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Application of Ground Penetrating Radar for hydro-geological study

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The open cast mining has, in some places, extended below the groundwater table. Impact of mining may affect availability of groundwater, and this has become a matter of concern because villages in that region (near open cast mines) suffer from water scarcity during dry periods. Exploitation of an enormous amount of ore may result in groundwater depletion. However, these effects are dependent mainly on the geological formations in the region and mining method. In some places, groundwater table occurs at shallow depth from the surface and some places underlying strata are impervious clay layers, which may be above groundwater table. In most places, clay layers exist above groundwater table. Due to presence of impervious clay layers above the groundwater table, extraction of ores will most likely not affect surrounding hydrological regime of those areas. This paper aims to highlight the significance of Ground Penetrating Radar (GPR) survey prior to excavation in areas where impervious clay layers occur as underlying strata. GPR will be very helpful to check groundwater depletion in open cast mines indirectly after exploring the subsurface geological scenario. Hydrological regime of the mining areas will be saved with the help of GPR by distinguishing between groundwater and clay.

Keywords: Attenuation, Clay, Electromagnetic, GPR, Hydrogeology, Reflection

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Introduction

Geophysical methods can give better solutions indirectly after locating voids and fractures within the rock-filled areas in the mining areas[1,2]. Among the geophysical methods, Ground Penetrating Radar (GPR), barring some limitations, is the most feasible technique to study for hydro-geological conditions related with mining activity for shallow workings[3]. GPR can provide more detailed pictures but has very limited depth penetration in areas with electrical conductive unconsolidated sediments, such as clayey soils. GPR depends on the emission, transmission, reflection and reception of an electromagnetic (EM) pulse perpendicular to the ground surface. It can produce continuous high-resolution profiles of the subsurface rapidly and efficiently[4-6].

Principle and Limitations of Ground Penetrating Radar

A very short time impulse is generated at a very high frequency (25 MHz-1 GHz) and radiated by an antenna, called a transmitter. When signal encounters an anomaly, it is reflected and picked up by a receiver, which transmits it to a graphic recorder (Fig. 1). This is referred to as a "scan", or radar echo. The waves reflected by anomalies in subsurface are observed successively with regular movement of the antenna along each profile. The data are presented as a "time section". A record shows the total travel time for a signal to pass through the subsurface, reflect from an inhomogeneity, and return to the surface. The two-way travel-time is measured in nanoseconds ($1\text{ns}=10^{-9}\text{sec}$). Determining the depth to a reflector involves using the following basic equations:

$$D = T.\,V/2 \qquad \ldots(1)$$

$$V = C/\sqrt{\varepsilon} \qquad \ldots(2)$$

where, D=depth to the reflector, m; T=two-way travel time, ns; C=velocity of light in free space (0.30 m/ns); ε=relative dielectric permittivity, a dimensionless ratio; V=electromagnetic wave velocity, m/ns.

The depth of exploration varies (1-30 m) for both natural soils and construction materials. The depth of penetration depends on the following[4,5,7] parameters: i) Pulser voltage of the emitter; ii) Emitted wave frequency; iii) Electric properties of subsurface materials (dielectric and conductivity); and iv) Moisture content.

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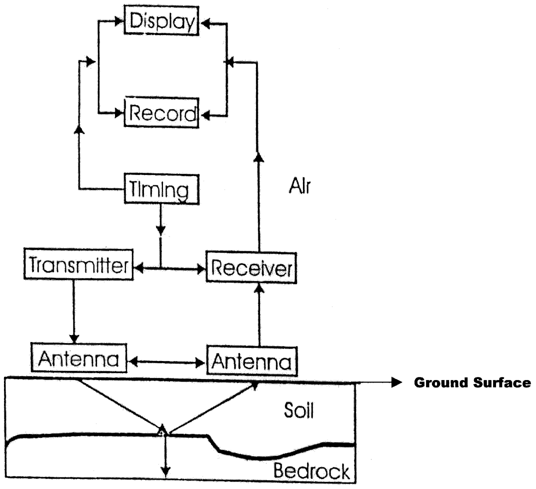

Fig. 1— Block diagram depicting main components of a GPR system

Discussions and Interpretations of GPR Signatures

There are many geological structures/inhomogeneities, which play very important role during the extraction of any mineral either from underground or open cast mines. In the case of hydrogeological study, recognition of clay layer and water-bearing strata plays very important role to foresee the problem posed at ground-water resources. GPR surveys were carried out at many sites, where underlying strata are clay layers and water bearing strata and GPR sections obtained at those sites were corroborated by existing borehole sections for the confirmation of different GPR signatures for clay and water-bearing strata.

Attenuation of GPR signatures is based on reflected EM wave characteristics. Attenuation constant of clay is very high with respect to freshwater and other geological formations except seawater. Therefore, EM waves passing through clay are highly attenuated so that one cannot get layers (good reflection). In water-bearing zone, water bearing strata, having higher attenuation values with respect to other geological materials except clay, can absorb EM waves, but in this case poor reflection zones (represented by dark lines with lower visibility) are observed due to high attenuation of EM waves in comparison to other geological formations except clay and seawater.

GPR surveys are carried out at many profiles on so many locations. Only four profiles were selected where borehole data were available for the corroboration. The GPR section along profile 1 (Fig. 2) shows good reflections (highlighted by thick dark black lines) up to 6 m depth, which can be attributed to presence of solid layer. The reflections gradually fade below 6 m depth, which can be attributed to presence of clay layer with moisture. To ascertain the GPR run results (signatures) with actual subsurface conditions, existing borehole litho-logs (BH2 and BH3) located at surface positions of 52 m and 142 m along this section respectively, were utilized. After correlation of borehole sections (BH2 & BH3) with GPR section, solid layers are inferred as sandy layers. Borehole section BH2 indicates solid sandy layer (good reflections) down to depths of 5 m from the surface and after that clay layer (absence of reflections due to highly attenuation of EM waves) is found. Similarly, borehole section BH3 indicates solid sandy layer (good reflection) down to depths of 6 m and then water-bearing zone (poor reflections due to attenuation but less attenuation with respect to clay layer) is confirmed at the depths of 6 m from the surface. These borehole sections support the radar signatures of the GPR section (Fig. 2).

The GPR section along profile 2 (Fig. 3) shows good reflections interpreted as solid layers exist from the surface to the depth of 7 m only except at surface positions 0-65 m and 78-90 m, where solid layers (good reflections) exist down to depths of 3-5 m from the surface. Below this, water saturated zones (poor reflections zone) and clay layers (absence of reflections) are present down to the depth of 17.5 m. Positions of borehole sections (BH4 & BH5) lie at the surface positions of 20 m and 70 m respectively on GPR section (Fig. 3). After correlation of borehole sections (BH4 & BH5) with GPR section, it is inferred that sandy layers exist at the depths of 3 m and 7 m from the surface, and below that clay layer and water saturation zones are found respectively. Borehole sections BH4 shows clay layers at the depth of 3 m and BH5 shows water-table layers at the depth of 7 m from the surface. Here, borehole data (BH4 & BH5) confirm the radar signatures of the GPR section along profile 2 (Fig. 3).

The GPR section along profile 3 (Fig. 4) shows good reflectors interpreted as solid layers exist down to depths of 10-12 m. These layers are interpreted as laterite layers when correlated with borehole section BH6 at the surface position 15 m of the GPR section. This correlation process applied for the entire length of the section. Here, water-bearing strata is dominant and is confirmed with borehole section (BH6) available at the surface position 15 m of GPR section from depths of 10-22 m (Fig. 4). In water-bearing

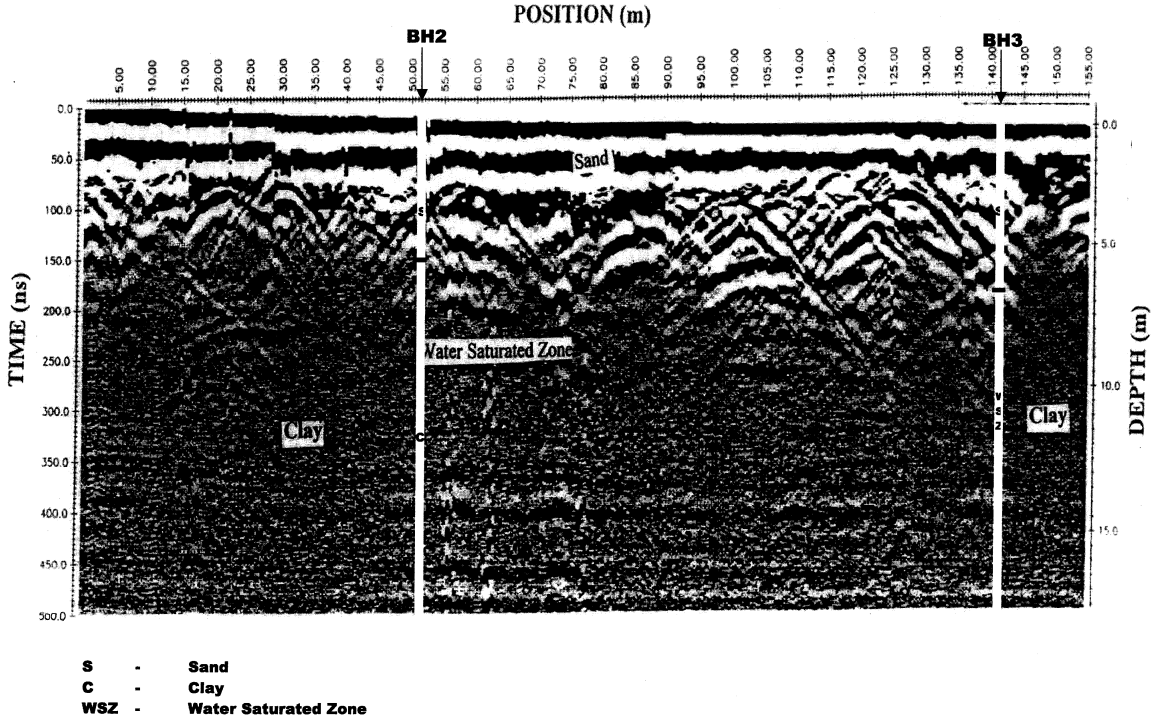

Fig. 2— GPR section of profile 1 in which thick dark black lines indicate solid sandy layer, Poor reflections are indicative of water saturated zone, followed by absence of reflections due to clay layers. This is corroborated by borehole sections BH2 & BH3 (shown on the right) at surface positions 52 m & 142 m respectively

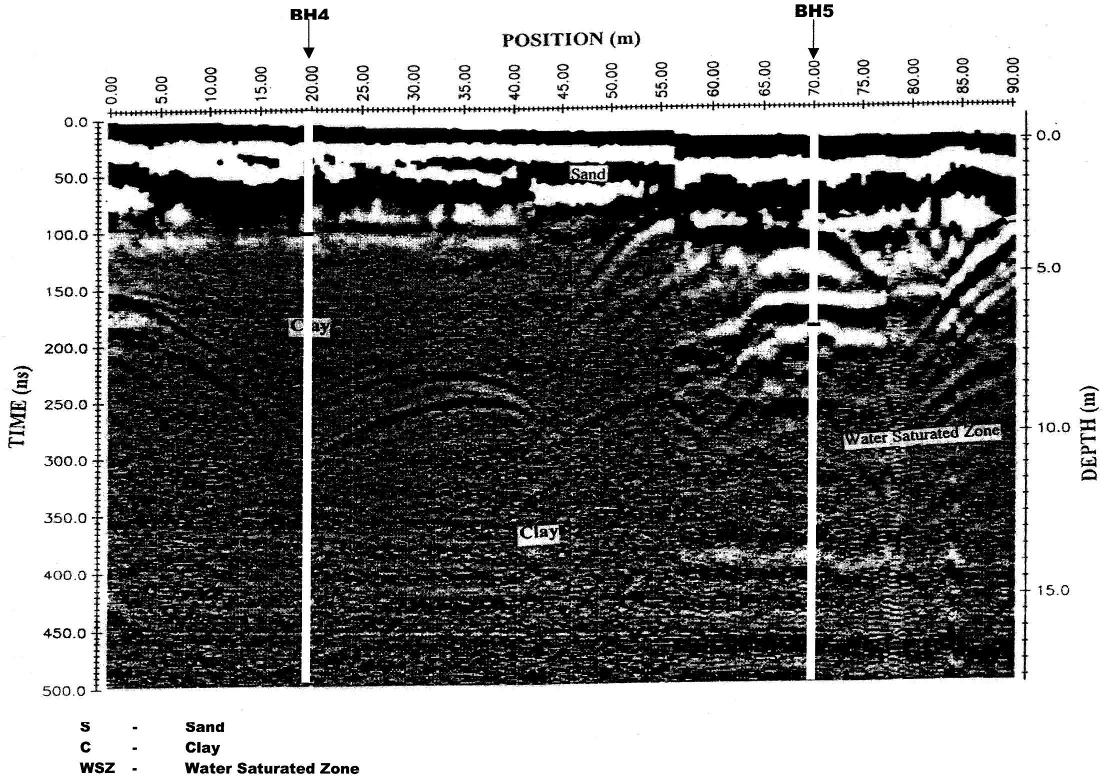

Fig. 3— GPR section of profile 2 in which thick dark black lines indicate solid sandy layer, Poor reflections are indicative of water saturated zone, followed by absence of reflections due to clay layers. This is corroborated by borehole sections BH4 & BH5 (shown on the right) at surface positions 20 m & 70 m respectively.

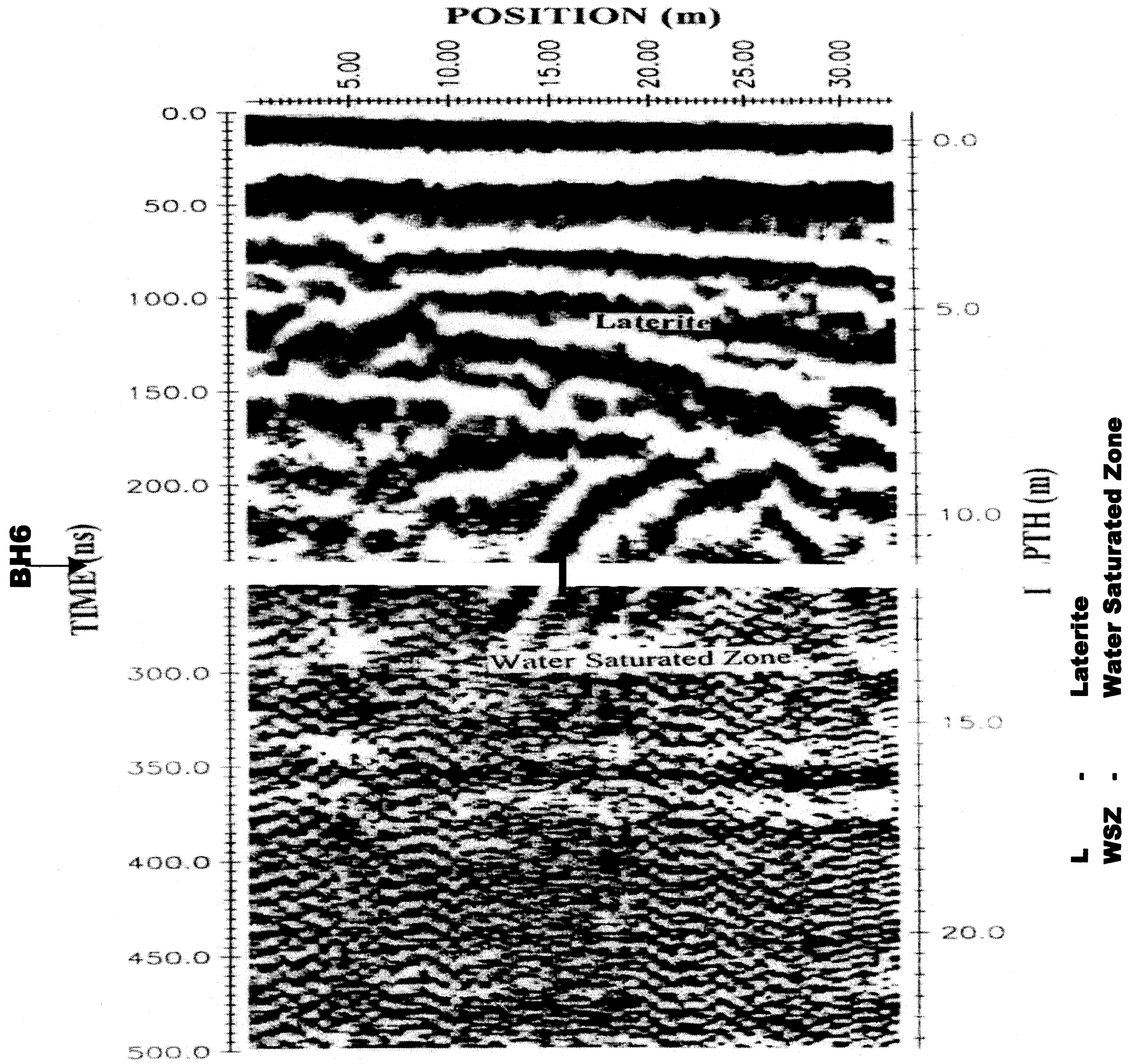

Fig. 4— GPR section of profile 3 in which thick dark black lines indicate solid sandy layer, Poor reflections are indicative of water saturated zone, followed by absence of reflections due to clay layers. This is corroborated by borehole section BH6 (shown on the right) at surface position 15 m.

zone, thick dark lines are not clearly visible as much as in case of solid strata (good reflection), because of poor reflection due to attenuation of EM waves.

GPR section along profile 4 (Fig. 5) shows good reflections, represented by dark lines interpreted as solid layers, are present at depths from 7 to 15 m from the surface, except at one surface location (60 m) where solid layers extend from the surface to 22 m depth. Water-bearing zones (poor reflections) exist at depths from 7 to 22 m at surface positions 16-59 m. In this section, the water table is also situated at a very shallow depth of 7 m. Solid layers (good reflections) are interpreted as laterites, and below that water-bearing zones (poor reflection) are interpreted, when GPR section is correlated with borehole section BH7 available at surface position 32 m of the GPR section (Fig. 5). It may be concluded that the mining process can deplete the groundwater in this zone, where this type of GPR signatures (poor reflection indicative of water-bearing strata) exist.

Conclusions

GPR can play very important role for recognition of clay layers and water-bearing zones. Mining will not affect groundwater table of those areas, where underlying strata is impervious clay layers above

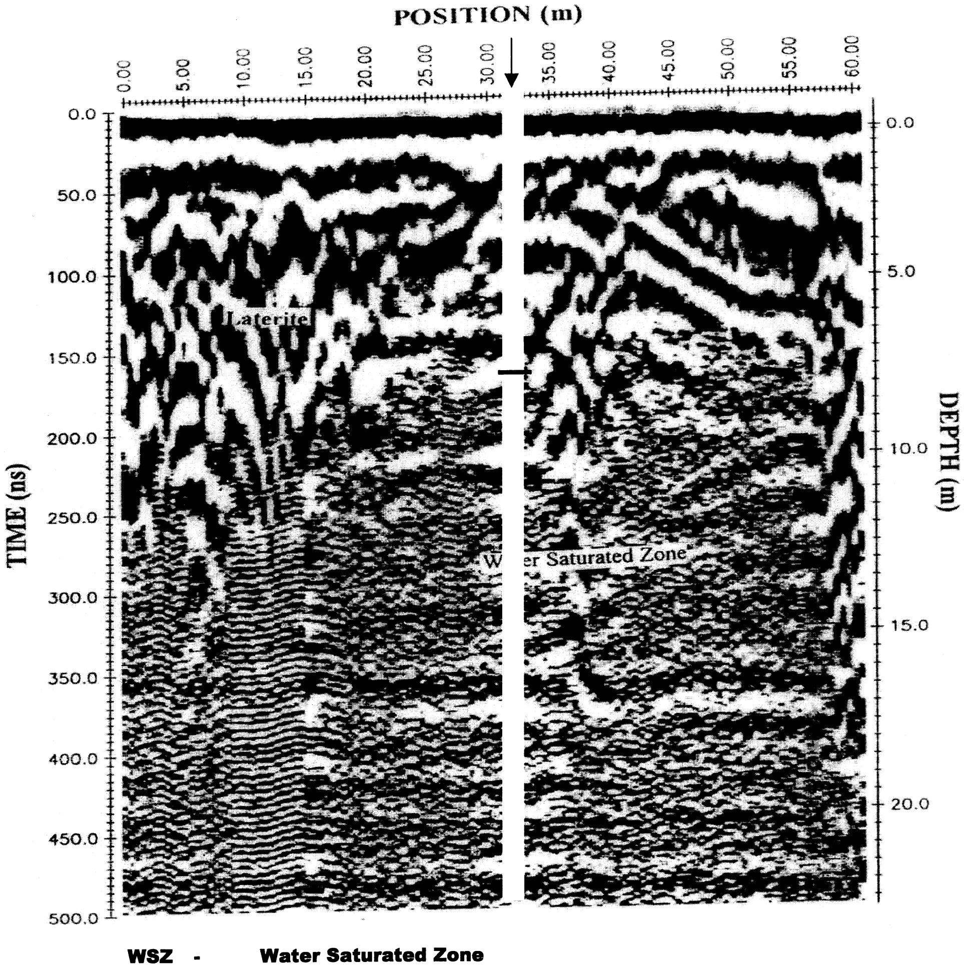

Fig. 5— GPR section of profile 4 in which thick dark black lines indicate solid sandy layer, Poor reflections are indicative of water saturated zone, followed by absence of reflections due to clay layers. This is corroborated by borehole section BH7 (shown on the right) at surface position 32 m.

groundwater table and will affect groundwater table, where underlying strata is water-bearing strata. It is not possible to mine without disturbing groundwater regime (if the water-table is shallow). Therefore, GPR survey can be very useful for scientific management of groundwater conditions and will be also very helpful for EMP study.

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References

1 Maomayez M, Hassani F P, Hara A & Sadri A, Application of GPR in Canadian mines, *CIM Bull*, **89** (1996) 107-110.

2 Cook J C, Radar transparencies of mine and tunnel rocks, *Geophysics*, **40** (1975) 865-885.

3 Singh K K K, Ground penetrating radar study for hydrogeological conditions related with mining activity, *Environ Geol*, **44** (2003) 20-27.

4 Benson A K, Application of ground-penetrating radar in assessing some geological hazards: Example of groundwater contamination, faults, cavities, *Appl Geophys*, **33** (1995) 177-193.

5 Beres M & Haeni F P, Application of ground penetrating radar methods to hydrogeological studies, *Ground Water*, **29** (1991) 375-386.

6 Beres M & Haeni F P, Ground-penetrating radar for high-resolution mapping of soil and rock stratigraphy, *Geophys Prospect*, **37** (1989) 531-551.

7 Olhoeft G R, Low-frequency electrical properties, *Geophysics*, **50** (1986) 2492-2503.