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A RESILIENT DEEP-WATER RHODOLITH BED OFF THE EGADI ARCHIPELAGO (MEDITERRANEAN SEA) AND ITS ACTUOPALEONTOLOGICAL SIGNIFICANCE

Valentina Alice Bracchi[1] , Lorenzo Angeletti[2], Fabio Marchese[1], Marco Taviani[2,3,4],
Frine Cardone[5], Irka Hajdas[6], Valentina Grande[2], Mariacristina Prampolini[2],
Annalisa Caragnano[7], Cesare Corselli[1], Daniela Basso[1]

[1] Department of Environmental and Earth Sciences - DISAT; CoNISMa Local Research Unit, University of Milano-Bicocca, Italy.
[2] Institute of Marine Sciences, National Research Council (ISMAR-CNR), Bologna, Italy
[3] Stazione Zoologica Anton Dohrn, Napoli, Italy.
[4] Biology Department, Woods Hole Oceanographic Institution, MA 02543, USA.
[5] Department of Biology, University of Bari, Italy.
[6] Laboratory of Ion Beam Physics in Zurich, ETH Zurich, Switzerland.
[7] Department of Life and Environmental Sciences - DiSVA, Polytechnic University of Marche, Ancona, Italy.

Corresponding author: V.A. Bracchi <valentina.bracchi@unimib.it>

ABSTRACT: Rhodolith beds are priority marine benthic habitats for the European Community, because of their relevance as biodiversity hotspots and their role in the carbonate budget. The high-Mg calcite calcified thalli promote their preservation through time, resulting in their common occurrence in the fossil record, thus making rhodoliths a significant archive of past environmental and climate changes. The present temperate Mediterranean Sea is home to rhodolith-rich up to rhodolith-dominated habitats which have been targeted over the years for ecological research and management actions. Furthermore, the Mediterranean Basin hosts an important fossil legacy of rhodolith beds that formed under contrasting climatic scenarios since the Neogene. Most examples of Mediterranean rhodolith beds lay within the depth range (30-75 m), while far less is known about deeper occurrences. An outstanding rhodolith bed has been recently identified off the Egadi Archipelago (70-95 m, Central Mediterranean Sea) in the frame of the Italian Marine Strategy Framework Directive project. The rhodolith bed carpets an area >7 km^2 between Marettimo and Favignana Islands (Egadi Archipelago), with a cover of live rhodoliths up to 95%. The dominant rhodolith morphotype is *pralines*, ellipsoidal to discoidal in shape (average size 11 mm, maximum size 31 mm) associated with biogenic gravelly-sand. They present both seafloor bedforms (megaripples and ripples) and frequent bioturbations by epifaunal and semi-infaunal sea urchins. Old algal nodules, biogenic sand/mud, or, less frequently, terrigenous particles serve as nucleus of individual rhodoliths. Living calcareous algae are *Lithothamnion valens*, *L.* cf. *minervae*, *Phymatolithon lenormandii*, and *Lithothamnion* spp. The latter characterize also the dead algal association close to the nucleus, with the subordinate presence of *Lithophyllum* sp. Benthic fauna corresponds to the circalittoral environment, with exclusive species of the Coastal Detritic biocoenosis or related to coarse sediments. Moreover, the general textural aspects and bedforms are in line with moderate water energy at the seafloor. Radiocarbon ages reveal that the cores of rhodoliths date back to 2334, 2159 and 1997 BP, which correspond to the Roman Warm Period. Calculated growth rate provides a very low figure (0.004 mm/yr). The inception of such rhodolith bed occurred under warmer climate conditions, but its development is continuing at present because of the persistence of adequate light conditions and bottom hydrological regime, with a very slow growth-rate. Therefore, the Egadi case history certifies a rare example of a deep-water resilient rhodolith bed, which should be taken into consideration for the potential recognition of fossil analogs in the Mediterranean Basin.

Keywords: rhodoliths, radiocarbon age, Roman Warm Period, Mediterranean Sea, Holocene.

1. INTRODUCTION

Calcareous coralline algae, slow-growing and long-lived organisms, form rhodoliths that occur from the intertidal zone down to 270 m in the tropics (Littler & Littler, 1984), occurring commonly at tropical, temperate and polar latitudes on modern carbonate shelves worldwide from the intertidal zone down to 270 m (Bosence, 1983a; Littler & Littler, 1984; Nelson, 2009; Teichert et al., 2012 Foster et al., 2013). They display considerably resilience to varying environmental disturbances (Bosence, 1983a, b; Steller et al., 2003). Rhodoliths boast an excellent fossil record and extant-type situations are well documented from the Oligocene onwards (e.g., Foster, 2001).

Rhodoliths often form aggregations named as Rhodolith Beds (RBs). Since the 1990s, growing attention has been given to evaluate the RBs' response to anthropogenic threats, such as physical damage due to fishing activities, aquaculture, or degradation of water quality (Massutti et al., 1996; Borg et al., 1999; Bordehore et al., 2000, 2003; Relini & Giaccone, 2009; Sanz-Lázaro et al., 2011; Teichert, 2014; Ordines et al., 2017). The identification of RBs, their areal distribution and vitality, their main features bioengineers, are all fundamental topics for a sustainable management of marine environment.

Mediterranean RBs are considered as marine benthic habitat of high conservation interest, and two of the main species structuring this habitat, *Phymatolithon calcareum* (Pallas) Areschoug (1852) and *Lithothamnion corallioides* (P.Crouan & H.Crouan) P.Crouan & H.Crouan 1867, are included in the European Community Habitat and Species Directive 92/43/EEC - Annex V. They are subjected to a special plan for the protection within the framework of the United Nations Program's Mediterranean Action Plan (UNEP MAP RAC/SPA, 2008) and one of the marine habitat included in the monitoring program in the Marine Strategy Framework Directive 2008/56/EC of European Community.

In the Mediterranean Sea, live RBs are scattered in infralittoral environments but mostly occur in circalittoral detritic bottoms (Basso et al., 2017 with references therein). They may occur between 9 and 150 m (Balearic Sea, Aguilar et al., 2009), typically within a depth range of 30-75 m (Basso et al., 2017). They are presently located around islands and capes, on top of submarine plateaux, seamounts, marine terraces, channels and banks (Basso et al., 2017 with references therein).

Because of their complexity, architecture, and three-dimensional structure hosting abundant flora and fauna RBs represent a hotspot of biodiversity (Basso et al., 2016; Riosmena-Rodríguez, 2017). Due to the carbonate composition of their cell walls (Mg-calcite), calcareous algae and consequently RBs play a key-role in the carbonate budget cycle, epitomizing a non-renewable resource because of the slow growth rate and related carbonate deposition (<1 mm/yr, Canals & Ballesteros, 1997; Martin & Gattuso, 2009; Basso, 2012). As for most top calcifiers, there is some concern about the fate of calcareous algae with respect to the on-going and future climate changes, and especially ocean acidification (Andersson et al., 2008; Nelson, 2009; Martin & Gattuso, 2009; Gao & Zheng, 2010; Teichert et al., 2012; McCoy & Regazzola, 2014; Williamson et al., 2014; Nash et al., 2015).

Rhodoliths can develop without any type of nucleus, or around skeletal or non-skeletal nuclei, usually producing a more or less concentric arrangement of the algal thalli. Calcareous algae show a wide variety of growth form, from foliose to fruticose to lumpy (Bosence, 1983b), depending from many factors that regulate their growth and distribution (main ones: water depth, light, hydrodynamics and sedimentation regime) (Wilson et al., 2004; Basso et al., 2009; Teichert et al., 2012; Sañé et al., 2016). The same is true for rhodolith shape, that can range among ellipsoidal, discoidal, and spheroidal (Bosence, 1983b; Basso, 1998). Commonly, rhodolith survival depends on overturning and consequently on

		Water Energy		
	LOW		**HIGH**	
Shape	flat discoidal	spheroidal	ellipsoidal	Bosellini & Ginsbourg (1971)
	discoidal	spheroidal	ellipsoidal	Bosence (1976)
		no relationship		Adey & MacIntyre (1973)
		not clear		Steller & Foster (1995) Lund et al. (2000) Steller et al. (2009)
Protuberance	+++		---	Foster et al. (2007) Sañé et al. (2016)
Growth-form	Laminar thalli	Wampy/Lumpy	Branching	Bosence (1976) Basso et al. (2009)
Voids	+++		---	Minnery et al. (1985) Sañé et al. (2016)
Morphotype	BW		PR	Bosence (1983) Basso (1998)
Nodule diameter	Large (BW)		small	Amado-Filho et al. (2007) Gagnon et al. (2012)
	Small		Large	Littler et al. (1991) Steller & Foster (1995) Riul et al. (2009) Bahia et al. (2010)
	DEEP		**SHALLOW**	
		Water depth		

Tab. 1 - A summary of available literature facing with the relation between rhodolith outer/inner structure and water energy/water depth.

the possibility to be continuing their accretion by avoiding overgrowing by other organisms and smothering. Moreover, rhodoliths are sensitive to burial (Bordehore et al., 2002, 2003; BIOMAERL team 2003; Riul et al., 2008; Bahia et al., 2010) and increasing nutrient and organic carbon are determined to their development (Sanz-Lázaro et al., 2011). Therefore, water motion is needed to maintain the rhodoliths unburied and in meso -oligotrophic conditions (Marrack, 1999; Steller et al., 2003), and actually, rhodoliths are often associated with sedimentary structures related to water motion such as ripplemarks and dunes (Barberá et al., 2012; Micallef et al., 2012; Sañé et al., 2016). Based upon tank experiments, Basso and Tomaselli (1994) calculated the relationship linking rhodolith shape and density with the current velocity needed to displace them, and provided evidence that storms may occasionally move rhodoliths down to >50 m depth. On the contrary, Marrack (1999), suggested that the bioturbation is fundamentally responsible for the overturning of rhodoliths and their survival in deep environment.

The relation between rhodolith outer/inner structure and water energy/water depth is debated in literature (Tab. 1) and no straightforward interpretation can be drawn from them. Nevertheless, this relation has been considered as a reliable tool for paleoenvironmental interpretation (Bosence & Pedley, 1982; Braga & Martin, 1988; Aguirre et al., 1993; Bassi, 1995, 2005; Bassi & Nebelsick, 2010).

Since the Neogene, RBs are recurrent components of Mediterranean carbonate shelves and frequent in shallow-water mixed siliciclastic deposits (Halfar & Mutti, 2005; Braga et al., 2010). They present an uneven stratigraphic distribution through time, with a maximum positive peak at the Middle Miocene Climate Optimum (Halfar & Mutti, 2005), and a decrease since the Pliocene (Braga, 2017; Coletti et al., 2017 with references therein). This assumption should be considered with caution since potentially reflecting a relative paucity of suitable carbonate outcrops of Plio-Pleistocene age. Due to carbonate structure, worldwide distribution, and occurrence in the fossil record, RBs represent a highly significant archive of past and present climate changes. Prager (1987) highlighted that taxonomic changes form the nucleus to the outer surface of a rhodolith might due to physical or biotic changes through time, but they cannot be related to ecological succession (Basso et al., 2009). Basso & Tomaselli (1994) and Basso et al. (1998) suggested that the analysis of changes in the growth forms of calcareous algae, as well as in the taxonomic composition from the nucleus to the surface of a rhodolith, could provide valuable information of paleoenvironmental shifts, a hypothesis later supported by Aguirre et al. (2017).

This paper discusses a new deep-water Mediterranean Rhodolith Bed (RB) discovered off Marettimo Island (Egadi Archipelago, Mediterranean Sea). The main characteristics of this live RB are discussed in term of morphology, ecology, taxonomy and temporal evolution from the Late Holocene to Present. The final goal of this study is to provide a suitable modern analog of a peculiar mesophotic habitat to assist the paleontological reconstruction in the Mediterranean Neogene record.

2. MATERIAL AND METHODS

A seabed sector between Marettimo and Favignana islands (Egadi Archipelago, Mediterranean Sea) (Fig. 1), has been investigated in the framework of Italian Marine Strategy Framework Directive (Directive 2008/56/EC, 2008) project, during the STRATEGIA MARINA LIGURE-TIRRENO oceanographic cruise (25 July - 5 August 2016) on board the R/V Minerva Uno.

2.1 Study area

Marettimo Island belongs to the Egadi Archipelago (Southern Italy) (Fig. 1a, b), placed in the westernmost sector of the Sicilian-Maghrebian chain (Catalano et al., 1996). Marettimo Island is isolated from the rest of the Egadi Islands by a channel. This channel is a long submarine valley (24 km), NNW-SSE oriented, with a depth ranging from 180 m up to 370 m and a width from 2 km up to 14 km (Polizzi et al., 2011). It has an important role in the water exchanges between the Sicily Channel and the southern Tyrrhenian Sea (Miller, 1972; Manzella et al., 1988). Its morphology reveals the occurrence of strong bottom currents probably related to the severe interchange of water masses between the Tyrrhenian Sea and the Sicily Channel (Polizzi et al., 2011).

The western Sicily continental shelf is small, with an average area of 200 km^2 and a maximum width of 40 km (Agate et al., 1999). Due to the reduced sedimentary supply from coastal erosion and river input, the Holocene sedimentary prism is very thin or absent around the Marettimo inner shelf compared to the usual values observed on the Sicilian shelf (Colantoni et al., 1993; Agate et al., 1998).

Sediments are constituted by heterogeneous mixtures of pebbles and gravels with medium to coarse sands in the inner shelf, turning to mud mixed with lithoclastic grains that overlies coarser sediments on the outer shelf (Lo Iacono, 2004). During the late Holocene highstand phase, the isolation from mainland sedimentary inputs and the reworking of sediments favored the limited preservation of fine sediment and the dominance of pebbles, gravels, and coarse sands on the shelf (Colantoni et al., 1993; Hermand et al., 1999). Seafloor presents sedimentary structures formed by bottom currents. Lo Iacono & Guillén (2008) described an extensive field of submarine dunes (Ashley, 1990) and sorted bedforms along the Marettimo inner shelf (10-50 m), forming on gravelly and pebbly sediments and related to strong storm events. In the SE sector of the Marettimo outer shelf, Colantoni et al. (1993) and Lo Iacono (2004) recognized two-dimensional dunes at depths between 60 and 90 m with a wavelength variable between 15 and 50 m, and three-dimensional dunes at a depth of 80 m characterized by a wavelength of 30 m and a lateral extent of 50 m.

2.2 Remote data

Remote data have been collected using a multibeam echosounder (Reson Seabat 7160) (Fig. 1c). Bathymetric dataset has been processed using dedicated software (PDS2000 and Caris HIPS&SIPS) to produce a 5 m resolution digital terrain model (DTM) and a 5 m resolution backscatter mosaic of the seafloor.

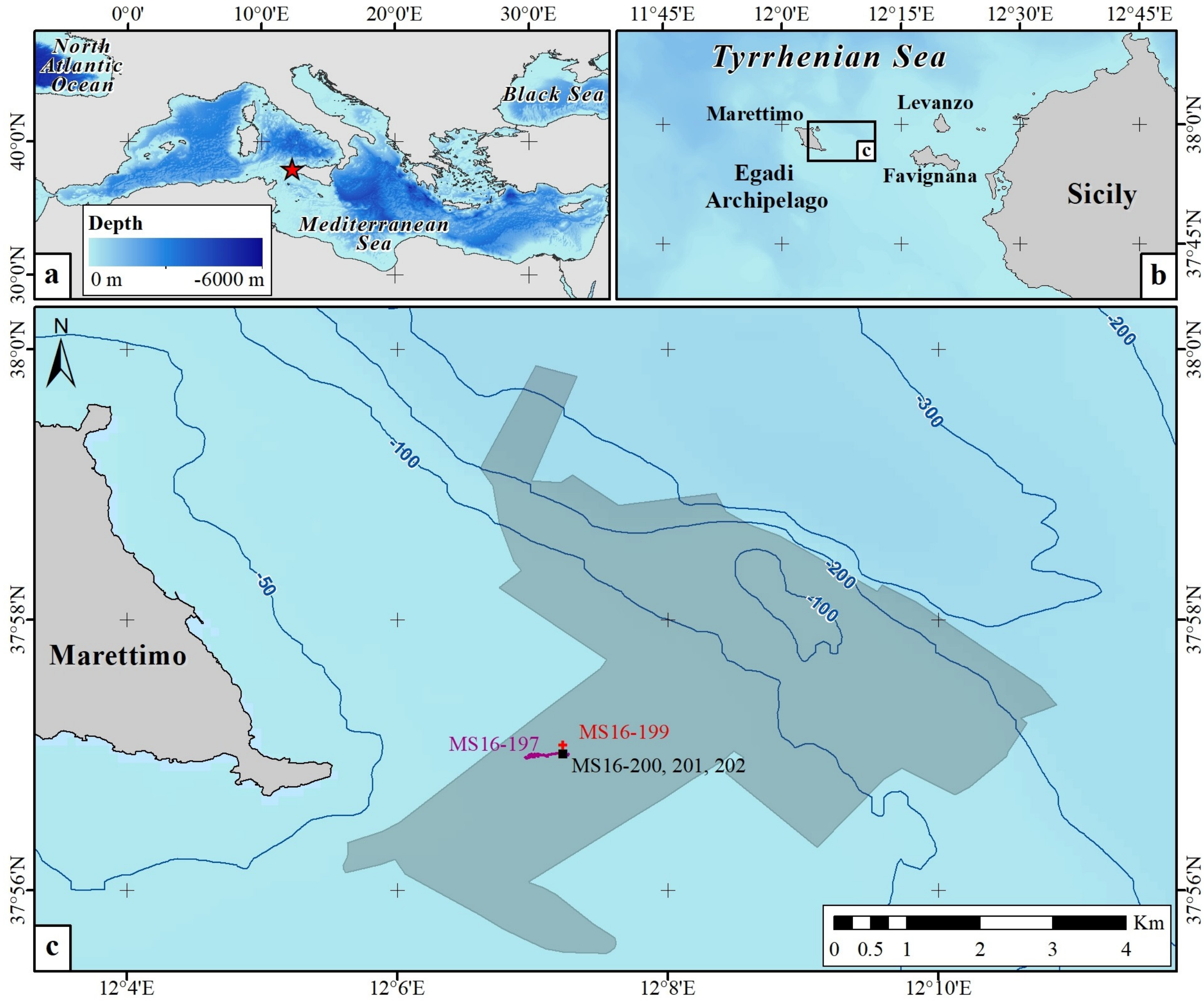

Fig. 1 - Geographical framework of the study area. a) Bathymetric map of the Mediterranean Sea, red star indicates the location of the Egadi Archipelago. b) Geographical setting of the Egadi Archipelago. c) Location of the surveyed area: grey polygon localizes the multibeam coverage. Red cross and black dots indicate respectively the position of the lander deployment and the grab samples. Violet line specifies the ROV navigation track. Bathymetry and isobaths from EMODnet Bathymetric Consortium (2018).

2.3 ROV dive and LANDER station

Seafloor bathymetry data have been ground-truthed by Remote Operated Vehicle (ROV - Pollux III of Stella Maris s.r.l.) (Fig. 1c). ROV is equipped with low-resolution CCD video camera for navigation and general description, and high-resolution (2034x1296 pixels) video camera (Sony HDR-HC7) for detailed description. Three laser beams at distance of 20 cm each other, provided the scale bar on the videos. Positioning is guaranteed by an acoustic position system, which provided the exact geographical and depth position every second.

Dive MS16-197 is ca. 1 km long, about E-W oriented (Fig. 1c), between 74.4 and 86.8 m water depth. ROV has been used to detect the occurrence of rhodoliths, the major geomorphological and sedimentological features, bioturbations, and associated megafauna. On the video, all the organisms larger than 2 cm have been identified at the lowest possible taxonomic level. Taxonomic identification follows the World Register of Marine Species (WoRMS Editorial Board, 2019).

Video has been analyzed with Adelie Video and Adelie GIS based on ArcMap® Geographic Information System (distributed by ESRI). The minifilms tool has been used to extract high-resolution images from ROV footage every 10 seconds: 540 photographs have been obtained with each image covering ca. 6 m^2. A total length of 1005.4 m, and for more than 6.000 m^2 of seafloor (buffer area 6 m large), has been surveyed during the dive.

Frames have been used to describe dominant rhodolith morphotypes and live cover. A RB is an area of soft substrate with a cover of more than 10% of living rhodoliths (Steller et al., 2003; Basso et al., 2015). Moreover, the RBs may be mosaicking with other types of bottoms. Two adjacent RBs are considered separate if, at any point along their limits, a minimum distance of 200 m separates them (Peña and Barbara, 2008; Basso et al., 2016). RB extension (i.e. cartography) results from the integration of direct and indirect observations.

A benthic lander station for the measuring of temperature, salinity and currents on the RB has been deployed in the site MS16-199 (37°57'3" 1 N, 12°7'13" E, 86.8 m) for almost 5 hours of continuos recording (Fig. 1c).

2.4 Seabed sampling

Where ROV images showed the highest rhodoliths cover, the MS16-200/201/202 (three replicas at the same station, 37°57'0 N, 12°7'13" E, 86.5 m) (Fig. 1c) have been collected using a modified Van Veen grab (volume =60 l) following Basso et al. (2016). Immediately after collection, three sub-samples of 200 g have been recovered for grain-size analysis. Live rhodoliths have been picked up and photographed onboard. According to Steneck (1986), the nodule is classified as rhodolith when more than 50% of their total volume is made of calcareous algae; otherwise, it is indicated as a coated grain. However, for monitoring, it has been suggested to consider as rhodoliths all those nodules showing a complete algal coating, with no need to cut them for checking the thickness of the algal coating in respect of the rhodolith nucleus (Basso et al., 2016). Rhodoliths have been classified based on their morphology (BW=boxwork, PR= *praline* or BR= branches) according to Basso (1998; 2012) plotting the results in a ternary diagram.

Rhodolith shape has been described following Bosence (1983b) by measuring the long (a), intermediate (b) and short (c) axes of all rhodoliths (n = 250), and applying the maximum projection sphericity formula

$$\sqrt[3]{\left[\frac{c \cdot c}{a \cdot b}\right]}$$

The results have been plotted in Sneed and Folk's (1958) pebble shape diagram using Origin software. Size of all rhodoliths was measured using the volume of an ellipsoid

$$\sqrt{\left[\frac{a \cdot b \cdot c}{4\pi}\right]}$$

as indicated in Bosence (1976), and the results are reported in a box plot.

Algal growth-form follows Woelkerling et al. (1993).

Selected sub-sample of live encrusting calcareous algae have been manually detached from the surface of live rhodoliths and treated for species identification, using the scanning electron microscope (SEM), and petrological thin sections. Moreover, twenty rhodoliths have been sliced to investigate 1) nucleus type, 2) potential changes in algal association close at the nucleus.

The identification of non-geniculate red algae follows the biological systematics framed by Woelkerling (1988), as revised by several subsequent contributions (Irvine & Chamberlain, 1994; Bressan & Babbini, 2003), and adapted to paleontology (Basso, 1994, 1995; Braga, 2003; Bressan et al., 2003; Hrabovský et al., 2015). Algal taxonomy follows Algaebase (Guiry & Guiry, 2019).

Following Basso & Corselli (2007), mollusk shells have been picked from the gravel fraction and analyzed in order to describe the associated thanatocoenosis, interpreted in the framework of the marine bionomy (Pérès & Picard, 1964; Pérès, 1982; Bellan-Santini et al., 1994).

Finally, three rhodoliths have been dated using the AMS radiocarbon technique dating at the Laboratory of Ion Beam Physics in the ETH of Zurich (CH).

Each rhodolith has been firstly broken, and then ^{14}C dating has been conducted on both the outer part of each rhodolith, and closest part to the nucleus, selecting the first calcareous algae carbonate layers directly encrusted on the nucleus and then its outermost layer. The resulting time interval between the two dates has been divided per the algal thickness to obtain the growth rate of the rhodolith.

Radiocarbon ages of the carbonate fraction of the three rhodoliths were calibrated with either OxCAL 4.3.2 (Ramsey, 2009) and marine calibration curve (Marine INTCAL13, Raimer et al., 2013) or data set of Hammer & Levin (2017) using CaliBomb after the ^{14}C age was corrected for the mean reservoir age of the ocean (400 ^{14}C yrs), which is an approximation of the values in the region (Siani et al., 2000).

3. RESULTS

3.1 Remote survey, ROV and LANDER station

The investigated area covered 22.7 km^2, from 55 to 350 m, a portion of the Marettimo shelf and upper slope on the western side of the channel between Marettimo and Favignana islands (Egadi Archipelago) (Figs. 1c, 2a, b). The shelf is a NE-oriented gentle slope with an average gradient of 0.5°, and a maximum of 2.5° in the central part, at depths ranging between 65 and 85 m (Fig. 2a). An isolated rocky structure characterizes the NE sector on the outer shelf (Fig. 2a). Backscatter response associated with RB is a composite texture of bands of high and low backscatter signal (Fig. 2b-c), and this is consistent with the main features observed in the video record where living rhodoliths are mosaicked with mobile biogenic sediments, mainly sand and gravel (Fig. 3a) possibly corresponding to the observed bedforms. The live algal cover is not homogeneous across the bed. Highest backscatter corresponds to an area where live rhodoliths are present, and the live cover is up to 95% (Figs. 2b-c, 3a-b). Low backscatter corresponds to seafloor where live rhodolith coverage is limited, less than 10% and corresponding to the patches of sediments observable on ROV (Fig. 2b-c). Based upon these observations, we contoured an area of 7.18 km^2 (Fig. 2d), SE of Marettimo Island and extended toward Favignana Island covered by live rhodoliths. The thickness of the live rhodolith layer corresponds to the dimension of a single rhodolith, therefore not exceeding 3.4 cm (Fig. 3b), that is to say that live rhodoliths occur as a single layer.

ROV images documented features characterized by large wavelength and thickness < 10 cm, interpretable as megaripples, complemented by smaller ripple-like features among on rhodolith (Fig. 3c). Such bedforms are consistent with vigorous bottom currents, whose measured intensity was 0.09 m/s and 306°N at the time of our survey (Angeletti et al., 2017). Intense sediment reworking by echinoderms is macroscopically obvious (Fig. 3e-f) as trails ascribable to foraging (ichnologically Fodinichnia) and walking activity (ichnologically Repichnia) by the semi-infaunal *Spatangus purpureus* (Fig. 3f).

Regarding physical attributes of the water column near the seabottom, we measured a temperature of 15.07° and a salinity of 38.18‰ (Angeletti et al., 2017).

Although irradiance has not been measured instrumentally, its natural decline at the seafloor was appreciated by the ROV (Fig. 3g-h).

3.1.1 Megafauna

Megafauna identified through ROV video analysis comprehends 15 species belonging to five Phyla (Cnidaria, Mollusca, Echinodermata, Arthropoda and Chordata (Tab. 2). In the rhodolith/mixed sediment, we spotted the presence of two pennatulaceans *Pennatula rubra* and *Ptereoides spinosum* (Fig. 4a-b), more often associated with muddy seabottom (e.g., Chimienti et al., 2018a, b). One individual of the anemone *Peachia cylindrica* (Fig. 4c) and one colony of the alcyonacean *Nidalia studeri* (Fig. 4a) were also detected. Identified molluscs include a cluster of the oyster *Neopycnodonte cochlear* (Fig. 4d), the filter-feeder scallop cf. *Aequipecten opercularis* (Fig. 4c) and the cnidarian-ectoparasitic gastropod *Acirsa subdecussata* at the base of the *P. spinosum* (Fig. 4b).

In terms of abundance, echinoids predominate (Figs. 3a, e-f; 4a, c, e-f) with the dominance of *Stylocidaris affinis* (663 individuals) and *S. purpureus* (55 individuals). Aggregations of the grazing echinoid *S. affinis* (Figs. 3a, 4e), were imaged atop rhodoliths whilst presumably feeding upon the algae.

Noticeably, the decapod *Inachus dorsettensis* settled over a *S. purpureus*, possibly taking advantage of the digested sediment (Fig. 4f). Observed fishes were a juvenile *Serranus cabrilla* and *Chelidonichthys* cf. *lastoviza*.

3.2 Seabed samples

The study area is characterized by rhodoliths (gravel to pebble fraction) laying on, or mosaicking with biogenic gravelly sand (Fig. 3a-d-g). Main morphotype is PR (Fig. 5) with medium size of long axis of 1.1 cm and max 3.4 cm (Fig. 5f-g). Sneed and Folk's (1958) pebble shape diagram showed a majority of ellipsoidal to discoidal shapes (Fig. 5e). The size range is between 0.3 and 1.8 cm (Fig. 5f-g). Rhodoliths are multispecific, with an encrusting-warty concentric and regular development around the nucleus and no protuberance on the surface

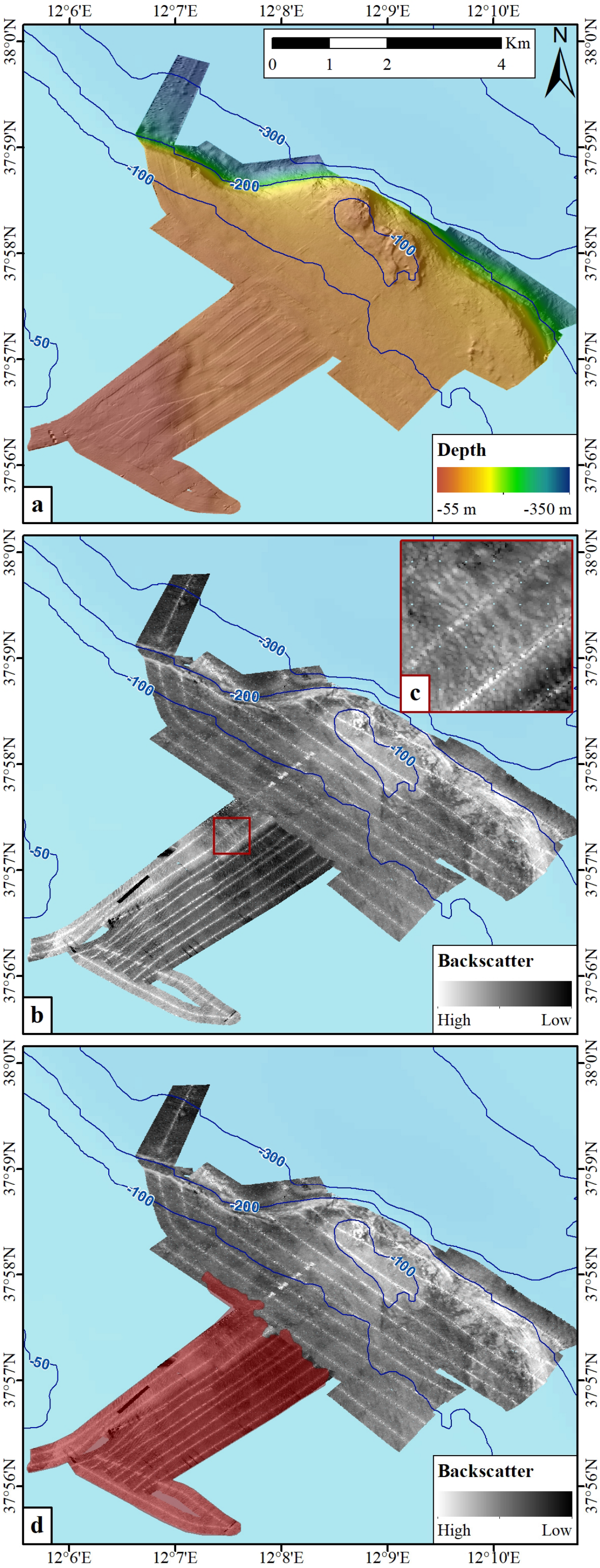

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Fig. 2 - Acoustics dataset resulting from multibeam data processing: a) Bathymetric map of the surveyed area. b) Backscatter photomosaic of the surveyed area with c) magnification that shows the composite texture of high and low signal bands associated with RB. d) Red polygon on the backscatter model indicates the mapping of RB distribution in the area.

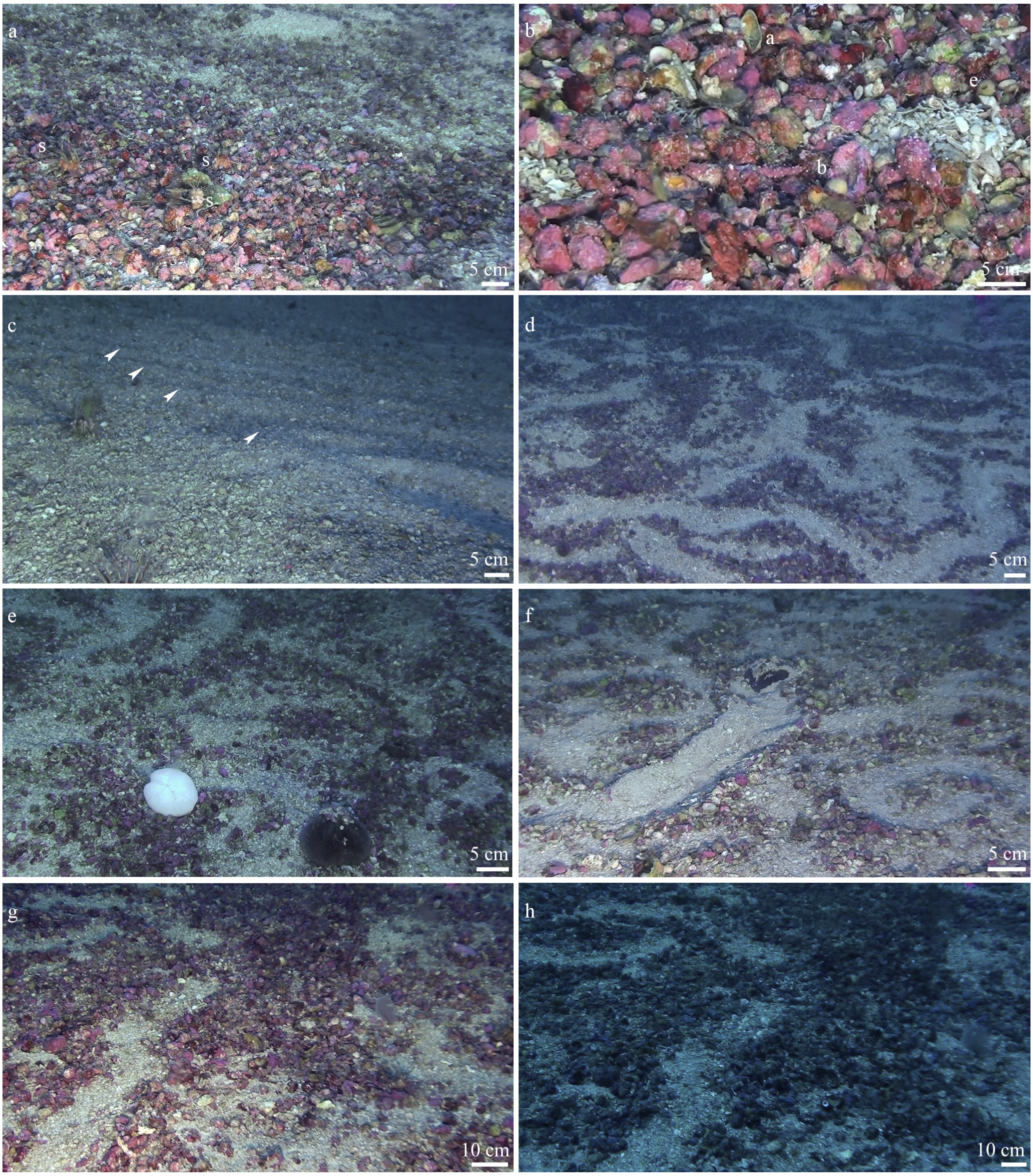


Fig. 3 - Some of the main features of the studied RB. a) Area with high coverage of living RB with *Stylocidaris affinis* (s). b) A detail of living rhodoliths with the indication of a =*Arca tetragona*; b =bivalve entirely covered by calcareous algae; e =juvenile dead specimen of *S. affinis*. c) Ripples (white arrows) identified on biogenic gravelly sand mosaicking live rhodoliths. d) The complex pattern of seabed forms and bioturbation traces by *Spatangus purpureus*. e) Motion traces of *S. purpureus*. f) *S. purpureus* partially digging into sediments. g-h) Direct irradiance measurement during the MS16-197 ROV dive (02/08/2016, 9:30 AM): the light have been turn on (g) and off (h) in the same area to test the natural lighting on the seafloor.

Phylum	Class	Order	Family	Species	N/1 km
Cnidaria	Anthozoa	Alcyonacea	Nidaliidae	*Nidalia studeri* (Koch, 1891)	1
		Actiniaria	Hormathiidae	*Calliactis parasitica* (Couch, 1842)	1
		Pennatulacea	Pennatulidae	*Pennatula rubra* (Ellis, 1761)	14
				Pteroeides spinosum (Ellis, 1764)	26
		Actiniaria	Haloclavidae	*Peachia cylindrica* (Reid, 1848)	1
Mollusca	Bivalvia	Pectinida	Pectinidae	*Aequipecten* cf. *opercularis* (Linnaeus, 1758)	1
Echinodermata	Crinoidea	Comatulida	Antedonidae	*Antedon mediterranea* (Lamarck, 1816)	2
	Asteroidea	Paxillosida	Astropectinidae	*Astropecten irregularis* (Pennant, 1777)	1
	Echinoidea	Cidaroida	Cidaridae	*Stylocidaris affinis* (Philippi, 1845)	663
	Echinoidea	Camarodonta	Toxopneustidae	*Sphaerechinus granularis* (Lamarck, 1816)	1
	Echinoidea	Spatangoida	Spatangidae	*Spatangus purpureus* O.F. Müller, 1776	55
	Holothuroidea	Synallactida	Stichopodidae	*Parastichopus regalis* (Cuvier, 1817)	1
Arthropoda	Malacostraca	Decapoda	Inachidae	*Inachus dorsettensis* (Pennant, 1777)	1
Chordata	Actinopterygii	Perciformes	Serranidae	*Serranus cabrilla* (Linnaeus, 1758)	1
			Triglidae	*Chelidonichthys* cf. *lastoviza* (Bonnaterre, 1788)	2

Tab. 2 - List of the megafauna associated with the studied RB.

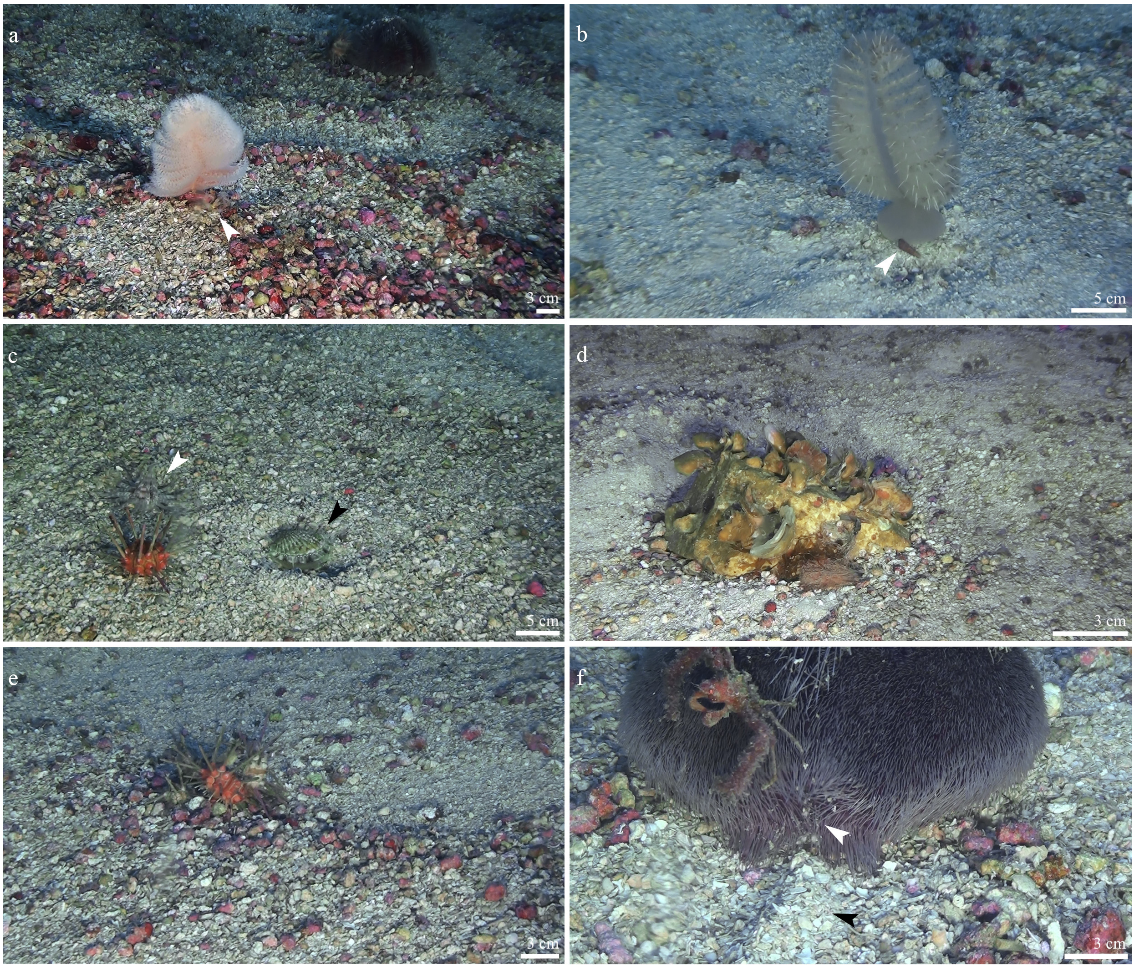


Fig. 4 - Megafauna observed during the ROV MS16-197 dive on the studied RB. a) *Pennatula rubra* inhabiting coarse biogenic sediment, white arrow marks the alcyonacean *Nidalia studeri*, note the echinoderms *Spatangus purpureus* and *Stylocidaris affinis* in the background.. b) A specimen of the relatively abundant *Ptereoides spinosum* here parasitized by the cnidarian-ectoparasite *Arcisa subdecussata* (arrow). c) Medium-coarse biogenic sediment characterized by the *S. affinis* in the foreground, the sea anemone *Peachia cylindrica* (white arrow) and the scallop cf. *Aequipecten opercularis* (black arrow). d) Cluster of the oyster *Neopycnodonte cochlear*. e) Aggregation of *St. affinis* feeding on living red algae. f) The decapod *Inachus dorsettensis* (white arrow) settled over the common echinoderm *S. purpureus* possibly feeding digested sediment (black arrow).

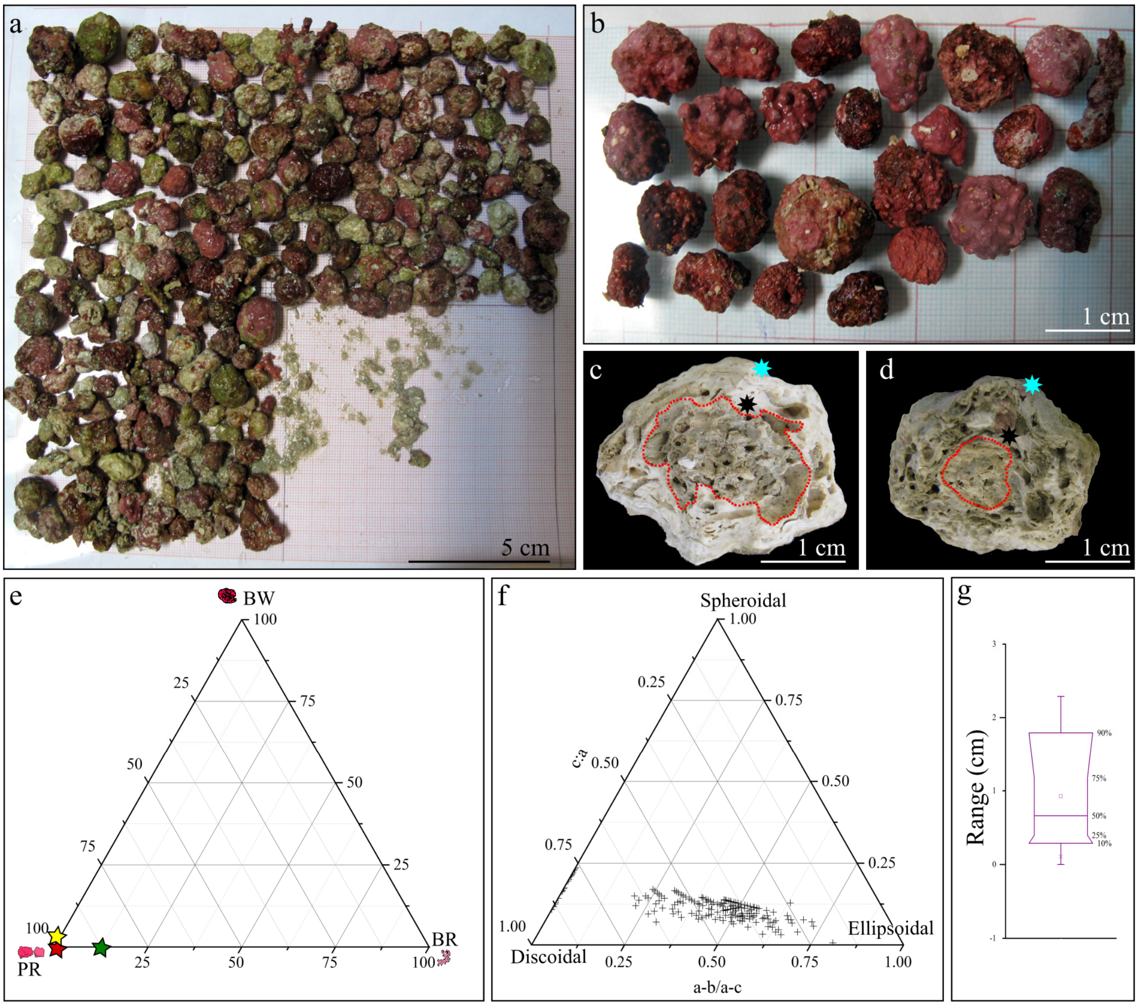


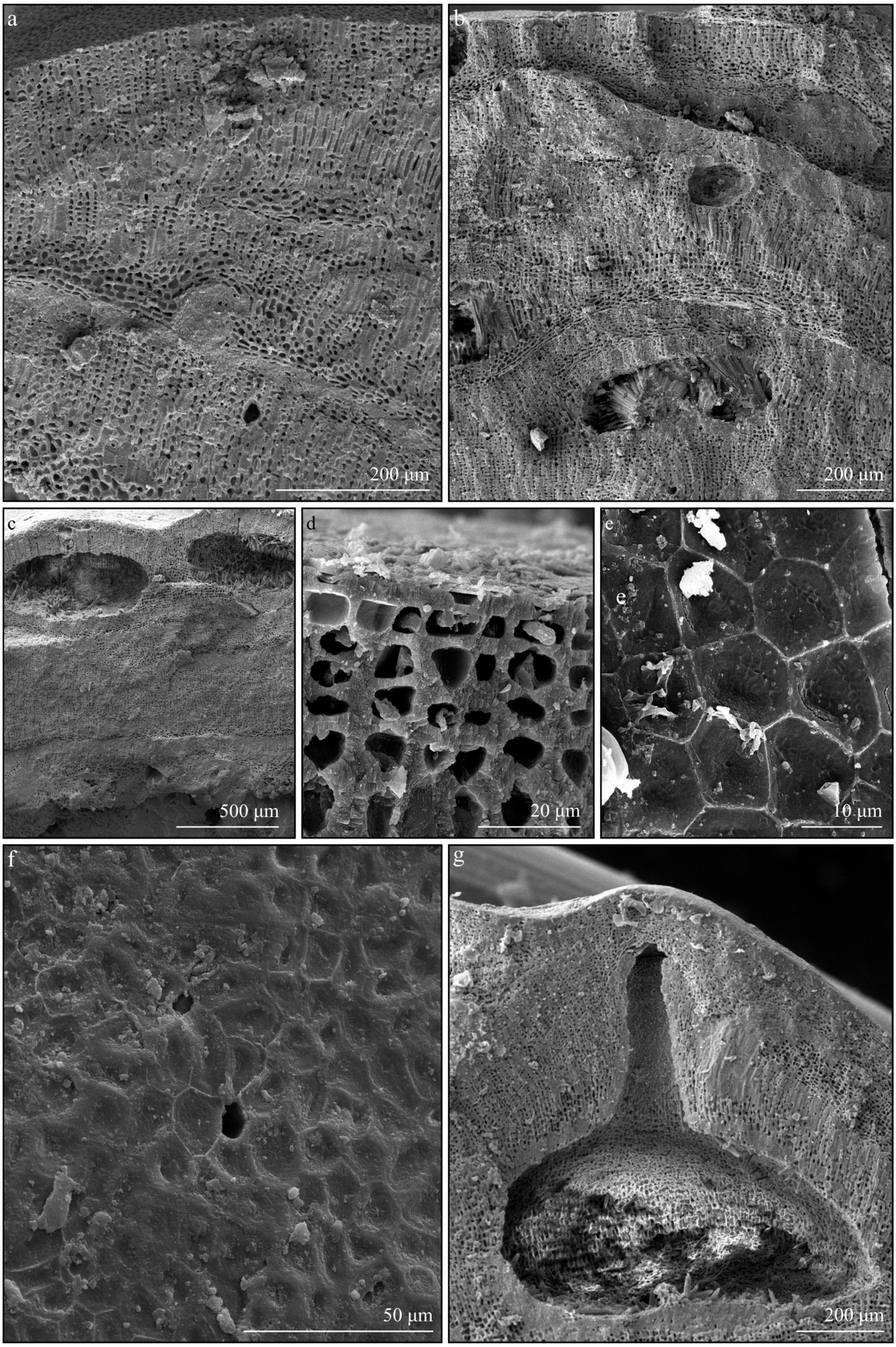
Fig. 5 - Detail on collected rhodoliths and graphic analyses of their morphology, shape and size. a) Collected rhodoliths from sample MS16-201. b) A detail of live rhodoliths collected from sample MS16-201; c-d) Rhodoliths with nucleus of c) biogenic sand/mud or d) old algal nodule. Red dotted contours indicate the nucleus. Stars indicate the point of picking of material for the AMS dating: black for inner samples, light blue for outer samples. e) Ternary plot of the main morphotypes. Yellow star = MS16-200, green star = MS16-201, red star = MS16-202. BW=boxwork, PR=pralines, BR=branches. f) Ternary plot of the shape based on measurements of long (a), intermediate (b) and short (c) axes as described in Sneed and Folk (1958). Black crosses indicates all the measured rhodoliths. g) Box plot showing size range of rhodoliths based on measurements using the volume of an ellipsoid as described in Bosence (1976).

(Fig.5a-d). The nucleus of 20 rhodoliths was formed by old calcareous nodules (n =11) (Fig. 5d), biogenic sand-mud (n =7) (Fig. 5c), and terrigenous fragments (n =2). The inner structure resulted very compact (Figs. 5c-d, 6a-b), with dominance of encrusting calcareous algae, very few voids or obvious evidence of bio-erosion, with the exception of one sample showing also encrusting bryozoans. The calcareous nodules at the nucleus are easily distinctive because of their porous structure, a poor conservation status with bio-erosion traces, and a yellowish to dark gray color (Fig. 5d). SEM confirms that the inners structure is highly compact (Fig. 6a, b). Identified calcareous algae species of the external live cover are, in order of abundance, *Lithothamnion* spp. (Fig. 6c-e), *Neogoniolithon brassica-florida* (Harvey) Setchell & L.R.Mason 1943 (Fig. 6f), *Lithothamnion* cf. *minervae* Basso 1995 (Fig. 6d), *Lithothamnion valens* Foslie (1909) and *Phymatolithon lenormandii* (Areschoug) W.H.Adey 1966. The algal association close to the nuclei contains once again *Lithothamnion* spp., and very rare *Lithophyllum* sp.

3.2.1 Mollusk thanatocoenosis

A total of 74 species among bivalves and gastropods have been identified at the species level (Fig. 3). Conservative index (Tab. 3) corresponds often to 3 or 4, therefore the thanatocoenosis can be considered as autochthons.

The mollusk thanatocoenosis is by large enriched (n =20) in shells indicative of species inhabiting coarse mobile bottoms (pss, gravel, shelly bottom, stone) (Tab. 3). Numerous taxa (n =11) are typically distributed in the


a
200 µm
b
200 µm
c
500 µm
d
20 µm
e
e
10 µm
f
50 µm
g
200 µm

circalittoral zone, mostly linked to Coastal Detritic (DC), Coralligenous (C), Muddy Coastal Detritic (DL), and Deep Mud (VP) biocoenoses (Pérès & Picard, 1964; Pérès, 1982). Among them: exclusive DC *Turritella triplicata*, *Melanella polita*; preferential DC: *Arca tetragona*; preferential C *Muricopsis cristata*; C: *Marshallora adversa*, *Cerithiopsis turbercularis*; exclusive DL *Astarte sulcata*; exclusive VP: *Limatula subauriculata*(Tab. 3).

Rare occurrences reports of species linked to strictly infralittoral biocoenoses are recorded (AP: *Pusia savignyi*; AP/HP: *Calliostoma* cf. *laugieri*) with respectively only one and three specimens. *Bittium reticulatum*, reported as indicative of AP/HP, although abundant, has to be considered a species with a large ecological distribution, so less significative.

3.4 AMS ^{14}C dating

Three selected rhodoliths gave six reliable data (Tab. 4). Ages of the inner part range between 2334 BP (MS16-201-17i) and 1997 BP (MS16-201-15i). Ages at the surface of rhodoliths (outer) range between 101 BP (MS16-201-17o) and modern (MS16-201-15o). The thickness of algal thalli from the nucleus to the outer surface is at least 1 cm (Fig. 5 c-d) Therefore, calculated growth-rate corresponds to 0.004 mm/yr.

4. DISCUSSION

The present study focused upon an area of ca. 7 km^2 (Fig. 2d), in the Egadi Archipelago, around the southeastern part of Marettimo Island. Live rhodoliths spread on such area achieving a live cover up to 95% in a bathymetric interval between 70-95 m (circalittoral zone) (Figs. 3, 5). Following Steller et al. (2003), this habitat can be conveniently referred to as ‘RB’. High cover of live rhodoliths alternates with patches of biogenic gravelly sand characterized by sparse live rhodoliths (<10%) (Fig. 3c). These patches display a lateral continuity <200 m, therefore this habitat is as a whole and single RB (Peña & Barbara, 2008) (Fig. 2d). The Marettimo RB compares well with analog situations in other sites of the Mediterranean Sea, although it is deeper than the usual bathymetric range of 30-75 m (Basso et al., 2017). Within the Coastal Detritic biocoenosis (Pérès & Picard, 1964; Pérès, 1982), the pralines facies has been described as developing on a mixed substrate of biogenic sand and gravel hosting an invertebrate association characteristic of several other circalittoral biocoenoses. Our data corresponds to the pralines facies of Pérès and Picard (1964), although the external morphology of our rhodoliths is encrusting and not protuberant (Fig. 5a), contrarily to those originally described by the authors, and later confirmed by others (among others: Basso, 1998; Toscano et al., 2006; Sciberras et al., 2009; Sañé et al., 2016).

4.1 Bottom currents and sedimentary structures associated to Marettimo RB

The backscatter signal appeared distinctly high at the occurrence of rhodoliths (Fig. 2b-c). It is consistently associated with continuous live beds (Bracchi et al., 2011; Micallef et al., 2012; Savini et al., 2012; Sañé et al., 2016).

Moreover, identified backscatter texture (alternated bands of high and low backscatter) (Fig. 2c) corresponds to the occurrence of megaripples on the seafloor, as observed on ROV video suggesting the occurrence of under bottom currents. In the Mediterranean Sea, offshore sandy-gravelly dunes have been observed in deeper areas (150-300 m) of the Aegean Sea and in the Messina Strait (Sicily) (Lykousis, 2001; Santoro et al., 2002). Such dunes have been related to strong current flows caused by water mass circulation or local tides (Lykousis, 2001; Santoro et al., 2002). Lo Iacono & Guillén (2008) have described coarse (gravelly and pebbly) dunes and sorted bedforms on the inner continental shelf of Marettimo Island. These last have been reported SE of Marettimo Island, in an area characterized by the same backscatter texture (high and low bands), but shallower, between 10 and 50 m of water deep, on a shelf with slope value of 2.5° degree. They interpreted them as the result of the effect of along-shelf current as described in other sites (Murray & Thieler, 2004; Coco et al., 2007).

Current velocity required for the entrainment of coarse sediments as the ones collected in the studied area, SE of Marettimo Island, corresponds to a near-bottom mean-current of ca. 0.8 m/s on the NW, as calculated for Mediterranean continental shelf during strong storms (Palanques et al., 2002; Guillén et al., 2006). According to the bedform-existence diagram (D50 vs mean current velocity) defined by Southard and Boguchwal (1990) and applied by Lo Iacono and Guillén (2008) on the Marettimo shelf sediments, a current of at least 0.4 m/s is required for the entrainment of sand-gravel, a grain fraction that corresponds to the sediments associated with live rhodoliths. Moreover, we have to consider the occurrence also of rhodoliths (pebble-sized): consequently, the needed velocity ranges between 0.4 and 1 m/s. Unfortunately, we collected measures of the bottom currents (0.09 m/s), only for few hours, and this value does not justify the occurrence of megaripples that we have observed by ROV analysis. Further measurements will detail better the hydrodynamic regime of the area and explain the occurrence of such bedforms.

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Fig. 6 - SEM images of the inner structure of rhodolith and some examples of the diagnostic characters for the identified calcareous algae species: a-b) the inner compact structure of rhodoliths, with superimposed layers of algal thalli, and no evident signs of bioerosion; c) tetrasporangial conceptacles, *Lithothamnion* sp.; d) epithallial flared cells in longitudinal section, *Lithothamnion* cf *minervae*; e) epithallial flared cells in surface view, *Lithothamnion* sp.; f) epithallial cells in surficial view: rosette cells with the opening of the porocanal of a multiporate conceptacle, *Lithothamnion valens*; g) uniporate conceptacle, *Neogoniolithon brassica-florida.*

	Sample						
	MS16-200		MS16-201		MS16-202		**Ecology**
	a	c	a	c	a	c	
BIVALVIA							
Arca tetragona Poli, 1795	6	3	34	4	11	4	pref DC, misto
Asperarca secreta La Perna, 1998	8	3	10	4	5	4	
Bathyarca philippiana (Nyst, 1848)	1	4			2	3	
Limopsis friedbergi Gilbert and Van de Poel, 1965	1	4	1	3			
Crenella arenaria Monterosato, 1875			2	3	1	3	
Palliolum striatum (O.F. Müller, 1776)			2	3			on coarse bottom, misto
Parvamussium fenestratum (Forbes, 1844)			1	3			
Aequipecten sp.			1	3			
Similipecten similis (Laskey, 1811)	5	4	1	3	3	2	pss, offshore sand gravel
Heteranomia squamula (Linnaeus, 1758)	12	3	11	3	7	4	offshore, fixed on the substrate
Limatula subauriculata (Montagu, 1808)			2	3	3	3	exl VP
Astarte sulcata (da Costa, 1778)	2	4	4	4			exl DL, gravel
Gonilia calliglypta (Dall, 1803)	1	3			2	4	gravel
Digitaria digitaria (Linnaeus, 1758)	4	4	17	4	10	4	sand, gravel
Venericardia sp.			1	2			
Coripia corbis (Philippi, 1836)	2	4	22	3	20	4	lre
Parvicardium scabrum (Philippi, 1844)					1	3	
Achantocardia sp.					2	3	
Peronidia albicans (Gmelin, 1791)			1	3			sand
Tellina sp.					1	2	
Timoclea ovata (Pennant, 1777)	19	4	21	4	29	4	misto
Neolepton sulcatum (Jeffreys, 1859)	12	4	6	4	11	3	
GASTROPODA							
Scissurella costata d'Orbigny, 1824	1	3			1	4	
Anatoma crispata (Fleming, 1828)	3	3					stone, shelly bottom
Emarginula rosea Bell, 1824	1	3					DC/C
Diodora sp.							
Parviturbo fenestratus (Chaster, 1896)					1	4	
Jujubinus montagui (Wood, 1828)			4	3			offshore, gravel
Jujubinus striatus (Linnaeus, 1758)	3	2	7	3	7	3	sspr, offshore on seeweeds and small stone
Gibbula cf. *guttadauri* (Philippi, 1836)	1	3	2	3	5	3	sspr
Gibbula sp. 1	2	3					
Gibbula sp. 2					3	3	
Calliostoma cf. *laugieri* (Payraudeau, 1803)			3	3			AP/HP
Calliostoma militare Ihring, 1907	6	4	12	4	9	3	
Bolma rugosa (Linnaeus, 1767)			4	4	1	3	C/DC
Homalopoma sanguineum (Linnaeus, 1758)	2	2	3	3			HP/C
Addisonia excentrica (Tiberi, 1855)	2	3	3	3	1	4	offshore, hard substrate
Pusillina incospicua (Alder, 1844)	1	4			2	4	
Pusillina sp.							
Alvania cimex (Linnaeus, 1758)	1	3	5	4	1	4	
Alvania hispidula (Monterosato, 1884)	2	4	12	4			
Alvania punctura (Montagu, 1803)	1	4	3	2	3	4	infra-circa
Alvania rudis (Philippi, 1844)	1	4					
'Vermetus' sp. 1	1	3					
'Vermetus' sp. 2					1	3	
Setia sp.							
Turritella triplicata (Brocchi, 1814)	10	3	18	3	13	2	exl DC
Bittium reticulatum (da Costa, 1778)	33	4	62	4	34	4	AP/HP, lre
Cerithidium submamillatum (De Reyneval and Pozi, 1854)	3	4	5	4	10	3	circa
Cerithiopsis tubercularis (Montagu, 1803)					5	4	C
Retilaskeia horrida (Monterosato, 1874)	3	3	1	2	1	2	
Marshallora adversa (Montagu, 1803)			4	2	5	3	C
Melanella polita (Linnaeus, 1758)	2	4	1	4	1	4	exl DC
Capulus ungaricus (Linnaeus, 1758)			1	4			infra, pss
Lamellaria latens (O.F. Müller, 1776)			1	4			
Euspira nitida (Donovan, 1804)	3	4					lre
Cochlis vittata (Gmelin, 1791)			1	4			sspr
Nassarius sp.			1	4			
Muricopsis cristata (Brocchi, 1814)	1	4					pref C
Murexsul aradasii (Monterosato in Poinier, 1883)			6	4			
Muricidae sp.			1	3			
Coralliophila sp.			3	3			
Pusia savignyi (Payraudeau, 1826)					1	4	exl AP
Mitrella minor (Scacchi, 1836)	3	2					
Columbella sp.			1	2			
Nassarius sp.					1	2	
Fusinus sp.			1	2			
Episcomitra cornicula (Linnaeus, 1758)			1	3			infra
Mitra sp.			1	3			
Comarmondia gracilis (Montagu, 1803)	1	2					infra-circa
Granulina mediterranea Landau, La Perna and Marquet, 2006	4	4	2	4	1	4	
Gibberula jansseni (Van Aartsen, Menkhorst and Gittembers, 1984)	1	4	1	4	2	3	
Gibberula sp.1			3	4			
Gibberula sp.2					1	4	
Mangelia sp.			1	3			

Sample Code	^{14}C age BP	±1σ	Corrected ^{14}C age BP	^{14}C age calibrate	Calibration
MS16-201-14o	283	22	-117	1955-1956 AD 2013-2016 AD	CaliBomb
MS16-201-14i	2559	23	2159	361-196 BC	Marine Intcal2013
MS16-201-15o	-48	22	-448	1956-1957 AD 2004-2010 AD	CaliBomb
MS16-201-15i	2397	23	1997	164 cal BC-6 AD	Marine Intcal2013
MS16-201-17o	501	22	101	1714-1906 cal AD	Marine Intcal2013
MS16-201-17i	2734	24	2334	621-387 cal BC	Marine Intcal2013

Tab. 4 - Results of AMS radiocarbon dating. Sample Code describes the position of sampling: i (inside) or o (outside) indicates the sampling point respectively from the surface or close to the nucleus. The correction for reservoir age is 400 ^{14}C years.

4.2 Bottom currents and rhodolith morphotypes

Bottom currents are considered as one of the most important variables governing rhodolith occurrence and development (Tab. 1). Moderate energy has been identified as the best condition (Ryan et al., 2007) although there is no consensus.

The Marettimo bed contains very small pralines, ellipsoidal to discoidal, without protuberances, and with a very high live cover of the seafloor. The inner structure revealed that encrusting calcareous algae dominated the framework, and they developed encrusting-warty, concentric, very compact structure, with few voids. Therefore, we can assess that moderate current energy is present, although the main rhodolith features do not fit the models reported in Table 1. The modern maerl bed of the Maltese Archipelago (Sciberras et al., 2003), especially in terms of rhodolith morphotype, represents a similar setting although pralines are never dominant and occur at shallower depths. In term of size, the studied rhodoliths are very small as expected following some authors (Tab. 1).

4.3 Rhodolith growth-rate and the inception of Marettimo RB

Since calcareous algae growth-rate is typically very low (up to 1 mm/yr; Sartoretto et al., 1996; Canals & Ballesteros, 1997; Martin & Gattuso, 2009; Basso, 2012), the formation of RBs may imply a long time. Steller et al. (2009) estimated that a rhodolith 3-8 cm in diameter in the Gulf of California would remain on the seabed from years to decades. Our live rhodoliths represent only the surficial veneer of present-day seafloor, with a thickness of maximum 3.4 cm. AMS dating demonstrated that they started to develop between 2334 BP and 1997 BP (Tab. 4). Therefore, depth and sedimentary regime at the inception stage of RB formation is assumed to have been the same as the present. We may hypothesize that the generally warmer condition under the Roman Climate Optimum somehow favored the development of calcareous algae. In this respect, warmer periods correspond to calcareous algae spread since the Neogene (Halfar & Mutti, 2005).

The growth-rate of 0.004 mm/yr is a mean value obtained by combining AMS dating and the rhodolith thickness. This rate is consistent with data reported in the pertinent literature (Sartoretto et al., 1996; Canals & Ballesteros, 1997; Martin & Gattuso, 2009; Basso, 2012). Interestingly, it corresponds to less than one layer of cells per year. Considering that a one-cell layer is the minimum discrete unit of thickening, the implication is that the growth of encrusting algae is not continuous during time. Despite this low value, the inner structure is very dense and macroscopically voidless, with superimposed layers of calcareous algae. Sediment associated with rhodoliths is only gravelly sand.

All these features are consistent and suggest that the Marettimo bed developed under bottom current responsible for their periodical overturning and maintenance in life by preserving from burial and fouling by encrusting organisms as bryozoans. Moreover, the water transparency and the absence of turbidity may favor calcareous algae that resist under such oligophotic conditions, with respect to other common organisms in such deep environment (i.e. bryozoans).

The combined evidence concurs in the interpretation of the Marettimo case study as an example of a resilient habitat at the millennial temporal scale.

4.4 The inner structure of Marettimo rhodoliths

The inner core of the rhodoliths is prevalently bioclastic, with a predominance of old algal nodules as nuclei. Other nuclei, such as terrigenous particles, are far less common. Similar reports, with more than one generation of algal framework, have been found in the rhodoliths of 1) the Peregrino oil field in the Campos Basin (Brazil) at approximately 100 m water deep (Tâmega et al., 2014), 2) the Pliocene of Cabo de Rocha (SW Spain) (Aguirre et al., 1993; Aguirre & Braga,

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Tab. 3 - List of identified mollusks in the studied samples. a is for abundance, c for conservation status sensu Basso and Corselli (2007). Ecology: infra = infralittoral zone, circa = circalittoral zone, exl = exclusive, pref = preferential, AP = Photophylous Algae biocoenosis; HP = Posidonia Meadow biocoenosis, C = Coralligenous biocoenosis; DC = Costal Detritic biocoenosis, DL = Muddy Costal Detritic biocoenosis, VP = Deep Mud biocoenosis, pss = small solid substrate, lre = large ecological distribution ; sspr = without a specific ecological indication; misto = mistophylous.

2012), and 3) the Miocene of Southern Apennines (Checconi et al., 2010). Further investigations will focus on this polyphasic aspect. In the studied rhodoliths, the form of old algal nodules drove the resulting shape. In other cases, nucleus is formed by biogenic sand and mud entrapped by encrusting calcareous algae. We can imagine that encrusting laminar thalli started developing, and, overturned by currents/benthic fauna, developed in various directions, up to entrapping material. Therefore, the developing of the calcareous algae themselves built the nucleus.

We did not identify a change in the bioengineers, with *Lithothamnion* spp. dominating both the external and the internal framework. *Lithothamnion* Heydrich, 1897, is commonly recognized as a typical deep-water genus (Adey & Adey, 1973; Henriques et al., 2012; Aguirre et al., 2017), and its dominance in the RB under scrutiny is consistent with the bathymetric interval.

4.5 Marettimo rhodolith and associated megafauna

RB situations are known to foster high biodiversity levels (e.g., Cabioch, 1969; Freiwald & Henrich, 1994; Teichert, 2014; Riosmena-Rodríguez, 2017) and to be habitat to a variety of epifaunal and infaunal organisms, many of which skeletonized and, therefore, capable to contribute durable particles to sediments. Our reports confirm the high biodiversity associated to the occurrence of a RB. Moreover, echinoids (*S. affinis* and *S. purpureus*) are really abundant (Tab. 2) and they are responsible of intensive reworking of sediments and rhodoliths (Fig. 3 d-e-f), thus confirming that bioturbation is fundamental for the overturning of rhodoliths and their survival in deep environment (Marrack, 1999).

Among skeletonized organisms, mollusks are one component commonly associated with these rhodalgal situations (e.g., Freiwald & Henrich, 1994; Basso & Brusoni, 2004; Jackson et al., 2004; Castriota et al., 2005; Sciberras et al., 2009), and, in fact, the prevalently biogenic sediment type at the study site contains a substantial mollusk skeletal fraction. Because of their abundance, relative geological durability and ecological value (cf. Pérès & Picard, 1964; Pérès, 1982), we examined the taxonomic composition of the sediment and results are reported in Table 3. The thanatocoenosis contains taxa reflecting the ecological heterogeneity of the seabottom. In fact, the fauna appears by large enriched in species (e.g., *Emarginula rosea*, *Jujubinus montagui*, *Homalopoma sanguineum*, *T. triplicata*, *A. tetragona, Gonilia calliglypta*) consistent with circalittoral coarse sediment and detritic bottoms (including RBs) which predominate at the site, plus many others likely derived from coralligenous (e.g., *M. cristata*, *Murexsul aradasii*), and muddy/mixed situations.

4.6 Marettimo RB and irradiance

Penetration of sunlight (irradiance) and its attenuation is a major forcer governing photosynthesis and the consequent macroalgal growth (Saulquin et al., 2013).

Calcareous algae are able to develop in dim-light conditions (Ballesteros, 2006). Although not quantified at this stage, the persistence of a sufficient sunlight illumination on the bottom at the study site has been qualitatively ascertained by the ROV. Given the taxonomic uniformity observable on the RB, such light conditions prevailed at the site throughout the Holocene time span recorded by the rhodoliths. The prime value of the habitat recognized at the Egadi Archipelago stays with its peculiarity to be a rare example of deep-water RB formed under a very low irradiance extending down to the edge of the mesophotic zone. It responds to a peculiar ecological situation on the seabed, likely to be met in areas characterized by a lack of or extremely reduced turbidity that would affect the penetration of sunlight deep in the water column. This may imply the existence of oligotrophic conditions in the water column and minimal terrigenous input. Such paleo-conditions may favor the development of calcareous algae and consequently rhodoliths that makes this recent case study a potential clue to better interpret past situations in the geological record from the Miocene onwards. With respect to the fossil legacy, several outcrops enriched in calcareous algae are, in fact, known since the Neogene, some of which interpretable as RBs. Most published data reveal, however, differences with the deep-water RB here presented in terms of general context and rhodolith morphologies. For instance, Coletti et al. (2016) found small pralines dominated by *Lithothamnion* spp., but the hosting context excludes that they represent a deep-water situation. Yet, many Plio-Pleistocene assemblages enriched in rhodoliths might indeed have been formed under deep-water conditions, but have been insufficiently studied thus far.The Egadi Archipelago case history may therefore serve as a diagnostic model because of its distinctive characteristics.

5. CONCLUSION

A deep-water RB has been mapped between 70 and 95 m SE of Marettimo Island (Egadi Archipelago, Mediterranean Sea). Live rhodoliths cover the seafloor, mosaicking with sand-gravel biogenic-dominate sediments and sculpturing megaripples. Rhodoliths are very small *pralines* (up to 3.4 cm), ellipsoidal to discoidal, *Lithothamnion* spp. dominate the assemblage, with very compact structure and partially polyphasic. The RB is bionomically compatible with the circalittoral zone, although the detailed study of rhodoliths reveal distinctive and unexpected elements (shape, dimension, growth-rate), which makes this RB an exception with respect to rhodolith descriptive models available in literature. Moderate energy at the seafloor, oligophotic condition and enough irradiance maintains in life such RB, and calcareous algae overall other organisms, since the Roman Climate Optimum, dated as the age of its inception. The Marettimo RB might serve as a modern model to assist the identification of similar facies of the Mediterranean Neogene deposits.

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