Sedimentation and depositional architecture of the delta of the São Francisco River using high-resolution seismic data

Adriane Gonçalves de Araújo Nunes Rangel* (LEC/UFBA & INCT-AmbTropic) and José Maria Landim Dominguez (LEC/UFBA & INCT-AmbTropic)

Abstract

During the Quaternary, sea level variations combined with sediment input from rivers resulted in the development of fluvial, estuarine and deltaic environments in the valleys of large rivers. The delta of the São Francisco River is internationally considered to be an example of a wave-dominated delta. The present study had the objective of investigating the submerged portion of this delta using high resolution seismic records (CHIRP). Part of the depositional sequence that accumulated during the last eustatic sea-level rise was documented. Three stratigraphic units were identified based on the internal character of the reflectors, their geometry and termination patterns. The two lower units (1 and 2) integrate the Transgressive Systems Tract and are separated from the upper unit (3) by a maximum flooding surface. The upper unit (3) integrates the Highstand Systems Tract and corresponds to the current clinoform of the delta. During the deposition of these three units there were changes in the depocenter, which moved from the NE portion of the investigated area (unit 1) to a more central position (unit 2), and later to a SW portion (unit 3). The current position of the depocenter is in accordance with the preferred transport and dispersion pattern of the present fluvial sediments. The present study allowed the reconstruction of the evolutional history of the São Francisco delta during the end of the Pleistocene/Holocene and demonstrated the importance of fluvial input in the construction of the delta.

Introduction

Although the delta of the São Francisco River has been extensively cited in the international literature as a classic example of a wave-dominated delta, very little is known about its dynamics and depositional architecture. Research carried out so far have been restricted to the emerged portion of the delta, where sedimentation is essentially sandy. Thus, the lack of information regarding the submerged portion of the delta motivated the present study, which presents for the first time a description of this submerged area, specifically of the delta front, near the continental shelf break, by means of high resolution seismic records.

High resolution seismic methods have been widely used in the investigation of shallow submerged areas to determine the morphology and thickness of sedimentary strata, geological contacts, presence of paleochannels, and to map the morphology of the acoustic basement (Souza, 2006).

During the Quaternary, sea-level variations combined with sediment input from rivers had an important role in the development of fluvial, estuarine and deltaic environments in the valleys of large rivers. During the last glacial maximum, approximately 20 ka AP, the continental shelf adjacent to the modern delta of the São Francisco River was exposed subaerially, and an incised valley had been excavated by the same river. Incised valleys are formed during falls in sea level as a result of rapid fluvial erosion on the continental shelf. With the subsequent rise in sea level, this valley was flooded, retaining fluvial and marine sediments, thus originating a wave-dominated estuary. Delta progradation only began some 8 ka AP as a result of the decrease in sea-level rise rates in regard to the input rate of sediments from the river (Guimarães, 2010).

Deltas are depositional environments associated to river mouths and are fed by various sources of sediments. In this environment, sediment supply surpasses sediment reworking by processes that act upon the depositional basin, which thus results in the irregular progradation of the coastline (Bhattacharya, 2006; Dominguez, 1990). Unlike estuarine systems that can be defined fundamentally as transgressive depositional systems, in which sedimentation occurs associated with the input of marine and fluvial sediments, delta sedimentation derives basically from fluvial inputs, composing a regressive depositional system (Dalrymple et al., 1992).

The São Francisco delta is located on the border between the states of Sergipe and Alagoas and presents a delta plain of approximately 800 km^2 (Medeiros et al., 2007). Due to intense reworking by waves, the delta plain is dominated by sandy beach deposits, with mean thickness of the order of 14 m. On the other hand, the delta clinoform on the continental shelf is composed essentially by muddy sediments. The continental shelf adjacent to the delta is narrow, with mean width of 30 km and a shelf break at about 50 m.

Currently, the dispersion of fluvial sediments along the coastline and on the continental shelf is predominantly towards SW.

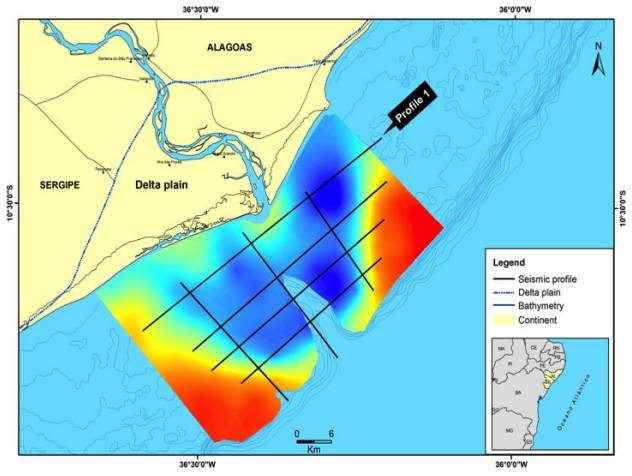

Figure 1: Map of the study site showing the location of the seismic profiles used in the present study and the distribution of the D50 values on the continental shelf. While the fine sediments (depicted in cool colors) are predominantly siliciclastic, the sediments found on the outer continental shelf are gravelly and composed by coralline algae fragments (depicted in warm colors).

Method

The seismic records used in the present study were acquired during two field surveys carried out in January and March 2012, using a sub-bottom profiler by EdgeTech®, model SB-216S, operating between frequencies of 2 and 16 kHz. Sub-bottom profilers are known generically as SBP and are intermediate power acoustic systems that emit high frequency spectra, thus allowing the visualization of subsurface features.

The sedimentary packages were individualized based on the principals of seismic and sequence stratigraphy, given the patterns of truncation and termination of the seismic reflectors. After identifying the sedimentary packages, each one was measured regarding their thickness, so to allow the elaboration of of isopach maps for each unit. Data processing, including the marking of seismic reflectors and determining the thickness of the identified units, was performed using SonarWiz5® software from Chesapeake Technology.

The data were exported to a GIS environment where isopach maps were generated for each of the observed sedimentary packages. Moreover, these data were integrated to the surfacel sampling data and shallow cores sampled during the execution of the present project.

Results

Major Stratigraphic Units

Acoustic masking due to the presence of gas in the sediment compromised greatly the penetration of the acoustic signal over most of the delta clinoform. Only in the more distant regions was it possible to adequately investigate the sedimentary units (Figures 2 and 3). The acoustic basement outcrops laterally and form the present continental shelf bottom, which is covered by bioclastic gravel composed of coralline algae, based on the information from surface sediment sampling.

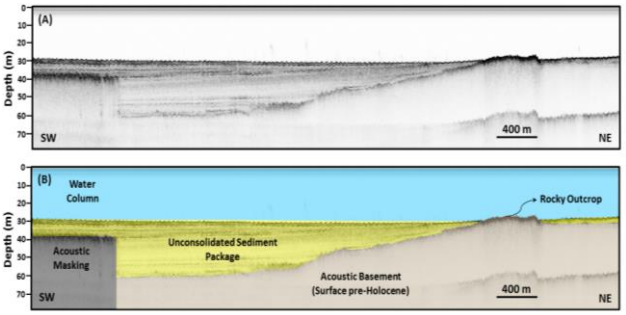

Figure 2: Northeastern extremity of seismic profile 1 depicting the acoustic masking caused by the presence of gas in the sediment, the acoustic basement, and the superimposed sedimentary package. (A) Uninterpreted profile, (B) Interpreted profile.

Stratigraphic units

The portions of the seismic sections that were not masked by the presence of gas allowed the identification and subdivision of the depositional sequence that infills the incise valley of the São Francisco River in 3 major units. These units are separated by clearly marked seismic/stratigraphic horizons, herein denominated h1, h2 and h3.

The acoustic basement marks a sequence boundary, formed during the subaerial exposure of the region during the last glacial maximum (20 ky BP). The more basal stratigraphic unit was deposited over the acoustic basement. This unit presents mean thickness of the order of 10 m and internally presents plane-parallel medium amplitude reflectors onlapping the acoustic basement. This unit is interpreted as the basal portion of the Holocene depositional sequence, which lies directly over the sequence boundary represented by the acoustic basement. Moreover, the unit can be considered to be part of the transgressive systems tract, which accumulated during the estuarine phase of the delta.

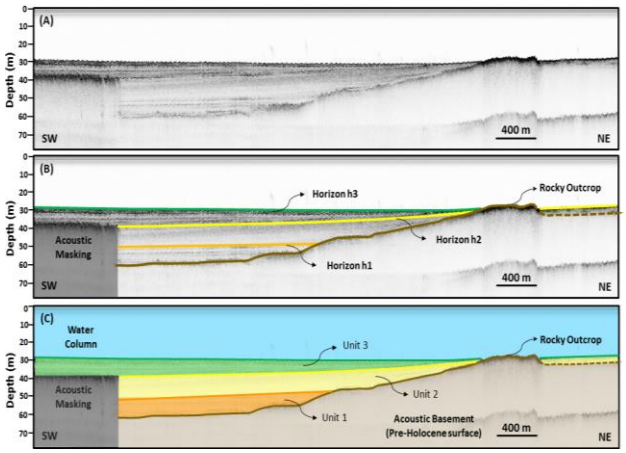

Figure 3: Northeastern extremity of seismic profile 1. (A) Uninterpreted high resolution seismic profile; (B) interpreted seismic profile showing the most important stratigraphic surface; (C) interpreted seismic profile showing the three stratigraphic units bounded by stratigraphic surfaces h1, h2 and h3.

The top of unit 1 is limited by a downlap surface herein denominated horizon h1. Unit 2 accumulated over this horizon and presents mean thickness of the order of 10 m. Moreover, this unit is seismically transparent and does not present internal reflectors, which suggests it is composed predominantly by very fine sediments that also onlap the acoustic basement and exhibit a very subtle downlap pattern over the Unit 1. Unit 2 is also considered to be part of the transgressive systems tract and interpreted as associated with the maximum flooding stage of the delta.

The top of unit 2 is a well-marked downlap surface (horizon h2), over which Unit 3 was deposited. Unit 3 presents mean thickness of 10 m and medium amplitude internal reflectors with offlap geometry. This unit is associated with the current delta clinoform, which downlaps horizon h2. Horizon h2 represents the maximum flooding surface separating the transgressive systems tract from the highstand systems tract, which corresponds to the current episode of delta progradation. The top of unit 3 is the current seafloor (horizon h3). The internal bedding shown by unit 3 reflects the episodic character of deposition by great river floods.

Figures 4, 5 and 6 depict isopach maps elaborated, respectively, for units 1, 2 and 3. Due to the presence of gas in the sediment, a large portion of the delta accumulation could not be insonified and the values presented in these maps should be regarded as the probable minimum values.

These isopach maps indicate, however, possible changes in the position of the sediment depocenters. Unit 1, which belongs to the transgressive systems tract, presents greater thickness in the northeastern portion of the investigated area. Unit 2, which is associated with the maximum flooding of the alluvial valley of the São Francisco River, and also part of the transgressive systems tract, presents a more or less symmetrical distribution in relation to the current river axis. The greatest thickness of this units is observed in the outermost portion of the current delta clinoform.

During deposition of Unit 3, which integrates the highstand systems tract, the depocenter migrated to the southwestern portion of the delta, which corresponds to the preferred direction of the current transport of fluvial inputs.

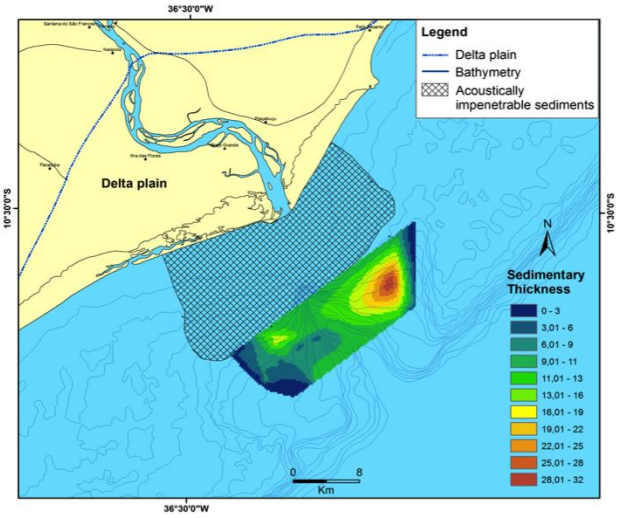

Figure 4: Isopach map of stratigraphic unit U1 (Transgressive systems tract).

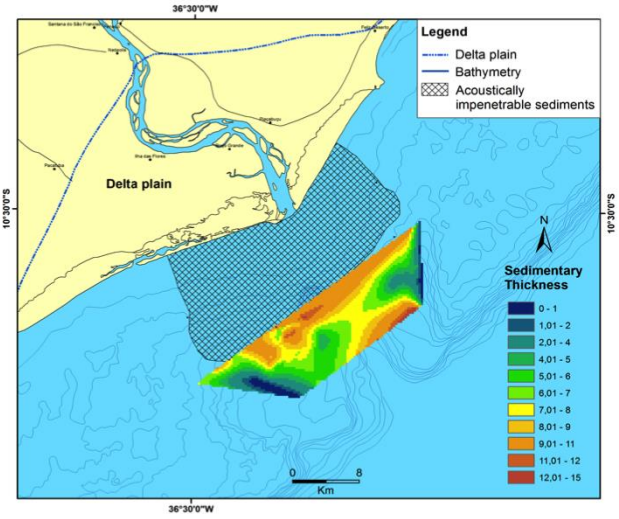

Figure 5: Isopach map of stratigraphic unit U2. (Transgressive systems tract - maximum flooding).

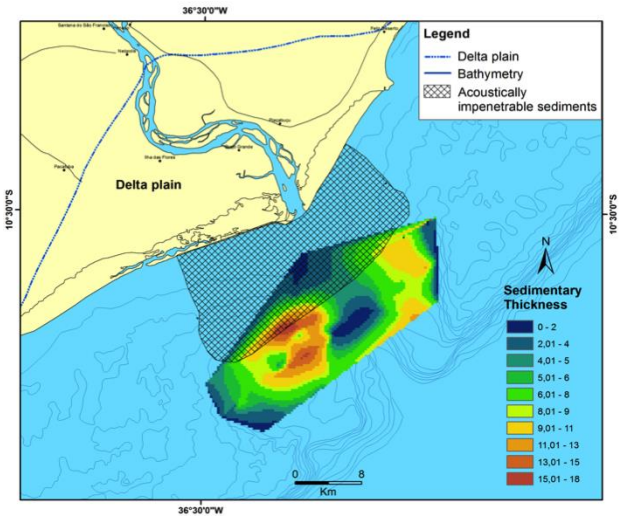

Figure 6: Isopach map of stratigraphic unit U3 (Highstand systems tract).

Conclusion

High resolution seismic records (sub-bottom profiler) of the submerged portion of the delta of the São Francisco River demonstrated the presence of three well-marked stratigraphic units that integrate the most recent depositional sequence associated with this delta. This sequence accumulated during the rise in eustatic sea level after the Last Glacial Maximum. The transgressive systems tract is composed by the two lower units (Units 1 and 2), while the highstand systems tract (Unit 3) corresponds to the current progradation of the delta clinoform. A well-marked maximum flooding surface separates the upper unit of the transgressive systems tract (unit 2) from the highstand systems tract (unit 3). These new data are compatible with the results produced recently by Guimarães (2010), who identified thick estuarine and marine sequences, of the order of 20-30 m, below the beach sand of the current delta plain.

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