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Utilizing Radar Imaging in Identification of Water Table and Sand Stratigraphy

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Abstract. Ground penetrating radar (GPR) is a geophysical method that has been developed for shallow subsurface investigation. It provides non-destructive and rapid way of obtaining continuous high resolution profiles which are based on the propagation of electromagnetic waves. Conductivity and dielectric properties are two important parameters in GPR method. As in sediment, water saturation primarily cause changes in dielectric properties and therefore, this method is best applied in estimation of depth to water table. Six parallel GPR lines were executed in Seri Iskandar, Tronoh, Perak with the aim of detecting the depth of water table and analyzing the environment of depositing sediments. GPR profiles successfully detected the saturated zone, which suggested water table with depth of >15m and also well map the sand stratigraphy of marine alluvium.

Keywords: GPR, water table, sediments.

1. Introduction

Ground penetrating radar, (GPR) is one of the near surface geophysical methods that involve the transmission of high frequency radar pulses from a surface antenna into the ground. It provides detailed information about the subsurface which is site-dependent and the quality of the results is dependent on the target, geologic environment, subsurface features and other factors that affect the contrast of the target to surrounding medium. It has been demonstrated that GPR is a useful sensor for shallow subsurface investigation and proven to be promising tool for subsurface characterization in the field of environmental and engineering. This is due to dielectric properties and conductivity governing GPR wave propagation are strongly correlated to basic physical properties such as water content and soil salinity. GPR method is efficiently used in a broad area focusing generally in hydrogeology study. The presence of small amount of water will dominate the behaviour of the dielectric permittivity of porous media in a multi-fluid system. The dielectric permittivity generally increases along the moisture content from the ground surface to the saturated zone [1]. GPR survey was performed in Seri Iskandar, Tronoh, Perak using 100MHz shielded antenna to identify depth of water table and stratigraphy of sediments deposition. Tronoh was a small tin mining town located about 30km south of Perak capital city, Ipoh, Malaysia. There are lots of manmade lakes found which are believed to occur due to tin mining industry since 20th century.

2. Methodology

2.1. Basic principle

Ground penetrating radar is a method that is commonly used for environmental, engineering, hydrogeological, and other shallow subsurface investigations [2]. It has been used for several years as a non-destructive method for locating subsurface anomalies. It uses the principle of scattering electromagnetic wave (EM) to locate target or interfaces buried within visually opaque substances or earth material [3]. An

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electromagnetic wave is transmitted into the ground and reflected based on different dielectric properties of subsurface materials (Fig.1). Reflected waves are received at the surface according to a general principle; the higher the frequency, the better the resolution and the shallower the depth of penetration [4].

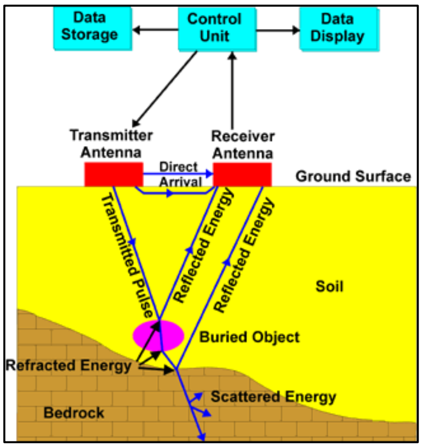


Fig. 1: EM wave propagation depends on dielectric and conductivity properties of material [5].

The recorded signal is registered as amplitude and polarity versus two way travel time. The electromagnetic wave propagates in air with the speed of light, 0.3 m/ns. Generally, in other medium such as ground, velocity of EM wave is reduced due to relative dielectric permittivity (ε_r), magnetic permeability (μ_r), and electrical conductivity (σ). Velocity of electromagnetic wave in a host material is given by equation 1,

$$v = \frac{c}{\sqrt{\varepsilon_r \mu_r \frac{1 + \sqrt{1 + (\sigma/\omega\varepsilon)^2}}{2}}} \quad (1)$$

Where; c = EM wave velocity in vacuum (0.3m/ns)

ε = $\varepsilon_r \varepsilon_0$, dielectric permittivity and dielectric permittivity in free space

ω = $2\pi f$, angular frequency

σ = conductivity

$\sigma/\omega\varepsilon$ = loss factor

For non-magnetic (μ_r = 1) low-loss materials, such as clean sand and gravel, where $\sigma/\omega\varepsilon \approx 0$, the velocity of EM wave is reduced to the expression 2,

$$v = \frac{c}{\sqrt{\varepsilon_r}} \quad (2)$$

Several processes lead to a reduction of electromagnetic signal strength. Among the important processes are attenuation, spherical spreading of energy, reflection/transmission losses at interfaces and scattering of energy [6].

2.2. Factors affecting GPR

Detectability of a subsurface feature depends on conductivity contrast, dielectric constant and geometric relationship between antennas, where electrical properties of geological materials are primarily controlled by water content and porosity. Conductivity is the ability of a material to conduct electrical current. For a solution of water, conductivity is highly dependent on salts concentration and ions, therefore the purer the water, the lower the conductivity. The dielectric constant is defined as the capacity of a material to store a charge when an electrical field is applied relative to the same capacity. Table 1 shows the dielectric constant, conductivity and velocity of common geological materials and medium.

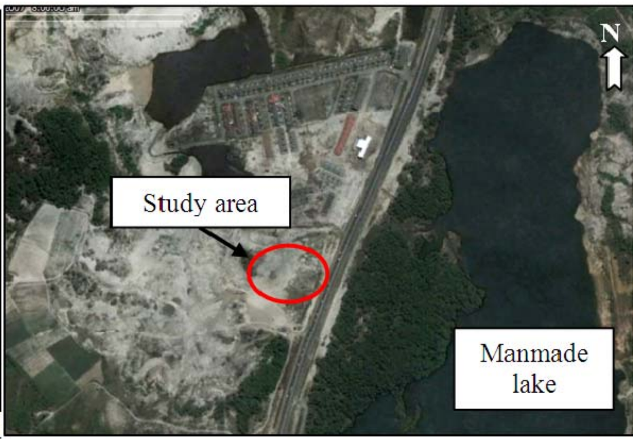
Table 1: Typical dielectric constant, conductivity and velocity value of common materials and medium [7].

Medium	Dielectric, ε_r	Conductivity, σ (mS/m)	Velocity, v (m/ns)
Air	1	0	0.30
Fresh water	80	0.5	0.033
Salt water	80	3×10^3	0.01
Dry sand	3-5	0.01	0.15
Saturated sand	20-30	0.1-1	0.06
Limestone	4-8	0.5-2	0.12
Clay	5-40	2-1000	0.06
Granite	4-6	0.01-1	0.13
Ice	3-4	0.01	0.16

3. Study Area

Study area takes place at Seri Iskandar, Tronoh, Perak. It is located almost 30km south of the Perak state capital, Ipoh, Malaysia. This area is said to be underlain by original limestone beds of the Kinta Valley, presumed to be Carboniferous [8] or possibly Permian age [9] and have been severely eroded and karstified. The clastic sequence exposed in the southern part of Kinta Valley consists of alternating beds of sandstone, shale, clay or mudstone and subordinate siltstone. Reddish-brown or diagenetic iron oxide nodules, laminae, dendrites, and fracture infill are common throughout the section. The clastic sequence in this area is most likely equivalent to Kati Beds, as Carboniferous to Permian age [10]. The sandstone beds can be up to several meters thick and are composed of rounded, well sorted, medium to coarse size quartz grain with a small proportion of black grains of heavy minerals. Six GPR survey lines were executed in parallel with total length of 40m for each profile and line spacing of 10m. Manmade lake due to tin mining industry is found located almost 500m toward Eastern of study area (Fig.2a and 2b).

a)



b)

Fig. 2: Ground penetrating radar. a) 100 MHz shielded antenna used in the study, b) study area across the sandy soil.

4. Results and Discussions

Fig.3 shows six GPR profiles obtained from the study. The results show a clear reflection event (yellow line) observed at depth <3m at all survey lines. These may indicate the dry sand layer noted as top soil due to reclamation. Deposition of alluvium made up of medium to coarse grain sand mix with clayey sand is identified at depth <10m, with some dipping features and non-uniform layer (red line). A zone with high moisture content, known as wet zone is identified at depth of 10-20m that may indicate wet sand. A strong boundary reflection (blue line) at depth of > 15-20m is observed which shows the indication of water table due to the reflection coefficient of water is 1. Electromagnetic wave cannot pass through the saturated area where the strength of the water table radar reflector is dependent on the contrast between the electrical properties of the unsaturated and saturated medium. The variation in electromagnetic parameters from the sand layers can be produced for example by changes water saturation or organic matter content. The relative permittivity is increased between areas of non-saturated sand and saturated sand which is detectable by radar.

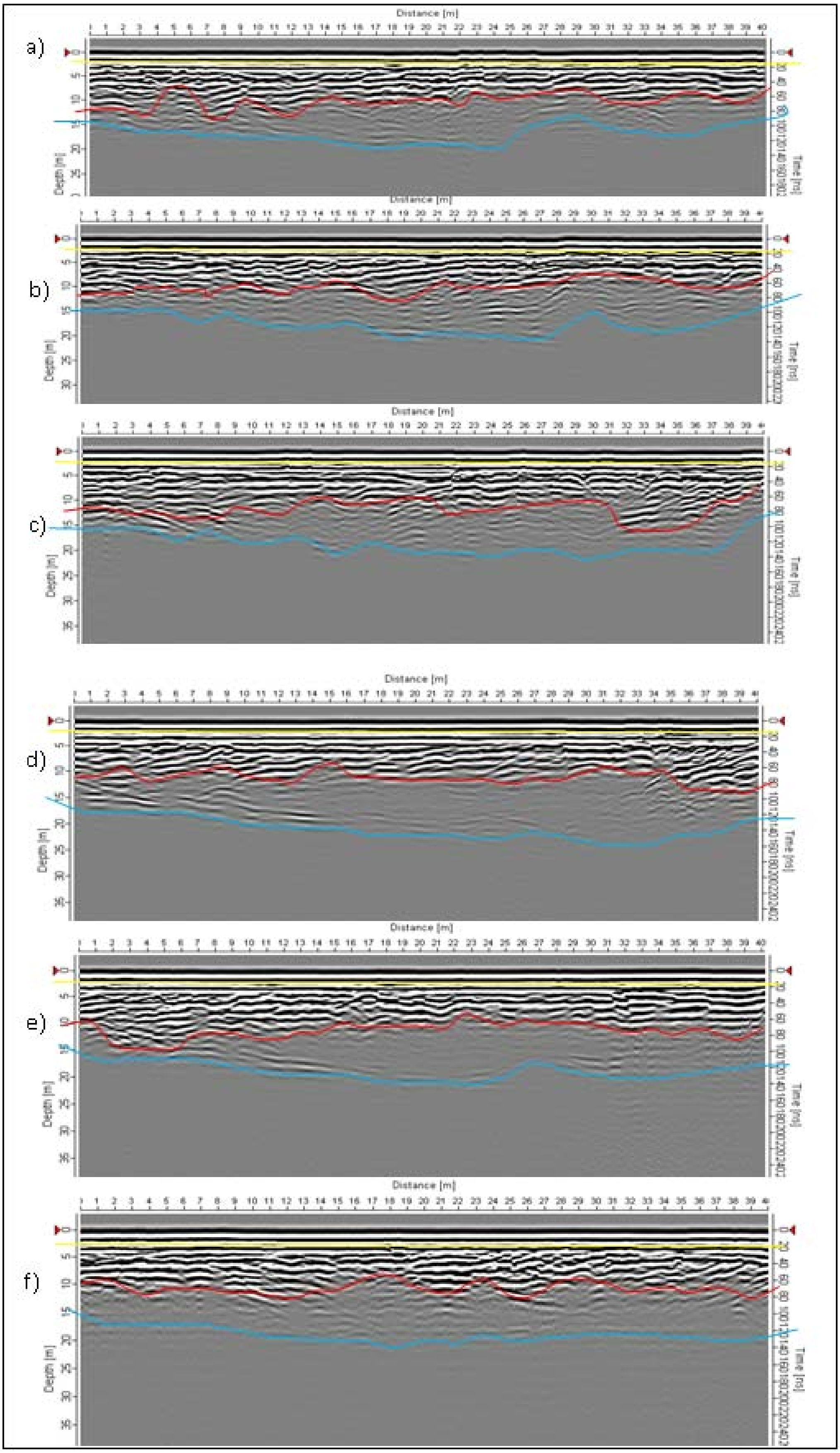


Fig. 3: Six radar images. a) L1, b) L2, c) L3, d) L4 e) L5 and f) L6.

5. Conclusion

Ground penetrating radar plays very important role for recognition of stratigraphy of the area as well as mapping the water table level. The results obtained from GPR method can be further used to analyze any processes such as sediment depositional process and also useful for monitoring the ground water flow. Based on this study, the radar profiles obtained using 100MHz shielded antenna clearly displays the water table at depth > 15-20m. Other reflectors which seem to be caused by reclaimed sand, non-uniform sedimentation of dry sand and wet zone (wet sand) are also successfully identified at depth <3m, <10m and <10-15m respectively.

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