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Spatial sediment variability in a tropical tide dominated estuary: Sources and drivers

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ABSTRACT

Surficial sediment composition and spatial variability reflect the dynamics and level of natural and anthropogenic impact in estuarine systems. The aim of this study is to evaluate some key environmental and sedimentary variables, as well as to evaluate the current environmental quality in the tide-dominated Caravelas estuarine system (Brazil). Sixty-five surficial sediment samples were studied for grain size as well as calcium carbonate, total organic carbon, total nitrogen, metals, semi-metals and rare earth elements and for organic matter $\delta^{13}C$. Based on the spatial distribution of these data and summarizing our findings, three sectors can be individualized in the Caravelas estuarine system: i. Barra Velha inlet; ii. the main channel of the Caravelas estuary, and iii. the channel interconnecting Caravelas and Nova Viçosa estuaries. In the inlet the sedimentary organic matter is provided essentially by marine sources, which corroborates the small continental input. Freshwater dissolved organic carbon and particulate organic carbon occur in the interconnecting channel, proving the occurrence of the residual transport towards the Caravelas estuary, with continental contribution towards Caravelas River. The geochemical fingerprint indicates that the Barreiras Group, composed by Neogene terrigenous deposits, located west of the study area, as an important source of terrigenous material to the entire Caravelas estuary system. The higher values of heavy rare earth elements (between 20 and 30 mg kg^{-1}) in the northern sector of the study area may be related to the high degree of chemical weathering in magmatic or metamorphic rocks, which occur to the north of the study area.

1. Introduction

Estuaries are natural places that provide goods and services that are of economic and ecological importance. They act as filters for river and streams' sediments and pollutants before its waters flow into the ocean and play an important role in the cycling of many biogeochemically important elements. According to Dürr et al. (2011), tidal systems account for 22% of the global coastline, showing its relevance while serving as active filters of both dissolved and suspended material being exchanged through the coastline. Being sensitive environments where rapid changes occur, it is of central importance to scientists, managers and policy makers to understand the response of these natural systems to ongoing changes (Mitchell et al., 2015). In the last decades, the coastal marine zones have been commonly submitted to high anthropogenic pressure and have been highly modified by urban, industrial and port developments and/or by natural processes (e.g., erosion, river discharge), leading to changes in the water quality and health of the ecosystem (e.g., Nichols et al., 1986; Alve and Olsgard, 1999; Cearreta et al., 2002; Azevedo et al., 2008). Therefore, ecosystem management has been increasingly common as well as decision making processes, which in turn are strongly dependent of the knowledge of ecosystem functioning (Azevedo et al., 2008).

In this study we focus into the tropical tide dominated Caravelas - Nova Viçosa estuarine system, located in the northeastern coast of Brazil (State of Bahia). Added to its importance is that it reaches the ocean nearby the Abrolhos reef complex, considered the largest

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tropical reef habitat in the South Atlantic, on the eastern Brazilian continental shelf (Leão, 1996; Leão and Kikuchi, 2001). The Abrolhos Bank is unique in terms of reef structure and building organisms in the South Atlantic, exhibiting high levels of endemism and mushroom-shaped coralline pinnacles (Leão and Kikuchi, 2005).

As a feedback mechanism, the development of the Abrolhos coral reefs has also played an important role in the dispersion and accumulation of sediments along the coastline, causing localized inversion in longshore sediment transport, promoting the formation of the Caravelas strandplain during the Quaternary (Andrade et al., 2003). Furthermore, according to Silva et al. (2013) there is an increase of the sedimentation rate of continent-derived sediment runoff, over the last decade, in the vicinity of the reefs nearest the coast, probably due to the local processes resulting from anthropogenic actions. Several of the potentially negative effects of sedimentation and turbidity on corals have been documented, such as, the smothering of filter-feeding organisms, the abrasion of coral colonies, and changes in coral morphology (e.g. Rogers, 1990; Pollock et al., 2014).

The estuarine system of Nova Viçosa – Caravelas, composed of channels that connect the Caravelas to the Nova Viçosa estuary, is located in one of the oldest urban occupied area on the northeastern Brazilian coast, and it has been subject to significant anthropogenic action (urban and industrial developments), mainly since the 1970s. During the last 50 years, the area has been exposed to intensive soil use due to establishment of the eucalyptus monoculture and cellulose industries. Therefore, this area has been received industrial waste from the cellulose treatment and urban effluents (Almeida et al., 2008), which could promote the increase of As and other metals, as reported by Sousa et al. (2014). Since at least the 1950s, the estuary has been subjected to a natural widening of a new inlet, and the outer part of the inlet channel, in the last decade, has been subjected to dredging operations (Sousa et al., 2014). These anthropogenic impacts and natural ecosystem changes led, according to Sousa et al. (2014), to significant modifications in the benthic foraminifera community and organic matter content in the sediments, and also an increase of fine sediments in the Caravelas estuarine system is observed in the last four decades. It should be also considered that this estuarine system is located only 200 km north of the Doce river inlet, recently affected by the collapse of a mining dam approximately 600 km upstream (considered Brazil's largest environmental disaster to date). Mining waste has been carried downstream reaching the ocean on November 22, 2015, with its plume being rapidly spread along the adjacent coastal zone. Although direct influence of the plume of sediments is not expected in the Caravelas estuarine area, future reworking of sediments deposited in the inner shelf may result in further unknown sediment spreading.

Despite of the importance of the Caravelas estuarine system in the context of the Abrolhos coral reef complex little is known about its sediment provenance, the spatial distribution of environmental variables, as well as its modern environmental assessment, which have a high importance in management purposes for the coastal area in the surroundings of Abrolhos reef.

Thus, we propose to evaluate some key environmental and sedimentary variables (textural and organic and inorganic geochemical data) in the Caravelas estuarine system, aiming to study the significance of their spatial distribution, sediment provenance and compare them to hydrological models proposed for the study area (e.g. Schettini et al., 2013), as well as to evaluate the current environmental quality of the estuarine system.

2. Study area

The Caravelas estuary is part of an estuarine system composed by the Caravelas and Peruípe (Nova Viçosa estuary) drainage basins that contrast in size with the Peruípe basin covering about 4600.00 km^2, while the Caravelas basin covers only 600 km^2 (Fig. 1). The Peruípe river discharge averages between 15 and 28 $m^3\ s^{-1}$, with maximum values of 57 $m^3\ s^{-1}$ during the wet summer months, contrasting with the low Caravelas discharge of about 4–5 $m^3\ s^{-1}$ (Pereira et al., 2010). When reaching the coastal plain, these two systems form the Nova Viçosa-Caravelas estuarine system, with interconnecting channels that lead to an important exchange of properties (e.g., Schettini et al., 2013). Both estuaries are well-mixed (Andutta et al., 2013; Schettini et al., 2013) with shallow and narrow connecting channels surrounded by mangroves. Water exchange between the estuarine system and the Atlantic Ocean occurs through three inlets, one at the Nova Viçosa estuary and two at the Caravelas estuary. Tides are semidiurnal, with a maximum height of 1.1 m during neap tides and 3.0 m during spring tides (Lessa and Cirano, 2006), resulting in a tidal prism that varies between 38,000 m^3 and 211,000 m^3 from neap to spring tides, respectively (Pereira et al., 2010).

Caravelas' main estuarine channel presents ebb dominated flows, with velocities varying between 0.3 m s^{-1} (flood) and −0.41 m s^{-1} (ebb) at neap tides and between 0.79 and −1.04 m s^{-1} at spring tides (Schettini et al., 2013). The estuarine dynamics is mainly driven by tides, presenting a vertical structure with well-mixed salinity and pronounced ebb-dominant currents (Schettini and Miranda, 2010). These authors found seaward water budgets of about 600 $m^3\ s^{-1}$, incompatible with the small fresh water inflow of about 4–5 $m^3\ s^{-1}$ (Pereira et al., 2010). This shows that there is a significant exchange through the channels that connect both estuaries, a hypothesis assessed and confirmed by Schettini et al. (2013). Based on in situ ADCP measurements, Schettini et al. (2013) observed that the net water and suspended sediment flux is from the Nova Viçosa inlet (south) to the Caravelas estuary. At the Caravelas' end of the interconnecting channel, residual flows are directed towards the Caravelas estuary, with velocities ranging from 0.25 to −0.28 m s^{-1} at neap tides and between 0.61 and −0.89 m s^{-1} at spring tides. Therefore, in addition to the net importation from the inner shelf, the Caravelas estuary also receives fine sediment input from the Peruípe River. Although the estuary acts as a sediment trap for fine grained sediments, the fine fraction of the sediments occurs locally in the upper estuary and Barra Velha inlet.

Dominant waves in the region are from NE-E with significant heights of about 1 m and period of 5 s in spring-summer and from SE-E with significant heights of about 1.5 m and period of 6.5 s in fall-winter (Pianca et al., 2010).

3. Materials and methods

Sixty-five superficial sediment samples were collected using a Van-Veen grabber in the Caravelas estuarine system, during the austral spring of 2010 (from 3rd to 6th November). The purpose of the sampling was to cover the whole system, the estuaries of Caravelas and Nova Viçosa, inlets (Barra Velha and Nova Viçosa) and the channel that interconnects the estuaries (Fig. 1). The location of the samples is presented in Appendix A.

3.1. Sedimentological and organic geochemistry analyses

Grain size of the sediments was determined by the sieve method for the coarse fractions and by the pipette method for the fine fractions (<63 μm), and the size intervals were classified using Wentworth scale (Wentworth, 1922 in Suguio, 1973). Approximately 30 g portions of dry sediment from each sample were treated with 1 N HCl and hydrogen peroxide 10% to remove calcium