Indications of a paleo-river mouth of the São Francisco River using ground-penetrating radar

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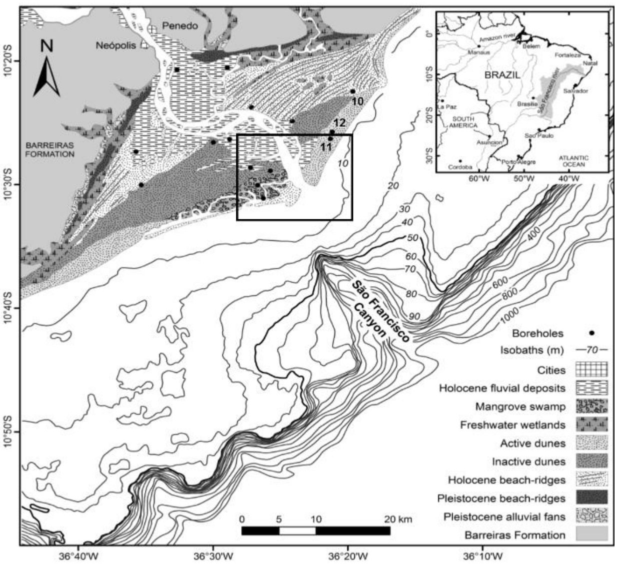
Abstract

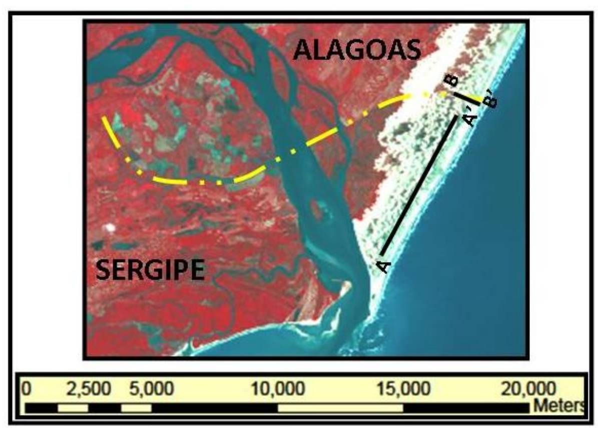
The present study used GPR (Ground Penetrating Radar) to investigate a possible paleo-river mouth of the São Francisco River, located to the northeast of the current mouth. Four radar facies were identified associated to the following depositional environments: beach face, sandy spit, dunes and channel infilling. The presence of a paleochannel was confirmed in the present survey. Maximum age was estimated as 3,430 years BP (Before Present) for this feature, based on radiocarbon dating.

Introduction

The mouth of the São Francisco River, one of the largest rivers in South America with an extension of 2,863 km, is located on the border between the states of Sergipe and Alagoas. A wave dominated delta has developed at the river mouth and occupies close to 800 km^2 (Figure 1A). The most important features of this delta plain are beach ridges, which occur on both sides of the river mouth, demonstrating the importance of waves to its construction.



(A)



(B)

Figure 1A – Map of the location of the study site with its main geomorphological units. Figure 1B – Detail of the study site with the location of the GPR sections (in black) and the position of the left margin of the paleo-river mouth (in yellow).

The central portion of the delta is characterized by a broad floodplain, which developed associated to the current river channel. This floodplain contains various morphological evidences that the river has changed its position several times throughout the history of the delta. These changes can be noted as truncation patterns of the beach ridges.

One of the most recent changes in the position of the river mouth is clearly observable from satellite images, as indicated in figure 1B. In this case, evidence indicates the existence of a paleo-river mouth located to the northeast of the current mouth. The objective of the present study was to confirm the existence and characterize this paleo-river mouth using GPR.

GPR utilizes propagation electromagnetic (EM) waves in shallow subsurface investigations. The propagation velocity of EM waves, which is the principal controlling factor on the generation of reflections, is determined by the relative permittivity ε_r contrast between layers.

The investigated area is located immediately northeastwards from the current river mouth. The site presents a field of active dunes, characterized by the presence of barchan dunes, separated by inter-dune regions where low shrub-type vegetation predominates. These dunes have advanced over the paleo-river mouth, smothering it completely. On the left margin, northwards of the paleo-river mouth, dunes cover beach deposits related to coastline progradation, as shown in SPT surveys carried out by Guimarães (2010).

Method

Two GPR sections were acquired on and near the site of the old river mouth: A-A' parallel to the beach; and B-B' perpendicular to the beach (Figure 1B). The first measured 5,738 m in length and the second, 1,497 m.

A GSSI SIR-3000 TERRASIRCH System (one-channel GPR) device was used with a GSSI Model 5106A - 200 MHz monostatic antenna (transmitter and receiver) (Figure 2).

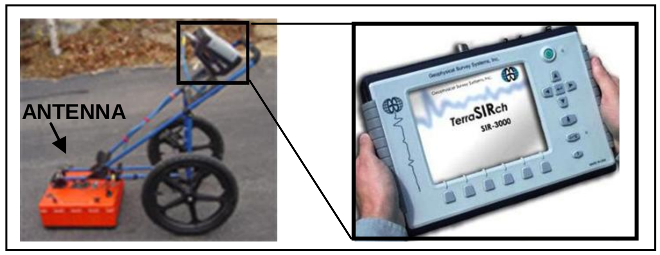


Figure 2 – Equipment used for data acquisition.

The transmitting antenna generates an EM pulse that travels on the surface, where part of this wave is subaerial and part direct. The other part of the wave travels into the subsurface and then either reflected off an interface or scatters off point sources (both caused by a contrast in relative permittivity ε_r). This reflected/scattered energy then travels back to the surface, where it is recorded by the receiving antenna. The time it takes for the wave to travel down to an interface and back up to the surface is called the travel time, which is given in nanoseconds (ns).

Relative permittivity is a critical parameter in GPR studies in that it controls signal propagation velocity and thus wavelength, where wavelength is, of course, critical in determining resolution constraints (Table 1). For example, material that has low relative permittivity will yield high GPR signal propagation velocities and, thus, long wavelengths, allowing only low resolution.

Table 1 – Relative permittivity (ε_r) and EM velocity for selected geologic materials.

Material	ε_r; Davis and Annan (1989)	ε_r; Daniels et al., (1995)	Velocity (m/ns)
Air	1	1	0.3
Fresh water	80	81	0.03
Sea water	80		0.03
Dry sand	3-5	4-6	0.12-0.17
Wet sand	20-30	10-30	0.05-0.09

Dry sandstone		2-3	0.17-0.21
Wet sandstone		5-10	0.09-0.13
Limestone	4-8		0.11-0.15
Clays	5-40		0.05-0.13

Processing

The data processing was carried out with Reflex-Win 5.0 software, using the following processing sequence: start time (static correction), background removal, DEWOW, remove header gain, energy decay, band pass frequency, trace georeferencing and correct 3Dtopography.

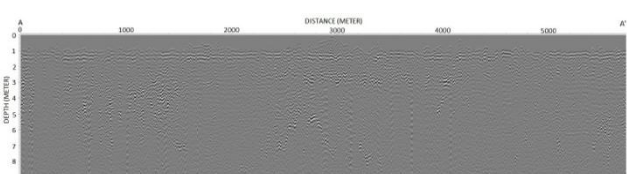
The first step in interpretation is to understand the behavior of the propagation velocity of the radar waves in the studied mean, so that the recorded data can then be converted to depth. Thus, a mean speed was used (0.07 m/ns and 0.13 m/ns, profiles A-A' and B-B'), which satisfactorily represented the investigated materials, allowing for the time scale to be converted to depth with good representation of the reality.

The reflectors that were present in the radargrams were analyzed and interpreted according to geophysical and geological criteria, using stratigraphy principals:

- Original horizontality of the strata;
- Lateral continuity;
- Spatial relationships between the reflectors;
- Lateral succession of facies.

Results

The processed profiles are illustrated in Figure 3.



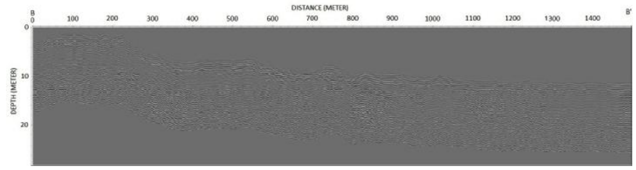


Figure 3 – Radargrams of profiles A-A' and B-B'.

Four radar facies were identified: (i) large amplitude reflectors gently dipping towards the coastline, (ii) moderately inclined large amplitude reflectors dipping parallel to the coastline, (iii) predominantly horizontal low amplitude reflectors; and (iv) transparent (no visible reflectors).

Figures 4 and 5 illustrate the spatial distribution of the radar facies in profiles, their stratigraphic relationships and the depositional environments in which they accumulated.

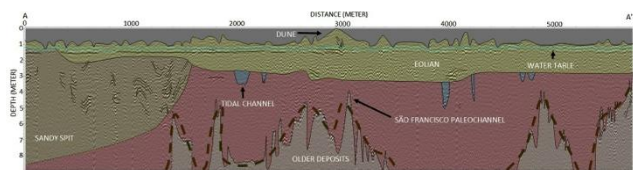


Figure 4 – Interpreted profile A-A'.

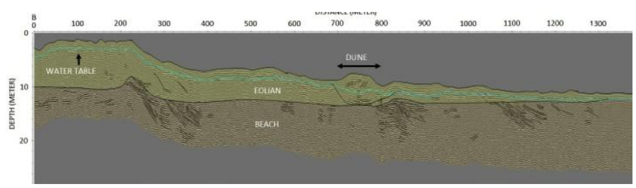


Figure 5 – Interpreted profile B-B'.

Radar facies 1 (large amplitude reflectors gently dipping towards the coastline) was only present in profile B-B' and was interpreted as being indicative for beach face deposits characterized by low-angle parallel stratification. This radar facies occurred continuously in the basal portion of profile B-B', which is in agreement both with the evolution history of the region and with the SPT survey results obtained in the same site by Guimarães (2010).

Radar facies 2 (moderately inclined large amplitude reflectors dipping parallel to the coastline) was only present at the beginning (southwestern extremity) of profile A-A'. This facies was interpreted as the result of deposition associated to the lateral extension of a sand spit. This sand spit would have been formed by longshore drift action and grew longitudinally southwestwards, partially obstructing the river mouth, especially during low discharge periods, such as what currently occurs in the mouth of the São Francisco River, as shown in Figure 1B.

Radar facies 3 (predominantly horizontal low amplitude reflectors) occurred continuously on the top of both profiles and was interpreted as the result of wind sedimentation that characterizes the surface of the current terrain.

Radar facies 4 (transparent with no visible reflectors) was only present in profile A-A' and overlied a well-marked reflector with high amplitude and channeled geometry. This radar facies was interpreted as a channel infilling deposit, dominated by fine sediments, either of fluvial or estuarine origin. At the top of this infilling, channeled features were identified measuring between 0.25 m and 1 m in width and 0.40 m and 1.6 m in depth. These dimensions are compatible with small tidal channels that are present in the surrounding areas and were interpreted as being so.

The reflector that composed the base of radar facies 4 occurred at increasingly greater depth towards the southwest, disappearing locally. This morphology suggests the bottom of a channel that was abruptly abandoned and later infilled by fine sediments. The depth of this paleochannel is around at least 8.8 m, which is compatible with the current depths shown by the São Francisco River at its mouth.

Although these radar facies have not been dated, beach deposits located to the side of this paleo-river mouth have been dated as 3,430 years BP by Guimarães (2010), which provides a maximum age for this paleochannel.

Conclusions

Georadar technology allowed the confirmation of the existence of a paleo-river mouth located northeastwards from the current mouth of the São Francisco River. The geometrical characteristics of this paleo-river mouth are compatible with the dimensions of the current channel of the São Francisco River near the current river mouth. A maximum age of 3,430 years BP can be attributed to this feature.

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