RICARDO PIAZZA MEIRELES

MARINE PALAEO-ECOLOGICAL AND DEPOSITIONAL PROCESSES ON THE SHALLOW-WATERS OF THE AZORES ARCHIPELAGO: THE MOBILE OSTRACODA (CRUSTACEA) AND THE SESSILE BRYOZOA AS CASE-STUDIES

UNIVERSITY OF THE AZORES - DEPARTMENT OF BIOLOGY - 2013

Marine palaeo-ecological and depositional processes on the shallow-waters of the Azores archipelago: the mobile Ostracoda (Crustacea) and the sessile Bryozoa as case-studies

by

Ricardo Piazza Meireles

A dissertation submitted to the University of the Azores in accordance with the requirements for award of degree of Doctor of Philosophy in the Department of Biology.
University of the Azores
May 2013

Advisors

Dr. Sérgio P. Ávila
Professor Dr. António M. de Frias Martins

First page designer by Suellen Cecilio & Ricardo Meireles.
Second page designed by Ricardo Ramalho, after Bristol University.

Author's Declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the result of the candidate's own independent research performed at the University of the Azores, Department of Biology, between January 2010 and May 2013.

Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author and not necessarily those of the University.

Ricardo Piazza Meireles

Very special thanks to my partner Suellen and to my family who always supported me, unconditionally. Thank you with all my heart.

Table of Contents

CHAPTER 1

GENERAL INTRODUCTION

1. THE AZORES ARCHIPELAGO

Located in the mid-North Atlantic (25° – 32° W and 37° - 40° N), about 1,500 km from the shores of mainland Portugal – is a group of very young oceanic islands, featuring youthful volcanic landforms that are generally devoid of exposed marine volcanic and sedimentary sequences (Serralheiro *et al*., 2003) (Fig. 1).

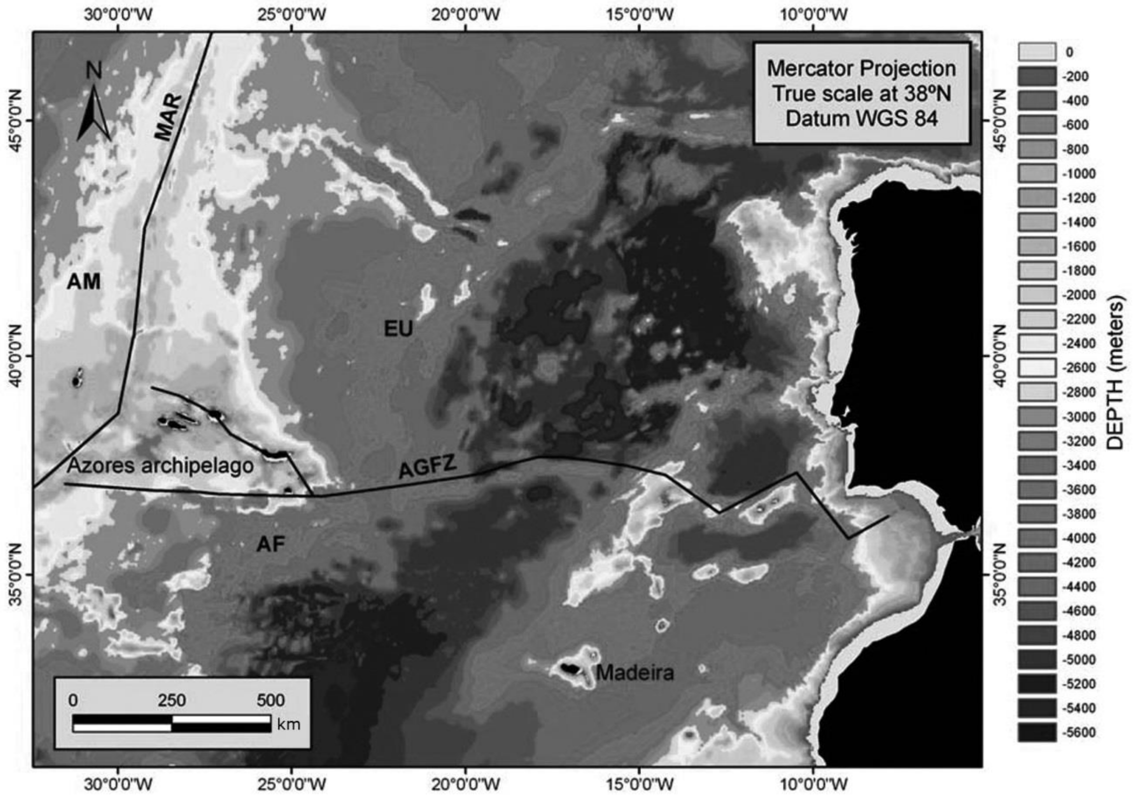


Figure 1. Geographical and tectonic setting of the Eurasia-Africa-North America plate boundary (modified from Argus *et al.*, 1989). AM=American plate; AF= African (Nubian) plate; AGFZ= Azores Gibraltar Fracture Zone; EU= Eurasian plate; MAR= Mid-Atlantic ridge. Bathymetry of the area Azores-Gibraltar from GEBCO (IOC IHO & BODC, 2003) (after Quartau, 2007).

The islands emerge from the Azores volcanic plateau (Fig. 2), which is a first-order morphological feature in the Atlantic basin. It has an overall triangular shape corresponding to a surface area of approximately 400,000 km^2 of elevated oceanic crust, roughly underlined by the 2,000 m isobath (Lourenço *et al.*, 1998). The plateau is mainly constructed of alkaline basalt volcanism. Geochemistry and petrology suggest a hotspot origin for this volcanism (White *et al.*, 1976). The plateau crosses to the west the Mid-Atlantic Ridge (MAR) and is limited to the south by the East Azores fracture

Zone (EAFZ). The western group of islands (Flores and Corvo) lie on the American plate, while the islands of the central (Terceira, Graciosa, S. Jorge, Pico and Faial) and eastern groups (S. Miguel, Santa Maria and Formigas) lie on the Azores plateau (Quartau, 2007).

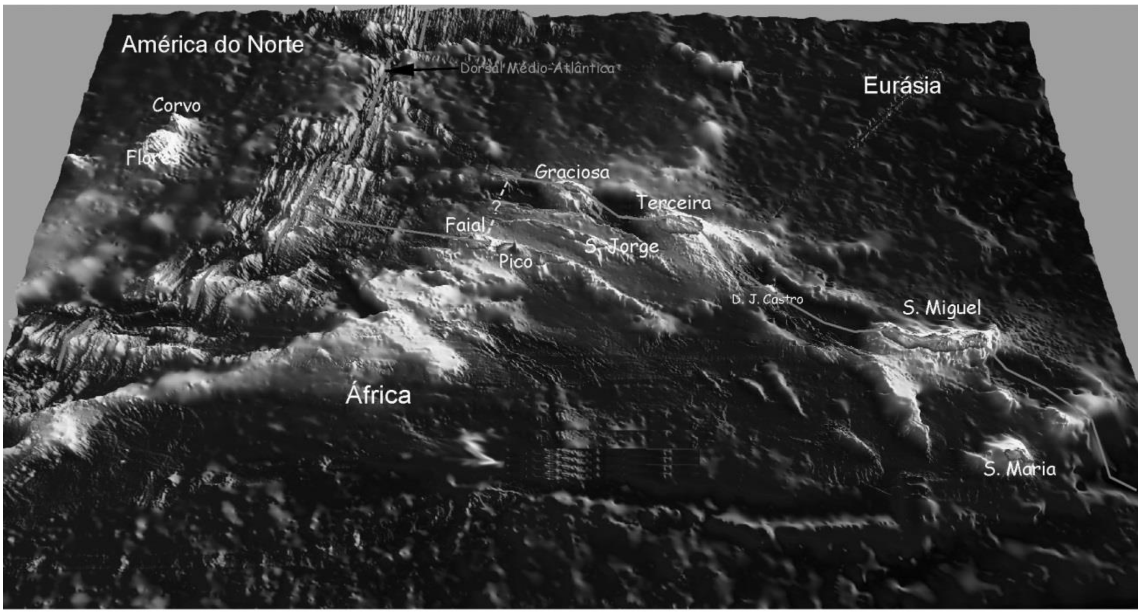


Figure 2. Tectonic setting of the Azores archipelago (after Luis *et al*., 1994).

Discovered by the Portuguese navigators in 1427, the Azores seem to have been previously known, according to old maps; after more than one century of biodiversity inventory, we still lack an estimate of the number of species occurring in the Azores (Borges *et al*., 2010).

In what regards the shallow marine groups, in particular the Ostracoda and Bryozoa fauna, the data are scarce. Meireles *et al*. (2012) were the first to publish on the Miocene marine ostracods from the Azores (Chapter 4) and this thesis (Chapters 5 and 6) presents the first account on the systematics, palaeo-ecology and taphonomics processes of the marine ostracods from these islands. Several papers were published reporting Bryozoa from the Azores: Jullien (1882), Jullien & Calvet (1903), Calvet (1931), Hondt (1975), Harmelin (1977, 1978, 1988), Harmelin & Aristegui (1988), Zabala, Maluquer & Harmelin (1993), Reverter-Gil & Fernández-Pulpeiro (2007), Berning & Kuklinski (2008), Amat & Tempera (2009) and Costa *et al*. (2010).

The lack of information about these groups in the Azores and the convenience of studying benthic species with contrasting "ways of life" (the sessile Bryozoa and the mobile Ostracoda) provided the trigger for the description and subsequent interpretations of the marine palaeo-ecological and depositional processes presented in this thesis. This work is the results of efforts between January 2010 to May 2013, and aims to study the fossil and Recent Ostracoda and Bryozoa of the Azores from a systematical, sedimentological, palaeontological, taphonomical, palaeo-ecological and palaeo-biogeographicals points of view. I hope with this thesis to fuel and encourage further research in the fields of Marine Biology-Zoology / Oceanography / Geology of the archipelago.

1.1. OSTRACODA

Ostracods are small crustaceans ranging in length from 0.08 to 3 mm, or more. Their entire body is encased in a bivalve, calcified carapace which can be smooth to variously ornamented. The two valves are joined by a dorsal hinge opposed by closing muscle. The body is unsegmented and has a reduced number of limbs. The head is larger than both the thorax and abdomen combined. It bears five paired appendages: first and second antennae, mandibles, and the first and second maxillae. Commonly, two additional thoracopods are also present. The second maxillae and the two thoracopods are often used as walking or cleaning legs. The abdomen terminates in a pair of furcae. Between the last thoracopods and the furcae there may be a pair of large male copulatory organs (Keyser, 1988). The general schematic classification is show in Fig. 3. Some 65,000 living and fossil species have been described, grouped into several orders. This group may not be monophyletic; ostracod taxa are grouped into a Class based on gross morphology (Horne *et al.*, 2002).

Although several authors have recently attempted to unify terminology pertaining ostracod limbs and their chaetotaxy (see Namiotko *et al.*, 2011 for an overview), there is still lack of consensus on this matter in the literature and many confusion exists about limb homologies with other crustacean taxa and even within Ostracoda. Here we adopted the terminology of the general limb morphology after Horne *et al.* (2002).

Ostracods have a short compact body with no true segmentation as often recognizable in other crustaceans. A faint constriction of the body usually just in front of the centre marks the indistinct boundary between two main parts, the anterior head (cephalon) and the posterior trunk (consisting of the reduced thorax and the rudimentary abdomen) (Namiotko *et al.*, 2011). The later portion shows in a few taxa some external traces of segmentation, suggesting 4-7 (subclass Myodocopa) or 10-11 (subclass Podocopa) barely discernible postcephalic segments (Horne *et al.*, 2002).

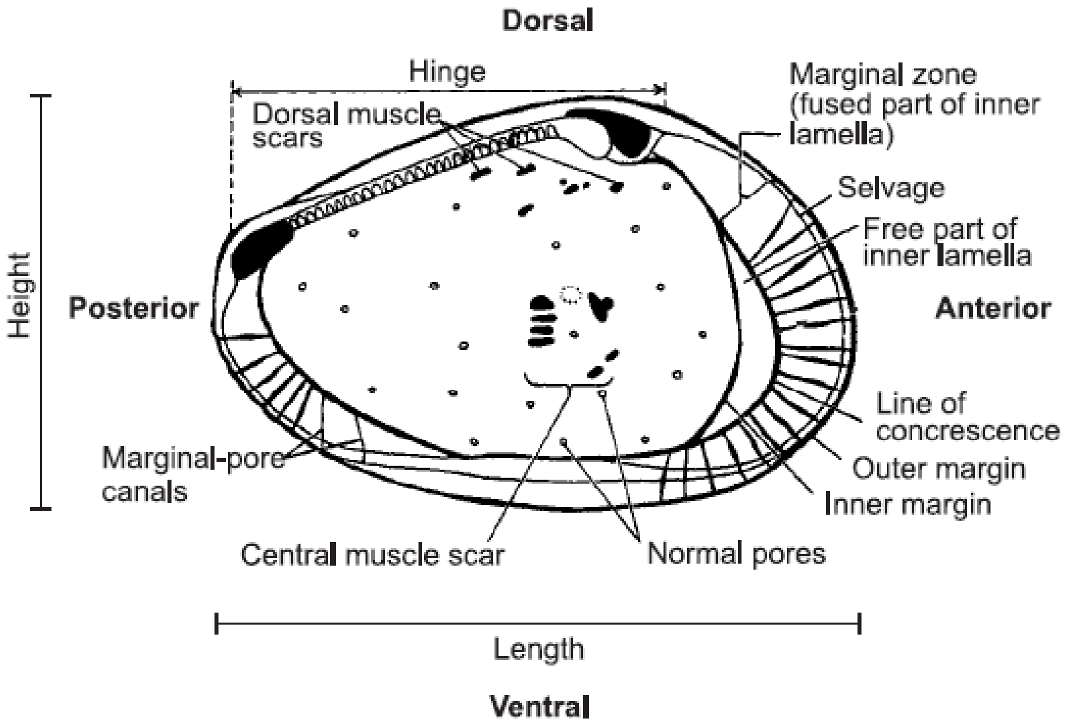


Figure 3. The internal features of a podocopida left valve (modified from Van Morkhoven, 1962).

Ostracod limbs (or appendages), except the antennule (or first antenna), are considered to derive from a generalized ancestral crustacean appendage composed of a basal protopod on which distally two rami are carried: an inner endopod (commonly larger) and an outer exopod (often strongly reduced). Adult ostracods possess up to eight pairs of functionally specialized limbs, including male copulatory appendages (Horne *et al.*, 2002) (Fig. 4).

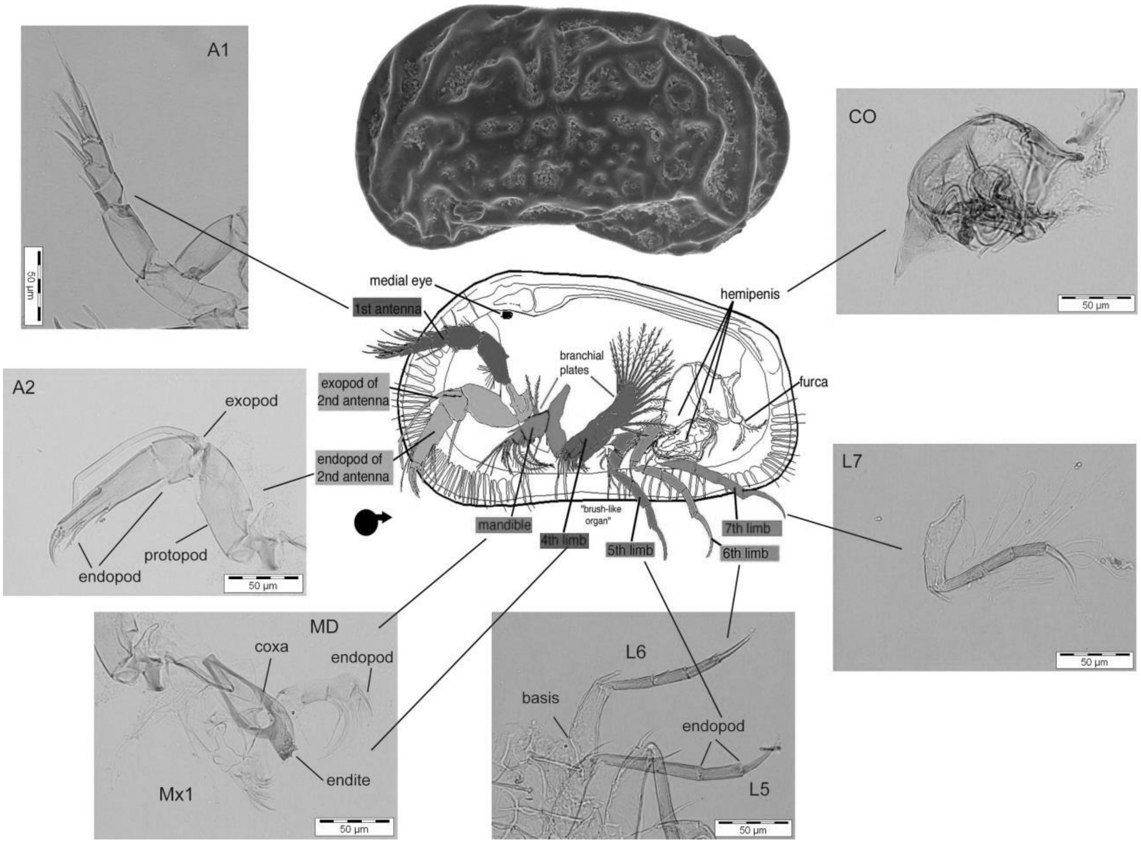


Figure 4. Central ostracod schematic drawing (male Podocopida) adapted from Horne *et al.* (2002). Morphology of a male of *Callistocythere insularis* sp. nov. (Azores archipelago), as an example of a leptocytheridean ostracod (Podocopida; Leptocytheridae). Left valve in external view: A1 – antennule, A2 – antenna, MD – mandible, Mx1 – maxillula, L5 – fifth limb (walking leg), L6 – sixth limb (walking leg), L7 – seventh leg (cleaning and walking leg), CO – copulatory organ (hemipenis).

1.2. BRYOZOA

Bryozoa is the name of a phylum for which Ectoprocta is generally regarded as a synonym, these names being used by zoologists according to personal preference. Entoprocta (synonym Calyssozoa) is likewise regarded as an independent phylum. A minority regards Ectoprocta and Entoprocta as subphyla within the Bryozoa, while others maintain Ectoprocta and Entoprocta as phyla (Margulis & Schwartz, 1999) but link them under Bryozoa as a name of convenience (Ryland, 1970).The phylum contains some 20,000 described species, one-fifth of them living. These are distributed among three classes and a somewhat variable number of orders. This phylum consists of sessile aquatic invertebrates (also called Polyzoa) which form colonies of zooids. Each zooid, in its basic form, has a lophophore of ciliated tentacles situated distally on an introvert, a looped gut with the mouth inside the lophophore and the anus outside, a coelomic body cavity, and (commonly) a protective exoskeleton. The colonies are variable in size and habit (Figs. 5, 6 and 7). Some are known as lace corals and others as sea mats, but the only general name is bryozoans (sea mosses) (Ryland, 1970).

Bryozoans are a paradoxical group of creatures. They are common aquatic animals, but few people other than professional zoologists recognize them. Their protean colony shape generally guarantees that they will be taken for hydroids, corals, or even seaweeds – anything but what they actually are. They are fascinating scientifically, but relatively few specialists study them. Even their precise relationships with other animal phyla are controversial (Nielsen, 1995). Yet their potential for yielding new discoveries, theories, and products is considerable, and anyone who starts researching their biology will certainly be rewarded. Bryozoans are a greatly understudied group, full of unsolved mysteries (Gordon *et al*., 2009).

Worldwide, approximately 6,000 living species and 15,000 fossil species have been recognised, and it is likely that several thousand unknown species have yet to be discovered and described. Bushy bryozoans used to be called moss animals, and flat encrusting ones, sea mats, but hardly anyone now uses these names. ‘Lace corals’ is a good descriptor for those species whose colonies look like ruffs and chalices of coloured lace, but bryozoans are coelomate animals unrelated to true cnidarian corals. No common names adequately apply to all the species, so the technical name Bryozoa (Greek for ‘moss animals’) is probably the best to use (Gordon *et al*., 2009).

In Azorean waters, bryozoan colonies range in size from microscopic to the size of footballs or cabbage heads. Bryozoans on wharf-piles, vessel hulls, pontoons, small rocks, and shells form small to moderate-sized encrustations or bushy colonies. The colony may be minute, of not more than a single feeding zooid and its immediate buds, or substantial, forming masses 1 m in circumference, festoons 0.5 m in length, or patches 0.25 m^2 in area. Commonly the colonies form incrustations not more than a few square centimeters in area, small twiggy bushes up to about 3 cm in height, or soft masses up to about 10 cm in the largest dimension. In many colonies much of the bulk consists of the zooid exoskeletons, termed zooecia, which may persist long after the death of the organism and account for the abundance of fossilized bryozoan remains.

The bryozoan body design is that of a colony of tiny individuals (zooids), each of which is somewhat box- or tube-shaped, with an opening at one end for feeding tentacles to emerge. Each zooid is generally about half a millimeter long but some may be smaller or very much larger. Most marine bryozoan zooids live inside a hard calcareous box, usually attached to other identical boxes to form a colony. Colony size ranges from microscopic to more than a metre in diameter (Smith & Gordon, 2011) (Fig. 6).

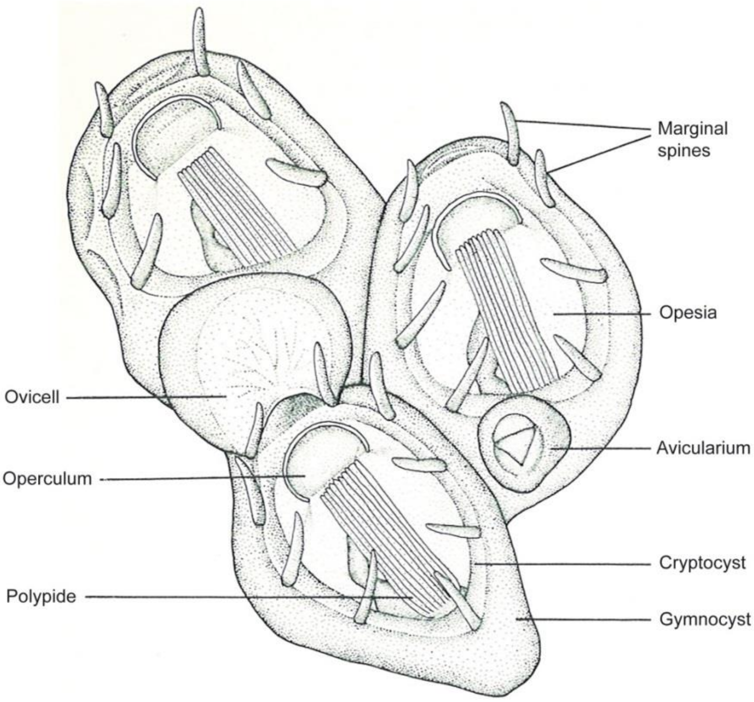


Figure 5. Zooid structure in *Callopora lineata* (Hayward & Ryland, 1979).

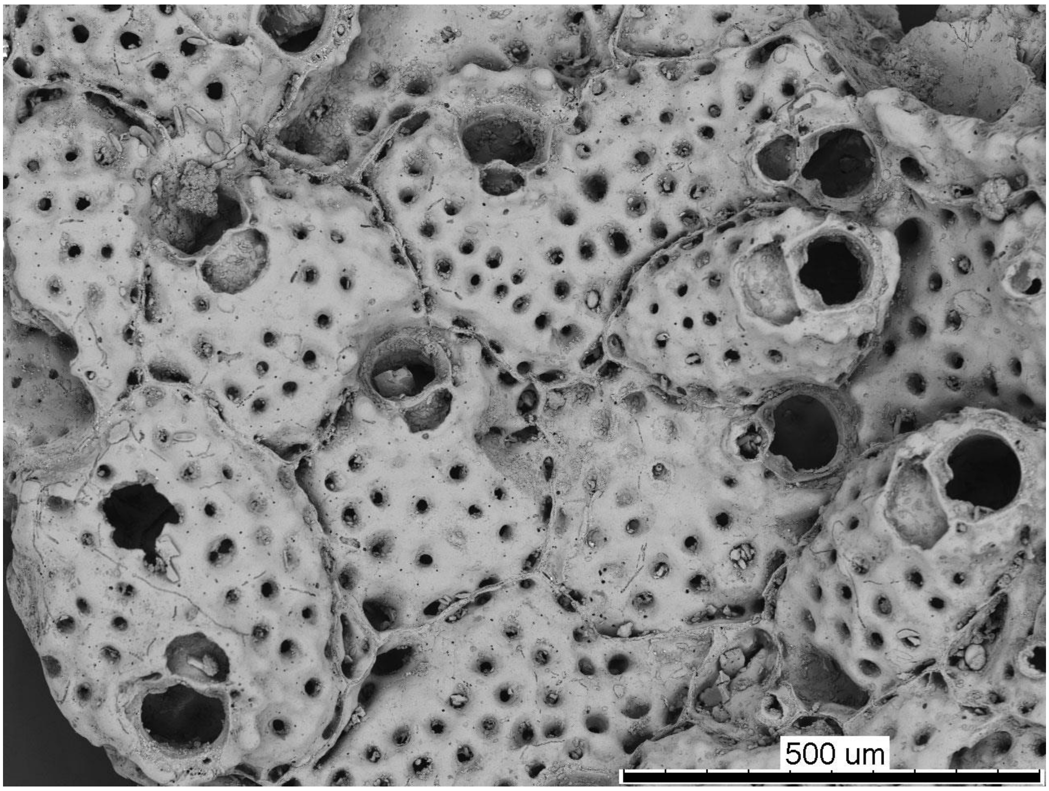


Figure 6. Scanning electron micrograph of zooid skeletons of *Schizomavella cornuta* (Heller, 1867) [=*Schizomavella cuspidata* (Hincks, 1880)].

Many bryozoans display polymorphism, having certain zooids adapted in particular ways to perform specialized functions, such as protection, cleaning the surface, anchoring the colony, or sheltering the embryo. The evolution of nonfeeding polymorphs is dependent upon some form of intercommunication between zooids (Ryland, 1970).

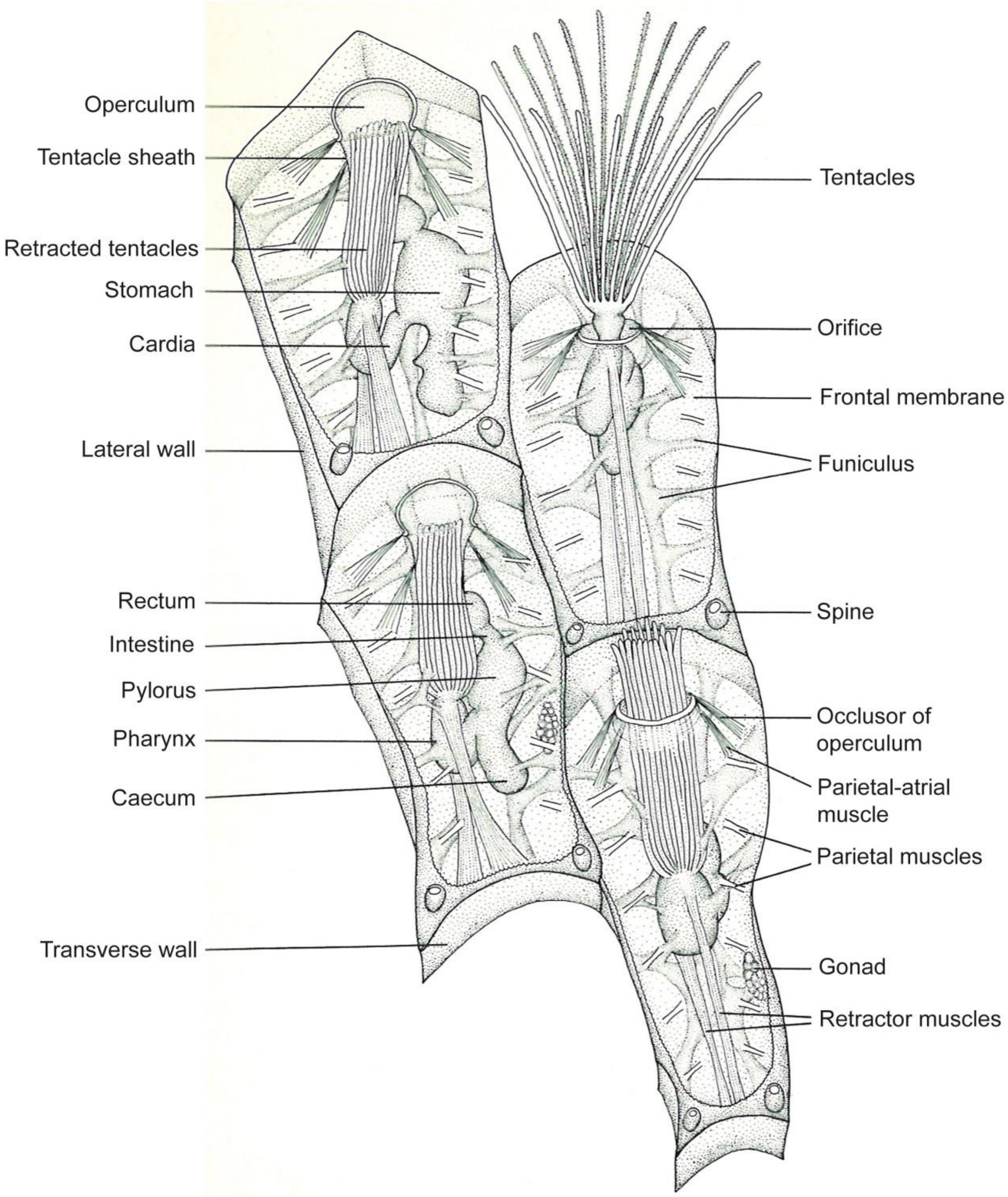


Figure 7. Zooid structure in the anascan cheilostome, *Membranipora membranacea* (Linnaeus, 1767) (Hayward & Ryland, 1979).

1.3. THESIS OUTLINE

In this thesis I aimed to **1)** undertake a taxonomic revision of the Fossil and Recent shallow (from the intertidal down to 100 m depth) Ostracoda and of the Recent shallow Bryozoa of the Azores; **2)** describe the zonation of the Recent species of Ostracoda on the Azorean shores; **3)** use the above-mentioned studies to compare with the palaeo-ecological studies that were done on the fossiliferous Late-Miocene-Early-Pliocene of the Santa Maria Island's outcrops; **4)** establish the palaeo-biogeographical relationships of the Recent and fossil ostracods; **5)** produce a Reference Collection of the Bryozoa and Ostracoda which will be deposited at the Departament of Biology, Universtity of the Azores, in order to provide additional tools for identifying the more conspicuous species of Bryozoa and Ostracoda from the Azores.

In **Chapter 2**, I assess the methods used to study the Recent and fossil records done on this thesis. Adaptations and suggestions to future works about these groups are also reported.

Chapter 3 is dedicated to the Scientific Curation of Collections. The identification processes and the methods used for the curation of the samples studied on this thesis (including holotypes, paratypes and topotypes specimens) are discussed. It includes the most recent and updated checklist of the benthic Bryozoa and Ostracods (Recent and fossil) of the Azores.

Chapter 4 reports the late Miocene-early Pliocene fossil ostracods from Santa Maria Island, and discusses the geological/micropalaeontological technics used to describe these fossils, as well as the importance of this palaeontological record.

In Chapter 5, I assess the systematics and biogeographical relationships of the Recent shallow-water marine ostracods of the archipelago. A systematic review is provided and the first biogeographical study of this class is done for the Azores. The importance of providing additional tools for identifying the more conspicuous species of Ostracoda from the Azores is also discussed.

Chapter 6 presents a study about the taphonomy and palaeoecology of the Quaternary shallow-water marine ostracods of the Azores.

Chapter 7 shows and discusses the research results about Ponta do Castelo locality as an outstanding outcrop for the explanation of the depositional processes of sedimentary bodies (containing fossils) on oceanic island shelves. This study proposes a general depositional model of sedimentation applicable to the insular shelves of reefless oceanic volcanic islands worldwide.

Figure 8 was designed to provide a fast view of the thesis outline. In this figure it is possible to see the thesis publications, other author publications (not directly related with the main theme of this thesis), scientific campaigns, and technical visits to museums, as well as the workshops, advanced courses and conferences in which the author participated, between January 2010 and May 2013.

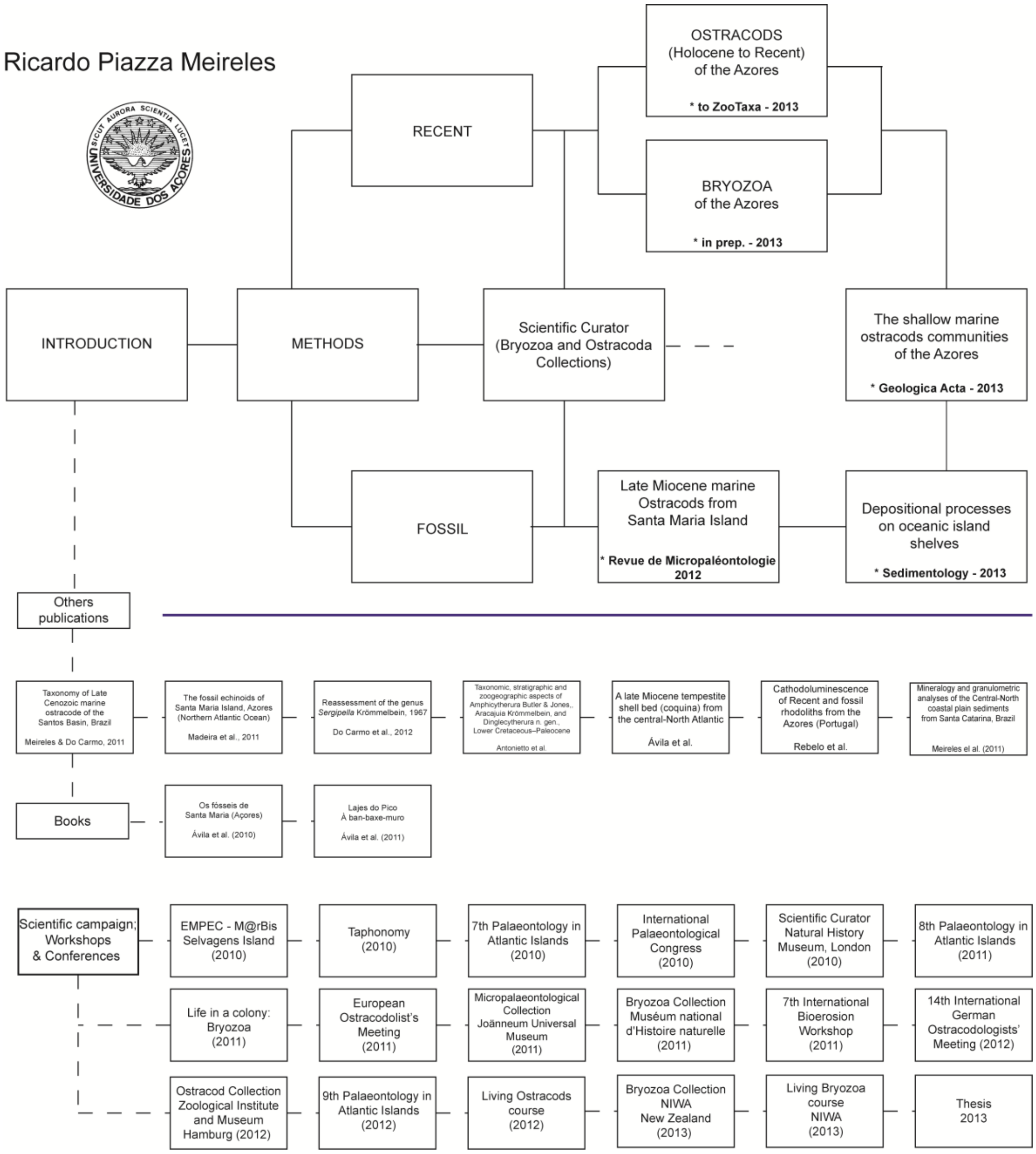


Figure 8. Schematic thesis outline (January 2010 - May 2013).

CHAPTER 2

METHODS USED TO STUDY THE RECENT AND THE FOSSIL RECORDS

1. Field Techniques

In general, there are six aspects on sedimentary rocks to consider in the field, which should be recorded in as much detail as possible. These are: **1)** the lithology, that is the composition and/or mineralogy of the sediment; **2)** the texture, referring to the features and arrangements of the grains in the sediment, of which the most important aspect to examine in the field is the grain-size; **3)** the sedimentary structures present on bedding surfaces and within beds, some of which record the palaeocurrents which deposited the rock; **4)** the colour of the sediments; **5)** the geometry and relationships of the beds or rock units, and their lateral and vertical changes; and **6)** the nature, distribution and preservation of fossils contained within the sedimentary rocks (Tucker, 2003).

The various attributes of a sedimentary rock combine to define a *facies*, which is the product of a particular depositional environment or depositional process in that environment. *Facies* identification and *facies* analysis are the next steps after the field data have been collected. Nowadays, there is much interest in the broaderscale aspects of sedimentary successions: the geometric arrangements of rock units, the lateral and vertical variation in such features as lithology and grain-size, the packaging and stacking patterns of units, and the presence of cycles and rhythms in the succession. These features reflect the longer-term, larger-scale controls on deposition, primarily relative sea level change, accommodation (the space available for sediments), tectonics, sediment supply/production, and climate. A general scheme for the study of sedimentary rocks in the field is given in Tucker (2003).

2. Petrography

Sample preparations for various analytical steps were made in the laboratories of the Centro de Vulcanologia e Avaliação de Riscos Geológicos (CVARG), University of the Azores. The details of these materials are showed in Chapters 4 and 7.

A preliminary washing with deionized water for a couple of days allowed removing salt, loose debris and organic matter from the bulk samples. After drying in an oven overnight (60°C), cleaned fragments were impregnated in epoxy in vacuum conditions. With this operation, open pores and fractures were sealed, increasing the resistance of samples which are naturally fragile.

Samples were then trimmed off with a diamond blade and grinded with coarse silica carbide abrasive powder (grit 220 or 400) to obtain a flat side, suitable for optical observations. The flat side was then grinded by the use of progressively thinner abrasives (up to grit 600) in order to produce a homogeneous and scratch-free surface.

Optical observations were made by the use of a stereoscopy binocular Nikon SMZ1000 equipped with a Nikon Coolpix 995 digital camera (3.34 Mpixel).

The thin sections for petrographic studies were prepared by using a Logitech PM5 semi-automated station. This machine allows the contemporaneous preparation of 6 samples with a jig (sample holder) equipped with a very precise system for thickness control.

Samples were lapped up to grit 800 and then cleaned in an ultrasonic bath.

Each sample was studied using an Olympus BX52 polarizing microscopy, equipped with a DP25 digital camera (10 Mpixel). Digital imaging allowed the capture of multiple images to assemble maps.

Modal counting of components in three selected thin sections was performed with a semiautomated digital stepper, by counting a total number of 1.500 points.

3. Carbonate Microinvertebrates (Ostracoda; Bryozoa and Foraminifera): Collection, Preparation and Preservation.

The work of the micropalaeontologist in the field usually consists in collecting not fossils but samples of rock, which he believes may contain the fossils in sufficient number and in satisfactory preservation (Glaessne, 1948). Experience is essential in collecting microsamples.

The usual samples taken for micropalaeontological analysis are 200 to 250 grams. The most important precaution to be exercised during sample collection is to avoid contamination. Hammers, chisels and shovels should be cleaned before each sample is taken. In general, the less the treatment necessary to free the fossils from the matrix the better (see Jones, 1956 for an overview). Least amount of crushing, boiling and sieving should be used in order to ensure minimum breakage of specimens.

The fossils are separated from the disintegrated material by Hydrogen peroxide (H_2O_2, vol. 30%) and washing. The fine grade of rock particles, smaller than the microfossils, is passed through fine sieves and discarded. This can be done by means of screening. A set of sieves with 40, 80 and 200 mesh to the inch is sufficient, for practical purposes. A jet of water under pressure is directed upon the sample and the sieves may be shaken. Much care has to be taken to clean the used screens with brushes and a strong jet of water before placing another sample on them.

All equipment must be kept thoroughly clean to prevent contamination; sieves are used can be made by dipping them in a solution of methylene blue after washing each sample. For more detail about the micropalaeontological techniques see Van Morkhoven (1962).

The final stage of separation involves removing the microfossils from the dried residue composed of mineral grains, fine rock fragments and microfossils. The most common practice is to pick individual specimens from the various screened fractions of the residue with a fine camel's -hair brush, and to mount them on a gummed micropalaeontological slide. Skill in using the moistened and pointed brush for picking up the specimens under the microscope can be acquired only with practice.

Moisten the brush in a small dish of water. Make it pointed and place in a hovering position over the field of' the microscope. The moistened brush is lowered over the specimen desired and allowed to touch the surface, to which the specimen will adhere. Then it is transferred to the slide.

Many types of micropalaeontological slides have been developed for specific uses. The faunal slide has 48, 60 or 100 divisions for mounting a representative fauna (see Chapter 3 for more information).

4. Living Bryozoa and Ostracoda: techniques of sampling and soft-parts preparation

Bryozoans' are sessile organisms and sampling, in general, was done during SCUBA dive and/or snorkel activity. When collecting bryozoans it is desirable to keep the specimens intact. Hard, brittle substrata, such as stone, require a hammer and cold chisel. The review about the Bryozoa checklist, presented in Chapter 3 (Table 1) was revised by Dennis Gordon (2013, *personal communication*), after a technical visit to the National Institute of Water & Atmospheric Research (NIWA), in Wellington (New Zealand).

Ostracods are mobile organisms and require a more specific method. For the Ostracoda sampling we used the method adapted by Keyser (2012; *personal communication*), after a technical course in the University of Hamburg (Germany). The Ostracoda checklist, presented in Chapter 3 (Table 2) was reviewed by Gliozzi & Faranda (2011) and by Keyser (2012).

For the sampling, it was necessary: a bucket, several nets of 80μm mesh size, sieves for coarse material and sample glasses. The sieves for the coarse material, which we do not want to have in our samples, must fit in the opening of the collection net. One can use other sieves, especially when the material is very coarse, or when we need other fractions.

During collection on the surface or in deeper waters (by SCUBA diving) the net should only be about two to five centimeters in the ground. The reason is that ostracods are not deeper than 2-4 cm burrying into the sediment. The net should be moved in waves over the ground, into the sediment out of the sediment and again into the sediment. The reason for this is to gather also the animals who might swim away.

The collected material is thoroughly washed in the net in the water to reduce the amount of very fine particles like clay or mud but to keep the ostracods which are held back by the net. To reduce the amount of the sample even more it is placed in the bucket and filled up with water.

In the laboratory it is best to work on the ostracods as quick as possible, for when they are still living and moving around, they are easier to spot. The sample is put into a Petri dish and look through it under the binoculars. All living ostracods you can pick out are collected with a pipette and transfered into another dish and then into 70% alcohol. When they are in the alcohol, they can stay there for a long time. The samples in seawater will very soon get spoiled and will stink terribly. If you do not have time to pick the living animals immediately, you can put the whole sample in alcohol and pick the ostracods later.

For the studies on the soft parts of the living ostracods we used the methodology by Namiotko *et al.* (2011). A set of materials are necessary for dissection and slide-preparation of ostracods: dissecting needles, pipettes, forceps, fine brushes, an embryo dish, nail varnish, mounting medium (Hydro-Matrix®), an aluminium holder for a glass slide and/or cover slips, a three-well embryo slide, a micropalaeontological slide, self-adhesive paper labels, a standard glass slide, depression glass slide, cover slips and a small Petri dish.

CHAPTER 3

SCIENTIFIC CURATION OF THE AZORES FOSSIL AND RECENT COLLECTIONS: BRYOZOA AND OSTRACODA

Ricardo Piazza Meireles

INTRODUCTION

This chapter allows users to search for information about individual fossil and Recent **BRYOZOA** and **OSTRACODA** collections housed at the Department of Biology of the University of the Azores. The information given is about collections rather than individual specimens and is intended to act as a “taster” so that more detailed enquiries can be made to the curator if necessary. For each collection, there is a list of taxa identified, associated with the sample number. The build-up of the collections was based in the Collection & Curations course accomplished in the NHM (Natural History Museum) in London (Giles Miller, 2010; *personal communication*). The Ostracoda checklist was supervised by Elsa Gliozzi (Università Roma Tre – 2011) and Dietmar Keyser (Hamburg University – 2012). The Bryozoa checklist was supervised by Dennis Gordon (NIWA – 2013).

The raw documentation of the material is based on laboratory books, papers published and work in progress, checklists, tables and SEM photos, which provide information about the processing techniques applied to each sample and the data when the work was completed (Fig. 1). For more information about Scientific Curator please consult Brunton (1979), Brunton *et al*. (1984), Fothergill (2005) and Beagrie (2006).

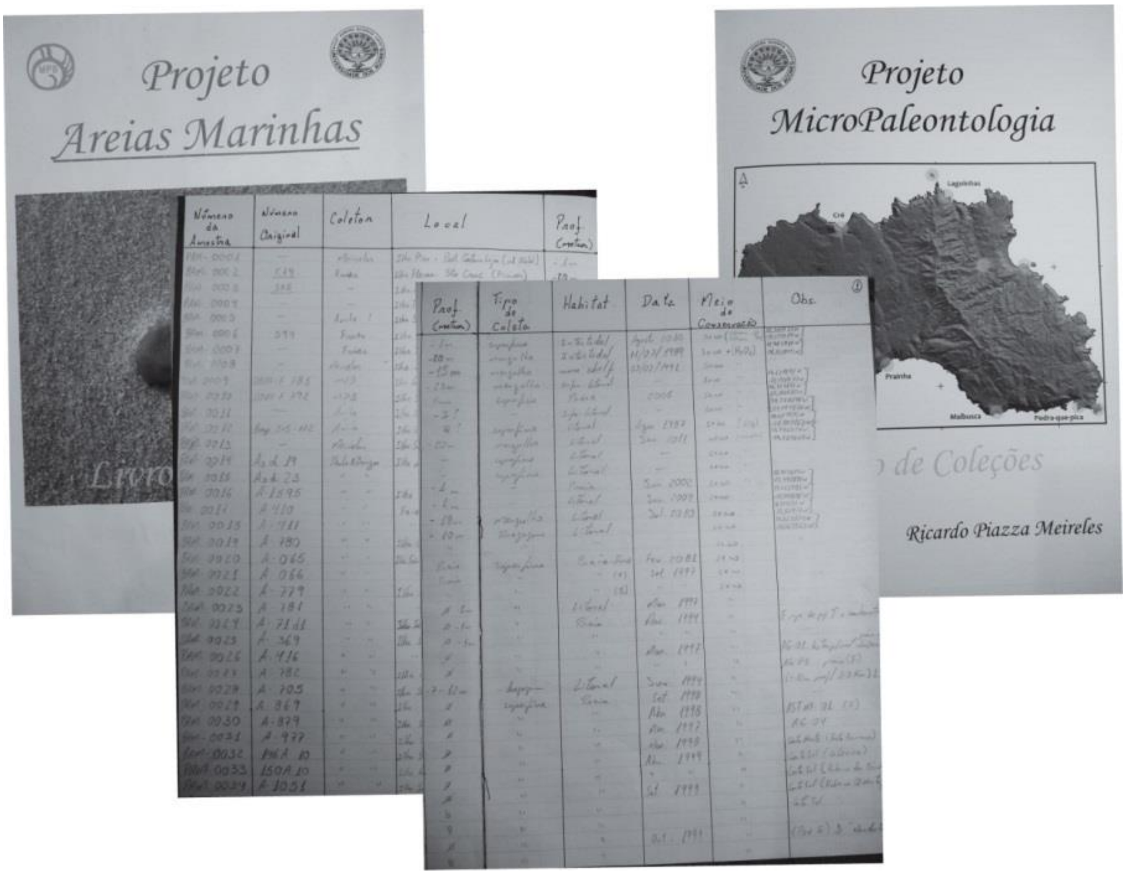


Figure 1. Laboratory books containing information about the processing of the works.

All material was curated and catalogued and the major part of the collection is now available as a searchable database on the Department of Biology, University of the Azores (DBUA, Ponta Delgada, Portugal), the Bryozoa under prefix "**DB/BRY n**$^{\text{o}}$" and the Ostracoda under prefix "**DB/OS n**$^{\text{o}}$". The Ostracoda are stored in micropalaeontological slides (Figs 3 and 4) and the Bryozoa (Fig. 4) are kept in bottles at the DBUA; both collections are available for further studies.

Figure 3. Micropalaeontological slides used to held the individual specimens of Ostracoda and Bryozoa.

Figure 4. Bottles used to held the specimens of Bryozoa.

The residues for every slide were kept and stored for future reference. These are a vital addition to the slide collection. Occasionally, if the residue was very small a stored reserve was not possible; consequently there are a few gaps in the run of sample numbers. The residues are held in wood drawers (Fig. 5).

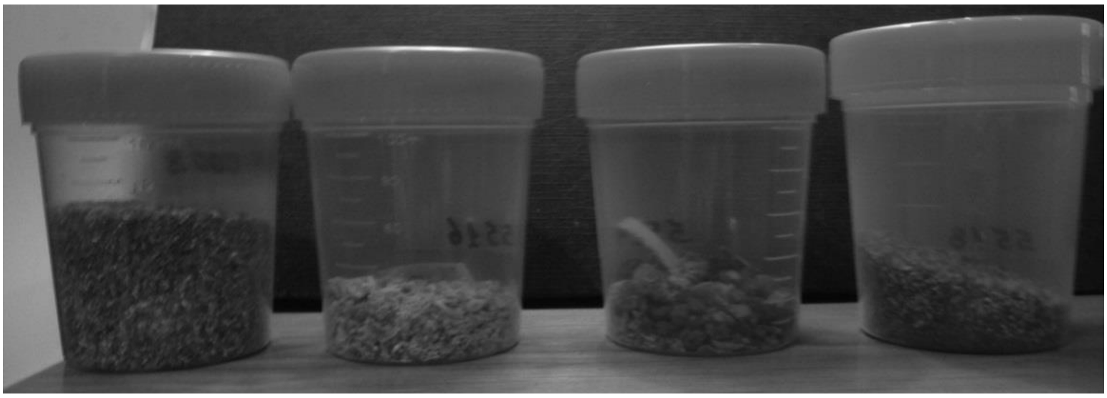


Figure 5. Residue containers used to fossil and Recent dry sediments.

These represent the biggest catalogue of the Bryozoa and Ostracoda Collections. In the future all collections will be accessible online in the MPB website (http://www.mpb.uac.pt/) (Fig. 2).

The 8th International Workshop "Palaeontology in Atlantic Islands" occurred in July 2011, at Santa Maria Island (Azores). A special emphasis was placed on the study of the Miocene fossils and on dating most of the outcrops. During this workshop, the MPB team showed the maritime tour of "The Route of Fossils", the first of five trails dedicated to this theme.

Figure 2. The MPB – Marine PalaeoBiogeography working group website.

THE BRYOZOA & OSTRACODA COLLECTIONS

1- Bryozoa and Ostracoda checklist of the Azores (Tables 1 and 2).

2- Bryozoa and Ostracoda (Recent and fossil) collection (Tables 3 and 4).

3- Slides; large bottles and residues from some different locations and depths around the Azores archipelago (Figs 3; 4 and 5).

4- SEM photos, soft-parts drawers and digital collection records database.

DONATIONS OF THE COLLECTIONS

Part of the material will be donated for other Institutions/Museums, and new reference numbers (for this secondary collection) will be proposed:

1º - Ostracoda Collection (Recente and Fossil) – paratypes – Natural History Museum, London; to Dr. Giles Muller.

2º - Ostracoda Collection (Recent and fossil) – partypes - Zoological Institute and Museum, University of Hamburg, Germany; to Dr. Dietmar Keyser.

3º - Ostracoda Collection (fossil) – paratypes - Dipartimento di Scienze Geologiche, Università Roma Tre, Italy; to Dra. Elsa Gliozzi.

4º - Ostracoda Collection (Recent and fossil) – paratypes – Universidade de Lisboa, Portugal; to Dra. Ana Cristina Cabral.

TABLE 1. CHECKLIST OF THE RECENT MARINE BRYOZOANS OF THE AZORES ARCHIPELAGO *

PHYLUM BRYOZOA

CLASS GYMNOLAEMATA ALLMAN, 1856

	Geographical Distribution	Bathymetry (m)	References
ORDER CHEILOSTOMATA BUSK, 1852			
SUPERFAMILY AETEOIDEA			
Family Aeteidae Smitt, 1868			
Genus *Aetea* Lamouroux, 1812			
Aetea anguina (Linnaeus, 1758)	Azores	5 – 6 m	Jullien & Calvet, 1903
Aetea truncata (Landsborough, 1852)	Azores	-	Jullien & Calvet, 1903
Aetea sica (Couch, 1844)	Azores	-	Jullien & Calvet, 1903
SUPERFAMILY CALLOPOROIDEA			
Family Calloporidae Norman, 1903			
Genus *Aplousina* Canu & Bassler, 1927			
Aplousina capriensis (Waters, 1898)	Azores	-	Meireles & Gordon, 2013 (unpublished)
Aplousina filum (Jullien & Calvet, 1903)	Azores	130 m	Jullien & Calvet, 1903
Genus *Amphiblestrum* Gray, 1848			

Amphiblestrum auritum (Hincks, 1877)	Azores	130 m	Jullien & Calvet, 1903
Family Chaperiidae Jullien, 1888			
Genus *Chaperiopsis* Uttley, 1949			
Chaperiopsis hirsuta Reverter, Souto & Pulpeiro, 2009	Azores	-	Meireles & Gordon, 2013 (unpublished)
Chaperiopsis annulus (Manzoni, 1870)	Azores	-	Jullien & Calvet, 1903
Family Farciminariidae Busk, 1852			
Genus *Farciminellum* Harmer, 1926			
Farciminellum alice (Jullien & Calvet, 1903)	Azores	578 – 3293 m	Calvet, 1931
SUPERFAMILY FLUSTROIDEA			
Family Flustridae Fleming, 1828			
Genus *Gregarinidra* Barroso, 1949			
Gregarinidra gregaria (Heller, 1867)	Azores	-	Meireles & Gordon, 2013 (unpublished)
Genus *Columnella* Levinsen, 1914			
Columnella magna (Busk, 1884)	Azores and Argentina	1240 – 1732 m	Calvet, 1931
SUPERFAMILY BUGULOIDEA			
Family Bugulidae Gray, 1848			
Genus *Bugula* Oken, 1815			
Bugula dentata (Lamouroux, 1816)	Azores	-	Meireles & Gordon, 2013 (unpublished)
Bugula neritina Linnaeus, 1758	Azores	-	Meireles & Gordon, 2013 (unpublished)
Bugula simplex Hincks, 1886	Azores	-	Tempera *et al.*, 2010

Bugula stolonifera Ryland, 1960	Azores	-	Tempera *et al.*, 2010
Genus *Bicellariella* Levinsen, 1909			
Bicellariella ciliata (Linnaeus, 1758)	Azores	-	Meireles & Gordon, 2013 (unpublished)
Bicellariella sp. ?	Azores	845 – 2460 m	Calvet, 1931
Family Beaniidae Canu & Bassler, 1927			
Genus *Beania* Johnston, 1840			
Beania cylindrica (Hincks, 1886)	Azores	-	Meireles & Gordon, 2013 (unpublished)
Beania mirabilis Johnston, 1840	Azores	130 m	Jullien & Calvet, 1903
Family Candidae d'Orbigny, 1851			
Genus *Scrupocellaria* van Beneden, 1845			
Scrupocellaria maderensis Busk, 1860	Azores	-	Meireles & Gordon, 2013 (unpublished)
Scrupocellaria incurvata Waters, 1896	Azores	-	Meireles & Gordon, 2013 (unpublished)
Scrupocellaria scrupea Busk, 1852	Azores, Belgian coast, British Isles, Portugal (WORMS, 2013)	130 m	Tempera *et al.*, 2010
Scrupocellaria hirsuta Jullien & Calvet, 1903	Azores	27 - 130 m	Calvet, 1931
Scrupocellaria scruposa (Linnaeus, 1758)	Azores and Cape Verde	52 – 550 m	Calvet, 1931
Scrupocellaria reptans (Linnaeus, 1758)	Azores	27 m	Calvet, 1931
Genus *Notoplites* Harmer, 1923			
Notoplites marsupiatus (Jullien, 1882)	Azores and NW Spain	65 – 1250 m	Calvet, 1931
Genus *Caberea* Lamouroux, 1816			
Caberea boryi (Audouin, 1826)	Azores	130 m	Meireles & Gordon, 2013 (unpublished)

SUPERFAMILY MICROPOROIDEA			
Family Microporidae Gray, 1848			
Genus *Micropora* Gray, 1848			
Micropora coriacea (Johnston, 1847)	Azores	130 m	Jullien & Calvet, 1903
SUPERFAMILY CELLARIOIDEA			
Family Cellariidae Fleming, 1828			
Genus *Cellaria* Ellis & Solander, 1786			
Cellaria salicornioides Lamouroux, 1816	Azores		Meireles & Gordon, 2013 (unpublished)
Cellaria gracilis (Busk, 1852)	Azores (Princess Alice seamount)	200 m	Calvet, 1931
Cellaria biseriata Maplestone, 1900	Azores; cap. Blane and Sargasses sea	1732 - 3530 m	Calvet, 1931
SUPERFAMILY CRIBRILINOIDEA			
Family Cribrilinidae Hincks, 1879			
Genus *Puellina* Jullien, 1886			
Puellina bathyalis (Harmelin & Aristegui, 1988)	Azores, Canary	220 – 900 m	Harmelin & Aristegui, 1988
Puellina orientalis azorensis (Harmelin, 1988)	Azores, Canary	10 – 300 m	Harmelin, 1988
Puellina orientalis lusitanica (Harmelin, 1988)	Azores, Portugal, Mediterranean, Gibraltar	205 – 690 m	Harmelin, 1988
Puellina radiata (Moll, 1803)	Azores, Madeira, Canarias; Atlantic oriental (France, Spain, Maroc), Mediterranean, Tristan da Cunha, Florida and Pacific (Australia, China, Philippines, Bornèo, etc.)	98 – 930 m	Calvet, 1931
Puellina sp. 1	Azores		Meireles & Gordon, 2013 (unpublished)
Genus *Membraniporella* Smitt, 1873			
Membraniporella alice Jullien, 1903	Azores	130 m	Jullien & Calvet, 1903

Membraniporella neptuni Jullien, 1903	Azores	130 m	Jullien & Calvet, 1903
Genus *Figularia* Jullien, 1886			
Figularia figularis (Johnston, 1847)	Azores	130 m	Jullien & Calvet, 1903
SUPERFAMILY LEPRALIELLOIDEA (UMBONULOIDEA)			
Family Umbonulidae Canu, 1904			
Genus *Umbonula* Hincks, 1880			
Umbonula verrucosa (Esper, 1790)	Azores	5 – 318 m	Jullien & Calvet, 1903 / Tempera *et al.*, 2010
Family Bryocryptellidae Vigneaux, 1949			
Genus *Porella* Gray, 1848			
Porella belli (Dawson, 1859)	Azores	1165 m	Calvet, 1931
Genus *Palmiskenea* Bishop & Hayward, 1989			
Palmiskenea skenei (Ellis & Solander, 1786)	Azores	736 m	Jullien & Calvet, 1903
Family Romancheinidae Jullien, 1888			
Genus *Escharella* Gray, 1848			
Escharella laqueata (Norman, 1864)	Azores	1165 m	Calvet, 1931
Family Tessaradomidae Jullien, 1903			
Genus *Tessaradoma* Norman, 1869			
Tessaradoma boreale (Busk, 1860)	Azores; coast of Bretagne.	224 – 1600 m	Calvet, 1931 / Meireles & Gordon, 2013 (unpublished)
SUPERFAMILY SMITTINOIDEA			
Family Smittinidae Levinsen, 1909			

Genus *Smittina* Norman, 1903			
Smittina ensifera Jullien & Calvet, 1903	Azores	130 m	Jullien & Calvet, 1903
Genus *Smittoidea* Osburn, 1952			
Smittoidea avicularia (Calvet, 1907)	Azores	349 – 1360 m	Meireles & Gordon, 2013 (unpublished)
Smittoidea azorensis (Jullien, 1903)	Azores; Princess Alice seamount	200 – 1250 m	Calvet, 1931
Smittoidea ophidiana (Waters, 1878)	Azores and Canarias	69 – 540 m	Calvet, 1931
Family Bitectiporidae MacGillivray, 1895			
Genus *Metroperiella* Canu & Bassler, 1917			
Metroperiella lepralioides (Calvet, 1903)	Azores	130 m	Jullien & Calvet, 1903
Genus *Schizomavella* Canu & Bassler, 1917			
Schizomavella cuspidata (Hincks, 1880)	Azores		Meireles & Gordon, 2013 (unpublished)
Schizomavella auriculata (Hassall, 1842)	Azores	95 – 130 m	Jullien & Calvet, 1903
Schizomavella triaviculata (Calvet, 1903)	Azores	98 – 550 m	Calvet, 1931 / Meireles & Gordon, 2013 (unpublished)
Schizomavella neptuni (Jullien, 1883)			
Family Lanceoporidae Harmer, 1957			
Genus *Stephanotheca* Reverter, Souto & Pulpeiro, 2012			
Stephanotheca richardi (Calvet, 1903)	Azores	130 m	Jullien & Calvet, 1903
Stephanotheca fayalensis (Calvet *in* Jullien & Calvet, 1903)	Azores	130 m	Jullien & Calvet, 1903
Family Watersiporidae Vigneaux, 1949			
Genus *Watersipora* Neviani, 1896			

Watersipora complanata (Norman, 1864)	Azores		Meireles & Gordon, 2013 (unpublished)
Watersipora subtorquata (d'Orbigny, 1852)	Azores	Tidal - 130 – 318 m	Jullien & Calvet, 1903 / Meireles & Gordon, 2013 (unpublished)
Watersipora cucullata (Busk, 1854)	Azores; Gibraltar; Cape Verde	0 – 219 m	Calvet, 1931
SUPERFAMILY SCHIZOPORELLOIDEA			
Family Schizoporellidae Jullien, 1883			
Genus *Schizoporella* Hincks, 1877			
Schizoporella dunkeri (Reuss,1848)	Azores		Tempera *et al.*, 2010
Schizoporella guttata Jullien & Calvet, 1903	Azores	130 m	Jullien & Calvet, 1903
Schizoporella jullieni Jullien & Calvet, 1903	Azores	130 m	Jullien & Calvet, 1903
Family Escharinidae Tilbrook, 2006			
Genus *Escharina* Milne Edwards, 1836			
Escharina vulgaris (Moll, 1803)	Azores	130 m	Meireles & Gordon, 2013 (unpublished)
Escharina protecta Zabala, Maluquer, Harmelin, 1993	Azores, Madeira, Mediterranean, Red Sea, ?Pacific Ocean	6 – 130 m	Zabala, Maluquer, Harmelin, 1993
Family Microporellidae Hincks, 1879			
Genus *Microporella* Hincks, 1877			
Microporella ciliata (Pallas, 1766)	Azores	130 m	Jullien & Calvet, 1903
Microporella hastigera (Busk, 1884)	Azores	130 m	Jullien & Calvet, 1903
Family Calwelliidae MacGillivray, 1887			
Genus *Ichthyaria* Busk, 1884			
Ichthyaria grimaldii Jullien & Calvet, 1903	Azores	318 – 1300 m	Jullien & Calvet, 1903

Ichthyaria picoensis Jullien & Calvet, 1903	Azores	736 m	Jullien & Calvet, 1903
Family Jaculinidae Zabala, 1986			
Genus *Jaculina* Jullien *in* Jullien & Calvet, 1903			
Jaculina blanchardi Jullien & Calvet, 1903	Azores	318 m	Jullien & Calvet, 1903
Jaculina dichotoma Calvet, 1931	Azores	1250 m	Calvet, 1931
SUPERFAMILY CELLEPOROIDEA			
Family Celleporidae Johnston, 1838			
Genus *Buffonellaria* Canu & Bassler, 1927			
Buffonellaria acorensis Berning & Kuklinski, 2008	Azores	135 – 230 m	Berning & Kuklinski, 2008
Buffonellaria nebulosa (Jullien & Calvet, 1903)	Azores	130 – 318 m	Jullien & Calvet, 1903
Genus *Buskea* Heller, 1867			
Buskea dichotoma (Hincks, 1862)	Azores; Canaries; Coast of Bretagne	98 - 2170 m	Calvet, 1931
Genus *Celleporina* Gray, 1848			
Celleporina decipiens Hayward, 1976	Azores		Meireles & Gordon, 2013 (unpublished)
Celleporina hassallii (Johnston, 1847)	Azores		Meireles & Gordon, 2013 (unpublished)
Celleporina costazii (Audouin, 1826)	Azores	0 - 550 m	Calvet, 1931
Genus *Galeopsis* Jullien, 1903			
Galeopsis pentagonus (d'Orbigny, 1842)	Azores	130 m	Jullien & Calvet, 1903
Galeopsis rabidus Jullien, 1903	Azores	318 – 736 m	Jullien & Calvet, 1903
Genus *Lagenipora* Hincks, 1877			
Lagenipora polita Jullien, 1903	Azores	318 m	Jullien & Calvet, 1903

Lagenipora socialis Hincks, 1877	Azores	130 m	Jullien & Calvet, 1903
Genus *Osthimosia* Jullien, 1888			
Osthimosia parvula Jullien, 1903	Azores	845 - 1250 m	Calvet, 1931
Genus *Omalosecosa* Canu & Bassler, 1925			
Omalosecosa ramulosa (Linnaeus, 1767)	Azores		Jullien & Calvet, 1903
Family Phidoloporidae Gabb & Horn, 1862			
Genus *Stephanollona* Duvergier, 1921			
Stephanollona armata (Hincks, 1862)	Azores		Meireles & Gordon, 2013 (unpublished)
Genus *Schizotheca* Hincks, 1877			
Schizotheca carmenae Reverter-Gil & Pulpeiro, 2007	Azores and SW Portugal (Sagres)	45 – 148 m	Reverter & Pulpeiro, 2007
Genus *Reteporella* Busk, 1884			
Reteporella septentrionalis (Harmer, 1933)	Azores	20 – 1300 m	Jullien & Calvet, 1903
Reteporella oceanica (Jullien & Calvet, 1903)	Azores	318 - 1300 m	Jullien & Calvet, 1903 / Calvet 1931
Reteporella gracilis (Jullien & Calvet, 1903)	Azores	523 – 845 m	Jullien & Calvet, 1903 / Calvet 1931
Reteporella tristis (Jullien & Calvet, 1903)	Azores	200 – 349 m	Jullien & Calvet, 1903 / Calvet 1931
Reteporella rara (Jullien & Calvet, 1903)	Azores	318 m	Jullien & Calvet, 1903
Reteporella producta (Busk, 1884)	Azores	318 m	Jullien & Calvet, 1903
Reteporella dichotoma (Hincks, 1878)	Azores	318 m	Jullien & Calvet, 1903
Reteporella sp.	Azores		Jullien & Calvet, 1903
Reteporella sp. 1	Azores		Meireles & Gordon, 2013 (unpublished)
SUPERFAMILY ADEONOIDEA			

Genus *Reptadeonella* Busk, 1884			
Reptadeonella violacea (Johnston, 1847)	Azores		Meireles & Gordon, 2013 (unpublished)
Reptadeonella insidiosa (Jullien, 1903)	Azores; Cape Verde, Morroco, Guernesey, Hasting, Gulf of Gascogne	52 – 219 m	Calvet, 1931
Genus *Adeonellopsis* MacGillivray, 1886			
Adeonellopsis distoma (Busk, 1858)	Azores; Madeira, Canaries, western Mediterranean and Indian Ocean	98 – 1262 m	Calvet, 1931
SUPERFAMILY HIPPOTHOOIDEA			
Family Hippothoidae Busk, 1859			
Genus *Hippothoa* Lamouroux, 1821			
Hippothoa divaricata Lamouroux, 1821	Azores	130 m	Jullien & Calvet, 1903
Hippothoa flagellum Manzoni, 1870	Azores	130 m	Jullien & Calvet, 1903
Hippothoa amoena Jullien & Calvet, 1903	Azores	130 - 318 m	Jullien & Calvet, 1903
Family Chorizoporidae Vigneaux, 1949			
Genus *Chorizopora* Hincks, 1879			
Chorizopora brongniartii (Audouin, 1826)	Azores	130 – 1300 m	Meireles & Gordon, 2013 (unpublished)
Family Trypostegidae Gordon, Tilbrook & Winston *in* Winston, 2005			
Genus *Trypostega* Levinsen, 1909			
Trypostega papillata (Busk, 1859)	Azores		Jullien & Calvet, 1903
Trypostega amaena Jullien, 1903	Azores		Jullien & Calvet, 1903
Family Haplopomidae Gordon *in* De Blauwe, 2009			
Genus *Haplopoma* Levinsen, 1909			
Haplopoma bimucronatum (Moll, 1803)	Azores		Meireles & Gordon, 2013 (unpublished)

SUPERFAMILY SCHIZOPORELLOIDEA			
Family Escharinidae Tilbrook, 2006			
Genus *Herentia* Gray, 1848			
Herentia hyndmanni (Johnston, 1847)	Azores	120 – 130 m	Jullien & Calvet, 1903
Family Lacernidae Jullien, 1888			
Genus *Nimba* Jullien & Calvet, 1903			
Nimba praetexta Jullien & Calvet, 1903	Azores	130 – 318 m	Jullien & Calvet, 1903
Genus *Nimbella* Jullien & Calvet, 1903			
Nimbella limbata Jullien & Calvet, 1903	Azores	120 m	Jullien & Calvet, 1903
ORDER CTENOSTOMATA BUSK, 1852			
SUPERFAMILY ALCYONIDIOIDEA			
Family Pherusellidae Osburn & Soule, 1953			
Genus *Pherusella* Soule, 1951			
Pherusella tubulosa (Solander, 1786)	Mediterranean, Atlantic Ocean (Dominique, Brazil, Azores, Cape verde) and Chile	91 – 318 m	Calvet, 1931
SUPERFAMILY VESICULARIOIDEA			
Family Vesiculariidae Hincks, 1880			
Genus *Amathia* Lamouroux, 1812			
Amathia lendigera (Linnaeus, 1758)	Azores	5 – 6 m	Jullien & Calvet, 1903
Genus *Bowerbankia* Farre, 1837			

Bowerbankia pusilla Jullien & Calvet, 1903	Azores		Jullien & Calvet, 1903
Genus *Zoobotryon* Ehrenberg, 1831			
Zoobotryon verticillatum (Delle Chiaje, 1822)	Azores		Tempera *et al.*, 2010
ORDER CYCLOSTOMATA BUSK, 1852			
SUBORDER TUBULIPORINA			
Family Annectocymidae Hayward & Ryland, 1985			
Genus *Annectocyma* Hayward & Ryland, 1985			
Annectocyma major (Johnston, 1847)	Azores	130 m	Jullien & Calvet, 1903
Genus *Entalophoroecia* Harmelin, 1976			
Entalophoroecia crisioides (Calvet *in* Jullien & Calvet, 1903)	Azores	130 m	Jullien & Calvet, 1903
Entalophoroecia deflexa (Couch, 1842)	Azores		Jullien & Calvet, 1903
Family Terviidae Canu & Bassler, 1920			
Genus *Tervia* Jullien, 1883			
Tervia irregularis (Meneghini, 1844)	Azores	318 m	Jullien & Calvet, 1903
Family Tubuliporidae Johnston, 1838			
Genus *Idmidronea* Canu & Bassler, 1920			
Idmidronea atlantica (Forbes *in* Johnston, 1847)	Azores	5 - 318 m	Jullien & Calvet, 1903
Idmidronea contorta (Busk, 1875)	Azores	95 m	Jullien & Calvet, 1903
Genus *Tubulipora* Lamarck, 1816			

Tubulipora notomala (Busk, 1875)	Azores		Jullien & Calvet, 1903
Tubulipora liliacea (Pallas, 1766)	Azores		Jullien & Calvet, 1903
Family Plagioeciidae Canu, 1918			
Genus *Diplosolen* Canu, 1918			
Diplosolen grimaldii Jullien & Calvet, 1903	Azores		Jullien & Calvet, 1903
Family Mecynoeciidae Canu, 1918			
Genus *Mecynoecia* Canu, 1918			
Mecynoecia idmoneoides Calvet, 1903	Azores	318 – 736 m	Jullien & Calvet, 1903
Mecynoecia sp.	Azores	454 m	Jullien & Calvet, 1903
SUBORDER CANCELLATA			
Family Horneridae Gregory, 1899			
Genus *Hornera* Lamouroux, 1821			
Hornera canui Calvet, 1911	Azores	880 - 1385 m	Calvet, 1931
Family Lichenoporidae Smitt, 1867			
Genus *Disporella* Gray, 1848			
Disporella novaehollandiae (d'Orbigny, 1853)	Azores		Jullien & Calvet, 1903
Disporella picoensis (Calvet *in* Jullien & Calvet, 1903)	Azores		Jullien & Calvet, 1903
Disporella fimbriata (Busk, 1875)	Antartic and subantartic Atlantic to Pacific; Azores, Cape Verde, Cile and Gulf of Gascogne	52 – 219 m	Calvet, 1931
SUBORDER ARTICULINA			
Family Crisiidae Johnston, 1838			

Genus *Crisia* Lamouroux, 1812			
Crisia eburnea (Linnaeus, 1758)	Azores	736 m	Meireles & Gordon, 2013 (unpublished)
Crisia denticulata (Lamarck, 1816)	Azores	tidal	Jullien & Calvet, 1903
Crisia ramosa Harmer, 1891	Azores, Mediterranean, Monaco	27 – 69 m	Calvet, 1931
Family Crisinidae d'Orbigny, 1853			
Genus *Biidmonea* Calvet, 1903			
Biidmonea fayalensis Calvet *in* Jullien & Calvet, 1903	?	?	?

* This checklist was development during a technical visit to Dr. Dennis Gordon (NIWA- National Institute of Water & Atmospheric Research, Wellington, New Zealand [February-July 2013]) and contains unpublished data. This table will submit to publish in a scientific journal.

TABLE 2. CHECKLIST OF THE RECENT AND FOSSIL MARINE OSTRACODA OF THE AZORES ARCHIPELAGO †

CLASS OSTRACODA LATREILLE, 1802

	Geographical Distribution	Bathymetry (m)	References
ORDER PODOCOPIDA MÜLLER, 1894			
Family Bairdiidae Sars, 1888			
Genus *Neonesidea* Maddocks, 1969			
Neonesidea longisetosa (Brady 1902)	Azores; Carribbean; Florida	1 and 85 m	Meireles *et al.*, 2013
Neonesidea sp. 1	Azores	249 - 371 m	Meireles (unpublished)
Family Leptocytheridae Hanai, 1957			
Genus *Leptocythere* Müller, 1927			
Leptocythere pellucida (Baird, 1850).	Azores; North Sea, Atlantic Coast of France and Britain, southern Norway and the western Baltic	1 to 50 m	Meireles *et al.*, 2013
Genus *Callistocythere* Ruggieri, 1953			
Callistocythere insularis n. sp.	Azores	1 to 23 m	Meireles *et al.*, 2013
Family Cytherideidae Sars, 1925			

Genus *Cyprideis* Jones, 1856			
Cyprideis torosa (Jones, 1850)	Azores; Widespread throughout Europe and as far north as Iceland, W and Central Asia, and N Africa.Also found in lakes in Central Africa.	freshwater to littoral	Meireles *et al.*, 2013
Family Trachyleberididae Sylvester-Bradley, 1948			
Genus *Carinocythereis* Ruggieri, 1956			
Carinocythereis whitei (Baird, 1850)	Azores; British Isles, the Atlantic coast of France and the Mediterranean	1 to 20 m	Meireles *et al.*, 2013
Family Hemicytheridae Puri, 1953			
Genus *Aurila* Porkorný, 1955			
Aurila convexa (Baird, 1850)	Azores; North Sea, France, Portugal, the Mediterranean and Britain	1 to 54 m	Meireles *et al.*, 2013
Aurila woutersi Horne, 1986	Azores; Southern British Isles	1 to 20 m	Meireles *et al.*, 2013
Aurila prasina Barbeito-Gonzalez, 197	Azores; Lecce and S. Maria di Leuca, in Adriatic Sea and in Naxos, Greece	1 to 20 m	Meireles *et al.*, 2013
Genus *Heterocythereis* Elofson, 1941			
Heterocythereis albomaculata (Baird, 1938)	Azores; North Sea and Atlantic	1 to 20 m	Meireles *et al.*, 2013
Genus *Urocythereis* Ruggieri, 1950			
Urocythereis britannica Athersuch, 1977	Azores; Atlantic, the North Sea and probably in the Mediterranean	1 to 69 m	Meireles *et al.*, 2013
Family Loxoconchidae Sars, 1925			
Genus *Loxoconcha* Sars, 1866			
Loxoconcha rhomboidea (Fischer, 1855)	Azores; Europe, from N Norway to Madeira and Canary Islands, off N Africa. Mediterranean	1 to 70 m	Meireles *et al.*, 2013

Loxoconcha cf. *ochlockoneensis* Puri, 1960	Azores; West coast of Florida and the Bermudas	1 to 20 m	Meireles *et al.*, 2013
Family Cytheruridae Müller, 1894			
Genus *Semicytherura* Wagner, 1957			
Semicytherura brandoni n. sp.	Azores	littoral	Meireles *et al.*, 2013
Semicytherura cf. *cornuta* (Brady, 1868)	Azores; Atlantic coast of France and S Norway	littoral (~18 m)	Meireles *et al.*, 2013
Family Xestoleberididae Sars, 1928			
Genus *Xestoleberis* Sars, 1866			
Xestoleberis rubens Whittaker, 1978	Azores; North Sea and the Atlantic coast of France	1 to 45 m	Meireles *et al.*, 2013
Xestoleberis cf. *depressa* Sars, 1866	Azores; North Sea, Scandinavia and also in the Western part of the Baltic	littoral	Meireles *et al.*, 2013
Xestoleberis sp.	Azores	littoral	Meireles *et al.*, 2013
Family Bythocytheridae Sars, 1866			
Genus *Sclerochilus* Sars, 1866			
Sclerochilus hicksi Athersuch & Horne 1987	Azores; N Atlantic, Mediterranean	littoral	Meireles *et al.*, 2013
Family Paradoxostomatidae Brady & Norman, 1889			
Genus *Lanceostoma* Schornikov & Keyser, 2004			
Lanceostoma simplex n. sp	Azores	1 to 20 m	Meireles *et al.*, 2013
ORDER MYODOCOPIDA SARS, 1866			
Family Cylindroleberididae Müller, 1906			

Genus *Cylindroleberis* Brady, 1867			
Cylindroleberis sp.	Azores	littoral	Meireles *et al.*, 2013
FOSSILS			
ORDER PODOCOPIDA MÜLLER, 1894			
Family Xestoleberididae Sars, 1928			
Genus *Xestoleberis* Sars, 1866			
Xestoleberis cf. *paisi* Nascimento, 1989			Meireles *et al.*, 2012
Family Loxoconchidae Sars, 1925			
Genus *Loxoconcha* Sars, 1866			
Loxoconcha stellifera Müeller, 1894			Meireles *et al.*, 2012
Loxoconcha rhomboidea (Fischer, 1855)			Meireles *et al.*, 2012
Family Leptocytheridae Hanai, 1957			
Genus *Callistocythere* Ruggieri, 1953			
Callistocythere oertlii Nascimento, 1989			Meireles *et al.*, 2012

Genus *Leptocythere* Sars, 1922			
Leptocythere azorica Meireles & Faranda, 2012			Meireles *et al.*, 2012
Family Hemicytheridae Puri, 1953			
Genus *Pachycaudites* Uliczny, 1969			
Pachycaudites cf. *armilla* Ciampo, 1986			Meireles *et al.*, 2012
Genus *Dameriacella* Liebau, 1991			
Dameriacella cf. *dameriacensis* (Keij, 1958)			Meireles *et al.*, 2012
Genus *Aurila* Pokorný, 1955			
Aurila sp.			Meireles *et al.*, 2012
Genus *Quadracythere* Hornibrook, 1952			
?*Quadracythere* sp.			Meireles *et al.*, 2012
Genus *Heliocythere* Bonaduce, Ruggieri, Russo, 1988			
Heliocythere magnei (Keij, 1953)			Meireles *et al.*, 2012
Family Bairdiidae Sars, 1888			
Genus *Neonesidea* Maddocks, 1969			

Neonesidea rochae Nascimento, 1989			Meireles *et al.*, 2012
Family Candonidae Kaufmann, 1900			
Genus *Paracypris* Sars, 1866			
Paracypris sp.			Meireles *et al.*, 2012
Family Cytherideidae Sars, 1925			
Genus *Cyamocytheridea* Oertli, 1956			
Cyamocytheridea sp.			Meireles *et al.*, 2012

[†] This table uses published and unplublished data, and is restricted to benthic species.

TABLE 3. THE BRYOZOA (FOSSIL AND RECENT) COLLECTION OF THE DBUA (Department of Biology of the University of the Azores).

BRYOZOA COLLECTION

Curator: Ricardo Piazza Meireles

Prefix	**Species**	**Family**	**Location**	**Deep (m)**	**Sample**
DB/BRY 0001	*Scrupocellaria* sp. 1	Candidae d'Orbigny, 1851	Faial Island	-30	PAM 0041
DB/BRY 0002	*Scrupocellaria maderensis* Busk, 1860	Candidae d'Orbigny, 1851	Faial Island	-30	PAM 0041
DB/BRY 0003	*Reteporella mediterranea*	Phidoloporidae Gabb & Horn, 1862	Faial Island	-30	PAM 0041
DB/BRY 0004	*Crisia eburnea*	Crisiidae Johnston, 1838	Faial Island	-30	PAM 0041
DB/BRY 0005	#	Tubuliporidae Johnston, 1838	Faial Island	-30	PAM 0041
DB/BRY 0006	*Celleporina hassallii* (Johnston, 1847)	Celleporidae Johnston, 1838	Faial Island	-30	PAM 0041
DB/BRY 0007	*Schizomavella cuspidata* (Hincks, 1880)	Bitectiporidae MacGillivray, 1895	Faial Island	-30	PAM 0041
DB/BRY 0008	*Watersipora subovoidea* (d'Orbigny, 1852)	Watersiporidae Vigneaux, 1949	Faial Island	-30	PAM 0041
DB/BRY 0009	Gen. and sp. indet 5	#	Faial Island	-30	PAM 0041
DB/BRY 0010	Gen. and sp. indet 2	#	Faial Island	-30	PAM 0041
DB/BRY 0011	*Beania cylindrica* (Hincks, 1886)	Beaniidae Canu & Bassler, 1927	Flores Island	-3	PAM 0002
DB/BRY 0012	*Watersipora subtorquata* (d'Orbigny, 1852)	Watersiporidae Vigneaux, 1949	São Miguel Island	-10	PAM 0014
DB/BRY 0013	Gen. and sp. indet 4	#	Graciosa Island	0	PAM 0022

DB/BRY 0014	*Caberea boryi* (Audouin, 1826)	Candidae d'Orbigny, 1851	São Miguel Island	0	PAM 0020
DB/BRY 0015	*Escharina vulgaris* (Moll, 1803)	Escharinidae Tilbrook, 2006	Pico Island	-46	PAM 0042
DB/BRY 0016	Gen. and sp. indet 8	#	Faial Island	-30	PAM 0046
DB/BRY 0017	*Caberea boryi* (Audouin, 1826)	Candidae d'Orbigny, 1851	São Miguel Island	-20	PAM 0047
DB/BRY 0018	*Chorizopora brongniartii* (Audouin, 1826)	Chorizoporidae Vigneaux, 1949	Faial Island	-30	PAM 0054
DB/BRY 0019	*Bicellariella ciliata* (Linnaeus, 1758)	Bugulidae Gray, 1848	São Miguel Island	-10	DOP-3896-BRY
DB/BRY 0020	*Stephanollona armata* (Hincks, 1862)	Phidoloporidae Gabb & Horn, 1862	Faial Island	-20	DOP-3900-BRY
DB/BRY 0021	*Bugula dentata* (Lamouroux, 1816)	Bugulidae Gray, 1848	Corvo Island	mergulho	DOP-3901-BRY
DB/BRY 0022	*Gregarinidra gregaria* (Heller, 1867)	Flustridae Fleming, 1828	Faial Island	-10 / -20	DOP-3955-BRY
DB/BRY 0023	*Reptadeonella violacea* (Johnston, 1847)	Adeonidae Busk, 1884	Faial Island	-5 / -10	DOP-3959-BRY
DB/BRY 0024	#	Tubuliporidae Johnston, 1838	Faial Island	-10 / -15	DOP-3960-BRY
DB/BRY 0025	*Watersipora complanata* (Norman, 1864)	Watersiporidae Vigneaux, 1949	Formigas Islet	-10	DOP-3992-BRY
DB/BRY 0026	*Watersipora complanata* (Norman, 1864)	Watersiporidae Vigneaux, 1949	Flores Island	-10 / -15	DOP-4003-BRY
DB/BRY 0027	#	#	Faial Island	-5 / -10	DOP-4011-BRY
DB/BRY 0028	*Cellaria salicornioides* Lamouroux, 1816	Cellariidae Fleming, 1828	Formigas Islet	#	DOP-4013-BRY
DB/BRY 0029	*Schizomavella triaviculata* (Jullien & Calvet, 1903)	Bitectiporidae MacGillivray, 1895	Açores Seamount	-219 / -329	E-1713-BRY
DB/BRY 0030	*Schizomavella triaviculata* (Jullien & Calvet, 1903)	Bitectiporidae MacGillivray, 1895	Pico Island	-200	E-2035-BRY
DB/BRY 0031	Anthoathecata	Stylasteridae	Princesa Alice Seamount	-238	E-1679-BRY
DB/BRY 0032	*Adeonellopsis distoma* (Busk, 1858)	Adeonidae Busk, 1884	Azores archipelago	#	E-2469-BRY

DB/BRY 0033	*Spiralaria* cf. *florea*	Flustridae Fleming, 1828	Rainbow (hydrothermal field)	#	E-2500-BRY
DB/BRY 0034	*Escharina vulgaris* (Moll, 1803)	Escharinidae Tilbrook, 2006	Faial Island	-10	DOP-3948-BRY
DB/BRY 0035	*Puellina* sp.	Cribrilinidae Hincks, 1879	Santa Maria Island	outcrop	#
DB/BRY 0036	*Escharina* sp.	Escharinidae Tilbrook, 2006	Santa Maria Island	outcrop	#
DB/BRY 0037	*Onychocella* sp.	Onychocellidae Jullien, 1882	Santa Maria Island	outcrop	#
DB/BRY 0038	*Schizotheca* sp.	Phidoloporidae Gabb & Horn, 1862	Santa Maria Island	outcrop	#
DB/BRY 0039	*Cribrilina* sp.	Cribrilinidae Hincks, 1879	Santa Maria Island	outcrop	#
DB/BRY 0040	*Cryptosula* sp.	Cryptosulidae Vigneaux, 1949	Santa Maria Island	outcrop	#
DB/BRY 0041	*Escharina* sp.	Escharinidae Tilbrook, 2006	Santa Maria Island	outcrop	#
DB/BRY 0042	#	#	Santa Maria Island	outcrop	#
DB/BRY 0043	#	#	Santa Maria Island	outcrop	#
DB/BRY 0044	#	#	Santa Maria Island	outcrop	#
DB/BRY 0045	#	#	Santa Maria Island	outcrop	#
DB/BRY 0046	#	#	Santa Maria Island	outcrop	DBUA-F 911
DB/BRY 0047	#	#	Santa Maria Island	outcrop	DBUA-F 494
DB/BRY 0048	#	#	Santa Maria Island	outcrop	#
DB/BRY 0049	#	#	Santa Maria Island	outcrop	#
DB/BRY 0050	#	#	Santa Maria Island	outcrop	#
DB/BRY 0051	#	#	Santa Maria Island	outcrop	#
DB/BRY 0052	#	#	Santa Maria Island	outcrop	#

DB/BRY 0053	#	#	Santa Maria Island	outcrop	#
DB/BRY 0054	#	#	Santa Maria Island	outcrop	#
DB/BRY 0055	#	#	Santa Maria Island	outcrop	MP 0001
DB/BRY 0056	#	#	Santa Maria Island	outcrop	MP 0001
DB/BRY 0057	#	#	Santa Maria Island	outcrop	MP 0007
DB/BRY 0058	#	#	Santa Maria Island	outcrop	MP 0007
DB/BRY 0059	#	#	Santa Maria Island	outcrop	MP 0009
DB/BRY 0060	#	#	Santa Maria Island	outcrop	MP 0009
DB/BRY 0061	#	#	Santa Maria Island	outcrop	MP 0009
DB/BRY 0062	#	#	Santa Maria Island	outcrop	MP 0009
DB/BRY 0063	#	#	Santa Maria Island	outcrop	MP 0009
DB/BRY 0064	#	#	Santa Maria Island	outcrop	MP 0018
DB/BRY 0065	#	#	Santa Maria Island	outcrop	MP 0018
DB/BRY 0066	#	#	Santa Maria Island	outcrop	MP 0018
DB/BRY 0067	#	#	Santa Maria Island	outcrop	MP 0018
DB/BRY 0068	*Tessaradoma boreale* (Busk, 1860)	Tessaradomidae Jullien, 1903	?	-304	DOP 2861
DB/BRY 0069	#	#	Açores Seamount	-441	DOP 3272
DB/BRY 0070	*Puellina* sp. 1	Cribrilinidae Hincks, 1879	Condor Seamount	-400	DOP 3257
DB/BRY 0071	*Aplousina capriensis* (Waters, 1898)	Calloporidae Norman, 1903	Pico-Faial chanal	-130	DOP 974
DB/BRY 0072	#	#	Formigas Islet	-20 / -30	68a
DB/BRY 0073	#	#	Formigas Islet	-20 / -30	68b

DB/BRY 0074	#	#	Faial Island	-23	47
DB/BRY 0075	*Schizoporella dunkeri*	Schizoporellidae Jullien, 1883	Faial Island	-10 / -12	25
DB/BRY 0076	#	#	Faial Island	-10 / -12	27
DB/BRY 0077	#	#	Santa Maria Island	-20	24
DB/BRY 0078	#	#	Formigas Islet	-30	97
DB/BRY 0079	*Smittoidea avicularia* (Calvet, 1907)	Smittinidae Levinsen, 1909	São Jorge Island	-188?	2701
DB/BRY 0080	*Cellaria salicornioides* Lamouroux, 1816	Cellariidae Fleming, 1828	Terceira Island	-354?	2918
DB/BRY 0081	*Scrupocellaria maderensis* Busk, 1860	Candidae d'Orbigny, 1851	38,524N/-28,585W	-457	DOP # 821
DB/BRY 0082	*Celleporina hassallii* (Johnston, 1847)	Celleporidae Johnston, 1838	Faial Island	-30	PAM 0041
DB/BRY 0083	*Celleporina decipiens* Hayward, 1976	Celleporidae Johnston, 1839	Flores Island	-20	PAM 0002
DB/BRY 0084	*Cellaria salicornioides* Lamouroux, 1816	Cellariidae Fleming, 1828	--	--	DOP 3125
DB/BRY 0085	*Escharina vulgaris* (Moll, 1803)	Escharinidae Tilbrook, 2006	Pico Island	-69	PAM 0055
DB/BRY 0086	*Schizomavella cuspidata* (Hincks, 1880)	Bitectiporidae MacGillivray, 1895	Faial Island	-30	PAM 0046
DB/BRY 0087	*Schizomavella cuspidata* (Hincks, 1880)	Bitectiporidae MacGillivray, 1895	Faial Island	-30	PAM 0046
DB/BRY 0088	*Haplopoma bimucronatum* (Moll, 1803)	Haplopomidae Gordon in De Blauwe, 2009	Faial Island	-30	PAM 0041
DB/BRY 0089	*Chaperiopsis hirsuta* Reverter-Gil, Souto & Fernández-Pulpeiro, 2009	Chaperiidae Jullien, 1888	Faial Island	-85	PAM 0043
DB/BRY 0090	*Chaperiopsis hirsuta* Reverter-Gil, Souto & Fernández-Pulpeiro, 2009	Chaperiidae Jullien, 1888	Faial Island	-85	PAM 0043
DB/BRY 0091	*Stephanollona armata* (Hincks, 1862)	Phidoloporidae Gabb & Horn, 1862	Faial Island	-85	PAM 0043
DB/BRY 0092	*Stephanollona armata* (Hincks, 1862)	Phidoloporidae Gabb & Horn, 1862	Faial Island	-30	PAM 0046
DB/BRY 0093	*Reteporella* sp.	Phidoloporidae Gabb & Horn, 1862	Açores Seamount	-402	DOP # 986

DB/BRY 0094	*Reteporella* sp.	Phidoloporidae Gabb & Horn, 1862	--	--	DOP # 79
DB/BRY 0095	*Reteporella* sp.	Phidoloporidae Gabb & Horn, 1862	Condor Seamount	-238 / -243	DOP # 1933
DB/BRY 0096	*Reteporella* sp.	Phidoloporidae Gabb & Horn, 1862	--	--	DOP # 19
DB/BRY 0097	*Reteporella* sp.	Phidoloporidae Gabb & Horn, 1862	--	--	DOP # 2607
DB/BRY 0098	*Reteporella* sp.	Phidoloporidae Gabb & Horn, 1862	Santa Maria Island	-25	DOP # 2456
DB/BRY 0099	*Reteporella* sp.	Phidoloporidae Gabb & Horn, 1862	Mar da prata	-278.5	DOP # 2930
DB/BRY 0100	*Reteporella* sp.	Phidoloporidae Gabb & Horn, 1862	São Miguel Island	-67,4 / -768	DOP # 2459
DB/BRY 0101	*Scrupocellaria* sp.	Candidae d'Orbigny, 1851	--	--	DOP # 1
DB/BRY 0102	*Scrupocellaria* sp.	Candidae d'Orbigny, 1851	Princesa Alice Seamount	-238 / -329	DOP # 1681
DB/BRY 0103	*Scrupocellaria* sp.	Candidae d'Orbigny, 1851	--	--	DOP # 71
DB/BRY 0104	*Scrupocellaria* sp.	Candidae d'Orbigny, 1851	--	--	DOP # 67
DB/BRY 0105	*Scrupocellaria* sp.	Candidae d'Orbigny, 1851	--	--	DOP # 5
DB/BRY 0106	*Scrupocellaria* sp.	Candidae d'Orbigny, 1851	Açores Seamount	-307	DOP # 1428
DB/BRY 0107	*Scrupocellaria* sp.	Candidae d'Orbigny, 1851			DOP # 22
DB/BRY 0108	*Scrupocellaria* sp.	Candidae d'Orbigny, 1851	38,524N/-28,585W	-457	DOP # 821
DB/BRY 0109	*Bugula dentata* (Lamouroux, 1816)	Bugulidae Gray, 1848	--	--	DOP # 17
DB/BRY 0110	*Bugula neritina* (Linnaeus, 1758)	Bugulidae Gray, 1848	--	--	DOP # 72

TABLE 4. THE OSTRACODA (FOSSIL AND RECENT) COLLECTION OF THE DBUA (Department of Biology of the University of the Azores).

OSTRACODA COLLECTION

Curator: Ricardo Piazza Meireles

Prefix	**Species**	**Location**	**Deep (m)**	**Sample**	**Habitat**
DB/OS 0001	*Loxoconcha* cf. *ochlockoneensis*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0002	*Loxoconcha* cf. *ochlockoneensis*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0003	*Loxoconcha* cf. *ochlockoneensis*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0004	*Loxoconcha* cf. *ochlockoneensis*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0005	*Loxoconcha* cf. *ochlockoneensis*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0006	*Xestoleberis rubens*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0007	*Xestoleberis rubens*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0008	*Xestoleberis rubens*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0009	*Xestoleberis rubens*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0010	*Xestoleberis rubens*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0011	*Cyprideis torosa*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0012	*Cyprideis torosa*	Pico Island	-1	PAM 0001	intertidal

DB/OS 0013	*Cyprideis torosa*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0014	*Cyprideis torosa*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0015	*Cyprideis torosa*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0016	*Urocythereis britannica*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0017	*Urocythereis britannica*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0018	*Urocythereis britannica*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0019	*Urocythereis britannica*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0020	*Urocythereis britannica*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0021	*Urocythereis britannica*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0022	*Urocythereis britannica*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0023	*Urocythereis britannica*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0024	*Urocythereis britannica*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0025	*Urocythereis britannica*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0026	*Loxoconcha rhomboidea*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0027	*Loxoconcha rhomboidea*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0028	*Loxoconcha rhomboidea*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0029	*Loxoconcha rhomboidea*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0030	*Loxoconcha rhomboidea*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0031	*Aurila woutersi*	Pico Island	-54	PAM 0045	inner shelf
DB/OS 0032	*Aurila convexa*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0033	*Aurila convexa*	Terceira Island	-1	PAM 0007	intertidal

DB/OS 0034	*Aurila convexa*	Terceira Island	-23	PAM 0004	inner shelf
DB/OS 0035	*Aurila convexa*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0036	*Heterocythereis albomaculata*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0037	*Heterocythereis albomaculata*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0038	*Heterocythereis albomaculata*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0039	*Aurila prasina*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0040	*Aurila prasina*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0041	*Heterocythereis albomaculata*	Terceira Island	-3	PAM 0006	intertidal
DB/OS 0042	*Heterocythereis albomaculata*	Terceira Island	-3	PAM 0006	intertidal
DB/OS 0043	*Heterocythereis albomaculata*	Terceira Island	-3	PAM 0006	intertidal
DB/OS 0044	*Heterocythereis albomaculata*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0045	*Heterocythereis albomaculata*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0046	*Aurila prasina*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0047	*Aurila prasina*	Graciosa Island	-1	PAM 0012	intertidal
DB/OS 0048	*Aurila prasina*	Terceira Island	-1	PAM 0007	intertidal
DB/OS 0049	*Aurila prasina*	São Miguel Island	-20	PAM 0047	inner shelf
DB/OS 0050	*Aurila prasina*	Faial Island	-30	PAM 0054	inner shelf
DB/OS 0051	*Cyprideis torosa*	Terceira Island	-3	PAM 0006	intertidal
DB/OS 0052	*Cyprideis torosa*	Terceira Island	-3	PAM 0006	intertidal
DB/OS 0053	*Cyprideis torosa*	Terceira Island	-3	PAM 0006	intertidal
DB/OS 0054	*Carinocythereis whitei*	Terceira Island	-23	PAM 0004	inner shelf

DB/OS 0055	*Carinocythereis whitei*	São Miguel Island	-20	PAM 0047	inner shelf
DB/OS 0056	*Carinocythereis whitei*	São Miguel Island	-20	PAM 0047	inner shelf
DB/OS 0057	*Leptocythere pellucida*	Terceira Island	-3	PAM 0006	intertidal
DB/OS 0058	*Leptocythere* sp. 2	São Miguel Island	-20	PAM 0047	inner shelf
DB/OS 0059	*Leptocythere* sp. 2	São Miguel Island	-20	PAM 0047	inner shelf
DB/OS 0060	*Leptocythere* sp. 2	São Miguel Island	-20	PAM 0047	inner shelf
DB/OS 0061	*Callistocythere insularis* sp. nov.	Terceira Island	-23	PAM 0004	inner shelf
DB/OS 0062	*Callistocythere insularis* sp. nov.	Graciosa Island	-1	PAM 0012	intertidal
DB/OS 0063	*Callistocythere insularis* sp. nov.	Flores Island	-3	PAM 0002	intertidal
DB/OS 0064	*Semicytherura* cf. *cornuta*	Santa Maria Island	-13	PAM 0013	inner shelf
DB/OS 0065	*Semicytherura* sp. 2	Pico Island	-54	PAM 0045	inner shelf
DB/OS 0066	*Semicytherura* sp. 2	Pico Island	-54	PAM 0045	inner shelf
DB/OS 0067	*Semicytherura* sp. 3	São Miguel Island	-20	PAM 0047	inner shelf
DB/OS 0068	*Lanceostoma simplex* sp. nov.	Flores Island	-3	PAM 0002	intertidal
DB/OS 0069	*Lanceostoma simplex* sp. nov.	Flores Island	-3	PAM 0002	intertidal
DB/OS 0070	*Lanceostoma simplex* sp. nov.	Terceira Island	-23	PAM 0004	inner shelf
DB/OS 0071	*Lanceostoma simplex* sp. nov.	Pico Island	-54	PAM 0045	inner shelf
DB/OS 0072	*Paradoxostoma* sp. 2	Pico Island	-54	PAM 0045	inner shelf
DB/OS 0073	*Xestoleberis paisi*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0074	*Xestoleberis paisi*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0075	*Xestoleberis paisi*	Santa Maria Island	outcrop	DBUA-F 717	fossil

DB/OS 0076	*Loxoconcha stellifera*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0077	*Loxoconcha stellifera*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0078	*Loxoconcha stellifera*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0079	*Loxoconcha rhomboidea*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0080	*Loxoconcha rhomboidea*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0081	*Loxoconcha rhomboidea*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0082	*Callistocythere oertlii*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0083	*Callistocythere oertlii*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0084	*Callistocythere oertlii*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0085	*Leptocythere azorica* sp. nov.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0086	*Leptocythere azorica* sp. nov.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0087	*Leptocythere azorica* sp. nov.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0088	*Pachycaudites* cf. *armilla*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0089	*Pachycaudites* cf. *armilla*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0090	*Pachycaudites* cf. *armilla*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0091	*Dameriacella* cf. *dameriacensis*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0092	*Dameriacella* cf. *dameriacensis*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0093	*Dameriacella* cf. *dameriacensis*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0094	*Aurila* sp.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0095	*Aurila* sp.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0096	*?Quadracythere* sp.	Santa Maria Island	outcrop	DBUA-F 717	fossil

DB/OS 0097	*?Quadracythere* sp.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0098	*?Quadracythere* sp.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0099	*Heliocythere magnei*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0100	*Heliocythere magnei*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0101	*Heliocythere magnei*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0102	*Neonesidea rochae*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0103	*Neonesidea rochae*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0104	*Neonesidea rochae*	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0105	*Paracypris* sp.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0106	*Paracypris* sp.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0107	*Cyamocytheridea* sp.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0108	*Cyamocytheridea* sp.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0109	*Cyamocytheridea* sp.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0110	*Leptocythere azorica* sp. nov.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0111	*Leptocythere azorica* sp. nov.	Santa Maria Island	outcrop	DBUA-F 717	fossil
DB/OS 0112	*Loxoconcha rhomboidea*	São Miguel Island	-2	PAM 0065	intertidal
DB/OS 0113	*Heterocythereis albomaculata*	São Miguel Island	-2,5	PAM 0060	intertidal
DB/OS 0114	*Heterocythereis albomaculata*	São Miguel Island	-2,5	PAM 0061	intertidal
DB/OS 0115	*Heterocythereis albomaculata*	São Miguel Island	-2,5	PAM 0062	intertidal
DB/OS 0116	*Heterocythereis albomaculata*	São Miguel Island	-5	PAM 0062	intertidal
DB/OS 0117	*Lanceostoma simplex* sp. nov.	São Miguel Island	-2,5	PAM 0060	intertidal

DB/OS 0118	*Xestoleberis rubens*	São Miguel Island	-2,5	PAM 0060	intertidal
DB/OS 0119	*Neonesidea longisetosa*	São Miguel Island	-2,5	PAM 0060	intertidal
DB/OS 0120	*Aurila woutersi*	São Miguel Island	-2,5	PAM 0060	intertidal
DB/OS 0121	*Lanceostoma simplex* sp. nov.	São Miguel Island	-2,5	PAM 0060	intertidal
DB/OS 0122	*Xestoleberis rubens*	São Miguel Island	-2	PAM 0065	intertidal
DB/OS 0123	*Semicytherura brandoni* sp. nov.	São Miguel Island	-2	PAM 0065	intertidal
DB/OS 0124	*Semicytherura brandoni* sp. nov.	São Miguel Island	-2	PAM 0065	intertidal
DB/OS 0125	*Heterocythereis albomaculata*	São Miguel Island	-1	PAM 0066	intertidal
DB/OS 0126	*Loxoconcha rhomboidea*	São Miguel Island	-2,5	PAM 0060	intertidal
DB/OS 0127	*Semicytherura brandoni* sp. nov.	São Miguel Island	-2,5	PAM 0060	intertidal
DB/OS 0128	*Loxoconcha* sp. (lost carapace)*	São Miguel Island	-2,5	PAM 0060	intertidal
DB/OS 0129	*Lanceostoma simplex* sp. nov.	São Miguel Island	-2,5	PAM 0060	intertidal
DB/OS 0130	*Semicytherura brandoni* sp. nov.	São Miguel Island	-2,5	PAM 0060	intertidal
DB/OS 0131	*Propontocypris* cf. *pirifera*	Formigas Islet	-10	PAM 0003	inner shelf
DB/OS 0132	*Neocytherideis* sp.	Terceira Island	-3	PAM 0006	intertidal
DB/OS 0133	*Neonesidea longisetosa*	Formigas Islet	-48	DBUA-1004	inner shelf
DB/OS 0134	*Heterocythereis albomaculata*	?	?	?	?
DB/OS 0135	*Callistocythere insularis* sp. nov.	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0136	*Neonesidea longisetosa*	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0137	*Xestoleberis* sp.	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0138	*Callistocythere insularis* sp. nov.	São Miguel Island	-15	PAM 0068	inner shelf

DB/OS 0139	*Aurila convexa*	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0140	*Loxoconcha romboidea*	São Miguel Island	-1	PAM 0064	intertidal
DB/OS 0141	*Lanceostoma simplex* sp. nov.	São Miguel Island	-1	PAM 0064	intertidal
DB/OS 0142	*Lanceostoma simplex* sp. nov.	São Miguel Island	-1	PAM 0064	intertidal
DB/OS 0143	*Neocytherideis* sp.	São Miguel Island	-1	PAM 0066	intertidal
DB/OS 0144	*Loxoconcha rhomboidea*	São Miguel Island	-1	PAM 0066	intertidal
DB/OS 0145	*Loxoconcha rhomboidea*	São Miguel Island	-1	PAM 0066	intertidal
DB/OS 0146	*Sclerockilus hicksi*	São Miguel Island	-9	PAM 0069	inner shelf
DB/OS 0147	*Callistocythere insularis* sp. nov.	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0148	*Callistocythere insularis* sp. nov.	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0149	*Callistocythere insularis* sp. nov.	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0150	*Callistocythere insularis* sp. nov.	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0151	*Callistocythere insularis* sp. nov.	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0152	*Aurila convexa*	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0153	*Aurila woutersi*	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0154	*Loxoconcha rhomboidea*	São Miguel Island	-15	PAM 0068	inner shelf
DB/OS 0155	*Neonesidea* sp.	Princesa Alice Seamount	-249 / -371	PAM 0081	insular slope
DB/OS 0156	*Neonesidea* sp.	Princesa Alice Seamount	-249 / -371	PAM 0081	insular slope
DB/OS 0157	Gen. et sp. indet.	Princesa Alice Seamount	-249 / -371	PAM 0081	insular slope
DB/OS 0158	Gen. et sp. indet.	Princesa Alice Seamount	-249 / -371	PAM 0081	insular slope
DB/OS 0159	Neonesidea sp.	Princesa Alice Seamount	-249 / -371	PAM 0081	insular slope

DB/OS 0160	Gen. et sp. indet.	Princesa Alice Seamount	-249 / -371	PAM 0081	insular slope
DB/OS 0161	*Neonesidea* sp.	Princesa Alice Seamount	-249 / -371	PAM 0081	insular slope
DB/OS 0162	Gen. et sp. indet.	Condor Seamount	-442	PAM 0082	insular slope
DB/OS 0163	Gen. et sp. indet.	Condor Seamount	-442	PAM 0082	insular slope
DB/OS 0164	Gen. et sp. indet.	Condor Seamount	-442	PAM 0082	insular slope
DB/OS 0165	Gen. et sp. indet.	Condor Seamount	-442	PAM 0082	insular slope
DB/OS 0166	Gen. et sp. indet.	Condor Seamount	-442	PAM 0082	insular slope
DB/OS 0167	Gen. et sp. indet.	Condor Seamount	-442	PAM 0082	insular slope
DB/OS 0168	*Neonesidea* sp.	Condor Seamount	-442	PAM 0082	insular slope
DB/OS 0169	Gen. et sp. indet.	Condor Seamount	-442	PAM 0082	insular slope
DB/OS 0170	Gen. et sp. indet.	Condor Seamount	-442	PAM 0082	insular slope
DB/OS 0171	Gen. et sp. indet.	Princesa Alice Seamount	-201	PAM 0083	insular slope
DB/OS 0172	*Neonesidea* sp.	Princesa Alice Seamount	-201	PAM 0083	insular slope
DB/OS 0173	*Neonesidea* sp.	Princesa Alice Seamount	-201	PAM 0083	insular slope
DB/OS 0174	Gen. et sp. indet.	Princesa Alice Seamount	-201	PAM 0083	insular slope
DB/OS 0175	Gen. et sp. indet.	Açores Seamount	-202,4	PAM 0084	insular slope
DB/OS 0176	Gen. et sp. indet.	Açores Seamount	-202,4	PAM 0084	insular slope
DB/OS 0177	*Neonesidea* sp.	Açores Seamount	-202,4	PAM 0084	insular slope
DB/OS 0178	*Neonesidea* sp.	Açores Seamount	-202,4	PAM 0084	insular slope
DB/OS 0179	*Neonesidea* sp.	Açores Seamount	-202,4	PAM 0084	insular slope
DB/OS 0180	*Cylindroleberis* sp.	São Miguel Island	-4	Sponge (*Tedania*)	intertidal

DB/OS 0181	*Xestoleberis* cf. *depressa*	Pico Island	-1	PAM 0001	intertidal
DB/OS 0182	Gen. et sp. indet.	Pico Island	-1	Pam 0001	intertidal

CHAPTER 4

LATE MIOCENE MARINE OSTRACODS FROM SANTA MARIA ISLAND, AZORES (NE ATLANTIC): SYSTEMATICS, PALAEOECOLOGY AND PALAEOBIOGEOGRAPHY

Ricardo P. Meireles; Costanza Faranda; Elsa Gliozzi; Adriano Pimentel; Vittorio Zanon; Sérgio P. Ávila

MEIRELES, R.P.; FARANDA, C.; GLIOZZI, E.; PIMENTEL, A.; ZANON, V. & ÁVILA, S.P., 2012. Late Miocene marine ostracods from Santa Maria Island, Azores (NE Atlantic): Systematics, palaeoecology and palaeobiogeography. Révue de Micropaléontologie, 55: 133-148. http://dx.doi.org/10.1016/j.revmic.2012.06.003 (Impact Factor 2011 = 1.394). [cited by 2]

ABSTRACT

The nine oceanic islands that comprise the Azores archipelago are located in the middle of the northern Atlantic Ocean. In this isolated archipelago there is a rich fossil record in one of the islands, Santa Maria. In this island, samples were collected in the Upper Miocene composite section of Malbusca outcrop, located in the southern shore of the island, and the fossil marine Ostracoda were studied. This work represents the first report of fossil ostracods from the Azores archipelago. Thirteen species were found, representing 7 families and 12 genera (*Xestoleberis, Loxoconcha, Callistocythere, Leptocythere, Dameriacella, Aurila, Heliocythere, Pachycaudites, Neonesidea, Cyamocytheridea, ?Quadracythere* and *Paracypris*). Among the identified species, one new species, *Leptocythere azorica* n. sp., is described. *Loxoconcha* (2 species) was the most diversified genus. The collected species are mainly ornamented and typical of warm waters and epi-neritic habitats (~10–50 m of depth).

Key words: Ostracoda; Miocene; Azores archipelago; Palaeoecology.

Résumé

Le neuf îles océaniques formant l'archipel des Açores sont situées au centre de l'Océan Atlantique Nord. Dans cet archipel isolé, l'île de Santa Maria présente de riches niveaux fossilifères. Les ostracodes ont été étudiés dans la coupe composite du Miocène de Mabusca sur la côte sud de l'île. Ce travail est le premier concernant les ostracodes fossiles de l'archipel des Açores. Treize espèces ont été identifiées, appartenant à 7 familles et 12 genres (*Xestoleberis, Loxoconcha, Callistocythere, Leptocythere, Dameriacella, Aurila, Heliocythere, Pachycaudites, Neonesidea, Cyamocytheridea, ?Quadracythere* and *Paracypris*). Parmis les espèces reconnues, une espèce nouvelle est créée, *Leptocythere azorica* sp. nov. Le genre *Loxoconcha* avec deux espèces est le plus diversifié. La plupart des espèces sont ornmentées et caractérisent des eaux chaudes epi-néritiques (~10-50 m de profondeur).

Mots clés: Ostracodes; Miocène; Archipel des Açores; Paléoécologie.

INTRODUCTION

Located in the central north Atlantic Ocean (36° 55’ N to 39° 45’ N, 24° 45’ W to 31° 17’ W), about 1,500 km off shore of mainland Portugal, nine oceanic islands form the archipelago of the Azores (Fig. 1). Due to their extreme isolation, these islands are a perfect place to study processes and patterns of dispersion, colonization and speciation, and to test ecological, evolutionary and biogeographical theories.

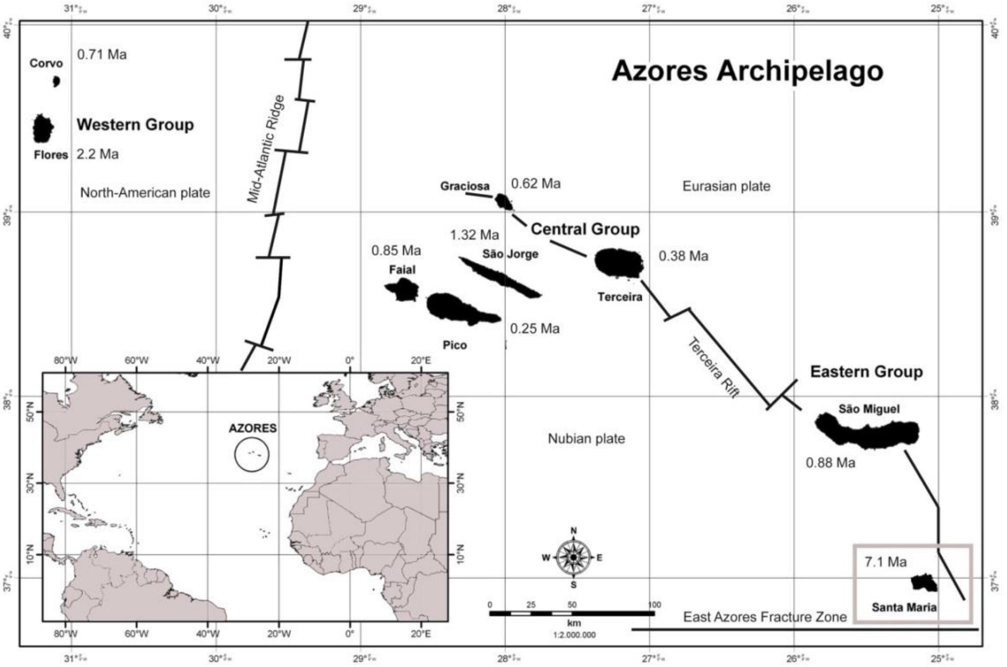


Figure 1. Map of the Azores archipelago, with the location of Santa Maria island. The the oldest radiometric ages for each island are reported, expressed in Ma (geochronological data from from Abdel-Monem *et al.*, 1975; Feraud *et al.*, 1980; Chovelon, 1982; Johnson *et al.*, 1998; Azevedo, 1999; Dias, 2001; Calvert *et al.*, 2006; Hildenbrand *et al.*, 2008).

Nowadays, the pattern of the sea currents in the North Atlantic is dominated by the Gulf Stream that flows from west to the east, that is, from the American coasts to Europe (Johnson & Stevens, 2000; Rogerson *et. al.*, 2004). Nevertheless, the present faunal affinities of the Azores show a consistent picture in several phyla, both terrestrial and marine (Morton & Briton, 2000; Ávila, 2000, 2005), that is different than what one might expect from the major sea-surface currents, generating what Ávila (2000) called "the Azorean Biogeographical Paradox". This suggests, perhaps, that factors other than the present sea-surface currents may play (or have played) an important role in building up the coastal faunal biogeography of the Azores (Ávila *et al.*, 2008; 2009a). For this reason, since 2002, a series of international workshops was put in place on the “Palaeontology in Atlantic Islands, in order to study the fossils of the Azores, the occurrence of which is restricted to Santa Maria Island. As a result, a number of papers was published regarding the fossil marine fauna: gastropods (Ávila *et al.*, 2002; 2007; 2009b; Janssen *et al.*, 2008), brachiopods (Kroh *et al.*, 2008), barnacles (Winkelmann *et al.*, 2010), echinoderms (Madeira *et al.*, 2011) and fish (sharks) (Ávila *et al.*, 2012). Although the marine fossils of Santa Maria Island are known since the pioneer works of Ferreira (1955; 1961), Hartung (1860), Zbyszewski & Ferreira (1961), Reiss (1862) and Mayer (1864), this is the first publication on the fossil ostracods from the Azores.

The aim of this work is to document and study the ostracod species that were present during the Late Miocene in the Azores in order to make palaeoecological, biostratigraphical and palaeobioegeographical scenarios for these oceanic islands.

Geological setting

The volcanic mid-Atlantic islands of the Azores are the emergent portions of submarine volcanic edifices that rise from the large Azores Oceanic Plateau (*e.g.* Needham & Francheteau, 1974; Searle, 1980; Lourenço *et al.*, 1998). The archipelago is located in a complex geodynamic setting where the North American, Eurasian and Nubian lithospheric plates meet at the Azores triple junction. In this region, plate boundaries are marked by the presence of three main structures: the Mid-Atlantic Ridge, the Terceira Rift and the East Azores Fracture Zone (Madeira & Ribeiro, 1990; Luís *et al.*, 1994; Vogt & Jung 2004).

Santa Maria Island is located in the eastern group of islands of the Azores archipelago with São Miguel Island and the Formigas Islets. Santa Maria is the oldest island of the Azores, being Late Miocene in age (about 7.1 Ma) (Abdel-Monem *et al.*, 1975; Feraud *et al.*, 1980), and is the only island where both marine and terrestrial Neogene fossils have been found. The Upper Miocene - Lower Pliocene sedimentary rocks of Santa Maria are grouped in two units: the Touril and the Facho-Pico Alto volcano-sedimentary Complexes (Madeira, 1986; Serralheiro, 2003). The older Touril Complex includes Ponta dos Frades, Cré, Figueiral and Malbusca fossiliferous localities; the younger Facho-Pico Alto Complex includes the fossiliferous localities of Pedra-que-Pica and Ponta do Castelo (Serralheiro & Madeira, 1990). All those sections have already been the object of paleontological studies concerning Brachiopoda (Kroh *et al.*, 2008), Mollusca (Gastropoda) (Janssen *et al.*, 2008), Crustaceans (Cirripedia) (Winkelmann *et al.*, 2010), Echinodermata (Madeira *et al.*, 2011), Bryozoa (Meireles *et al.*, unpublished data), and also some geochemical dating by means of Strontium isotopes analyses (Kirby *et al*., 2007). The ostracods studied in the present paper were collected at the main sedimentary layer closer to the base of Malbusca sequence - a sequence that essentially corresponds to a subhorizontal pile of submarine lava flows and hyaloclastites intercalated by a few calcarenitic beds.

The outcrop at Malbusca, located in the southern shore of Santa Maria, was studied in detail and a composite stratigraphic section was performed (Fig. 2). The base of the section is formed by basaltic lavas belonging to the underlying Touril Complex, whereas the top of the section is erosive and covered by basalt flows. The sedimentary succession is made of three different lithologies, from the base to the top: a) 1 m-thick coquina level very rich in benthic foraminifers, ostracods, molluscs, bryozoans and echinoids; b) 2 m-thick fine-grained fossiliferous sandstones (calcarenites) with benthic foraminifers, ostracods and bryozoans; and c) 4 m-thick cross-bedded fine-grained sandstones (calcarenites) with benthic foraminifers and bryozoans.

Based on the calcareous nannofossils reported in Winkelman *et al.* (2010) and, in particular, on the concomitant presence of the species *Reticulofenestra pseudombilicus* and *Reticulofenestra rotaria*, the Malbusca section has been dated to Messinian (nannofossil biozone NN11b, from the end of the *R. pseudombilicus* paracme at 7.08 Ma to 5.88 Ma (LO of *R. rotaria* in the Atlantic Ocean) (Theodoridis, 1984; Huang, 1997; Lourens *et al*., 2004, Waterman *et al*., 2011).

MATERIALS AND METHODS

A total of 8 bulk samples were collected from the Upper Miocene Malbusca section (Fig. 2). Ostracods were collected at the coquina and the fossiliferous sandstone levels (Fig. 2: A and B). Additionally, samples were collected on all the three levels for petrographic and mineralogical analyses (Fig. 2: **A)** DBUA-F 818, **B)** DBUA-F 819 and, **C)** DBUA-F 821); (Fig. 3). Samples were processed in the Sedimentology Laboratory of the University of the Azores using conventional techniques for the study of ostracods and petrographic analyses. For the analyses, each sample, approximately 100g of sedimentary rock, was disaggregated in a 5% H_2O_2 solution and washed over a 0.063mm sieve. The residues were dried and sieved into fractions greater than 0.250mm, 0.125mm and 0.063mm, respectively, to access species distribution in individual size fractions. Hand-picked specimens were photographed using the scanning electronic microscope (SEM) at the Biology Department of the University of the Azores. Ostracods abundance was quantified by counting the number of carapaces. A semi-quantitative method was used, with three different classes: Rare (≤10 carapaces), Frequent (11 to 20), Abundant (>20). The material is made up mainly by carapaces, more rarely by loose valves. Therefore, internal details are not usually available to help the taxonomic identification. We followed Horne *et al.* (2002) for the nomenclature of suprageneric taxa. Ostracods specimens studied in this work are housed in the Microfossil Collection of the Department of Biology of the University of the Azores (DB/OST 0073 - 0109). Petrographic sections studied are housed in the Fossil Collection of the Department of Biology (DBUA-F 818, 819 and 821).

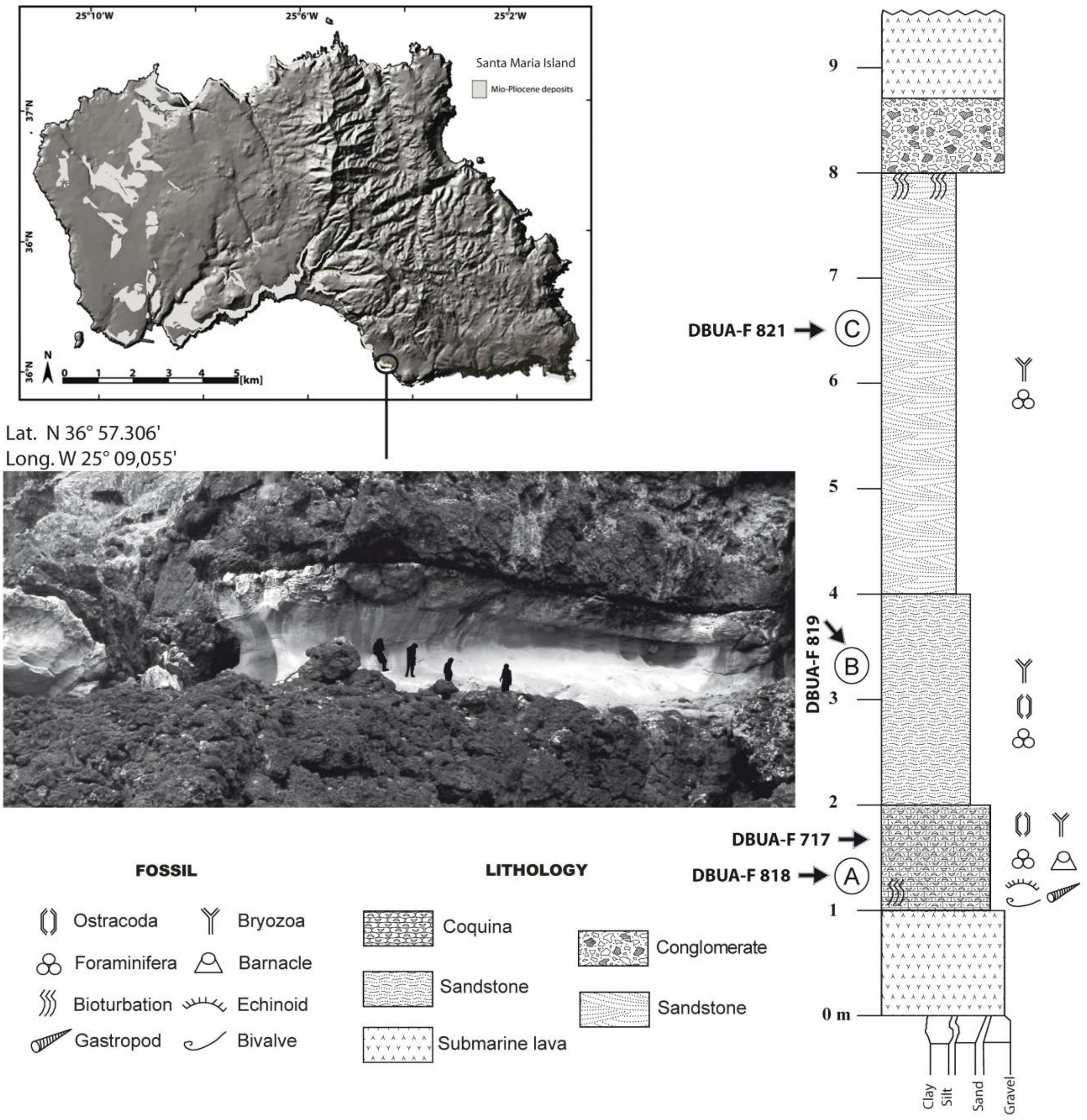


Figure 2. Top left: Map of the sedimentary deposits of Santa Maria Island (modified from Serralheiro, 2003). Bottom left: photograph of the Malbusca outcrop (people height about 1.70 m). Right: Malbusca composite section with the location of samples (A, B, C) for petrographical and mineralogical analyses, and (A, B) paleontological (ostracods) analyses.

RESULTS

4.1. Petrographic description of the Malbusca composite section

The lithological composition of the exposed sediments forming the stratigraphic section is homogeneous (Fig. 2), as revealed by the petrographic study of three samples, considered as representative of the entire section. Modal analyses have also been carried out with a point-counter stage.

All samples are sandstones (calcarenites) composed of detrital grains, crystals and fossils in different amounts and with different size and textural degrees of evolution. Coarse to medium-coarse sparite is the typical cement in all three samples (Fig. 3).

The first sample comes from the base of the stratigraphic sequence, from a 1-m-thick coquina deposit following an erosive contact and a basaltic lava deposit. The sample is composed of bioclasts (43.2%), detrital volcanic grains of lithic volcaniclastic origin (9.8%) and separate crystals (12.4%). Calcite cement (34.6%) is fairy coarse (sparite), sometimes forming microgeods (Fig. 3: A). Secondary fractures, filled with microcrystalline calcite, indicate high-energy conditions during sedimentation. Detrital grains are mature fragments of basaltic lavas (Fig 3: B and C). Separate crystals (∅ 80-250 µm) are olivine, plagioclase, clinopyroxene, magnetite, hematite, nepheline and calcite in order of decreasing abundance (Fig. 3: D). Bioclasts (~150-400 µm) are represented by ostracods, echinoid spines, barnacles, planktonic foraminfers, gastropods and bryozoans. This high diversity indicates the presence of different source-areas.

The second sample comes from a ~2-m-thick fossiliferous, fine- to medium-grained sandstone, which rests on top of the coquina level. The general characteristics are similar to the previous sample, but, in general, the constituents show different amounts of detrital fragments (31.6%), separate crystals (18.6%), bioclasts (11.2%) and sparite cement (38.6%). The characteristics of the constituents are similar to the previous sample, except that ooids (Fig. 3, E and F), nepheline and calcite crystal are missing. The general degree of morphological evolution of the constituents is also similar to the previous sample.

The third sample was collected from a ~4m-thick sandstone, at the top of the stratigraphic section, beneath the uppermost conglomerate. It is very similar to the previous sample, but with a reduced amount of bioclasts and a general smaller grain size of the constituents, which again are represented by basaltic lava fragments (32%), separate crystals (18.6%), fossils (5.8%) and sparite cement (43.6%) (Fig. 3: G and H).

The progressive reduction in grain size of the constituents of all studied samples, collected from the bottom to the top of the sequence, indicates a decrease in environment energy during the sedimentation process. We envisage deposition during a transgressive phase.

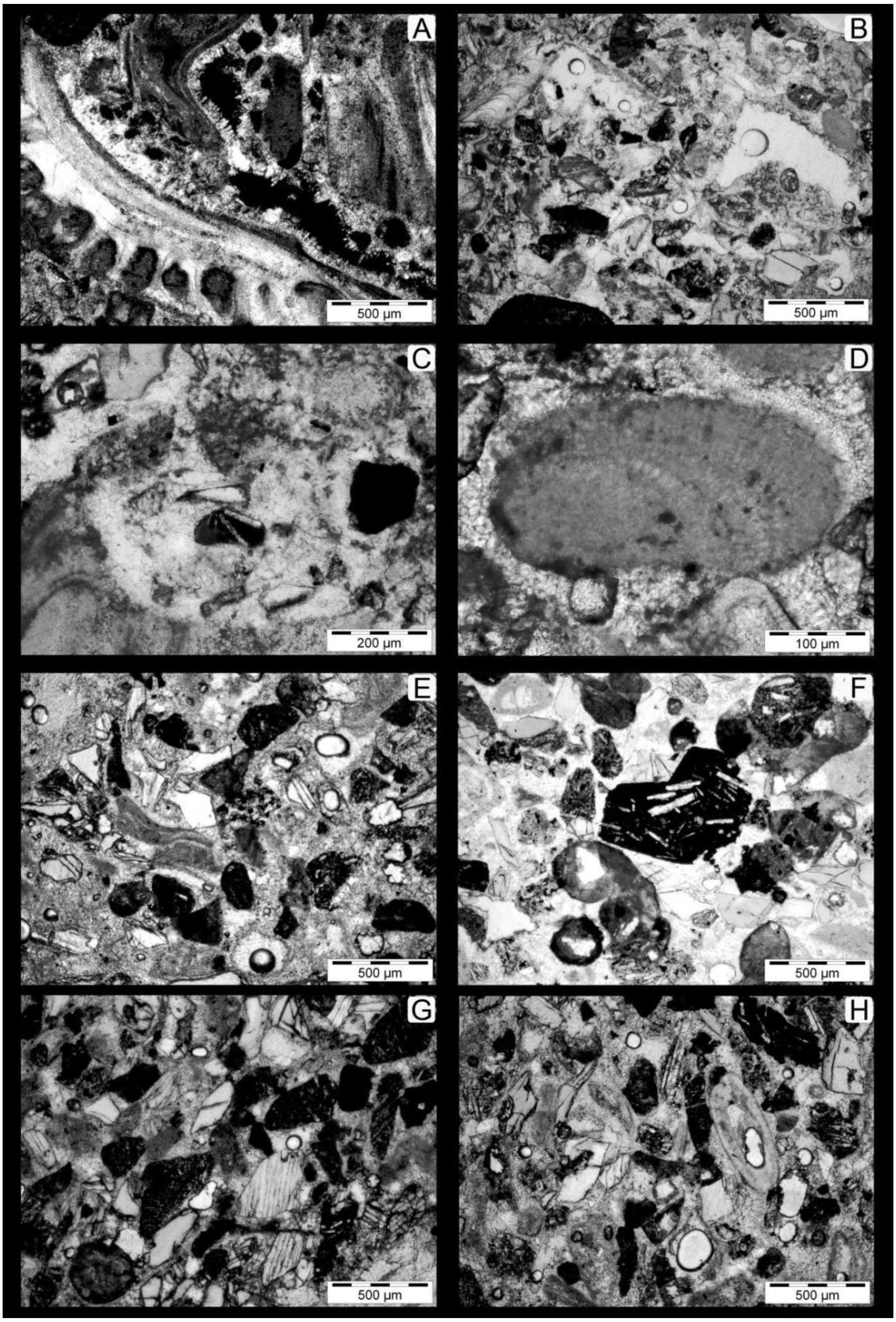


Figure 3. Thin section photographs of the Malbusca sandstones (Touril Complex), under the polarized-light microscope: **A–D)** DBUA-F 818 = level A on the column of Fig. 2; **E–F)** DBUA-F 819 = level B on the column of Fig. 2; **G-H)** DBUA-F 821 = level C on the column of Fig. 2.

TAXONOMY

Class Ostracoda Latreille, 1802

Order Podocopida Müller, 1894

Family Xestoleberididae Sars, 1928

Genus *Xestoleberis* Sars, 1866

Xestoleberis cf. *paisi* Nascimento, 1989

(Plate 1, figs 1 - 3)

1988 *Xestoleberis paisi* n. sp. Nascimento, p. 200-201, pl. 14, figs. 3-5. (*nomen nudum*)

1989 *Xestoleberis paisi* n. sp. Nascimento, p. 123, pl. 3, figs. 12-14.

Material: 29 carapaces (abundant).

Dimensions: DB/OST 0073: length = 0.62 mm, height = 0.38 mm, width = 0.36 mm; DB/OST 0074: length = 0.50 mm, height = 0.33 mm, width = 0.26 mm; DB/OST 0075: length = 0.60 mm, height = 0.38 mm, width = 0.33 mm.

Description: Carapace sub-rounded in lateral view. Greater height located slightly posteriorly to the middle portion of the shell. Right valve larger, with valve overlap in the anterior, ventral and postero-dorsal area. Sub-rectilinear ventral margin, slightly convex in the posterior half, arched dorsal margin, bending anteriorly. Surface of the carapace smooth.

Remarks: The collected specimens are comparable to *X. paisi* Nascimento (1989) (holotype dimensions: length = 0.64 mm, height = 0.36 mm, width = 0.34 mm), mainly for its sub-rounded form, elongated anterior margin, sub-angular posterior margin and smooth surface.

Stratigraphic and geographic distribution: Early Miocene (Aquitanian to Serravallian) of Tejo Bay, Lisbon (Nascimento, 1988, 1989); Late Miocene (Messinian) of Santa Maria Island, Azores (this paper).

Ecology and palaeoecology: Nascimento (1988) defines this species as brackish-infralittoral.

Family Loxoconchidae Sars, 1925

Genus *Loxoconcha* Sars, 1866

Loxoconcha stellifera Müeller, 1894

(Plate 1, figs 4 - 6)

1894 *Loxoconcha stellifera* n.sp. Müeller, p. 343-344, Pl. 27, figs. 15, 18, 21; Pl. 28, figs. 2,7.

1992 *Loxoconcha* aff. *stellifera* Müeller - Bonaduce *et al*., p. 82, Pl. 24, fig. 11; in Bonaduce *et al*. (1992), it is indicated as *Loxoconcha* aff. *stellifera*.

Material: 46 carapaces (abundant).

Dimensions: DB/OST 0076: length = 0.52 mm, height = 0.38 mm, width = 0.33 mm; DB/OST 0077: length = 0.57 mm, height = 0.31 mm, width = 0.33 mm; DB/OST 0078: length = 0.52 mm, height = 0.36 mm, width = 0.29 mm.

Description: Carapace sub-rhomboidal in lateral view. Maximum height located slightly anterior to the mid of the valve. Left valve larger than the right one with reduced overlap in the anteroventral area. Ventral margin with strong convexity in the posteroventral area. Sub-rectilinear dorsal margin, truncated in the posterodorsal area. Punctate carapace.

Remarks: The collected specimens are comparable to *L. stellifera* Müeller (1894) and with *L.* aff. *L. stellifera* in Bonaduce *et al.* (1992) (holotype dimensions: length = 0.65-0.68 mm) for the sub-rhomboidal form, anterior truncated area, posterior area and the small concavity in the central ventral area.

Stratigraphic and geographic distribution: Late Miocene (Messinian) of the Gulf of Gabés, Tunisia (Bonaduce *et al*., 1992); Late Miocene (Messinian) Santa Maria Island, Azores, Portugal (this paper); Recent of the Gulf of Naples (Müeller, 1894).

Ecology and palaeoecology: in the Mediterranean, Bonaduce *et al.* (1976) signal the abundant presence of *L. stellifera* in littoral environment influenced by subterranean freshwater not deeper than 20 m; Lachenal (1989) reports the species from mediolittoral to infralittoral stages on *Posidonia* leaves and vegetated bottoms.

Loxoconcha rhomboidea (Fischer, 1855)

(Plate 1, figs 7 - 9)

1854 *Cythere flavida* Müeller - Zenker, p. 86-87, Pl. 5, figs. B 1-4.

1855 *Cythere rhomboidea* n. sp. Fischer, p. 656.

1968b *Loxoconcha impressa* (Baird), Brady, 433, pl. 25, figs. 35-40, pl. 40, fig. 4.

1985 *Loxoconcha rhomboidea* (Fischer, 1855) – Guillaume *et al*., 1985, p. 363, pl. 109, figs. 7-9.

Material: 11 carapaces (frequent).

Dimensions: DB/OST 0079: length = 0.60 mm, height = 0.38 mm, width = 0.33 mm; DB/OST 0080: length = 0.55 mm, height = 0.29 mm, width = 0.24 mm; DB/OST 0081: length = 0.60 mm, height = 0.36 mm, width = 0.26 mm.

Description: Carapace rhomboidal in shape in lateral view. Median maximum height. Left valve larger than the right one with overlap in the anteroventral area. Ventral margin with strong convexity in the posteroventral area. Rounded dorsal margin. Pitted carapace.

Remarks: The collected specimens are reportable to *L. rhomboidea* (Fischer, 1855) (Guillaume *et al*., 1985) (holotype dimensions: length = 0.68 mm, height = 0.41 mm, width = 0.34 mm) for their rhomboidal shape, carapace overlap and ornamentation.

Stratigraphic and geographic distribution: Late Miocene (Tortonian) of Rio Mazzapiedi (Piedmont, Italy) (Ciampo, 1986); Late Miocene (Messinian) of Santa Maria Island, Azores (this paper); Quaternary of the Bay of Biscaye (Guillaume *et al*., 1985); Recent on most of the British coasts, Madeira, and the Canary Islands (Athersuch, *et. al*., 1989) and Mediterranean (Bonaduce *et al*., 1976; Lachenal, 1989).

Ecology and palaeoecology: intertidal to littoral depths, with vegetated bottoms (Guillaume *et al*., 1985; Athersuch *et. al*., 1989; Lachenal, 1989).

Family Leptocytheridae Hanai, 1957

Genus *Callistocythere* Ruggieri, 1953

Callistocythere oertlii Nascimento, 1989

(Plate 1, figs 10 - 12)

1965 *Callistocythere* aff. *C. canaliculata* (Reuss) - Moyes, p. 28, pl. 3, fig. 10.

1979 *Callistocythere* aff. *C. canaliculata* (Reuss) – McKenzie *et al*., p. 36.

1983 *Callistocythere* aff. *C. canaliculata* (Reuss) – Nascimento, p. 432.

1988 *Callistocythere oertlii* n. sp. Nascimento, pp. 76-78, pl. 3, figs. 6-7. (*nomen nudum*)

1989 *Callistocythere oertlii* n. sp. Nascimento, p. 119, pl. 1, figs. 10-11.

Material: 19 carapaces (frequent).

Dimensions: DB/OST 0082: length = 0.38 mm, height = 0.21 mm, width = 0.17 mm; DB/OST 0083: length = 0.48 mm, height = 0.21 mm, width = 0.19 mm; DB/OST 0084: length = 0.40 mm, height = 0.21 mm, width = 0.17 mm.

Description: sub-rectangular carapace in lateral view. Maximum height in front of the mid of the valve. Left valve slightly larger than right valve with overlap in the anterior area. Ventral margin with slight median concavity. Slightly convex dorsal margin in the anterior portion and rectilinear truncation in the median-posterior portion. Prominent median rib.

Remarks: The collected specimens are similar to *C. oertlii* Nascimento, 1989 (holotype dimensions: length = 0.72 mm, height = 0.34 mm, width = 0.28 mm) in the sub-rectangular form and strong ornamentation. In comparison with the holotype, the Azorean specimens are smaller, but the two posterior ribs, parallel to the posterior margin and the shape are similar.

Stratigraphic and geographic distribution: Oligocene- Early Miocene (Aquitanian) of the Aquitaine Basin; Late Miocene (Aquitanian-Tortonian) of Tejo Bay, Lisbon (Nascimento, 1988, 1989); Late Miocene (Messinian) of Santa Maria Island, Azores (this paper); Pliocene of Pombal (Portugal).

Ecology and palaeoecology: infralittoral, coastal areas (McKenzie *et al*., 1979; Nascimento, 1988).

Genus *Leptocythere* Sars, 1922

Leptocythere azorica Meireles & Faranda **n. sp.**

(Plate 1, figs 13 - 17)

2011 *Leptocythere azorica* sp. nov. Meireles and Gliozzi, p. 128, Fig. 2,5 (*nomen nudum*).

Derivation of name: with reference to the Azores archipelago (NE Atlantic).

Holotype: Adult carapace; DB/OST 0085: length = 0.48 mm, height = 0.24 mm, width = 0.21 mm.

Type locality: Malbusca outcrop, sample DBUA-F 717.

Age: Messinian (Late Miocene).

Material: 13 carapaces (frequent).

Dimensions: Holotype DB/OST 0085: length = 0.48 mm, height = 0.24 mm, width = 0.21 mm; Paratype DB/OST 0086: length = 0.48 mm, height = 0.24 mm, width = 0.19 mm; Paratype DB/OST 0087: length = 0.48 mm, height = 0.24 mm, width = 0.21 mm.

Diagnosis: In lateral view, posterior area with two well-marked sulci and in dorsal view, two well-marked ribs running from the posterior end to the median area.

Description: Carapace sub-rectangular in lateral view; rectilinear dorsal margin with alar process in the anterior area, sub-rectilinear ventral margin with moderate concavity in the median portion; two well-marked sulci in the posterior portion. In dorsal view two well-marked "ribs" running from the posterior end to the median area are visible.

Remarks: Although no inner characters are visible, but *Leptocythere azorica* was compared, in terms of external morphology, with several Miocene other species of *Leptocythere*, for example: *Leptocythere cleopatrae* Bonaduce, Ruggieri, Russo and Bismuth, 1992; *Leptocythere complicata* Bonaduce, Ruggieri, Russo and Bismuth, 1992; *Leptocythere festiva* Bonaduce, Ruggieri, Russo and Bismuth, 1992; *Leptocythere johnnealei* Bonaduce, Ruggieri, Russo and Bismuth, 1992; *Leptocythere arabesca* Stancheva, 1964; *Leptocythere bisulcata* Stancheva, 1964 and *Leptocythere slatinensis* Stancheva, 1964. No other known *Leptocythere* species shows similar posterior sulci and two dorsal ribs. However, there are discussions about the generic attribution.

Stratigraphic and geographic distribution: Late Miocene (Messinian) of Santa Maria Island, Azores (this paper).

Family Hemicytheridae Puri, 1953

Genus *Pachycaudites* Uliczny, 1969

Pachycaudites cf. *armilla* Ciampo, 1986

(Plate 2, figs 1- 3)

Material: 25 carapaces and 3 valves (abundant).

Dimensions: DB/OST 0088: length = 0.76 mm, height = 0.40 mm, width = 0.36 mm; DB/OST 0089: length = 0.79 mm, height = 0.45 mm, width = 0.40 mm; DB/OST 0090: length = 0.74 mm, height = 0.48 mm, width = 0.36 mm.

Description: Carapace sub-trapezoidal, in lateral view. Greater height in the anterior area. Left valve larger than the right one. Rectilinear ventral margin with a slight gap in the anterior area and an inclination of about 30^{o} in the posterior area. Dorsal margin with prominent eye-tubercle. Two prominent tubercles are well evident, one located on the postero-dorsal angle and the second in the mid of the valve. A short ventral keel is visible in the middle portion of the valve.

Remarks: The collected specimens are very similar to *Pachycaudites armilla* Ciampo, 1986 from the early Messinian of Rio Mazzapiedi (Piedmont, northern Italy). They differ from this species for the smaller size (*P. armilla*: length = 0.87-0.90 mm, height = 0.43-0.49 mm,) and for the less developed central rib. The bad preservation of the valve surfaces prevents to establish a new species.

Stratigraphic and geographic distribution: Late Mioecene (Early Messinian) of Italy (Ciampo, 1986); Late Miocene (Messinian) of Santa Maria Island, Azores (this paper).

Genus *Dameriacella* Liebau, 1991

Dameriacella cf. *dameriacensis* (Keij, 1958)

(Plate 2, figs 4 - 6)

1955 *Cythereis macropora* (Bosquet)- Apostolescu p. 270, pl. 7, figs. 116-117 (non *Cythere macropora* Bosquet 1952).

1991 *Dameriacella dameriacensis* (Keij) - Liebau, p. 125-126; pl. 39, figs; 1-4, pl. 40, figs. 1-4, 6-8, pl. 41; figs. 1-5, pl. 50, fig. 3., tex-fig. 58, 95.

Material: 38 carapaces and 5 valves (abundant).

Dimensions: DB/OST 0091: length = 0.55 mm, height = 0.29 mm, width = 0.26 mm; DB/OST 0092: length = 0.64 mm, height = 0.38 mm, width = 0.36 mm; DB/OST 0093: length = 0.74 mm, height = 0.40 mm, width = 0.36 mm.

Description: Carapace sub-triangular, in lateral view. Greater length in the ventral area and greater height in the anterior area. Left valve larger than the right one. Sub-rectilinear ventral margin. Dorsal margin with remarkable eye tubercle; pointed postero-dorsal tubercle and prominent tubercle in the central portion of the valve; presence of a short rib running from the anteroventral to the posteroventral area; posteriorly it ends with a rounded tubercle. In dorsal view the eye tubercles and the edge of the dorsal rib are prominent.

Remarks: The collected specimens are similar to *D. dameriacensis* (Keij, 1958) (holotype dimensions: length = 0.50 mm, height = 0.29 mm, width = 0.26 mm) for their sub-triangular shape and for the rib pattern, but differs slightly for the more prominent caudal process of the left valve. The bad preservation of the valve ornamentation prevents a certain attribution of the S. Maria valves to that species. Moreover, up to now *D. dameriacensis* is known only from older deposits [Middle Eocene (Lutetian) of Marne, France (Keij, 1958); Middle Eocene (Lutetian) of Paris basin, France (Apostolescu, 1961; Ducasse *et. al.*, 1985); Oligocene of Western Europe (Bosquet, 1852)]. Until better preserved material is collected, we prefer to refer the collected valves to a species similar to *D. dameriacensis*.

Stratigraphic and geographic distribution: Middle Eocene (Lutetian) of Marne, France (Keij, 1958); Middle Eocene (Lutetian) of Paris basin, France (Apostolescu, 1961); Late Miocene (Messinian) of Santa Maria Island, Azores (this paper).

Genus *Aurila* Pokorný, 1955

Aurila sp.

(Plate 2, figs 7 - 9)

Material: 6 carapaces (rare).

Dimensions: DB/OST 0094: length = 0.86 mm, height = 0.50 mm, width = 0.40 mm; DB/OST 0095: length = 0.95 mm, height = 0.62 mm, width = 0.45 mm.

Description: Carapace sub-triangular, in lateral view. Greater height located in the middle of the valve. Left valve larger than the right one with overlap throughout the entire dorsal margin and anterior area. Convex ventral margin in the central ventral area and concave anteroventrally. Highly arched dorsal margin. Rib running from the posteroventral to the anteroventral area and bordering a central inflation. In dorsal view the eye tubercles are visible.

Remarks: the scarcity of the collected material coupled with the poor preservation prevents a specific identification.

Genus *Quadracythere* Hornibrook, 1952

?*Quadracythere* sp.

(Plate 2, figs 10 - 12)

Material: 41 carapaces (abundant).

Dimensions: DB/OST 0096: length = 0.71 mm, height = 0.40 mm, width = 0.31 mm; DB/OST 0097: length = 0.67 mm, height = 0.38 mm, width = 0.29 mm; DB/OST 0098: length = 0.70 mm, height = 0.40 mm, width = 0.30 mm.

Description: Carapace sub-rectangular in lateral view, with anterior area just a little higher than the posterior; left valve larger than the right one with overlap in the anterior and ventral area. Winding ventral margin with median concavity. Dorsal sub-rectilinear margin. Dorsal and ventral ribs run parallel from the anterior to the posterior border. A third subparallel rib is less visible in the central area of the valve, particularly in the right valve; rib extending throughout the entire ventral area. Eye tubercle visible mainly in dorsal view. Surface of the valve rather strongly reticulated. Amphidont hinge.

Remarks: notwithstanding the abundance of the collected material, its poor preservation makes difficult even the generic attribution. The absence of well preserved loose valves prevented the observation of internal characters. On the basis of the general shape in lateral and dorsal view and on what it is possible to argue about the surface ornamentation, we dubitatively refer the collected material to ?*Quadracythere*.

Genus *Heliocythere* Bonaduce, Ruggieri, Russo, 1988

Heliocythere magnei (Keij, 1953)

(Plate 3, figs 7 - 9)

1953 *Hemicythere magnei* n.sp. Keij, p. 123, pl. 18, figs. 3-4.
1965 *Aurila magnei* Keij – Moyes, p. 105, pl. 12, fig. 4.
1988 *Heliocythere magnei* Keij - Bonaduce *et. al*., p. 356, pl. 4, figs. 1-3.

Material: 12 carapaces and 2 valves (frequent).

Dimensions: DB/OST 0099: length = 0.62 mm, height = 0.36 mm, width = 0.31 mm; DB/OST 0100: length = 0.60 mm, height = 0.31 mm, width = 0.24 mm; DB/OST 0101: length = 0.60 mm, height = 0.30 mm, width = 0.23 mm.

Description: Carapace sub-rectangular, in lateral view. Greater height in the anterior area. Left valve larger than the right one with small anterior overlap from the mediodorsal to the medioventral areas. Ventral margin with a feeble concavity in the antero-ventral portion. Dorsal margin with well developed eye tubercle and sharp rib that end in a dorsally protruding posterior tubercle. A second, more marked rib extends throughout the ventral area. Two V-shaped ribs are visible beginning in the anterocentral area and extending one towards the anterior border and the other towards the posterior one. Surface of the valve pitted anteriorly and reticulated posteriorly.

Remarks: The collected specimens are similar to *H. magnei* (Keij, 1953) (holotype dimensions: length = 0.78 mm, height = 0.45 mm) as illustrated by Bonaduce *et al.* (1988) for their sub-rectangular shape and ornamentation pattern.

Stratigraphic and geographic distribution: Early Miocene(Aquitanian) of the Aquitaine Basin (Bonaduce *et al*., 1988); Late Miocene, Messinian, Santa Maria Island, Azores (this paper).

Ecology and palaeoecology: Moyes (1965) reports this species from the coastal-epineritic facies of the Villandraut area (Aquitaine Basin, France).

Family Bairdiidae Sars, 1888

Genus *Neonesidea* Maddocks, 1969

Neonesidea rochae Nascimento, 1989

(Plate 3, figs 1- 3)

1988 *Neonesidea rochae* n. sp.– Nascimento, p. 63-65, pl. 2, figs. 6-8.

1989 *Neonesidea rochae* n. sp.– Nascimento, p. 119, pl. 1, figs. 7-9.

Material: 7 carapaces (rare).

Dimensions: DB/OST 0102: length = 0.71 mm, height = 0.43 mm, width = 0.26 mm; DB/OST 0103: length = 0.57 mm, height = 0.33 mm, width = 0.29 mm; DB/OST 0104: length = 0.57 mm, height = 0.33 mm, width = 0.21 mm.

Description: Carapace sub-triangular, in lateral view. Greater height located at the middle of the valve. Left valve larger than the right one with overlap throughout the entire margin. Slightly convex ventral margin in the right valve, slightly convex in the left one. Broadly arched rounded dorsal margin. Smooth carapace surface.

Remarks: The collected specimens are similar to *N. rochae* Nascimento (1989) (holotype dimensions: length = 1.00 mm, height = 0.64 mm, width = 0.46 mm) for their sub-triangular form and for presenting a well-marked overlap in right lateral view. The Azorean specimens are consistently smaller than the European ones.

Stratigraphic and geographical distribution: Early Miocene (Aquitanian-Burdigalian) of the Tejo Basin, Lisbon (Nascimento, 1989); Late Miocene (Messinian) of Santa Maria Island, Azores (this paper).

Ecology and palaeoecology: the species has been recovered in coastal and infralittoral environments (Nascimento, 1989).

Family Candonidae Kaufmann, 1900

Genus *Paracypris* Sars, 1866

Paracypris sp.

(Plate 3, figs 4 - 6)

Material: 5 carapaces (rare).

Dimensions: DB/OST 0105: length = 0.60 mm, height = 0.29 mm, width = 0.19 mm; DB/OST 0106: length = 0.60 mm, height = 0.31 mm, width = 0.24 mm.

Description: Carapace sub-triangular in lateral view. Greater height in the mid of the valve. Left valve larger than the right one with overlap in the anterior area. Rather sinuate ventral margin (particularly in the right valve) and highly arched dorsal margin. Smooth carapace. Poorly preserved.

Remarks: The specimens were comparable with species of *Paracypris*, but the smooth carapace, the poorly preserved and the rare material did not allow better identification.

Stratigraphic and geographic distribution: Late Miocene (Messinian) of Santa Maria Island, Azores (this paper). The genus is also known from Miocene level of coastal areas in NE Brazil (Nogueira *et al*., 2011).

Family Cytherideidae Sars, 1925

Genus *Cyamocytheridea* Oertli, 1956

Cyamocytheridea sp.

(Plate 3, figs 10 - 12)

Material: 3 carapace (rare).

Dimensions: DB/OST 0107: length = 0.81 mm, height = 0.40 mm, width = 0.38 mm; DB/OST 0108: length = 0.81 mm, height = 0.40 mm, width = 0.40 mm; DB/OST 0109: length = 0.50 mm, height = 0.26 mm, width = 0.24 mm.

Description: Bean-shaped carapace, elongated in lateral view. Greater height slightly in front of the middle of the valve. Left valve larger than the right one with slight overlap throughout the ventral and postero-dorsal margin. Sub-rectilinear ventral margin that become subrounded in the postero-ventral portion. Surface pitted with large, rare and shallow pits.

Remarks: The specimens were comparable with species of *Cyamocytheridea*, but the smooth carapace, the poorly preserved and the rare material did not allow better identification.

Stratigraphic and geographic distribution: Late Miocene (Messinian) of Santa Maria Island, Azores (this paper).

DISCUSSION

Stratigraphic and geographic distribution of the ostracods assemblage

The ostracods fauna of the Messinian Malbusca section is represented by 13 taxa, including a new species, five taxa left in open nomenclature and one species identified with doubt. All species are new records for the fossil fauna of the Azores and they significantly increase the knowledge of the fossil diversity at Santa Maria Island. They belong to 7 families and 12 genera, of which *Loxoconcha* (2 species) is the most diversified.

The majotity of the identified species are present in deposits older than the Messinian's *e.g.*: *Dameriacella* aff. *D. dameriacensis* (Middle Eocene), *Callistocythere oertlii* (Oligocene), *Xestoleberis* cf. *paisi*, *Heliocythere magnei*, and *Neonesidea rochae* (Aquitanian) (Fig. 4). Only *Loxoconcha stellifera* and *Loxoconcha rhomboidea* are known starting from the Late Miocene. Some of them disappeared during the Messinian (*Dameriacella* aff. *D. dameriacensis, H. magnei*), whilst others, supposed to be extinct, have recently been found in the living ostracod fauna of the Azores (*L. stellifera* and *L. rhomboidea* , *X. paisi, C. oertlii, N. rochae*) (Meireles, unpublished data) (Fig. 4). It is worth to note that, in some cases (*Dameriacella* aff. *D. dameriacensis*, *H. magnei*, *N. rochae*), the recovery in the Messinian deposits of Malbusca represents the last and southernmost occurrence in the central Atlantic domain. Only two species among those identified at the Malbusca outcrop are widespread from Late Miocene to Recent in the Mediterranean domain: *L. stellifera*, whose occurrence in the Messinian of Malbusca represents the first recovery in the Atlantic, and *L. rhomboidea*, well known as fossil and still present in the Mediterranean and the Atlantic (Fig. 5).

Palaeoecological and Palaeobiogeographical considerations

Most of the species of ostracods found at Malbusca are ornamented, indicating shallow coastal environments (Van Morkhoven, 1962). Among them, the most abundant are *Loxoconcha stellifera*, *Dameriacella* aff. *D. dameriacensis*, and *?Quadracythere* sp., followed by *Xestoleberis* cf. *paisi* and *Pachycaudites* aff. *P. armilla* (Fig. 6).

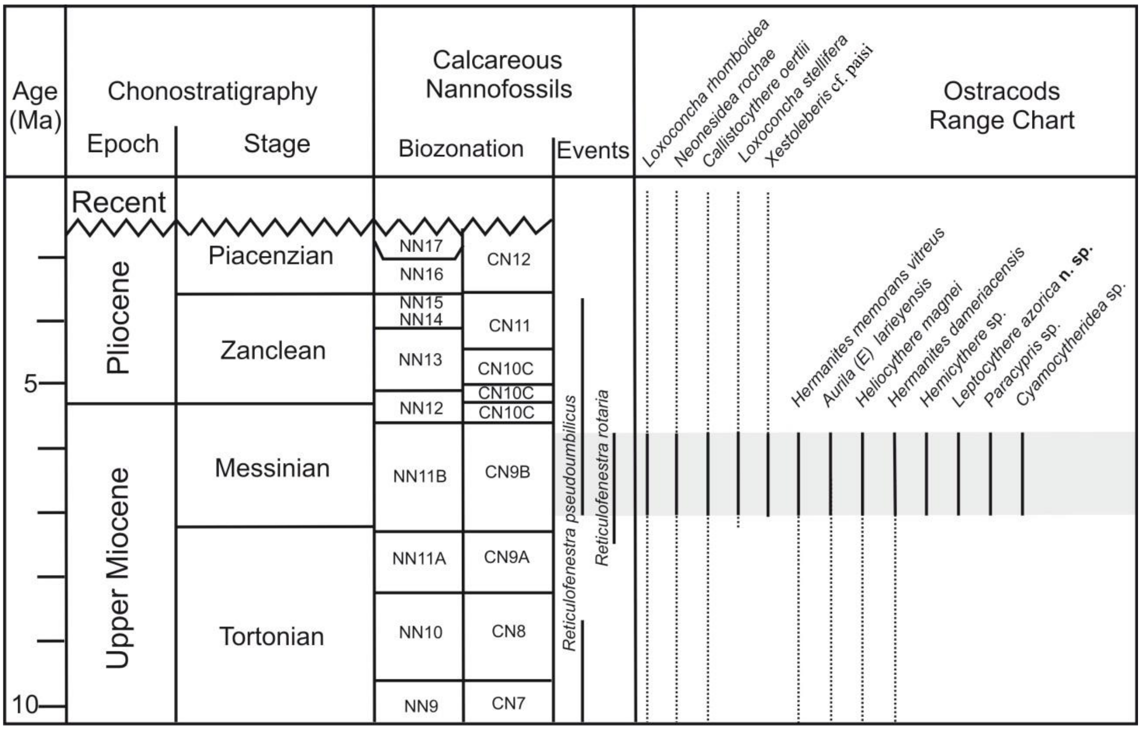


Figure 4. Stratigraphic range of the Late Miocene ostracod species collected at the Malbusca outcrop (Santa Maria Island, Azores). Biostratigraphic interval based on selected species of calcareous nannofossils (modified from Theodoridis, 1984).

Within the ostracods assemblage, 5 out of the 13 Miocene taxa are species that still occur nowadays in the Azores (*Xestoleberis* cf. *paisi*, *Loxoconcha rhomboidea, L. stellifera*, *Callistocythere oertlii* and *Neonesidea rochae)* in shallow-water environments (from the intertidal zone down to 40 m depth), thus we interpret them as eurithermic species. The other taxa of the assemblage disappeared from the Azores and the Atlantic domain after the Messinian (including the new species *Leptocythere azorica*), and it is possible to hypotesize that they were warm-water taxa that did not survive the Plio-Pleistocene climatic deterioration. Some of the extinct species, such as *Heliocythere magnei* is also interpreted as epineritic dweller (Moyes, 1965; Carbonel, 1985). The majority of the marine species from other phyla found in this fossil assemblage are also thermophilic, *e.g.* the brachiopod *Novocrania turbinata* (Poli, 1795) (Kroh *et al.*, 2008), the sea-urchins *Eucidaris tribuloides* (Lamarck, 1816), *Echinoneus* cf. *cyclostomus* Leske, 1778, and the extinct *Clypeaster altus* (Lamarck, 1816) (Madeira *et al.*, 2011), the also extinct endemic barnacle *Zullobalanus santamariaensis* Buckeridge & Winkelmann, 2010 (Winkelmann *et al.*, 2010), the extant bivalve *Manupecten pesfelis* (Linnaeus, 1758), the extinct bivalves

Gigantopecten latissimus (Brocchi, 1814) and *Hinnites crispus* (Brochi, 1814), the endemics and also extincts *Lopha plicatuloides* (Mayer, 1864) and *Cardium hartungi* (Bronn *in* Hartung, 1860), as well as several species of gastropods (Zbyszewski & Ferreira, 1962).

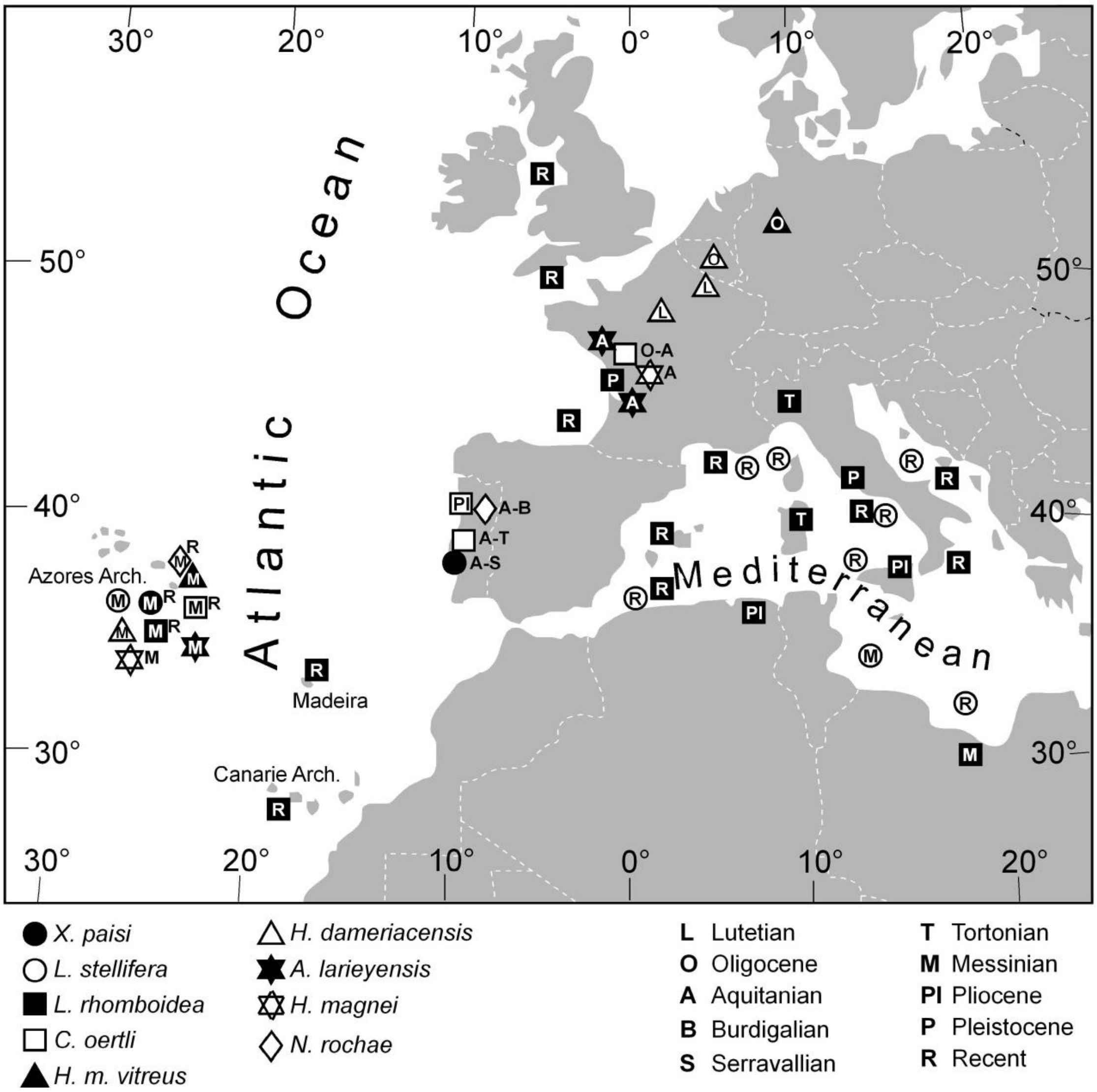


Figure 5. Geographic distribution and stratigraphic occurrence of the fossil ostracod species recovered in the Messinian deposits of Malbusca composite section.

Thus, for the Messinian sedimentary deposits outcropping at the Malbusca section it is possible to infer an epineritic environment characterised by vegetated bottoms and warm-water conditions.

All the identified Messinian Azorean ostracods are of European affinity (Fig. 5); not a single species is reported from the Miocene of the western Atlantic. This pattern is also seen in other well-studied phyla of similar age from the Azores such as the echinoderms (Madeira *et al*., 2011) and the molluscs (Zbyszewski & Ferreira, 1962).

Ostracods are mainly benthic epifaunal detritivore-grazer species that, in some cases, brood their instars. This gives them an enormous potential for a successful colonization after chance events of dispersal in rafts provided by detached algae, a plausible process for reaching such an isolated island as Santa Maria would be about 5-7 Ma ago. Indeed, available geophysical and geological data agree in considering that in the area of the Azores plateau, at that time, Santa Maria was probably the only emerged island (Madeira, 1986; Serralheiro & Madeira, 1990; Serralheiro, 2003).

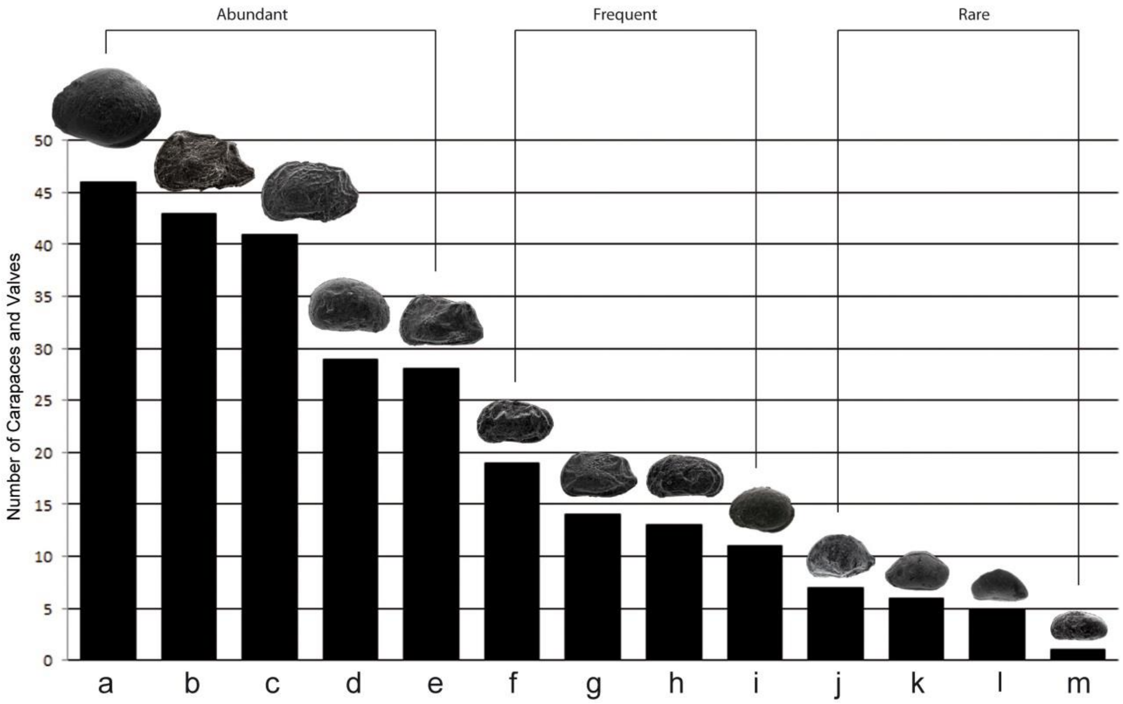


Figure 6. Abundance of the Late Miocene marine ostracod species collected from the Malbusca outcrop (Santa Maria Island, Azores). Absolute numbers refer to the occurrence of carapaces and valves in the Malbusca locality. **a)** *Loxoconcha stellifera*; **b)** *Dameriacella* aff. *D. dameriacensis*; **c)** ?*Quadracythere* sp.; **d)** *Xestoleberis* cf. *paisi*; **e)** *Pachycaudites* aff. *P. armilla*; **f)** *Callistocythere oertlii*; **g)** *Heliocythere magnei*; **h)** *Leptocythere azorica*; **i)** *Loxoconcha rhomboidea*; **j)** *Aurila* sp. ***k)*** *Neonesidea rochae*; **l)** *Paracypris* sp., and **m)** *Cyamocytheridea* sp.

CONCLUSIONS

The outcrop of Malbusca, located in the southern shores of Santa Maria Island, was studied in detail from a composite stratigraphic section. Petrographic data (decrease in grain size from the base to the top of the sequence, presence of ooids only at the base of the succession) and paleontologic data provided by ostracods and other phyla indicates that the entire Malbusca section was deposited in low energy shallow warm waters (~10-50 m depth) that slightly deepens upwards, suggesting a transgressive phase during the time of deposition of the studied sequence.

All the identified Azorean ostracods species are of European affinity. For them a passive dispersal through rafts provided by detached algae is proposed.

It is worth to stress that despite the fact that fossils of Santa Maria Island are known since the 19th century, there is still much to be discovered and this is especially true for some less well-studied marine phyla (e.g.: Porifera, Foraminifera, Bryozoa, Cnidaria). The new information herein provided by the fossil marine ostracods of Santa Maria Island is just another piece for this biogeographic puzzle, highlighting the crucial role of the Azores archipelago for understanding the biogeographical history of the North Atlantic faunas and floras during the last 10 Ma of the Neogene period.

ACKNOWLEDGEMENTS

We thank the Direcção Regional da Ciência, Tecnologia e Comunicações (Regional Government of the Azores), Direcção Regional do Ambiente e do Mar (Regional Government of the Azores), FCT (Fundação para a Ciência e a Tecnologia) of the Portuguese government for financial support, and we also thank the Clube Naval de Santa Maria and Câmara Municipal de Vila do Porto for field assistance. We are grateful to the organizers and participants of the International Workshops "*Palaeontology in Atlantic Islands*" who helped in the fieldwork. The first author would like to thank Giles Miller (Natural History Museum, London) for allowing access to the collections and bibliography; Artur Gil (CITA/Azores) for the French support; António M. de Frias Martins (CIBIO/Azores) and Ricardo Ramalho (Bristol University) for important reviews and discussion about this manuscript; Jorge Medeiros (CIRN/ Azores) for the SEM photographs. Ricardo Piazza Meireles benefited from a grant SFRH/BD/60518/2009 of FCT (Fundação para a Ciência e a Tecnologia), Portugal. Finally, we wish to thank Antonio Russo, Martin Gross and Jean-Paul Colin who, with their comments, greatly helped us to improve this paper.

PLATE 1.

Figs. 1 – 3. *Xestoleberis* cf. *paisi* Nascimento, 1989. DB/OST 0073.

Figs. 4 – 6. *Loxoconcha stellifera* Mueller, 1894. DB/OST 0076.

Figs. 7 – 9. *Loxoconcha rhomboidea* (Fischer, 1855). DB/OST 0079.

Figs. 10 - 12. *Callistocythere oertlii* Nascimento, 1989. DB/OST 0082.

Figs. 13 – 15. *Leptocythere azorica* Meireles & Faranda **n. sp.** DB/OST 0085.

Figs. 16. *Leptocythere azorica* **n. sp.** DB/OST 0110. Right valve in the external view.

Figs. 17. *Leptocythere azorica* **n. sp.** DB/OST 0111. Right valve in the external view.

PLATE 1

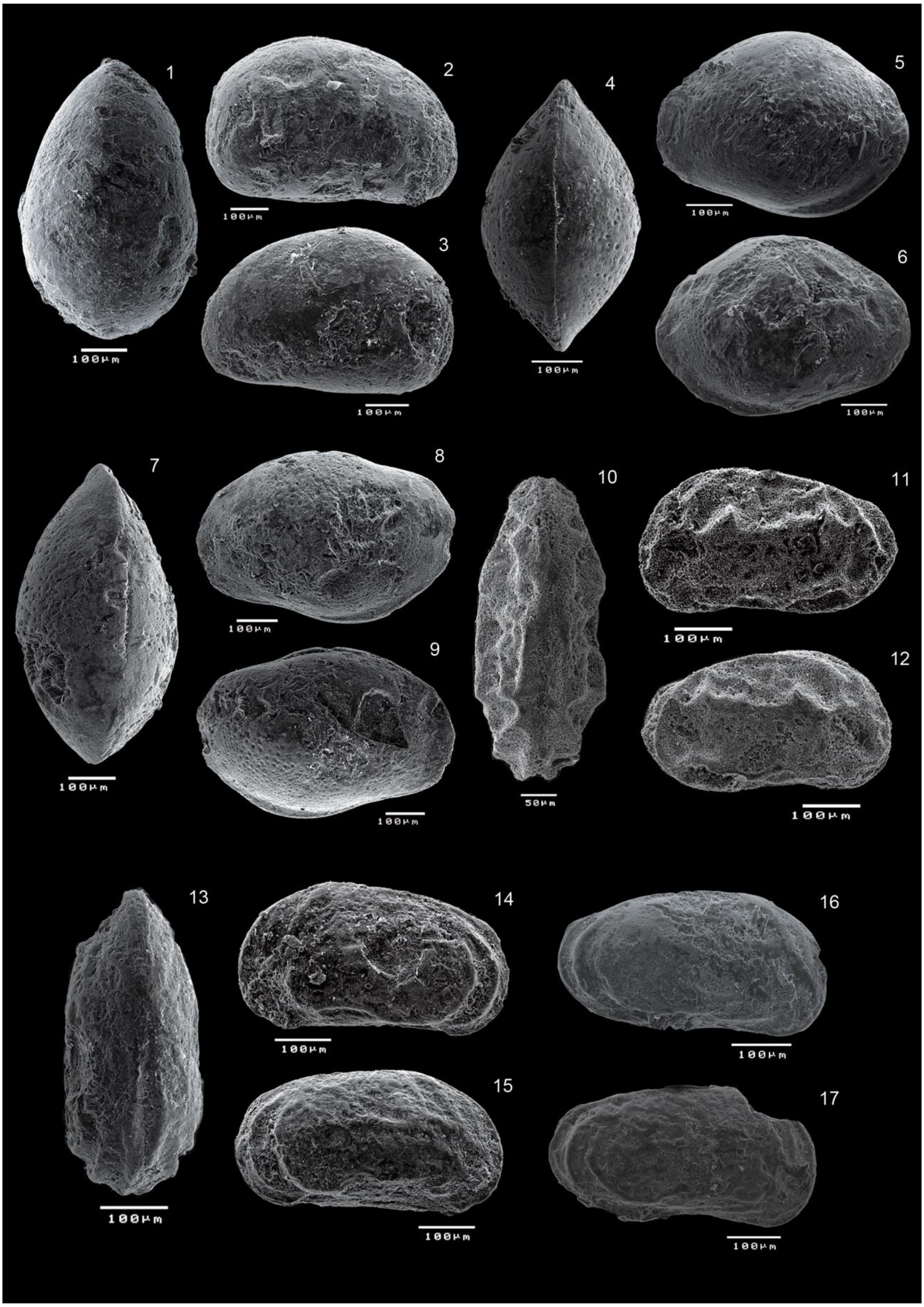

1
100µm
2
100µm
3
100µm
4
100µm
5
100µm
6
100µm
7
100µm
8
100µm
9
100µm
10
50µm
11
100µm
12
100µm
13
100µm
14
100µm
15
100µm
16
100µm
17
100µm

PLATE 2.

Figs. 1 – 3. *Pachycaudites* aff. *armilla* Ciampo, 1986. DB/OST 0088.

Figs. 4 – 6. *Dameriacella* aff. *dameriacensis* (Keij, 1958). DB/OST 0091.

Figs. 7 – 9. *Aurila* sp. DB/OST 0094.

Figs. 10 – 12. ?*Quadracythere* sp. DB/OST 0096.

PLATE 2

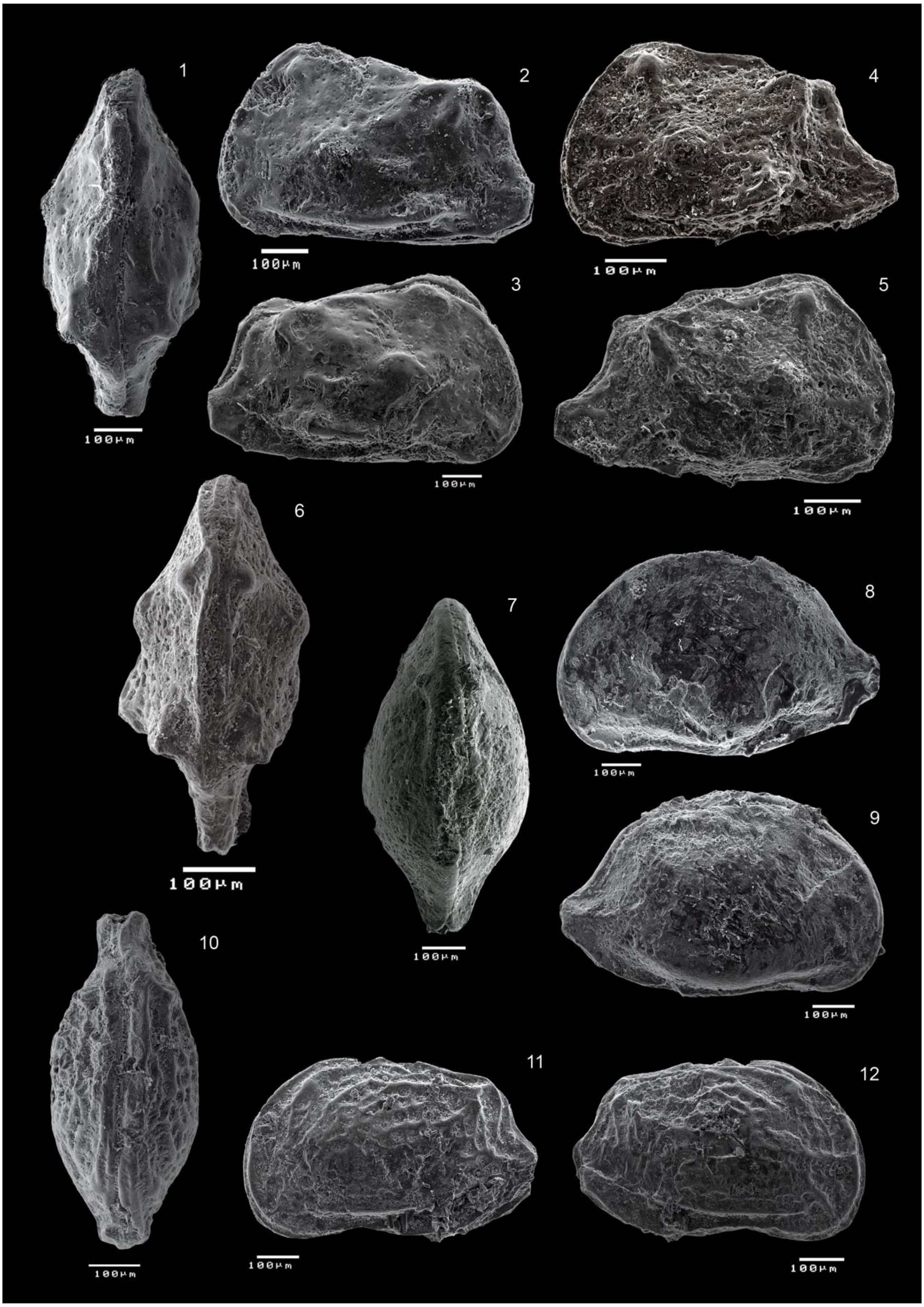

1
100µm
2
100µm
3
100µm
4
100µm
5
100µm
6
100µm
7
100µm
8
100µm
9
100µm
10
100µm
11
100µm
12
100µm

PLATE 3.

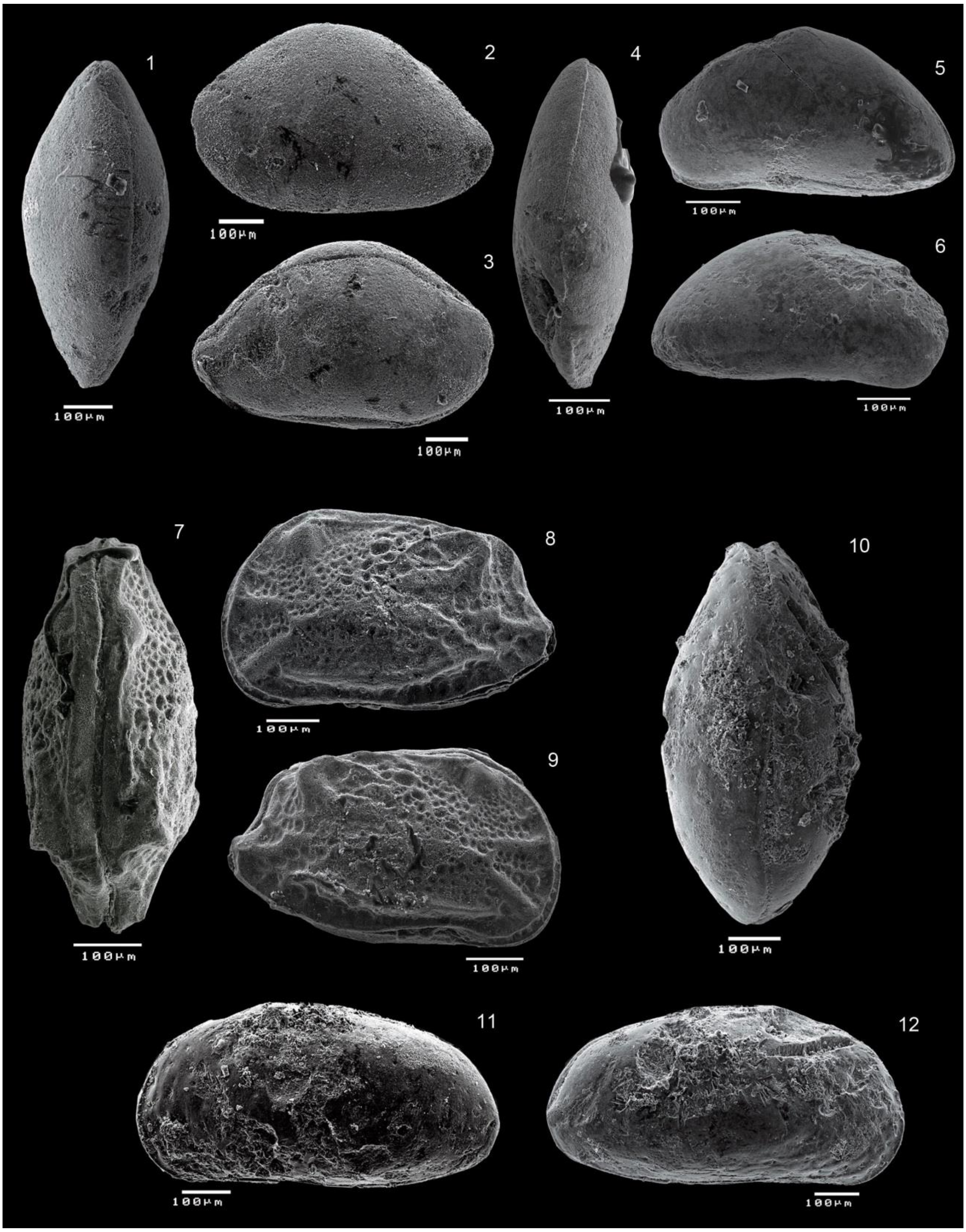
Figs. 1 – 3. *Neonesidea rochae* Nascimento, 1989. DB/OST 0102.

Figs. 4 – 6. *Paracypris* sp. DB/OST 0105.

Figs. 7 – 9. *Heliocythere magnei* (Keij, 1953). DB/OST 0099.

Figs. 10 – 12. *Cyamocytheridea* sp. DB/OST 0107.

PLATE 3


1
100µm
2
100µm
3
100µm
4
100µm
5
100µm
6
100µm
7
100µm
8
100µm
9
100µm
10
100µm
11
100µm
12
100µm

CHAPTER 5

THE HOLOCENE TO RECENT OSTRACODS OF THE AZORES (NE ATLANTIC): SYSTEMATICS AND BIOGEOGRAPHY

Ricardo Piazza Meireles; Dietmar Keyser; Sérgio P. Ávila

Paper in prep. to **Zootaxa**

ABSTRACT

This is the first report about the systematics and the biogeography of the Holocene to Recent shallow marine ostracods of the Azores archipelago (Portugal). Twenty species were found, representing 10 families and 14 genera (*Neonesidea*, *Leptocythere*, *Callistocythere*, *Cyprideis*, *Carinocythereis*, *Aurila*, *Heterocythereis*, *Urocythereis*, *Loxoconcha*, *Semicytherura*, *Xestoleberis*, *Sclerochilus*, *Lanceostoma* and *Cylindroleberis*). Seven new taxa are here reported for the Azores: 5 new records – the species *Neonesidea longisetosa* (Brady 1902), *Cyprideis torosa* (Jones, 1850), *Aurila prasina* Barbeito-Gonzalez, 1971 and *Sclerochilus hicksi* Athersuch & Horne 1987 – and 3 new species to Science, *Callistocythere insularis* n. sp. *Semicytherura brandoni* n. sp. and *Lanceostoma simplex* n. sp., which are herein described. The representatives of the families present in the Azores are typical of infralittoral marine environments around the world. Based on our results, the Azorean shallow-water marine ostracod communities (between 1 to 100m) appear to be less diverse than similar communities found elsewhere. In terms of biogeography context, the faunal founded are typical of Celtic, Gascoynian and Mediterranean zoogeographical provinces and secondarily at Lusitanian province. Ostracods bear great potential for applications in environmental studies. Our checklist and systematic study provide a base for the identification of ostracods from shallow water in the Azores region.

Key words: Ostracods; Holocene; Recent; Systematics; Biogeography; Azores archipelago.

INTRODUCTION

Ostracods are small crustaceans ranging in length from 0.08 to 3 mm, or more. Their entire body is encased in a bivalved, calcified carapace which can be smooth to variously ornamented. The two valves are joined by a dorsal hinge and by a closing muscle. The body is unsegmented and has a reduced number of limbs. The head is larger than both the thorax and abdomen combined. The ostracod bears normally eight pairs of appendages: first and second antennae, mandible, maxilla and three additional thoracopods with a pair of caudal rami. The three thoracopods are often used as walking or cleaning legs. The abdomen terminates in a pair of caudal rami. Between the last thoracopods and the caudal rami are the genital organs. Obvious are often the large male copulatory organs (Keyser, 1988) which fill up the posterior half of the whole carapace. Some 65,000 living and fossil species have been described, grouped into several orders. The class of Ostracoda is based on gross morphology and may not be monophyletic (Horne *et al.*, 2002).

The Azores Archipelago is a group of nine islands located in the North Atlantic approximately between 25° – 32° W and 37° – 40° N, about 1,500 km from mainland Portugal. The archipelago is located in an area defined by a complex tectonic setting whose meaning is a matter of extensive discussion among scientists. Two of the Azorean islands – Flores and Corvo – rise from the western flank of the mid-Atlantic Ridge, whilst the remaining seven islands are located to the east of this structure along the western segment of the Eurasia–Nubia boundary (Fig. 1).

Few studies have been published on the Recent ostracod fauna of the Azores, and most of them were related with the freshwater ostracods (Richard, 1896; Petkowski, 1963; Meisch & Broodbaker, 1993; Petkowski *et al.*, 1993). The only papers devoted to the marine ostracods were published by Poulsen (1972) and Angel (1973), who reported on the bathyal myodocopids from the Azores.

Meireles *et al.* (2012) were the first to study the fossil record of the Azores. These authors examined the Late Miocene ostracods of the island of Santa Maria, reporting 13 species, representing 7 families and 12 genera (*Xestoleberis*, *Loxoconcha*, *Callistocythere*, *Leptocythere*, *Dameriacella*, *Aurila*, *Heliocythere*, *Pachycaudites*, *Neonesidea*, *Cyamocytheridea*, *?Quadracythere* and *Paracypris*).

Meireles *et al.* (Chapter 6) studied the palaeoecology and the taphonomical aspects of the Holocene to Recent ostracods from the Azores. Fifteen species were recovered, representing 8 families and 12 genera (*Loxoconcha*, *Neonesidea*, *Xestoleberis*, *Aurila*, *Urocythereis*, *Heterocythereis*, *Carinocythereis*, *Callistocythere*, *Leptocythere*, *Semicytherura*, *Lanceostoma* and *Cylindroleberis*). Large-scale (sea-surface currents, Holocene relative sea-level, storms) and small-scale processes (geographical location, coastal fragmentation into dynamic cells with impermeable lateral boundaries, physiognomy of the coast line, seafloor stability of the sediments) are responsible for shaping the Azorean Holocene to Recent ostracods communities.

The aims of our study are to: **1)** improve the knowledge about the shallow-water marine ostracods of the Azores; **2)** present the first systematic study about these organisms, review all reported species and describe new species; **3)** establish the biogeographical relationships of this invertebrate group.

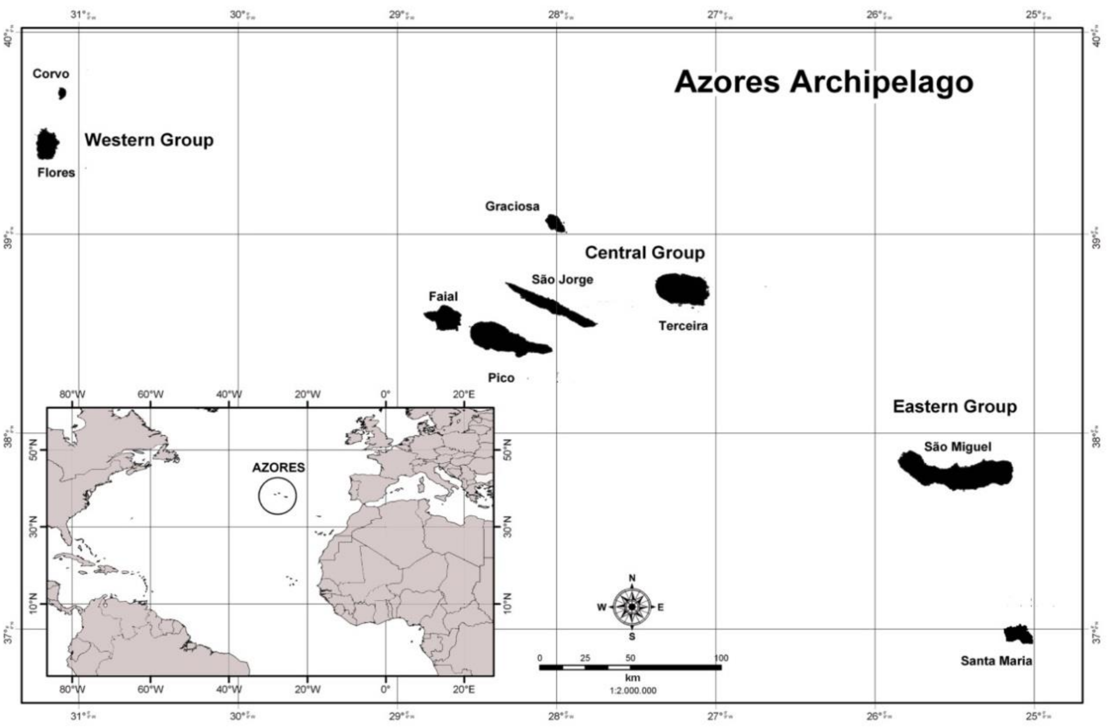


Figure 1. Map of the Azores archipelago.

MATERIALS AND METHODS

Holocene samples collected around the Azores and Recent samples collected on São Miguel and Santa Maria Islands were used for this study. For a complete list of the stations please consult Table 1 (Meireles *et al*., Chapter 6). The animals were sampled with grabs, corers and handnet. They were sieved, dried and handpicked from the sediments under a stereomicroscope. Specimens used for SEM studies were coated with gold-palladium, and viewed under a JEOL JSM-5410 Scanning Microscope. For light microscopy the ostracods were dissected with small needles and embedded in Hydro-Matrix solution. Light microscopy photographs were taken and also the soft parts drawn.

The taxonomy and classification adopted follows Horne *et al.* (2002). The figured specimens (SEM) are stored in the Ostracoda Collection of the Department of Biology, University of the Azores, under prefix "**DB/OS nº**". Other abbreviations used: RV=right valve, LV=left valve. For a complete list of stations please see Chapter 3 (Table 4).

A table was constructed with the geographical distribution of the Ostracoda species reported from the Azores (Table 1). We used the ostracod biogeographical provinces of Wood & Whatley (1994) modified by Frenzel *et al.* (2010) with the frontiers as in Fig. 2. For the biogeographical study, the species endemic to the Azores and all species identified only to the genus were excluded of the analysis. A simple percentage index was used to compare the number of species in a given location in relation to the total number of ostracod species occurring in the Azores (Table 2). A dendrogram showing the biogeographical relationships of the Azorean ostracods' fauna was drawn using non-transformed presence-absence data, the Bray-Curtis similarity index and UPGMA method, PRIMER version Plymouth Marine Laboratory package (Fig. 3).

Figure 2. Ostracod biogeographical provinces of Wood & Whatley (1994) modified by Frenzel *et al.* (2010). Records from the western-Atlantic (Tropical biogeographical province) not shown in this map.

RESULTS

Systematic part

Class OSTRACODA Latreille, 1802

Order PODOCOPIDA Müller, 1894

Family Bairdiidae Sars, 1888

Genus *Neonesidea* Maddocks, 1969

Neonesidea longisetosa (Brady, 1902)

(Plate 2, Figs A-L)

1902 *Bairdia longisetosa* Brady, p.197, pl.25, fig 8,9

1963 *Neonesidea gerda* (Benson and Coleman).pp. 19, 20, fig.8, pI. 1, figs. 14-16.

1969 *Neonesidea gerda* Maddocks, pp.24 25, fig.7

Material examined: DB/OS 0119, 0133, 0136.

Description: Carapace sub-triangular, in lateral view. Greater height located at the middle of the valve. Left valve larger than the right one with overlap throughout the entire margin. Slightly convex ventral margin in the right valve, slightly convex in the left one. Broadly arched rounded dorsal margin. Smooth carapace surface.

Remarks: The collected specimens are identical to *N. longisetosa* considering the carapace morphology. The morphology of the soft parts is comparable to the figures Maddocks (1969) gave for *Neonesidea gerda*, and by this reason we consider *N. gerda* as a junior synonym of *N. longiseta*. This is the first record for the Azores.

Geographical Distribution: The species *N. longisetosa* was described by Brady (1902) from the Caribbean. Benson & Coleman (1963) reported *N. gerda* from Florida. *N. longiseta* has so far been recorded around the Azores archipelago, between 1 and 85 m depth (Meireles *et al*., submitted; Chapter 6).

Family Leptocytheridae Hanai, 1957

Genus *Leptocythere* Müller, 1927

Leptocythere pellucida (Baird, 1850).

(Plate 5, Fig. Q)

1850 *Cythere pellucida* sp. nov. Baird, 173, pl. 21, fig. 7.

1925 *Leptocythere pellucida* (Baird); Sars, 172, pl. 79, fig. 1.

1989 *Leptocythere pellucida* (Baird); Athersuch *et al.*, pl. 1(3,4), fig. 33.

Material examined: DB/OS 0057.

Description: Carapace strongly calcified, elongated, with large pits, sometimes also smooth.

Remarks: The collected specimens are identical to *L. pellucida* in regards to its elongated, robust carapace with large fossae.

Geographical Distribution: A marine, sublittoral species (to 50 m depth), common on sandy bottoms in the North Sea, Atlantic Coast of France and Britain, southern Norway and the western Baltic (Athersuch *et al.*, 1989). Rare material, found on Terceira (this study) and on São Miguel and Faial (Meireles *et al.*, submitted; Chapter 6).

Genus *Callistocythere* Ruggieri, 1953

Callistocythere insularis Meireles & Keyser **n. sp.**

(Plate 8, Figs A-F)

(Plate 9, A-E)

Chapter 6 *Callistocythere* sp.; Meireles *et al.*, fig. 2 (photo 11), DB/OS 0148.

Derivation of name: With reference to the insular shelf of the Azores archipelago (NE Atlantic).

Holotype: Male, adult valve; DB/OS 0148: length = 0.48 mm, height = 0.24 mm.

Type locality: São Miguel Island (ETAR Pranchinha; N 37º 44' 32,1"/ W 025º 38' 55,5"), Azores Archipelago, Portugal. Recent.

Figured specimens: DB/OS 0148 (holotype, male), DB/OS 0147 (female). Collected alive from ETAR Pranchinha localities in the inner shelf by Ricardo Meireles and Paulo Antunes, September 2011; salinity 32 to 35‰, water temperature 14 to 17°C, at 15 m depth.

Age: Holocene to Recent.

Material examined: Holotype: DB/OS 0148. Paratypes: DB/OS 0135, 0149, 0150. Other material: DB/OS 0061, 0062, 0063, 0138, 0147, 0150, 0151.

Dimensions: Holotype DB/OS 0148: length = 0.48 mm, height = 0.24 mm; Paratype DB/OS 0135: length = 0.52 mm, height = 0.25 mm; Paratype DB/OS 0149: length = 0.48 mm, height = 0.24 mm, width = 0.19 mm; Paratype DB/OS 0150: length = 0.48 mm, height = 0.24 mm, width = 0.19 mm.

Diagnosis: Nearly rectangular carapace in lateral view. Maximum height anterior and posterior of the middle of the valve, due to a ventral margin with strong median concavity. Left valve slightly larger than right valve with overlap in the anterior area. Dorsal margin straight and rectilinear truncation in the median-posterior portion. Three prominent posterior ribs running dorso-ventral with a very distinct rib connecting the first and second posterior rib on the ventro-caudal edge. Distinct copulatory organ.

Description: Carapace robust, rather small with three prominent ribs in dorso-ventral direction. Dorsal margin straight, ventral margin with strong concavity. One distinct ridge connecting first and second posterior ridge on ventro-caudal edge. Normal pore canals. Inner lamella broad, radial pore canals branched with distinct large anterior and smaller posterior vestibule.

Antennule: 5 jointed (4:3:1:2:1,4), second joint with one ventro-distal seta, third joint with a short dorso-distal claw, fourth joint with one median seta and one short and one medium dorso-medial claws,as well as one big and one small dorso-distal claws and a seta as long as the big claw. Also with a long ventro-distal seta. Ultimate joint with one big claw and a small and long seta.

Antenna: Endopod three-jointed (5:16:1). Exopodit two-jointed reaching to the tip of the claws of the endopod. First joint of endopod with one strong ventro-distal seta. Second joint long at three-fifth of length dorso-median one long and one short seta, the long seta reaching the distal end of joint. Ventro-median also one small and one strong seta. Ventro-distal a strong claw reaching to the distal end of endopod. Ultimate joint with two strong claws, ventral one slightly shorter than the dorsal one.

Mandible and maxilla as for the genus.

P1: Four-jointed with long distal claw (7:4:2,5:2,5:3,5). First joint with one ventral seta proximal, one dorsal seta median and two setae at the distal part of the joint. Second joint with one ventro-distal seta. Last joint with two small setae at the base of the claw.

P2: Four-jointed with long distal claw (7:3:2,5:3:4). First joint with one ventral seta proximal, one dorsal seta median and one small and one longer seta at the distal part of the joint. All other joints without setae.

P3: Four-jointed with long distal claw (7:4:3:3,5:4). First joint with one dorsal seta median and one seta at the distal part of the joint. Second joint with one ventro-distal seta. Third joint with a small seta ventrally. Last joint with two small setae at the base of the claw.

Copulatory organ: With a typical pointed triangular process; ductus ejaculatorius sclerified and looped.

Remarks: This species has probably been confused with *Callistocythere littoralis* (Müller, 1894) and *Callistocythere badia* (Norman 1862) *fide* Athersuch & Whittaker (1977), from which it can be distinguished by its more rectangular carapace and the above mentioned ridges, and the different copulatory organ (text-pl. 9; Athersuch & Whittaker, 1977).

Geographical Distribution: Recent; shallow marine, *Callistocythere insularis* n. sp. has so far been recorded on six islands of the Azores archipelago: Santa Maria (18 m depth), São Miguel Island (15 to 20m depth), Terceira (3 to 23 m depth), Pico (1 to 54 m depth), Graciosa (1 m depth) and Flores (3 m depth) (Chapter 3 - table 4 and Meireles *et al*., submitted; Chapter 6).

Family Cytherideidae Sars, 1925

Genus *Cyprideis* Jones, 1856

Cyprideis torosa (Jones, 1850)

(Plate 7, Figs H-L)

1850 *Candona torosa* sp. nov. Jones, 27, pl. 3, figs 6a-e.

1974 *Cyprideis torosa* (Jones); Kilenyi & Wittaker, 21-32.

1989 *Cyprideis torosa* (Jones); Athersuch *et al*., pp. 114, fig. 44a-k.

Material examined: DB/OS 0011, 0012, 0013, 0014, 0015, 0051, 0052, 0053.

Description: Female carapace subovate in lateral view; inflated posteriorly. Male carapace more elongate and not inflated posteriorly. Valves smooth to variably pitted, sometimes nodose. Big sieve pores present.

Remarks: The collected specimens are identical to *Cyprideis torosa* (Jones, 1850) with regards to the subovate carapace. Apparent sexual dimorphism, with valves smooth to variably pitted, sometimes with strong nodes in very low salinity (Keyser & Aladin 2004). Found in a wide range of salinities from almost freshwater to over 60‰ in inland ponds, lakes, lagoons, estuaries, fjords, deltas and other marginal marine environments, down to a depth of around 13 m. *C. torosa* appears to prefer a muddy or sandy mud substrate but is sometimes also found on algae. This is the first record for the Azores.

Geographical Distribution: Widespread throughout Europe and as far north as Iceland, Mediterranean region, W and Central Asia, and Middle East and North Africa. Also found in lakes in Central Africa. In the Azores, it is reported from Pico and Terceira.

Family Trachyleberididae Sylvester-Bradley, 1948
Genus *Carinocythereis* Ruggieri, 1956
Carinocythereis whitei (Baird, 1850)
(Plate 8, Figs L-N)

1850 *Cythereis whitei* sp. novo W. Baird, pl. 20, figs. 3, 3a.

1969 *Carinocythereis bairdi* sp. novo F. Uliczny, pp. 79, pI. 5, fig. 7; pl.16, fig. 7.

1985 *Carinocythereis whitei* (Baird); J. Athersuch, D. J. Home & J. E. Whittaker, pp. 153-158, pl. 1, figs. 12-15; pl. 2, figs. 7, 8.

1987 *Carinocythereis whitei* (Baird); Athersuch, J. & Whittaker, J. E., pp. 103-110.

Specimens: Material collected alive on São Miguel and Terceira Islands at 20 and at 23 m depth, respectivelly.

Material examined: DB/OS 0054, 0055, 0056.

Description: Carapace rectangular in lateral view, ornaments consisting of three longitudinal carinae (costae) of which the ventral one bends anteriorly upwards.

Remarks: The species was long time misinterpreted and was described as *C. antiquate* (Baird) or *C. bairdi*. Athersuch *et al*. (1985) reinstated the name C. *whitei* (Baird) after careful investigation of the syntypes of Baird.

Geographical Distribution: A species found in the South of the British Isles, the Atlantic coast of France and the Mediterranean. Typically living on sand, in the Azores archipelago *C. whitei* has been recorded from São Miguel Island and Terceira (this study) and also from Santa Maria (at the beach), Pico (54 m depth) and Faial (10 to 30 m depth) (Meireles *et al*., submitted; Chapter 6).

Family Hemicytheridae Puri, 1953
Genus *Aurila* Porkorný, 1955
Aurila convexa (Baird, 1850)
(Plate 5, Figs A-K)

1850 *Cythere convexa* sp. nov. Baird, pp. 174, pl. 21, fig. 3.

1894 *Cythereis convexa* (Baird); G.W. Müller, pp. 366, pl. 28, figs 14, 19; pl. 30, figs 49-51; pl. 35, figs 6, 13, 19-21.
1982 *Aurila convexa* (Baird), "form A"; Horne, pl. 1, fig. 13.
1989 *Aurila convexa* (Baird); Athersuch *et al.*, pp. 157, fig. 62; pl. 5(1).

Specimens: Material collected alive from ETAR Pranchinha, in inner shelf, 4th September 2011; salinity 32 to 35‰, water temperature 14 to 17°C, at 15 m depth. Also collected on Terceira Island, at 1 m and 23 m depth.

Material examined: DB/OS 0032, 0033, 0034, 0035, 0139, 0152.

Description: The species shows a clear postero-dorsal angle; two ridges in the frontal region, and postero-ventral rounded caudal process.

Remarks: *A. convexa* has previously been confused with *A. woutersi* Horne, 1986; the two species were formerly considered by Horne (1982) as "form A" and "form B" respectively of *A. convexa* (see Horne (1986) for further discussion).

Geographical Distribution: Recent; a common littoral to shallow sublittoral marine species in southern North Sea, typically living amongst algae such as *Corallina*, *Laminaria* holdfast, algae debris, or on sand; it is known from France, Portugal and the Mediterranean, but not from Scandinavia; it therefore appears to be at the northern limit of its distribution in southern Britain (Athersuch *et al.*, 1989). Typically living on sand, *A. convexa* is one of the commonest ostracods in the Azores and it has so far been recorded from Formigas Islets (20 m depth), São Miguel (1 to 15 m depth), Pico (46 to 69 m depth), Faial (10 to 85 m depth, Graciosa (1 m depth), Flores (3 m depth), and Terceira (intertidal down to 23 m depth).

Aurila woutersi Horne, 1986

(Plate 6, Figs A-E)

1973 *Aurila convexa* (Baird); Wouters, pp. 16, pl. 2, fig. 2.
1982 *Aurila convexa* (Baird), "form B."; Horne, pp. 1, pl. 1, fig. 14.
1986 *Aurila woutersi* Horne; pp. 33-38.

Specimens: Material collected alive on São Miguel Island: at Caloura, in the inner shelf, 15th March 2012, salinity 32 to 35‰, water temperature 16 to 19°C, at 2.5 m depth; and at ETAR Pranchinha, in the inner shelf, 4th September 2011, salinity 32 to

35‰, water temperature 14 to 17°C, at 15 m depth. Also collected alive on Pico Island, locality in the insular shelf, November 2003, at 54 m depth.

Material examined: DB/OS 0031, 0120, 0153.

Description: This species is more quadrate than the previous; the posterior-ventral region is curved and runs into a rounded caudal process. Only one frontal ridge and a larger one in the posterior region are present.

Remarks: *A. woutersi* has previously been confused with *A. convexa*; the two species were formerly considered by Horne (1982) as *A. convexa* "form A" and "form B". "The two species are most easily distinguished by comparison of their left valves; that of *A. woutersi* is more quadrate, while that of *A. convexa* is subtriangular with a distinct angle at the highest point of its dorsal margin" (Horne, 1986).

Geographical Distribution: A Recent marine ostracod species living mainly on sand in the littoral area. It is part of the phytal community and lives here in the holdfasts and the area between the algae. It seems to be common in the Southern British Isles (Athersuch *et al.*, 1989). *A. woutersi* has so far been recorded from three islands on the Azores archipelago: São Miguel (intertidal down to 20 m depth) Pico (54 m depth) and Terceira (intertidal down to 23 m depth) (this study and Meireles *et al.*, submitted; Chapter 6).

Aurila prasina Barbeito-Gonzalez, 1971

(Plate 6, Figs F-M)

1971 *Aurila prasina* Barbeito-Gonzalez, 277, pl. 12, figs 1a, 2a, 3a, pl. 46, figs 11, 12.

1975 *Aurila prasina* Barbeito-Gonzalez; Bonaduce *et al.*, 44, pl. 20, figs 1-7.

Material examined: DB/OS 0039, 0040, 0046, 0047, 0048, 0049, 0050.

Description: This species shows a strong postero-dorsal angel; the anterio-ventral region is broadly rounded; ocular tubercle present. Valves are finely punctated, with conspicuous normal and sieve pores.

Remarks: *A. prasina* has previously been confused with *A. woodwardi* (Brady, 1868). This is the first record for the Azores.

Geographical Distribution: Recent, this species is a typical near-shore form. It has been found only between Lecce and S. Maria di Leuca, in Adriatic Sea, at depths not exceeding 20 m (Bonaduce *et al.*, 1975) and in Naxos, Greece (Barbeito-Gonzalez, 1971). Typically found on sands, *A. prasina* was found in Holocene sediments on Terceira Island (1 m depth), Graciosa (1 m depth), São Miguel (20 m depth) and Faial (30 m depth).

Genus *Heterocythereis* Elofson, 1941

Heterocythereis albomaculata (Baird, 1938)

(Plate 7, Figs A-G)

1838 *Cythere albo-maculata* sp. nov. Baird, pp. 142, pl. 5, fig. 23.
1957 *Heterocythereis albomaculata* (Baird); Wagner, pp. 57, pl. 24, figs 1-7.
1979 *Heterocythereis albomaculata* (Baird); Athersuch & Wittaker, pp. 117-124.
1989 *Heterocythereis albomaculata* (Baird); Athersuch *et al*., pp. 165, pl. 5(4), fig. 66.

Specimens: Material collected alive on São Miguel Island, Caloura, in the inner shelf, 15th March 2012, salinity 32 to35‰, water temperature 16 to 19°C, at 2.5 m depth.

Material examined: DB/OS 0036, 0037, 0038, 0041, 0042, 0043, 0044, 0045, 0113, 0114, 0115, 0116, 0125, 0134.

Description: Valves finely punctate, with conspicuous normal and sieve pores; lineate and often faintly reticulate ventrally. Sexual dimorphism pronounced, male considerably longer than female. Male copulatory organ specific.

Remarks: The collected specimens are identical to *H. albomaculata* (Baird, 1938) in respect to the carapace morphology. Male copulatory appendage with a "tapering, somewhat sinuous distal process and a moderately long ejaculatory duct (text-fig. 1)" (Athersuch *et al*., 1989).

Geographical Distribution: Recent; a common littoral to shallow littoral marine species found along the shores of the North Sea and the Atlantic. Living on sand and in phythal communities (Athersuch *et al*., 1989), *H. albomaculata* is one of the commonest ostracods of the Azores, being reported from Santa Maria (18 m depth), São Miguel (intertidal down to 20 m depth), Graciosa (1 m depth), Terceira (intertidal down to 3 m depth), Pico (54-69 m depth) and Faial (10-30 m depth).

Genus *Urocythereis* Ruggieri, 1950

Urocythereis britannica Athersuch, 1977

(Plate 4, Figs A-P)

1868b *Cythere oblonga* Brady; Brady, pp. 400, pl. 31, figs 14-17 (non Brady, 1866).

1977 *Urocythereis britannica* sp. nov. Athersuch, 255, pl. 1, figs 4-6; pl. 2, figs 1-6; pl. 3, figs 1-6; pl. 4, figs 1-5; text-figs 3a, b, 4a, e, g.

1989 *Urocythereis britannica* Athersuch, 1977; Athersuch *et al.*, 1989, pp. 170, fig. 68a-f.

Material examined: DB/OS 0016, 0017, 0018, 0019, 0020, 0021, 0022, 0023, 0024, 0025.

Description: Carapace subrectangular, strongly calcified, ornament reticulate with different sized fossae.

Remarks: "This species was long confused with the Mediterranean species, *U. oblonga* (Brady, 1866), itself a junior objective homonym of *Cythere oblonga* M´Coy, 1844, and renamed *U. distinguenda* by Neviani (1928), the two differ in the shapes of their carapaces and male copulatory appendages" (Athersuch *et al.*, 1989).

Distribution: This species is found along the coasts of the Atlantic, the North Sea and probably in the Mediterranean. In the Azores, it seems to be more frequent on the southern shores (Meireles *et al.*, submitted; Chapter 6). It lives mainly on sands and prefers shallower marine habitats. *U. britannica* has so far been recorded from Santa Maria (intertidal), São Miguel (intertidal down to 20 m depth), Terceira (0-3 m depth), Pico (1-69 m depth) and Faial (10-85 m depth) (this study and Meireles *et al.*, submitted; Chapter 6).

Family Loxoconchidae Sars, 1925

Genus *Loxoconcha* Sars, 1866

Loxoconcha rhomboidea (Fischer, 1855)

(Plate 1, Figs A-J)

1854 *Cythere flavida* O.F.Müller; W.Zenker, pp. 20, pp. 86, pl. 5, fig. B4, figs. B1-3 (non *C. flavida* O.F.Müller, 1785).

1855 *Cythere rhomboidea* sp. nov., Fischer pp. 656.

1976 *Loxoconcha rhomboidea* (Fischer); Athersuch & Whittaker, pp. 81-90.

Specimens: Samples collected alive on São Miguel Island, Rosto do Cão, in tidal pool, 15th March 2012, salinity 32 to 35‰, water temperature 16 to 19°C, at 1 m depth.

Material examined: DB/OS 0026, 0027, 0028, 0029, 0030, 0112, 0126, 0140, 0144, 0145, 0154.

Description: Carapace rather inflated in dorsal view, subrhomboid in lateral view, dorsal margin of female strongly arched. Ornament of concentrically arranged fine to medium sizes puncta.

Remarks: The collected specimens are identical to *Loxoconcha rhomboidea* (Fischer, 1855) in carapace outline and sexual dimorphism.

Geographical Distribution: Recent: a common phytal species in the eulittoral and sublittoral zones of the coasts of Europe, from N Norway to Madeira and Canary Islands, off N Africa. Mediterranean records need careful revision (Athersuch & Whittaker 1976). Late Miocene of Santa Maria Island (Azores) (Meireles *et al*., 2012). Typically living on sand near or amongst algae, *L. rhomboidea* was recorded from all the sampled islands of the Azores: Santa Maria (intertidal down to 18 m depth), Formigas Islets (20 m depth), São Miguel (intertidal down to 20 m depth), Terceira (intertidal down to 23 m depth), Pico (46-69 m depth), Faial (intertidal down to 30 m depth), Graciosa (intertidal down to 1 m depth) and Flores (3-20 m depth) (Meireles *et al*., submitted; Chapter 6). On São Miguel, it was found living associated with brown-algae and sponges, between 1 and 15 m depth.

Loxoconcha cf. *ochlockoneensis* Puri, 1960

(Plate 1, Figs K-R)

1960 *Loxoconcha ochlockoneensis* Puri pp. 111, pl. 3, figs. 13, 14.

2000 *Loxoconcha ochlockoneensis* Puri; Keyser & Schöning, pp.573, pl. 5, figs. 81-82.

Specimens: Sample collected on Lajes do Pico, in tidal pool, August 2010, salinity 28 to 34‰, water temperature 16 to 19°C, at 1 m depth.

Material examined: DB/OS 0001, 0002, 0003, 0004, 0005.

Description: Strongly dimorphic, male larger, female more subovate. Posterior and anterior margins of the carapace flat, dorsal margin almost straight in male, slightly arched in female. Valves finely punctated.

Remarks: This *Loxoconcha* has in common with *L. elliptica* Brady, 1868 the finely punctated surface, which readily discriminate this species from the other Loxoconchidae found in the Azores. However, it differs from *L. elliptica* in having anteriorly and posteriorly along the margin, flat parts of the carapace, which look like they are glued together. Although the original drawings of Puri (1960) are hard to interpret, we are positive that our species is a close relative to *Loxoconcha ochlockoneensis*.

Geographical Distribution: A mainly brackish water species. It is found on muddy to sandy grounds with growth of algae. It is known from the West coast of Florida and the Bermudas (Keyser & Schöning, 2000). We have recorded it from São Miguel (1-2 m depth), Santa Maria (18 m depth), Formigas Islets (20 m depth), Terceira (3-23 m depth), Pico (1-54 m depth), Graciosa (1 m depth) and Flores (20 m depth) (Meireles *et al*., submitted; Chapter 6).

Family Cytheruridae Müller, 1894

Genus *Semicytherura* Wagner, 1957

Semicytherura brandoni Meireles & Keyser **n. sp.**

(Plate 8, Figs G-J)

(Plate 10, A-E)

Chapter 6 *Semicytherura* sp.; Meireles *et al*., fig. 2 (photo 12), DB/OS 0123

Derivation of name: In honor to Dra. Simone Nunes Brandão by her important studies on marine ostracods.

Holotype: Male, adult carapace; DB/OS 0123: length = 0.43 mm, height = 0.23 mm. Carapace was destroyed during soft-parts studies.

Type locality: São Miguel Island (Mosteiros, N 37º 53' 56,6" / W 025º 49' 18,0"), Azores Archipelago, Portugal. Recent, littoral.

Figured specimen: DB/OS 0130 (paratype, female). Sample collected alive on São Miguel Island, Mosteiros, in tidal pools, 15th March 2012, salinity 32 to 35‰, water temperature 16 to 19°C, at 2 m depth.

Age: Recent.

Material examined: Holotype: DB/OS 0123, Paratypes: DB/OS 0124, 0127, 0130.

Dimensions: Holotype DB/OS 0123: length = 0.43 mm, height = 0.23 mm; Paratype: DB/OS 0124: length = 0.47 mm, height = 0.24 mm; Paratype: DB/OS 0127: length =

0.47 mm, height = 0.24 mm; Paratype: DB/OST 0130: length = 0.43 mm, height = 0.25 mm.

Diagnosis: Carapace small, subquadrate, with caudal process above mid-height. Ornament reticulate with conspicuous longitudinal muri, which are merging anteriorly. Typical strong depression dorso-anteriorly.

Description: Carapace small, subquadrat. Caudal process present. Slightly bulged in ventro-posterior region. Ridges merging anteriorly. Flat and smooth area dorso-anteriorly. Inner lamella typical for the genus calcified.

Antennula: Sixth-jointed and a distal claw (8: 7: 3,5: 5: 4: 2,5: 5), third joint with one distal seta, fourth joint with one distal seta, fifth joint with one long seta reaching beyond the tip of the distal claw and two smaller setae. Last segment with one strong claw, one long and one short setae.

Antenna: Endopodit four-jointed (4:6,5:11:1,5), exopodit as long as the endopodit with two segments. First joint of endopodit with one ventro-distal seta, second joint with one strong and one smaller setae and one aethetask seta, third joint with one dorso-median seta and one ventro-distal seta. Last joint with two strong claws.

Mandibula: not observed.

Maxillula: Slender with one palpus and three endites. Vibratory plate with two aberrant bristles.

P1: Four-jointed (6:3:2:2,5). First joint with one long basic ventral, one dorso-median seta and one strong and one small distal setae, second joint with one distal seta. Last segment with strong claw.

P2: Four-jointed (7:4:2:3). First joint with one dorso-median and one distal setae, second joint with one distal seta, last segment with strong claw.

P3: Four-jointed (7,5:6:2,5:4). First joint with one short distal seta, second joint with one seta and distal segment with strong claw.

Copulatory organ: With anvil-like main process and shoe-like smaller secondary process. Ductus ejaculatorius coiled in one circle, three quarter strongly chintinized.

Remarks: The species is defined by the small size. The typical male copulatory organ (text-pl. 10) resembles the one in *Semicytherura tela* Horne & Whittaker, 1980, but having a more straight anvil-like processus, while *S. tela* exhibits a more pointed leaf-like processus. This species has probably been confused with *S. tela* and *Semicytherura cornuta* (Brady, 1968), from which it can be distinguished by its smaller size, an alar process in the postero-ventral margin, and distinctive copulatory organ.

Geographical Distribution: Recent; shallow marine, in the Azores, *Semicytherura brandoni* n. sp. has so far been recorded from Santa Maria (18 m depth), the Formigas Islets (20 m depth), São Miguel (1-9 m depth), Terceira (intertidal) and Pico (1 m depth) (Meireles *et al*., submitted; Chapter 6).

Semicytherura cf. *cornuta* (Brady, 1868)

(Plate 8, Fig. K)

1868 *Cytherura cornuta* sp. nov. Brady, 445, pl. 32, figs 12-15 (female).
1974 *Semicytherura cornuta* (Brady); Wittaker, 77-84.
1989 *Semicytherura cornuta* (Brady); Athersuch *et al.*, 213, fig. 86a-d.

Specimen: Collected alive on Santa Maria Island, on Ilhéu da Vila, July 2010, salinity 32 to 35‰, water temperature 13 to 16°C, at 13 m depth.

Material examined: DB/OS 0064.

Description: Carapace subquadrate, with caudal process above mid-height. Ornament reticulated, with conspicuous longitudinal muri merging anteriorly and one of which runs into a postero ventral alar protuberance.

Remarks: Our species is similar to *S. cornuta,* but it is strikingly smaller (length = 0.46 mm, height = 0.23 mm). It has a higher and more conspicuous caudal process than *S. sella* and is more elongated than *S. acuticostata*, and the ornamentation is also different (see Athersuch *et al.*, 1989 for further discussion). The absence of copulatory organ in the material prevents us of describing a new species.

Geographical Distribution: This species has been mentioned as *S. cornuta* only from the British Isles; two records under the name of *S.intumescens*, however, are from the Atlantic coast of France (de Vos, 1957) and S Norway (Sars, 1925). This species seems to live among littoral marine algae (Athersuch *et al.*, 1989).

Family Xestoleberididae Sars, 1928

Genus *Xestoleberis* Sars, 1866

Xestoleberis rubens Whittaker, 1978

(Plate 3, Figs A-O)

1978 *Xestoleberis rubens* Whittaker pp. 35-44.

1989 *Xestoleberis rubens* Whittaker; Athersuch et al, 239, fig. 101a-e;

Specimens: Material collected alive on São Miguel Island, at Caloura and Mosteiros, in tidal pools, March 2012, salinity 32 to 35‰, water temperature 16 to 19°C, at 2 m depth.

Material examined: DB/OS 0006, 0007, 0008, 0009, 0010, 0118, 0122.

Description: Shell moderately inflated in dorsal view; in lateral view sub-reniform with rounded dorsal margin and distinctive ventral sinuosity.

Remarks: The carapace morphology of the collected specimens are identical to *Xestoleberis rubens* Whittaker, 1978.

Geographical Distribution: A marine phytal species, known from the North Sea and the Atlantic coast of France (as *X. aurantia*, by de Vos, 1957 and Yassini, 1969) (Athersuch *et al.*, 1989). Typically living on sandy sediment, in the Azores *Xestoleberis rubens* has so far been recorded from Santa Maria (4-18 m depth), Formigas Islets (20 m depth), São Miguel (1-20 m depth, associated with brown-algae and sponges), Terceira (0-23 m depth), Pico (1-54 m depth), Faial (10 m depth), Graciosa (1 m depth) and Flores (20 m depth) (Meireles *et al*., submitted; Chapter 6).

Xestoleberis cf. *depressa* Sars, 1866

(Plate 3, Figs P-Q)

1866 *Xestoleberis depressa* sp. nov. Sars, 68.

1989 *Xestoleberis depressa* Sars, Athersuch *et al.*, pp. 235, fig. 99a-f.

Specimens: Collected alive on Pico, Lajes do Pico, in tidal pool, August 2010, salinity 28 to 34‰, water temperature 16 to 19°C, at 1 m depth.

Material examined: DB/OS 0181.

Description: Shell moderately long in lateral view with strong dimorphism; ventral margin straight or weakly sinuous.

Remarks: Notwithstanding the abundance of the collected material, its poor preservation makes difficult even the generic attribution. On the basis of the general shape in lateral and dorsal view and on what it is possible to argue about the surface ornamentation, we dubitatively refer the collected material to *Xestoleberis depressa*.

The collected specimens have affinities to *X. depressa* Sars, 1866 in respect to the general morphology (see Athersuch *et al*., 1989, for further discussion).

Geographical Distribution: *X. depressa* is known from frequent stations in the North Sea, Scandinavia and also in the Western part of the Baltic. It was found associated with coarse sediment and algae (Athersuch *et al*., 1989). In the Azores, this species is reported from Santa Maria (18 m depth), Formigas Islets (20 m depth), São Miguel (10 m depth), Terceira (23 m depth), Pico (1m depth) and Graciosa (1 m depth) (Meireles *et al*., submitted; Chapter 6).

Xestoleberis sp.

(Plate 3, Figs R-X)

Specimens: Material collected alive on São Miguel Island, ETAR Pranchinha, 4th September 2011, salinity 32 to 35‰, water temperature 14 to 17°C, at 15 m depth.

Material examined: DB/OS 0137.

Dimensions: length = 0.53 mm, height = 0.27 mm.

Description: Carapace sub-rectangular in lateral view. Greater height located slightly posterior of the middle portion of the shell. Right valve larger, with valve overlap in the anterior, ventral and postero-dorsal area. Rectilinear ventral margin, arched dorsal margin, bending anteriorly and posteriorly. Surface of the carapace smooth.

Remarks: The scarcity of the collected material prevents a specific identification. Reported from São Miguel (this study) and Terceira (0-3 m depth; Meireles *et al*., submitted; Chapter 6).

Family Bythocytheridae Sars, 1866

Genus *Sclerochilus* Sars, 1866

Sclerochilus hicksi Athersuch & Horne 1987

(Plate 5, Figs L-P)

1987 *Sclerochilus hicksi* Athersuch & Horne 1987, pp. 211-212, fig.9A-J

1989 *Sclerochilus hicksi* Athersuch *et al*., p. 268-69, fig.114

Specimens: Material collected alive on São Miguel Island, ETAR Pranchinha, 4th September 2011, salinity 32 to 35‰, water temperature 14 to 17°C, at 9 m depth.

Material examined: DB/OS 0146.

Description: Carapace smooth, bean shaped, compressed laterally. Size: length: 0.48 mm; height: 0.25 mm. Few normal pores. Typical copulatory organ (Athersuch & Horne 1987).

Remarks: The animals have been collected alive on sandy bottoms. This is the first record for the Azores.

Geographical Distribution: European waters (General Sea Area [include North Sea and Mediterranean]) (Horne *et al*., 2001); United Kingdom Exclusive Economic Zone (Medin, 2011); Azores archipelago (this work).

Family Paradoxostomatidae Brady & Norman, 1889

Genus *Lanceostoma* Schornikov & Keyser, 2004

Lanceostoma simplex Meireles & Keyser **n. sp.**

(Plate 2, Figs M-U)

(Plate 11, Figs A-D)

Chapter 6 *Lanceostoma* sp.; Meireles *et al*., fig. 2 (photo 13), DB/OS 0117.

Derivation of name: With reference to the simple form of the species.

Holotype: Only soft-parts; Male, adult valve; DB/OS 0117: length = 0.67 mm, height = 0.28 mm, width = 0.20 mm. Carapace was destroyed during soft-parts studies.

Type locality: São Miguel Island (Caloura; N 37º 42' 48,2"/ W 025º 29' 44,9"), Azores Archipelago, Portugal. Recent, littoral.

Figured specimens: DB/OS 0121 (paratype) and DB/OS 0068 (paratype). Material collected alive on Caloura, in tidal pools, March 2012; salinity 32 to 35‰, water temperature 16 to 19^{o}C, at 2 m depth.

Age: Holocene to Recent.

Material examined: Holotype: DB/OS 0117, Paratypes: DB/OS 0068, 0121, 0129. Other material: DB/OS 0069, 0070, 0071, 0141, 0142.

Dimensions: Holotype DB/OS 0117: length = 0.67 mm, height = 0.28 mm, width = 0.20 mm; Paratype: DB/OS 0121: length = 0.69 mm, height = 0.32 mm; Paratype: DB/OS 0129: length = 0.69 mm, height = 0.31 mm.

Diagnosis: Carapace ellipsoid, with distinct caudal process. Surface smooth with relative few normal lateral pores. Calcified inner lamella broad, line of congrescens showing one big frontal vestibule, one small medio-ventral and one ventro-posterior vestibule. Copulatory organ with a cuneiform process connected to a clasping structure at the back.

Description: Shell pointed ovoid. Anterior rounded and slightly pointed, posterior with slight caudal process. Dorsal margin slightly convex, ventral margin slightly concave, anteriorly of the middle. Inner calcified lamella broad with about the same distance from the ventral margin. Line of congrescens displays three different vestibules, one anterior, one venbtral and one in the posterior of the shell. Muscelscars four in a row with one rather small frontal one.

Antennula: Six-jointed (5:4,5:5:7:2,5:1). Second segment with 1 distal seta, third joint with one short distal seta, fourth joint with one small distal seta, fifth joint with 2 short and one long distal setae and last segment with 3 setae.

Antenna: Exopod three-jointed (11:2,5:4) as long as the endopod. Endopod four-jointed (3:5:6:1). First segment of endopod with one strong distal seta, second and third joint each with small distal seta and last segment with two strong claws.

Mandibula and Maxillula are not well preserved and could not be figured.

P1: Four-jointed (5:4:2:2,5). First joint with basal long seta and one thick distal seta reaching to the end of the second segment.second joint with small distal seta, last segment with distal claw.

P2: Four jointed (6:3,5:2:2,5). First segment with small median seta and distal a thick (less than P1) seta. Second segment with one distal seta and the last joint with a distal claw.

P3: Four-jointed (7:6:2,5:3). First and second segment with thin distal seta, last segment with distal claw.

Copulatory organ: With a well defined cuneiform process connected to a clasping structure on the opposite side. Ductus ejaculatorius within this attachment.

Remarks: The shell of this species resembles *L. tenerifense* Schornikov & Keyser, the line of congrescens as well as the extension of the inner lamella are similar. However, the copulatory organ is different in having an extension of the cuneiform process which seems to be a kind of clasping structure.

Geographical Distribution: Recent; shallow marine, *L. simplex* was reported by Meireles *et al*. (submitted; Chapter 6) to Santa Maria (4 m depth), Formigas Islets (20 m depth), São Miguel (1-15 m depth), Terceira (23 m depth), Pico (54 m depth) and

Graciosa (1 m depth). This study enlarges the distribution of this species to Flores Island, at 3 m depth.

Order Myodocopida Sars, 1866

Family Cylindroleberididae Müller, 1906

Genus *Cylindroleberis* Brady, 1867

Cylindroleberis sp.

(Plate 5, Figs R-T)

Specimens: Material collected alive on São Miguel Island, Caloura, by Joana Xavier and Andreia Cunha, March 2012; associated with sponges (genus *Haliclona* Grant, 1836) at 4 m depth.

Material examined: DB/OS 0180.

Description: In lateral view oval, elongate, with greatest height slightly behind middle; anterior and posterior margins evenly rounded; lateral surface smooth, with scattered normal pore canals, some with short hairs; incisure deep, narrow, with upper margin overlapping lower proximally.

Remarks: The scarcity of the collected material prevents a specific identification. Typically living upon sponges, *Cylindroleberis* sp. has so far been recorded on São Miguel.

DISCUSSION

Systematics

Ostracoda fauna differ in the number of families and species around the world, usually with more species in continental margins than in insular habitats (see Chapter 6 for an overview). Before our study, only two species of marine ostracods had been reported from the Azores, the widespread podocopids *Heterocythereis albomaculata* and *Loxoconcha rhomboidea* (Costa, 2003). This chapter expands to 20 the number of benthic species occurring nowadays in the archipelago, with 10 families and 14 genera represented. The Azorean Ostracoda assemblages include genus/species that also occur in other regions, namely *Xestoleberis* and *Semicytherura* in the Pacific (Allison & Holden, 1971); *Callistocythere*, *Loxoconcha*, *Semicytherura*, *Leptocythere* and *Xestoleberis* in Kuwait Bay (Al-Abdul-Razzaq *et al.*, 1983); *Xestoleberis* and

Semicytherura in the UK (Hull, 1997); *Xestoleberis* and *Callistocythere* in Brazil (Machado *et al*., 2005); *Callistocythere, Leptocythere, Semicytherura, Xestoleberis* and *Urocythereis*, and the species *Aurila convexa* and *Loxoconcha rhomboidea* in Holocene mainland Portugal (Cabral *et al*., 2006); *Xestoleberis, Loxoconcha, Urocythereis, Callistocythere* and the species *Aurila convexa* in Cyprus (Athersuch, 1979); and the genus *Urocythereis* and the specie *Aurila convexa* in the Basque shelf (Pascual *et al*., 2008). The representatives of the families present in the Azores are thus typical of infralittoral marine environments around the world (Machado *et al*., 2005, for an overview). According to Meireles *et al*. (Chapter 6), the Recent assemblages are dominated by specimens of the Loxoconchidae, whereas the Holocene assemblages are dominated by specimens of the Loxoconchidae, Hemicytheridae and Bairdiidae. The most abundant species, *Loxoconcha rhomboidea*, occurred in both Recent (0-40 m depth) and Holocene sediments (here, together with *Aurila convexa*, *Neonesidea longisetosa*, *Xestoleberis rubens* and *Heterocythereis albomaculata*). The shift from life-dominated assemblages in the shallower depths to death assemblages at greater depths is a consequence of significant transport downwards (cf. Meireles *et al*., Chapter 6). Interestingly, no living specimens were found in the samples collected at the beach faces, thus reinforcing the interpretations of Ávila *et al*. (2008) and Ávila (in press) who proposed that sandy beaches in far-away reefless small volcanic oceanic islands located at temperate latitudes are almost devoid of life due to historical reasons related with the sea-level drops associated to cyclic glacial-interglacial-glacial episodes, which are responsible for the local disappearances of most (if not all) species associated to fine sand habitats from the shores of such islands, every time sea-level drops below the shelf edge of the island.

The 3 newly described endemic species for the Azores are the confirmation that many novelties are still to be discovered in these oceanic islands, especially in the less-known invertebrate groups (Ostracoda, Bryozoa, Foraminifera, Ctenophora, Sipuncula).

Biogeography

The Azores islands are located almost midway between Europe and America and are one of the most remote oceanic islands in the Atlantic. The geographical situation of this archipelago thus raises interesting biogeographical questions related with the patterns and processes of colonization of these islands, the times of colonization and of speciation events and the origins of the ancestral of the shallow water biota presently living there (*e.g.* Wirtz & Martins, 1993; Tittley & Neto, 1995, 2006; Ávila, 2000, 2005; Almada *et al*., 2001; Ávila *et al*., 2009, 2012). Most of the species that occur at the Azores are also reported from the Celtic province (73.3%), the Mediterranean Sea (46.7%), the Gascoynian province (46.7%) and the Lusitanian province (40%) (Table 2). The low number of species shared with Portugal (Lusitanian province) is probably an artefact, for the shallow marine Portuguese ostracods is one of the least known faunas in Europe. Moro *et al.* (2003) reported 42 ostracod species to the Canary Islands, of which 35 are planktotrophic; of the remaining 7 benthic species, 3 species are considered as endemic from Canaries (*Eupolycope pnyx* Kornicker and Iliffe, 1995, *Danielopolina phalanx* Kornicker and Iliffe, 1995, and *Danielopolina wilkensi* Brady, 1880), and only one species (*Loxoconcha rhomboidea*) is shared with the ostracods' checklist from the Azores (cf. Table 2).

Table 2. Biogeographical relationships of the ostracods species of shared with the Azores (in %).

	AZO (%)
CEL	80.0
MED	46.7
GAS	46.7
LUS	40.0
NWA	20.0
TRO	13.3
WAF	6.7
MAD	6.7
CAN	6.7

Similarly to other biogeographical studies made on the shallow marine fauna and flora of the Azores (Tittley & Neto, 1995, 2006; Wirtz, 1998; Ávila, 2000, 2005; Almada *et al*., 2001; Ávila & Albergaria, 2002; Ávila *et al*., 2009a, 2012a; Xavier & Soest, 2012), the majority of the identified Azorean ostracods are of European affinity (Fig. 3). However, it is surprising the low similarity of the ostracod fauna between the Mediterranean Sea and the Azores (47%; Table 2), which contrasts with the numbers known for the Recent shallow marine molluscs (78.0%; Ávila, 2005). With the exception of a possible gap on the taxonomic knowledge of the benthic ostracods of both the Gascoynian and the Lusitanian provinces, we do not envisage other plausible explanation for the higher similarities of the Azorean ostracods with the Celtic province instead of the nearer Lusitanian province or the Mediterranean Sea (Fig. 3). This peculiar pattern does not occur with any of the best known marine animal groups in the Azores: fishes (Santos *et al*., 1997), molluscs (Ávila, 2005), sponges (Xavier & Soest, 2012) and echinoderms (Micael *et al*., 2012), all of them showing higher biogeographical similarities with the western Mediterranean and the Macaronesian archipelagos (Madeira and Canary Islands). In a similar manner, the floristic affinities of the marine algae of the Azores are mainly with Madeira and Canary Islands (Tittley & Neto, 2006).

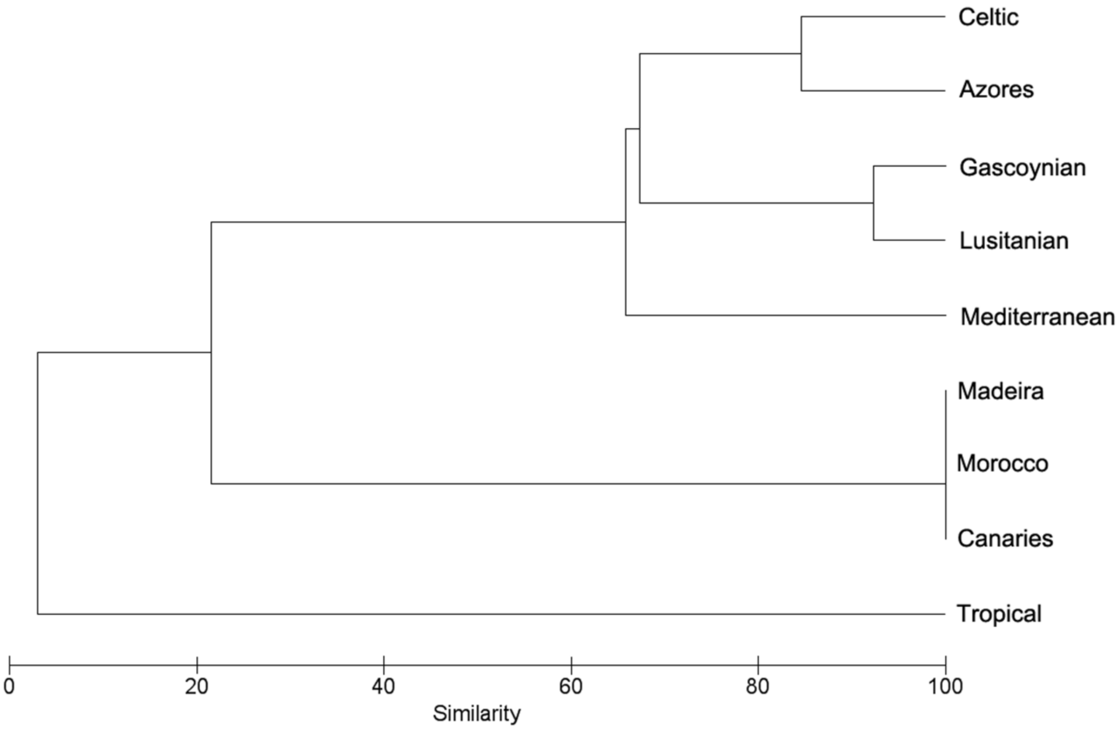


Figure 3. Biogeographical relationships of the Azorean ostracods.

CONCLUSIONS

Twenty species were found, representing 10 families and 14 genera, with eight new records for the Azores. The Recent assemblages are dominated by specimens of the Loxoconchidae, whereas the Holocene assemblages are dominated by specimens of the Loxoconchidae, Hemicytheridae and Bairdiidae. The most abundant species, *Loxoconcha rhomboidea*, occurred in both Recent (0-20 m depth) and Holocene sediments, and together with *Neonesidea longisetosa*, *Xestoleberis rubens* and *Heterocythereis albomaculata*.

3 new species to Science which are herein described: *Callistocythere insularis* n. sp. *Semicytherura brandoni* n. sp. and *Lanceostoma simplex* n. sp.

Ostracods bear great potential for applications in environmental studies. Our checklist and systematic study provide a base for the identification of ostracods from shallow water in the Azores region. When identified, the ostracod taxa can be used as environmental proxies.

Furthermore, the data set presented here can be used as a reference in biogeographical and systematic studies.

ACKNOWLEDGMENTS

We thank the Direcção Regional da Ciência, Tecnologia e Comunicações (Regional Government of the Azores), Direcção Regional do Ambiente e do Mar (Regional Government of the Azores) and FCT (Fundação para a Ciência e a Tecnologia) of the Portuguese government for financial support. We would like also to thank Paulo Amaral Borges (UAc); Filipe Porteiro and Valentina Matos (IMAR-Azores); Joana Xavier and Andreia Cunha (CiBio-Azores) for loaning samples and Jorge Medeiros (CIRN/University of the Azores) for the SEM photographs support. Ricardo Piazza Meireles benefited from a grant SFRH/BD/60518/2009 of FCT, Portugal.

Table 1. Geographical distribution of the Azorean species of ostracods. LUS – Lusitanian province: western Atlantic shores of Spain and Portugal, from Cabo Vilán (Northern Galicia) to Cape São Vicente (western tip of Algarve); AZO – Azores; GAS – Gascoynian province: Atlantic shores of Spain and France, from 48°31'N, 4°46'W south to Cabo Vilán; CEL – Celtic province: including British Isles, Ireland, the Channel and the North Sea; MED – Mediterranean Sea; TRO – Tropical biogeographical province: Atlantic shores of USA, south of Cape Canaveral (28.30° N), including western and eastern shores of Florida, Gulf of Mexico (Louisiana and Texas shores, as well as Yucatan Peninsula, Mexico), Bahamas, Caribbean Sea, south to Cabo Frio (Brazil) (23° S); WAF – West African shores: Atlantic Morocco, from Straits of Gibraltar south, Western Sahara, and Mauritania, Cape Verde (Senegal); MAD – Madeira; CAN – Canary Islands; NWA – North Western Atlantic shores, from the Arctic south to Cape Hatteras, North Carolina (35° N).

	LUS	**AZO**	**GAS**	**CEL**	**MED**	**TRO**	**WAF**	**MAD**	**CAN**	**NWA**
Neonesidea longisetosa		1				1				
Leptocythere pellucida	1	1	1	1	1					1
Cyprideis torosa	1	1	1	1	1					
Carinocythereis whitei		1	1	1	1					1
Aurila convexa	1	1	1	1	1					
Aurila woutersi		1		1						
Aurila prasina		1			1					
Heterocythereis albomaculata		1		1	1					
Urocythereis britannica	1	1	1	1						
Loxoconcha rhomboidea	1	1	1	1	1		1	1	1	
Loxoconcha cf. *ochlockoneensis*		1				1				
Semicytherura cf. cornuta		1		1						
Xestoleberis rubens	1	1	1	1						
Xestoleberis cf. *depressa*		1		1						1
Sclerochilus hicksi		1		1						
TOTAL	6	15	7	12	7	2	1	1	1	3

PLATE 1

A-J) *Loxoconcha rhomboidea* (Fischer, 1855);

A) RV ♀; B.) LV♀; C) Inner view RV ♀; D) RV ♂; E) LV ♂; F) Inner view LV ♂;G) Muscel scars; H) sieve pore; I) anterior part of hinge LV♂; J) posterior part of hinge RV♀.

K-R) *Loxoconcha ochlockoneensis* Puri, 1960;

K) RV♂; L) LV♂; M) RV ♀; N) LV ♀; O) sieve pore; P) RV♂; Q) sieve pore; R) sieve pore.

PLATE 1

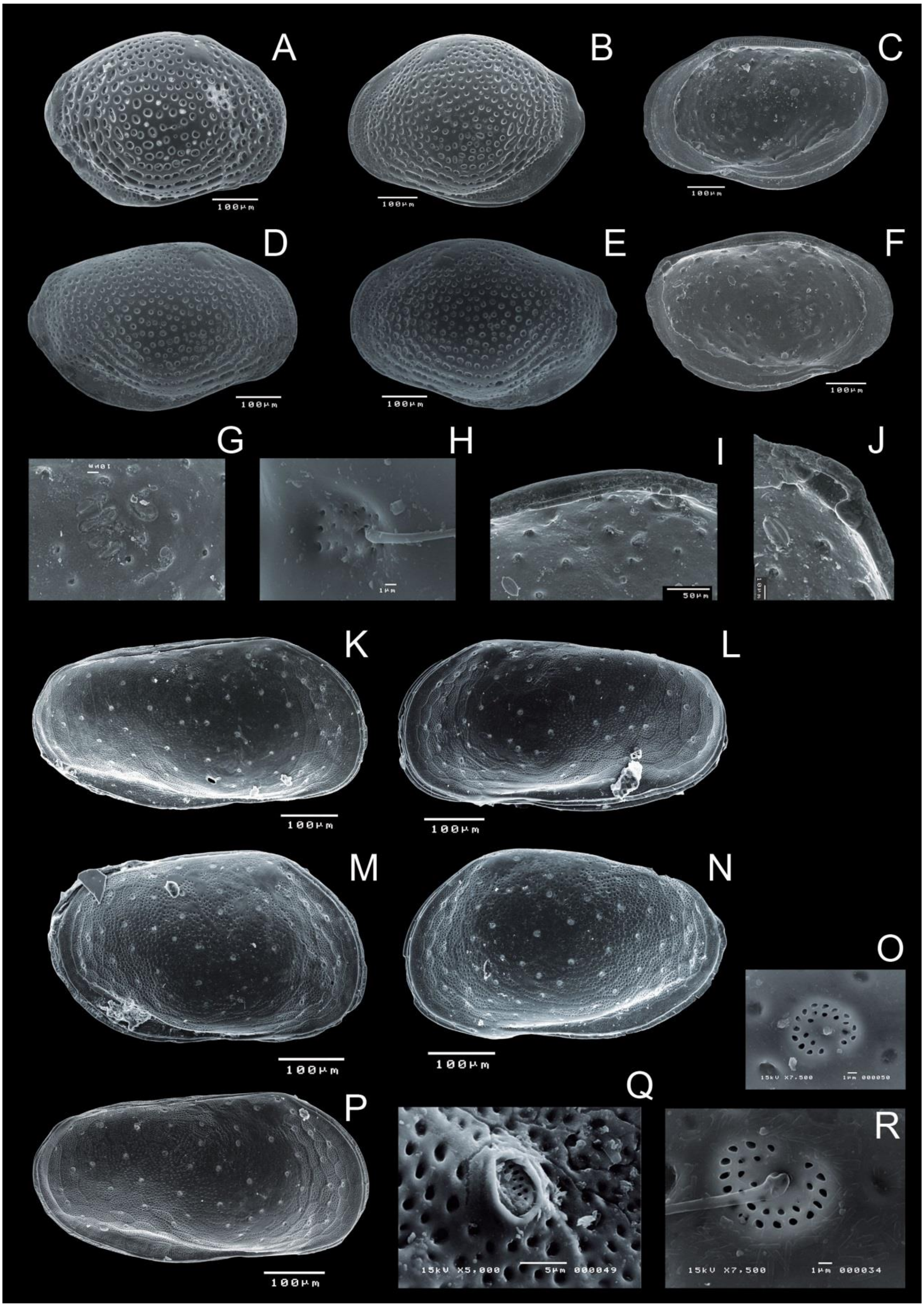

A
100μm
B
100μm
C
100μm
D
100μm
E
100μm
F
100μm
G
10μm
H
1μm
I
50μm
J
10μm
K
100μm
L
100μm
M
100μm
N
100μm
O
15kV X7,500 1μm 000050
P
100μm
Q
15kV X5,000 5μm 000049
R
15kV X7,500 1μm 000034

PLATE 2

A-L) *Neonesidea longisetosa* (Brady, 1902);

A) Dorsal View; B) LV♀; C) RV♀; D) Inner view RV ♀; E) Inner view LV ♀; F) LV juvenil; G) RV juvenil; H) Inner view RV juvenil; I) Muscel scars; J) sieve pore; K) sieve pore; L) Inner view LV.

M-U) *Lanceostoma simplex* Meireles & Keyser n. sp.;

M) RV♂; N) LV♂; O) posterior part of hinge RV♂; P) Inner view RV♂; Q) Inner view LV♂; R) Inner view LV♂; S) RV♂; T) LV♂; U) Muscel scars.

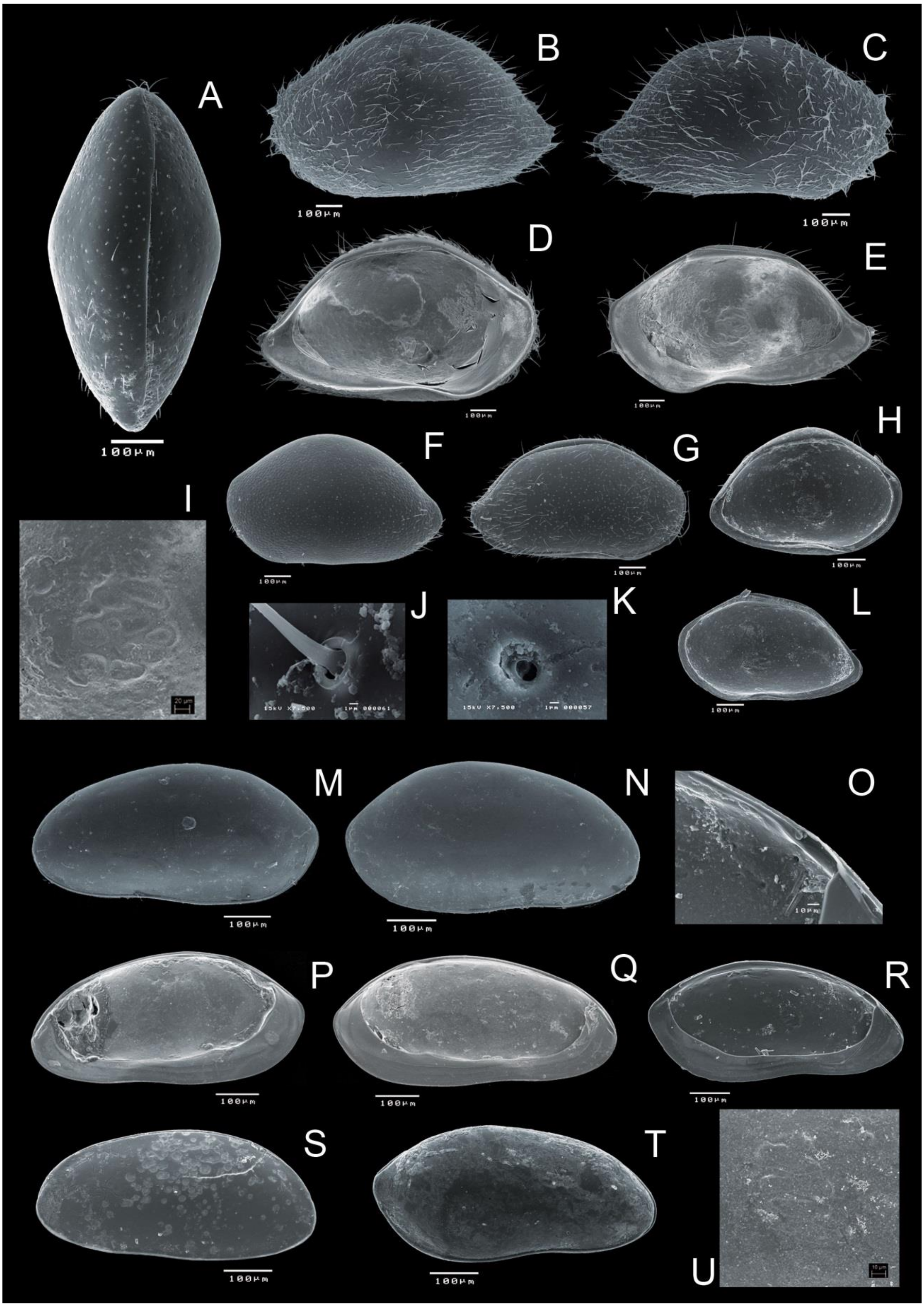

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
100μm
20 μm
10 μm
15kV X7,500 1μm 000061
15kV X7,500 1μm 000057

PLATE 3

A-O) *Xestoleberis rubens* Whittaker, 1978;

A) Dorsal View; B) LV ♀; C) LV ♀; D) Muscel scars; E) RV ♀; F) LV ♀; G) sieve pore; H) Dorsal View; I) RV ♀; J) Inner view LV ♀; K) posterior part of hinge RV ♀; L) Inner view RV ♀; M) sieve pore; N) sieve pore; O) sieve pore.

P-Q) *Xestoleberis depressa* Sars, 1866;

P) RV ♀; Q) sieve pore.

R-W) *Xestoleberis* sp.;

R) RV ♀; S) LV ♀; T) sieve pore; U) Inner view RV ♀; V) Inner view LV ♀; W) Muscel scars.

PLATE 3

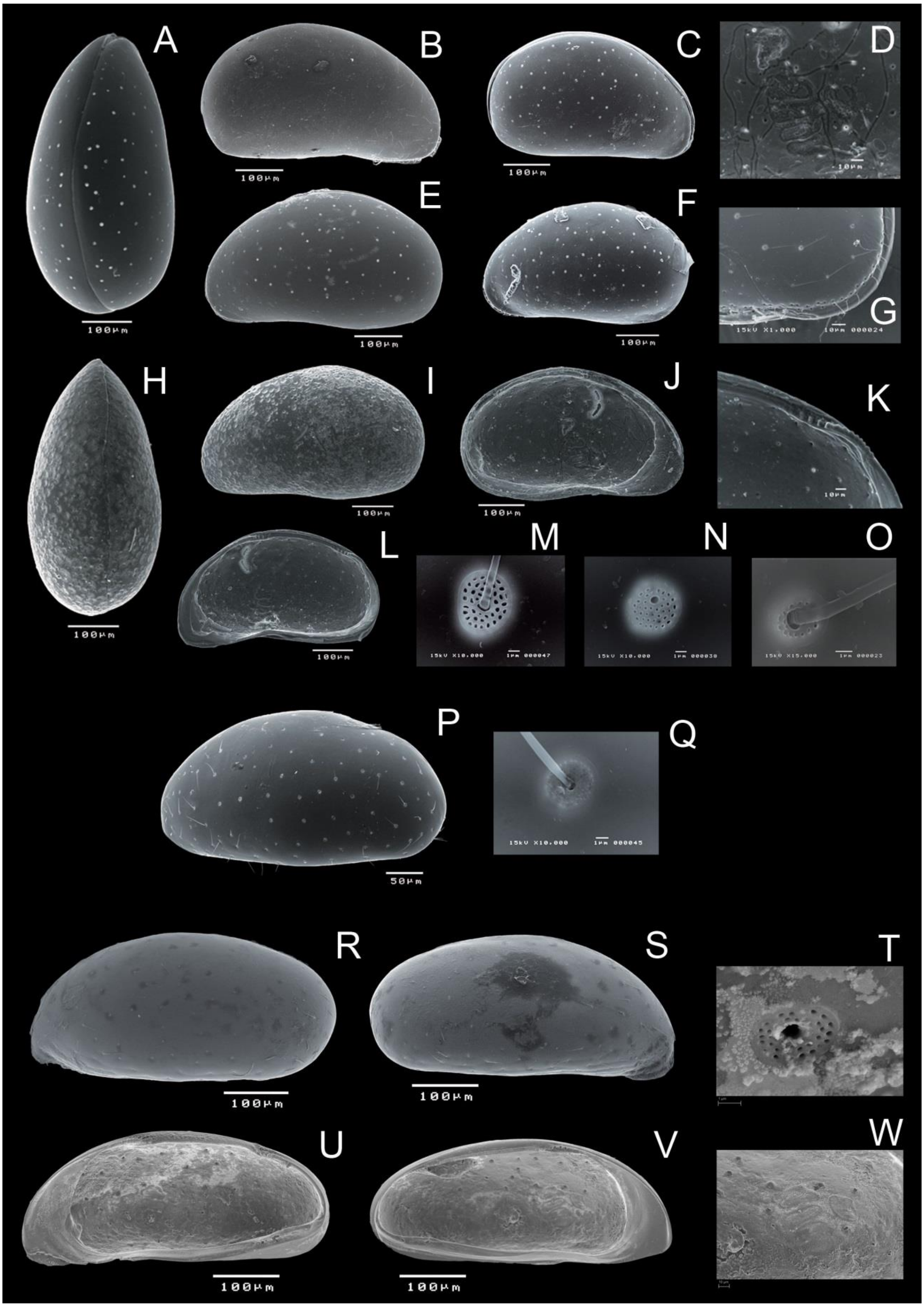

A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
100µm
10µm
50µm
1µm
15kV X1,000 10µm 000024
15kV X10,000 1µm 000047
15kV X10,000 1µm 000030
15kV X15,000 1µm 000023
15kV X10,000 1µm 000045

PLATE 4

A-Q) *Urocythereis britannica* Athersuch, 1977;

A) Dorsal view; B) RV ♀; C) RV ♀; D) LV ♀; E) LV ♀; F) anterior part of hinge LV ♀; G) RV ♀; H) LV ♀; I) posterior part of hinge RV ♀; J) sieve pore; K) Inner view LV ♀; L) Inner view LV ♀; M) Inner view RV ♀; N) anterior part of hinge LV ♀; O) sieve pore; P) Muscel scars; Q) posterior part of hinge RV ♀.

PLATE 4

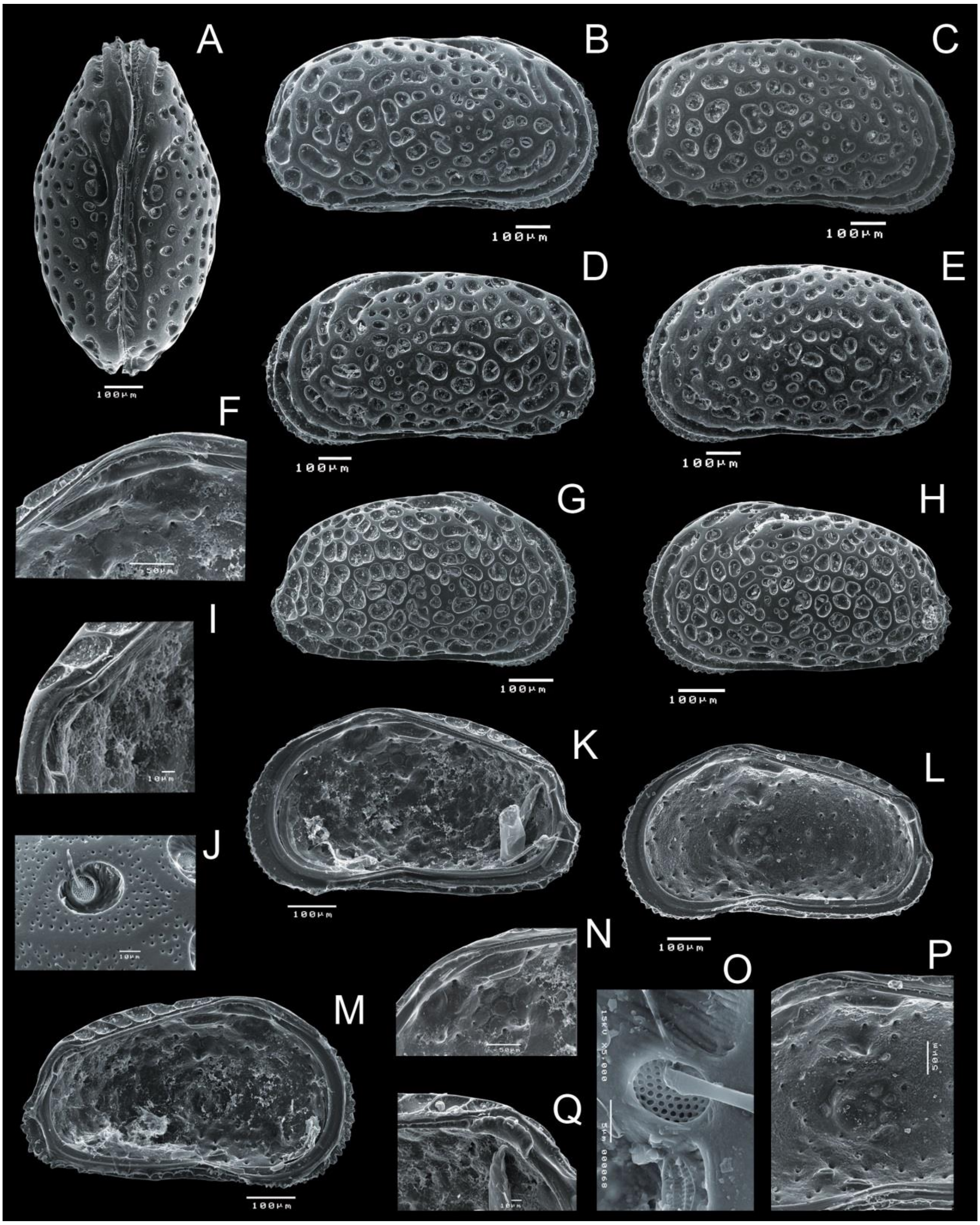


PLATE 5

A-K) *Aurila convexa* (Baird, 1850);

A) Dorsal view; B) LV ♀; C) LV ♀; D) Muscel scars; E) RV ♀; F) LV ♀; G) sieve pore; H) sieve pore; I) Inner view LV ♀; J) Inner view RV ♀; K) anterior part of hinge RV ♀.

L-P) *Sclerochilus hicksi* Athersuch & Horne, 1987;

L) RV ♀; M) LV ♀; N) Muscel scars; O) Inner view RV ♀; P) Inner view LV ♀.

Q) *Leptocythere pellucida* (Baird, 1850);

Q) RV.

R-T) *Cylindroleberis* sp.;

R) RV ♀; S) Rostrum; T) LV ♀.

PLATE 5

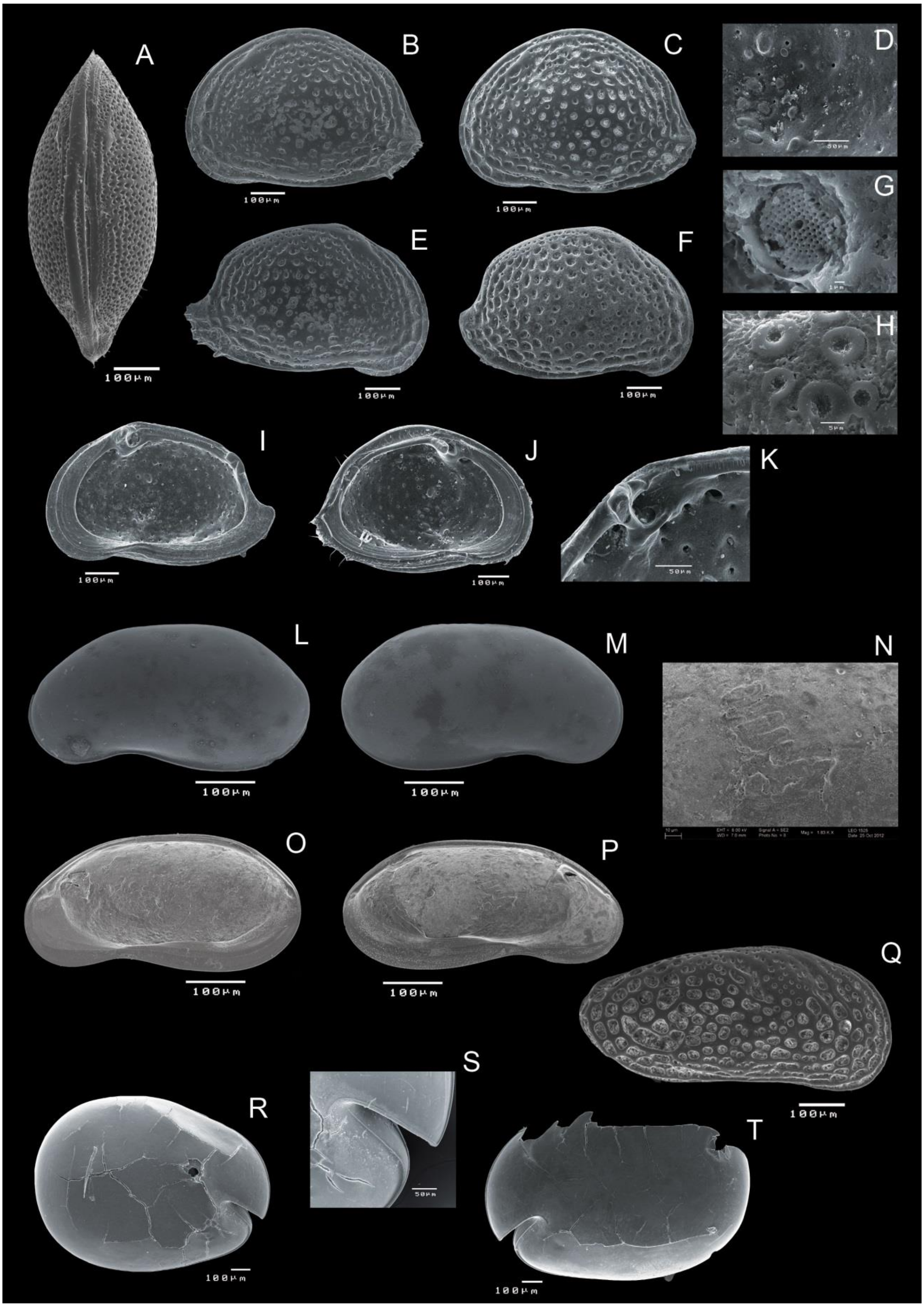

A
100µm
B
100µm
C
100µm
D
50µm
E
100µm
F
100µm
G
1µm
H
5µm
I
100µm
J
100µm
K
50µm
L
100µm
M
100µm
N
10 µm
EHT = 8.00 kV
WD = 7.0 mm
Signal A = SE2
Photo No. = 8
Mag = 1.83 K X
LEO 1525
Date :25 Oct 2012
O
100µm
P
100µm
Q
100µm
R
100µm
S
50µm
T
100µm

PLATE 6

A-E) *Aurila woutersi* Horne, 1986;

A) LV ♀; B) LV ♀; C) LV (A-1); D) sieve pore; E) LV (A-3).

F-M) *Aurila prasina* Barbieto-Gonzalez, 1971;

F) RV ♀; G) LV ♀; H) sieve pore; I) RV ♀; J) LV ♀; K) sieve pore; L) LV (A-4); M) sieve pore.

PLATE 6

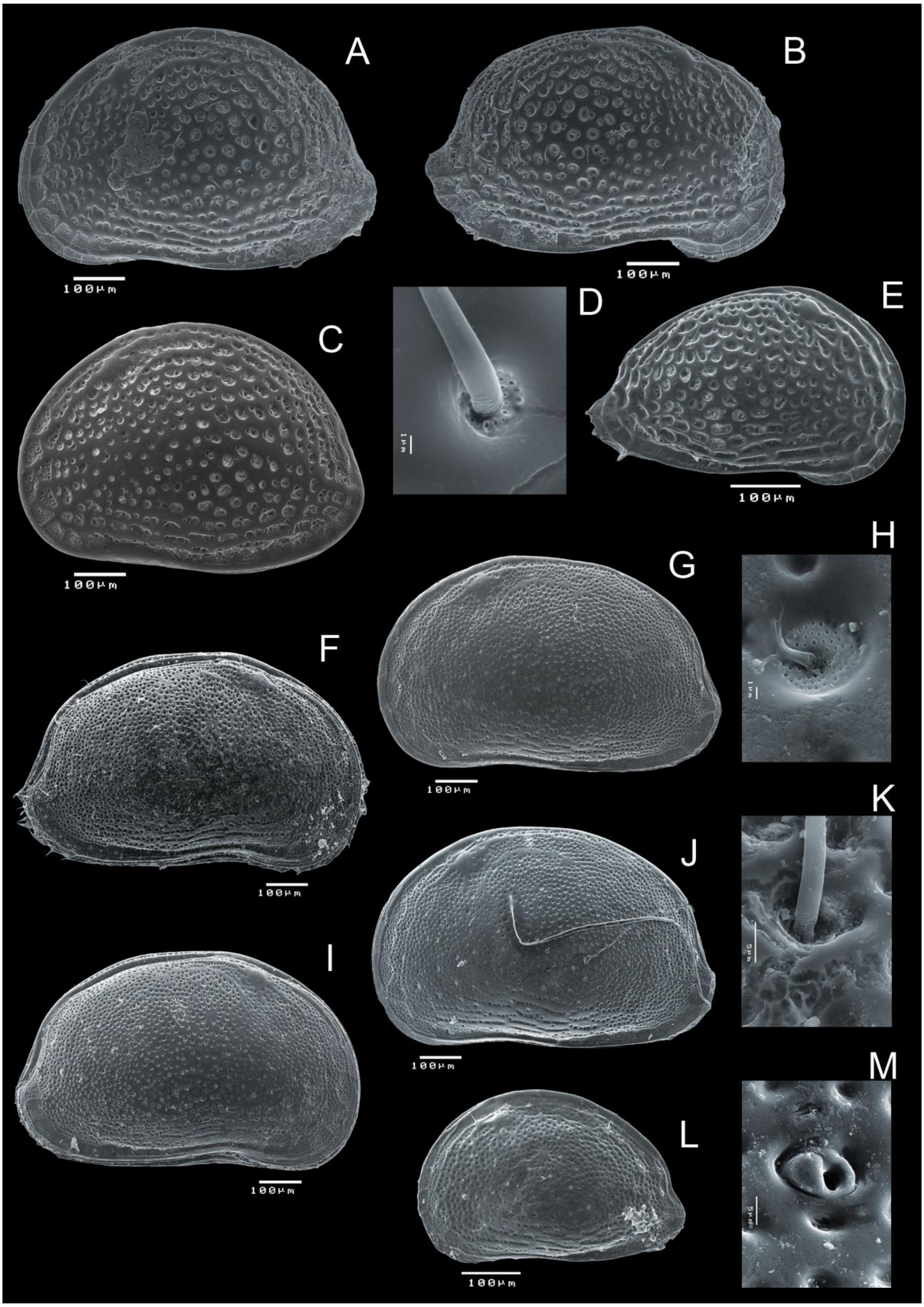


PLATE 7

A-G) *Heterocythereis albomaculata* (Baird, 1838);

A) Dorsal View; B) LV ♂; C) sieve pore; D) RV ♂; E) Muscel scars; F) Inner view RV ♂; G) Inner view LV ♂.

H-L) *Cyprideis torosa* (Jones, 1850);

H) Dorsal View; I) LV ♂; J) sieve pore; K) LV ♂; L) RV ♂.

PLATE 7

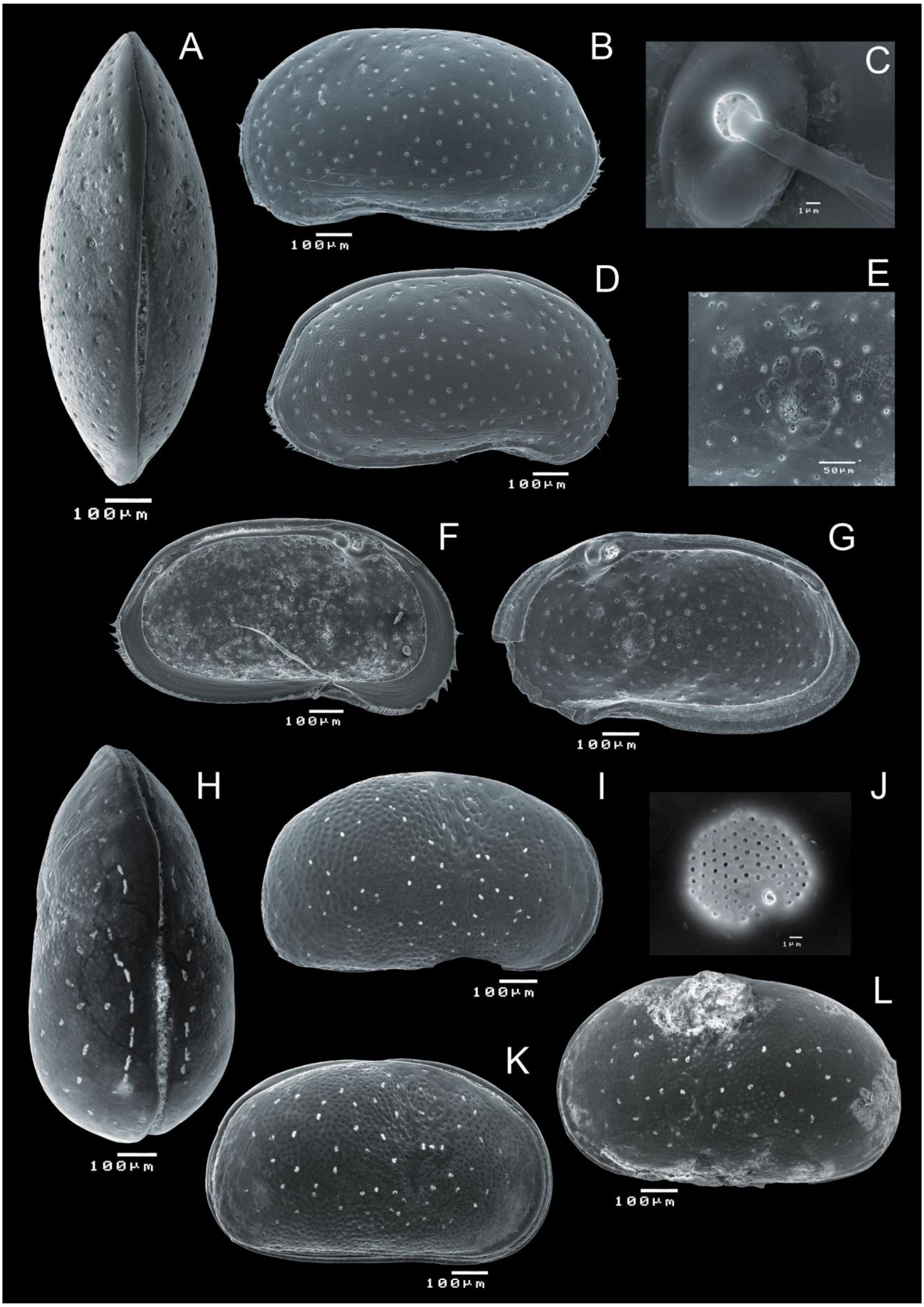

A
B
100µm
C
1µm
D
100µm
E
50µm
100µm
F
100µm
G
100µm
H
I
100µm
J
1µm
100µm
L
K
100µm
100µm

PLATE 8

A-F) *Callistocythere insularis* Meireles & Keyser n. sp.;

A) LV ♂; B) RV ♂; C) sieve pore; D) Inner view RV ♂; E) Inner view LV ♂; F) RV ♂.

G-J) *Semicytherura brandoni* Meireles & Keyser n. sp.;

G) LV ♂; H) RV ♂; I) Inner view RV ♂; J) Inner view LV ♂.

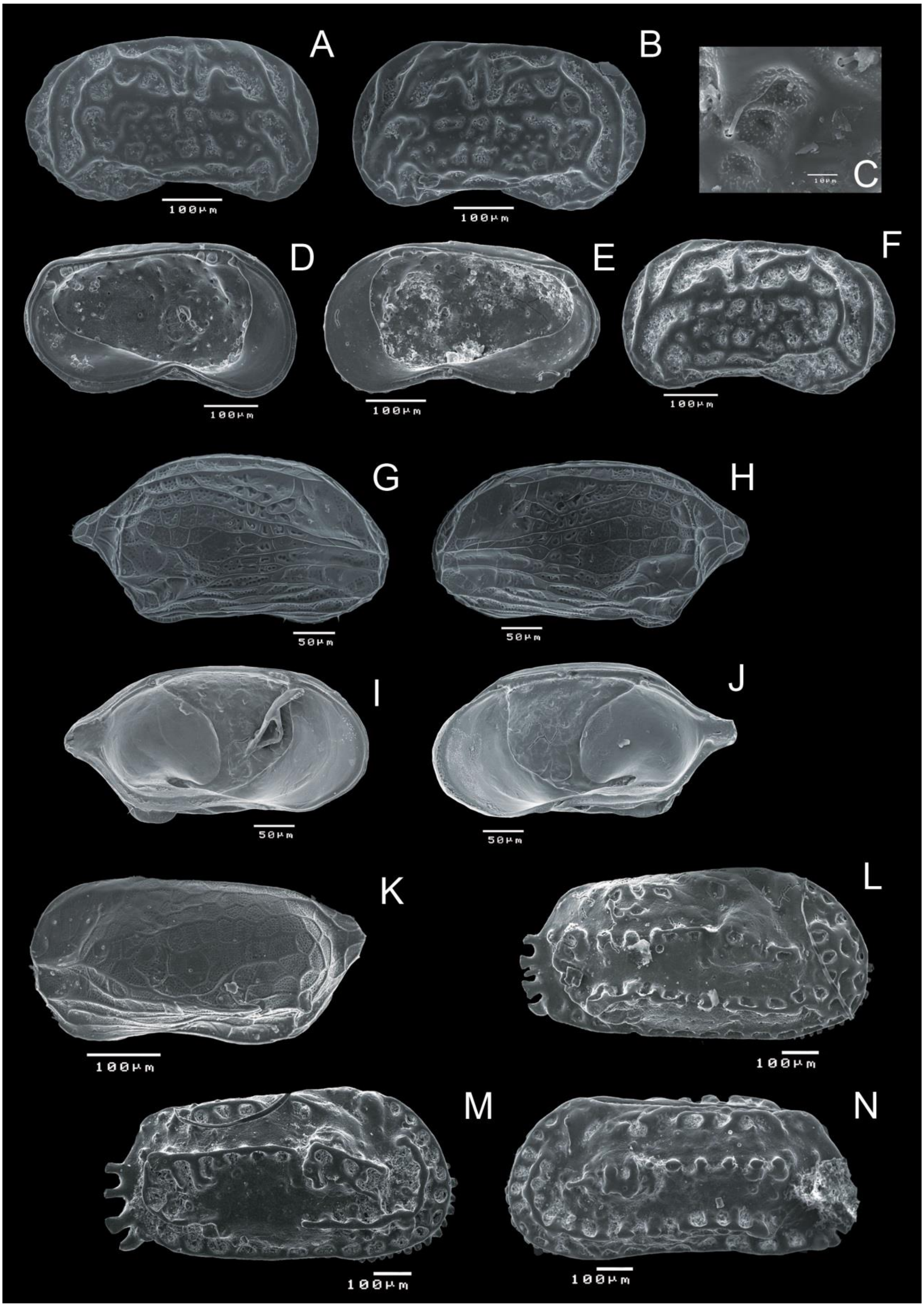
K) *Semicytherura* cf. *cornuta*;

K) RV ♂.

L-N) *Carinocythereis whitei* (Baird, 1850);

L) LV ♂; M) LV ♂; N) RV ♂.

PLATE 8


A
100µm
B
100µm
10µm
C
D
100µm
E
100µm
F
100µm
G
50µm
H
50µm
I
50µm
J
50µm
K
100µm
L
100µm
M
100µm
N
100µm

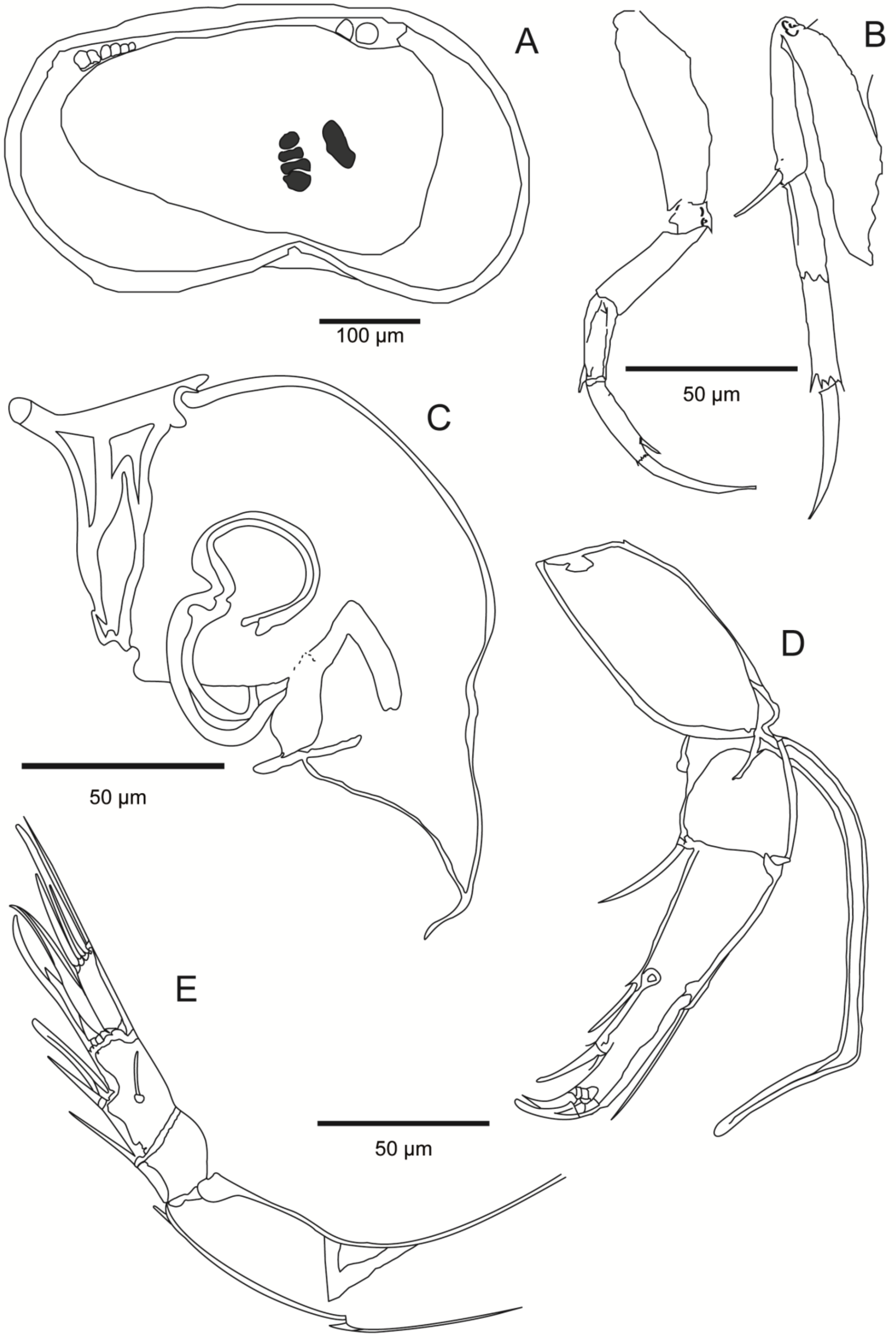


Plate 9 - *Callistocythere insularis* Meireles & Keyser n. sp. A) Internal view; B) P1 and P2; C) Copulatory organ; D) Antennule; E) Antenna.

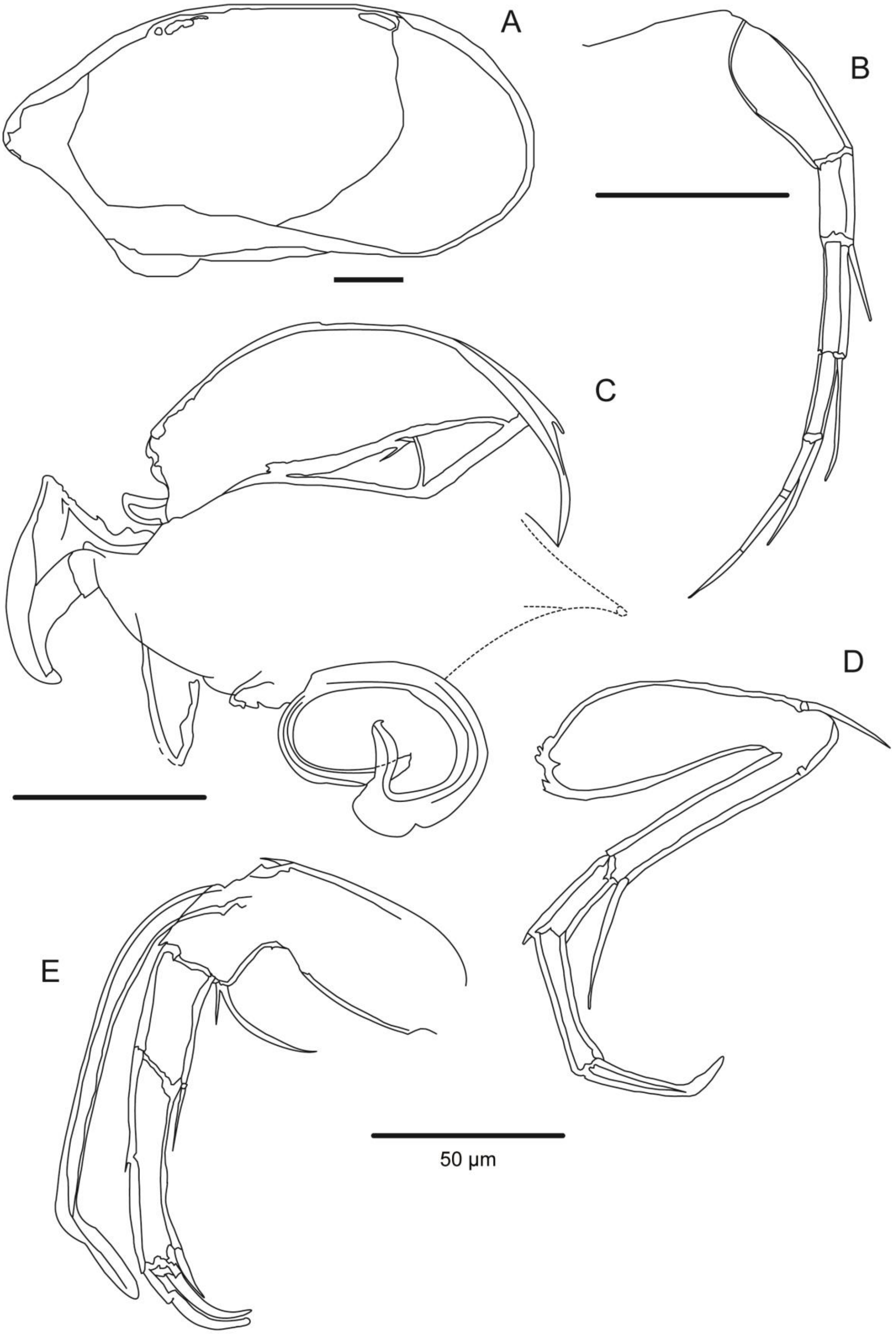


Plate 10 - *Semicytherura brandoni* Meireles & Keyser n. sp. A) Internal view; B) Antenna; C) Copulatory organ; D) P1; E) Antennula.

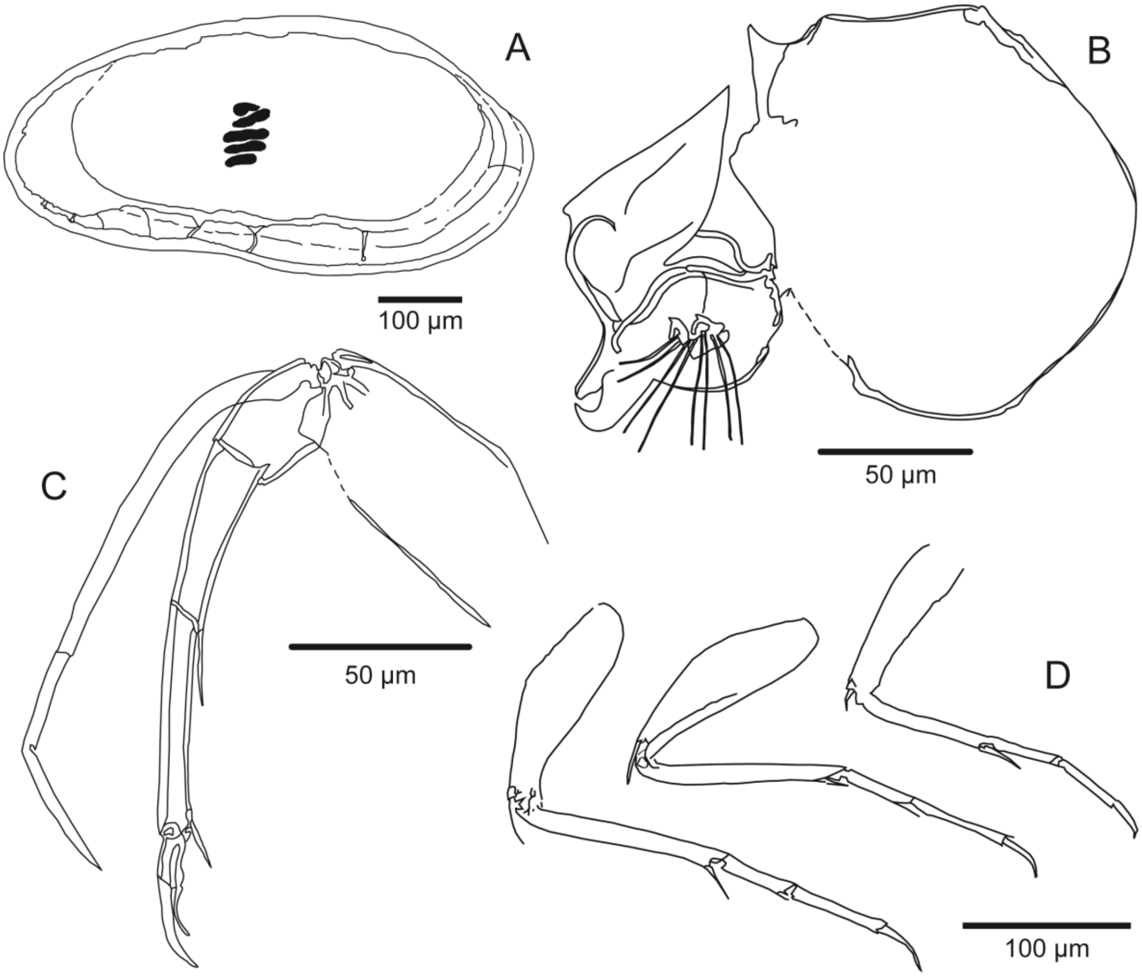


Plate 11 - *Lanceostoma simplex* Meireles & Keyser n. sp. A) Internal view; B) Copulatory organ; C) Antennula; D) P1 and P2.

CHECKLIST OF THE SHALLOW-WATER MARINE OSTRACODS OF THE AZORES ARCHIPELAGO

CLASS Ostracoda Latreille, 1802

ORDER Podocopida Müller, 1894

- **Family** Bairdiidae Sars, 1888
  - **Genus** *Neonesidea* Maddocks, 1969
    - *Neonesidea longisetosa* (Brady 1902)

- **Family** Leptocytheridae Hanai, 1957
  - **Genus** *Leptocythere* Müller, 1927
    - *Leptocythere pellucida* (Baird, 1850)
  - **Genus** *Callistocythere* Ruggieri, 1953
    - *Callistocythere insularis* Meireles & Keyser **n. sp.**

- **Family** Cytherideidae Sars, 1925
  - **Genus** *Cyprideis* Jones, 1856
    - *Cyprideis torosa* (Jones, 1850)

- **Family** Trachyleberididae Sylvester-Bradley, 1948
  - **Genus** *Carinocythereis* Ruggieri, 1956
    - *Carinocythereis whitei* (Baird, 1850)

- **Family** Hemicytheridae Puri, 1953
  - **Genus** *Aurila* Porkorný, 1955
    - *Aurila convexa* (Baird, 1850)
    - *Aurila woutersi* Horne, 1986
    - *Aurila prasina* Barbeito-Gonzalez, 1971
  - **Genus** *Heterocythereis* Elofson, 1941
    - *Heterocythereis albomaculata* (Baird, 1938)
  - **Genus** *Urocythereis* Ruggieri, 1950
    - *Urocythereis britannica* Athersuch, 1977

Family Loxoconchidae Sars, 1925

- **Genus** *Loxoconcha* Sars, 1866
  - *Loxoconcha rhomboidea* (Fischer, 1855)
  - *Loxoconcha* cf. *ochlockoneensis* Puri, 1960

Family Cytheruridae Müller, 1894

- **Genus** *Semicytherura* Wagner, 1957
  - *Semicytherura brandoni* Meireles & Keyser **n. sp.**
  - *Semicytherura* cf. *cornuta* (Brady, 1868)

Family Xestoleberididae Sars, 1928

- **Genus** *Xestoleberis* Sars, 1866
  - *Xestoleberis rubens* Whittaker, 1978
  - *Xestoleberis* cf. *depressa* Sars, 1866
  - *Xestoleberis* sp.

Family Bythocytheridae Sars, 1866

- **Genus** *Sclerochilus* Sars, 1866
  - *Sclerochilus hicksi* Athersuch & Horne 1987

Family Paradoxostomatidae Brady & Norman, 1889

- **Genus** *Lanceostoma* Schornikov & Keyser, 2004
  - *Lanceostoma simplex* Meireles & Keyser **n. sp.**

ORDER Myodocopida Sars, 1866

- **Family** Cylindroleberididae Müller, 1906
  - **Genus** *Cylindroleberis* Brady, 1867
    - *Cylindroleberis* sp.

CHAPTER 6

THE SHALLOW MARINE OSTRACOD COMMUNITIES OF THE AZORES (MID-NORTH ATLANTIC): TAPHONOMY AND PALAEOECOLOGY

Ricardo Piazza Meireles; Dietmar Keyser; Paulo A. Borges; Luís Silva; António M. de Frias Martins; Sérgio P. Ávila

Manuscript submitted to ***Geologica Acta***.

ABSTRACT

This is the first palaeoecological and taphonomical study of the Holocene to Recent ostracods from the Azores. The aims of this work were to address the following questions: 1) to establish the typical ostracod assemblages from the shallow marine depths of the Azores; 2) to determine the bathymetric ranges for each ostracod species; 3) to investigate the time span and depth in which significant transport occurs; 4) to quantify the amount of out of habitat transport between sandy beaches, tidal pools and the infralittoral; 5) to determine distinctive taphonomic features that can be used to recognize the amount of temporal resolution in ostracod assemblages. Fifteen species were recovered, representing 8 families and 12 genera genera (*Loxoconcha*, *Neonesidea, Xestoleberis*, *Aurila*, *Urocythereis*, *Heterocythereis*, *Carinocythereis*, *Callistocythere*, *Leptocythere*, *Semicytherura*, *Lanceostoma* and *Cylindroleberis*). The Recent assemblages are dominated by specimens of the Loxoconchidae family, whereas the Holocene assemblages are dominated by specimens of the families Loxoconchidae, Hemicytheridae and Bairdiidae. The shift from life-dominated assemblages in the shallower depths to death assemblages at greater depths is a consequence of significant transport downwards. In both Recent and Holocene samples, the abundance of ostracods is higher in the first 10 m depth, especially in fine to medium sandy substrates. Considerable differences among islands were supported by the Bayesian model, as a consequence of the factors (e.g., depth, type of sediment, physiognomy of the coast line, geographical location, and hydrodynamic local conditions) that differently affect each of the Azorean islands. Large-scale (sea-surface currents, Holocene relative sea-level, storms) and small-scale processes (geographical location, coastal fragmentation into dynamic cells with impermeable lateral boundaries, physiognomy of the coast line, seafloor stability of the sediments) are responsible for shaping the Azorean Holocene to Recent ostracods communities.

Keywords: Ostracods; Holocene; Recent; Taphonomic process; Palaeoecology, Bayesian model.

.

INTRODUCTION

Ostracods are small crustaceans characterized by a bivalved carapace that totally encloses the body and appendages. Their bodies show reduced trunk segmentation and 5-8 pairs of limbs, which are protruded from the gaping valves for locomotion. They are typically 0.5-2.0 mm long in the adult stage (Horne *et al*., 2002). Ostracod are one of the most diverse groups of living crustaceans, with over 20,000 estimated living species, of which, approximately 8,000 have been described (Morin & Cohen, 1991). Ostracods species are particularly sensitive to environmental changes and are, thus, very useful in palaeoenvironmental interpretations (Whatley, 1983; Cronin *et al*., 2002, Holmes & Chivas, 2002).

Ostracoda fauna differ in the number of families and species around the world, usually, with more species in continental margins than around insular habitats. Due to their high level of isolation, far-away oceanic islands are a perfect place for the study of evolutionary processes, patterns of dispersion, colonization and speciation (*e.g.* Schornikov & Keyser, 2004; Wilson, 2007; Ávila *et al*., 2012). As truly volcanic oceanic islands, the Azores have been the subject of several studies with a biogeographical perspective: molluscs (Ávila, 2000, 2005), sponges (Xavier & van Soest, 2012), algae (Tittley & Neto, 1995). There are no published studies on the Ostracoda of the Azores; therefore the shallow marine ostracods from these islands can add an important contribution to the present biogeographic puzzle of this region of the Northern Atlantic. This study provides important elements for deciphering the relationships between different populations and how the environmental stress can determinate the biocenosis (living population), thanatocoenosis (fossils preserved in situ) and allochthonous assemblages (taphocoenosis).

In this work we focused on the Holocene to Recent shallow marine ostracod diversity and its distribution around the archipelago of the Azores. We can relate this assemblages with several factors including physical (like: orientation/exposure, depth, tidal range, waves), ecological (habitat type, assemblage) and sedimentological to the ostracods communities. A comprehensive characterization of the study area from the taphonomic, ecological, and sedimentological point of view was done in order to evaluate the influence of the environment and the effect of the depositional processes in shallow-water areas. Specifically, we wished to address the following questions: 1) Is there a typical ostracod assemblage from the shallow marine depths of the Azores? 2) Which are the bathymetric ranges for each ostracod species? 3) What is the time span and depth in which significant transport occurs? 4) When transport occurs, is there a difference in the amount of out of habitat transport between sandy beaches, tidal pools and the infralittoral? 5) Do ostracods assemblages bear distinctive taphonomic features that can be used to recognize the amount of temporal resolution in other deposits?

Study area

The Azores archipelago – located in the mid-North Atlantic (Fig. 1) (25° – 32° W and 37° - 40° N), about 1.500 km from the shores of mainland Portugal – is a group of young oceanic islands. The easternmost Santa Maria Island is much older than the remaining in the archipelago, having emerged during the Late Miocene (Abdel-Monem *et al.*, 1968, 1975; Féraud *et al.*, 1980, 1981) and is very rich in Neogene fossiliferous sediments, including Late Miocene marine Ostracods (Meireles *et al.*, 2012).

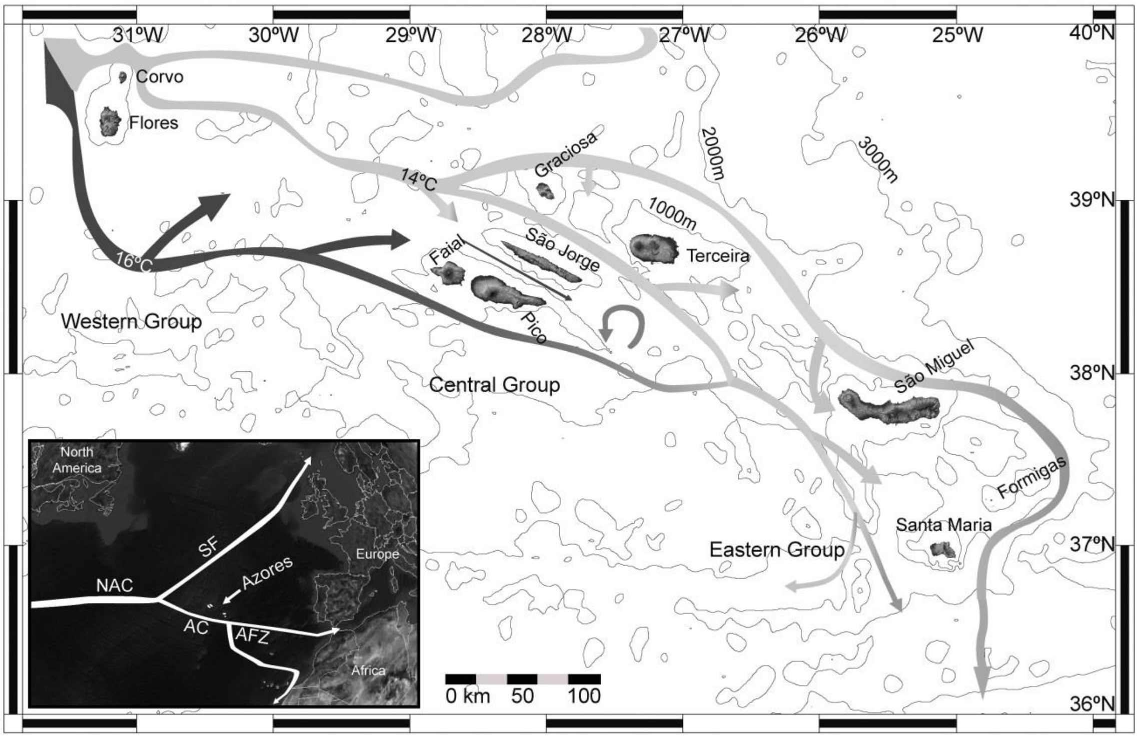


Figure 1. Geographical location of the Azores Archipelago (Western, Central and Eastern Groups), and the Azores Current (approximate position for the 30.6 meters depth and temperature; modified from Johnson & Stevens, 2000) around the archipelago. Detail, main oceanic currents of the North Atlantic Ocean; SF = Subpolar Front, NAC = North Atlantic Current, AC = Azores Current, AFZ = Azores Frontal Zone (adapted from Rogerson *et al.*, 2004; Storz *et al.*, 2009). The bathymetry of the Azores archipelago is from IOC IHO & BODC (2003).

Today, generally the coastline of these islands has a NW-SE to WNW-ESE orientation, coincident with the major tectonic trends of each of the islands (Borges, 2003). The climate is temperate, with a low thermal amplitude, high precipitation, and high air humidity and persistent wind (Calado *et al*., 2011). Annual average sea-surface temperature is about 19ºC, ranging from 14ºC in winter to 24ºC in the summer period (Whissak *et al*., 2010). The pattern of the sea-surface currents in the North Atlantic is dominated by the Gulf Stream that flows from West to the East, that is, from the American coasts to Europe. One of the branches of the Gulf Stream, the Azores Current, is a meandering jet across the Atlantic at around latitude 38^{o}N, just south of the Azores islands (Johnson & Stevens, 2000; Rogerson *et al*., 2004) (Fig. 1).

The long fetch that characterizes the Azores results in a high-energy wave climate where both sea and swell are relevant sources of coastal energy, with the northern-facing shore of each island in general being more exposed (Borges *et al*., 2002). The steep submarine slopes and absence of large shallow shelves (Ávila *et al*., 2008; Quartau *et al*., 2012) produce localized patterns of wave shoaling, refraction and diffraction which, especially during storms, occur just before they break. This leads to coastal fragmentation into a number of dynamic cells, limited in terms of longshore sediment movement by virtually impermeable lateral boundaries (Borges *et al*., 2002). The Azores littoral is microtidal to low mesotidal with tides and tidal currents being minor contributors to coastal morphology and sediment dynamics. These are semidiurnal with a yearly average and maximum spring tidal range of 0.75 to 1 m and 1.3 m respectively; the storm events are frequent and variable from year to year (Borges, 2003).

The transport processes of the coastal sediments are controlled by four main factors, namely: **i)** steep submarine slopes and absence of large shallow shelves; **ii)** coastal storms; **iii)** local sediment supply; and **iv)** littoral drift currents induced by the Atlantic surface waters. Coastal drift currents are residual, although influenced by the North Atlantic circulation, and have a small effect on the sediment redistribution of the Azorean littoral, being this role attributed mainly to stormy waves that have the capability of disturbing the dynamic cells already mentioned (Borges, 2003).

The Azores coast has diverse forms, ranging from low rocky coasts to bluffs, plunging cliffs, pocket beaches, dunes, lagoons and tidal pools. Sandy beaches are rare and small, and do not occur in all islands. Since coastal cliffs are usually plunging cliffs, the intertidal zone is also vertical in large areas of the shore, with a reduced area available for the settlement of the intertidal organisms. On the subtidal zone, basaltic rocky shores covered by algae dominate. Unconsolidated sediments of different sizes are also common, ranging from boulders and pebble gravel to sand environments, covering the marine rocky substrate.

MATERIALS AND METHODS

Collection and examination of specimens

Three field campaigns were done for this study. The first one was aimed to know reveal the characterization and distribution of the beach surface sediments. A total of 600 samples were collected from 1994 to 1999, which allowed to establish a general sedimentary composition, as well as charts of grain-sized fractions and carbonate contents (Borges, 2003). The second campaign collected 20 samples (with a Van Veen grab) in inner shelf of the islands of the Central and Western groups, between 20 and 86 m depth. For the sedimentary samples (first and second campaigns), a subsample of 100 g of material was retrieved from each sample and was washed and sieved (250 µm, 120 µm, 63 µm) in the laboratory, split and sorted. The campaigns to collect sediments were carried out by the authors in collaboration with the Department of Geosciences, and the Department of Oceanography and Fisheries of the University of the Azores.

The third campaign collected 27 samples, containing living ostracods. All biotopes sampled (coastal rocky shore habitats such as intertidal pools, sedimentary traps, in the intertidal coastal rocky platforms and lava caves) were shallow, with maximum depths lower than 15 meters depth. A 180 µm mesh hand dredge net was used. The hand dredge was dragged over the bottom surface to a depth of 3–5 cm. The sample was washed through a set of sieves with a mesh width of 1.0 and 0.25 mm. All taxa from the same fraction were sorted, washed in fresh water and fixed in 70% alcohol in separate tubes.

Of the 640 samples collected, 60 were screened, and ostracods were found in 45 samples (Table 1). Although sandy sediments were also sampled on the northern shores of the islands, no ostracods were found there. A total of 2,950 ostracods were handpicked, included Holocene and living ostracods. Specimens picked from the samples were placed on standard micropalaeontological cavity slides for further examination and counting. Only the autochthonous ostracods were identified (Plate 1). The taxonomy and classification adopted follows Horne *et al.* (2002) (see complete list of species in Appendix A). A detailed taxonomic description of the ostracod species is out of the scope of this paper and will be dealt with separately (Meireles *et al*, Chapter 5). The figured specimens (SEM) are held in the collections of the Department of Biology, University of the Azores, Section of Ostracoda, under prefix "**DB/OS no.**". Other abbreviations used: RV=right valve, LV=left valve.

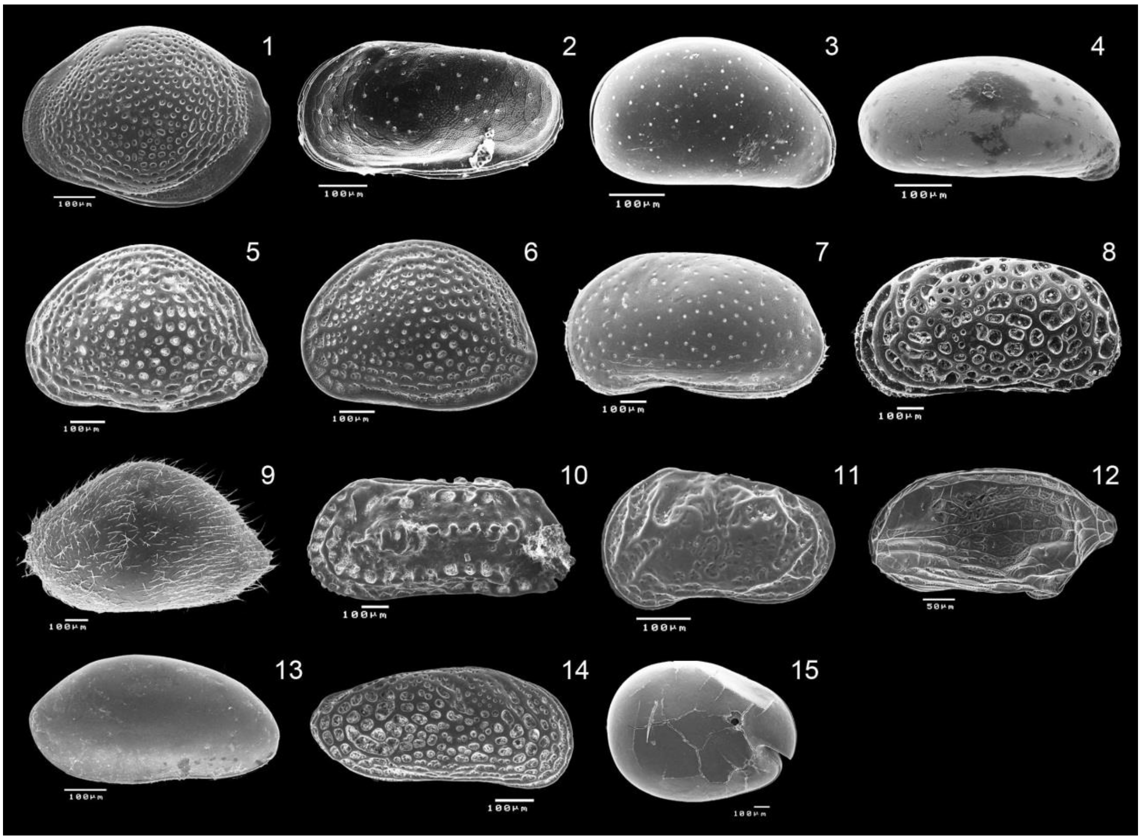


PLATE 1. 1) *Loxoconcha rhomboidea* (Fischer, 1855). DB/OS 0144. LV; **2)** *Loxoconcha* cf. *ochlockoneensis* Brady, 1868. DB/OS 0001. LV; **3)** *Xestoleberis rubens* Whittaker, 1978. DB/OS 0118. LV; **4)** *Xestoleberis* cf. *depressa* Sars, 1866. DB/OS 0181. LV; **5)** *Aurila convexa* (Baird, 1850). DB/OS 0039. LV; **6)** *Aurila woutersi* Horne, 1986. DB/OS 0120. LV; **7)** *Heterocythereis albomaculata* (Baird, 1838). DB/OS 0113. LV; **8)** *Urocythereis britannica* Athersuch, 1971. DB/OS 0017. LV; **9)** *Neonesidea schulzi* (Hartmann, 1964). DB/OS 0133. LV; **10)** *Carinocythereis whitei*. DB/OS 0054. LV; **11)** *Callistocythere* sp. DB/OS 0148. LV; **12)** *Semicytherura* sp. DB/OS 0123. LV; **13)** *Lanceostoma* sp. DB/OS 0117. LV; **14)** *Leptocythere pellucida* (Baird, 1850). DB/OS 0057. RV; **15)** *Cylindroleberis* sp. DB/OS 0180. RV.

Statistical analysis

Several indices were calculated to describe the diversity of the ostracods assemblages, namely abundance (number of individuals), species richness, Shannon-Wiener diversity, Equitability, Dominance, and alpha of Fisher. All ostracod species/specimens were used in the statistical analysis (including autochthonous and allochthonous).

Data were analyzed using a Bayesian inference with the application WinBUGS (Spiegelhalter *et al*., 2003), since it was shown to be an adequate tool for data analysis in ecology, allowing studying a wide range of models (McCarthy, 2007; Kéry, 2010; King *et al*., 2010). This methodology permits building different models, in order to determine the possible differences in parameter estimates for different communities. We opted to use Bayesian inference, since all parameters are considered as random variables, thus uncertainty is included at all components of the models (Gelman *et al*., 1995) which seemed as highly adequate to the type of available data. The best models were selected based on their complexity and fit and also included, as derived quantities, comparisons between community types. They allowed a more comprehensive and easily interpretable approach than more traditional analysis which usually imply sequential interpretation of multivariate, univariate, and post-hoc tests (Zuur *et al*., 2007). We used the normal distribution as a prior for Shannon-Wiener diversity and for equitability, and the Poisson distribution for total abundance and species richness (Gelman *et al*., 1995; McCarthy, 2007; King *et al*., 2010). The following models were calculated: **i)** island effect model, allowing different parameters for each of the islands; **ii)** habitat model, allowing different parameters for each habitat type (beach, infralittoral, tidal pool); **iii)** depth model, allowing different parameters for each depth class (≤10 m, <30 m, ≥30 m); **iv)** geographical location model, allowing different parameters for location class (South, Southeast, North, East); and **v)** sediment model, allowing different parameters for sediment types (fine, fine to medium, medium, medium to coarse). Besides estimating the different probability distributions for each community type ($group.mean_i$), we also calculated, as derived quantities, the differences in estimates (d_i) among islands, habitats types, depth classes, location classes and sediment types. In all cases we used three Markov chains and updated the model the required number of times to be clearly sufficient to reach convergence, by using normally accepted criteria (King *et al*., 2010), including analysis of trace plots, the Brooks-Gelman-Rubin diagnostic, and the magnitude of Monte Carlo error, as provided by WinBUGS. To estimate model parameters we only considered the estimates obtained after convergence. We used Deviance Information Criteria (DIC) as a measure of model complexity and fit (Spiegelhalter *et al*., 2002) (Table 2). In general, we found that updating the model 100,000 times and using the last 30,000 updates to estimate model parameters and DIC was clearly sufficient to assure chain convergence.

Table 2. Evaluation of four Bayesian models assessing the effect of five different factors (Location, Island, Depth, Habitat, Sediment) on the diversity (Eveness, Shannon Diversity, Total Abundance, Species Richness) of Holocene Ostracoda assemblage in Azores Archipelago. DIC values obtained after convergence (75,000 model updates).

	DIC				
Diversity measures	Geographical location	Island effect	Depth	Habitat	Sediment
Eveness	17.0	16.4	16.6	16.8	17.4
Shannon diversity	65.5	59.6	65.8	65.0	64.5
Total abundance	3396.2	2431.2	3354.3	3301.4	3238.5
Species richness	191.6	187.6	192.6	189.9	191.8
Total	3670.4	2694.8	3629.3	3573.2	3512.2

In order to have a global vision of the effect of habitat type (beach, infralittoral, tidal pools) on community composition and diversity, we applied a discriminant analysis to a data set including species abundances, total abundance and species richness (all log transformed), and Shannon-Wiener and Equitability diversity indices. The classification module of SPSS v.18 was used.

We used the R package *indicspecies*, available through Cran (http://cran.r-project.org/web/packages/indicspecies/), to determine indicator species among the different habitat types sampled in this study. The package was written by De Cáceres *et al*. (2010) as a refinement of the IndVal method originally developed by Dufreen & Legendre (1997). The algorithm determines both fidelity (restriction to a site or group of sites) and consistency (consistent species occurrence among sites within site groups) and provides a statistic (IndVal) and an associated p-value. Only species significant at the p<0.05 level were selected as indicator species.

RESULTS

Recent Ostracoda assemblages

Around the island of São Miguel, eight families were found: Loxoconchidae is the dominant family, comprising 46% of all specimens recovered, followed by Hemicytheridae (18%), Bairdiidae (13%), Xestoleberididae and Trachyleberididae (both

9%), Leptocytheridae and Paradoxostomatidae (both 2%) and Leptocytheridae (1%). Fourteen living species were found: *Loxoconcha rhomboidea* (Fischer, 1855); *Loxoconcha* cf. *ochlockoneensis* Puri, 1960; *Neonesidea schulzi* (Hartmann, 1964); *Aurila convexa* (Baird, 1850); *A. woutersi* Horne, 1986; *Xestoleberis rubens* Whittaker, 1978; *Heterocythereis albomaculata* (Baird, 1838); *Urocythereis britannica* Athersuch, 1977; *Leptocythere pellucida* (Baird,1850); *Carinocythereis whitei* (Baird, 1850); *Callistocythere* sp.; *Semicytherura* sp.; *Lanceostoma* sp., and *Cylindroleberis* sp. (Fig. 2 and Plate 1). Living shallow marine ostracod species occur in tidal pools and infralittoral (inner shelf) zones, between 1 and ~20 meters depth, in fine to medium sands, usually in association with algae and sponges. *Loxoconcha rhomboidea* was the most abundant species, occurring in all Recent samples, with a bathymetric range from 0 to 20 meters depth (including Holocene sediments) (Fig. 2). In general, four species were found living together: *Loxoconcha rhomboidea; Neonesidea schulzi, Xestoleberis rubens* and *Heterocythereis albomaculata*. The highest concentrations were found on the southern shores of São Miguel Island, at depths ranging from 1 to 15 m. Species with more ornamentation like *Callistocythere* sp. *Semicytherura* sp.; *Urocythereis britannica* and *Carinocythereis whitei* seem to be restricted to the South shores.

Comparisons of the total number of specimens (both live and dead) along a bathymetric sampling at all sites in São Miguel Island indicate that there is not a direct relationship between abundance and depth (between 0 at 20 meters depth) (Fig. 3A). Nevertheless, in both Recent and Holocene samples, the abundance of ostracods is higher in the first 10 m depth.

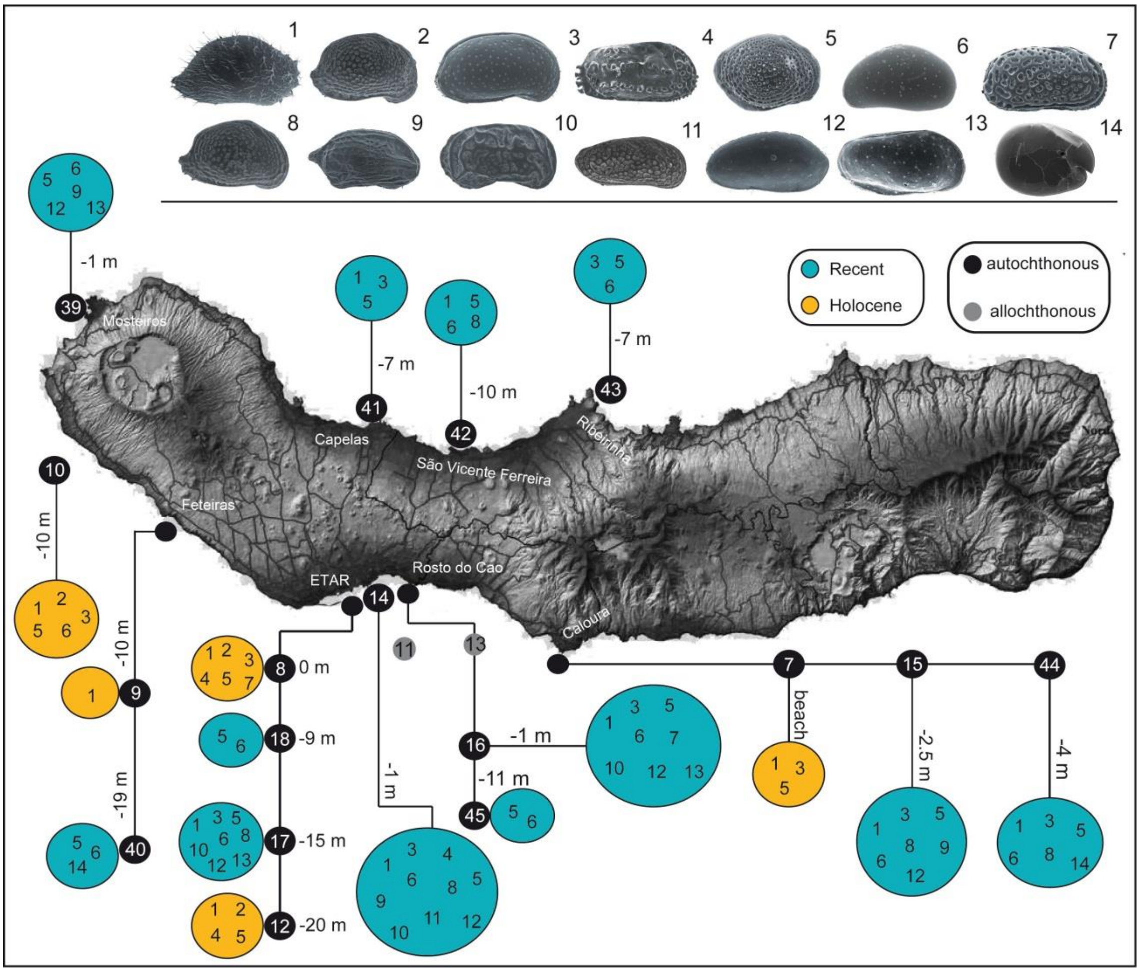


Figure 2. Distribution of living ostracods faunal and autochthonous Holocene ostracods around São Miguel Island.

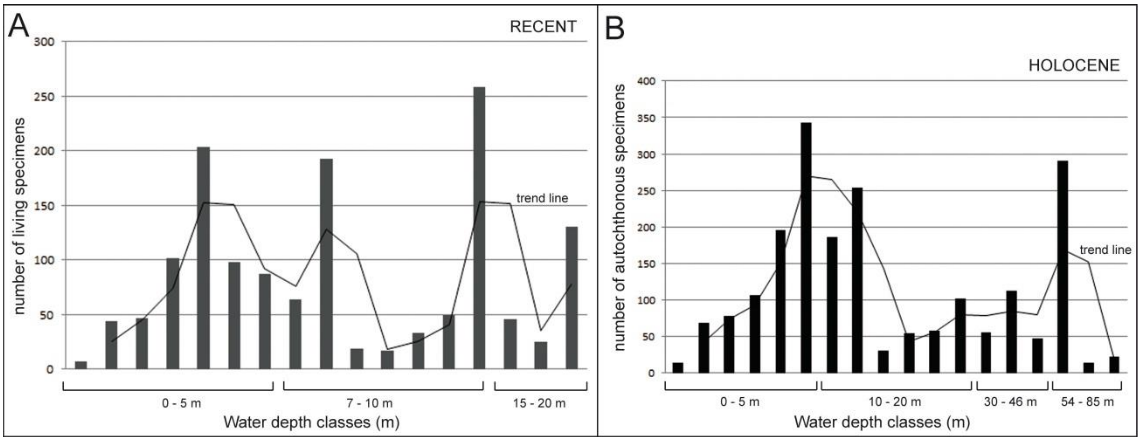


Figure 3. Total of number of specimens for water depth classes. **A)** number of Recent specimens, and **B)** number of autochthonous Holocene specimens.

Holocene Ostracoda assemblages

The Holocene ostracods are relatively diverse and represented by different ontogenetic stages (instars). It comprises 8 families, and 12 genera. The autochthonous fossil assemblages are dominated by specimens belonging to Loxoconchidae (32%), Hemicytheridae (25%), Bairdiidae (21%), Xestoleberididae (11%) and Trachyleberididae (5%) (Figs 2, 4 and Table 3).

The sediments with a higher ostracod abundance and diversity come from depths between 0 and 54 m, where fine to medium sand predominates. The highest ostracod concentration by sample occurs at different depths and places: two samples between 0 and 23 m depth in the South and the East coast of Terceira Island; four samples between 0 and 20 m depth, all in the South coast of São Miguel Island (in this case, two of them were at the same area, around the sewage treatment system of Ponta Delgada); two samples between 10 and 30 meters depth in the Southeast coast of Faial; and finally, two samples between 1 and 54 meters depth, both in the Southeast coast of Pico Island (Figs 2 and 4).

The model based on depth only showed differences among depth classes for total abundance (total number of dead ostracods found), with the intermediate depth class (class 2: from 10 to 30 meters depth) showing the highest abundance (Fig. 5A). Regarding habitat type, the highest abundance was found for communities located at the infralittoral (Fig. 5B) and the lowest number of species was found in the samples collected at beaches (Fig. 5C), where not a single specimen was found alive.

Ostracods' Holocene species richness is higher in fine-to-medium to medium grain size, whereas total abundance was found to be higher in medium to coarse sediments (Fig. 6). Fine to medium sand are mostly located at depths lower than 30 m depth, where low depositional energy predominates. At higher depths, coarse to granule sands are dominant and the faunal autochthonous association is typically composed by species of the genus *Loxoconcha*, *Neonesidea*, *Aurila*, *Urocythereis* and *Xestoleberis* (Fig. 7).

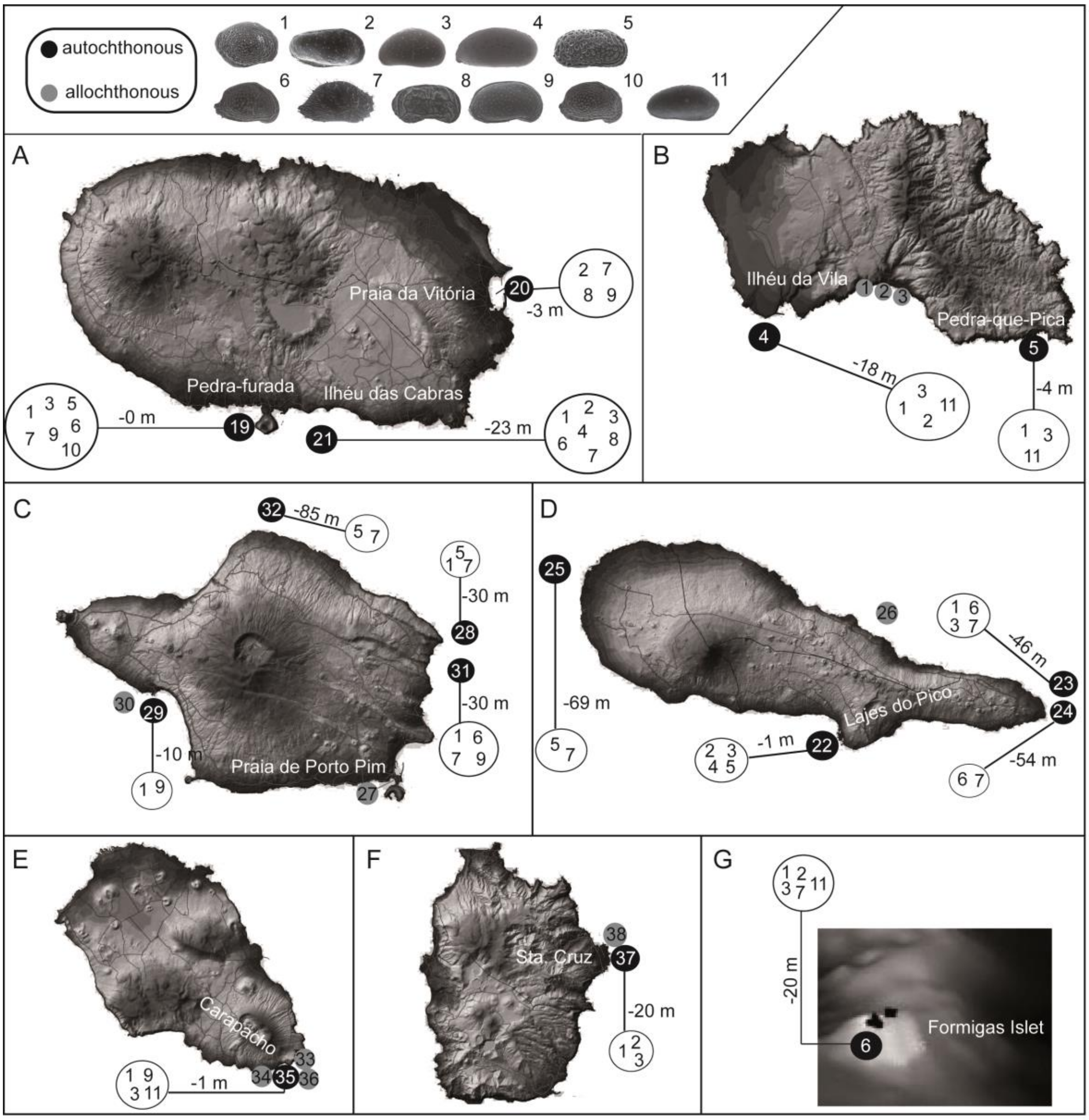


Figure 4. Distribution of autochthonous Holocene ostracods faunal around Azores archipelago. **A)** Terceira; **B)** Santa Maria, **C)** Faial, **D)** Pico; **E)** Graciosa, **F)** Flores Island and **G)** Formigas islet.

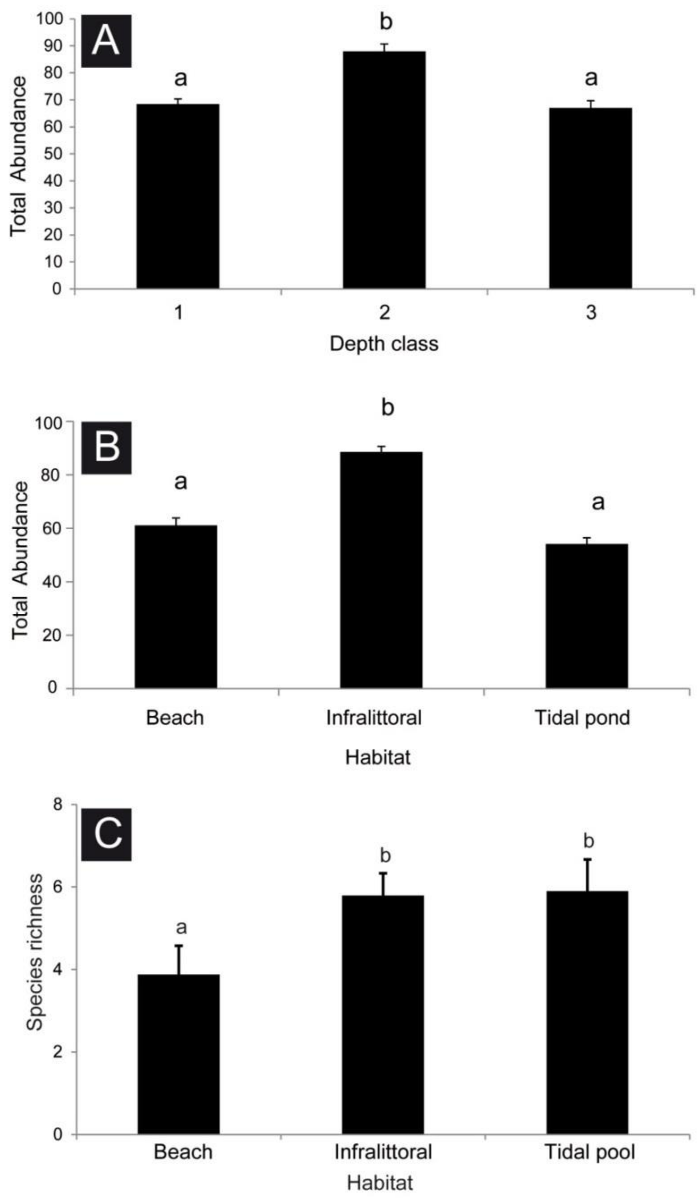


Figure 5. Effect of environmental factors on the abundance and diversity of Holocene ostracod communities in the Azores Archipelago (35 samples). Evaluation of Bayesian models assessing the effect of: **A)** Depth class on total abundance (depth classes: 1, < 10 m; 2, 10 - 30 m; 3, > 30 m); **B)** Habitat type on total abundance (beach; infralittoral; and tidal pool); and **C)** Habitat type on species richness (beach; infralittoral, and tidal pool). Bars represent mean + standard error. The posterior distributions of the parameters were obtained after convergence (100000 model updates). Different letters indicate that the posterior distribution of the difference between the means does not include zero (based on the analysis of the 95% credibility interval).

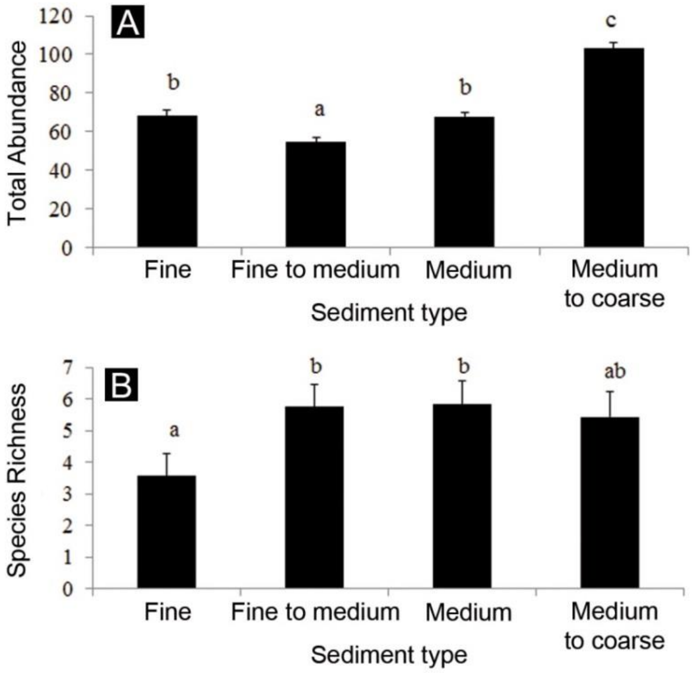


Figure 6. Effect of environmental factors on the abundance and diversity of Holocene ostracods communities in the Azores Archipelago (35 samples). Evaluation of a Bayesian model assessing the effect of sediment type on: **A)** total abundance; **B)** species richness. The posterior distributions of the parameters were obtained after convergence (100000 model updates). Different letters indicate that the posterior distribution of the difference between the means does not include zero (based on the analysis of the 95% credibility interval).

According to the DIC values (Table 2), the more informative Bayesian model (lowest DIC) incorporated island effect, particularly due to a better adjustment to the possible differences in total abundance between islands. The model based on geographic location did not show any significant differences, while the model based on depth only showed differences among depth classes for total abundance, with the intermediate depth class (between 10 and 30 m depth) showing the highest abundance (cf. Fig. 5A).

As regards to the maximum bathymetric range for species around the Azores insular shelf, *Aurila woutersi*, *Loxoconcha* cf. *ochlockoneensis*, *Xestoleberis* cf. *depressa*, *Carinocythereis whitei*, *Callistocythere* sp. and *Lanceostoma* sp. are shallow-water species, occurring in waters less than 30 m depth; *Aurila convexa*, *Xestoleberis rubens*, *Loxoconcha rhomboidea* and *Heterocythereis albomaculata* occur between 30 and 55 m depth; and *Neonesidea schulzi* and *Urocythereis britannica* may occur as deep as ~90 m depth (Fig. 8).

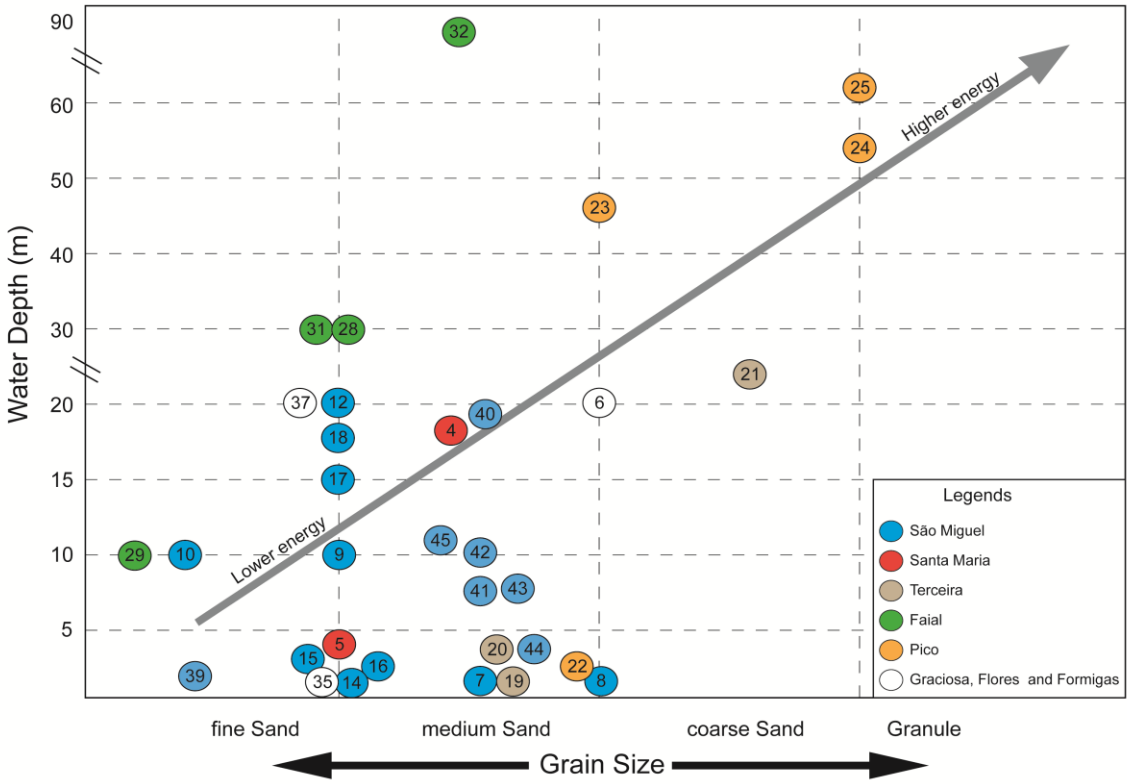


Figure 7. Distribution of ostracods, depth and grain size as a function of depositional energy (Azores archipelago). Fine-sand: low energy; medium sand: medium energy; coarse sand and granule: high energy (cf. Table 3).

DISCUSSION

Taphonomic approach

If one were to estimate grain size, water depth and environmental depositional energy, samples could be plotted onto a schematic representation, reflecting the taphonomic fidelity of each deposit. These plots can be considered as taphonomically-controlled facies and can serve as predictive tool for estimating how much time-averaging is likely to affect a deposit (see Park *et al*., 2003 for an overview) (Fig. 7). The Azores shores are considered as a high energy environment, with the exception of a few protected sites. In these oceanic islands, dynamic cells make long shore currents to be negligible in comparison with downwelling shore oblique currents, which transport the sediments, moving them from the exposed beach to the underwater beach (cf. Fig. 8) (Meireles *et al*., Chapter 5). In these high energy environments, the diversity of ostracods is higher in depth ranges of 0-20 m (Fig. 5B), in fine- to medium-sandy substrates (Fig. 6B), with inferred lower energy (cf. Fig. 7).

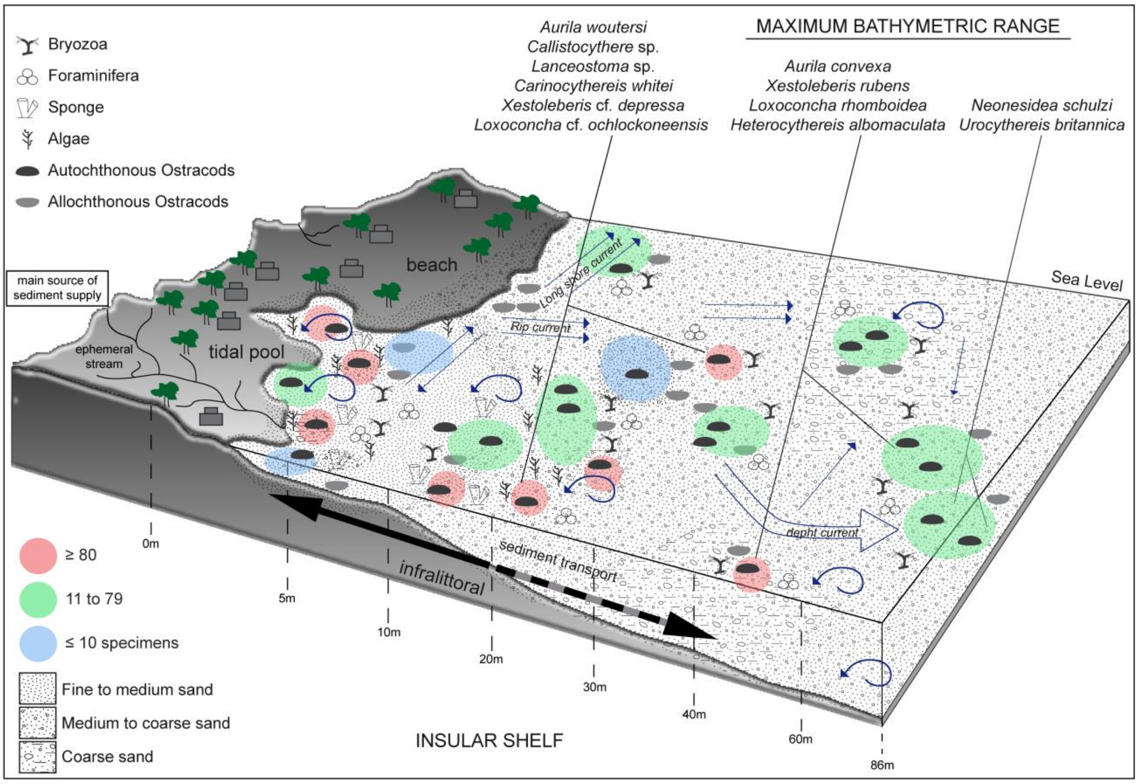


Figure 8. Cross-insular shelf profile showed the distribution of the Recent to Holocene autochthonous ostracods in relationship of depth and sediments preferred. Maximum bathymetric range of the ostracods founded on Azores shallow marine environment.

The analyses of the distribution of the remains of dead organisms in Recent sediments are strongly influenced by the method used to establish and report abundance. Comparisons of abundance from Recent and ancient strata are affected by the composition of the sediment, its history, and the type of sample upon which these counts are based (Kornicker, 1959).

Kontrovitz *et al*. (1998) made one equation to discriminate if some taphonomic processes were important in altering an assemblage of ostracods. They showed that such assemblages may be sampled and the width, thickness, and MPS (maximum projection sphericity) of the shells determined as a function of each species. The amount of pressure required to crush each ostracods could then be estimated by using the equation for that species. If within the assemblage the pressure that would be required to crush the samples varies greatly, then one could conclude that the assemblage is unlikely to have been altered by pressure. Otherwise, the weaker ostracods shells probably would have been crushed. If, however, the only ostracods present are found to require large pressures to be crushed or all require about the same pressure, then one might suspect that the assemblage may have lost shells due to forces exerted by the overlying sediments. Under the latter conditions, the investigator could misinterpret palaeoenvironmental conditions, if wrongly assuming the presence of a nearly complete and useful assemblage for such a purpose (Kontrovitz *et al*., 1998). In addition to this, ecologic models based only upon death assemblages will be always less resolving than those models based upon live assemblages (Park *et al*., 2003). Our samples include a mixture of fragile and resistant shells, the latest being predominant (cf. Fig. 2). Fragile shells (e.g., *Lanceostoma* sp.) are better represented in the Recent samples. Thus, transport becomes important when ostracods are used as proxy indicators for biodiversity and conservation practices in shallow, steep gradient coasts such as those around the Azores islands, and should be considered in any model developed (cf. Fig. 8).

Other important components that were present in the taphonomic studies are the synecology indices (*i.e.* describing associations in relation to environmental parameters), which are based on the quantitative analysis of the assemblages and that may shed light on the stability of the environment. Low diversity assemblages with few or single dominating species point to stressed, unstable conditions (Frenzel & Boomer, 2005). For instance, high sedimentation rates, recorded for areas of the Baltic Sea, showed low diversity and abundance (Rosenfeld, 1977). The number of autochthonous dead specimens decreases with depth, suggesting a shift from life-dominated assemblages in the shallower depths to death assemblages at greater depths (Fig. 3B). This trend is expected when significant transport occurs and is in agreement with Park *et al*. (2003) and Machado *et al*. (2005).

The abundance of the Holocene Azorean ostracod species' presents a zonation in relation to both depth (Figs 3, 5 and 7), and grain size (Figs 6 and 7), as well as with geographical coast location, with a preference towards southern and eastern shores. Probably this is a result of a relatively higher stability of the bottom sediments, as the mean wave height in the northern coasts exceeds up to 20% the value of the southern coasts (cf. Borges, 2003). We cannot, however, exclude that these deposits and their faunas have undergone transport, particularly in areas with higher-energy conditions, by downwelling shore oblique currents.

Comparison of live and dead assemblages from similar depths and substrates around the archipelago, indicate that there are some distribution oddities. For example, all Holocene species occurred at Terceira Island with the exception of *Lanceostoma* sp.

However, this species also occurs at Graciosa Island, just ~60 km distance. Santa Maria Island and Formigas Islet have similar species composition, except for *Neonesidea schulzi* that is not present at Santa Maria (cf. Fig. 4).

The standard of length classes' distribution present in one taphocoenosis can be used to describe how the death of the animals occurred (Shipman, 1981). We identified two different types of death: 1) non-selective death (catastrophic) or 2) selective death (natural); in both cases we can add fast or slow burial. Using this method plus ontogenetic structure of the populations (after Whatley, 1988) the samples present in most cases a selective death (natural) with the exception of assemblages nos. 6, 7, 9, 25 and 32 (cf. Table 3, as these five present a non-selective death [catastrophic] with slow burial). All other assemblages present a selective death (natural). The North Faial assemblage (no. 28) and North Pico assemblage (no. 23) present a selective death (natural) with slow burial rate, which we interpret as the result of high wave-energy and sea-currents which are stronger on the North shores of these islands (Fig. 4). In general, the samples collected in protected sites or on the South shores of the islands present a selective death (natural) with fast burial (e.g., assemblages nos. 4, 8, 10, 12, 19, 20 21, 29, 31; cf. Figs. 2 and 4; Table 3). These areas present a reduced hydrodinamism and high sedimentation rates. Based on these findings and the characteristics of the present-day taxa we were able to develop a model of how assemblages occur on these settings, relating these items with the bathymetric range of the ostracod species (Fig. 8). Considering the substrate, depth, marine environment (tidal pool, beach and infralittoral) and the main sea-surface currents, we were able to display the distribution of the autochthonous ostracods on the insular Azorean shelf (see complete list of the typical association of species in Table 3).

Ecological setting

In terms of abundance, we found considerable variation between samples, a situation that is in agreement with previous studies (Figs 5 and 6). Allison & Holden (1971) described differences in abundance, depending on the depth, with relatively lower values closer to the surface. Hull (1997) reported that abundances differ over the years, and also along the year, and gave abundance values (50 to 150 specimens) that are within the range found in our study. In Brazil, species abundance was even higher, with some species with more than 2,000 specimens, but also with the already noted variation between samples (Machado *et al.*, 2005). Cabral *et al.* (2006) reported abundances between 10 to 100 specimens, depending on the area, for the Holocene of mainland Portugal. Athersuch (1979) found similar abundance values for the littoral of Cyprus, with some species with more than 100 specimens. For the Basque shelf, abundances were also similar, ranging from 11 to 156 specimens (Pascual *et al*., 2008).

If we consider ostracods as a sand grain, the zonation displayed on Fig. 8 suites well with the coastal fragmentation into dynamic cells, limited in terms of longshore sediment movement by virtually impermeable lateral boundaries where the dynamics of the beaches are essentially transverse (cf. Borges *et al*., 2002), and with a morphodynamic continuum between two extreme situations, the profile of high energy (storm or winter profile) and the profile of low energy (swell or summer profile) with the sandy sediments moving from the exposed beach to the underwater beach and vice-versa, respectively (see Short, 1999 for an overview).

Ostracod species richness estimates are impacted by time-averaging because transport of dead valve material occurs at higher percentages in the shallow depths and on the infralittoral, suggesting that the ostracods death assemblages in these sensitive areas will be a mirror of the life assemblages. The beach areas are sensitive for the ostracods too, but will not necessarily be reflective of the life assemblages, as all species are considered to be allochthonous. We found differences in diversity and abundance between habitat types, depth classes, sediment types, and between different islands (cf. Figs 2, 4, 5 and 6). Several environmental factors affect the distribution and abundance of ostracods, in particular, the textural characteristics of the bottom substrate. Benson & Maddocks (1964), Puri (1966), Montenegro *et al*. (1998) and Coimbra *et al*. (1999) reported that grain size is one of the significant factors controlling the population structure, density and distribution of ostracod species, fine-grained sands with a high percentage of silt and clay being favoured (Machado *et al*., 2005). However, it should be noted that silt and clays are uncommon around the Azores archipelago. High algal concentrations and seasonal changes can also influence the presence of ostracods (Hull, 1997). Furthermore, other factors like depth also affect ostracods richness. For instance, Ascoli (1964) found that the most favourable environmental conditions for a high number of ostracod species was a depth between 50 and 250 m, on a muddy and clayey bottom; towards either littoral or bathyal environments, the number of species decreased. This is in agreement with our observations, which showed more species at the infralittoral than at the beaches (Fig. 8). However, tidal pools in shallow waters seem to be an exception, deserving further studies. Besides sediment type and water depth, the physiognomy of the coast line might also be important; for example, living ostracods in Kuwait Bay were abundant except in the tidal flat areas and the central channel (Al-Abdul-Razzaq *et al*., 1983).

With all these factors affecting ostracods occurrence, it is not surprising that considerable differences among islands have been found, since all those factors might interact differently at each Azorean island, as demonstrated by the more informative Bayesian model: Island effect (cf. DIC values in Table 2). Also, habitat types, by differently combining several of the above mentioned factors (e.g. depth, type of sediment, physiognomy of the coast line) were clearly discriminated in this study. Thus, in regards to the shaping of the Azorean Holocene to Recent ostracods communities, we might be in the presence of large-scale (sea-surface currents, Holocene relative sea-level, storms) and small-scale processes (geographical location, coastal fragmentation into dynamic cells with impermeable lateral boundaries, physiognomy of the coast line, seafloor stability of the sediments).

CONCLUSIONS

This is the first palaeoecological study of the Holocene to Recent ostracods from the Azores. So far, only two species had been reported: *Loxoconcha rhomboidea* and *Heterocythereis* albomaculata (Costa, 2010). This work increases the number of benthic shallow-water marine ostracods from this archipelago to 15 species, representing 8 families and 12 genera (*Loxoconcha, Neonesidea, Xestoleberis*, *Aurila*, *Urocythereis*, *Heterocythereis*, *Carinocythereis*, *Callistocythere*, *Leptocythere*, *Semicytherura*, *Lanceostoma* and *Cylindroleberis*).

The Recent assemblages are dominated by specimens of the Loxoconchidae family, whereas the Holocene assemblages are dominated by specimens of the families Loxoconchidae, Hemicytheridae and Bairdiidae. The most abundant species, *Loxoconcha rhomboidea*, occurred in both Recent (0-20 m depth) and Holocene sediments and together with *Neonesidea schulzi*, *Xestoleberis rubens* and *Heterocythereis albomaculata* outlines an assemblage of species that are usually found together in the Recent samples. The shift from life-dominated assemblages in the shallower depths to death assemblages at greater depths is a consequence of significant transport downwards. In both Recent and Holocene samples, the abundance of ostracods is higher in the first 10 m depth, especially in fine to medium sandy substrates. Interestingly, no living specimens were found in the samples collected at beaches, thus reinforcing the interpretations of Ávila *et al*. (2008) and Ávila (in press) who advocate that sandy beaches in oceanic islands located at temperate latitudes are almost devoid of life due to historical reasons related with the sea-level drop associated to cyclic glacial episodes.

The new information herein provided by the marine ostracods of the Azores and the sustained development of this new research line, for which the present work is a first contribution, will most likely bring novel palaeoecological and taphonomic ideas to the global understanding of the Azorean shallow marine biota, both Recent and fossil.

ACKNOWLEDGMENTS

We thank the Direcção Regional da Ciência, Tecnologia e Comunicações (Regional Government of the Azores), Direcção Regional do Ambiente e do Mar (Regional Government of the Azores) and FCT (Fundação para a Ciência e a Tecnologia) of the Portuguese government for financial support. We would like also to thank Filipe Porteiro and Valentina Matos (IMAR-Azores); Joana Xavier and Andreia Cunha (CiBio-Azores) for loaning samples and Jorge Medeiros (CIRN/University of the Azores) for the SEM photographs support. Sérgio Ávila acknowledges his Ciência 2009 research contract funded by FCT. Ricardo Piazza Meireles benefited from a grant SFRH/BD/60518/2009 of FCT, Portugal.

Table 1. Characterization of the sampling stations.

Nº	Island	Code	Lat. (N)	Long. (W)	Depth (m)	Habitat	Location	Grain size
1	Santa Maria	SMA_BE_S_5	36.930066	-25.024709	0	Beach	South	Fs to Ms
2	Santa Maria	SMA_BE_S_9	36.949994	-25.094447	0	Beach	South	Fs to Ms
3	Santa Maria	SMA_BE_S_10	36.949994	-25.094447	0	Beach	South	Fs
4	Santa Maria	SMA_SU_S_13	36.941454	-25.170836	-18	Sublittoral	South	Ms
5	Santa Maria	SMA_TP_S_71	36.941454	-25.170836	-4	Tidal pool	South	Fs to Ms
6	Formigas	FOR_SU_S_3	37.269408	-24.781723	-20	Sublittoral	South	Ms to Cs
7	São Miguel	SMG_BE_S_20	37.712072	-25.495147	0	Beach	South	Ms
8	São Miguel	SMG_SU_S_50	37.741653	-25.648505	0	Sublittoral	South	Ms to Cs
9	São Miguel	SMG_SU_S_24	37.795745	-25.795512	-10	Sublittoral	South	Ms
10	São Miguel	SMG_SU_S_14	37.823819	-25.864477	-10	Sublittoral	South	Fs
11	São Miguel	SMG_SU_S_8	37.746506	-25.625782	-20	Sublittoral	South	Fs
12	São Miguel	SMG_SU_S_47	37.741653	-25.648505	-20	Sublittoral	South	Fs to Ms
13	São Miguel	SMG_TP_S_57	37.750036	-25.629902	-1	Tidal pool	South	Fs to Ms
14	São Miguel	SMG_TP_S_59	37.744614	-25.640019	-1	Tidal pool	South	Fs to Ms
15	São Miguel	SMG_TP_S_60	37.707412	-25.508177	-2.5	Tidal pool	South	Fs to Ms with Ag
16	São Miguel	SMG_TP_S_66	37.749984	-25.630073	-1	Tidal pool	South	Fs to Ms

17	São Miguel	SMG_SU_S_68	37.741942	-25.647754	-15	Sublittoral	South	Fs to Ms
18	São Miguel	SMG_SU_S_69	37.741942	-25.647754	-9	Sublittoral	South	Fs to Ms
19	Terceira	TER_BE_S_7	38.654952	-27.237167	0	Beach	South	Ms
20	Terceira	TER_BE_S_6	38.718599	-27.054176	-3	Beach	East	Ms
21	Terceira	TER_SU_E_4	38.631891	-27.146873	-23	Sublittoral	South	Cs
22	Pico	PIC_TP_SE_1	38.389975	-28.251514	-1	Tidal pool	South-East	Ms to Cs
23	Pico	PIC_SU_SE_42	38.413920	-28.012561	-46	Sublittoral	South-East	Ms to Cs
24	Pico	PIC_SU_SE_45	38.412710	-28.015480	-54	Sublittoral	South-East	Ms to Cs
25	Pico	PIC_SU_SE_55	38.525070	-28.562736	-69	Sublittoral	South-East	Cs to G
26	Pico	PIC_SU_SE_56	38.496056	-28.219070	-65	Sublittoral	South-East	Cs to G
27	Faial	FAI_BE_SE_16	38.524935	-28.627281	0	Beach	South-East	Fs
28	Faial	FAI_SU_SE_46	38.573567	-28.596550	-30	Sublittoral	South-East	Fs to Ms
29	Faial	FAI_SU_SE_40	38.524197	-28.627624	-10	Sublittoral	South-East	Fs
30	Faial	FAI_SU_SE_41	38.560117	-28.765517	-30	Sublittoral	South-East	Cs
31	Faial	FAI_SU_SE_54	38.556800	-28.596533	-30	Sublittoral	South-East	Fs to Ms
32	Faial	FAI_SU_SE_43	38.658437	-28.712081	-85	Sublittoral	South-East	Ms
33	Graciosa	GRA_BE_S_22	39.013531	-27.953134	0	Beach	South	Ms
34	Graciosa	GRA_TP_S_52	39.012523	-27.958853	-1	Tidal pool	South	Fs to Ms with Ag

35	Graciosa	GRA_TP_S_12	39.012523	-27.958853	-1	Tidal pool	South	Fs to Ms with Ag
36	Graciosa	GRA_TP_S_51	39.012523	-27.958853	-1	Tidal pool	South	Fs to Ms with Ag
37	Flores	FLO_SU_E_2	39.462919	-31.127994	-20	Sublittoral	East	Fs to Ms with Ag
38	Flores	FLO_TP_E_48	39.461643	-31.118602	-3	Tidal pool	East	Fs
39	São Miguel	SMG_TP_SW_64	37.893415	-25.825939	-1	Tidal pool	SouthWest	Ag
40	São Miguel	SMG_TP_SW_85	37.795745	-25.795512	-19	Sublittoral	South	Ms with Sp
41	São Miguel	SMG_TP_SW_86	37.849103	-25.685005	-7	Sublittoral	South	Ms with Sp
42	São Miguel	SMG_TP_SW_87	37.836903	-25.664405	-10	Sublittoral	North	Ms with Sp
43	São Miguel	SMG_TP_SW_88	37.842054	-25.480728	-7	Sublittoral	North	Ms with Sp
44	São Miguel	SMG_TP_SW_89	37.707412	-25.508177	-4	Sublittoral	South	Ms with Sp
45	São Miguel	SMG_TP_SW_90	37.750036	-25.629902	-11	Sublittoral	South	Ms with Sp

Fs: Fine sand; **Ms:** Medium sand; **Cs:** Coarse sand; **G:** Granule; **Ag:** Algae; **Sp:** Sponge (sedimentological grain-size by Wentworth, 1922).

Table 3. Occurrences of Autochthonous Ostracods and Associated faunal (include allochthonous ostracods) examined in this study. The classification of the environmental energy for each sample was done using two different methods: 1) the analysis of the instars (population structure), based on Whatley (1988); and 2) the classification according to the direct sediment analysis of the grain-size (fine-sand: low energy; medium sand: medium energy; coarse sand and granule: high energy) (cf. Fig. 7).

Nº	Autochthonous Ostracods	Associated Faunal	Environmental Energy (ostracods' instars; Whatley, 1988)	Environmental Energy (sediment grain-size)
1	----	*Loxoconcha rhomboidea* (1 valve), *Carinocythereis whitei* (1 valve). Foraminifera and Bryozoa fragments).	High energy	----
2	----	*Urocythereis britannica* (1 valve). Bryozoa fragments.	High energy	----
3	----	?*Xestoleberis rubens* (1 carapace). Foraminifera.	High energy	----
4	*Loxoconcha rhomboidea*, *Loxoconcha cf. ochlockoneensis*, *Xestoleberis rubens*, *Xestoleberis* cf. *depressa.*	*Neonesidea schulzi* (1 carapace and 6 valves), *Semicytherura* sp. (1 valve), *Heterocythereis albomaculata* (1 valve), *Callistocythere* sp. (1 valve). Foraminifera and Bryozoa fragments (genus *Crisia* and *Scrupocellaria*).	Low energy	Medium energy
5	*Xestoleberis rubens*, *Loxoconcha rhomboidea*, *Lanceostoma* sp.	----	High energy	Medium energy

6	*Loxoconcha rhomboidea*, *Loxoconcha cf. ochlockoneensis*, *Xestoleberis rubens*, *Lanceostoma* sp., *Neonesidea schulzi.*	*Xestoleberis* cf. *depressa* (3 carapaces and 1 valve), *Aurila convexa* (4 valves), *Lanceostoma* sp. (2 valves), *Semicytherura* sp. (1 valve). Foraminifera, Echinoidea and Bryozoa fragments (genus: *Crisia*, *Scrupocellaria*, *Celleporina*, *Schizomavella*).	High energy	High energy
7	*Neonesidea schulzi*, *Loxoconcha rhomboidea*, *Heterocythereis albomaculata.*	*Aurila woutersi* (1 carapace and 2 valves), *Urocythereis britannica* (3 carapaces). Foraminifera and Bryozoa fragments (genus *Crisia*, *Scrupocellaria*, *Disporella*).	Medium energy	Medium energy
8	*Carinocythereis whitei*, *Loxoconcha rhomboidea*, *Aurila woutersi*, *Neonesidea schulzi*, *Heterocythereis albomaculata*, *Urocythereis britannica*.	Foraminifera and Bryozoa fragments (genus *Crisia*, *Scrupocellaria*).	Medium energy	High energy
9	*Neonesidea schulzi.*	*Loxoconcha rhomboidea* (5 valves), *Aurila convexa* (2 carapaces), *Urocythereis britannica* (1 valve). Foraminifera and Bryozoa fragments (genus: *Crisia*, *Scrupocellaria*, family: Tubuliporidae).	Medium energy	Medium energy
10	*Neonesidea schulzi*, *Loxoconcha rhomboidea*, *Xestoleberis rubens*, *Aurila woutersi*, *Heterocythereis albomaculata.*	*Urocythereis britannica* (4 valves), *Xestoleberis* cf. *depressa* (3 carapaces and 1 valve). Foraminifera and Bryozoa fragments (genus *Crisia* and *Scrupocellaria*).	Low energy	Low energy
11	----	*Leptocythere pellucida* (2 valves), *Callistocythere* sp. (1 carapace). Foraminifera, Echinoidea and Bryozoa fragments.	High energy	----
12	*Carinocythereis whitei*, *Loxoconcha rhomboidea*, *Aurila woutersi*, *Neonesidea schulzi.*	*Xestoleberis rubens* (6 valves), *Urocythereis britannica* (4 valves),. *Leptocythere pellucida* (3 valves), *Heterocythereis albomaculata* (1 carapace and 6 valves), *Carinocythereis whitei* (1 valva).	High energy	Medium energy

		Foraminifera and Bryozoa fragments (genus *Crisia*, *Scrupocellaria*).		
13	----	*Heterocythereis albomaculata* (1 carapace and 2 valves). *Loxoconcha rhomboidea* (1 valve), *Aurila woutersi* (1 valve). Bryozoa fragments (genus *Crisia*, and family*:* Tubuliporidae).	High energy	----
14	*Heterocythereis albomaculata, Xestoleberis rubens, Loxoconcha rhomboidea, Neonesidea schulzi, Semicytherura* sp., *Lanceostoma* sp., *Aurila convexa, Callistocythere* sp., *Carinocythereis whitei, Leptocythere pellucida.*	----	Low energy	Medium energy
15	*Heterocythereis albomaculata, Lanceostoma* sp., *Loxoconcha rhomboidea, Xestoleberis rubens, Semicytherura* sp., *Neonesidea schulzi, Aurila convexa.*	----	Low energy	Low energy
16	*Heterocythereis albomaculata, Neonesidea schulzi, Loxoconcha rhomboidea, Xestoleberis rubens, Loxoconcha cf. ochlockoneensis*, *Urocythereis britannica, Lanceostoma* sp., *Callistocythere* sp.	----	Low energy	Medium energy
17	*Loxoconcha rhomboidea, Xestoleberis rubens, Callistocythere* sp., *Lanceostoma* sp., *Aurila convexa, Heterocythereis albomaculata, Neonesidea schulzi, Loxoconcha cf. ochlockoneensis.*	----	Medium energy	Medium energy
18	*Xestoleberis rubens, Loxoconcha rhomboidea.*	*Aurila convexa* (5 valves), *Semicytherura* sp. (2 valves).	High energy	Medium energy

19	*Loxoconcha rhomboidea*, *Neonesidea schulzi, Aurila convexa*, *Aurila woutersi*, *Heterocythereis albomaculata*, *Urocythereis britannica*, *Xestoleberis rubens.*	*Aurila prasina* (8 valves), *Carinocythereis whitei* (1 carapace), *Xestoleberis* sp. (1 carapace). Bryozoa fragments (genus *Crisia*, *Scrupocellaria*).	Low energy	Medium energy
20	*Heterocythereis albomaculata*, *Callistocythere* sp., *Loxoconcha cf. ochlockoneensis, Neonesidea schulzi.*	*Xestoleberis rubens* (3 valves), *Xestoleberis* cf. *depressa* (3 carapaces and 1 valve), *Loxoconcha rhomboidea* (2 valves), *Aurila convexa* (4 valves), *Cyprideis torosa* (1 carapace and 3 valves), *Urocythereis britannica* (1 carapace and 1 valve), *Aurila woutersi* (1 valve), *Callistocythere* sp. (1 valve), *Xestoleberis* sp. (1 valve). Foraminifera, Echinoidea and Bryozoa fragments (genus *Crisia*, *Scrupocellaria*).	Low energy	Medium energy
21	*Loxoconcha rhomboidea*, *Loxoconcha cf. ochlockoneensis*, *Xestoleberis rubens*, *Xestoleberis* cf. *depressa*, *Aurila convexa*, *Neonesidea schulzi*, *Callistocythere* sp.	*Aurila woutersi* (1 valve), *Lanceostoma* sp. (4 valves). Foraminifera and Bryozoa fragments (genus *Crisia*, *Scrupocellaria*).	Medium energy	High energy
22	*Loxoconcha cf. ochlockoneensis*, *Xestoleberis rubens*, *Xestoleberis* cf. *depressa* e *Urocythereis britannica.*	*Neonesidea schulzi* (1 carapace and 1 valve), *Callistocythere* sp. (1 carapace and 1 valve) and *Semicytherura* sp. (1 valve). Foraminifera and Bryozoa fragments (genus *Crisia* and family*:* Tubuliporidae).	Low energy	Medium energy
23	*Neonesidea schulzi*, *Aurila convexa.*	*Loxoconcha rhomboidea* (2 carapaces and 2 valves), *Urocythereis britannica* (1 carapace and 2 valves). Foraminifera and Bryozoa fragments (genus *Crisia*, *Scrupocellaria* and family*:* Tubuliporidae).	High energy	High energy

24	*Neonesidea schulzi, Loxoconcha rhomboidea, Xestoleberis rubens, Aurila convexa.*	*Heterocythereis albomaculata* (7 valves), *Urocythereis britannica* (2 valves), *Carinocythereis whitei* (2 valves), *Loxoconcha cf. ochlockoneensis* (4 valves), *Lanceostoma* sp. (2 valves), *Callistocythere* sp. (1 carapace). Foraminifera, Echinoids and Bryozoa fragments (genus *Crisia, Schizomavella* and family*:* Tubuliporidae).	High energy	High energy
25	*Urocythereis britannica, Neonesidea schulzi.*	*Aurila convexa* (2 carapaces and 1 valve), *Loxoconcha rhomboidea* (2 carapaces), *Heterocythereis albomaculata* (1 carapace and 1 valve). Foraminifera and Bryozoa fragments (genus *Crisia, Scrupocellaria, Reteporella, Disporella, Schizomavella* and family*:* Tubuliporidae).	High energy	High energy
26	----	*Loxoconcha rhomboidea* (2 valves). Foraminifera and Bryozoa fragments (genus *Crisia, Scrupocellaria*).	High energy	----
27	----	*Neonesidea schulzi* (1 valve), *Loxoconcha rhomboidea* (1 valve). Foraminifera and Bryozoa fragments (genus *Crisia*).	High energy	----
28	*Neonesidea schulzi, Urocythereis britannica, Loxoconcha rhomboidea.*	*Heterocythereis albomaculata* (1 carapace and 4 valves), *Aurila convexa* (1 carapace and 3 valves), *Carinocythereis whitei* (1 carapace), *Leptocythere pellucida* (1 carapace). Foraminifera, Echinoids and Bryozoa fragments (genus *Crisia, Scrupocellaria, Bugulla, Schizomavella* and family*:* Tubuliporidae).	Low energy	Medium energy

29	*Heterocythereis albomaculata, Loxoconcha rhomboidea.*	*Aurila convexa* (4 carapaces and 1 valve), *Leptocythere pellucida* (4 valves), *Xestoleberis rubens* (1 carapace and 3 valves), *Lanceostoma* sp. (2 valves), *Urocythereis britannica* (2 valves), *Neonesidea schulzi* (1 valve), *Carinocythereis whitei* (1 valve). Foraminifera, Mollusca and Bryozoa fragments (genus: *Crisia, Scrupocellaria, Bugulla).*	Low energy	Low energy
30	----	*Neonesidea schulzi* (1 carapace and 7 valves), *Aurila convexa* (1 carapace), *Heterocythereis albomaculata* (2 valves), *Urocythereis britannica* (3 carapaces and 2 valves). Foraminifera and Bryozoa fragments (genus *Crisia, Scrupocellaria* and family*:* Tubuliporidae).	High energy	----
31	*Neonesidea schulzi, Loxoconcha rhomboidea, Aurila convexa, Heterocythereis albomaculata.*	*Urocythereis britannica* (2 carapaces and 5 valves), *Carinocythereis whitei* (1 carapace). Foraminifera and Bryozoa fragments (genus *Crisia, Scrupocellaria, Reteporella* and family*:* Tubuliporidae).	Low energy	Low energy
32	*Neonesidea schulzi, Urocythereis britannica*.	*Aurila convexa* (3 carapaces), *Leptocythere pellucida* (1 carapace). Foraminifera and Bryozoa fragments (genus *Crisia, Scrupocellaria, Disporella, Schizomavella* and family*:* Tubuliporidae).	High energy	Medium energy
33	----	*Neonesidea schulzi* (1 carapace and 2 valves), *Loxoconcha rhomboidea* (2 carapaces and 1 valve). Foraminifera and Bryozoa fragments (genus *Crisia, Scrupocellaria* and *Celleporina*).	High energy	----

34	----	*Xestoleberis rubens* (4 carapaces). Bryozoa fragments (genus *Crisia*, *Bugulla*).	High energy	----
35	*Loxoconcha rhomboidea*; *Heterocythereis albomaculata*; Lanceostoma sp.; *Xestoleberis rubens.*	*Loxoconcha cf. ochlockoneensis* (4 valves); *Xestoleberis* cf. *depressa* (3 carapaces); *Neonesidea schulzi* (1 valve); *Aurila convexa* (1 valve). Foraminifera and Bryozoa fragments (genus *Crisia, Scrupocellaria* and *Schizomavella*).	Medium energy	Low energy
36	----	*Xestoleberis rubens* (3 carapaces and 2 valves). Foraminifera and Bryozoa fragments (genus *Crisia*, *Scrupocellaria*, *Bugulla*, *Schizomavella* and family: Tubuliporidae).	High energy	----
37	*Loxoconcha rhomboidea*; *Loxoconcha cf. ochlockoneensis*; *Xestoleberis rubens*.	Foraminifera and Bryozoa fragments (genus: *Crisia, Scrupocellaria;* family: Tubuliporidae).	Medium energy	Low energy
38	----	*Loxoconcha rhomboidea* (4 valves); *Neonesidea schulzi* (1 valve); *Aurila convexa* (1 valve). Bryozoa fragments (genus *Crisia, Scrupocellaria, Bugulla* and family: Tubuliporidae).	High energy	----
39	*Loxoconcha rhomboidea*; *Loxoconcha cf. ochlockoneensis*; *Xestoleberis rubens*; *Semicytherura* sp.; *Lanceostoma* sp.	----	Low energy	Low energy
40	*Loxoconcha rhomboidea*; *Xestoleberis rubens*.	Sponge	High energy	Medium energy
41	*Loxoconcha rhomboidea; Neonesidea schulzi; Xestoleberis rubens; Heterocythereis albomaculata.*	Sponge	High energy	Medium energy

42	*Loxoconcha rhomboidea; Neonesidea schulzi; Xestoleberis rubens.*	Sponge	High energy	Medium energy
43	*Loxoconcha rhomboidea; Xestoleberis rubens; Heterocythereis albomaculata.*	Sponge	High energy	Medium energy
44	*Loxoconcha rhomboidea; Xestoleberis rubens; Heterocythereis albomaculata; Aurila convexa.*	Sponge	Medium energy	Medium energy
45	*Loxoconcha rhomboidea; Neonesidea schulzi; Xestoleberis rubens.*	Sponge	High energy	Medium energy

Appendix A. Autochthonous Ostracods examined in this study.

Class Ostracoda Latreille, 1802
Order Podocopida Müller, 1894
Family Loxoconchidae Sars, 1925
    Genus *Loxoconcha* Sars, 1866
        Loxoconcha rhomboidea (Fischer, 1855)
        Loxoconcha cf. *ochlockoneensis* Puri, 1960
Family Bairdiidae Sars, 1888
    Genus *Neonesidea* Maddocks, 1969
        Neonesidea schulzi (Hartmann, 1964)
Family Xestoleberididae Sars, 1928
    Genus *Xestoleberis* Sars, 1866
        Xestoleberis rubens Whittaker, 1978
        Xestoleberis cf. *depressa* Sars, 1866
Family Hemicytheridae Puri, 1953
    Genus *Aurila* Porkorný, 1955
        Aurila convexa (Baird, 1850)
        Aurila woutersi Horne, 1986
    Genus *Urocythereis* Ruggieri, 1950
        Urocythereis britannica Athersuch, 1971
    Genus *Heterocythereis* Elofson, 1941
        Heterocythereis albomaculata (Baird, 1838)
Family Trachyleberididae Sylvester-Bradley, 1948
    Genus *Carinocythereis* Ruggieri, 1956
        Carinocythereis whitei (Baird, 1850)
Family Leptocytheridae Hanai, 1957
    Genus *Callistocythere* Ruggieri, 1953
        Callistocythere sp.
    Genus *Leptocythere* Sars, 1922
        Leptocythere pellucida (Baird, 1850)
    Genus *Semicytherura* Wagner, 1957
        Semicytherura sp.
Family Paradoxostomatidae Brady & Norman, 1889

Genus *Lanceostoma* Schornikov & Keyser, 2004

Lanceostoma sp.

Order Myodocopida Sars, 1866

Family Cylindroleberididae Müller, 1906

Genus *Cylindroleberis* Brady, 1867

Cylindroleberis sp.

CHAPTER 7

DEPOSITIONAL PROCESSES ON OCEANIC ISLAND SHELVES – EVIDENCE FROM STORM-GENERATED NEOGENE DEPOSITS FROM THE MID-NORTH ATLANTIC

Ricardo P. Meireles; Rui Quartau; Ricardo S. Ramalho; Ana C. Rebelo; José Madeira; Vittorio Zanon; Sérgio P. Ávila

MEIRELES, R.P.; QUARTAU, R.; RAMALHO, R.; MADEIRA, J.; REBELO, A.C.; ZANON, V. & ÁVILA, S.P., 2013. Depositional processes on oceanic island shelves – evidence from storm-generated Neogene deposits from the mid-North Atlantic. *Sedimentology* (Impact Factor 2011 = 2.295) (in press).

ABSTRACT

Oceanic islands - such as the Azores in the mid-North Atlantic - are periodically exposed to large storms that often remobilize and transport marine sediments along coastlines, and into deeper environments. Such disruptive events create deposits - denominated tempestites - whose characteristics reflect the highly dynamic environment in which they were formed. Tempestites from oceanic islands, however, are seldom described in the literature and little is known about storm-related sediment dynamics affecting oceanic island shelves. Therefore, the geological record of tempestite deposits at oceanic islands can provide invaluable information on the processes of sediment remobilization, transport and deposition taking place on insular shelves during and after major storms. In Santa Maria Island (Azores), a sequence of Neogene tempestite deposits was incorporated in the island edifice by the on-going volcanic activity (thus preserved) and later exposed through uplift and erosion. Since it was overlain by a contemporary coastal lava delta, the water depth at the time of deposition could be inferred, constituting an excellent case-study to gain insight on the still enigmatic processes of insular shelf deposition. Sedimentological, palaeontological, petrographic and palaeo-water depth information, allowed the reconstruction of the depositional environment of these sediments. The sequence typifies the characteristics of a tempestite (or successive tempestites) formed at ~50 m depth, in a steep, energetic open insular shelf, and with evidence for massive sediment remobilization from the nearshore to the middle or outer shelf. We claim that cross-shelf transport induced by storm events is the main process of sediment deposition acting on steep and narrow shelves subjected to high energetic environments such as the insular shelves of open-sea volcanic islands.

Keywords Tempestite; storm-induced flows; sediment transport; insular shelf; depositional model; palaeo-water depth.

INTRODUCTION

Oceanic islands are, by nature, exposed to open sea conditions and thus affected by severe coastal erosion. Their coasts are continually being cut back by the sea, producing large amounts of sediments, but clastic depositional coasts are rarely seen on these islands. There is also a clear lack of knowledge concerning sedimentation processes on rocky shoreline environments such as those of volcanic islands (Felton, 2002). The few published studies are restricted to nearshore settings in mixed siliciclastic-carbonate systems (Schneidermann *et al*., 1976; Morelock *et al*., 1983; Schwab *et al*., 1996; Harney *et al*., 2000; Calhoun *et al*., 2002; Harney & Fletcher, 2003; Ogston *et al*., 2004; Storlazzi *et al*., 2004; Conger *et al*., 2009; Ryan-Mishkin *et al*., 2009). Unfortunately, these studies focused mainly on sediment characterization rather than on processes of deposition. Based on their observations, Tsutsui *et al*. (1987), Chiocci and Romagnoli (2004) and Quartau *et al*. (2012) suggested that bottom downwelling currents, generated during storms, transport nearshore sediments perpendicular to the coast onto the shelf and slope environments, building sandy deposits offshore. However, this model is controversial because, although the geological record of storm deposits confirms this hypothesis, modern oceanographers find it difficult to explain how purely unidirectional flows can cross the entire shelf. Therefore, models of tempestite deposition are still under debate, with scientists describing density induced flows, wave oscillation flows, geostrophic currents and combinations between these three (Myrow & Southard, 1996; Myrow, 2005) as possible transport processes. Thus, the key to understand the mechanisms behind island shelf sedimentation is to look back into the geological record as we did in this study.

The Azores Archipelago – located in the mid-North Atlantic –is often struck by violent storms (Borges, 2003; Andrade *et al*., 2008) associated with remarkable wave energy (Quartau *et al*., 2012; Rusu & Guedes Soares, 2012). This archipelago is a group of very young oceanic islands, featuring youthful volcanic landforms that are generally devoid of exposed marine volcanic and sedimentary sequences. The easternmost island of Santa Maria, however, is an exception to this scenario. The island is much older than the remaining – having emerged during the Late Miocene (Abdel Monem *et al*., 1968, 1975; Féraud *et al*., 1980, 1981) – and is rich in Neogene submarine volcanic sequences and fossiliferous marine sediments, due to a combination of coastal erosion and uplift during the Plio-Quaternary (Serralheiro *et al*., 1987; Serralheiro & Madeira, 1990; Serralheiro, 2003; Ávila *et al*. 2012). Santa Maria is, thus, a prime locality to study tempestite deposits allowing insight into sediment dynamics taking place on exposed oceanic island shelves. In this work we focused on the sedimentary outcrops at Ponta do Castelo, in SE Santa Maria, because the overlying volcanic sequence – a lava delta – allow us to accurately infer the palaeo-water depth for the top of the sedimentary package. A comprehensive characterization of the outcrop from volcanostratigraphic, sedimentological, palaeontological and petrographical points of view allowed us to reconstruct the palaeo-environment of deposition. In this work, we provide supporting evidence that storm-induced downwelling currents have transported sediments from the nearshore to deeper offshore environments. We further suggest that this is the main process of deposition on steep, narrow and high-energetic shelves, such as those found on oceanic islands.

Geological setting

The Azores archipelago is a group of nine islands located in the North Atlantic (25° – 32° W; 37° - 40° N), in a complex tectonic setting. Two of the Azorean islands - Flores and Corvo - rise from the western flank of the mid-Atlantic Ridge, whilst the remaining seven islands - including Santa Maria – are located to the east of this feature along the western segment of the Eurasia-Nubia boundary (Fig. 1A).

Santa Maria is the easternmost island of the Archipelago and was, supposedly, the first to have emerged during the Late Miocene, sometime before 8.1 Ma (Abdel-Monem *et al*., 1975; Serralheiro & Madeira, 1990; Serralheiro, 2003). The general volcanostratigraphic sequence of Santa Maria, as defined by Serralheiro et al. (1987), basically reflects (see Serralheiro & Madeira, 1990; Serralheiro, 2003; Ávila *et al.* 2012): 1) the emergence of a volcanic edifice during the Late Miocene (Cabrestantes and Porto Formations); 2) the construction of a basaltic shield volcano during the Late Miocene (Anjos Complex); 3) subsequent erosion and probable total immersion of the shield volcano, sedimentation of marine and terrestrial sediments, with synchronous submarine volcanic activity on the eastern side of the island, during the Late Miocene/Early Pliocene (Touril Complex); 4) increase in volcanic activity – initially exclusively submarine and later subaerial with the formation of lava deltas along coeval coastlines – and re-emergence of the edifice during the Early Pliocene (Facho - Pico Alto Complex); 5) erosion followed by low volume volcanic activity, forming a set of monogenetic magmatic and hydromagmatic cones, during the Late Pliocene (Feteiras Formation); uplift and erosion of the edifice from Late Pliocene to the present.

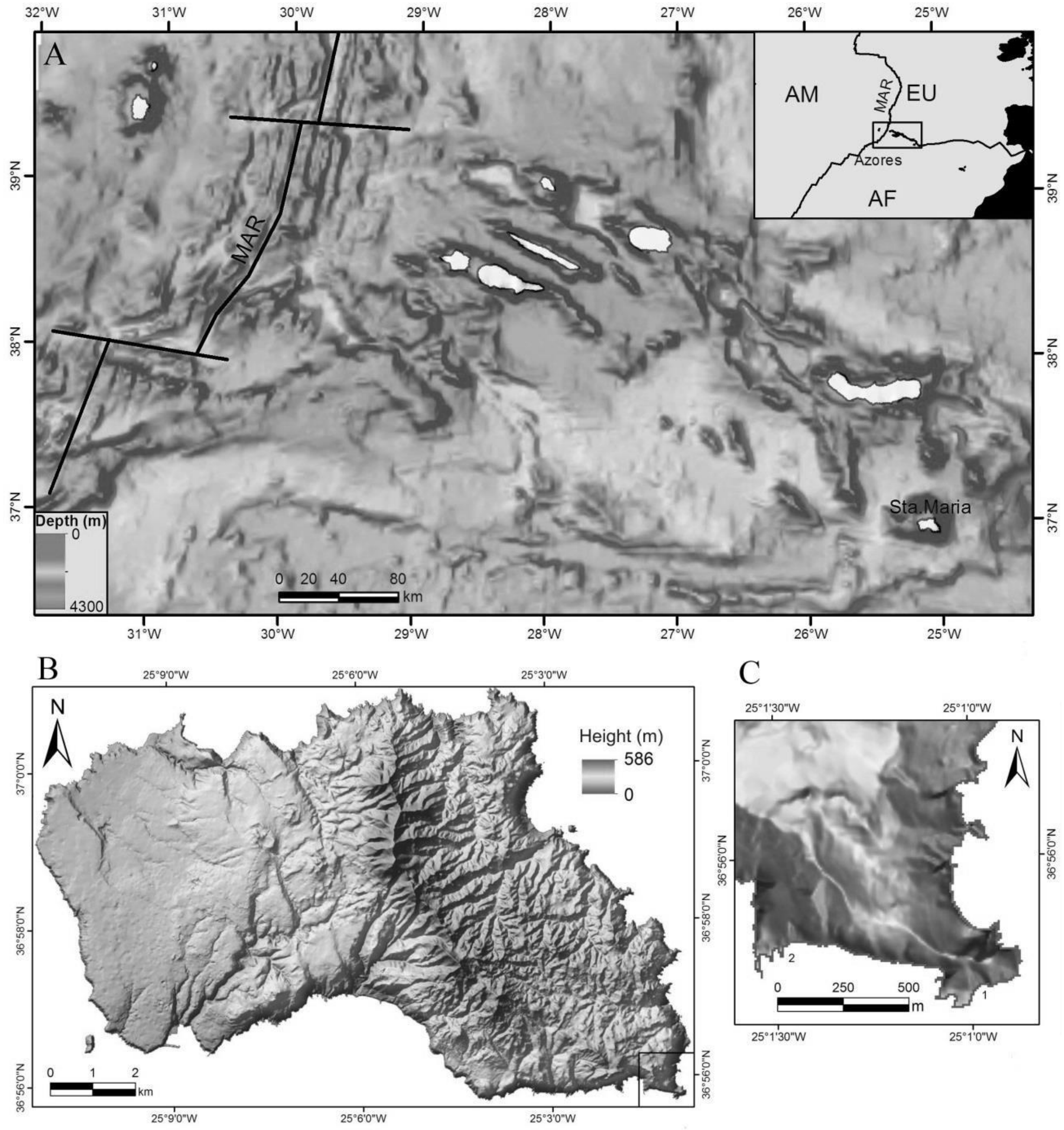


Figure 1. Location maps: (A) of Santa Maria, within the Azores Archipelago, MAR – Mid-Atlantic Ridge, AM – American Plate, EU- European Plate, AF – African Plate; (B) of Ponta do Castelo on south-east Santa Maria ('1' Rocha Alta); (C) detailed image of the outcrop area (‘1′ Ponta do Castelo; ‘2′ Pedra-que-pica).

Ponta do Castelo is a tall prominent headland forming the southeasternmost tip of the island (see Figs 1B and 1C). In this place the sequence comprises (Fig. 2), from the base to the top: a) fossiliferous marine sediments with high volcaniclastic content; b) a typical lava delta sequence constituted by a steeply dipping foreset unit of basaltic pillow-lavas and hyaloclastites, and a topset unit of flat-lying subaerial lava flows; and c) basaltic pillow-lavas (where the lighthouse stands), part of another lava delta sequence stacked on top of the first and whose topset unit has been locally removed by erosion. The foresets of pillow-lavas and hyaloclastites of the main lava delta sequence dip 25° - 35° to the E, suggesting a coeval coastal progradation to this direction, under moderate extrusion rates, and over a shelf where the sediments rested. The continuous exposure along the coast towards the W shows that the sediments at Ponta do Castelo partially correspond to the remobilization of tuffs and water-settled tuffites from the surtseyan cone whose remains can still be seen farther west at Rocha Alta. The overall sequence is attributed to the Facho – Pico Alto Complex to which an Early Pliocene age was suggested (Serralheiro *et al*., 1987). Effectively, the underlying sediments at Pedra-que-Pica (a nearby sedimentary outcrop 800 m to the west; see Fig. 1C) yielded an isotopic age around 5.5 Ma (Kirby *et al*. 2007), thus supporting this age estimate.

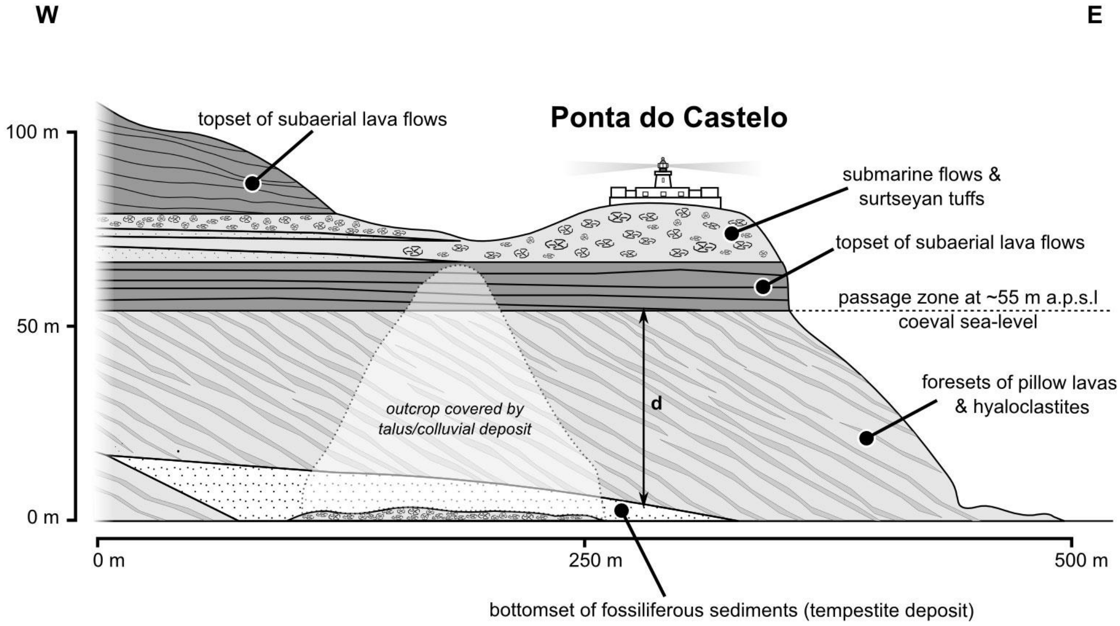


Figure 2. General cross-section of Ponta do Castelo volcano-sedimentary sequence, showing the volcanostratigraphic setting of the basal sedimentary sequence (tempestite deposit), and location of the passage zone between subaerial and submarine flows (representing coeval sea-level) within the overlying lava delta sequence; d represents the contemporaneous palaeo-water depth for the top of the sediments, as inferred from the overlying lava delta structure; apsl = above present sea-level.

METHODS

Sedimentological and palaeontological characterization

The outcrop at Ponta do Castelo was studied in detail to reconstruct the overall structure, geometry and field relationships between the sedimentary deposit and the underlying/overlying volcanic sequences. Two cross-sections were made along the south side of Ponta do Castelo: a general section of the sequence (Fig. 2); and a detailed composite section (Fig. 3) showing the arrangement, internal structures and erosional contacts of the tempestite deposit. Strip logs for stratigraphic sections (Fig. 4) represent the variability and facies succession found at this outcrop. Special care was taken to record the geometry and dimensions of the observed sedimentary structures, the lateral and vertical continuity of facies, and the position and taphonomical aspects of the fossil content. Macrofossil content was verified *in situ*, carefully recorded and classified to the genus and species level, whenever possible. Thin sections, representative of the main subunits within the deposit were studied under polarizing microscopy to infer structures, micro-textures, mineralogy and microfossil content. All fossil specimens collected in this work are housed in the Fossil Collection of the Department of Biology of the University of Azores (DBUA-F).

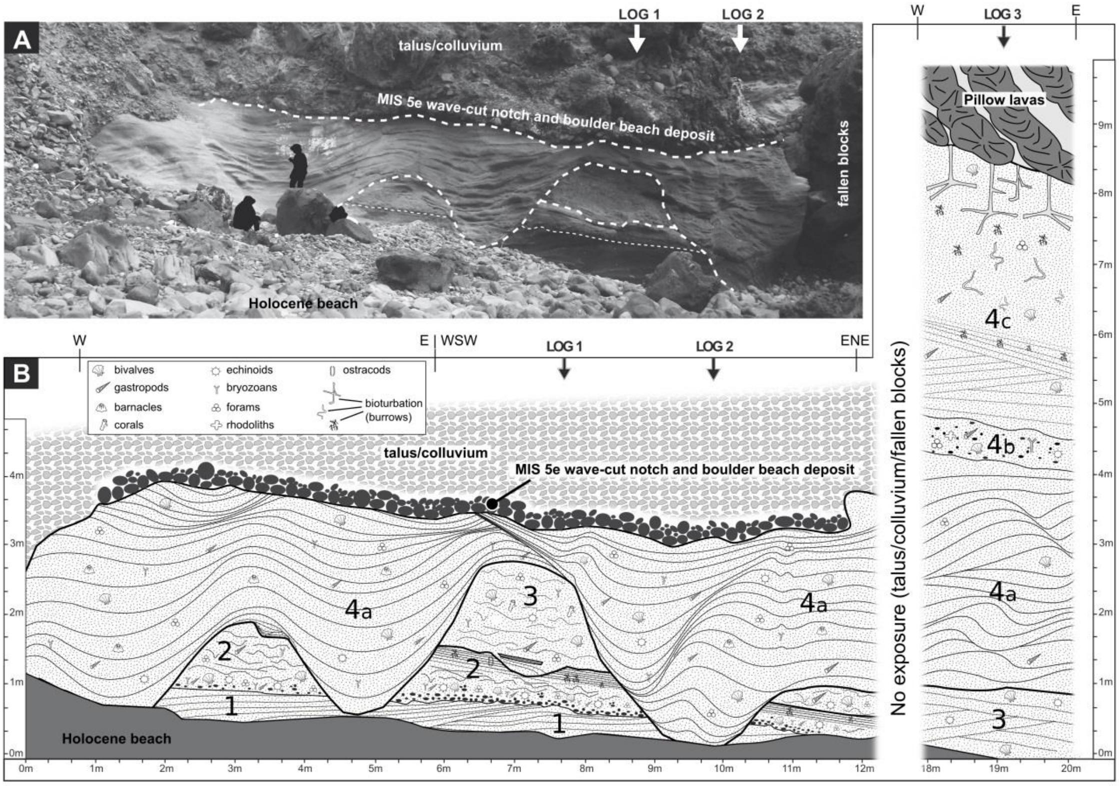


Figure 3. Sedimentary/tempestite deposit at Ponta do Castelo, SE Santa Maria. (A) Photograph of the main outcrop (western portion of the outcrop), with people for scale (ca 1 8 m tall), and main erosional contacts marked as dashed lines. Location of strip logs are labelled in the picture; Log 3 was performed to the E of this picture, behind the fallen boulders. (B) Simplified cross-section of the studied sediments, representing main lithologies, sedimentary structures, contacts, fossiliferous content and the location of strip logs. Main erosional unconformities are represented by thicker solid black lines and numbering corresponds to the described depositional units.

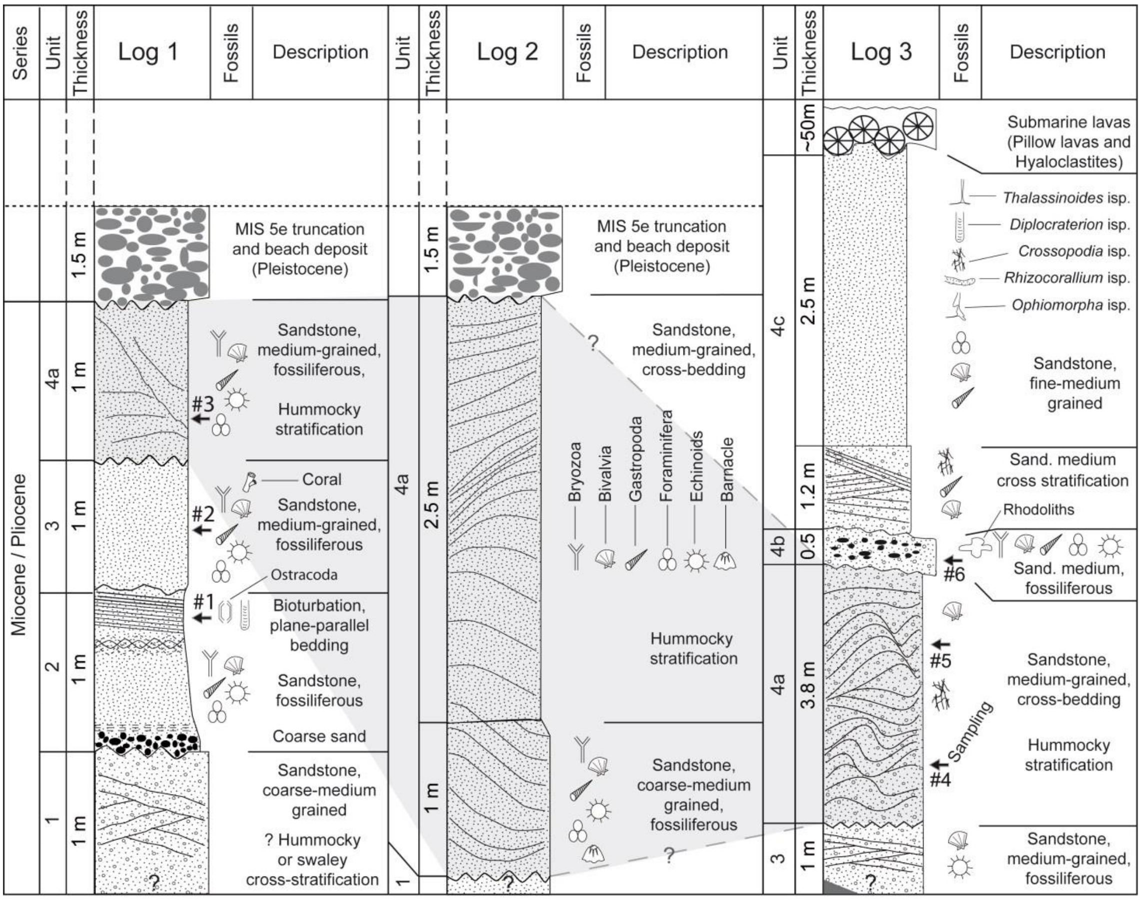


Figure 4. Strip logs along the locations identified in Fig. 3. Labels #1,2,6 represent sampling location for thin sections, of which pictures of the 4 most representative lithologies are shown in Fig. 6.

Palaeo-water depth estimations using the volcanic structure

Coastal lava deltas constitute excellent sea-level tracers because the passage zone between the topset unit (composed by flat-lying subaerial lava flows) and the foreset unit (composed by prograding foresets of submarine lavas) marks very accurately the position of coeval relative sea-level (Jones & Nelson, 1970; Porebski & Gradzinski, 1990; Smellie, 2000; Immenhauser, 2009; Ramalho 2011). Therefore, the vertical distance between the base of a foreset and the passage zone at its top can be used to estimate very accurately the water depth at the time of extrusion (see Fig. 2). If pillow-lavas from the foreset unit cast load marks on the underlying sediments, it means that these sediments were still soft when they were covered by the effusive sequence. Thus, one can reasonably assume that the palaeo-water depth inferred for the base of the volcanic sequence corresponds to the water depth contemporaneous to the top of the underlying sediments. Furthermore, if sedimentation rates were high and sea-level did not change during deposition, palaeo-water depth information may be transposed into the sediments below. In this study, vertical distances were measured with an Impulse 200LR laser distance meter produced by Laser Technologies, Inc. (LTI), with a range up to 500 m.

4. RESULTS

The studied sequence is outstanding for its characteristics, even within the island context. Some of its most striking features are the mega-ripples (hummocks) that can be seen in the basal sediments and the very clear lava delta structure overlying the sediments (see Figs 2, 3, 4 and 5). The outcrops are partially truncated by a Late Pleistocene shore platform, beach and former cliff, with an age that probably corresponds to the last interglacial (Marine Isotopic Stage 5e, ~115-135 ka) (Ávila *et al.*, 2008); these were later covered by slope deposits (constituting the talus/colluvial fan where the former whaling station is located). The geometry of the sedimentary body seems to be sigmoidal or wedge-like, with the top dipping about 15° to the ENE and located at a maximum elevation of ~9 m above present sea-level (apsl). The base of the sequence is buried by the modern beach; however, nearby outcrops of underlying lavas and the sequence’s geometry suggests it is not far from the surface. The overlying lava delta exhibits a passage zone at ~55 m apsl, suggesting a palaeo-water depth of 45-55 m for this deposit (*d* in Fig. 2).

The sedimentary sequence is entirely composed of fossiliferous sandstones that resulted from the remobilization of hydromagmatic tuffs. Grain composition is, hence, dominated by angular or poorly-rounded, glassy, non-vesicular and palagonitized volcanic clasts (~58%), with a reduced amount of mineral clasts (olivine, pyroxene, plagioclase, tiny cubic oxides, and calcite), fossil shell fragments (amounting to ~20% and comprising gastropods, bivalves, rhodoliths, echinoids, bryozoans, corals, and balanids), and microfossils (foraminifera and ostracoda), all cemented by calcite (sparite) – see Fig. 6. However, despite the homogeneous lithology, the deposit shows large lateral and vertical variations in the sedimentary structure.

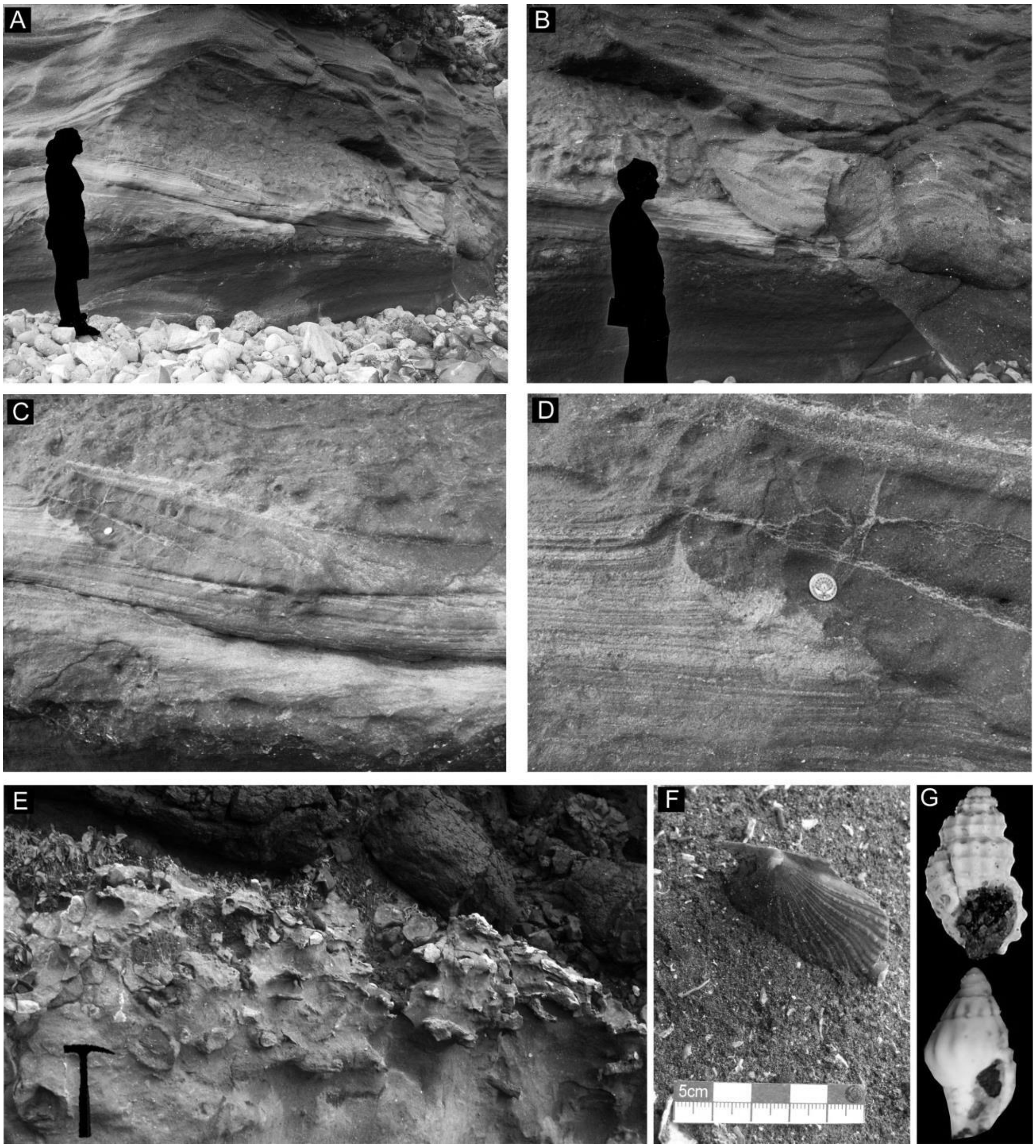


Figure 5. Photographs of detailed aspects of the outcrop, fossils and existing sedimentary structures. **A** – view of the outcrop, showing the erosional unconformity between unit 4a and an underlying crest comprising units 1, 2 and 3. Location of strip log 1; **B** – detail of the erosional contact between the massive tempestite unit 4a (exhibiting preserved swales and hummocks) and the underlying sequence comprising units 1, 2 and 3. Location of strip log 2; **C** – detail of the erosional unconformity between unit 2 and 3, showing the palaeo-channel and large rip-up clast of unit 2 floating in unit 3; **D** – detail of one the sides of the palaeo-channel, showing flame and fluid escape structures of bioclastic-rich sediment of unit 2 onto unit 3. Side of rip-up clast is also visible in upper right section of photograph; **E** – contact between top of the sedimentary sequence and the overlying submarine lavas (pillow lavas and hyaloclastites); **F** – detail of imbrication of bivalvia shell in fossiliferous sandstone; G – examples of allochthonous fossil gastropods found at the outcrop: *Alvania sleursi* (top), *Anachis avaroides* (base) typical of shallow marine water conditions (common size 2-4 mm).

The exposed lower part of the sequence (henceforth called “unit 1”) is composed by coarse- to medium-grained sandstones up to 1 m thick, almost devoid of macrofossils, and showing a wide, large-scale cross stratification with centimetre- to decimetre-thick slightly wavy sets, forming low but wide swales and possibly hummocks (see Figs 3; 5A and 5B). There is some weak normal grading within individual beds. The base of the deposit is not exposed and the small extent of the outcrop precludes any solid large-scale geometric reconstruction. However, it is possible that the observed features are actually part of a larger hummocky or swaley cross-stratified structure. Petrographic investigation revealed it to be composed mainly of rounded to angular glassy shards with a few subrounded lava lithics. Loose mineral clasts and fossils are rare (Fig. 6A).

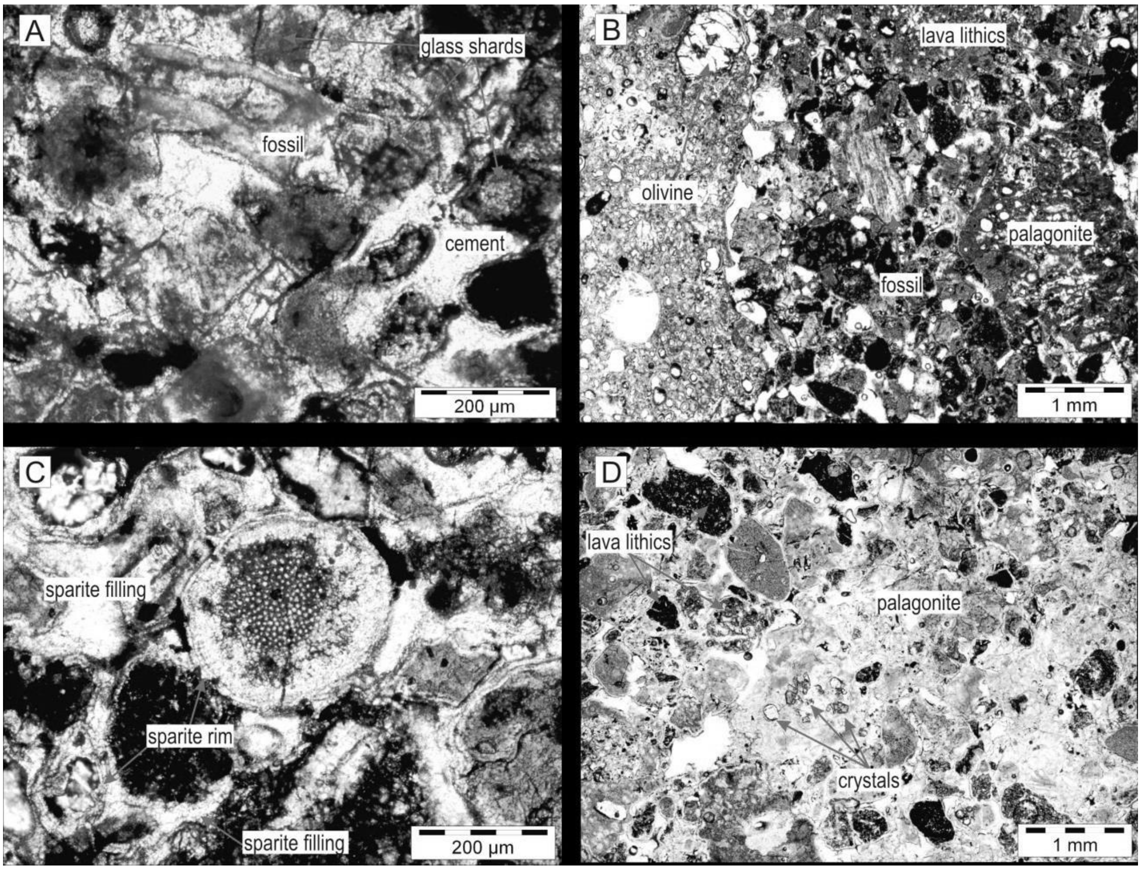


Figure 6. Photographs of thin sections, according to sample locations marked in Fig. 4. A – microphotograph showing the structure and lithological composition of a sample from the unit 1. Good sorting and a reduced amount of fossils and loose crystals characterize this sample; B – microphotograph of a medium-grained sandstone from unit 2. A sharp reduction in abundance of glassy shards and the presence of palagonite clasts are the main characteristics of this sample.; C – two kinds of sparite cement are well evident in this picture of a sample of unit 2; D – massive (unsorted) structure of a sandstone of unit 3. Palagonite clasts are present in large amounts.

Above the previous sediments, sits a wedge-shaped sedimentary package (henceforth called “unit 2”) that gradually loses thickness towards the ENE (i.e., from about 1.20 m to about 50 cm) and exhibits a pronounced vertical variation in sedimentary structures and in grain size (see Fig. 3). This unit is bounded by erosional unconformities: the lower unconformity is irregular, forming a centimetre- to decimetre-high palaeo-topography, while the upper unconformity is more regular and parallel to bedding, with the exception of a shallow but wide palaeo-channel (see Fig. 5C). Unit 2 gradually grades from micro-conglomerates/coarse sandstones at the base, into coarse- to medium-grained sandstones (Fig. 6B) with chaotic/diffuse bedding in the middle (both very rich in shell debris), then into medium- to fine-grained sandstones with plane-parallel bedding/lamination at the top, composed by alternating bioclastic-rich and volcaniclastic-rich laminae. Two species of ostracoda were found within bioclastic-rich laminae: *Pachycaudites* aff *armilla* Ciampo, 1986 and *Neonesidea rochae* Nascimento, 1989. Small-scale bioturbation (*Diplocraterion* isp.) interrupt the topmost beds/laminae. The mid subunit (with chaotic/diffuse bedding) increases in thickness towards the WSW and the upper subunit (with plane-parallel bedding/lamination) is absent towards this direction – probably removed by the subsequent erosion that created the upper unconformity. Thin-section observations show that constituents are somewhat different from those present in Unit 1. Glassy shards of volcanic origin are less abundant than the lava lithics, but very large (up to 0.5 cm across) palagonite clasts are present. Lithics are represented by small rounded vesicular and porphyritic pyroclasts. Loose mineral clasts and fossils are also more abundant. It is evident the presence of a first thin sparite rim around all clasts, and a second sparite cement filling all the pores, suggesting the occurrence of two events of cement deposition characterized by different levels of kinetic energy (Fig. 6C).

The following unit (henceforth called “unit 3”) comprises a medium-grained fossiliferous sandstone, poorly-sorted and with chaotic/diffuse bedding, and reaching up to 1.5 m in thickness (see Figs 3 and 4). It lies unconformably on the previous unit and infill the referred palaeo-channel; in one of the edges of this palaeo-channel, flame structures and tails of entrained sediment from the previous sequence and a large intraclast (rip-up clast) are present (see Figs 5C and 5D), suggesting strong erosion and rapid settling. In a similar fashion, remains of rock-encrusting bryozoan colonies that were ripped from their hard-substrate are found “floating” within the sandstones (Björn Berning, pers. comm.) - probably corresponding to *Ellisina* sp., *Onychocella* sp., *Hemicyclopora* sp. and *Reteporella* sp. - as well as remains of isolated corals. Fossils and shell debris are generally dispersed in random/chaotic positions. It is not possible to confidently match units observed along the western portion of the outcrop with its eastern portion (see Figs 3 and 4); however, it seems that the sediments at the base of Log 3 may be etheropic with the above-described unit. If that is the case, there is a lateral variation from chaotic/diffuse stratification in the western portion of the outcrop, to a faint cross-stratification towards the E. The petrographic analysis shows that the constituents are represented mostly by palagonite fragments and a reduced amount of lithics (small rounded vesicular pyroclasts and angular lava fragments), all randomly arranged and with a very heterogeneous grain size (Fig. 6D). The presence of two sparite cement types is also confirmed here.

The next event produced a profound erosive unconformity that cuts through all the previous units, forming an irregular palaeo-topography with abrupt troughs, up to 3-4 m deep and about as wide as they are deep (see Figs 3, 5A and 5B). This palaeo-topography was, in turn, filled by a 4-5 m thick unit (henceforth called "unit 4a") of fossiliferous, medium-grained sandstones exhibiting a distinctive metre-scale hummocky structure. This stratification is generally characterized by 1-3 m wide, 0.3-1.5 m high slightly asymmetric hummocks and swales that coarsely follow the underlying topography and exhibit onlapping contacts along the steep channel/trough sides; beds typically fan out from conformable almost-parallel fine beds, internal truncation surfaces are rare, and hummocks are almost ubiquitously preserved (see Figs 3 and 5B). The small extension of the outcrop and the lack of a proper 3D view unfortunately preclude the observation of a preferred dip direction in the third dimension, i.e. making it very difficult to verify if the existing stratification is isotropic or anisotropic. The sediments are generally poorly sorted, although some layers of slightly coarser grain size help defining the overall bedding structure, and typically stand in positive relief along the outcrop face as a result of differential erosion. Sediments tend to be coarser and richer in shell debris at the bottom of the troughs, or at the base of deeper swales. Gradually, towards the top, bedding becomes almost plane-parallel, with occasional smaller-scale ripples. In the western portion of the outcrop, the sedimentary sequence is incomplete since it was truncated atop by the later (MIS 5e) shore platform, located ~4.5 m apsl and contemporary of other known MIS 5e features found around the island and at similar elevations (Callapez & Soares, 2000; Ávila *et al.*, 2009). In the eastern side, however, the sequence is complete and the top can be observed, albeit the poor accessibility and a more intense weathering. Fossil content comprises allochthonous components of a shallow fauna. Specifically, the presence of extant microgastropods such as *Anachis avaroides* Nordsieck, 1975 and *Alvania sleursi* Amati, 1987 (living respectively at around 3-6 m and 10-20 m apsl, Ávila, 2003) (Fig. 5G), together with the shallow extinct balanid *Zullobalanus santamariaensis* and various sublittoral echinoids – e.g., spines and fragments of *Eucidaris tribuloides* (Lamarck, 1816), complete tests of *Echinoneus* cf. *cyclostomus* Leske, 1778 and *Echinocyamus pusillus* (Müller, 1776) (Madeira *et al*., 2011) - as well as rock-encrusting bryozoan colonies that were ripped from their rocky substrate at intertidal to subtidal levels, once again confirms the energetic removal and transport of sediment/organisms from shallow littoral zones to deeper settings. This is also supported by the presence of other fossil debris resulting from shored epipelagic species such as *Janthina typica* (Brönn, 1861) and typical littoral faunas (e.g. *Arca noae* Linnaeus, 1758, *Crassadoma multistriata* (Poli, 1795), *Gari depressa* (Pennant, 1777) [=*Psammobia aequilateralis*]) that can be found mixed within the sediment. Complete fossil organisms and shell fragments are generally dispersed within the sediment and in random/chaotic positions; in fact, shells are often found (single, disarticulated valves) in nearly vertical positions. The remainder part of the sequence is only seen in the eastern portion of the outcrop.

Above the previous sediments (only visible in log 3), and bounded by two faint erosive surfaces of minor importance, it follows a thin layer (about 0.5 m thick, henceforth called “unit 4b”) of fossil-rich, medium- to coarse-grained sandstone, with no apparent bedding structures. This layer is very rich in microgastropods, bivalves, fragments of *Zullobalanus santamariaensis* Buckeridge & Winkelmann, 2010 (Winkelmann *et al*., 2010), several bryozoan species, echinoids and rhodoliths. Shell debris are randomly/chaotically distributed within this layer, with no preferential geometric arrangement.

Finally, the sedimentary sequence ends with a massive sandstone unit (henceforth called “unit 4c”), amounting to ~3.7 m in total thickness (see Figs 3 and 4). Unit 4c is fossil-bearing and shows normal graded bedding. The first ~1.2 m correspond to medium-grained sandstones exhibiting a faint cross-stratification, and with some minor bioturbation (burrows) towards the top. These grade from medium- to fine-grained sandstones; the transition is conformable, gradual and only marked by the presence of bioturbation and the change from faint cross-stratification to an almost imperceptible plane-parallel sparse stratification. Bioclastic debris decrease in abundance towards the top of the sequence, where few sparse valves showing some slight downslope imbrication occur (see Fig. 5F). The uppermost ~1.5 m of this sequence is intensely bioturbated by burrowing organisms (*Diplocraterion* isp., *Thalassinoides* isp., *Ophiomorpha* isp., *Rhizocorallium* isp. and *Crossopodia* isp.), leading to destruction of the original sedimentary structures. Basaltic pillow lavas of the overlying lava delta cap the sequence, imprinting load casts in the once soft sediments and showing without any doubt that the volcanic sequence is penecontemporaneous of the underlying sediments (see Fig. 5E).

DISCUSSION

Sedimentological and palaeontological evidence

Marine sedimentary bodies exhibiting hummocky and swaley cross-stratification has been related to storm events that transport sediment under the influence of wave oscillation conditions and/or combined wave oscillation and unidirectional flows from coastlines onto the shelf (Myrow & Southard, 1996; Myrow, 2005; Dumas & Arnott, 2006). On the other hand, turbidity-like deposits are thought to be deposited below storm-wave base because they miss the characteristics of the deposits formed under bidirectional flows. In our opinion, the sedimentary sequence at Ponta do Castelo represents a rapid succession of 4 or 5 different events, each involving voluminous sediment transport from shallow waters to greater depths followed by rapid deposition by the action of storm-related unidirectional and/or combined flows:

Unit 1

The first event is partially exposed since its base lies below present-day beach sediments. It is inferred, however, that the observed stratification is part of a much larger structure of hummocks and swales, and thus interpreted as a tempestite formed under wave oscillations (or combined flows) above or close to storm wave base.

Unit 2

The next event with turbidite-like features was most likely generated by a density-induced flow that brought sediments from shallower levels (as suggested by the presence of allochthonous littoral faunas), initially eroding the sea-bed and eventually settling as it gradually lost energy. In our opinion, since the shelves in other Azorean islands can be quite steep (average 2^o-3^o, but can reach locally much more) (Mitchell *et al*., 2012; Quartau *et al*., 2010), it is not that peculiar to have storm-related turbidites. The sequence is probably not complete, as it lacks the rippled facies that are normally found atop similar sequences. It was probably eroded by the following event, as indicated by the presence of the upper unconformity. Nevertheless, it was not strong enough to remove entirely the bioturbation towards the top of this sequence that shows at least a period of fair weather between events, allowing biological colonization of the top of the deposit.

Unit 3

The third event is sandy, rich in shell debris, some of them in random positions, and exhibits chaotic/diffuse bedding that eventually grades into cross-bedding. The sequence infilled the palaeo-channel carved in the previous unit and the presence of rip-up clasts (intraclasts) suggests that erosion and sedimentation (under very rapid aggradation rates) were violent and almost instantaneous. The existence of well-preserved bryozoan colonies that were ripped from their shallow-water rocky substrate and that are now mixed in the sediment, attests the vigorous energy of the event and the transport of shallow-water/littoral material to greater depths. This unit is thus interpreted as another tempestite deposit, although the missing distinctive sedimentary structures precludes unequivocal inferences concerning the type of mechanism involved in the deposition.

Unit 4

In contrast, the massive deposit that follows – unit 4a, representing the fourth event - is outstanding and crucial to understand the sedimentary dynamics occurring here. First, the deposit overlies a deeply irregular palaeo-topography – with 3-4 m deep troughs cutting deep into the previous sequences – attesting the vigorous erosion necessarily associated to very strong seafloor currents. Secondly, but no less important, it exhibits a distinct mega-hummocky stratification, with preserved metric, slightly asymmetrical hummocks with rare internal truncations, suggesting a deposition under extremely high aggradation rates – perhaps corresponding to a deposition time of just a few hours - as a result of combined flow conditions above or at storm wave base (see Dumas & Arnott, 2006). Sedimentation under extremely high aggradation rates is also supported by the presence of the following features: bedding coarsely parallel to the underlying topography; beds with onlapping contacts on the sides of the troughs/channels but with lateral continuity outside/above these depressions; the absence of internal truncations inside the channels; the presence of tails of sediment eroded from the previous sequence and entrained in the infilling sediments; and fossils chaotically distributed and in random positions (including vertical positions). Similarly to other units, it contains fossils that lived in shallow littoral settings and were transported downslope.

Above the previous package lies a 0.5 m debris flow deposit (unit 4b) that might have been associated with the same event or, less likely, occurred during a different event. The latter brought more organisms/sediments from littoral (intertidal to sublittoral) zones, as its fossil content suggests.

Finally, the last sedimentary unit – unit 4c - in our opinion represents the transition to the fair-weather suite. The cross-stratification at the base still represents wave oscillation influence but with a gradual passage to less energetic conditions (as attested to by the fining upwards graded bedding); the intense bioturbation present towards the top of the sequence is probably related to the very rapid, opportunistic biological colonization that typically occurs after a storm event, in such revolved "new" bottom environments. Sedimentation cycle was subsequently interrupted by rapid progradation of a costal lava-fed delta sustained by an eruption on land, and the sedimentary structures/deposits preserved.

In summary, the sedimentary features described above suggest that the deposition occurred under very high levels of seafloor flow energy. The mega-hummocky stratification, the erosive unconformities, sedimentary structures, poor selection of grain-size, deposition of elongated bioclasts in vertical position, local accumulations of shells in chaotic positions are all a clear evidence of storm-wave and storm-current imprint onto the seafloor (Dumas & Arnott, 2006; Kidwell & Bosence, 1991; Mount & Kidder, 1993; Myrow & Southard, 1996; Myrow, 2005; Vierek, 2010). Therefore, we believe that the sedimentary deposits at Ponta do Castelo were created by a sequence of storm events, each one deposited in a single storm and partially eroded by subsequent events.

Present-day oceanographic and sedimentological evidences of tempestite deposition in the Azorean insular shelves

We believe that the full sedimentary sequence was deposited very rapidly, during a few tens or hundreds of years, and preservation was only possible due to ongoing volcanic activity. This assumption is fairly confident because present-day rates of sedimentation are very high in insular shelves of the Azores archipelago. Sedimentary deposits around the Faial insular shelf that can reach up to 50 m in thickness are believed to have formed during the last 6.5 ka based on estimations from coastal and subaerial erosion and explosive volcanism (Quartau *et al.*, 2012). This implies modern sedimentation rates around 8 mm/year or even more because there is evidence of sediments crossing the shelf break to the slope of the island. Thus, if the whole tempestite sequence at Ponta do Castelo corresponds to the sedimentation of several season/storm events that occurred in a short time interval (due to the very short recurrence period of storms in the Azores), as we believe, then the top of the deposit is penecontemporaneous with its base and the palaeo-water depth inferred through the overlying volcanic structure (~45 m) could be extended to the underlying tempestite deposit, with important implications. One is that storm wave base in such environments reaches down to depths of 50-60 m and the other is that storm-induced downwelling currents are responsible for bringing large amounts of littoral sediments to those depths. This is not surprising since the nearshore part of the insular shelves surrounding Faial and Pico islands are mostly rocky and sedimentary deposits develop mostly on the middle to the outer shelf (Mitchell *et al.*, 2012; Quartau *et al.*, 2012), most likely transported by storm-induced downwelling currents as observed in other energetic environments (Field & Roy, 1984; Nittrouer & Wright, 1994; Hernández-Molina *et al.*, 2000; Chiocci *et al.*, 2004).

The estimation of fair and storm-wave base in the Azores shows that sediments can react to wave action at water depths of 50 m and below. Wave base is defined as the water depth beyond which wave action ceases to stir the sediment bed (Cowell *et al.*, 1999). Conventionally, this limit is taken to be where the water depth (h_{LS}) is half the deep-water wavelength (L_0) -Equation 1 - which corresponds to the deep-water transition to intermediate- water waves.

$$h_{LS} = \frac{L_0}{2} \qquad (1)$$

The general expression for wavelength according to linear Airy wave theory is (Dean & Dalrymple, 1991):

$$L = \frac{gT_s^{\ 2}}{2\pi}\tanh\left(\frac{2\pi}{L}\right) \qquad (2)$$

And for the special case of deep-water waves, $\tanh(2\pi/L)\rightarrow 1$, so that wave length simply becomes:

$$L_0 = \frac{gT_s^{\ 2}}{2\pi} \qquad (3)$$

where L_0 is the deep-water wavelength, T_s is the period and g the acceleration due to gravity (9.81 m/s^2). The calculations are made using a 14-year period (1989-2002) of wave hindcast data from Carvalho (2003). Average and maximum peak wave period (T_p) are respectively 9.9 and 19.8 s. By converting to average and maximum significant wave period (T_s) using Tucker's (1991) relationships between T_p and T_s, we obtain respectively 8.3 and 16.5 s. By replacing these values in equation 3 we see that average waves are able to remobilise sediments to around 50 m water depth and the strongest storm recorded in the considered period is able to do it to 213 m.

Lastly, the analysis of a current meter deployed at around 20 m water depth during 8 months in the southern coast of Faial Island provides evidence for extremely strong bottom currents. Most of them (80%) were related to storm surges (Youssef, 2005) and the highest bottom velocity recorded was 2 m/s during a period in which the significant wave height reached 5.12 m. It is likely to expect even higher bottom velocities since the maximum significant wave height attained during the 14-year period analysed reached 16.7 m (Carvalho, 2003). We are, assuming however, that despite the warmer climate inferred for the Neogene, storm conditions did not differ considerably from modern ones. Our assumption is supported by the field evidence at Ponta do Castelo that could only be formed by storms as strong or even stronger than today.

Depositional model of sedimentation in the insular shelves of ocean volcanic islands

Based on the current work and the oceanographic and sedimentological characteristics of the Azores, we were able to develop a model of how sedimentation occurs on settings similar to these. Although alongshore sedimentation might occur during storms, the prevailing one appears to be directed offshore.

Storms, in favourable conditions (e.g. depending on wind direction to the shoreline and morphology of the coastline and shelf), may cause coastal setup and develop storm surge ebb-currents normal to the shore. In the case of the Faial shelf, around 50% of the currents measured had angles higher than 45° to the shore (Youssef, 2005). Moreover, the data showed a positive relationship between wave height and storm surge current speed. The balance of forces involved during storms, however, can explain this. According to Myrow & Southard (1996), offshore transport is aided by high-pressure gradient, high excess weight and low Coriolis force (or stronger friction force). High-pressure gradient is easily attained during big storms in the Azores as storm surges produce high coastal setups which need to be compensated by opposite strong ebb or downwelling currents. On the other hand, turbulence added by high waves maintains particles in suspension creating high excess weight. The magnitude of this force is a function of the downslope component of the excess weight (per unit volume) of a sediment-rich dispersion relative to the clear water and of the bottom gradient. Therefore, offshore gravity driven transport to the middle and outer insular shelf is promoted by strong ebb-currents (high pressure gradient) and high excess weight (high concentrations of suspended sediment and high shelf gradients). The Coriolis force would normally deflect these currents towards the alongshore direction, however the sum of the three forces plus the high friction force (bottom friction, acting opposite to the direction of the currents) generated during the event, attenuates Coriolis force allowing currents to maintain high angles to the shore (Fig. 7A; Duke, 1990; Myrow & Southard, 1996). Therefore, in shallow waters (above storm wave base), strong oscillatory fluid motion coupled with unidirectional currents transport sediments from the near-shore and form hummocky cross-stratifications and wave ripples whilst at greater depths (below storm wave-base), the unidirectional flows dominate and turbiditic sequences form. During the ensuing fair-weather conditions (Fig. 7B) the new sea-bottom sedimentary cover is rapidly colonized by endobenthonic organisms producing bioturbation of the upper part of the deposit. We believe that this study may help to resolve the conflict between the commonly oceanographical observations of shore-parallel geostrophic storm flows and the geological observations which outcrop data suggests mostly cross-shelf transport mechanisms. Most researchers believe that the mobilization of large quantities of sand towards offshore would happen very rarely, with recurrence intervals of tens of thousands of years (Myrow & Southard, 1996). However, according to Tsutui *et al.* (1987), hurricane Iwa in Oahu, Hawaii that produced significant wave heights of about 5 m, a maximum wave height of approximately 9 m, and sustained winds of 30-35 knots, was able to transport coarse sands and gravels from sediment bodies located on the shallow shelf onto the slopes of the island. In the Azores the returning period of maximum wave heights of 12 m is 5 years (Carvalho, 2003), which supports our claim of high recurrence storm deposition. Therefore, the studied outcrop coupled with our knowledge of the present-day sedimentary processes in these islands shows that in wave- to storm-dominated island shelves, as these are, it is possible to have significant cross-shelf transport of sediments and that storms are the main process of deposition on these settings. We believe that these conclusions can be extended to a much wider range of environments such as those on narrow and steep continental shelves with a suitable wave energy regime. Modelling (Cookman & Flemings, 2001; Quiquerez *et al.*, 2004) and observations (Amos *et al.*, 1996; Cacchione *et al.*, 1994; Gagan *et al.*, 1990; Li *et al.*, 1997) suggest that winter storms are the main agent causing sediment dispersal on the worldwide continental shelves. Therefore, on narrow, steep and wave- to storm-dominated shelves, cross-shore sediment transport is apparently the main mechanism of deposition (e.g. Chiocci *et al.*, 2004; Field & Roy, 1984). This model could even be applied to wide continental shelves during low stands of sea level.

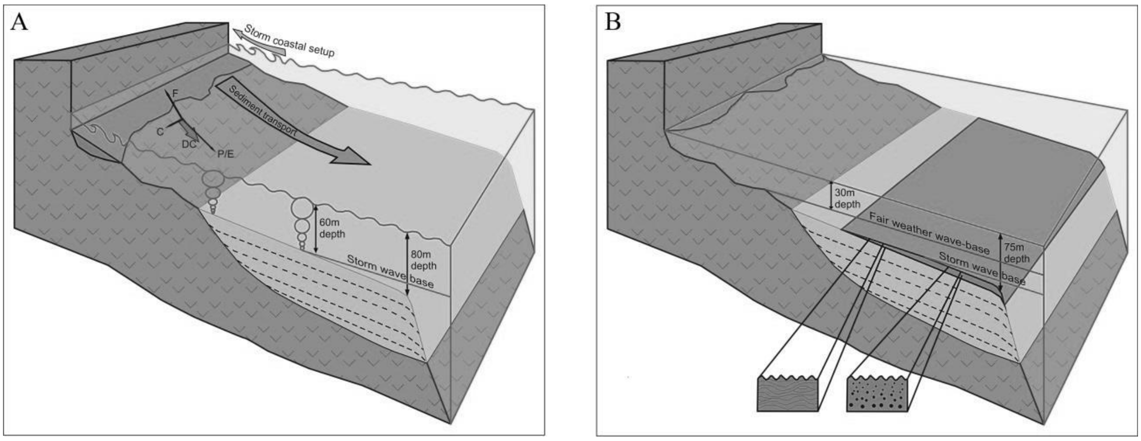


Figure 7. Cross-insular shelf profile: **A** - Storm conditions. Storm coastal setup is balanced by strong downwelling shore oblique currents (DC). These result from the sum (red arrow) of strong high pressure gradient, excess weight (P/E), strong friction force (F) and low Coriolis force (C) (see text for explanation). **B** – Fair-weather conditions. Nearshore sediment was transported basinward and deposited below 50 m water depth. Above and below storm-wave base, respectively, hummocky cross-stratifications and turbidite deposits are found.

CONCLUSIONS

This study, combined with the current knowledge of the modern oceanographic and sedimentological characteristics of the Azorean shelves provided important clues to unveil the main process responsible for the transport and deposition of sediments around open-sea volcanic islands:

1) The sedimentary deposits of the sequence at Ponta do Castelo are interpreted as tempestites and thus storms were the main agent of transport and deposition on the insular shelf of Santa Maria during the Neogene.

2) The described sedimentary sequence was probably deposited very rapidly, during decades or centuries and was only preserved because it was covered by a lava delta, hence protected, and afterward exposed subaerially by uplift and erosion.

3) The inferred rapid deposition of the sedimentary sequence and the lava delta on top of it were used to estimate very accurately the water depth at which the deposition occurred, around 50 m, which is not that peculiar given the modern examples in the literature (e.g. Tsutui *et al*., 1987).

4) Storms are very frequent in the Azores, with very high waves and strong winds that produce storm surges. High-pressure gradients against the coastline are balanced by offshore-directed ebb-currents. Thus, nearshore sediments are easily entrained and maintained in suspension by storm-waves and currents. The combination of high excess-weight of the suspended sediments, relatively high gradients of the shelf and the strong-storm surge ebb-currents provides the mechanism to transport sandy sediments down to depths of 50 m and more.

5) We claim that the main processes of transport and deposition on insular shelves are strong ebb-return currents that are formed during storm events. The hummocky stratification and ripples found within the sequence are deposited above the storm wave-base and the turbidite-like beds are deposited below storm wave-base.

We hope that this work will increase the debate on the mechanisms of tempestite deposition. Further research on other uplifted volcanic islands is needed to contribute to a better understanding of the sedimentary processes acting on the insular shelves of these islands. We also consider that this model could be applied to other environments such as narrow and steep continental shelves or even to wide continental shelves during sea-level lowstands as long as remarkable wave energy is present.

ACKNOWLEDGEMENTS

The following agencies are gratefully acknowledged for providing funding: Direcção Regional da Ciência, Tecnologia e Comunicações (DRCT) of the Regional Government of the Azores and Fundação para a Ciência e a Tecnologia (FCT) of the Portuguese Government; field assistance: Clube Naval de Santa Maria and Câmara Municipal de Vila do Porto; and GIS topographic mapping of Santa Maria Island: DRTC and Direcção de Serviços de Cartografia e Informação Geográfica. We are also grateful to the organizers and participants of several editions of the International Workshop "Palaeontology in Atlantic Islands" who helped in the fieldwork. We greatly appreciated helpful comments from Stephen Rice (Editor), Jess Trofimovs (Associate Editor), Brian Jones and an anonymous reviewer. DFG-The German Research Foundation provided Ricardo Ramalho's funding, through the project "Investigation of ocean island uplift in the Azores Island Region". Vittorio Zanon was funded by DRCT grant M3.1.7/F/008A/2009. Rui Quartau and Sérgio Ávila acknowledge their Ciência 2008 research contracts funded by FCT. Ana Cristina Rebelo and Ricardo Piazza Meireles benefited respectively from FCT grants SFRH/BD/77310/2011 and SFRH/BD/60518/2009.

FINAL CONSIDERATIONS

The results presented in this thesis suggest that the privileged location gave to this archipelago one important insular characteristic and absolutely marine indication of ocean migration pathways. Bryozoa & Ostracoda groups living in association around the Azores. Almost few cases showed the relationship these both organisms in Azoreans' marine shallow water and fossil (Chapter 4 – fig. 2; Chapter 6 – fig. 8; Chapter 7 – figs 3 and 4).

During all works we verified the presence of Bryozoa and Ostracoda in the samples (see outcrops and schematics figures in **Chapters 4, 6** and **7**). As new species continue to be discovered, it is likely that the Azores and the maritime Portugal Economic Zone have many species still waiting to be described. The checklist of these species provides important data for the bathymetric distribution and help ecological and depositional processes discussions about these species in the Azores archipelago (Tables 1 and 2).

The deep water (below 300 meters) ostracods, also occurring in association with Bryozoans, should contribute to the comprehension of the survey and its biological caracters and ecological context. Unpublished data confirms that the ostracod fauna found in water depths greater than 300 m occur in conjunction with bryozoans, but the number of records is low. More efforts in collecting and detailing of these samples should be done (Fig. 1).

The material figured in Figure 1, is listed in the reference collection of the Department of Biology (DB/OS/0155 to DB/OS/0176) and its inventory is in this thesis database.

Field work on the fossiliferous outcrops of Santa Maria Island should continue in the next years, in order to better establish the palaeobiogeographical relationships of the fossils and to compare these results with the neobiogeographical relationships of the Azores.

This study increases to 128 the number of Recent bryozoan species and to 34 the number of Recent ostracod species reported from the Azores (Chapter 3: Tables 1 and 2). The fossil Bryozoa are being presently revised by other researchers of the MPB group.

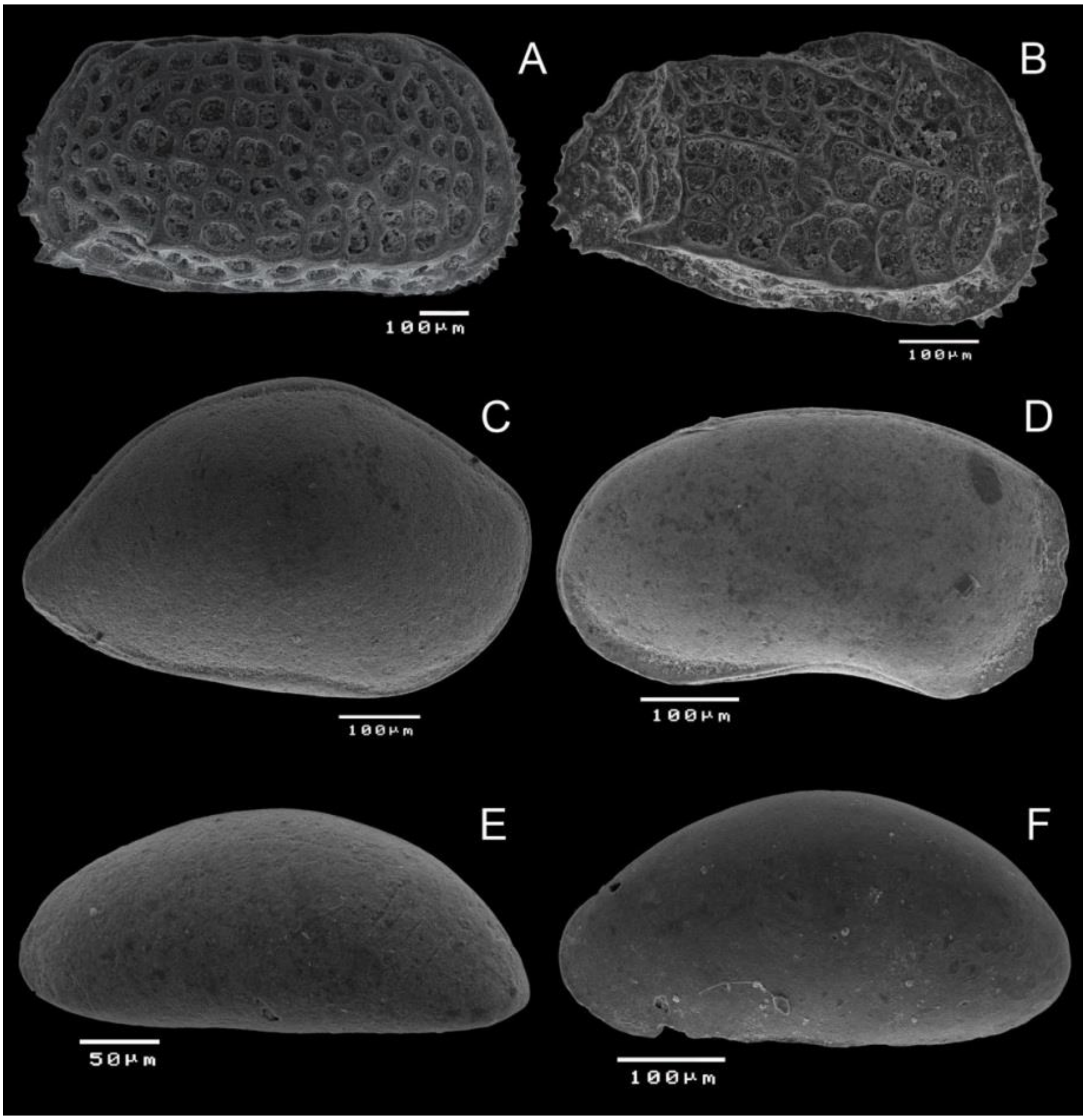


Figure 1. A) DB/OS 0171. RV; **B)** DB/OS 0163. RV; **C)** DB/OS 0172. RV; **D)** DB/OS 0160. RV; **E)** DB/OS 0166. LV; **F)** DB/OS 0166. LV.

The degree of endemism of the Azorean Bryozoa and Ostracoda species (both Recent and fossil) needs to be checked in the near future, as more material becomes available for study. The MPB-Marine PalaeoBiogeography working group of the University of the Azores should continue these studies in order to provide additional tools for identifying the more conspicuous species from the Azores and so, to better support governments' decisions. This benthos database can be a helpful tool for future actions in Conservation and Science. The installation/composition/support/ conservation of these Natural collection require attention and more support. The next step "***The Micropalaeontological Collection***" started on Department of Biology/University of Azores will need a proper cabinet (*e.g.* Fig. 3). Additionally, a website database should be done, as in other museums. The creation of Manuals and Field identification guides of the species of the Azores archipelago should be reinforced (Figs. 4 and 5).

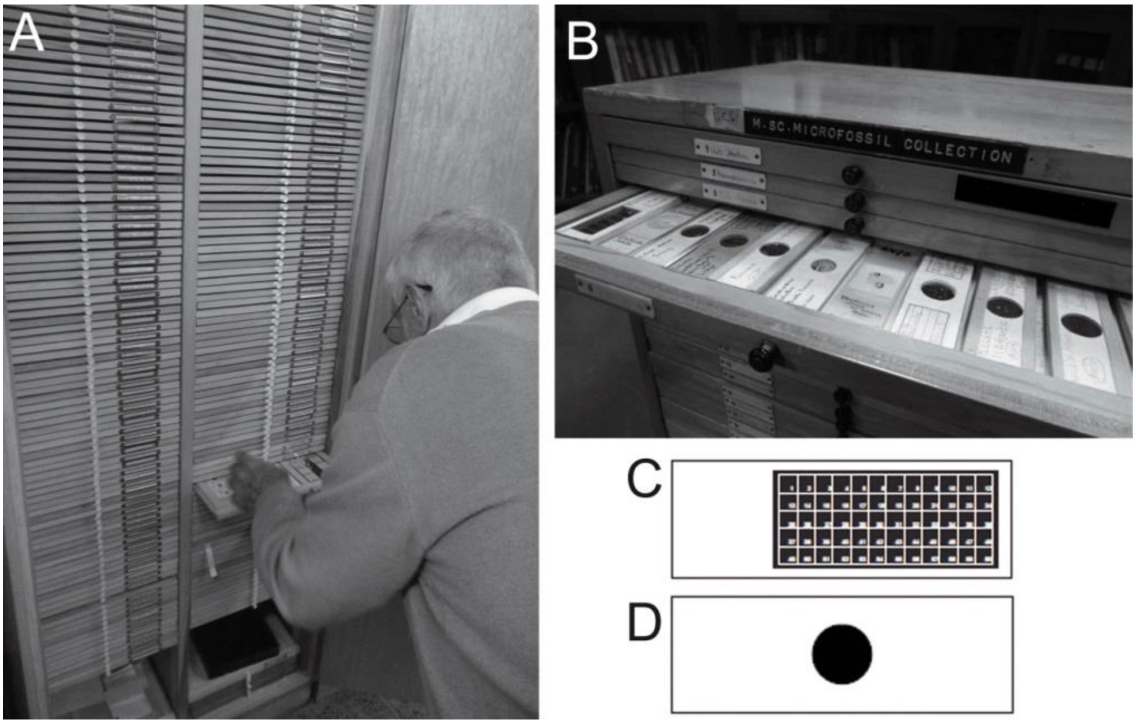
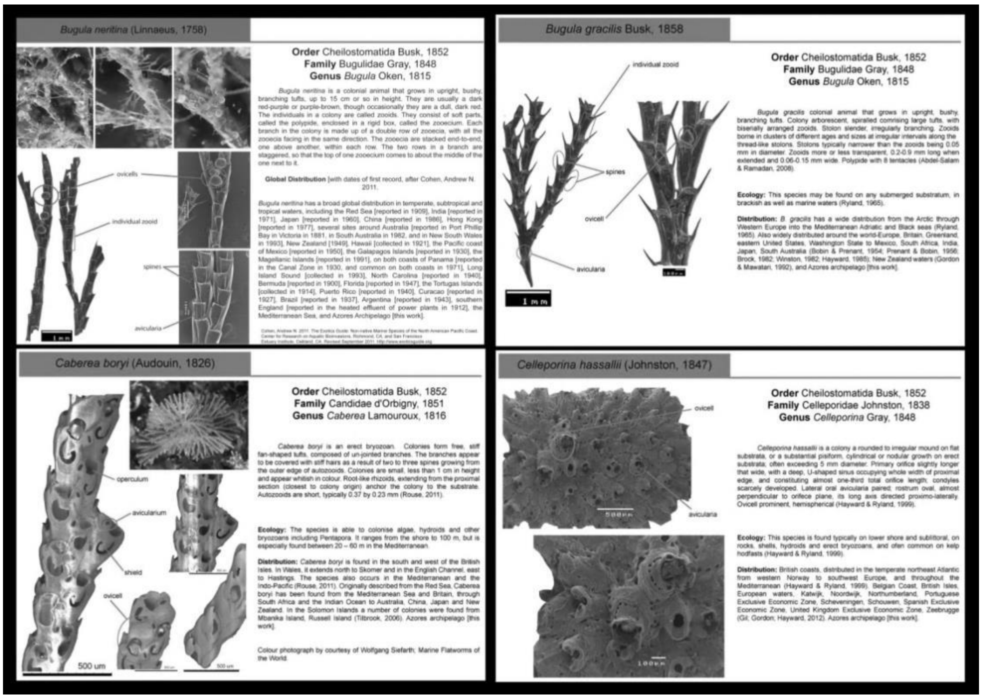


Figure 3. Example of an Ostracoda Collection; **A)** Zoological Museum/University of Hamburg (Germany); **B)** Natural History Museum (London); **C)** micropalaeontological slides used to held all handpicked material; **D)** individual micropalaeontological slide used to held only one specimen (Holotype for example).



Order Cheilostomatida Busk, 1852
Family Bugulidae Gray, 1848
Genus *Bugula* Oken, 1815

Bugula neritina is a colonial animal that grows in upright, bushy, branching tufts, up to 15 cm or so in height. They are usually a dark red-purple or purple-brown, though occasionally they are a dull, dark red. The individuals in a colony are called zooids. They consist of soft parts, called the polypide, enclosed in a rigid box, called the zooecium. Each branch in the colony is made up of a double row of zooecia, with all the zooecia facing in the same direction. The zooecia are stacked end-to-end, one above another, within each row. The two rows in a branch are staggered, so that the top of one zooecium comes to about the middle of the one next to it.

Global Distribution [with dates of first record, after Cohen, Andrew N. 2011.

Bugula neritina has a broad global distribution in temperate, subtropical and tropical waters, including the Red Sea [reported in 1909], India [reported in 1971], Japan [reported in 1960], China [reported in 1986], Hong Kong [reported in 1977], several sites around Australia [reported in Port Phillip Bay in Victoria in 1881, in South Australia in 1982, and in New South Wales in 1993], New Zealand [1949], Hawaii [collected in 1921], the Pacific coast of Mexico [reported in 1950], the Galapagos Islands [reported in 1930], the Magellanic Islands [reported in 1991], on both coasts of Panama [reported in the Canal Zone in 1930, and common on both coasts in 1971], Long Island Sound [collected in 1993], North Carolina [reported in 1940], Bermuda [reported in 1900], Florida [reported in 1947], the Tortugas Islands [collected in 1914], Puerto Rico [reported in 1940], Curacao [reported in 1927], Brazil [reported in 1937], Argentina [reported in 1943], southern England [reported in the heated effluent of power plants in 1912], the Mediterranean Sea, and Azores Archipelago [this work].

Cohen, Andrew N. 2011. The Exotics Guide: Non-native Marine Species of the North American Pacific Coast. Center for Research on Aquatic Bioinvasions, Richmond, CA, and San Francisco Estuary Institute, Oakland, CA. Revised September 2011. http://www.exoticsguide.org

Order Cheilostomatida Busk, 1852
Family Bugulidae Gray, 1848
Genus *Bugula* Oken, 1815

Bugula gracilis colonial animal that grows in upright, bushy, branching tufts. Colony arborescent, spiralled comrising large tufts, with biserially arranged zooids. Stolon slender, irregularly branching. Zooids borne in clusters of different ages and sizes at irregular intervals along the thread-like stolons. Stolons typically narrower than the zooids being 0.05 mm in diameter. Zooids more or less transparent, 0.2-0.9 mm long when extended and 0.06-0.15 mm wide. Polypide with 8 tentacles (Abdel-Salam & Ramadan, 2008).

Ecology: This species may be found on any submerged substratum, in brackish as well as marine waters (Ryland, 1965).

Distribution: *B. gracilis* has a wide distribution from the Arctic through Western Europe into the Mediterranean Adriatic and Black seas (Ryland, 1965). Also widely distributed around the world-Europe, Britain, Greenland, eastern United States, Washington State to Mexico, South Africa, India, Japan, South Australia (Bobin & Prenant, 1954; Prenant & Bobin, 1956; Brock, 1982; Winston, 1982; Hayward, 1985); New Zealand waters (Gordon & Mawatari, 1992), and Azores archipelago [this work].

Order Cheilostomatida Busk, 1852
Family Candidae d'Orbigny, 1851
Genus *Caberea* Lamouroux, 1816

Caberea boryi is an erect bryozoan. Colonies form free, stiff fan-shaped tufts, composed of un-jointed branches. The branches appear to be covered with stiff hairs as a result of two to three spines growing from the outer edge of autozooids. Colonies are small, less than 1 cm in height and appear whitish in colour. Root-like rhizoids, extending from the proximal section (closest to colony origin) anchor the colony to the substrate. Autozooids are short, typically 0.37 by 0.23 mm (Rouse, 2011).

Ecology: The species is able to colonise algae, hydroids and other bryozoans including Pentapora. It ranges from the shore to 100 m, but is especially found between 20 – 60 m in the Mediterranean.

Distribution: *Caberea boryi* is found in the south and west of the British Isles. In Wales, it extends north to Skomer and in the English Channel, east to Hastings. The species also occurs in the Mediterranean and the Indo-Pacific (Rouse, 2011). Originally described from the Red Sea, *Caberea boryi* has been found from the Mediterranean Sea and Britain, through South Africa and the Indian Ocean to Australia, China, Japan and New Zealand. In the Solomon Islands a number of colonies were found from Mbanika Island, Russell Island (Tilbrook, 2006). Azores archipelago [this work].

Colour photograph by courtesy of Wolfgang Siefarth; Marine Flatworms of the World.

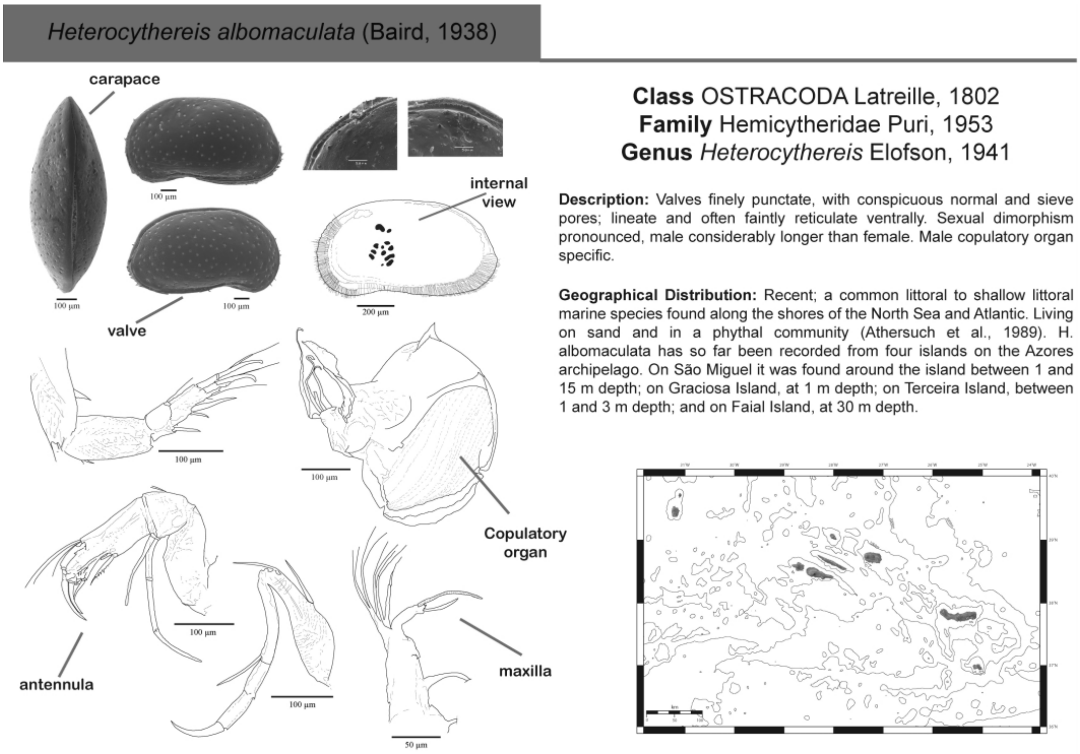
Order Cheilostomatida Busk, 1852
Family Celleporidae Johnston, 1838
Genus *Celleporina* Gray, 1848

Celleporina hassallii is a colony a rounded to irregular mound on flat substrata, or a substantial pisiform, cylindrical or nodular growth on erect substrata; often exceeding 5 mm diameter. Primary orifice slightly longer that wide, with a deep, U-shaped sinus occupying whole width of proximal edge, and constituting almost one-third total orifice length; condyles scarcely developed. Lateral oral avicularia paired; rostrum oval, almost perpendicular to orifece plane, its long axis directed proximo-laterally. Ovicell prominent, hemispherical (Hayward & Ryland, 1999).

Ecology: This species is found typically on lower shore and sublittoral, on rocks, shells, hydroids and erect bryozoans, and ofen common on kelp hodfasts (Hayward & Ryland, 1999).

Distribution: British coasts, distributed in the temperate northeast Atlantic from western Norway to southwest Europe, and throughout the Mediterranean (Hayward & Ryland, 1999). Belgian Coast, British Isles, European waters, Katwijk, Noordwijk, Northumberland, Portuguese Exclusive Economic Zone, Scheveningen, Schouwen, Spanish Exclusive Economic Zone, United Kingdom Exclusive Economic Zone, Zeebrugge (Gil; Gordon; Hayward, 2012). Azores archipelago [this work].

Figure 4. Exemple of the layout of the Bryozoa field identification guide.



Heterocythereis albomaculata (Baird, 1938)

Class OSTRACODA Latreille, 1802
Family Hemicytheridae Puri, 1953
Genus *Heterocythereis* Elofson, 1941

Description: Valves finely punctate, with conspicuous normal and sieve pores; lineate and often faintly reticulate ventrally. Sexual dimorphism pronounced, male considerably longer than female. Male copulatory organ specific.

Geographical Distribution: Recent; a common littoral to shallow littoral marine species found along the shores of the North Sea and Atlantic. Living on sand and in a phythal community (Athersuch et al., 1989). H. albomaculata has so far been recorded from four islands on the Azores archipelago. On São Miguel it was found around the island between 1 and 15 m depth; on Graciosa Island, at 1 m depth; on Terceira Island, between 1 and 3 m depth; and on Faial Island, at 30 m depth.

Figure 5. Exemple of the layout of the Ostracoda field identification guide.

FUTURE PROSPECTS

For future work we will develop:

1. The taxonomy about two new Bryozoa species: *Scrupocellaria* sp. and *Reteporella* sp.;
2. Further studies are required on the genus *Bugulla*, *Crisia*, *Celleporina*, *Disporella*, *Onicocella*, *Reteporella*, *Schizomavella*, *Scrupocellaria* and on the family Tubuliporidae, all of them important ecological groups in the sandy substrates of the Azores (Chapter 6: Tables 3).
3. The taphonomic studies of the benthic organisms (with a special emphasis on the Ostracoda and Bryozoa) should be continued, as they provide an important perspective for palaeo-environmental interpretations;
4. The curatorial work of the natural collections housed at the Department of Biology (including, of course, the Micropalaeontological collection) should be a priority for the University of the Azores (Chapter 3: Tables 1, 2, 3 and 4).
5. A Field guide about the most common marine species of the Azores could be done (*e.g.* Figs. 4 and 5).

For the shallow-water **Bryozoa & Ostracoda**, we developed the data about the bathymetric and geographical distribution (Tables 1 and 2). This data will support new research about these organisms in the Azorean Insular Shelf.

Table 1. Bathymetry and geographical distribution of the Azorean Bryozoa shallow-water species.

Bryozoa	Depth	Geographical Distribution
Aetea anguina (Linnaeus, 1758)	5 – 6 m	Azores
Aplousina capriensis (Waters, 1898)	shelf	Azores
Aplousina filum (Jullien & Calvet, 1903)	130 m	Azores
Amphiblestrum auritum (Hincks, 1877)	130 m	Azores
Chaperiopsis hirsuta Reverter, Souto & Pulpeiro, 2009	shelf	Azores
Gregarinidra gregaria (Heller, 1867)	shelf	Azores
Bugula dentata (Lamouroux, 1816)	shelf	Azores
Bugula neritina Linnaeus, 1758	shelf	Azores
Bugula simplex Hincks, 1886	shelf	Azores
Bugula stolonifera Ryland, 1960	shelf	Azores
Bicellariella ciliata (Linnaeus, 1758)	shelf	Azores
Beania cylindrica (Hincks, 1886)	shelf	Azores
Beania mirabilis Johnston, 1840	130 m	Azores
Scrupocellaria maderensis Busk, 1860	shelf	Azores
Scrupocellaria incurvata Waters, 1896	shelf	Azores
Scrupocellaria scrupea Busk, 1852	130 m	Azores
Scrupocellaria hirsuta Jullien & Calvet, 1903	27 - 130 m	Azores
Scrupocellaria scruposa (Linnaeus, 1758)	52 – 550 m	Azores and Cape Verde
Scrupocellaria reptans (Linnaeus, 1758)	27 m	Azores
Notoplites marsupiatus (Jullien, 1882)	65 – 1250 m	Azores and NW Spain
Caberea boryi (Audouin, 1826)	130 m	Azores
Micropora coriacea (Johnston, 1847)	130 m	Azores
Cellaria salicornioides Lamouroux, 1816	shelf	Azores

Puellina orientalis azorensis (Harmelin, 1988)	10 – 300 m	Azores, Canary
Puellina radiata (Moll, 1803)	98 – 930 m	Azores, Madeira, Canarias; Atlantic oriental (France, Spain, Maroc), Mediterranean, Tristan da Cunha, Florida and Pacific (Australia, China, Philippines, Bornèo, etc.)
Puellina sp. 1	shelf	Azores
Membraniporella alice Jullien, 1903	130 m	Azores
Membraniporella neptuni Jullien, 1903	130 m	Azores
Figularia figularis (Johnston, 1847)	130 m	Azores
Umbonula verrucosa (Esper, 1790)	5 – 318 m	Azores
Smittina ensifera Jullien & Calvet, 1903	130 m	Azores
Smittoidea ophidiana (Waters, 1878)	69 – 540 m	Azores and Canarias
Metroperiella lepralioides (Calvet, 1903)	130 m	Azores
Schizomavella cuspidata (Hincks, 1880)	shelf	Azores
Schizomavella auriculata (Hassall, 1842)	95 – 130 m	Azores
Schizomavella triaviculata (Calvet, 1903)	98 – 550 m	Azores
Stephanotheca richardi (Calvet, 1903)	130 m	Azores
Stephanotheca fayalensis (Calvet *in* Jullien & Calvet, 1903)	130 m	Azores
Watersipora complanata (Norman, 1864)	shelf	Azores
Watersipora subtorquata (d'Orbigny, 1852)	Tidal - 130 – 318 m	Azores
Watersipora cucullata (Busk, 1854)	0 – 219 m	Azores; Gibraltar; Cape Verde
Schizoporella dunkeri (Reuss,1848)	shelf	Azores
Schizoporella guttata Jullien & Calvet, 1903	130 m	Azores
Schizoporella jullieni Jullien & Calvet, 1903	130 m	Azores
Escharina vulgaris (Moll, 1803)	130 m	Azores
Escharina protecta Zabala, Maluquer, Harmelin, 1993	6 – 130 m	Azores, Madeira, Mediterranean, Red Sea, ?Pacific Ocean
Microporella ciliata (Pallas, 1766)	130 m	Azores
Microporella hastigera (Busk, 1884)	130 m	Azores
Buskea dichotoma (Hincks, 1862)	98 - 2170 m	Azores; Canaries; Coast of Bretagne
Celleporina decipiens Hayward, 1976	shelf	Azores
Celleporina hassallii (Johnston, 1847)	shelf	Azores
Celleporina costazii (Audouin, 1826)	0 - 550 m	Azores
Galeopsis pentagonus (d'Orbigny, 1842)	130 m	Azores

Lagenipora socialis Hincks, 1877	130 m	Azores
Stephanollona armata (Hincks, 1862)	shelf	Azores
Schizotheca carmenae Reverter-Gil & Pulpeiro, 2007	45 – 148 m	Azores and SW Portugal (Sagres)
Reteporella septentrionalis (Harmer, 1933)	20 – 1300 m	Azores
Reteporella sp.	shelf	Azores
Reteporella sp. 1	shelf	Azores
Reptadeonella violacea (Johnston, 1847)	shelf	Azores
Reptadeonella insidiosa (Jullien, 1903)	52 – 219 m	Azores; Cape Verde, Marrocos, Guernesey, Hasting, Gulf of Gascogne
Adeonellopsis distoma (Busk, 1858)	98 – 1262 m	Azores; Madeira, Canaries, Mediterranean occidental and Indian Ocean
Hippothoa divaricata Lamouroux, 1821	130 m	Azores
Hippothoa flagellum Manzoni, 1870	130 m	Azores
Hippothoa amoena Jullien & Calvet, 1903	130 - 318 m	Azores
Haplopoma bimucronatum (Moll, 1803)	shelf	Azores
Pherusella tubulosa (Solander, 1786)	91 – 318 m	Mediterranean, Atlantic Ocean (Dominique, Brazil, Azores, Cape verde) and Chile
Amathia lendigera (Linnaeus, 1758)	5 – 6 m	Azores
Zoobotryon verticillatum (Delle Chiaje, 1822)	shelf	Azores
Idmidronea atlantica (Forbes *in* Johnston, 1847)	5 - 318 m	Azores
Idmidronea contorta (Busk, 1875)	95 m	Azores
Disporella fimbriata (Busk, 1875)	52 – 219 m	Antartic and subantartic Atlantic to Pacific; Azores, Cape Verde, Cile and Gulf of Gascogne
Crisia eburnea (Linnaeus, 1758)	shelf - 736 m	Azores
Crisia denticulata (Lamarck, 1816)	tidal	Azores
Crisia ramosa Harmer, 1891	27 – 69 m	Azores, Mediterranean, Monaco

Table 2. Bathymetry and geographical distribution of the Azorean Ostracoda species.

Ostracods	**Depth**	**Geographic**
Neonesidea longisetosa	1 and 85 m	Azores; Caribbean; Florida
Leptocythere pellucida	1 to 50 m	Azores; North Sea, Atlantic Coast of France and Britain, southern Norway and the western Baltic
Callistocythere insularis n. sp.	1 to 23 m	Azores
Cyprideis torosa	freshwater to littoral	Azores; Widespread throughout Europe and as far north as Iceland, W and Central Asia, and N Africa.Also found in lakes in Central Africa.
Carinocythereis whitei	1 to 20 m	Azores; British Isles, the Atlantic coast of France and the Mediterranean
Aurila convexa	1 to 54 m	Azores; North Sea, France, Portugal, the Mediterranean and Britain
Aurila woutersi	1 to 20 m	Azores; Southern British Isles
Aurila prasina	1 to 20 m	Azores; Lecce and S. Maria di Leuca, in Adriatic Sea and in Naxos, Greece
Heterocythereis albomaculata	1 to 20 m	Azores; North Sea and Atlantic
Urocythereis britannica	1 to 69 m	Azores; Atlantic, the North Sea and probably in the Mediterranean
Loxoconcha rhomboidea	1 to 70 m	Azores; Europe, from N Norway to Madeira and Canary Islands, off N Africa. Mediterranean
Loxoconcha ochlockoneensis	1 to 20 m	Azores; West coast of Florida and the Bermudas
Semicytherura brandoni n. sp.	littoral	Azores
Semicytherura cf. *cornuta*	littoral (~18 m)	Azores; Atlantic coast of France and S Norway
Xestoleberis rubens	1 to 45 m	Azores; North Sea and the Atlantic coast of France
Xestoleberis cf *depressa*	littoral	Azores; North Sea, Scandinavia and also in the Western part of the Baltic
Xestoleberis sp.	littoral	Azores
Sclerochilus hicksi	littoral	Azores; NE England
Lanceostoma simplex n. sp.	1 to 20 m	Azores
Cylindroleberis sp.	littoral	Azores

REFERENCES

Abdel-Monem, A.A., Fernandez, L.A., Boone, G.M., 1975. K-Ar ages from eastern Azores group (Santa-Maria, SaoMiguel and Formigas Islands). Lithos, 8: 247–254.

Abdel-Monem, A., Fernandez, L.A. and Boone, G.M., 1968. Pliocene-Pleistocene minimum K-Ar ages of the older eruptive centers, Eastern Azores. Transactions - American Geophysical Union, 49(1): 363.

Al-Abdul-Razzaq, S., Shublaq, W., Al-Sheikh, Z., Kittaneh, W., 1983. Ecology and distribution of ostracods in Kuwait Bay. Journal of Micropalaeontology, 2: 39 – 45.

Allison, E.C. & Holden, C.H., 1971. Recent Ostracodes from Clipperton Island Eastern Tropical Pacific. San Diego Society of Natural History, 16(7): 165-214.

Amat, J.N. & Tempera, F., 2009. *Zoobotryon verticillatum* Della Chiaje, 1822 (Bryozoa), a new occurrence in the archipelago of the Azores (North-Eastern Atlantic). Marine Pollution Bulletin, 58(5): 761-764.

Amos, C., Li, M. and Choung, K. (1996) Storm-generated, hummocky stratification on the outer-Scotian Shelf. Geo-Mar. Lett., 16, 85-94.

Andrade, C., Trigo, R.M., Freitas, M.C.; Gallego, M.C.; Borges, P. and Ramos, A.M., 2008. Comparing historic records of storm frequency and the North Atlantic Oscillation (NAO) chronology for the Azores region. The Holocene, 18: 745-754.

Angel, M. V., 1973. The description of the female of the ostracod *Bathyconchoecia sagittarius* Deevey, 1968 (Myodocopida, Halocyprididae). Crustaceana 25: 211-219.

Angel, M. V., 1989. "Vertical profiles of pelagic communities in the vicinity of the Azores Front and their implications to deep ocean ecology." Progress in Oceanography 22: 1-46.

Argus, D.F., Gordon, R.G., DeMets, C. and Stein, S., 1989. Closure of the Africa-Eurasia-North America plate motion circuit and the tectonics of the Gloria fault. Journal of Geophysical Research, 94: 5585-5602.

Apostolescu, V., 1961. Contribution i àl'étude paléontologique (Ostracodes) et stratigraphique des bassins Crétacés de Tertiaires de l'Afrique Occidentale: Revue de Institut Français du Pétrole, v. 16, no. 7/8, p. 779-786, 1 text-fig., 18 pl., 5 tables.

Ascoli, P., 1964. Preliminary ecological study on Ostracoda from bottom cores of the Adriatic Sea. Pubblicazioni della Stazione Zoologica di Napoli, 33 supplement, 213-246.

Athersuch, J. & Whittaker, J. E., 1976. On *Loxoconcha rhomboidea* (Fischer). Stereo-Atlas of Ostracod Shells, 3, 81-90.

Athersuch, J., 1977. The genus *Urocythereis* (Crustacea: Ostracoda) in Europe, with particular reference to Recent Mediterranean species. Bulletin British Museum Natural History, 32(7): 247-283.

Athersuch, J., 1979. The ecology and distribution of the littoral ostracods of Cyprus. Journal of Natural History, 13: 135-160.

Athersuch, J. & Horne, D. J., 1987. Taxonomy of the genus *Sclerochilus* Sars (Crustacea: Ostracoda) from British waters with a pictorial key. Zoological Journal of the Linnean Society, 91: 197-222.

Athersuch, J., Horne, D. J., Whittaker, J. E., 1985. G.S. Brady's Pleistocene ostracods from the Brickearth of the Nar Valley, Norfolk, U.K. Journal of Micropalaeontology, 4: 153-158.

Athersuch, J., Horne, D.J., Whittaker, J.E., 1989. Marine and brackish water ostracods (superfamilies Cypridacea and Cytheracea). In Kermack, D. M. & Barnes, R. S. K. (eds.): Synopses of the British Fauna (New Series) 43. 343 pp. E. J. Brill, Leiden.Barbeito-Gonzalez, 1971.

Athersuch, J., Horne, D.J., Whittaker, J.E., 1989. Marine and Brackish Water Ostracods. Synopses of the British Fauna (N.S.), 43p.

Athersuch, J. & Whittaker, J. E., 1977. On *Callistocythere badia* (Norman). Stereo-Atlas of Ostracod Shells, 4: 53-58.

Athersuch,J. Whittaker, J.E. 1987. On *Carinocythereis whitei* (Baird). Stereo-Atlas of Ostracod Shells 14(24): 103-110.

Ávila, S.P., 2000. Shallow-water marine molluscs of the Azores: biogeographical relationships. Arquipélago. Life and Marine Sciences. Supplement 2 (Part A): 99-131.

Ávila, S.P., Amen, R., Azevedo, J.M.N., Cachão, M. & García-Talavera, F., 2002. Checklist of the Pleistocene marine molluscs of Prainha and Lagoinhas (Santa Maria Island, Azores). Açoreana, 9(4): 343-370.

Ávila, S. P. & Albergaria, A., 2002. The shallow-water Polyplacophora of the Azores and some comments on the biogeographical relationships of the Azorean malacofauna. Bollettino Malacologico, 38(1-4): 41-44.

Ávila, S.P., 2003. The littoral molluscs (Gastropoda, Bivalvia and Polyplacophora) of São Vicente, Capelas (São Miguel Island, Azores): ecology and biological associations to algae. Iberus, 21(1): 11-33.

Ávila, S.P., 2005. Processos e padrões de dispersão e colonização nos Rissoidae (Mollusca: Gastropoda) dos Açores. PhD Thesis, Universidade dos Açores, Ponta Delgada, 329 p. (unpublished).

Ávila, S.P., Madeira, P., García-Talavera, F., Marques da Silva, C., Cachão, M., Frias Martins, A.M.de, 2007. *Luria lurida* (mollusca: gastropoda), a new record for the Pleistocene of Santa Maria (Azores, Portugal). Arquipélago, 24: 53-56.

Ávila, S.P., Madeira, P., Mendes, N., Rebelo, A., Medeiros, A., Gomes, C., García-Talavera, F., Marques Da Silva, C., Cachão, M., Hillaire-Marcel, C. & Frias Martins, A.M.de, 2008. Mass extinctions in the Azores during the last glaciation: fact or myth? Journal of Biogeography, 35: 1123-1129.

Ávila, S.P., Madeira, P., Marques da Silva, C., Cachão, M., Landau, B., Quartau, R., Frias Martins, A.M.de, 2008. Local disappearance of bivalves in the Azores during the last glaciation. Journal of Quaternary Science, 23: 777-785.

Ávila, S.P., Marques Da Silva, C., Schiebel, R., Cecca, F., Backeljau, T. & Frias Martins, A.M.de, 2009a. How did they get here? Palaeobiogeography of the Pleistocene marine molluscs of the Azores. Bulletin of the Geological Society of France, 180: 295-307.

Ávila, S. P., Madeira, P., Zazo, C., Kroh, A., Kirby, M., Da Silva, C. M., Cachão, M.& Frias Martins, A.M.de, 2009b. Palaeocology of the Pleistocene (MIS 5.5) outcrops of Santa Maria Island (Azores) in a complex oceanic tectonic setting. Palaeogeography, Palaeoclimatology, Palaeoecology, 274: 18-31.

Ávila, S.P., Goud, J., Frias Martins, A.M.de, 2012a. Patterns of diversity of the Rissoidae (Mollusca: Gastropoda) in the Atlantic and the Mediterranean Region. The Scientific World Journal. Article ID 164890: 1-30.

Ávila, S.P., Ramalho, R. and Vullo, R., 2012b. Systematics, palaeoecology and palaeobiogeography of the Neogene fossil sharks from the Azores (Northeast Atlantic). Annales de Paléontologie, 98, 167-189.

Ávila, S.P., in press. Unravelling the patterns and processes of evolution of marine life in oceanic islands: a global framework. Climate Change: past, present and future perspectives. A global synthesis from the Atlantic. Universidad de La Laguna, Tenerife.

Azevedo, J.M.M., 1999. Geologia e Hidrogeologia da Ilha das Flores, Açores. Ph D Thesis. FCTUC, Coimbra University, Portugal, Volumes I and II. 403p. (unpublished).

Baird, W., 1838. The Natural History of the British Entomostraca. Magazine of zoology and botany, 2: 132-144.

Baird, W., 1850. Description of several new species of Entomostraca. Annals and Magazine of Natural History, series 2, 10: 56-59.

Barbeito-Gonzales, P. J., 1971. Die Ostracoden des Küstenbereiches von Naxos (Griechenland) und ihre Lebensbereiche. Mitteilungen aus dem Hamburgischen Zoologischen Museum und Institut, 67, 255-326.

Beagrie, N. 2006. Digital Curation for Science, Digital Libraries, and Individuals. The International Journal of Digital Curation, 1(1): 3-16.

Benson, R. H. & Coleman, G. L., 1963. Recent marine Ostracodes from the eastern Gulf of Mexico. *In:* R. C. Moore (Ed), Arthropoda. University of Kansas Publications, Paleont. Contr., pp. 1-52.

Benson, R.H. & Maddocks, R.L., 1964. Recent Ostracodes of Knysna Estuary, Cape Province, Union of South Africa. Univ. Kansas Paleontol. Contrib. 5: 1– 39 (Arthropoda).

Berning, B. & Kuklinski, P. 2008. North-east Atlantic and Mediterranean species of the genus Buffonellaria (Bryozoa, Cheilostomata): implications for biodiversity and biogeography. Zoological Journal of the Linnean Society 152(3): 537-566.

Bonaduce, G., Ciampo, G., Masoli, M., 1975. Distribution of ostracoda in the Adriatic Sea. Pubblicazioni della Stazione zoologica Di Napoli, 40(1): 1-154.

Bonaduce, G., Ciampo, G., Masoli, M., 1976. Distribution of Ostracoda in the Adriatic Sea. Pubblicazione della Stazione Zoologica di Napoli, 40 Suppl., 1-304.

Bonaduce, G., Ruggieri, G., Russo, A., 1988. New Ostracode genera of the Mediterranean Miocene. Bollettino della Società Paleontologica Italiana 27 (3): 349-360.

Bonaduce, G., Ruggieri, G., Russo, A., Bismuth, H., 1992. Late Miocene Ostracods from the Ashtart 1 well (Gulf of Gabès, Tunisia). Bollettino della Società Paleontologica Italiana 31: 3–93.

Bosquet, J., 1852. Description des Entomostracés fossiles des terrains tertiaires de la France et de la Belgique. Acandeme Royale, Belgique, 24: 142p.

Borges, P., Andrade, C., Freitas, C., 2002. Dune, bluff and beach erosion due to exhaustive sand mining – the case of Santa Bárbara, S. Miguel (Azores, Portugal). Journal of Coastal Research, Special Issue, 36: 89-95.

Borges, P., 2003. Ambientes litorais nos grupos Central e Oriental do Arquipélago dos Açores. Doctoral thesis, Universidade dos Açores, 413p.

Borges, P.A.V., Costa, A., Cunha, R., Gabriel, R., Gonçalves, V., Martins, A.F., Melo, I., Parente, M., Raposeiro, P., Rodrigues, P., Santos, R.S., Silva, L., Vieira, P. & Vieira, V. (Eds.) (2010). A list of the terrestrial and marine biota from the Azores. Princípia, Cascais, 432 pp.

Brady, G.S., 1868. A monograph of Recent British Ostracoda. The transactions of the Linnean Society of London, 353p.

Brady, G. S., 1902. On new or imperfectly known Ostracoda, chiefly from a Collection in the Zoological Museum, Copenhagen. Trans.zool.Soc.London, 16: 179-210.

Brunton, H. 1979. The development of a computer-based curatorial system for Palaeontology at the British Museum (Natural History). Special Papers in Palaeontology, 22: 159-173.

Brunton, H., Besterman, T., Cooper, J. (eds) 1984. Guidelines for the curation of geological materials. Geological Society of London Miscellaneous Paper, 17, xxx pp.

Cacchione, D.A., Drake, D.E., Ferreira, J.T., Tate, G.B., 1994. Bottom stress estimates and sand transport on northern California inner continental shelf. Cont. Shelf Res., 14: 1273-1289.

Cabral, M.C., Freitas, M.C., Andrade, C., Cruces, A., 2006. Coastal evolution and Holocene ostracods in Melides lagoon (SW Portugal). Marine Micropaleontology, 60: 181–204.

Calado, H., Borges, P., Phillips, M., Alves, K.Ng.F., 2011. The Azores archipelago, Portugal: improved understanding of small island coastal hazards and mitigation measures. Natural Hazards, 58: 427–444.

Calhoun, R.S., Fletcher, C.H., Harney, J.N., 2002. A budget of marine and terrigenous sediments, Hanalei Bay, Kauai, Hawaiian Islands. Sed. Geol., 150: 61-87.

Callapez, P. & Soares, A.F., 2000. Late Quaternary marine mollusks from Santa Maria (Azores); paleoecologic and paleobiogeographic considerations. Ciências da Terra (UNL), 14: 313-322.

Calvet, L., 1931. Bryozoaires provenant des campagnes scientifiques du Prince Albert I de Monaco. Campagnes Scientifiques Albert I Prince Souverain de Monaco. Imprimerie de Monaco, 152p.

Calvert, A.T., Moore, R.B., McGeehin, J.P., Rodrigues da Silva, A.M., 2006. Volcanic history and 40Ar/39Ar and 14C geochronology of Terceira Island, Azores, Portugal. Journal of Volcanology and Geothermal Research, 156: 103-115.

Carbonel, P., 1985. Néogène. In: Oertli, H. (Ed.), Atlas des Ostracodes de France. Bulletin des Centres de Recherches Exploration Production Elf- Aquitaine, Pau, Mémoire 9: 313–345.

Carvalho, F., 2003. Elementos do clima de agitação marítima no grupo central dos Açores. Instituto de Meteorologia, Lisboa. 97 pp.

Ciampo, G., 1986. Ostracodi del limite Tortoniano-Bessiniano in alcune sezioni italiane. Bollettino della Società Paleontologica Italiana, 24(1): 29-110.

Chiocci, F.L. & Romagnoli, C., 2004. Submerged depositional terraces in the Aeolian Islands (Sicily). In: Atlas of submerged depositional terraces along the Italian coasts (Eds F.L. Chiocci, S. D'Angelo and C. Romagnoli), Memorie Descrittive della Carta Geologica d'Italia, vol. 58. APAT, Roma, 81-114.

Chiocci, F.L., D’Angelo, S., Romagnoli, C., 2004. Atlas of Submerged Depositional Terraces along the Italian coasts. Memorie Descrittive della Carta Geologica d’Italia, vol. 58. APAT. Roma. 197 pp.

Coimbra, J.C., Pinto, I.D., Wqrdig, N.L., Carmo, D.A., 1999. Zoogeography of Holocene Podocopina Ostracoda from the Brazilian equatorial continental shelf. Marine Micropaleontology. 37: 365– 379.

Costa, A. C., 2003. Diversidade de invertebrados das comunidades algais do subtidal de São Miguel e perturbação ambiental, XV+196pp. Unpublished Ph.D. thesis, Universidade dos Açores, Ponta Delgada.

Costa, 2010. List of marine invertebrates – Arthopoda (Copepoda, Amphipoda, Ostracoda). *In*: Borges, P.A.V., Costa, A., Cunha, R., Gabriel, R., Gonçalves, V., Martins, A.F., Melo, I., Parente, M., Raposeiro, P., Rodrigues, P., Santos, R.S., Silva, L., Vieira, P. & Vieira, V. (eds.) A list of the terrestrial and marine biota from the Azores. pp. 9-33, Princípia, Cascais, 432 pp.

Cronin, T.M., Boomer, I., Dwyer, G., Rodríguez-Lázaro, J., 2002. Ostracoda and Paleoceanography. In: Holmes, J., Chivas, A.R. (Eds.). The Ostracoda. Applications in Quaternary Research. American Geophysical Union, Washington, 99–119.

Conger, C.L., Fletcher, C.H., Hochberg, E.H., Frazer, N. and Rooney, J.J.B., 2009. Remote sensing of sand distribution patterns across an insular shelf: Oahu, Hawaii. Marine Geology, 267: 175-190.

Cookman, J.L. & Flemings, P.B., 2001. STORMSED1.0: hydrodynamics and sediment transport in a 2-D, steady-state, wind- and wave-driven coastal circulation model. Comput. Geosci., 27: 647-674.

Cowell, P.J., Hanslow, D.J., Meleo, J.F., 1999. The shoreface. In: Handbook of beach and shoreface morphodynamics (Ed A.D. Short), pp. 39-71. Wiley and Sons, Chichester.

Chapman, G., 1955. Aspects of the fauna and flora of the Azores. VI. The density of animal life in the Coralline alga zone. Annals and Magazine of Natural History, 12(8): 801-805.

Chovelon, P., 1982. Évolution volcanotectonique des iles de Faial et de Pico, Archipel des Açores - Atlantique Nord. Thèse de Doctorat de 3ème Cycle, Université de Paris-Sud, Centre D'Orsay. 193p.

Dean, R.G. and Dalrymple, R.A., 1991. Water wave mechanics for Engineers and Scientists. Advanced series on Ocean Engineering, 2. World Scientific Publishing, Singapore, 353 pp.

De Cáceres, M., Legendre, P., Moretti, M., 2010. Improving indicator species analysis by combining groups of sites. Oikos, 119: 1674-1684.

Dias, J., 2001. Geologia e tectónica da ilha do Corvo (Açores-Portugal): Contributos para o ordenamento do espaço físico. MSc Thesis, Faculdade de Ciências e Tecnologia, Universidade de Coimbra, 102p.

Ducasse, O., Guernet, C., Tambareau, Y., 1985. Paléogène. In: Oertli, H. (Ed.), Atlas des Ostracodes de France. Bulletin des Centres de Recherches Exploration Production Elf- Aquitaine, Pau, Mémoire 9: 313–345.

Dufrene, M., Legendre, P., 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs, 67: 345-366.

Dumas, S. & Arnott, R.W.C., 2006. Origin of hummocky and swaley cross-stratification - The controlling influence of unidirectional current strength and aggradation rate. Geology, 34: 1073-1076.

Duke, W.L., 1990. Geostrophic circulation or shallow marine turbidity currents - the dilemma of paleoflow patterns in storm-influenced prograding shoreline systems. J. Sed. Petrol., 60: 870-883.

Felton, E.A., 2002. Sedimentology of rocky shorelines: 1. A review of the problem, with analytical methods, and insights gained from the Hulopoe Gravel and the modern rocky shoreline of Lanai, Hawaii. Sed. Geol. 152: 221-245.

Feraud, G., Kaneoka, I., Allègre, J.C., 1980. K/Ar ages and stress pattern in Azores: geodinamic implications. Earth and Planetary Science Letters, 46: 275-286.

Feraud, G., Schmincke, H.U., Lietz, J., Gastaud, J., Pritchard, G. and Bleil, U., 1981. New K-Ar Ages, Chemical Analyses and Magnetic Data of Rocks from the Islands of Santa Maria (Azores), Porto Santo and Madeira (Madeira Archipelago) and Gran Canaria. Bulletin of Volcanology, 44(3): 359-375.

Ferreira, O. da Veiga, 1955. A fauna Miocénica da Ilha de Santa Maria (Açores). Comunicações dos Serviços Geológicos de Portugal, Lisboa. XXXVI: 40p.

Ferreira, O. da Veiga, 1961. Afloramentos de calcário miocénico da Ilha de Santa Maria (Açores). Comunicações dos Serviços Geológicos de Portugal, Lisboa. XLV: 493-501.

Field, M.E. & Roy, P.S., 1984. Offshore transport and sand-body formation; evidence from a steep, high energy shoreface, southeastern Australia. J. Sed. Res., 54: 1292-1302.

Fischer, S., 1855. Beitrag zur Kenntnis der Ostracoden. Akademie der mathematisch-physikalischen. Classe der Königlich-Bayerischen Akademie der Wissenschaften 7: 635–666.

Fothergill, H. 2005. The state and status of geological collections in United Kingdom museums: 2001. The Geological Curator 8(3): 53–136.

Frenzel, P., Keyser, D., Viehberg, F.A., 2010. An illustrated key and (palaeo)ecological primer for Postglacial to Recent Ostracoda (Crustacea) of the Baltic Sea. Boreas 10.1111/j.1502-3885.2009.00135.x.

Frenzel, P., Boomer, I, 2005. The use of ostracods from marginal marine, brackish waters as bioindicators of modern and Quaternary environmental change. Palaeogeography, Palaeoclimatology, Palaeoecology, 225: 68–92.

Gagan, M.K., Chivas, A.R. and Herczeg, A.L., 1990. Shelf-wide erosion, deposition, and suspended sediment transport during Cyclone Winifred, central Great Barrier Reef, Australia. J. Sediment. Petrol., 60: 456-470.

Gelman, A., Carlin, J.B., Stern, H.S., Rubin, D.B., 1995. Bayesian Data Analysis. Chapman & Hall, London.

Guillaume, M-C, Peypouquet, J-P, Tetart, J., 1985. Quaternaire et Actuel. In: Oertli, H. (Ed.), Atlas des Ostracodes de France. Bulletin des Centres de Recherches Exploration Production Elf- Aquitaine, Pau, 9: 313–345.

Gordon, Taylor, Bigey, 2009. Phylum BRYOZOA: moss animals, sea mats, lace corals. In Gordon, D.P. (Ed.), New Zealand Inventory of Biodiversity Volume One. Kingdom Animalia: Radiata, lophotrochozoa, Deuterostomia. Canterbury University Press, Christchurch.

Hayward , P.J. & Ryland, J.S., 1979. British Ascophoran Bryozoans: keys and notes for the identification of the species. The Linnean Society of London, 312p.

Harmelin, J.G., 1977. Bryozoaires du banc de la Conception (nord des Canaries). Campagne Cineca I du «Jean Charcot». Bulletin du Muséum National d'Histoire Naturelle, série 3, 492: 1057-1075.

Harmelin, J.G., 1978. Sur quelques Cribrimorphe (Bryozoa, Cheilostomata) de lÁtlantique oriental. Tethys, 8(2): 173-192.

Harmelin, J.G., 1988. Espèces affines microsympatriques chez *Puellina* (Bryozoa, Cheilostomata) et description déspèces nouvelles. Zoologica Scripta, 17(1): 25-38.

Harmelin, J.G. & Aristegui, J., 1988. New Cribrilinidae (Bryozoa, Cheilostomata) from the upper bathyal of the Atlanto-Mediteranean region. Journal of Natural History, 22: 507-535.

Hartmann, G., 1964. Asiatische Ostracoden: systematische und zoogeographische Untersuchungen. Internationale Revue der Gesamten Hydrobiologie, System. Beiheft 3: 7-155.

Harney, J.N., Grossman, E.E., Richmond, B.M. and Fletcher Iii, C.H., 2000. Age and composition of carbonate shoreface sediments, Kailua Bay, Oahu, Hawaii. Coral Reefs, 19, 141-154.

Harney, J.N. & Fletcher, C.H., III, 2003. A budget of carbonate framework and sediment production, Kailua Bay, Oahu, Hawaii. J. Sed. Res., 73: 856-868.

Hartung, G., 1860. Die Azoren in ihrer äusseren Erscheinung und nach ihrer geognostichen Natur, Engelmann, Leipzig. 355p.

Hernández-Molina, F.J., Fernández-Salas, L., Lobo, F., Somoza, L. and Díaz-del-Río, V., 2000. The infralittoral prograding wedge: a new large-scale progradational sedimentary body in shallow marine environments. Geo-Mar. Lett., 20(2): 109-117.

Hildenbrand, A., Madureira, P., Ornela Marques, F., Cruz, I., Henry, B., Silva, P., 2008. Multi-stage evolution of a sub-aerial volcanic ridge over the last 1.3 Myr: S. Jorge Island, Azores Triple Junction. Earth and Planetary Science Letters, 273: 289-298.

Holmes, J.A. & Chivas, A.R., 2002. The Ostracoda. Applications in Quaternary Research. American Geophysical Union, Washington, 185-203.

Hondt, J.L., 1975. Bryozoaires Cténostomes et Cheilostomes (Cribrimorphes et Escharellidae exceptés) provenant des dragages de la campagne océanographique Biaçores du «Jean-Charcot». Bulletin du Muséum National d'Histoire Naturelle, Zoologie 209, 3º serie, 553-600.

Horne, D. J. & Whittaker, J. E., 1980. On *Semicytherura tela* Horne & Whittaker sp. nov. Stereo-Atlas of Ostracod Shells, 7: 125-130.

Horne, D.J., 1982a. The vertical distribution of phytal ostracods in the intertidal zone at Gore Point, Bristol Channel, U.K. Journal of Micropalaeontology, 1:71-84.

Horne, D.J., 1982b. The vertical distribution of phytal ostracods in the intertidal zone at Gore Point, Bristol Channel, U.K. Journal of Micropalaeontology, 1:71-84.

Horne, D. J. 1986. On *Aurila woutersi* Horne sp. nov. Stereo-Atlas of Ostracod Shells 13(1): 33-38.

Horne, D.J., Bruce, A., Whittaker, J.E., 2001. Ostracoda, in: Costello, M.J. et al. (Ed.) (2001). European register of marine species: a check-list of the marine species in Europe and a bibliography of guides to their identification. Collection Patrimoines Naturels, 50: pp. 244-251.

Horne, D.J., Cohen, A., Martens, K., 2002. Taxonomy, morphology and biology of Quaternary and living ostracoda. – In: Holmes, J.A. & Chivas, A.R. (eds.), The Ostracoda. Application in Quaternary Research. - Geophysical Monograph 131, Washington DC: 5-36.

Hornibrook, N. de B., 1952. Tertiary and Recent marine Ostracoda (Crustacea) of New Zealand. Palaeontological Bulletin New Zealand Geological Survey 18: 1–182.

Huang, L., 1997. Calcareous nannofossil biostratigraphy in the Pearl River Mouth Basin, South China Sea, and Neogene reticulofenestrid coccoliths size distribution pattern. Marine Micropaleontology, 32: 31-57.

Hull, S.L., 1997. Seasonal changes in ostracod abundance and diversity on four species of algae with differing structural complexity. Marine Ecology Progress Series, 161: 71-82.

Immenhauser, A. 2009. Estimating palaeo-water depth from the physical rock record. Earth-Sci. Rev., 96(1-2): 107–139.

IOC IHO & BODC, 2003. Centenary Edition of the GEBCO Digital Atlas, published on CD-ROM on behalf of the Intergovernmental Oceanographic Commission and the International Hydrographic Organization as part of the General Bathymetric Chart of the Oceans. British Oceanographic Data Centre, Liverpool, U.K.

Janssen, A.W., Kroh, A., Ávila, S.P., 2008. Early Pliocene heteropods and pteropods (Mollusca, Gastropoda) from Santa Maria Island (Azores, Portugal): systematics and biostratigraphic implications. Acta Geologica Polonica, 58: 355-369.

Johnson, C.L., Wijbrans, J.R., Constable, C.G., Gee, J., Staudigel, H., Tauxec, L., Forjaz, V.H., Salgueiro, M., 1998. 40Ar/39Ar ages and paleomagnetism of São Miguel lavas, Azores. Earth and Planetary Science Letters, 160: 637-649.

Johnson, J. & Stevens, I., 2000. A fine resolution model of the eastern North Atlantic between the Azores, the Canary Islands and the Gibraltar Strait. Deep-Sea Reserch part I, 47: 875-899.

Jones, T.R., 1850. Description of the Entomostraca of the Pleistocene beds of Newbury, Copford, Clacton and Grays. Annals and Magazine of Natural History; series 2, 6: 25-28.

Jones, J.G. & Nelson, P.H.H., 1970. The flow of basalt lava from air into water, its structural expression and stratigraphic significance. Geol. Mag., 107: 13-19.

Jullien, J., 1882. Dragages du 'Travailleur', Bryozoaires. Espèces draguées dans lÓcean Atlantique en 1881. Bulletin de la Société Zoologique de France, 6: 271-285.

Jullien, P.J. & Calvet, L., 1903. Bryozoaires provenant des campagnes de l'HIRONDELLE. Campagnes Scientifiques Albert I Prince Souverain de Monaco. Imprimerie de Monaco, 188p.

Keij, A.J., 1953. Preliminary note on the Recent Ostracoda of the Snellius Expedition. Koninkl. Nederl. Akademie Van Wetenschappen - Amsterdam. Ser. B, 56(2): 155-168.

Keij, A.J., 1958. Note on the Lutetian Ostracoda of Damary (Marne), France. Koninkl. Nederl. Akademie Van Wetenschappen - Amsterdam. Proc., Ser. B, 61(1): 63-73.

Kéry, M., 2010. Introduction to WinBUGS for Ecologists. A Bayesian approach to regression, ANOVA, mixed models and related analyses. Academic Press, Elsevier, Burlington, MA.

Keyser, D. 1988. Ostracoda. Introduction to the Study of Meiofauna. R. P. Higgins and H. Thiel. Washington,D.C.-London, Smithsonian Institution Press: 370-376.

Keyser, D. & Schöning, C., 2000 Holocene Ostracoda (Crustacea) from Bermuda. Senckenbergiana Lethaea, 80: 567-591.

Keyser, D. & Aladin, N., 2004. Ostracods and their adjustment to saline environments. Mitteilungen aus dem Hamburgischen Zoologischen Museum und Institut 101: 157-167.

Kidwell, S.M. & Bosence, D.W.J., 1991. Taphonomy and time-averaging of marine shelly faunas. In: Taphonomy, Releasing the Data Locked in the Fossil Record (Eds P.A. Allison & D.E.G. Briggs), pp. 115-209. Plenum Press, New York.

Kilenyi, T. I. & Whittaker, J. E., 1974. On *Cyprideis torosa* (Jones, 1850). Stereo-Atlas of Ostracod Shells, 2: 21-32.

King, R., Morgan, B.J.T., Gimenez, O., Brooks, S.P., 2010. Bayesian analysis for Population Ecology. Chapman & Hall/CRC, Boca Raton.

Kirby, M.X., Jones, D.S., Ávila, S.P., 2007. Neogene shallow-marine palaeoenvironments and preliminary Strontium isotope chronostratigraphy of Santa Maria Island, Azores. In: Proceedings of the 1st "Atlantic Islands Neogene" International Congress, Ponta Delgada, (Eds S.P. Ávila & A.M. de Frias Martins). *Açoreana*, 5: 112–115.

Kontrovitz, M., Pani, E.A., Bray, H., 1998. Experimental crushing of some podocopid ostracode valves: an aspect of taphonomy. PALAIOS, 13(5): 500-507.

Kornicker, L.S., 1959. Analysis of factors affecting quantitative estimates of organism abundance. Journal of Sedimentary Petrology, 29(4): 596-601.

Kroh, A., Bitner, M.A., Ávila, S.P., 2008. *Novocrania turbinata* (Brachiopoda) from the Early Pliocene of the Azores (Portugal). *Acta Geologica Polonica*, 58: 473-478.

Lachenal, A.M., 1989. Écologie des ostracods du domaine Méditerranéen. Application au Golfe de Gabès (Tunisie orientale). Les variations du niveau marin depuis 30.000 ans. Documents Laboratoire de Géologie Lyon, 108: 1-239.

Leckie, D.A. & Walker, R.G. (1982) Storm-dominated and tide-dominated shorelines in Cretaceous Moosebar-Lower Gates Interval - outcrop equivalents of deep basin gas trap in Western Canada. *AAPG Bull.*, 66: 138-157.

Li, M.Z., Amos, C.L., Heffler, D.E., 1997. Boundary layer dynamics and sediment transport under storm and non-storm conditions on the Scotian Shelf. Marine Geoogy., 141: 157-181.

Liebau, 1991. Skuptur-Evolution bei Ostrakoen am beisbel europäischer "*Quadracytheren*". - Geolgie und Paläontologie in Westfalen, 13: 395p.

Lourenço, N., Miranda, J.M., Luís, J.F., Ribeiro, A., Mendes Victor, L.A., Madeira, J., Needham, H.D., 1998. Morpho-tectonic analysis of the Azores Volcanic Plateau from a new bathymetric compilation of the area. Marine Geophysical Researches, 20: 141-156.

Lourens, L., Hilgen, F., Shackleton, N.J., Laskar, J. Wilson, J., 2004. Appendix 2. Orbital tuning calibrations an conversions for the Neogene Period. In: Gradstein, F. Ogg, J. Smith, A. (eds.), A Geologic Time Scale 2004., Cambridge University Press, 469-484.

Luis, J.F., Miranda, J.M., Galdeano, A., Patriat, P., Rossignol, J.C. and Mendes Victor, L.A., 1994. The Azores triple junction evolution since 10 Ma from an aeromagnetic survey of the Mid-Atlantic Ridge. Earth and Planetary Science Letters, 125: 439-459.

Machado, C.P., Coimbra, J.C., Carrenõ, A.L., 2005. The ecological and zoogeographical significance of the sub-Recent Ostracoda off Cabo Frio, Rio de Janeiro State, Brazil. Marine Micropaleontology, 55: 235– 253.

Maddocks, R.F., 1969. Revision of Recent Bairdiidae (Ostracoda). United States National Museum Bulletin, 295: 1-126.

Madeira, J.E.O., 1986. Geologia estrutural e enquadramento geotectónico da ilha de Santa Maria (Açores). MSc. Thesis, Universidade de Lisboa. 107p.

Madeira, J. & Ribeiro, A., 1990. Geodynamic models for the Azores triple junction: a contribution from tectonics. Tectonophysics, 184: 405-415.

Madeira, P., Kroh, A., Cordeiro, C., Meireles, R.P., Ávila, S.P., 2011. The fossil echinoids of Santa Maria Island, Azores (Northern Atlantic Ocean). Acta Geologica Polonica, 61: 243-264.

Margulis, L & Schwartz, K.V., 1999. Five kingdoms. An illustrated guide to the phyla of life on Earth, 520 pp. W.H. Freeman and Company, New York.

Mayer, K., 1864. Die Tertiär-Fauna der Azoren und Madeiren. Systematisches Verzeichniss der fossilen Reste von Madeira, Porto Santo und Santa Maria nebst Beschreibung der neuen Arten, Zürich, VI: 107p.

McKenzie, K.G., Ducasse, O., Dufour, E., Peypouquet J.-P., 1979. Monographie bibliographique, stratigraphique et paléoécologique sur les Ostracodes cénozoïques du Bassin d'Aquitaine et du Golfe de Gascogne. Bulletin de l'Institut de Geologie du Bassin d'Aquitaine, numéro special, 1-195.

McCarthy, M.A., 2007. Bayesian Methods for Ecology. Cambridge University Press, Cambridge, UK.

Medin, 2011. UK checklist of marine species derived from the applications Marine Recorder and UNICORN, version 1.0.

Meireles, R.P.; Frias Martins, A.; Ávila, S., 2011a. Recent Ostracodes from the Azores Archipelago. Joannea Geologie und Paläontologie, 11:132-136p.

Meireles, R.P.; Gliozzi, E.; Faranda, C.; Frias Martins, A.; Ávila, S., 2011b. Late Miocene marine Ostracodes from Azores, north Atlantic. Joannea Geologie und Paläontologie, 11:128-131p.

Meireles, R.P., Faranda, C., Gliozzi, E., Pimentel, A., Zanon, V. & Ávila, S., 2012. Late Miocene marine Ostracodes from Santa Maria Island, Azores (NE Atlantic): Systematics, Palaeoecology and PalaeoBiogeography. Revue de Micropaléontologie. 55: 133–148.

Meireles, R.P., R. Quartau, R. Ramalho, A.C. Rebelo, J. Madeira, V. Zanon, S.P. Ávila, 2013. Depositional processes on oceanic island shelves – evidence from storm-generated Neogene deposits from the Mid North Atlantic. Sedimentology (accept).

Meireles, R.P., Silva, L., Borges, P., Keyser, D., Martins, A.M.deF. & Ávila, S.P., 2013. The shallow marine ostracods communities of the Azores (Mid-North Atlantic): taphonomy and palaeo-ecology. Geological Acta (submitted a).

Meireles, R.P., Keyser, D., Ávila, S.P., 2013. Holocene to Recent shallow marine ostracods of the Azores (NE Atlantic): taxonomy and biogeography. (submitted b).

Meisch, C. & Broodbakker, N. W., 1993. Freshwater ostracoda (Crust.) collected by Prof.J.H.Stock on the Canary and Cape Verde islands. With an annotated checklist of the freshwater Ostracoda of the Azores, Madeira, the Canary, the Selvagens and Cape Verde Islands. Traveaux Scientifiques du Musée d'Histoire Naturelle de Luxembourg 19: 1-75.

Micael, J., Alves, M.J., Jones, M.B., Costa, A.C., 2012. Diversity of shallow-water asteroids (Echinodermata) in the Azorean archipelago. Marine Biodiversity Records, 5: e.49. doi:10.1017/S1755267211000534.

Mitchell, N.C., Quartau, R., Madeira, J., 2012. Assessing landslide movements in volcanic islands using near-shore marine geophysical data: south Pico Island, Azores. Bull. Volcanol., 74: 483-496.

Montenegro, M.E., Pugliese, N., Bonaduce, G., 1998. Shelf ostracods distribution in the Italian seas. In: Crasquin-Soleau, S., Braccini, E., Lethiers, F. (Eds.), What About Ostracoda! Elf Ep-E´ ditions, Paris-Bierville, 317–327.

Morelock, J., Grove, K. and Hernandez, M.L., 1983. Oceanography and patterns of shelf sediments, Mayaguez, Puerto Rico. J. Sed. Res., 53: 371-381.

Morin, J.G., Cohen, A.C., 1991. Bioluminescent displays, courtship, and reproduction in ostracodes. In: R.T. Bauer and J.W. Martin (Eds), Columbia University Press, New York, 1-16.

Morton, B. & Britton, J.C., 2000. The origins of the coastal and marine flora and fauna of the Azores. Oceanography and Marine Biology: an Annual Review, 38: 13-84.

Mount, J.F. and Kidder, D. (1993) Combined flow origin of edgewise intraclast conglomerates - Sellick Hill Formation (Lower Cambrian), South-Australia. Sedimentology, 40, 315-329.

Moyes, J., 1965. Les Ostracodes du Miocène aquitain. Essai de paléoécologie stratigraphique et de paléogéographie. Imprimerie Drouillard, Bordeaux.

Müeller, G.W., 1894. Die Ostracode des Golfes von Neapel und der Angrenzenden Meeres-Abschnitte: Zoologischen Station Zu Neapel, Fauna und Flora des Golfes von Neapel, Monographie, 21: 404p.

Myrow, P.M. & Southard, J.B., 1996. Tempestite deposition: J. Sed. Res., 66: 875-887.

Myrow, P.M., 2005. Storms and Storm Deposits. In: *Encyclopedia of Geology* (Eds. Selley, R.C., Cocks, R., Pilmer, I.), pp. 580-587. Elsevier Limited, Oxford.

Namiotko, T., Danielopol, D.L., Baltanás, A., 2011. Soft body morphology, dissection and slide-preparation of Ostracoda: a primer. Joannea Geologie und Paläontologie, 11: 327-343.

Nascimento, A., 1988. Ostracodos do Miocénico da Bacia do Tejo: sistematica, biostratigrafia, paleoecologia, paleogeografia, e relações Mediterrâneo-Atlântico. Dissertação do Grau de Doutor em Geologia (Estratigrafia e Paleobiologia), Universidade Nova de Lisboa, 1-305.

Nascimento, A., 1989. Nouvelles espèces d’ostracodes du Miocène du bassin du Tage (Portugal). Ciências da Terra (UNL), Lisboa, 10: 107-126.

Needham, H. & Francheteau, J., 1974. Some characteristics of the rift valley in the Atlantic Ocean near 36° 48′ north. Earth and Planetary Science Letters, 22: 29-43.

Nielsen, C., 1995. Animal Evolution. Interrelationships of the living phyla, 467 pp. Oxford University Press, Oxford.

Nittrouer, C.A. & Wright, L.D., 1994. Transport of particles across continental shelves. Rev. Geophys., 32: 85-113.

Nogueira, A. A. E., Ramos, M. I. F., Puckett, T. M., 2011. The Genera *Haplocytheridea* Stephenson, 1936 and *Cytheridea* Bosquet, 1852 (Subphylum Crustacea, Class Ostracoda) from the Early Miocene Pirabas Formation, Brazil. Revue de Micropaléontologie 54: 215-235.

Nunes, J.C., 2006. The Azores, islands of geodiversity: the contribution of Santa Maria Island. Açoriana, proceedings of the 1st Atlantic Islands Neogene, International, Congress (AINIC), 14p.

Oertli, H., 1956. Ostrakoden aus der oligozänen und miozänen Molasse der Schweiz. Inauguraldissertation der Philosophisch-naturwissenschaftlichen Fakultät der Universität Bern zur Erlangung der Doktorwiirde, 74: 1–118, T. 1–16.

Ogston, A.S., Storlazzi, C.D., Field, M.E., Presto, M.K., 2004. Sediment resuspension and transport patterns on a fringing reef flat, Molokai, Hawaii. Coral Reefs, 23: 559-569.

Pascual, A., Rodriguez-Lazaro, J., Martín-Rubio, M., Jouanneau, J-M., Weber, O., 2008. A survey of the benthic microfauna (foraminifera, Ostracoda) on the Basque shelf, southern Bay of Biscay. Journal of Marine Systems, 72: 35–63.

Park, L.E., Cohen, A.S., Martens, K., 2003. The impact of taphonomic processes on interpreting paleoecologic changes in large lake ecosystems: ostracodes in Lakes Tanganyika and Malawi. Journal of Paleolimnology, 30: 127-138.

Petkovski, T. K., 1963. Über Süsswasser-Ostracoden der Azoren. Boletim do Museu Municipal do Funchal, 17: 49-65.

Petkovski, T.K., Meisch, C., Wouters, K, 1993. Taxonomic revison of the freshwater Ostracoda species *Cypridopsis lusatica* Schäfer, 1943 (Crustacea). Travaux Scientifiques du Musee national d'histoire naturelle de Luxembourg, 19: 49-66.

Porebski, S.J. & Gradzinski, R., 1990. Lava-fed Gilbert-type delta in the Polonez Cove Formation (Lower Oligocene), King George Island, West Antarctica. In: Coarse-grained deltas (Eds. Colella, A and Prior, DB), International Association of Sedimentologists, Special Publication, 10: 335-351.

Poulsen, E. M., 1972. "On the *Bathyconchoecia* (Ostracoda, Myodocopa) from the Azores collected by the bathyscaphe "Archimede" in 1969." Tethys 4 (2): 445-456.

Pokorný, V., 1955. Grundzüge der zoologischen Mikropaläontologie. II. Verb. Deutscher Verlag Wiss, 453p.

Puri, H. S., 1960. Recent Ostracoda from the west coast of Florida. Transactions Gulf Coast Association of Geological Societies 10: 107-149.

Puri, H.S., 1966. Ecological distribution of Recent Ostracoda. Proceeding in the Symposium of Crustacea, 457–495.

Quartau, R., 2007. The insular shelf of Faial: Morphological and sedimentary evolution. Ph.D. thesis. Universidade de Aveiro, Aveiro, Portugal. 301 pp.

Quartau, R., Trenhaile, A.S., Mitchell, N.C., Tempera, F., 2010. Development of volcanic insular shelves: Insights from observations and modelling of Faial Island in the Azores Archipelago, Marine Geology, 275(1–4): 66–83, doi:10.1016/j.margeo.2010.04.008.

Quartau, R., Tempera, F., Mitchell, N.C., Pinheiro, L.M., Duarte, H., Brito, P.O., Bates, C.R., Monteiro, J.H., 2012. Morphology of the Faial Island shelf (Azores): the interplay between volcanic, erosional, depositional, tectonic and mass-wasting processes. Geochemistry, Geophysics, Geosystems, 13, doi:10.1029/2011GC003987.

Quiquerez, A., Allemand, P., Dromart, G., J.-P.Garcia (2004) Impact of storms on mixed carbonate and siliciclastic shelves: insights from combined diffusive and fluid flow transport stratigraphic forward model. Basin Res., 16: 431-449.

Ramalho, R., 2011. Building the Cape Verde Islands, Springer. 1st Edition. 262 p.

Reiss, W., 1862. Mittheiluengen über die tertiären Schichten von Santa Maria, der südlichsten der Azoren, und ihre organischen Einschlüsse. Neues Jarhrbuch für Mineralogie, Geognosie, Geologie und Petrefactenkunde, 1-48.

Reverter-Gil, O. & Fernández-Pulpeiro, E., 2007. Species of genus *Schizotheca* (Bryozoa, Cheilostomata) described in the Atlantic-Mediterranean region, with notes on some species of *Parasmittina* Osburn. Journal of Natural History, 41(29-32): 1929-1953.

Richard, J., 1896. Sur la faune des eaux douces des Acores. Bulletin de la Societe Zoologique de France 21: 171-178.

Rogerson, M., Rohling, E.J., Weaver, P.P.E., Murray, J.W., 2004. The Azores Front since the Last Glacial Maximum. Earth and Planetary Science Letters 222: 779-789.

Rosenfeld, A., 1977. Die rezenten Ostracoden-Arten der Ostsee. Meyniana 29: 11–49.

Ruggieri, G., 1953. Età e faune di un terrazzo marino sulla costa ionica della Calabria. Giornale di Geologia serie 2A, 23: 19-168.

Rusu, L., & Guedes Soares, C., 2012. Wave energy assessments in the Azores islands. Renewable Energy, 45: 183-196.

Ryan-Mishkin, K., Walsh, J.P., Corbett, D.R., Dail, M.B., Nittrouer, J.A., 2009. Modern sedimentation in a mixed siliciclastic-carbonate coral reel environment, La Parguera, Puerto Rico. Carib. J. Sci., 45: 151-167.

Ryland, J.S., 1970. Bryozoans. Hutchinson Univerity Library, London, 175p.

Santos, R.S., Porteiro, F.M., Barreiros, J.P., 1997. Marine Fishes of the Azores: An annotated checklist and bibliography. Arquipélago. Life and Marine Sciences. Supplement 1: XXVIII + 244 pp.

Sars, G.O., 1866. Oversight of Norges Marine Ostracoder. Videnskabsselskabet i Christiana Förhandlingar 7: 1–130.

Sars, G. O., 1925. An account of the Crustacea of Norway with short descriptions and figures of all the species. In, Bergen Museum 1925, pp. 73-208.

Sars, G.O., 1922. An account of the Crustacea of Norway. Vol. 9, Crustacea: Bergen Mus., pt. XV-XVI, 277p.

Schneidermann, N., Pilkey, O.H., Saunders, C., 1976. Sedimentation on the Puerto Rico insular shelf. *J. Sed. Res.*, 46: 167-173.

Schornikov, E.I. & Keyser, D., 2004. The morphology and classification of Lanceostomatinae (Ostracoda) from the nearshore zone of Madeira and the Canary islands. Lanceostomatinae (Ostracoda) from the nearshore zone of Madeira and the Canary islands. Revista Española de Micropaleontología, 36(1): 57-81.

Schwab, W.C., Rodriquez, R.W., Danforth, W.W., Gowen, M.H., 1996. Sediment distribution on a storm-dominated insular shelf, Luquillo, Puerto Rico, USA. Journal of Coastal Research, 12: 147-159.

Searle, R., 1980. Tectonic pattern of the Azores spreading centre and triple junction. Earth and Planetary Science Letters, 51: 415-434.

Serralheiro, A., Alves, C.A.M., Forjaz, V.H., Rodrigues, B., 1987. Carta Vulcanológica dos Açores, Ilha de Santa Maria. Escala 1:15.000 (Folhas 1 e 2). Serviço Regional de Protecção Civil dos Açores e Universidade dos Açores (Ed.). Ponta Delgada.

Serralheiro, A. & Madeira, J., 1990. Stratigraphy and geochronology of Santa Maria island (Azores): 357-376. Livro de Homenagem ao Prof. Carlos Romariz. Departamento de Geologia da Faculdade de Ciências da Universidade de Lisboa.

Serralheiro, A. 2003. A geologia da Ilha de Santa Maria, Açores. Açoreana, Revista de Estudos Açoreanos, 10 (1): 141-192.

Shipman, P., 1981. Life history of a fossil. Harvard University Press, London, 288p.

Short, A.D., 1999. Handbook of beach and shoreface morphodynamics. Wiley, Chichester, 379.

Smellie, J.L., 2000. Subglacial eruptions. In: Encyclopedia of Volcanoes (Ed. H. Sigurdsson). Academic Press, San Diego, California, 403–418.

Smith, A.M. & Gordon, D.P., 2011. Bryozoans of southern New Zealand: a field identification guide. Ministry of Fisheries. Report nº 75.

Spiegehalter, D.J., Best, N.G., Carlin, B.P., van der Linde, A., 2002. Bayesian measures of model complexity and fit. Journal of the Royal Statistical Society: Series B, 64: 583-639.

Spiegehalter, D.J., Thomas, A., Best, N.G., 2003. WinBUGS User Manual, Version 14 MCR Biostatistics Unit, Cambridge.

Stancheva, M., 1964. Ostracoda from the Neogene in north-western Bulgaria. III. Maeotian Ostracoda Bulgarian Akademic Nauk., Geological Institute, Series Palaeontology, 6: 83-84.

Storz, D., Schulz, H., Waniek, J.J., Schulz-Bull, D.E., Kucera, M., 2009. Seasonal and interannual variability of the planktic foraminiferal flux in the vicinity of the Azores Current. Deep-Sea Research I, 56: 107-124.

Storlazzi, C.D., Ogston, A.S., Bothner, M.H., Field, M.E., Presto, M.K., 2004. Wave and tidally-driven flow and sediment flux across a fringing coral reef: Southern Molokai, Hawaii. Cont. Shelf Res., 24: 1397-1419.

Teeter, J.W., 1973. Geographic distribution and dispersal of some Recent shallow-water marine Ostracoda. The Ohio Journal of Science 73(1): 46-54.

Theodoridis, S., 1984. Calcareous nannofossils biozonation of the Miocene and revision of the *Helicoliths* and *Discoaster*. Utrecht Micropaleontological Bulletins, 32: 271p.

Tittley, I. & Neto, A.I., 1995. The marine algal flora of the Azores and its biogeographical affinities. Boletim do Museu Municipal do Funchal, 4: 747-766.

Tsutsui, B., Campbell, J.F., Coulbourn, W.T., 1987. Storm-generated, episodic sediment movements off Kahe Point, Oahu, Hawaii. Marine Geology, 76: 281-299.

Tucker, M.J., 1991. Waves in Ocean Engineering: Measurement, analysis, interpretation. Ellis Horwood Series in Marine Science. Ellis Horwood Limited, Chichester, 431 pp.

Tucker, M.E., 2003. Sedimentary rocks in the field (2nd edition). Wiley. Chichester, 153p.

Uffenorde, H. 1972. Ökologie und jahreszeitliche Verteilung rezenter benthonischer Ostracoden des Limski Kanal bei Rovinj (nördliche Adria). Göttinger Arbeiten zur Geologie und Palaeontologie 13: 1-121.

Uliczny, F., 1969. Hemicytheridae und Trachyleberididae (Ostracoda) aus dem Pliozän der Insel Kephallinia (Westgriechenland). In. Dissertation Ludwig Maximmilian Universität, München, pp. 1-152.

Van Morkhoven, F.P.C.M., 1962. Post-Palaeozoic Ostracoda. Their Morphology, Taxonomy, and Economic Use. Volume I, General. Elsevier Publishing Company.

Van Morkhoven, F.P.C.M., 1963. Post-Palaeozoic Ostracoda: Their morphology, taxonomy, and economic use. Volume II. Elsevier Publishing Company. 478p.

Vierek, A., 2010. Source and depositional processes of coarse grained limestone event beds in Frasnian slope deposits (Kostomoty-Mogiki quarry, Holy Cross Mountains, Poland). Geologos, 16(3): 153-168.

Vogt, P.R. & Jung, W.Y., 2004. The Terceira Rift as hyper-slow, hotspot-dominated oblique spreading axis: a comparison with other slow-spreading plate boundaries. Earth and Planetary Science Letters, 218: 77-90.

Vos, A.P.C.de, 1957. Liste annotée des Ostracodes marins des environs des Roscoff. Trav.Stn.biol.Roscoff, 41: 1-74.

Wagner, C. W., 1957. Sur les Ostracodes du Quaternaire récent des Pays- Bas et leur utilisation dans l'étude géologique des dépots holocenes. In. Université de Paris, A, 707, pp. 1-259.

Waterman, A.S., Center, M.W., George, R.A., Vallette, N.S., Porter, A.F. Jr., Reilly, T.M., Weber, R.A., Roederer, R.V., Schmieder, J., Sarao, J.A., Fillon, R.H., 2011. Biostratigraphic Chart - Gulf Basin, USA. Quaternary and Neogene. PaleoData®, Inc., http://paleodata.com/downloads/PDI_Biochart_Neogene_8_ 11.pdf

Whatley, R.C., 1983. The application of Ostracoda to palaeoenvironmental analysis. In: Maddocks, R.F. (Ed.), Applications of Ostracoda. University of Houston, Geoscience, Houston, 51-77.

Whatley, R.C., 1988. Population structure of ostracods: some general principles for recognition of paleoenvironments. In: De Deckker, P., Colin, J.-P., Peypouquet, J.P. (Eds.), Ostracoda in the Earth Sciences. Elsevier, Amsterdam, 245– 256.

Whittaker, J. E., 1974. On *Semicytherura cornuta* (Brady). Stereo-Atlas of Ostracod Shells, 2, 77-84.

Whittaker, J.E., 1978. On *Xestoleberis rubens* Wittaker sp. nov. Stereo-Atlas Ostracod Shells, 5: 35-44.

White, W.M., Schilling, J.-G., Hart, S.R., 1976. Evidence for the Azores mantle plume from strontium isotope geochemistry of the Central North Atlantic. Nature, 263: 659-663.

Wilson, B., 2007. Recent Ostracoda of the Coconut and Mahogany fields, offshore SE Trinidad. Caribbean Journal of Science, 43(2): 181-188.

Winkelmann, K., Buckeridge, J.S., Costa, A.C., Dionísio, M.A.M., Medeiros, A., Cachão, M., Ávila, S.P., 2010. *Zullobalanus santamariaensis* sp. nov. a new late Miocene barnacle species of the family Archeobalanidae (Cirripedia: Thoracica), from the Azores. Zootaxa, 2680: 33-44.

Wirtz, P. 1998. Opisthobranch molluscs from the Azores. Vita Marina, 45: 1-16.

Wisshak, M., Form, A., Jakobsen, J., Freiwald, A., 2010. Temperate carbonate cycling and water mass properties from intertidal to bathyal depths (Azores, N-Atlantic). Biogeosciences, 7: 3297–3333.

Wood, A.M. & Whatley, R.C., 1994. Northeastern Atlantic and Arctic faunal provinces based on the distribution of Recent ostracod genera. The Holocene 4: 174–192.

Yassini, I., 1969. Ecologie des Associtions d'Ostracodes du Bassin d'Arcachon et du littoral Atlantique. Application à l'interpretation de quelques populations du Tertiaire Aquitain. Bulletin de l'Institut de Géologie du Bassin d'Aquitaine, 7: 1-288.

Youssef, W.B.H., 2005. Caractérisation in situ de l'environnement physique des habitats benthiques occupés par Codium elisabethae au sein de sites d'études particuliers (Faial, Açores), MSc thesis, Univ. de Liège, Liège, France.

Xavier, J.R. & Van Soest, R.W.M., 2012. Diversity patterns and zoogeography of the Northeast Atlantic and Mediterranean shallow-water sponge fauna. Hydrobiologia, 687:107–125.

Zabala, M.; Maluquer, P.; Harmelin, J.G., 1993. Epibiotic bryozoans on deep-water scleractinian corals from the Catalonia slope (western Mediterranean, Spain, France). Science Marine, 57(1): 65-78.

Zbyszewski G. & Ferreira, O. da V., 1962. La faune Miocène de l'île de Santa Maria (Açores). Comunicações dos Serviços Geológicos de Portugal, XLVI: 247-289.

Zuur, A.F., Leno, E.N., Smith, G.M., 2007. Analysing ecological data. Springer, New York.

SUMMARY

This thesis shows published and unpliblished data and is divided in 7 Chapters. Most of the work was developed at the University of the Azores (Portugal) and funding was provided by FCT-Portugal (grant. SFRH/BD/60518/2009).

Chapters 1 and 2 show a general introduction and describe and discuss the diverse methodologies used to study the Azorean fossil and Recent Bryozoa and Ostracoda. Chapter 3 discusses the importance of proper natural collections for biodiversity and biogeographical studies and emphasizes the role of the fossil and Recent collections that are housed at the University of the Azores and provide the biggest checklist of the bryozoa and ostracoda species from the Azores archipelago.

Chapter 4 presents the first report on the fossil ostracods from the Azores. Thirteen species were found, representing 7 families and 12 genera (*Xestoleberis, Loxoconcha, Callistocythere, Leptocythere, Dameriacella, Aurila, Heliocythere, Pachycaudites, Neonesidea, Cyamocytheridea, ?Quadracythere* and *Paracypris*). Among the identified species, one new species, *Leptocythere azorica* n. sp., is described. *Loxoconcha* (2 species) was the most diversified genus. The collected species are mainly ornamented and typical of warm waters and epi-neritic habitats (~10–50 m of depth).

Chapter 5 reports about the systematics and the biogeography of the Azorean Holocene to Recent shallow marine ostracods (between 1 to 100m depth). Twenty species were found, representing 10 families and 14 genera (*Neonesidea*, *Leptocythere*, *Callistocythere*, *Cyprideis*, *Carinocythereis*, *Aurila*, *Heterocythereis*, *Urocythereis*, *Loxoconcha*, *Semicytherura*, *Xestoleberis*, *Sclerochilus*, *Lanceostoma* and *Cylindroleberis*), with eight new records for the Azores: 5 new records – the species *Neonesidea longisetosa* (Brady 1902), *Cyprideis torosa* (Jones, 1850), *Neocytherideis* sp., *Aurila prasina* Barbeito-Gonzalez, 1971 and *Sclerochilus hicksi* Athersuch & Horne 1987 – and 3 new species to Science, *Callistocythere insularis* n. sp. *Semicytherura brandoni* n. sp. and *Lanceostoma simplex* n. sp.Chapter 6 reports the first palaeoecological and taphonomical study of the Holocene to Recent ostracods from the Azores. The shift from life-dominated assemblages in the shallower depths to death assemblages at greater depths is a consequence of significant transport downwards. In both Recent and Holocene samples, the abundance of ostracods is higher in the first 10

m depth, especially in fine to medium sandy substrates, as a consequence of depth, type of sediment, physiognomy of the coast line, geographical location, and hydrodynamic local conditions that differently affect each of the Azorean islands. Large-scale (sea-surface currents, Holocene relative sea-level, storms) and small-scale processes (geographical location, coastal fragmentation into dynamic cells with impermeable lateral boundaries, physiognomy of the coast line, seafloor stability of the sediments) are responsible for shaping the Azorean Holocene to Recent ostracods communities.

Chapter 7 describes a study about a fossiliferous outcrop of Santa Maria Island and a sequence of Neogene tempestite deposit that was incorporated in the island edifice by the on-going volcanic activity (and thus preserved) and later exposed through uplift and erosion. The sequence typifies the characteristics of a tempestite (or successive tempestites) formed at ~50 m depth, in a steep, energetic open insular shelf, and with evidence for massive sediment remobilization from the nearshore to the middle or outer shelf. Cross-shelf transport induced by storm events is the main process of sediment deposition acting on steep and narrow shelves subjected to high energetic environments such as the insular shelves of open-sea volcanic islands.

RESUMO DA TESE

O presente trabalho apresenta os resultados de pesquisa, desenvolvidos no âmbito da tese de doutoramento do autor (bolseiro FCT - SFRH/BD/60518/2009). São aqui apresentados dados inéditos e publicações, em jornais internacionais indexados com fator de impacto, que ampliam, revisam e abrem novas perspectivas para os trabalhos científicos desenvolvidos na Universidade dos Açores – Portugal.

A tese é composta por 7 capítulos, divididos por publicações. Os 1º e o 2º capítulos abordam de maneira geral o tema e os métodos de coleta utilizados no desenvolvimento dos trabalhos. O 3º capítulo ilustra o trabalho de montagem da coleção de referência dos Briozoários e Ostracodes, bem como o trabalho de curadoria destas coleções.

O 4º capítulo traz uma abordagem taxonômica, paleoecologica e paleobiogeográfica dos ostracodes do Mioceno da ilha de Santa Maria – Açores. O 5º capítulo aborda a taxonomia, ecologia e biogeografia dos ostracodes marinhos costeiros, do Holoceno ao Recente, dos Açores, com descrições detalhadas das espécies, incluindo novos *taxa*. Pela primeira vez são descritos os ostracodes fósseis dos Açores.

O 6º capítulo descreve aos trabalhos de tafonomia e paleoecologia dos ostracodes marinhos de águas rasas dos Açores, traz uma abordagem bastante detalhada de como esses organismos se distribuem ao longo das ilhas do arquipélago e infere prováveis fatores e processos deposicionais.

Para finalisar o conteúdo científico de caráter único, é apresentado o 7º capítulo, que descreve e propõe um novo método para o estudo de depósitos sedimentares de tempestade em ilhas oceânicas, esse trabalho inovador desenvolvido por uma equipe de cientistas, teve grande impacto e forte aceitação por parte dos editores e revisores da *Sedimentology*. Apresenta de forma clara e consistente, resultados de campo e discussões sobre os processos sedimentares envolvidos em plataformar insulares, com impacto global.

AUTHORS ADDRESSES

ADRIANO PIMENTEL

CVARG, *Centro de Vulcanologia e Avaliação de Riscos Geológicos, Universidade dos Açores, 9501-801 Ponta Delgada, Açores, Portugal (adriano.hg.pimentel@azores.gov.pt).*

ANA C. REBELO

Departamento de Biologia, Universidade dos Açores, 9501-801 Ponta Delgada, Açores, Portugal.
CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Pólo dos Açores, Açores, Portugal (anacrisrebelo@hotmail.com).
MPB-Marine PalaeoBiogeography Working Group of the University of the Azores, Rua da Mãe de Deus, 9501-801 Ponta Delgada, Açores, Portugal.

ANTÓNIO M. DE FRIAS MARTINS

Departamento de Biologia, Universidade dos Açores, 9501-801 Ponta Delgada, Açores, Portugal.
CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Pólo dos Açores – Departamento de Biologia da Universidade dos Açores, 9501-801, Ponta Delgada, Açores, Portugal (frias@uac.pt).

COSTANZA FARANDA

Dipartimento di Scienze Geologiche, Università Roma Tre, Italy (costanza.faranda@gmail.com).

DENNIS GORDON

NIWA - National Institute of Water & Atmospheric Research Ltd; 301 Evans Bay Parade, Kilbirnie, Wellington, New Zealand (dennis.gordon@niwa.co.nz).

DIETMAR KEYSER

Zoological Institute and Museum, University of Hamburg, Martin-Luther-King Platz 3, 20146 Hamburg, Germany (keyser@zoologie.uni-hamburg.de).

ELSA GLIOZZI

Dipartimento di Scienze Geologiche, Università Roma Tre, Italy (gliozzi@uniroma3.it).

JOSÉ MADEIRA

Departamento de Geologia, Faculdade de Ciências da Universidade de Lisboa, Instituto Dom Luiz (LA), 1749-016 Lisboa, Portugal (jmadeira@fc.ul.pt).

LUIS SILVA

Departamento de Biologia, Universidade dos Açores, 9501-801 Ponta Delgada, Açores, Portugal.

CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Pólo dos Açores – Departamento de Biologia da Universidade dos Açores, 9501-801, Ponta Delgada, Açores, Portugal (lsilva@uac.pt).

PAULO A. BORGES

Department of Geoscience, University of the Azores, Ponta Delgada, Azores, Portugal (amaral.borges@gmail.com).

RICARDO PIAZZA MEIRELES

Departamento de Biologia, Universidade dos Açores, 9501-801 Ponta Delgada, Azores, Portugal.

CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Pólo dos Açores – Departamento de Biologia da Universidade dos Açores, 9501-801, Ponta Delgada (ricomeireles@gmail.com).

MPB-Marine Palaeo-Biogeography Working Group of the University of the Azores, Azores, Portugal.

RICARDO S. RAMALHO

Institut für Geophysik, WWU Münster, Corrensstraße 24, 48149 Münster, Germany (ric.ramalho@bristol.ac.uk).

School of Earth Sciences, University of Bristol, Wills Memorial Building, Queen's Road, Bristol, BS8 1RJ, UK.

RUI QUARTAU

Divisão de Geologia e Georecursos Marinhos. Instituto Português do Mar e da Atmosfera. Rua C do Aeroporto, 1749-077 Lisboa, Portugal (rui.quartau@ipma.pt).

SÉRGIO P. ÁVILA

Departamento de Biologia, Universidade dos Açores, 9501-801 Ponta Delgada, Azores, Portugal.

CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Pólo dos Açores – Departamento de Biologia da Universidade dos Açores, 9501-801, Ponta Delgada (avila@uac.pt).

MPB-Marine Palaeo-Biogeography Working Group of the University of the Azores, Azores, Portugal.

Faculdade de Ciências da Universidade do Porto, Rua do Campo Alegre, 4169-007 Porto, Portugal

VITTORIO ZANON

CVARG - *Centro de Vulcanologia e Avaliação de Riscos Geológicos, Universidade dos Açores, 9501-801 Ponta Delgada, Açores, Portugal (vittorio.vz.zanon@azores.gov.pt).*

PUBLICATIONS (2010 – 2013)

MEIRELES, R.P.; KEYSER, D.; ÁVILA, S.P. Holocene to Recent shallow marine ostracods of the Azores (NE Atlantic): taxonomy and biogeography. To submitted to **ZooTaxa in** 2013.

MEIRELES, R.P.; KEYSER, D.; BORGES; P.A.; SILVA, L.; FRIAS MARTINS, A.DE.; ÁVILA, S.P. The shallow marine ostracods communities of the Azores (Mid-North Atlantic): taphonomy and palaeoecology. Submitted to ***Geologica Acta*** in 2013.

MEIRELES, R.P.; QUARTAU, R.; RAMALHO, R.; MADEIRA, J.; REBELO, A.C.; ZANON, V.; ÁVILA, S.P. Depositional processes on oceanic island shelves – evidence from storm-generated Neogene deposits from the mid- North Atlantic. ***Sedimentology***. *In press* (doi: 10.1111/sed.12055).

MEIRELES, R.P.; FARANDA, C.; GLIOZZI, E.; PIMENTEL, A.; ZANON, V.; ÁVILA, S., 2012. Late Miocene marine ostracods from Santa Maria island, Azores (NE Atlantic): Systematics, palaeoecology and palaeobiogeography. ***Revue de micropaléontologie***.

MEIRELES, R.P.; ABREU, J.G.N de; HORN FILHO, N.O., 2011. Mineralogia e Análise Granulométrica dos sedimentos da planície costeira Centro-Norte do Estado de Santa Catarina. ***Revista de Geociências de Guarulhos***, 10(1): 5-15p.

MEIRELES, R.P.; DO CARMO, D.A., 2011. Taxonomia dos Ostracodes Marinhos do Cenozóico da Perfuração 1-SPS-9, Bacia de Santos, Brasil. ***Revista de Geociências de Guarulhos***, 10(1): 16-35p.

Contributions

ÁVILA, S.P., RAMALHO, R., HABERMANN, J., QUARTAU, R., KROH, A., **MEIRELES**, R.P., BERNING, B., KIRBY, M., ZANON, V., GOSS, A., REBELO, A.C., MELO, C., MADEIRA, P., CORDEIRO, R., BAGAÇO, L., MARQUES DA SILVA, C., CACHÃO, M., MADEIRA, J., 2013. A late Miocene storm-induced shell bed (coquina) from the central-North Atlantic: taphonomy, palaeoecology and palaeo-environmental reconstruction. Submitted to ***Journal of the Geological Society of London*** in 2013.

ANTONIETTO, L.S.; ABRAHÃO, A.; DO CARMO, D.A.; **MEIRELES**, R.P., Taxonomy, biostratigraphy and palaeozoogeography of *Amphicytherura* Butler & Jones, 1957, *Aracajuia* Krömmelbein, 1967 and *Dinglecythere* n. gen. (Crustacea, Ostracoda). ***Marine micropaleontology***. Accept (2013).

DO CARMO, D. A.; COLIN, J.P.; HIDALGO, P.P.; **MEIRELES**, R.P.; BORN, M.L.B.; ALMEIDA, C.M., 2012. Reassessment of the genus *Sergipella* Krömmelbein, 1967 (Ostracoda, Trachyleberididae), uppermost Aptian-Albian of Brazil and West Africa: Taxonomy and paleogeographic distribution. ***Revue de micropaléontologie***.

MADEIRA, P., KROH, A., CORDEIRO, R., **MEIRELES**, R.P., ÁVILA, S.P., 2011. The fossil echinoids of Santa Maria Island, Azores (Northern Atlantic Ocean). ***Acta Geologica Polonica***, 61: 243-264.

TECHNICAL VISITS

1. Bryozoa Collection, NIWA – National Institute of Water and Atmosphere Research – Wellington – ***New Zealand*** (2013).

2. Ostracoda Collection, Zoological Institute and Museum, University of Hamburg – Hamburg - ***Germany*** (2012).

3. Zoological Marine Collection, DOP – Department of Oceanography and Fisheries, University of the Azores – Faial - ***Portugal*** (2011).

4. Micropalaeontological Collection, Joänneum Universal Museum – Graz - ***Austria*** (2011).

5. Fossil Collection, Muséum national d'Histoire naturelle – Paris - ***France*** (2011).

6. Ostracoda BP Collection (British Petroleum Ostracoda Collection – Atlantic Ocean), Natural History Museum – London - ***UK*** (2010).

ACKNOWLEDGEMENTS

I would like also to thank to all my co-Authors; my wife Suellen and to my Family who always supported me, unconditionally; Friends and *Kitty*. Thank you with all my heart.

I would like to thank Dr. Sérgio P. Àvila and Professor Frias Martins, my supervisors, Thanks also for the care and concern that were beyond supervision responsibilities.

The following agencies are gratefully acknowledged for providing funding Fundação para a Ciência e a Tecnologia (FCT) of the Portuguese Government for Ricardo Piazza Meireles financial support (grant SFRH/BD/60518/2009 of FCT, Portugal). Direcção Regional da Ciência, Tecnologia e Comunicações (DRCT) of the Regional Government of the Azores and the University of the Azores (UAc) / Department of Biology (DB) / Department of GeoScience / Department of Oceanography (DOP).

A grateful to the organizers and participants of several editions of the International Workshop "*Palaeontology in Atlantic Islands*" who helped in the fieldwork. Field assistance: Clube Naval de Santa Maria and Câmara Municipal de Vila do Porto; and GIS topographic mapping of Santa Maria Island: DRTC and Direcção de Serviços de Cartografia e Informação Geográfica.

A thank you for all people supported this works. José Pacheco / Ana Rita Mendes / Ana Cheila Pinheiro / Carlos Melo (CVARG-Azores) for laboratorial support. Filipe Porteiro & Valentina Matos (IMAR-Azores) and Joana Xavier & Andreia Cunha (CiBio-Azores) for loaning samples. Jorge Medeiros (CIRN-University of the Azores) and Daniel Leduc (NIWA-New Zealand) for the SEM photographs support.

Giles Miller (Natural History Museum, London) for allowing access to the collections and bibliography. Martin Gross (Joänneum Universal Museum – Graz-Austria), Jean-Paul Colin & Ana Cristina Cabral (Universidade de Lisboa), Stephen Rice (Editor), Jess Trofimovs (Associate Editor), Brian Jones, Antonio Russo, António Ponte, Artur Gil (CITA-Azores), Nuno Lourenço & Paulo Alexandrino (EMEPC/M@rBis /Selvagens/2010 and CiBio-Porto), Leandro Vieira (USP-Brazil), Peter Frenzel (Universität Rostock, Albert-Einstein - Germany). Finn Andreas Viehberg (Universitätt zu Köln) and anonymous reviewer who, with their comments, greatly helped us to improve these studies.