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Research Article

APPLICATION OF GROUND PENETRATING RADAR (GPR) METHOD FOR THE CHARACTERIZATION OF SOIL NEAR TIARET (NORTH-WEST OF ALGERIA)

K. Hebbache[1] and D. Boubaya[2]

[1]Department of Civil Engineering, University of Ferhat Abbas-Setif 1, Algeria

[2]Water and Environment Laboratory, University of Tebessa, Tebessa 12000, Algeria

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ABSTRACT

The Tiaret-Saida is a new high-speed railway under construction in northwestern Algeria. The main objective of this study is to map the shallow subsurface geological features and soil characterization. A geophysical tool comprising ground penetrating radar (GPR) has been applied for identifying the possible presence of cavities and fractures in the subsoil. GPR measurements were taken from a total of 24 profiles. The total length of the profiles was 240 m. The results of the GPR profiles obtained by two central frequencies 200 and 400 MHz indicate the existence of several anomalies that can be attributed to cavities and fractures in the bottom of several excavations, at depth ranging from 1 to 2.2 m. The interpreted results of GPR data were calibrated with the available lithological data from five boreholes drilled.

Keywords: Ground penetrating radar; Radargram; Tiaret; Algeria.

Author Correspondence, e-mail: hebbache.kamel@univ-setif.dz

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1. INTRODUCTION

The detection of underground voids in subsurface limestone by geophysical methods is an effective technique. They offer the ability to inexpensively collect vast quantities of two or three-dimensional subsurface data, including seismic, electrical resistivity, microgravity, ground penetrating radar and other methods used to measure the variation of the physical properties of materials such as shear wave velocities, density and electrical resistivity. These methods can be used to give information about the subsoil properties, such as depth to water table, thickness of layers, depth to bedrock, location of fault and fracture zones [1,2].

The method that has proved extremely useful is ground penetrating radar (GPR) technique. The GPR appear in recent years to be the most successfully non-destructive and non-invasive geophysical exploration applied method for mapping and identifying shallow subsurface geological structures and locating underground objects. GPR produces vertical cross-section images of the shallow ground.

Because of the good resolution of GPR, several applications were carried out by this method, to detect and investigate shallow structures such as natural or made-man underground cavities, as well as the estimation of risk of subsidence or collapse of a sinkhole [2-7], in geological investigations to define lithological contacts of sedimentary bedrock [8], in environmental studies to identify the features of coastal system includes the thickness of the sand deposit, internal dune structure and depth to water table [9] and in hydrology to delineate clay layers and estimate the groundwater level in dry season [10]. Moreover, this method has proved its efficacy in engineering studies. Carbonel et *al.* [7] used a combination of multiple surface and subsurface surveying techniques involving geophysical explorations (GPR and ERT), geodetic measurements, geological, geomorphological informations and borehole reports, in order to explore the suitability, the advantages and some limitations, of different techniques for characterizing the damage of buried sinkhole cluster and their development, in an urban area.

This study aims to map the shallow subsurface geological features and soil characterization, as well as to detect and map the undersgornd cavities/fractures in a limestone area. The survey site is located near Tiaret City, north-west of Algeria, at a mean elevation of ~1165m above sea level (Fig. 1a, b).

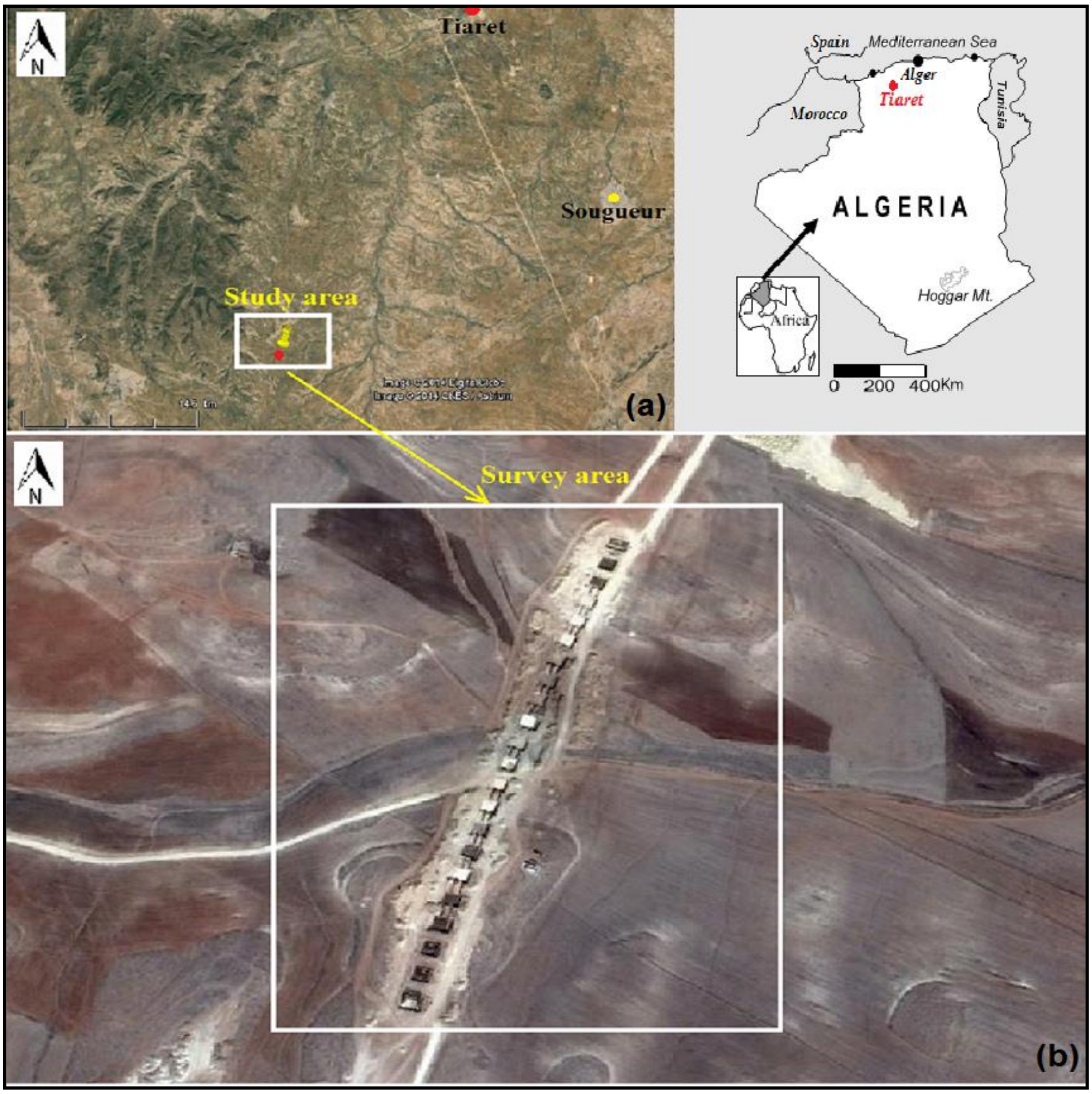

Fig.1. a and **b** Location map showing the study area (the square shows the studied area)

2. GEOLOGICAL SETTING

The study area belongs to the zone of transition between the Tellian Atlas in the North and the Saharan Atlas in the South. In the tectonic setting, this area belongs to the domain of "Hannania" which forms a broad band expanding from the mounts of Traras to Djebel Nador, close to Tiaret passing through the mounts of Ghar Roubane, mounts of Daia, mounts of Saida and finally those of Frenda. The North eastern limit is represented by the Tellian Atlas, that of the South by the high plains. The area is characterized by a compartmentalized structure of horsts and grabens (low dip) (Fig. 2). The major faults are of NW-SE direction. The region of Tiaret is represented by marine and continental formations spanning from the Trias to Quaternary. The local geology is characterized by the outcropping of upper Cretaceous formations, mainly, Cenomanian, Turonian and Senonian (Fig. 3). From a hydrogeological point of view, two aquifers occur in the vicinity of the study area. The Plio-Quaternary aquifer is dominated by coarse-grained gravel, sand and silt. This lithology gives low permeability for the near surface aquifer. The second aquifer is the underlying Jurassic carbonates.

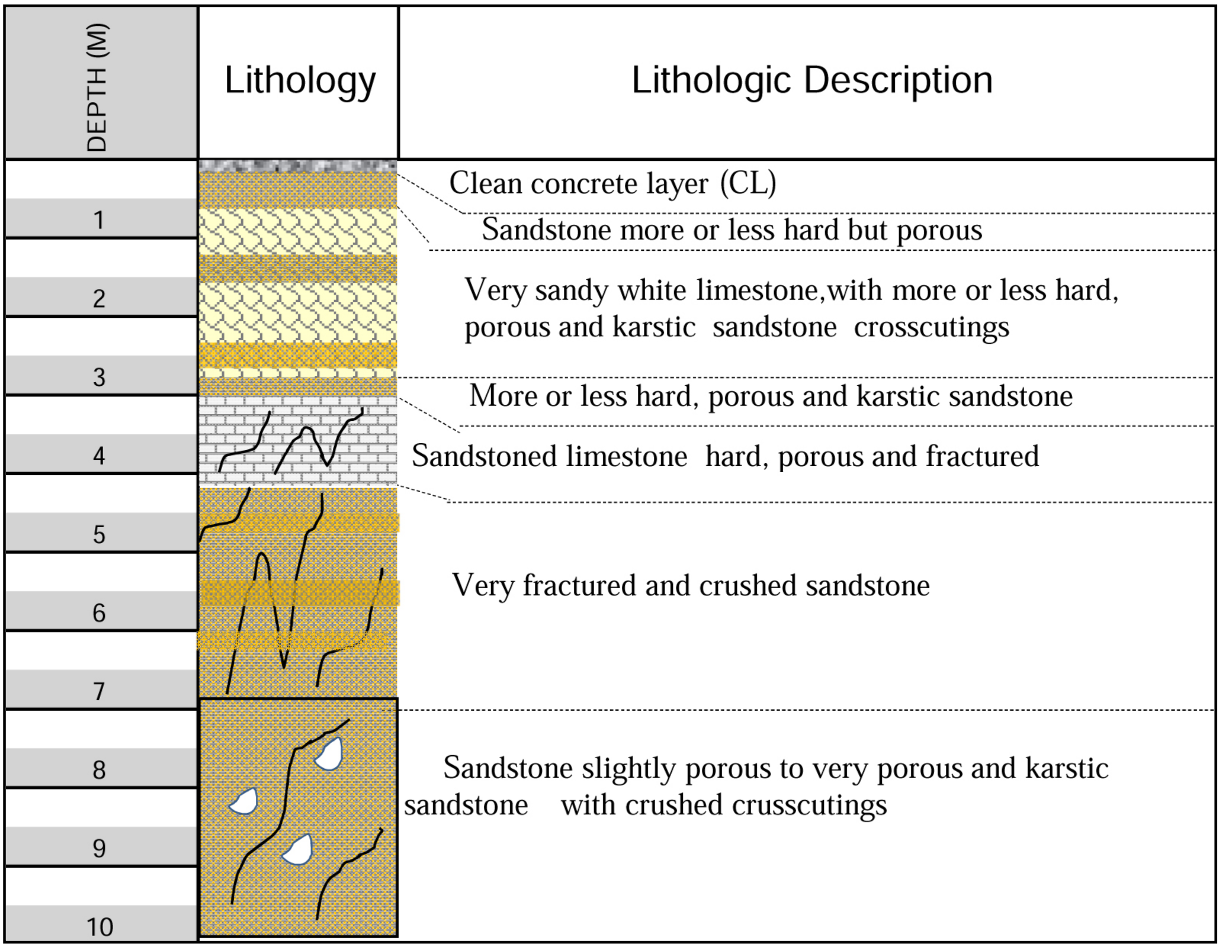

Fig.2. Lithological section of the study area (realized on the pile N° 3)

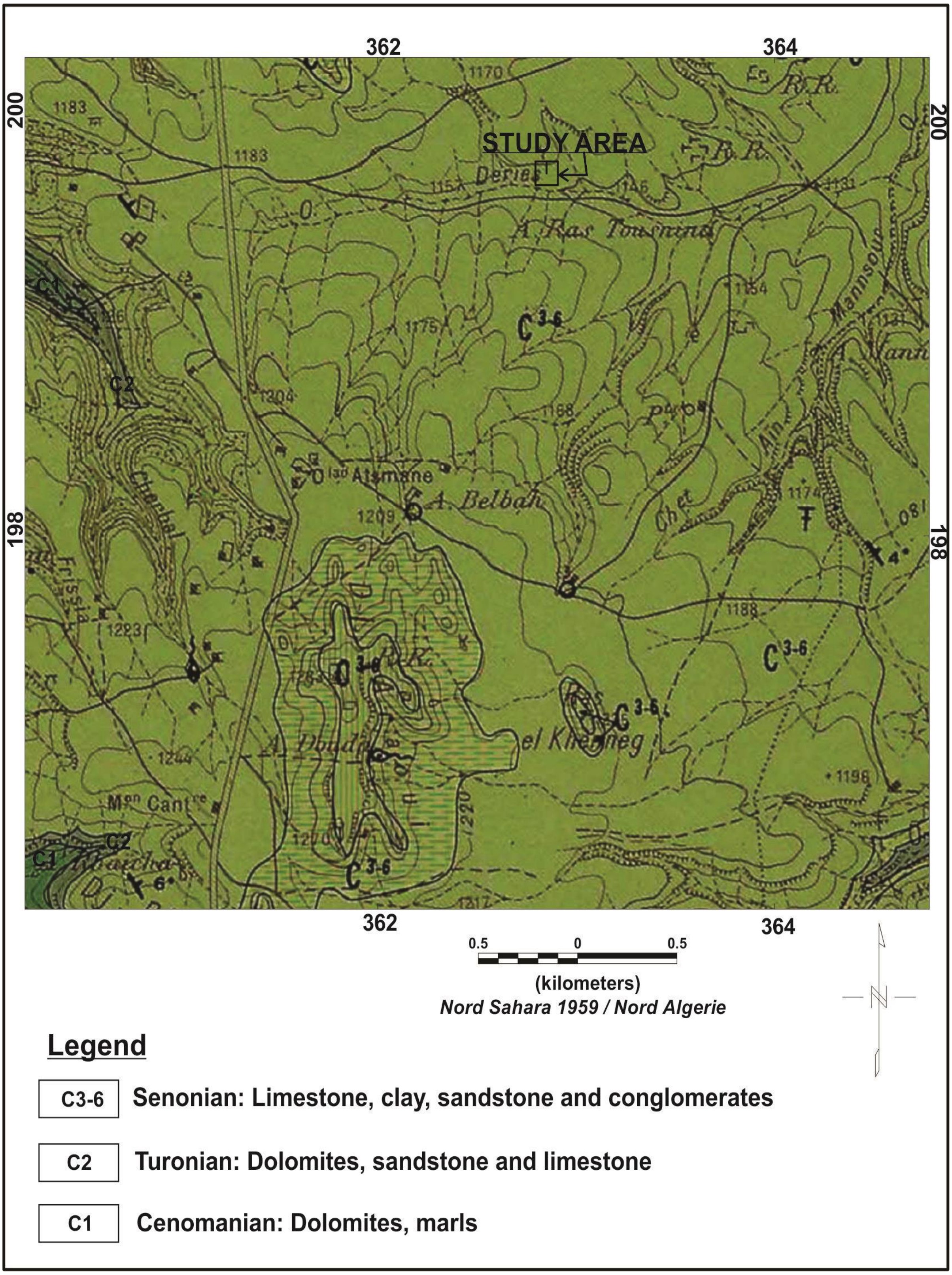

Fig.3. Geological map of the study area (Extracted from the geology of Frenda. Scale 1:50,000)

3. MATERIALS AND METHODS

GPR Survey

GPR is a non-destructive geophysical technique of imaging the subsurface at high resolution. This technique is very efficient tool for mapping shallow targets. The principle of GPR is based on electromagnetic waves (EM) propagation emitted in the form of the pulses within the subsurface soil (Fig. 4). Reflected waves are collected by the receiver and transformed via the central processing unit in continuous image called radargram (Fig 5a). The transmitted energy is reflected from various buried objects or distinct contacts between different earth materials.

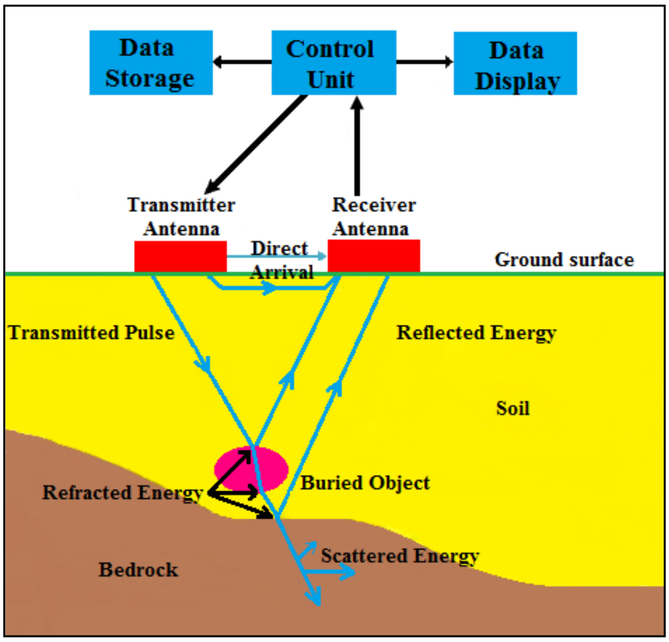

Fig. 4. Shematic diagram of GPR system

The technique of GPR is very similar in its principles to the seismic reflection method, but almost mutually exclusive in terms of where they work well, because one is based on EM wave propagation and the other on acoustic wave propagation. The main limitation of the GPR method is due to the attenuation of the radar signal in the subsoil, associated with electrically conductive materials, which substantially reduces the depth of investigation [12]. More detailed information on the basics of the GPR method can be found in [11-15].

The reflections of EM waves are usually generated by changes in the dielectrical properties of rocks (conductivity and magnetic permeability), variations in water content, and changes in bulk density at stratigraphic interfaces [16]. The propagation velocity *v* of the EM wave in soil is characterized by the dielectric permittivity (ε) and magnetic permeability (μ) of the material by the simplified equation:

$$v = \frac{c}{\sqrt{(\mu_r \varepsilon_r)}} \qquad \text{(m/ns)} \qquad (1)$$

Where ε is the permitivity = $\varepsilon_r\varepsilon_o$, ε_r is the relative dielectric constant and ε_o is the permittivity of free space. $\mu_r = \mu/\mu_o$ is the relative magnetic permeability of the medium, and c = 0.30 m/ns is the velocity of EM waves in free space, the approximate of depth is given as:

$$Depth = travel\ time \times V\ medium / 2 \quad \text{(m)} \qquad (2)$$

Best results of radar are obtained when the topographic surface is smooth and the material in subsurface is dry [12]. Resolution of GPR increases with frequency of signal (typically ranging from 10 to 1,000 MHz). The GPR is very effective for the investigations of geological structures at a shallow depth (Fig. 5a). Therefore, GPR results depend on the soil type and its state such as saturation degree, compaction, etc. [17], but they also depend on the equipment used. The penetration depth achieved for radar is a function of both its frequency and the electrical conductivity of the ground. The GPR profiles were obtained using Radar SIR-3000 developed by GSSI (Geophysical Survey Systems Inc-USA) Instrument, equipped with 200 and 400 MHz central frequencies antennas were used in this study. The 400 MHz antenna has a very good vertical resolution on the first three meters (Fig. 5b). For converting the two-way travel times (TWT in ns) to real depth, the EM waves velocity was considered through hyperbola fitting across each survey is between 70 and 80 mm/ns, representative for agricultural soil [12]. All GPR field data were processed using the RADAN software package, comprising; zero-time correction, scans/unit, running average filter, gain function and band-pass frequency filtering, etc., are applied.

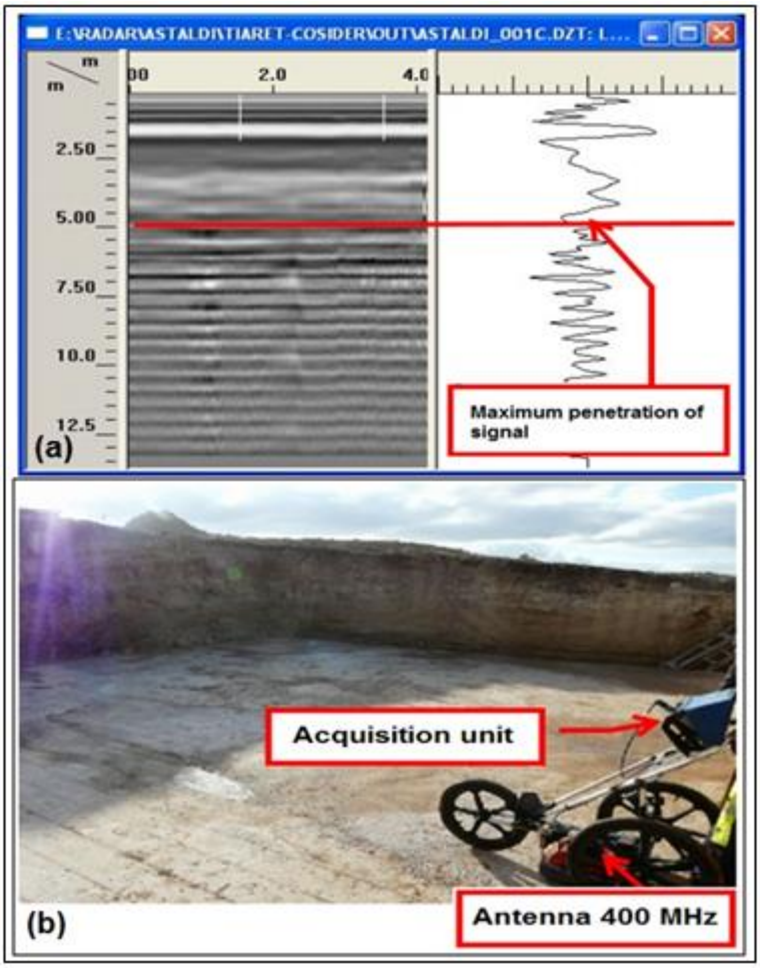

Fig.5. (**a**) Limit penetration of the signal for GPR. (**b**) Methodology of GPR

3. RESULTS AND DISCUSSION

From the GPR profiles, the presentations of results are following in below sections, to characterize the features of the subsurface anomalies (cavities and fractures). Moreover, heterogeneous zones existing in the study area.

The GPR profiles acquired from the study area have been carried out on thirteen excavations of foundations (EF) (Fig. 1b). About twenty-four GPR profiles were conducted at the bottoms of each EF. For sake of brevity, only three of them are described here (P3, P6 and P10). The reflections observed in the radargrams have been interpreted as the presence of cavities, fractures and heterogeneous zones. Three longitudinal GPR profiles have been carried out for each excavation. Survey line directions were assigned to extend from east to west, one in the middle of the excavation and the other profiles are two meters far from each side (Fig. 6).

Furthermore, other GPR profiles were carried out transversally in order to properly determine the subsurface features in P3. The presence of cavity is characterized by an amplification of the signal and a reversal of the polarity when the cavity is positioned. Concerning fractures, the signal appears as a sharp and linear interface [2].

Fig.6 Photograph showing the orientation of GPR profiles

Excavation of foundation P3 results:

The results from GPR around P3 are illustrated as vertical sections showing several anomalies. The profile located at the middle of P3 (Nº 2), shows an anomaly interpreted as the presence of a cavity at about 10.5 m from the starting point and at a depth of about 1.1 m, as can be seen in (Fig. 7a, b). The permittivity was set equal to 8. Thus, the mean velocity value obtained is 10.6 cm/ns. The reflections due to this cavity are very similar for both antennas used 400 and 200 MHz. The Fig. 7c, shows a radargram obtained using 200 MHz antenna for the profile (Nº 3), with the location of a cavity at the end of this profile located at a depth ranging from 1.5 to 2.5 m. A new sub horizontal fracture was identified at about 5.8 m from the starting point of the profile, located at 2.2 m mean depth, as well as a probable cavity located at 7 m from the starting point of the profile and about 2 m beneath the ground surface.

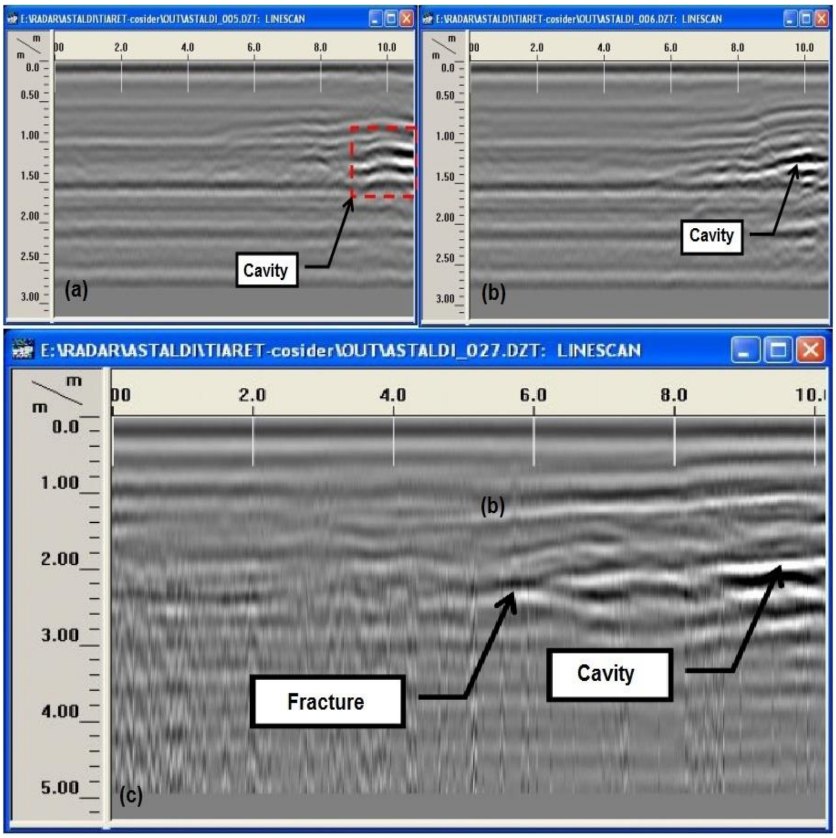

Fig.7. a and **b** Longitudinal axis profile radargrams with antennas 400 and 200 MHz. **c** Longitudinal radargram Nº3 for excavation of foundation P3

Once detected the probable occurrence of cavities from the interpretation of the observed reflections, a transverse profile in P3 have been carried out, in order to better define these anomalies. The first transversal profile (Nº 4), presented in the (Fig. 8a) also shows several anomalies. There is a reflection corresponding to a fracture between 1.8 m and 5 m and about 1.9 m beneath the ground surface. Moreover, the occurrence of two cavities has been detected: one located at 5.4 m (2.1 m of depth), and the other between 6.4 m until the end of profile at about 1.8 m of depth. The profile Nº 5, carried out at 2 m from edge of the excavation, does not exhibit so intense reflections as in the previous one (Fig. 8b). However, the anomaly located at a horizontal distance between 2 m and 5 m and at a depth of 2 m can be interpreted as the presence of a cavity. Similar to this, the reflections located between 6 m and 10 m located at 2 m deep (Fig. 8b) have also been interpreted as a cavity. The profile Nº 6 was carried out at 4 m of the edge and the observed reflections are less important. These reflections are interpreted as fractured zone the reflections observed from 6.9 m until the end of the profile, and about 2 m beneath the ground surface (Fig. 8c). The main limitation of the GPR results in this study is related to the limit of depth of penetration. This limit of penetration due to the presence of conductive material beneath the surface, caused by the following of heavy rainfall and snow, and the nature of the soil (clayey formation), which substantially reduces the depth of investigation. Finally, the dimensions and positions of these anomalies are represented in Fig. 9.

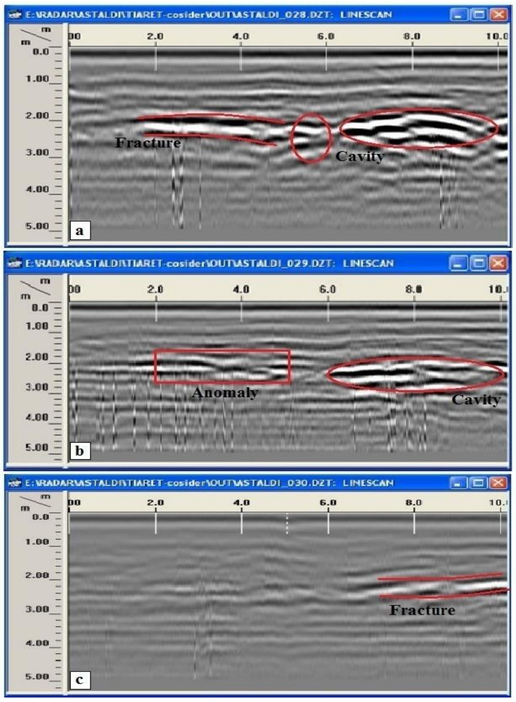

Fig.8. a, b and **c** Transverse radargrams with 45 cm, 2 m, and 4 m, respectively of the edge for excavation of foundation P3

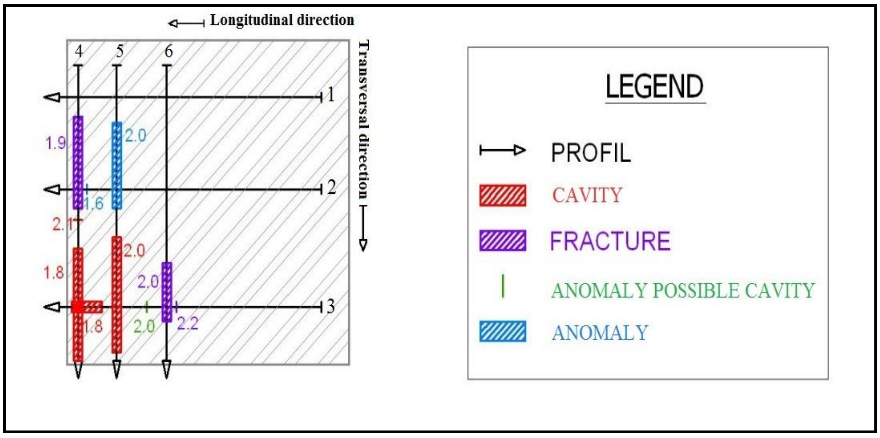

Fig.9. Legend of GPR results for excavation of foundation P3, the number indicates the depth of the anomaly

Excavation of foundation P 6 and P10 results:

The results from GPR profiles for the excavation of foundation P6 also exhibit on the radargram Nº 1 a heterogeneous zone located at ~1.7 m depth (Fig. 10). The data for P10 was acquired with a 400 MHz antenna, an anomaly detected on the radargram Nº 1 (Fig. 11a), located at 2.6 m from the starting point and at ~1.75 m depth. Two heterogeneous zones were identified for the second and the third profiles (Nº 2 and Nº 3, Fig. 11b, c), extending at a depth ranging from 1 to 3 m. Furthermore, the Fig.12 shows the characteristics (dimensions and positions) for the GPR profiles of P6 and P10, to estimate the subsurface features.

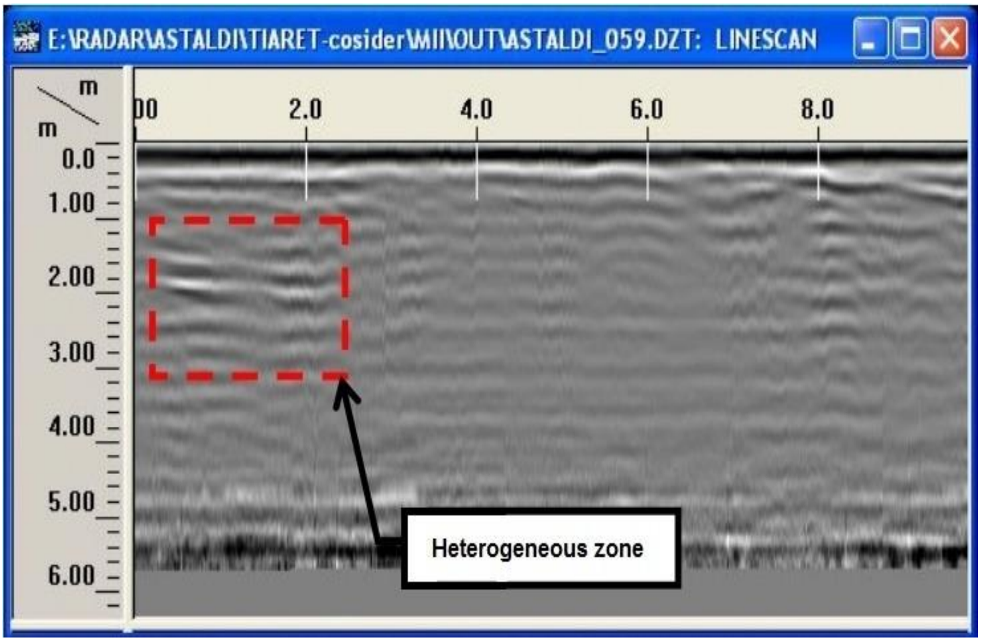

Fig. 10. a Profile radargram Nº 3 for excavation of foundation P6

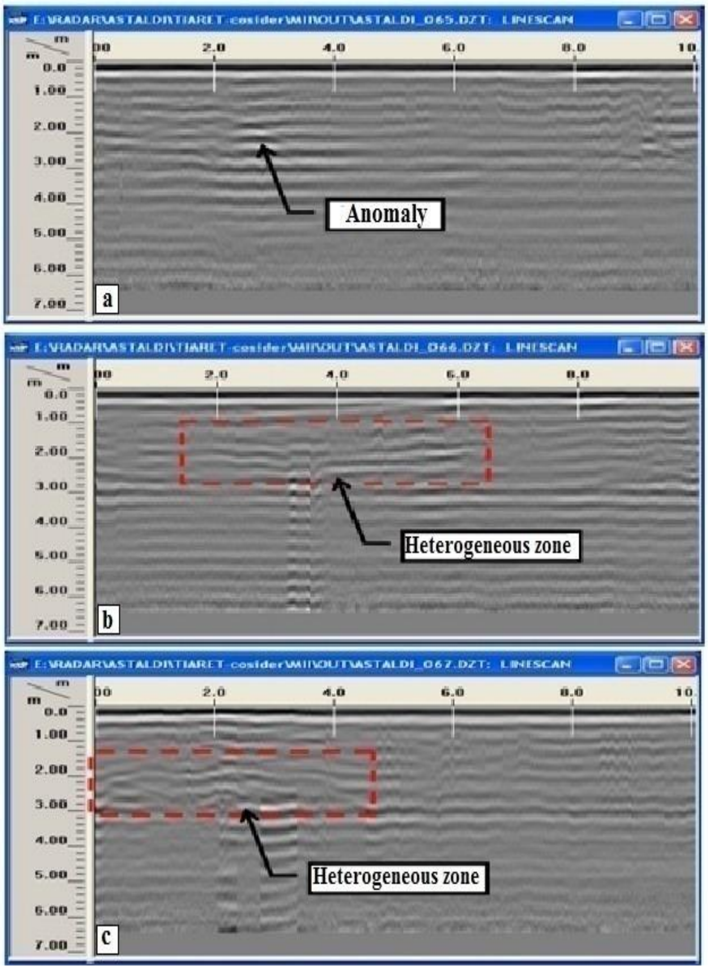

Fig. 11. a, b and **c** Profile radargrams for excavation of foundation P10, for the profiles N º1, Nº 2, and N º3 respectively

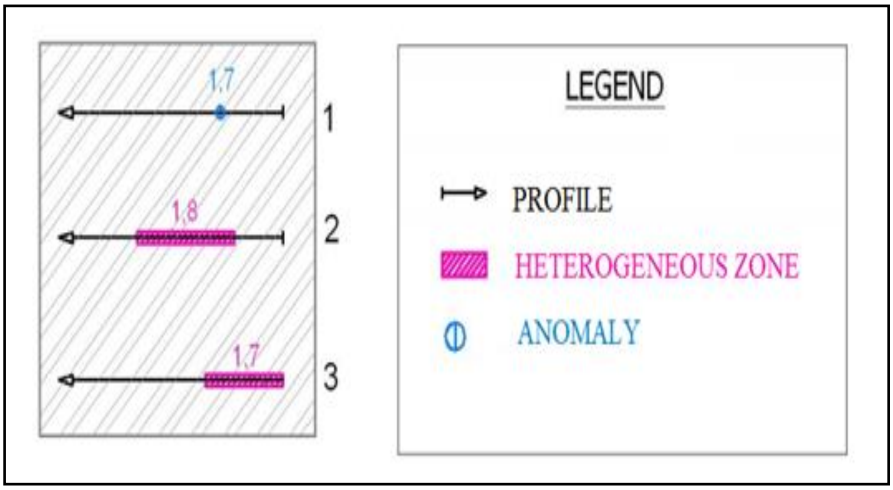

Fig. 12. Legend of GPR results for excavation of foundation P6 and P10, the number indicates the depth of the anomaly

4. CONCLUSION

This study was conducted to characterize the shallow subsurface soil, using the geophysical technique of GPR. This technique was an excellent tool for detecting the shallow subsurface structures, and proved its capability in a limestone area, with high resolution. The GPR surveys were made by two central frequencies of 200 and 400 MHz. GPR results indicate the presence of several fractures and cavities have been detected in P3, P6 and P10, as mentioned earlier. The only limitation found during this study was the shallow depth limits of the GPR which, depending on the materials of the study area (wet clayey soil). The depth of investigation was limited to 5 m, wasn't the desired depth of 10 m. Nevertheless, the bottom surfaces for some excavations are not smooth. The comparison of the results obtained of GPR, with available borehole observations, also allows improvement of the interpretations. Geotechnical investigations were carried out by surveys cored on the level of these anomalies, in order to interpret the results of geophysical technique.

5. ACKNOWLEDGEMENTS

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