The Origin of the Santo Antônio Bank: interpretation using high resolution seismic data.

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This paper was prepared for presentation during the 14th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 3-6, 2015.

Abstract

The Santo Antônio Bank (SAB) is a positive feature of the Inner Continental Shelf of Salvador, adjacent to the entrance of the Todos os Santos Bay. Some studies have indicated its potential use as a deposit of siliciclastic sediments for the nourishment of urban beaches in Salvador. However, the methods that have been applied so far have not been able to determine the volume of sediments stored in this feature. Moreover, its origin on the shelf was also unknown. The objective of the present study was to determine the origin and the volume of sediments stored in this feature by means of high resolution seismic mapping (Sparker operating on frequencies between 0.3 to 1.5 kHz). Three major stratigraphic units were identified: Acoustic Basement, Pre-Holocene Unit and Holocene Unit. The bank originated from a paleo-high in the acoustic basement, which trapped sediments mobilized by the flood and ebb tides of the Todos os Santos bay. The volume of sandy siliciclastic sediments stored in the Holocene unit of the SAB was determined as 1 billion cubic meters, which meets with considerable ease the possible demands for urban beach nourishment and construction in the city of Salvador for over the next 100 years. The sparker operating on frequencies between 0.3 to 1.5 kHz was effective for insonification of the sandy sediments at depths greater than 100 m below the sediment-water interface.

Introduction

Detailed knowledge of coastal zones and submerged areas is essential for the management of the marine environment and for creating response scenarios for this region in face of climate changes. The use of geophysical methods has been shown to be very efficient in the study of submerged areas, especially for the investigation of geological structures, sediment deposits and geotechnical studies for coastal constructions such as ducts, submerged tunnels and bridges, among others (SOUZA, 2006; AYRES NETO, 2001). Geophysical methods such as side scan sonography, single and multibeam echo sounders, as well as sub-bottom profiling, have been used to study shallow regions, such as reservoirs, rivers, bays, the coastal zone and regions of the inner continental shelf. These systems operate on frequencies between 50-1000 kHz, for high frequency systems such as multibeams and side scan sounders, and up to 2 kHz-500 Hz in systems such as high energy Chirps, Boomers and Sparkers. The latter are able to penetrate up to 100 m within the sedimentary package and aid in the mapping and calculation of the cubage of sedimentary deposits (GOMES et al., 2011; SOUZA et al., 2013; AYRES NETO, 2011).

The Santo Antônio Bank (SAB) is a positive feature of the Inner Continental Shelf of Salvador, adjacent to the entrance of the Todos os Santos bay. This feature was already mentioned in the first reports of chroniclers that visited the region during the 16th century.

The SAB is 12.7 km long and presents mean width between 3 and 3.5 km, with approximate N-S orientation. The top of the bank is very shallow (minimum depths of 5 m) and is covered by large hydraulic dunes (REBOUÇAS, 2008; DOMINGUEZ et al, 2011). In total, the bank occupies 35.8 km², which is equivalent to 19 soccer stadiums. Several authors (Rebouças 2008, 2010, Dominguez et al. 2011) have indicated this feature as a potential sand deposit for the municipality of Salvador. However, the total volume of sediments and their origin were still unknown, because the geophysical systems used so far (CHIRP) were not able to penetrate the sedimentary cover.

The importance of the present study lies on the need to identify and calculate the volume of potential sandy siliciclastic sedimentary deposits that can be used in the future for the recovery of urban beaches in Salvador, some of which have now completely disappeared. Moreover, in face of a scenario of climate change, the identification of this type of deposit is essential to increase resilience in urban areas against sea-level rise. Another aspect that motivated the present study was the need to determine the geological origin of this feature, which intrigues many researchers due to its unique geomorphological character.

Method

Seismic lines were acquired along approximately 62 km (Figure 1) using Meridata Multi-Mode System equipment, and a Sparker seismic source operating within a frequency spectrum of 0.3 to 1.5 kHz. Survey took place in December 2014.

The digital data were processed and interpreted using MDPS software from Meridata. Three major stratigraphic units were identified in the acquired profiles: the Acoustic Basement, Pre-Holocene deposits, and Holocene deposits. The latter corresponds to the potential sediment deposit under investigation.

The depth values of the top and base of the sedimentary units and the top of the acoustic basement were later exported to a GIS environment. They were then interpolated the Natural Neighbor method to produce isopach maps of the different units and of the depth of the acoustic basement.

These maps were used to calculate the volume of sediments stored in the SAB. A preliminary estimate was also carried out to determine the necessary volume of sediments to recover the beaches of Salvador.

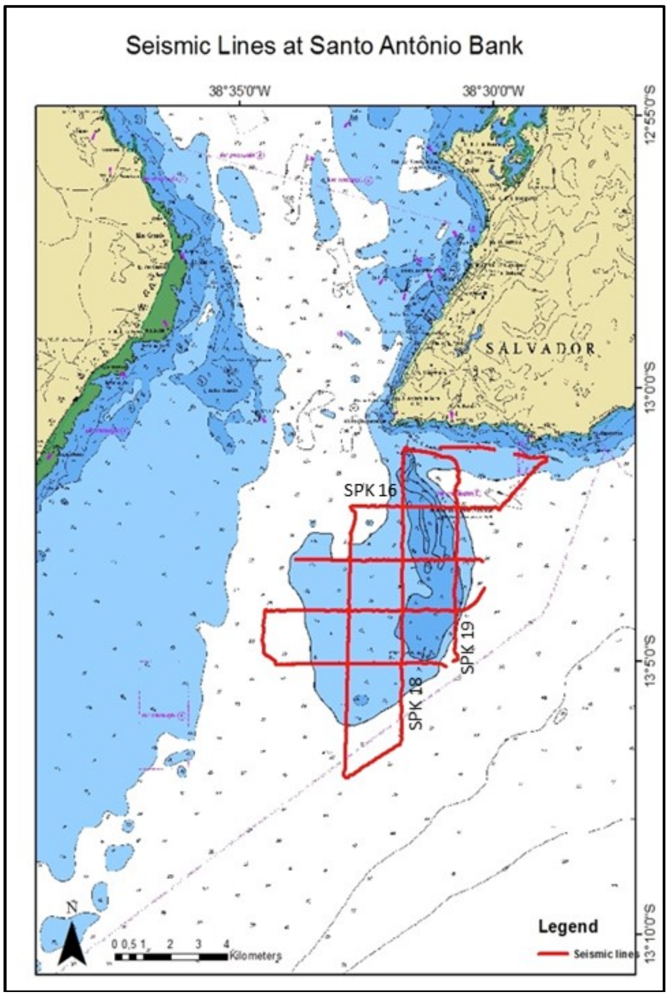

Figure 1- Study site and location of seismic lines

Results

Stratigraphic Units

Three major stratigraphic units were identified in the seismic profiles: (i) Acoustic Basement, (ii) Pre-Holocene Unit, and (iii) Holocene Unit.

Acoustic Basement – the acoustic basement consists of sedimentary rocks from the drift phase of the Camamu sedimentary basin (Figures 2 and 3). This unit is a topographic high, indented by small incised valleys. This high feature is separated from the coastline by a deeper incised valley, where today the Santo Antônio channel is located, and it is possibly controlled by the Barra fault that separates the Camamu from the Recôncavo basin. The top of the acoustic basement is located at a mean depth of 60 m below current sea level. Figure 4 shows a map of the top of the acoustic basement.

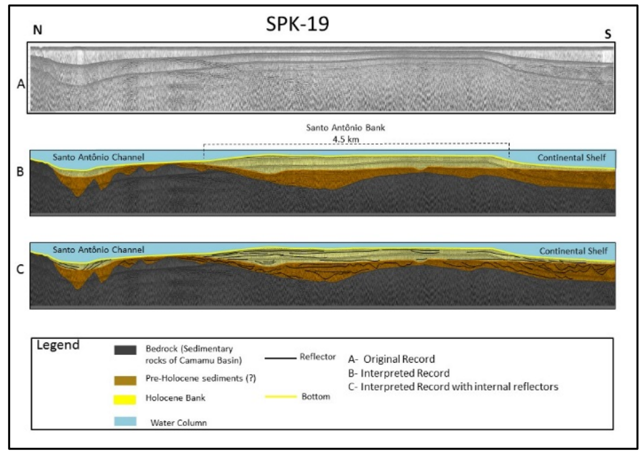

Figure 2 - Seismic profile of the SAB in its shallower portion. In this profile it is possible to observe the three major stratigraphic units identified for the SAB. 2A - High resolution uninterpreted seismic profile SPK19. 2B – Interpreted seismic profile. 2C - Interpreted seismic profile showing internal reflectors. See figure 1 for location.

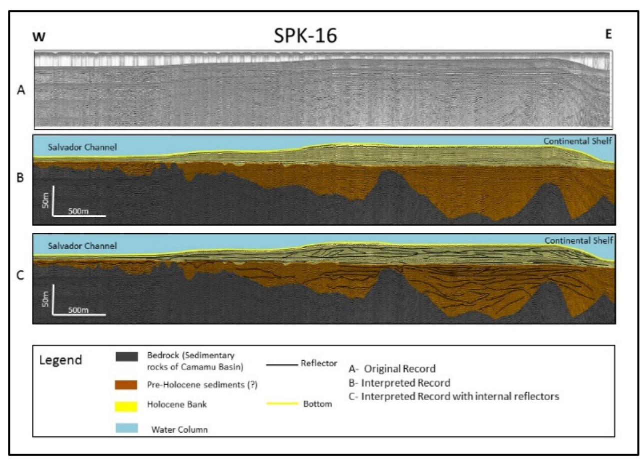

Figure 3 - (a) High resolution seismic profile SPK13- (B) Interpreted seismic profile. (C) Interpreted seismic profile with internal reflectors. See figure 1 for location.

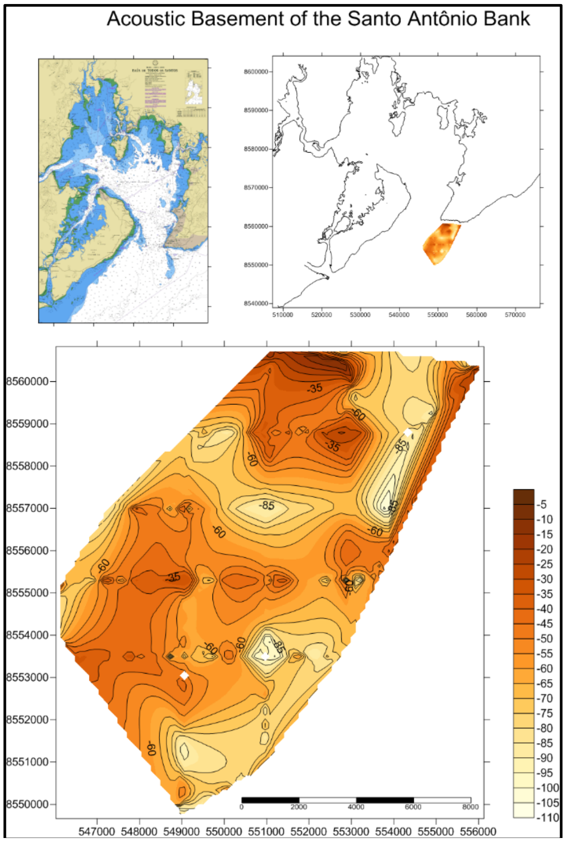

Figure 4- Top of the Acoustic Basement of the Santo Antônio Bank

Pre-Holocene Unit – this unit infills the incised valleys of the acoustic basement. The internal reflectors in this unit present a typically channeled geometry and the top of the Pre-Holocene Unit is characterized by a flattened surface (Figure 5). Moreover, the unit is located at a mean depth of 40 m below current sea level and extends along the whole bank, thus composing the base of the superimposed Holocene unit.

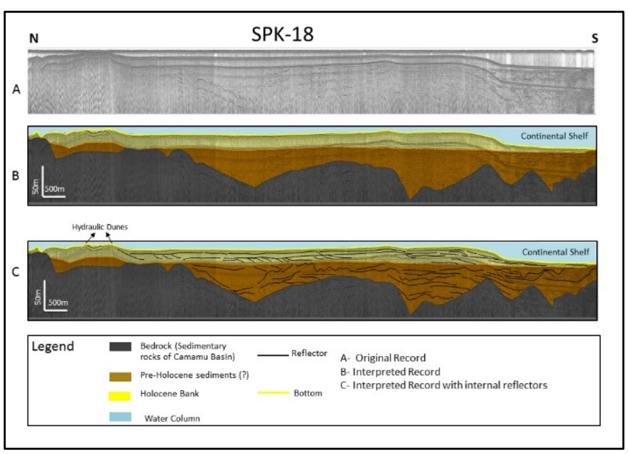

Figure 5- (a) High resolution seismic profile SPK13- recorded at the Santo Antônio Bank. (B) Interpreted seismic profile. (C) Interpreted seismic profile with internal reflectors. See figure 1 for location.

Holocene Unit – this is the main unit of interest in the present study, and comprises the current SAB per se. On the surface, this unit is covered by medium to fine siliciclastic sands. The character of the internal reflectors present in this unit indicates apparently uniform textural characteristics. The reflectors present typically aggradational and progradational patterns.

Figures 6 and 7 show, respectively, an isopach map of the total thickness of Quaternary sediments (Pre-Holocene and Holocene units) and an isopach map of the Holocene unit alone.

The volume of siliciclastic sand stored in the Holocene unit was calculated as 1.07 billion cubic meters of sand, which corresponds to a “Super Deposit” of sand.

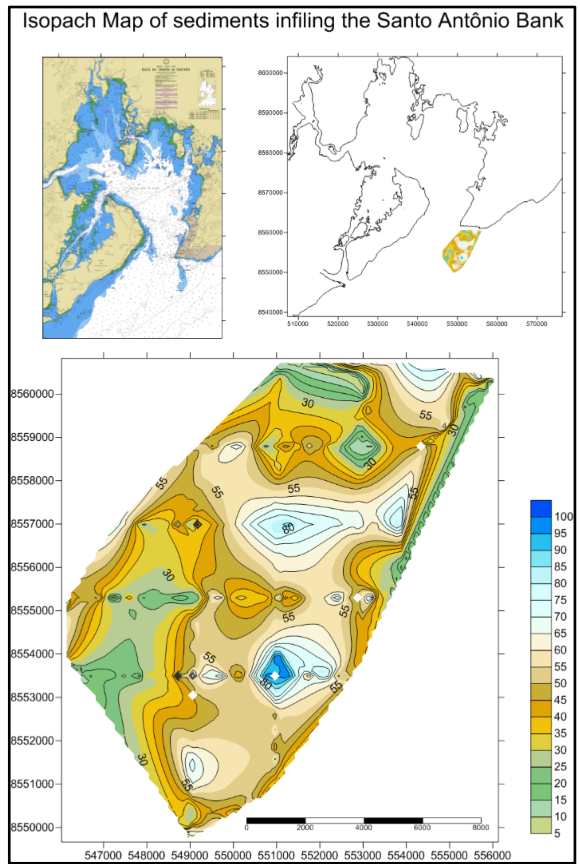

Figure 6- Total Isopach map of the Pre-Holocene and Holocene sedimentary units.

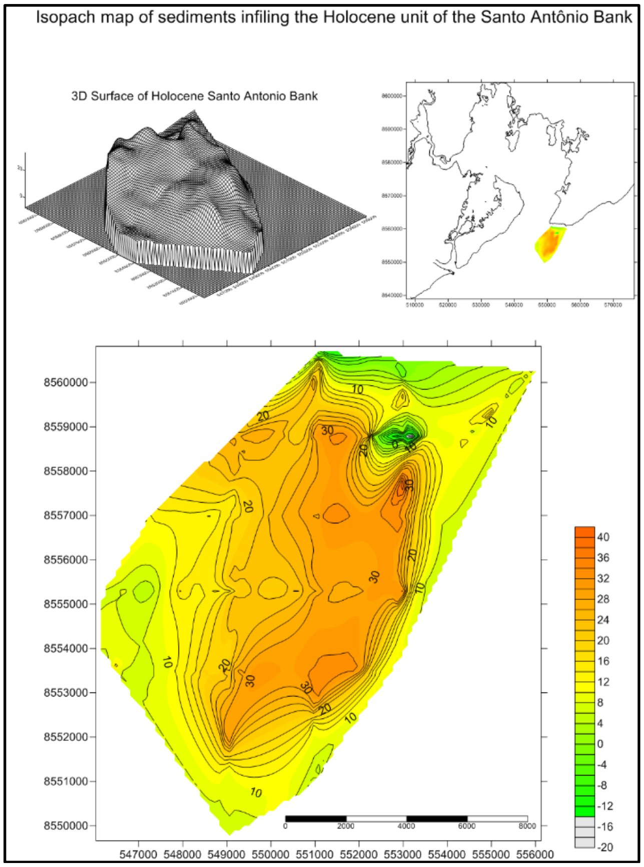

Figure 7 – Isopach map of the Holocene unit.

Origin of the Santo Antônio Bank

Three construction phases were identified for the SAB (Figure 8):

Phase 1 – Last Glacial Maximum – during the last glacial maximum (20,000 years BP) the sedimentary rocks of the Camamu Basin (acoustic basement) were totally exposed to subaerial erosion, resulting in the incision or deepening of the channels that drained its surface. The maximum depth of the top of the acoustic basement is presently -119 m, which indicates complete exposure during the glacial maximum when the sea level was at -120 m.

Phase 2 – With the rise in sea level after the last glacial maximum, the paleo-relief of the acoustic basement was progressively flooded with the incise valleys initially forming small estuaries. Around 10,000 years ago, the whole paleo-relief of the acoustic basement had already been flooded. The flattened surface that separates the pre-Holocene and the Holocene units may be related to a possible stabilization in sea level rise.

Phase 3 – This phase corresponds to the construction of the current SAB. Holocene age was attributed to the bank because its base is located 40 m below current sea level. This depth was only reached according to the available eustatic sea level variation curves after the beginning of the Holocene, about 10,000 years ago.

The Holocene unit is thicker along its north-south axis, and becomes thinner laterally eastwards and westwards. In the lateral portions of this unit, internal reflectors indicate bidirectional flows dipping towards the east and west, with onlap terminations on the underlying unit.

The most important hydrodynamic agent acting on the site are the tidal currents, which reach magnitudes of up to 1.1 m/s. These currents are controlled by the flood and ebb tides of the Todos os Santos bay, which produce a flow convergence over the paleo-high of the acoustic basement, in the same way that happens today in the SAB. This paleo-high feature acted as a trap for the sediments mobilized by the tidal currents. During flood tides, sediments are trapped on the eastern side of the bank, while during ebb tides sediments are trapped on its western side.

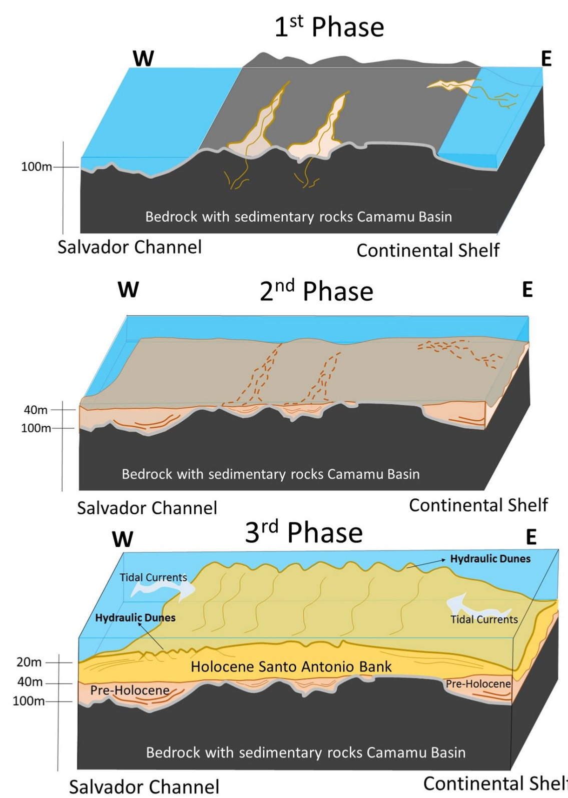

Figure 8- Schematic model for the origin of the SAB.

The Mineral Deposit

The volume of siliciclastic sand stored in the Holocene Unit of the SAB is of the order of 1,000,000,000 m³.

The municipality of Salvador presents close to 20 km of urban beaches. If we consider a beach nourishment project of a magnitude such as to increase beach width to 40 m, in all of the urban beaches in the municipality, a total of approximately 9-10 million m^3 of sand would be needed. Thus, the volume of sediment stored in the Holocene unit of the SAB is close to 100 times greater than what is needed to recover all urban beaches in the municipality. The proximity of this super deposit to a large urban center such as Salvador makes beach recovery through nourishment a very attractive option to mitigate erosive processes that affect the region, and which will be aggravated with a future sea level rise scenario.

Thus, the municipality of Salvador potentially presents great resilience to climate changes, considering sea level rise. Estimates have shown that by the end of the current century there will have been a sea level rise of the order of 0.26 m to 0.55 m, with a rise rate of 3.7 mm/year, depending on the scenario of greenhouse gas emission that was used. Moreover, greater frequency and intensity of extreme events, such as storm surges, has also been predicted (IPCC, 2013)

Beach nourishment is becoming increasingly common in Brazil as a method of coastline stabilization, and maintenance of tourism infrastructure. Some examples of beach nourishment projects in Brazil include Jaboatão in Recife (PE), Marataízes (ES), Copacabana (RJ), Piçarras (SC), Balneário Camboriú (SC), and Camburi (ES), among others (PRATA, 2005; MENEZES, 2008; ARAÚJO *et al*., 2010; ANDRADE, 2013).

Beach nourishment projects should be carefully planned, observing the morphodynamics of the beach, mean grain size, and oceanographic variations of the site, such as wave climate and occurrence of cold fronts. A well-executed project will guarantee its greater lifespan. Moreover, the costs for this type of endeavor are high and can vary between US$3.00 and US$13.00 (including the project aspects and design) per cubic meter. Depending on the volume of sediment necessary for the project, the total value can vary between US$0.5 and US$3.0 million per kilometer of beach (Davis Jr & Fitzgerald, 2004).

Conclusions

The Santo Antônio Bank is a feature formed over and controlled by a topographic high of the acoustic basement (sedimentary rocks of the drift phase of the Camamu sedimentary basin). Three major stratigraphic units were identified. Construction of the present SAB began 10,000 years ago after the flooding of this paleo-high by sea-level rise. This feature trapped sediments mobilized by flood and ebb tides at the Todos os Santos bay.

The volume of sandy sediments stored in the SAB consists on an important sand deposit for future use in civil engineering projects and for the recovery of urban beaches in Salvador.

The high resolution seismic method (Sparker) used in the present study, operating at a frequency of 0.3 to 1.5 kHz, was shown to be an efficient tool in the identification of geologic structures in sandy sediments, thus allowing an understanding of the origin of the Santo Antônio Bank, as well as identification of the major units present within this feature.

Acknowledgments

Ana Clara Coni e Mello and José Maria Landim Dominguez thank CNPq, respectively, for Master and Research Productivity felowships. The authors also thank the Technological Research Institute of São Paulo (*Instituto de Pesquisas Tecnológica de São Paulo*- IPT) and the NOVOS TALENTOS program.

Iana Durr thanks FAPESB for the IC Fellowship.

This study is a contribution of inctAmbTropic—Brazilian National Institute of Science and Technology for Tropical Marine Environments, CNPq/FAPESB Grants: 565054/2010-4 and 8936/2011 and FAPESB grant 8412/2014.

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