Magnetic and 2D Electrical Imaging Methods to Investigate an Archaeological Site at Sungai Batu, Kedah, Malaysia

S. Y. Moussavi Alashloo¹ *, R. Saad ¹, M. N. M. Nawawi ¹, M. Saidin ² and M. M. Alashloo ¹

¹ School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia
² Global Center for Archaeological Research, Universiti Sains Malaysia, 11800 Penang, Malaysia

Abstract. The Sungai Batu archaeological area is believed to be the earliest entrepot and religious center in Malaysia and a high-potential archaeological area where scientists search for signs of civilization. With the aim of locating archaeological remains and characterizing the shallow subsurface geology in a non-destructive manner, a geophysical investigation including magnetometry and electrical resistivity tomography (ERT) techniques was carried out at an unexplored site in Sungai Batu, northwest Malaysia. The magnetometry survey was performed using a G-856 proton precession magnetometer over 15 profiles. The magnetometry results displayed two main anomalies which had a high magnetic value, indicating buried structures. The ERT survey was designed in 5 profiles employing a pole-dipole array. The ERT data was processed by utilizing the smoothness constrained least-squares inversion which revealed three main layers of alluvium soil mixed with sand and clay, saturated zone and the bedrock layer. An excavation test, conducted by archaeologists, confirmed the geophysical results. The joint analyses of magnetic and ERT data demonstrated that geophysical techniques are powerful tools to obtain useful information about underground for planning a fast, cost-effective and environmentally friendly archaeological prospecting.

Keywords: magnetometry, electrical resistivity tomography, archaeological prospecting, Sungai Batu

1. Introduction

Geophysical methods have been successfully applied in archaeological prospecting in recent years. Also, the joint application of these non-invasive techniques acquires high resolution images of the subsurface to decrease the environmental damage, time and cost of archaeological surveys. These methods comprise magnetic, geoelectric, ground penetrating radar (GPR) and seismic [1-3]. The magnetic and electrical resistivity tomography (ERT) are commonly used in geophysical survey because of acquiring large amounts of data, quickly, and providing a high-quality image of subsurface structures [4, 5]. These methods represent a wide range of non-invasive applications for the archaeological purpose [2].

One of the Sungai Batu archaeological sites was prospected to achieve the principal goals of detecting the location of archaeological remains and characterizing the shallow geological structure to show the usefulness of geophysical methods in archaeological prospection. Sungai Batu archaeological area in Bujang Valley along the road from Sungai Petani to Merbok demonstrates that civilization in Malaysia had begun much earlier and was the oldest in southeast Asia (Figure 1). These sites might have been a remnant of an ancient jetty applied for exchange traded goods that may have involved iron ores [6].

In this study, data were collected using two geophysical methods, magnetic and ERT. In the first step, which was magnetic survey, a total of 15 profiles were acquired by a G-856 proton precession magnetometer. Then, according to the magnetic result, the resistivity survey was designed in 5 profiles. 2D resistivity data were acquired utilizing the pole-dipole configuration to achieve a high resolution image of underground structure. This paper presents and discusses the processing and joint interpretation of the data to certify the successful application of magnetic and ERT methods for planning the excavation survey.
2. Study Area

Sungai Batu is considered by archaeologists as a high-potential archaeological area where scientists search signs of civilization. This area is located in Bujang Valley along the road from Sungai Petani to Merbok in northwestern Malaysia. Studies of the Bujang Valley civilization began more than a century ago and Bujang Valley is believed to be the earliest entrepot and religious center in the country. Its role can be confirmed by the discovery of archaeological evidence such as the discovery site of the Hindu-Buddhist temple, statues, porcelain, beads and many other artifacts [7, 8].

The study area is part of Jerai formation in Kedah, and its elevation is about 12 m above sea level. The drainage pattern on the Kedah Peak massif is radial [9]. Away from the peak area, however, the pattern becomes more complicated. This area is covered by Jerai Formation which consists of two distinct facies. One of the facies is clay comprised of schist, semi-schist and mudstone. Another one is metamorphosed sand including quartzite, granulite, and grit. Distribution of the two facies cannot be sharply delineated, due to complex interbedding and the gradational character of contacts between them throughout the formation. Generally however the sediments are very poorly sorted, and the sand and clay strata are frequently interbedded [10].

3. Geophysical Methods

Magnetic and ERT techniques were applied in the present geophysical study. These techniques are known as fast, high resolution, non-invasive and cost-effective techniques. Furthermore, it is possible to provide useful information for mapping shallow structures and planning guidelines for the future archaeological prospection. At this study, first, a magnetometry investigation was executed followed by ERT survey.

3.1. Magnetometry survey

The magnetic survey is a passive geophysical technique depends on the contrasts in a magnetic property between the feature of interest and its surrounding environment. The most significant magnetic factors for archaeological investigation are magnetization and magnetic susceptibility. As most archaeological materials contain magnetic particles, they will have magnetic properties and cause magnetic anomalies that can be applied in different ways [11]. Magnetometry is one of the magnetic survey methods which records the magnetic fields produced by a contrast in magnetization, whether it is produced due to a magnetic susceptibility contrast, or remanent, for instance from thermoremanent magnetization.
In the present study, the magnetic measurements were performed in 15 profiles using a G-856AX proton precession magnetometer with 5 m sampling interval along 10 m spaced parallel survey lines (Figure 2). The coordinates of the beginning and end points of each line were recorded by GPS for use in the Surfer software to create a plot of the survey area. A base station was set up around 200 meters away from the survey area where a G-856 magnetometer recorded magnetic readings at a time interval of 1 minute to remove the diurnal variation effects of the earth’s magnetic field from survey measurements. While the data acquisition procedures were well performed, it was still not practical to make all the readings needed to clearly process data. First step in magnetic processing was inspecting raw data for spikes, gaps, instrument noise or any other irregularities in the data. The next step involved diurnal variation correction and IGRF correction. Once corrections were done, the data were exported into a grid file to the program Surfer 8. After calculating a grid from XYZ data in Surfer, residual was carried out to compute the difference between a grid value and the raw data at any definite location of the site.

3.2. 2D Electrical Resistivity Tomography

The ERT technique, as an active method, enables geophysicists to achieve high resolution images of subsurface electrical properties. Basically, in resistivity method, two current electrodes are utilized to inject the low frequency direct current into the ground. Then, the resulting potential difference is measured at two
other potential electrodes. The development of modern computer-controlled multielectrode systems [12] and 2D and 3D inversion models [13] allows scientists to obtain a detailed picture of the subsurface.

Five resistivity profiles were collected using a pole-dipole electrode configuration with 2 m electrode spacing (Figure 2). The profiles of $R_1$, $R_2$, $R_4$ and $R_5$ involved 3 spreads, had 120 m length, but profile $R_3$ with 4 spread, covered 160 m. The pole-dipole configuration was employed because of relatively good horizontal coverage. This array required a remote electrode, which was set adequately far from the survey line, to obtain deeper penetration. The acquired 2D resistivity data were processed by utilizing the RES2DINV software based on the smoothness constrained least-squares inversion [14].

4. Results and Discussion

4.1. Magnetometry Method

After data processing, magnetic data were input into the program Surfer 8 to produce contour maps. A residual map was produced from the magnetic data for providing more visible results and highlighting the main anomalies. Figure 3 illustrates the total magnetic field map and the residual magnetic map in which magnetic survey lines are indicated by yellow symbols in the first one, and in the other one the most distinct anomalies are rounded for further discussion.

![Fig. 3: Magnetometry survey results, a) Total magnetic field contour map, b) Residual magnetic map with anomalies labelled. The contour interval is 5 nT.](image)

The residual magnetic map gives magnetic values which vary from about -30 nT to 35 nT. Six anomalies are rounded on the residual map. Two magnetic anomalies 1 and 2 have the same magnetic value of about 20 nT in the positive pole and -5 nT in the negative pole. Magnetic anomaly 3 is a dipole anomaly which the positive pole is 15 nT and the negative pole is -5 nT. Another magnetic anomaly, which is found in lines 7 and 8, is number 4 which has a magnetic value the same as anomaly 3. A large dipole anomaly with a positive value 25 nT and a negative value -15 nT is found in the northeast of the site, marked by number 5. Finally, lines of 12 to 14 show the dipole anomaly of number 6 with a value of 15 nT and -20 nT for positive and negative poles, respectively. Two anomalies 1 and 2 have low magnetic values which can be produced
by a change in soil material properties. Also, in the other four survey lines \( M_5 - M_8 \), the magnetic value for anomalies 3 and 4 is low. Therefore, they are not able to generate enough information to make any convincing conclusion about the archaeological remains. This can be confirmed by ERT results which show the change in subsurface geology near these anomalies. However, 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 an evidence for this idea which is the archaeological excavation in some part of anomaly 6 and in adjacent site, where ruins of mudbrick building have been found.

4.2. Electrical Resistivity Tomography

The ERT data were inverted by using the RES2DINV software \[14\] to obtain a more detailed image of subsurface. Figure 4 displays the images of 5 ERT lines. These images basically illustrate the presence of three levels. The upper level, with a resistivity value of 50 -1000 \( \Omega \cdot \text{m} \), is interpreted as an alluvium soil consisting of sand and clay, the depth of which changes from 1 to 10 m. The second level, with low resistivity value (< 50 \( \Omega \cdot \text{m} \)), is consistent with a zone saturated with water. The thickness of this layer is from 5 to 20 m in different parts of the site. The third level has a high resistivity value (> 1000 \( \Omega \cdot \text{m} \)), which is most probably related to quartzite bedrock. In the first level, some anomalies with high resistivity can clearly be seen, caused by boulders, and these abnormalities can be the reason of low magnetic anomalies. The depth of these anomalies also indicates that they cannot be related to archaeological materials, since the normal depth of artifacts, which were found at the Sungai Batu area, starts from 0.5 to 1.5 m. The anomaly K and L, labelled in lines of \( R_1 \) and \( R_3 \), corresponds to the magnetic anomaly 5 and 6. The saturated zone could be referred to fluvial system and this evidence can assist archaeologists for tracing the ancient river which...
may affirm the significance of the Sungai Batu area not only as a center for religious and production activities, but also the exchange of goods.

5. Conclusions

Magnetic and electrical resistivity tomography methods were used in this study to detect the location of buried remains, ruins of old buildings, and to map the shallow geological stratigraphy and thickness of layers at the Sungai Batu archaeological area. The magnetic survey evidenced the presence of two main anomalies, due to buried structures. An excavation test was performed by Archaeologists indicated the ruins of old building in correspondence of these anomalies. Furthermore, the results of ERT survey revealed three main layers of alluvium soil mixed with sand and clay, saturated zone and the bedrock layer. The joint interpretation of the geophysical results demonstrated that the small anomalies on the magnetic map have caused by the geological changes of the subsurface and they cannot be related to archaeological remains.

Overall, this study and its results confirmed that the application of magnetic and ERT techniques in archaeological prospection yields useful information upon which archaeologists can base further investigations of the site to decrease the time, cost and destruction of extra excavation.

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7. References


