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Imaging Subsuperficial Water In Tropical Soils Using Ground Penetrating Radar

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Abstract

The ground penetration radar has been a very useful tool to assessing stratigraphical features, buried objects and fluids in the shallower portions of the ground. Although this method to be quite spread, nowadays is still scarce the works that approach the aspects related to water mapping in soils formed by strong tropical wheathering conditions. This kind of wheathering forms soils with great amount of clayel material. This fine material also constitutes the commonest part of the sedimentary deposits that recover the landscape. These soils and sediments possess resistives characteristics that allow a good transmission and reflection of the radar waves in the substratum. This work aim to show some study-cases of the visualization by radar reflection. For this, the radargrams generated by radar relection were observed in three sites in the Southeast of Brazil.

INTRODUCTION

Geophysical surveys using radar waves reflections have been broadly used in the characterization and mapping of fluids contents in the porosity of several geological materials

Advanced wheathering stages of tropical rocks produce a great amount of clay minerals wich could be limiting factor to the survey, once they present high values of electric conductivity. In Brazil the first work using GPR was accomplished by Sauck (1995) on soils and sediments in the Amazon area. It was the first aproach to evaluate the attenuation of radar waves due to the composition of the tropical clays.

Sauck (1995, 1997) proposed that clays formed in tropical wheathering conditions were not conductive, and so were not a impediment to GPR use. Penetration below the water table was also excellent due to low dissolved solids contents and low eletric conductivity.

Stratigraphical mapping studies (Madeira et al. 1997a, 1997b and Neves et al.,1997) also showed a radar waves penetration, besides the silty-calyel covering materials.

In Brazil recent works of Aquino et al. (1998) in the saline intrusion mapping; Nascimento et al. (1998) in the characterization of the organic spreading in the soil and; Grazinoli (1998) in the characterization of contaminated areas by organic products are remarkable.

This work aim to to show study-cases of the effect of groundwater in the visualization of the reflection patterns of radar waves in areas with a thick recent sedimentary covering and intense tropical pedogenesis. For this three sites were selected in the Southeast of Brazil.

REFLECTIONS PATTERNS RELATED TO SUBSUPERFICIAL WATER

Below the water table intergranular pores and the fractures are totally filled by water under pressures grater than atmospheric pressure. This zone is also denominated saturated zone. Above the water table is the capillary fringe that corresponds to a zone where the pores are completely filled with water held up by capillary tension. If the pores are very narrow, as it happens in silts and clays the capillary fringe can reach several meters, while in the larger pores of rude materials, as sands and gravels the capillary forces are weaker and the capillary fringe is smaller. Above teh capillary fringe is the unsaturated soil-water zone (Dune & Leopold, 1978).

The top of the saturated zone is usually the clearest and most continuous reflector below the soil surface reflector. The clarity of these reflector depends on the contrast between the electric properties of the unsaturated zone and the saturated zone. To obtain a clear image of the water-table is also necessary that the size of the capillary fringe is compatible with the resolution limit of the radar wave length transmitted to the soil Also if the water-table reflector is very close to the surface it can be masked by the topographical surface reflector.

In thick sands the capillarity fringe is generally small specially during the dry periods. The water-table reflector is generally very distinctive in these deposits and its position in the radargram is easily located.

In silts and clays the capillary fringe can have several thickness. Such a behavior generates an uncertainty in the positioning of the saturated zone reflector. In addition the electric condutivity contrast is not strongly marked, once there is a gradual change in the electric impedance that turns the contact diffuse or imperceptible.

Shih et al. (1986 apud Johnson, 1988) determined that the eletromagnetic contrast among dry and wet layers decreases with an increase in the amount of fine material. This tendency is partially responsible for the presence of reflectors strongly marked in coarse material. However, according to Johnson (1988) not all the coarse materials behave like that due to the high number of layers (stratigraphical and sedimentological) in the soil that commonly overcome to the reflector of the water-table turning its identification very difficult.

The water-table sign described in literature is generally strong, continuous and it cuts the reflectors that are related to sedimentological and stratigraphical variations. In higher frequencies the water-table can appear as a very marked

triplesignal (Johnson, 1988). It can also be clearly marked by a continuous reflection with negative polarity (van Ovemerren, 1998), for the regional water-table and for the perched water table.
Harari (1996) working in sandy dunes of Saudi Arabia recognized the water-table by the clear straight reflectors. However in some places it was observed a strong attenuation related with the presence of the capillarity fringe.
Freeland et al (1996) show in the radargrams columms structures related to vertical movements of humidity through the profile (fingering) that happens in a clay soil that recovers a coarse dry soil.

REGIONAL SETTINGS
3 sites were selected in two different regions; the first region is Paraíba do Sul river medium valley, it corresponds to the limit between São Paulo and Rio de Janeiro States, where two of the sections are located (Sites 1 and 2). The second region is Doce river medium valley and it corresponds to the portion NE of the Minas Gerais State, where Site 3 is located.
Both regions are characterized by a thick covering of coluvial-aluvional sediments of recent age, that are intimately related with the typical relief forms of the Southeast area of Brazil. Common geomorphological features are the amphitheater like headwater where the coluvial material (mass movement) and residual soils of the basement are preserved, and the alluvial terraces, formed by sandy sediments of fluvial channels and silt-clayel sediments of floodplains. In both regions detailed studies in sedimentology and stratigraphy develoed an allostratigraphical column for the Quaternary sediments (Moura & Mello, 1991; Mello, 1997).
Climatically the Paraíba do Sul river medium valley is characterized by a typical tropical climatic regime, with two marked seasons: a rainy summer and a dry winter (Nimer, 1989). The annual average temperature is around 20°C and the annual average rainfall is 1500mm.. The Doce river medium valley is also characterized by a tropical climate, hot, semi-humid (Nimer 1989) with average temperatures between 20^{o} C and 22^{o} C and annual average rainfall between 1250 to 1500mm with rains concentrated on the summer months

METODOLOGY

The pulseEkkoTM 100 radar system was employed, with 400V transmitter and antennas of 50MHz frequency. For propagation velocities calculus in the investigated materials we used the CMP/WARR survey method. Also, for the stratigraphical reflection profile survey antennas oriented in the broadside mode were used (cf. Annan, 1992). It was chosen a 2m antenna separation and soundings were acquired at 0,5m step. SITE 1 showed a propagation velocity of 0,07 m/ns and SITE 2, 0,08 m/ns. Which are typical to clayey and silty materials (Davis & Annan, 1989). SITE 3 showed a propagation velocity of 0,102m/ns. This improvement in the wave's propagation velocity was caused by the higher sand contents in these sediments. It should also be noted that all profile have some degree of vertical exaggeration, not correct in this work.

RESULTS

REGION 1 - PARAÍBA DO SUL RIVER MEDIUM VALEY

SITE 1

The GPR section shows a strong attenuation of the radar signal below the 7m depth. which is associate with the higher water content in the soil. As the water-table is below this depth the signal attenuation is due to the presence of the capillary fringe.
The attenuation, in the lateral portions of the section, is due to the geomorphological divisors of the drainage headwater follows the topographical surface. In the central portion of the section where the headwater axia is located, it is noticed that the zone without radar signal is shallower. The signal penetration in this radar facies (like descontinuos clinoforms) is a little larger such a behavior can be due to the fact that this material have a higher amount of sands than the adjacent ones. However the central portion of this facies presents the attenuation level compatible with the penetration in the clayel beds. The regional mapping of this unit characterized it by tabular layers vertically stacked, with rare lateral variations of texture. So the elevation of the attenuated zone can be caused by a convergence of flows of subsurficial water in the axis of the drainage headwater.

SITE 2
In this place mensurations of the water table were accomplished in piezometers during the acquisition of the GPR section, that indicate thaht the water table was below 12m depth.
The strong attenuation of the radar signal was attributed to the high capillary moisture contents in the sediments. Considering the attenuation begining in 6.5m the capillarity fringe can have more than 5m thick.
In the NW portion of the section, inside the channel feature we found the highest amount of sand of the section which provided a good definition of the reflectors. These sands were probably responsable for a thin capillary fringe

REGION 2 - DOCE RIVER MEDIUM VALLEY

SITE 3

The radargrams (figure 1) show 2 reflections patterns, that were related with 2 stratigraphical units. The lower unit shows a complex reflections pattern that probably is due to the geometric complexities of the sandy facies in the fluvial channels deposits.
The upper unit is marked by a gravel layer at the base and by the topographical surface in the top. This unit shows a

tabular shape, with a straight not much continuous reflection pattern. The sediments of this unit are coarse to medium sands in the central and north part while sand-silty in the south part. The reflection pattern in the south part is slightly different from the remaining, as it is more continuous. This unit was related to the fluvial portion of moderate energy (central portion and N) grading to floodplain facies in the South portion of the section.

The water-table measured in drill-holes, during the survey is inclined in the South direction, founded at 7m, 7.7m and 8.9m deep. The radar section shows in the N portion a negative reflection pattern. Starting from this point going to the South direction the pattern becomes diffuse, being mixed to the complex pattern of reflection related to stratified sandy sediments.

CONCLUSIONS

In silt-clayel and silt-sandy sediments that are the stratigraphical framework of sedimetary coverings of the Southeast area of Brazil the presence of the clay minerals is not a limitant factor for a good GPR sections acquisition. However the presence of intersticial water in these materials strongly attenuates the radar signal. By this way the mappping of the water-table can be very hindered and it is also dependent of the capillary fringe thickness. In SITES 1 and 2 the capillary fringe was sufficiently thick for not allowing the imaging of the water-table. Even so the mapping of this fringe allowed the observation of spatial variations of the water-table, indicating a direct relationship with the material to form sediment. In addition in places of similar granulometric characteristics the variation of the attenuation indicated variation of water-table position.

In sandy sediments with good selection and lower clays contents its reflection pattern is not clear. The water-table is only well characterized in the discontinuous portions of the section and it is represented by a negative and strong signal. It is obscured by the sedimentological and stratigraphical complexities of the sandy facies that filled the fluvial channels.

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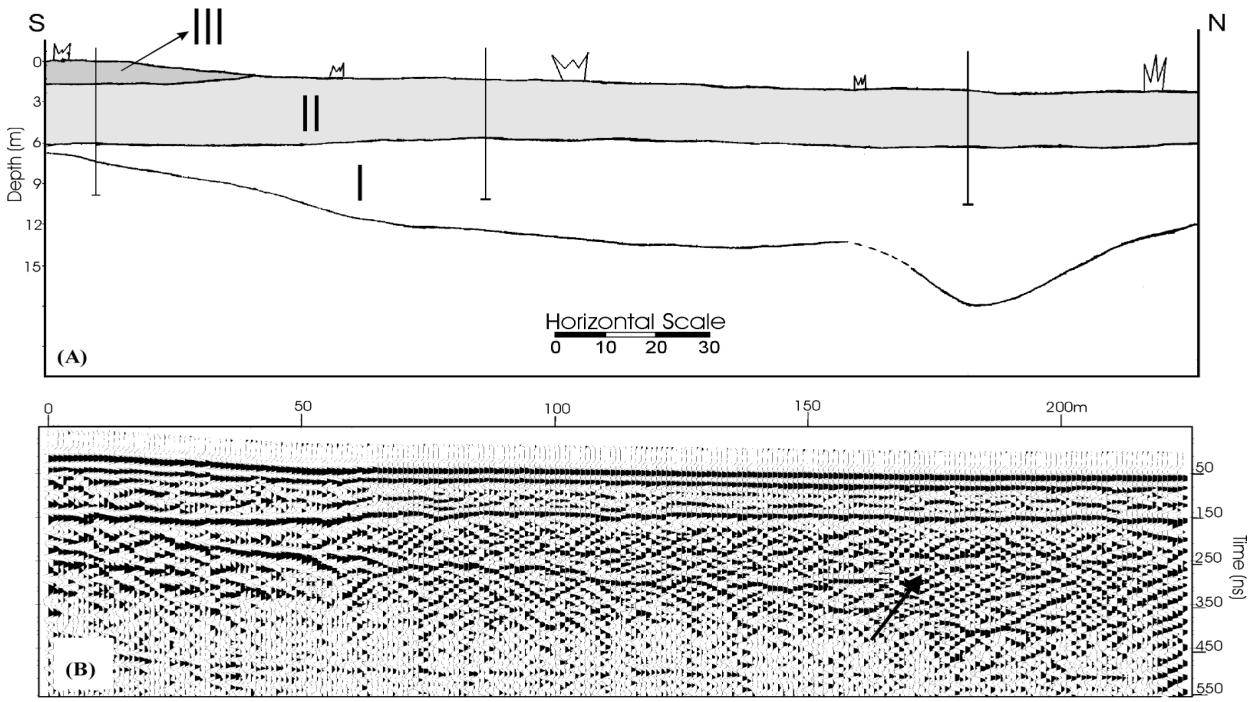

Figure 1 – Cross sections of Site 3 (Doce river medium valley). The figure A shows the stratigraphic interpretation made with the three stratigraphic drill holes and GPR radargram. The figure B shows the acquisition data. The arrow mark the water table signal.