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CORALLIGENOUS: INSIGHTS FOR A NEW GEOMORPHOLOGICAL DEFINITION

Abstract
Mediterranean marine benthic bionomists refer to Coralligenous (C) de plateau as a circalittoral biocoenosis consisting of a biogenic framework forming a solid substrate settled on an originally mobile substrate. Pérès & Picard (1951) indicated that the true C de plateau develops from the coalescence of rhodoliths, although they already underlined the problem of the identification of its substrate. C de plateau falls into the "bank" category sensu Ballesteros (2006): flat frameworks mainly built over more or less horizontal substrate with lateral continuity. Actually few examples of C de plateau have been documented in literature, and present-day examples of C de plateau are much rarer than originally thought. Large areas along the Apulian coast have been investigated from the coastline down to 100 m water depth in the framework of BIOMAP project aimed at mapping the C habitat. Collected remote data have been ground-truthed by ROV and camera inspections. This large data set allowed the categorization of several morphologic types of C, all falling into the bank category: from smallest type forming isolated columns, to large platforms. Through a systematic analysis carried out on the acoustic data and thanks to the detailed scale of observation (i.e.: from 0.5 m up to tens of meters), a new morphological categorization to describe C frameworks found along the shelf is proposed.

Key-words: Coralligenous, Mediterranean Sea, remote sensing, geomorphology, category

Introduction
In the framework of Mediterranean marine benthic zonation Coralligenous (C) is indicative of a circalittoral biocoenosis consisting of a three dimensional biogenic build up that forms a new solid substrate primarily dominated by coralline algae (Laborel, 1961; Pérès & Picard, 1964; Bellan-Santini *et al.,* 1994; Bressan *et al*., 2001).
Marine bionomists consider the substrate to be a key factor in distinguishing C typologies, although it represents a difficult aspect to investigate. Only recent acoustic-sismic techniques have been applied to determine the type of substrate were the coralligenous develops (Georgiadis *et al*., 2009; Bracchi *et al*., *in press*).
Pérès & Picard (1951) firstly specified C *de plateau*-type as a biogenic framework developed from the coalescence of rhodoliths, even if they underlined the problem of the substrate identification. C *de plateau* was hereafter indicated as the biogenic build-up forming a solid substrate settled on a general originally mobile substrate (Pérès & Picard, 1964). Hard substrate is instead reported for C *d'horizon inférieur de la roche littoral* type. However some authors suggest that C *de plateau* frameworks have probably grown on rocky outcrops (Got & Laubier, 1968; Laborel, 1987).
Moreover C build-ups vary in shape and dimension and their morphological expression have not been exhaustively categorized. From this point of view, two main morphologies have been indicated (Pérès & Picard, 1964; Laborel, 1987; Ballesteros, 2006): 1) banks – flat frameworks with thickness ranging from 0.5 to 4 m mainly built over more or less horizontal substrata, and 2) rims – structures on submarine vertical cliffs or surrounding

the opening of submarine caves, generally located in shallower waters than banks. Nevertheless various definitions, reflecting different building morphologies, are found in the scientific literature: columnar crustose coralline algal build-ups described as heads, blocks patches, or banks (Sarà, 1968), vertical pillar (Di Geronimo *et al*., 2002), horizontal pillar (Sartoretto, 1994), algal reefs (Bosence, 1983), and minute reef aggregation (Georgiadis *et al*., 2009). These definitions all fall into bank category *sensu* Ballesteros (2006), although these terms better express the real geomorphological aspect of C build-ups.

If we try to relate marine bionomists C definitions and morphological definitions, C *de plateau* falls into the bank category, although the horizontal substrate must be represented by mobile substrate to have the C *de plateau* in its genetic definition. C *d'horizon inférieur de la roche littoral* type falls into rim category. Bank growing on hard substrate does not correspond with any bionomic definition.

Apulian coralligenous is known in literature since decades (Sarà 1966; 1968; Parenzan, 1983). Large areas along the Apulian coast have been investigated from the coastline down to 100 m water depth in the framework of BIOMAP project aimed at mapping the C distribution. C is well developed all along the Apulian coasts (BIOMAP Final Report, 2014).

Through a systematic analysis carried out on the acoustic remote data, ground-truthed by video inspections, we documented the highest variability of C morphologies and distribution (preliminary results in Bracchi *et al*., *in press*). All the peculiar morphologic types of Apulian C fall into the bank category. Probably due to the different type of substrate Apulian C build-ups occupy, rarely they can be identified as C *de plateau* in its original definition, but because of the sub-horizontal substrate, they do not correspond with the other definition of marine bionomists (*i.e.*: C *d'horizon inférieur de la roche littoral*). We spotted that present-day available categorizations, both the bionomic one than the morphological one, even though they totally work, should be revised, properly thank to the availability of new data obtained from new acoustic sampling.

Consequently the result of this work is to indicate some examples of the peculiarity of C build-ups in terms of different geomorphological expression they present and associated settled substrate. The aim of this study is to give some indications of which is the best strategy to follow to study these aspects, and to open a discussion about the possibility to develop a more detailed categorization, starting from the known and overall accepted categories.

Materials and methods

We analyzed acoustic data obtained from ship-based research surveys, performed between March 2012 and October 2012 under the framework of the BIOMAP project. Data spanned areas located offshore Puglia coasts, ranging from 5 and 100 m in water depth. The R/V Minerva 1 (property of Sopromar SPA) was used to explore the deepest areas, whereas the boat Calafuria ISSEL (property of CoNISMa) was used to investigate the shallowest ones.

Positional data were provided by a Hemisphere Crescent R-Series dGPS. The BIOMAP project's datum was WGS84 and the projection chosen for navigation and display was UTM fuse 33.

The remote technical devices we used included two models of dual frequency Side Scan Sonar (SSS) (the 100/500 kHz Klein3000 system and the 100-400 kHz EdgeTech 4- 2000), two different Multi-Beam (MB) Echosounders (the 50kHz Reson Seabat 8160

for the deepest areas, and the 455 kHz Reson Seabat 8125 for the shallowest ones) and, only during the BIOMAP II cruise (May 2012), the GeoAcoustic (3/7 kHz) chirp sonar to collect seismic-stratigraphic data.
Water sound velocity was obtained using the Seabird SBE 21 device.
SSS operated at 200 m range setting and we reached 50% of overlap between adjacent lines. SSS data processing, performed using Triton ISIS (Triton Elics Information-TEI) suite software packages, produced geo-referenced gray-tone acoustic images of the seafloor at 0.5 m resolution. Only for SSS data acquired during the survey on the R/V Minerva 1, the track of the *fish* was computed using the position of the ship, the length of the tow cable, and the elevation of the fish above the sea floor. On the Issel boat the SSS *fish* was anchored on a vertical pole, consequently a simple fixed offset (from the dGPS antenna position) was used to obtain georeferenced SSS images.
Acquired MB data did not cover all the investigated areas with 100% of coverage, but provided high-resolution bathymetry of the surveyed seafloor (*i.e.* a 2 m cell size at 100 m in wd). The digital terrain model (DTM), provided by the MB survey, was used for the final georectification of the processed SSS mosaic obtained from the R/V Minerva 1 surveys.
Seismic-stratigraphic data have been processed using Triton SB Interpreter (TEI).
To ground-truth the acoustic remote data, video inspections have been collected during all the oceanographic cruises, using a ROV system (Prometeo) and a subaqueous trawled camera (Quasi-Stellar © Elettronica Enne – this latter was used only during the Issel surveys).
All data were integrated and analyzed using GIS-based procedures (ArcGIS TM software).
In our present work, two sectors along the Apulian coast (one in the Adriatic Sea, between Otranto and Santa Maria di Leuca and one in the Ionian Sea, in the area of Ugento coast) have been selected to illustrate the high geomorphological variability of the Apulian C build-ups.

Results

The collected video data allowed identifying different morphologies of C build-ups as positive relief on the seafloor, and verify which type of acoustic response we obtained in correspondence of such frameworks.
On SSS mosaic C build-ups generally show a pattern of intermediate to very high backscatter. Two typical textures have been identified: 1) continuous spotted/spackled intermediate to high backscatter, or 2) distinct circular features characterized by high backscatter. These textures are strongly different from adjacent ones, characterized by intermediate to low backscatter.
MB data allowed us to sketch the most relevant morphometric features of C outcrops. C provided seafloor relief varying between 0.5 and 4 m. The elevated structures show steep flanks and are often sub-vertical with sharp boundaries. The lateral continuity of C structures marks a very variable morphological feature.
Texture 1 is generally associated to C build ups with metrical lateral continuity, whereas texture 2 shows C build ups that are generally characterized by constrained lateral continuity, from 0.5 to 4 m.
On MB data the surface of C structures are not homogeneous and show a high level of roughness. From a geomorphological point of view we can distinguish two end-members within the variety of the investigated C outcrops: from 1) isolated squat columns

randomly scattered to 2) large ridges with metric lateral continuity and variable geometry (from circular to ellipsoidal or elongated structures alternated to channels yielding a sort of ridge/channel pattern). However, several intermediate expressions have been reported where blocks begin to coalesce although their distinct shape is still identifiable.
Chirp profiles crossing the identified C build-ups have been selected to investigate the substrate. Echo types associated to C build-ups are 1A or IIB-2 of Damuth and Hayes (1977). This is due to the nature of C build-ups that are hard frameworks of biogenic origin able to create a rugged morphology, producing an irregular physiography on the seafloor profile. These echo-types have no apparent sub-bottom reflector, and no internal stratigraphic structures are traceable. Consequently it is not possible to distinctly identify/outline any type of substrate. In addition C build-ups often depicted a topographic relief, from 3 to 12 ms (i.e.: from 1 up to 4 m) in height. Where C build-ups are not reported and where a flat seafloor characterized by mobile sediment (as identified on other remote acoustic data or video data) occur, the seismic profiles show a weaker signal, sometimes with the occurrence of a layering pattern.

Discussion and conclusions
According to our results Apulian C build-ups generally grew on more or less sub-horizontal substrate. Consequently they do not correspond with the definition reported by marine bionomists (*i.e.*: C *d'horizon inférieur de la roche littoral*). Moreover, due to the different type of substrate they apparently occupied, rarely they can be definitely identified as C *de plateau* according to its original definition. In addition, all the peculiar and different morphological expressions of the Apulian C fall into the bank category.
Nowadays seafloor mapping techniques allow obtaining large scale high-resolution seafloor images useful for understanding the submarine environment. Properly thank to this scale of observation, we documented the high variability of Apulian C build-ups in term of geometry, dimension, areal distribution and settled substrate.
In this work, we distinghuish different of C build-ups. Considering the first three aspects (geometry, dimension and areal distribution) we reported C build ups forming topographic relief from 0.5 up to 4 m high, with a lateral continuity ranging from 0.5 m up to hundreds of meters and with an areal coverage of several square kilometers, definitely falling into the bank category. Such term (i.e.: *bank*) is evocative of build-ups characterized by lateral continuity. Indeed the definition reports *flat frameworks with thickness ranging from 0.5 to 4 m mainly built over more or less horizontal substrata* (Ballesteros, 2006). Generally Apulian C build-ups are characterized by the same order of thickness, and more or less the same horizontal substrate. The limit lies in the spatial definition of the adjective "flat". Indeed, the ridge structures we identified surely represent flat structures that can be ascribed to this category, but the isolated columns or all the intermediate situations we found from isolated columns to ridge, can be hardly ascribed to bank category, although this is the only existing category we can use to describe such structures.
As a result of the Habitat Directive (92/43/EC), marine bioconstructions, generically indicated as "reefs", have been recognized as marine habitats worth of protection and among Mediterranean marine bioconstructions, C undoubtedly is one of the most important in extension and biodiversity. Acoustic seafloor mapping technique used to investigate the continental shelf, are able to produce images of the seafloor with a suitable scale to properly depict the extension of benthic habitats (Kenny *et al.*, 2003; Savini, 2011). Such remote images are therefore instrumental to fulfill the gaps in the current

scientific knowledge on the different geomorphological expression that C build-ups can show, and to refine the general, but still efficient, definition of bank. Such acoustic devises allow especially measuring the morphometric features of C build-ups, to precisely describe their pattern of distribution and to quantify their areal coverage, without losing the natural variability of C itself.
Seismo-stratigraphic profiles could be useful to investigate another substantial aspect for the definition of C: the substrate. The definition of the substrate should be considered essential to provide a geomorphological definition (which requires also the definition of the genesis of build-ups). Furthermore the substrate represents the key-element to distinguish C bionomic typologies (C *de plateau* or C *d'horizon inférieur de la roche littoral*), although it also represents a difficult aspect to investigate. Even in this case the term *de plateau* is evocative of the C on the continental shelf with more or less horizontal substrate, but actually it represents a very precise definition. Consequently it is not correct to apply this definition in most of the Apulian cases, because of the lack of data or evidence of other type of substrate (non mobile sediment). Actually Apulian C build-ups are often surrounded by soft sediment, although its occurrence does not mean that it serves as substrate for the C build-ups. We cannot exclude the outcropping of hard substrate or the occurrence of relict hard structures that could provide a solid substrate for C development. On chirp sonar profiles, especially in the ones that cross the large ridges, the topographic highs are formed by C build-ups that seem to be grown over an inherited complex morphology, we thus confidently suppose that such highs are not only the result of C development.
The bionomic definitions of C *de plateau* can be instead properly applied to fossil records, where the substrate can be easily distinguishable (Basso *et al*., 2007).
Nevertheless the substrate represents a descriptive aspect that can be directly correlated to different geomorphological expressions. The problem is that it must be conveniently investigated, and this is not an easily aspect to consider because seismo-stratigraphic survey rarely have the necessary sub-metric resolution (under the meter). The solution should be the direct sampling *via* appropriate tools like vibro-corers, but it represents a destructive method not easily applicable to a protected habitat.
Finally we indicated Apulian C build-ups as "C settled along the shelf growing on variable, quite horizontal substrate", encouraging a discussion on the lack of suitable framework of geomorphological definitions for describing and mapping all the types of C outcrops.

Acknowledgments

This study benefited from funding and ship-time through the BIOMAP project (P.O FESR 2007/2013, Puglia Region, Italy). The authors' work also benefited from the RITMARE project funded by the Italian Ministry of University and Research. F. Marchese was funded through a PhD fellowship in Earth Sciences by the Milano-Bicocca University.

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