Palaeogeography, Palaeoclimatology, Palaeoecology 462 (2016) 101–111

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Origin and sedimentary evolution of sinkholes (*buracas*) in the Abrolhos continental shelf, Brazil

Alex C. Bastos [a], Gilberto M. Amado-Filho [b], Rodrigo L. Moura [c], Frederico M. Sampaio [b], Davide Bassi [d], Juan C. Braga [e,*]

[a] *Departamento de Oceanografia, Universidade Federal do Espírito Santo, Avenida Fernando Ferrari 514, Vitória, ES29090-600, Brazil*
[b] *Instituto de Pesquisas Jardim Botânico do Rio de Janeiro, Rua Pacheco Leão 915, Rio de Janeiro, RJ22460-030, Brazil*
[c] *Departamento de Biologia Marinha, Instituto de Biologia, Centro de Ciências da Saúde, Universidade Federal do Rio de Janeiro, Ilhado Fundão, CP68011, Rio de Janeiro, RJ21944-970, Brazil*
[d] *Dipartimento di Fisica e Scienze della Terra, Università degli Studi di Ferrara, via Saragat 1, I-44122 Ferrara, Italy*
[e] *Departamento de Estratigrafía y Paleontología, Universidad de Granada, Campus Fuentenueva s/n, 18002 Granada, Spain*

ARTICLE INFO

Article history:
Received 14 April 2016
Received in revised form 7 September 2016
Accepted 12 September 2016
Available online 13 September 2016

Keywords:
Submarine sinkholes
Radiocarbon dating
Carbonate sedimentation
Pleistocene-Holocene
Abrolhos continental shelf
Brazil

ABSTRACT

Cup-shaped depressions (termed *buracas* by local fishermen) are common geomorphic features on the north-eastern Abrolhos continental shelf (Brazil). Samples collected by technical diving from the walls of two depressions (Buraca Funda, B1, top at 59 m, and Buraca Rasa, B2, top at 26 m) and seismic profiles provide evidence of the processes leading to their formation. The top of the sedimentary succession consists of two units bounded by erosion unconformities. Unit 1 overlies an erosion surface (MR1) and is older than the radiocarbon dating limit. It is made up of packstone to rudstone accumulated on mid- to outer-shelf paleoenvironments. Voids in the limestone are filled by a meteoric cement 29,000 cal yrs BP in B2. It is assumed that Unit 1 formed in the late Pleistocene, mainly during MIS 5e. An erosion surface (MR2) carved sinkholes in Unit 1, with karstification taking place while the ACS was emergent during the last glacial period. The timing and span of subaerial exposure changes with depth within the shelf. Unit 2 accumulated on this karst surface in the Holocene, after postglacial sea level rise. At the B1 margin, Unit 2 consists of early-lithified packstone to rudstone with attached corals. In B2, the Holocene unit comprises a boundstone of encrusting invertebrates and calcareous algae similar to the living ones attached to the wall today. High productivity in the sinkholes probably promoted the growth of encrusting suspension feeders but also led to intense, multistory bioperforation of carbonates on the wall. The cup-shaped depressions are, therefore, the result of sinkhole formation during the last-glacial low sea levels and later carbonate accretion at sinkhole margins during the Holocene.

1. Introduction

The Abrolhos continental shelf (ACS) encloses the richest and largest coral-reef system in the South Atlantic (Moura et al., 2013). It covers 46,000 km^2 between the south of Bahia state and the north of Espírito Santo state (Fig. 1). The ACS comprises a mosaic of ecosystems with high endemism, composed of shallow reefs, seagrass and algal meadows, unconsolidated sediments, and the largest rhodolith beds in the world (Amado-Filho et al., 2012; Moura et al., 2013; Bastos et al., 2013). The geomorphology and sedimentology of the ACS, from 25 m depth to the slope, has been characterized since 2007 through acoustic and video images, bottom sampling through diving and remotely operated vehicle, and the acquisition of seismic data (Bastos et al., 2013; Moura et al., 2013; D'Agostini et al., 2015).

Studies on the ACS show that spatial distribution of main habitats is related to prior geomorphic evolution due to sea-level oscillations during the Quaternary (Vicalvi et al., 1978; Leão and Ginsburg, 1997; Leão and Kikuchi, 1999; Moura et al., 2013; D'Agostini et al., 2015). The record of sea-level oscillations is stored in the mixed siliciclastic-carbonate sediments that make up this platform's Quaternary stratigraphic sequences (Bastos et al., 2013; D'Agostini et al., 2015).

The geomorphic diversity of the Abrolhos shelf includes shallow reefs, pinnacles, mesophotic reefs, paleochannels, and thirty-six structures termed *buracas* by local fishermen (Bastos et al., 2013; Moura et al., 2013; Fig. 1). *Buracas* are cup-shaped depressions in a consolidated carbonate substrate, and are known as hotspots of primary productivity and fishing (Land et al., 1995; Cavalcanti et al., 2013).

Cup-shaped depressions in the seafloor can be pockmarks caused by fluids flowing out from the sediment pile or sinkholes of karstic origin (Michaud et al., 2005; Betzler et al., 2011; Kan et al., 2015). Bastos et al. (2013) described these structures, mainly based on geophysical assessments, and suggested two hypotheses for their origin. One

* Corresponding author.
E-mail address: jbraga@ugr.es (J.C. Braga).

http://dx.doi.org/10.1016/j.palaeo.2016.09.009

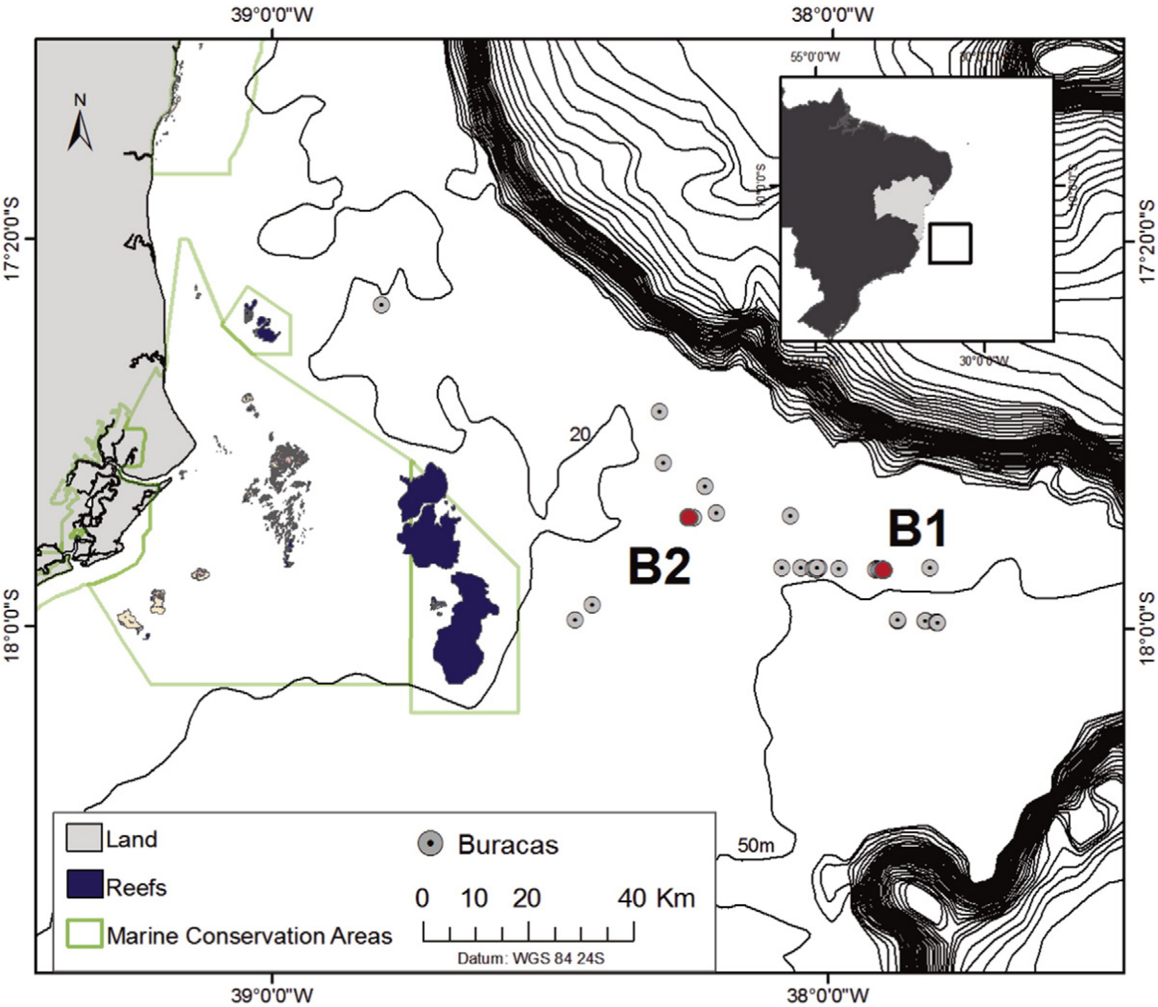

Fig. 1. Location of the *buracas* (grey dots) in the Abrolhos continental shelf. B1and B2 (red dots) are the examples studied.

hypothesis considers the *buracas* formed by karst processes during sea-level lowstands associated with later, very low sedimentation rates. Accordingly, *buracas* would be expected to have formed during the Last Glacial Maximum (LGM, late Pleistocene MIS 2) or during earlier lowstand periods (middle Pleistocene MIS 6, MIS 8, etc.). The second hypothesis was that the *buracas* are, partially, a carbonate accretionary feature on top of sinkhole topography. Thus, recent sedimentation on these structures would be represented by granular carbonate sediments or biogenic incrustation on the wall (Bastos et al., 2013). In the latter case, the *buracas* would record the drowning of the ACS during the post-glacial transgression, and thereby, help to understand the platform's paleoenvironmental evolution.

The lithofacies and components of samples collected directly from the *buraca* walls were analysed in detail and successive phases of carbonate sedimentation were radiocarbon dated. The aims of this paper are to: (1) describe the lithofacies and chronostratigraphy of the *buraca* depressions; (2) discuss the sources of bias in radiometric dating of rocks on exposed submarine walls; and (3) show that the bizarre cup-shaped *buracas* are a product of erosional karstic processes and the accretion of carbonate sediments promoted by the high productivity characteristic of submarine sinkhole-shaped depressions.

2. Material and methods

Two *buracas* were selected for this study (Fig. 1) based on distance from the coast and depth (Table 1). The Buraca Funda (Deep Buraca, B1) is part of a group of *buracas* at intermediate depths in the ACS (tops at 50 to 70 m), and the Buraca Rasa (Shallow Buraca, B2) belongs to a group of *buracas* at relatively shallow depths (tops at 25 to 40 m). In March 2012 the *buraca* walls were logged through TRIMIX technical diving. In the section logged in B1, 4 carbonate samples were collected at 80 m, 77 m and 65 m (2 samples). In the B2 section 5 samples were taken at 42 m, 40 m, 38 m (2 samples) and 35 m.

A basic macroscopic description of each sample was made with the aid of the hand lens and stereoscopic microscope. From these observations, sample regions were selected for petrographic analysis, and $3 \times 3 \times 1$ cm blocks were cut with the aid of a tungsten handsaw. Nineteen thin sections were prepared from the nine samples (eight from B1 and eleven from B2) by the National Petrographic Service, Inc. (Houston, Texas, USA).

Thin sections were examined under an Olympus BX43 optical microscope with digital camera (Moticam) attached. The images were captured using the Dynamic Scope Image Pro 2009 software. Microfacies analyses of thin sections included carbonate lithofacies identification

Table 1
Morphometric information of both *buracas* studied, including the coordinates (WGS84).

	Shallow Buraca (B2)	Deep Buraca (B1)
Latitude/Longitude	−17.9002/−37.9151	−17.0844/−38.2026
Distance from coast	105 km	144 km
Top depth	26 m	54 m
Top diameter	39 m	30 m
Base depth	42 m	93 m