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Mapping Subsurface Karst Formation Using 2-D Electrical Resistivity Imaging (2-DERI)

Zul Fadhli

Postgraduate Student at Geophysics Section, School of Physics, 11800 Universiti Sains Malaysia, Penang, Malaysia.
Department of Geophysics Engineering, Faculty of Engineering, Syiah Kuala University, Banda Aceh - Indonesia.
e-mail: zulcmc@gmail.com

Dr. Rosli Saad

Senior Lecturer, Geophysics Section, School of Physics, 11800 Universiti Sains Malaysia, Penang, Malaysia; e-mail: rosli@usm.my

Dr. M. M. Nordiana

Lecturer, Geophysics Section, School of Physics, 11800 Universiti Sains Malaysia, Penang, Malaysia
e-mail: mmnordiana@usm.my

N. Azwin

Postgraduate Student, Geophysics Section, School of Physics, 11800 Universiti Sains Malaysia, Penang, Malaysia
e-mail: nurazwinismail@yahoo.com

A. A. Bery

Postgraduate Student, Geophysics Section, School of Physics, 11800 Universiti Sains Malaysia, Penang,Malaysia
e-mail: andersonbery@yahoo.com.my

ABSTRACT

Karst environments are characterized by distinctive landforms which are related to dissolution and dominant subsurface drainage. The interaction of limestone with water able to create karst features such as cavity, pinnacle, boulder and sinkhole through the dissolution process. The existence of subsurface karst features are always be concern maters to engineers before any development start, because these features could cause disaster in the future. The study was conducted at Tapah, Perak (Malaysia) with the objective is to map karst features at limestone formation. The 14 survey lines of 2-D Electrical Resistivity Imaging (ERI) using the Wenner-Schlumberger array and the results were correlated with 14 boreholes. The inversion model shows that the study area is consisted of two main layers. The first layer with resistivity value >250 Ohm.m was interpreted as alluvium. The second layer is classified as hard layer with resistivity value of >350 Ohm.m. Each line has different range of limestone values because it's depending on the conductivity and density of the rock which influence by dissolution process**.** The karst features such as fill cavity, boulder, pinnacle, discontinuity and overhang were detected in the survey lines. The 2-DERI results showed a good correlation with all the borehole records in determining the subsurface of limestone formation. The 2-DERI method is capable in mapping karst features and bedrock depth.

KEYWORDS: 2-D Electrical Resistivity Imaging (ERI), Borehole, Limestone, Karst Features, Perak.

INTRODUCTION

The water interaction toward limestone able to formed karst features (pinnacle, boulder, cavity and sinkhole) through dissolution process. The karst features formed by the dissolution process. The cavity is a big problem in infrastructure works. Detecting karst feature such as cavity is challenging work, because the karst subsurface is complicated and difficult to predict. Using one method such as geotechnical or geophysical for subsurface characterization is not highly accuracy and efficient. The geotechnical method is costly due to drilling works especially when drilling point is needed many point of borehole and can cause damage to the subsurface area (destructive). The geophysical method should be integrated with another method to get good accuracy, such as correlation with others geophysical method such as seismic refraction or correlation with geotechnical methods. The integration of geophysical and geotechnical methods were applied in this study to get good accuracy and reliable results to determine the karst features on the subsurface of study area.

In this study, geotechnical method used is drilling to get the borehole record. This method required soils sampling and description of the sample, based on standard penetration test (SPT). Rocks sampling is based on rock quality designation (RQD) test. The sample from the drilling can described the characteristic of the subsurface layers and possibility the presence of karst features at the point. The geophysical method used in this study is 2-D electrical resistivity imaging (2-DERI). This Geophysical method is useful for studying karst terrains because of the intrinsic heterogeneity of the medium (Van Schoor, 2002 and Vouillamoz et al., 2003). The electrical resistivity method has proven useful for the subsurface imaging (Vouillamoz et al., 2003; Zhou et al., 2000 and Zhou et al., 2002). This geophysical method is to identifying anomalies related to underground cavities, gaps, underground bodies or aquifers under pressure and has been developed recently using miniature geophysical apparatus, data acquisition and complex calculation methods (Mcdowell, 1981; Rigby-Jones et al., 1997; Zonge et al., 2005).

GENERAL GEOLOGY

Figure 1 shows the general geology of Tapah (Geology map of Malaysia, 1985). The southern part consist of phyllite, and slate Schist and Limestone while the northern part consist of intrusive rocks mainly granite with minor granodionate, On the west part consist of phyllite, schist, slate and limestone. The limestone and sandstone are locally prominent with some interbeds of conglomerate; chert and rare volcanic while on the eastern part consist of igneous rock together with phyllite, schist, slate and limestone.

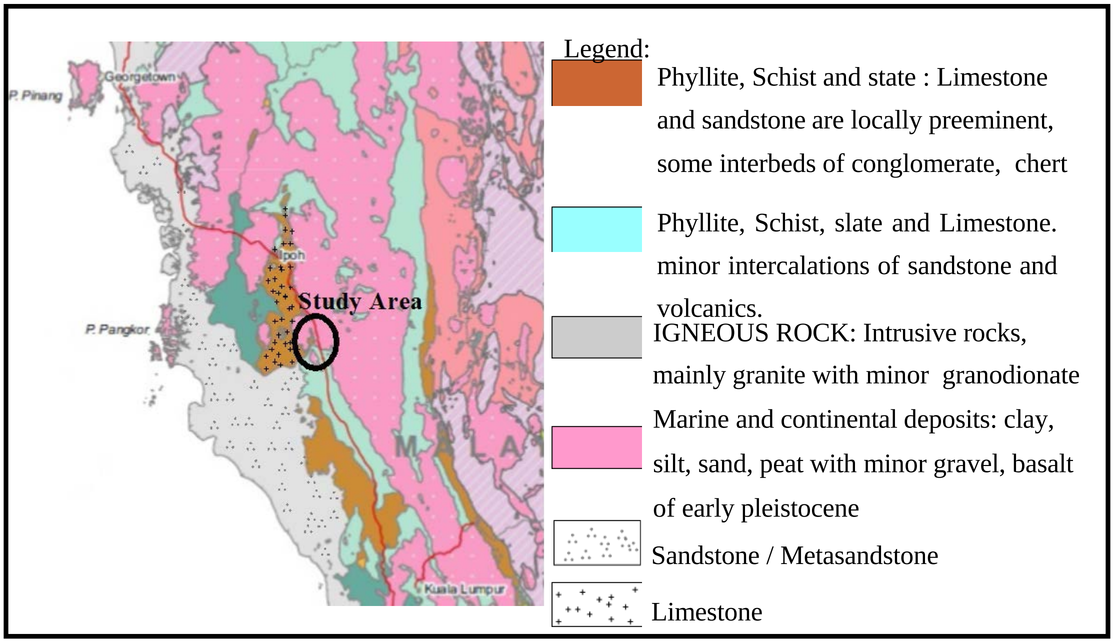

Figure 1: Geological map of study area (Geological map of Malaysia, 1985).

THEORY OF 2-D ELECTRICAL RESISTIVITY IMAGING METHOD

2-D electrical resistivity imaging (2-DERI) method is to measure resistivity distribution at the subsurface by injecting DC current into the ground using 2 current electrodes (C_1 and C_2). The potential difference is measured using 2 potential electrodes (P_1 and P_2). The method is used to determine the electrical properties of the ground, detection of three-dimensional bodies of anomalous electrical conductivity (Kearey et al., 2002), locating subsurface cavities, mineral and groundwater exploration. Besides that, this method extensively used in borehole logging in oil exploration.

The 2-DERI is now mainly carried out with a multi-electrode resistivity meter system (Figure 2). Such surveys use a number (usually 25 to 100) of electrodes laid out in a straight line with a constant spacing. A computer-controlled system is used to automatically select the active electrodes for each measure (Griffith and Barker, 1993).

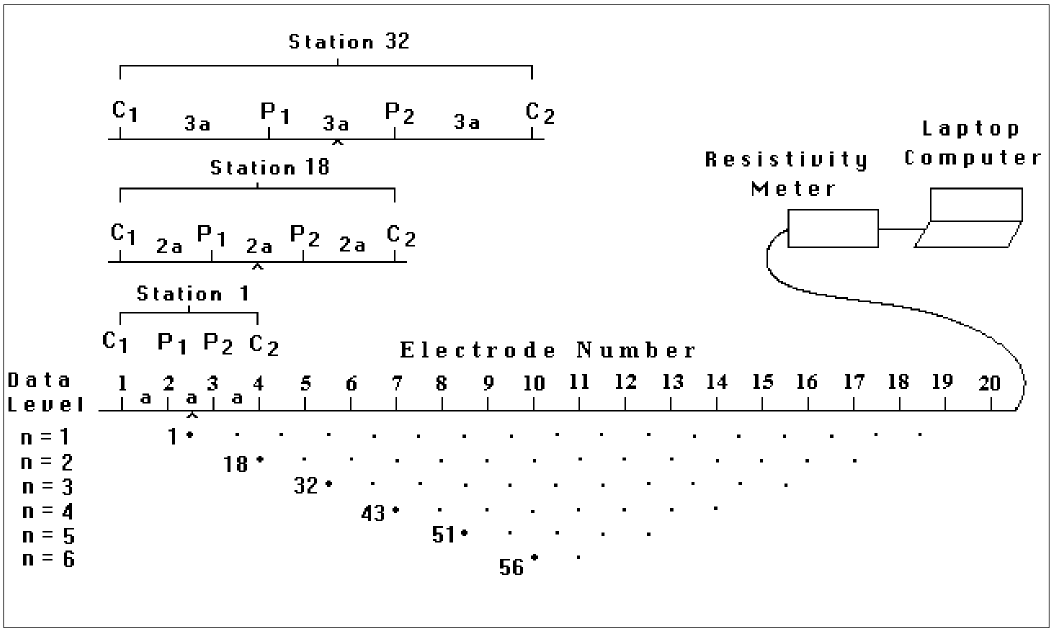

Figure 2: The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudosection.

Table 1 shows the resistivity value of some typical rocks and soil materials (Keller and Frischknecht, 1996). Igneous and metamorphic rocks typically have high resistivity values. The resistivity value of these rocks is mainly dependent on the degree of fracturing. If the water table shallow, the fractures are normally filled by ground water.

Table 1: Resistivity of some of common geological materials (Reynolds, 1997)

Rock Type	**Resistivity range (Ωm)**
Granite	$3 \times 10^2 - 10^6$
Granite (weathered)	$3 \times 10 – 5 \times 10^2$
Schist (calcareous and mica)	$20 - 10^4$
Schist (graphite)	10×10^2
Sandstones	$1 – 7.4 \times 10^8$
Limestone	$50 - 10^3$
Clays	1×10^2
Alluvium and sand	$10 – 8 \times 10^2$
Consolidated shale	$20 – 2 \times 10^3$
Sand and gravel	$30 - 22^5$
Fresh Water	10 - 100

METHODOLOGY

The 2-DERI survey was conducted using ABEM SAS4000 Terrameter, electrode selector (ES10-64C), 4 resistivity cables with 5 m takeouts and stainless steel electrodes. Each 2-DERI survey line consisted of a single spread of 61 electrodes, with minimum 5 m electrode spacing for the inner cable and 10 m electrode spacing for the outer cables. The Wenner-Schlumberger array was used with roll-along technique. 12 survey lines trending north to south and 2 lines are from west to east (Table 2).

Table 2: Distribution of 2-DERI survey lines

No	line	Trending	Length (m)
1	LVA1	North - South	700
2	LV1	North - South	800
3	LV2	North - South	900
4	LV3	North - South	800
5	LV4	North - South	900
6	LV5	North - South	800
7	LV6	North - South	800
8	LV7	North - South	800
9	LV8	North - South	600
10	LV9	North - South	800
11	LV10	North - South	800
12	LV11	North - South	800
13	LH1	West - East	1100
14	LH2	West - east	1100

Figure 3 shows 14 survey lines design in such away to cover the whole of study area. The 2-DERI data was modeled using Res2Dinv software (Loke and barker, 1996). A least-squares inversion of the resistivity data was conducted using a finite element mesh with surface topography to generate a 2-D resistivity model. Then the data is transferred into surfer format for correlation with borehole data, gridding, contouring and final presentation.

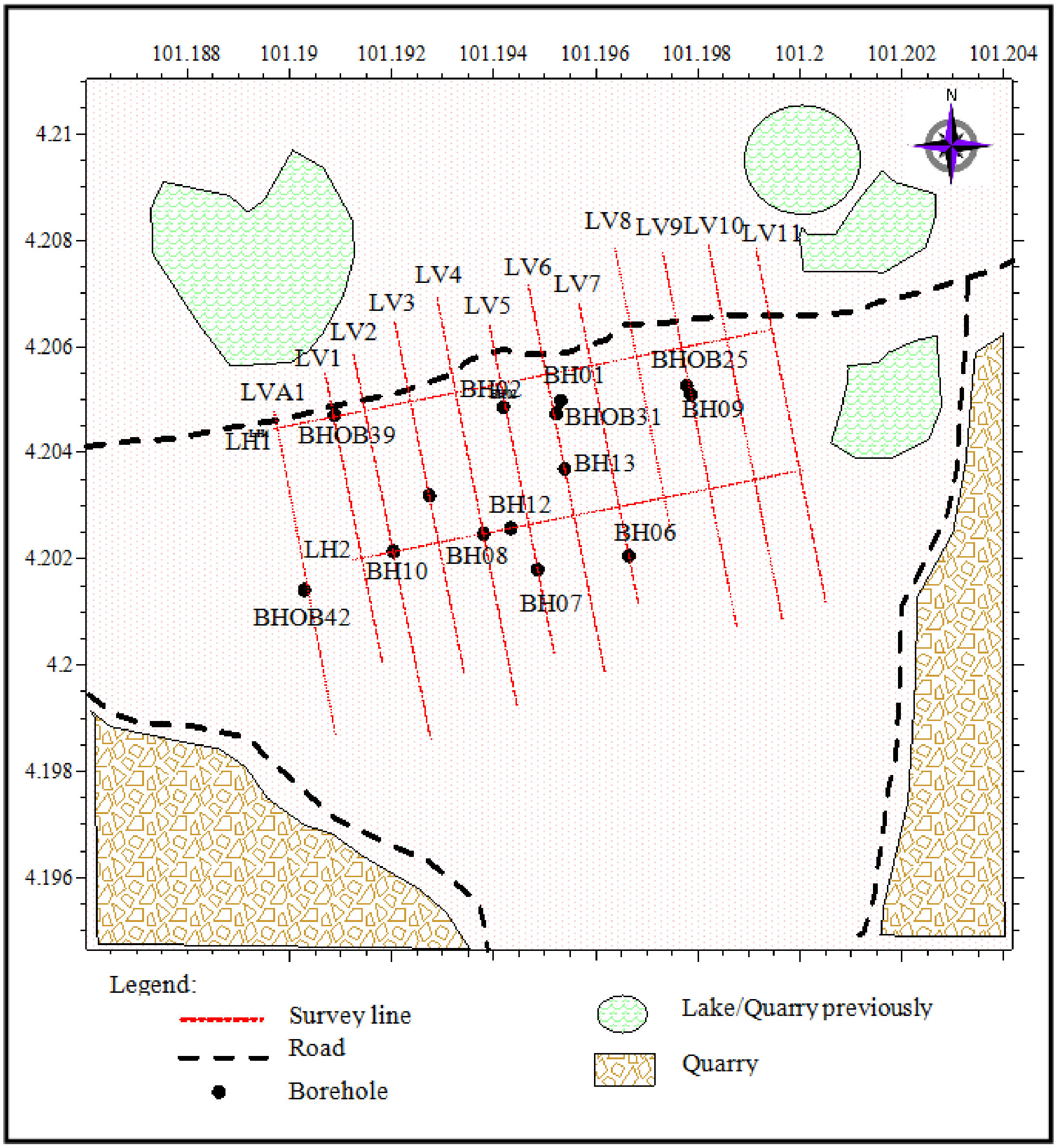

Figure 3: 2-DERI survey lines with boreholes at study area in Tapah, Malaysia.

RESULTS AND DISCUSSION

This study has 14-survey lines, but the results will show two lines only for interpretation examples. The others result will be shown in general for bedrock formation mapping.

Figure 4 shows the inversion model of resistivity for line LV1 with penetration depth of 80 m consists of two main layers. The length of the line LV1 is 800 m with ground surface elevation is 28-38 m and crossed borehole BHOB39 at a distance of 200 m. The first layer is classified as saturated / conductive layer with resistivity value of <250 Ohm.m and interpreted as sandy clay.

The second layer was interpreted as limestone with resistivity value of >350 Ohm.m. The borehole point, indicate an interface between the two layer is at depth of 26.9 m with resistivity value of 350 Ohm.m. Karst features (Pinnacles, boulders and fill cavities) are detected.

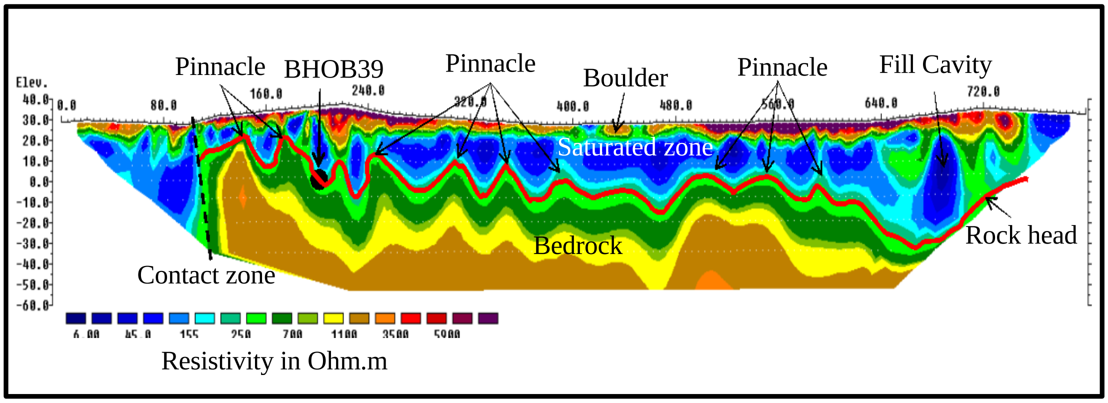

Figure 4: 2-DERI inversion model of line LV1 and borehole BHOB39 at 200 m.

The Figure 5 shows the inversion model of line LV3 and correlation with BH11. The borehole point is located at the distance of 400 m with elevation of 30.2 m and detected of rockhead is at depth of 18 m. The LV3 has depth penetration of 80 m and consists of two main layers. The first layer is saturated zone with resistivity value of <50 ohm.m was interpreted as alluvium. The second layer was interpreted as limestone bedrock with resistivity value of >63 ohm.m. Karst features (Pinnacles, boulders and fill cavities) are detected. The cavity is spotted at distance of 190 m and depth of 24 m.

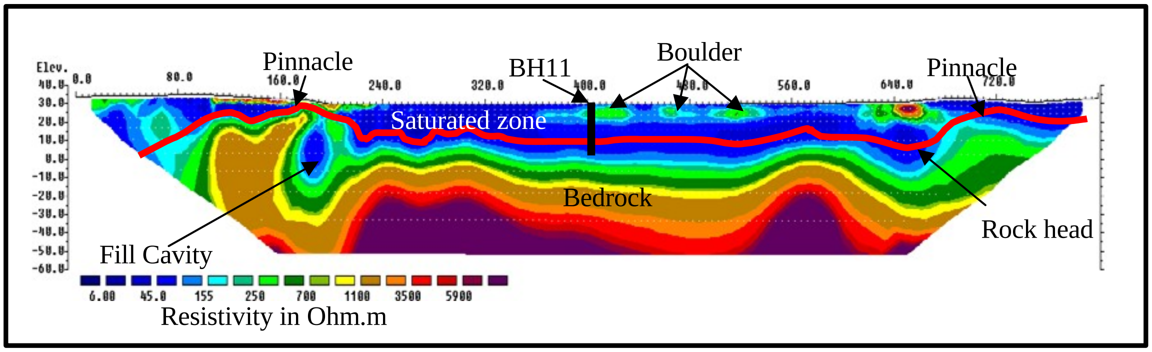

Figure 5: 2-DERI inversion model of line LV3 and borehole BH11 at 400 m.

The result of the survey lines were interpreted as the same as line LV1 and LV3. The rockhead of all the survey lines are digitized and processed using software Surfer8 to produce 3-D rockhead map. Figure 6 shows the 3-D rockhead map of limestone for the survey area with a lot of pinnacles identified.

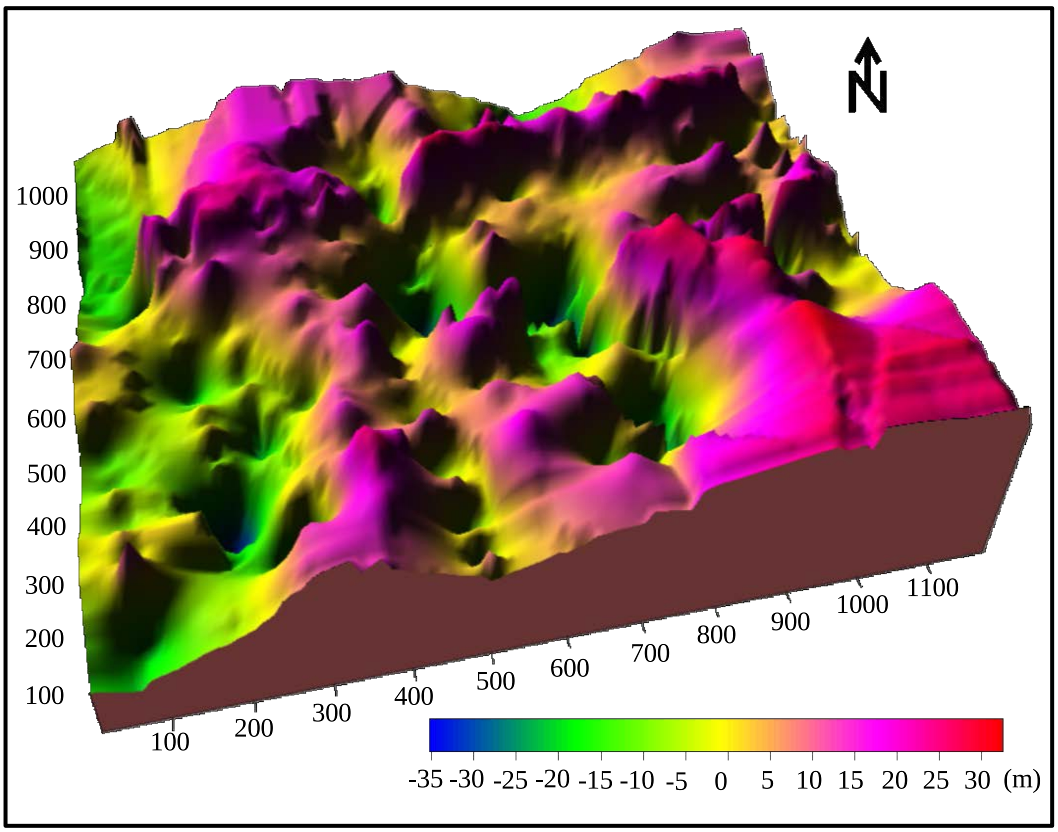

Figure 6: Bedrock formation in study area

CONCLUSION

The 2-DERI method is successfully determine the soft and hard layers at various depths and positions including the karst features: fill cavities, boulders and pinnacles. The soft layer with resistivity values of <250 Ohm.m which is not suitable for piling foundation while the hard layer with resistivity values of >350 Ohm.m is good for piling foundation. The study is capable to map the rockhead features of the study area.

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