Identifying Resistivity Anomalies of Sungai Batu Ancient River using 3D Contour Map

R. Yusoh¹, R Saad¹, M Saidin², S B Muhammad¹, S T Anda¹,², M A M Ismail³ and Z A M Hazreek⁴

¹ Geophysics Section, School of Physics, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia  
² Centre for Global Archeological Research, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia  
³ School of Civil Engineering, University Science Malaysia, Engineering Campus,  
14300 Nibong Tebal, Malaysia  
⁴ Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor  
⁵ Department of Physics, Usmanu Danfodiyo University, Sokoto, PMB 2346 Sokoto, Nigeria  
⁶ Department of Engineering Geophysics, Syiah Kuala University, Banda Aceh, Indonesia

E- mail: raisyusoh@gmail.com

Abstract. Electrical resistivity method was undertaken at archeological site at Sungai Batu in Lembah Bujang, located at Sungai Merbok in northwestern of Malaysia. The survey was implemented near the excavation site. This paper shows the results of 5 ground resistivity survey line was carry out using SAS4000 equipment. The wenner-schlumberger array was applied for measurement. Resistivity data are used to obtain valuable information to identify the remain buried archeology. The ground resistivity data were presented in contour map for various depth by using Surfer 13 software visualized clearly the anomalies evidenced for every single depth section. The results from the survey has found the appearance of sedimentation formation that believe happen long time ago after ancient river was buried by sediment from weathering process due to increasing sea level. Otherwise, another anomaly was found in the middle of the survey area which shows high resistivity value about 1000 – 2000 ohm.m

1. Introduction

Sungai Batu area located in Lembah Bujang district, have revealed iron smelting sites, jetty remains and clay brick monument which believed to be dated before 110AD. It was recorded as the oldest man-made structure in Southeast Asia [1]. These makes archeologist interest in exploring Sungai Batu area and excavation has been made base on existing ancient monument which is still fixated on the surface. However, they believe that there are some other ancients monument buried in the ground which is difficult to locate with random excavate. Conventional method applied for archeology study provide limited information and sometimes no clue on unexcavated subsurface archeological aspect [2]. Nevertheless, researchers have found that geophysical method can be associated with geo-archeological investigation and it has changed the scientific approaches toward archeological study [3].

An application of geophysics for archeology study start from early 1950’s. With evolution of technology, geophysical method becoming more reliable for investigative tools. Geophysical approach allows the physical parameters of subsurface to be mapped in large-scale of exploration area. In some cases, geophysical survey can provide useful information on shape and depth of buried structures and
provide subsurface formation which related to ancient river. The most commonly applied geophysical method is ground resistivity method which provide specific electrical resistivity of subsurface material. The method is suitable in detecting buried structure, cavities and other structures at differing depth [4;5;6;7;8].

The exploration of intensive geophysical field surveys was implemented with the objective of exploring the buried ancient river and ancient structure of Lembah Bujang civilization. The outcome of the ground resistivity exploration was prepared to help archeologists for further excavation and identifying previous excavated site yet contained reasonable buried structure.

The next sections represent detail study area including geological aspect, methodology, data processing, 2-D pseudo section of contoured resistivity data and anomaly source as focused by 3-dimensional contoured map based on archeological significance.

2. Study Area

Study area was located at Sungai Batu, Kedah (Malaysia) which considered by archeologists as a historical area with sign of civilization. The area situated in Lembah Bujang district near Merbok in northwestern Peninsular Malaysia. Researche on Sungai Batu civilization increases and it was proven that the area was a religious center in the country and earliest entrepot. Sungai Batu role has been discovered from the archeological evidence with the existing of statues, Hindu-Buddhist temple, beads, and porcelain [9;10]

The study area was situated in sungai Batu area near Sungai Merbok and Gunung Jerai. Gunung Jerai is made up of two rock types which is sedimentary rocks and granite (western region). The sedimentary rock of Gunung Jerai was formed from Cambrian Age, consists of sandstone or metasandstone with mixture of siltstone, shale and minor conglomerate (Figure 1). Mid-south of Kedah was documented as marine soil area in the first and second century. The area was changed to be flat landed area in the year of 1400 since the sea level was rise [11]. The lithology of the area is sandy clay covered with fine sand. The sediment was carried from the river flow and deposited around this area. Now, the topography of the study area was flat landed fill with palm oil and rubber tree. There are few swamp and small river located at the eastern part of the area.
3. Methodology

Ground resistivity originally started in 1920’s discovered by Schlumberger brothers, with basic measurement of four electrodes in measuring one point of data. After 60 years, this method has been modified to increase computable interpretation, and sounding survey [13]. Further enhancement of this method was found [14], where a multi-electrode resistivity equipment has been invented, combining with a new creation of inversion software for 2-D resistivity survey interpretation [15]. The used of 2-D resistivity method is to visualize the subsurface pseudo-section where the true resistivity is predicted by measuring on the ground surface [16]. Ground resistivity basic theory remains the same since 1920’s which measures the electrical potential contrast at specific locations while injecting a specific arrangement of electric current at other locations [17]. Usually, the 2-D resistivity method apply about 25 to 100 of electrodes, laid on a straight line with constant spacing. To produce a better 2-D picture of subsurface, the coverage of the data point must be on 2-D as well. Figure 2 shows the possible outcome of evaluation for the Wenner electrode array for an arrangement of 20 electrodes. Electrode 1, 2, 3, and 4 was used as the first measurement which electrode 1 and 4 was used as current source C1 and C2 followed by electrode 2 and 3 used as potential electrode P1 and P2. The next measurement continues by selecting electrode 2, 3, 4, and 5 used for C1, P1, P2 and C2. The process was repeated until electrode 17, 18, 19 and 20. After completing the sequence, the spacing of measurement increasing multiplier by 2 which increasing depth penetration by using electrode 1, 3, 5 and 7 followed by next measurement using electrode 2, 4, 6 and 8 until electrodes 14, 16, 18 and 20. The processed continue by increasing the spacing multiplier until maximum spacing can reach. All the measurement was controlled by a computer-controlled system which automatically select an active electrode for measurement.
Figure 2. The establishment of electrodes for a 2D electrical resistivity survey and the sequence of measurements used to build up a pseudosection [17].

The ground resistivity method measures resistivity value of the subsurface materials. Table 1 shows resistivity values of common rocks and soil materials [18]. Usually, Igneous and metamorphic rocks indicate high resistivity values. The resistivity value of these rocks mainly based on of fracturing level and water content. Generally, water table in Malaysia is shallow, and fractures are filled with water which effect the resistivity value of rock to reduce. The higher the fracturing, resistivity value of the rock will become lower. Soils above the water level are usually drier and indicate higher resistivity value, while soils below the water table generally have resistivity values of less than 100 Ωm.

Table 1: Resistivity values of common rocks and soil materials in survey area (Keller and Frischnecht, 1966).

| Material             | Resistivity (Ωm) |
|----------------------|------------------|
| Alluvium             | 10 to 800        |
| Sand                 | 60 to 1000       |
| Clay                 | 1 to 100         |
| Groundwater (fresh)  | 10 to 100        |
| Sandstone            | 8 - 4 x 10³      |
| Shale                | 20 - 2 x 10³     |
| Limestone            | 50 - 4 x 10³     |

The study located at Sungai Batu, Kedah (Malaysia) which localized at 5.697099°N, 100.449495°E to 5.695385°N, 100.451504°E (Figure 3). Ground resistivity measurements were performed using multielectrode resistivity meter system (ABEM Terrameter SAS 4000 system) with wenner-schlumber array to investigate the hydrogeological conditions. Five ground resistivity survey lines was conducted which L1-L4 were 150 m long each and L5 was 100 m long. Each length survey line is pegged with 51 stainless steel electrodes for 150 m long and 41 stainless steel electrodes for 100 m long at 2.5 m spacing. The connecting cable (jumper) was used to connect the electrode with the cable take-out. To obtained high-quality electrical resistivity measurements, the resistance between the soil and electrode was measured to check if the contacts were reliable and consistence. The current was set between 1 to 50 mA. A computer-controlled system was used to automatically select the active electrodes.
The data was processed using res2Dinv software to produce inversion models of actual subsurface structure [16; 19; 20; 21]. Least-squares inversion technique was applied to reduce measured resistivity to apparent resistivity values. The inversion routine utilized by the software was based on the standard constrained technique that attempts to minimize the square of the difference between the observed and calculated apparent resistivity values. The apparent resistivity from which pseudo sections were developed and subsequently inverted to true resistivity 2-D section (Figure 4).

A 3D contour maps were developed from the processed resistivity data using Surfer 13 software and presented in depth slices for interpretation based on the resistivity table (Table 1).
4. Results and Discussion
Figure 5 shows resistivity inversion model of L1 – L5 with max penetration depth of 38 m and resistivity value of 0 – 3000 ohm.m. Generally, they are classified into two main resistivity values which is >300 ohm.m located at the top and bottom of all the sections, and <300 ohm.m which located all in the middle of the section. The top section interpreted as dry and low conductance while the bottom section is interpreted as original ground [11]. The middle section interpreted as saturated soil (clay/sandy clay).
Figure 5. 2-D resistivity inversion model; (a) L1, (b) L2, (c) L3, (d) L4 and (e) L5.

Figure 6 shows a 3-D section of line L1-L5 which slices into depth section. Literally the resistivity of Sungai Batu river can be seen on Figure 5a – 5c with depth up to 2.774 m and resistivity value of <300 ohm.m. The resistivity value of >300 ohm.m is identified as dry & low conductance soil cover the area up to 5.509 m depth. Starting at depth of 7.086 m, the Sungai Batu ancient river start to appear and it grow wide up to >100 m with increasing depth up to 26.917 m.
Figure 6. 3-D resistivity section of Sungai Batu slices for various depth of; (a) 0 m, (b) 2.774 m, (c) 4.076 m, (d) 5.09 m, (e) 7.086 m, (f) 10.727 m, (g) 15.133 m, (h) 20.464 m, (i) 26.915 m, (j) 30.632 m.
5. Conclusion

Ground geophysical technique of resistivity are widely used for various application, including environmental studies (e.g. oil spills), groundwater exploration in finding aquifer, lithology variation and archeological exploration [22;23;24]. However, the accuracy and effectiveness of these techniques in site exploration are based on ancillary data (geological data) which are enhanced when integrated together which define the aim of investigation. Therefore, to enhance the target interpretation, the physical signature must be acquired in investigation to increase prediction.

For this study, the 3D contour map gives a significant homogeneous data which give better visualization when the interpretation was made for each depth. With help of ground resistivity study and extracted out using 3D contour map technique, the ancient river is almost visible. From the result obtain can finalized that the the ancient river was buried about 7 – 8 m depth below ground level and the depth of ancient river was about 17 – 19 m deep which is possible that the Lembah Bujang was known as the largest port in Kedah long time ago. Results also found some unknown anomaly at the middle of study area where the length of the unknown object was about 9 m and 5 m width. The buried object need to be confirmed by further research by focusing on it and the coverage area of study need to be widen where from the results obtain gives narrow coverage area and it is hard to identify the riverbank.

Acknowledgement

The authors would like to thank Center for Global Archeological Research (CGAR) for funding this research with an account of 1002/PARKEO/910328, USM geophysics staff and postgraduate students for their effort during the data acquisition.

References

[1] Razak A F, Said M A M, and Yusoh R 2015 Riverbank filtration site suitability selection using spatial data techniques: case study for Kota Lama Kiri, Kuala Kangsar Applied Mechanics and Materials 802 p 557-562

[2] Joachim S 2015 Origin of man in Southeast Asia, Volume 5, Part 2: Hindu temple in the Malay Peninsula and archipelago Phnom Penh

[3] Renfrew C and Bahn P 1996 Archeology: theories, methods, and practice Thames and Hudson, London

[4] Saad R, Saidin M, Fauzi A and Tarmizi H 2015 Identify Sungai Batu Ancient River by magnetic method Electroni Journal of Geotechnical Engineering 20(18) p 11143-11148

[5] Ullrich B, Gunther T and Rucker C 2007 Electrical resistivity tomography methods for archaeological prospection Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA) Berlin, Germany 35 p 1-7

[6] Gaffney 2008 Detecting trends in the prediction of the buried past: a review of geophysical techniques in archeology Archaeometry 50(2) p. 313-336

[7] Leopold M, Plockl T, Forstenaicher G and Volkel J 2010 Integrating pedological and geophysical methods to enhance the effectiveness of archeological prospection: the example of Roman villa rustica near Regensburg, Germany Archeological Science 37(7) p 1731-1741
Leopold M, Gannaway E, Volkel J, Haas F, Becht M, Sheekmann T, Kuswestphal M and Zimmer G 2011 Geophysical prospection of a bronze foundry on the southern slope of the acropolis at Athens, Greece *Archaeological prospection* 18 p 27–41

Thacker P T and Ellwood B B 2002 Detecting Paleolithic activity areas through electrical resistivity survey: an assessment from Vale de Obidos, Portugal *Journal of Archaeological Science* 29 p 563-570

Wales Q H 1970 Malayan archaeology of the "Hindu Period": Some reconsiderations *Journal of the Malaysian Branch of the Royal Asiatic Society* 43 p 1-34.

Rahman, H S N A 2008 Lembah Bujang: Dari Perspektif Arkeologi dan Pelancongan (Lembah Bujang: From Archaeological and Tourism Perspective) *Institut Alam dan Tamadun Melayu*, Universiti Kebangsaan Malaysia ISBN: 9834141858.

Wheatley P 1961 “The Golden Kherosonese. Kuala Lumpur” *University of Malaya Press*

Jabatan Mineral Dan Geosains 2012 Geological Map of Peninsular Malaysia: Modified based on the 8th edition, 1985 *Director-General of Minerals and Geoscience Malaysia*

Koeofoed O 1979 Geosounding Principles 1: Resistivity sounding measurements *Elsevier science publishing company, Amsterdam.*

Griffiths D, Turnbull J and Olayinka A (1990) Two-Dimensional resistivity mapping with a computer-controlled array *First Break* 8(4) p 121–129.

Loke M H 1994 The inversion of two-dimensional resistivity data *Unpublished Ph.D. Thesis School of Earth Sciences, University of Birmingham.*

Loke M H, Acworth A and Dahlin T 2003 A comparison of smooth and blocky inversion methods in 2d electrical imaging surveys *Exploration Geophysics* 34 p 182-187.

Loke M H 2000 Electrical imaging surveys for environmental and engineering studies *Sundbyberg Sweden: ABEM*

Keller G V and Frischknecht F C 1966 Electrical methods in geophysical prospecting *Pergamon Press Inc., Oxford.*

Asry Z, Samsudin A R, Yaacob, W Z and Yaakub J 2012 Groundwater investigation using resistivity imaging technique at Sg. Udang, Melaka, Malaysia *Bulletin of the Geological Society of Malaysia* 58 p 55-58.

Ratmakumari Y, Rai S N, Thiagarajan S and Kumar D 2012 2D electrical resistivity imaging for delineation of deeper aquifers in a part of the chandrabhaga river basin, Nagpur District, Maharashtra, India *Current Science* 102(1) p 61-69.

Rai S N, Thiagarajan S, Shankar G B K, Kumar M S, Venkatesam V, Mahesh, G. Rangarajan, R., (2015). Groundwater Prospecting in Deccan Traps Covered Tawarja Basin Using Electrical Resistivity Tomography. *Journal of the Indian Geophysical Union*, 19(3), pp 256-269.
[22] Yusoh R, Said M M A, Ismail M A M and Razak M F A 2015 Subsurface Characterization Using Ground and Underwater Resistivity Techniques for Groundwater Abstraction Applied Mechanics and Materials 802 p 629-633

[23] Saad R, Saidin M M, Muztaza N M, Ismail N A and Ismail N E H 2011 Subsurface Study Using 2-D Resistivity Imaging Method for Meteorite Impact at Bukit Bunuh, Perak Electronic Journal of Geotechnical Engineering 16 p 1507-1513

[24] Saad R, Saidin M M, Muztaza N M, Ismail N A and Ismail N E H 2011 Subsurface Study Using 2-D Resistivity Imaging Method for Meteorite Impact at Bukit Bunuh, Perak Electronic Journal of Geotechnical Engineering 16 p 1507-1513