DOI:10.21715/GB2358-2812.2019334378

Interpretation of GPR (Ground Penetrating Radar) and soil profiles at selected veredas of the Formoso River Basin, Buritizeiro, Minas Gerais, Brazil

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RESUMO

Este trabalho apresenta correlação entre os dados do GPR (Ground Penetrating Radar) e a distribuição geoquímica dos perfis de solos de veredas selecionados na bacia do rio Formoso, para mostrar a correlação entre a distribuição vertical das unidades do solo e o perfil do GPR. Essa interpretação é importante para demonstrar de forma fácil a evolução dessas importantes unidades geomorfológicas com o aumento das atividades humanas no cerrado. Assim, é extremamente importante a implementação de mecanismos necessários para a proteção desses ambientes como fontes de água na região. Esta pesquisa pode contribuir para a criação de áreas protegidas de modalidade de uso sustentável, especificamente áreas de interesse ecológico (ARIE) para a proteção das veredas consideradas estratégicas para a conservação do solo e da água.
Palavras chave: GPR; Vereda; proteção ambiental; sustentabilidade

ABSTRACT

This work shows a correlation between the GPR (Ground Penetrating Radar) data and the geochemical distribution of the selected soil profiles in the Formoso river basin, to show the correlation between the vertical distribution of the soil units and the GPR profile. This interpretation is important to easily demonstrate the evolution of these important geomorphological units with the increase in human activities in the cerrado. Thus, it is extremely important to implement the necessary mechanisms to protect these environments as water sources in the region. This research can contribute to the creation of protected areas of sustainable use, specifically areas of ecological interest (ARIE) for the protection of paths considered strategic for the conservation of soil and water.
Keywords: GPR; Vereda; environmental protection; sustainability

1 INTRODUCTION

1.1 LOCALIZATION AND ACCESS

The studied area, the Formoso River basin, is located in the Buritizeiro County in the northern part of Minas Gerais State – Brazil, specially the southwest portion of the municipality of Buritizeiro (Figure 1) and is limited by the coordinates 15° 05' and 15° 36' latitude south and 44° 56' and 45° 26' longitude west, draining an area of approximately 826 km^2. The town of Buritizeiro is approximately 377 km far from Belo Horizonte, and the county occupies a land area of 7,226 km^2. Access to the town is given by federal highway system using BR-040 and BR-365 and by State road systems on MG-161, MG-408 and MG-496.

Figure 1
Localization map of the investigated basin. The Formoso river basin is situated at the Buritizeiro county in the State of Minas Gerais (Source: Viana, 2006).

1.2 VEREDA

Vereda is an ecosystem that is formed under well-defined moisture conditions and limited to the region of the Cerrado (Savannah), forming normally springs or spring galleries, which supply the major drainage basins of Brazil (VIANA, 2006). The Formoso River basin is an important tributary of the São Francisco River, and is located in the north of the State of Minas Gerais. It hosts innumerous different Vereda types (Figures 2 and 3).

Vereda is also considered a natural ecological corridor in the Cerrado area (MELO, 1992) because the alignments of its buritis palms serve as trail for animals to move, find food and breeding places. According to the same author these areas not only serve as ecological corridors but also have an important function in water distribution to the river, such as retaining water in wet periods and liberating it in dry ones maintaining perennity (continuity) of creeks and rivers. The aquifer exudes, forming wetlands drenches very close to the surface, while the top of the steep-sided sandstone plateaus, works as a recharge area for the aquifers. Another important aspect of veredas, in relation to local communities, is their economic importance due to the large potential of the buriti palm in supplying the various products to local communities, like oil, charcoal, leaves, and construction material.

The soil (substrate) of the veredas is permanently saturated with water, forming in this way islands in arid regions. Due to this, agricultural activities are attracted and concentrated in this part of the Cerrado, influencing the highly sensible equilibrium in this biome. These activities may also change the quality of water and soil and, therefore, influences the whole water support and quality of the connected basins.

The veredas were classified regarding their environmental, geological and morphological features, and three representative sites were selected. The aim of this work was to characterize the soil of the three selected veredas and to determine the changes due to human activities.

2. GEOLOGICAL SITUATION

The Formoso River basin is located in the southern portion of the Sanfranciscana Basin, within the limits of the São Francisco Craton, in the eastern part of the Cretaceous area covering the Minas Gerais State. The rocks that determine the studied area belong to the geological units of Areado e Mata da Corda groups and their corresponding formations (Figure 2).

The Três Marias Formation, the upper unit of Bambuí Group, located in the northern portion of the basin, is represented by their main lithofacies, siltstones with thin sand beds, clay inter-laminations, siltstones with coarse-grained lenses, violet siltstones showing load and drying cracks, sandstones with sigmoidal cross-stratification, sandstones with cross-stratification formed by waves, sandstones with hummocky and sandstone with horizontal stratification together with arkosean sandstones and arkoses (CHIAVEGATTO, 1992).

The Areado Group located in the central part of the basin, is represented by the Abaeté and Três Barras formations. The Abaeté formation represents the basal lithostratigraphic unit of the Sanfranciscana Basin and is represented, in some places of the Formoso River basin, by fluvial conglomerates containing wind canter, gravel and a large volumes of rudicious sediments, deposited under a high energetic regime under arid and semi-arid conditions (SGARBI, 2001). The Três Barras formation is composed of fine to medium sandstones from deposition in dry windy environments and fluvial-deltaic systems, cemented by limestone. The generally pink colored sediments are cut by irregular whitish spots due to selective reduction effects (SGARBI, 1991).

The Mata da Corda Group is composed of volcanic and volcanoclastic rocks covering discordantly the terrigenous Areado Group and is divided into the Patos and Capacete formations. The later one is exposed in the investigated area as vast plateaus (SGARBI, 2001). This plateaus are covered by more recent deposits, mostly elluvial to colluvial and alluvial.

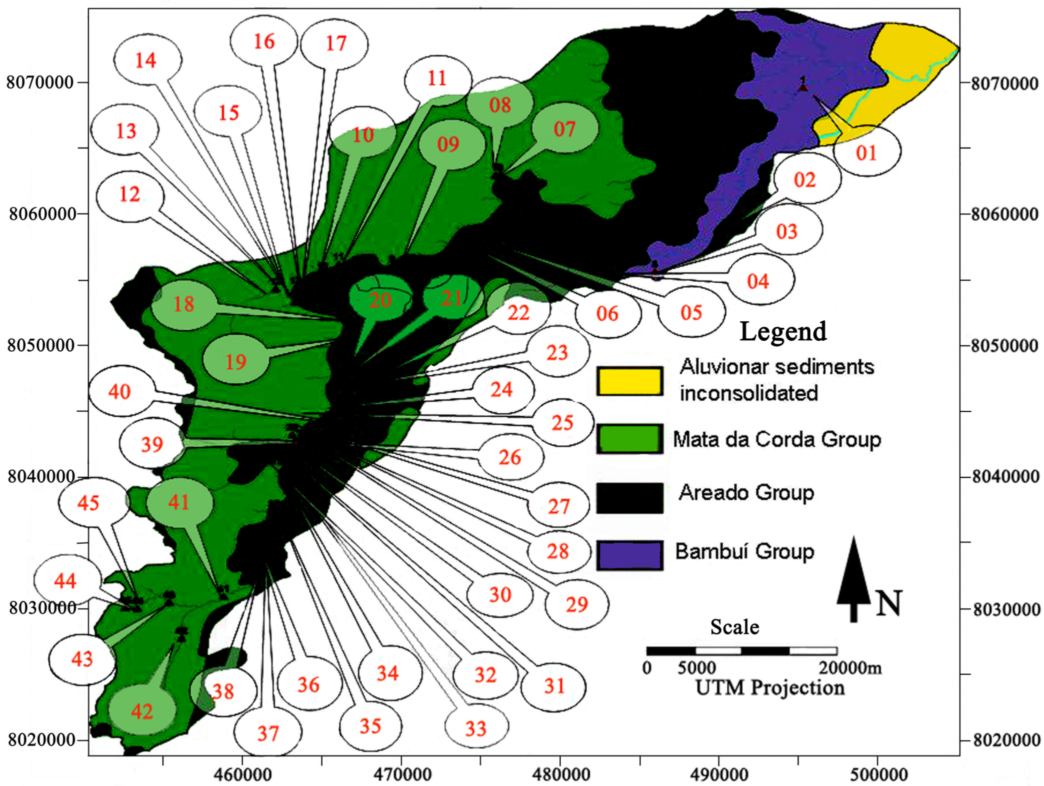

Figure 2
Geological sketch map of the Formoso Basin. The map shows the distribution of the geological units in the investigated basin and the localization of all the veredas. (BAGGIO, 2008). Selected veredas: 42: Vereda Laçador; 09: Vereda Jaraguá; 01: Vereda Urbana.

2.1. PEDOLOGY

With respect to soil evolution and occurrence in the studied area, it can be shown that in the medium segment has formed mainly Gleisoils with humic-alic affinity, usually associated with the Vereda type in this section (BAGGIO, 2008). Indiscriminate hydro-morphic soils (Gleissoils and Organosoils), typically for Vereda formation, are occurring extended in the surrounding and underlying latosoils and quartz rich sands and micro conglomerates, showing the typical dark grey to black colors of Gleis (MELO, 1992).

These soils are imperfectly to poorly drained, very poor chemically, strongly acidic (pH between 4 and 5.4) with very low base saturation values and a high saturation in aluminum. The gleisoils possess profile with an ACg horizons sequence, in which the A appears much darkened by organic matter, and C sometimes can be subdivided into C1g and C2g (MELO, 1992).

A distribution of the soils and the soil use in the investigated area can be seen in Figure 3. Figure 4 shows the surface soil color distribution of the investigated veredas.

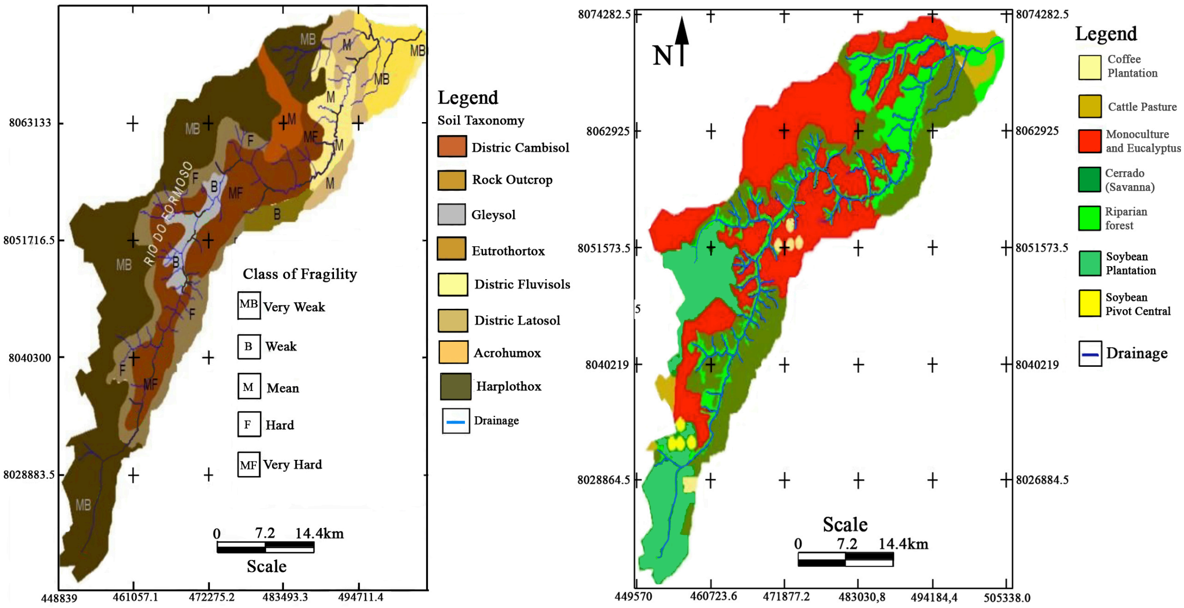

Figure 3

Distribuition of soils and the land use (agriculture; cattle, forests) in the basin of Formoso river (Adapted from Baggio, 2008)

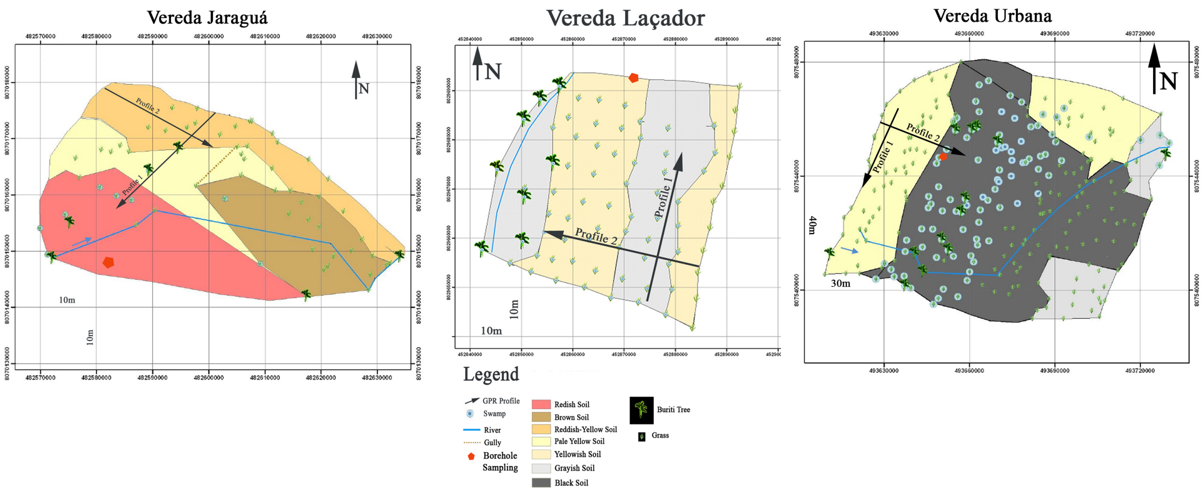

Figure 4

Location and soil maps of the three investigated Veredas, the GPR profiles and the sampled drill holes.

3. METHODOLOGY

3.1. GPR INVESTIGATIONS

The geophysical data were obtained in the study area using a GPR, RAMAC equipment, from Mala GeoScience. Concomitantly, CMP (common mid point) profiles were done to define the velocity profile of the EM wave in the investigated area. Antennas with a central frequency of 100 MHz were used. The survey was performed with constant distance antennas (common offset) and the system was transported along a direction to obtain a profile of reflections versus position. The 16 stack mode was applied in order to increase the signal/noise ratio of the emitted wave, improving the quality of data acquired in the field. The other parameters used for the elaboration of the profiles were sampling frequency approximately 10 times of the central frequency of used antenna and a 450 ms time window. The spacing between the data acquisition points was 0,10 m.

The data processing aimed to improve the quality of the results of the field data, so that the interpretation of the images presented a better accuracy. The edition comprised the organization of data, *declipping, dewow, set time zero, migration, filtering, elevation statics, and depth conversion*.

3.2. SOIL SAMPLING

Soil samples were collected in the selected veredas in horizontal and vertical profiles. In horizontal profiles one sample (5 kg) was taken every 2 m in the upper 20 cm of the soil. The soil sampling was conducted in December 2008, February and May 2009, based on the USP-EPA (1992; 2007) methodology of the soil sampling (Figure 4). On selected positions, vertical sampling was carried out taking 2-3kg samples every 20 cm down to a maximum depth of 2 m (Figure 5). The samples were obtained by "Wolf mouth" type samplers and for deeper profiles a normal soil sampler. At the Laçador Vereda soil samples were obtained along six stratigraphic profiles. In Jaraguá Vereda, samples were collected along two stratigraphic profiles. In the Urbano Vereda, the samples were taken along two trenches opened by caving.

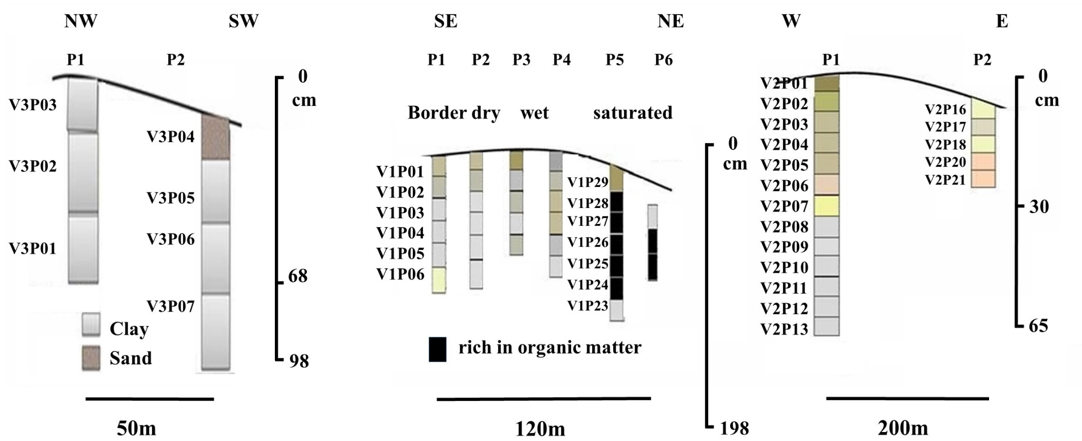

Figure 5
Indication of profiles and soils of the three investigated veredas. Left: Urbano; Middle: Laçador; right: Jaraguá.

3.3. LABORATORY TREATMENT

After collection, samples were homogenized, packed in plastic bags and transported to the environmental laboratory (NGqA) of the Manoel Teixeira da Costa Research Center (CPMTC/IGC/UFMG) where preparation and chemical analyses were carried out.

The samples were placed in paper trays and dried at room temperature for a period of 15 to 20 days. After drying, 500 g of each soil sample were submitted to particle size separation following the technical standard ABNT NBR 7181/1982 (ABNT, 1984).

The wet and dry soil colors were determined using Soil Color Charts (MUNSELL, 1975) as well as the soil pH in water (Table 1) and the cationic exchange capacity (CTC), using Embrapa procedure (EMPRAPA, 1997;

Table 2), the organic matter content was determined by colorimetric method and the metals by ICP-OES (Tables 3a, 3b 3c). Qualitative to semi quantitative mineralogical analysis was performed in the Laboratory of CPMTC by X-ray Diffraction.

Table 1: pH obtained in the profiles. V1: Vereda Laçador; V2: Vereda Jaraguá; V3: Vereda Urbana. Numbers from figure 5.

Sample	Depth (cm)	pH	Sample	Depth (cm)	pH	Sample	Depth (cm)	pH
V1S01	0-20	6,51	V2S01	0-20	4,57	V3P01	39-52	2,59
V1S02	0-20	6,16	V2S02	0-20	4,50	V3P02	29-35	1,68
V1S03	0-20	4,36	V2S03	0-20	4,38	V3P03	09-23	2,4
V1S05	0-20	6,59	V2S04	0-20	3,08	V3P04	0-20	3,28
V1S06	0-20	4,72	V2S05	0-20	4,70	V3P05	20-40	5,15
V1S07	0-20	5,81	V2S06	0-20	4,46	V3P06	48-65	4
V1S08	0-20	4,41	V2S07	0-20	3,99	V3P07	76-96	5,34
V1S08B	0-20	6,07	V2S08	0-20	5,23	V3S01	0-20	4,76
V1S09	0-20	6,52	V2S09	0-20	5,38	V3S02	0-20	4,8
V1S10	0-20	4,68	V2S10	0-20	4,72	V3S03	0-20	4,07
V1S11	0-20	4,73	V2S11	0-20	5,78	V3S04	0-20	4,97
V1S12	0-20	5,66	V2S12	0-20	5,12	V3S05	0-20	4,71
V1S13	0-20	4,57	V2S13	0-20	4,73	V3S06	0-20	5,73
V1S14	0-20	5,38	V2S14	0-20	4,89	V3S07	0-20	2,65
V1S15	0-20	5,27	V2S15	0-20	5,42	V3S08	0-20	1,22
V1S16	0-20	5,06	V2S16	0-20	4,17	V3S09	0-20	3,1
V1S17	0-20	5,18	V2S18	0-20	5,31	V3S10	0-20	2,45
V1S18	0-20	4,1	V2S19	0-20	5,31	V3S11	0-20	0,75
V1S19	0-20	2,87	V2S22	0-20	6,26	V3S12	0-20	1,88
V1S20	0-20	4,54	V2S23	0-20	6,04	V3S13	0-20	1,21
V1S21	0-20	5,25	V2S24	0-20	6,03	V3S14	0-20	5,04
V1S22	0-20	5,05	V2S25	0-20	3,78	V3S15	0-20	4,53
V1S23	0-20	4,98	V2P01	0-5	3,41	V3S16	0-20	4,87
V1S24	0-20	4,34	V2P02	15-20	5,29	V3S17	0-20	4,48
V1S24A	0-20	3,99	V2P03	15-20	4,22	V3S18	0-20	5,36
V1S25	0-20	4,12	V2P04	15-20	3,08	V3S19	0-20	5,7
V1S26	0-20	5,09	V2P05	20-25	4,27	V3S20	0-20	1,53
V1S27	0-20	5,08	V2P06	25-30	4,48	V3S21	0-20	3,03
V1S28	0-20	3,4	V2P07	30-35	4,31	V3S22	0-20	1,69
V1S29	0-20	5,37	V2P08	35-40	5,57	V3S23	0-20	1,69
V1S30	0-20	3,71	V2P09	40-45	4,88	V3S24	0-20	3,03
V1S31	0-20	4,25	V2P10	45-50	4,33	V3S25	0-20	3,06
V1S32	0-20	4,81	V2P11	50-55	5,75	V3S26	0-20	4,18
V1P01	0-20	6,67	V2P12	55-60	4,43	V3S27	0-20	3,83
V1P02	20-40	6,49	V2P13	60-65	4,32	V3S28	0-20	3,04
V1P03	40-60	6,79	V2P16	0-5	4,08	V3S29	0-20	3,38
V1P04	60-80	6,15	V2P17	0-15	4,14	V3S30	0-20	3,14
V1P05	80-100	4,5	V2P18	15-20	4,77			
V1P06	100-127	4,57	V2P20	15-20	5,03			
V1P07	0-17	5,77	V2P21	20-25	4,25			
V1P08	17-34	5,92						
V1P09	34-51	4,44						
V1P10	51- 68	5,58						
V1P11	68-85	3,45						
V1P12	85-103	3,04						
V1P13	0-20	6,67						
V1P14	20-40	6,97						
V1P15	40-60	6,64						
V1P16	60-80	6,41						
V1P17	80-100	6,32						
V1P18	0-19	3,48						
V1P19	19-38	2,79						
V1P20	38-57	4,03						
V1P21	57-76	3,87						
V1P22	76-95	3,88						
V1P23	95-114	3,18						
V1P24	160-180	2,49						
V1P25	128-148	2,47						
V1P26	100-120	3,13						
V1P27	70-90	2,44						
V1P28	40-60	2,52						
V1P29	10-30	3,42						
BS	180-193	2,65						
V1P30	30-53	2,75						
V1P31	53-76	2,02						
V1P32	76-100	1,41						

Table 2 - Values of determined CTC exchange capacity.V1: Vereda Laçador; V2: Vereda Jaraguá; V3: Vereda Urbana. Numbers from figure 5.

Indication	Vereda	Samples used	T ($cmol_c/dm^3$)
CTC 01	V3	V3P01 + V3P02 + V3P03	5,33
CTC 02	V3	V3P04	1,42
CTC 03	V3	V3P05 + V3P06 + V3P07	4,34
CTC 04	V2	V2P01 + V2P02 + V2P03 + V2P04	1,5
CTC 05	V2	V2P06+ V2P07 + V2P08 + V2P09	0,79
CTC 06	V2	V2P10 + V2P11 + V2P12 + V2P13	1,34
CTC 07	V2	V2P16 + V2P17 + V2P18 + V2P21	1,24
CTC 08	V1	V1P01 + V1P02 + V1P04 + V1P05	5,24
CTC 09	V1	V1P07 + V1P12	2,04
CTC 10	V1	V1P13 + V1P14 + V1P15 + V1P16	5,57
CTC 11	V1	V1P18 + V1P19 + V1P22 + V1P23	2,53
CTC 12	V1	V1P30 + V1P31 + V1P32	3,23

Table 3a - Heavy metal contents (mg/kg) in soil profile from Vereda Laçador. Depth in cm**.**

Sample	Depth	Cr	Co	Cu	Cd	Ni	Zn	Ba	Pb
V2S01	0-20	23,7	1,6	13,5	0,81	0,34	18,9	26,3	35,4
V2S02	0-20	25,8	2,1	14,3	0,84	0,34	16,4	32,7	33,2
V2S03	0-20	67,1	3,4	17,0	1,26	0,34	31,3	45,8	43,4
V2S04	0-20	46,0	1,8	15,5	0,85	0,34	17,4	37,8	40,8
V2S05	0-20	35,8	2,9	16,8	1,03	1,31	21,7	63,5	44,5
V2S06	0-20	23,0	1,6	13,0	0,81	0,34	12,5	30,4	31,0
V2S07	0-20	35,6	2,8	15,8	1,04	0,34	29,0	60,9	43,2
V2S08	0-20	70,0	4,1	13,9	1,01	0,34	16,3	33,8	39,0
V2S09	0-20	37,0	3,6	18,3	1,16	0,87	24,9	62,7	58,3
V2S10	0-20	39,6	1,3	15,6	0,73	0,34	25,3	18,0	37,6
V2S11	0-20	22,7	1,1	14,4	0,70	0,34	14,4	47,1	32,6
V2S12	0-20	18,6	0,9	13,6	0,61	0,34	13,1	22,7	21,8
V2S13	0-20	40,4	2,4	14,3	1,12	0,34	15,0	30,4	57,6
V2S14	0-20	37,3	2,4	16,1	0,84	0,34	18,3	57,1	42,2
V2S15	0-20	33,7	1,3	16,9	0,76	0,34	13,9	30,1	46,0
V2S16	0-20	53,3	2,5	18,1	1,05	1,07	17,9	34,1	53,2
V2S18	0-20	54,3	1,6	19,0	0,93	0,34	15,5	24,2	47,9
V2S19	0-20	146,0	3,4	20,0	1,29	4,63	27,2	60,6	80,0
V2S22	0-20	22,2	2,0	9,8	1,01	0,34	12,0	10,8	23,8
V2S23	0-20	35,9	1,5	15,7	0,77	0,34	9,0	67,3	55,4
V2S24	0-20	50,5	1,4	12,4	0,77	0,34	11,8	14,5	38,7
V2S25	0-20	26,2	1,5	26,1	0,95	0,34	26,4	89,8	91,7
V2P01	0-5	37,8	2,8	16,3	0,89	0,34	25,7	55,1	41,9
V2P02	5-10	37,2	2,6	15,4	0,92	0,34	13,2	59,2	40,0
V2P03	10-15	40,5	2,9	17,2	1,28	0,34	14,6	79,9	53,7
V2P04	15-20	45,9	1,9	21,2	0,92	0,34	13,5	73,7	52,9
V2P05	20-25	62,3	1,9	17,1	0,85	0,34	17,1	38,3	52,2
V2P06	25-30	71,2	2,0	19,1	0,79	0,67	15,7	60,8	48,9
V2P07	30-35	66,6	1,2	13,9	0,64	0,34	15,6	36,8	41,8
V2P08	35-40	98,3	2,4	17,4	1,03	0,34	25,4	80,9	69,3
V2P09	40-45	81,2	2,0	16,1	0,90	0,34	14,9	52,9	46,9
V2P10	45-50	104,1	2,2	22,7	1,16	0,34	10,5	124,5	67,4
V2P11	50-55	84,9	2,3	13,4	1,07	0,34	12,1	48,8	55,0
V2P12	55-60	101,8	1,3	21,7	0,73	0,34	9,9	90,8	72,0
V2P13	60-65	90,3	1,7	17,6	0,85	0,34	11,4	63,7	53,3
V2P16	0-5	91,6	3,0	13,3	1,21	2,99	15,8	22,2	42,2
V2P17	5-10	74,1	2,4	12,3	1,07	0,34	15,3	21,8	33,9
V2P18	10-15	89,8	2,4	18,0	0,99	3,49	27,9	36,6	41,9
V2P20	15-20	171,3	4,0	17,2	1,61	7,34	33,4	59,4	94,4
V2P21	20-25	42,1	3,3	15,4	1,14	0,34	18,9	46,1	40,8

Table 3b - Heavy metal contents (mg/kg) in soil profile from Vereda Jaraguá. Depth in cm.

Amostra	Depth (cm)	Cr	Co	Cu	Cd	Ni	Zn	Ba	Pb
V1S01	0-20	136,4	1,5	28,0	1,2	1,0	40,8	34,0	120,2
V1S02	0-20	121,9	1,4	22,0	0,9	0,3	18,9	5,6	100,4
V1S03	0-20	145,3	1,8	22,5	1,2	0,9	21,1	9,1	117,6
V1S05	0-20	138,7	1,3	21,2	1,1	0,3	38,4	15,9	123,8
V1S06	0-20	140,3	1,2	22,2	0,9	0,3	18,1	10,3	119,9
V1S07	0-20	147,5	1,6	21,0	1,1	0,3	21,1	6,0	108,0
V1S08	0-20	157,3	1,8	32,4	1,0	0,3	21,6	11,7	125,3
V1S08B	0-20	142,2	1,2	25,5	0,9	0,3	28,1	9,3	119,4
V1S09	0-20	145,4	1,2	28,1	1,0	0,3	28,7	14,5	121,5
V1S10	0-20	163,9	1,3	30,5	1,0	0,3	21,0	9,1	134,3
V1S11	0-20	157,0	1,8	25,5	1,2	0,3	15,5	9,0	129,8
V1S12	0-20	164,9	1,6	27,6	1,0	0,3	16,9	9,8	139,2
V1S13	0-20	166,2	2,6	22,9	1,6	0,3	18,5	12,5	150,6
V1S14	0-20	164,8	1,4	27,2	1,0	0,3	15,3	14,6	142,2
V1S15	0-20	172,6	1,4	29,2	1,0	0,3	17,0	12,3	151,4
V1S16	0-20	157,4	1,3	25,5	0,9	0,3	17,5	19,8	143,8
V1S17	0-20	180,1	1,4	26,5	1,0	0,3	15,2	17,3	162,6
V1S18	0-20	162,3	1,4	25,4	0,9	0,3	16,8	18,1	165,3
V1S19	0-20	158,1	1,2	23,1	0,8	0,3	20,6	11,9	143,6
V1S20	0-20	155,1	1,6	28,1	1,2	0,3	22,9	22,0	157,8
V1S21	0-20	158,8	2,1	22,5	1,4	0,4	17,2	20,8	187,6
V1S22	0-20	170,9	2,6	19,7	1,5	0,3	17,2	15,1	166,8
V1S23	0-20	149,6	1,7	23,2	1,1	0,3	14,2	23,6	181,9
V1S24	0-20	172,6	2,1	22,5	1,3	0,3	20,0	12,7	161,9
V1S24A	0-20	152,8	1,7	23,3	1,1	0,3	17,9	19,0	179,2
V1S25	0-20	154,1	1,5	20,8	1,0	0,3	14,6	8,5	118,0
V1S26	0-20	162,6	1,6	21,1	1,0	0,9	20,7	18,6	123,1
V1S27	0-20	186,1	2,2	24,2	1,4	2,0	20,1	11,6	134,7
V1S28	0-20	164,2	1,7	33,9	1,1	0,3	18,7	10,1	124,5
V1S29	0-20	166,9	2,1	19,5	1,4	0,3	21,2	9,8	140,0
V1S30	0-20	144,0	1,4	22,3	1,0	0,3	18,0	18,7	155,2
V1S31	0-20	146,0	2,8	21,1	1,6	0,3	22,0	19,4	184,9
V1S32	0-20	110,3	1,3	26,9	1,0	0,3	22,4	22,3	205,7
V1P01	0-20	127,8	1,7	24,4	1,2	0,3	70,8	37,6	111,3
V1P02	20-40	114,3	1,2	16,2	0,8	0,3	17,7	9,6	75,3
V1P03	40-60	118,1	1,9	15,9	1,2	0,3	13,3	3,2	74,3
V1P04	60-80	114,9	1,2	17,3	1,0	0,3	12,1	3,1	89,2
V1P05	80-100	102,7	0,9	14,0	0,7	0,3	10,2	1,9	64,8
V1P06	100-127	97,3	1,5	14,2	1,1	0,3	8,9	1,9	64,2
V1P07	0-17	133,7	2,0	22,7	1,3	0,3	58,8	33,0	112,1
V1P08	17-34	128,2	2,0	14,9	1,3	0,3	25,3	4,8	87,9
V1P09	34-51	135,9	1,7	18,3	1,2	0,3	15,2	1,9	83,0
V1P10	51- 68	114,7	1,2	16,2	0,8	0,3	12,7	1,9	70,6
V1P11	68-85	114,9	1,7	17,0	1,1	0,3	15,5	1,9	75,6
V1P12	85-103	155,6	1,9	17,5	1,1	0,3	12,6	1,9	100,3
V1P13	0-20	148,7	2,8	27,3	1,6	4,1	80,1	26,8	156,8
V1P14	20-40	140,2	2,3	15,8	1,3	0,3	37,0	11,7	111,0
V1P15	40-60	159,0	2,4	16,6	1,3	0,3	15,4	4,0	116,0
V1P16	60-80	180,8	2,1	19,6	1,2	1,5	12,1	3,5	108,3
V1P17	80-100	149,6	2,1	15,7	1,3	0,3	10,2	10,5	93,1
V1P18	0-19	118,5	2,4	17,9	1,3	4,5	23,0	17,7	177,9
V1P19	19-38	192,9	1,9	19,5	1,1	0,3	19,0	1,9	127,6
V1P20	38-57	145,9	1,7	20,4	1,0	0,3	19,5	1,9	83,2
V1P21	57-76	168,6	2,4	15,7	1,3	0,3	14,9	3,5	89,8
V1P22	76-95	163,8	1,2	16,8	1,0	0,3	11,4	3,4	77,9
V1P23	95-114	194,6	2,3	12,0	1,3	0,3	17,2	4,1	73,3
V1P29	10-30	119,4	2,2	18,4	1,2	1,1	21,2	11,1	134,6
V1P28	40-60	122,0	2,5	25,8	1,3	2,9	25,3	19,6	179,1
V1P27	70-90	147,5	1,8	29,0	1,0	2,0	19,1	15,0	191,3
V1P26	100-120	145,6	1,3	24,0	0,7	2,3	17,5	14,1	162,8
V1P25	128-148	145,4	2,2	29,6	1,2	1,0	20,7	22,8	247
V1P24	160-180	140,4	2,0	32,8	1,2	1,8	22,9	29,7	190,1
BS	180-193	67,6	2,3	12,1	1,3	0,3	15,9	5,9	70,2
V1P30	30-53	179,8	2,1	16,3	1,1	0,3	15,2	5,8	130,0
V1P31	53-76	74,3	1,9	21,4	1,3	0,3	19,9	25,6	209,9
V1P32	76-100	47,3	0,9	17,5	0,7	0,3	13,0	20,5	196,4

BS – Base Sample

Table 3c - Heavy metal contents (mg/kg) in soil profile from Vereda Urbana. Depth in cm.

Sample	Depth (cm)	Cr	Co	Cu	Cd	Ni	Zn	Ba	Pb
V3P01	39-52	76,1	5,9	46,1	1,0	12,7	33,7	183,0	92,2
V3P02	29-35	121,2	6,4	75,2	0,6	22,1	47,0	295,3	128,7
V3P03	0-29	205,4	5,7	87,7	0,8	21,1	47,9	291,1	161,8
V3P04	0-20	30,1	2,1	15,9	0,8	<0,3	20,1	40,0	22,3
V3P05	20-40	47,4	5,1	18,8	1,3	6,2	28,6	115,1	56,9
V3P06	48-65	47,9	4,0	30,7	0,9	10,8	60,7	141,6	68,1
V3P07	76-96	59,7	2,9	34,8	0,7	4,6	27,0	157,5	64,9
V3S01	0-20	38,9	2,2	21,9	0,7	2,8	17,7	42,3	47,9
V3S02	0-20	39,3	2,8	19,8	0,9	1,1	30,8	46,8	60,6
V3S03	0-20	59,7	4,9	25,8	1,0	10,8	36,6	91,2	89,4
V3S04	0-20	65,3	5,3	32,6	0,9	15,6	40,5	148,8	103,9
V3S05	0-20	48,5	6,1	31,0	0,8	14,2	40,6	228,1	67,1
V3S06	0-20	50,6	3,9	32,9	0,6	8,5	33,9	154,6	66,6
V3S07	0-20	53,6	5,4	34,1	0,7	15,5	48,4	134,5	63,9
V3S08	0-20	58,5	5,9	33,6	1,0	15,3	44,8	131,6	71,3
V3S09	0-20	60,5	7,5	35,2	1,1	18,5	52,5	179,6	62,6
V3S10	0-20	45,6	3,9	22,2	1,0	6,9	21,4	130,6	48,6
V3S11	0-20	61,0	6,2	26,0	1,0	15,2	31,6	183,4	54,3
V3S12	0-20	64,5	4,2	24,6	0,9	11,4	34,7	163,7	51,6
V3S13	0-20	54,1	5,1	32,5	0,7	14,5	63,4	158,3	48,0
V3S14	0-20	52,0	5,2	28,5	0,8	15,0	35,8	180,4	60,5
V3S15	0-20	62,1	6,5	34,4	0,9	17,5	42,9	207,2	59,7
V3S16	0-20	23,4	1,6	15,7	0,7	<0,3	15,4	25,7	29,1
V3S17	0-20	33,4	2,2	19,9	0,7	1,5	21,9	48,4	47,9
V3S18	0-20	48,6	3,3	28,6	0,8	9,6	24,6	77,7	75,0
V3S19	0-20	49,9	4,0	28,7	1,0	12,6	28,1	75,6	91,2
V3S20	0-20	69,0	6,3	32,9	1,4	13,4	45,7	85,5	113,0
V3S21	0-20	56,4	5,3	32,1	1,0	15,8	30,3	100,2	93,4
V3S22	0-20	46,4	4,7	27,2	0,9	15,7	25,2	79,6	74,8
V3S23	0-20	45,4	4,0	24,4	0,8	12,3	23,7	73,9	123,5
V3S24	0-20	58,7	4,5	34,3	0,9	13,6	27,6	85,8	95,9
V3S25	0-20	60,8	4,9	37,3	0,9	16,9	31,4	101,4	103,8
V3S26	0-20	42,5	3,7	26,3	0,9	9,9	27,2	71,5	73,9
V3S27	0-20	45,6	4,5	28,5	0,9	13,8	27,3	85,2	93,0
V3S28	0-20	49,7	6,0	31,8	1,1	19,7	36,0	92,5	94,4
V3S29	0-20	46,7	4,8	25,3	1,1	12,0	26,2	94,2	81,1
V3S30	0-20	42,6	4,1	23,9	0,8	14,6	30,3	88,6	68,6

4. RESULTS AND DISCUSSION

The obtained soil profile characteristics were compared with the GPR-results to decipher the correlation of these two methods and to see the importance of previous GPR survey to support chemical, mineralogical and genetic investigations.

4.1. GPR-RESULTS

In each of the studied veredas, three geophysical profiles were performed. Always two of these profiles intersect at one point and have approximately perpendicular directions to each another. The data were acquired with 100 MHz antennas in the common-off-set mode. The third profile was in CMP mode, to obtain the velocity of the EM wave on the subsurface. The photo from the Vereda Laçador (Figure 6) shows the opening of the profile trails, the proper acquisition of the profiles, as well as the relative position between them.

Figure 6
Photos of the GPR profile acquisition at the Vereda Laçador.

In the Radargram from profile 1 obtained at Vereda Laçador (Figure 7), the reflection of the EM wave is related to the low depth groundwater level of the area. This level was determined by the observations obtained in the drill holes near the site of acquisition of the GPR profiles. This reflection is marked blue in the interpreted profile. The presence of prominent but discontinuous reflections, indicate the presence of alluvial sediments and their internal structures.

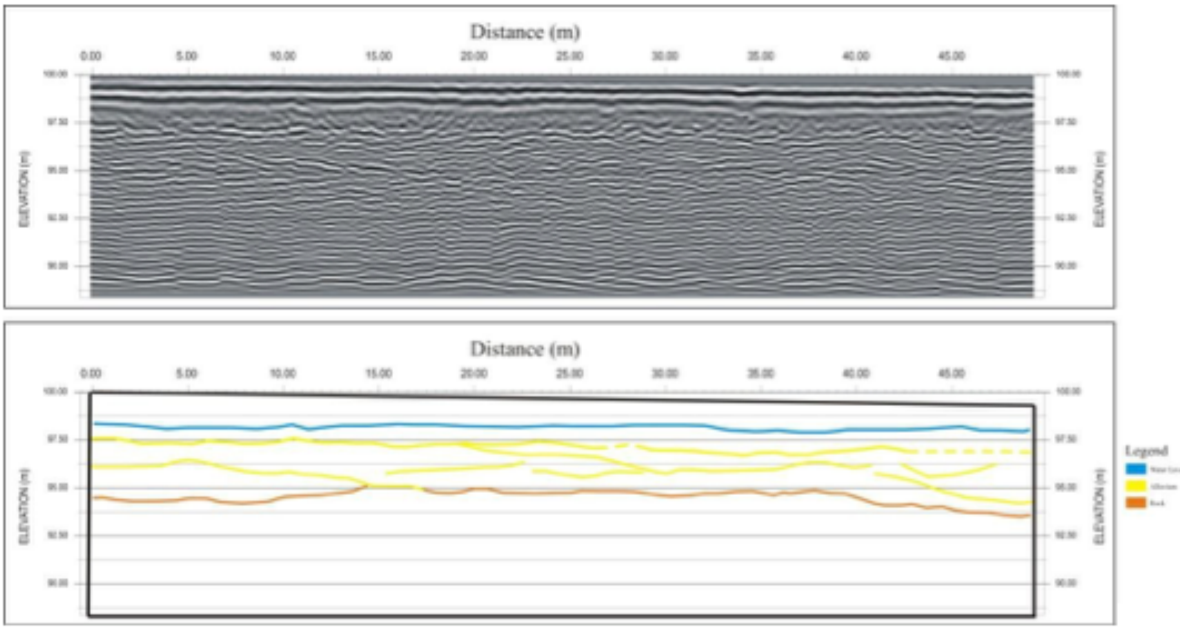

Figure 7
Radargram 1 from Vereda Laçador and its interpretation.

The Radargram of Profile 2 in this Vereda (Figure 8) presents similar patterns like the Radargram 1 (Figure 7). The reflections of the groundwater level are indicated in blue, the discontinuities and overlapped reflections are marked in yellow presenting the pattern of cross stratification, typical of fluvial sedimentary deposits. This part of the Vereda can be considered as an abandoned river arm, with its channel and margins. Below this upper level, the reflections of the basement with completely different patterns from the one that occurs in the interfaces of the alluvial situation can be observed. Also in Vereda Jaraguá the GPR-profiles were obtained perpendicularly to each another (Figure 9).

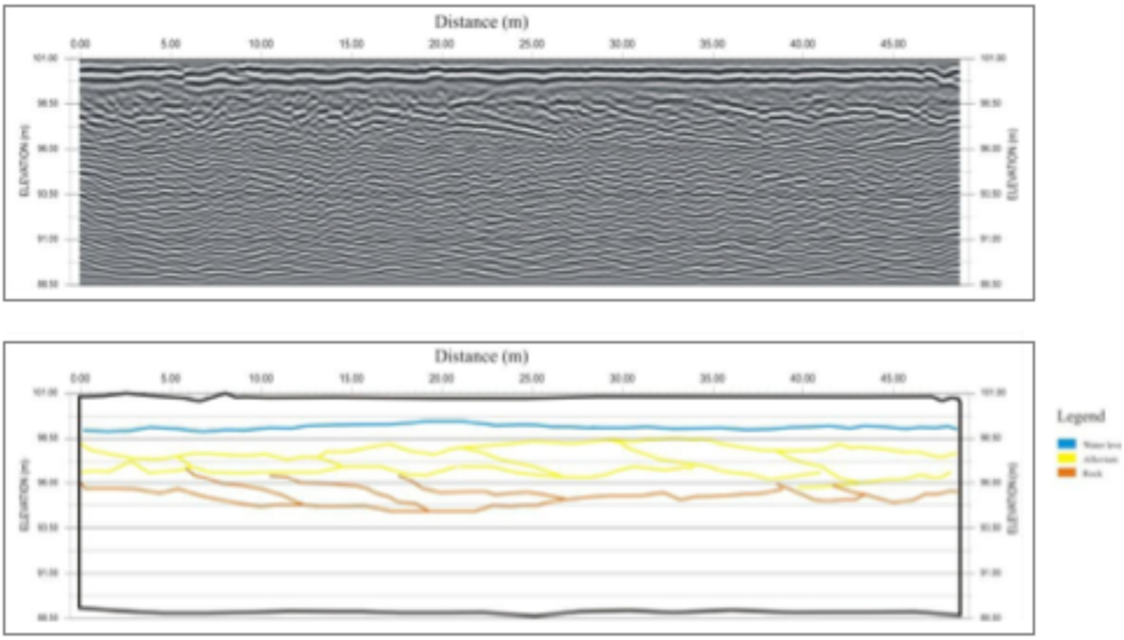

Figure 8
Second radargram of Vereda Laçador and its interpretation

Figure 9
Photos of the locations where profiles 1 and 2 of Vereda Jaraguá were prepared and executed.

The Radargram 1 obtained along a profile of the Vereda Jaraguá (Figure 10) shows some very distinct reflections patterns of the EM wave. Between the distances from 0 to 7 m, one can observe the presence of a well-marked depression representing presence of a well-defined fluvial paleochannel. About 20 m distance another small current drainage channel can be seen, and just below them a well-defined paleochannel, however narrower than the paleochannel of the left part of the radargram. Just below the depth of 96.7 m in the first meters of the radargram, in the upper part the presence of a reflector with strong amplitude marking the contact between the alluvium and the saprolite can be seen. Just below this reflector, the drill holes show the presence of the not altered bedrock

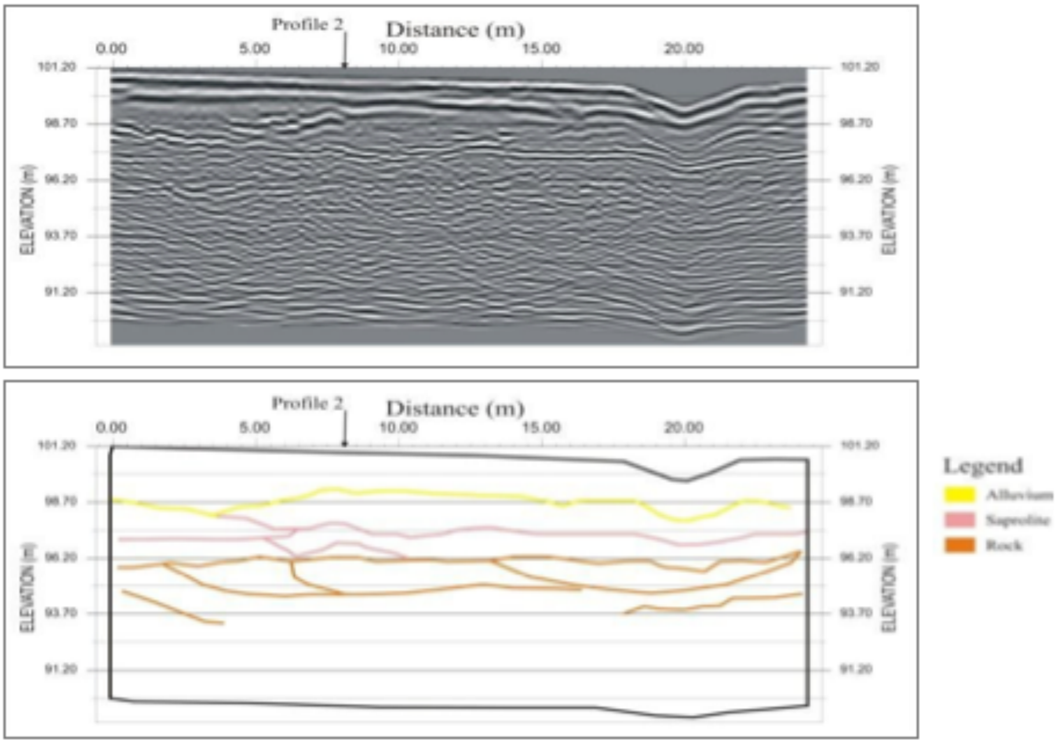

Figure 10
First radargram of the Vereda Jaraguá and its interpretation.

In the second radargram obtained in the Vereda Jaraguá, throughout the left portion of the radargram (Figure 11), a predominance of sub-horizontal-flat parallel reflectors is noted. These extend up to 15 meters away, with angular orientation in relation to the surface, indicating a newer deposit. Approaching to the center of the profile, at 5 meters depths, a truncation between different lithological strata is observed. The reflectors exhibit features with asymmetric and discontinuous pattern, possibly indicating a cross-stratified deposition. Right below in the diagram, the reflectors patterns of acrolith can be observed. At the intersection between the profiles, the observations are congruent for the two profiles

In the area of Vereda Urbana two profiles were obtained, one along a road and another cutting the Vereda perpendicularly (Figure 12). In the upper part of the radargram obtained in Profile 1 (Figure 13), a wavy, well-highlighted reflector is observed. This structure is related to the presence to small fluvial paleochannels, and some internal reflectors indicating the sedimentation process of the alluvial sediments. Below it is a more flat-plane reflector indicating the presence of the paleosurface, formed by the rocky saprolitic basement.

The presence of sub vertical planes, related to discontinuities or fractures present in the rock is noted. In the radargram of profile 2 (Figure 14), perpendicular to the first, in the upper part the reflections on the alluvial sediments can be observed. Just below, the presence of a continuous and flat reflector indicates the contact to the rocky basement. In this basement formed by sandstone, flat reflectors are observed, showing possible internal sedimentation plans during its deposition.

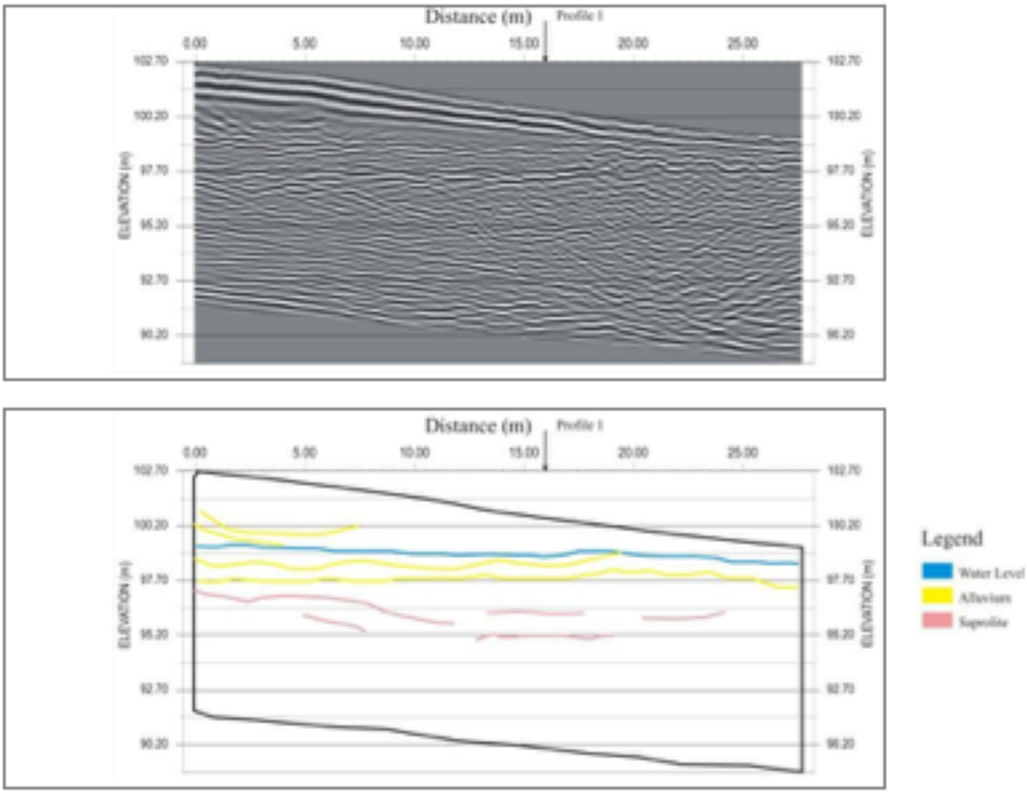

Figure 11
Second radargram of the Vereda Jaraguá and its interpretation.

Figure 12
Photographs of Vereda Urbana with the localization of the GPR profile lines.

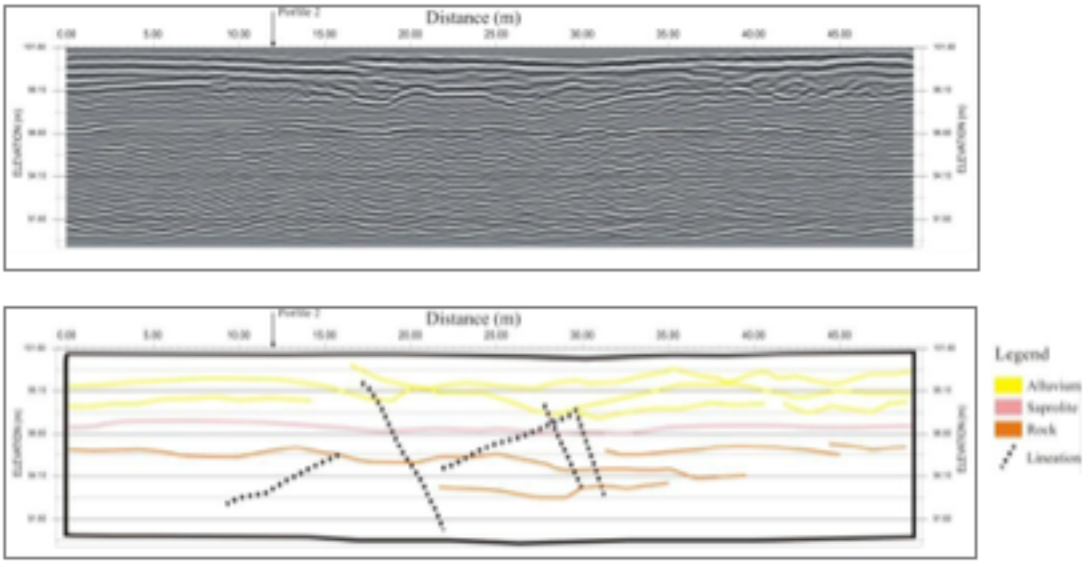

Figure 13
First radargram of Vereda Urbana and its interpretation.

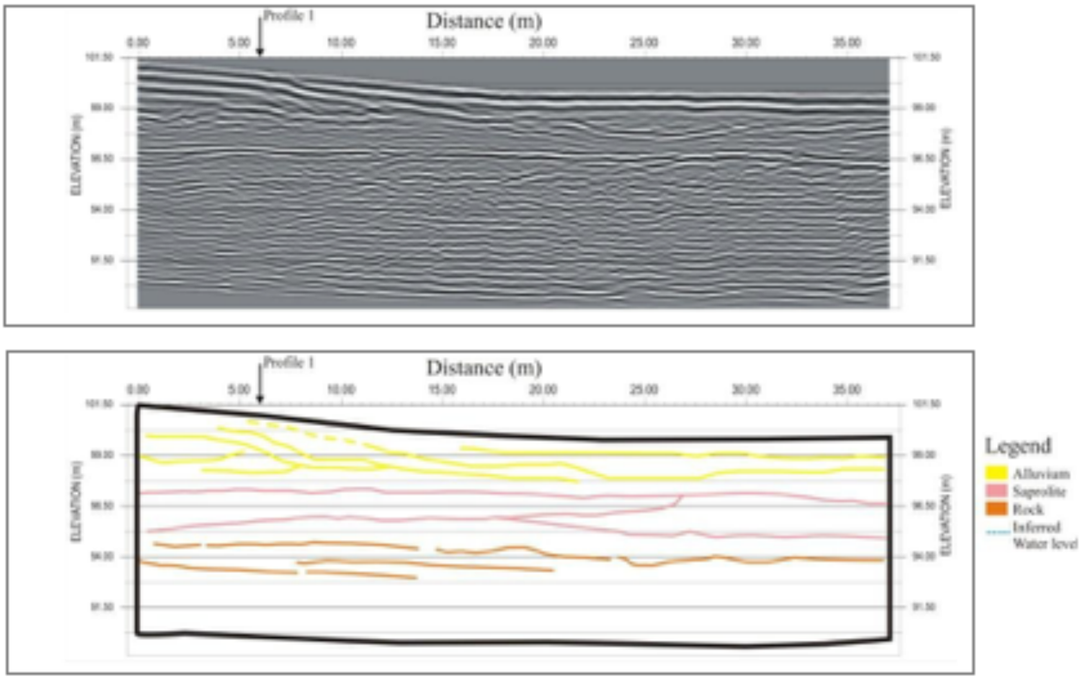

Figure 14
Second radargram of Vereda Urbana and its interpretation

4.2. SOIL PROFILE INTERPRETATION

Using the obtained information, the results of GPR, soil profiles, mineralogy and grain size distribution were combined to create additive profiles over the selected veredas.

4.2.1. SOIL COLOR

In the Vereda Laçador samples, the color ranges from 5Y (light grey) to 2.5 N (black), in Vereda Jaraguá from 2.5 Y (light grey) the 2.5 YR (brown greyed) and for the samples of Vereda Urbano the colors are distributed from 10 YR 7/3 (brown with very slightly clear-greyed touch) to 10 YR 2/1 (black). The color distribution is typical for very poorly drained soils with high organic content and formed under reduced conditions.

4.2.2. MINERAL COMPOSITION

The obtained results by X-rays diffraction indicate a predominance of quartz, kaolinite, gibbsite and subordinate of muscovite as important constituents of mineralogy of the soil samples. Using this data and field observations it was possible to show additive typical profiles for the three investigated veredas.

4.2.3. SOIL CHEMISTRY

As shown in tables 1, 2 and 3(a, b and c) it is possible to see that the results are connected to each other. Higher CTC indicates higher concentrations of clay minerals (Figure 15). The CTC-capacity is also correlated with the mineral distribution in the profile samples. The GPR defined contacts are indicative for the changes in profile mineral composition (grainsize; composition) and therefore in this way for the metal concentrations.

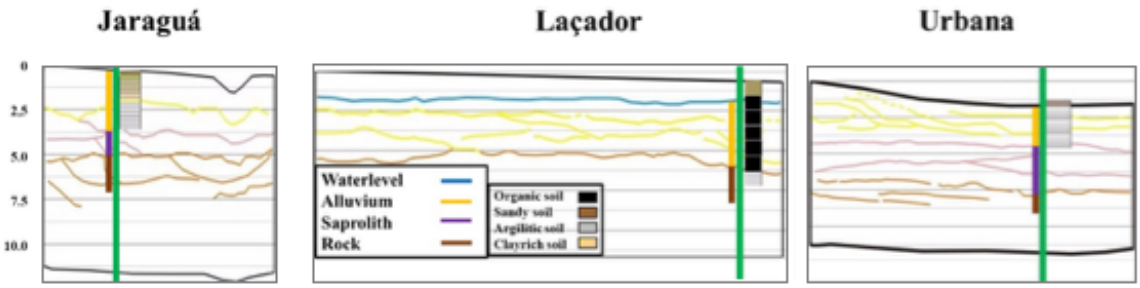

Figure 15
Integration of GPR data, drill and soil sampling results. Depth approximately in meters. Green: Drill hole; left column: Rock distribution in the drill; right column: Soil profile.

5. CONCLUSIONS

Data from the interpretation of radargrams allow to define the structures of the subsurface of the area. These data indicate the presence of paleochannels, and favorable conditions for the slow percolation of water in the basement. Only in the profiles from Vereda Urbana the presence of lineaments in the rock can be noted. However, these lineaments did not prevent a greater accumulation of water over the basement. The structures observed in the subsurface of each of the veredas, reflectors with horizontal tendency, few fractures in the not weathered rock, conditioned the process of soil evolution present in the area with its characteristics observed in the samples collected and analyzed.

These conditions favor a similar development, although the veredas are located in different geographical and geological positions in the basin, and even in different elevations. The GPR proved to be very efficient in observing the structures of the subsurface, revealing forms and continuities of sedimentation plans, as well as the presence of few lineaments in the sound rock and to correlate with other analytical data to form an integrated model.

6. ACKNOWLEDGMENTS

To the UFMG, UNIMONTES and the project "Evolution of the paleo-geo-Quaternary environment of the veredas of the São Francisco River basin CNPq (MCT/CNPq 15/2007- Universal), municipality of Buritizeiro, Minas Gerais, Brazil: environmental geochemistry, depositional environment and Palynology" for logistic and financial support. To CAPES for granting a master scholarship.

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