VALUATION OF GROUND PENETRATING RADAR FOR THE RECORD OF STRUCTURES IN FLUVIO LACUSTRINE SOILS

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ABSTRACT

In this work, the response of Ground Penetrating Radar (GPR) to geological characteristics of fluvio-lacustrine soils is analyzed. GPR method is a very useful tool for structural studies of the geological media because it provides continuous profiles from the subsoil (radargrams). The identification of thin geological structures in the radar profiles allowed the evaluation of the detection capacity of the GPR Zond 12c for stratigraphical purposes. Its detection capacity depends on the achieved depth of penetration and resolution, on the transmitted wave frequency, and of the system used for acquisition and processing of the signals. The prospecting principle is based on the emission and reception of short electromagnetic pulses that are reflected by electric discontinuities related to physical or structural properties of the ground.

RESUMEN

En este trabajo se analiza la respuesta del Radar de Penetración Terrestre (RPT) a las características geológicas de suelos fluvio-lacustres. El RPT constituye una herramienta útil para el estudio de la estructura del medio geológico debido a que proporciona perfiles continuos del subsuelo (también llamados radargramas). La identificación de estructuras delgadas en las capas de suelos fluvio-lacustres de los radargramas presentados permite evaluar la capacidad de detección del RPT Zond 12c para fines estratigráficos. La capacidad de detección del método depende principalmente de la profundidad alcanzada y de la resolución obtenida durante la prospección, de las frecuencias utilizadas, así como del sistema electrónico para adquisición y procesamiento de las señales. El principio de la prospección se basa en la emisión de impulsos electromagnéticos de corta duración, los cuales son captados después de haber sido reflejados por discontinuidades eléctricas. Estas se asocian normalmente a discontinuidades físicas o estructurales en el subsuelo y dependen directamente de las propiedades del mismo.

KEYWORDS: Radar Parameters, Antenna, Transmitter-Receiver, Detection capacity, Radargrams, Soil properties, geological prospecting.

1. INTRODUCTION

The Ground Penetrating Radar (GPR) is a geophysical method of non destructive and indirect prospecting of the ground. Principle and application of GPR to diverse geological and geotechnical problems have been discussed in detail in the literature [1, 2, 3, 4, and 5]. GPR equipments send short electromagnetic pulses in the frequency range of 10 MHz to 3000 MHz, to the ground by a transmitter antenna. When the transmitted wave finds heterogeneities in the electric properties of the ground materials the energy is partially absorbed by the media and/or transmitted to greater depths. Part of the transmitted signals travel trough the prospected terrain and are reflected newly to the surface. In Figure 1 a general schema of the stages of the transmitted signal and reflected on specific geological targets is presented.

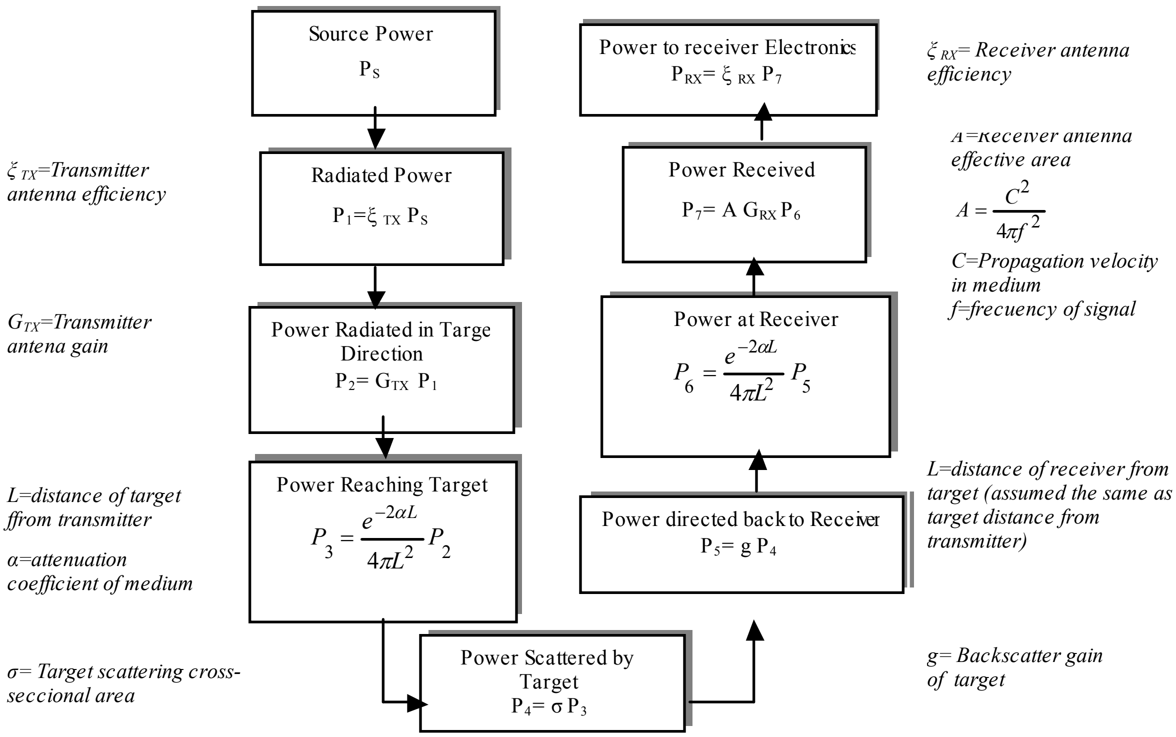

Figure 1. Stages of the signal transmitted and received by the GPR system.

When the signal arrives to the antenna in surface, it is amplified by a receiver modulus and subsequently digitized and processed by the signal control system. The control system digitally filters each signal, applies algorithms to obtain the spectrum of frequency, and sends the data to the computer to display an image of a continuous profile of the prospected media. The record of the total time of the wave for propagation, reflection in a heterogeneity and return to the surface allows determination of the reflectors depth when the velocity of propagation in the prospected media is known. In this way, the distance-time records (or radargrams) can be transformed into continuous profiling of the ground similar to a geological section (Figure 2). Transforming scales from time to depth is possible when the electromagnetic waves velocity of propagation is assessed in the studied media from measurements in field or laboratory [6, 3]. The resolution achieved (the capacity of distinguish between two reflectors separated by a determined distance), depends on the wavelength □ in the studied media, which is a function of the velocity of propagation in media and the frequency of the transmitted signal [7]. The resolution can be defined also in terms of the velocity of propagation and the bandwidth of the system by the Rayleigh's criterion [8].

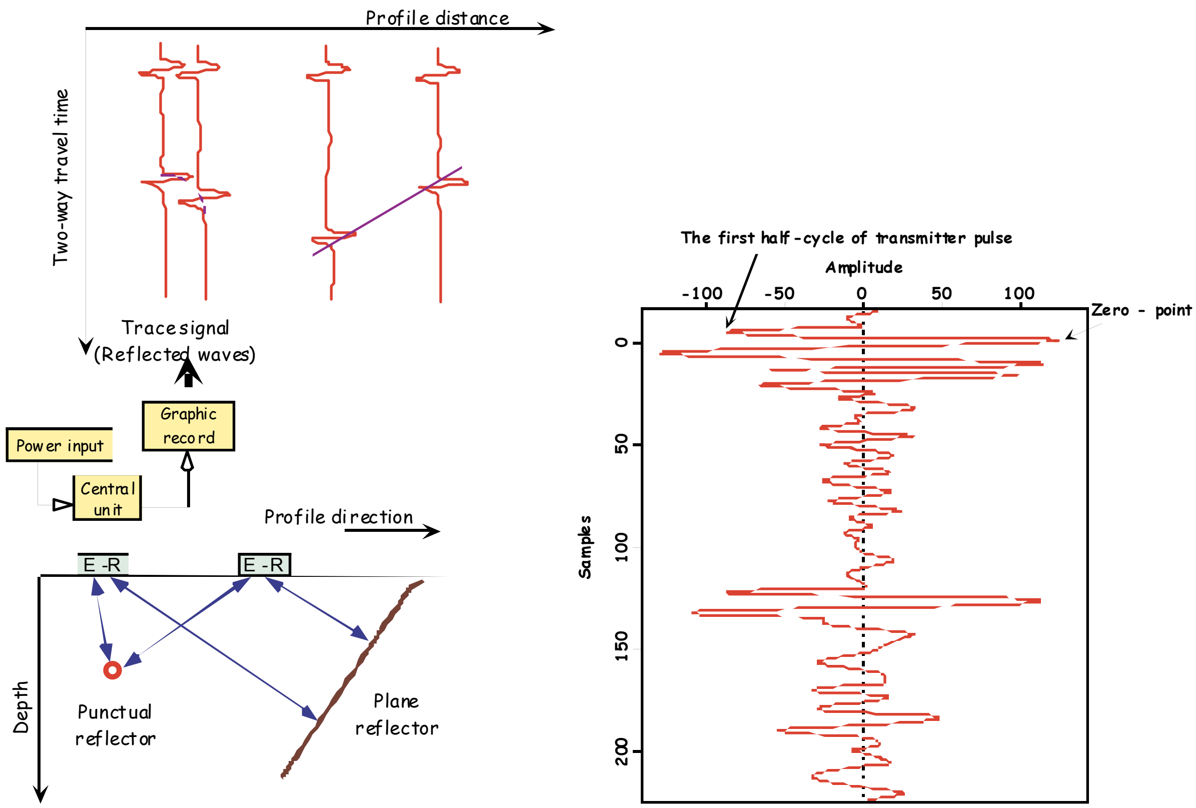

Figure 2. GPR prospecting: (a) Transformation of the profile time-distance to depth-distance, (b) Record of the reflected signal.

In this work, the electric parameters of both the geological media (i.e. permittivity and conductivity) and the radar system (i.e. power, gain, and dynamic range), that determine the GPR record of specific structures are discussed with the aim of valuate their influence in the bulk GPR response in two contrasting media.

2. GROUND PENETRATING RADAR Zond 12c

2.1 Description.

The GPR Zond 12c radar consists of a central unit that operates the prospecting frequencies and is controlled by any portable computer with the software PRISM 4.1 installed.

The software allows adjustment of the radar parameter such as: antenna type, permittivity of the prospected media, number of traces, gain, filtering applied to the signal, and the time delay necessary to equal the transmitted and the synchrony pulses (see block diagram in Figure 3). It also permits the signal processing necessary to obtain the frequency spectra and the graphical display of the profiles.

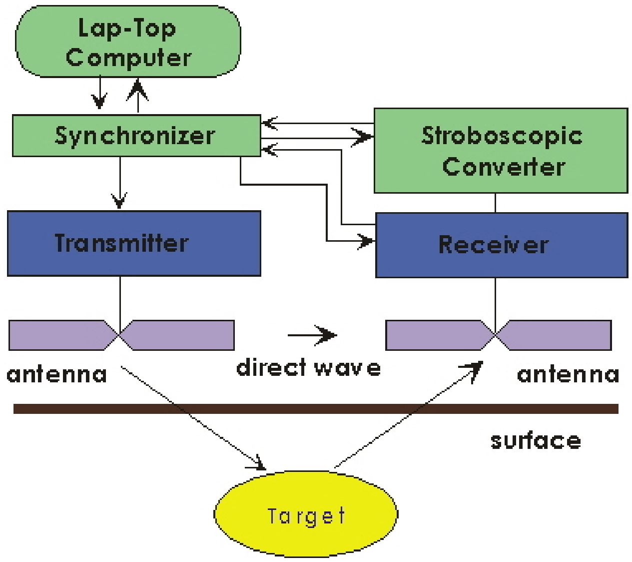

Figure 3. Block diagram of the GPR Zond 12c system.

The software considers the parameters mentioned (see Figure 1) included in the well known radar equation [8]:

$$Q = 10\log\left(\frac{\xi_{TX}\cdot\xi_{RX}\cdot G_{TX}\cdot G_{RX}\cdot c^{2}\cdot g\sigma\cdot e^{-4\alpha L}}{64\,\pi^{3}\,f^{2}\,L^{4}}\right) \qquad (1)$$

This equation describes the propagation of electromagnetic waves through a material considering dielectric losses. In the case of ground penetrating radar, the radar equation describes how the propagating wave is modified or changed in: (a) the direction of transmission by; the antenna properties (gain, antenna pattern, and frequency dependence), coupling to the ground (efficiency, frequency dependence), the geometric spreading losses (like the power being spread over the surface of a balloon being blown up around the antenna), the exponential material dissipation losses (including frequency dependent dispersion from electrical conduction, and dielectric relaxation), the scattering (reflection, refraction, diffraction) from a change in properties (depending upon contrast , orientation, and polarization); and (b) in the direction of the receiving antenna by; exponential material losses, geometric spreading, coupling, and the receiver antenna properties. The result is the ratio between the maximum power emitted and the minimum power detected [8, 9].
In order to construct the profile of the signal traveling through different media, the rapid pulses (nanoseconds) are synchronized with the returned signal of lower frequency using synchrony pulses generated in the system of time control and a sampling technique.

2.2 Electric specifications and antenna types of the GPR Zond 12c.

The main parameters of the equipment include:
Average time of sounding: 50 a 200 ns
Repetition of the transmission pulse: 115 Khz
Maximum average of traces: 14 traces / s
Gain function: linear or exponential type
Range of average gain: 0 to 84 dB
Dynamic range: 128 Db
Sounding mode: continuous or stepped

The antennas GPR Zond 12c are Hertz type, unidirectional bi-static dipoles of half the wavelength [10], located inside resonant boxes of different size, optionally shielded or unshielded, air coupled or superficial. The characteristics of the two antennas used in this work (300 and 900 MHz) are presented in Table I, and a schema of the 300 MHz antenna is shown in figure 4.

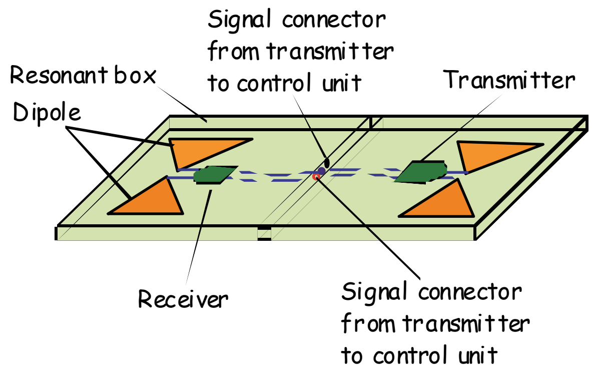

Figure 4. Schematic diagram of the 300 MHz antenna, GPR Zond 12c.

Table I. Characteristics of the antennas used with the GPR Zond 12

Parameter	300 MHz	900 MHz
Transmitted pulse amplitude [Volts]	400	120
Resolution [m]	0.74	0.25
Blind zone [m]	1	0.20
Sounding depth [m]	15	5
Dimensions [m]	0.98, 0.52, 0.04	0.43, 0.22, 0.04
Weight [kg]	7	2
Type	Superficial	Superficial

3. RADARGRAMS OF SEDIMENTARY STRUCTURES IN FLUVIO-LACUSTRINE SOILS

In order to compare the electromagnetic record for diverse stratigraphic conditions and to assess the depth of detection and resolution of the 300 and 900 MHz, soundings were carried out in two different geological settings: a quarry of dry sedimentary materials in the Queretaro Valley and a wet lacustrine sequence of Texcoco, Mexico State.

3.1 Quarry of sedimentary materials.

The prospected profile is located in a quarry of sedimentary materials 8 km west of Queretaro City, and is approximately 8 m depth (Figure 5). The stratigraphic column presents a layer of soil in the first meter overlying silty-sand layers with abundant gypsum veins up to the 4.5 m; at this depth, a compact, dry clayey material layer is observed followed by 2 m of loosed silty-sand deposited over the volcanic tuff that constitute the base of deposit. In figure 6 we present a radargram of this site collected with the 300 MHz antenna. Comparing this radar section with the stratigraphy presented in figure 5, the reflector of the lower contact of the soil layer was recorded at 40 ns. The contacts between the clay and the sand material and of the sand with the volcanic tuff were recorded respectively at 160 ns and 200 ns. Between 60 and 160 ns, some irregular reflectors can be associated to the gypsum veins cross-cutting the clayey layers. Furthermore, a difference in soil composition (from superficial organic rich to carbonated soil) at 20 ns and changes in the silty-sand layer between 40 and 50 ns, can be observed clearly in the profile collected with the 900 MHz antenna, in which we obtained better definition up to the first 40 ns (Figure 7).

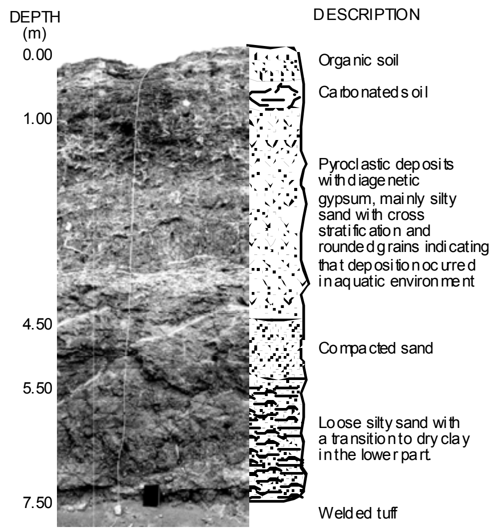

Figure 5. Shallow stratigraphy of the quarry of sedimentary materials.

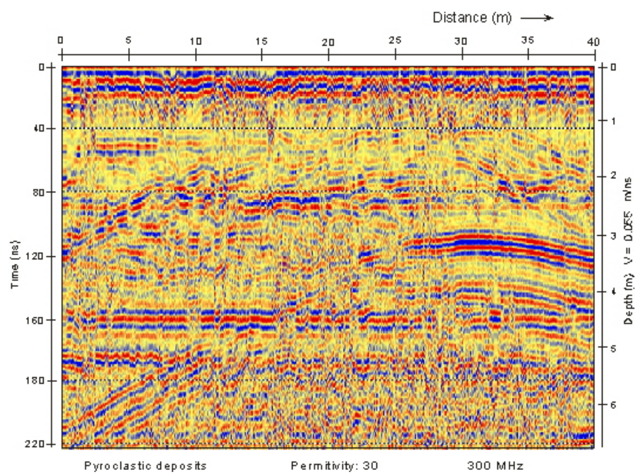

Figure 6. Radargram of granular sedimentary material sequence collected with 300 MHz antenna in the quarry of sedimentary materials

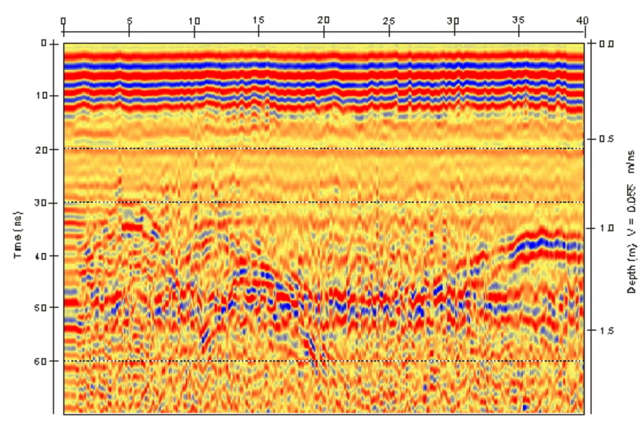

Figure 7. Radargram of granular sedimentary material sequence collected with 900 MHz antenna in the quarry of sedimentary materials.

3.2 Former Texcoco Lake

The stratigraphic profile of the materials studied in this site was previously reported by [11], and the sequence consists of different amorphous clays in contact with the groundwater level. The analyzed profile has a total depth of 1.62 m and is divided by a layer of volcanic ashes from 39 to 69 cm depth.

In Figure 8 we show the radar section obtained with the 300 MHz antenna. The attenuation observed in the signal is higher when compared with radargrams in figures 6 and 7, since the media in Texcoco is constituted by amorphous clays with high water content and salinity. In the first 40 ns, several reflection patterns were recorded and two reflectors were identified at 100 and 200 ns. A wedged structure at 30 ns recorded with the 900 MHz, is probably associated with a sand layer that divides the clayey sequence (Figure 9).

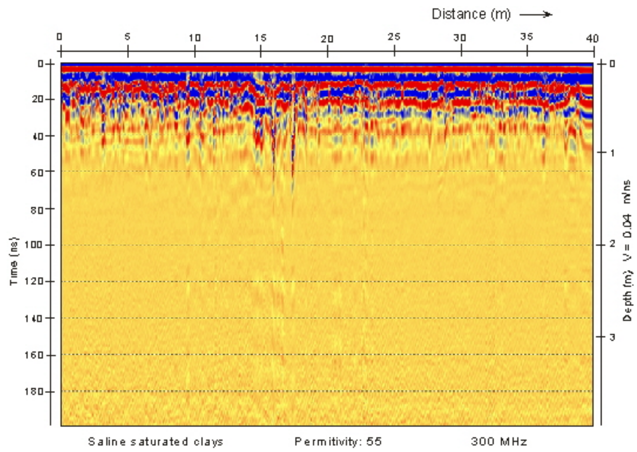

Figure 8. Radargram of clayey material sequence collected with 300 MHz antenna in Texcoco.

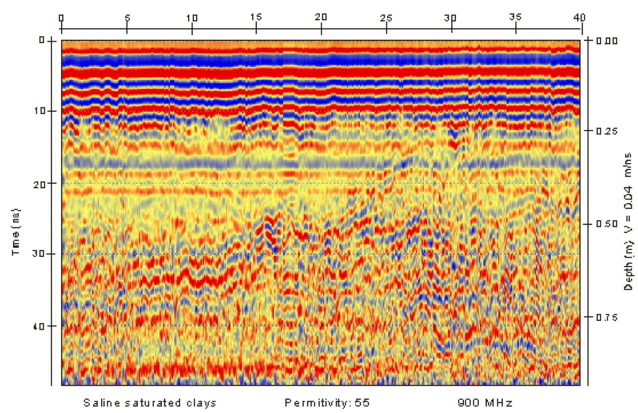

Figure 9. Radargram of clayey material sequence collected with 900 MHz antenna in Texcoco.

4. RESULTS

The GPR prospecting in fluvio-lacustrine sites is conditioned by characteristics of the subsoil, such as the different dielectric constants ε of geologic materials (silt, sand, and clay mainly), and the attenuation of propagating waves, which depends on the magnitude of the frequency used, the dielectric characteristics of media and looses of energy [11].

Establishing appropriately the parameters of the prospected site makes possible to obtain stratigraphical information of the studied soils, as seen in the radargrams presented. The dynamic range (128 db) of this equipment makes GPR a useful tool for prospecting of high electrically contrasting media with a wide range of intensities and frequencies of transmission and reception from 38 MHz to 2 GHz.

The wavelength and the depth of penetration decreases when the transmission frequencies are increased, therefore the resolution and prospecting depth required must be considered in the objective of prospecting. The gain of the receptor increases with lower frequency of transmission from 17 to 40 dB for 2000 and 300 MHz antenna respectively.

The PRISM software facilitates the application of basic processing techniques and algorithms to the signal recovery. In this type of radar, a sampling technique for signal recovery is useful because the received frequency is lower than the transmitted. Pulses of 115 KHz are sent and 14 traces by second are recovered at a rate of 152, 256, or 512 samples per trace. The number of samples influences the conversion of scales from time to depth because larger numbers are required for optimize the signal reconstruction. If desired, digital filters can be applied to the signals in order to obtain a better resolution in profiles for each objective, for example, the filters can be applied for distinguish between diverse layers composing the fluvial-lacustrine sequence.

It is important to note that estimations of the GPR prospecting depth most include such factors as the geometric dispersion due to the emitted pattern (the energy is attenuated progressively because it diffuses over a larger wave front), the characteristics of the reflector, and the system efficiency (gain, signal/noise ratio, power).

5. CONCLUSIONS

Ground Penetrating Radar is a complex method of subsoil prospecting that implies consideration of diverse parameters to study adequately the geological media. Precise identification of geological reflectors requires a detailed study of the stratigraphy, supported with characterization of samples, and correlation of the electric discontinuities recorded in radargrams. It is critical to analyze the variation of the parameters conditioning the GPR prospecting of the soil structure such as, water content and changes of conductivity, texture, and structure of different types of soils. A better coupling of impedances between the prospected soil and the radar results in enhanced profitability of the radar power.

The software used by the radar equip ZOND 12c includes control over most of the parameters that have an influence for obtaining the best resolution in profiles. One disadvantage of the equipment is that the real profitable power is lower than specified. The Zond 12c is first-rate equipment for prospecting when compared to others with higher cost and good quality results can be obtained in the identification of the components of a fluvial-lacustrine soil.

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