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Effects of Holocene sea level changes on subtidal palaeoecosystems, southeastern Brazil

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ABSTRACT

Southeastern Brazilian marine coastal deposits provide an excellent opportunity to investigate environmental changes such as sea level and trophic variability during the Holocene period. In this study, we present a sediment record from Arraial do Cabo Bay, Rio de Janeiro State. In order to improve the understanding of the upper subtidal palaeoecosystem evolutionary dynamics of this Bay, we provide a microfacies analysis of Holocene carbonate and mixed siliciclastic-carbonate deposits cropping out today from the supratidal to the subtidal zones. The age-depth model is based on ^{14}C dating and revealed a basal age of ~7000 cal. years BP. In the six distinguished microfacies, the biogenic components are dominated by vermetids and coralline algae. A number of subordinate components are also present, including the microfacies determining thin-shelled bivalves. Fossil vermetids are represented by monospecific clusters of overgrowing *Petaloconchus varians*. Coralline red algae are represented by *Lithophyllum pustulatum*, *Spongites fruticulosus*, *Spongites yendoi*, *Mesophyllum engelharti*, and unidentified geniculate corallines. The microfacies analysis revealed that the substrate of the benthic community in the upper subtidal ecosystem of the Bay changed according to the relative sea level: (1) during the rapid sea transgressive trend it was coarse soft substrate, (2) after the postglacial sea level maximum succeeding a slow decline to present sea level it changed into fine soft substrate. At ~7000 years ago the coarse soft substrate was characterised by fruticose corallines and composed of quartz grains from continental run off input. After the postglacial sea level maximum the highstand elevation along with the established upwelling system brought about a predominantly carbonate deposition. Vermetids and corallines, along with thin-shelled bivalves, thrived in a low sedimentation rate setting and high nutrient level environment.

1. Introduction

Estimation of the overlying depth of water is crucial for the reconstruction of past sea levels from geological deposits. This approach has succeeded in producing archives of Holocene sea level from a variety of Brazilian locations (e.g., Angulo and Suguio, 1995; Angulo and Lessa, 1997; Angulo et al., 1999, 2006; Castro et al., 2009; Dias et al., 2009; Castro et al., 2012, 2014; Suguio et al., 2013; Shennan et al., 2015; Tâmega et al., 2016; Bastos et al., in press).

In this study, we present microfacies and palaeoecological analyses of new data regarding Holocene subtidal sedimentary deposits and investigate the effects of sea level changes on the related benthic communities in the Arraial do Cabo area, off the northern coast of the state of Rio de Janeiro, southeastern Brazil.

Arraial do Cabo has unique features related to its marine environment, being a Marine Extractive Reserve (RESEX-MAR Arraial do Cabo). Within the framework of an ecological survey project carried out in the Arraial do Cabo Bay, several Holocene outcrops of beachrocks, now-a-day cropping out from the supratidal to the subtidal zones, characterised by vermetids and coralline algae were found. Here, we document these deposits to assess the evolutionary dynamics of the upper subtidal palaeoecosystem of the Bay during the last ~7000 years BP. After performing a microfacies analysis of carbonate and mixed siliciclastic-carbonate deposits, the sea level changes were assessed coupling palaeoecological interpretations and estimated ages. This study provides an integrated palaeoecological model highlighting the role of subtidal benthic communities in recording sea level changes.

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Since Delibrias and Laborel (1971), several typologies of biological proxies have been used as sea level indicators. Many palaeoshorelines are characterised by upper subtidal marine fauna/flora, constituting hard-cemented deposits which mark the altitude of formation relative to the sea level. Among these proxies, the colonial vermetid gastropods form dense bioconstructions together with coralline red algae in intertidal and shallow-subtidal water, from depths of 0 to ~6 m (e.g., Chemello and Silenzi, 2011; Aguirre et al., 2014; Spotorno-Oliveira et al., 2015).

Vermetids, whose geographic distribution is restricted to winter temperatures higher than 14 °C (e.g., Chemello and Silenzi, 2011), are characterised by a high phenotypic adaptation that makes them excellent organisms to withstand high hydraulic energy in shallow-water sedimentary deposits. They form bioconstructions referred to as vermetid reefs, trottoires or corniche from tropical to warm-temperate sea waters (e.g., Bosence, 1985a). These formations are highly diversified being a refuge for many invertebrates (Morse, 1992; Hall-Spencer, 1998; Milazzo et al., 2014).

As a result of the vermetid wide geographical distribution, their continuous growth, the possibility of dating the fossil specimens using accelerator mass spectrometry (AMS) ^{14}C, and their bathymetrical distribution generally restricted to a very narrow belt, vermetids are of great importance in palaeoenvironmental reconstructions, being utilized as fossil biological sea level indicators as well as to estimate tectonic uplift of land (Laborel, 1986; Laborel and Laborel-Deguen, 1996; Antonioli et al., 1999; Silenzi et al., 2004; Chemello and Silenzi, 2011).

The taxonomic coralline assemblage, as well as differences in coralline algal thallus morphology, reflects changes in environmental parameters such as water temperature and bathymetry, which constrain coralline algal growth (e.g., Foster et al., 1997; Foster, 2001; Bassi et al., 2010; Aguirre et al., in press). These variations in taxonomic composition as well as differences in coralline morphology can be used to assess the palaeoecological settings (e.g., Braga and Aguirre, 2001; Nebelsick et al., 2005; Checconi et al., 2010; Bassi et al., 2012a; Aguirre et al., in press).

Concretioned vermetid-coralline assemblages can be observed in several places along the Brazilian coast, between São Roque Cape (Rio Grande do Norte State) and Rio de Janeiro State (Laborel and Kempf, 1965; Spotorno-Oliveira et al., 2012). These assemblages are located at the lower intertidal/upper subtidal zone (in the lower limit of the midlittoral zone, *sensu* Stephenson and Stephenson, 1949), as described in Bermuda and the Mediterranean (Laborel and Kempf, 1965).

2. Regional setting

2.1. Geographical, oceanographical and geomorphological settings

This work was carried out at Arraial do Cabo Bay, Rio de Janeiro State (23° S, 42° W; Fig. 1). Study sites included the continental part of Arraial do Cabo, Praia dos Anjos (AJ, 22°58′41.1″ S, 42°00′48.2″ W), Prainhas do Pontal (PR, 22°59′18.4″ S, 42°00′46.8″ W), and two islands, Porcos Island (PO, 22°57′57.9″ S, 41°59′37.3″ W), and Cabo Frio Island (Praia do Farol; A0, A1, B, C, IL, 22°01′41″ S, 42°01′41″ W; Maramutá, MA, 22°59′49.1″ S, 41°59′79.5″ W; Anequin, AN, 22°59′06.8″ S, 41°59′26.3″ W; Fig. 1). The Recent marine environment of Arraial do Cabo sustains highly diversified reef faunas and floras (Castro et al., 1995; Guimaraens and Coutinho, 1996; Ferreira et al., 1998) that flourish in embayment conditions upon a rocky reef formation. This is covered with a diverse epilithic algal community (Guimaraens and Coutinho, 1996), patches of *Palythoa caribaeorum*, colonies of *Millepora alcicornis*, and hermatypic corals (Castro et al., 1995).

The whole region is influenced by a coastal upwelling event associated with the local wind regime and bathymetry in summer and spring periods (Castelao, 2012; Belem et al., 2013). This occurs when the wind blows across the ocean surface and pushes away the Brazilian Current (BC), carrying surface Tropical Waters (TW) far from the coast and as a result the South Atlantic Central Water (SACW) subsurface water, formed in the confluence zone Brazil-Malvinas emerges. The SACW is generally colder, richer in nutrients and biologically more productive than the TW (Castelao, 2012; Belem et al., 2013). The upwelling in the region is strictly related to the coast topography (changes in the cost line orientation), wind directions (predominantly NE) and the convergence of forces generated by the Brazilian Current and the Coriolis Effect (Valentin, 1984).

The upwelling in the region is intermittent, occurring as short episodic events all year-round, but particularly enhanced during austral spring/summer under prevailing NE winds on the inner shelf (Castro et al., 1987; Campos et al., 2000). In contrast, cold front S-SW winds during fall and winter inhibit the surface upwelling of SACW (Valentin et

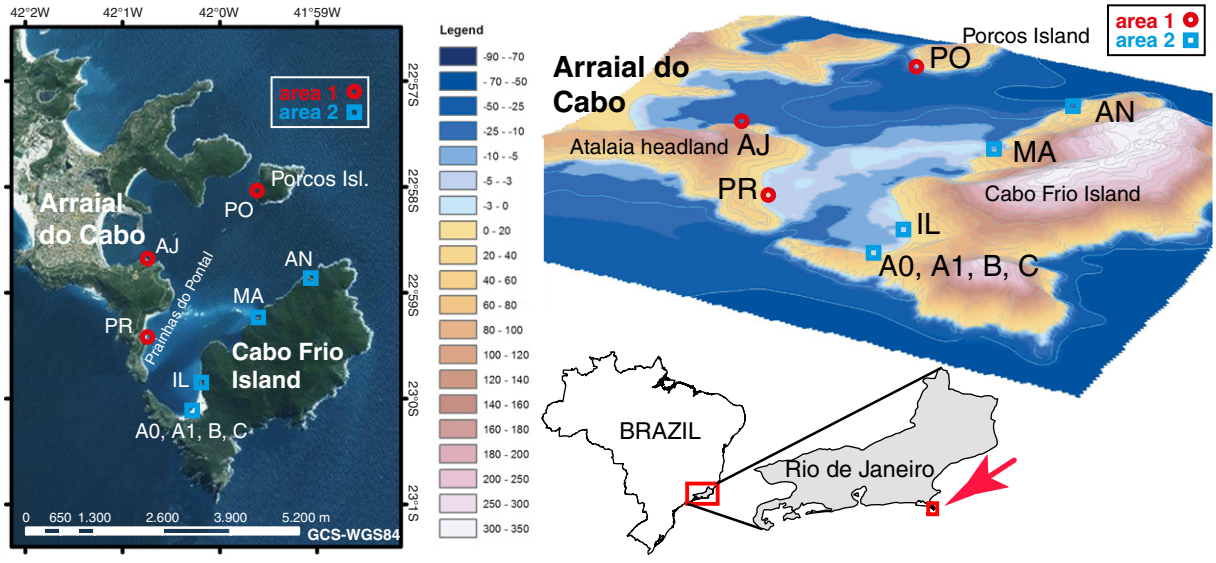

Fig. 1. Geographic maps of the studied area (red arrow) with the locations of the analysed samples. Area 1 (on metamorphic basement) represents the continental part of Arraial do Cabo, and the western coast of Porcos Island, whilst Area 2 (on nepheline syenite basement) comprehends the western coast of the Cabo Frio Island.