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The use of electrical and seismic methods for imaging shallow subsurface structure of limestone at Batu Caves, Kuala Lumpur, Malaysia

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Abstract: Geoelectrical resistivity and seismic surveys were conducted to investigate subsurface structure of a selected limestone area at Batu Caves, Kuala Lumpur. The limestone in the area belongs to the Kuala Lumpur Limestone formation. The formation generally show two geomorphologic expressions, one above the ground and the other buried beneath alluvium. The buried limestone shows highly irregular karst topography with pinnacle structures. These features have caused a variety of geotechnical problems in both the design and construction of structural foundation in the area.

Two dimensional (2-D) geoelectrical imaging survey was carried out along two traverses by using ABEM SAS 300C Terrameter. The first traverse which comprises of three resistivity profiles with a total length of 144 meters was established by using Wenner configuration, and the second traverse was located on cavities at depth ranging from 15 to 26 meters below ground.

Result of the two dimensional resistivity inverse model of the first traverse indicates an anomalous area of low resistivity in the middle (approximately 50 m width) and high resistivity at both ends of the traverse. The subsurface low resistivity anomaly is interpreted as buried channel at shallow depth and the high resistivity is associated with massive pinnacle limestone bedrock. The second traverse has also detected the presence of water-filled cavities which are indicated as zones of low resistivity in the inversion model.

Seismic refraction and reflection surveys conducted on both of the traverses substantiate the presence of pinnacle structures and possible channel in the limestone of the first traverse and cavity filled up with water in the second traverse.

INTRODUCTION

Geophysical methods allow subsurface conditions to be examined indirectly, quickly, cheaply, and reliably with sufficient results. The methods utilize different physical properties of the earth materials to study subsurface structure. Two dimensional geoelectrical resistivity and seismic imaging are two geophysical techniques which are now widely used in geotechnical and environmental studies. The contrast in geoelectrical conductivity between the limestone bedrock and soil cover as well as water-filled cavities can produced a measurable change in the apparent resistivity especially for shallow bedrock. The seismic refraction method is the most widely used geophysical technique for shallow subsurface investigation (Burger, 1992; Abdul Ghani Rafek and Gred Duplitzer, 1988) whereas the seismic reflection method has been used for underground exploration for deeper target (Miller *et al.*, 1993; Steeples and Miller, 1993). Many case studies illustrate the use of shallow seismic reflection method in detecting fault, cavities, and alluvial deposit at shallow depth. The technique has been used successfully in mapping bedrock topography beneath alluvium in the vicinity of hazardous waste sites (Steeples and Miller, 1993).

Buried karstic limestone with pinnacles, cavities, and overhang structures can caused considerable geotechnical problems during constructions of foundation structures (Ting, 1986). It is therefore necessary to determine the nature of the subsurface structure of the limestone bedrock to ensure a proper design of foundation as well as for remedial work purposes. Geophysical and geological studies were conducted by Soepadmo and Hua (1971) and Jamaludin Othman (1995a) to

investigate the subsurface karstic feature of the limestone beneath alluvium at Batu Caves, Kuala Lumpur

This paper describes the results of seismic and geoelectrical resistivity imaging of subsurface structure of limestone at an abandoned JKR quarry of Batu Caves, Kuala Lumpur.

GEOLOGICAL SETTING

The study area is located south of the Batu Caves limestone hill (Fig. 1). The site is relatively flat with the limestone bedrock covered by an alluvial deposit. The Batu Caves limestone has formed a karstic topographic hill with the highest elevation at about 200 m (Ibrahim Komoo, 1989). Figure 2 shows the geological map of Kuala Lumpur and its surrounding area. The limestone in the Batu Caves area belongs to the Kuala Lumpur Limestone formation. Generally, it composes of fine to coarse-grained white to gray calcitic and dolomitic marble. Figure 3a shows a north-south section of the limestone hill and bedrock covered by the alluvial deposits with thicknesses ranging from few to several tens of meters.

Geologically, the limestone is interpreted to have been uplifted, compressed, folded, and heated into a mosaic of large crystals which had changed to marble in most places during the Triassic period (Soepadmo and Hua, 1971). The rock was deposited originally in shallow warm water and dry climatic conditions.

Previous studies indicated that the carbonate rocks are karstifiable (Bögli, 1980) and those buried beneath the river alluvium usually forms high-relief karstic topography (Fig. 3b, Yeap (1986)). The karstic topography with pinnacles and channels have created major foundation problems (Ibrahim Komoo, 1989) in the study area.

The Geological Survey Department of Malaysia has drilled several bore holes in the study area (Jamaludin Othman, 1995b). The drilling records (Fig. 4) indicate that the subsurface geology of the survey area is mainly made up of three layers. The first layer corresponds to a relatively thin humid soil and the second layer is alluvium which comprises slightly brownish to white clay, silty sand with traces of muscovite and fine quartz grains. The third layer corresponds to light grey limestone bedrock showing several cavities at depth of ranging from 15 to 26 meters under ground.

FIELD SURVEY

Geoelectrical resistivity and both seismic refraction and reflection surveys were conducted along two selected traverses. Location of the traverses is shown in Figure 5.

An ABEM Terraloc 24-Channel Seismograph was used in the seismic data acquisition with geophone spacing of 3-meters. Geophones with natural frequency of 14 Hz, and a 10-kg sledgehammer source energy were used to perform the refraction and reflection surveys. Seismic refraction was carried out on both traverses using thirteen shots configuration system and common depth point (CPD) reflection survey was conducted with 15 meters offset shot.

ABEM SAS 300C Terrameter was used to collect the geoelectrical resistivity imaging data with 50-electrodes system connected to a multicore cable and switch box. The box switching unit was used to select electrode numbers and electrode spacing during measurements manually. Each measurement was made with Wenner array and the same measurement was repeated with increasing electrode spacing.

The first traverse which consists of three geoelectrical resistivity and three seismic profiles was established in an area of suspected subsurface pinnacles structure. Geoelectrical resistivity imaging was conducted along the first traverse with a total length of 144 meters. Figure 5 shows the first resistivity traverse which comprises of three overlapping electrical resistivity profiles **AB**, **CD**, and **BC**. The length of profiles **AB** and **CD** were 98 and 96 meters respectively with electrode spacing of 2 meters. The third profile **BC** was carried out on the middle of the traverse line with its mid point located at **E**. An electrode spacing of one meter was used for this profile with total length coverage of 49 meters.

Two seismic refraction profiles **SS'** and **S'S"** were carried out along the first traverse line. The length of each profile was 69 meters. A common depth point (CDP) seismic reflection survey was also conducted along the same traverse line with first geophone located at **S** as illustrated in Figure 5. The total coverage length of the seismic reflection profile was 75 meters.

For the second traverse line, three different geophysical profiles were established. The first profile is a geoelectrical resistivity imaging profile with electrode spacing of 2 meters and a total length of 98 meters. The second seismic refraction profile **LL'** was conducted with total length of 69 meters. The third CDP seismic reflection profile was established along the same traverse line, where the location of the first geophone lies at **L** as illustrated in Figure 5. A total coverage length of the CDP seismic reflection profile was 75 meters.

The measured apparent resistivity values of the geoelectrical resistivity imaging profiles were interpreted by using two dimensional resistivity

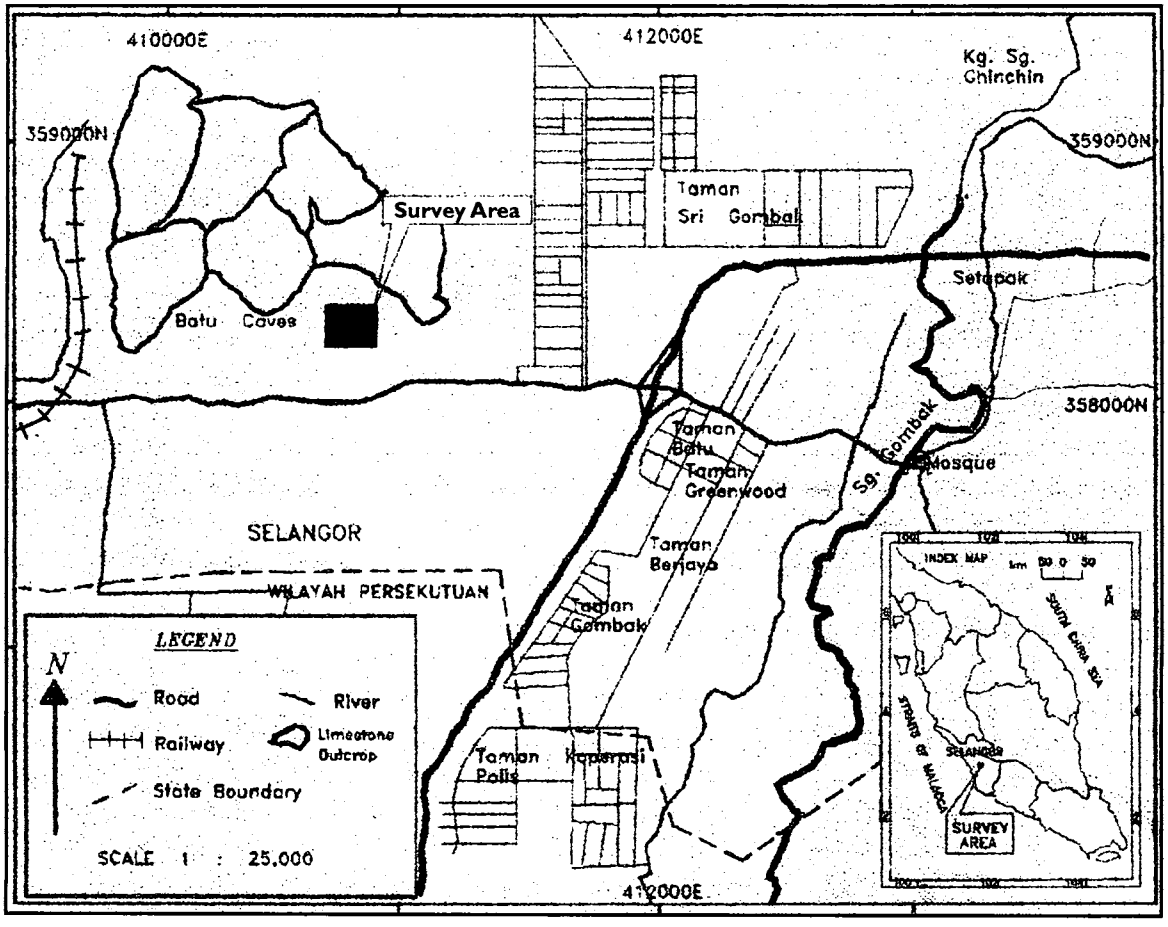

Figure 1. Location map of the survey area.

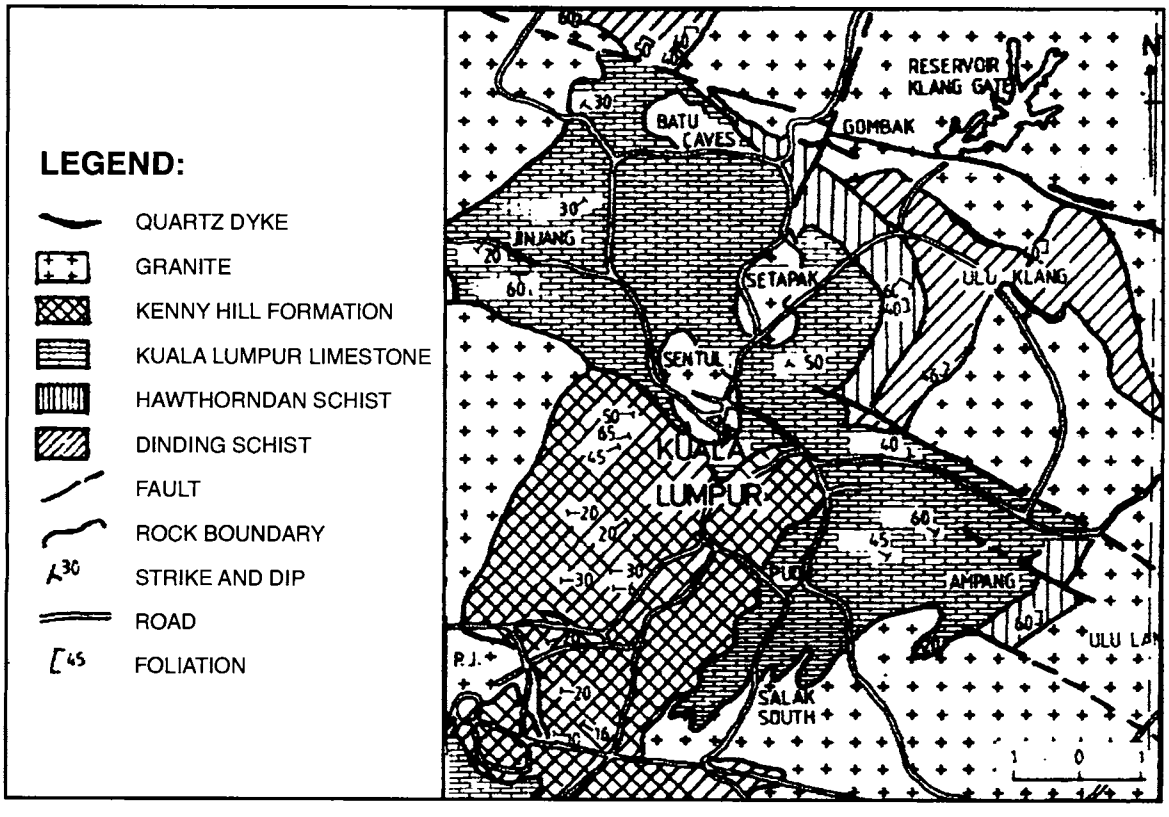

Figure 2. The geology of Klang Valley-Kuala Lumpur area (after Fatt and Pee, 1986).

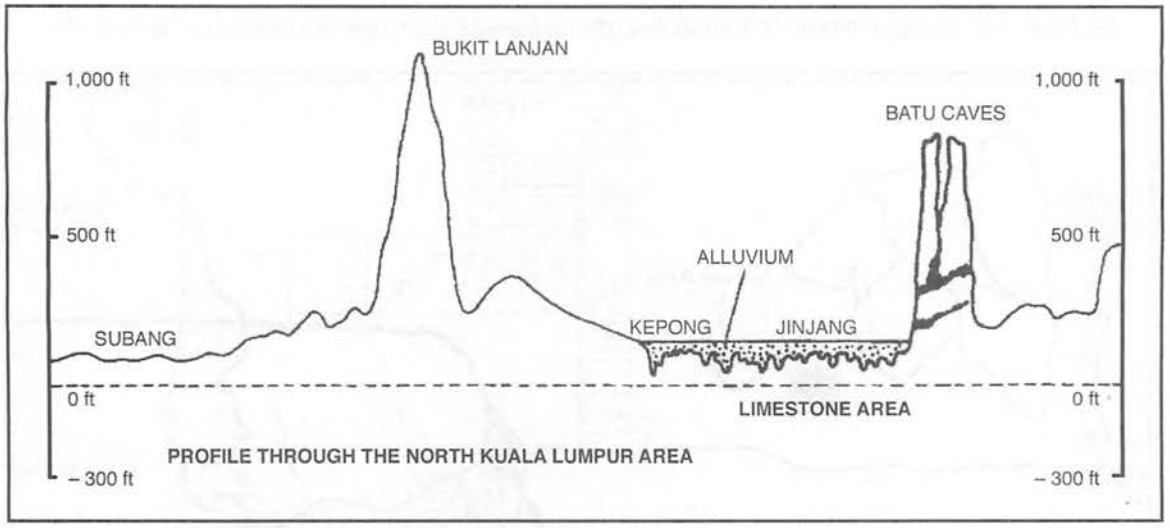

Figure 3a. Profile illustrates the common karstic topography expression through Subang to Batu Caves, north Kuala Lumpur (after Yeap, 1986).

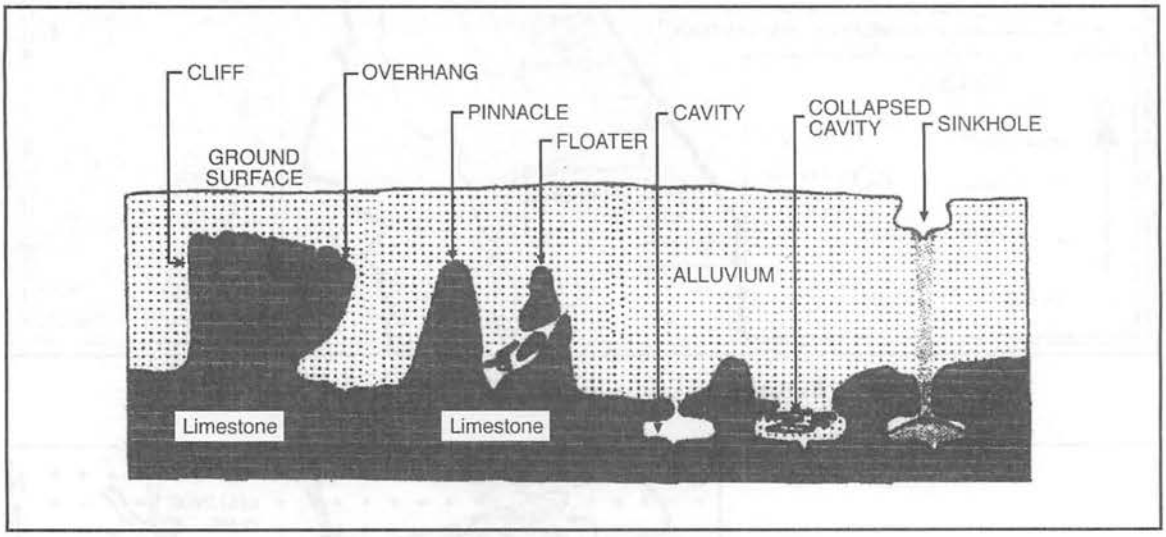

Figure 3b. Some features of subsurface karstic limestone bedrock in the Kuala Lumpur area (after Fatt and Pee, 1986).

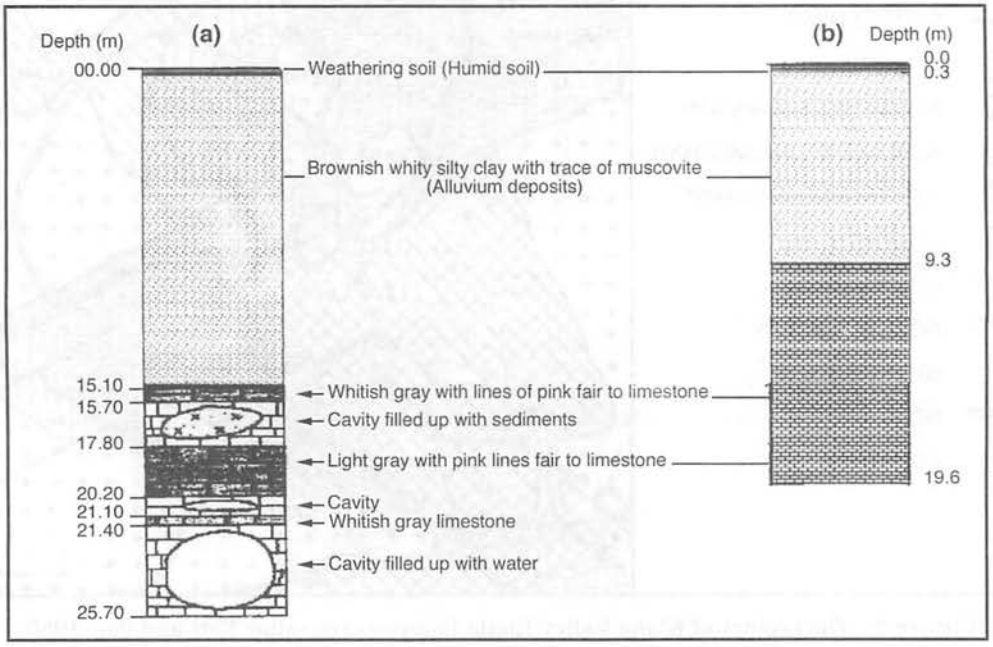

Figure 4. The geological log of the boreholes in the survey area, (a) borehole No. 6 and (b) borehole No. 2.

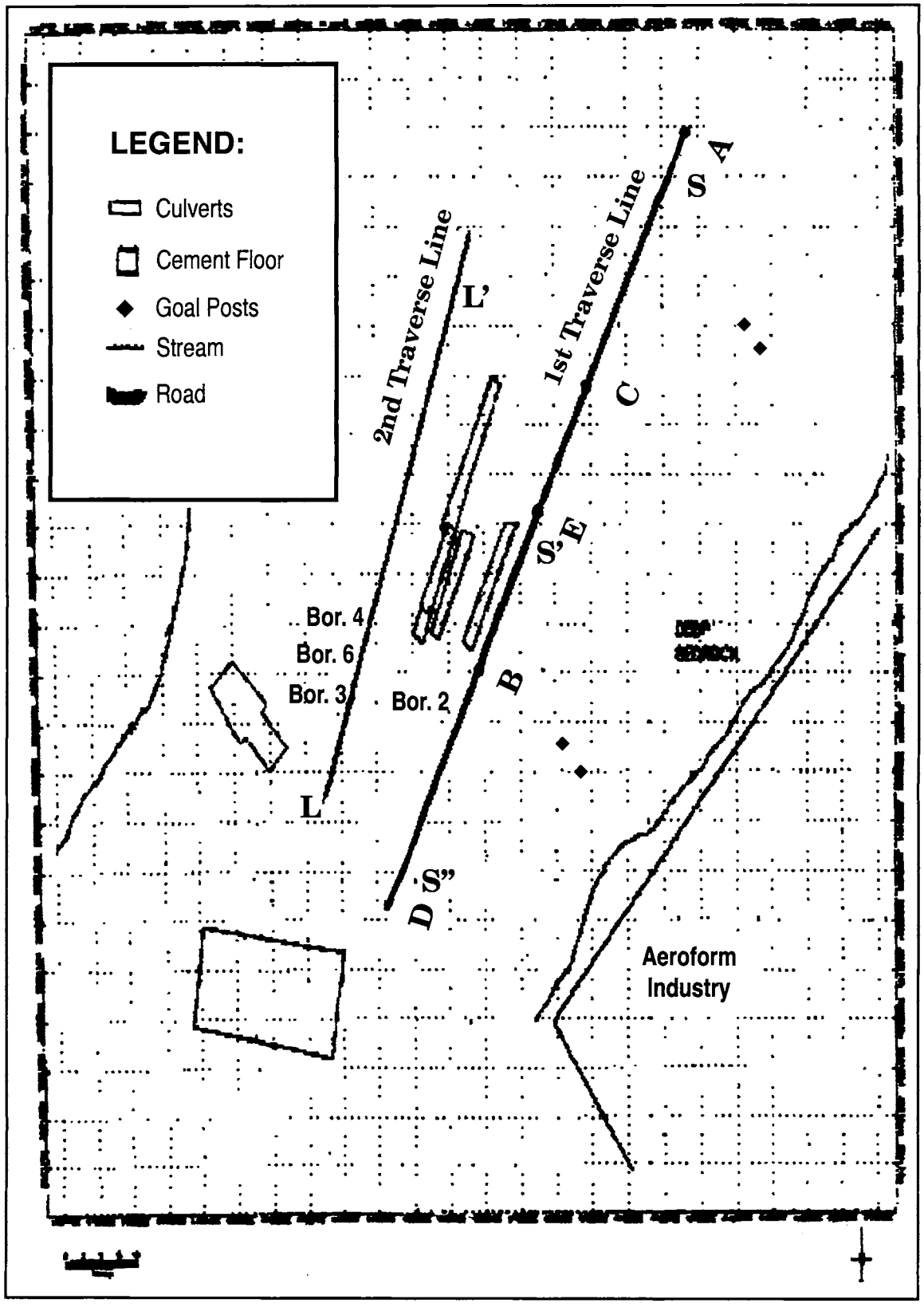

Figure 5. Location map of the traverse lines.

inversion program "RES2DINV" (Loke, 1997). Whereas the seismic refraction and reflection data were interpreted by using "Biasan" and "Eavesdropper" softwares respectively.

RESULTS AND DISCUSSION

First traverse line

Results of the interpreted 2D electrical resistivity profiles **AB**, **CD**, and **CB** along the first traverse line are shown in Figures 6, 7, and 8 respectively.

The measured apparent resistivity pseudosection and computer inverse model resistivity sections of profile **AB** are shown in Figure 6. The inverse model section shows a thin layer of low resistivity zone on the right side of section. The low resistivity anomaly is interpreted as corresponds to water saturated alluvial deposits. It is underlain by a high resistivity zone described as limestone bedrock with a sharp margin of the pinnacle structure at approximately below 50 meters mark. The resistivity on the left side of the section at 50 to 98 meter marks is relatively low with values between 30 Ωm to 600 Ωm. An elongated shape of the anomalous low resistivity contour suggests the presence of water saturated buried channel.

The calculated apparent resistivity pseudosection and computer inverse model section of the second profile **CD** are shown in Figure 7. The low resistivity value (30 to 600 Ωm) observed on the right side of the section is associated with alluvial deposits and possibly related to the buried channel. The inverse model also shows a possible small cavity filled up with water on the left side of the section approximately under 62 to 66 meter marks. The high resistivity limestone bedrock lies beneath the alluvial deposits at shallow depth with pinnacle structure located approximately below 50 meter mark.

The measured and inverse sections of the third profile **BC** are shown in Figure 8. The pseudosection and inverse model show resistivity values of less than 600 Ωm which is related to the alluvial materials. The low resistivity anomaly of less than 30 Ωm represents the water saturated buried channel.

A single 2-D resistivity subsurface model was produced for the first traverse line by overlapping results of the two resistivity inverse models for profiles **AB** and **CD** as illustrated in Figure 9. The resistivity subsurface model shows high resistivity

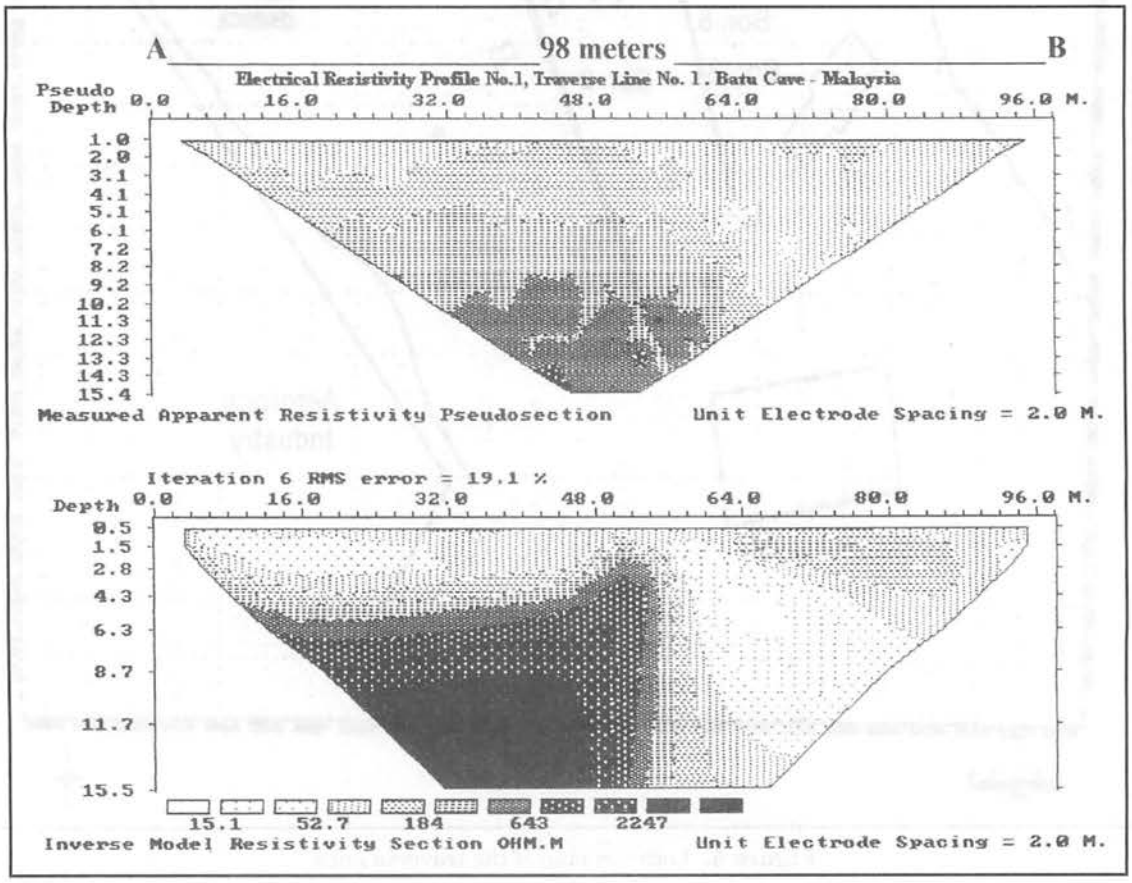

Figure 6. The pseudosection and the resistivity inverse model of profile **AB** carried out along the first traverse line.

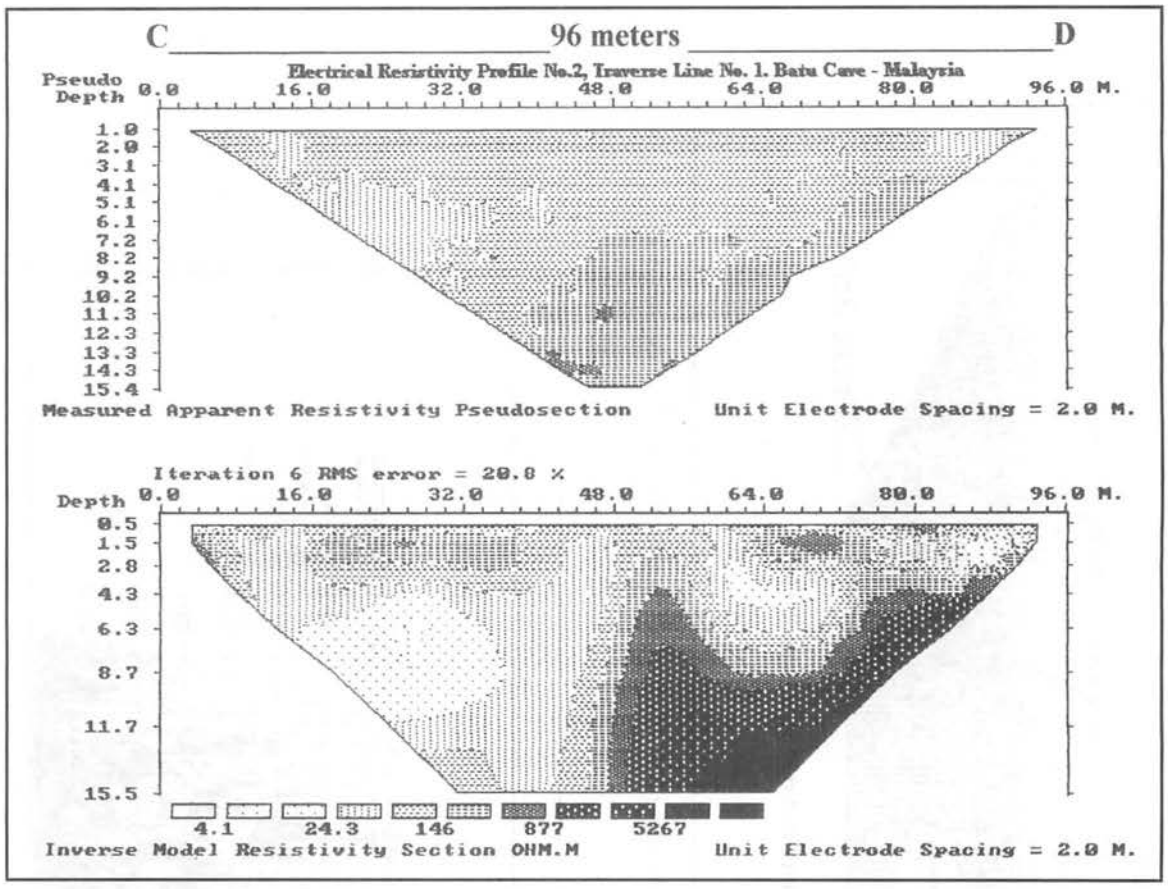

Figure 7. The pseudosection and the resistivity inverse model of profile **CD** carried out along the first traverse line.

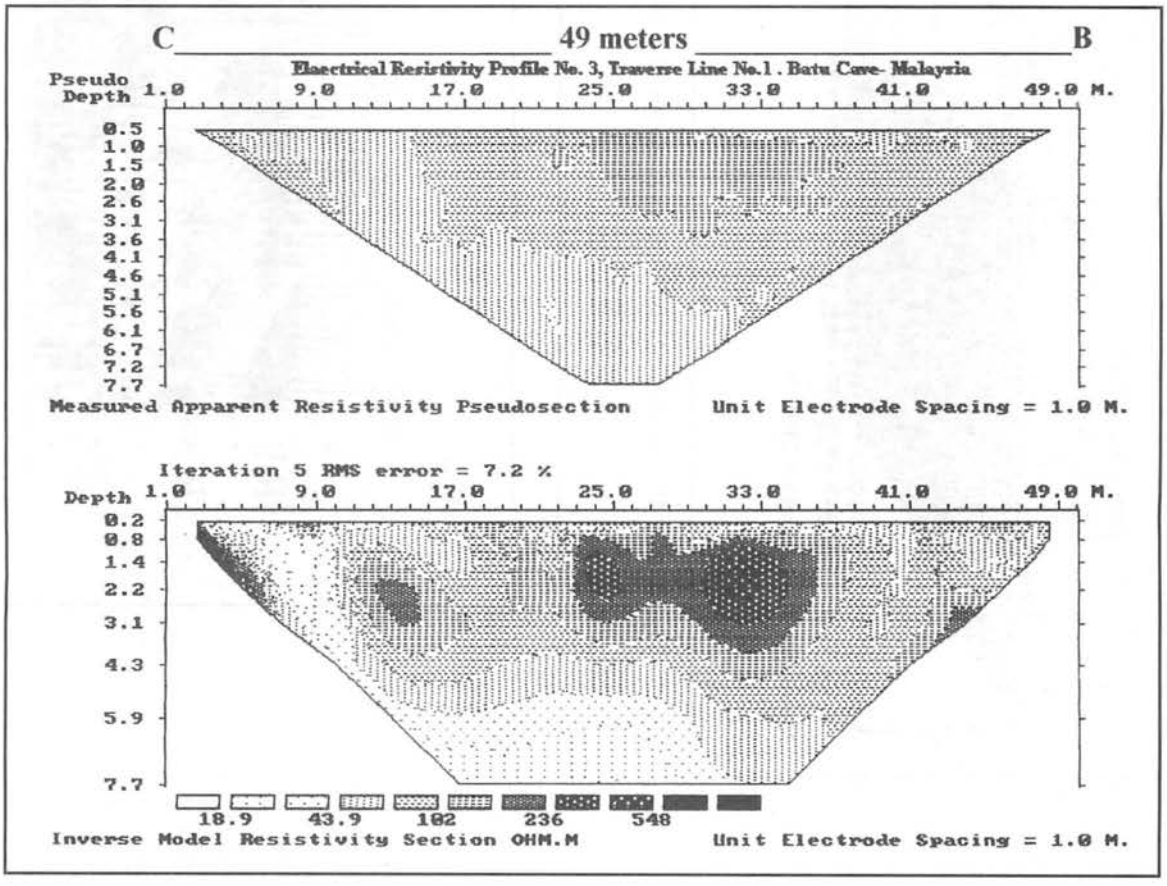

Figure 8. The pseudosection and the resistivity inverse model of profile **CB** carried out along the first traverse line.

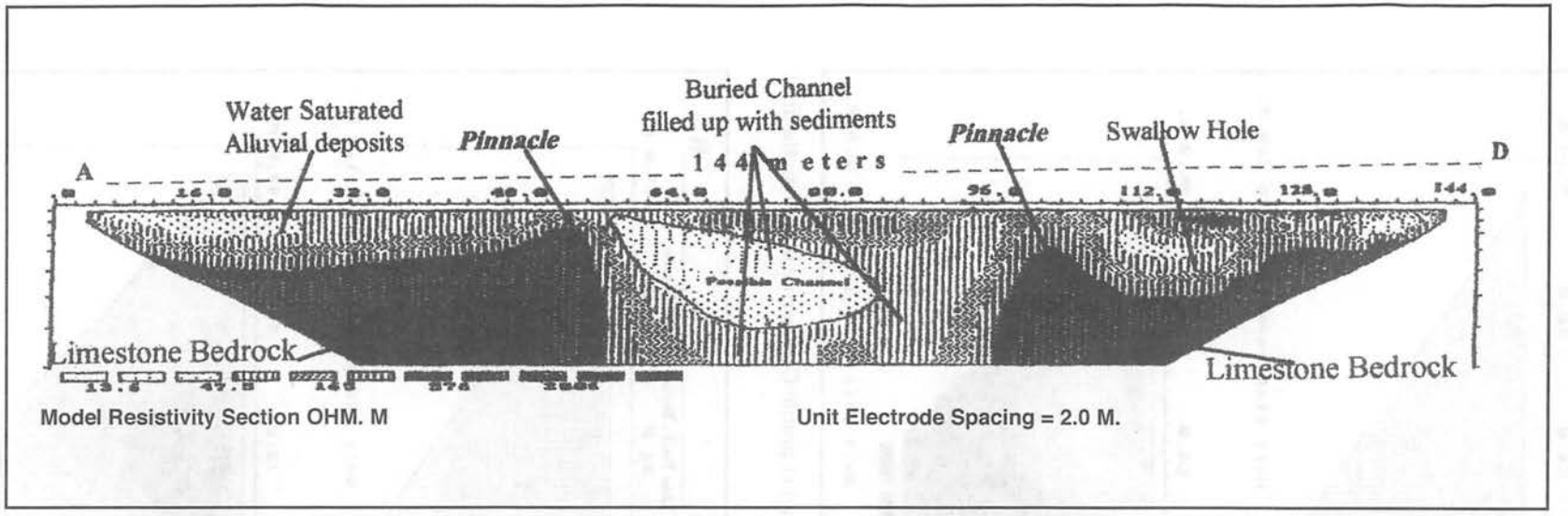

Figure 9. 2-D geoelectrical resistivity inverse model of the first traverse produced by overlapping of the profiles **AB** and **CD**.

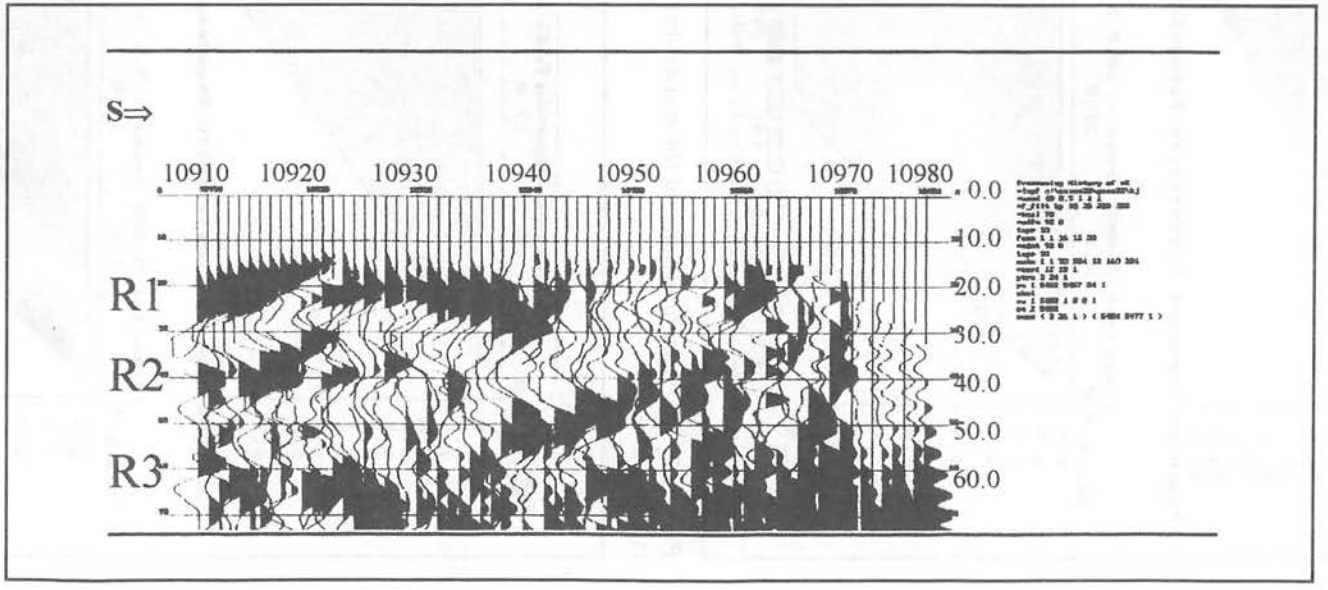

Figure 10. CDP shallow seismic reflection section of the first traverse line.

anomalies of limestone bedrock at both sides of the traverse line. The limestone bedrock shows highly irregular subsurface topography with pinnacle structures. A synclinal shape resistivity contours interpreted as swallow hole is observed on the left side of the model. The low resistivity zone at the middle of the model is likely corresponds to a possible water saturated buried channel within the alluvial sediments as a result of mining activities. High resistivity suggests that the limestone bedrock was exposed at shallow depth on both left and right sides of the section.

A CDP seismic reflection section of the first traverse (Fig. 10) shows a strong discontinuous reflector that is located approximately between 15 to 30 ms two-way time with an area of weak reflection between station 10,942 and 10,960. The poor reflection data quality coincides well with the resistivity interpreted buried channel. Another strong reflector is observed between 35 and 55 ms two-way time and a zone of poor reflector between station 10,920 and 10,940 which probably related to a possible cavity. The seismic section shows that the first and second reflectors have undergone some displacement which probably associated with slow subsidence or sinkhole caused by chemical dissolution.

The interpreted seismic refraction sections of profile **SS'** and **S'S"** observed three subsurface geological layers which agree well with the bore hole data. The top layer refers to a humid soil with compressional P-wave velocity ranges from 200 m/s to 600 m/s. The thickness of this layer varies from 0.1 to 2.4 m. The P-wave velocity of the second layer ranges from 1,024–1,754 m/s with layer thickness ranges from 0.2 to 15.2 m. This layer is associated with alluvial deposits. The bedrock was represented as the third layer with P-wave velocity ranges between 2,782 to 3,528 m/s.

Second traverse line

A 2-D resistivity inverse model of the second traverse (Fig. 11) shows a relatively low resistivity anomaly which is interpreted to be a buried channel which extends beyond 15 meters depth. The model also shows a rounded shape of low resistivity anomaly which is related to swallow hole filled up with alluvial deposit. Elongated anomaly on the

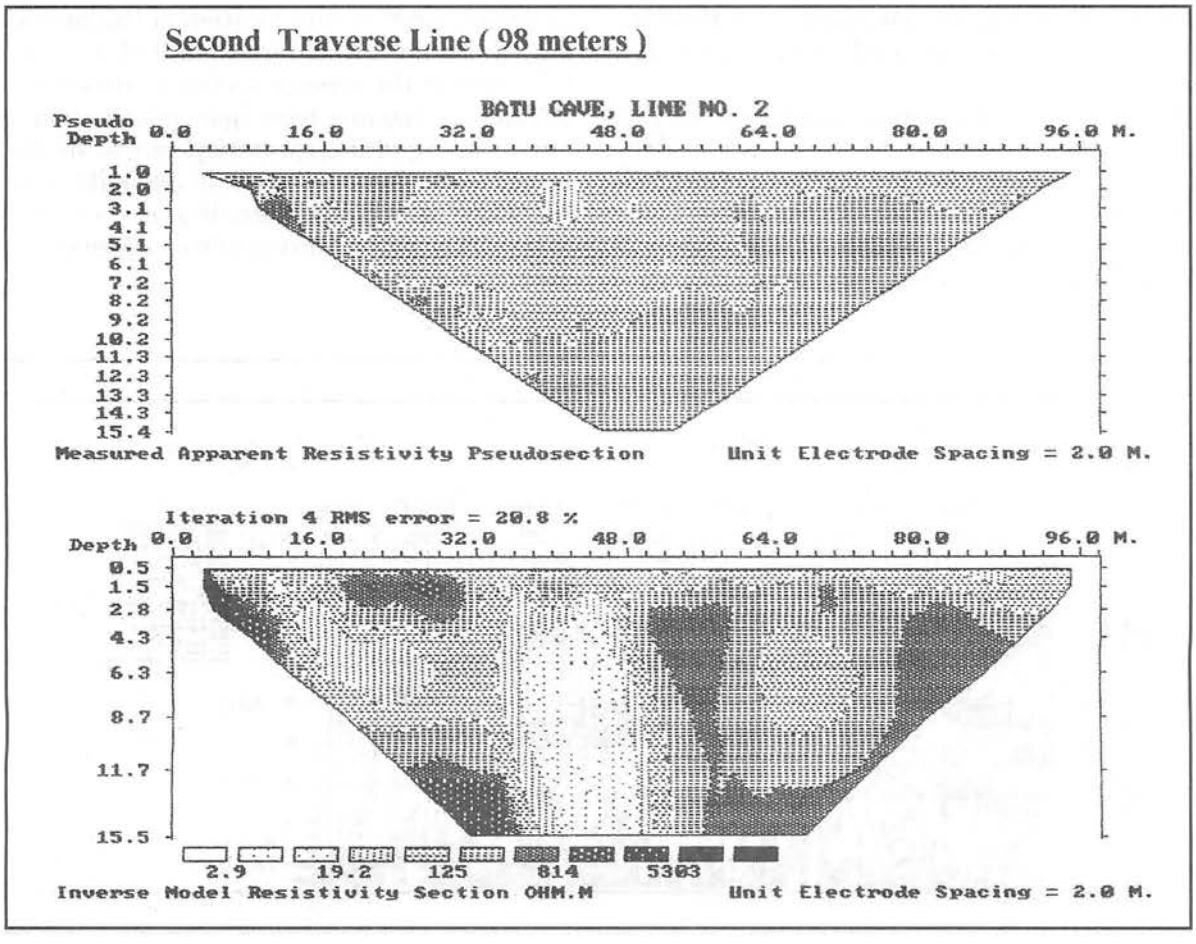

Figure 11. The apparent resistivity pseudosection section and the geoelectrical resistivity inverse model section of Wenner configuration carried out along the second traverse line.

right side of the model is interpreted to be a small cavity filled up with water. High resistivity zone located under the cavity is interpreted as the limestone bedrock. The limestone bedrock in the left side of the inversion model shows the pinnacle structure at shallow depth.

A multifold CDP shallow seismic reflection section of the second traverse (Fig. 12) shows a strong and continuous first reflector between 18 and 25 ms two-way time. Second strong and discontinuous reflector of anticlinal structure is located approximately between 38 to 52 ms two-way time. The seismic section shows an absence of second reflector between station 10,840 and 10,860. The strong reflection event is interpreted as being the top of the limestone bedrock, whereas the underlying zone of no reflection illustrates the presence of cavity at shallow depth which is in good agreement with the resistivity model and boreholes information. Two short strong reflectors appear between 50 to 55 ms and 60 to 68 ms two-way time on the right side of the section. Below 65 ms two way time a zone of poor reflection is observed for a highly irregular subsurface layer of the karstic limestone bedrock. The seismic section shows the system of displacements that are located around station 10,835 to 10,855 and between 18 to 65 ms two-way time associated with sinkhole or slow subsidence.

The interpreted seismic refraction section indicates the compressional wave velocity of the top layer varies from 243 to 833 m/s. The thickness of this layer ranges from 0.1 to 2.3 meters and represents the top soil. The second layer having a compressional wave velocity of 1382 m/s with thickness of 0.2 to 14.6 meters is associated with alluvial deposits. The high velocity layer corresponds to limestone bedrock. The compressional wave velocity of the limestone bedrock is around 3,700 m/s. The subsurface geological section shows no refraction between 36–42 meters marks and this is interpreted as cavity which is in good agreement with the previous results.

CONCLUSION

In conjunction with bore hole data, the geoelectrical resistivity and seismic techniques have been successfully used to image the complex subsurface karstic features of the limestone at Batu Caves, Kuala Lumpur.

The two dimensional geoelectrical resistivity images indicate the presence of buried channel running across the study area. The resistivity technique also detected the irregular subsurface topography of the pinnacle karstic limestone bedrock and swallow hole filled up with alluvial sediments as well as cavities.

The seismic technique on the other hand provide true depth of the limestone bedrock, subsurface geological profiles and location of the cavities and buried channel which are indicated as zone of no reflection in the seismic sections. However, these techniques require bore hole information before any meaningful interpretation can be made. The interpreted seismic section reveals that the limestone bedrock has been displaced probably due to the development of sinkhole or subsidence in the area.

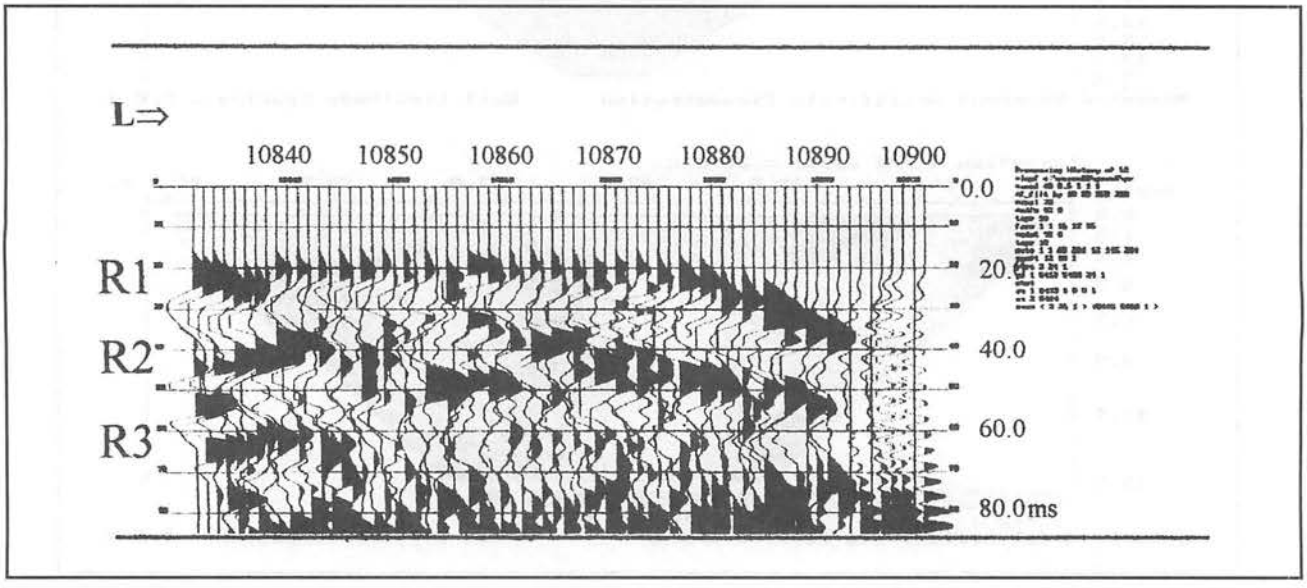

Figure 12. CDP shallow seismic reflection section of the second traverse line.

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