Estimating volumes and tonnage using GPR data

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Abstract—This work presents the use of ground-penetrating radar (GPR) data in the determination of overburden volumes and tonnage in mining context. The geophysical method of GPR was used in three distinct areas, located, inside the old Bejanca Mining Complex (parish of Queirã, Viseu District, Portugal), to determine and delineated the soil and sediment/bedrock interface. The interpretation of GPR data, and its correlation with borehole data, allowed the successful detection of this interface and the estimate of the volume and tonnage of the overburden sediments and soils. For this characterization, three-dimensional imaging methodologies were applied to create a volumetric reconstruction. The GPR system was found to be an effective tool for delineating the bedrock interface as did three-dimensional imaging methodologies in calculating the volume and tonnage for each study area. It provides not only a detailed view of the subsurface but allows the information to be gathered quickly and easily. It can also help companies revise volume and tonnage calculations and help them estimate the volume of potential new deposits as well as providing a greater financial control. Furthermore, it can be used to plan and develop prospective areas with little environmental impact.

Keywords—GPR; volume; tonnage; Bejanca

I. Introduction

Ground-penetrating radar (GPR) has been widely used in recent years in many applications, ranging from, for example, civil engineering [7; 10; 20] to geology [4] and mineral exploration [14; 18] as well as in the detection of landmines and unexploded ordnances [8] or in the monitoring of contaminant infiltration in soils [6].

The basic operation of the GPR resides in the emission of electromagnetic impulses through a transmitting antenna, which, when propagating through a medium, will encounter structures or interfaces between materials or objects with different dielectric properties. These impulses or waves will then undergo phenomena of refraction, diffraction and reflection [3; 11], the latter being detected and recorded by the receiving antenna, thus obtaining a continuous record of signals along a profile [12].

The ability to transform the collected GPR data into workable data is a challenge on its own, nevertheless, with the right processing sequence and some good user judgment it is a task that becomes easier over a period of time.

The present paper arises from work that was developed in the scope of a master's degree project, and was carried out using the GSSI (Geophysical Survey System Inc.) SIR-3000 and two antennas (200 and 400 MHz). The aim of this work is mainly focused on the estimation of volumes and tonnage of a given area using GPR data and three-dimensional imaging software that will complement the collected data by allowing 3-D images to be created and volume and tonnage to be calculated. This is very important since the "Bejanca Eluvium" is rich in wolframite and cassiterite, ence the need, due to the relative density of these minerals to map the bedrock. The ability to provide a mining company with such data is of great importance, especially since the data can be gather at a very rapid pace and very easily when compared to traditional prospecting methods.

The information presented here is also an important contribution to the "Bejanca Eluvium" [2] project and prospection works and therefore hope still remains that this work might lead to a step closer in the reopening of part of the old mining complex located in the parish of Queirã (Viseu, Portugal).

II. Study Area

The three study areas (A1-A2-A3) are located inside the so-called "Bejanca Eluvium" [2] (Fig. 1) situated in the old Bejanca Mining Complex in the parish of Queirã district of Viseu (Central Portugal). The area is mostly comprised by agricultural fields as well as abandoned fields with dense bush growth and areas of tree plantations.

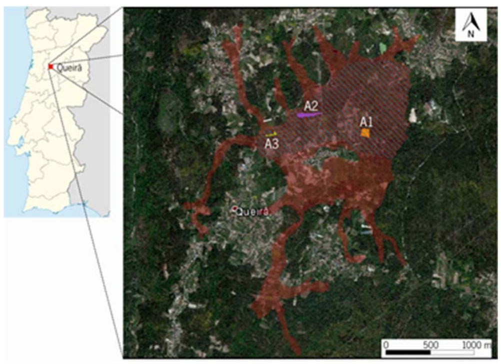

Fig. 1. Location of the study areas (A1-A2-A3) in the parish of Queirã (Viseu - Portugal) and representation of the "Bejanca Eluvium" with the red filling. The eluvium covers an area of approximately 3Km^2.

The "Bejanca Eluvium" (Neogene - Quaternary age) comprises of alluvial deposits and valley bottom deposits as well as fluvial terraces [13]. The first occur along the valleys of some rivers and streams, in generally narrow strips. They correspond to mixed materials transported by the water courses with the materials of runoff from the slopes. The second corresponds to small fragments of gravel in the bottom of some valleys, where granite, quartz, schist and greywacke stones can be observed [13]. It is in the quartz gravels were the rich cassiterite and wolframite minerals can be found.

This sedimentary unit lays over a greisenized bedrock of a porphyritic two mica granite [17]. This granite contains tourmaline and is traversed by small greisenized veins, with NW-SE strike. Faults are frequently filled by quartz, wolframite, cassiterite and clay [17]. The concentrations of Sn (Tin) and W (Tungsten) are limited laterally by two faults (N-S and NO-SE), agglomerating these two mineralizations in an area of intense fracturing. Due to the deposition conditions and the high density of these minerals (wolframite and cassiterite) they concentrate in the gravels just above the greisenized bedrock layer and thus the need to map this layer for a better exploitation of these resources.

III. GPR Data Acquisition

For this study, GPR data was acquired in three distinct areas comprising mostly of agricultural land with some vegetation. Area 1 is comprised of five different, but adjoining, fields that where designated "A-B-C-D-E". The field at Area 2 was designated "F" and the field from Area 3 was designated "G". The GPR data was collected using a GSSI (Geophysical Survey System Inc.) SIR-3000 equipment. The surveys were carried out using a 200 and 400 MHz monostatic antennas in common-offset mode. As an example Fig. 2 illustrates the orientation and disposition of the surveys that were conducted in Area 1. The GPR data was recorded with a 16-bit sample size, a 60 Hz sampling rate with a 2cm scan interval and a time window of 150 ns for the 200 MHz antenna and 120 ns for the 400 MHz antenna. Each radar traces contains 512 points per trace.

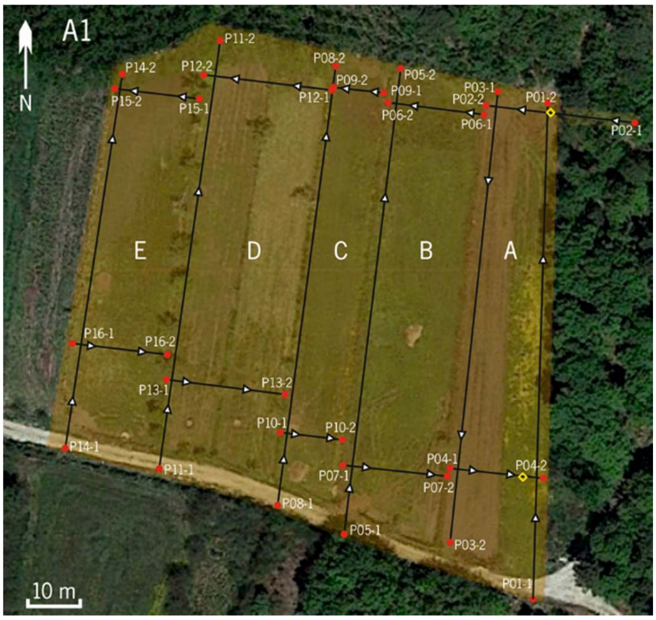

Fig. 2. Orientation and disposition of the surveys in Area 1 and respective ID of the beginning and end of each survey. A-B-C-D-E represent the five fields composing this area. Yellow dots represent the sample pits.

IV. Processing GPR Data

The processing of GPR data is fundamental for a proper interpretation, hence the need to improve the interpretability of radar sections and thus improve the final resulting image. This process is done by enhancing the desired weak signals at the expense of the unwanted signals [1; 19], also described as noise.

The conversion of the radar signal velocity into depth was defined by the WARR (Wide Angle Reflection and Refraction) method. The selected processing sequence for the acquired GPR data is as follows in Fig. 3. The processing software utilized was the ReflexW v7.5 2D data analysis (K.J. Sandmeier).

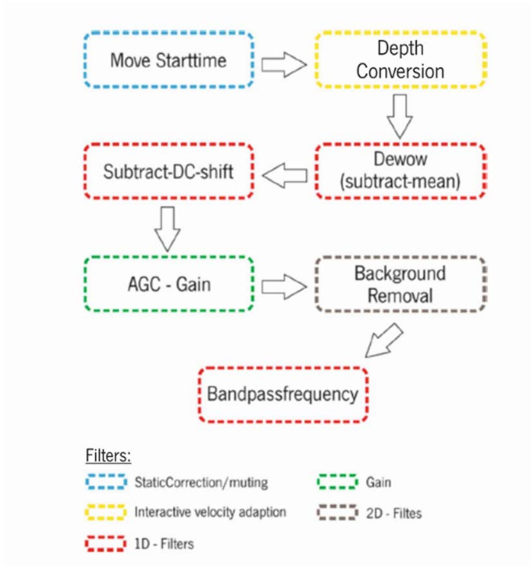

Fig. 3. Selected processing sequence for the GPR data.

As an example, Fig. 4 shows two resulting radargrams obtained by applying the selected process sequence. The first radargram is 93.78 m in length and the second, perpendicular to the first, is 29.78 m in length.

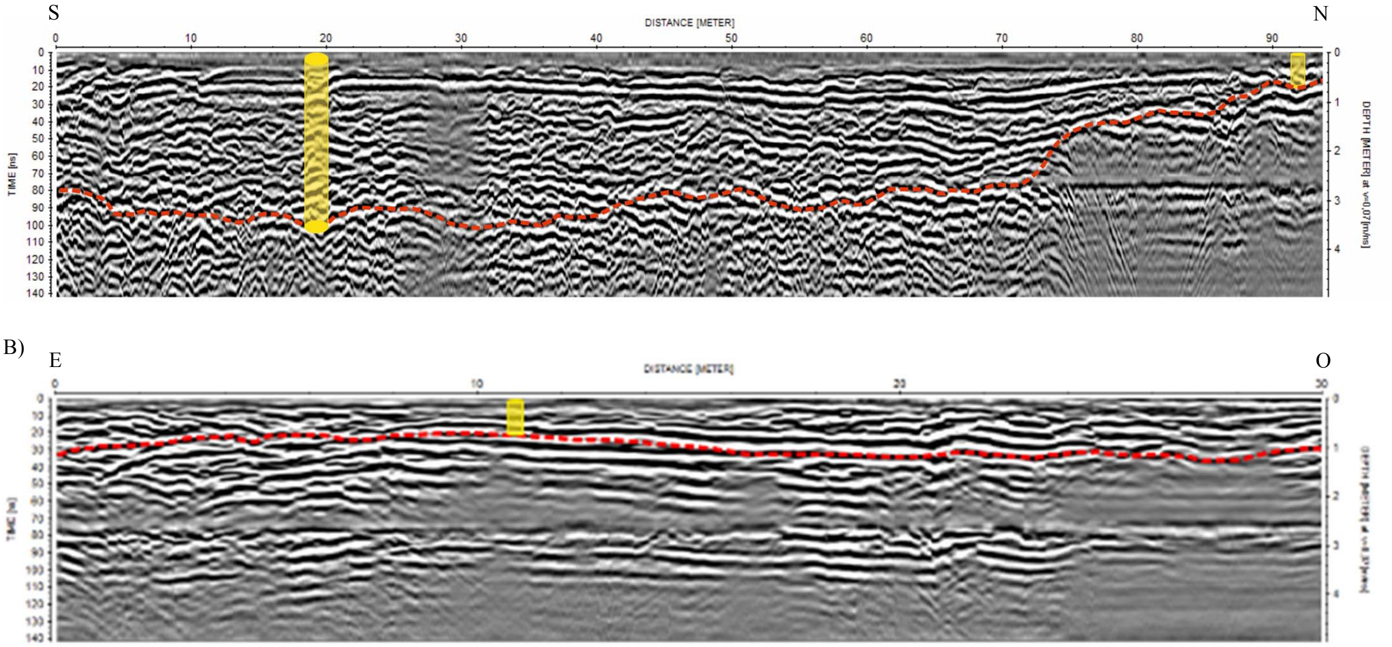

Fig. 4. Area 1, Field A. A) Survey 1, ID F_040, 93.78 m in leght, S-N orientation; B) Survey 2, ID F_041, 29.78 m in length, E-O orientation. Red dashed line represents the bedrock while the markings in yellow represent the location and depths of the sample pits. Both surveys were conducted with the 200 MHz antenna.

V. Estimating Volumes and Tonnage

From the acquired data and the interpretation phase of each radargram, the estimate depth to bedrock was deduced. A major contributing factor for this deduction was the information provided by Minerália - Minas, Geotecnia e Construções, Lda. regarding the sample pit locations as well as the bedrock depths. Following this process this data was then used to create a grid file in the Surfer™ 11 (Golden Software, LLC) software. It should be noted that two “X-Y-Z” grid files need to be created, one corresponding to the bedrock layer and another representing the surface. X and Y correspond to the system coordinates while Z refers to either the surface or the bedrock. To simplify the calculations the surface level was considered flat and so the same value was attributed to it. The software then allows the user to subtract the surface grid to the bedrock grid producing the required information.

The software through one of its options then transforms the data into a contour map that then can be transformed into a 3-D surface of the bedrock (Fig. 5). It was with this 3-D surface that the volume for each study area was calculated by another option within the software. As an example, the obtained volume for Area 1 was 753.229 m^3.

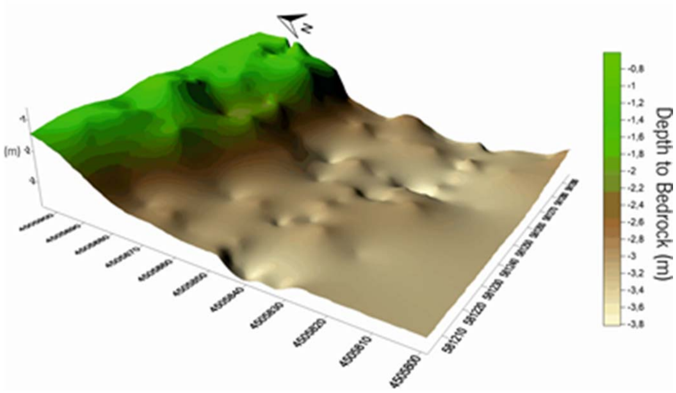

Fig. 5. 3-D map of the bedrock layer at Area 1. Depth increases from left (green) to right (pale brown). Values range from 0.70 m to 3.90 m.

To calculate the tonnage of each study area we have to remember that the overall weight of a certain soil is controlled [15] by:

- The density of soil particles;
- Water content;
- Porosity.

The values for these control factors can be found in Table 1. All of these values where inferred.

Table 1. Utilized values for tonnage calculations.

Porosity	Water Content	Density
15%	20%	2

With the values from Table 1 and the volumes from each study area, we can now calculate the three major equations that will lead us to the final weight of a given area. The volume of voids, volume of solids and volume of water can be calculated using the following equations [15]:

- Volume of Voids (V_v):

$$V_{v=V_t \times n\%}$$

Where V_t corresponds to the total volume and $n\%$ to the percentage of porosity;

- Volume of solids (V_s):

$$V_{s=V_t - V_v}$$

- Volume of water (V_a):

$$V_{a=V_v \times n\%}$$

Where $n\%$ corresponds to the water content of the soil.

The total weight of any given area can now be calculated. The results for the three study areas can be found in Table 2.

Table 2. Overall weight of each study area (t - Tonnes).

Area 1	Area 2	Area 3
1303.09 t	675.41 t	200.12 t

These results are on par with our expectations, since Area 1 reaches greater depths and comprises overall a larger area.

VI. Discussion and Conclusion

Estimating depth to bedrock can be a challenging task as it is based on user judgment in detecting an appropriate pattern [5] and can be especially difficult if the data is clouded with noise or a weak signal response. Always consider all possible uncertainties. However, this is a crucial step to achieve acceptable estimates in the volume and tonnage of each study area. Hence the need of a good interpretation of all available data.

The method described in this paper allows any user to calculate in a simple manner the volume and tonnage of any study area. The actual process of creating the grid file in the Surfer™ 11 software is very time consuming, depending on the volume of information, so this as to be taken into account when developing this type of work.

The results shown here prove that GPR data associated with specific software can be very useful for not only mapping the bedrock but also estimating volumes and tonnage, reducing field time and the costs of traditional prospecting methods as much as 70% while increasing efficiency by 210% [9]. However, it should be emphasized that accurate quantitative GPR measurements do require frequent ground truth information [16], especially when no clear contact between soil/bedrock is visible and thus sample pits are required to support the final interpretation and results.

In a company's point of view the biggest advantage associated with the implementation of this method comes from the potential of quantifying in advance the necessary expenditure for the extraction of the soil, by measuring the costs of machinery and personnel, allowing companies greater financial control. Therefore, ground-penetrating radar will provide suitable information on the prospected sites and anticipate variations along each area allowing for better planning of the exploitation. With the "fine-tuning" of the implemented method, it will be possible, with time, to resort less and less to exploratory wells, reducing the expenses with machinery, and thus enabling the allocation of these resources to other locations.

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