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Origin of holocene beachrock cements in northeastern Brazil: Evidence from carbon and oxygen isotopes

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ABSTRACT

This study has utilized carbon and oxygen isotopic data to unravel the origin of Holocene beachrock cements of Rio Grande do Norte State coast, northeastern Brazil. The cements are exclusively constituted of Mg-calcite, with isopachous prismatic rim, equant spar, cryptocrystalline coating or pore-filling, pseudo-peloidal, radial and scalenohedral habits. The $\delta^{18}O_{VPDB}$ values of most (93%) of the samples range from −1.8‰ to +0.5‰, which are compatible with precipitation from marine waters. The $\delta^{13}C_{VPDB}$ values of these cements are +1.7 to +3.6‰ (average + 3.05‰) suggesting derivation from marine dissolved carbon. In a few cases, the Mg-calcite cement shows low $\delta^{13}C_{VPDB}$ (−7.3‰ and −7.8‰) and $\delta^{18}O_{VPDB}$ (−4.4‰ and −4.3) values, which may indicate precipitation or recrystallization of marine cements under the influence of meteoric waters.

1. Introduction

Beachrocks are defined as friable to well-cemented rocks, formed in the intertidal zone in tropical or subtropical regions. They consist of sand or gravel (clastic and/or bioclastic) cemented with calcite (Bates and Jackson, 1987). Despite the relatively extensive study of beachrocks all over the world (Queensland, Australia: Chivas et al., 1986; Togo, West Africa: Amieux et al., 1989; Egypt: Holail and Rashed, 1992; San Salvador Island, Bahamas: Kindler and Bain, 1993; Cyprus: Ertek et al., 2008; Turkey: Erginal et al., 2008, 2010; India: Thomas, 2009; Greece: Psomiadis et al., 2009; Argentina: Aliotta et al., 2009; Great Britain: Howie, 2009; Tromelin, Indian Ocean: Marriner et al., 2010), the specific processes responsible for their generation are still controversial. Precipitation from fresh waters (Russell, 1959; 1962; Stoddart and Cann, 1965), mixing of marine and meteoric waters (Schmalz, 1971; Moore, 1973), evaporation (Taylor and Illing, 1969; Moore and Billings, 1971), CO_2 degassing of shallow groundwater (Hanor, 1978; Binkley et al., 1980; Gischler and Lomando, 1997) and direct or indirect activity of organisms (Webb et al., 1999; Neumeier, 1999; Khadkikar and Rajshekhar, 2003) have been most commonly pointed out as the processes responsible for beachrock cementation.

The importance of beachrocks is based upon many aspects: their impact upon coastal evolution (Cooper, 1991), their significance as former sea-level indicators (Hopley, 1986), their evidence on the processes of shallow carbonate cementation (Longman, 1980), their archaeological content and consequent importance to the study of human evolution (Galili et al., 2007), their implication for the recreational use of beaches (Vousdoukas et al., 2009), their importance as habitat of a great variety of organisms (Bonnet et al., 2009). A review of the general characteristics and formation mechanisms of beachrocks from different places of the world can be found in Vousdoukas et al. (2007).

Extensive beachrock ledges are common features along both the eastern and northeastern shores of the state of Rio Grande do Norte, northeastern corner of the Brazilian coast (Fig. 1). Previous studies on these beachrocks (Oliveira et al., 1990; Vieira and De Ros, 2006) revealed that they show a wide variability in diagenetic processes, fabrics and textures, even on a centimeter scale. Such diagenetic processes include not only different types of calcite cementation,

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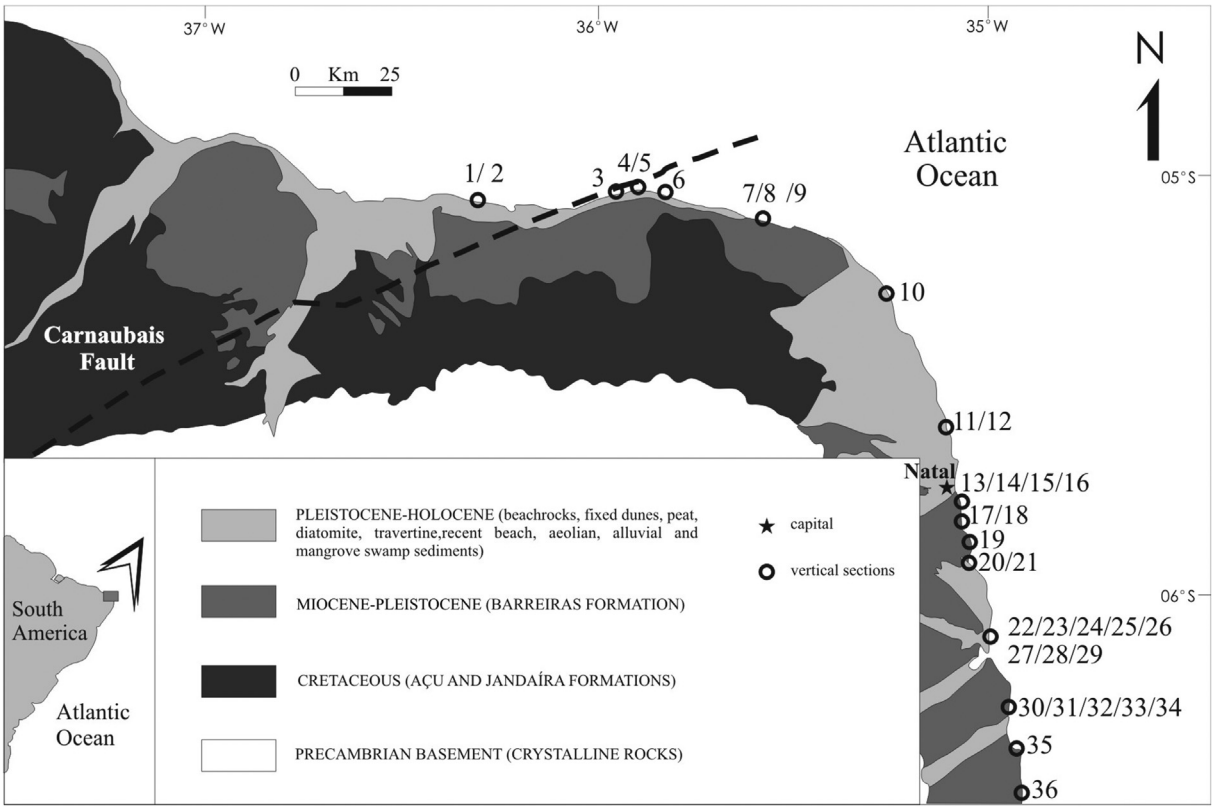

Fig. 1. Location and simplified geological map of the study area. Black circles and adjacent numbers correspond to the constructed vertical sections.

but also mechanical infiltration of carbonate and hybrid siliciclastic/carbonate fine-grained sediments. Despite the importance of stable-isotope geochemistry in deciphering the environmental conditions under which beachrock cementation has occurred (Holail and Rashed, 1992; Calvet et al., 2003; Holail et al., 2004), only one previous study performed isotopic measurements in carbonate cements from beachrocks located on Rio Grande do Norte coast (Caldas, 2002). Taking into account this fact, the aim of this paper is to contribute to a better understanding of the origin and diagenetic evolution of Holocene beachrocks from Rio Grande do Norte, northeastern Brazil, and their relation to sea level variation, based on the carbon and oxygen stable isotope values of their cements.

2. Climate, seawater and geological setting of study area

The area in which the studied beachrock ledges are located has a tropical climate with typical air temperatures of 30 °C and average rainfall between 600 and 1000 mm/year (Nimer, 1989). The coast of Rio Grande do Norte presents a semidiurnal mesotidal regime in which the tide interval varies from 3.2 m to 0.8 m, along the northern coast, and from 2.7 m to 0.1 m, along the eastern coast. Throughout most of the year, southeasterly and northeasterly winds that blow towards the eastern and northern coast, respectively, result in longshore currents that flow to the north along the eastern coast, and to the west along the northern coast (Bittencourt et al., 2002).

The studied beachrocks were formed by cementation of Quaternary sediments deposited in two distinct geological provinces (Fig. 1): the Potiguar Basin, with a NE-SW general direction, along the northern coast and part of the eastern coast; and the N-S trending Pernambuco-Paraíba Basin, along the remaining eastern coast. Miocene-Pleistocene conglomerates, sandstones, and mudrocks of the alluvial Barreiras Formation form cliffs along the entire coast of the state, which are in some places overlain by marine terraces formed during Late Pleistocene transgressions (220 ± 2 ka to 110 ± 10 ka BP; Barreto et al., 2002). Besides beachrocks, Quaternary units also include dunes, peat, diatomite, and travertine, as well as Recent beach, aeolian, alluvial, and mangrove swamp sediments (Silva and Nogueira, 1995).

3. Geomorphology and lithofacies

Beachrocks are discontinuously exposed along the shoreline of Rio Grande do Norte and nearly parallel to it, with up to 8 km of continuous extension, ranging in thickness from a few centimeters to nearly 3 m and in width from 2 to 50 m. Most of these ledges are located on the present intertidal zone, being characterized by the presence of gently seaward dipping (<10°) tabular beds that are 5–150 cm thick, with lower and upper abrupt contacts, and light-brown in color. A few ledges are permanently submerged (Vianna et al., 1993; Santos et al., 2007; Cabral Neto et al., 2010) or can be found 200 m inland from the beach. Radiocarbon dating of samples collected at various sites between the towns of Macau and Baía Formosa yielded ages from *c.* 7460 to 110 cal yr BP (calibrated years Before Present; Bezerra et al., 2003; Caldas et al., 2006).

The upper surface of the beachrocks displays erosional features similar to those described in South African beachrocks and aeolianites (Miller and Mason, 1994). *Spitzkarren* (upward-pointing pyramids separated by clefts or solution basins) and near-circular depressions (solution basins and potholes) are the most common ones.

Textural characteristics and sedimentary structures were used to group the studied beachrocks into five lithofacies, named 1 to 5