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Studio delle associazioni a foraminiferi epibentonici nel Mare di Ross (Antartide): nuove prospettive sulla biodiversità di ambienti profondi

New insight from a hidden world: deep epibenthic foraminiferal assemblages from the Ross Sea (Antarctica)

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ABSTRACT

Samples for this master thesis dissertation were taken in the Eastern Ross Sea, during the XXXII Italian Expedition of the Italian Programme of Researches in Antarctica (PNRA 2017) in the framework of the ODYSSEA project, that is a multidisciplinary study to resolve the relationship between climatic and oceanic changes in West Antarctic Ice Sheet (WAIS), particularly its evolution through the Quaternary. In this framework, I focused my study on deep living benthic foraminifera which live attached on hard substrates such as hydrocorals skeleton, shells and clasts and within the sediment (0-1cm) along a bathymetric transect along-slope on the Hillary Canyon with the aim to characterize the specialized epibenthic foraminiferal taxa. Most of them are hidden species highlighting their importance for the foraminiferal biodiversity total budget: in fact, sampling of superficial sediment for the same stations has demonstrated totally different foraminiferal assemblages compared to the hard substrates, with few species in common. As a result, I interpret a general decreasing trend in the foraminiferal abundance and biodiversity along the bathymetric transect of the Hillary Canyon. However, the abundance on Hard Substrates is higher respect the superficial (0-1cm) Sediment foraminiferal species which shows also a lower biodiversity. Anyway, they have in common the general

dominance of agglutinated foraminiferal species both on Hard Substrates and Sediment, allowing also to find a new genus among Monothalamous agglutinated foraminifera. Those assemblages could be shaped by the extreme features of the canyon where high bottom currents and dense shelf water cascade (DSWC), in an oligotrophic environment, create high disturbance and an unstable habitat. By attaching themselves hardly on clasts or biogenic structures, epibenthic foraminifera could face that extreme environment.

The relative high presence of Hard substrates foraminiferal assemblages increases the total biodiversity budget, together with species living at interface water-sediment usually studied, thus highlighting the dominance and importance of this phylum in the deep ocean floor.

RIASSUNTO

Durante la XXXII spedizione italiana del Programma italiano di ricerche in Antartide (PNRA 2017) nell'ambito del progetto ODYSSEA, è stato campionato un transetto batimetrico lungo l'Hillary canyon nel Mare di Ross (parte orientale): dalla sua parte apicale fino alla base in scarpata. Questa spedizione multidisciplinare è stata condotta per risolvere il rapporto tra clima e cambiamenti oceanici nella calotta glaciale dell'Antartico occidentale (WAIS), in particolare la sua evoluzione attraverso il Quaternario. In questo contesto, il materiale campionato è stato utilizzato per studiare le tanatocenosi a foraminiferi che permettono di ricostruire il paleoambiente e la paleoceanografia dell'area di studio e le biocenosi per studiare l'ecologia e la biodiversità dei foraminiferi in questo particolare habitat profondo. In particolare, nella presente tesi presenterò uno studio sui foraminiferi bentonici viventi che vivono attaccati a substrati duri rappresentati da idrocoralli, conchiglie e ciottoli insieme a quelli che colonizzano l'interfaccia acqua-sedimento, e che vengono maggiormente studiati, con lo scopo di caratterizzare la componente epibentonica. La maggior parte di queste specie epibentoniche si nasconde tra le fessure di rocce o trovano riparo su materiale biogenico, come gli spazi più interni di scheletri di idrocoralli. Prenderli in considerazione è importante, in quanto si è visto che aumentano il budget totale di biodiversità: infatti campionando la parte superficiale di sedimento,

nelle stazioni in cui son stati presi i substrati duri, si osservano associazioni a foraminiferi totalmente diverse fra loro, con poche specie in comune. In particolare, c’è una generale diminuzione di abbondanza e biodiversità delle specie di foraminiferi lungo il transetto verticale dell'Hillary Canyon, come già visto in letteratura per tali ambienti nei campioni di sedimento. Tuttavia, l'abbondanza sui substrati duri è più elevata rispetto a quella dei sedimenti superficiali (0-1 cm), con una minore diversità di specie. Come risultato generale abbiamo una dominanza di specie agglutinanti sia per i substrati duri che per il sedimento superficiale. Anche la composizione tassonomica rivela la particolarità dell’habitat con la dominanza della componente agglutinante sia monotalamica che politalamica su quella biocalcificante. Tale distribuzione può essere messa in relazione alle acque definite corrosive con un pH acido che non permette quindi la biomineralizzazione delle specie calcaree.

Queste associazioni a foraminiferi bentonici potrebbero essere modellate dalle caratteristiche ambientali estreme presenti nel canyon in cui le forti correnti di fondo e i fenomeni di cascading superficiale (DSWC), in un ambiente oligotrofico, creano un habitat instabile insieme a fenomeni di disturbo.

Queste variabili fisiche ambientali, infatti, rendono difficile la vita per la maggior parte degli organismi; fatta eccezione per spugne sporadiche e qualche briozoo, i foraminiferi sembrano i maggiori rappresentanti della comunità bentonica.

Si ipotizza che la presenza di questi foraminiferi epibionti sia correlata alla loro capacità di vivere e nascondersi su substrati duri, come clasti di dimensioni centimetriche, e strutture biogeniche (scheletro di idrocoralli, conchiglie), in modo da trovare protezione da eventi di disturbo legati ad esempio a forti correnti di fondo. Inoltre, tali substrati elevati e duri forniscono eterogeneità spaziale, nonché una superficie ruvida favorevole alla loro colonizzazione. In questo modo, il budget totale di biodiversità aumenta: infatti, delle 65 specie totali, 34 provengono da substrati duri e solo 21 da campioni di sedimento superficiale, avendo in comune solo 10 specie. Poiché le biocenosi dei substrati duri sono state meno studiate alcuni morfotipi di foraminiferi risultano indescritti tali da giustificare la presenza di un nuovo genere come nel caso di *Spiculotuba* n. gen. (d'Agnessa, Sabbatini & Morigi 2019). Interessante è il ritrovamento, nei campioni studiati, di specie *(Chondrodapis, Cibicides lobatulus, Hemisphaerammina* sp, *Placopsilina* sp*.,* morfotipo non descritto che propongo come nuovo genere *Spiculotuba, Tolypammina vagans)* che sono state monitorate anche in altri ambienti profondi, come ad esempio in sedimenti solidificati di fango di fuoriuscite termali a 4000 m di profondità e incrostanti su noduli polimetallici che si formano nelle pianure abissali. Tali ritrovamenti, indicano l'ampia gamma di adattabilità ecologica di questi foraminiferi legata sia alla possibilità di resistere in ambienti con poco cibo e soggetti a forti correnti e di conseguenza la loro sopravvivenza legata alla presenza di un substrato duro ed elevato sui cui attaccarsi indipendentemente dalla sua composizione. Finora tali substrati duri sono stati poco studiati e si rivelano come degli hot-spot di biodiversità rispetto ai substrati interfaccia acqua-sedimento dove le faune a foraminiferi bentonici sono dominate solo da specie opportuniste. In particolare, nei campioni di sedimento da noi studiati domina una specie agglutinante,

Glomospira charoides, definita "disaster species" ossia una specie opportunista che riesce a ripopolare per prima gli ambienti sedimentari dopo eventi di disturbo come succede nei canyon; la sua bassa abbondanza nella frazione di taglia più piccola (150-63 µm) può indicare proprio un inizio di colonizzazione nell' Hillary canyon dopo un evento stocastico insieme a *Psammosphaera fusca* già segnalata anch'essa come specie opportunista che può rapidamente colonizzare aree impattate dalle correnti di acque profonde.

In conclusione, sarebbe bene svolgere ulteriori studi per questo gruppo di protisti che, sempre un maggior numero di studi, accredita come uno dei maggiori protagonisti di ecosistemi profondi marini, in termini di abbondanza. Inoltre, i loro optimum ecologici, la loro plasticità ad adattarsi ai più disparati ambienti, nonché la loro biodiversità su substrati duri lascia ancora spazio a nuove scoperte.

CHAPTER 1

INTRODUCTION

FORAMINIFERA

1.1 General characteristics

Foraminifera are single-celled heterotrophic organisms with test (shell), and a protoplasm divided in two different parts: endoplasm (occurring within the test) and ectoplasm (outside the test in contact with the environment). All Foraminifera possess reticulopodia, thread-like extensions of the ectoplasm with granular texture (granuloreticulose pseudopodia), that are extruded through apertural openings in the test. Pseudopodia have multiple functions: locomotion, feeding, building and structuring test, protection, and some aspects of respiration and reproduction. Pseudopodia also provide the mechanism by which Foraminifera interact with their surroundings (Goldstein, 1998).

1.1.1 Classification of Foraminifera

Notoriously molecular analyses placed Foraminifera in the supergroup Rhizaria (Adl et al., 2005) together with radiolarian and other protists that are characterised by root-like branching pseudopods (Pawlowski & Burki, 2009). But more recently in 2013, Pawlowksi and co-authors proposed a new supraordinal classification of Foraminifera, merging molecular data with traditional morphology-based classification (Pawlowski, Holzmann, & Tyszka, 2013). In addition, the World Register of Marine Species (WoRMS) provides an authoritative and comprehensive list of species of Foraminifera and taxonomic interpretation.

Unfortunately, for some Foraminfera, such as Komokiacea, it is not possible yet to have DNA samples, as the extraction is complicate and not fully comprised. In those cases, the “classical” classification based on morphology is taken into account: currently adopted and best known is the Loeblich & Tappan morphological classification of 1964, updated by the authors themselves in 1992.

However, based on morphological interpretation and molecular data integrated by Pawlowski et al. (2013), the new taxonomical system considers Foraminifera as a phylum composed of three groups:

- The paraphyletic assemblage of “monothalamids” grouping all single-chambered species having organic and agglutinated walls.
- The class Tubothalamea grouping multi-chambered species whose chambers are typically tubular;
- The class Globothalamea grouping multi-chambered species whose chambers are typically globular;

The new high-rank phylogenetic classification by Pawlowski et al. (2013) is reported as follow:

Phylum Foraminifera (d'Orbigny, 1826)

Monothalamids

Single chamber (monothalamous) test with an organic or agglutinated wall; the group comprises all genera traditionally included into the orders Allogromiida and Astrorhizida, as well as the deep-sea giant Xenophyophorea; it also includes freshwater and marine “naked” amoeboid species and environmental clades with unknown morphology (Pawlowski et al. 2011). The diversity of this mainly unfossilized group is poorly known and has been largely overlooked in micropaleontologically oriented foraminiferal research.

Class Tubothalamea classis nov

Diagnosis: Bi- or multi-chambered test with tubular chambers at least in the juvenile stage; wall agglutinated or calcareous; in ancestral forms the test is composed of a spherical proloculus followed by a spirally enrolled tubular chamber; more evolved forms have multi-chambered tests.

Order Miliolida (Delage and Hérouard, 1896)

Test bi- or multi-chambered, chambers tubular or elongate, some with complex internal structures adapted to host algal endosymbionts; wall generally imperforate, calcareous of high magnesium calcite with randomly oriented crystals refracting light in all directions and resulting in a porcellaneous appearance of the test; may be agglutinated or siliceous in some taxa (*Miliammina* and *Miliammellus*).

Order Spirillinida (Hohenegger and Piller, 1975)

Test composed of proloculus followed by an enrolled tubular chamber, aperture terminal; wall of low magnesium calcite, optically a single crystal in Spirillinidae and Patellinidae; wall agglutinated in Ammodiscidae.

Class Globothalamea classis nov

Diagnosis: Test multi-chambered, typically trochospirally enrolled but may be triserial, biserial or uniserial; chambers globular or crescent-shaped in early stage; wall agglutinated or calcareous.

Order Rotaliida (Delage and Hérouard, 1896)

Wall of low magnesium calcite, optically radial, bilamellar, perforate; some with internal canal system; possibly include all or most of planktonic globigerinids.

Order Robertinida (Loeblich and Tappan, 1984)

Wall of hyaline, perforate, optical radial aragonite; chambers with internal partitions in modern taxa.

Order "Textulariida" (Delage and Hérouard, 1896)

Wall agglutinated, with foreign particles attached to organic lining or cemented by low-magnesium calcite; possibly paraphyletic group. The term "Textulariida" is here used only partially in the sense of the definition given by Loeblich and Tappan (1988), and includes the most of the Lituolida, the Loftusiida, and the Textularida (*sensu stricto*) of Kaminski (2004).

Order Carterinida (Loeblich and Tappan, 1981)

Wall composed of rodlike spicules of low magnesium calcite held in organic lining; chambers numerous, trochospirally coiled.

Incertae sedis orders

Order Lagenida (Delage and Hérouard, 1896)

Test single- or multi-chambered, chambers uniserial, biserial, or planispirally coiled; wall of low magnesium calcite, monolamellar; possibly an independent class.

Order Fusulinida (Wedekind, 1937)

Extinct; test multi-chambered wall microgranular, calcareous; possibly could be partly attached to Globothalamea and Tubothalamea.

Order Involutinida (Hohenegger and Piller, 1977)

Test composed of proloculus and spirally coiled tubular second chamber; wall aragonitic; possibly belong to Tubothalamea.

1.1.2 Foraminifera morphology

Although being exclusively unicellular, they carry out almost all of the fundamental life functions performed by multicellular animals. They eat, move, grow, reproduce, and respond to a series of external stimuli, while metazoans evolved organs through multicellularity.

Foraminifera first appeared in the Cambrian, and, over the course of the Phanerozoic, invaded most marginal to fully marine environments and diversified to exploit a wide variety of modes of life (Marcelle K. BouDagher-Fadel, 2015). Due to their great adaptability, they display great diversity in morphology: the simplest forms are undivided spheres, or tubes with apertures at one or both ends. More advanced forms are divided into chambers arranged in various ways (fig. 1.1).

These single-celled organisms display a huge variability in the composition and microstructure of the test; however, there are three basic wall compositions recognised:

- Organic test: proteinaceous mucopolysaccharide membrane (made of tectin) that confers elasticity and allows changes in shape without fossilization potential.

- Agglutinated test: composed of different particles cemented together onto a layer of tectin. These grains can be randomly accumulated or specifically selected based on shape, size or specific gravity. Some species also arrange particular grains in specific parts of the test.

- Calcareous test: composed of calcium carbonate (calcite or aragonite) prisms and in rare cases silica, with different quantity of magnesium carbonate. It can be distinguished in hyaline shell (composed of interlocking microcrystals of $CaCO_3$ with pores) and porcelanaceous shell (composed of microscopic rod-shaped crystals of $CaCO_3$ with no pores).

Foraminiferal test may be provided with one or more chambers (monothalamous or polythalamous). However, it is the aperture that gives the group its name, assigned by d'Orbigny in the early nineteenth century: Foraminifera means 'aperture-bearing'.

External ornamentation of various types may also be present. The process of shell or test secretion, named *biomineralisation* or calcification, is still poorly understood, but it preserves an isotopic environmental signal that is of great value in paleoenvironmental interpretation. In fact, foraminifera have been used as great proxies for climate change studies and paleo-oceanography/ecology as well. Indeed, they are found throughout the marine environment (John Murray, 2006) from shallow waters to the deep sea, as well as freshwater (Holzmann & Pawlowski, 2002) and on land too (Lejzerowicz, Pawlowski, Fraissinet-Tachet, & Marmeisse, 2010).

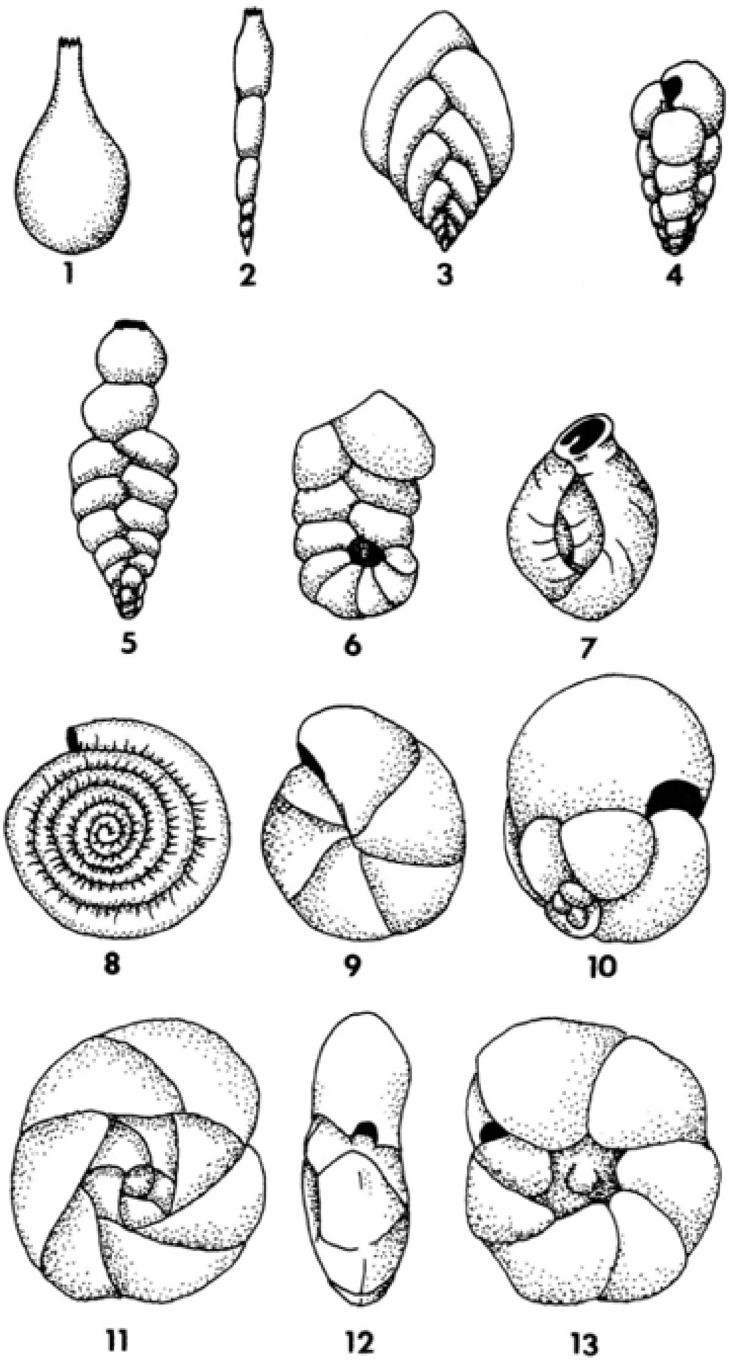


Figure 1.1: Principal types of chamber arrangement. 1. Single-chambered; 2. Uniserial; 3. Biserial; 4. Triserial; 5. Triserial to uniserial; 6. Planispiral to biserial; 7. Milioline; 8. Planispiral evolute; 9. Planispiral involute; 10. Streptospiral; 11-13. Trochospiral (dorsal, edge, ventral view). From Loeblich and Tappan 1964a.

In addition, they are united by a life cycle (fig. 1.2) made of alternation of sexual and asexual generations, becoming secondarily modified in some groups.

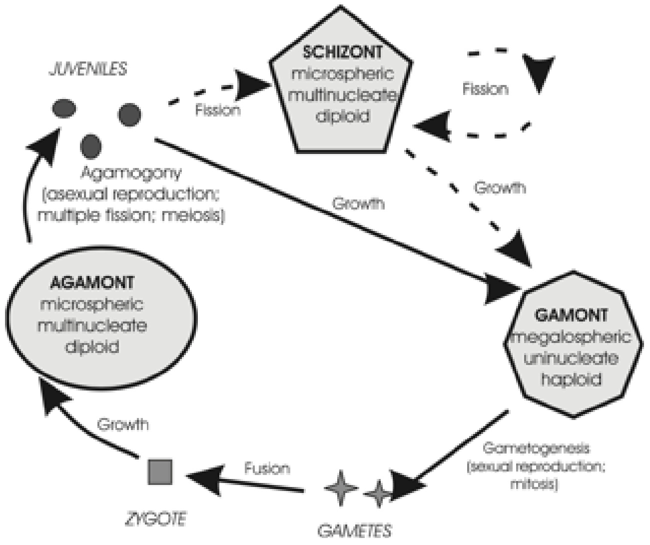


Figure 1.2: schematic representation of the classic life cycle (alternation of generations) of benthic foraminifera (based on Lee et al., 1991b; Goldstein, 1999). Black arrows indicate classical alternation between haploid and diploid phases. Dashed arrows are for the asexual phase.

They can have different ways of colonization of marine environment related to trophic source and other environmental drivers: one active and three passive(Alve & Olsgard, 1999). Active dispersal is via self-locomotion: even though this could operate over short distances, the speed of movement and the lack of direction make it an unlikely method of dispersal on a bigger scale. The passive methods involve suspension in the water column so that they can be transported. It involves gametes, zygotes, propagules or juveniles; a temporary planktonic juvenile phase; or entrainment of individuals from the sediment by waves, currents or biotic activity.

1.2 Ecology of benthic Foraminifera

There are an estimated 4,000 species living in the world's oceans today: some are planktonic, but the majority are benthic, living on or in the sand, mud, rocks, organisms or plants at the bottom of the ocean.

They can, in fact, occupy epibenthic to deep infaunal microhabitats and utilize a diversity of trophic mechanisms (Barun K. Sen Gupta, 2003): they are heterotrophs or consumers, typically eating Bacteria, Algae and organic detritus. Thus, potentially they play an intermediate link in the lower trophic levels of benthic marine food. In turn, they are eaten by large variety of invertebrates (Murray, 1991; Berry, 1994) underlining their poorly recognized importance throughout the food web.

As mentioned above, they exhibit a great variety of feeding mechanisms, which are in relation with their ecology and their test morphology.

Many benthic foraminifera are omnivorous opportunistic feeders that consume organic detritus, unicellular algae, protists, and metazoans (Haynes, 1981). Some branching forms are suspension feeders and utilize their pseudopodia to capture food from the water column. Sediment dwellers, instead, absorb dissolved organic matter using their pseudopodia, but they are mostly deposit feeders, gathering organic detritus and bacteria with their pseudopodia. Despite this variety of diet, most of the foraminifera are deposit feeders (Hickman & Lipps, 1983) and bacteria constitute an important element in their diet (Goldstein & Corliss, 1994), due to their high nutritional value. This is also important for species that live attached on substrates, hard or soft bottom or organisms, in order to elevate themselves and intercept organic matter particulate in the water column.

Moreover, benthic foraminifera are considered good environmental indicators as their distribution is related to the physical, characteristics of the habitat as well as chemical and biological, for example: organic matter availability, bottom water dissolved oxygen concentration, the nature of substrata, and water depth (Barras et al., 2014).

Many foraminifera are opportunistic and great survivors; they exist in small numbers for long periods even when conditions are far from optimal, but when conditions change in their favour, they rapidly increase their numbers.

In 2006, Murray identified salinity, temperature, oxygen and food supply, as well as competition and predation, as primary factors, both biotic and abiotic, influencing foraminiferal assemblages.

- *Salinity*

As stated by Murray in 2006 (John Murray, 2006), Foraminifera can stand from brackish or hyposaline (0–33), euhaline or normal marine (33–37), to hypersaline (>37) waters. They in fact can tolerate the range from fresh water to strongly hypersaline (0 to at least 70).

- *Temperature*

They can be found from arctic or polar waters to temperate as tropical ones. Organisms that are confined to water of restricted temperature are said to be stenothermal. Those tolerant of a wide range of temperatures are eurythermal. The upper temperature limit for marine organisms is around 45°C.

- *Oxygen*

The concentration of dissolved oxygen depends on the temperature and salinity of the water. In seawater the range is from zero to around 8.5ml l-1; 379mM. The range varies from anoxic (zero dissolved oxygen), to dysoxic (0.2–1.0 ml l-1; 9–45mM) and oxic (>1.0 ml l-1; >45 mM) (after Allison et al., 1995).

The critical range for foraminifera is from anoxia to dysoxia. Moodley et al. (1998b) carried out laboratory experiments, which examined the migratory activity of some common benthic foraminifera in relation to pore water oxygen.

- *food supply*

foraminifera eat a wide range of food and some have symbionts or husband chloroplasts. Although some species have more than one feeding strategy, there is resource partitioning (i.e., feeding on different parts of the available food). Anyway, food availability may control the foraminiferal microhabitat depth mostly in oligotrophic environments. In this condition, Foraminifera are present only at the topmost levels because the small quantity of labile organic matter on the surface-sediment is rapidly consumed, determining their food limitation.

- *Competition and Predation*

Foraminifera are a potential food resource for other organisms especially as they are major contributors to meiofaunal biomass in many environments. Predation is important in structuring marine communities and in controlling the numbers of benthic organisms (Jere H. Lipps, 1988). Predation may be selective or unselective (as in deposit feeding).

Some foraminifera eat other (Christiansen, 1964; Hallock & Talge, 1994) but the predators are mainly from other groups: gastropods (Hickman & Lipps, 1983; Herbert, 1991; Chester, 1993) like *Retusa obtusa* as stated by Berry 1994, scaphopods (Langer, Lipps, & Moreno, 1995), nematodes (Sliter, 1971), holothurians(Goldbeck, Houben, & Langer, 2005), echinoids

(Reidenauer, 1989), prawns (Rainer, 1992; Wassenberg and Hill, 1993), fish (Palmer, 1988; Culver & Lipps, 2003).

- *Disturbace*

Disturbance is important as well. It could be from damage, displacement or mortality caused by physical, chemical or incidentally by biotic activity. Disturbances range in duration from discrete events that last for a fraction of the average lifespan of the affected species too much longer periods affecting several generations.

The causes of disturbance are: physical (storm waves and currents, sediment slumps, volcanic ash fall); chemical (freshwater, hypersalinity, anoxia, pollution); biological (bioturbation, sediment movement by foragers, accumulation of living or dead plant material).

Despite their abundance in modern sediments, benthic foraminifera are often ignored by biologists investigating modern ecosystems, even though protozoans in general are important grazers of biofilms in these environments (Patterson, Gehrels, Belknap, & Dalby, 2004). Thus, Foraminifera are an important component of benthic communities and particularly in the deep sea, where they are sometimes a dominant component both in abundance and biomass (Goineau & Gooday, 2017).

Indeed, in the deep sea, they are one of the most important contributors to the meiofaunal biomass, and their distribution is linked to the flux of particulate organic matter from the upper ocean to the sea floor (Volker Altenbach & Struck, 2001; Gooday, 2003). They are often considered as a key group in the marine food web (Altenbach, 1992) as one of the dominant parts among benthic communities in both shallow and deep-sea environments (Alongi, 1992; A. J. Gooday, Levin, Linke, & Heeger, 1992)

Anyway, considering foraminiferal species distribution at regional scale, a prediction of relationship between species and single parameters is difficult to determine. Moreover, substrate characteristics, such as sediment grain size, influence foraminiferal species distribution as well. Species prefer to select substrates (e.g. Debenay, Tsakiridis, Soulard, & Grossel, 2001; Diz et al., 2004; Frezza, Pignatti, & Matteucci, 2010) and their distribution is strongly influenced by the sediment type (Hyams-Kaphzan, Almogi-Labin, Sivan, & Benjamini, 2008).

1.3 Antarctic Foraminifera

Foraminifera have been collected in Antarctic waters since the first half of the 19th century (d'Orbigny, 1839; Brady, 1884). Sampling sites are concentrated around the Antarctic Peninsula, in the Drake Passage, the Weddell and Scotia Seas and the Ross Sea, particularly the McMurdo Sound area (Cornelius & Gooday, 2004).

Several authors carried out studies on the foraminiferal distribution in Antarctic areas (e.g. Heron-Allen & Earland, 1922; 1936; Wiesner, 1931; Parr, 1950; McKnight 1962; Finger & Lipps, 1981; Ishman & Domack, 1994; Murray & Pudsey, 2004); but, few investigations exist on the distribution of recent benthic foraminifera in the Ross Sea (Pflum, 1966; Osterman & Kellogg, 1979; Bernhard, 1987; Ward, Barrett, & Vella, 1987; Mackensen & Douglas, 1989; A. Mackensen, Grobe, Kuhn, & Fütterer, 1990; Violanti, 1996; Capotondi, Bergami, Giglio, Langone, & Ravaioli, 2018). Foraminifera are present at all depths around Antarctica. In shallow-water settings, such as coastal fjords, assemblages are related to their proximity to glaciers, sedimentary regime and distance from the open ocean, as well as to bathymetry (Chang & Yoon, 1995; Majewski, 2005). In deeper water, depth-related assemblages have been recognised in Lutzow-Holm Bay (Uchio, 1960), the Ross Sea (McKnight, 1962), the Drake Passage (Herb, 1971) and the Scotia Sea area (Echols, 1971). Changes in water masses with depth are clearly identified as the primary factor that influences the distribution of foraminifera in Antarctica, in some cases, even local variations of water masses and the seasonal melting of the ice cover may affect the composition of foraminiferal associations (Massom & Stammerjohn, 2010). Majewsky & Anderson (2009) have also indicated the ice cover, the activity of bottom currents, and the intensity of primary production as factors influencing the distribution of benthic foraminifera. It should also be noted that downslope transport might create spurious depth distributions (Uchio, 1960). Moreover, the conservation of calcareous foraminifera also depends on the Calcium Carbonate Compensation Depth (CCD) that in the Ross Sea is shallower because of the low temperature, the high CO_2 content and the low surface primary productivity, which are reduced owing to the presence of a thick pack-ice (Kennett 1966, 1968; Anderson, 1975; Kellogg et al., 1979). Many common Antarctic foraminiferal species are known from other parts of the World, Earland (1934) concluded that Antarctic deep-water Foraminifera are cosmopolitan that have reached the Southern Ocean (SO) from deep-sea areas adjacent. Bathyal and abyssal regions, in particular, are inhabited by typical deep-sea forms. Murray, (1991) recognised a series of SO deep-water associations dominated by cosmopolitan species such as *Cyclammina pusilla, Epistominella exigua, Globocassidulina subglobosa and Nuttallides umboniferus*. The few foraminiferal species that may be endemic to the

Antarctic deep sea include *Haplophragmoides umbilicatum and Notodendrodes antarctikos*, reported from the abyssal Weddell Sea (Pearcey, 1914) depths down to 5000 m west of the Antarctic Peninsula (Theyer, 1971) and shallower sites in the Ross Sea (Kennett, 1968). Benthic foraminiferal species in the deep ocean are recognized based almost entirely on test morphology. Studies involving molecular analysis are available for some groups: as reported by Brandt et al. in 2007 (Brandt et al., 2007), in a study of Pawlowski et al.(2005) on the morphological and molecular diversity of Monothalamous foraminifera and gromiidss, from a site off the Ross Ice Shelf (923 m water depth), indicates a high degree of endemism, with approximately 50% of the allogromiid phylotypes being unknown at other localities (McMurdo Sound, Weddell Sea, Arctic Ocean). Thus, it is also possible that apparently bipolar and cosmopolitan species consist of a number of cryptic species. As Mikhalevich stated in 2014 (Mikhalevich, 2014), in general, Antarctic foraminifera fauna shows:

a high degree of endemism which, for the shelf depths of 2 – 50 m, sometimes reaching 80%; the gigantism of many species; a wide range of vertical bathymetric distribution of many species; introduction of deep-water species of other oceans onto the shelf and the upper part of the bathyal zone; high species diversity and high quantity abundance; The majority (and often the predominance) of agglutinated forms compared to calcareous ones, which is obviously determined by low water temperatures and undersaturation of the water by CaCO3.

1.4 Epibenthic Foraminifera

Sessile foraminiferal species, in particular, depend on the availability of firm attachment surfaces. In the predominantly sediment-covered deep ocean, suitable substrates include rocky outcrops, glacial drop stones, manganese nodules, biogenic structures like hydrocorals, scalopp’s shell, and larger sessile or even mobile animals. Distinctive epifaunal assemblages have been recorded, in particular associated with elevated current flows encountered in some deep-sea areas (Schonfeld, 1997).

In the present work I have focused my attention particularly on foraminifera living on hard substrates such as animals, shells and rocks.

Epifaunal taxa may be sessile (attached immobile of Sturrock and Murray, 1981), clinging (attached mobile of Sturrock and Murray, 1981; Arai, Oba, Kitazato, Horibe, & Machida, 1981), or free living.

Attachment is usually made using organic glue, glycosaminoglycan, a mucopolysaccharide (Langer, 1993).

Benthic foraminifera that are cemented by calcium carbonate that are firmly fixed to hard surfaces are known as *encrusting* or attached epibenthic foraminifera. (fig. 1.3)

Distribution of individual species of foraminifera can exhibit spatial heterogeneity from micro to regional scales, and this may contribute to spatial patterns in composition and abundance of foraminiferal populations (Semeniuk, 2000).

As mentioned above, in the deep sea, the usual place of attachment for encrusting foraminifera is on objects found on the seafloor, such as manganese nodules (Goineau & Gooday, 2017), larger grains, concretions and shells or organisms. In this way, they are able to rise from the bottom and can use the pattern of the host to support their pseudopodial network.

For example, this behaviour has been documented for *Rupertia stabilis* living on hydroid colonies on the Norwegian continental margin (Lutze & Altenbach, 1988) and Mediterranean Sea (Di Camillo et al., 2008), or for foraminifera colonizing seagrasses and macroalgae (Semeniuk, 2000).

Many encrusting foraminifera should be found in areas with relatively strong currents, feeding on bacteria and organic detritus (Goldstein, 1999).

Reasons for attachment include the ability to colonize high energy environments, protection, and the attached foraminifera in the Antarctic environment often settle on glacially transported drop stones and other hard substrates, as in this study.

Sessile species usually belong to the agglutinated genera *Dendrophrya*, *Dendronina*, *Sorosphaera* and *Tholosina* and are in the Antarctic Peninsula (Earland, 1933; 1934).

Antonietta d'Agnessa

Figure 1.3: Encrusting foraminifera from Odyssea Expedition PNRA 2017 (site BC08)

Benthic foraminifera have been used since long time to assess changes in past environment, and to monitor actual changes. In order to be more accurate as possible, there is the necessity to better study modern foraminifera, their thanatocenosis as well as ecology and biodiversity to infer for past dynamics and highlighting new species findings.

CHAPTER 2

SOUTHERN OCEAN

Antarctica is a vast and hostile continent: the coldest, driest, and windiest on Earth (Schwerdtfeger, 1984). It is covered by ice up to four kilometers (4,572 m) and surrounded by the Southern Ocean, which reaches up to the sub-tropical front (Deacon, 1937).

It is oceanographically important as a major driver of global ocean circulations as it interacts with deep-water circulation in Atlantic, Pacific and Indian oceans, playing an important role in the ocean water mass and energetic balance (Russo, Artegiani, Budillon, Paschini, & Spezie, 1999).

The Antarctic Circumpolar Current, in fact, is the fastest ocean current in the world and circles the continent driven by strong westerly winds, from west to east, without touching lands. Closer to the continent, easterly winds form a series of clockwise gyres, especially in the Ross and Weddell seas, that form the westward-flowing Antarctic Coastal Current (Griffiths, 2010). Indeed, there are different narrow fronts, with sharp gradients in water properties, that separate these zones (Gordon, 1971; Taylor, Gordon, & Molinelli, 1978; Patterson & Whitworth, 1990). These fronts include (from north to south): a limit in the northern part of the region, the Subtropical Front (SBT), the Polar Front (PF) and the northern and southern branches of the Subantarctic Front (nSAF and sSAF).

In order to define them, different parameters such as temperature, salinity, Dissolved Oxygen (DO), nutrients, etc. have been used (Russo et al., 1999).

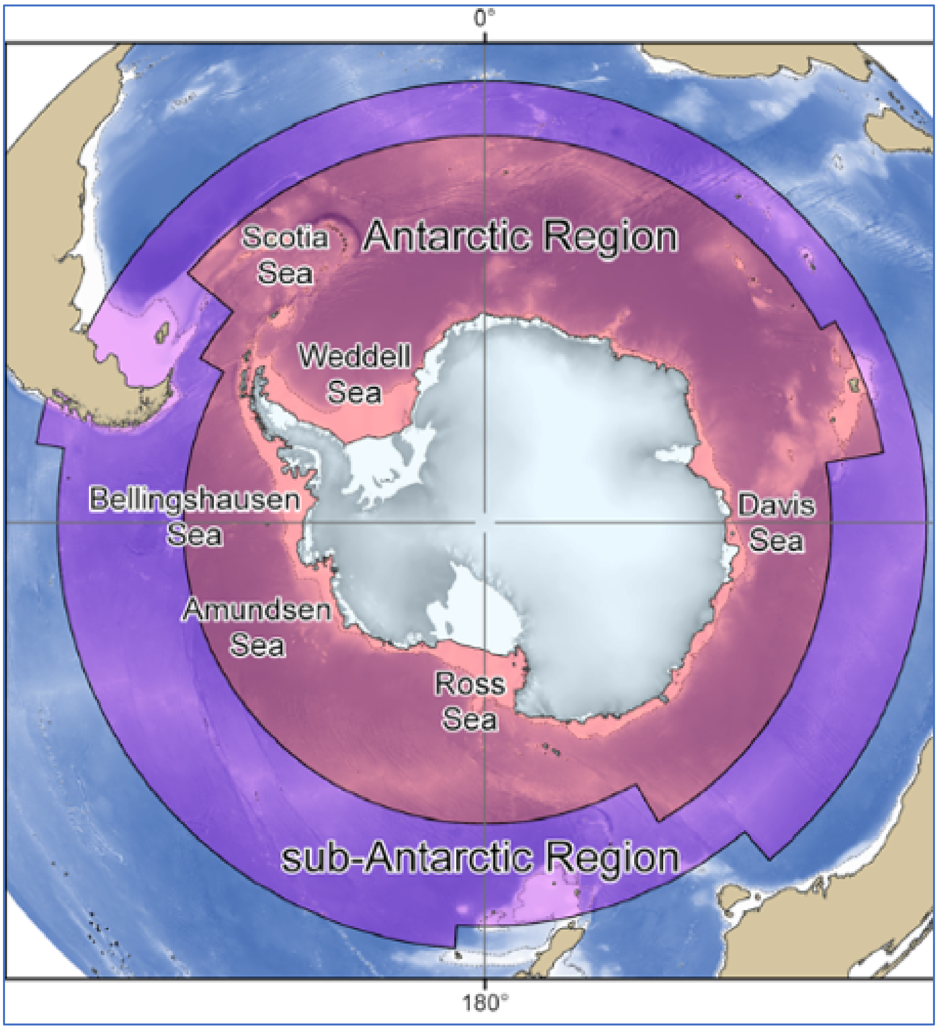


Figure 2.1: areas of interest in the Southern Ocean (Griffith, 2010)

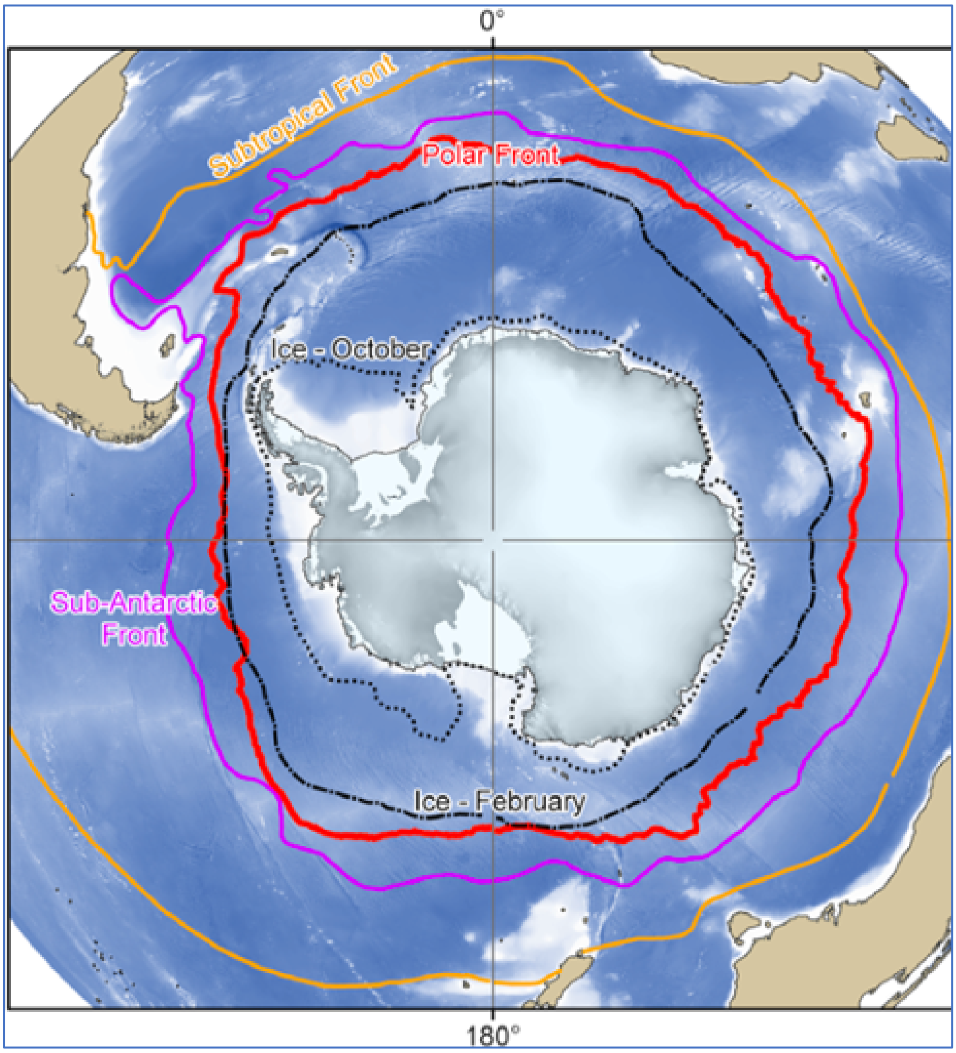


Figure 2.2: oceanographic features of the Southern Ocean. Positions of the major oceanographic fronts and summer and winter ice extents. (Griffith, 2010).

Extremely cold winds blowing off the Antarctic Ice Sheet, push water and sea ice offshore and contribute to sea ice formation (fig. 2.3).

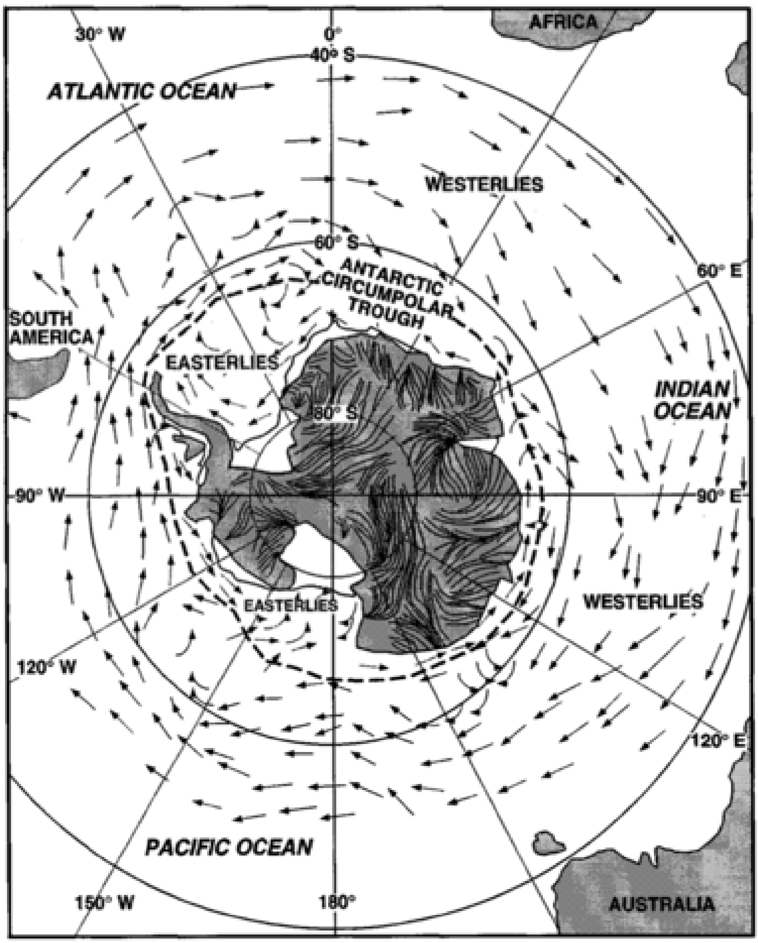


Figure 2.3: surface wind streamlines (lines) of winter flow over Antarctica (modified from Parish and Bromwich 1987) and surface wind directions (arrows) in the Southern Ocean (modified from Bigg 1996). (from Anderson, Antarctic marine Geology 2010)

This sea ice formation creates cold, dense, salty water that sinks to the seafloor and forms very dense Antarctic bottom water (AABW). This in turn pushes the global ocean's nutrient-rich, deep water closer to the surface, helping to create upwelling areas of high primary productivity.

The Southern Ocean (SO) appears as a key region driving the Global Thermohaline Circulation system, since unique exchange processes and water transformation over the Antarctic continental shelf are responsible for the formation of the Antarctic Bottom Water (AABW); (fig. 2.4). The main sources of deep waters in the SO are the Weddell Sea (WS) and the Ross Sea (RS), and the last one is the formation site of two main AABW components: the high salinity shelf water (HSSW) and the ice shelf water (ISW) (Jacobs, 2004; Bergamasco, Defendi, Budillon, & Spezie, 2004). HSSW production results from the extensive brine rejection in the RS polynya, while ISW is formed under the Ross Sea Ice Shelf (RIS) by means of basal melting. They interact under the RIS to become the densest water masses in the SO and flow towards the continental shelf break to interact with the Circumpolar Deep Water (CDW), branched off from the Antarctic Circumpolar Current (ACC) into the cyclonic Ross Gyre (RG), producing the AABW (Jacobs, 2004; Assmann, Hellmer, & Beckmann, 2003; Bergamasco et al., 2004).

For what concern the morphology of the continental slope is predominantly made up of glacial sediments. Whereas the continental shelf is unusually deep in Antarctica (an average of 450 m, and in places over 1,000 m deep) and shelf sediments are a combination of glacial deposits and diatomaceous muds. As well as being deeper than other continental shelves, some unique features of the Antarctic Shelf are the glacially excavated inner basins. Moreover, it is characterized by glacial embayments that support floating ice shelves, the largest of which are the Ross and Weddell seas.

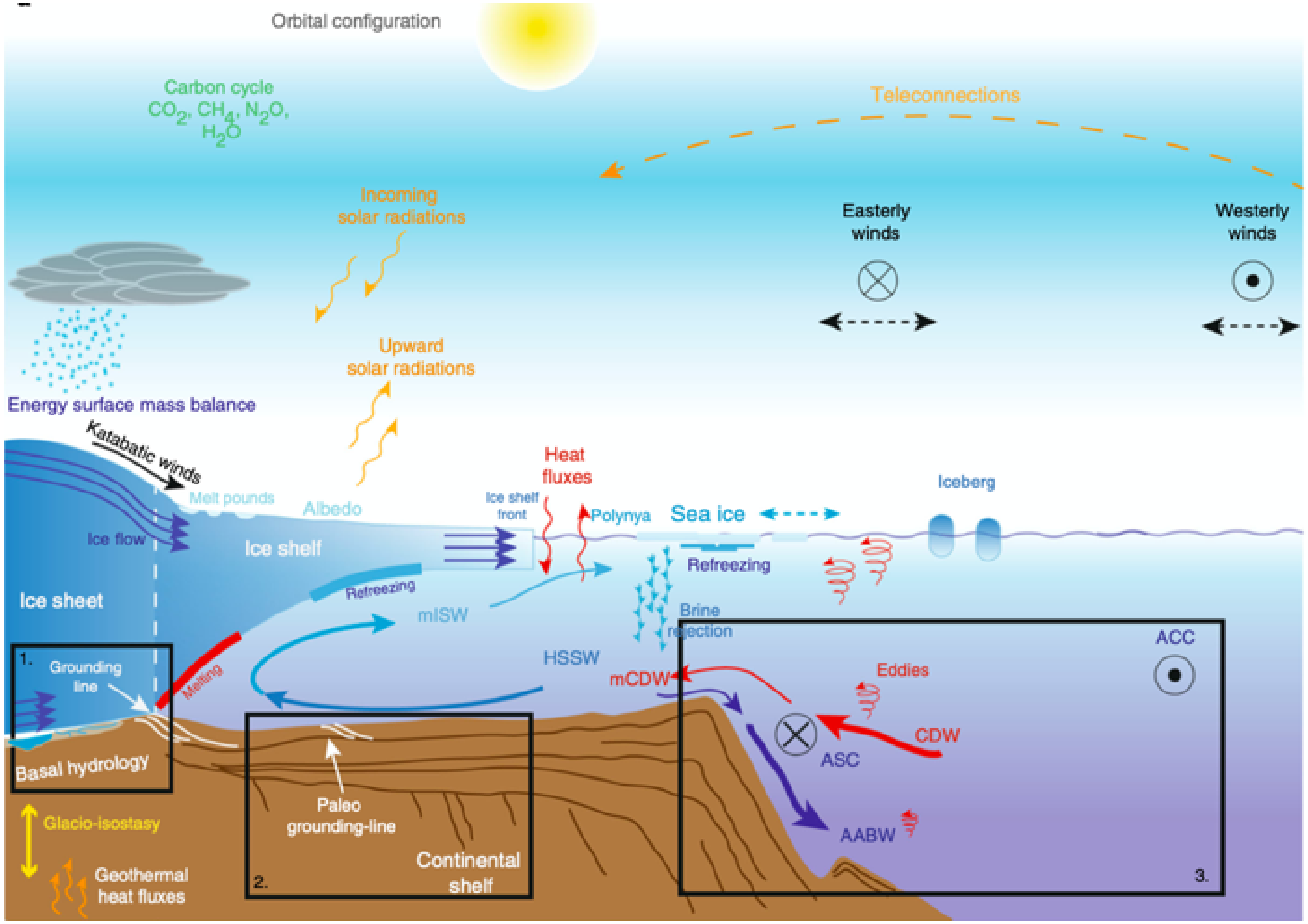


Figure 2.4: variability of processes across Antarctic ice-bed–ocean interfaces (Colleoni et al., 2018).

2.1 Ross Sea

2.1.1 Oceanography

In the present work we will consider particularly the Ross Sea, where samples were taken (fig. 2.5): it lies to the north of Earth's largest ice shelf, the Ross Ice Shelf (RIS).

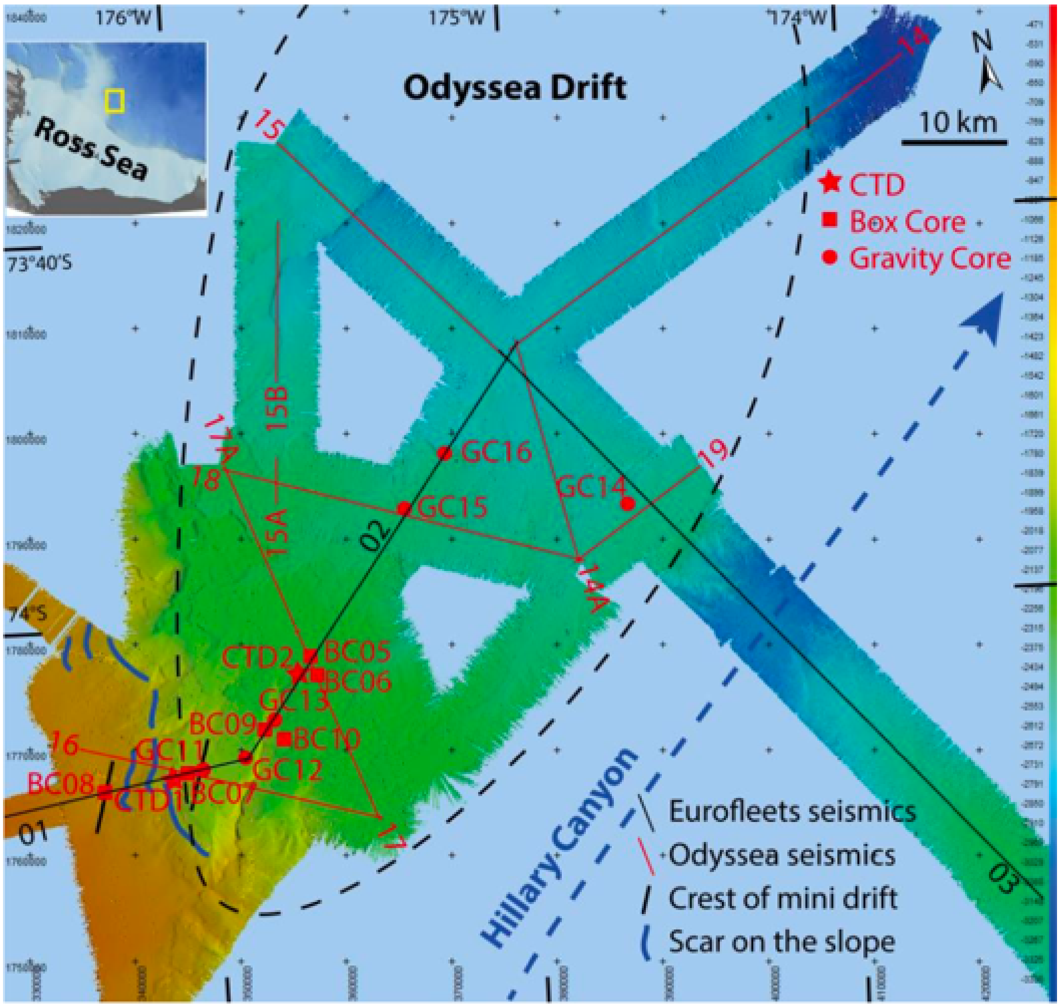


Figure 2.5: Report Explora Antartide 2017 ODYSSEA-PNRA (Rebesco et al., 2017)

The outer portion of the ice shelf floats on seawater that, as mentioned before, is modified beneath the shelf and that mixes and exchanges with waters to the north over the continental shelf.

Most of the abyssal ocean is presently filled with cold dense waters produced within the large polynyas of the Ross Sea and mixed with ambient waters. The Ross Sea (RS), facing the Pacific sector of the Southern Ocean, is approximately centered between Cape Adare 170°E to Cape Colbeck 158°W (fig. 2.6). On the southern side, it is bounded by the RIS,

at around 78.5° S.

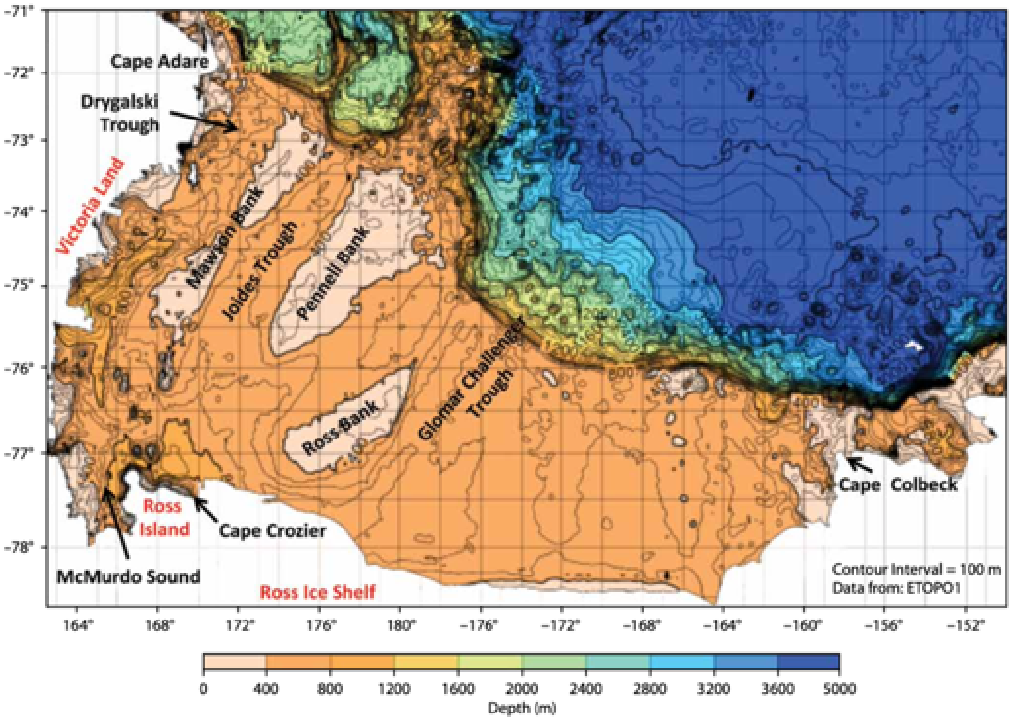


Figure 2.6: bathymetry of the Ross Sea (Smith 2010).

Although the average depth is 500 m, there are depressions that reach 1200 m and behave as dense waters reservoirs. Indeed, the Ross Sea is characterized by a deep and irregular continental shelf. Its eastern region is composed by slightly elevated reliefs, while the western side shows an extremely irregular topography, largely due to glacial erosion (Anderson et al., 1984). The central western sector is characterized by alternating reliefs and depressions, forming canyons which are important trough for sediments and turbidity currents due to cascading phenomena (Budillon et al., 2002).

The circulation on the Ross Sea shelf is complex and variations in physical properties along the seawater column determine a vertical structure from the surface to the bottom.

At the sea-surface: the Antarctic Surface Waters (AASW) enter in the Ross Sea around Cape Colbeck as part of a narrow coastal flow that, in addition to importing sea ice and icebergs, also incorporates continental meltwater derived from sea ice-air interactions farther upstream (Jacobs et al., 1985). In summer, AASW is a warm (temperature up to 2.0 °C) and fresh (salinity 33.5-34.5 per mil) water mass produced from the mixing of shelf waters and ice meltwater, or from the up-welling of the Circumpolar Deep Waters (CDW). It is the most variable water mass in the Ross Sea (Cincinelli et al., 2008). Low Salinity Shelf Water (LSSW), characterized by relatively high temperatures and low salinities (~ 34.4-34.6 per mil), flows below the AASW mainly on the eastern part of the Ross Sea Shelf (Jacobs et al., 1985).

The intermediate waters: are usually characterized by oceanic waters, entering in the Ross Sea from outside the shelf. The CDW is the greatest volume water mass in the Southern Ocean (SO), it is a mixture of Atlantic Deep Water and Antarctic Water, as well as recirculated deep water from the Indian and Pacific Oceans (e.g.,Callahan, 1972; Georgi, 1981; Charles & Fairbanks, 1992; You, 2000). CDW is a relatively warm, salty and nutrient-rich water mass carried around Antarctica by the Antarctic Circumpolar Current (ACC) (Whitworth & Nowlin, 1987), that evolves by mixing, cooling and by inputs from precipitation, melting and brine formation into several new water masses on and near the Antarctic Continental Shelf (Jacobs et al., 1985; Catalano et al., 2000; Russo, 2000). In the Ross Sea, the mixing of the CDW with the surface and shelf waters forms the Modified CDW (MCDW; fig. 2.7), characterized by a temperature between +1.0 and -1.5° C. (Cincinelli et al., 2008). MCDW intrudes into the continental shelf in several locations, mostly along the east side of troughs (Joides and Drygasky Basins), but also in the Glomar Challenger Basin (Jacobs & Giulivi, 1999; Budillon et al., 2003; Orsi, Wiederwohl, & Sea, 2009; Kohut, Hunter, & Huber, 2013). MCDW waters form warmer and saltier layer in the water column. Below this layer, temperatures decreased gradually with depth, while salinities increased (Cincinelli et al., 2008).

Deeper waters: mostly derive from High Salinity Shelf Waters (HSSW): low temperatures (-1.9 °C) and high salinities (34.7 per mil) (Jacobs et al., 1985). HSSW are the densest waters of the Ross Sea (Jacobs et al., 1985) formed during the Austral winter on the wind-generated coastal polynyas of Victoria Land, particularly in Terra Nova Bay (TNB), that provides salt fluxes large enough to increase the water column salinity and thus form the HSSW (Bromwich & Kurtz, 1984; Kurtz & Bromwich, 1985; Jacobs, 2004; Budillon & Spezie, 2000; Bergamasco et al., 2004). This water mass plays a crucial role in the formation of Antarctic Bottom Water (AABW) (Kurtz & Bromwich, 1985; Slonaker & Van Woert, 1999), contributing to deep ocean ventilation and the global thermohaline circulation (Jacobs et al., 1985; Orsi et al., 1999; Jacobs, 2004). For this main reason, changes in temperature and/or meltwater input to the Ross Sea could disrupt global meridional overturning circulation (Orsi et al., 2009; Purkey & Johnson, 2010), models are necessary to understand a possible variation and its impact. Over the past 40 years, Ross Sea derived Antarctic Bottom Water (AABW) has freshened as a result of increased meltwater input to the Amundsen and Bellingshausen Seas from melting ice shelves/glacial systems (Jacobs et al., 2002; 2011).

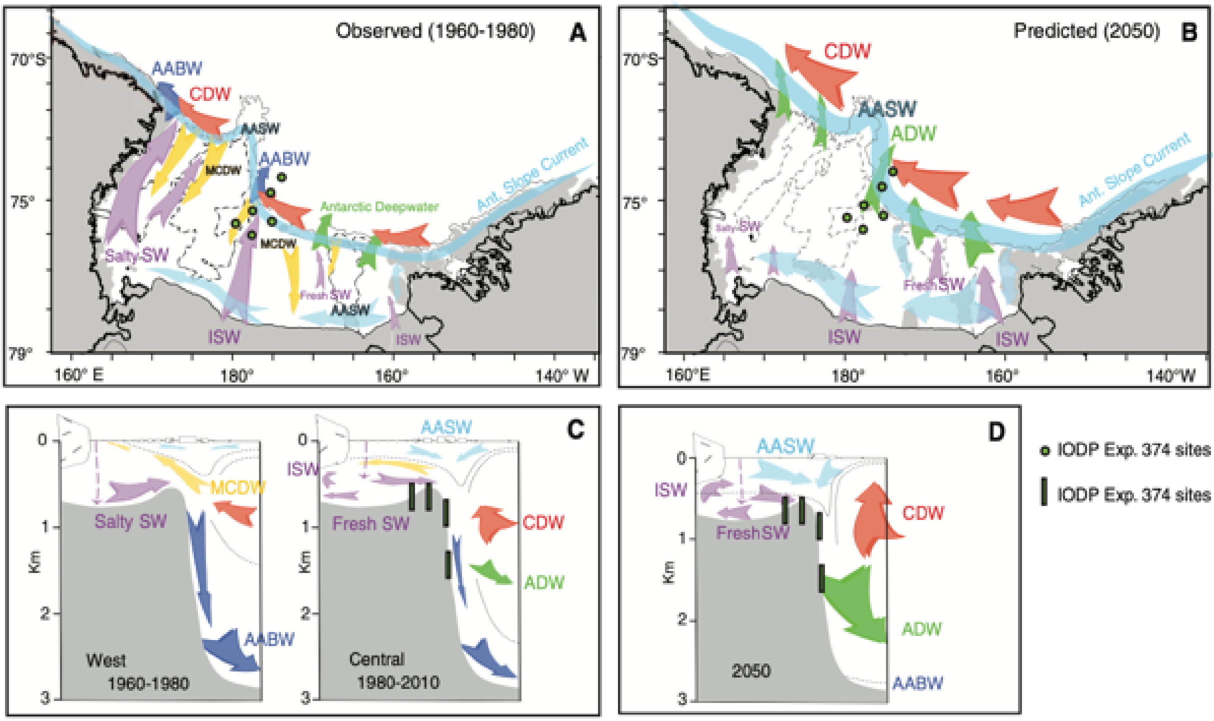


Figure 2.7: potential changes in Ross Sea. The lower panel shows potential intensification of flow and air-sea-ice interactions leading to an alternative mode of deep ocean ventilation during the next century. arrow width indicates the relative strength of each flow, and color represents individual water masses. antarctic Surface Water (AASW): light blue. Shelf Water (SW): purple. Modified circumpolar deep Water (MCDW): orange. circumpolar deep Water (CDW): red. New antarctic deep Water: green. New antarctic bottom Water: dark blue.(from The Ross Sea in a sea of change, WO Smith 2012)

2.1.2 Trophic sources

The Ross Sea is a heterogeneous ecosystem, characterized by a large variability in space and time of macro and micronutrients (Guglielmo et al., 2000; Gordon et al., 2000; Fitzwater, Johnson, Gordon, Coale, & Smith, 2000; Sedwick, Di Tullio, & Mackey, 2000), which exhibits the highest productivity of the Southern Ocean (Robinson, Arrigo, Kolber, Gosselin, & Sullivan, 1998). Annual primary production has been estimated to be about four times greater than elsewhere in the Southern Ocean, with large seasonal variations in biomass accumulation and production, and less pronounced interannual variability (Nelson et al., 1996). Maximum primary production occurs in late spring and decreases in summer in the central region, when this area is defined as a high nutrient low chlorophyll (HNLC) zone. The low production in offshore areas has been ascribed to iron limitation (Sedwick & DiTullio, 1997), as well as to light limitation due to the deep vertical mixing (Nelson & Smith, 1991; Saggiomo, Catalano, Mangoni, Budillon, & Carrada, 2002). In the Ross Sea the distributions of organic matter and algal biomass show similar patterns, with higher concentrations in stations where photosynthetic processes are more intense, however, high heterotrophic biomass and activity may be observed in ice free waters after ice melting (Nelson et al. 1989; Fabiano et al., 2000; Saggiomo et al., 2000; Gardner et al., 2000; Smith & Asper 2001; Smith, Mincks, & DeMaster, 2006). A large amount of particulate and dissolved organic matter, deriving from primary production, is available to consumers of the higher trophic levels in the upper water column also entering in the detritus food web by means of the microbial loop (Azam, Smith, & Hollibaugh, 1991; Riebsell et al., 1991; González, 1992).

In the Ross Sea, particulate organic carbon seems to satisfy the organic C requirement of the deep marine biota representing the main organic fuel of the biological pump (Ducklow et al., 2000) and ruling the mechanism of deep-sea remineralization (Azzaro, La Ferla, & Azzaro, 2006) in spring-summer period. However, degradation processes change the concentration and composition of particulate and dissolved matter with depth. (Catalano et al., 2014)

2.2 Hillary Canyon

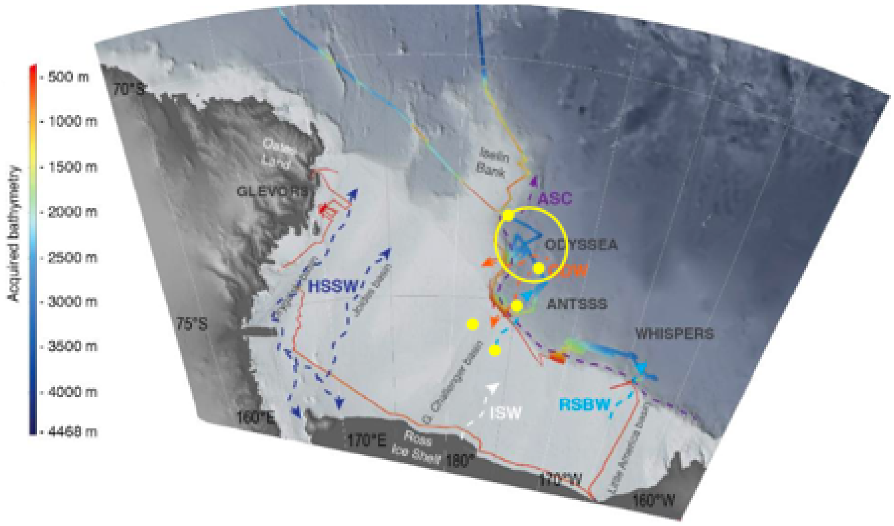


Figure 2.8: ITRS17-ODYSSEAPNRA expedition. (From De Santis OGS_Napoli, 2019)

As mentioned above, the Ross Sea is one of the major areas for Antarctic Bottom Water (RSBW) formation, representing the densest ocean water mass, filling the deepest ocean basins connected to the Southern Ocean. Periodic refill of the RSBW occurs through formation of dense, cold and saline water masses forming on the shelf in the Ross Sea permanent polynya. The HSSW periodically overspills the shelf area and descends along the slope. This mechanism represents the engine of the global ocean circulation regulating the world climate.

The Hillary Canyon, crossing the Ross Sea continental slope, represents one of the main conducts through which the HSSW descends the slope to reach the deeper ocean with evidence of turbidite activity relating to transport of cascading water masses (e.g., AABW) down the canyon (Mckay, 2019). On its western levee, there is a mounded that was mapped and ground-sampled during the Italian ITRS17-ODYSSEA expedition (fig. 2.8) on board the RV OGS-Explora (January-February 2017).

Geophysical data allowed interpreting such feature as a sediment drift (ODYSSEA Drift), generated by along-slope, contour currents sediment transport and accumulation through several hundred-thousand years.

It was inferred that contour currents transported and deposited the sediments that descent the Hillary Canyon by means of the HSSW. (Lucchi et al., 2019). Therefore, the depositional sequence of the ODYSSEA Drift potentially contains the record of the variability of HSSW formation, the along slope current intensity in association to climate change, and the interplay between the two bottom currents. Figure 2.9 shows the different currents involved in the environmental setting of the Hillary canyon.

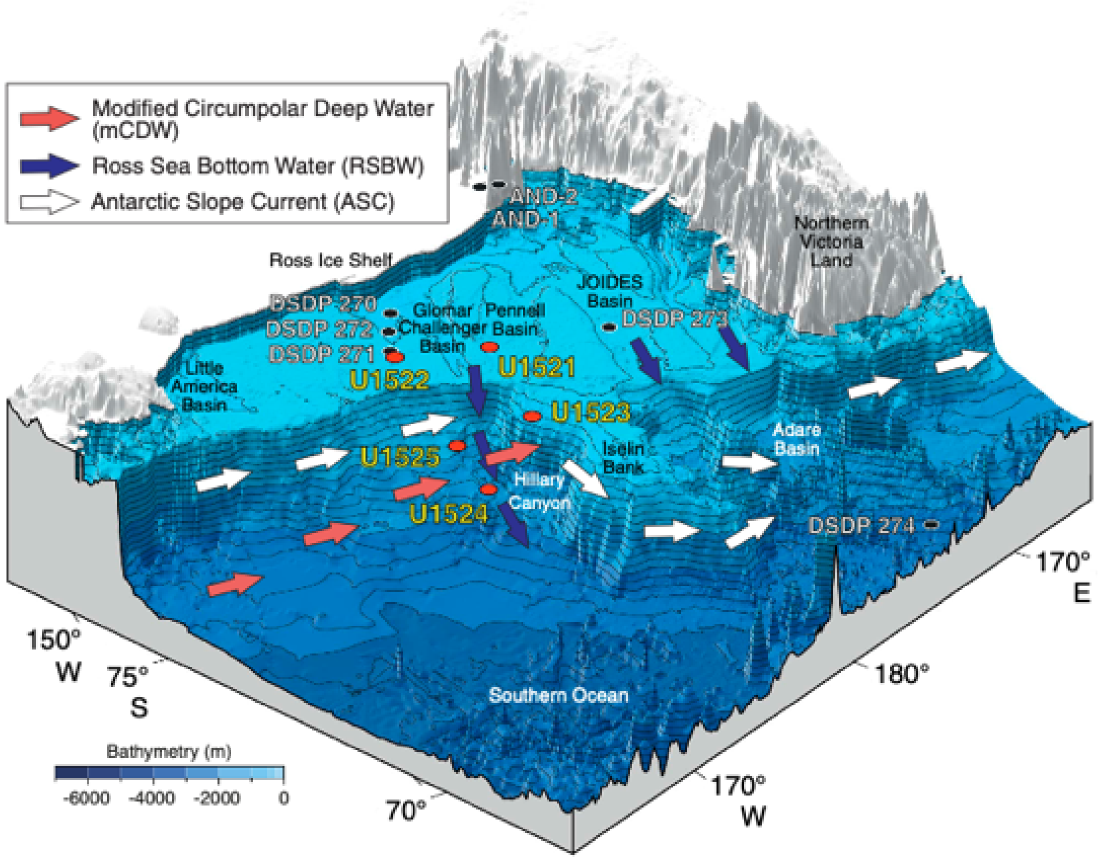


Figure 2.9: PNRA/ODYSSEA project PI: Michele Rebesco (OGS) Partners: CNR-ISMAR Bologna; University Pisa, Univ. Parma, INGV-Roma; Univ. Plymouth UK, FIO China (Bergamasco A. Unpublished)

CHAPTER 3

MATERIAL AND METHODS

Samples were collected on the oriental continental shelf of the Ross Sea (Southern Ocean) during a multi-disciplinary expedition of the PNRA programme. (fig. 3.1)

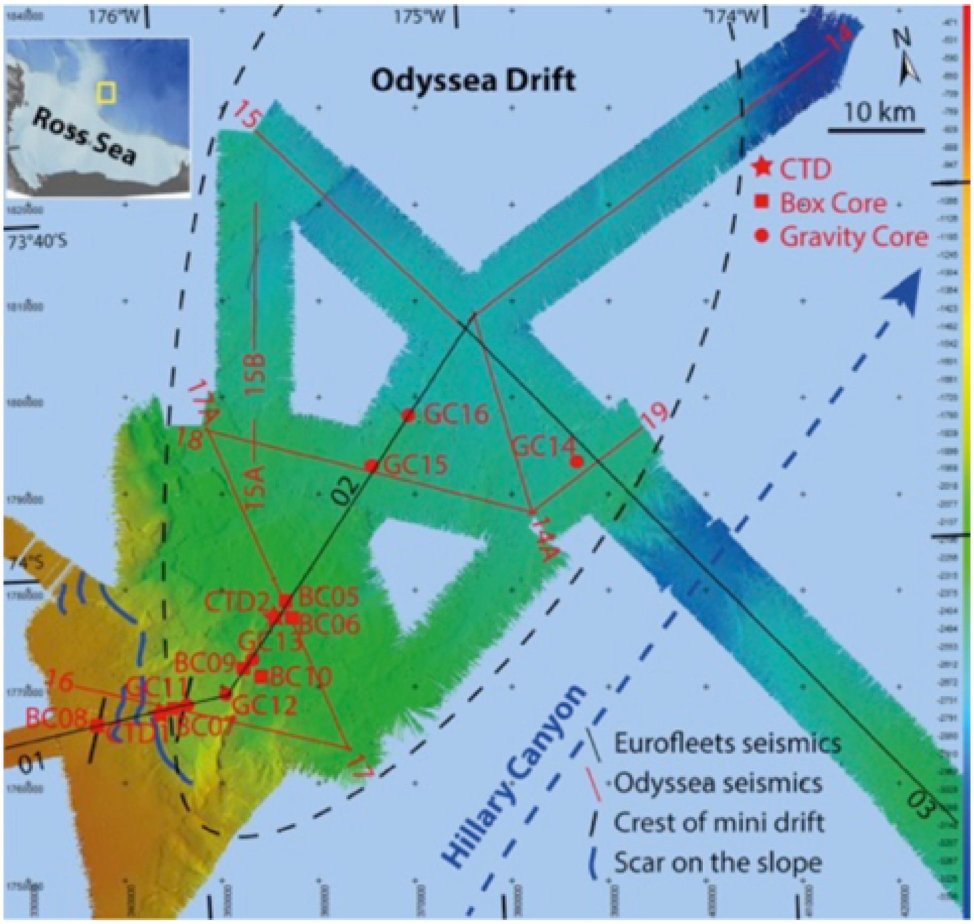
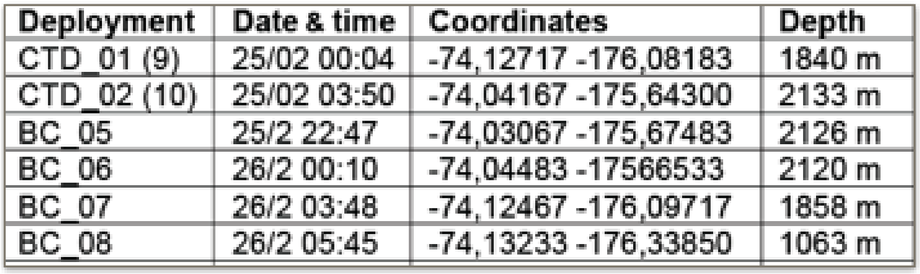


Figure 3.1: Location map and sampling sites from preliminary report R/V OGS Explora PNRA 2017

3.1 Sampling procedures

Sediment samples were collected from three stations, namely BC08, BC07 and BC06, using a box corer (Table 3.1). BC08 was collected on the sediment drift from the upper part of the slope at around 1000 m depth; the superficial sediments were characterized by the presence of several clasts and corals which were stored separately for the analyses of the attached fauna. BC07 and BC06 were collected along the slope at depth of 1858 and 2120 m respectively; the superficial sediments collected from these stations were characterized by the occurrence of only small clasts. Coral and clast samples were collected from the surface of the box-corer and stored dry for laboratory-based analyses of encrusted foraminiferal fauna (fig. 3.2, 3.3). Sediment samples were collected by subsampling with small plastic tubes the box cores. Indeed, each box-corer deployment was subsampled equidistantly (distributed at triangle) and three replicates of sediment cores were frozen at -20°C in order to preserves the organic living material for each sampling station.



Deployment	Date & time	Coordinates	Depth
CTD_01 (9)	25/02 00:04	-74,12717 -176,08183	1840 m
CTD_02 (10)	25/02 03:50	-74,04167 -175,64300	2133 m
BC_05	25/2 22:47	-74,03067 -175,67483	2126 m
BC_06	26/2 00:10	-74,04483 -17566533	2120 m
BC_07	26/2 03:48	-74,12467 -176,09717	1858 m
BC_08	26/2 05:45	-74,13233 -176,33850	1063 m

Table 3.1: Coordinates and depth of the stations sampled BC08, BC07, BC06.

Figure 3.2: Example of biogenic Hard Substrates, a hydrocoral skeleton, found at the surface of BC08.

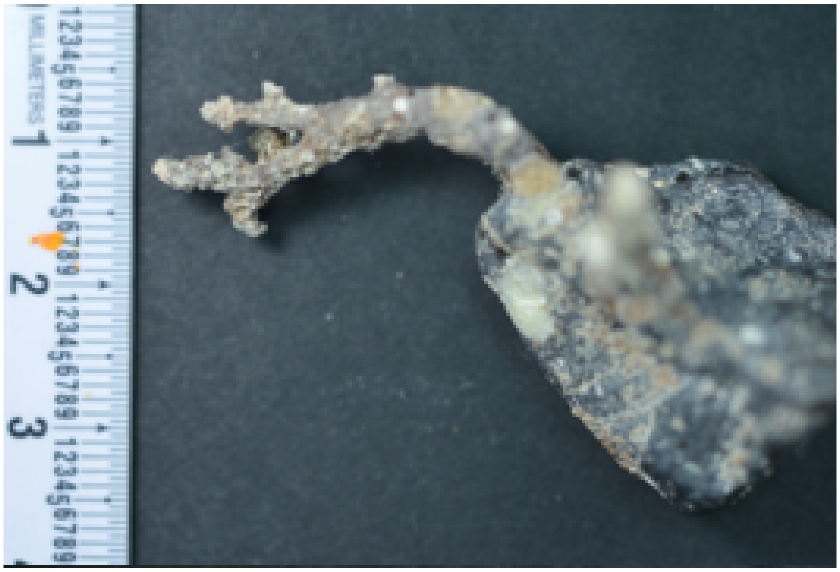


Figure3.3: Example of Hard Substrates found at BC08, encrusted clasts with hydrocoral skeleton encrusted as well.

3.2 Laboratories activity

3.2.1. Hard Substrates

Laboratories activity were performed using, at first, a binocular microscope to explore each clast and coral sample in order to look for encrusting epibenthic foraminiferal specimens that were identified at species level when possibile. Morphological studies were performed using SEM (scanning electron microscope) *Hitachi TM3030 plus tabletop microscopes* to take images (fig. 3.4) that allowed us to pick also small foraminifera not detectable by eye and clarify 3D structures hardly evident by eye.

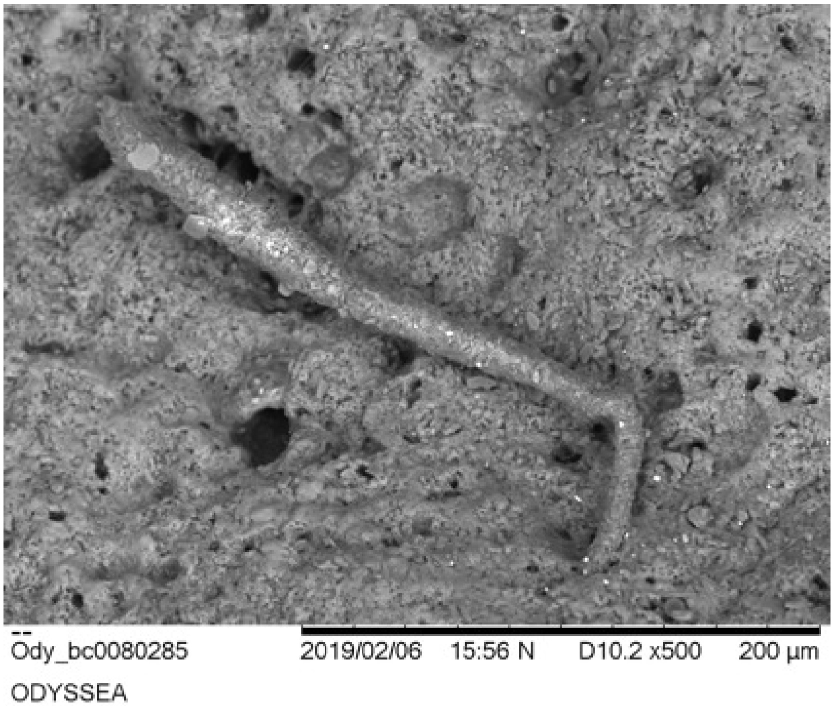


Figure 3.4: SEM image of a foraminifera (Marsipella elongata) on a Hard Substrates of site BC08.

This was paired with a Microscan *Oxford instrument*, a scanning electron microprobe (EDS) that analyze the organic composition and contribution of different elements/metals. All foraminiferal specimens found in clast samples were counted.

3.2.2 Sediment

Sediment cores collected on board were defrost in laboratory. With the aid of a "cores extruder" (fig. 3.5) handmade we cut 1 cm of each cores sample until 10 cm; then each slice was stored in plastic jars, weighed and then fixed with Formalin 4% buffered with Sodium Borax and colored with Rose-bengal (1g/l) left for 24 h under the laminar flow hood before to analyze them.

Figure 3.5: "cores extruder" handmade used to cut each cores centimeter.

Samples over >10 cm were directly dried in the oven at 50°C approximately. Only the fractions 0-1 cm and 1-2 cm, for each replicate cores, were processed in order to analyze them under the binocular microscope (Leica M165C) to perform the picking of the living foraminifera specimens. Thus, we washed the samples to remove the formalin, under the laminar flow hood, and sieved them at three different fractions: 1 mm, 150 μm and 63 μm, in order to evaluate the size structure of foraminiferal assemblages. All the samples thus prepared were then stored in 4% formalin buffered solution with one drop of Rose Bengal solution. The residues were kept wet and hand-sorted for stained benthic Foraminifera in water in a Petri dish using the stereomicroscope (Leica M165C). All the foraminiferal specimens were counted because it was impossible found at least 300 organisms for all fractions (standardized to the total sample). All the specimens were counted, and their numbers standardized as Number of individuals per 50 cm^2. The observation of the test morphologic features, and its composition, have been used to identify all the collected species or, when this was not possible, genera. After that residues were dried in the oven using filter paper and weighed with the analytical balance (accuracy of ± 0.0001 mg).

The total density expressed as n°ind/50 cm^2 was calculated as the sum of total individuals for the surface 0-1 cm studied for each station. Samples have been split as fractions: 1 mm; between 1 mm and 150 μm and for 150 μm - 63 μm, then a total >63 μm was also calculated. Every biodiversity index was calculated considering total assemblages n°ind/50 cm^2 and considering only the total assemblages present in the first centimeter (>63 µm). Foraminiferal biodiversity was estimated using different diversity indices: species richness (S) measured as the number of species, dominance (D) measured by the 1-Simpson Index, species diversity (H loge) measured by the Shannon–Wiener (H) information function and species evenness (J) measured using the Pielou (1975) Index. All indices were calculated using Paleontological Statistics Data Analysis (PAST) software (Hammer-Muntz, Harper, & Ryan, 2001).

3.2.3 Taxonomical composition and biodiversity

After the species identification, foraminifera has been divided in five taxonomical group, based on the test composition and the number of chambers, calculating the percentage contribution given by each category at each level. These taxonomical groups are Total Polythalamous calcareous (TPC), Total Polythalamous Miliolids (TPM), Total Polythalamous Agglutinated (TPA), Total Monothalamous Agglutinated (TMO), Total Monothalamous Organic (TMO). The taxonomical composition has been then calculated as percentage contribution for total Miliolids, Agglutinated and Calcareous.

CHAPTER 4

RESULTS

4.1. Biodiversity Census

A resume of the total recognized species is shown in table 4.1: here I report the presence and description of the species for Hard Substrates (HD) and/or Sediment (S). The entire data set accounts 65 species totally; the Hard Substrates have the higher biodiversity with 44 species, while Sediment species are only 31. Of those species, only 10 are in common for both Hard Substrates and Sediment, in particular: *Epistominella* sp. *Husezima & Maruhasi 1944; Patellina corrugata Williamson 1858; Rupertia stabilis Wallich 1877; Spirillina Ehrenberg 1843; Trifarina angulosa (Williamson 1858); Cornuspira Schultze 1854; Glomospira charoides (Jones & Parker 1860); Hemisphaerammina bradyi Loeblich & Tappan 1957; Lepidoparatrochammina lepida (Brönnimann & Whittaker 1986)* and *Psammosphaera fusca Schulze 1875.*

Species ID	HARD SUBSTRATES	SEDIMENT
Alabaminella sp.	✗	
Astrononion stelligerum	✗	
Cibicides refulgens	✗	
Cibicidoides sp.	✗	
Cibicidoides lobatulus	✗	
Cibicidoides pachyderma	✗	
Epistominella exigua	✗	
Epistominella sp.	✗	✗
Eponides sp.	✗	
Fissurina sp.	✗	
Glandulina rotonda	✗	
Globocassidulina pacifica	✗	
Globocassidulina subglobosa	✗	
Miniacina miniacea var. antarctica	✗	
Neoconorbina	✗	
Oolina hexagona	✗	
Parafissurina		✗
Patellina corrugata (ant)	✗	✗
Patellina williamson	✗	
Pseudonodosinella		✗
Rupertia stabilis	✗	✗
Spirillina obconica		✗
Spirillina sp.	✗	✗
Spirillina vivipara	✗	
Trifarina angulosa	✗	✗
Miliolide sp.		✗
Pyrgo sp.		✗
Adercotyma glomerata		✗
Ammobaculites sp.		✗
Ammodiscus sp.		✗
Ammolagena sp.		✗
Ammopemphix	✗	
Chondrodapis	✗	
Crithionina hispida	✗	
Cornuspira	✗	✗
Cribrostomoides bradyi		✗
Cyclammina trulissata		✗
Dendronina var. antarctica	✗	
Glomospira charoides	✗	✗
Glomospira gordialis	✗	
Halyphysema sp.	✗	
Haplofragmoides sp.		✗
Hemisphaerammina bradyi	✗	✗
Hyperammina		✗
Karreriella bradyi	✗	
Komokiacean like	✗	
Labrospira crassimargo		✗
Lagenammina antarctica		✗
Lagenammina arenulata		✗
Lepidoparatrochammina lepida	✗	✗
Lituotuba lituiformis	✗	
Marsipella elongata	✗	
Paratrochammina (Lepidoparatrochammina) haynesi	✗	
Portatrochammina antarctica	✗	
Placopsilina bradyi	✗	
Psammosphaera fusca	✗	✗
Recurvoides contortus		✗
Reophax sp.		✗
Rhabdaminella cylindrica		✗
Rhizammina sp.		✗
Sagenina	✗	
Spiculosiphon	✗	
Spiroplectammina biformis		✗
Tolypammina vagans	✗	
Spiculotuba n. gen.	✗	

Table 4.1: Species Identification. Presence in Hard Substrates (HD) or sediment(S). Highlighted panels stand for presence both in HD and S.

4.1.1 Systematic account and morphotypes

Some of encrusting species found in HD are difficult to detect and identify and usually they are poorly studied. Among these foraminifera there are hidden morphotypes found in almost all stations (11 of total 17) that could represent a new genus. In addition, among already epibenthic known taxa, there is a variety of morphotypes displaying, adapted to local environment, some morphological shifting from the usual form described. In this paragraph, I propose the description of a new genus of encrusting foraminifera together with the description of some morphotypes of epibenthic known taxa.

4.1.2 Spiculotuba n. gen.

Class MONOTHALAMEA Pawlowski et al., 2013

Order ASTRORHIZIDA Lankester, 1885

Superfamily ASTRORHIZOIDEA Brady, 1881

Family HALYPHYSEMIDAE Loeblich & Tappan, 1984

Genus **SPICULOTUBA n. gen.** d'Agnessa, Sabbatini & Morigi 2019 (fig 4.2, 4.3)

Derivation of name: from the tubular shape of the test composed entirely in cemented siliceous sponge spicules.

Material: single individuals attached to clasts or biogenic hard substrates for a total of 452 n°ind/50cm^2. Specimens were recovered from clasts and biogenic structures of site BC08.

Locality: Ross sea at >1000m depths

Description: test agglutinated, with a basal part attached to the surface (fig. 4.2a), having a convex dorsal side from which detaches an elongated tubular chamber (fig. 4.2b). Individuals are found as isolated even though they could be close but without any correlation between tests.

Test wall agglutinated, thin, made entirely of siliceous sponge spicules intricated and finely elaborated like a wicker basket and not just attached in the direction of test growths (like *Halyphysema* sp.) all cemented and with a translucent/white aspect. Aperture single on the tubular extremity, simple, rounded.

Dimension: holotype (Fig 4.2) is 800µm. Paratypes (eight individuals) are almost range from 90µm up to 1,5mm, evident by eyes.

Remarks: Spiculotuba n. gen. is one of the more commonly occurring attached agglutinated foraminiferal specimens at the BC 08 (Order Asthrorhizida, Lenkester 1885) both on clasts and coral skeletons. It can be found with the basal part attached in depressions on clastic and biogenic hard substrates, somehow hiding itself; this could be due to their delicate form that could be easily damaged, getting hard its finding. Therefore, there is only one example of a similar morphotype found by Jonasson & Schrooeradams (1996) in the hydrothermal vent site of Middle Valley, on the Juan de Fuca Ridge, northeastern Pacific. Authors did not describe this morphotype and they report one image in the paper labelled “Unknown tubular attached organism with a siliceous test”. SEM (Scanning electron microscope) analysis evidences also the possible presence of different morphotypes (possibly species) regarding the arrangement of the sponge spicules and/or the basal part, not detectable by eyes (fig. 4.4, 4.5, 4.6). For this reason, I propose three different descriptions, in addition to those of the holotype representing the new genus, relating to different morphological features as evidenced by SEM analyses.

The morphotype one, has very regular packed spicules (fig. 4.2) with an oval shaped basal part (fig. 4.2a) with spicules arranged as “rice grain”, very regular and ordinated. Morphotype two has a more “semilunar” disposition of the spicules for the basal part, not shaped regularly and oval, with longer spicules departing in the first part of the tube, which is more regular as morphotype one (fig. 4.4) A close up of the spicules is possible to see in figure 4.5.

Whereas, the morphotype three has basal part with very long and abundant extruding spicules, which presence continue also on the tube, being more irregular (fig. 4.6). Also figure 4.7 has this same disposition, with a hidden basal part. Thus, this could be an early stage of the species that is starting to arrange spicules suggesting that further studies should be done. SEM photography evidences the formation of the test made entirely by sponge spicules, micro and macrosclere where present such us morphotype 3. The scanning electron microprobe (EDS) confirms the presence of Silica in the test (fig. 4.8). Indeed, as shown in table 4.1 there is a peak in the Si with a weight% of 35.38. Those are finely intricated, showing the high potential rielaboration of environmental elements made by foraminifera. Indeed, it is widely known this particular feature of extreme selection for environmental material. Selectivity appears to be based on either the type of mineral (Kaminski, Armitage, Jones, & Coccioni, 2008; Makled & Langer, 2010; Makled & Langer, 2010b; Rothe, Gooday, & Pearce, 2011; Sabbatini et al., 2016) or on particle size (Heron-Allen, 1915a; J H Lipps, 1973; Bowser & Bernhard, 1993; Bowser, Gooday, Alexander, & Bernhard, 1995; Bowser et al., 2002). Some species construct their test from a variety of different grains, but others choose one particular grain type or sponge spicules (Heron-Allen, 1915; Murray, 2006). For example, *Deuterammina* sp. Brönnimann 1976 picks up exclusively barite cristals, while *Reophax spiculifer* Brady 1879 and *Spiculosiphon oceana* (Maldonado et al., 2013) are made up entirely of sponge spicules but agglutinated parallel to the major axis, not elaborated as in this case.

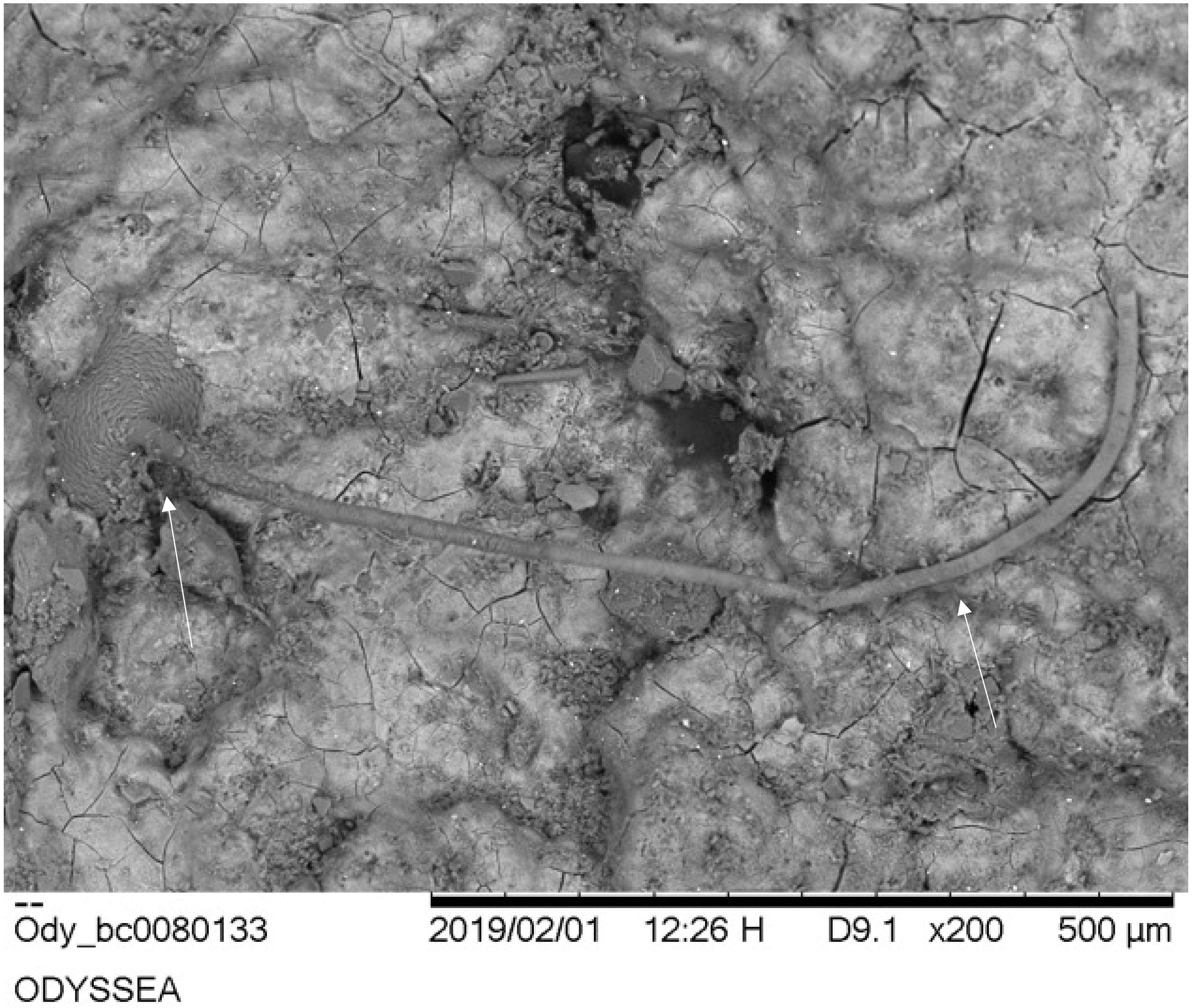


Figure 4.2: holotype specimen of Spiculotuba n. gen. *at SEM. It has a range of nearly 700 µm. It is possible to see how regular the spicules are shaped. Preservation is quite good, and some salt minerals are present. (Morphotype one)*

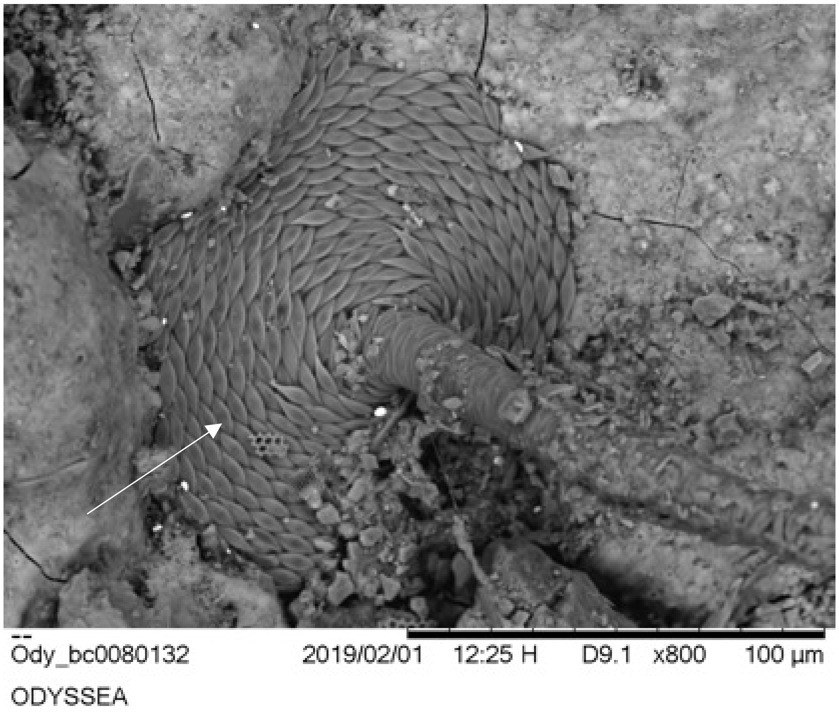


Figure 4.2a: SEM images of The basal part of the individual is often found in a depression on the hard substrates, it could be exposed or not to the external environment. Spicules are regular, “rice grain”, and from the middle part depart the elongated tube.

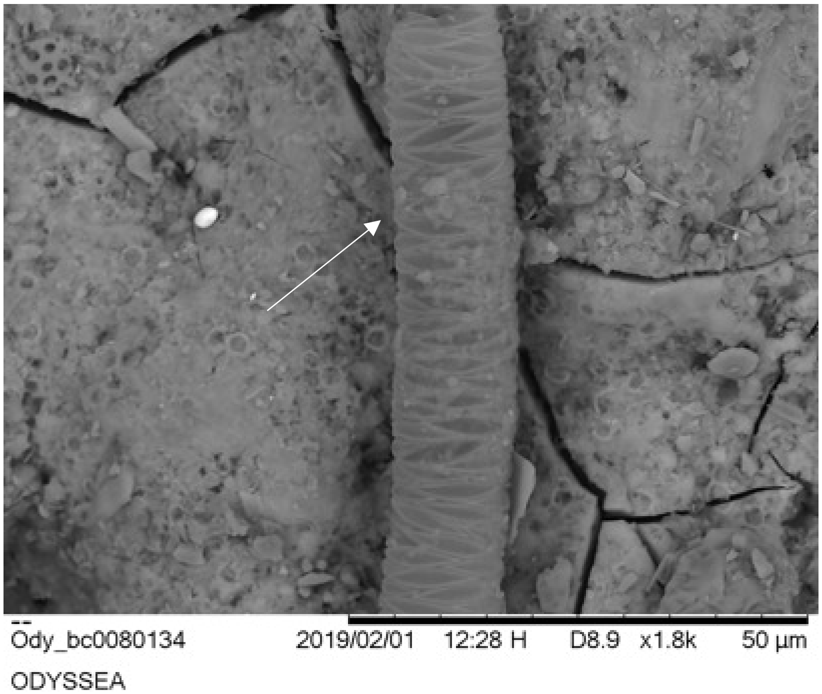


Figure 4.2b: the regular tube spicules, with the aperture at the end, finely packed intersected. It is nearly 15 µm elongated.

Figure 4.3: image at stereo-microscope 7,5x of a Spiculotuba n. gen. *The spicules test made it traslucent.*

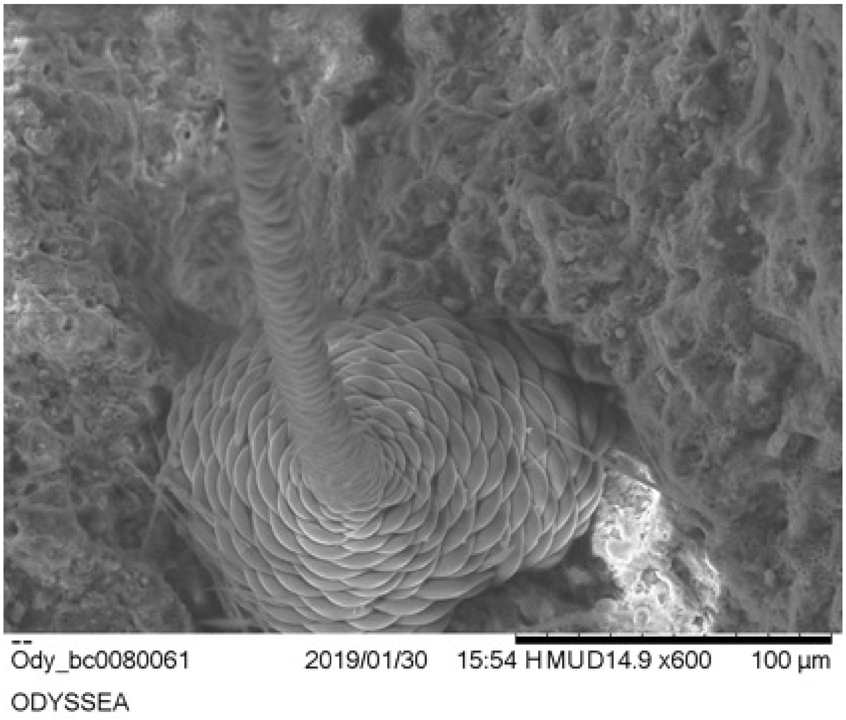


Figure 4.4: SEM image of morphotype two of Spiculotuba n. gen*. Here the spicules are arranged in a "semilunar" way, respect the "rice grain" morphotype.*

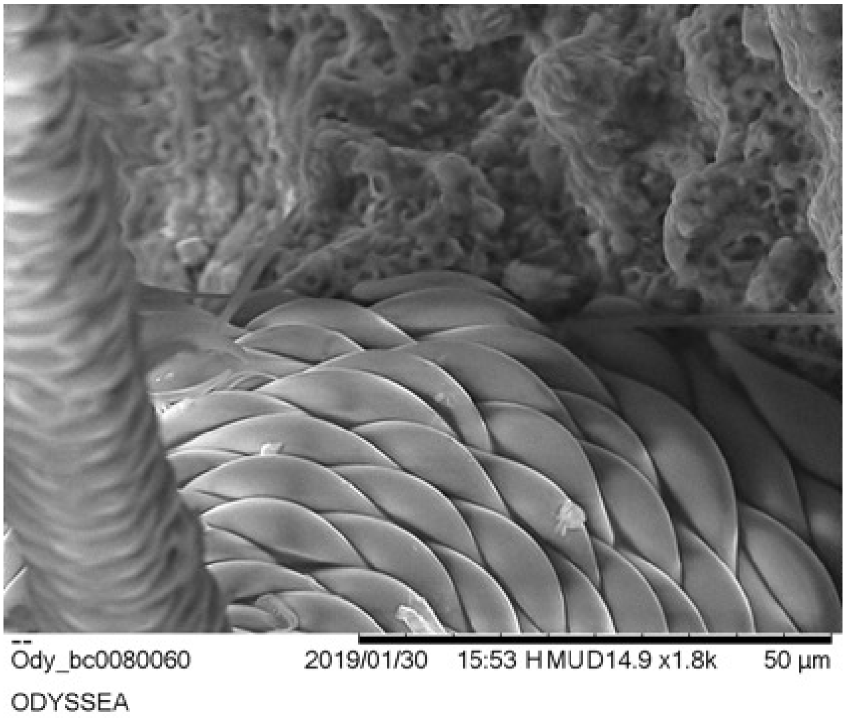


Figure 4.5: close up SEM image of Spiculotuba n. gen*. It is clearly shown the basal semilunar intersection of the sponge spicules.*

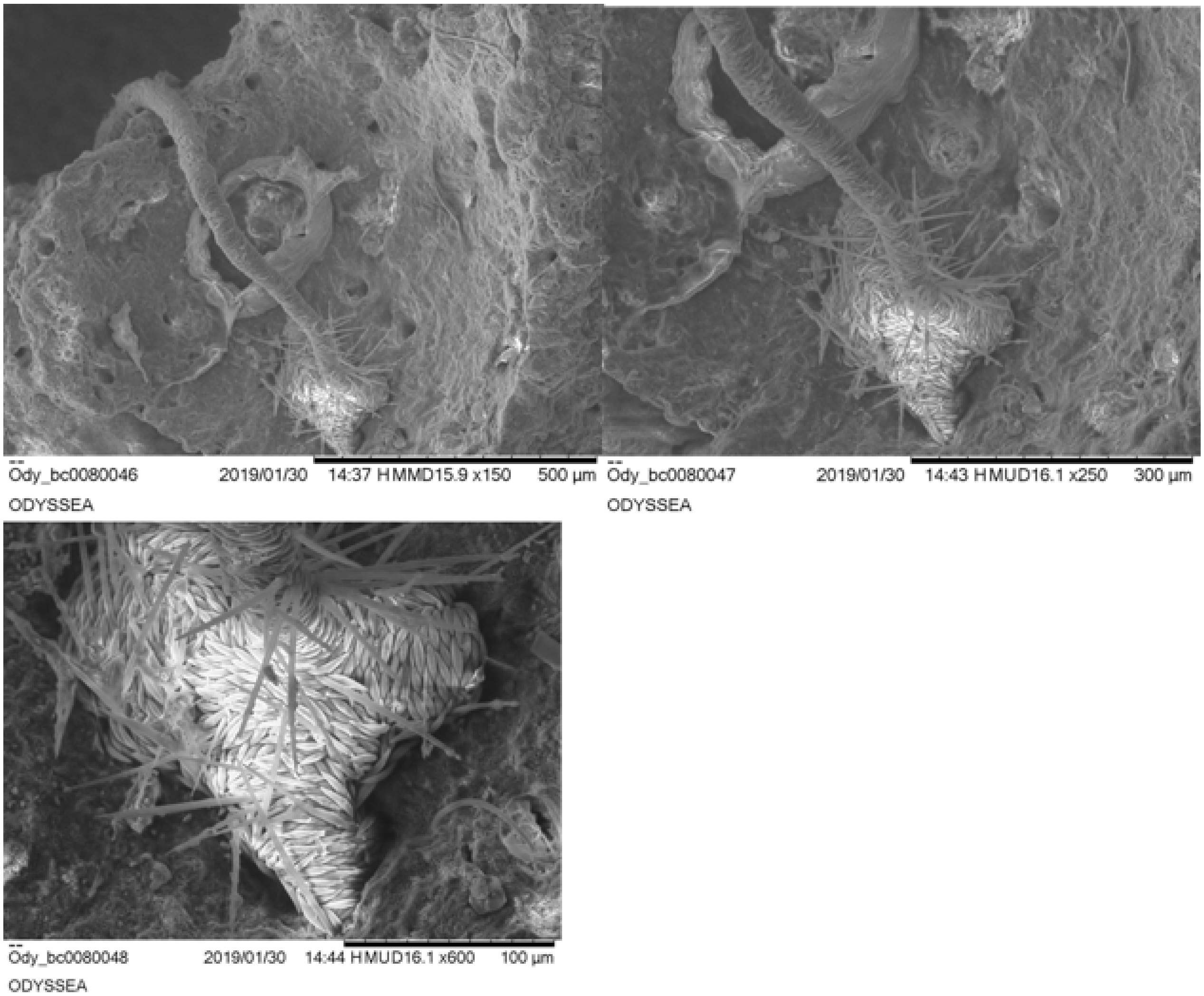


Figure 4.6: morphotype three of Spiculotuba n. gen*. SEM images with Close up.*

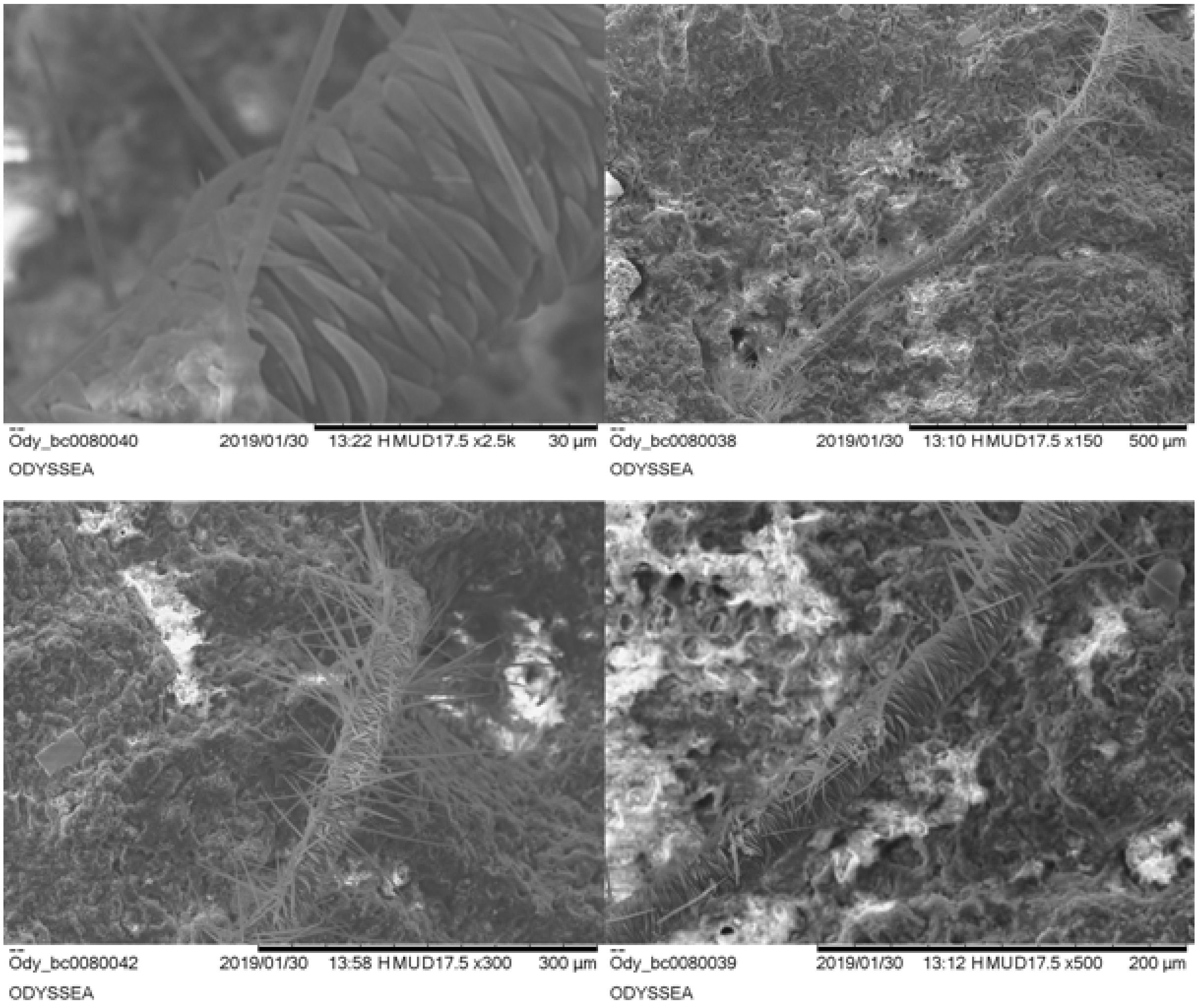


Figure 4.7: morphotype three of Spiculotuba n. gen. *SEM images with Close up. it is possible to see the packed spicules and the extruding ones.*

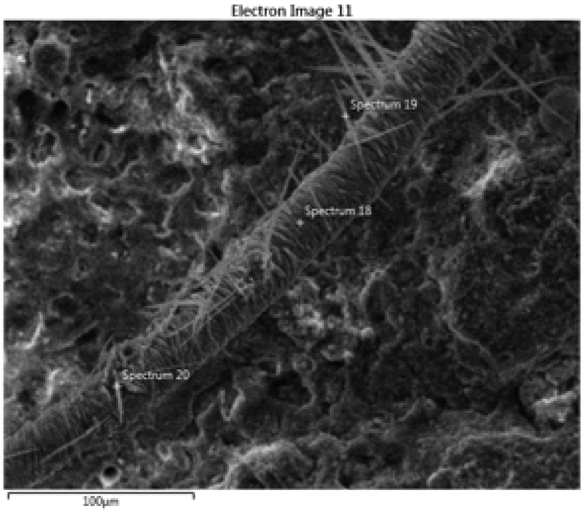


Figure 4.8: spectrum image for Spiculotuba n. gen*. Highlighting the spicules test*

SPECTRUM 18

Element	Line Type	Weight %	Weight % Sigma	Atomic %	Oxide	Oxide %	Oxide % Sigma
O	K series	46.58	0.56	63.16			
Si	K series	35.20	0.51	27.19	SiO2	75.29	1.08
Ca	K series	14.63	0.44	7.92	CaO	20.48	0.61
Cl	K series	1.41	0.20	0.86		0.00	0.20
Mn	K series	2.19	0.44	0.86	MnO	2.82	0.57
Total		100.00		100.00		98.59	

Table 4.1: resulting spectrum for Spiculotuba n. gen.*: it is possible to see the Siliceous peak thus demonstrating the composition of the test entirely made of environmental spicules attached and finely intricated.*

Moreover, I would like to report also another possible finding of this tiny world, not included in the Phylum of foraminifera but always belonging to protists and to Phylum of Radiozoa: Acantharia. They are holoplantonik monophyletic taxon within the radiolarians in the eukaryotic super-group Rhizaria (Krabberød et al., 2011; Adl et al., 2012) currently comprise around 50 genera and 150 species (Bernstein et al., 1999) grouped into 18 families and distributed in four suborders: Holacanthida, Chaunacanthida, Symphiacanthida and Arthracanthida (fig. 4.9; Bernstein et al., 1999; Suzuki & Aita, 2011), subdivided following skeleton arrangement: 10 diametral or 20 radial spicules that are spatially organized. (Müller, 1859; Wilcock, Perry, Williams, & Mantoura, 1988). The acantharian cell typically exhibits a characteristic star-shaped mineral skeleton made of strontium sulfate (Odum, 1951; Suzuki& Aita, 2011; Decelle, 2015).

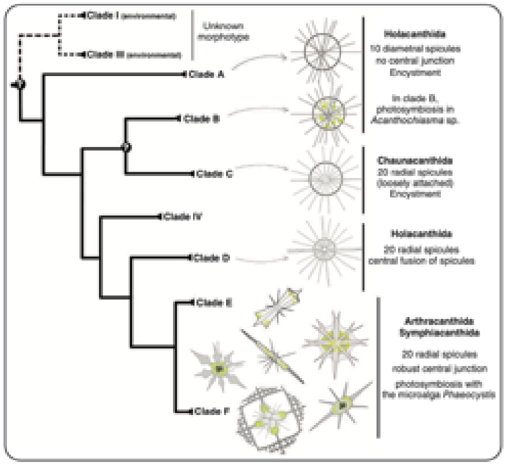


Figure 4.9: Acantharia taxonomical subdivision based on Decelle, 2015

During the census of foraminiferal species, I have picked up two epibenthic attached individual identifying them as *Spiculosiphon* sp. Instead, SEM analysis coupled with a scanning electron microprobe (EDS) for elements identification, show a totally different result; the two individuals are made by strontium sulfate mineral exclusive of Acantharia species. This could imply that they are Acantharian specimens showing a unique benthic behavior since they are only reported as marine planktonic.

They follow the general distinctive features of Acantharia having an internal star-shaped skeleton made of strontium sulfate mineral.

SEM photography evidences the internal structure, with spicules that follow the specific geometric pattern of this group (fig. 4.10, 4.11). highlighting also the presence of a stem made by the same geometrical spicules. The scanning electron microprobe (EDS) confirms the presence of strontium sulfate (*celestite*) both in the cell (fig. 4.12) and the stem part. (fig. 4.13) The cell spicules as shown in spectrum 2 (tab. 4.2, 4.3) evidences a peak in the S and Sr element with a weight% of 17.41 and 38.37. Also in the stem those two peaks are respected with values of weight % 8.57 and 25.22.

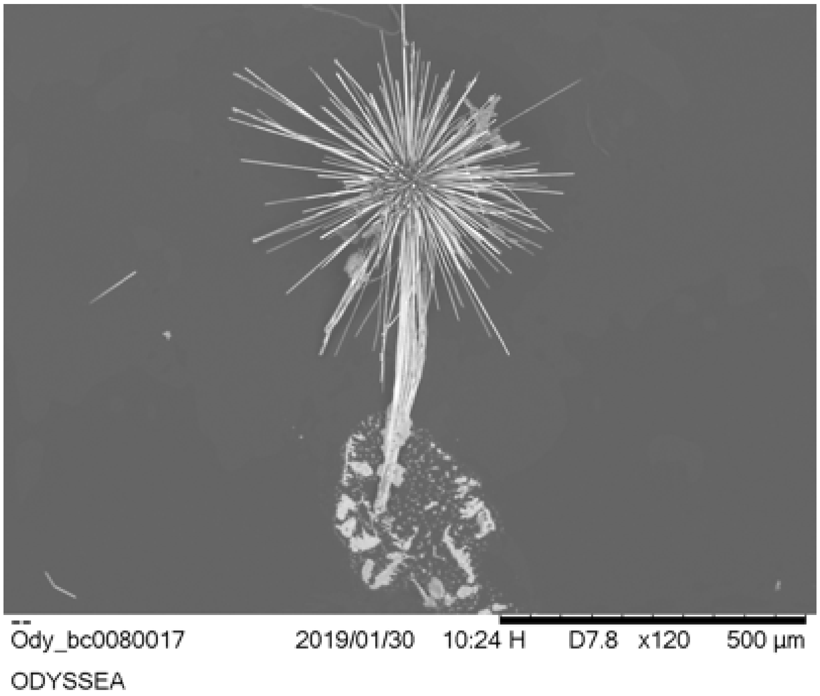


Figure 4.10: specimen of "Benthic Acantharia" on stub. It is possible to see the "cell" part attached to a stem: both are made in Strontium Sulfate (celestite)

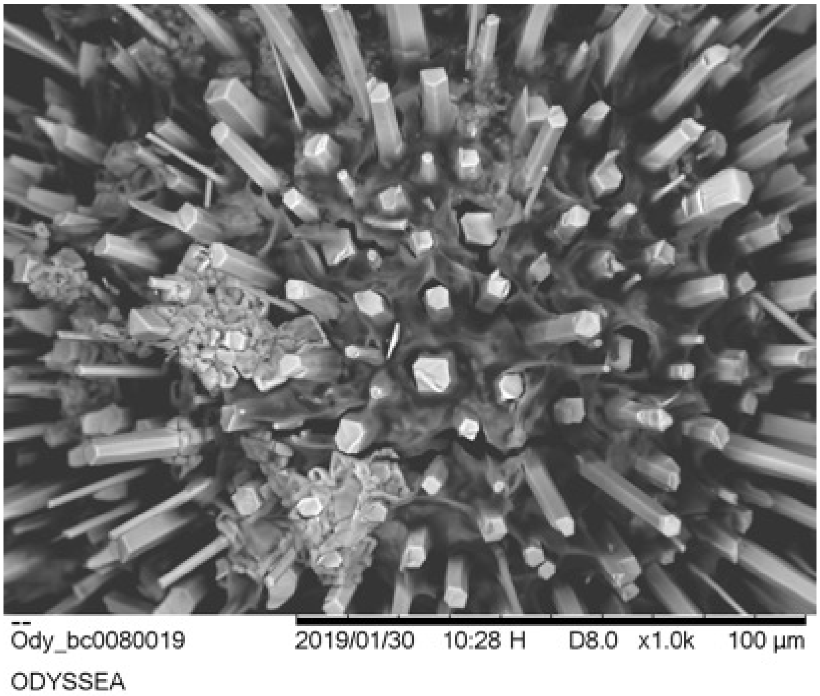


Figure 4.11: cellular cytosolic organic part, degraded, with geometrical spicules departing from it. It is covered in salt in some parts.

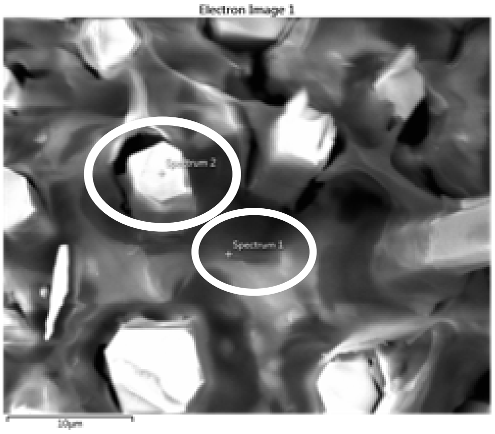
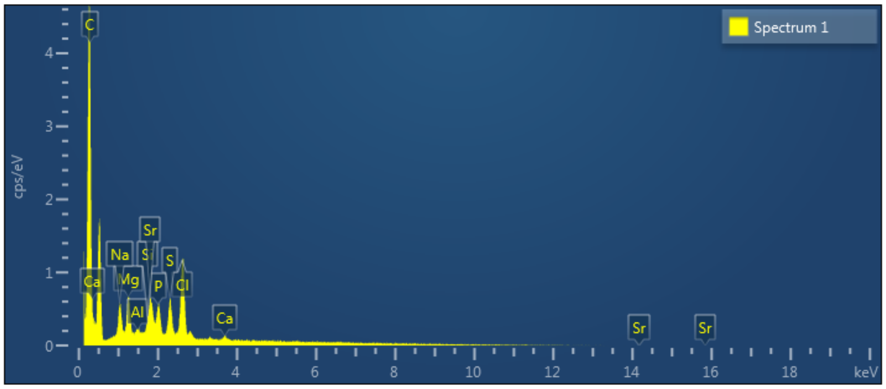
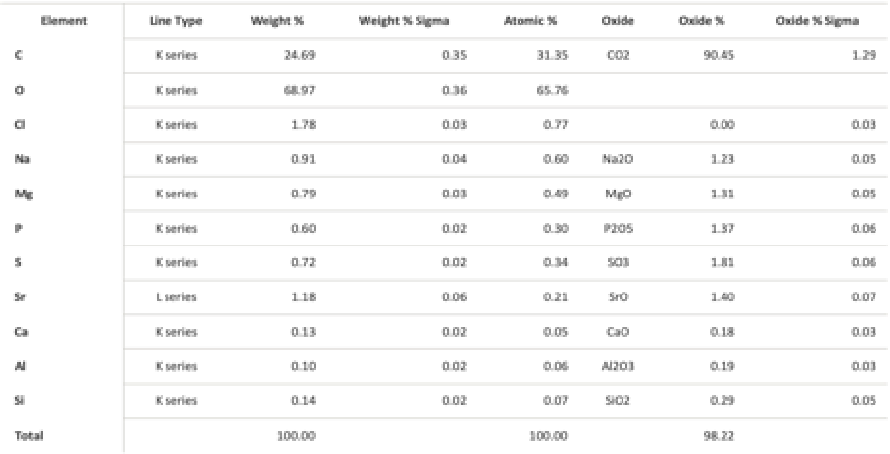


Figure 4.12: Spectrum image for element presence in the cellular part of the Acantharia: both for spicules and organic remains.

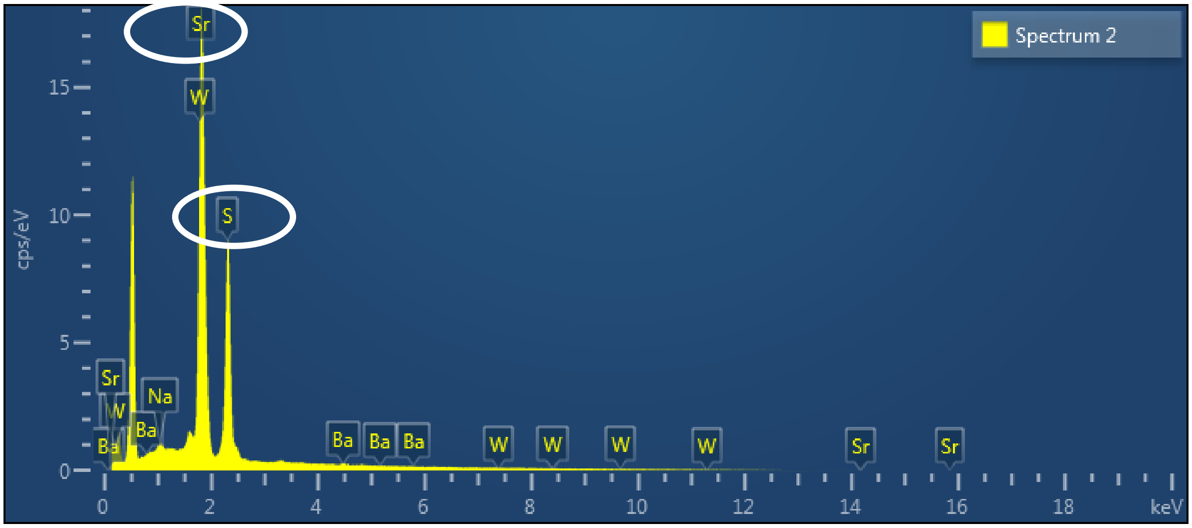


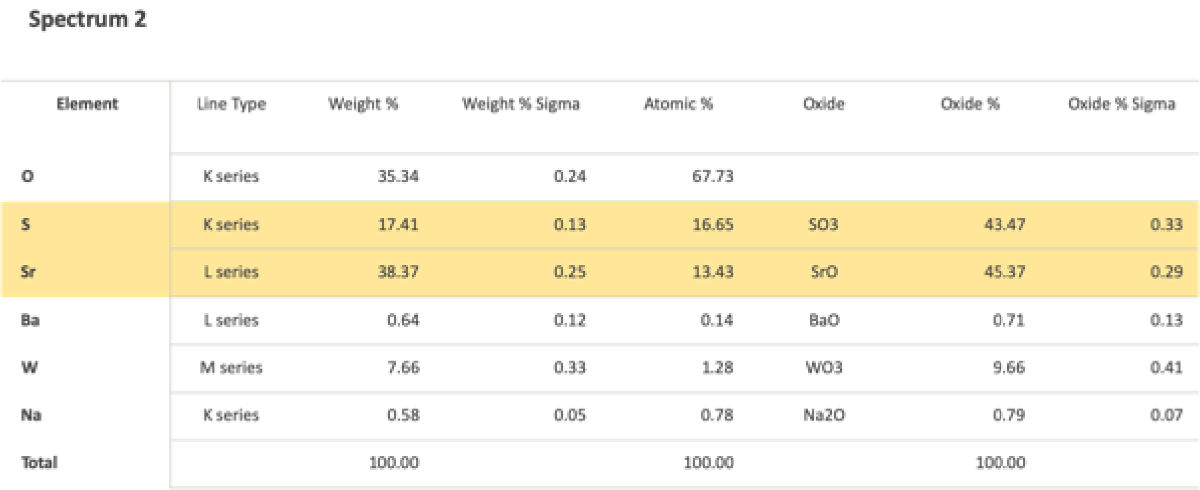
Spectrum 1



Element	Line Type	Weight %	Weight % Sigma	Atomic %	Oxide	Oxide %	Oxide % Sigma
C	K series	24.69	0.35	31.35	CO2	90.45	1.29
O	K series	68.97	0.36	65.76			
Cl	K series	1.78	0.03	0.77		0.00	0.03
Na	K series	0.91	0.04	0.60	Na2O	1.23	0.05
Mg	K series	0.79	0.03	0.49	MgO	1.31	0.05
P	K series	0.60	0.02	0.30	P2O5	1.37	0.06
S	K series	0.72	0.02	0.34	SO3	1.81	0.06
Sr	L series	1.18	0.06	0.21	SrO	1.40	0.07
Ca	K series	0.13	0.02	0.05	CaO	0.18	0.03
Al	K series	0.10	0.02	0.06	Al2O3	0.19	0.03
Si	K series	0.14	0.02	0.07	SiO2	0.29	0.05
Total		100.00		100.00		98.22	

Table 4.2: resulting spectrum of the analysis for the organic part. Sr and S are present in low weight%, while elements are more represented by C, O, Cl, Na and Mg.





Spectrum 2

Element	Line Type	Weight %	Weight % Sigma	Atomic %	Oxide	Oxide %	Oxide % Sigma
O	K series	35.34	0.24	67.73			
S	K series	17.41	0.13	16.65	SO3	43.47	0.33
Sr	L series	38.37	0.25	13.43	SrO	45.37	0.29
Ba	L series	0.64	0.12	0.14	BaO	0.71	0.13
W	M series	7.66	0.33	1.28	WO3	9.66	0.41
Na	K series	0.58	0.05	0.78	Na2O	0.79	0.07
Total		100.00		100.00		100.00	

Table 1.3: resulting spectrum of the analysis for the spicules of the cellular part: the peak of Sr and S are clearly evident, thus identifying this specimen as Acantharia.

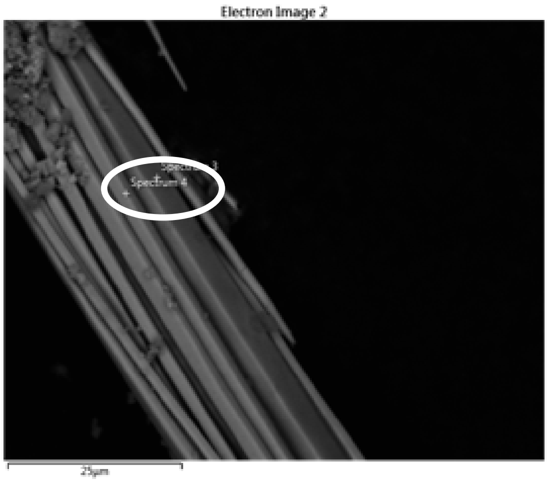
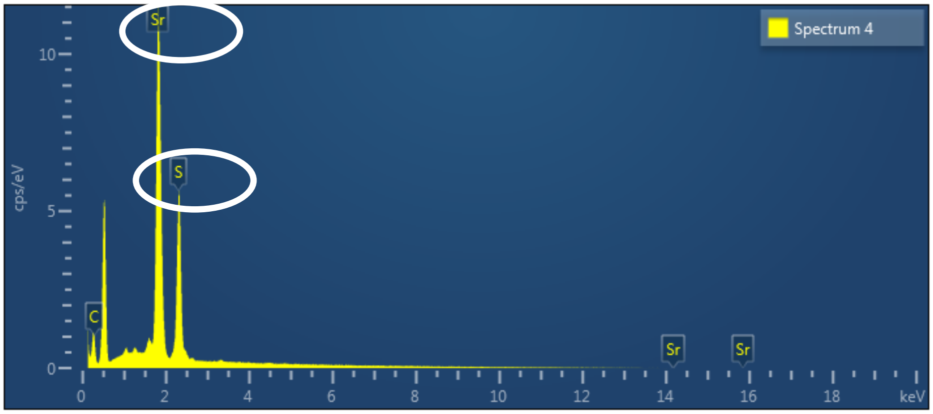
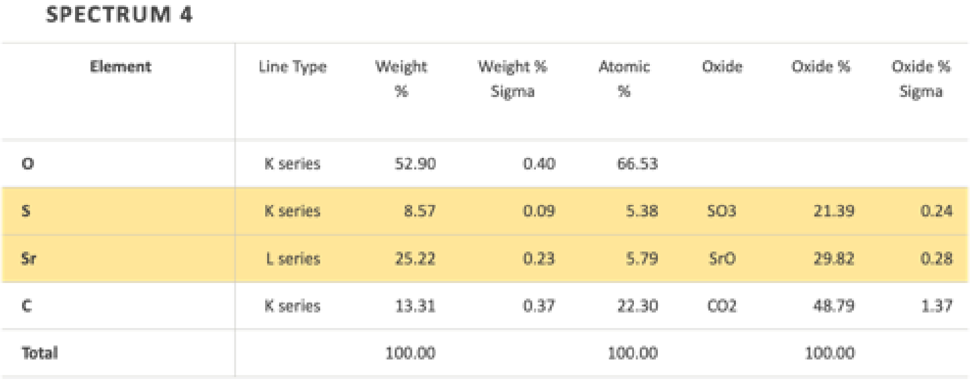


Figure 4.13: Spectrum image for element presence in the stem part of the Acantharia. spicules are clearly geometrical and packed in an elongated way.





SPECTRUM 4

Element	Line Type	Weight %	Weight % Sigma	Atomic %	Oxide	Oxide %	Oxide % Sigma
O	K series	52.90	0.40	66.53			
S	K series	8.57	0.09	5.38	SO3	21.39	0.24
Sr	L series	25.22	0.23	5.79	SrO	29.82	0.28
C	K series	13.31	0.37	22.30	CO2	48.79	1.37
Total		100.00		100.00		100.00	

Table 4.4: resulting spectrum of the analysis for the spicules of the stem part: the peak of Sr and S are clearly evident, thus supporting the hypothesis of a benthic Acantharia.

4.1.3 Morphological description of other morphotypes of known genera

Another result is the evidence of already epibenthic known taxa that displays a slightly different morphology, maybe adapted locally to this extreme environment, from the usual description of the genus, which is already pointed out for other organisms (eg. corals) following a "gradient".

Here, I would like to describe the morphotypes belonging to these species and their varieties that i am going to identify as follow to simplify their identification: *Dendronina arborescens* var. antarctica Heron-Allen & Earland, 1922; *Halyphysema tumanowiczii* var. abyssicola Goës, 1894*;* *Miniacina miniacea* (Pallas ,1766) Antarctic variant; and compare them with the type descriptions.

- *Dendronina arborescens* var. Antarctica-like Heron-Allen & Earland, 1922

Is described by Heron-Allen & Earland as test attached, expanded basal part (fig. 4.14) containing ramifying passages that converge to a central cavity (fig. 4.15). More than one tubular portion may arise from a single basal expansion; wall fragile, of fine sand and sponge spicules (fig. 4.16) oriented parallel to the side of the tube; apertures are simple terminal openings on the constricted ends of the branches and may be bordered by projecting spicules (fig. 4.17).

Here we find only a very thick and dense unique expansion, with an expanded basal part and spicules arranged as a crown at the end of the extremity. Different signs on clasts have been found (fig. 4.18): we have the same agglutinated particles and the polichambers at the basis that makes speculate about a morphotype of this *Dendronina* variety or it could be a totally different new individual.

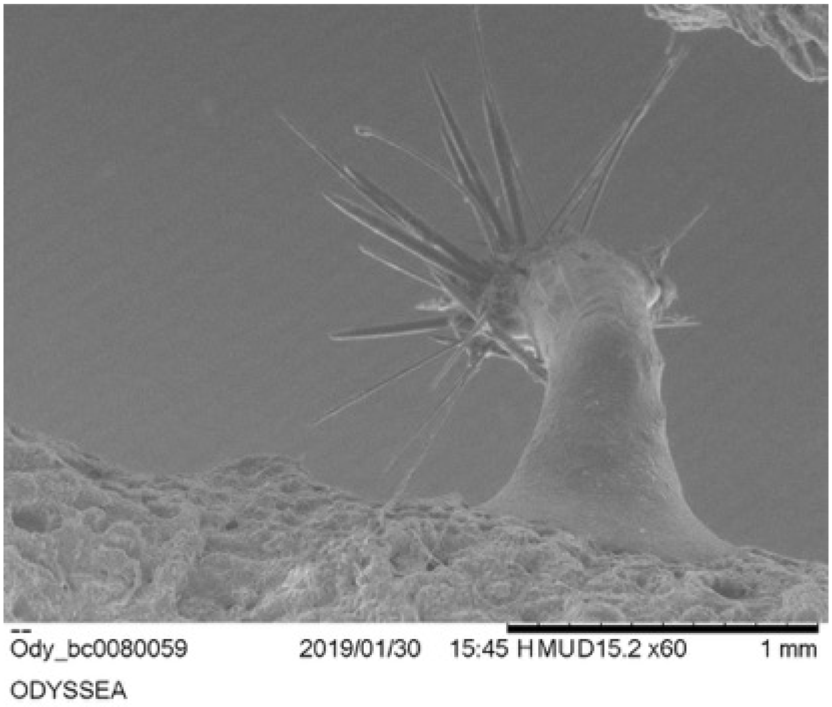


Figure 4.14: SEM image of a Dendronina var Antarctica*. Here it is evident the espanded attach*
appears in the background

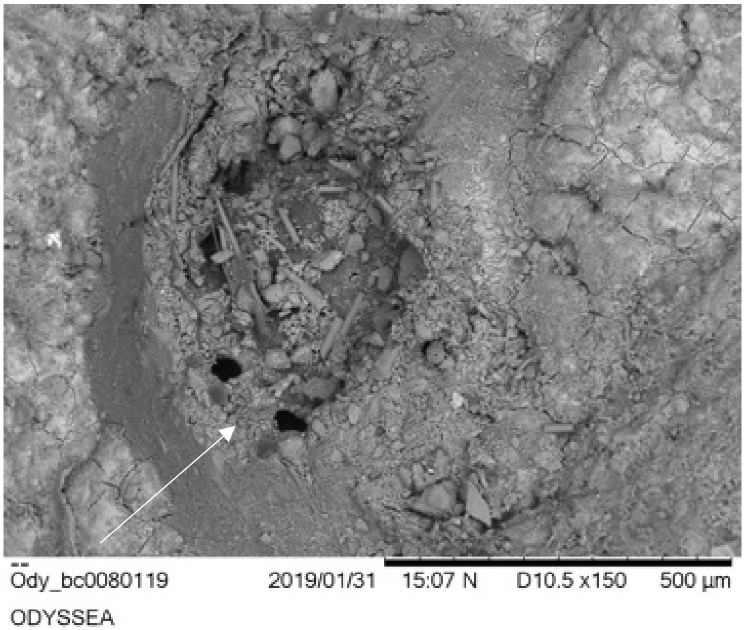


Figure 4.15: imprint on stone of a Dendronina var Antarctica-like *(basal fragment). It is possible to see the convergent chambers system to a unique central and the agglutinant particles with spicules in between.*

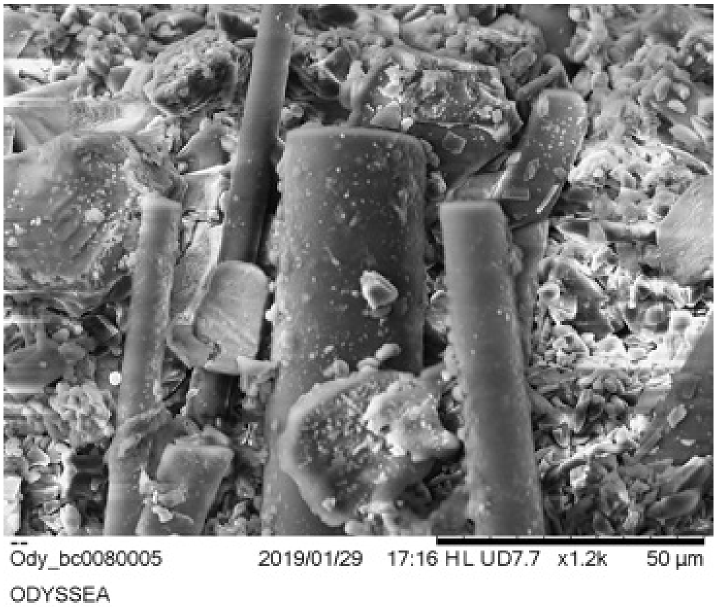


Figure 4.16: close up of agglutinant material of a Dendronina var Antarctica-like*. Spicules are horiented on the elongated axis of growth. small grains and clasts are visible, salt too.*

Figure 4.17: Dendronina var Antarctica-like *at stereo-microscope 10x. It is clearly evident the fine grains and particles agglutinated, spicules too. the crown is partially undamaged.*

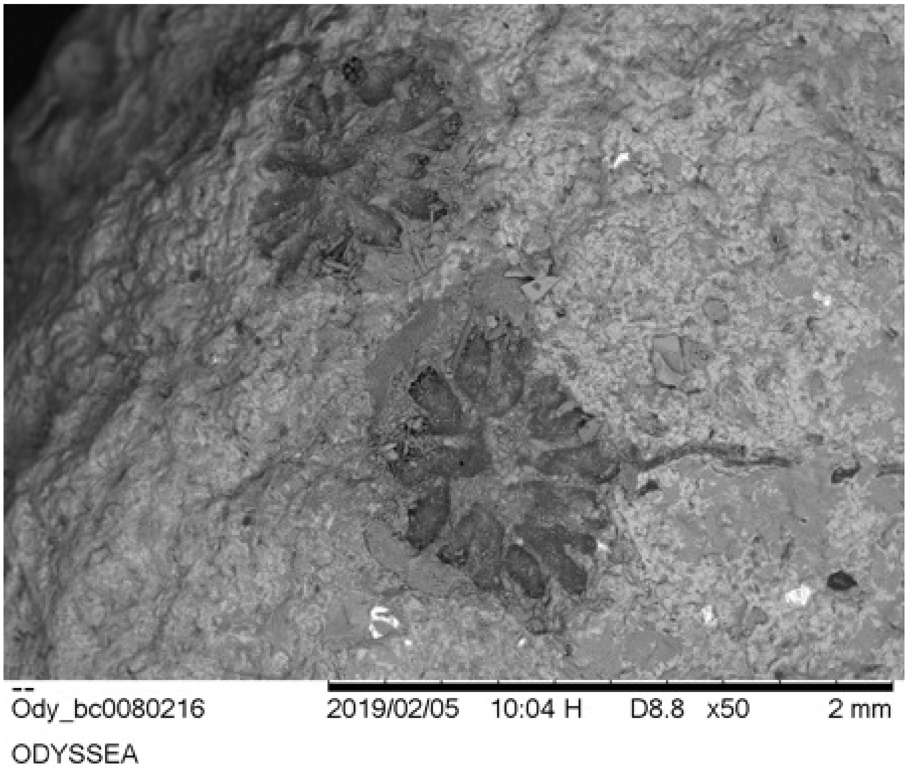


Figure 4.18: signs of Dendronina var antarctica-like *on clasts. Polichambers are visible converging to a central one.*

- *Halyphysema tumanowiczii* var. abyssicola-like Goës, 1894

Test attached and consisting of a spreading basal expansion with a later erect conical or club-shaped portion. In some species the chamber may bifurcate; wall agglutinated, that of the basal expansion fine grained and including sponge spicules, erect portion more coarsely and with very numerous, elongate spicules; aperture obscured by the clustering of spicules. Here, in particular it forms a sort of tent, fig 4.19, with sponge spicules, with an elongated part. It is very thick, the basal portion is wide, attached to the substrates (4.20). SEM image 4.21.

Instead, the "usual" one is higher and more elongated, becoming a risk in very high current environment.

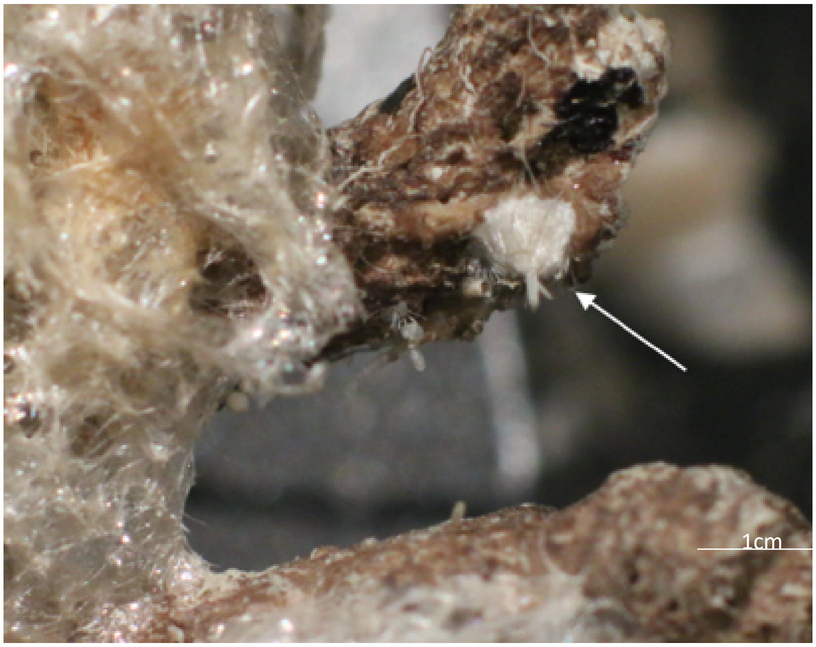


*Figure 4.19: stereo-microscope 10x image of a Halyphysema-*like *individual on a Hydrocoral skeleton.*

Figure 4.20: close-up at stereo-microscope 7,5x image of the individual. It is possible to see the wide attached basal part and the erected portion.

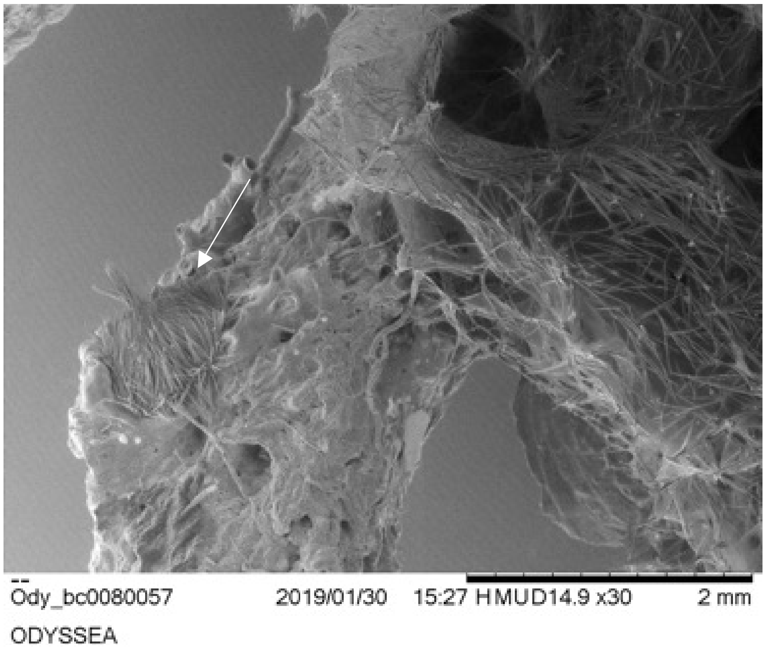


Figure 4.21: SEM image of a Halyphysema-like*. Spicules are clearly evident and form the majority of the individual.*

- *Miniacina miniacea* (Pallas, 1766) Antarctic variant.

Test encrusting or branching, early stage with spiral or “raspberry” chamber arrangement with pores (fig. 4.22); wall calcareous, red pink or white; surface with openings of two sizes, smaller wall perforations and larger pores.

Here are evident smaller pores on a rough calcareous surface, with thick branches. Larger basal attachment. (fig. 4.23; 4.24)

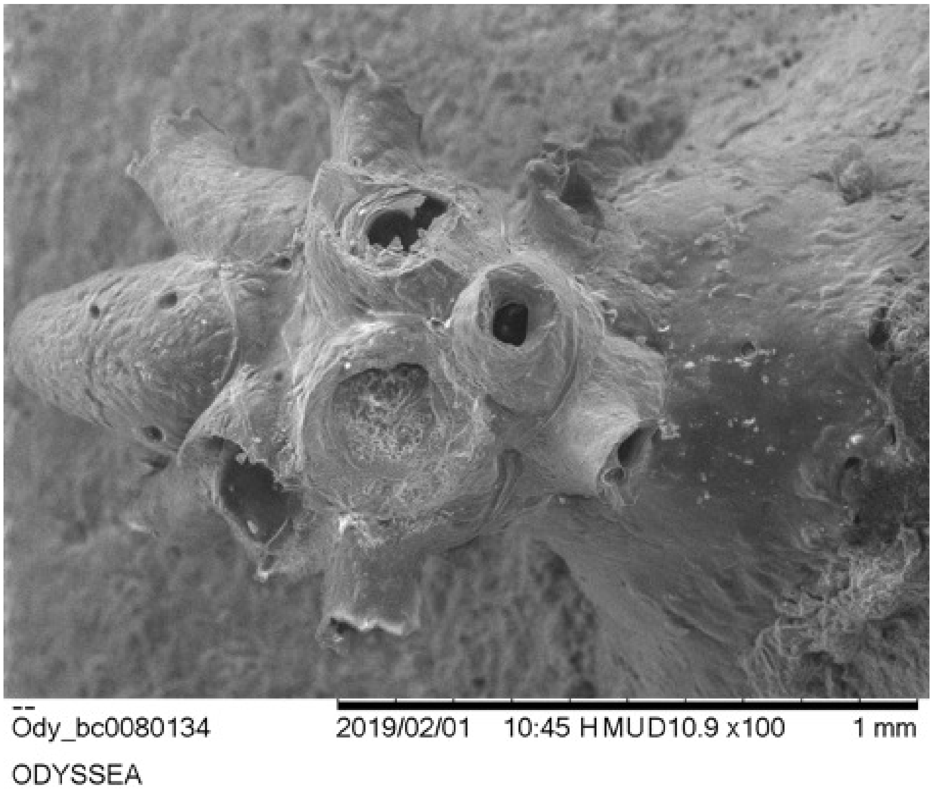


Figure 4.22: Miniacina miniacea var antarctica*. Rough calcareous surface with smaller pores; branches thick departing from an extend basal attached part.*

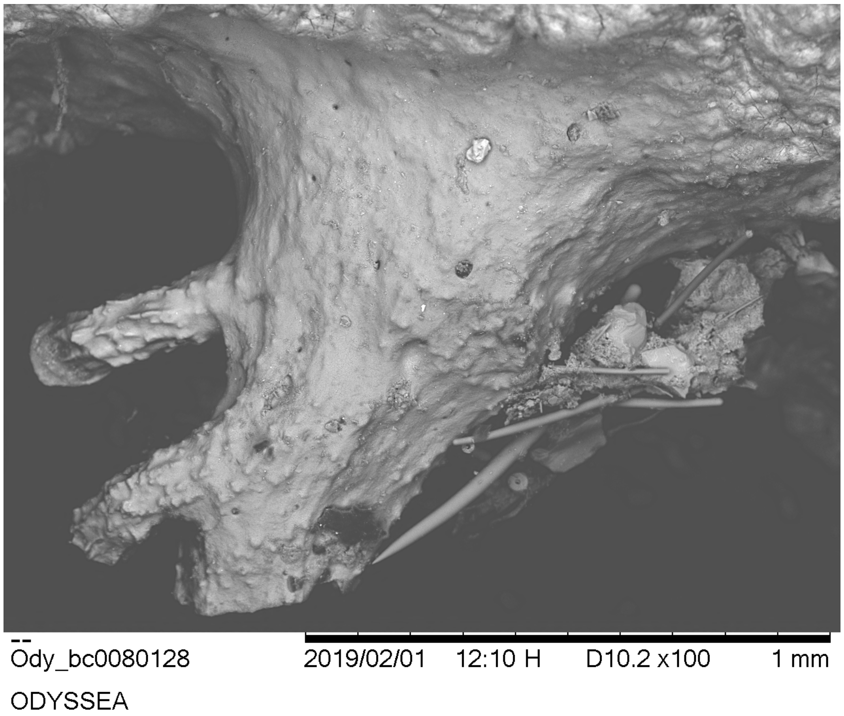


Figure 4.23: SEM image of another Miniacina miniacea var. antarctica*. Pores are visible, branching parts as well.*

Figure 4.24: stereo-microscope 7,5x image of Miniacina miniacea. The white color is due to the lack of symbionts as this is a very a depth living individual.

- *Ammopemphix hemisphaericus* Waśkowska & Kaminski 2018

Test monothalamous, attached, pseudocolonial. The chamber is hemispherical, planoconvex, with a flat attachment surface and a convex dorsal side. The attachment surface consists of a thin agglutinated wall with a smooth inner surface. Individuals are sometimes found as isolated pecimens, but more often the species forms pseudocolonies. Grain size of agglutinated grains is variable, with finer grains used in the interior of the test and around the aperture. Aperture single, simple, rounded, oval, or subtriangular, situated on a elevated collar on the dorsal side of the test. Here it can be found on a *Hemisphaerammina* sp. colonizing its surface (fig. 4.25) where the convexal side is evident. Almost eight individuals are present as evident in figure 4.26. In image 4.27 there are two *Ammopemphix hemisphaericus* on a clast, where they display a different morphology with larger grain size agglutinated and an aperture on a side of the dorsal convex part.

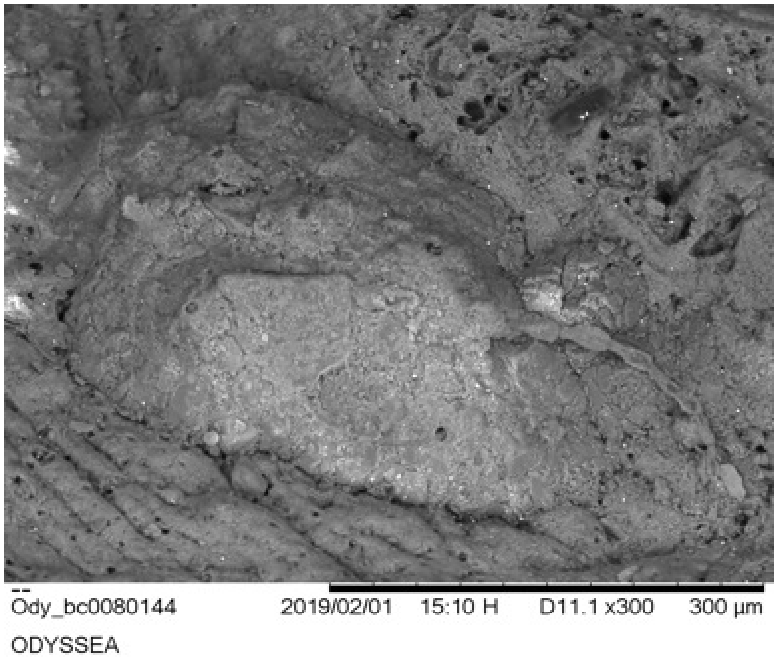


Figure 4.25: SEM image of a Hemisphaerammina sp. *with Ammopemphix hemisphaericus individuals on it.*

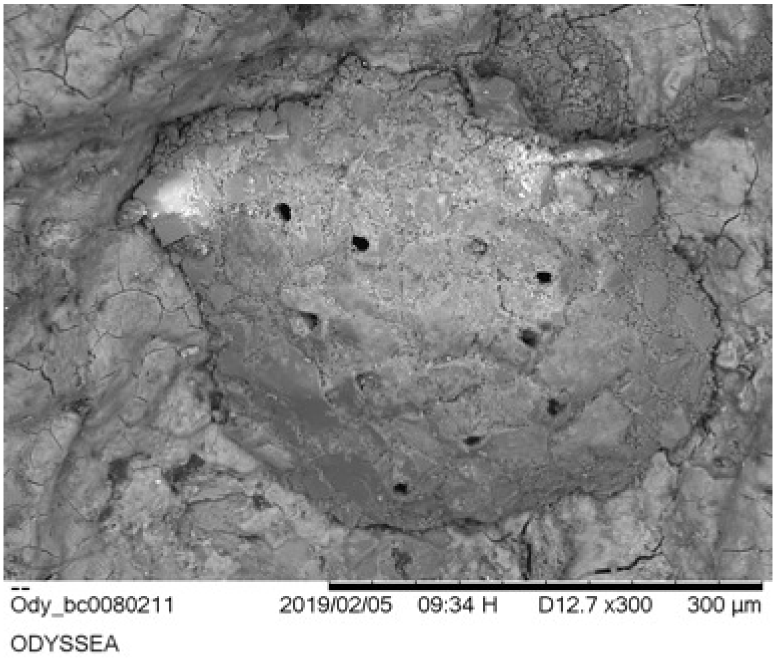


Figure 4.26: SEM image frontal for Hemispaerammina with Ammopemphix haemispericus on it, apertures are evident and individuate almost eight specimens.

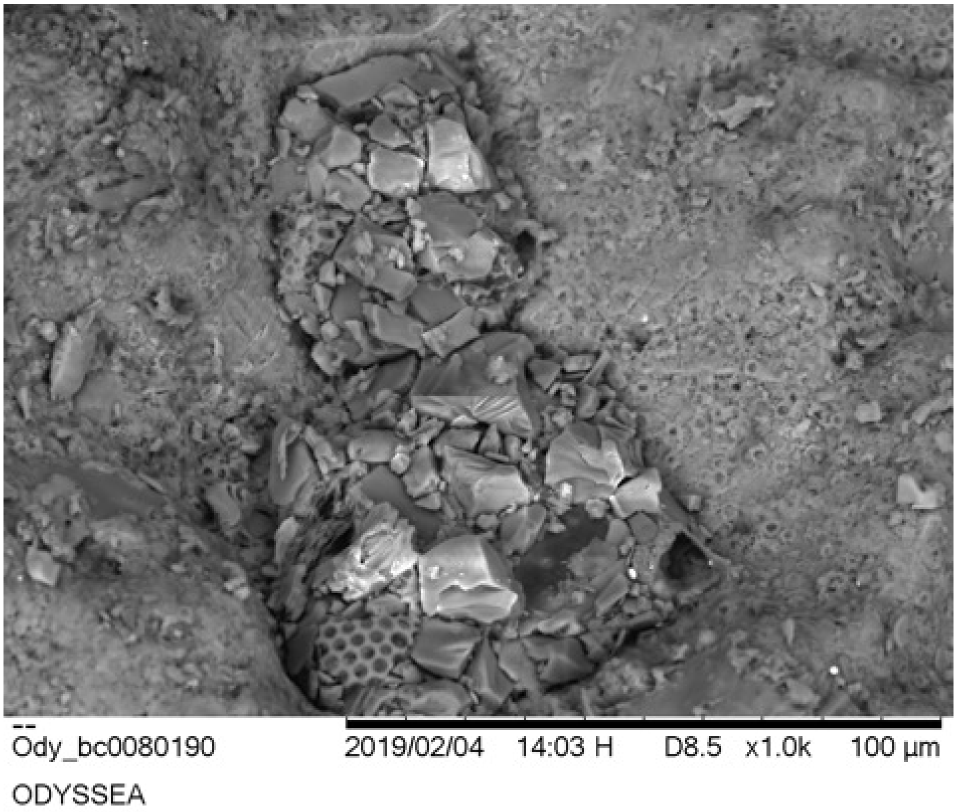


Figure 4.27: Ammopemphix hemisphaericus on a clast with coarse grain size and a dorsal side aperture

4.2 Hard Substrates

Density

Samples taken along the vertical slope of the Odyssea drift show a great variety in hard substrates presence, followed by the density of the foraminiferal assemblages: it is higher at BC08 site, which has a great number of hard substrates, whereas is lower at the BC06 site and even more in BC07, which has only one big clast without organisms. A resume of the total hard substrates' density is shown in fig. 4.28: we have one clast in site BC06, and up to seventeen different hard substrates at BC08. The clasts and biogenic structures form an optimal microhabitat for encrusting attached foraminifera. Indeed, certain samples are densely overgrown by taxa with tubular or hemispherical tests, and densities varies among hard substrates (fig. 4.29). Here I report foraminiferal density for each labelled clast from sampling stations. There is a high presence of foraminifera in BC08 hard substrates; in particular, clasts 5d, 14, 5 show the major abundance with 1800 n°ind/50 cm^2, 1133 n°ind/50cm^2 and 733 n°ind/50cm^2 respectively. As a result, the foraminiferal density is higher for BC08 rather than BC06 due to the major presence on hard substrates (fig. 4.30). Thus, the overall foraminiferal density varies among the sampling sites but also on small scale on the different Hard Substrates for example on Coral3 there are twenty different species, while on Clast1 there are eight species and similar for other Hard Substrates (fig. 4.30).

Taxonomic composition

The taxonomic composition takes into account the division of polythalamous and monothalamous calcareous agglutinated and miliolids (fig. 4.31), even though here miliolids on HS are not present.

It is expressed as densities, n°ind/50cm^2, for each sampling site BC06 and BC08, but BC07 is not taken into account as density is zero due to a lack of individuals on it (fig. 4.28). In particular, the foraminiferal assemblages of HS are dominated mainly by Total Polythalamous agglutinated (TPA) species with 4980 n°ind/50cm^2 present only in BC08. Total Monothalamous agglutinated (TMA) foraminifera are then following with 4809 n°ind/50cm^2 in BC08, with 44 n°ind/50cm^2 in BC06 with a total of 4853 n°ind/50cm^2. Total Polythalamous calcareous (TPC) foraminifera reach a value of 1656 n°ind/50cm^2 with a value of 1611 n°ind/50cm^2 for site BC08 and 44 n°ind/50cm^2 in BC06. Total Polythalamous miliolids (TPM) are absent.

Thus, taking into account a wider view the agglutinated species are predominant.

Biodiversity

A general view of the most abundant hard substrates species is now given, therefore I am going to consider species with a density >100 n°ind/50cm^2, that are the most abundant, as shown in fig. 4.32: species such as *Ammopemphix hemisphaericus* Waśkowska & Kaminski 2018 (fig. 4.27) reaches 980 n°ind/50cm^2; *Dendronina arborescens* var. antarctica Heron-Allen & Earland 1922 (fig. 4.14) is 121 n°ind/50cm^2; *Halyphysema tumanowiczii* Bowerbank 1862 (fig. 4.19) despite being reported in literature as important encrusting species is just about 50 n°ind/50cm^2; *Placopsilina bradyi* Cushman & McCulloch 1939 with 2872 n°ind/50cm^{2}is the most abundant species (fig. 4.33) and *Tolypammina vagans* (Brady 1879) reaches 322 n°ind/50cm^2 (fig. 4.34). Those are, typically, reported as attached and encrusting species to which I add the new proposed genus *Spiculotuba* (fig. 4.2) and their morphotypes inhabiting hard substrates, both on clasts and corals, reaching n°ind/50cm^2. Moreover, HD host other typically calcareous and agglutinated free-living species that can be found attached due to particular favorable environment conditions, such as: *Alabaminella* sp. *Saidova, 1975* having an abundance of 153 n°ind/50cm^2; *Eponides repandus (Fichtel & Moll 1798)* with 587153 n°ind/50cm^2; *Cibicidoides lobatulus (Walker & Jacob 1798)* with 261 n°ind/50cm^2; *Marsipella elongata Norman 1878* having 511 n°ind/50cm^2; *Spirillina* sp. *Ehrenberg 1843* instead has 219 n°ind/50cm^2 and *Lepidoparatrochammina lepida (Brönnimann & Whittaker 1986)* with 260 n°ind/50cm2. Interesting, I report also the occurrence of a morphotype of Miniacina *miniacea (Pallas*

1766), whitish in aspect instead of typical reddish color of *M. miniacea* with symbionts inhabiting tropical shallow water with symbionts. I suppose it could belong to the species *Miniacina alba (Carter 1877)* or for its white/pale color to a morphotype of *Miniacina miniacea* var. Antarctica (fig. 4.22) typical of cold and deep Antarctic waters with 150 n°ind/50cm^2. For the calcareous and agglutinated free-living species ranges are from 2 n°ind/50cm^2 to a maximum of 200 n°ind/50cm^2 for some taxa. However, despite those abundant species >100 n°ind/50cm^2, there is an important contribution in terms of total biodiversity, of rare species with density lower than <50 N°ind/50cm2 which are not described here. For what concern Biological indices, in particular Dominance(D), Shannon index(H), Evenness(e^H/S) and Equitability(j) have been calculated. The highest species richness occurs at site BC08 with 42 species while BC06 has only 2 species. The Dominance is lower for BC08 and increase at site BC06 respectively 0.2 and 0.6. The Shannon index is very high for site BC08 (2.44) and decrease at site BC06 (0.64). The Eveness, instead, is higher at BC06 (0.94) and decrease at BC08 (0.23). The Equitability value follows the same trend: is 0.91 at site BC06 and decrease at BC08 at 0.65. (Tab. 4.5)

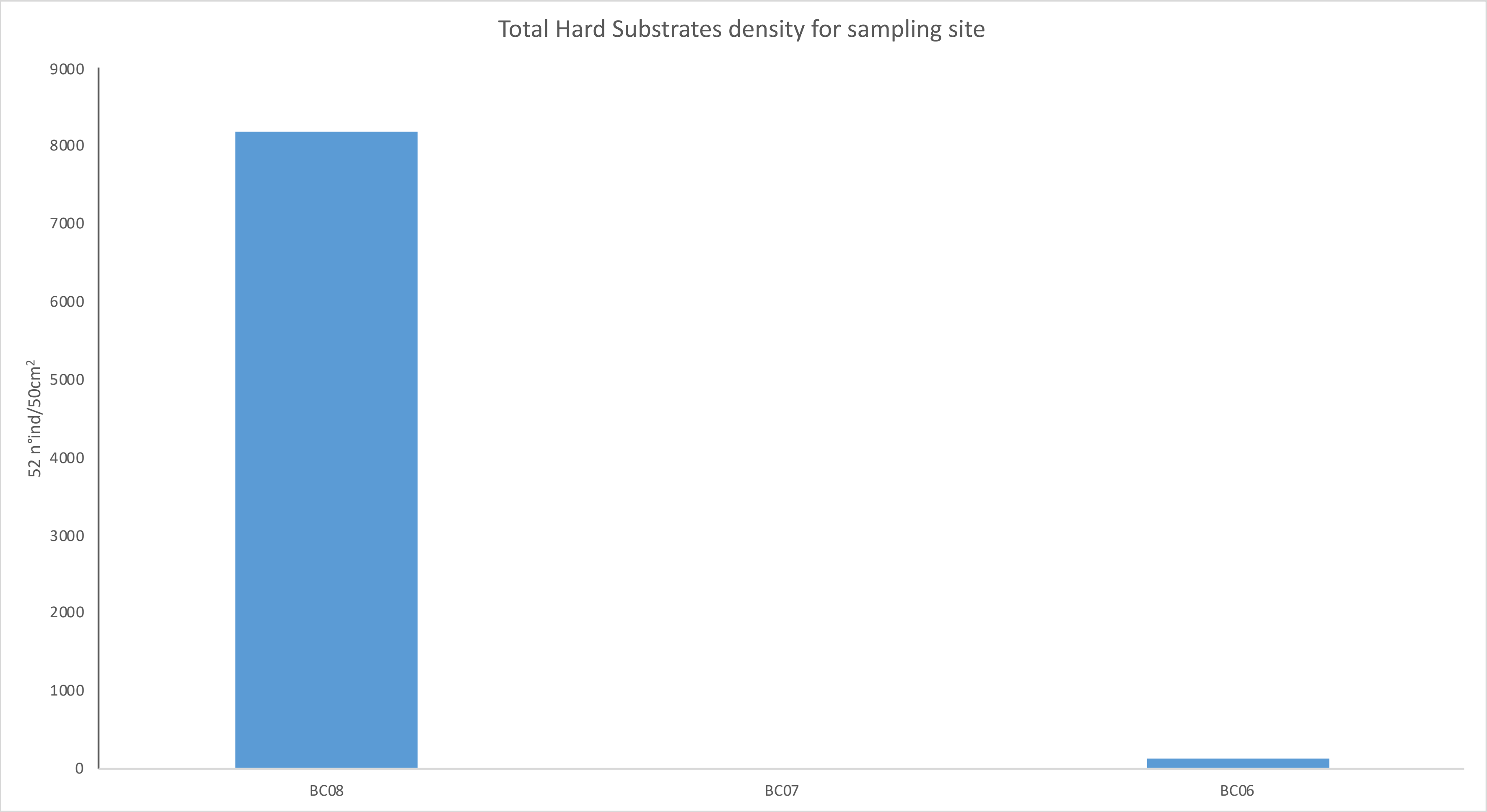


Figure 4.28: Total hard substrates density as n°ind/50cm2 for sampling site

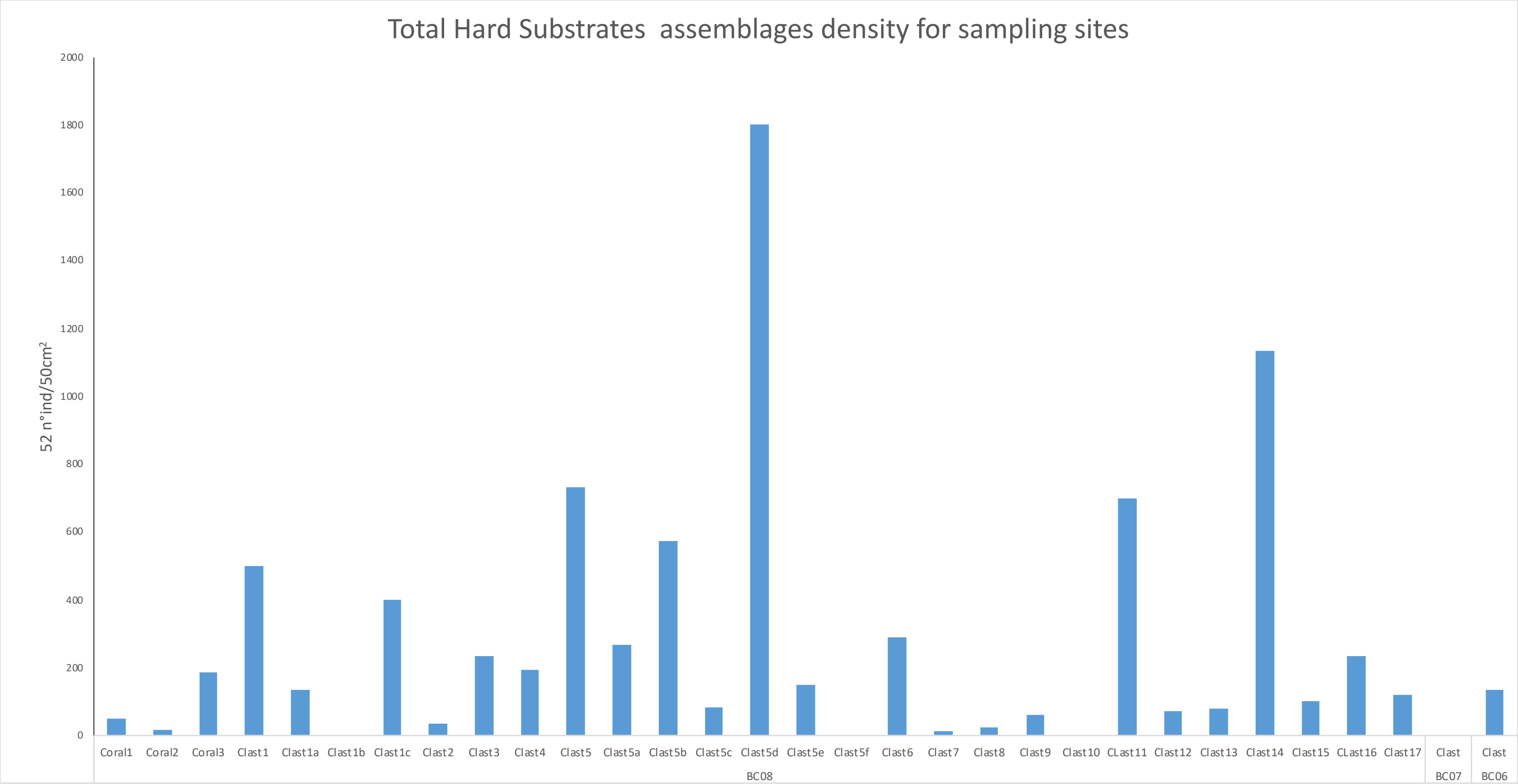


Figure 4.29: Total Hard Substrates density as n°ind/50cm² for each HS.

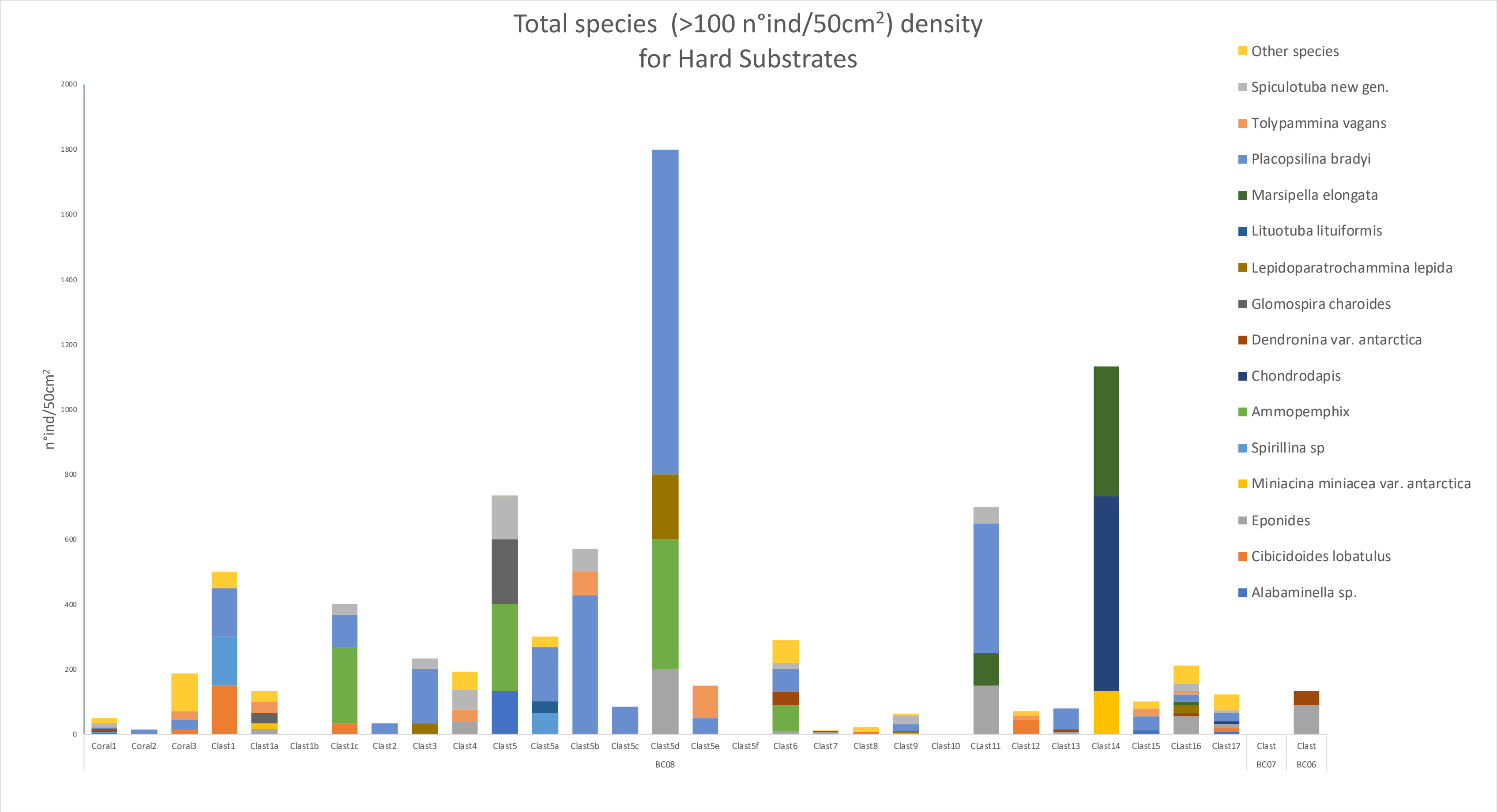


Figure 4.30: Total species density for each Hard Substrates for BC08; BC07 and BC06

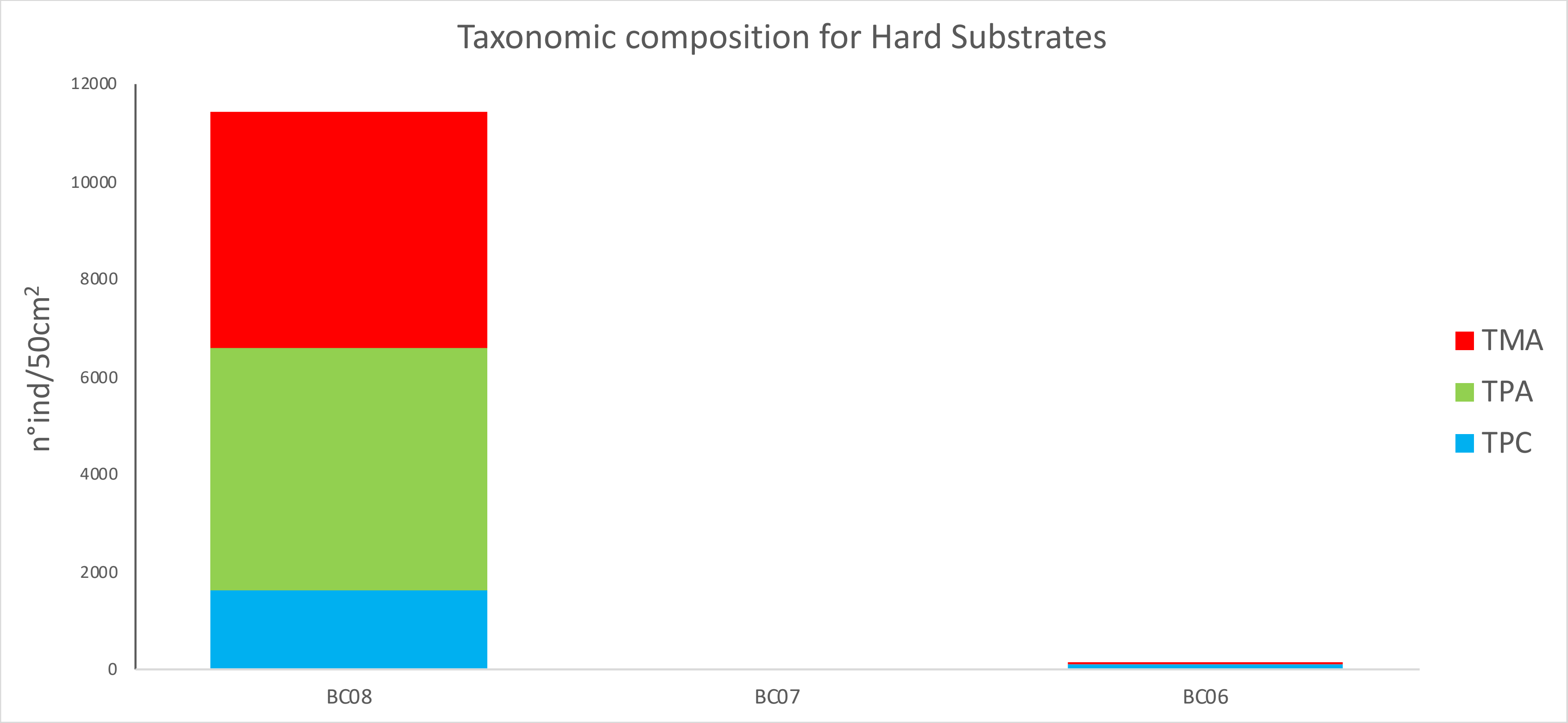


Figure 4.31: Taxonomic composition of HS. Here it is shown a subdivision between Total Polythalamouscalcareous(TPC); Total Polythalamous agglutinated (TPA) and Total Monothalamous agglutinated (TMA) foraminifera.

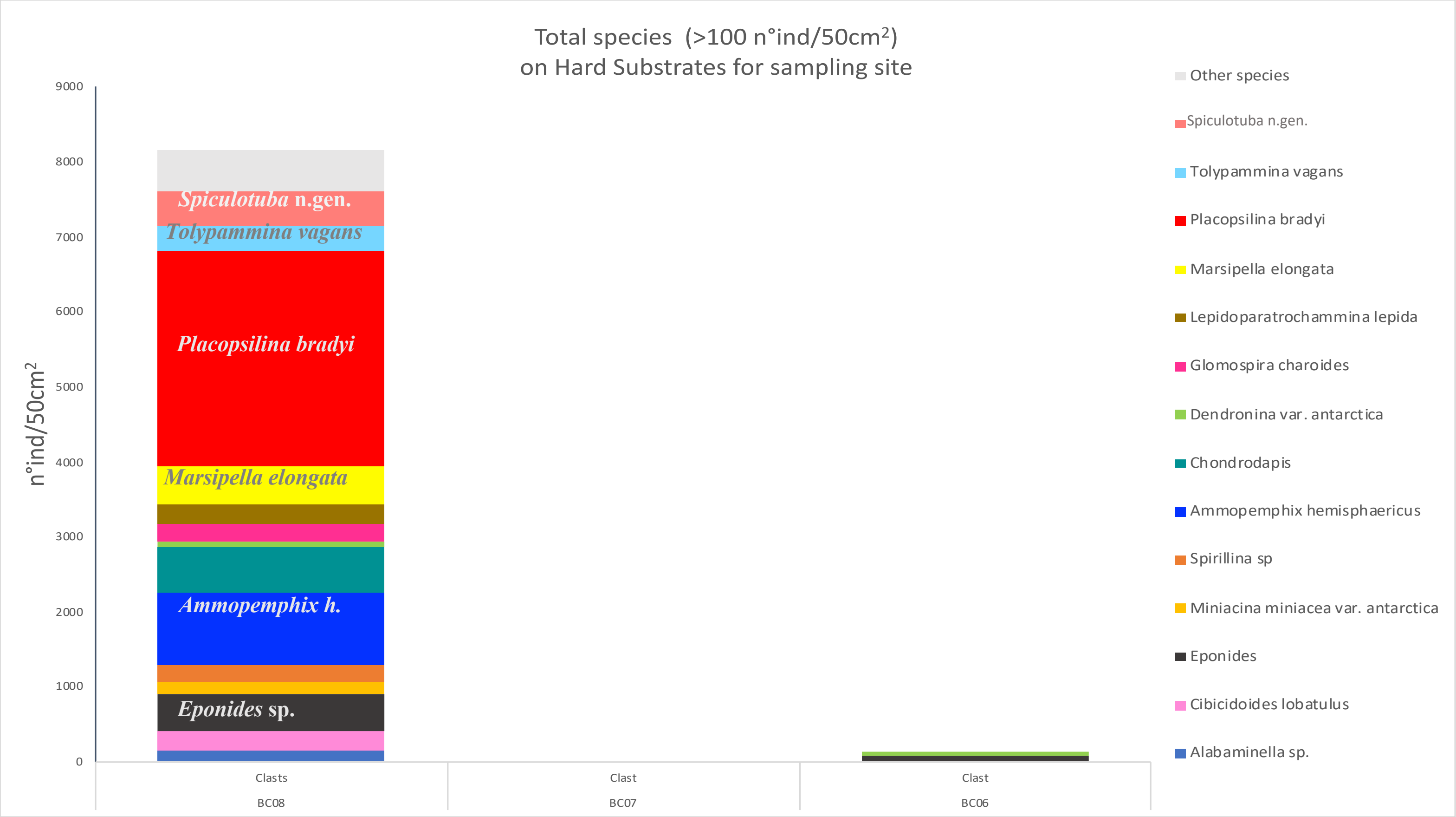
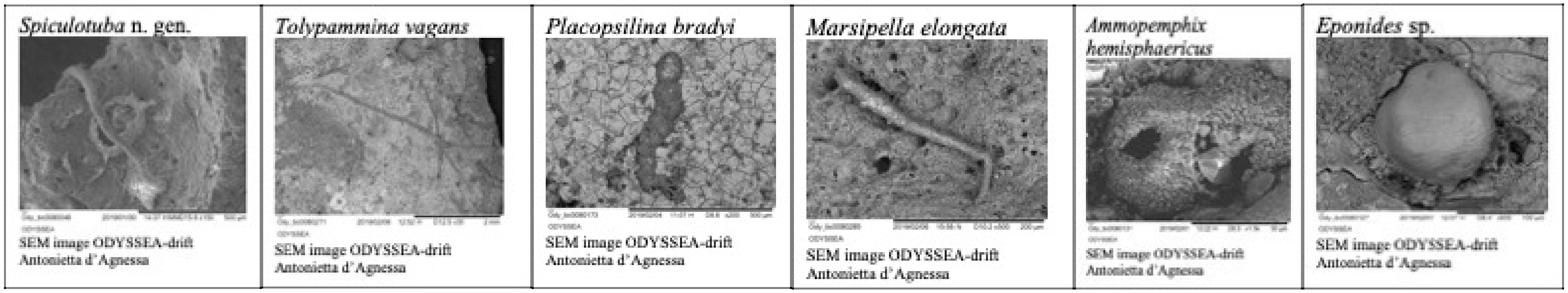


Figure 4.32: total specimen presence (>100n°ind/50cm²) for each sampling sites. A picture for each abundant species is shown as follow.



Spiculotuba n. gen.
SEM image ODYSSEA-drift
Antonietta d'Agnessa

Tolypammina vagans
SEM image ODYSSEA-drift
Antonietta d'Agnessa

Placopsilina bradyi
SEM image ODYSSEA-drift
Antonietta d'Agnessa

Marsipella elongata
SEM image ODYSSEA-drift
Antonietta d'Agnessa

Ammopemphix hemisphaericus
SEM image ODYSSEA-drift
Antonietta d'Agnessa

Eponides sp.
SEM image ODYSSEA-drift
Antonietta d'Agnessa

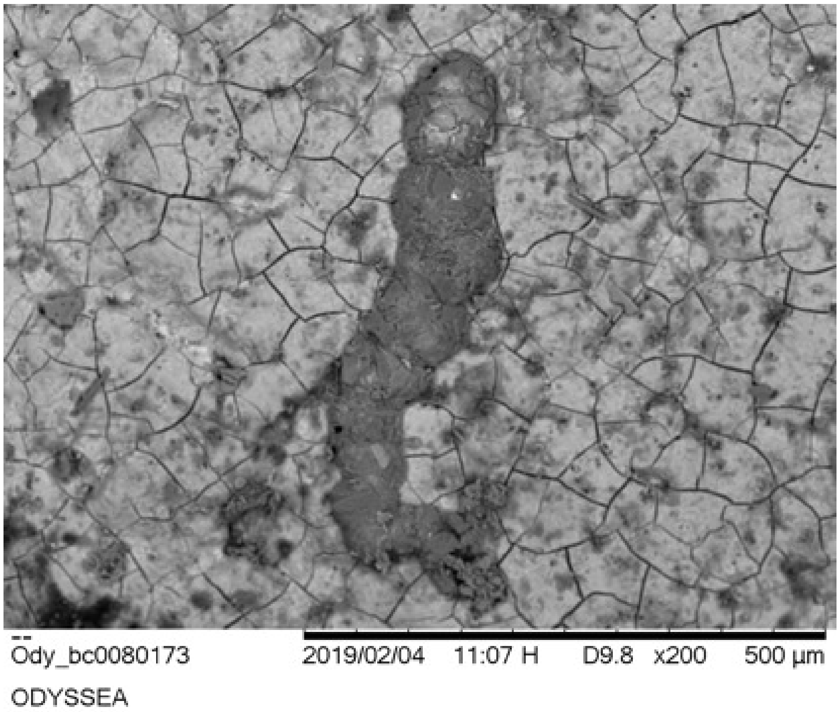


Figure 4.33: Placopsilina bradyi attached on a clast, site BC08.

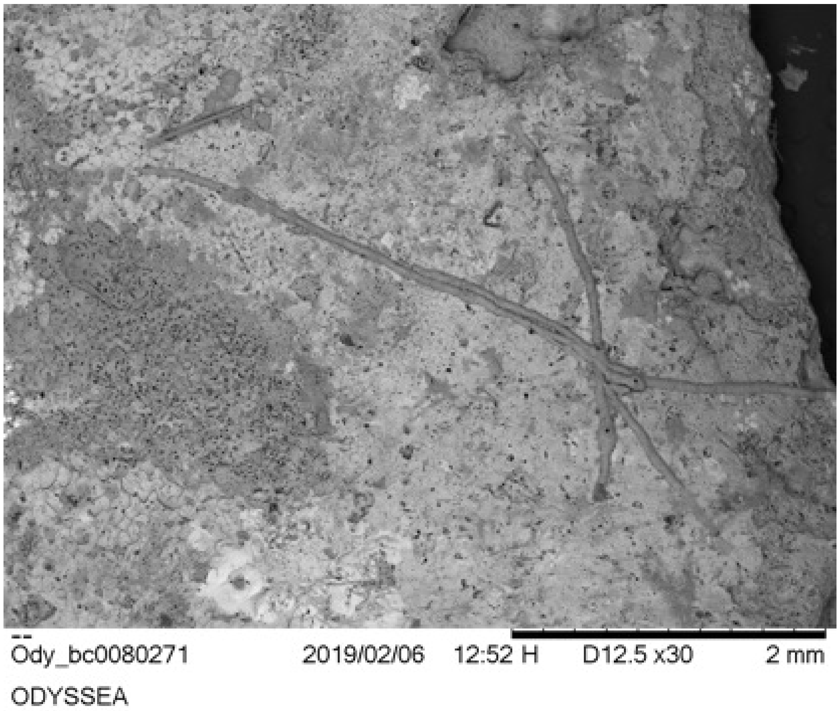


Figure 4.34: Tolypammina vagans spreading on a clast of site BC08.

4.3 Sediment samples

Density

For each station sampled the superficial first centimeter of sediment (0-1) cm have been studied, that allows to have a general idea of the potential biodiversity of this micro-world. In general living (Rose Bengal stained) foraminiferal densities are low in the sediment for all sampling sites as shown in Figure 4.35 where it is clear the abundance of tanatochoenosis vs biochoenosis.

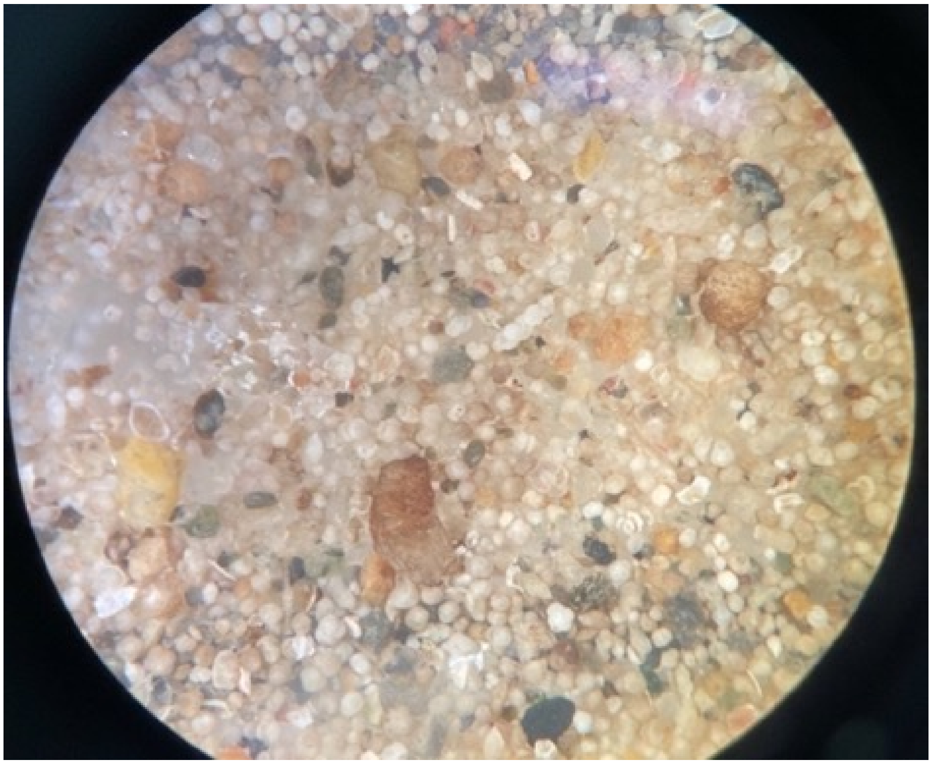


Figure 4.35: washed samples BC08 1mm-150 µm. Empty foraminiferal tests and clasts at stereo-microscope 7x5.

Foraminiferal assemblages have been studied split in fractions >1mm; 1mm-150µm; 150µm-63µm and also in general for the total fraction >63µm.

Living foraminiferal densities reach a maximum average of 52 n°ind/50cm^2 for the total size fraction >63µm (fig. 4.36) at BC06 and BC 08 stations, while BC07 shows a total average value of 45n°ind/50cm^2.

As a result, foraminiferal density is quite regular in each sampling site.

Living foraminiferal average abundance for each fraction >1mm, 1mm-150µm and 150-63µm have different trend (fig. 4.37): for BC06 we have a great abundance in the bigger fraction (>1mm) 31 n°ind/50cm2. To 16 n°ind/50cm^2 in the 1mm -150µm fraction and 4 n°ind/50cm^2 for the smaller one 150-63µm. BC07 has an opposite trend with 1mm fraction having few individuals, 9 n°ind/50cm^2, 14 n°ind/50cm^2 in the 1mm -150µm and 21 n°ind/50cm^2 in the 150-63µm fraction. Finally, BC08 has a higher value in the 1mm fraction, 21 n°ind/50cm^2, 14 n°ind/50cm^2 and 16 n°ind/50cm^2 in the 150-63µm.

The standard deviation is very high, due the few species available for each site, indeed it becomes lower for the total site as shown in fig. 4.36

Taxonomic Composition

The taxonomic composition highlights the abundance, as for the Hard Substrates, of the agglutinated foraminifera (fig. 4.38), even though they are different species, that are going to be showed in the *Taxonomical Appendix* paragraph. It takes into account the division of Total Polythalamous and Monothalamous foraminifera both for calcareous agglutinated and miliolids.

In particular, the foraminiferal assemblages are dominated mainly by Monothalamous agglutinated (TMA) species with 57 n°ind/50cm^2 present in each station BC06; BC07 and BC08 with values of 22 n°ind/50cm^2, 14 n°ind/50cm^2 and 19 respectively.

Polythalamous agglutinated (TPA) foraminifera are then following with a total of 54 n°ind/50cm^2: in BC06 with a value of 15 n°ind/50cm^2; BC07 has a value of 21 n°ind/50cm^2 and BC08 with 18 n°ind/50cm^2, thus having an opposite trend respect the HS species. Total Polythalamous calcareous (TPC) foraminifera have a low value such as in HS for a total of 18 n°ind/50cm^2 for site BC06 they have a value of 3 n°ind/50cm^2 in BC07 there are 2 n°ind/50cm^2 while BC08 has a value of 13 n°ind/50cm^2. Here there is also a small fraction of Polythalamous Miliolids (TPM) for a total of 4 n°ind/50cm^2: only for sites BC07 and BC08 with 2 n°ind/50cm^2 respectively.

Biodiversity

A general view of the foraminiferal abundance and diversity for sediment samples is shown in fig. 4.39: abundance values range from 4 to 9 n°ind/50cm^{2}for the majority of the species, while species >10 n°ind/50cm^2 are quite regular in each station. They are: *Psammosphaera fusca* Schulze, 1875, respectively 44 n°ind/50cm^2 in BC06, 34 n°ind/50cm^2 for BC07 and BC08. *Glomospira charoides* (Jones & Parker 1860) has a very high value in BC07 with 54 n°ind/50cm^2, at BC08 has 29 n°ind/50cm^{2}while BC06 is just 4 n°ind/50cm^2, but this site shows a high value for *Hemisphaerammina bradyi* Loeblich & Tappan 1957 with 19 n°ind/50cm^2 and totally absent in BC07 and BC08 sampling sites. Considering the foraminiferal assemblages for sediment samples from 0-1 cm, for the fraction >63µm, the highest species richness occurs at site BC08 with 16 identified species and decrease at BC06 with 12 identified species to 9 species at BC07.

The Dominance is lower for BC08 and increase to site BC06 and BC07 respectively 0.11 0.16 and 0.24. The Shannon index is very high for site BC08 at 2.49 and decrease respectively at site BC07 with 1.73 and BC06 0.68. The Eveness is higher at BC08 with 0.75 and decrease at BC06 0.68 to BC07 at 0.63. The Equitability value follows the same trend: 0.90 for site BC08 and decrease at BC06 with 0.84 to 0.79 for site BC07. (Tab. 4.6)

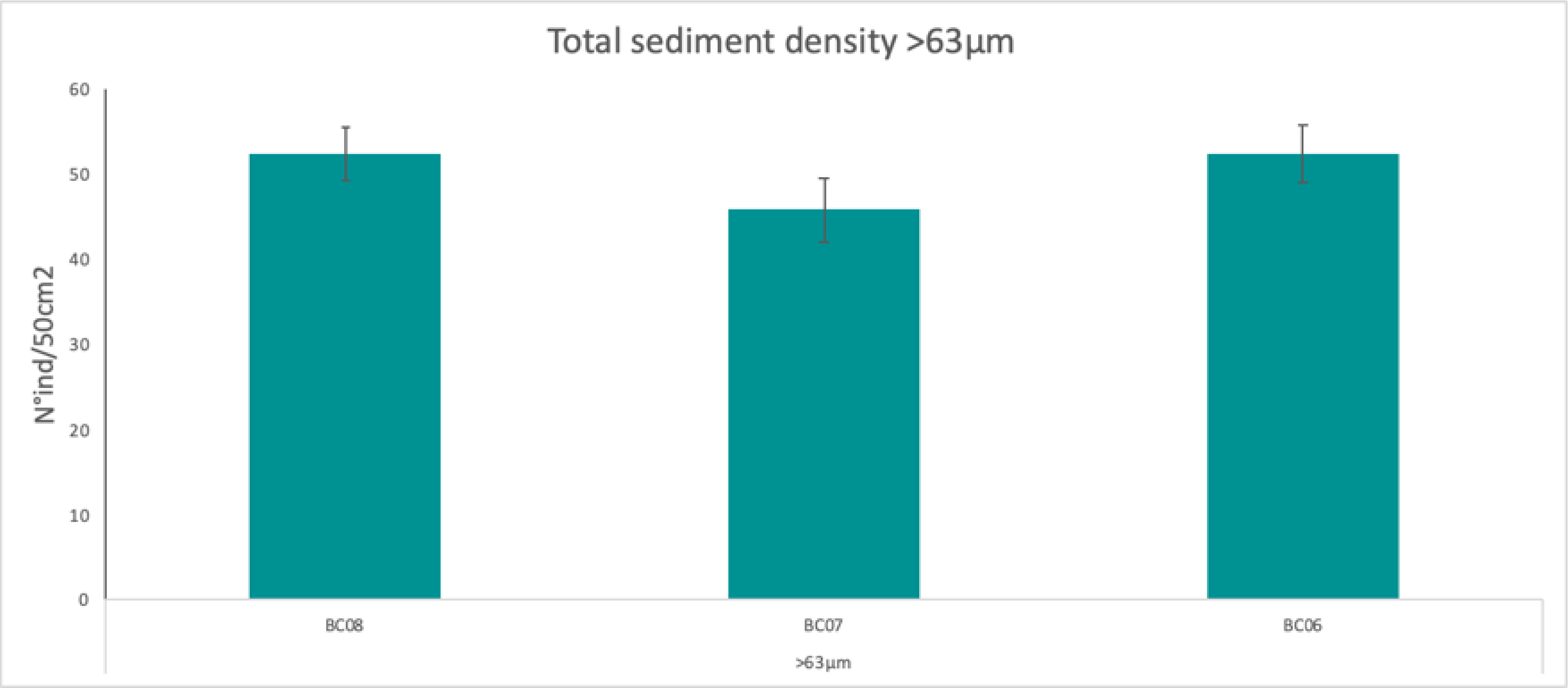


Figure 4.36: total average of sediment density >63µm for sampling site

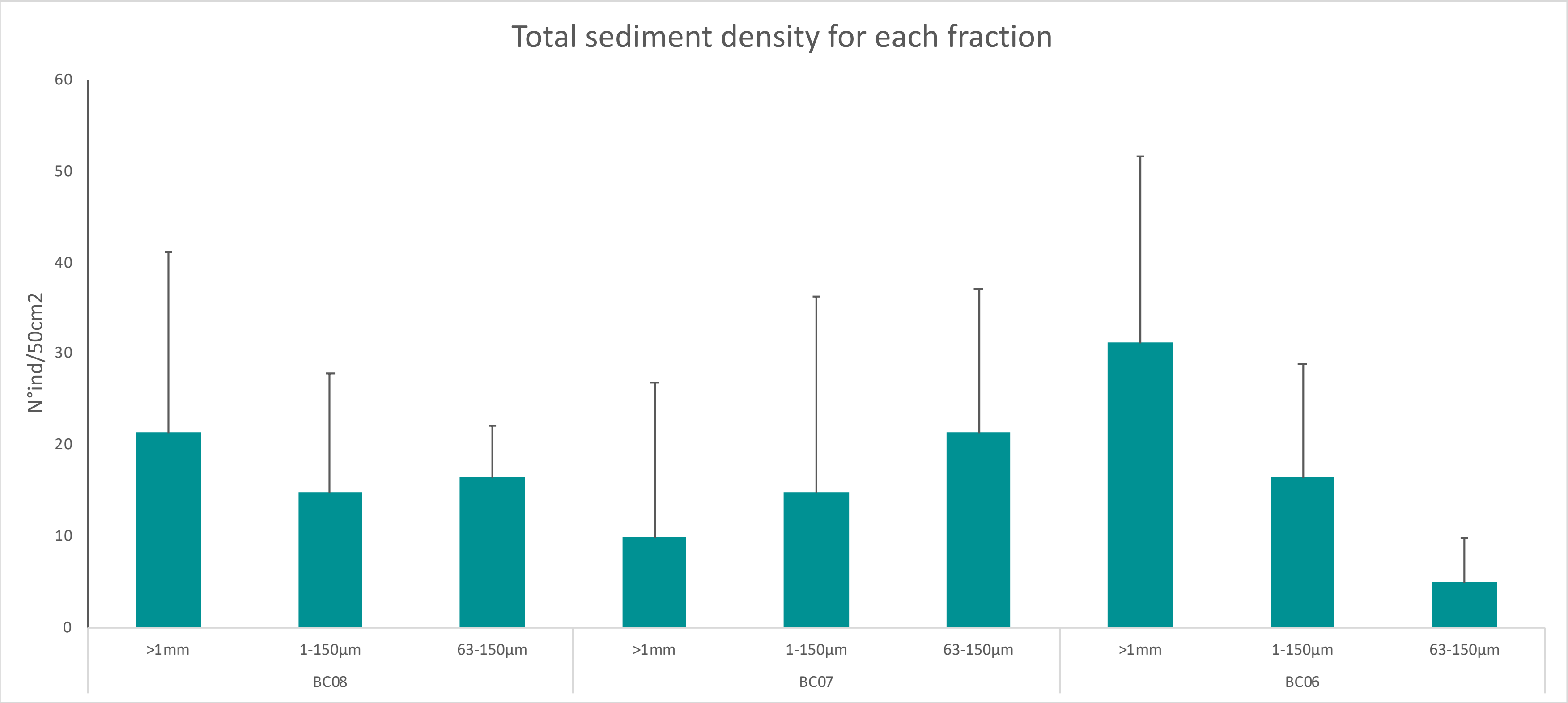


Figure 4.37: total average for each fraction >1mm, 1mm-150µm and 150-63µm for sampling site. Standard deviation is very high as there are few specimen.

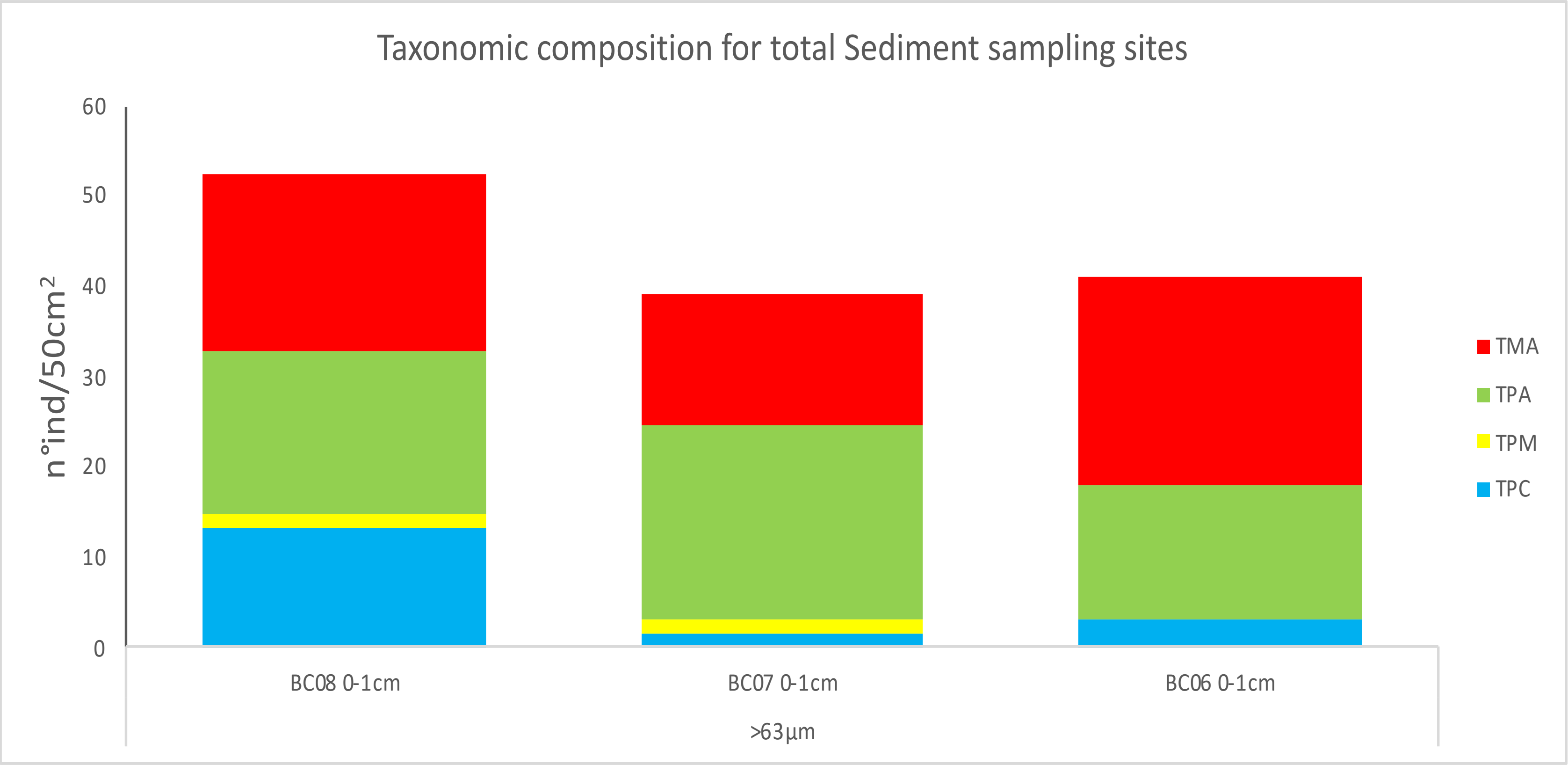


Figure 4.38: taxonomic composition for each sediment sampling site for Total Monothalamous agglutinated (TMA); Total Polythalamous agglutinated (TPA); Total Polythalamous Miliolids (TPM) and Total Polythalamous Calcareous (TPC)

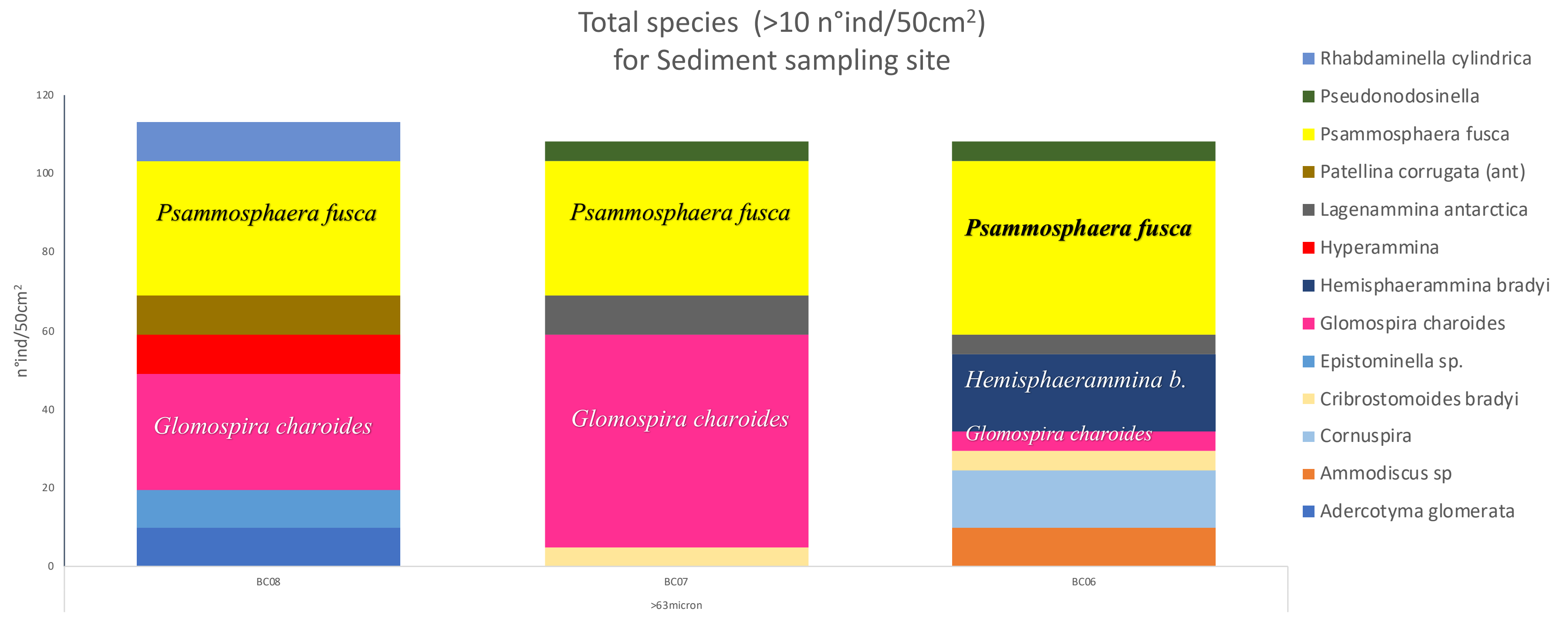


Figure 4.39: Total specimen presence for each sampling site n°ind/50cm^2. There is clearly a predominance for Psammopshaera fusca Glomospira charoides in each station and at BC06 also Hemisphaerammina bradyi; a picture for each species is shown as follow.

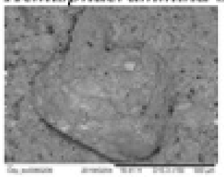
Psammosphaera fusca

Hesemann, M. 2020
Foraminifera.eu Project Database

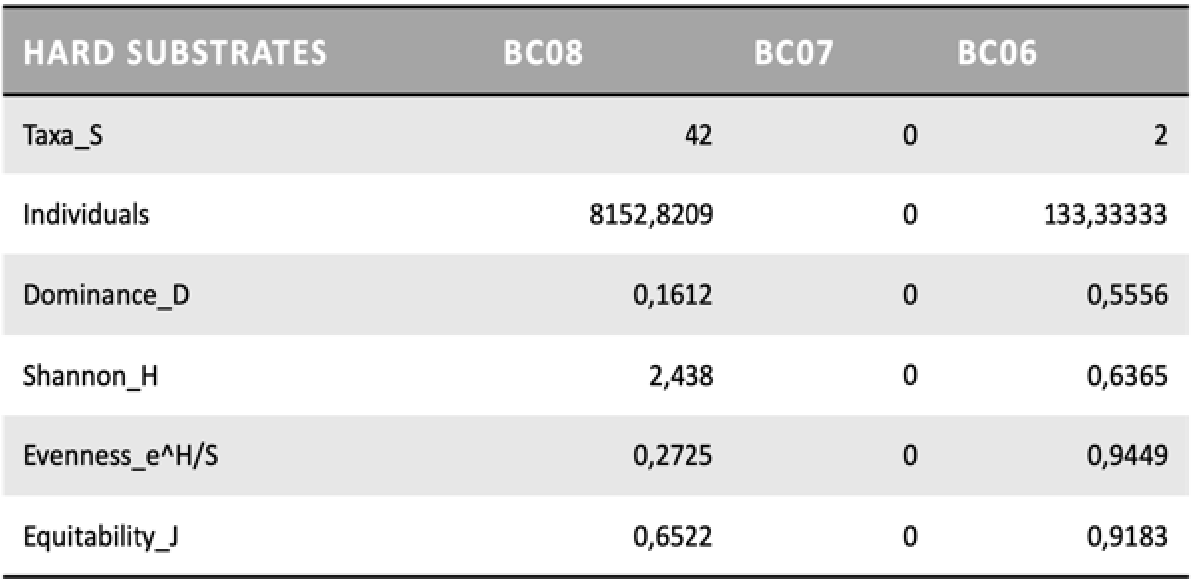
Glomospira charoides

WoRMS
World Register of Marine Species

Hemisphaerammina bradyi

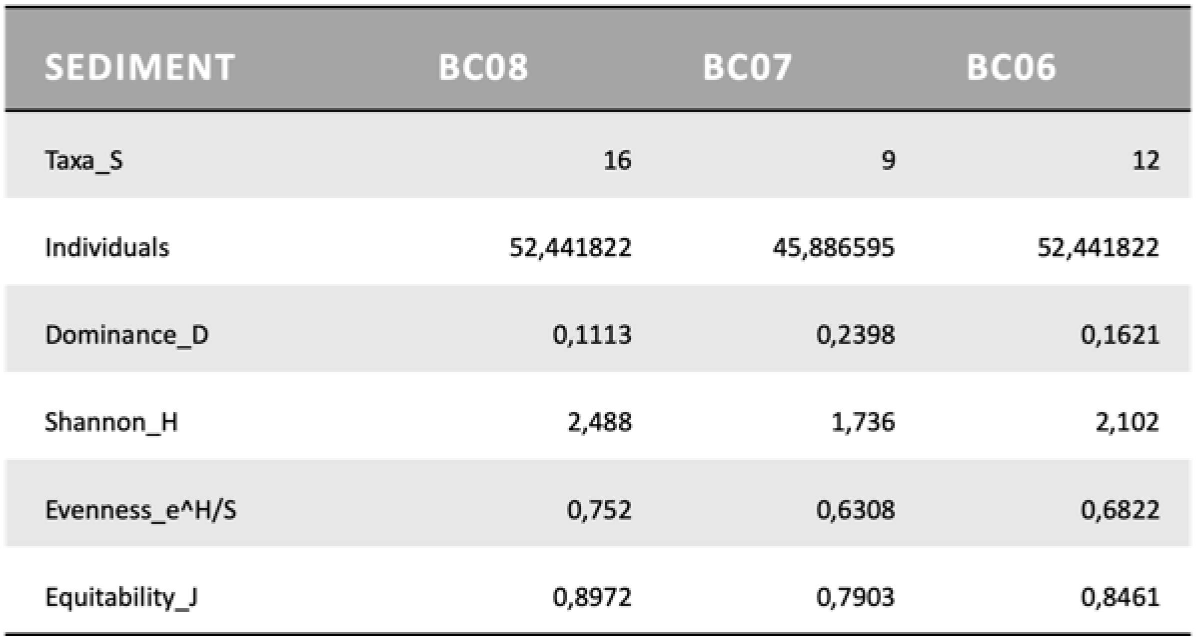


Sem image ODYSSEA-drift
Antonietta d'Agnessa



HARD SUBSTRATES	BC08	BC07	BC06
Taxa_S	42	0	2
Individuals	8152,8209	0	133,33333
Dominance_D	0,1612	0	0,5556
Shannon_H	2,438	0	0,6365
Evenness_e^H/S	0,2725	0	0,9449
Equitability_J	0,6522	0	0,9183

Table 4.5: species indices for Hard substrates foraminiferal assemblages.



SEDIMENT	BC08	BC07	BC06
Taxa_S	16	9	12
Individuals	52,441822	45,886595	52,441822
Dominance_D	0,1113	0,2398	0,1621
Shannon_H	2,488	1,736	2,102
Evenness_e^H/S	0,752	0,6308	0,6822
Equitability_J	0,8972	0,7903	0,8461

Table 4.6: species indices for sediment foraminiferal assemblages.

CHAPTER 5

DISCUSSIONS

As pointed out by Margreth et al., 2009 a combination of environmental parameters controls the spatial distribution of benthic foraminifera (Lutze & Coulbourn, 1984; Gupta, 1997; Schonfeld 2002a, b; Gooday, 2003; John Murray, 2006; Jorissen et al., 2007).

In particular, the most important parameters controlling the distribution of these organisms in the deep sea are the organic flux to the seafloor and the bottom water oxygenation (e.g. Jorissen, 1988; Mackensen et al., 1990, 1995; Schmiedl, Mackensen, & Müller, 1997).

The quality of the organic matter, and the degree of seasonality in its delivery to the seafloor, are also important (Fontanier et al., 2002, 2005).

But where current velocities are high, bottom flow, together with substrate characteristics, play a central role in the distribution of benthic foraminiferal assemblages (J. Schönfeld, 1997, 2002) as in the present contest.

The result of epibenthic foraminiferal assemblages census, for the transect along the slope of the Odyssea drift, evidences a hidden biodiversity for the micro-world of the epibenthic encrusting foraminifera together with foraminiferal Sediment species inhabiting an oligotrophic substrate. The majority of the Hard

Substrates species are represented by rare agglutinated taxa most of them included in the class “Monothalamea” (Pawlowski et al., 2013) such as *Ammopemphix hemisphaericus*, *Dendronina arborescens* var. antarctica, *Placopsilina bradyi* or *Tolypammina vagans*. Wherease, the Sediment samples are characterized mainly by *Glomospira charoides Psammosphaera fusca* and *Hemisphaerammina bradyi.*

Interestingly, in the Hard Substrates samples it has been possible describe a new genus of encrusting agglutinated foraminifera namely *Spiculotuba* n. gen. d’Agnessa, Sabbatini & Morigi 2019 (fig. 4.2). In general, the taxonomic composition for all studied samples shows a high presence of Polythalamous and Monothalamous agglutinated foraminifera both for Hard Substrates and Sediment samples, therefore calcareous foraminifera are poorly represented, reflecting the corrosive water that prevent calcification.

In the following paragraph I would like to discuss why the Hard Substrates represent a micro hot-spot of biodiversity compared to the Sediment, as a result of the environmental physical parameters that here plays a fundamental role in shaping the Foraminieral community.

5.1 Environmental considerations

The Ross Sea is one of the major areas for Antarctic Bottom Water formation (the Ross Sea Bottom Water, RSBW), representing the densest ocean water mass, filling the deepest ocean basins connected to the Southern Ocean. Periodic refill of the RSBW occurs through formation of dense, cold and saline water masses (brine) forming on the shelf at the Ross Sea permanent polynya by freezing and salt rejection (high-salinity shelf water, HSSW). The HSSW periodically overspills the shelf area and descends along the slope (Lucchi et al., 2019). The Hillary Canyon, crossing the Ross Sea continental slope, represents one of the main conducts through which the HSSW descends the slope to reach the deeper ocean. On its western levee, there is a sediment drift (ODYSSEA Drift), generated by along-slope, contour currents sediment transport and accumulation through several hundred-thousand years. It was inferred that contour currents transported and deposited the sediments that descent the Hillary Canyon by means of the HSSW. Preliminary study during the Italian ITRS17-ODYSSEA expedition on board the RV OGS-Explora pointed out a relatively high Ca content with common presence of biogenic component. And the presence of contour current deposition during relatively warm conditions and bioturbated sediments with abundant, sparse and/or layered Ice Rafted Debris, and high Ca content. The superficial sediments are characterized by a prominent Mn peak, associated with strong bottom currents.

The Hillary Canyon represents the passage to the deeper ocean with evidence of turbidite activity relating to transport of cascading water masses (e.g., AABW) down the canyon (Santis et al., 2019) The head of the Hillary Canyon system is located at the mouths of the Pennell Basin and Glomar Challenger Basin. Intense and irregular sedimentary dynamics, consisting of down-slope transport of material, associated turbidity currents, cascading of dense shelf can disturb the benthic communities but also create habitats for new faunal colonization of foraminifera, as demonstrated in previous study in a similar environment. (Nardelli, Sabbatini, Bonnot, Mea, Pusceddu, Danovaro, et al., 2018; Di Bella et al., 2019). Indeed, The Hillary Canyon is also a main route for glacial sediments eroded and transported by ice streams from the innermost continental shelf to its edge. (McKay, R.M. et al 2019). Thus, providing a wide range of coarse material (e.g.: clasts) that organisms can use as Hard Substrates. Foraminiferal distribution is greatly influenced by specific ecological conditions within canyons, related to turbidity, current activity and/or organic carbon fluxes (Schmiedl et al., 2000); Fontanier et al., 2005; Koho, Kouwenhoven, de Stigter, & van der Zwaan, 2007; Nardelli et al., 2018, Di Bella et al., 2019). Sediment samples analyzed by McKay, R.M. et al., 2019 at Site U1524, location of the Hillary Canyon, analyzed, the total organic carbon, TOC and CaCO3 contents. TOC content is generally low (<0.9 wt%). The Total Nitrogen content (TN) is very low also (<0.1 wt%) throughout the site, thus indicate an oligotrophic environment.

5.2 Foraminiferal distribution and biodiversity due to environmental drivers

5.2.1 Foraminiferal Density

Foraminiferal density and biodiversity might decrease with increasing depth, following the general rule for canyons environment as pointed out by Di Bella et al. (2019), even though for Mediterranean ones. In particular, from the continental shelf (BC08) there is a total density of 8172 n°ind/50cm^2, following the slope of the canyon at BC06 site the density is only 133 n°ind/50cm^{2}at the end of the canyon. In site BC07 there haven't been recorded any hard substrates and associated fauna. This trend is followed both for encrusting foraminifera on elevated substrates and foraminifera inhabiting superficial sediment, even though with lower abundance (fig. 5.1). Indeed, from site BC08 there are 52 n°ind/50cm^2, followed by 45 n°ind/50cm^2 on the slope BC07 and 52 n°ind/50cm^2 in site BC06. Anyway, I would like to underline that there could have been a bias during sampling procedures, so we might have an underestimation or data variations in each site for the collection of pebbles and biogenic structures. Therefore, I am going to elaborate a hypothetical interpretation for a general trend based on samples that I have studied. On the other hand, we might be more accurate and confident for the Sediment trend for each sampling sites, as it presents the usual sampling procedures. In particular, for Sediment samples, there are differences in the studied fractions >1mm, 1mm-150µm, 150µm-63µm: foraminifera from the bigger fraction dominates the shelf in site BC08, >1mm and 1mm-150µm in particular *G. charoides* and *P. fusca*; the same species are then along the slope on site BC07 and BC06 but in the smaller fractions 1mm-150µm and 150µm-63µm, interpreted as a juveniles supporting the recolonizing hypothesis in a disturbed environment (fig. 4.39). This distribution is mainly due to strong bottom current and cascading events, coupled with water depth and low TOC content, thus reflecting previous observations for foraminiferal assemblages in canyons habitat, even though for the Mediterranean district (Contreras-Rosales et al., 2012, Di Bella et al., 2019). Indeed, a decrease in species reachness (S) and Shannon index (H) with the depth in the canyon, as reported from Di Bella et al., 2019, are observed both for epibenthic foraminiferal assemblages and species living in the first centimeter of the sediment (see tab 4.5, 4.6) .The higher density of epibenthic foraminifera for the studied sites BC08 and BC06 along the bathymetrical transect, could be related to the fact that Hard Substrates can provide an optimal elevated micro-habitat in an extreme environment with unstable conditions both in physical terms and biological with strong currents and stochastic events (e.g. Shelf-Cascading). Substrate and attachment surfaces are known to be important for epifaunal foraminifera (Lutze & Thiel, 1989; Burkett, Rathburn, Elena Pérez, Levin, & Martin, 2016), and increased abundances of epifaunal taxa in coarser-grained sediments has been noted in deep-water environments (Joachim Schönfeld, 2002b; Venturelli, Rathburn, Burkett, & Ziebis, 2018). Hard Substrates such as clasts or biogenic structures, enhance the habitat heterogeneity and provide stability in an extreme environment where strong physical features such as strong bottom currents and sediment contourites make it difficult to live in sediment.(Rebesco, Hernández-Molina, Van Rooij, & Wåhlin, 2014)

5.2.2 Taxonomic composition and diversity

Abundances are high for site BC08, on the continental shelf, where Hard Substrates foraminiferal density, as specified in the results, reach 4980 n°ind/50cm^2 for Total Polythalamous Agglutinated (TPA) taxa and 4809 n°ind/50cm^2 for Monothalamous Agglutinated (TMA) ones, Total

Polythalamous calcareous reach a value of 1656 n°ind/50cm^2 while miliolids on HS are not represented (fig. 4.32). In Site BC07 situated along the slope there haven't been reported any pebble or biogenic clast, so I do not report any value. Site BC06 located at the end of the slope shows lower values, with no Polythalamous Agglutinated foraminifera and 44 n°ind/50cm^2 for Monothalamous agglutinated (TMA) foraminifera. Instead, Total Polythalamous calcareous (TPC) foraminifera reach 44 n°ind/50cm^2. Sediments samples show a very low abundance, dominated mainly by Monothalamous agglutinated species, with a similar trend for each site that reaches a total of 57 n°ind/50cm^2 (TMA) while Polythalamous agglutinated account for 54 n°ind/50cm^2(TPA). Total Polythalamous calcareous (TPC) foraminifera have a low value such as in Hard Substrates for a total of 18 n°ind/50cm^2. Moreover, in the sediment we found a small fraction of Miliolids (TPM 4 n°ind/50cm^2) not present on the Hard Substrates. In general, agglutinated foraminifera dominates on calcareous one as discussed previously and between agglutinated species is different the response to face environmental pressures due to the extreme environment and episodic food supply.

Therefore, on Hard susbstrates there is a prevalence of Monothalamous agglutinated species, with stubby and hardly attached forms, displaying different morphological features (see Taxonomical Appendix), while in the sediment there are more Polyhtalamous agglutinants ones, such as *G. charoides.* Among Monothalamous agglutinated foramifera *Spiculotuba* n. gen. specimens hide themselves in cracks in the clasts or biogenic structures. This new genus has been recovered once as “unknown tubular species” on indurated sediment at Middle Valley at depths >1000m, dominated by agglutinated species too. In fact, Jonasson (1996) found it on indurated mud samples of the basal areas of hydrothermal mounds in Middle Valley together with *Tolypammina vagans. Placopsilina bradyi* was recorded by the same author on the bituminous hydrocarbon substrate of the barite hydrocarbon chimney with presence of Fe- and Mn-rich crusts that seem to offer favorable environmental conditions for encrusting agglutinated deep-sea foraminifera. *Tolypammina vagans* and *Placopsilina bradyi* are present also on pebble clasts, distributed along the Odyssea drift. On the other hand, *G. charoides* it is a pioneer agglutinant specie in the sediment: an early colonizer after strong disturbance (Di Bella et al., 2019). Its presence with higher values along the slope~~,~~ associated to low abundances of the rest of foraminiferal fauna suggests a stage of re-colonization after a possible stochastic mass depositional event, underlying the instability of this environment. Here it is accompanied by few juvenile miliolid species and *Nodellum*-like specimens; those taxa, commonly observed in oligotrophic conditions (e.g.De Rijk, Jorissen, Rohling, & Troelstra, 2000; Anna Sabbatini, Morigi, Negri, & Gooday, 2002), reflects the low available organic matter sedimentary contents expressed in TOC (<0,9 wt%). Indeed, *Glomospira charoides* is often reported to behave as an opportunistic species in oligotrophic environments (De Rijk et al., 2000; Contreras-Rosales et al., 2012; Nardelli et al., 2018; Di Bella et al., 2019), or also in extreme environments such as hydrocarbon seepages (Kaminski et al., 1988) or hydrothermal vents (Jonasson et al., 1995). Indeed, it has been reported as a "disaster species" (Alegret et al., 2009; Di Bella et al., 2019), common in oligotrophic environments (De Rijk et al., 2000), together with low foraminiferal abundances is supportive of this hypothesis as reported also by Nardelli et al. 2018, even though we have only the total organic carbon TOC (<0,9%wt) datas and not biopolymeric carbon. Thus, the presence of this species in my samples could support the presence of stressful conditions, consisting in low organic matter and/or hydrodynamic disturbance generated by turbidity currents and contourite. Moreover, its living depth in the sediment is linked to a sea-floor carbon flux value of around 2.5 gC/m^2-yr, but the species only flourishes under conditions of very low carbon flux (<0.7 gC/m^2-yr) (Kaminski et al. http://www.nhm2.uio.no/norges/atlas/ Atlas of Agglutinated Foraminifera) and therefore interpret the presence of *G. charoides* as reflecting oligotrophic conditions. Together with *P. fusca,* found in both sites BC07 and BC08 they strongly support, as seen in literature yet, the oligotrophic condition of the environment of the Hillary canyon and its unstable extreme conditions with strong bottom contourite currents and events of Shelf-cascading through the canyon.

5.2.3 Foraminiferal biodiveristy

The biodiversity decrease following the bathymetrical trend from the shelf (BC08) to the slope (BC07) and the base of the canyon (BC06) as seen in previous canyon environments (Contreras-Rosales et al., 2012; Di Bella et al., 2019;). I have reported a total of 65 species, with 44 from the Hard Substrates and 31 from Sediment, with only 10 species in common. As indicated by species richness the high biodiversity is in site BC08 both for Hard substrates and Sediment, followed by a decrease along the slope in site BC07, and rising a bit in site BC06 at the end of the slope. A similar trend is present for Shannon index (S) for both Hard Substrates and Sediment. Moreover, the almost exclusive presence in the Sediment of *G. charoides* and *P. fusca* for each sampling sites, justify a very high Equitability (J) value near 1. (tab. 4.6)

Another example of Hard Substrates that has been studied are also polymetallic nodules where biodiversity is high. Because of their potential economic importance, the sessile organisms, mainly protists (foraminifera) that live attached to their surfaces, have attracted since 1970 scientific attention (Brent K. Dugolinsky, Stanley V. Mar, 1977; Mullineaux, 1987, 1988a; Veillette et al., 2007a; Andrew J. Gooday, Goineau, & Voltski, 2015) studied foraminifera colonizing polymetallic nodules located in the eastern part of the Clarion Clipperton Fracture Zone (CCFZ) at depths >1000m, equatorial Pacific. In particular, they found Monothalamous foraminifera, mainly with agglutinated walls as in the present study. Records of *Cibicides* sp*.,* *Placopsilina bradyi, Chondrodapis, Hemisphaerammina* sp*., Tolypammina vagans* and *Glomospira charoides* have been found with lower abundance (48 individuated species) in comparison to data present in this study. Many deep-sea foraminifera have wide geographical distributions (Schröder et al., 1988; Murray, 1991; Nils Cornelius, Gooday, 2004), thus indicate that they have wide optimal ecological range and could inhabit also different types of habitat from indurated mud of hydrothermal vents, to abyssal polymetallic nodules, ice-rafted debris or biogenic materials. The link that gives them the possibility to develop in different type of environments could be the availability of Hard Substrates that enhance the heterogeneity and stability with rough surface where to attach or hiding, protecting themselves from disturbing events, and the unstable surrounding environment, resulting in an implementation of the total biodiversity budget.

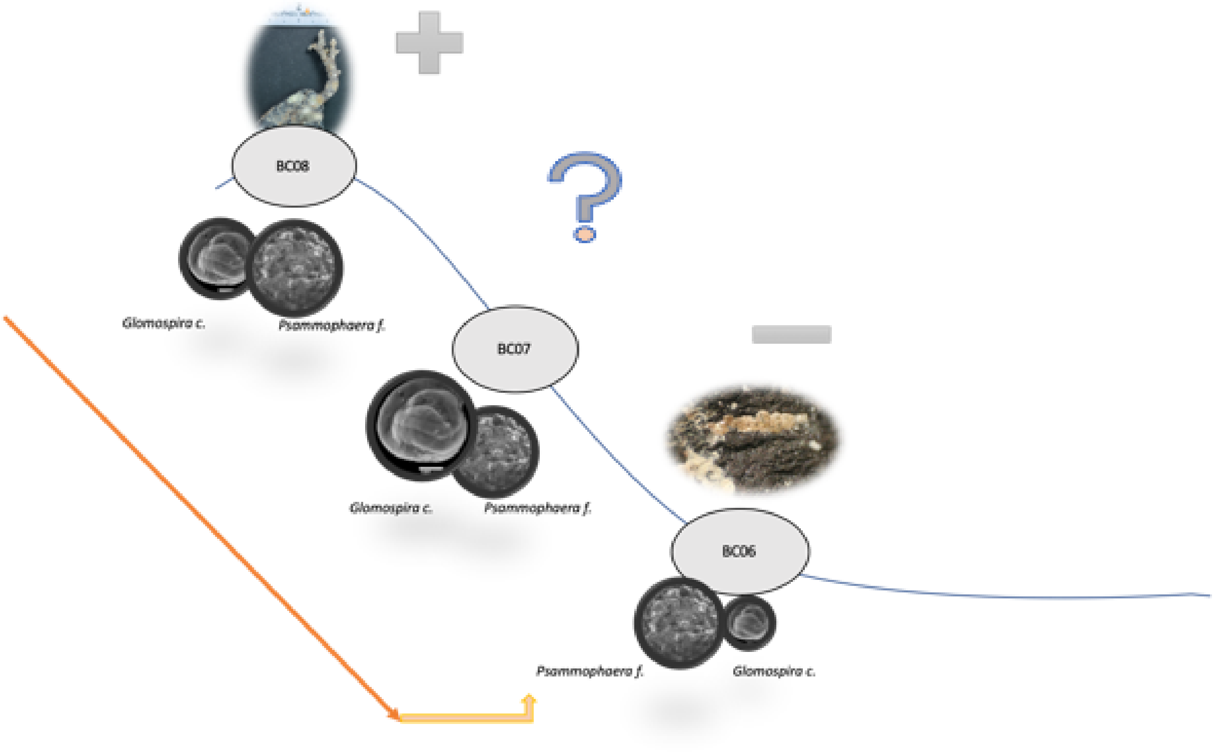


Figure 5.1: schematic resume of biological features along the bathymetrical transect of the Hillary canyon. Location of sites alonge the slope together with hypothetical epibenthic foraminifera abundance on top, higher on the shelf site BC08, absent in BC07 due to a lack of HD and lower in the final site BC06. The same trend is followed by the infaunal species in the Sediment (orange arrow, rising a bit in site BC06 due to an early stage of recolonization of G. charoides.)

CHAPTER 6

CONCLUSIONS

Deep Epibenthic foraminiferal assemblages are studied in Hillary canyon (Ross Sea, Antarctica), an extreme environment where shelf cascading (HSSW) through the canyon and strong bottom contourite currents dominated a tough habitat where few organisms can survive. Those physical aspects, together with a general oligrotrophic environment, are faced by, apart for sporadic sponges and singular bryozoans, from a wide species of foraminifera, in particular monothalamous and polythalamous agglutinated, with few calcareous ones, due to a corrosive environment that prevent calcification. One of the main determining factors of the density of those peculiar agglutinated attached foraminifera is the ability to live and "hide" themselves, finding protections, on Hard Substrates such as clasts deriving from ice-rafted debris and biogenic structures like hydrocorals skeleton. Those elevated Hard Substrates provide heterogeneity and a rough surface for their attachment and therefore, increasing the biodiversity, allowing also to the discover of new a genus as *Spiculotuba* n. gen. Indeed, of the total 65 species, 34 are from Hard Substrates and only 21 from Sediment samples, thus having in common only 10 species. Interesting is also the occurrence of some taxa *(Tolypammina vagans; Cibicides* sp.*;*

Placopsilina sp., *Chondrodapis, Hemisphaerammina* sp.*)* found also in different extreme deep environment, such as indurated mud sediments of hydrothermal vents, or polymetallic nodules; this could indicate the wide range of adaptability of these foraminifera and the fact that it is not important the type material but fundamental is an hard-rough surface where to attach, elevated. Here they could increase the total biodiversity budget, underlaying the importance of a combined study of foraminifera both in the sediment and epibenthic ones.

In the sediment samples, it is dominant *Glomospira charoides,* an accepted "disaster" species with an opportunistic behaviour especially found in small dimension and low abundance in canyons, indicating a beginning of colonization after a disturbing event. Together with *Psammosphaera fusca*, already reported as opportunistic species, that can rapidly colonize as *G. charoides* areas disturbed by deep-sea currents. In conclusion, species distribution and abundance, could testify as foraminifera, are able to adapt an epibenthic strategy: attaching themselves to Hard Substrates providing a more stable and protect environment, and allow them to live in higher abundance respect the Sediment species, more affected by shelf cascading events through the canyon and strong bottom contourite currents.

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