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Quartz grain assessment for reconstructing the coastal palaeoenvironment

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A B S T R A C T

This study proposes a combination of sedimentological techniques as a tool to understand depositional palaeoenvironments. Grain size, mineralogy, compositional data, stratigraphic framework, degree of rounding, optical appearance and microtextures of quartz grains were analyzed; sub-surface sediments were collected from 4 boreholes spaced across coastal settings, from the beach towards the continent, from locations on the south-central coast of the state of Espírito Santo, southeast Brazil. Five palaeoenvironments were identified: fluvial (characterized by gravelly sand facies, composed predominantly of sub-angular and sub-rounded dirty quartz grains with microtexures caused by sudden impact and grain surfaces modified by chemical action, as well as other non-quartz terrigenous minerals); continental deposit with marine influence, such as an estuary (characterized by muddy sand facies, composed of immature grains with natural glow and non-abraded grains with a "fresh" clean surface, little to no chemical change, a few bioclastic fragments, carbonate nodules and grains embedded with carbonate); modern estuary (characterized by sandy mud facies, composed of mixed mature and immature quartz grains, chemically frosted, bioclastic fragments, carbonate nodules, and high organic matter content); bay (characterized by sandy mud and mud facies, composed predominantly of mature grains, highly chemically frosted, with microtextures clearly associated with post-depositional alteration, many bioclastic fragments, and organic matter); and beach (characterized by gravelly sand facies, composed predominantly of sub-rounded dirty grains, followed by shiny grains, with smooth edges, signs of former impact, little chemical dissolution on the quartz grain, and bioclastic fragments). The association between the degree of rounding, optical aspect and microtextures of quartz grains was essential to estimate the extent and strength of seawater intrusion in filling of the sedimentation basin. The palaeoenergy of each deposition was not always clearly recognized using only statistical particle size distribution parameters and compositional data.

1. Introduction

Statistical patterns in the grain size of coastal sediment in depositional environments have been used successfully to interpret both transport processes and the current and ancient depositional environments (Razik et al., 2014; Rajganapathi et al., 2013; Morgan and Bull, 2007; Friedman, 1979). However, few studies use granulometric analysis as the main tool to properly interpret palaeogeography (Gyllencreutz et al., 2010). An unacceptably high number of misinterpretations have arisen from these studies, highlighting limitations of this method and associated models (Boggs, 2006).

The shape and surface characteristics of quartz sands provide important information on the processes responsible for sediment deposition (Kalinska and Nartiss, 2014; Madhavaraju et al., 2009, 2006, 2004; Armstrong et al., 2005; Mahaney, 2002; Madhavaraju and Ramasamy, 1999; Krinsley and Doornkamp, 1973). Fluvial grains, for example, tend to be sub-angular to sub-rounded with heterogeneous shapes and features (Vos et al., 2014; Kleesment, 2009; Mahaney, 2002; Nanson et al., 1995), while beach grains

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are predominantly rounded to sub-rounded and shiny (Madhavaraju et al., 2009; Mycielska-Dowgiallo and Woronko, 2004; Chapman et al., 1982; Roy et al., 1980). Grains from diagenetic environments are more chemically altered than the grains from environments without diagenesis (Asumadu et al., 1987; Doornkamp and Krinsley, 1971).

Determining the grain size distribution (manual or automated) and multivariate statistical analyses involve homogenization of the sample, which could mask the processes that may have occurred before or after deposition (Morgan and Bull, 2007). Analysis of the form and superficial aspects of the grains, such as degree of rounding (Kalinska and Nartiss, 2014; Woronko and Pochocka-Szwarc, 2013; Mycielska-Dowgiallo and Woronko, 2004) and surface microtexture of quartz grains identified with scanning electron microscopy (SEM), (Vos et al., 2014; Madhavaraju et al., 2009, 2006, 2004; Armstrong et al., 2005; Strand et al., 2003; Madhavaraju and Ramasamy, 1999; Bull and Goldbergb, 1985; Doornkamp and Krisnsley, 1971) are important to better discriminate between the environments described above.

The association of independent and complementary techniques of sediment analysis (Morgan and Bull, 2007) gives more credibility to palaeoenvironmental interpretations (Kalinska-Nartisa et al., 2015; Rajganapathi et al., 2013; Gyllencreutz et al., 2010; Kleesment, 2009; Newsome, 2000; Asumadu et al., 1987). The results of these analyses are more conclusive when combined with facies characteristics (lithology, textural attributes and sediment appearance) (Catuneanu, 2006) and other sediment parameters, such as the mineralogical composition of grains (Drago et al., 2004; Lessa et al., 2000) and the percentage of organic matter and calcium carbonate (Rios and Amaro, 2012) often associated with geological, geomorphological, climatic and hydrodynamic sites.

The objective of this investigation was to combine sedimentological techniques as a tool to understand depositional palaeoenvironments from the coastal plain of the Vitoria region, southeast coast, Brazil. Analyses used were grain size, mineralogy, compositional data, stratigraphic framework, degree of rounding and optical appearance of quartz grains using optical microscopy and microtexture of quartz grains using scanning electron microscopy.

2. Area description

The study area is located on the south-central coast of the state of Espírito Santo, southeast Brazil. The area is characterized by two narrow sedimentary plains (Mestre Alvaro Plain and Camburi Plain) and two bays (Espírito Santo Bay and Vitoria Bay) (Fig. 1), forming the Great Vitoria region.

The coastline is highly indented, with alternating rocky promontories and soft cliffs (Fig. 1, Martin et al., 1996, 1997). The coastal plains are spatially limited; their sedimentary evolution is associated with sea level fluctuations and the availability of river sediments (Albino et al., 2006).

Sand deposits, wetlands, beach ridges and modern estuaries are geomorphological evidence of marine transgressions on the coastal plain of Vitoria. The Quaternary records of the Vitoria Plain are characterized by fluvial-marine sand and mangrove deposits, both limited toward the mainland by the tablelands (Neogene) of the Barreiras Formation and the Pre-Cambrian hills (granite andgneiss) of the Paraiba do Sul Complex (Fig. 1).

The Mestre Alvaro Plain corresponds to the most interior part of the embayment, characterized by sandy deposits that extend noncontiguously to the base of the Pre-Quaternary units, truncated by a palaeoriver channel. These deposits, not exceeding 5 m (m) elevation, are distributed among slightly depressed wetlands; they are flooded during the rainy season and occasionally by the tide in some areas. Camburi Plain is a coastal deposit that is controlled by headlands and islands with a sand barrier near the beach. This sandy deposit has discrete aligned ridges, with a maximum altitude of 5–6 m that dips towards the mainland. The wetlands, with topographic dimensions that do not exceed 2–3 m above sea level, decline towards mangroves.

3. Materials and methods

3.1. Field processes and sedimentary analysis

Sub-surface sediment samples from the Mestre Alvaro and Camburi Plains were collected from four 20-m-deep boreholes using a “Standard Penetration Test” (SPT) (ABNT BR-6484/01) (Fig. 1). The SP1 core is 2 m above sea level onn a sandy deposit; the SP2 core is 1.6 m above sea level in a seasonally flooded area; the SP3 core is 0.6 m above sea level near mangroves; the SP4 core is 4.4 m above sea level on a sandy deposit.

Samples were collected from the cores at one meter depth intervals, a total of 20 sediment samples per borehole. During the collection, two samples were not recovered by the equipment. A total of 78 sediment samples were therefore obtained from the four sites. The thickness and location of stratigraphic facies along the profile are referenced using the depth in meters where the sample was collected.

The organic matter content was determined by loss on ignition using a temperature of 450 °C for four hours. The calcium carbonate content was obtained by dissolving the sample in 10% hydrochloric acid (HCl). Quantification of the levels was obtained using the difference between initial and final weight of each sample.

The mineralogical composition of the grains was determined by visual analysis with a binocular magnifying glass with a 1.6 to 2 times magnification for three size fractions: 0.25, 0.35 and 0.5 mm. In each fraction, 100 grains were randomly selected and separated into classes: 1) lithoclasts (quartz, feldspar, heavy minerals and other, besides quartz grains embedded and surrounded by carbonate) and 2) bioclasts (mollusks, foraminifera, echinoderms, algae, carbonate nodules and others). Carbonate nodules represent grain concretions with genesis and source unidentified, but which dissolved in HCl.

For particle size, dry sieving was used to analyze sand fractions, while laser particle size (Master Size_2000) was used to analyze mud fractions. The sand was separated from the mud fraction using a wet sieve with 0.062 mm mesh. The mud fraction was processed without organic material, which was previously removed by burning the sample on a plate at 70 °C with hydrogen peroxide.

Gradistat freeware (Blott and Pye, 2001) was used to classify grain size parameters, adopting the grading scale of Wentworth (1922) and the Folk and Ward (1957) equations. The granulometric size distribution results of both techniques were converted to percentage based on the proportion of mud and sand in each sample.

3.2. Roundness and optical appearance

In this study, 100 quartz grains were randomly selected from three sand fractions (0.25, 0.35 and 0.5 mm). These three fractions of sand were selected because all are present in the collected samples and represent the average grain size. A total of 23,400 grains were analyzed using optical morphoscopy based on the method proposed by the Laboratoire de l'Institut de géographie de l 'Université de Strasbourg (Ligus, 1958) to assess the degree of roundness and optical appearance (Table shown in Fig. 2).

The Kalinska and Nartiss (2014) method was adapted for this study to address the main characteristics of the local setting (fluvial