Ground Penetrating Radar (GPR) over Calembre Glacial Striated Pavement, Parnaíba Basin, SE Piauí State, NE Brazil.

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Abstract

This paper provides an overview about a geophysical survey with Ground Penetrating Radar (GPR) imaging over a striated glacial pavement close to the SW border of the Parnaíba Paleozoic Basin in the NE of Brazil Platform. The striated pavement is situated in the upper part of the Cabeças Formation where there is an erosional unconformity separating the Cabeças sandstones and overlying tillites. The Cabeças Formation consists of cross-bedded conglomeratic sandstones and sandstones, massive tillites, and laminated rhythmites with dropstones. Clasts in tillites range in size from small pebbles to boulders, with some of them striated, faceted and polished. The Cabeças Formation is as old as Famennian (late Devonian). The Famennian time lasted from 374.5 to 359 million years ago and it was preceded by the Frasnian stage and followed by the Tournaisian (Mississipian) stage. This formation was deposited on a plataform setting, tidal-dominated deltaic system and was accumulated under periglacial and glacial conditions. The principal objective of the GPR application over this glacial pavement was to know if the EM GPR system is able to show some important internal sedimentary structures below to the surface. The good resolution of the 200 Mhz antenna results shows indeed several internal structures, radar facies and differences in the signal amplitude that could be correlated with changes in sedimentary layers/deposition/facies and correlations with the ice flow direction records in depth. Almost 3 selected radar packages interpreted as equivalent to lithofacies assemblages were observed.

Introduction

The Calembre Striated Pavement Area is located in southern portion of Parnaíba Paleozoic Sedimentary Basin, 360 km South of Teresina City and near the Calembre village, in the Brejo do Piauí Municipality.

This site was close to the area released by Malzahn (1957), who was the first to describe striated pavements, when he was mapping the region for Petrobras (Brazilian State Oil Company). On the other hand several papers from Caputo described glacial rocks in northern Brazil (Caputo, 1984,1985, Caputo et al. 2005, 2008, Caputo and Ponciano, 2013). The most interesting paper was the record of the Calembre Striated Pavement as a Geologic and Paleontologic Site in Brazil (Caputo & Ponciano, 2013). Figure 1 shows the geographical localization of the Calembre Site in the Parnaíba Basin, in the NE portion of Brazil, in the Piauí State.

The site is located about 360 km in the south direction of Teresina City. The nearest town is Canto do Buriti, where through the BR 324 road we can reach the village of Calembre in São Raimundo Nonato city direction (Figure 1).

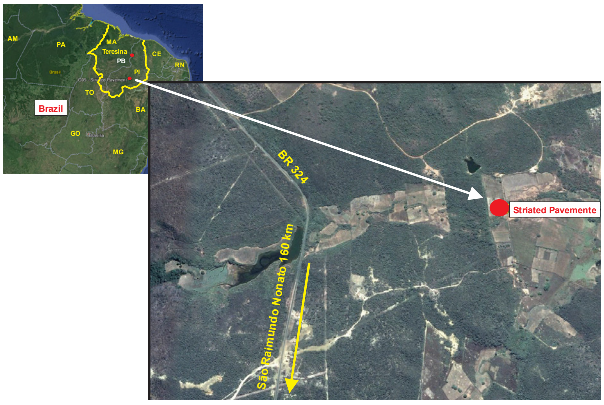

Figure 1: Localization of the glacial striated pavement close to the SE border of the Parnaíba Sedimentary Basin-NE Brazil. Central coordinates: 2562214 UTM W, 9226338 UTM S. AM – Amazonas, PA – Pará, MA – Maranhão, TO –Tocantis, GO – Goiás, BA – Bahia, MG – Minas Gerais, CE - Ceará, RN – Rio Grande do Norte, PI – Piauí, PB – Parnaíba Basin.

General Geological Remarks-Geological Settings

Malzahn (1957) mapped tillite-like and varve-like sediments overlying a striated surface at the top of the supposed Serra Grande Formation (now Serra Grande Group), but later it was shown that the glacial beds lay at the top of the Cabeças Formation (Caputo, 1985) of Late Devonian age. Clasts in sandstones and tillites consist of quartz, quartzite, conglomerate, gneiss, and igneous acidic rocks. The tillites are composed of diamictite beds consisting of unstratified sediments with subrounded to angular outsized polymictic clasts dispersed in a structureless silty and clayey matrix.

Other authors point out diamictites beds as paraconglomerate at the topo of late Devonian Cabeças

Formation (Della Piazza & Santos, 1967). Malzahn (1957) reaches describe a stratigraphic sequence based on a local section near Canto do Buriti. A good general description of the Cabeças Formation unit is given by Della Favera (1982). Figure 2 shows the Paleozoic glacial records of Calembre (Brejo do Piauí) and the main geologic units of the Parnaíba Paleozoic Sedimentary Basin near the site (Assine & Veseley, 2008).

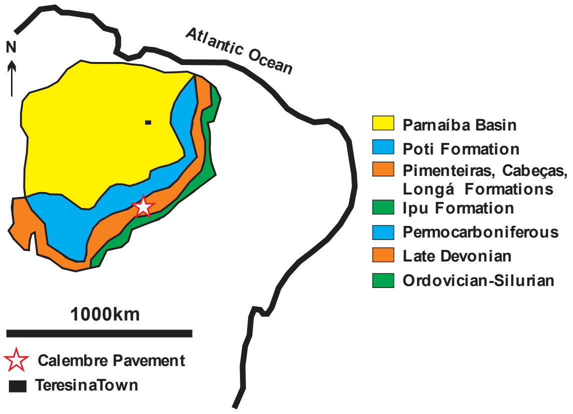

Figure 2: The Paleozoic glacial records of Calembre (Brejo do Piauí) and the main geologic units of the Parnaíba Paleozoic Sedimentary Basin, NE Brazil. (Modified from Assine & Veseley.(2008)

A brief lithologic summary very important for this abstract, and based on several authors, was presented in the paper of Playford et al (2012). The Cabeças Formation, composed mainly of sandstones and subordinate siltstones of Late Devonian (Famennian) age, was deposited in storm to tide-dominated, shallow marine, deltaic, and fluvial environmental settings. Glaciogenic rhythmites, mudstones, slumped sandstones, diamictites, and tillites, locally associated with striated pavements and erratic boulders, occur in the upper part of the formation.

Figure 3 shows images of the Calembre site with the striae oriented clasts (quartz) and details of some clast shapes. They are round, oval, balls, elongated, faceted and sometimes polished and striated.

Figure 3: General view of the Calembre site. Details of the striated pavement and clast shapes in the Cabeças Formation (Upper Devonian).

The Brejo do Piauí striated pavement, first described by Caputo & Ponciano (2013), is a large horizontal surface located in the uppermost portion of the Cabeças Formation, with striation direction Az300° or N60°W and with clasts inside the striation marks. Sometimes along the striae there is a sequence of clasts. The clast dimensions vary from centimetric to decimetric.

Geophysical Method and Results

In sedimentary geology, ground penetrating radar (GPR) is used primarily for stratigraphic studies where near-continuous, high-resolution profiles aid in determining many features as stratigraphic architecture, sand-body geometry, correlation and quantification of sedimentary structures. In the past, to investigate lateral continuity and variability of sediments, we had to infer the correlation between boreholes, outcrops or shallow trenches. The application of GPR in sediments is expanding rapidly because GPR provides high-resolution images of the shallow subsurface that cannot be derived by any other non-destructive method. The use of GPR has gone beyond characterizing environments by reflection patterns and radar facies and is moving into a more quantitative assessment of sand-body geometry and architecture Bristow & Jol (2001). Like as GPR over dunes and paleodunes the results over resistive sandstones are very good geophysical application.

Ground Penetrating Radar (GPR) is very well appropriate to use in dry, sandy, dunes or cobble poor sediments. It has, however, been used in relatively few glaciogenic, aeolian dune-paleodunes, beachrocks, alluviums, several types of sandstones or loess deposits. Too many others application of a GPR system are known in the domain of geosciences, engineering, geotechnical, archaeological studies, ground-water, hydrogeologic studies, environmental and forensic.

A GPR system can operates using a pair of antennas (bistatic) or, as used here, a single antenna in monostatic mode with a central frequency of 200 MHz (Figure 4). The transmitter antenna generates a radar signal and transmits it into the ground. After reflecting off objects in the subsurface, the signal is detected by the receiver antenna. The monostatic antenna consist of the transmitter and receiver part. Antenna sets are designated by their approximate peak signal frequency, measured in MHz ranging from tens of MHz, to about two GHz. Typical radar velocities in geological media range from around 15 cm/ns in dry sand to 8 cm/ns in glacial till and as low as 4 cm/ns in fully saturated sand (McCann et al., 1988; Gawthorpe et al., 1993).

The choice of targets, the depth of investigation and the physical properties of the ground determine the good frequency of the antenna to be used. After processing the data, the result obtained is a high resolution image of the subsurface. The 200 MHz antenna used in this research provides the most useful combination of signal penetration and resolution for most initial surveys of near-surface features.

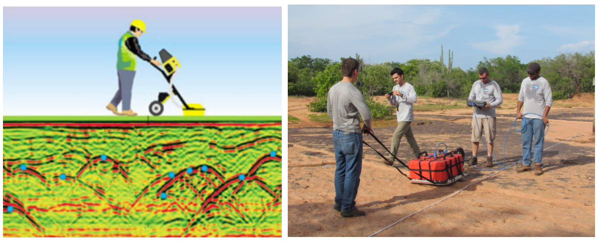

Figure 4: (left) The GPR principle of EM imaging and the (right) 200 MHz antenna and GSSI SIR 3000 system used over the striated pavement. Left image from http://seismo.berkeley.edu.

Four profiles were acquired in the common offset mode in two direction, and data acquisition parameters were: trace spacing of 0.05 meters, 512 samples, sample interval time (Δt) 0.390625 ns, time window of 200ns; sampling frequency of 2560MHz. Here we present the result of two GPR sections acquired in the direction of the glacial striation Az300° and the other one, more or less orthogonal. Figure 5 shows the positioning and orientation of the sections in the Calembre site. The 094 section has 33,95 meters in length in the striae orientation Az300° and the 091 section has 46,35 meters in length acquired in the orthogonal direction.

Figure 5: GPR sections 091/092 and 093/094 in the glacial striated pavement, 2562214 UTM W, 9226338 UTM S.

The GPR sections were processed using the ReflexWin software, version 6.0.5 (Sandmeier, 2011). The routine of data processing consisted of: converting file format, static correction, background removal, subtract-mean - dewow, a FK filter, gain, migration and time to depth conversion.

Figure 6 shows the resultant processed 094 section based on this processing flow. The best velocity value based on the interactive velocity adaption (a calculated reflection hyperbola define the velocity and width) for the ground was v=0,12m/ns; this was the FK migration stolt value. This “v” is the velocity of propagation of the electromagnetic wave in the ground.

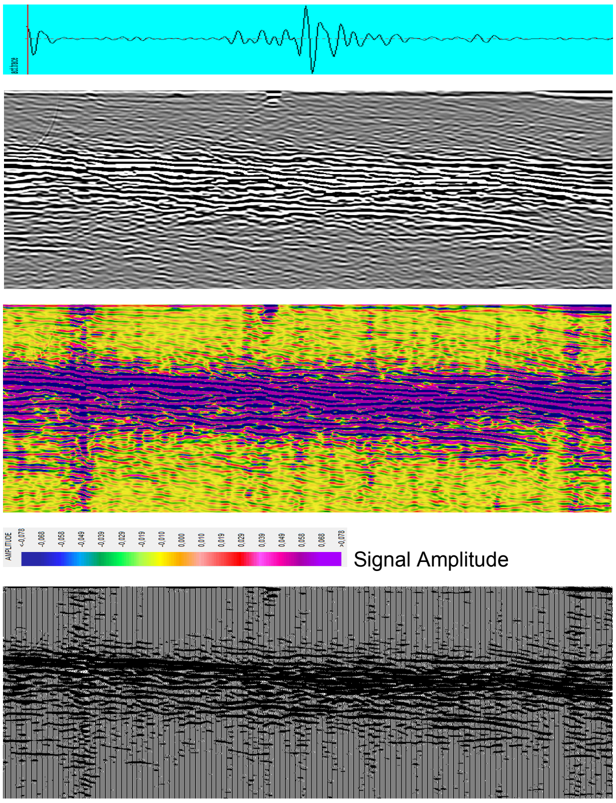

Figure 6: Three views of GPR processed 094 section in the glacial striation direction - processed data, 2562214 UTM W, 9226338 UTM S.

A large number of reflections can be seen in the 094 processed GPR section and a great number of linear and low angle inclined features that correspond to internal sedimentary structures in depth of the Upper Cabeças Formation. Considering that the velocity migration adopted is reasonable for these lithotypes the GPR section shows a 10 meters depth image (Figure 7). Briefly, is possible to note, a subhorizontal reflection that runs across the top of the profile in very shallow depth; a lower-amplitude dipping reflections to a depth of 3,5m showing in SE portion sedimentary structures of low angle (9 ° to 14 °) dipping to SE; its follows in the middle of the section, between depths of 3,5 to 7m, a high-amplitude dipping reflections where the linear structures have a very low angle (<6 °) dipping to SE; from this last radar package to the base of the section (10m) is possible to see a low-amplitude portion with almost without reflections, many of them parallels (see signal amplitudes in figure 6). These interpreted radar package or radar facies can be seen more easily in the figure 7.

We have also extracted the principal radar lineaments based in the electromagnetic wavelength and reflectors. Like this, was possible to see a large number of sedimentary structures below the surface as shown in figure 8. Analyzing this figure is clear to see that all this linear features dipping southeast with angles varying from 4-6° (central part) to 14° (upper part).

It is too early to say if those (the shallow) sedimentary structures are derived from the glacier movement and efforts during ice flow direction along the section (unlikely). At the moment, at least there are coincidences with the general paleocurrents directions of the upper Cabeças Formation fluvial system. The three radar package identified by differences in amplitude-reflectors (yellow, pink, red) interpreted in figure 8 certainly correspond to changes in sedimentary facies and physical properties (e.x. permeability/porosity, grain size, texture, e.g.).

So, the first package probably correspond to the upper Paraconglomarate Member of the Cabeças Formation composed also of laminated sandstones beds; the second package with high reflectors and a large amplitude may correspond to a sub-parallel structured level of dry interbedded sandstones with subordinate siltstones, sometimes cross-bedded and coarse-grained. The third package corresponds probably to a less clay/silt material but is difficult to interpret at the time. Some clasts can be interpreted (red balls) in depth and shallow levels of the section by several hyperbola eliminated by migration process (Figure 8).

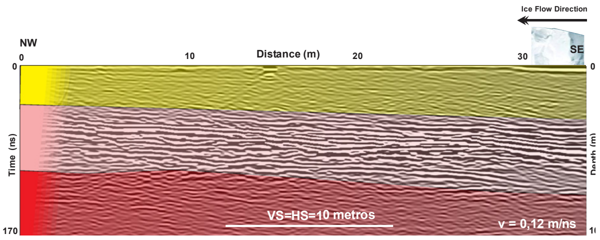

Figure 7: Radar facies and package interpreted for GPR 094 section, 2562214 UTM W, 9226338 UTM S. The figure illustrates also the ice flow direction over the pavement.

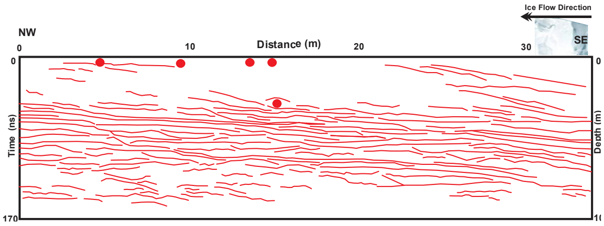

Figure 8: Sedimentary structures of GPR 094 section, 2562214 UTM W, 9226338 UTM S.

Conclusions

This preliminary research shows that GPR is a very positive way to study shallow depths and reconstruct subsurface information of glacial deposits. The internal architecture is very well mapped with a good resolution as sedimentary structures and sedimentary facies. On the other hand new GPR field works will be necessary using others antennas and more parallels sections to get data to 3D processing. Detailed geological and sedimentological data need to be collected as well as parametric direct data.

Acknowledgments

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