Visualizing Sungai Batu Ancient River, Lembah Bujang
Archeology Site, Kedah – Malaysia using 3-D Resistivity Imaging

R. Yusoh\textsuperscript{1}, R Saad\textsuperscript{1}, M Saidin\textsuperscript{2}, S B Muhammad\textsuperscript{1,4}, S T Anda\textsuperscript{1,3}, M. A. M Ashraf\textsuperscript{6} and Z A M Hazreek\textsuperscript{6}

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

E- mail: raisyusoh@gmail.com

Abstract. Sungai Batu at lembah bujang has become an interest spot for archeologist since it was discover as earliest entrepot in history of Malaysia. It is believe that there was a large lost river near the ancient jetty remain. Ground resistivity method was implement with large coverage area to locate the ancient river direction. Eleven ground resistivity survey line was carry out using SAS4000 equipment and wenner-schlumberger array was applied for measurement. Ground resistivity method was used to detect the alluvial deposit made by the ancient river deposition. The ground resistivity data were produce in 2D image and presented in 3D contour map for various selected depth by using Rockwork 15 and Surfer 8 software to visualize the alluvial deposits area. The results from the survey has found the appearance of sedimentation formation due to low resistivity value (0 – 330 ohm.m) was found near the existing river. However, the width of alluvial deposition was 1400 m which too wide for river width unless it was a deposition happen form age to age by movement of river meander. It’s conclude that the river was still at the same direction and its direction was change due to sediment dumping factor waking it shifting to the east.

1. Introduction
Lembah Bujang was known as a popular religious center and one of the earliest entrepot in the history of Malaysia [1]. Various series of archeological excavation activities have taken place near the Sungai Batu, Lembah Bujang – Kedah, has found an iron smelting sites, jetty remain and a clay brick monument were uncovered and preserved which believe dating back to 110 AD. Archeologists concluded that a large and deep river stream have existed near the jetty remain to serve as a main water transportation in those days, which has probably been buried by sedimentation due to a number of factors such as topography changes, weathering processes, flooding, rise and fall in sea level and so on. This buried river is called Ancient River by the archeologist and still being searched upon by various techniques. Recent developments using geophysical techniques as alternatives in archeological investigations which have revolutionized archeological researches since 20th century.
Geophysical approach allows the physical parameters of the subsurface to be measured, analyses of which results in a large-scale mapping of the subsurface for exploration surveys. In some cases, geophysical survey can provide useful information on the shape, size and the depth of buried structures and may help in detecting subsurface formations which can be related to the ancient river. One of the most commonly applied geophysical techniques is the ground resistivity method, which provides the measurement of the specific electrical resistance of subsurface material. This method has so far been proven to be a useful technique suitable for detecting buried structures, cavities and other structures at differing depths [2;3;4;5;6]. This study has thus applied ground resistivity method on site with the sole objective of exploring the buried ancient river of the Lembah Bujang civilization. The outcome of this study will help archeologists for further understanding of the nature and location of the buried ancient river stream.

2. Geology of Study Area
The study area is situated near Sungai Merbok and Gunung Jerai, north – western Malaysia. Gunung Jerai is made up of two rock types which are sedimentary rocks and granite (western region). The sedimentary rock of Gunung Jerai was formed in the Cambrian Age, it consists of sandstone or metasandstone with mixed siltstone, shale and minor conglomerate (Figure 1). The map also shows that the mid-south of Kedah was documented as marine soil area in first and second century. The area was changed to be flat landed area in year 1400 since the sea level rise [7]. The lithology types of the area are sandy clay covered with fine sand. The sediment was carried by the river stream and deposited around this area. At present, the topography of the study area is flat landed, mostly covered by palm and rubber trees. There are a few swamps and a small river located at the eastern part of the area.
3. Theory of Ground Resistivity Method

Ground resistivity method, originally started in 1920’s, was discovered by Schlumberger brothers. It basically requires four electrodes for one datum measurement. After 60 years, [9] modified this method to increase computable interpretation and sounding survey. Further enhancement of this method was conducted by Griffiths [10], who invented multi-electrode resistivity equipment followed by the creation of new inversion software to convert apparent resistivity measurements in to subsurface resistivity model sections by [11].
Generally, ground resistivity method measures the electrical potential contrast at specific locations after injecting a specific amount of electric current [12]. Usually, about 25 to 100 electrodes are laid on a straight line at constant spacing. A computer-controlled system is then used to automatically select the active electrodes for each measurement.

Table 1 shows the resistivity values of common rocks and soil materials [13]. Usually, Igneous and metamorphic rocks have high resistivity values. They can however sometimes have relatively lower values depending on their degree of fracture and saturation, especially for the fact that water table in Malaysia is shallow. Soils above the water level are usually drier and give higher resistivity values compared to soils below it whose resistivity values can go to as low as 100 Ωm or even less.

Table 1. Resistivity values of common rocks and soil materials in survey area [13].

| Material         | Resistivity (Ωm) |
|------------------|------------------|
| Alluvium         | 10 to 800        |
| Sand             | 60 to1000        |
| Clay             | 1 to 100         |
| Groundwater (fresh) | 10 to 100     |
| Sandstone        | 8 - 4 x 10³     |
| Shale            | 20 - 2 x 10³    |
| Limestone        | 50 – 4 x 103    |
| Granite          | 5000 to 1,000,000|

4. Ground Resistivity Method Survey Planning

Study area is located at Sungai Batu, precisely in range 5.703341° N, 100.439958°E to 5.684240°N, 100.461379°E (Figure 2). Ground resistivity method was conducted using multi electrode resistivity meter (ABEM Terrameter SAS4000 instrument) to measure the subsurface resistivity along eleven survey lines of different length and spacing depending accessibility (Figure 2). All eleven lines were distributed uniformly in the study area to get a consistent data measurement. Each line has different number of spread, and the spreads were overlaid at half their lengths to minimize blanking due to the prism shape effect of section measurements. Every spread was pegged with 61 stainless steel electrodes connected to the cable take – out using jumper. The resistance between the soil and electrode was measured to check if the contacts were reliable and steady to obtain high-quality electrical resistivity measurements. The current was set between 1 mA to 100 mA. A computer-controlled system Terrameter SAS4000 was used to automatically select the active electrodes for each measurement. The pole – dipole array protocol was applied for both long and short arrangements; the short being for the normal electrode spacing and the long for a double of the spacing.
5. 2D and 3D Resistivity Image Processing

In order to obtain the resistivity model section that approximates the actual subsurface, RES2DINV software was used to process the apparent resistivity field data [14]. The processing started with downloading the raw data from ABEM Terrameter SAS 4000 instrument and converting it to .DAT format file extension. The least-squares inversion was then applied to estimate the true subsurface resistivity from the measured 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 of the model section (Figure 3, 4 and 5).
Figure 3. Pseudo section of ground resistivity image. a) 2D image for survey Line 1; b) Line 2; c) Line 3; and d) Line 4.

Figure 4. Pseudo section of ground resistivity image. a) 2D image for survey Line 5; b) Line 6; c) Line 7; and d) Line 8.
Figure 5. Pseudo section of ground resistivity image. a) 2D image for survey Line 9; b) Line 10; and c) Line 11.

All eleven ground resistivity pseudo sections need to be georeferenced so that each data point of true resistivity created from inversion can be assigned with its coordinate. Coordinate of each resistivity data point was digitized based on WGS1984 coordination grid and reassembled thereafter as X – axis: Easting, Y-axis: northing, Z-axis: depth including resistivity value. The 3D resistivity model was then produced using Rockwork 15 software. In the process of creating the 3D solid model, closet point gridding was used, because this type of modeling is best suited for data that is not gradational (mix type of rock/soil). Smoothing option was applied to reduce “noise” within the solid model thereby emphasizing the regional trends. The smoothening process was controlled by using only one iteration in order to maintain originality of the data. High-fidelity has also been applied before the 3D modeling process to act as control to reduce smoothness effect. Figure 6 shows the 3D solid model as iso-surface diagram.
6. Results and Discussion

The resistivity values were extracted at every 3 – meter depth from the 3D resistivity model to visualize it in detail. Resistivity values at depths of 0 m, 3 m, 6 m, 9 m, 12 m, 15 m, 18 m, 21 m, 24 m, 27 m, 30 m and 33 m were extracted, gridded and contoured in to 2D maps using Surfer 10 software. Figure 7 and 8 shows the contour maps of resistivity. In order to detect the ancient river from the contour map, the resistivity contour values of the sediment materials were categorized on the basis of composition; sand, silt and clay, and color level was assigned using medium cold colours of blue and green to represent electrical resistivity value of 0 – 330 ohm.m.

It was observed that the resistivity value shows continuous and consistent contour values range until a depth of about 33 m from the surface. Figures 7(a) – 7(f) shows contour maps of resistivity from depth at 0 m – 15 m and Figures 8(a) – 8(f) at depth of 18 m – 33 m. The existing river was drawn on each contour map as a reference from topography. Figures 7 and 8 identifies three resistivity zones, Low (0-50 ohm.m), medium (50-330 ohm.m) and high (330-6000 ohm). The images show low to medium resistivity values (0 – 330 ohm.m) at the middle area, while the rest are higher than 330 ohm.m. The low resistivity zone started to disappear at 12 m depth and disappeared completely at 33 m. The medium resistivity zone has the average width of 1400m at the middle area and start to decrease until 200 m at depth of 33 m.
Figure 7. Resistivity contour map extracted for 3D resistivity model at Sungai Batu. a) contour map for depth of 0 m; b) 3 m; c) 6 m; d) 9 m; e) 12 m; and f) 15 m.
Figure 8. Resistivity contour map extracted for 3D resistivity model at Sungai Batu. a) contour map for depth of 18m; b) 21 m; c) 24 m; d) 27 m; e) 30 m; and f) 33 m.

The result indicates large alluvial soil at the middle area (resistivity value 0-330 ohm.m) where it continued to disappear at every change in depth. If this result is related to the suspected ancient river, the river then keeps changing from years to years. The existing river has maximum width of 200 – 300 m exactly at the location where the result shows the alluvium deposit width was about 1400 m. It is therefore obvious to say that it is almost impossible that the river was 1400 m wide. But then, this can happen owing to the fact that river flow keeps changing and moving towards the area where the deposit was spread around. The flow of Ancient River was from north to south in continuation with the existing river as original ground [11]. The middle section interpreted as saturated soil (clay/sandy clay).

7. Conclusion
The use of ground resistivity method has become an ease to evaluate the earth subsurface and even it is reliable in archeological exploration. The 3D resistivity image visualization can become a dependable method to increase the understanding of subsurface strata or anomaly existence. Result of 3D resistivity image at Sungai Batu, Lembah Bujang site area has visualize the ancient river existence referred to resistivity value which based on river deposition lithology. The suspected of ancient river has conclude the width of river bed should be similar to existing river about 200 - 300 m and due to
river meander change by age make the sediment deposit more wider. It is proven that, the ancient river were still below the existing river with just a bit shifting to the east.

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References
[1] Nordiana M M and Saad R 2014 Archeomagnetic Studies of Anomaly at Sungai Batu, Lembah Bujang, Kedah (Malaysia) Research Paper Universiti Sains Malaysia.
[2] 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
[3] Gaffney 2008 Detecting trends in the prediction of the buried past: a review of geophysical techniques in archeology Archaeometry 50(2) p 313-336
[4] Leopold M, Plochl 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
[5] Leopold M, Gannaway E, Volkel J, Haas F, Becht M, Scheckmann 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
[6] 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
[7] Wheatley P 1961 The Golden Kherosonese. Kuala Lumpur University of Malaya Press
[8] Jabatan Mineral Dan Geosains 2012 Geological Map of Peninsular Malaysia: Modified based on the 8th edition, 1985 Director-General of Minerals and Geoscience Malaysia
[9] Koefoed O 1979 Geosounding Principles 1: Resistivity sounding measurements Elsevier Science publishing company, Amsterdam.
[10] Griffiths D, Turnbull J and Olayinka A 1990 Two-Dimensional resistivity mapping with a computer-controlled array First Break 8(4) p 121–129
[11] Loke M H 1994 The inversion of two-dimensional resistivity data Unpublished Ph.D. Thesis School of Earth Sciences, University of Birmingham.
[12] Loke M H 2000 Electrical imaging surveys for environmental and engineering studies Sundbyberg Sweden: ABEM.
[13] Keller G V and Frischknecht F C 1996) Electrical methods in geophysical prospecting Pergamon Press Inc., Oxford.
[14] 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.