CHARACTERIZATION OF SUNGAI BATU ANCIENT RIVER SYSTEM BY INTEGRATED GEOPHYSICAL TECHNIQUE

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CHARACTERIZATION OF SUNGAI BATU ANCIENT RIVER SYSTEM BY INTEGRATED GEOPHYSICAL TECHNIQUE

by

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LIST OF SYMBOLS

ρ	Density
ε	Electric conductivity
μ	Shear modulus
ρ_a	Apparent resistivity
E	Elastic coefficients
G	Rigidity modulus
h	Thickness
Hz	Hertz
I	Current
K	Bulk modulus
k	Geometric factor
km	kilometer
km^2	Kilometer square
L	Length
m	Meter
m/s	Unit meter per second
r	Distance between the current electrodes
R	Resistance
R^2	Regression
t	Time
t_i	Intercept time
V	Potential
v	Velocity
x_{co}	Crossover distance
θ_i	Refraction angle
θ_{ic}	Incidence critical angle
Ω	Ohm
Ω.m	Ohm meter

LIST OF ABBREVIATIONS

1-D	One Dimensional
2-D	Two Dimensional
3-D	Three Dimensional
BH	Borehole
C	Current Electrode
CE	Common Era
CGAR	Centre for Global Archaeological Research (CGAR)
CPT	Cone Penetration Test
DC	Direct current
E	East
EM	Electromagnetic
ERI	Electrical Resistivity Imaging
ES	Electrode Selector
FDEM	Frequency Domain Electromagnetic
GPR	Ground Penetrating Radar
GPS	Global Positioning System
IP	Induce Polarization
N	North
NW-SE	North West-South East
NW-SW	North West-South West
P	Potential Electrode
P-wave	Primary wave
RES2DINV	Resistivity 2-D Inversion software
S	South
SAS4000	Signal Averaging System 4000
SH	Secondary Horizontal
SPT	Standard Penetration Test
SV	Secondary Vertical
S-wave	Secondary wave
TEM	Transient Electromagnetic Method
USM	Universiti Sains Malaysia
W	West

PENCIRIAN SISTEM SUNGAI KUNO MENGGUNAKAN TEKNIK INTEGRASI GEOFIZIK DI KAWASAN SUNGAI BATU

ABSTRAK

Tahun 2007 Pusat Penyelidikan Arkeologi Global (PPAG) Universiti Sains Malaysia menemukan adanya peninggalan sejarah yang terletak di kawasan Sungai Batu, Kedah. Berdasarkan hasil penggalian, diketahui bahawa Sungai Batu merupakan tamadun tertua yang ada di Asia Tenggara. Hal ini mencetus ahli arkeologi untuk memperluaskan kawasan penggalian kaedah percubaan dengan menjalankan penggalian secara rawak boleh memakan masa, gagal menemukan objek yang tertanam dan akan merosakkan bukti peninggalan sejarah. Kajian ini menggunakan kaedah pengimejan keberintangan 2-D dan seismik pembiasan untuk menentukan dan mengesahkan nilai keberintangan dan halaju Sungai Batu dan mencirikan profil geologi dan geomorfologi sistem sungai kuno di kawasan Sungai Batu. Sebanyak tiga puluh garisan tinjauan pengimejan keberintangan 2-D menggunakan susun atur Pole-Dipole bagi mendapatkan penembusan kedalaman maksimum dan sembilan garis tinjauan seismik pembiasan telah dijalankan di kawasan kajian. Empat daripada garisan telah dihubungkait dan disahkan dengan lubang gerudi yang sedia ada untuk mengenal pasti jenis di kawasan sekitar. Nilai pengesahan digunakan untuk baki garis tinjauan yang tiada rekod lubang gerudi untuk memetakan subpermukaan kawasan kajian. Berdasarkan hasil kajian, kawasan Sungai Batu terdiri daripada tanah lempung dengan nilai keberintangan 7-26 Ω.m dan nilai halaju 717-1607 m/s; tanah lempung berpasir dengan nilai keberintangan 6-

265 Ω.m dan nilai halaju 1004-1901 m/s dan batuan dasar/lapisan keras telah dikenal pasti dengan nilai keberintangan lebih daripada 669 Ω.m dan nilai halaju lebih daripada 2052 m/s. Sempadan antara lempung/lempung berpasir dengan syal telah dikesan dengan nilai keberintangan 314 Ω.m dan nilai halaju 1822 m/s. Profil geologi dan geomorfologi subpermukaan di kawasan Sungai Batu dicirikan oleh ketebalan alluvium kini (lempung dan lempung berpasir) dan topografi batuan dasar. Sungai kuno disyaki mengalir dari arah utara ke barat daya, di mana terletaknya pantai. Di bahagian timur kawasan kajian menunjukkan sungai mengalir dan sebahagian kecilnya dari saluran asal untuk menghasilkan tasik ladam. Saiz dan bentuk sungai kuno telah berubah secara beransur-ansur menjadi sungai yang kini dikenali sebagai Sungai Batu.

CHARACTERIZATION OF SUNGAI BATU ANCIENT RIVER SYSTEM BY INTEGRATED GEOPHYSICAL TECHNIQUE

ABSTRACT

In 2007, the Centre for Global Archaeological Research (CGAR) Universiti Sains Malaysia (USM) has discovered existence historical object in Sungai Batu, Kedah. Based on excavation result, known that Sungai Batu was declare as an early civilization in Southeast Asia. This triggering archaeologist to extend the excavation site. Try and error methods by excavate random area is time consuming, failure to find buried object and can disturb the historical evidence. This study used 2-D resistivity imaging and seismic refraction methods to determine and validate the resistivity and velocity value at Sungai Batu and to identify and characterize subsurface geology and geomorphology profile Sungai Batu ancient river system. A total of thirty, 2-D resistivity imaging survey lines using Pole-Dipole array for maximum depth penetration and nine seismic refraction survey lines were conducted at the study area. Four of the lines were correlated and validated with existing on-site borehole to identify soil type. The validated values applied to the remaining survey lines which no borehole record to map the subsurface of the study area. Based on the results, Sungai Batu area consist of clay with resistivity value of 7-26 Ω.m and velocity value of 717-1607 m/s; sandy clay with resistivity value of 6-265 Ω.m and velocity value of 1004-1901 m/s; while bedrock/hard layer was identified with resistivity value of more than 669 Ω.m and velocity value of more than 2052 m/s. Boundary between clay/sandy clay with shale was identify with resistivity value of

314 Ω.m and velocity value of 1822 m/s. Subsurface geology and geomorphology profile of Sungai Batu area is characterized by recent alluvium (clay and sandy clay) thickness and bedrock topography. The ancient river is suspected to flow from north to southwest direction, where the shore is located. On the east part of the study area shows the river meanders and partially cutoff from the original channel to produce an oxbow lake. The size and shape of the ancient river has evolved gradually to become present river which is known as Sungai Batu.

CHAPTER 1

INTRODUCTION

1.0 Background

In 2007, the Centre for Global Archaeological Research (CGAR), Universiti Sains Malaysia (USM) has discovered Sungai Batu area as an early civilization in Southeast Asia. A total of 97 mounds have been mapped and identified around Sungai Batu area which covered about 3 km^2. Excavations of this area discovered some ritual monuments, iron smelting sites were built in the 1^{st} century Common Era (CE) and a riverside jetty which built in the 2^{nd} century CE along Sungai Batu river. The discovery identified that within the 1^{st} century, Sungai Batu area was a basis of economic region where Sungai Batu river had been used as an international enterport (Saidin et al., 2011).

Between the 1^{st} and 2^{nd} century, mid-south of Kedah was recorded as marine area, but with the rise of sea level in 14^{th} century it changes the area to be landed area (Wheatly, 1961). Sediments from weathering process such as soil and mineral was transported either from river (Sungai Muda and Sungai Batu) or ocean to lower area vicinity which strongly influenced by geology and geomorphology of the surrounding environments continuous. Deposition process and erosion factor have changes the area transform to higher ground or landed region. Sedimentation process of Sungai Batu area were controlled by depositional process of the Sungai Merbok river geomorphology, Sungai Batu river and Malacca Strait. Sediments from Gunung Jerai was transported by Sungai Merbok and Sungai Batu river systems to lower region with high turbidity current until it settled down due to gravity factor (Saad et al., 2016). Marine sediments of Malacca Strait play an important role in deposition process of Sungai Batu area (Zakaria et al., 2016). The marine sediments from Malacca Strait are transported due to longshore drift current from tidal current ridge range of landforms.

Sedimentation process around Sungai Batu has resulted or transformed this area covered by marine alluvial and changes the geomorphology for this locality including the ancient river of Sungai Batu. Therefore, geophysical methods were used to identify Sungai Batu ancient river system and characteristic including recent alluvium thickness and environmental depositional in Sungai Batu area. Geophysical methods; 2-D resistivity imaging and seismic refraction tomography was carried out in this study.

1.1 Problem statements

Previous research related with the ancient river studies have successfully established with various application from geosciences methods, such as resistivity and velocity values from Reynolds (1997) have been use as references by many researchers regarding with the resistivity and velocity values of the subsurface materials. Despite that, the information related with numerical values of the materials is general and in a very wide range.

The geophysical methods have become a reliable source of information to determine and characterize the subsurface materials. Misinterpretation of the data might happen when the result is only the from one geophysical or geotechnics methods and no comparison methods is applied at the same area.

There are many kinds of geological and geomorphological processes that can take place in an ancient river such as river level and sediment deposition. Both effects will subsequently change the river flow.

1.2 Research objectives

The objectives of this study are;

i. To determine the resistivity and velocity value of Sungai Batu.

ii. To validate resistivity and velocity value.

iii. To identify and characterize subsurface geology and geomorphology profile of Sungai Batu ancient river channel system.

1.3 Scope of study

The 2-D resistivity imaging and seismic refraction methods ware applied at Sungai Batu area for subsurface study in 5.5 km^2 area. Thirty 2-D resistivity imaging and nine seismic refraction survey lines was design for mapping possible ancient river flow. From all survey lines, four 2-D resistivity imaging and four seismic survey lines were correlated with four borehole records to validate resistivity and velocity values. All the survey lines used in identifying and characterizing geology and geomorphology subsurface at Sungai Batu area.

1.4 Thesis layout

This thesis composed of five chapters are organized as follows:

Generally, chapter two consist of two parts. The first part discussed on the geomorphology of river channel systems. The second part is the previous studies of the geophysical methods delineating of ancient river and geophysical methods in identification of recent alluvium and archaeological evidence.

Chapter three discussed on theoretical and methodology part of both methods, which are 2-D resistivity imaging and seismic refraction methods. The location and geology of the study area were discussed briefly in this chapter. The data acquisitions and geophysical equipment used for this study are also provided in this chapter.

Chapter four presented the results and discussion. Correlation and validation between 2-D resistivity imaging and seismic refraction with borehole records are discussion, and regression analysis from results also discusses. Finally, the geomorphology subsurface Sungai Batu are discusses in this chapter.

Finally, chapter five concluded the 2-D resistivity imaging and seismic refraction methods in this research including useful suggestions for future study.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

During the last four decades, geophysical methods have been applied in archaeology works. Several geophysical methods used for archaeological research are 2-D resistivity imaging, induced polarization, seismic refraction, magnetic, gravity, transient electromagnetic and ground penetrating radar. Such geophysical results provide significant indications of study areas that have been significantly modified by erosion, agriculture activities, sedimentation deposit, and another physical factor. The previous study present previous work on sedimentation and archaeological research using geophysical method in triggering possible research gaps.

2.1 Geomorphology of river channel

Three geomorphological regions can be recognized within river systems (Figure 2.1). The zone of sediment production, where most of sediment is derived, is located in the headwaters region of the river system. Much of the sediment carried by streams begins as bedrock that is subsequently broken down by weathering and then moved downslope by way of sheet flow and rills. Bank sediment production can also contribute significant amounts of sediment. In addition, scouring of the channel bed depends the channel and adds to streams sediment load. Sediment acquired by a stream is transported through the channel network along sections referred to as trunk streams. When trunk streams are in balance, the amount of sediment eroded from their banks equals the amount deposited elsewhere in the channel. Although trunk streams rework their channels over time, they are not a source of sediment, nor do they accumulate or store it. The zone of sediment depositions, when a river reaches the ocean or another large body of water, is slows and the energy to transport sediment is greatly reduced. Most of the sediments either accumulate at the mouth of the river to form a delta, are reconfigured by wave action to form a variety of coastal features, or are moved far offshore by ocean currents. Because coarse sediments tend to be deposited upstream, it is primarily the fine sediment (clay, silt and fine sand) that eventually reach the ocean. Taken together erosion, transportation and deposition are the process by which rivers move Earth surface materials and sculpt landscapes (Lutgens et al., 2014).

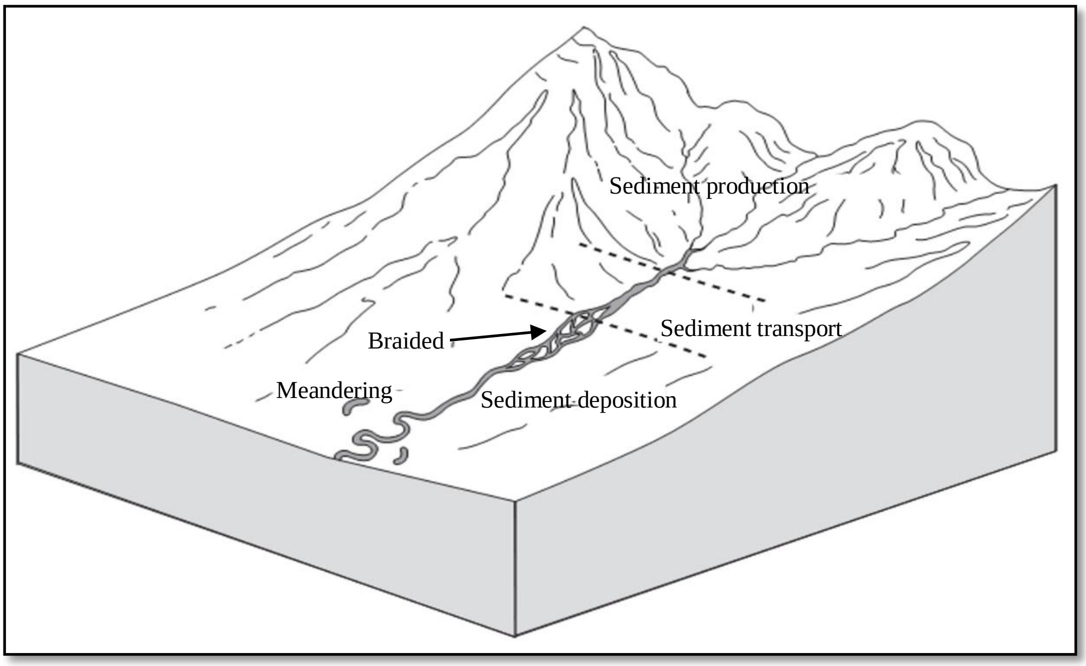

Figure 2.1: The fluvial system (Modified from Charlton, 2007).

A basic characteristic that distinguishes streams flow overland flow is that it is confined in a channel. A stream channel can be through of as an open conduit consisting of the streambed and banks that act to confine flow except of course during flood. Although this is somewhat oversimplified, stream channel divide into two types; which is bedrock channels and alluvial channels (Lutgens et al., 2014).

2.1.1 Bedrock channel

Bedrock channel are cut into the underlying strata and typically from in the headwaters of river system where streams have steep slopes. The energetic flow tends to transport coarse particles that actively abrade the bedrock channel. Pothole are often visible evidence of the erosional forces at work (Lutgens et al., 2014).

Steep bedrock channels often develop a sequence of steep and polls, relatively flat segments (pools) where alluvium tends to accumulate and steep segment (steeps) where bedrock is exposed. The channel pattern exhibited by streams cutting into bedrock is controlled by the underlying geological structure (Lutgens et al., 2014).

2.1.2 Alluvial channel

Alluvial channels form in sediment that was previously deposited in the valley. When the valley flood reaches sufficient width, material deposited by the stream can form of floodplain that borders the channel. Because the banks and beds of alluvial channels are composed of unconsolidated sediment (alluvium), they can undergo major changes in shape material is continually being eroded, transported and deposited. The major factor affecting the shapes of these channels are the average size the sediment being transported, the channel gradient and discharge (Lutgens et al., 2014).

Alluvial patterns reflect a stream ability to transport its load at a uniform rate while expending the least amount of energy. Thus, the size and type of sediment being carried help determine the nature of the stream channel. Two common types of alluvial channels are meandering channels and braided channels (Lutgens et al., 2014).

Meandering channels streams that transport much of their load in suspension generally move in sweeping bends called meanders. These streams flow in relativity deep, smooth channels and primarily transport mud (silt and clay), sand and occasionally fine gravel. Meandering channels evolve time as individual bend migrate across the floodplain. Most of the erosion is focused at the outside of the meander, where velocity and turbulence are greatest. In time, the outside bank is undermined, especially during periods of high water. Because the outside of a meander is a zone of active erosion, it is often referred to as a cut bank. Debris acquired by the stream at the cut bank moves downstream, where the coarser material is generally deposited as point bars on the insides of the bends. In this manner, meanders migrate laterally by eroding the outside of the bends and changing theirs shape (Lutgens et al., 2014).

In additional to migrating laterally, the bends in a channel also migrate down the valley. This occurs because erosion is more effective on the downstream side of the meander. Sometimes the downstream migration of a meander is slowed when it reaches a more resistant bank material. This allows the next meander upstream to gradually erode the material between the two meanders. Eventually, the river may erode through the narrow neck of land, forming a new shorter channel segment called cutoff. Because of its shape, the abandoned is called an oxbow lake (Lutgens et al., 2014).

Braided channels some streams consist of a complex network of converging and diverging channels that thread their way among numerous islands or gravel bars. Because these channels have an interwoven appearance, they are called braided channels. Braided channels form where a large portion of streams load consist of coarse material (sand and gravel) and the stream has a highly variable, braided channel are wide and shallow (Lutgens et al., 2014). Figure 2.2 show meandering of channels.

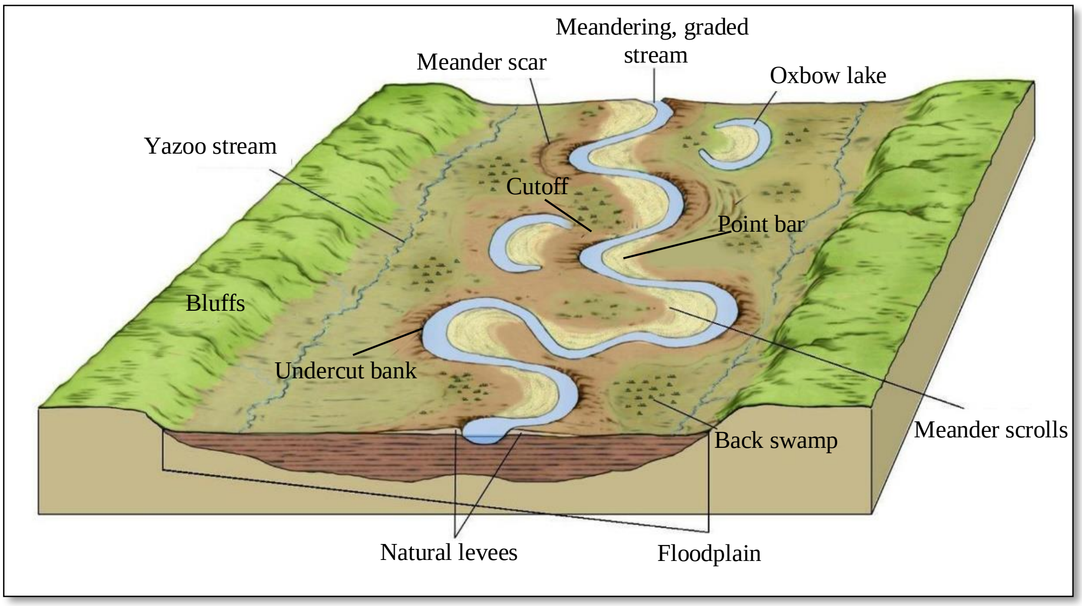

Figure 2.2: The meandering diagram of channels (Modified from Ludgens et al., 2014).

2.2 Previous study

The previous study for this research were discussed accordingly to ancient river identification, sediment deposit characteristic and archaeological studies.

2.2.1 Geophysical methods in delineating of ancient river

Muztaza et al. (2012) had perform a study at a small section of Sungai Batu (Kedah) area of 1600 m^2 with the aimed is to study river sediment thickness using 2-D resistivity imaging. The results has shown that the study area was divided into two types of sediment; top layer consist of clay with resistivity value of 0-5 Ω.m and bottom layer consist of sandy clay/sand with resistivity value of 8-300 Ω.m with depth of <10 m. The resistivity values show an indication that the study area is an ancient river system with a depth of more than 20 m.

Similar effort by Ihsan et al. (2015), successfully detect an ancient river of Sungai Batu river (Kedah) using ground magnetic method. The study used G-856 proton magnetometer with 20 m station spacing. The magnetic data was processed using Microsoft excels and Surfer8 software. The result shows low magnetic residual values of -280 to -400 nT which indicates the exiting of ancient river within the study area.

A geophysical method; electrical resistivity imaging (ERI) and ground penetrating radar (GPR) has been conducted on the lowest terrace levels of Guadalquivir river, province of Jaen, Spain. The applications of the two methods have been utilized for analyzing and comparing in stratigraphic and sedimentological studies. The geometry and lithofacies of subsurface deposits were characterized using ERI and compared with field observations. A total of 5 ERI survey lines were obtained. The changes in electric resistivity values, highlight a granulometric differences in terrace sediments. This technique can identify the morphology of silt, sand or gravel and buried channel pattern. In addition, 16 GPR survey lines was acquired using 100 and 250 MHz antennas. Results show more detail terrace morphology and filling sedimentary bodies compared with ERI. The study concludes that the existence of channel migration, lateral accretion of point bars and presence of vertical accretion deposits attributable to floodplains (Rey et al., 2013).

Seismic refraction was conducted by Khorshid and Al-Awsi (2014) along Euphrates river banks at northwestern of AL-Anbar to investigate the subsurface structures. The right bank of Euphrates river is characterized by complex geological situation and the left bank is characterized by horizontal layers. No evidence of any subsurface faults in this part. Seismic refraction result indicates four main layers. The first layer represents overburdens which correspond to quaternary deposits with velocity value of 600-950 m/s and thickness of 2.26-7.4 m. The second layer correspond to Euphrates Formation with velocity value of 1400-2000 m/s and thickness of 6.2-21.2 m. Third layer correspond to Anah Formation with velocity value of 2400-3000 m/s and thickness of 20.6-40.4 m and the fourth layer corresponding to Baba Formation with velocity value of 3333-4000 m/s.

2.2.2 Geophysical methods in identification of recent alluvium and archaeological evidence.

Saad et al. (2014) has presented geophysical survey results from an archaeological site of Sungai Batu (Kedah) using 2-D resistivity imaging method with 15 survey lines. The objective of the above study is to identify buried archaeological. 2-D resistivity inversion software (Res2Dinv) was used to process the data. The inversion results revealed that a rectangular gridding pattern and a dense anomaly that shows resistivity value of >3500 Ω.m existed at depth of 0-1 m. Based upon on-site calibration at partly exhumed sites, such anomalies are interpreted as fired clay bricks material. The 2-D resistivity imaging is a useful and efficient method in assign archaeological artifact.

Alashloo et al. (2011) have applied integrated geophysical methods; seismic refraction and ground magnetic to investigate subsurface geological properties and to locate artifacts at Sungai Batu (Kedah). The seismic refraction was applied using ABEM MK8 seismograph with 24 channels for data acquisition and the data was processed using FISRTPIX and GREMIX15 software. Magnetic data were acquired using G-856 proton precession magnetometer with 5 m interval station spacing and the data were processed using Microsoft excels and Surfer8 software. Seismic refraction result shows that the area generally interpreted to two main layers; top layer which is alluvium and sandy clay with velocity of 250-400 m/s and the second layer is saturated soil with velocity of 1650-2000 m/s with depth of 2-3.2 m. Generally, magnetic results show contrast magnetic residual value of -30 to 35 nT for this area and anomaly from mud bricks indicate positive magnetic residual value of -20 to 25 nT.

Magnetic method was conducted by Muztaza et al. (2014) to locate buried object at Sungai Batu (Kedah) archaeological sites. The study conducted using G-856 proton magnetometer for data acquisition. Gridding technique with 1-2 m stations spacing was employed for 3-dimensional views. Microsoft excels and Surfer8 software were applied in processing the magnetic data. The result shows high distribution of magnetic residual anomaly; 30-180 nT surrounded by background magnetic residual value. The contrast is due to fired bricks clay.

The objective of the survey at Sungai Batu (Kedah) is to identify buried archaeological objects located at shallow depth using ground magnetic survey. The survey acquired using G-856 proton magnetometer with 5-20 m station spacing. The result shows distribution of magnetic anomaly features within the study area with high magnetic residual values of 40-100 nT. The anomaly features are indicated by magnetic contrast between objects (fired clay bricks) and the surrounding (sandy clay soil) which is low magnetic residual value (-50 to 40 nT). Magnetic method is powerful tool to obtain useful information about subsurface for archaeological prospecting (Maslinda et al., 2015).

Baines et al. (2002) study sediment deposits (buried sand and gravel fluvial) using 2-D resistivity imaging. The model resistivity values variations represent different lithologies. The geometry of homogeneous deposits is represented by zones of similar resistivity values. 2-D resistivity imaging identified complex changes and maps the geometries. This means that 2-D resistivity imaging can detect and delineate resistive and conductive sediments. It is proven that 2-D resistivity imaging is highly useful and possibly indispensable tool for investigating fluvial and other depositional successions.

In 2014, Selim et al. conducted a geophysical survey which is 2-D resistivity imaging and seismic refraction methods at western bank archaeological site, Old Luxor City, Egypt. The purpose of this survey is to characterize and reconstruct the geometry of subsurface structure. 12 survey lines was conducted across the study area in the direction of NW-SE which each line have 2-D resistivity and seismic refraction. Each line was aligned parallel with each other from line 1 to 12 with 3 m spacing. The 2-D resistivity result shows two-layer cases were identified which arranged from top to bottom. A clay soil with thickness of 3.82-4 m and wetted clay/mud with depth of 25.3-26.23 m were identified in first layer while a second layer consist of a massive body composed of Alabaster limestone or granite. The inversion model of 2-D resistivity imaging was combined to produce 3-D resistivity modeling as depth slices. The model identified a continuous high resistivity anomalous feature in continued depth slices. From seismic refraction analysis, the velocity value of 400-1350 m/s which interpreted as the present of a bedrock.

A study had presented by Shahrukh et al. (2012) to characterize archaeological site of Priniatikos Pyrgos at Iston using seismic refraction and 2-D resistivity methods. Twenty-nine seismic refraction lines were conducted to determine soil thickness and bedrock. The seismic refraction lines were overlapped with six 2-D resistivity survey lines. The integration enhanced the knowledge regarding the geological conditions and contribution to archaeo-environmental reconstruction of Istron area by providing indications regarding the ancient harbour of the nearby settlement.

Missiaen et al. (2008) had applied geophysical method; seismic refraction, 2-D resistivity imaging and electromagnetic, and geotechnical methods; Cone Penetration Test and manual drilling, to study an information of shallow subsurface in a tidal estuary at Verdronken Land van Saeftinge. Western Scheldt (Netherlands). The study area is cut by numerous tidal gullies and high tidal amplitudes. The data acquisition only focused on the upper of active sediment bodies (10-20) m. In general, the seismic refraction method provides more reliable and detail interpretation of the sedimentation structures. The result shows that the combination between geophysical methods and geotechnical investigation provide a comprehensive answer for this researcher while no single geophysical method can provide all the answer for the case.

Al-Heety and Shanshal (2015) reported integration of seismic refraction tomography and 2-D resistivity imaging have been used to characterize subsurface materials and map geological features of teaching hospital project site in Mosul, Iraq. Twelve seismic refraction survey lines and ten 2-D resistivity lines using Wenner array were conducted. Seismic refraction results identified three layers case. On the other hand, 2-D resistivity result shows alteration zones consisting of two main zones. The results from the integration of these two methods provide a synergy for better interpretation and reduce ambiguities.

Attwa et al. (2011) was conducted 2-D resistivity imaging, frequency domain electromagnetic (FDEM) and induced polarization (IP) surveys to characterize subsurface sediment deposit within the tidal deposits at North Sea coast, northern part of Germany. The inversion results indicate that the subsurface resistivity distribution of tidal sediments change quickly within a short distance. A low resistivity value of 2 Ω.m that was interpreted as saltwater perched which observed above peat and clay layers. Base on IP result, the saltwater found above a layer of clay. A good resolution of the images clearly recognized the boundaries of clay layer due to high membrane polarization of the clay. A shallow channel feature was shown from EM and 2-D resistivity imaging profiles within the tidal deposits. The study concludes as basic method to model sediment deposit in coastal tidal area.

Leopold et al. (2010) presents geophysical methods (magnetic, electrical resistance mapping, 2-D resistivity imaging and Ground Penetrating Radar) approach which carried out at a site with buried remnants of Roman villa Rustica at Southern Germany. The interpretation results lead to a geocodation of all outcomes and a final archaeological information. The study shows a formation of ground floors, both with and without hypocausts, perimeter walls and kilns are detected in several buildings at different states of preservation which helped in the soil mapping by outsourcing soil erosion and accumulation areas.

Pellicer and Gibson (2011) has conducted geophysical methods at Midlands (Ireland) with the objective is to identify unconsolidated sediments. Two geophysical method choose for the survey which are 2-D resistivity imaging and Ground Penetrating Radar (GPR). Geology setting for this study area is consist of broad range of glacial and postglacial sediments, diamicton, esker sand and gravel, glaciolacustrine sand, glaciolacustrine silt/clay and peat. The study also includes geomorphology mapping, lithostratigraphic analysis of exposures and borehole drilling. All data help in interpreting geophysical data. Four 2-D resistivity imaging survey were conducted which has allowed the investigation of the depth to bedrock and determining lithological classification of the sediments. Five GPR cross-section were performed at study area and the results depicting the subsurface internal architecture within low conductivity unconsolidated sediments and help in classification of sedimentological and deformational structures. It is proved that both geophysical method has successfully used in this study.

Bates (2000) integrated geophysical methods; 1-D resistivity sounding, 2-D resistivity imaging, gamma logging and electromagnetic logging together with borehole to model subsurface stratigraphy in identifying potential locations of archaeological evidences. The research was conducted at southern England, to model buried gravel surfaces, peats within alluvial stacks and buried former chief lines in Holocene and Pleistocene sediments. The results are presented in form of geotechnical data that can be used to integrate selected area for further information in archaeological investigations, especially when conventional archaeological survey techniques are inappropriate.

The significant problems of archaeology evidences buried by thick stratified alluvium of estuary from major river valley are usually presented by archaeologist. A collaboration between geotechnical method; CPT and geophysical methods; 2-D resistivity imaging and EM had performed by Bates et al. (2007) at southern England. The study focusses on sediment deposits and depth modelling to located important archaeological remains using microfossil assignment. Subsequently, this approach enhances the subsurface understanding in locating archaeological sites (buried and developed project) which include fossil-bearing sequences and stratigraphy mapping.

Alhasan et al. (2011) discussed the seismic refraction survey conducted at southern part of Niger State College of Education Minna, using a three-channel seismograph. The total profile line of 1 km length was conducted and marked every 100 m. The results show that the subsurface with overview of lateral difference in lithological changes. The study identified the basement surface varied from 2.05-10.13 m in depth consist of sand, saturated clay, gravel and granite are the main materials found in the study area.

Seismic refraction method was used to describe general stratigraphy and determine velocities and thicknesses of Sabkha's uppermost layers and water table depth at inland Sabkha of Jayb Uwayyid eastern Saudi Arabia. A reversed-refraction seismic profile consisting of 48 geophones with 5 m minimum geophones spacing was acquired for the seismic refraction data acquisition. The seismic refraction result shows three main layers; the first layer with average velocity of 600 m/s and thickness of 15 m consists of dry to partially saturated sand, underlain by fully saturated sand. The second layer is weathered sedimentary layer with average velocity of 2300 m/s and 113 m thickness. The average velocity of 3850 m/s represents the sabka bedrock as the third layer (Abdullatif et al., 2013).

Almadani et al. (2015) was conducted a geophysical survey on an urban extension site in southwest of Ahud Rufeidah town, southwest Saudi Arabia using ground magnetic and seismic refraction methods. The survey was purpose to demonstrate thickness of alluvium and bedrock. Base on theory, the assumption taken that the magnetic value of alluvial sediments is lower than gneiss basement rock. A total of 3750 survey points was conducted using ground magnetic survey and four survey line of seismic refraction was laid across the pathway of buried alluvial channel. These techniques were used to enhance the depth and boundaries of buried channels. Ground magnetic results show the presence of a basin where two sub-basins were identified connected to each other. This basin was identify based on filled material that occupy the middle area. Seismic refraction results identified the thickness of alluvium sediment which is >20 m.

Seismic refraction and seismic reflection were conducted to located and map an ancient port at the archaeological site of Itanos (Greece). The geology of this area is Permian-Triassic phyllites covered by alluvial deposits. The seismic refraction results show that this area consists of two main layers; first layer indicated water table at depth of 1-2 m and second layer is phyllites with velocity value of >1400 m/s. Seismic reflection result also shows two main layers which is top and bottom consist of eroded phyllites. Base on the results, an ancient port was covered by recent deposits which was surrounded by sea (Vafidis et al., 2003).

Albani et al. (1976) used seismic reflection method, studied about ancient river channel, formed during a period of lower sea level at Sydney Airport, Australia.

The river valleys are now buried under the considerable thickness of sands and clays. The depths to bedrock obtained by various techniques have been collated and presented in the form of a contour map. The outline of present coast is preserved for reference purposes, but it is the bedrock form to which attention should be directed. Perhaps the most important feature on this map is the previously unsuspected ridge at 30-40 m below the present sea level which runs between Sydney Airport and Inscription Point (Northernmost tip of Kurnell peninsula). This clearly divided two drainage systems which existed at lower sea level time.

The sedimentary sequence of deltaic plain deposits of Selinous river mostly consists of fine lithofacies interbedded occasionally with conglomerate facies. Fine grained lithofacies based on sediment types, structure, color, as well as contact depths. Bedding characteristics were interpreted as floodplain, crevasse splay, back swamp/fresh water swamp, permanent shallow fresh water lake and ephemeral fresh water lake facies. The coarse grained lithofacies consists of pebble-conglomerate and interpreted as paleochannels. The transient electromagnetic method (TEM) was applied by Koutsios et al. (2010) in order to define the spatial distribution of lenses of conglomerates, paleochannels and fine grained sedimentary material to be recognized at depth up to 35 m. Base on the sedimentological and geophysical approaches, in combining with available geological and geomorphological data of the area, it provide information about evolution, existence and geometry of paleochannels of Selinous river floodplain, and the paleoenvironment of ancient Helike area.

2.3 Chapter summary

This chapter described the geomorphology of river channel. In this chapter also discussed several previous studies that mostly related in sediment deposit, ancient river and archaeology using geophysical and geotechnical methods. The application of the geophysical methods were utilized to investigate the subsurface of the earth, where the geophysical survey was conducted at the archaeological site using one geophysical method no comparison with others methods. Most study of the subsurface has depended on using the geophysical methods and resistivity and seismic is two of the methods than can describe the subsurface profile efficiently. A standard rage of resistivity and velocity values for the materials has been use widely as border to determine the type of materials in general. Specific range of resistivity and velocity values for the certain type of materials can be obtained when the survey is conducted within the same region, which in this study is focus at the Sungai Batu site.

The geophysical methods are well demonstrated in characterizing the subsurface profile through imaging result. Besides using the geophysical technique such as the 2-D resistivity imaging and seismic refraction methods can be used to determine the geological of shallow subsurface. Every geophysical method has certain limitations and gives difficulties during interpretation. Misinterpretation usually happens when the result is in term image, more than on geophysical methods usually used during data acquisition to show the correlation. This study used 2-D resistivity imaging and seismic refraction methods to determine the type of materials.

CHAPTER 3

RESEARCH METHODOLOGY

3.0 Preface

Geophysical methods are based on physics principles applied to study the Earth materials. The principles involve indirect measurements of physical parameters attributed to the Earth subsurface. The contrasts resulting from ground surface measurement defines the geophysical anomaly. In geophysical survey, understanding the basic theory for each of geophysical method is very important. This study was conducted at Sungai Batu, Kedah using two geophysical methods; 2-D resistivity imaging and seismic refraction, in which the results were correlated with existing borehole information for validation. Figure 3.1 shows the flow chart for this research.

3.1 2-D resistivity imaging

Resistivity method were among the first geophysical methods developed since 1900s (Reynolds, 1997). The basic concept originated from Conrad Schlumberger study, who conducted the initial resistivity field tests in Normandy, France during 1912 (Sharma, 1997). Resistivity method was first applied in petroleum exploration by Conrad Schlumberger and Marcel Schlumberger, it was later found useful in mining industries, environmental, hydrological, geotechnical investigations and archaeological research. Expansion in resistivity data acquisition techniques in the late 1980s and early 1990s has transformed the basic resistivity method into an efficient and effective equipment to estimate geological features.

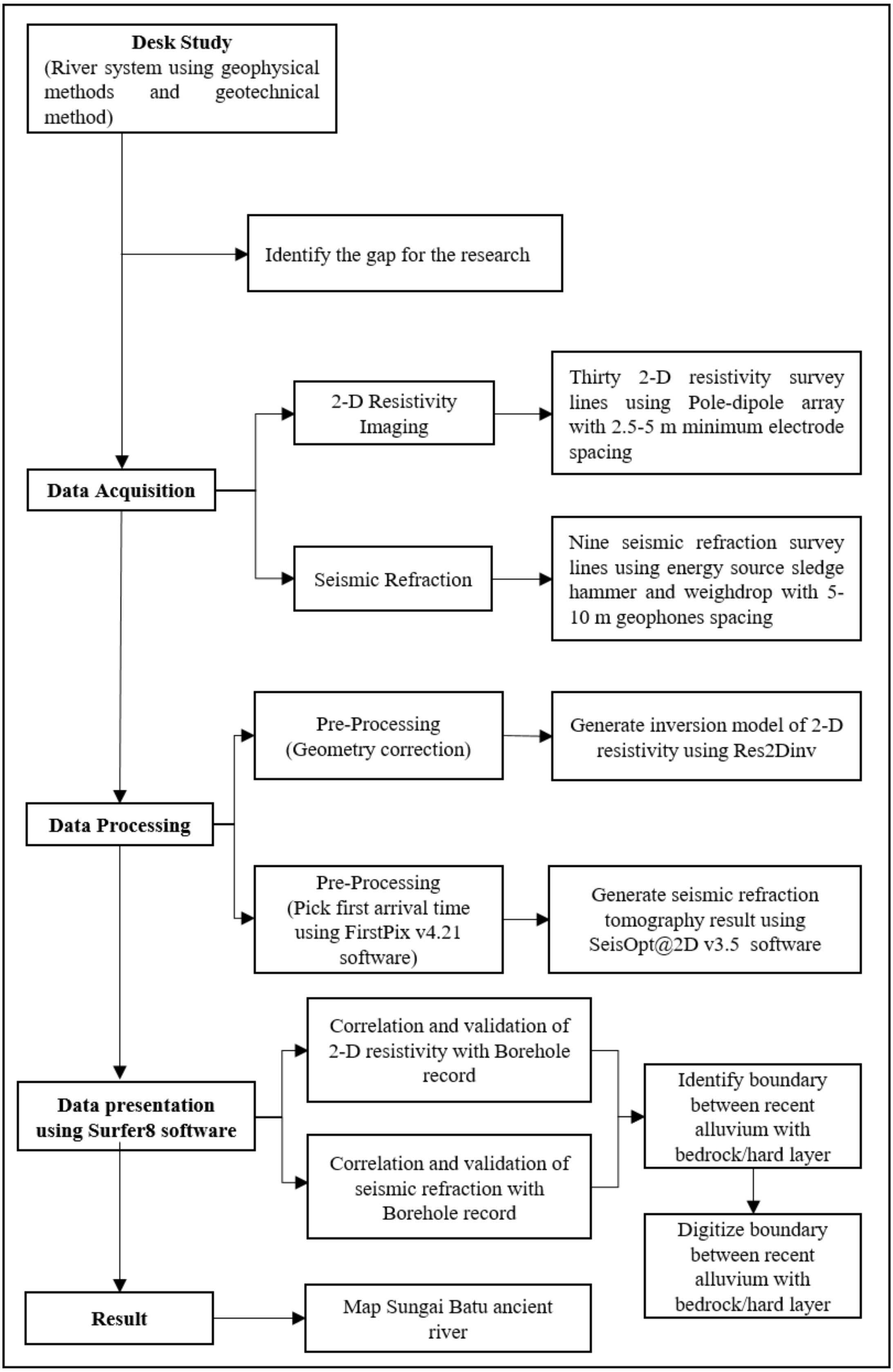

Figure 3.1: Research flow chart.

The basic theory of resistivity considers a cylinder composed of uniform material, with length, *L* and a cross-sectional area, *A* (Figure 3.2).

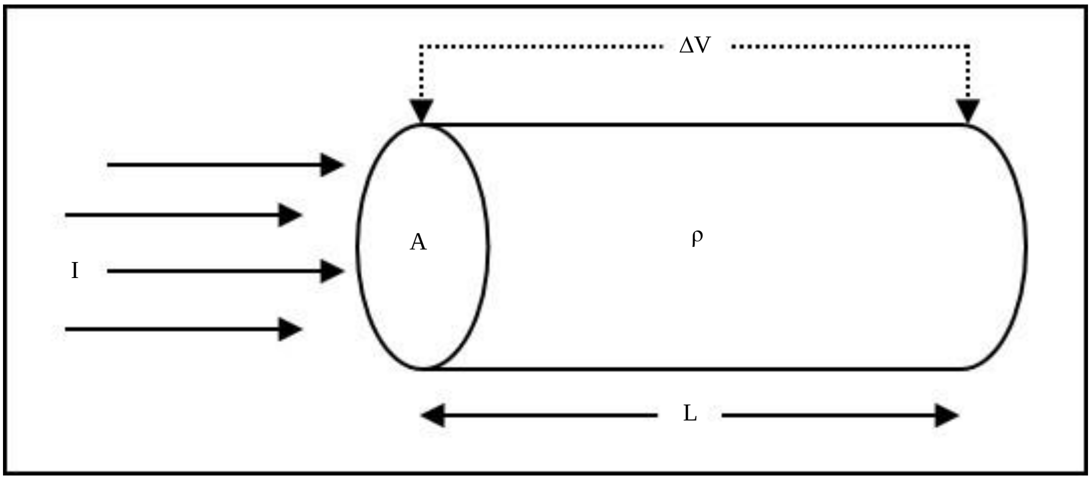

Figure 3.2: Flow of electric current, *I*, through a cylinder composed of uniform material with resistivity, ρ, which produces a difference in an electric potential, Δ*V* for a cross-section, A and length, L (Modified from Allred et al., 2008).

An electric current, *I* defined as the flow rate of electric charges injected at one end of the cylinder and exits through the end. The cylinder, to a greater or lesser stage, defy the flow of the electric current, thereby causing a drop in electric potential, ΔV, along the cylinder. The electric potential, ΔV is a potential energy for a charge within an electric field explained by Ohm's Law (Equation 3.1).

$$\Delta V = RI \tag{3.1}$$

where;

I = Current

R= Resistance

The resistance, *R* of the cylinder can itself be expressed as Equation 3.2

$$R = \frac{\rho L}{A} \tag{3.2}$$

where;

L = Length
A = Cross-section of the cylinder
ρ = Resistivity

Resistivity, ρ is the ability of a material to oppose an electrical current, with the unit of resistivity is ohm-meter (Ω.m). Electrical conductivity, σ is the opposite of resistivity which indicate a material's ability to convey electrical current, not oppose it and presented in a unit of millisiemens/meter (mS/m), which the value of 1 Ω.m is equal to 1000 mS/m (Allread et al., 2008).

Resistivity of rocks is greatly dependent on the degree of fracturing and percentage of fractures filled with ground water. Igneous and metamorphic rocks typically have high resistivity values, while sedimentary rocks normally produce lower resistivity values because they are more porous and possess higher water content. Wet soils condition and fresh ground water provide lower resistivity values compare to clayey soil. The resistivity of rock and soil depends on few factors such as porosity, water saturation and mineral. Table 3.1 shows resistivity values of various rocks and soil types (Loke, 1999).

Table 3.1: Resistivity value of some rock and soil (Modified from Reynolds, 1997).

Material	Resistivity (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
Sandstone	$1 - 7.4 \times 10^8$
Limestone	$50 - 10^7$
Shale	$20 - 2 \times 10^3$
Clays	1×10^2
Alluvium	$10 - 8 \times 10^2$
Consolidated shale	$20 - 2 \times 10^3$
Sand and gravel	30 – 225