ. Coimbra - Pólo II, 3030-790 Coimbra, Portugal

[3]Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, Edifício C6, Campo Grande 1749-016, Lisbon, Portugal

[4]Departamento de Geologia, Faculdade de Ciências, Universidade de Lisboa, Edifício C6, Campo Grande 1749-016, Lisbon, Portugal

[5]Institute for Neotectonics and Natural Hazards, RWTH Aachen University, Lochnerstr. 4-20, 52056 Aachen, Germany

ABSTRACT

This study presents results from two sediment cores collected on the southern Portuguese shelf attempting to, partially, fill the knowledge gap of the offshore record of high-energy events. The results were obtained based on lithostratigraphy, microtextural analysis of quartz grains and foraminiferal taphonomy. The lithostratigraphy, corresponding to late Holocene sedimentation, consist of silt to very fine sand, with intercalations of sand-rich in bioclastic fragments. Within this sequence a unit has been associated with backwash sedimentation based on a group of sedimentological criteria (grain-size, erosive basal contact, composition, etc.).In terms of microtextures, a high degree and presence of mechanical marks on the grains associated with tsunami deposition was observed in samples from this study and reflects the high-energy hydrodynamic processes. In compositional terms it was observed a higher presence of quartz grains in these units, when compared to over and underlying layers. This, also favours the increase of mechanical marks, because grain-to-grain contact is more intense compared to the impact with bioclasts. Additionally, the bathymetric and geomorphological setting of the coring sites determined the degree and type of mechanical microtextures observed. This is due to the presence of the Portimão canyon. The backwash flow along the Portimão canyon favours more violent collisions, as it was observed on core GeoB23512-02, located contiguous to this geomorphic structure. Furthermore, post-depositional changes and characteristics of the original sediment source contribute to explain the occurrence of dissolution in silt-rich units of GeoB23513-02.

The foraminiferal taphonomy displayed a predominance of dissolution alteration in the tests surfaces that was more evident in the silty layers. On the other hand, similarly to quartz grains microtextural signature, the sandy high-energy units exhibit a slight predominance of physical processes (abrasion) despite the still strong presence of dissolution derived either from the original sedimentary source features or related with post-depositional processes. Furthermore, the sole presence of species (middle to outer shelf) in some units is an indication that there was little reworking of these specimens. Finally, the results obtained in this study show potential to recognize the microtextural signature of Holocene tsunami events in offshore environments.

KEYWORDS

offshore; backwash; taphonomy; high-energy events; SEM

INTRODUCTION

The limitations of data collection and interpretation on the frequency and magnitude of past tsunamis constrains present-day studies aiming to define risks of these phenomena. Therefore, geological archives are keys to reconstruct and understand past intensities and dynamics of these events. In this sense, evidence in coastal stratigraphy left by tsunamis allows correlating the type of waves and their characteristics with sediment transport and deposition during these events (Costa et al., 2012a).

The 2004 Indian Ocean tsunami (e.g. Chagué-Goff et al., 2011; Hori et al., 2007; Szczucinski et al., 2006; 2012), the 2010 Chilean tsunami (e.g. Morton et al., 2011; Yamakaki and Cheung, 2011) and the 2011 Tohoku-oki tsunami in Japan (e.g. Fujiwara et al., 2012; 2014; Kuwatani et al., 2014; Tamura et al., 2015), awakened the world to the dangers inherent to these natural disasters. Consequently, studies on these extreme events have grown in number and in detail over the last two decades.

In the Atlantic basin, tsunamis are relatively rare at the scale of human life. Using the geological record, Costa et al., (2021) have made a compilation of the main documented tsunami deposits along the Atlantic coasts. In Portugal, work initiated by Andrade (1990, 1992) in several areas of the Algarve coast, allowed to find sandy deposits associated with the waves of the November 1st 1755 CE tsunami. Several sites have been investigated on the Portuguese coast such as the Boca do Rio estuary (e.g. Dawson et al., 1995; Hindson et al., 1996; Hindson and Andrade, 1999, Feist et al., 2019), Lagoa dos Salgados (e.g. Costa et al., 2009; 2012a; 2012b) and Martinhal (e.g. Kortekaas and Dawson, 2007) among others. These works rely on multiparametric analyses for the recognition of tsunami deposits, namely, on their peculiar sedimentary and micropalaeontological characteristics that provided important evidence for the occurrence of the 1755 CE tsunami.

In sedimentology, the application of microtextural analysis on quartz grains through images obtained by Scanning Electron Microscopy (SEM) was initiated in the 1970s (Doornkamp and Krisley, 1971) and more recently with different purposes the works of Mahaney (2002) and Vos et al., (2014) deserve special notice for the progress and review made on this technique. This technique was also applied to extreme marine inundation deposits, where the relative increase in mechanical impact marks on the grain surface was, generally, observed and which may reflect the dynamics of the high-energy event, (e.g. Mahaney and Dohm, 2011; Costa et al., 2012a; 2012b; 2014; Bellanova et al., 2016; Tudor et al., 2020).

Another approach regularly used as a proxy in investigations of tsunami deposits, is the study of foraminiferal assemblages. Changes in the assemblage composition when compared with under and overlying layers, are corresponding with the period before and after the tsunami event, may allow inferences about the transport distance of the inundation flow and return (backwash) (Bahlburg and Weiss 2007; Hawkes et al., 2007; Uchida et al., 2007). Taphonomic aspects of foraminiferal shells can also point to information on flow hydrodynamics and on post-depositional processes (Kortekaas and Dawson, 2007; Pilarczyk and Reinhardt, 2012; Quintela et al., 2016). Mamo et al., (2009) address the use of foraminifera as a tool on tsunami deposit studies, describing the procedures, characteristics and recommendations of this tool in the recognition of tsunami deposits.

Evidence of backwash on the shelf is still little explored compared to onshore deposits.The study by Abrantes et al., (2008) in the Tagus delta, on the central western shallow shelf of Portugal, proved that offshore settings have the potential to preserve evidence of tsunami deposits. In order to contribute informations on offshore tsunami deposits, surveys were conducted on the Algarve shelf (southern Portugal), which revealed not only the record of the 1755 CE tsunami but also of another event, which occurred about 3400 years BP (Reicherter et al., 2019). This event was not recorded in the onshore geological record and leads to a change in the definition of recurrence periods of these phenomena for the SW sector of Iberia.

In this study we investigate the tsunami record on the southern Algarve continental shelf by applying, microtextural analysis of quartz grains (125-500 μm fraction) and taphonomic aspects of the foraminifera assemblage as the main discriminant tools. For this purpose, two offshore sediment cores (GeoB23512-01 and GeoB23513-02 – Figure 1) were studied. With this study we aim to increase the understanding of dynamics during Holocene high-energy events and to characterise their backwash phases through the different imprints left in the sedimentary offshore record of the Portuguese Algarve shelf.

STUDY AREA

The southern Algarve continental shelf is located on the southern Portuguese margin. Its width varies between 8 km and 28 km and is characterised by a gentle slope between 0.5% and 2% (Andrade, 1990). According to Lopes and Cunha (2010) three domains are identified in this sector: the inner shelf (up to 40 m depth), the middle shelf (between 40 m and 90 m deep) and the outer shelf (between 90 m and the platform edge). In turn, the platform edge is well defined and lies between 110-150 m depth (Vanney and Mougenot, 1981). On it are carved some submarine canyons (e.g. Portimão, Lagos and Faro canyons), embedded by the marginal plateaus of contouritic origin (Moita, 1986). This morphological configuration reflects the clear structural control of the geological evolution of this sector, combined with the hydrodynamic of the Mediterranean Water Vessel circulation, a high density current that circulates through the ocean floor, eroding transporting and depositing sediments along the continental slope (Moita, 1986; Relvas and Barton, 2002 and Lopes and Cunha, 2010).

The oceanographic conditions along the southern Algarve coast are typically low energy, with annual average significant wave height (Hs) < 1 m and with two predominant wave directions between SW and SE, being the first direction dominant (Costa et al., 2001). According to Moita (1986), the tides on the Algarve coast are regular semidiurnal type, with maximum amplitudes in a single cycle of up to 3.5m. The current regime is weak on the shelf, with a predominance of drift currents (by wind action) over tidal currents.

The tectonic setting of the SW Iberian margin corresponds to a wide zone of dextral transpressive deformation, associated to the convergence of the Nubian and Eurasian plates (Rosas et al., 2008; Zitellini et al., 2009). This landscape is responsible for significant seismicity that is evidenced by earthquakes and tsunamis, such as the Lisbon earthquake and tsunami in 1755 CE, which devastated the Algarve coast (Duarte et al., 2013). The geological signatures of these events have been very well documented in the works of several authors, (Hindson and Andrade, 1999; Hindson et al., 1996; Kortekaas and Dawson, 2007, Costa et al., 2012a, 2012b, 2021). In addition, older tsunamis, that may have affected this region, have also been reported, such as the Tavira tsunami of 1722 CE, among other historical events, compiled in Baptista and Miranda (2009).

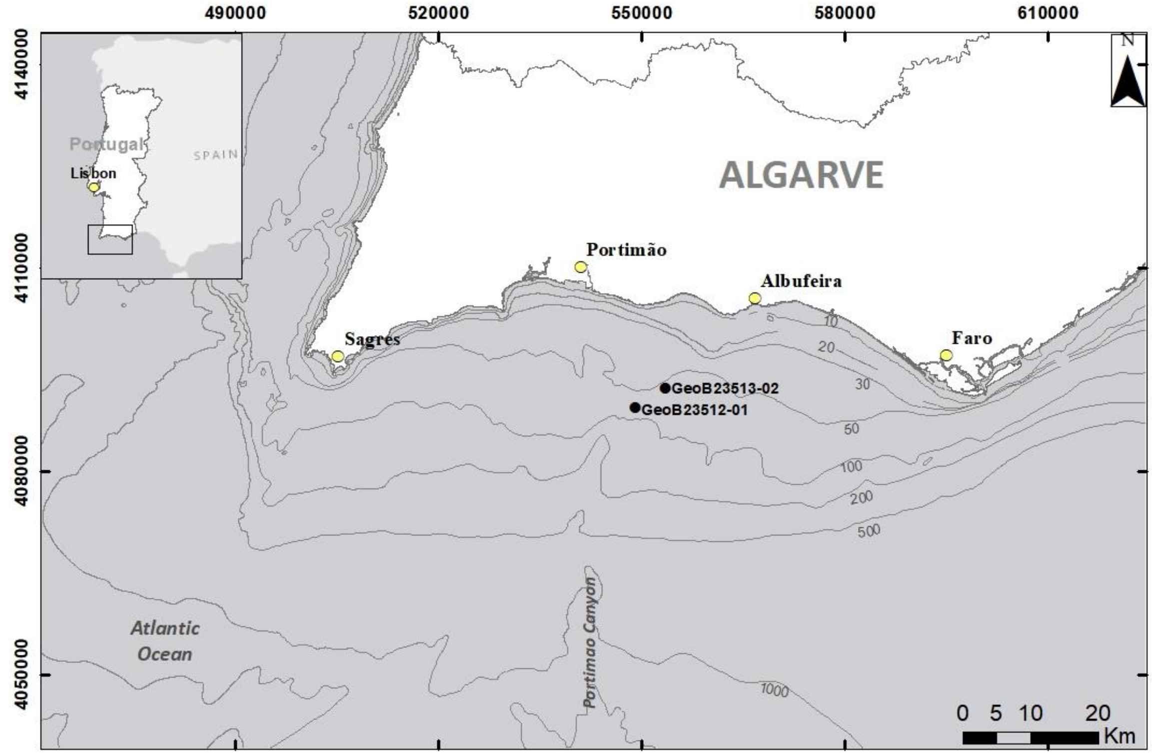


Figure 1 – Study area and offshore coring locations.

METHODS

Sediment cores used in this work were collected by the RV METEOR expedition M152 conducted in November 2018 along the southern Algarve shelf, aiming to study sedimentological data from the 1755 CE tsunami and other possible previous events (Reicherter et al., 2019). The specific area of this study is located on the southern Algarve middle shelf. This study focusses on two obtained sediment cores GeoB23512-01 (548084.685m E/4089698.08m N) and GeoB23513-02 (553721.943m E/4.092394.269m N)

The samples were collected using a vibrocoring system, with maximum recovery of approximately 5,5 m. GeoB23512-01 was collected at approximately 14 km from the present-day coastline and was recovered at 88 metres water depth. In turn, core GeoB23513-02 was retrieved at approximately 12 km from the present-day coast and was collected with 50 meters of water depth. The horizontal distance between the two core samples is approximately equivalent to 5.3 km. After opening the cores, they were described macroscopically. Because sandy layers were identified interspersed between levels of finer hemipelagic sediments. The units studied in this work were sandy layers in the upper parts of both cores (coarser units within the muddy lithostratigraphic sequence). For this study, 39 samples were obtained from core GeoB23512-01 and 19 from core GeoB23513-02.

The laboratory procedures, applied to the sediment samples, were aimed at separating and treating the fraction greater than 63µm. Initially it was necessary to disaggregate the sediments, using a 10% diluted NaOH solution in water for 24h. Subsequently, the samples were washed with distilled water through a 63µm sieve. The coarser fraction (> 63µm) was recovered and taken to the oven at 60^{o} C. Once dried, the samples were sieved at 0.5 ϕ intervals. These procedures were carried out in the Micropalaeontology Laboratory of the Geology Faculty, Rio de Janeiro State University (UERJ).

The compositional analysis of the sediments was carried out only on the 250-500 µm fraction. With the aid of a spatula, this fraction was sub-sampled carefully, weighed and then placed in a foraminifera sorting tray (black chequered plate), and finally analysed under a Zeiss-Stemi 2000C binocular microscope of the Micropalaeontology Laboratory of UERJ. The counted elements were grouped in bioclasts (fragments of shells, mollusks, foraminifera and other organisms), quartz, feldspar, opaques and micas (muscovite and biotite).

For the microtextural analysis (aka. exoscopy) quartz grains of the 125-500 µm particle size fraction were analysed. These grains were selected under the Zeiss binocular microscope-Stemi 2000C and prepared for scanning electron microscopy. Mahaney (2002) and Costa et al. (2012a) investigated the statistical representativeness of this analysis and concluded that the minimum number of grains for data to be viable is between 15 and 20 per sample. The analysis of the selected quartz grains was carried out in two laboratories: at the Laboratory of the Centre of Mineral Technology (CETEM), using the SEM TM3030 Plus-HITACHI and at the Department of Stratigraphy and Paleontology of the Geology Faculty of UERJ, using the SEM ZEISS model EVO MA 10. The work by Costa et al. (2012a; 2014a) was applied to classify the grains. Costa et al. (2012a) suggests the analysis of, at least, five different microtextural characteristics to obtain valid results. This is because a single microtexture is not sufficient to characterize a certain sedimentary environment. Furthermore, these microtextural associations should involve the contrast between marks resulting from mechanical action (percussion marks and fresh surfaces, fractures), typically formed in a context of high-energy and shock between particles and, features resulting from chemical action (dissolution and adherent particles) usually associated with poor mobility thus, discriminating low-energy environments. There are also features that commonly result from long-term actions, such as grain roundness.

In the present study, each grain was described according to the microtextural characteristics revealed on its surface, for example:

- Percussion marks: these are V-shaped or triangular depressions and are associated with the usually the result of collision between grains;

- Fresh surfaces: characterized by the absence of dissolution, precipitation or posterior mechanical mark. In many cases, they are associated with fracture or abrasion marks, responsible for their (recent) exposure;

- Fractures: these are linear or conchoidal with variable incision depth, being related to the exposure of fresh surfaces. They are produced by mechanical impact;

- Dissolution: microtexture of chemical nature indicating the degree of dissolution on the surface of grains. The notable effects of this attribute are the destruction of fresh surfaces and angular edges and by the formation of cavities;

- Adherent particles: these are characterized by the presence of exotic microparticles on the surface of the quartz grains. Interpreted as the result of chemical action.

After the identification, a semi-quantitative approach was applied to each grain, based on the proportion of the microtexture present on its surface. For this, a scale of 0-5 was adopted, where: 0 (absent); 1 (up to 10% of the grain surface); 2 (10-25% of the grain surface); 3 (25-50% of the grain surface); 4 (50-75% of the grain surface); and 5 (>75% of the grain surface). Roundness was also evaluated as a complementary attribute, according to Powers (1953), using a rating scale from 0 to 5 (0 - very rounded; 1 - rounded; 2 - sub-rounded; 3 - sub-angular; 4 - angular; 5 - very angular).

The focus of foraminifera analysis in this study was the external surface marks that where imprinted in the foraminifera tests. A simplified foraminifera examination was performed on the medium-sized tests. Palaeoecological results should be interpreted with caution due to the limited size-fractions analysed. The preparation, sorting and scanning electron microscopy analysis of the foraminifera were conducted at the Institute of Neotectonics and Natural Hazards, RTWH Aachen University. Samples were sieved to >63 µm and dried at 40°C. The dried samples were homogenized and subdivided into smaller sample sizes of approx. 0.01 g. The foraminifera in each sample were counted with a Zeiss Stemi 200C microscope with 80x magnification. Of these, a minimum of 300 individuals was picked, identified and stored in Krantz-cells for further investigations. Following Fatela and Taborda (2002) 300 individuals in the samples are representative for high diversity assemblages of offshore samples. Taxonomic identification up to the rank of genera was based on several reference publications (e.g. Murray, 1971 and 2006; Boltovskoy et al., 1980; Kennett & Srinivasan, 1983; Loeblich & Tappan, 1988; Armstrong & Brasier, 2005; Mendes et al., 2012; Milker & Schmiedl, 2012;). Further identification, images of the organisms found at the selected levels were taken by a FE-SEM (Zeiss Supra 55) with the secondary electron (SE) at a voltage of 3 kV and analysed in order to assess the conservation the surface of its tests.

The individuals were classified according to the degree of physical alteration when they presented fragmentation or abrasion, and dissolution marks were used to identify chemical alterations. Analytical criteria were applied in order to establish the degree of alteration. These were based on the works of Pilarczyk et al. (2011; 2012; 2019). Thus, it was considered: (0) when the shells were unaltered, being considered well-preserved; (1) slightly altered; (2) moderately altered and (3) very altered.

RESULTS

4.1 General description of cores

Core GeoB23512-01 recovered 4.42 m of sediment and core GeoB23513-02 recovered 5.48 m of sediment. For this study, only samples from the upper parts of the cores were analysed. The lithostratigraphic description was based on macroscopic physical aspects, such as colour, type of contact, sediment composition and amount of bioclastic fragments. Macroscopically, the upper part of GeoB23512-01 (Fig. 2a) is composed of dark green sandy silt and silty material, with intercalations of sand that is rich in bioclastic fragments. For description purposes, such intercalations are designated as units (units B, C and D). The basal contacts of the units are clearly erosive or abrupt. The units were identified between 81-82 cm (unit B), 127-158 cm (unit C) and 217-218 cm (unit D) below seafloor (bsf) in the referred sediment core. An intercalation of fine greyish sand was observed at the level between 33-38 cm bsf (Unit A).

On sediment core GeoB23513-02 (Fig. 3a) from the 144 cm bsf to 45 cm bsf, an extensive layer of very fine sand occurs (unit B1). It has a greyish colour and is intensely bioturbated. Overlying this layer, between 45 cm bsf and the top, a greenish sandy silt occurs. This silt layer is interrupted by a level of sand rich in bioclastic fragments between 21-25 cm bsf (unit A1). This level presents an erosive basal contact.

The sediment composition analysis (Appendix 1) revealed that the sandy layers of both sediment cores are predominantly composed of bioclasts and secondarily of quartz, feldspar and few grains of opaque minerals and micas. In GeoB23512-01 (Fig. 2b) the interval with the highest average of bioclasts (87%) occurs in the very fine sand layer (unit A), between 33-38 cm bsf while at 81-82 cm bsf is the interval with the lowest average of bioclasts (79%) and highest occurrence of quartz (average of 15%). Unit C displays the greatest variation of bioclastic elements, with values between 73%-91%. The lower values occur on the levels with the highest percentage of quartz grains. Opaque minerals are more frequent in the basal levels of unit C (154-158 cm bsf) whereas micas occur with higher percentages between 127-131 cm bsf. Finally, unid D has a percentage of elements very similar to unit C.

In GeoB23513-02 (Fig. 3b), between 21-25 cm bsf (unit A1) the average of bioclasts is 72.2%. It is important to note that in sand layer shows the highest increment of lithoclastic elements when compared to those observed on unit B1 (very fine sand) between 48-79 cm bsf. The highest values of quartz and opaques occur at the base of unit A1 (between 23-25 cm bsf). Feldspars variation occurs without a well-defined tendency, whereas micas present a higher percentage at the top of this same unit (21-22 cm bsf). In the sample within unit B1 occurs a higher percentage of bioclasts (79%), relatively to the lithoclastic elements.

4.2 Quartz microtextures

The microtextural attributes of 315 grains from fifteen samples from GeoB23512-01 and 281 grains from twelve samples from GeoB23513-02 were identified and classified through the analysis of SEM images. The results are illustrated respectively in Figures 2c and 2d, 3c and 3d. (Appendices 2 and 3). Microtextural features resulting from mechanical action (percussion marks, fresh surfaces, fractures) and others derived of chemical action (dissolution and adherent particles), were identified.

4.2.1 GeoB23512-01

The analysis of the microtextural attributes in this sediment core disclosed distinct distributions and mean values between units A (very fine sand) and B, C and D (bioclastic sand). In unit A, between 33-38 cm bsf, there is an abundance of chemical features such as dissolution (25%) and adherent particles (22%), as opposed to percussion marks, fresh surface and fractures, which are noticeably less frequent. In terms of mean values of the surface of grains occupied by each microtextural feature, dissolution stands out obtaining the highest value (mean $3.31 \pm \sigma 1$ 0.17), followed by adherent particles (2.06 ± 0.25). The values of mechanical action marks, such as percussion marks (0.98 ± 0.26), fresh surfaces (1.61 ± 0.58) and fractures (1.31 ± 0.40), are relatively lower in this layer.

On the other hand, in samples from units B, C and D, it is observed that the microtextural attributes related to mechanical impacts are more frequent and dominant on the surfaces of the quartz grains, especially on the lower and upper limits of the expressive sand layer of unit C (127-128 cm bsf and 157-158 cm bsf). Percussion marks, fresh surfaces and fractures present very regular occurrence distributions, with 24% of occurrence each. Regarding grain surface dominance, fresh surfaces dominate (3.40 ± 0.23), followed by percussion marks (3.05 ± 0.36) and fractures (2.93 ± 0.33). The features of dissolution (1.56 ± 0.24) and adherent particles (0.94 ± 0.18) occur more discretely here.

Regarding roundness, the grains do not present a substantial variation among the different layers. In the bioclastic sand units (B, C and D) the analysed grains exhibit and average of 2.78 ± 0.26, characterized as sub-angular. At the same time, where the very fine sand occurs (unit A), the mean values are 3.26 ± 0.21, therefore, the grains are considered as sub-angular to sub-rounded.

4.2.2 GeoB23513-02

In sediment core GeoB23513-02, the distribution of microtextural features did not show significant differences along the vertical analysis performed. The occurrence percentages of microtextural features differ by 1% or 2% throughout the samples analysed. Dissolution dominating, followed by fresh surfaces, percussion marks and fractures while adherent particles are the least frequent. In unit A1 (21-25 cm bsf), considering the mean values of grain surface dominance, fresh surfaces (2.46±0.18), percussion marks (2.10±0.71) and dissolution (1.80±0.25) are the most relevant microtextural features.

In unit B1 (48-68 cm bsf), the dissolution coverage is clearly more expressive (mean 2.44±0.52) in relation to the other microtextural attributes. The percussion marks and fresh surfaces present very similar distributions and average values. In turn, regarding microtextural feature dominance, adherent marks are more discrete with averages ranging between 0.94-2.00. Roundness presents values of 3.14±0.19 in unit A1 and 2.82±0.25 in B1.

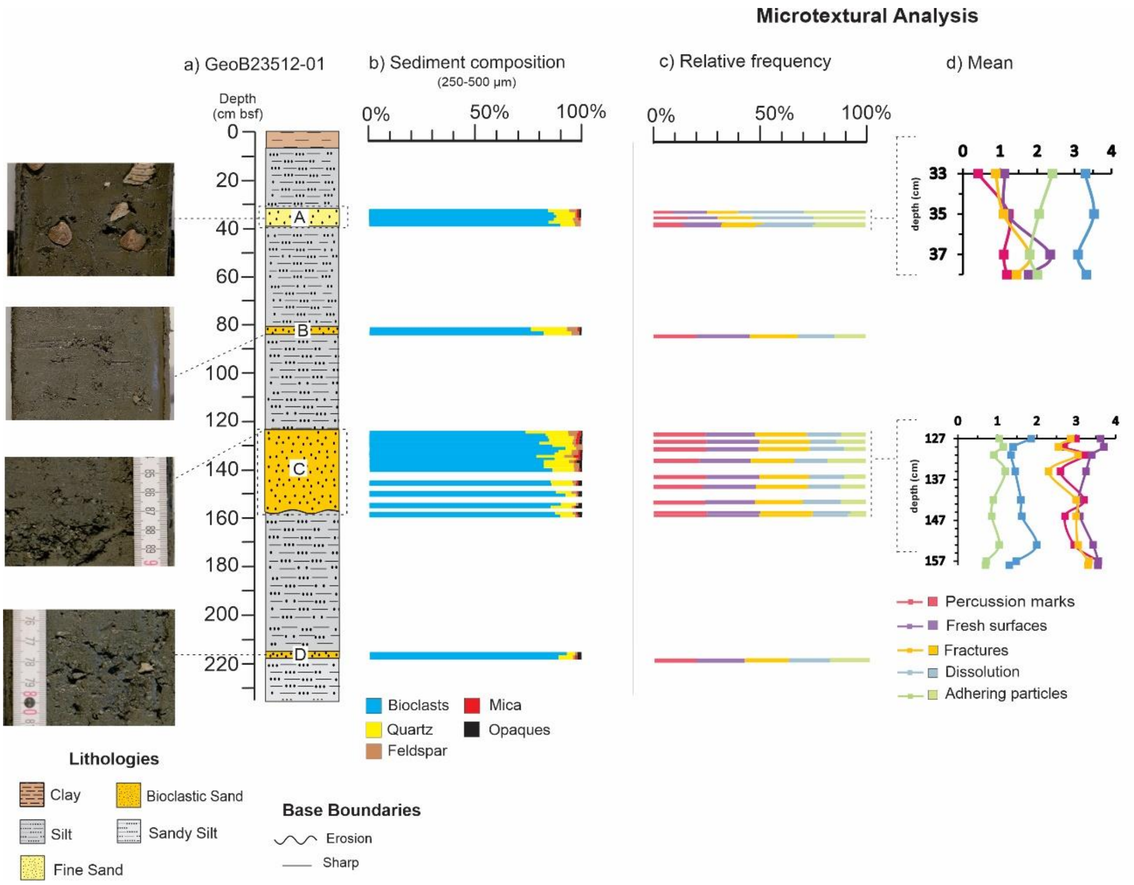
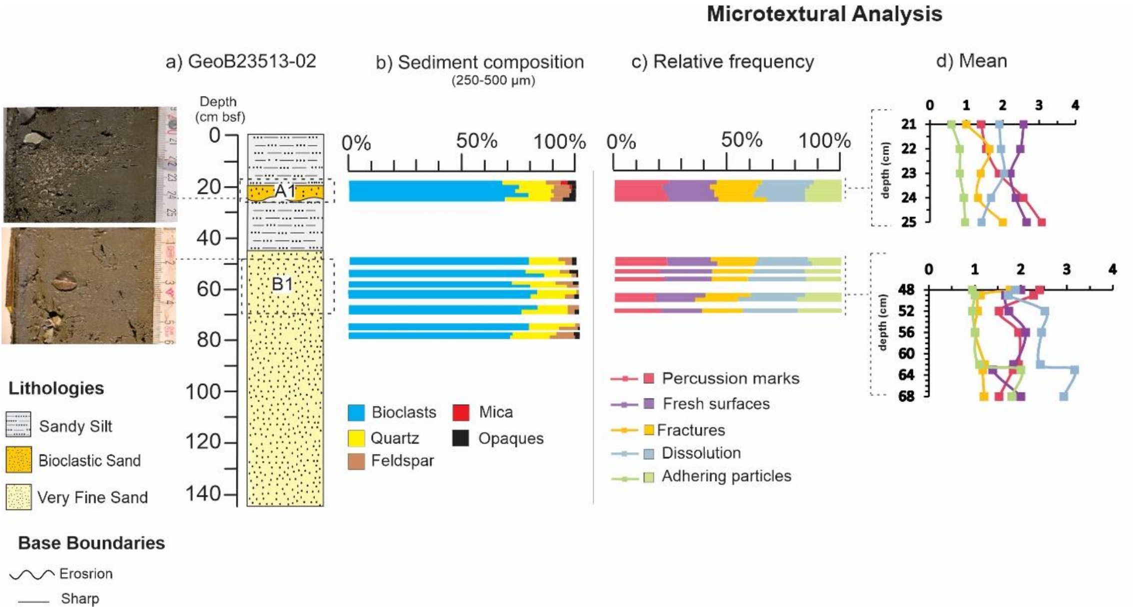


Figure 2: Results from sediment core GeoB23512-01, (a) – lithostratigraphic units; (b) –



morphoscopic (compositional) variation; (c) – microtextural relative frequency; (d) average values of the semi-quantitative microtextural classification on the microtextural feature dominance on the grain’s surfaces.

Figure 3: Results from sediment core GeoB23513-02, (a) – lithostratigraphic units; (b) – morphoscopic (compositional) variation; (c) – microtextural relative frequency; (d) average values of the semi-quantitative microtextural classification on the microtextural feature dominance on the grain’s surfaces.

4.3 Foraminifera analysis

A total of 846 SEM images of foraminifera individuals were analysed and 31 species. The foraminifera were retrieved from 32-34 cm bsf, 54-59 cm bsf, 62-66 cm bsf, and 74-78 cm bsf from GeoB23513-02, (Tab. 1; Appendix 4). Regarding abrasion, it was observed that 24% of the foraminiferal foreheads are unaltered, whereas the remaining 76% present some level of alteration (Fig. 4). Individuals showing fragmentation, breakage and abrasion marks were classified with physical alteration and those showing dissolution marks with removal of the forehead surface were classified with chemical alteration (Tab. 2).

The results show that the type and degree of alteration differs between the sandy and the silty layers. In the silty layer, between 32-34 cm bsf, it can be observed that dissolution occurs more aggressively, with a percentage of 64% (average 1.42), exhibiting from small alterations to almost total destruction of the specimens. On the other hand, the effect of physical alteration in this interval occurs in only 36% of foraminifera with mean values of 1.00.

In contrast, the intervals 54-59 cm bsf, 62-66 cm bsf and 74-78 cm bsf of unit B1, exhibit a slight predominance of foreheads worn by physical alteration, with very similar percentages, varying between 55% and 58% and with degrees of alteration between 1.11 - 1.31. The marks of alteration by dissolution are less abundant in this layer and the average values vary between 0.79 (54-59 cm bsf) and 1.10 (62-66 cm bsf).

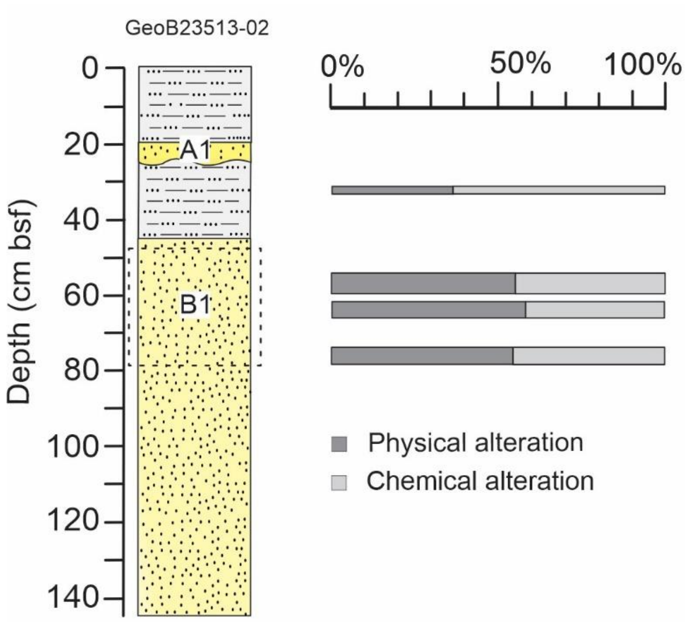


Figure 4 – Frequency of altered foraminifera tests.

Table 1 – Foraminifera species list observed in this work.

Amphycorina scalaris (Batch, 1791)	*Fissurina cf. lucida* (Williamson, 1848)
Bolivina ordinaria (Phleger & Parker, 1952)	*Fissurina orbignyana* (Seguenza 1862)
Bolivina pseudoplicata (Heron-Allen e Earland, 1930)	*Fissurina sp.*
Bolivina spathulata (Williamson 1858)	*Globigerina bulloides* (d'Orbigny, 1826)
Bolivina variabilis (Williamson, 1858)	*Globigerina falconensis* (Blow, 1959)
Bolivinellina pseudopunctata (Höglund, 1947)	*Neogloboquadrina dutertrei* (d'Orbigny, 1839)
Bolivinellina translucens (Phleger & Parker, 1951)	*Nonion fabum* (Fichtel & Moll, 1798)
Brizalina pseudopunctata (Höglund, 1947)	*Nonionella turgida* (Williamson, 1858)
Bulimina cf. B. alazanensis (Cushman, 1927)	*Quinqueloculina stalkeri* (Loeblich & Tappan 1953)
Bulimina gibba (Fornasini, 1902)	*Quinqueloculina stelligera* (Schlumberger, 1893)
Bulimina marginata (d'Orbigny, 1826)	*Rectuvigerina phlegeri* (Le Calvez, 1959)
Bulimina aculeata (d'Orbigny, 1826)	*Stainforthia complanata* (Egger, 1893)
Cribroelphidium gerthi (van Voorthuysen, 1957)	*Stainforthia feylingi* (Knudsen & Seidenkrantz 1994)
Discorbis parkeri (Natland, 1950)	*Valvulineria candeiana* (d'Orbigny, 1839)
Eilohedra vitrea (Parker, 1953)	*Valvulineria bradyana* (Fornasini, 1900)
Elphidium sp.	

Table 2 – Classification in the foraminifera tests surfaces abrasion. 0 – unaltered; 1 – poor alteration; 2 – moderated alteration; 3 – highly altered.

Depth (cm bsf)	Number of foraminifera	Physical alteration	Chemical alteration
32-34	154	1,00	1,42
54-59	299	1,11	0,79
62-66	211	1,22	1,10
74-78	182	1,31	1,00

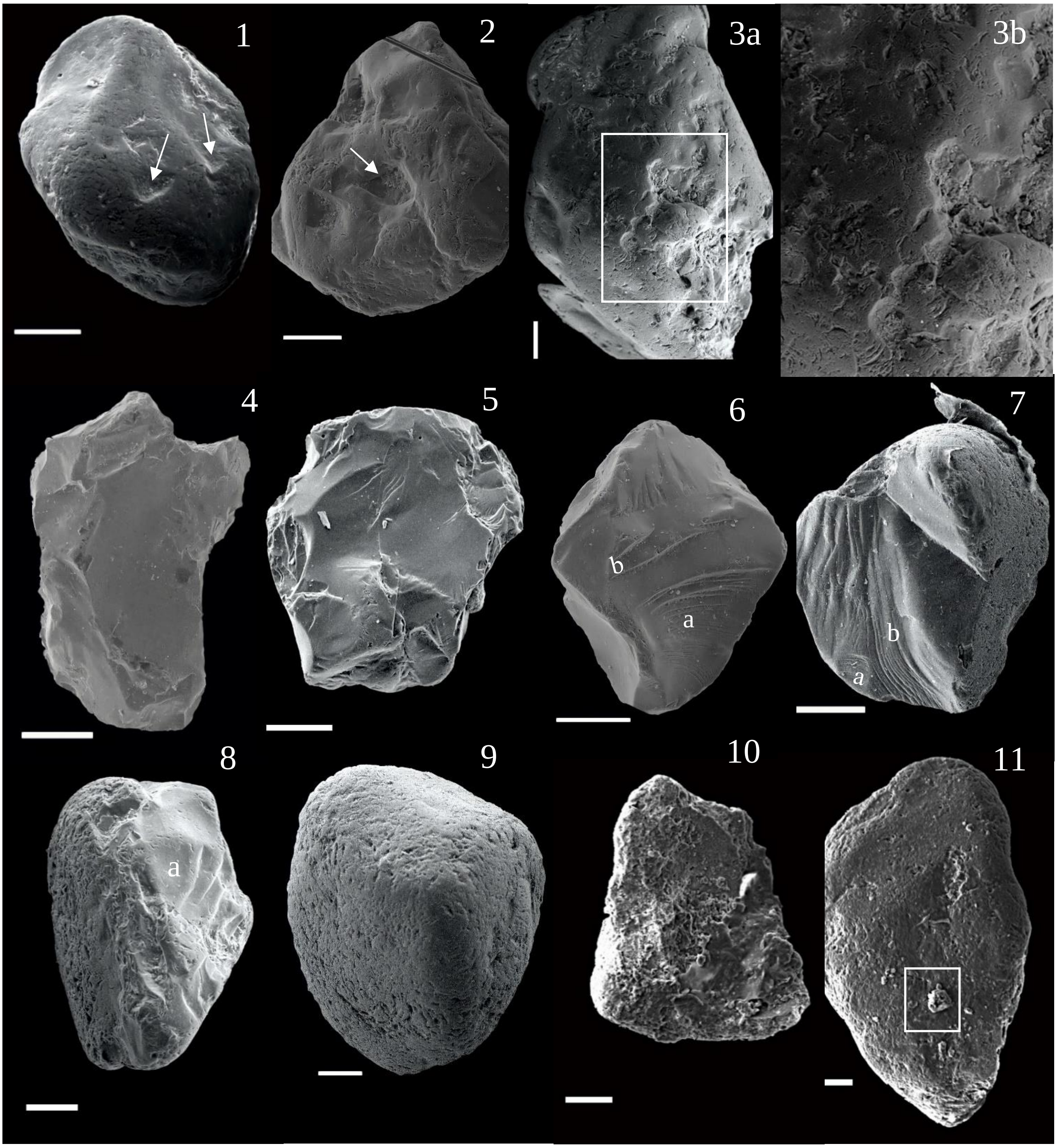


Figure 5: SEM quartz grains imagery with Scale bar: 100 µm. 1-3b: V-shaped percussion marks; 4-5: Fresh surfaces nearly totally resurfacing the grain; 6-7: grains with fresh surfaces: a) conchoidal fractures, (b) linear; 8: grain with strong dissolution but (a) presenting fractures; 9: grain with high degree of dissolution; 10-11grains where chemical features dominate – e.g. adhering particles in the grain's surface.

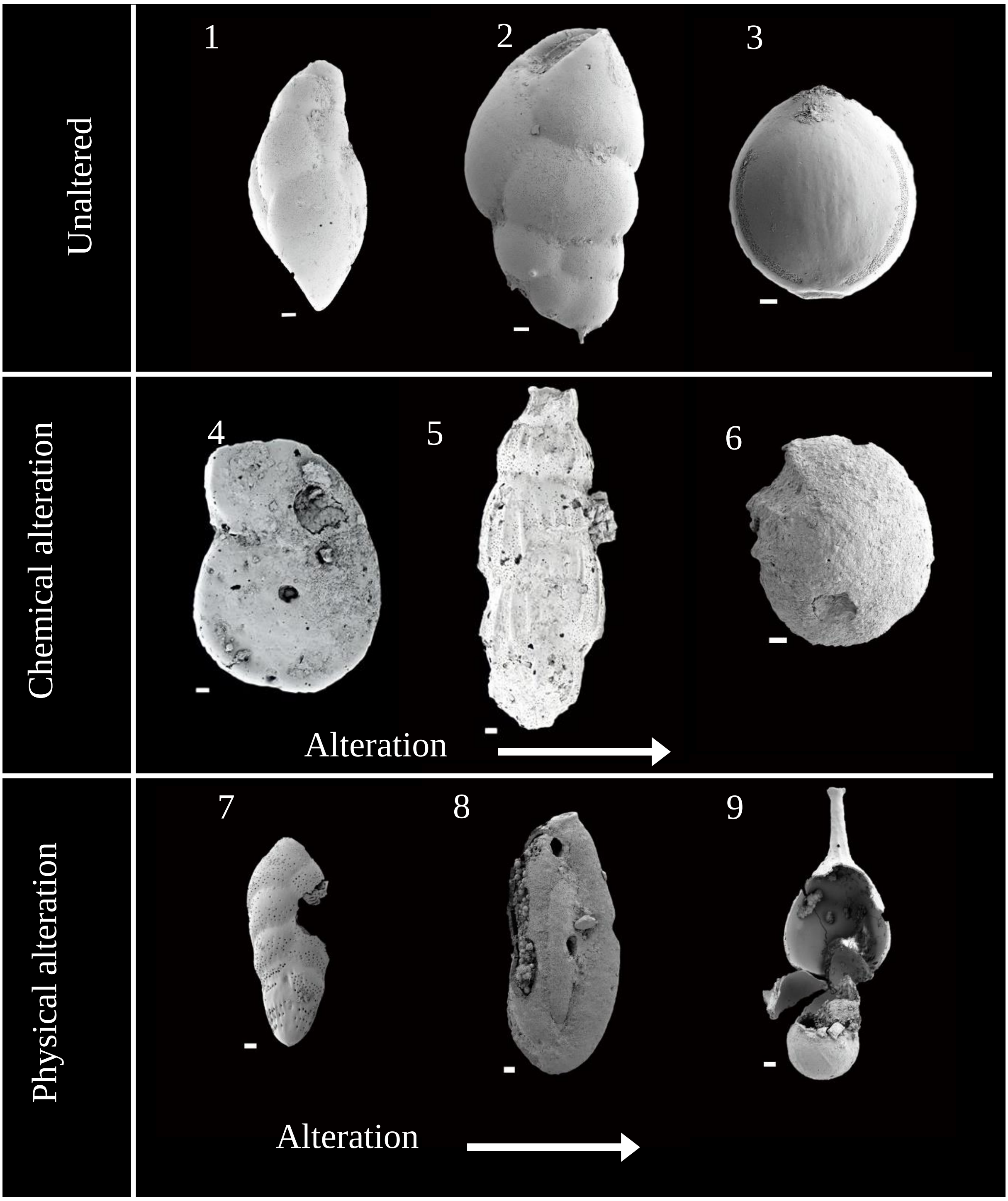


Figure 6: SEM imagery of foraminifera tests with scale bars of 10 μm. (1-3) Well-preserved species. (4-6) Tests chemically altered (arrow points for increasing degree of chemical alteration). (7-9) Images displaying degree of physical alteration. All are equal to.

DISCUSSION

5.1 Lithostratigraphic interpretation

The data obtained show that, at least, two high-energy events (likely tsunamis) were detected on the southern Portuguese mid-shelf, characterised by the sudden incursion of coarse material rich in shell fragments, which deposited units with thicknesses of approximately 5 and 30 cm (units A1 and C respectively) interrupting the low-energy sedimentation regime (Reicherter et al., 2019). According to Goff et al., (1999, 2000, 2010), richness in shell fragments is one of the attributes that can characterise tsunami deposits and is a good marker of the high-energy involved in sediment transport. The presence of the bioclastic sand layers therefore suggests that they were likely deposited under conditions of higher hydrodynamic energy.

The base between the high-energy deposits with the underlying layer shows a sharp erosional contact and indicates a high tensile force caused by (tsunami) flow incursion or backwash, reinforcing the genetic difference between both layers. Erosive surfaces were observed in deposits from the 1755 CE tsunami on the southern Portuguese coast and are commonly used to define the lower limit of deposits (e.g. Hindson and Andrade 1999; Kortekaas and Dawson 2007; Costa et al., 2012a; 2014b).

Tsunami effects in the offshore sector were addressed by Abrantes et al., (2008) in the Tagus delta, in the SSW stratigraphic record of the shallow shelf of Portugal, referring to the events of 1969 to 1755 CE. Also in the offshore sector of the SSW Iberian Margin, Gracia et al., (2010) recognized seven turbiditic events with erosive basis, linked to instrumental and historical earthquakes, tsunamis and paleotsunamis. In deeper waters, Thomson and Weaver (1993) associated the turbidite deposits of the Horseshoe and Tagus Abyssal Plains with the Lisbon earthquake of 1755 CE, based on accelerator mass spectrometer (AMS) radiocarbon dating of planktonic foraminifera. These works prove that the offshore sector has the potential to preserve evidence from high-energy events.

5.2 Microtextural Analysis

The results of microtextural analysis, in an offshore context, represent a challenge for the sedimentological interpretation. The microtextures evaluated in this study are summarised in Figure 5. High-energy deposits present intrinsic peculiarities that are sensitive to their depositional environment. This is clear when comparing the data obtained from sediment cores GeoB23512-01 and GeoB23513-02. Considering GeoB23512-01, it is notable that the quartz grains of unit A (33-38 cm bsf), present contrasting microtextural characteristics with units B, C and D (81 cm bsf; 127-158 cm and 218 cm bsf), considered as syn-event deposits.

In unit A, the high occurrence of chemical marks over mechanical marks is observed in the quartz grains. The high proportion of these features is attributed to post-depositional changes, such as diagenetic processes or bioturbation. It has been described that low- energy environments are more susceptible to chemical weathering (Mahaney, 2002; Vos et al., 2014). The abundance of adherent particles in these grains also justifies diagenetic traces (Mahaney, 2002). Furthermore, the high mean value for its presence on the surface of grains suggests a calm and long residence time in the environment, which would be possible in a low-energy marine depositional environment.

In contrast, units B, C and D present higher values of mechanical marks, indicating stronger hydrodynamic processes during deposition (Mahaney, 2002). The increase of percussion marks is promoted by erosion and incorporation of sediments during the initial phase of tsunami backwash. According to Costa et al., (2012a) this feature is linked to the high concentration of sediments in the water column, favouring intensive contact between grains. This justifies the maximum mean values found at 157-158 cm bsf, at the base of unit C. Moreover, this scenario promotes the highest fracturing of the grains at these levels (157-158 cm bsf) as fractures are related to strong impacts on the grain surface (Vos et al., 2014), whose incision size reflects the energy associated with their formation (Higgs, 1979; Mahaney, 2002).

The presence of fresh surfaces on the quartz grains of units B, C and D in GeoB23512-01 corroborates strong hydrodynamic processes immediately prior or during deposition. Their occurrence results from violent collisions, to the point of subtracting large percentages of the grain surface generating fractures and fresh surfaces. According to Costa et al., (2012a) the low concentration of sediments in the water column should favour the increase of these features, because the particles would have more space in the aqueous medium and thus, the impact velocity would be higher and more energetic (higher kinetic energy). The highest mean values of fresh surfaces were detected at the top of unit C, between 127-129 cm bsf. The lower sediment concentration at the top of the deposit can probably result from the last backwash phase (before settling of the fine sediments), as erosion and remobilization of sandy sediments were intensely caused by the previous waves. A slight increase of mica grains at the top of the deposit, between 127-131 cm bsf, reinforces this reasoning and might attest as the product of the final backwash phase. This is because the properties of these minerals (its density and habit) give them more buoyancy in the water column, being deposited, in lower energetic conditions.

These observations coincide with results from other tsunami deposits, located in the onshore sector of Portugal (e.g Martinhal, Boca do Rio and Salgados), Scotland (Hebrides Islands, Shetland Islands) and Indonesia (Lhok Nay Bay) (Costa et al., 2012a). The authors point out that the Portuguese deposits present as characteristic the high value of percussion marks and fresh surfaces, while in the other deposits only display the increase of fresh surfaces was verified. This is due to the presence of an extra source of sediment (dunes) that raises the concentration of particles in the water column, thus causing more impacts between grains, however, impacts with less kinetic energy involved since the grains would have less space to gain velocity (Costa et al., 2012a). According to Mahaney et al., (2010) tsunamis are able to rework quartz grains, causing even complete resurfacing like no other sedimentary system, within such a short time interval.

Regarding the average degree of roundness, this characteristic was not significantly different among the grains analysed from both sediment cores. In the bioclastic sand layers (units B, C, D and A1) the grains are sub-angular, while in the fine and very fine sand layers (respectively A and B2) the average values correspond to grains between sub-angular and sub-rounded. It is considered that the brief duration of the event did not generate more notable changes in the grain shape. Costa et al., (2017) point out that roundness is more a long-term feature, thus it is a feature that requires more time to produce more striking changes.

Regarding the microtextural results obtained from GeoB23513-02, it is noted that the contrasts between the mechanical and chemical attributes are not statistically significant between unit A1 (21-25 cm bsf) and B1 (48-68 cm bsf). This is due to the occurrence of dissolution marks on the grains in unit A1. It is worth noting that at the base of unit A1 fresh surfaces and percussion marks exhibit an increase, whereas at the top fresh surfaces occur with higher average values than the other attributes. Similarly, the same reasoning can be applied to units B, C and D of core GeoB23512-01, and one can infer that the concentration of sediments in the water column influences the generation and intensity of mechanical microtextures (Costa et al., 2012a). Regarding quartz grains of unit B1, the mechanical marks occur discretely, without very contrasting mean values, as observed in the very fine sand layer of unit A (33-38 cm bsf) of GeoB23512-01. On the other hand, the dissolution is the most expressive attribute on these grains.

The processes responsible for producing chemical features and mechanical impact marks do not share similarities (Mahaney, 2002; Costa et al., 2012a; Vos et al., 2014). Therefore, it is considered that the dissolution features on the grains in units A1 and B1 of GeoB23513-02 are related with post-depositional changes or poor resurfacing (predominance of source sediment features). There are paleodunes, submerged at around 40 m water depth, according to the continental shelf surface sediment chart (Hydrographic Institute, 2009). Dunes have been commonly described with strong dissolution features (Mahaney, 2002; Costa et al., 2012a; Vos et al., 2014). Thus, it is possible that the quartz grains analysed already held chemical imprints which supports the lack of microtextural heterogeneity in core GeoB23513-02. Difficulties in recognising microtextural signatures related to tsunami events were reported in Kümmerer et al., (2020), who investigated sediments from the 1755 CE tsunami on the southern Portuguese continental shelf, the in the vicinity of Faro. The authors detected only a small increase in percussion marks, and that a possible change in general sedimentation after the 1755 CE event may have influenced the signature in the outer shelf sedimentary record.

The compositional analysis of only particles of the 250-500 µm fraction, somewhat limits reaching more conclusive interpretations. However, It indicates the compositional elements that can be related to higher hydrodynamics. Although the biogenic elements dominate in more than 70% of the samples from both cores, it is noteworthy that there are levels in the bioclastic sand layers (units B, C, D and A1) where there is an increase in the percentage of quartz grains (Fig. 2 and 3; Appendix 1). This may indicate changes in hydrodynamics that are reflected on the composition of the sediments, Hindson and Andrade (1999) stated that the transport carried out by tsunami waves involves a greater volume of terrigenous sediments or coastal palaeocoastlines, usually from the erosion of beach sands and dunes, which justifies the (slight) increase of terrigenous materials conducted in these deposits. Therefore, the incorporation of quartz grains in the water column induces higher mechanical stress during collisions, since these materials have higher density than the biogenic elements, which is translated by the formation of higher number of mechanical microtextures.

Another important factor that argues for the microtextural differentiation exhibited in the samples analysed in this study, is the configuration of the local bathymetry and its geomorphic setting. Turbulent backwash flows return to the sea causing erosion and re-deposition of sediments with velocities influenced by the submarine topography (Dawson and Stewart, 2007; Sugawara et al., 2008). In this study, although the horizontal distance between the two coring sites is around 5.3 km, GeoB23512-01 is located in the vicinity of the Portimão canyon, which causes an 8 km-long incision in the shelf (Dias, 1987). This pronounced structure may act as an "outlet" through which flow transports and deposits sediments. This would mean, a strong backwash current concentrated at the topographic lows and with higher velocities. From a hydrodynamic point of view, the flow velocity is directly related to the depth of the water column, calculated using the formula $v=\sqrt{gh}$, in which g is the acceleration of gravity and h is the depth (Barman, 2020). Thus the wave travels faster in deeper areas than in a shallower area. For this reason, the energy of the backwash flow on the Portimão canyon and its vicinity played a determining role in the higher degree of sediment reworking, having a direct effect on the final configuration of the deposit and justifying the microtextural and compositional lateral variation observed between the two sediment cores studied. This reasoning, supports the presence of more mechanical marks in GeoB23512-01 than in GeoB23513-02.

Recognising microtextural signatures in tsunami deposits in the offshore context is not a simple task, as it is a dynamic environment open to processes that impair the preservation of these features. However, we proved that through the application of this technique, we were able to distinguish signatures that allow identifying high hydrodynamic processes, such as tsunami backwash, mainly in the GeoB23512-01 core. Despite the challenges in establishing a vertical trend along the tsunami deposit of GeoB23513-02 (due to the strong presence of dissolution), it is possible to detect at the base and top of A1 deposit (21-25 cm bsf) an increase in mechanical marks, especially, fresh surfaces. Many local factors can influence the formation of such features, such as the energy of the event, the source and sediment concentration, and also post-depositional processes, as already reported here. Furthermore, it is observed that the sedimentary composition plays an important role in the formation of microtextural signatures.

5.3 Foraminifera taphonomy

Preservation and taphonomic features in foraminiferal tests can reveal information of tsunami flow velocity, sediment concentration, abrasion and post-depositional environmental processes (Mamo et al., 2009). This translated in terms of the nature and severity of abrasion and in the disarticulation that a tests has experienced (Mamo et al., 2009). Thus, the surface condition of these individuals may aid in distinguishing between materials deposited in syn-event layers compared to the adjacent units. In this study we evaluated the taphonomic features from SEM images of foraminifera to decipher the inundation and backwash events.

According to Kotler et al., (1992) low-energy environments favour high deposition of organic matter in the sediment which can favour boring fauna to rework the organic matter, producing acid-saturated microenvironments that lower the pH of the water, triggering chemically altered shells (Cottey and Hallock, 1988; Murray, 1989; Walter and Burton, 1990). This scenario may account for the occurrence and degree of dissolution (Fig. 6: 4,5 and 6) observed in tests from the silty layer (32-34 cm bsf) of GeoB23513-02.

In unit B1 (54-59 cm bsf, 62-66 cm bsf and 74-78 cm bsf), a combination of physical and chemical processes occurs with a slight predominance of physical alteration marks, some of them often of difficult recognition (Fig. 06: 7,8 and 9). The occurrence of physical alteration marks can be attributed to an increase in the energy of the environment. Therefore, providing deposition of particles in the very fine sand fraction, in contrast to the overlying low-energy silty layer. However, the resulting transport energy was not sufficient to generate more intense abrasion and fragmentation, possibly because in these very fine sand layer there is a dominance of bioclastic components in about 80% of the sedimentary composition. Moreover, the reworking of foraminifera tests did not seem to have caused the effective mechanical wear during transport. The experiments by Martin and Liddell, (1991) prove that even in high-energy environments, the foraminifera tests are not totally altered by abrasion caused by friction with carbonate sediments. However, in mixed and siliciclastic environments the taphonomic changes may be more marked, consequently, the composition is a factor which directly influences the degree of physical abrasion on foraminifera.

Moreover, the species identified in this study are from the middle to outer shelf. It is interpreted that these individuals did not undergo relevant reworking triggered by the phase tsunami inundation and backwash flows. Briguglio and Hohenegger (2011) attest that the poor preservation of foraminifera shells by abrasion, is a consequence of transport processes. In turn Quintela et al., (2016) verified the presence of broken/altered marine species, however, in onshore deposits as a product of the highly energetic transport of the initial tsunami inundation phase along which the foraminifera were transported until their subsequent deposition on land.

Overall, the use of foraminiferal taphonomy to make inferences on tsunami deposits is still a challenge, as many factors influence the taphonomic character, inducing a lack of contrast between event sediments with pre- and post-event layers. Yawsangratt et al., (2012) reported that the marine foraminiferal assemblage from the 2004 tsunami deposits on Kho Khao Island, Thailand were partially or completely dissolved, only five years after the Indian Ocean tsunami. Satyanarayana et al., (2007) reported the lack of fragmented foraminifera in the deposit of the same tsunami in 2004 in India. Similarly, Pilarczyk et al., (2011) examined foraminiferal taphonomy in a lagoon located in Sur, (Oman) to distinguish a unit from the 1945 CE tsunami, however, the overall taphonomic character was not significantly different from the pre- and post-event units due to little or no occurrence of fragmented specimens during the event.

In this work, it is emphasized that the microtextural characteristics of the quartz grains of the very fine sand layer (unit B1 of GeoB23513-02) are interpreted as a characteristic inherited from the sedimentary source, or even, a result of post-depositional changes, as carved in the grains by the abundance and degree of dissolution marks. In fact, bioturbation imprints are present in this unit and have the capability to trigger the occurrence of dissolution in foraminifera test (Walter and Burton, 1990; Parsons and Brett, 1991; Kotler et al., 1992). This can help to cover-up mechanical marks previously imprinted.

In summary, although many studies highlight the ability of foraminiferal taphonomy in tsunami deposits studies, the results obtained in this work show that this technique was not entirely able to discriminate marine inundation deposits through the sedimentary record of GeoB23513-02 because of the simultaneous occurrence of physical and chemical alteration marks within the sandy units. For this reason, foraminiferal taphonomy should be better applied in the context of multiproxy approaches to allow for more consistent interpretations and not as a stand-alone toll. In order to synthesise the hydrodynamic processes discussed in this paper, a conceptual scheme of the inundation and backwash stages and their effects on the offshore and onshore sedimentary record is presented in Figure 7.

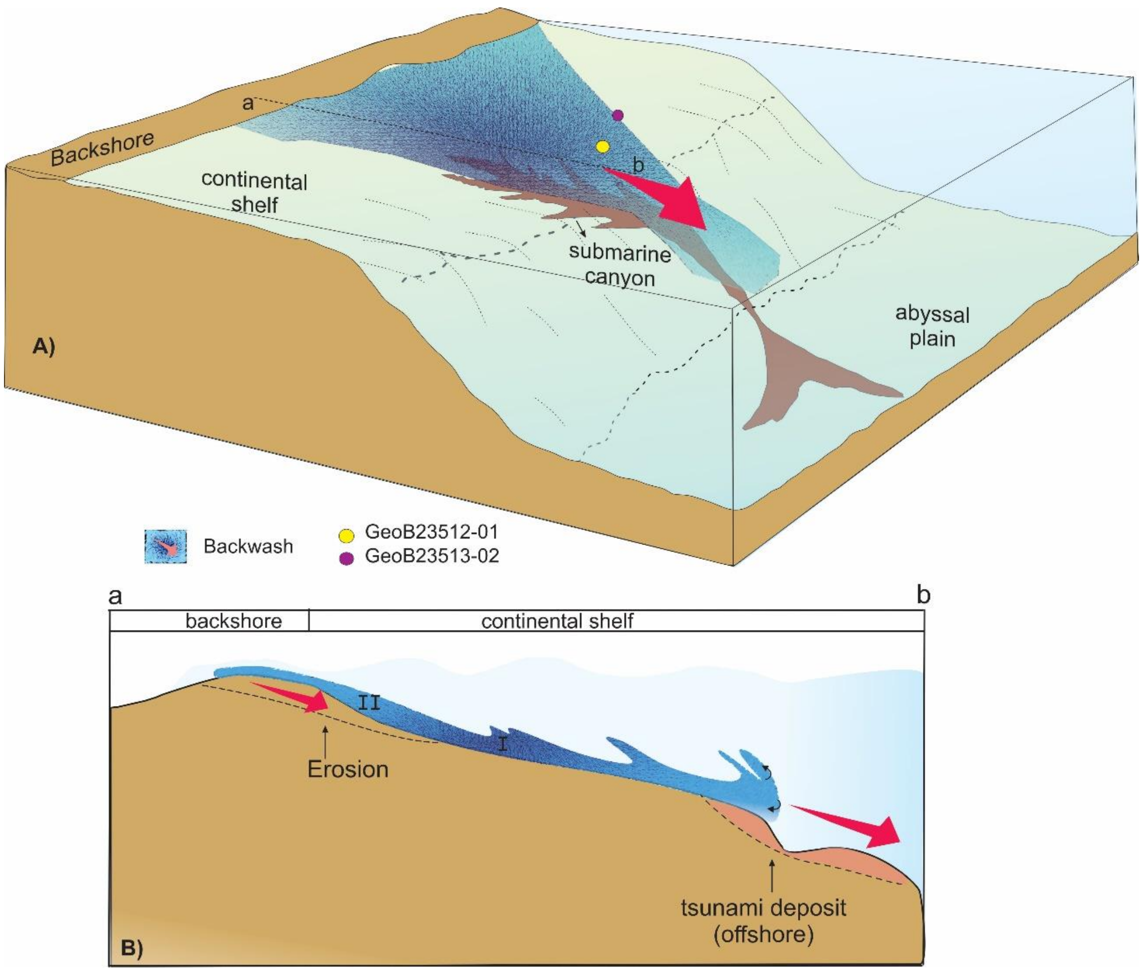


Figure 07: Conceptual model of backwash dynamics: A) Diagram illustrating approximately the position of the cores in relation to the Portimao canyon. The backwash flow concentrated in the canyon reaches higher velocities as the depth increases. As the energy is proportional to the velocity, the flow channeled by the Portimão canyon promotes more generation of mechanical marks on the quartz grains, which is observed in the GeoB23512-01 sounding. B) Schematic profile a-b, backwash transports high density offshore flows this can lead to more offshore erosion and reinsertion; (I) High concentration of sediments carried by erosion favors the formation of fractures and percussion marks. (II) The low concentration of sediment in the water column generates more energetic collisions and fresh surfaces in the grains.

CONCLUSION

In this work two sediment cores obtained in from the Algarve shelf (Portugal) were studied. Based on the lithostratigraphic characteristics, at least two significant sandy layers (C and A1) contrasting in lithostratigraphy and with abundant bioclastic fragments were identified. These layers, whose basal contact is erosive and abrupt with the underlying layer, were interpreted as the result of a high hydrodynamic flow from the coast towards the sea caused by tsunami backwashes.

From the microtextural analysis, it was established that one of the cores (GeoB23512-01) recorded higher frequency and degree of mechanical marks in tsunami deposit layers. This abundance, also previously noted in other tsunami deposits along the Algarve coast, indicates that these features were carved in a high-energy hydrodynamic environment, capable of imprinting new microtextures on the grains. On the other hand, GeoB23513-02, despite showing high values of mechanical action at the base of the tsunami deposit (unit A1), displays little microtextural contrast with the lower unit (B1) namely due to stronger presence of dissolution on the grains deposited by the tsunami. It is highly likely that the local bathymetry and geomorphic setting plays an important role in the impression of microtextures, as the turbulent backwash flow was more intensively channelled through the Portimao canyon which led to higher flow velocities thus, promoted the generation of mechanical marks. This scenario justifies the microtextural differences between the two sediment cores, as GeoB23512-01 is located more adjacent to the Portimão canyon. Furthermore, post-depositional changes and original sediment source features, can help explain the occurrence of dissolution in units A1 and B1, therefore, the lack of microtextural heterogeneity in GeoB23513-02.

Sediment composition also played a role on the generation of microtextures. This is likely because, prior to deposition layers richer in quartz were eroded and enriched the tsunami layers with a slight addition of quartz grains. This is shown to be sufficient to intensify the mechanical shock between the grains, since these elements have the same density which contrast on bioclast-rich units that imprint fewer mechanical marks on quartz grains.

The use of foraminifera taphonomy, through its analysis using SEM images, evidenced that in the silty layer shells seem essentially altered by dissolution. On the other hand, in the sandy units there is a slight increase on the tests abrasion, despite that the occurrence of dissolution is still noted. The sole presence of marine foraminifera (middle to outer shelf) in the sandy units attests that there was little time for reworking. Therefore, foraminifera microtextural signatures seems to be partially controlled by coarser grain-sizes which can increase abrasion fatigue on the foraminifera tests. Finally, for a better understanding of the dynamics of tsunami depositional processes it will be important to increase the horizontal and spatial resolution of the analysis performed in this study, to obtain a stronger statistical and geographic representation of tsunami event dynamic.

ACKNOWLEDGEMENTS

The authors thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the financial support for the scholarship granted. We also express our thanks to

Professor Luiz C. Bertolino for the technical support during the SEM microscopy at the facilities of CETEM. Likewise, we want to acknowledge the SEM utilization (DEPA, UERJ), under the responsibility of Sérgio Bergamaschi. The authors are deeply grateful to the research and technical crew under the command of Captain R. Hammacher from RV METEOR – M152. Fundação para a Ciência e Tecnologia (FCT) is acknowledged for its funding of project OnOff PTDC/CTAGEO/28941/2017.

REFERENCES

Abrantes, F., Alt-Epping, U., Lebreiro, S., Voelker, A., & Schneider, R. (2008). Sedimentological record of tsunamis on shallow-shelf areas: The case of the 1969 AD and 1755 AD tsunamis on the Portuguese Shelf off Lisbon. *Marine Geology*, 249(3-4), 283–293. https://doi.org/10.1016/j.margeo.2007.12.004

Andrade, C., (1990). O ambiente de barreira da Ria Formosa (Algarve, Portugal). Dissertação apresentada à Universidade de Lisboa para obtenção do grau de Doutor em Geologia, na especialidade de Geologia do Ambiente, Departamento Geologia da Faculdade de Ciências da Universidade de Lisboa, Lisboa, 645 p.

Andrade, C., (1992). Tsunami Generated forms in the Algarve Barrier Islands (South Portugal). Sci. Tsunami Haz. 10, 21–34

Armstrong, H. A., & Brasier, M. D. (2009). Microfossils. Blackwell.

Bahlburg, H., & Weiss, R. (2006). Sedimentology of the December 26, 2004, Sumatra tsunami deposits in eastern India (Tamil Nadu) and Kenya. *International Journal of Earth Sciences*, 96(6), 1195–1209. https://doi.org/10.1007/s00531-006-0148-9

Baptista, M. A., & Miranda, J. M. (2009). Revision of the Portuguese catalog of tsunamis. *Natural Hazards and Earth System Sciences*, 9(1), 25–42. https://doi.org/10.5194/nhess-9-25-2009

Barman, S. K. (2020). Physics of Tsunami: Generation, Propagation and Rise of the Ocean. *International Journal of Oceans and Oceanography*, *14*(1), 169. https://doi.org/10.37622/ijoo/14.1.2020.169-182

Bellanova, P., Bahlburg, H., Nentwig, V., & Spiske, M. (2016). Microtextural analysis of quartz grains of tsunami and non-tsunami deposits – A case study from Tirúa (Chile). *Sedimentary Geology*, 343, 72–84. https://doi.org/10.1016/j.sedgeo.2016.08.001

Briguglio, A., & Hohenegger, J. (2011). How to react to shallow water hydrodynamics: The larger benthic foraminifera solution. *Marine Micropaleontology*, *81*(1-2), 63–76. https://doi.org/10.1016/j.marmicro.2011.07.004

Boltovskoy, E., Giussani, G., Watanabe, S., Wright, R., 1980. Atlas of benthic shelf foraminifera of the Southwest Atlantic. Dr. W. Junk b.v., Publishers, The Hague, 147 pp., pl. 36.

Candella, R. N. (2014). Statistical and spectral characteristics os the 2011 east Japan tsunami signal in Arraial do Cabo, RJ, Brazil. *Revista Brasileira de Geofísica*, 32(2), 235. https://doi.org/10.22564/rbgf.v32i2.480

Candella, R.N., Rabinovich, A.B., Thomson, R.E., 2008. The 2004 Sumatra tsunami as recorded on the Atlantic coast of South America. *Advances in Geosciences*. 14, 117–128. https://doi.org/10.5194/adgeo-14-117-2008

Chagué-Goff, C., Schneider, J.-L., Goff, J. R., Dominey-Howes, D., & Strotz, L. (2011). Expanding the proxy toolkit to help identify past events — Lessons from the 2004 Indian

Ocean Tsunami and the 2009 South Pacific Tsunami. *Earth-Science Reviews*, 107(1-2), 107–122. https://doi.org/10.1016/j.earscirev.2011.03.007

Costa, M., Silva, R., & Vitorino, J. (2001). Contribuição para o estudo do clima de agitação marítima na costa portuguesa. *2ª Jornadas Portuguesas de Engenharia Costeira e Portuária*, 20.

Costa, P. J. M., Andrade, C., & Freitas, M. D. C. (2014a). Assinaturas microtexturais de processos, ambientes e fontes sedimentares. O depósito de tsunami de 1755 na Boca do Rio- um caso de estudo. Proveniência de materiais geológicos: abordagens sobre o Quaternário de Portugal, 37-56.

Costa, P. J. M., Andrade, C., & Freitas, M. D. C. (2014b). Análise microtextural: princípios, procedimentos e caracterização micromorfológica de grãos de quartzo. Proveniência de materiais geológicos: abordagens sobre o Quaternário de Portugal, 19-36.

Costa, P. J. M., Andrade, C., Dawson, A. G., Mahaney, W. C., Freitas, M. C., Paris, R., & Taborda, R. (2012a). Microtextural characteristics of quartz grains transported and deposited by tsunamis and storms. *Sedimentary Geology*, 275-276, 55–69. https://doi.org/10.1016/j.sedgeo.2012.07.013

Costa, P. J. M., Andrade, C., Freitas, M. D. C., Oliveira, M. A., & Jouanneau, J. M. (2009). Preliminary results of exoscopic analysis of quartz grains deposited by a palaeotsunami in Salgados lowland (Algarve, Portugal). *Journal of Coastal Research*, 39-43.

Costa, P. J. M., Andrade, C., Freitas, M., Oliveira, M., Lopes, V., Dawson, A., … Jouanneau, J-M. (2012b). A tsunami record in the sedimentary archive of the central Algarve coast, Portugal: Characterizing sediment, reconstructing sources and inundation paths. *The Holocene*, 22(8), 899–914. https://doi.org/10.1177/0959683611434227

Costa, P. J. M., Dawson, S., Ramalho, R. S., Engel, M., Dourado, F., Bosnic, I., & Andrade, C. (2021). A review on onshore tsunami deposits along the Atlantic coasts. *Earth-Science Reviews*, 212, 103441. https://doi.org/10.1016/j.earscirev.2020.103441

Costa, P. J. M., Gelfenbaum, G., Dawson, S., La Selle, S., Milne, F., Cascalho, J., Lira, C.P., Andrade, C., Freitas, M.C. and Jaffe, B. (2017). The application of microtextural and heavy mineral analysis to discriminate between storm and tsunami deposits. Geological Society, London, Special Publications, 456(1), pp.167–190. doi:10.1144/sp456.7.

Cottey, T. L., & Hallock, P. (1988). Test surface degradation in Archaias angulatus. *The Journal of Foraminiferal Research*, *18*(3), 187–202. https://doi.org/10.2113/gsjfr.18.3.187

Dawson, A. G., Hindson, R., Andrade, C., Freitas, C., Parish, R., & Bateman, M. (1995). Tsunami sedimentation associated with the Lisbon earthquake of 1 November AD 1755: Boca do Rio, Algarve, Portugal. *The Holocene*, 5(2), 209–215. https://doi.org/10.1177/095968369500500208

Dias, J. M. A. Dinâmica sedimentar e evolução recente da plataforma continental portuguesa setentrional. 1987, p.384, Dissertação de doutorado, Faculdade de Ciências, Lisboa, 1987.

Doornkamp, J. C., & Krinsley, D. (1971). ELECTRON MICROSCOPY APPLIED TO QUARTZ GRAINS FROM A TROPICAL ENVIRONMENT. *Sedimentology*, 17(1-2), 89–101. https://doi.org/10.1111/j.1365-3091.1971.tb01133.x

Duarte, J. C., Rosas, F. M., Terrinha, P., Schellart, W. P., Boutelier, D., Gutscher, M.-A., & Ribeiro, A. (2013). Are subduction zones invading the Atlantic? Evidence from the southwest Iberia margin. *Geology*, 41(8), 839–842. https://doi.org/10.1130/G34100.1

Einsele, G., Chough, S. K., & Shiki, T. (1996). Depositional events and their records—an introduction. *Sedimentary Geology*, 104(1-4), 1–9. https://doi.org/10.1016/0037-0738(95)00117-4

Fatela, F., & Taborda, R. (2002). Confidence limits of species proportions in microfossil assemblages. *Marine Micropaleontology*, 45 (2), 169-174. https://doi.org/10.1016/s0377-8398(02)00021-x

Feist, L., Frank, S., Bellanova, P., Laermanns, H., Cämmerer, C., Mathes-Schmidt, M., Biermanns, P., Brill, D., Costa, P. J. M., Teichner, F., Brückner, H., Schwarzbauer, J., & Reicherter, K. (2019). The sedimentological and environmental footprint of extreme wave events in Boca do Rio, Algarve coast, Portugal. *Sedimentary Geology*, 389, 147–160. https://doi.org/10.1016/j.sedgeo.2019.06.004

Fujiwara, O., & Tanigawa, K. (2014). Bedforms record the flow conditions of the 2011 Tohoku-Oki tsunami on the Sendai Plain, northeast *Japan. Marine Geology*, 358, 79–88. https://doi.org/10.1016/j.margeo.2014.04.013

Fujiwara, O., Sawai, Y., Shishikura, M., & Namegaya, Y. (2012). Sedimentary features of the 2011 Tohoku earthquake tsunami deposits on the central Kujukuri coast, east Japan. *The Quaternary Research* (Daiyonki-Kenkyu), 51(2), 117–126. https://doi.org/10.4116/jaqua.51.117

Goff, J. R., Crozier, M., Sutherland, V., Cochran, U., & Shane, P. (1999). Possible tsunami deposits from the 1855 earthquake, North Island, New Zealand. Geological Society, London, Special Publications, 146(1), 353–374. https://doi.org/10.1144/gsl.sp.1999.146.01.21

Goff, J. R., Rouse, H. L., Jones, S. L., Hayward, B. W., Cochran, U., McLea, W., … Morley, M. S. (2000). Evidence for an earthquake and tsunami about 3100–3400 yr ago, and other catastrophic saltwater inundations recorded in a coastal lagoon, New Zealand. *Marine Geology*, 170(1-2), 231–249. https://doi.org/10.1016/s0025-3227(00)00076-1

Goff, J., Pearce, S., Nichol, S. L., Chagué-Goff, C., Horrocks, M., & Strotz, L. (2010). Multi-proxy records of regionally-sourced tsunamis, New Zealand. *Geomorphology*, 118(3-4), 369–382. https://doi.org/10.1016/j.geomorph.2010.02.005

Gràcia, E., Vizcaino, A., Escutia, C., Asioli, A., Rodés, Á., Pallàs, R., Garcia-Orellana, J., Lebreiro, S., & Goldfinger, C. (2010). Holocene earthquake record offshore Portugal (SW Iberia): testing turbidite paleoseismology in a slow-convergence margin. Quaternary Science Reviews, 29(9-10), 1156–1172. https://doi.org/10.1016/j.quascirev.2010.01.010

Hawkes, A. D., Bird, M., Cowie, S., Grundy-Warr, C., Horton, B. P., Shau Hwai, A. T., … Aik, L. W. (2007). Sediments deposited by the 2004 Indian Ocean Tsunami along the

Malaysia–Thailand Peninsula. *Marine Geology*, 242(1-3), 169–190. https://doi.org/10.1016/j.margeo.2007.02.017

Hindson, R. A., & Andrade, C. (1999). Sedimentation and hydrodynamic processes associated with the tsunami generated by the 1755 Lisbon earthquake. *Quaternary International*, 56(1), 27–38. https://doi.org/10.1016/s1040-6182(98)00014-7

Hindson, R. A., Andrade, C., & Dawson, A. G. (1996). Sedimentary processes associated with the tsunami generated by the 1755 Lisbon earthquake on the Algarve coast, Portugal. *Physics and Chemistry of the Earth*, 21(1-2), 57–63. https://doi.org/10.1016/s0079-1946(97)00010-4

Hori, K., Kuzumoto, R., Hirouchi, D., Umitsu, M., Janjirawuttikul, N., & Patanakanog, B. (2007). Horizontal and vertical variation of 2004 Indian tsunami deposits: An example of two transects along the western coast of Thailand. *Marine Geology*, 239(3-4), 163–172. https://doi.org/10.1016/j.margeo.2007.01.005

Instituto Hidrográfico (2009). Carta dos Sedimentos Superficiais da Plataforma Continental – Cabo São Vicente ao Rio Guadiana, Folha SED 7 e 8, Escala 1: 50 000, 2a edição, Lisboa, Portugal.

Kennett, J. P., & Srinivasan, M. S. (1983). Neogene planktonic Foraminifera: a phylogenetic atlas. Hutchinson Ross.

Kortekaas, S., & Dawson, A. G. (2007). Distinguishing tsunami and storm deposits: An example from Martinhal, SW Portugal. *Sedimentary Geology*, 200(3-4), 208–221. https://doi.org/10.1016/j.sedgeo.2007.01.004

Kotler, E., Martin, R. E., & Liddell, W. D. (1992). Experimental Analysis of Abrasion and Dissolution Resistance of Modern Reef-Dwelling Foraminifera: Implications for the Preservation of Biogenic Carbonate. *PALAIOS*, 7(3), 244. https://doi.org/10.2307/3514972

Krinsley, D. H., & John Charles Doornkamp. (1973). Atlas of quartz sand surface textures [by] David H. Krinsley [and] John C. Doornkamp. Cambridge [England] University Press. 91 pp.

Krinsley, D., & Margolis, S. (1969). SECTION OF GEOLOGICAL SCIENCES: A STUDY OF QUARTZ SAND GRAIN SURFACE TEXTURES WITH THE SCANNING ELECTRON MICROSCOPE*. Transactions of the New York Academy of Sciences, 31(5 Series II), 457–477. https://doi.org/10.1111/j.2164-0947.1969.tb02929.x

Kümmerer, V., Drago, T., Veiga-Pires, C., Silva, P. F., Magalhães, V., Mena, A., Lopes, A., Rodrigues, A. I., Schmidt, S., Terrinha, P., & Baptista, M. A. (2020). Exploring Offshore Sediment Evidence of the 1755 CE Tsunami (Faro, Portugal): Implications for the Study of Outer Shelf Tsunami Deposits. *Minerals*, 10(9), 731. https://doi.org/10.3390/min10090731

Kuwatani, T., Nagata, K., Okada, M., Watanabe, T., Ogawa, Y., Komai, T., & Tsuchiya, N. (2014). Machine-learning techniques for geochemical discrimination of 2011 Tohoku tsunami deposits. Scientific Reports, 4(1). https://doi.org/10.1038/srep07077.

Loeblich Jr., A.R., Tappan, H., 1988. Foraminiferal Genera and Their Classification. Van Nostrand Reinhold, New York, 970 pp.

Le Ribault, L., (1977). L'Exoscopie des Quartz. Ed. Masson, 150 pp.

Le Roux, J. P., & Vargas, G. (2005). Hydraulic behavior of tsunami backflows: insights from their modern and ancient deposits. *Environmental Geology*, 49(1), 65–75. https://doi.org/10.1007/s00254-005-0059-2

Lopes, F. C., & Cunha, P. P. (2010). The Algarve continental shelf and adjacent provinces: a geomorphological analysis. Ciências Geológicas–Ensino e Investigação e sua História, 1, 479-489.

Madhavaraju, J., García y Barragán, J. C., Mohammad Hussain, S., & Pachaiveedu Mohan, S. (2009). Microtexturas de granos de cuarzo de los sedimentos de playa de Puerto Peñasco y Bahía Kino, Golfo de California, Sonora, México. *Revista mexicana de ciencias geológicas*, 26(2), 367-379.

Magalhães, F.M.Q., 1999. Os sedimentos da plataforma continental Portuguesa: Contrastes espaciais, perspectiva temporal, potencialidades económicas. Dissertação apresentada à Universidade de Lisboa para obtenção do grau de Doutor em Geologia, na especialidade de Sedimentologia, 289p.

Mahaney, W. C. (2002). Atlas of sand grain surface textures and applications. New York: Oxford University Press.

Mahaney, W. C., & Dohm, J. M. (2011). The 2011 Japanese 9.0 magnitude earthquake: Test of a kinetic energy wave model using coastal configuration and offshore gradient of Earth and beyond. *Sedimentary Geology*, 239(1-2), 80–86. https://doi.org/10.1016/j.sedgeo.2011.06.001

Mahaney, W. C., Dohm, J. M., Costa, P., & Krinsley, D. H. (2010). Tsunamis on Mars: Earth analogues of projected Martian sediment. *Planetary and Space Science*, 58(14-15), 1823–1831. https://doi.org/10.1016/j.pss.2010.08.010

Mamo, B., Strotz, L., & Dominey-Howes, D. (2009). Tsunami sediments and their foraminiferal assemblages. *Earth-Science Reviews*, 96(4), 263–278. https://doi.org/10.1016/j.earscirev.2009.06.007

Martin, R.E. & Lidel, W.D. The taphonomy of foraminifera in modern carbonate environments: implications for the formation of foraminiferal assemblages. In: DONOVAN, S.K. (Coord.), The processes of fossilization, Columbia University Press, p. 170-193, 1991.

Mendes, I., Dias, J. A., Schönfeld, J., Ferreira, Ó., Rosa, F., & Lobo, F. J. (2013). Living, dead and fossil benthic foraminifera on a river dominated shelf (northern Gulf of Cadiz) and their use for paleoenvironmental reconstruction. *Continental Shelf Research*, 68, 91–111. https://doi.org/10.1016/j.csr.2013.08.013

Milker, Y., & Schmiedl, G. (2012). A taxonomic guide to modern benthic shelf foraminifera of the western Mediterranean Sea. *Palaeontologia Electronica*. https://doi.org/10.26879/271

Moita, I. (1986) Carta dos Sedimentos Superficiais. Notícia Explicativa da Folha SED 7 e 8. Cabo de S- Vicente ao Rio Guadiana. Instituto Hidrográfico, Lisboa, Portugal.

Morton, R. A., Gelfenbaum, G., Buckley, M. L., & Richmond, B. M. (2011). Geological effects and implications of the 2010 tsunami along the central coast of Chile. *Sedimentary Geology*, 242(1-4), 34–51. https://doi.org/10.1016/j.sedgeo.2011.09.004

Murray, J.M. (1971). An Atlas of British Recent Foraminifererids. Heinemann Educational Books Ltd, London, p. 244.

Murray, J. M. (2006). Ecology and Applications of Benthic Foraminifera. Cambridge University Press, p. 426.

Murray, J. W. (1989). Syndepositional dissolution of calcareous foraminifera in modern shallow-water sediments. *Marine Micropaleontology*, *15*(1-2), 117–121. https://doi.org/10.1016/0377-8398(89)90007-8

Parsons, K.M. & Brett, C.E. Taphonomic processes and biases in modern marine environments: an actualistic perspective on fossil assemblage preservation. In: DONOVAN, S.K. (Coord.), The processes of fossilization, Columbia University Press, p. 22-65, 1991.

Pilarczyk, J. E., Dura, T., Horton, B. P., Engelhart, S. E., Kemp, A. C., & Sawai, Y. (2014). Microfossils from coastal environments as indicators of paleo-earthquakes, tsunamis and storms. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 413, 144–157. https://doi.org/10.1016/j.palaeo.2014.06.033

Pilarczyk, J. E., Horton, B. P., Witter, R. C., Vane, C. H., Chagué-Goff, C., & Goff, J. (2012). Sedimentary and foraminiferal evidence of the 2011 Tōhoku-oki tsunami on the Sendai coastal plain, Japan. *Sedimentary Geology*, 282, 78–89. https://doi.org/10.1016/j.sedgeo.2012.08.011

Pilarczyk, J. E., Reinhardt, E. G., Boyce, J. I., Schwarcz, H. P., & Donato, S. V. (2011). Assessing surficial foraminiferal distributions as an overwash indicator in Sur Lagoon, Sultanate of Oman. *Marine Micropaleontology*, 80(3-4), 62–73. https://doi.org/10.1016/j.marmicro.2011.06.001

Pilarczyk, J. E., Sawai, Y., Matsumoto, D., Namegaya, Y., Nishida, N., Ikehara, K., … Horton, B. P. (2020). Constraining sediment provenance for tsunami deposits using distributions of grain size and foraminifera from the Kujukuri coastline and shelf, Japan. *Sedimentology*, 67(3), 1373–1392. https://doi.org/10.1111/sed.12591

Powers. (1953). A New Roundness Scale for Sedimentary Particles. SEPM *Journal of Sedimentary Research*, Vol. 23. https://doi.org/10.1306/d4269567-2b26-11d7-8648000102c1865d

Quintela, M., Costa, P. J. M., Fatela, F., Drago, T., Hoska, N., Andrade, C., & Freitas, M. C. (2016). The AD 1755 tsunami deposits onshore and offshore of Algarve (south Portugal): Sediment transport interpretations based on the study of Foraminifera assemblages. *Quaternary International*, 408, 123–138. https://doi.org/10.1016/j.quaint.2015.12.029

Reicherter, K., Vött, A., Feist, L., Costa, PJM, Schwarzbauer, J., Schüttrumpf, H., Jens, H., Raeke, A., & Huhn-Frehers, K. (2019). Lisboa 1755, Cruzeiro nº M152/1, 02.11. - 14.11.2018, Funchal (Portugal) - Hamburgo (Alemanha). Em METEOR-Berichte (Vol. M152, pp. 1-36). Gutachterpanel Forschungschiffe. https://doi.org/10.2312/cr_m152

Relvas, P., and E. D. Barton. (2002). Mesoscale patterns in the Cape São Vicente (Iberian Peninsula) upwelling region. *Journal of Geophysical Research*, 107(C10). https://doi.org/10.1029/2000jc000456

Roger Higgs. (1979). Quartz-Grain Surface Features of Mesozoic-Cenozoic Sands from the Labrador and Western Greenland Continental Margins. *SEPM Journal of Sedimentary Research*, Vol. 49. https://doi.org/10.1306/212f779d-2b24-11d7-8648000102c1865d

Rosas, F. M., Duarte, J. C., Terrinha, P., Valadares, V., & Matias, L. (2009). Morphotectonic characterization of major bathymetric lineaments in Gulf of Cadiz (Africa–Iberia plate boundary): Insights from analogue modelling experiments. *Marine Geology*, 261(1-4), 33–47. https://doi.org/10.1016/j.margeo.2008.08.002

Satyanarayana, K., Reddy, A. N., Jaiprakash, B. C., Chidambaram, L., Srivastava, S. H. E. K. H. A. R., & Bharktya, D. K. (2007). A note on foraminifera, grain size and clay mineralogy of tsunami sediments from Karaikal-Nagore-Nagapattinam beaches, Southeast Coast of India. *Journal Geological Society of India*, 69(1), 70.

Sugawara, D., Minoura, K., & Imamura, F. (2008). TSUNAMIS AND TSUNAMI SEDIMENTOLOGY. *Tsunamiites*, 9–49. https://doi.org/10.1016/b978-0-444-51552-0.00003-5

Szczuciński, W. (2011). The post-depositional changes of the onshore 2004 tsunami deposits on the Andaman Sea coast of Thailand. *Natural Hazards*, 60(1), 115–133. https://doi.org/10.1007/s11069-011-9956-8

Szczuciński, W., Chaimanee, N., Niedzielski, P., Rachlewicz, G., Saisuttichai, D., Tepsuwan, T., ... & Siepak, J. (2006). Environmental and Geological Impacts of the 26 December 2004 Tsunami in Coastal Zone of Thailand - Overview of Short and Long-Term Effects. *Polish Journal of Environmental Studies*, v.15, n. 5, p.793-810.

Tamura, T., Sawai, Y., Ikehara, K., Nakashima, R., Hara, J., & Kanai, Y. (2015). Shallow-marine deposits associated with the 2011 Tohoku-oki tsunami in Sendai Bay, Japan. *Journal of Quaternary Science*, 30(4), 293–297. https://doi.org/10.1002/jqs.2786

Thomson, J., & Weaver, P. P. E. (1994). An AMS radiocarbon method to determine the emplacement time of recent deep-sea turbidites. Sedimentary Geology, 89(1-2), 1–7. https://doi.org/10.1016/0037-0738(94)90079-5

Tudor, M., Ramos-Pereira, A., & Costa, P. J. M. (2020). A Possible Tsunami Deposit Associated to the CE 1755 Lisbon Earthquake on the Western Coast of Portugal. *Geosciences*, 10(7), 257. https://doi.org/10.3390/geosciences10070257

Vanney, J. R.; Mougenot, D. La plateforme continentale du Portugal et les provinces adjacentes: analyse géomorphologique. *Serviço Geológico Português*, Lisboa, v. 28, p. 86, 1981.

Veloso, J.A.V., 2015. Tremeu a Europa e o Brasil também, 1st ed. Editora Chiado, Lisbon. 444 pp.

Vos, K., Vandenberghe, N., & Elsen, J. (2014). Surface textural analysis of quartz grains by scanning electron microscopy (SEM): From sample preparation to environmental interpretation. *Earth-Science Reviews*, 128, 93–104. https://doi.org/10.1016/j.earscirev.2013.10.013

Walter, L. M., & Burton, E. A. (1990). Dissolution of Recent platform carbonate sediments in marine pore fluids. *American Journal of Science*, *290*(6), 601–643. https://doi.org/10.2475/ajs.290.6.601

Yamazaki, Y., & Cheung, K. F. (2011). Shelf resonance and impact of near-field tsunami generated by the 2010 Chile earthquake. *Geophysical Research Letters*, 38(12), n/a-n/a. https://doi.org/10.1029/2011gl047508

Yawsangratt, S., Szczuciński, W., Chaimanee, N., Chatprasert, S., Majewski, W., & Lorenc, S. (2011). Evidence of probable paleotsunami deposits on Kho Khao Island, Phang Nga Province, Thailand. *Natural Hazards*, 63(1), 151–163. https://doi.org/10.1007/s11069-011-9729-4

Zitellini, N., Gràcia, E., Matias, L., Terrinha, P., Abreu, M. A., DeAlteriis, G., … Mulder, T. (2009). The quest for the Africa–Eurasia plate boundary west of the Strait of Gibraltar. Earth and Planetary Science Letters, 280(1-4), 13–50. https://doi.org/10.1016/j.epsl.2008.12.005