GPR and low-induction EM-38 survey applied on coastal *sambaqui* (shell mound) archaeological site in Santa Catarina State, south Brazil

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*Abstract* - The technological advance in the last decades have motivated the application of geophysical methods in archaeological investigation in order to select suitable places for excavation, and to optimize the time and costs involved with the exploratory process. In this paper, some GPR and EM38 survey results in Santa Marta-IV coastal *sambaqui* archaeological site are presented. Santa Marta-IV site is in Santa Catarina state, in the South of Brazil. This *sambaqui* consists of sand mound covered by decimetre black sediment layer with carbonatic shells, dated of 4970-4830 years AP (Beta 189713), and could be constructed by societies that inhabited this region during pre-colonial period. GPR profiles show interesting anomalous reflectors, which can be related to targets of archaeological interest. A strong horizontal reflector can be related with *sambaqui* bottom and a punctual hyperbolic reflector probably is related with some archaeological artefact. GPR depth slices show an anomaly with high amplitude that is related to a punctual reflector. Magnetic susceptibility shows an anomaly region in which presents a good agreement with GPR results for same place. GPR synthetic model presented good accordance with real data obtained in the field. GPR reflection pattern anomaly was related with a burned material (fire place) and a strong horizontal reflector was related with the *sambaqui* bottom in which is characterized by the rich archaeological layer, in which were excavated after of results analysis. The geophysical results permit to orientate the excavation and guarantee the success of this research. The next step of this research will be collect sample of the fire place and send it to be dated.

*Keywords* - GPR, EM-38, FDTD modelling, archaeology, coastal *sambaquis*, fire-places, Brazil.

I. INTRODUCTION

Present archaeological studies are been carried out since scientific methodological integration, such as, archaeological, geophysical, geological, biological, among others. This way allows a time decrease as well as cost involved in characterization, excavation, and archaeological artefacts analysis.

Among scientific methods, geophysical one is frequently used in the characterization and structure delimitation covered by geological material. Some geophysical studies applied in archaeology can be found in the literature. GPR – Ground Penetrating Radar method is distinguished for being not destructive, and allows investigating shallow subsurface with high resolution as lateral as vertical [1, 2]. In Brazil, the use of GPR method in archaeological sites is still incipient [3, 4, 5, 6, 7, 8]. Gomes [9] has used inductive electromagnetic method (EM-38) to study a fluvial *sambaqui* archaeological site in Ribeira de Iguape valley, São Paulo state, and he has found a fire-place.

In this study, geophysical surveys had been done by using inductive electromagnetic (with EM-38 equipment) and GPR methods in Santa Marta IV coastal *Sambaqui* archaeological site, located in Santa Marta Lighthouse, Jaguarauna city, Santa Catarina state, south of Brazil (Figure 1). This work had as objective to detect structures with archaeological potentials as well as to optimize resources involved in the exploration process.

*Sambaquis* from that region are characterized by accumulating of carbonatic shells with variable concentrations of sand and mud, being constructed by societies that inhabited South Brazil during pre-colonial period, since at least about 6,000 years AP [10]. Santa Marta IV archaeological site is formed by four *sambaqui* archaeological sites. The presence of successive layers consisting of burials, lithic materials and alimentary rests (shellfishes, fishes) provided last years, a descriptive analysis, mainly based on funerary structures, it means, *sambaquis* from cemeteries [11].

The integration of GPR and EM-38 results allowed characterizing geophysical anomalies with archaeological poten-
tials. GPR profiles show anomalous reflectors, which can be related to structures of archaeological interest, and presented good accordance with 2D numerical simulation results. These simulations were important in order to give reliability in result interpretation, besides verifying if contrasting physical properties among materials are significant to generated GPR reflections. Anomalies obtained with EM-38 were subtle, showing low electric conductivity values and high magnetic susceptibility values, seeming to be a pointer of fire-place presence, as already observed for Gomes [9]. Geophysical results were sufficiently interesting, and allowed guiding archaeological excavation, in which a fire-place, which is important for archaeological studies in progress in that region, was found.

II. METHODOLOGY: DATA ACQUISITION AND TREATMENT

EM-38: Twenty electromagnetic profiles were acquired with Vertical Magnetic Dipole – VMD. Profiles have 5 m of extension and with 0.5 m in distance each other. Measuring points were in each 0.5 m. Acquisition with VMD was adopted because allowing higher depth of observation, around 1.5 m [12]. Data set allowed 3D grid was constructed through concatenation of some 2D parallel profiles to one grid 2D.

Amongst the main stages involved in inductive electromagnetic data treatment are distinguished: organization of profiles in spreadsheets, instrumental drift correction, construction of apparent electric conductivity and magnetic susceptibility graphs and maps. Instrumental drift is a variation in mean apparent conductivity that occurs due to variation of environmental temperature [13]. This effect was corrected since a base-point chosen next to the study area, and it is based on reading of previous and posterior measured points obtained along profile.

Profiles were organized in spreadsheets, and since field data, in apparent conductivity versus distance, and magnetic susceptibility versus distance graphs were constructed using Surfer 8 (Golden Software) software. Results were generated by Krigagem method and finally plotted in a map of contour curves in terms of apparent electric conductivity.

GPR: Twenty GPR profiles with 200 MHz armoured antennas were acquired by GSSI system SIR-3000 model. Profiles were acquired in a continuous way, with distance between the profiles of 0.5 m, and 0.04 m of trace interval, doing a linear distance of 5 m. GPR profiles were acquired in a square area in order to obtain a 3D mesh by 2D data interpolation, in the same line where were acquired EM-38 data. GPR profiles had been acquired on sambaqui with the intention to characterize archaeological targets and geological layers related to sambaqui sitting.

Radan software (GSSI) was used to data processing; to data modelling, Reflex software. The main steps used in data processing were: time-zero correction, band-pass filters to removal of low and high frequency noises, gains in time to compensate signal losses, and then to amplify reflector signals, which can be related to archaeological artefacts, and time-depth conversion in which 0.09 m/ns velocity was employed, obtained from velocity analyse [14].

2D numerical modelling was done to give reliability to GPR profile results. In order to study propagation and reflection behaviour of electromagnetic fields, a numerical method of Finite Difference Time Domain (FDTD) was used [15]. The model is discretized in a compound grid by a finite set of points, represented by knot mesh. Each knot represents a vector field with electrical and magnetic properties. In this way, modelling can predict results obtained in real data acquisition, besides helping to interpret these real data, through integrate analysis.

Physical properties, electrical conductivity ($\sigma$), and relative dielectric permittivity ($\varepsilon_r$) were used to construct a synthetic model according to literature (Table 1), and relative magnetic permeability value was equal to 1 for all simulated materials. 200 MHz antennas were used to numerical modelling, with spacing between traces of 0.02 m, Ey-Ey antenna polarization (TE mode), and source of plane wave type.

Table 1. Electric properties used in synthetic model of Santa Marta IV sambaqui [16].

<table>
<thead>
<tr>
<th>Materials</th>
<th>$\varepsilon_r$</th>
<th>$\sigma$ (S/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human bones</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>Organic sediment</td>
<td>9</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Combustion material (fire-place)</td>
<td>14</td>
<td>5 x 10</td>
</tr>
<tr>
<td>Carbonatic shell</td>
<td>12</td>
<td>$10^4$</td>
</tr>
<tr>
<td>sand-clay sediments saturate</td>
<td>15</td>
<td>$10^2$</td>
</tr>
</tbody>
</table>

III. DISCUSSION OF RESULTS

Results of GPR and EM-38 surveys obtained in Santa Marta IV archaeological site are presented in Figure 2. Figure 2a shows a GPR depth slice in 1.5 m of depth. A clear region of anomalous high amplitude reflection in positions of $x = 2$ m, and $y = 2$ m is observed. According to Conyers [1], GPR reflections with higher amplitude have more possibilities to be related to archaeological targets. Note this anomaly was also characterized by EM-38 data. Exactly in this position, there are low electric conductivity values (Figure 2b), and high magnetic susceptibility values (Figure 2c). Although this value inversion is subtle between electric conductivity and magnetic susceptibility data, this response pattern seems to be related with
burnt material presence proceeding from fire-places, as already observed in the literature [9].

To assist the interpretation of geophysical results, numerical 2D GPR simulation was done considering an artefact of archaeological interest observed in the referring GPR profile to this position (Figure 2a).

Figure 3a shows a 2D GPR profile corresponding to the position \( y = 1.8 \text{ m} \), corrected of topographical variation. In this profile two strong sub-horizontal reflectors are observed. According to DeBlasis et al. [10], continuous reflectors can be indicating the presence of archaeological layers consisting by burials, lithic materials and food rests, common in \textit{sambaquis} from this region. Deeper sub-horizontal reflector (~2.5 m of depth) can be indicating \textit{sambaqui} basis sitting. Besides sub-horizontal reflectors, a punctual reflector well located between 1.5-2 m positions and 1.5 m of depth is clearly observed. This reflector could be indicative of archaeological vestiges. This reflector was well delimited as shown in depth slice (Figure 2a).

According to field observation, structures associated to archaeological vestiges normally are found in two-archaeological layer contact. This fact reinforce the hypothesis of this punctual reflector is related to an artefact of archaeological interest, located next to the contact with the first archaeological layer. On the other hand, for specific literature [3], the presence of archaeological artefacts in funerary rituals is common in this \textit{sambaqui} community. To assist the interpretation of results, numerical 2D GPR simulation was made considering an artefact of archaeological interest as observed in GPR profile (Figure 2a).

Figure 3b presents Santa Marta IV \textit{sambaqui} synthetic model characterized by three layers, such as, organic sediment, carbonatic shells and wet sandy-clay sediments, as well a target that simulate archaeological artefacts buried. It is worth to emphasize this synthetic model refers to a supposed archaeological structure, based on information of other \textit{sambaquis} that have already been excavated.

Figure 3c shows 2D numerical modelling result obtained with 200 MHz antennas. Synthetic section was characterized by sub-horizontal reflectors that correspond to simulated layers. O hyperbolic reflectors characterize a punctual target, which simulate archaeological artefacts. These results are encouraging because present good accordance with real data. Later, archaeological excavation had been executed in this place, having as direct reference the geophysical information. Results had proved the presence of burnt materials in a fire-place (Figure 4). Next steps of this research consist in carrying out archaeological excavations in other areas of the Santa Marta IV site based on geophysical profiles.

IV. CONCLUSION

GPR and EM-38 results permitted to localize combustion materials found in a fire-place that was delimited by GPR depth slice. Moreover, inside the archaeological area was possible identified some sub-horizontal structures with greater potential to finding artefacts of archaeological interest. One of sub-horizontal structures seems to be related to \textit{sambaqui} basis. Numerical modelling present good accordance with real data, and served to give greater reliability in the interpretation. Geophysical result integration with field observation serves of reference-guide to direct excavation activities, reducing costs of exploration stages. These results are important to archaeological studies in Santa Maria IV site, corroborating development researches.

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REFERENCES


Figure 1. Localization of study area, Santa Catarina state, south of Brazil.
Figure 2. Depth slice in 1.5 m depth obtained in Santa Marta IV archaeological site. a) GPR profiles. b) Electric conductivity (EM-38). c) Magnetic susceptibility (EM-38).
Figure 3. a) GPR profile showing a punctual target of archaeological interest. b) Synthetic model built starting from Figure 3a. c) Result of numerical simulation obtained with 200 MHz antennas.

Figure 4. Photography showing the presence of materials burnt in a fire-place.