INTEGRATION OF REMOTE SENSING AND GEOPHYSICAL METHODS IN IDENTIFYING SHALLOW ARCHAEOLOGICAL REMAINING STRUCTURES AT SUNGAI BATU, LEMBAH BUJANG, KEDAH, MALAYSIA

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by

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LIST OF SYMBOLS

A_L	Band-specific additive (RADIANCE_ADD_BAND_x)
BT	Brightness Temperature
Hz	Hertz
I	Current
k	Magnetic susceptibility
K	Kelvin
K_1	Band-specific thermal conversion constant (K_1_CONSTANT_BAND_x)
K_2	Band-specific thermal conversion constant (K_2_CONSTANT_BAND_x)
kg	Kilogram
km	Kilometer
L_λ	TOA spectral radiance
m	Meter
M	Mega
M_L	Band-specific multiplicative (RADIANCE_MULT_BAND_x)
n	Nano
P	Plank Constant
P_v	Vegetation Proportion
Q_{cal}	correspond to band 10 or band 6
R	Resistance
s	Second
T	Tesla
V	Voltage
Ω	Ohm

$\leq$	Less than or equal
°C	Degree Celcius
1^{st}	First
2^{nd}	Second
4^{th}	Forth

LIST OF ABBREVIATIONS

CE	Common Era
CGAR	Centre for Global Archaeological Research
DC	Direct Current
DEM	Digital Elevation Model
DSM	Digital Surface Model
EM	Electromagnetic
GIS	Geographic Information System
GPR	Ground Penetrating Radar
GPS	Global Positioning System
Landsat	Land Remote-Sensing Satellite (System)
LST	Land Surface Temperature
MAP	Map for Pilot
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NIR	Near-Infrared
N-S	North-South
OLI	Operational Land Imager
PCA	Principal Component Analysis
RES2DINV	Resistivity 2-D Inversion software
RMS	Root Mean Square
SB	Sungai Batu
SCA	Single-channel Algorithm
SIR	Subsurface Interface Radar
SWA	Split-window Algorithm
TIR	Thermal Infrared
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TOA	Top of Atmosphere
UAV	Unmanned Aerial Vehicle
USGS	United State Geological Survey
USM	Universiti Sains Malaysia

W-E	West East
2-D	Two-Dimensional
3-D	Three-Dimensional

LIST OF APPENDICES

INTEGRASI PENDERIAAN JAUH PERSEKITARAN DAN KAEDAH GEOFIZIK DALAM MENGENAL PASTI STRUKTUR SISA ARKEOLOGI CETEK DI SUNGAI BATU, LEMBAH BUJANG, KEDAH, MALAYSIA

ABSTRAK

Lembah Bujang yang juga dikenali sebagai Kedah Tua dipercayai sebagai pusat entrepot terawal dan pusat agama di negara ini. Peranannya dapat dibuktikan dengan penemuan bukti arkeologi seperti penemuan tapak candi Hindu-Buddha, seramik yang pecah, dan banyak artifak lain yang berhubungan dengan perdagangan. Tujuan kajian ini adalah untuk mengenal pasti kawasan struktur yang terkubur yang mempunyai potensi arkeologi yang besar di Sungai Batu dengan menggunakan kaedah penderiaan jauh persekitaran dan geofizik di empat kawasan yang berbeza iaitu SB2ZZ, SB1, SB2 dan SB3. Dua ciri utama yang boleh diperhatikan di permukaan adalah kawasan bonggol dan bata tanah liat yang terdedah. Penderiaan jauh persekitaran telah digunakan di kawasan kajian keseluruhan dengan menggunakan data Landsat 5 dan Landsat 8 untuk mendapatkan suhu permukaan tanah (SPT). Kemudian, SPT data telah disahkan dengan menggunakan tiga kaedah geofizik untuk setiap tapak iaitu pengimejan keberintangan 2-D, magnetik dan radar tusukan bumi (RTB). Pesawat udara tanpa pemandu (PUTP) juga digunakan untuk mengambil gambar udara tapak SB2 menghasilkan model permukaan digital (MPD). Kawasan SB2ZZ, SB1 dan SB2 masing-masing menunjukkan nilai keberintangan dan magnet yang tinggi iaitu $\geq$5000 Ωm dan $\geq$50 nT. Nilai keberintangan dan magnet yang tinggi menunjukkan anomali yang menarik iaitu bata tanah liat kerana kesan haba pada suhu tinggi. Oleh itu, keputusan kedua-dua kaedah geofizik menunjukkan potensi struktur tertanam yang membawa kepada penggalian di kawasan SB2ZZ.

Kaedah GPR hanya diaplikasikan pada kawasan SB1 dan SB2 kerana projek ekskavasi yang dibuat pada masa yang sama dengan pemerolehan data untuk kawasan SB2ZZ dan keadaan kawasan SB3 yang dipenuhi dengan tumbuhan renek menjadikannya mustahil untuk menjalankan kaedah GPR. Profil radargram menunjukkan amplitud tertinggi yang ditunjukkan dengan pantulan yang ditemui di lokasi dalam garis kaji selidik tertentu. Anomali tersebut adalah disebabkan oleh objek kecil artifak arkeologi yang tertanam di bawah lokasi yang dilihat. Di kawasan SB3, hanya kaedah pengimejan keberintangan 2-D yang digunakan dan nilai keberintangan tertinggi untuk tapak SB3 adalah (≤5000) Ωm dan berbanding dengan tiga tapak yang lain, tidak terdapat sebarang anomali yang berkaitan dengan struktur arkeologi. Dalam kajian ini, data yang digabungkan dari SPT, MPD dan tiga teknik geofizik telah berjaya digunakan untuk mengesan potensi struktur sisa tertanam arkeologi yang cetek di Sungai Batu. Kaedah geofizik boleh memberikan sumbangan penting kepada penyiasatan arkeologi dengan bergantung kepada kontras fizikal yang ada di antara ciri arkeologi yang terkubur dan sifat-sifat bawah tanah sekitarnya.

INTEGRATION OF REMOTE SENSING AND GEOPHYSICAL METHODS IN IDENTIFYING SHALLOW ARCHAEOLOGICAL REMAINING STRUCTURES AT SUNGAI BATU, LEMBAH BUJANG, KEDAH, MALAYSIA

ABSTRACT

Bujang Valley which is also known as Kedah Tua is believed to be the earliest entrepot and religious center in the Malaysia. Its role can be proved by the discovery of archaeological evidence such as the discovery site of Hindu-Buddhist temples, broken ceramics and many other artefacts related with the trade. The aim of this study is to identify the buried structure area that has great archaeological potential at Sungai Batu by using remote sensing and geophysical methods at four different areas which are SB2ZZ, SB1, SB2 and SB3. Two main characters that can be observed on the surface are mound area and exposed clay bricks. Remote sensing was applied to the whole study area by using Landsat5 and Landsat8 data to retrieve land surface temperature (LST). Then, the LST data were verified by using three geophysical methods which are 2-D resistivity imaging, magnetic and ground penetrating radar (GPR) methods. An unmanned aerial vehicle (UAVs) was also used to capture the aerial photos of the SB2 area to produce the digital surface model (DSM). SB2ZZ, SB1 and SB2 areas show the results of high resistivity and magnetic values which are ≥5000 Ωm and ≥50 nT respectively. The high resistivity and magnetic values indicate the interesting anomaly which is clay bricks due to the effect of heat at high temperature. Thus, the results of two geophysical methods show the potential of buried structures leading to an excavation at SB2ZZ area. GPR method was only applied at SB1 and SB2 areas because of excavation project was

done at the same time during data acquisition for SB2ZZ area and the condition of SB3 area that is full of shrub vegetation area make it impossible to conduct GPR method. Radargram profiles show the highest amplitude that indicates as the reflections that were uncovered in the location in certain survey lines. The anomalies are due to the small object of archaeological artefact buried beneath the spotted location. At the SB3 area, only 2-D resistivity imaging method was employed and the result shows the highest resistivity values (≤5000 Ωm) and compared with the other three sites, there is no anomalies related with archaeology remain structures. In this study, data combined from LST, DSM and three geophysical methods been successfully applied in order to approach the potential in detecting shallow buried archaeological remain structures at Sungai Batu. Geophysical methods can make an important contribution to archaeological investigations by relies upon a physical contrast to exist between the buried archaeological feature and the properties of the surrounding subsoil.

CHAPTER 1

INTRODUCTION

1.1 Background

Archaeology has been expressed as the study of the age-old and modern human past through material remnants. The field of archaeology proposes a unique context on human history and culture that has contributed greatly to our understanding of both the age-old and the modern past (Smith et al., 2001). In archaeological studies, with the assistance of an important source which is a report from previous research, researchers carry out a study on an archaeological site. Archaeology has grown a range of approaches to retrieve partial remnants as they tend to be lost, buried and abandoned (Drewett, 2011). Data from archaeological sites should be stored expeditiously so as not to ruin the site or the original site conditions during the process of collecting data in the field. Therefore, a fast and non-destructive method should be utilized to help this process because the excavation site may be exposed to hazard and debris due to soil conditions that might not be stable (Azhar and Ahmad, 2014).

Archaeologists are increasingly turning to geophysical methods to improve their understanding of archaeological sites. Geophysical methods have been widely practiced in the archaeological application since 1946 while aerial photography has been used since 1919 (Wynn, 1986). The data acquired in a study allowed archaeologists to select the site of their excavation with preliminary information that assists in improving their resources and increase the potency of excavations (Sala et al., 2012). Ideally, geophysical methods allow the archaeologist to view the subsurface without destroying the site (Weymouth and Huggins, 1985). Magnetic, 2-

D resistivity imaging and ground penetrating radar (GPR) methods are the most frequently used geophysical methods in this modern time. Remote sensing method could be combined with geophysical and archaeological research methods in order to determine an archaeological site and to characterize factors for site-occurrence prediction. The proficiency of remote sensing method offers the improvement of providing a synoptic view, covering enormous areas, and demonstrating the capability to identify features not easily noticeable on the ground surface that may be vital for archaeological studies (Brivio et al., 2000).

Geomorphologically, Bujang Valley is consists of three major units: mountain, hills and fluvial and marine deposits. Report from geomorphological studies has aided archaeologists to detect and to characterize where, when and why specific locations have been used by men in the past. A site for a settlement will commonly be preferred because of specific circumstances such as accessibility, safety from risk and attacks from outside and the presence of food supply. Three kind of location have been selected by men in setting their settlements in Bujang Valley which are the shore and beach ridges along the Sungai Merbok, the natural levees along the Sungai Muda and the foot hills slopes. But because of lateral erosion and meandering of Sungai Merbok and Sungai Muda which have continued till today, the ancient settlements are now situated further away from the rivers than the past.

In 2007, the discovery of the Sungai Batu by the Centre for Global Archaeological Research (CGAR) Universiti Sains Malaysia is symbolic in learning about the previous civilisations in Malaysia (Saidin et al., 2011). The Department of National Heritage, Ministry of Information, Communications and Culture asked the Centre for Global Archaeological Research (CGAR), Universiti Sains Malaysia to re-map and research the palaeoenvironment of the Bujang Valley sites. CGAR discovered a new site, Sungai Batu, that seems to disclose older evidence by employing GIS (global information system), geophysical and geological mapping. A total of 97 mounds were mapped and identified in a 3 km^2 area that has great archaeological potential. Up until, excavations at 16 mounds area revealed ritual monuments (Figure 1.1), a riverside jetty built in the 2nd century Common Era (CE), and iron smelting sites that were used from the 1st century CE. The discovery of the iron smelting industry in this complex showed that the Sungai Batu civilisation had an economic base. The Bujang Valley civilisation was speculated to date as early as the end of the 4th century CE and to be mainly a Hindu-Buddhist site based on a previous study (Backus et al., 1969). To date, the influential discovery of a 110 CE monument means Sungai Batu contributes the earliest evidence of a monument (with chronometric dates) in Southeast Asia.

Figure 1.1 One of the temples found in Lembah Bujang, Kedah, Malaysia (Saidin et al., 2011).

1.2 Problem statement

Lembah Bujang is situated in northern Malaysia (Kuala Muda, Kedah) which is one of the most significant archaeological sites and 2000 years ago it was an international cultural and commercial crossroad (Norzailawati et al., 2016). Currently, many of these prehistoric sites are being briskly ruined due to modern land-use practices such as infrastructure development and industrialization together with the development of townships are major destructive factors and require urgent conservation by the local authority. Lembah Bujang Archaeological sites are threatened by rapid development due to the demolishment of excavation sites near Sungai Batu that contain hidden shrines during land clearing work by the developer.

In Sungai Batu sites, there are a lot of visible remains of the ancient past exposed on the surface and mound areas that can be marked as a potential archaeological site. However, the suspected mound areas may represent other occurrences due to modern human activities. Archaeologists are very well aware that random excavation will cause harm and destroys the site being studied (Samsudin and Hamzah, 1999). Since geophysical methods are non-destructive methods and very useful to archaeologists who wish to preserve the cultural heritage as well as to study it, some geophysical methods were proposed in this study. Geophysical methods, if applicable, can delineate archaeological sites and help archaeologists in their initial planning of excavation work. The information from geophysical studies would also indirectly cut operating cost on-site investigation by reducing the number of pits and avoiding unnecessary digging.

Remote sensing includes many applicable methods depending on the study area which is suitable for it. Remote sensing was used as a preliminary investigation before other geophysical methods were applied for confirmation to the potential of study areas. Applying remote sensing prior to the fieldwork will lead to better results. Magnetic, 2-D resistivity imaging and GPR methods were employed in this study. Magnetic surveying is quick and easy to interpret but cannot easily conduct close to the interfering magnetic sources, such as a modern building or power lines. The 2-D resistivity imaging method is slower and somehow more complicated to portray but is free from the intrusion of close buildings and power lines (Weymouth and Huggins, 1985). One of the challenges for the use of GPR in archaeology is the complexity of the results since the shape of anomalies described in the radargram does not correspond necessarily with the real geometry of buried objects (Jol, 2008). The physical values displayed in the results could represent other features which may lead to misinterpretation during data analysis. Therefore, the combined geophysical methods were used to give a better interpretation in an archaeology study.

1.3 Research objectives

The objectives of this research are:

i) To identify the buried structure area that has great archaeological potential at Sungai Batu by using remote sensing and geophysical methods; magnetic, 2-D resistivity imaging and GPR.

ii) To integrate remote sensing and geophysical methods to locate the shallow buried archaeological remain structures at Sungai Batu.

iii) To characterize the possible signatures that signify the buried structure from archaeological view, Land Surface Temperature (LST), Digital Surface Model (DSM), magnetic residual map, 2-D inversion model and radargram results.

1.4 Scope of study

Remote sensing and geophysical methods; magnetic, 2-D resistivity imaging and GPR method were implemented in this research and conducted at four study areas at Sungai Batu, Lembah Bujang, Kedah. The study presented applied a continuous interpretation of the site characteristics through research phases, depending upon the information obtained during the previous phases. Study areas were chosen based on archaeological views which are mound areas and exposed clay bricks on the surface. Landsat 5 and Landsat 8 data were employed at Sungai Batu areas to retrieve land surface temperature (LST) by using ArcMap 10 software. An unmanned aerial vehicle (UAV) was employed at the SB2 site to capture aerial photos and the data was processed using agisoft photoscan. All of three geophysical methods that mentioned above were carried out at SB1 and SB2 site meanwhile only magnetic and 2-D resistivity imaging methods were employed at SB2ZZ and only 2-D resistivity imaging was conducted at the SB3 site. The main purpose of this research is to characterize the surficial remnant that indicates the buried structure from LST, DSM, magnetic residual map, 2-D inversion model and radargram results. All of the geophysical methods were conducted on the same line. The data acquired were processed using ArcMap 10, Agisoft Photoscan, Surfer8, Res2Dinv and Reflexw software.

1.5 Significance of study

The research aims to determine buried structure areas that have great archaeological potential at Sungai Batu using remote sensing and geophysical methods. Mound areas and exposed clay bricks on the surface are two main characteristics in choosing study areas from the archaeological perspective. In this study, the combination of remote sensing method and other geophysical method which were magnetic, 2-D resistivity imaging and GPR were applied to get detail interpretation and were focused at one place only which is Sungai Batu, Lembah Bujang, Kedah, Malaysia since a lot of Sungai Batu area is still less explored than other archaeological sites. The excavation was also done at SB2ZZ site to prove that combination methods give an accurate data interpretation. The successful application of the methods relies on a great deal of expertise in archaeology, geophysics and digital image processing.

1.6 Layout of the thesis

Basically, the layout of this research is as follow:

Chapter 2 explained the theories behind remote sensing, magnetic, 2-D resistivity imaging and GPR methods. The previous studies using remote sensing and various geophysical methods applied in the archaeological study were divided into two subtopics which are Sungai Batu studies and outside of Sungai Batu studies being discussed for better understanding on this topic.

Chapter 3 includes the research flowchart. The geology of the study areas is explained in details. There are four study areas which are SB2ZZ, SB1, SB2 and SB3 sites that are located at Sungai Batu, Lembah Bujang, Kedah. The chapter also explained in details about the equipment, data acquisition and data processing of the geophysical methods that were used in this study.

In Chapter 4, the data has been displayed. The detail information or data involving the archaeological study being discussed for each method and well explained. Based on archaeologist perspective, mound areas and exposed clay bricks on the surface are main characteristics for an area to be recognized as one of the potential archaeology sites in Lembah Bujang. Based on geophysics interpretation, higher resistivity values and higher magnetic value probably showed the anomalous of clay bricks on the shallow subsurface.

Finally, Chapter 5 concluded the whole research to characterize from remote sensing, magnetic residual map 2-D inversion model and radargram results by using geophysical methods; magnetic, 2-D resistivity imaging and GPR. The recommendations are also discussed in this chapter for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Geophysical methods were originally developed for the study of landforms beneath the earth and studying geological forms, but during the latest years, they have become more crucial for archaeological investigating (Smekalova et al., 2008). The practice of geophysical methods to delineate, interpret or figure historical remnant at minimum cost and in a non-damaging approach allows inventing archaeological works in various ways. The methods may be categorized as passive or active. Active methods are the methods which use artificial sources to send the signal into the earth such as electrical resistivity and seismic methods. Passive methods do not require sources but use the natural signal of the earth for example gravity, magnetic and self-potential method (Weymouth and Huggins, 1985). Archaeological prospection is basically about the classification of differences between materials inside and outside of archaeological structures. These can affect the surface of the ground if there are buried remains that can cause changes in physical features. There is a feasibility of identifying subsurface remains through measuring these physical properties across buried features. Remote sensing method will easily help if the changes in the physical properties are noticeable (Batayneh, 2011).

2.2 Remote sensing

Remote sensing is a method of acquiring data from distant objects without being in direct contact (ManiMurali, 2015). There are several ways to practice remote sensing method either by ground-based instrumentations or airborne sensors, for archaeological studies has already long antiquity of study, scientific publications, and utilizations in the field (Tapete, 2018). Remote sensing instruments have two primary types which are active and passive. Active sensors such as Lidar and Radar provide their own source of energy to illuminate the objects they observe. An active sensor emits radiation in the direction of the target to be investigated. The sensor then detects and measures the radiation that is reflected or backscattered from the target. Passive sensors such as radiometer and spectrometer on the other hand, detect natural energy (radiation) that is emitted or reflected by the object or scene being observed. Remote sensing may expose archaeological features directly, where they are still extant in the form of topographical variations. Archaeological features may be disclosed in the form of variations in the coloring and height of the vegetation when they no longer exist above the subsurface (Campana S., 2017). The success of remote sensing in archaeological applications depends not only on the date of data capture but also on the quality of the collected evidence. At least four parameters are involved here: spatial, spectral, radiometric, and temporal resolutions (Lillesand et al., 2015). Spatial resolution represents one of the most important parameters for archaeological remote sensing, in that it is critical to determining the size of archaeological features that can be identified in the resulting data. Temporal resolution relates to the frequency of overflights by the satellite, aircraft, or any other recording platform. It is extremely relevant in archaeological studies, making it possible in some instances to monitor landscape or site transformations over time (measured in days, years, or even decades).

2.2.1 Landsat satellites

On 1st March 1984, Landsat 5 started by National Aeronautics and Space Administration (NASA), the agency's last originally mandated Landsat satellite and continue operational until 5 June 2013 (Giannini et al., 2015). The Thematic Mapper (TM) sensor on board of the Landsat 5 satellite supplies images of the Earth's surface consisting of six spectral bands with a spatial resolution of 30 meters which include Bands 1-5 and Band 7 with one thermal band (Band 6) (Table 2.1) (Sobrino et al., 2004).

Table 2.1 List of Landsat 5 spectral bands (Sobrino et al., 2004).

Bands	**Wavelength (μm)**	**Resolution (m)**
1-Blue	0.45-0.52	30
2-Green	0.52-0.60	30
3-Red	0.63-0.69	30
4-Near Infrared (NIR)	0.76-0.90	30
5-Shortwave Infrared (SWIR)1	1.55-1.75	30
6-Thermal	10.40-12.5	120
7-Shortwave Infrared (SWIR)2	2.08-2.35	30

Landsat 8 was launched on 11th February 2013 and positioned into orbit with two instruments on-board: (1) the Operational Land Imager (OLI) collects data at a 30 m spatial resolution with nine spectral bands in the visual, near-infrared (NIR), the shortwave infrared (SWIR) spectral regions and an additional panchromatic band of 15 m spatial resolution.; and (2) the Thermal Infrared Sensor (TIRS) senses the Thermal Infrared (TIR) radiance at a spatial resolution of 100 m using two spectral bands in the Longwave Infrared (LWIR) located in the atmospheric window between

10 and 12 µm (Table 2.2) (Rozenstein et al., 2014; Du et al., 2014; Anandababu et al., 2018).

Table 2.2 List of Landsat 8 spectral bands (Barsi et al., 2014).

Bands	Wavelength (µm)	Resolution (m)
1-Ultra Blue (coastal/aerosol)	0.433-0.453	30
2-Blue	0.450-0.515	30
3-Green	0.525-0.600	30
4-Red	0.630-0.680	30
5-NIR	0.845-0.885	30
6-SWIR 1	1.560-1.660	30
7-SWIR 2	2.100-2.300	30
8-Panchromatic	0.500-0.680	30
9-Cirrus	1.360-1.390	30
10-TIRS 1	10.6-11.2	100
11-TIRS 2	11.5-12.5	100

2.2.1(a) Land surface temperature

The land surface temperature is an important parameter in the physical process and the interaction between the land and the atmosphere. Land surface temperature data can contribute knowledge on spatial and temporal variations of the Earth's surface in numerous applications on a global scale (Bunai and Wibowo, 2018; Wang et al., 2015). There are three major variables that must be deliberate and rectified: atmosphere, angular and emissivity to acquire the land surface temperature values from satellite data. Now there are three common methods: multi-channel algorithm, split-window algorithm (SWA) and single-channel algorithm (SCA) to retrieve the land surface temperature which are extremely crucial application field of thermal infrared remote sensing (Jiang et al., 2013; Wang et al., 2017).

2.2.2 Aerial photography

Since the 20th century, aerial photography has been integral to the field of archaeology (Bewley, 2003). Podiums for aerial photography consist of fixed-wing aircraft, helicopters, unmanned aerial vehicles (UAVs or "drones"), balloons and parachutes. The photographs are taken while in flight over a designated study area. These photographs are then examined for signs of ancient remains. Historic aerial photographs are very beneficial in landscape and geo-archaeological study, as it allows the reconstruction of changes in the landscape, changes in land usage as well as being a record for archaeological remains that have been covered by vegetation or otherwise vanished (Nilsson, 2010; Rinaudo et al., 2012).

2.3 Magnetic

One of a passive geophysical method is the method of a magnetic survey which is based on the detection of contrasts in the magnetic properties of different materials. Magnetic susceptibility, k, is the physical parameter to which magnetic surveys are sensitive. The difference in the magnetic properties of the subsurface material (sediments, rocks, or artificial materials such as brick) can create a noticeable variation (anomaly) in the measured magnetic field (Schmidt, 2007). Anomalies may be caused by structures such as walls, ditches, foundations, fire hearths, pits, or even an area of more intensive habitation. The geologic materials consist of iron particles have distinct magnetic behaviours and these iron particles can be magnetized by natural or human processes, form local magnetic fields that can be measured. The surface layers of earth are likely to present higher magnetism than deeper materials because of the exposure to the sun, to the atmosphere and to human activity (Smekalova et al., 2008). Magnetic methods are one of the most competent and common among the geophysical methods used for archaeology because many archaeological objects have different magnetic properties which allow one to differentiate them on the surface of the site by the specific magnetic anomalies they create.

2.4 2-D resistivity imaging

The 2-D resistivity imaging method is an active geophysical survey. The electricity flows through the rocks by the current is implanted into the ground by a pair of electrodes, metal sticks installed into the ground. Electric current is described as the rate of flow of charge passing through a cross-section of a conducting medium for a specific length of time. To cause charge to flow, a voltage (also known as potential difference, a measure of the energy used to move the charges) must be employed. When a voltage is utilized and current flows, resistance is encountered in the movement of the charge, which is relied on the characteristics of the medium in which the charges are moving. These three physical quantities are related by Ohm's law (Equation 2.1):

$$R = \frac{V}{I} \tag{2.1}$$

Where;

R: Resistance of the conductor (Ω)

V: Voltage (V)

I: Current

The pseudo-section contouring method is commonly used when to plot data from 2-D resistivity imaging (Loke, 2004). The pseudo-section gives a very estimate illustration of the true subsurface resistivity distribution. However, the pseudo-section gives a twisted picture of the subsurface because the shapes of the contours rely on the type of array used as well as the true subsurface resistivity. In practice, the arrays that are most normally used for 2-D resistivity imaging surveys are the (a) Wenner, (b) dipole-dipole (c) Wenner-Schlumberger (d) pole-pole and (d) pole-dipole. In this research, we solely focused on using a pole-dipole array because it has good horizontal coverage (Loke, 2004).

2.5 Ground-penetrating radar

The Ground-Penetrating Radar (GPR) is the geophysical method that employs radar pulses to figure the subsurface. A typical GPR includes a transmitting antenna and a receiver antenna. The transmitter antenna transmits electromagnetic waves with a fixed frequency into the subsurface. The receiver antenna accepts the portion of the energy, which is reflected by variations in material properties of the subsurface and records the amplitude of this response for mapping purposes (Figure 2.1) (Muztaza et al., 2012). In general, antennas with a frequency range of approximately 200–500 MHz are appropriate for most archaeological studies as they provide a depth of investigation up to about 3 m and an acceptable resolution

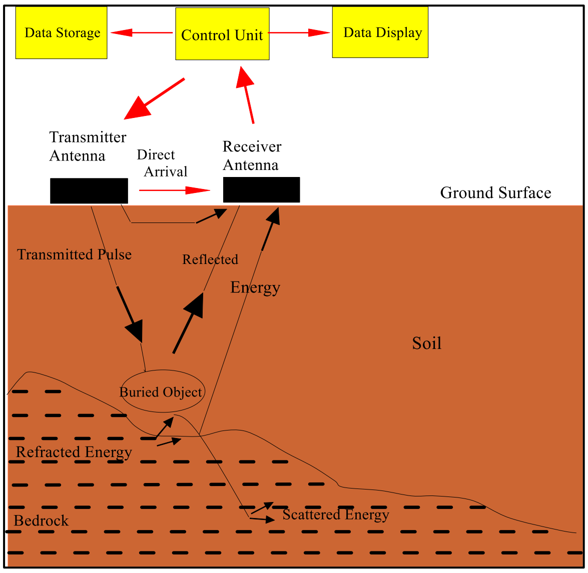


Figure 2.1 GPR schematic (Muztaza et al., 2012).

2.6 Previous study

In the past, there are several studies about the application of geophysical surveys in the research of archaeological prospections. In this subtopic, it's divided into two parts which are Sungai Batu studies and outer part of Sungai Batu studies by using remote sensing and geophysical methods in archaeological prospecting.

2.6.1 Sungai Batu

Sheyh et al. (2014) explained about archaeological evidence detection by using the GPR method at SB2K site, Sungai Batu, Lembah Bujang, Kedah, Malaysia. The primary focus of this research is to identify the location of potential buried archaeological evidence. The research location was situated at SB2K, covered area 12 m x 11 m approximately. GPR cross-section of south-north survey lines has been performed, as Figure 2.2. From the 11 lines survey, only line L1 – L5 has been presented in 3-D GPR data processing. Three lines were discovered have potential anomalies at L3; 7.9 – 8.6 m at depth 0.5 m, L6; 2.0 – 7.8 m at depth 0.9 m and L7;

1.4 – 7.9 m at depth of 0.9 m respectively. The anomalies are because of the existence of a small object of archaeological artefact entombed underneath the seen location. Figure 2.3 shows the study area presented in a 3-D cube with the top view, side view and front view. Possible anomalies detected with a red mark showing distribution location of the potential archaeological artefact. GPR propitiously identified a potential historical archaeological sample buried underneath the earth but cannot determine each anomaly by specific types such as iron slags, pottery, freshwater shells, beads and ceramics. 3-D views present a clearer image of the subsurface over the survey area where the distributions of anomalies are well mapped.

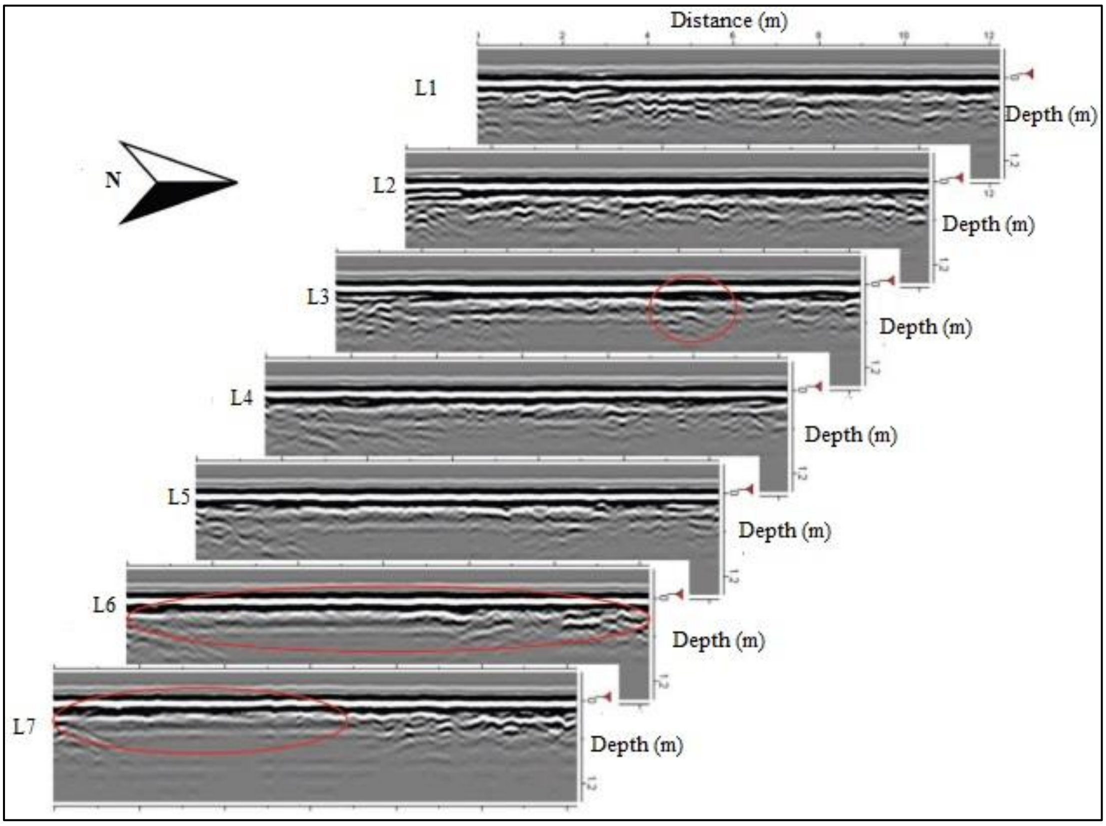


Figure 2.2 Seven parallel GPR cross-sections for survey lines oriented in a south-north direction. Location of anomalies are marked in the red circle (Sheyh et al., 2014).

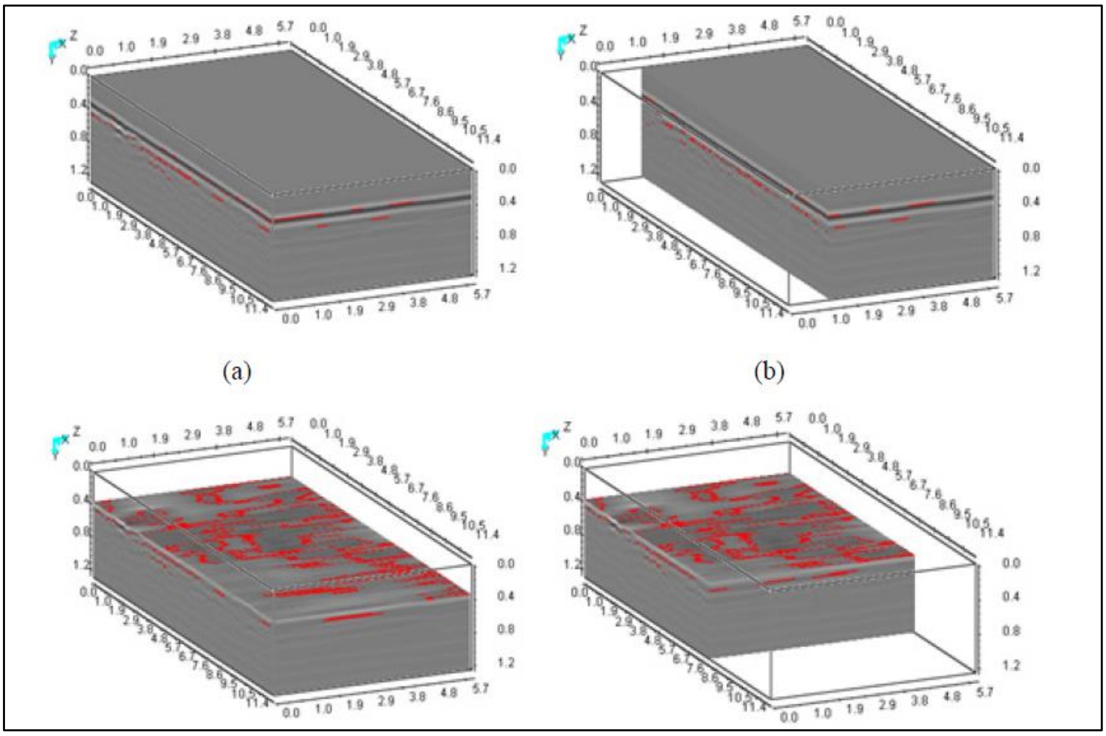


Figure 2.3 Block and sub-block views to focus on the anomaly at SB2K (a) 3-D cube of GPR data that covers area of 12 m x 5 m x 1.4 m (b) 3-D cube cut at z = 1 m (c) 3-D cube cut at y = 0.4 m (d) 3-D cube cut at x = 7.6 m and y = 0.4 m (Sheyh et al., 2014).

Ihsan et al. (2015) carried out a magnetic method at Sungai Batu, Lembah Bujang, Kedah, Malaysia. The magnetic method was carried out using G-856 proton magnetometer and the spacing between stations was about 5 m to 20 m. Figure 2.4 shows the magnetic map on which the black dotted are the magnetic stations. The magnetic map gives the magnetic value ranges from -50 nT to 100 nT. The high magnetic value between 40 nT and 100 nT marked distribution of the anomaly features within the study area. There are few interesting anomalies identified and the anomaly that detected is interpreted as baked clay bricks. These anomaly features detected according to the magnetic contrast and the surrounding mainly sandy clay. This result is proved by the excavation of archaeologist from the Centre for Global Archaeological Research (CGAR), Universiti Sains Malaysia. In this survey, at the high magnetic values was interpreted as baked clay bricks and at the low magnetic values was interpreted as the ancient river. The magnetic method helps the archaeologist in detecting the buried structure and the characteristic for the magnetic result in archaeological purpose will help for further investigation.

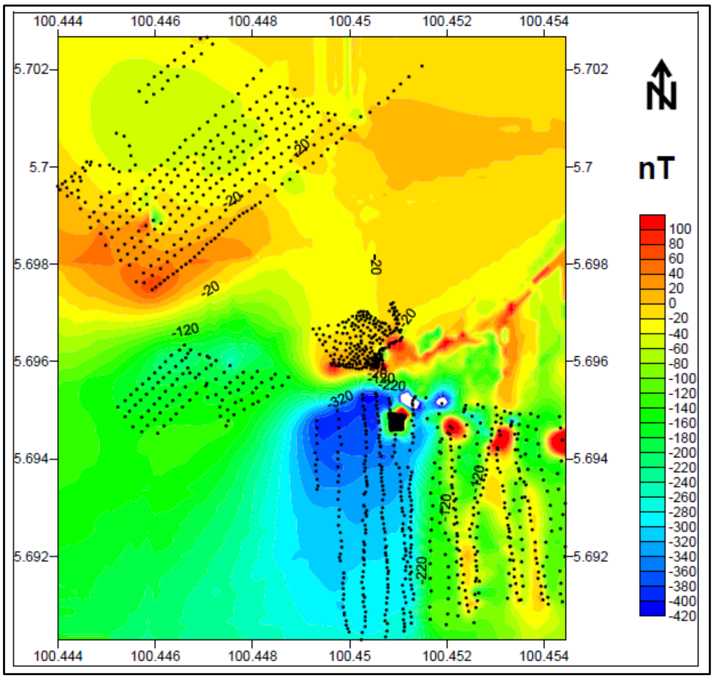
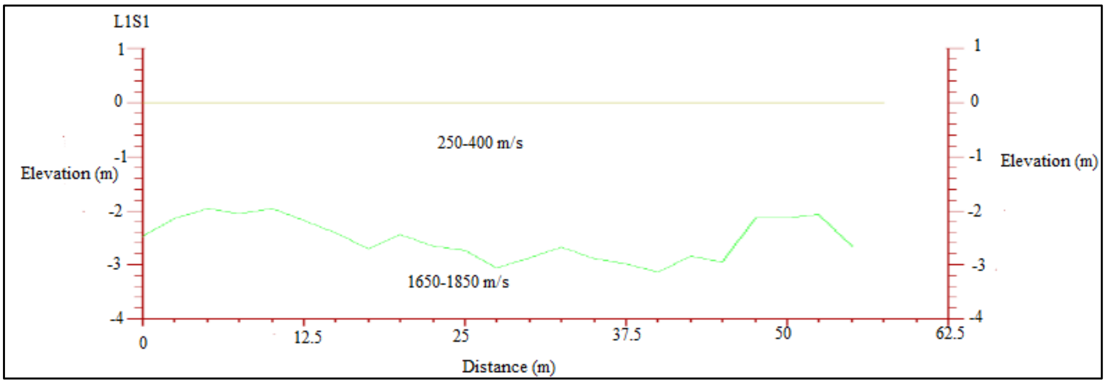


Figure 2.4 Magnetic anomaly in Sungai Batu, Lembah Bujang (Ihsan et al., 2015).

Alashloo et al. (2011) presented non-invasive geophysical methods; seismic refraction and magnetic at Sungai Batu Archaeological Site, Lembah Bujang, Kedah, Malaysia with the purpose of detecting buried artefacts and specifying subsurface geological properties. Seismic refraction method was carried out for two profiles using a 24 channel seismograph. The data of profile S_1 and S_2 are plotted in Figure 2.5, also the profile S_2 is shown in Figure 2.6. The profile S_1 consists of two layers with velocity 250 to 400 ms^{-1} in the first layer and 1650 to 2000 ms^{-1} in the second layer. The profile S_2 has a range of wave velocity as same as the wave velocity of profile S_1 in two layers where the depth of the first layer is from 1.2 to 3.3 m. It can clearly be seen that there is no anomaly caused by archaeological structures over the seismic profiles. The magnetic measurements were carried out in 15 profiles using a

G-856AX proton precession magnetometer with 5 m sampling interval along 10 m spaced parallel survey lines. Two versions of the same residual magnetic map can be seen in Figure 2.7 which magnetic survey lines are indicated by yellow symbols in the first one, and in another one, the most distinct anomalies are rounded for further discussion and analysis. Two anomalies 5 and 6 are large dipoles with high magnetic values which can be related to ruins of old buildings made of mud bricks. There is evidence for this idea which is the archaeological excavation in some part of anomaly 6 and in the adjacent site, where ruins of mud-brick building have been found. An excavation test was performed by archaeologists indicated the ruins of an old building in correspondence of these anomalies. The use of seismic refraction and magnetic methods in archaeological research bring in more information upon which archaeologists can refer to further investigations of the site.



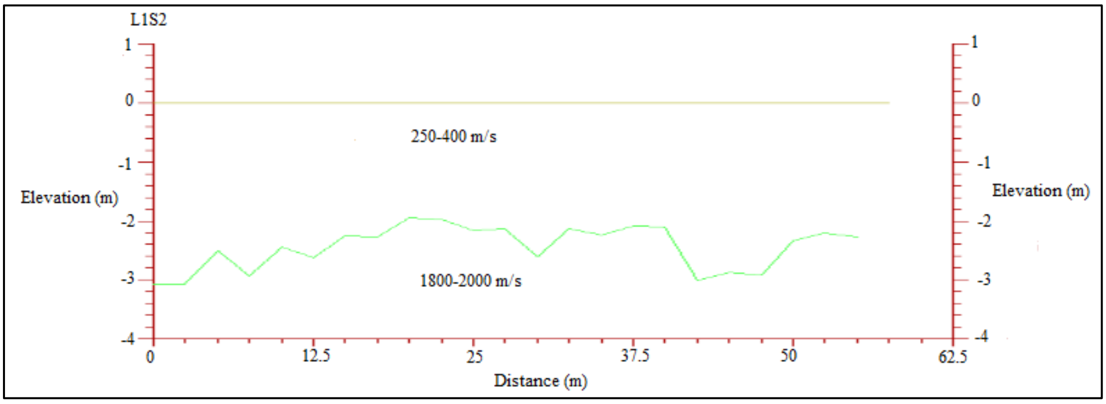


Figure 2.5 Seismic refraction profile S_1, the first and second spread (Alashloo et al., 2011).

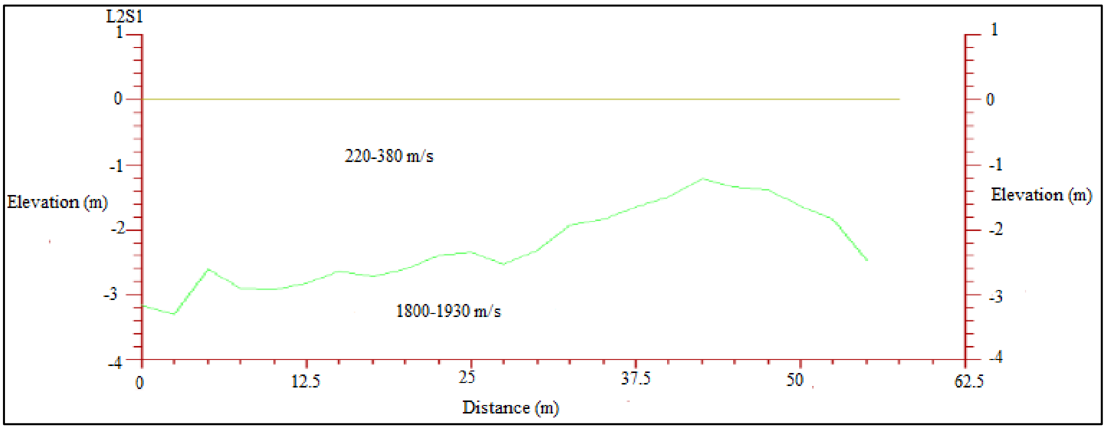


Figure 2.6 Seismic refraction profile S_2 (Alashloo et al., 2011).

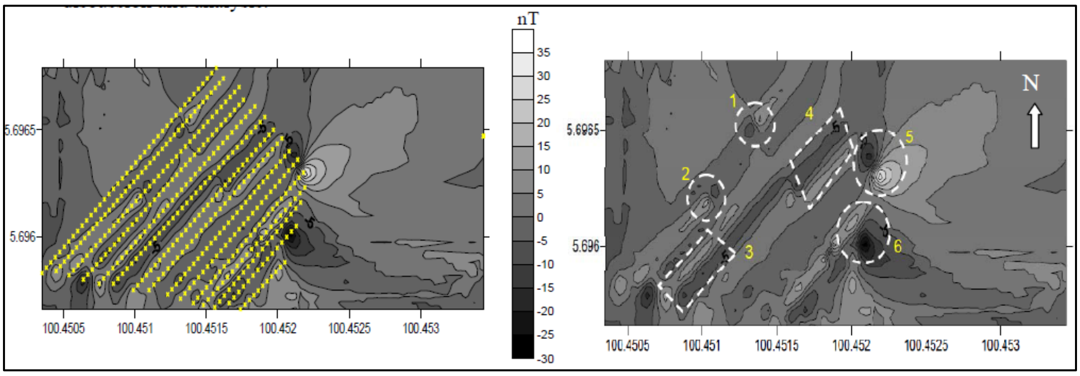


Figure 2.7 Residual maps with magnetic profiles with 5 nT contour interval (Alashloo et al., 2011).

2.6.2 Outside of Sungai Batu

Samsudin and Hamzah (1999) conducted various geophysical methods at three different archaeology sites in Malaysia. The first site is situated at Sungai Mas village in Kuala Muda District of Kedah, north-west of Malaysia. 2-D resistivity imaging method was employed using a dipole-dipole array with four- in-line metal electrodes. Figure 2.8 illustrates the result of 2-D resistivity imaging map over buried remains of building at Sungai Mas archaeological site. Based on results of 2-D resistivity imaging survey, three types of soil resistivity were observed for the study site: i) soil with resistivity less than 20 Ωm is interpreted to be related to marine sediment or sandy soil with saltwater content, ii) soil with resistivity ranges from 20 to 200 Ωm is referred to alluvium or sandy soil with brackish to freshwater contents and iii) soil with a resistivity greater than 200 Ωm could be related to the soil material associated with the buried archaeological objects.

The second site is located in a fisherman's village on the northern bank of Kedah River mouth and it lies in a coastal lowland area of Kuala Kedah District. 2-D resistivity imaging using Wenner array and magnetic methods were performed only on chosen areas of the site due to the lack of ground condition. Figure 2.9 shows the resistivity anomalous areas of the archaeological site in Kuala Kedah, Kedah. Field evidence shows that the high resistivity anomalies range between 450 to 600 Ωm corresponds to the wall of the fort foundation which was buried in the low resistivity soil of marine clay appeared at depths ranging from 0.1 to 5.0 meters beneath the ground. The magnetic method was performed at the remains of the partially buried brick floor and the wall of the fort. The high magnetic gradient was acquired in the area of the floor structure which proposes that the anomaly could probably due to the bricks of the floor material or other highly magnetic objects of archaeological significance. The third archaeological site is situated in the area of Pasir Salak historical complex in Kampong Gajah District, south of Perak. 2-D resistivity imaging employed dipole-dipole array and magnetic surveys were performed to identify any probability of buried artefact in the studied area. Figure 2.10 shows the presence of several anomalies of high resistivity which ranges between 400 to 600 Ωm in the studied area. A magnetic gradient map shows two anomalous areas. Results of 2-D resistivity imaging and magnetic surveys illustrate that the methods are non-destructive and very helpful in providing information about the subsurface content of archaeological sites. The success of these methods relied upon the resistivity and magnetic contrasts of the artefacts with soils surrounding it.

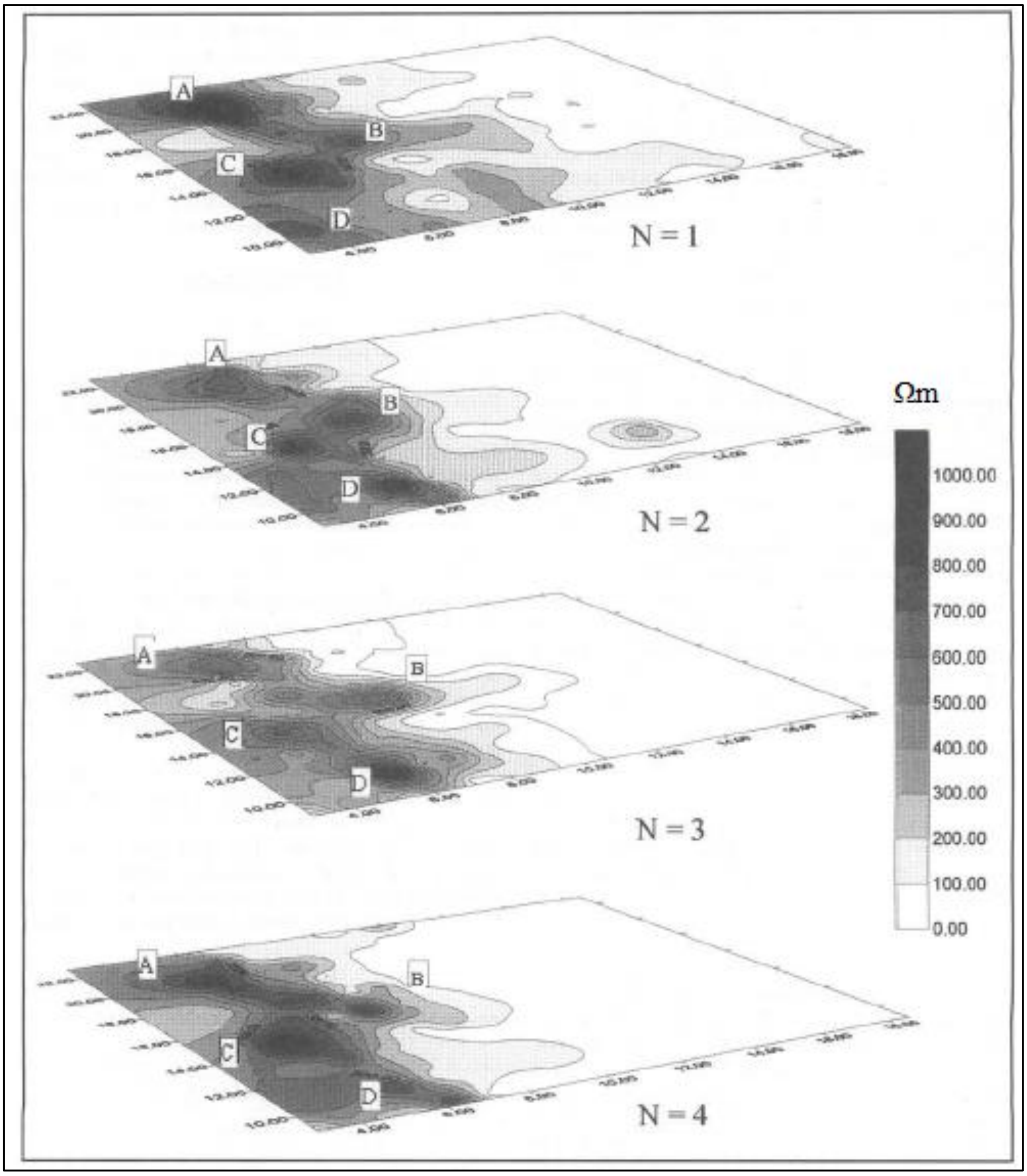


Figure 2.8 2-D resistivity imaging map over buried remains of building at Sungai Mas archaeological site (Samsudin and Hamzah, 1999).

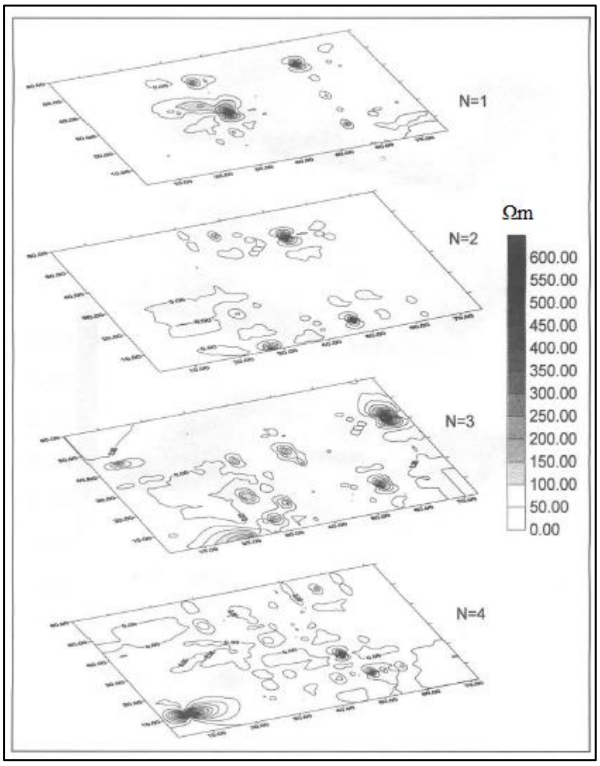


Figure 2.9 Resistivity anomalous areas of the archaeological site in Kuala Kedah, Kedah (Samsudin and Hamzah, 1999).

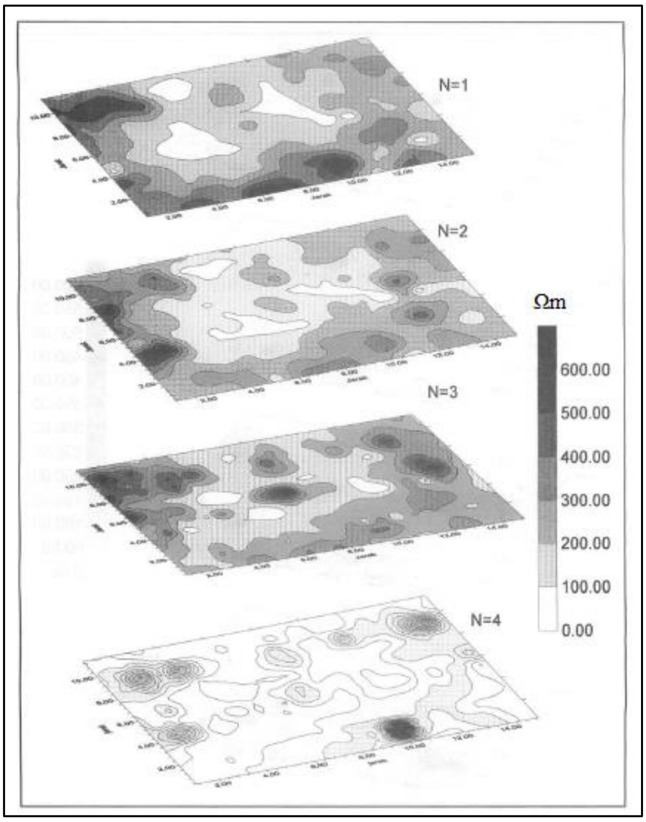


Figure 2.10 Pasir Salak archaeological site showing anomalous resistivity zones (Samsudin and Hamzah, 1999).