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Resistivity imaging and Ground Penetrating Radar survey at Gualeguaychú landfill, Entre Ríos Province, Argentina: Evidences of a contamination plume.

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SUMMARY

This paper presents the first geophysical results of a multidisciplinary project which includes geological, isotope geochemical, and geophysical approaches. These results belong to geoelectric and GPR surveys at an urban solid waste landfill. The study area is located to the south of Gualeguaychú, Southern Entre Ríos Province, Argentina.

Some multi-electrode resistivity studies were performed within and outside the landfill as part of the environmental project. The apparent-resistivity data were collected using a dipole-dipole survey with 21 electrodes (spaced a=5m with n= 1, …,18), to give a total line-length of 100 meters. Data inversion was carried out using the DCINV2D program. All the subsequent inversions had a RMS less than 2. The depth of investigation (DOI) was estimated around 25 meters.

The 2D model obtained within the landfill shows three or four layers, depending on the profile considered. The first layer is 2 to 3 m-thick and resistivity ranges from 100 to 1000 ohm-m. This layer hosts the domestic and industrial wastes. The depth of the bottom of this layer agrees with the average depth of buried bodies obtained by a ground magnetic study performed in the same area.

The second layer is 4 to 5 m-thick and has a low resistivity (3 to 6 ohm-m). This layer is attributed to the contaminated zone and is located close to the water table. The third layer has a resistivity of 15 ohm-m and a thickness of more than 10 m. Another conductive layer (5ohm-m) is observed further below.

The 2D model obtained immediately outside the landfill presents a conductive layer (4 ohm-m) at a depth of 5 m with a thickness of 10 meters. This result shows the presence of contamination at the landfill boundary.

A total of four GPR profiles with 150 –500 MHz antennae were surveyed, two within and two outside the landfill. The main objectives of the GPR survey were to determine the depth of the water table and evaluate the horizontal extension of contamination. The upper limit of the contaminant plume was identified along the profile by the absence of reflectors or the existence of very weak signals. In this zone, the 2D resistivity model shows high electrical conductivity materials which do not allow radar waves to reach greater depths.

The dipole-dipole and GPR results show a good agreement and the integrated interpretation was supported by local geology.

Keywords: Environmental Geophysics, Resistivity imaging, Georadar, Landfill

INTRODUCTION

To achieve an appropriate management of solid waste, planning at different scales should be performed. The trend in most developed countries shows a decrease in the quantity of waste produced, and an important increase in the amount of recycling programs. The major part of the waste in new sanitary landfills comes from sources like homes, offices, and small shops, which do not use and discard dangerous materials. However, such apparently inoffensive waste contains frequently toxic substances. As the discarded objects are decomposed or biodegradated, they release their pollutant constituents. These toxic chemicals mix with water and moisture forming the leachate. If such leachate is uncontrolled, it can migrate and contaminate groundwater and/or aquifers. In some cases, solid waste is disposed in unsuitable and/or clandestine places, producing important environmental damage. In other cases, the regulations established in order to protect the environment are not observed. Therefore, it is convenient to keep on monitoring with an efficient and multidisciplinary activity.

Here, we present the first geophysical results of a multidisciplinary project which includes geological, isotope geochemical, and geophysical approaches. These results belong to geoelectric and GPR surveys at an urban solid waste landfill (see photo in Figure 2).

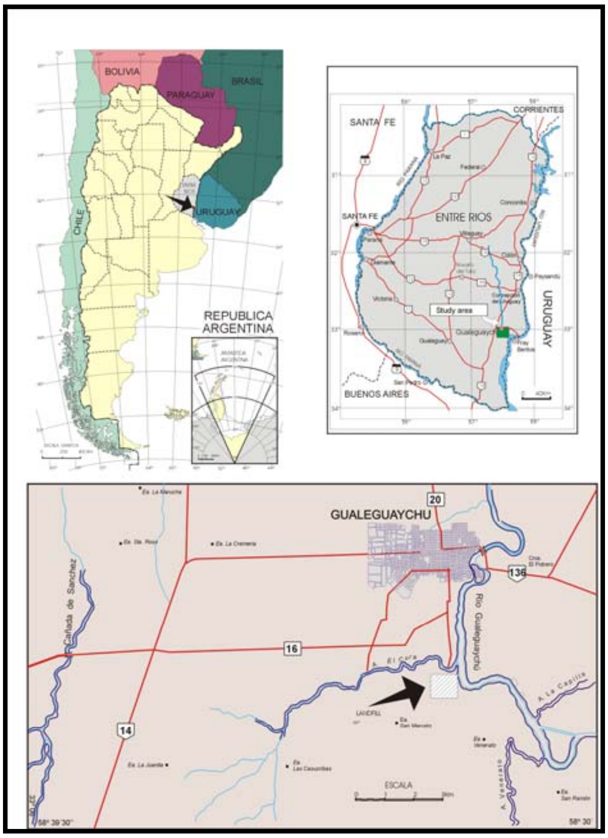

Figure 1. Location map of Gualeguaychú city, showing the study area (landfill) Entre Ríos Province, Argentina.

BACKGROUND

The study area corresponds to the present municipal sanitary landfill. It is located to the south of Gualeguaychú city, Entre Ríos Province, Argentina (Figure 1). This town has a population of 80000, and it shows numerous commercial, industrial, and agricultural activities.

The activities in the sanitary landfill were suspended during the last four years and the environment protection (if any) undertaken during the operation time are unknown. Nowadays, the operation of the waste deposit was resumed by the Municipal Urban Hygiene Company, which has requested an evaluation of the actual state of the old sanitary landfill.

As part of this environmental project, some multi-electrode resistivity studies and GPR profiles with 150 –500 MHz antennae were surveyed, inside and outside the landfill area. The main objectives of the GPR survey were to determine the depth of the water table and evaluate the horizontal extension of contamination.

Figure 2. Landfill landscape.

GEOLOGIC SETTING OF STUDY AREA

This region forms part of the Chaco-Paranense plain. The most important outcropping Formations are described below (Iriondo, 1980).

Holocene: La Picada Formation Brown medium to fine quartzose sandstones towards the top, and yellowish-brown silts and clay towards the base. It corresponds to the alluvial fillings of previous fluvial valleys formed before the deposition of these sediments. The water is of poor quality and shows chemical (sulfates) and bacteriological contamination.
Circulation is restricted to the area beneath the riverbed and the thickness ranges from 1.2 to 3.5 meters.

Middle-Upper Pleistocene: Punta Gorda Group Brown, yellow and greenish silts and clay containing calcareous concretions, formed in lacustrine and eolian environments. It has a thickness of 20-40 m, and constitutes the substratum of the sanitary landfill. These sediments form an aquitard that contains the water table. Water quality is poor and calcium and sodium bicarbonate are present. The depth ranges from 5 to 30 meters .

Lower Plio-Pleistocene: Salto Chico Formation White and yellowish coarse and fine sandstones in the base, which gradually turn reddish towards the top. Green silt and clay layers and coarse and fine conglomerates are intercalated throughout the sequence. It forms the main aquifer with water of good quality containing calcium and sodium bicarbonate. The depth ranges from 50 to 120 meters.

FIELD WORK

Spatially coincident profiles for multi-electrode resistivity and GPR were carried out. A scheme of the distribution of the profiles in the studied area is shown in Figure 3. The profiles Lan 01 and Lan02 are located inside the landfill area while the profiles Lan 03, Lan04 and Lan05 are outside the landfill, where there are no waste deposits.

The apparent resistivity data were collected using a dipole-dipole geometry with 21 electrodes (spaced a=5m with n= 1, …,18), to give a total profile length of 100 meters. GPR field work was carried out with 150 and 500 MHz antennas.

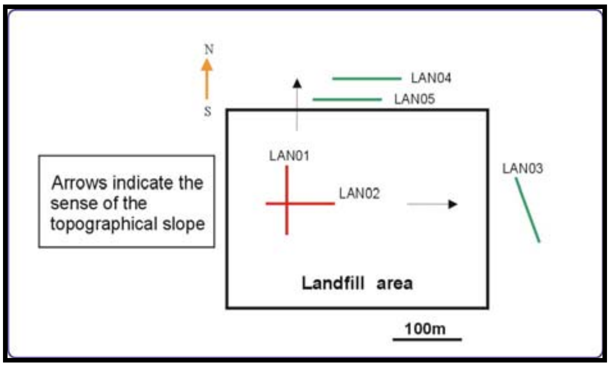

Figure 3 Schematic map of the survey site showing the multi-electrode resistivity and GPR profile.

RESULTS

The resistivity model was obtained from the data inversion using the DCINV2D algorithm of Oldemburg et al. (1993). We compared results using half-space reference models of 0.001, 0.01 and 0.1 mS/m.

For these particular inversions we set ws, wx, wz equal to unity and chose αs =.001, αx = 1 and αz=.1. Figure 4 shows the inverted 2D model of LAN02 using a reference model of 0.1 mS/m. The depth of investigation index (DOI) as defined by Oldenburg et al. (1994) was calculated using a reference model of 0.001 mS/m and a cut off = 0.5. This model shows a first layer with a thickness of 2 to 3 m and a resistivity ranging from 100 to 1000 ohm-m. This layer hosts the domestic and industrial wastes. The depth of the bottom of this layer agrees with the average depth of buried bodies obtained by a ground magnetic study performed in the same area (Orgeira et al. 2004)

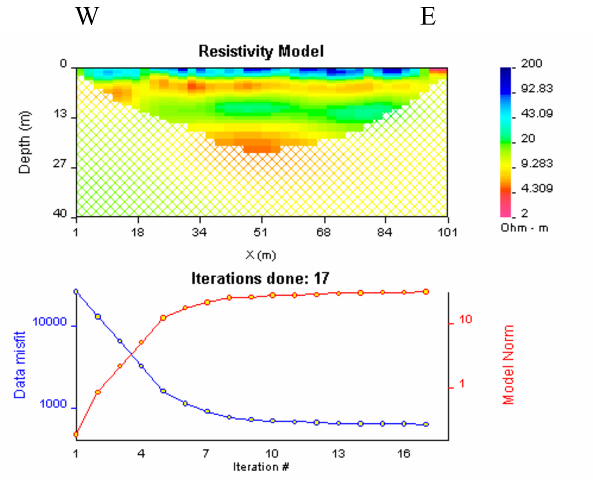

Figure 4 2D resistivity model obtained within the landfill (LAN02), (DCINV2D).

A second layer with a thickness of 4 to 5 m and a low resistivity value (3 to 6 ohm-m) can be attributed to the contaminated zone and is located near the water table. The third layer has a resistivity of around 15 ohm-m and a thickness of more than 10 meters. A new conductive layer (5ohm-m) is observed further below.

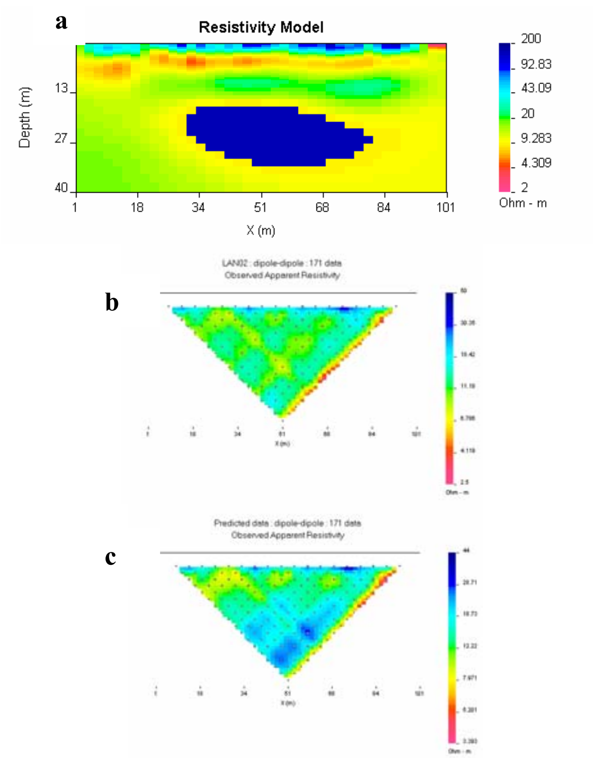

Figure 5 a) Forward modeling of LAN02 assuming a resistive feature at depth, **b)** experimental data and **c)** predicted data in the forward modeling.

Another way of testing the investigation depth is to use forward modeling techniques. We changed the last conductive body by a resistive feature in order to compare the predicted data with the experimental data (Figure 5). The predicted data in the forward modeling are quite different from the experimental data. Since replacement by the resistive area drastically changes the predicted data, then the depth of investigation should be at least as deep as the top of it.

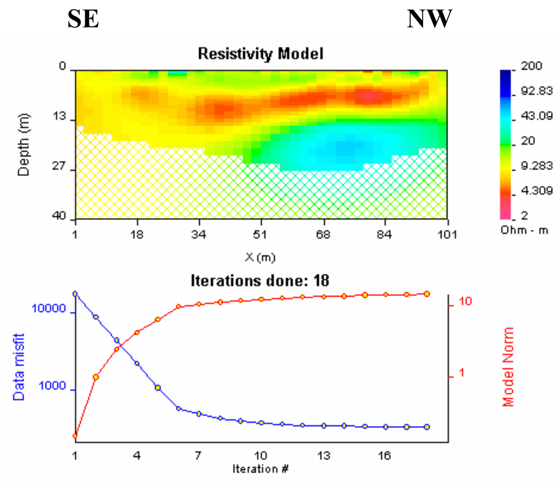

Figure 6 2D resistivity model obtained outside the landfill (LAN03), (DCINV2D).

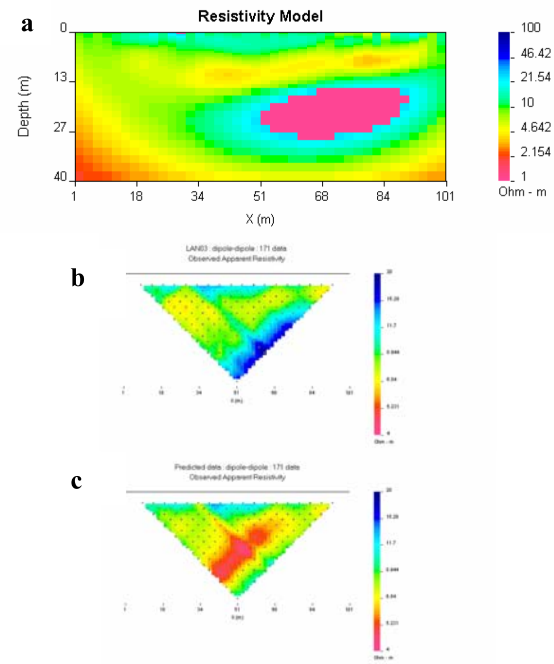

Figure 7 a) Forward modeling of LAN03 assuming a resistive feature at depth, **b)** experimental data and **c)** predicted data in the forward modeling.

Figure 6 shows the inverted model of LAN03, using the same conditions of the LAN02 inversion. The depth of investigation index (DOI) was calculated using a reference model of 0.001 mS/m and a cut off = 0.6.

The 2D model obtained immediately outside the landfill presents a conductive layer (4 ohm-m) at a depth of 5 m with a thickness of 10 meters.

A resistive body is observed immediately below. In this case we assumed a conductive feature to define the depth of investigation using the forward modeling techniques (Figure 7).

In figure 8 we present the resistivity model of LAN01 with the GPR profile (150 Mhz). In this case, we observed a conductive body in the place where there is a shadow zone in the GPR profile. These highly conductive materials are attributed to contaminated fluids, rich in total dissolved solids TDS, which do not allow radar waves to reach greater depths.

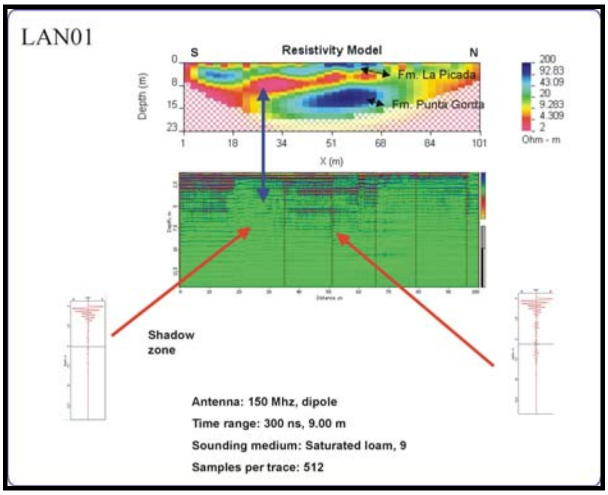

Figure 8 Resistivity model and GPR profile of LAN01.

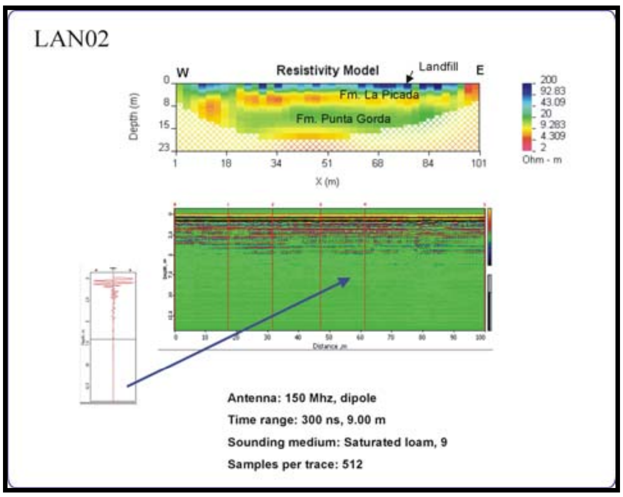

Figure 9 Resistivity model and GPR profile of the LAN02

In Figure 9 we present the resistivity model and GPR profile (150 MHz) of LAN02. The resistivity layer (3 to 6 ohm-m) is attributed to the contaminated zone and coincides with the top of the shadow zone.

In Figure 10 we present the resistivity model of the LAN03 (outside the landfill) and the GPR profiles using 500 and 150 MHz antennas. In the 500 MHz profile, a strong reflector was observed, which is considered to be the groundwater table. For the 150 Mhz profile, the upper limit of the contaminant plume could be identified by the absence of reflectors or the existence of very weak signals.

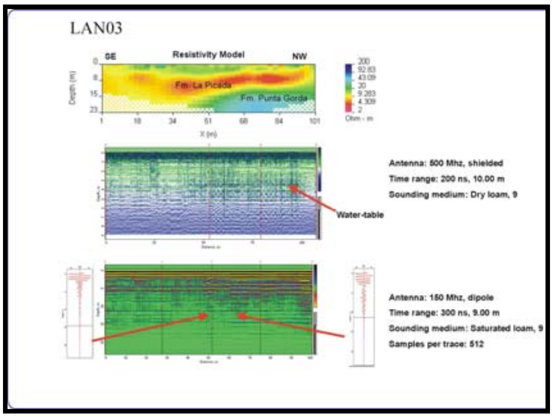

Figure 10 Resistivity model and GPR profiles of the LAN03.

CONCLUSIONS

The 2D model obtained within the landfill for LAN01 and LAND02 shows a first layer with high resistivity (100 to 1000 ohm-m) with a thickness of less than 4 meters. This layer hosts the domestic and industrial wastes.

A second layer with a thickness of 4 to 5 m and low resistivity value (3 to 6 ohm-m) is attributed to the contaminated zone and is located close to the water table. This layer corresponds to the La Picada Formation.

The third layer has a resistivity of 15 Ohm-m and a thickness of more than 10 m which has been interpreted as the Punta Gorda Group.

The 2D model obtained immediately outside the landfill presents a conductive layer (4 ohm-m) at a depth of 5 m with a thickness of 10 meters. This result shows the presence of contamination at the border of the landfill.

The results of GPR profiles showed a strong reflector, which is considered to be the groundwater table.
The upper limit of the contaminant plume was identified along the profile by the absence of reflectors or the existence of very weak signals. In this zone, the 2D resistivity model shows the presence of high electrical- conductivity materials, which do not allow radar waves to reach greater depths.

The dipole-dipole and GPR results show a good agreement and the integrated interpretation, and were supported by local geology.

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