GPR application in disposal structures of iron ore waste

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Abstract

The tailings generated by iron mining in Brazil are already in big quantities and increase in a huge speed. These are arranged in known structures such as tailing dams and piles, which demands mostly large areas inside the mine complex. The limitations of natural source as well as new areas for waste disposal have leaded a paradigm change. Therefore, this study aimed the application of a geophysical technique known as Ground Penetrating Radar (GPR) in order to define the existence of sedimentation patterns in the subsurface of the Diogo's tailing dam in Rio Piracicaba (Minas Gerais- Brasil). This technique consists in the emission and reception of electromagnetic waves in the subsurface via antennas. A methodology for GPR application in reservoirs was developed. Different textures in submerged soil reservoir were observed from the survey of geophysical data, obtained using the technique of single reflection profiles. The GPR profiles presented clear images of the reservoir bed and the internal sedimentary structures could be recognized. The main contribution of the GPR images for the embankment operations in the iron mining's complex is the knowledge of deposition lines, which might indicate the concentration points and critical trends handling these wastes.

Introduction

Mining produces significant volume of waste materials that need to be moved and managed. Safe disposal of mining waste is generally recognized as the single largest environmental challenge facing the mining industry worldwide and a major expense for mining companies. Historically, environmental impacts emanating from onland mining waste can be widespread and may continue to affect livelihoods, health and the environment long after the mining has ceased. Some common impacts are forest clearance, land disturbance and removal, change of landscape due to excavation, disposal of significant amount of waste material, and pollution of watershed and nearby areas (Sopac, 2015)

According to the Brazilian National Politic of Solid Waste (Brasil, 2010), the wastes from mining are divided in waste rock, from the mining, and processing waste, from ore processing. The Brazilian National Standards Organization (ABNT, 2006) defines processing waste as every material which is not economical useful and produce during ore processing. It may consist of natural material without any modification other than crushing or of natural material processed to varying degrees during the ore processing phase, and possibly containing chemical, inorganic and organic components. The amount and behaviour of waste rock products that are generated during any mining operation depend largely on the geological characteristics of the orebody and host rock, type of mining used and the scale of production (Sopac, 2015).

The environmental paradigm of resources reduction brings the central theme in this work. The lack of new areas for mining waste disposal and the decrease of iron ore with high hematite concentration create the possibility of reutilization of mining waste already disposed in Tailings dams. Then, the GPR (Ground Penetration Radar) technique was applied in order to evaluate the mining waste deposition in Diogo's tailing dam. This nondestructive method allows analyzes of sub-superficies by the emission and catchment of electromagnetic waves (Davis & Annan, 1989).

Study area

The mining center Água Limpa is one important area for iron ore production in Minas Gerais state (Brasil). One significant way of mining waste disposal is by tailings dams. In the Água Limpa center, there are some tailings dams, which receive predominantly crushed rock materials in mud way. They are produced during ore processing and usually transported from the processing plant via pipeline to a final storage area (Espósito, 2000).

The Diogo's dam (Lat. 19º55'51"S e Long. 43º11'20"W) is one this tailings dams and its drainage is in Rio Piracicaba watershed. Its reservoir was created by dam in Córrego Pé da Serra and has 61.4 hm^3. Total area inundated by reservoir is 140 ha (Martini, 2014).

Ground Penetration Radar (GPR)

GPR is a nondestructive geophysical method that can accurately map the spatial extent of nearsurface objects and changes in soil media and ultimately produce images of those materials (Conyers and Goodman, 1997). Its profiles are used for evaluating the location and depth of buried objects and to investigate the presence and continuity of natural subsurface conditions and features (Do, 2003).

The GPR transmit ultra high frequency radio waves (generally 10 MHz to 1,000 MHz) into the ground through an antenna. The waves are then reflected from various buried objects or different materials (i.e. soil, water, contaminant plume). The reflected waves are catch by the antenna which stores them in the digital control unit. This process is known as electromagnetic wave propagation and scattering and it is used to image, locate and quantitatively identify changes in electrical and magnetic properties within the ground (Beres & Haeni, 1991; Daniels et. al., 1995).

There are some limitations in GPR application. Some of them are related to subsurface characteristics such as soil conductivity, which can limit the depth of wave penetration. In the water, one important physical property of at GPR frequencies, the dielectric constant (ε), is high because the water polar molecules. Thus, waves propagating through such a material both go slower and are subject to more attenuation (Popini, 2001).

Method

In this study, the blinded antennas (100MHz and 200 MHz) were used in order to avoid the interferences of external environmental. They were monostatic which means that the transmitter and receiver are in the same place. The method of simple reflection was applied. In this proceeding, the transmitter and receiver are separated by constant distance and the antenna is transported along the profile. The GPR model was the TerraSIR from GSSI® and the equipment choice was according to soil media and water as well as the possible resolution and penetration of electromagnetic waves.

In the Diogo's tailing dam, GPR antenna was inside a inflate boat in order to avoid metal interferences. A main metal boat with engine towed the inflate boat and the team, which were a steersman and two technical people, were inside it. In order to know the accurate position of GPR profile, a differential GPS (Global Positioning System) from Topcon was used. One GPS antenna was in reservoir bank and the second was coupled in the GPR computer. The steersman worked in order to keep the straight and constant movement during the catchment of GPR profile (Figure 1). Twenty (20) profiles were collected

After the field sampling, the profiles were processing in Gradix Interpex, Reflexw 2D data-analysis e Radan® 7. The pos-processing analyses were: declip, analyses of frequency spectrum, dewow filter, set time zero, window trances, remove background, gain application, velocity analyses, time/depth conversion and length correction using the GPS information.

The hyperboles found in the GPR profiles gave the wave propagation velocity, which was obtained by the software. Then, the depth correction was made.

Disposed waste sampling

The disposed material in the Diogo's tailing dam was sampled in the areas where the GPR profile were done. This sampling aimed at featuring of waste propriety in order to help the analyses of GPR images. The "sample 1" was collected in "setor 1" and the "sample 2" was collected in "setor 3" (Figure 1).

Analyses of humidity, mineral composition, electrical conductivity and granulometry were performed. Besides that, the samples were submitted in specific mass tests, X-Ray diffractometer studies and fluorescence analyses.

GPR profiles

Three different areas in Diogo's reservoir were identified once the processing waste comes from one side of reservoir (Figure 1):

- "Setor 01": Area with high amount of processing waste with low depth.
- "Setor 02": Area near to spillway with big depth.
- "Setor 03": Area with high amount of processing waste with low depth. The processing waste was dark and heavy.

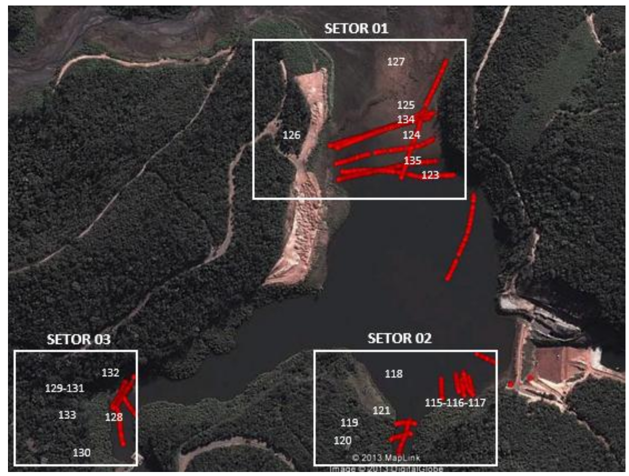

Figure 1 – Diogo tailing dam: three different areas were sampling and were studied with GPR

Results

Characteristics of disposed waste

The electrical conductivity results showed the "Amostra 2", which is from "Setor 03" conduct the electromagnetic wave more than "Amostra 1", which is from "Setor 02". The water presence in the media was able to change the electrical conductivity of sample. It almost doubled the values obtained in dry sample (Table 1).

Tabela 1 - Condutividade elétrica das amostras 1 e 2.

Sample	Humid	Electrical Condutivity (μS/cm)
"Amostra 1"	Yes	59.8
"Amostra 1"	No	26.9
"Amostra 2"	Yes	113.9
"Amostra 2"	No	63.2

The mineral compostion tests gave the following information:

- "Amostra 1": Fine granulometry with part of clay and silt. Rarely quartz and hematite grains could be observed;
- "Amostra 2": Predominance of small plates of hematite with angular and round quart grain, which reached the maximum of 1 mm. The hematite plate reached the maximum of 0.3 mm. Proportion: 60% hematite and 40% quartz.

The specific mass was higher in "Amostra 2" was 3.154g/cm^3 than in "Amostra 1" 2.864g/cm^3. The qualitative studies in X-Ray diffractometer confirmed the presence of quartz and hematite.

The fluorescence indicated the predominance of ferrous oxides and silica that composed almost all chemical composition.

The humidity test showed the "Amostra 1" was able to retain 53.31% water and "Amostra 2" retained 15.76% water. The granulometry analyses allowed to create the curves (Fig. 2) and showed the "Amostra 1" was finer than "Amostra 2".

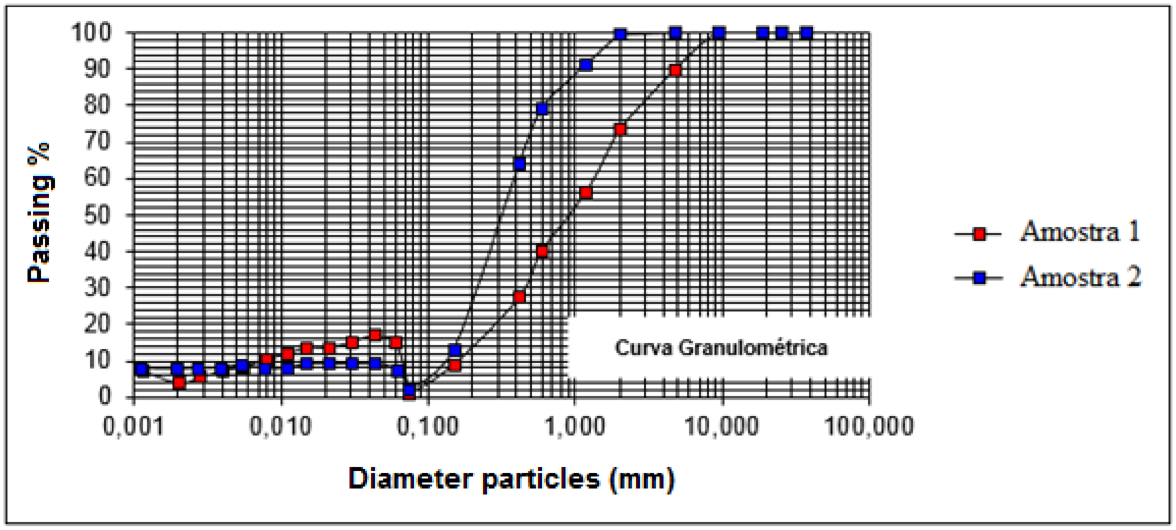

Figure 2 - Granulometry curves of "Amostra 1" and "Amostra 2".

GPR Profiles

The analyses of processing profiles showed multiple reflections due to water. However, the attenuation caused by water was not enough to derail the information of waste disposal.

In the other profile of "setor 03" (Fig. 3), there were some water noises (red line) and it was possible to identify the reservoir bed (pink line), the waste deposition line (green line) and alterations in the signal (blue line). This last one occurs probably due to the high hematite concentration of this waste. The radargrams of "setor 01" (Fig. 4) indicated some concave reflections which means changes in the deposition process (yellow line) and deposition lines (green line). The red line indicated a multiple reflection.

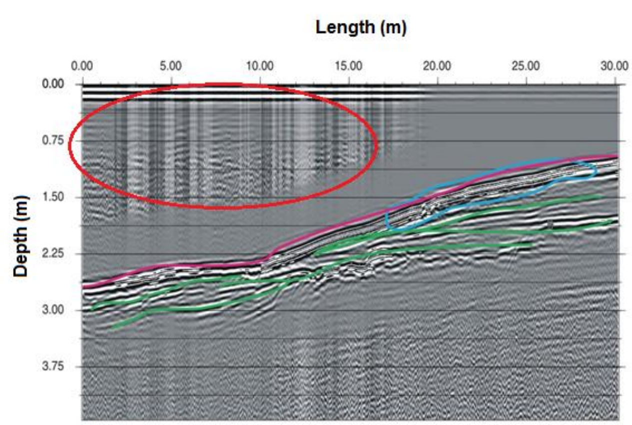

Figure 3 – Radargram fo 128 Profile in "Setor 03" with antenna of 200 MHz

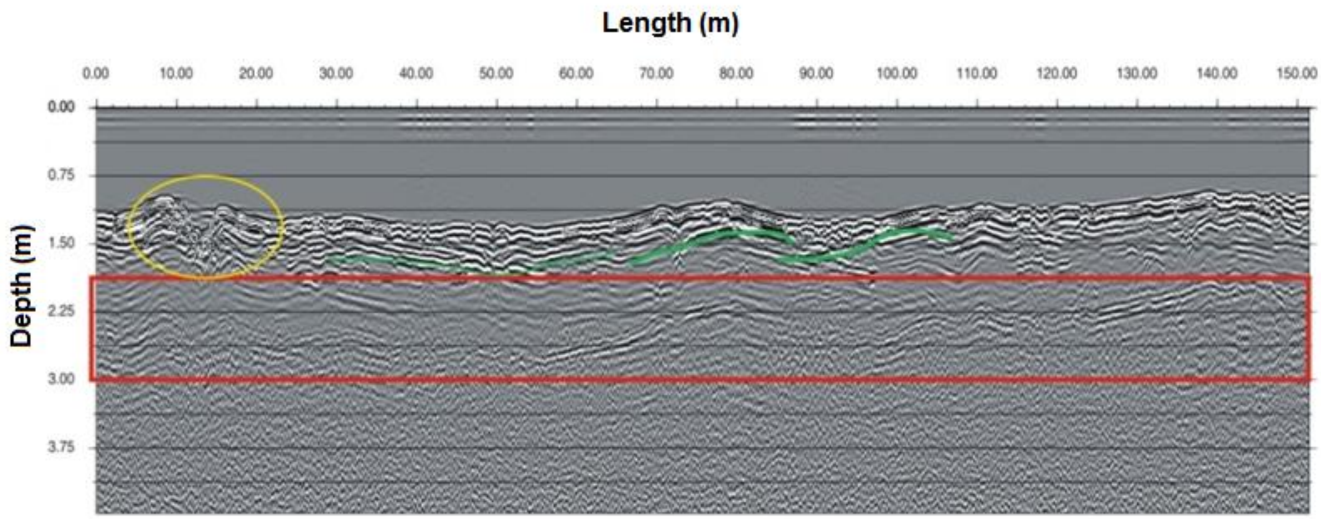

Figure 4 – Radargram of 127 Profile in "Setor 01" with antenna of 200 MHz

The radargrams obtained by antenna 100MHz gave deeper information than 200 MHz radargrams. However, the depth difference was around 1 meter and detailed information was loosen by 100MHz antenna application. Some structures such as hyperboles (yellow line), batimetry (pink line), deposition line (green line), and change in material due to change in wave patterns (blue line) could be observed in some profile (Fig. 5)

Conclusions

This work showed that it is possible to apply the GPR technique in disposal structures of iron ore waste. Although the high electrical conductivity of media (between 59.8 and 113.9 □S/cm), which was composed by waste with hematite and quartz concentration and water, some deposition structures could be identified, such as hyperboles, batimetry, deposition line and change in material due to change in wave patterns.

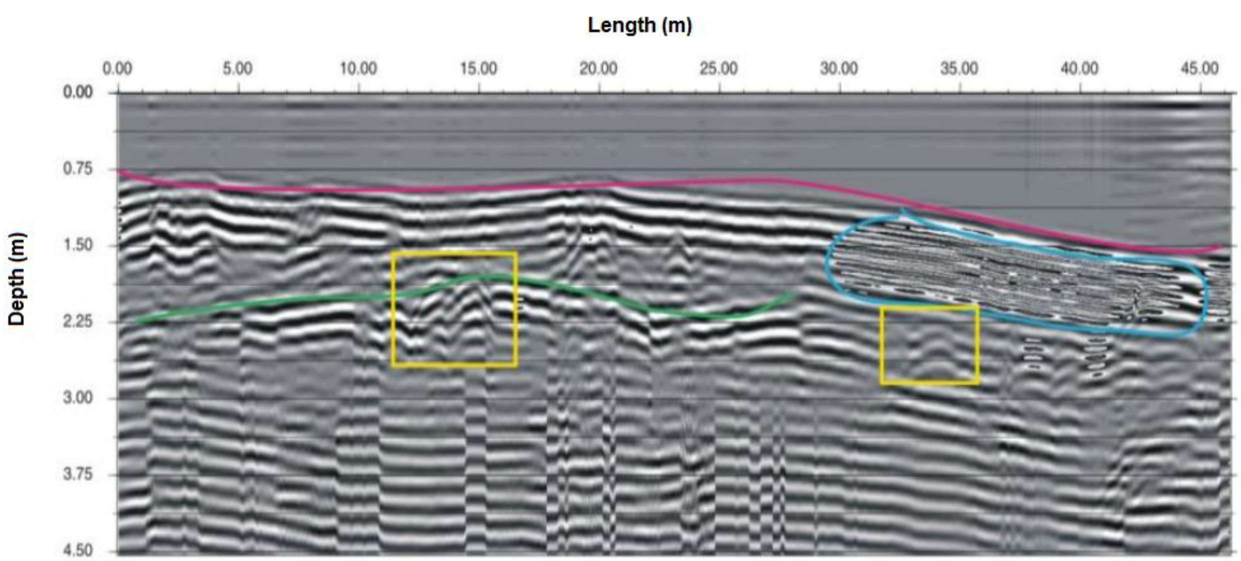

Figure 5 – Radargram of 132 Profile in "Setor 03" with antenna of 100 MHz

There were some attenuation of electromagnetic wave in the water but it was not enough to derail the analyses of subsurface structure. The presence of high conductivity solids in the water could improve its capacity in transmit the electromagnetic wave. This hypothesis should be verify in future works.

It is the initial study about the possibility of GPR in disposal of iron ore waste and the results will subsidize reutilization process of this kind of waste. Nowadays, the environmental paradigm and natural resource limitation pressure the mining companies to have eco-friendly politics. The application of GPR for future reutilization process is the first step for a new practice in mining area.

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