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Non-invasive Geophysical Techniques for Prospecting the Sungai Batu Archaeological Site, Kedah, Malaysia

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Abstract. A geophysical survey that involved two different techniques of seismic refraction and magnetic was carried out with the aim of locating buried artifacts and specifying subsurface geological properties in a non-invasive manner at the Sungai Batu archaeological site, Kedah, Malaysia. Sungai Batu archaeological area is considered by archaeologists as a high-potential archaeological area where scientists search for signs of civilization. Seismic refraction method was performed for two profiles with using a 24 channel seismograph. The processing of the seismic refraction data was based on the FIRSTPIX and GREMIX15 software. The seismic results indicated that the area is composed of two main layers: the upper layer, made up of soil consisting of alluvium and sandy clay, and the second layer, made up of mixed saturated soil with water. The magnetic survey was conducted using a G-856 proton precession magnetometer with 5m sampling interval along 10m spaced parallel survey lines over 15 profiles. Six significant anomalies were found from residual magnetic map which two anomalies had high magnetic values, which can be related to ruins of old buildings made of mud bricks. An excavation test, performed by archaeologists, confirmed the geophysical results. Consequently, the investigated results approved the usefulness of geophysical techniques in mapping the subsurface structure and buried artifacts to design a more efficient plan for reducing the prospecting time and minimizing the environmental damage of archaeological excavation.

Keywords: seismic refraction, magnetic method, archaeology, Sungai Batu.

1. Introduction

During the last years, geophysical methods have been broadly applied in archaeology. Also, the combination of these non-invasive techniques acquires high resolution images of the subsurface to assist the archaeologists to decrease the environmental damage, time and cost of archaeological surveys. These methods comprise of magnetic, geoelectric, ground penetrating radar (GPR) and seismic [1-3]. The utilization of seismic methods in archaeology is restricted due to a low data acquisition ratio compared to other geophysical procedures, Nevertheless, some seismic methods such as refraction have been used to locate buried structures, underlying geology, and specify properties like layer depth and shape [4, 5]. On the other hand, magnetic method is commonly used in archaeological exploration to detect features such as buried walls and structures, bricks, kilns, ditches, pottery, pits, buried pathways, and tombs [6, 7]. Magnetic method acquires large amounts of data rapidly. Many geophysicists have accepted the successful application of the magnetic method in archaeological investigation [2, 8] due to the high-quality images gained from the magnetic data by employing signal and image processing techniques [9, 10].

In this study, one of the 97 archaeological sites of Sungai Batu archaeological complex was investigated to achieve primary objectives of predicting the location of archaeological remains and specifying the shallow geological stratigraphy and thickness of subsurface layers 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

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southeast Asia (Figure 1). These sites might have been a remnant of an ancient jetty applied to exchange trade goods that may involve iron ores.

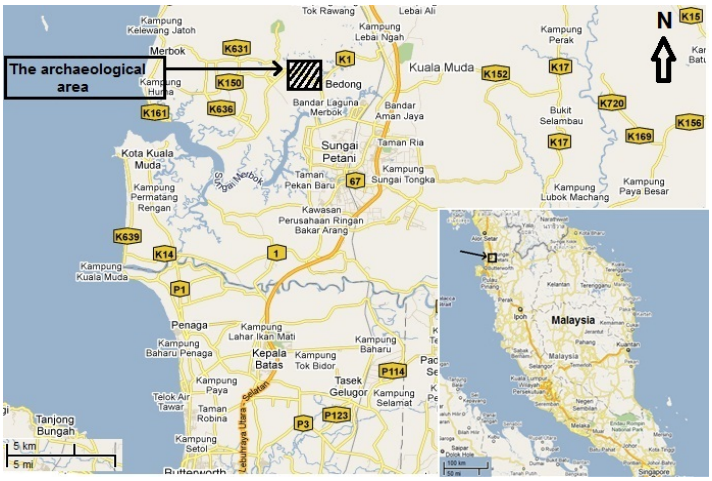

Fig. 1: The location of investigation site in Sungai Batu.

In this study, data were collected using two geophysical methods that are seismic refraction and magnetic. Two profiles employing seismic refraction method using a 24 channel ABEM Terraloc seismograph and 28 Hz geophones with 2.5 m spacing. Seismic data were then processed by using the FIRSTPIX and GREMIX15 software. For magnetic survey, a total of 15 profiles were acquired by a G-856 proton precession magnetometer. The distance between parallel profiles was 10 m, and stations spacing was 5 m. Processing of the magnetic data started with editing of the raw data, then continued with diurnal and IGRF correction. The corrected data were exported into a grid file to the program Surfer 8 to create a contour map. The results of magnetic and seismic refraction surveys indicated that non-invasive geophysical techniques are useful tools for planning the archaeological excavation surveys.

2. Site Description

Sungai Batu archaeological area is considered by archaeologists as a high-potential archaeological area where scientists search signs of civilization. This area is located in Bujang Valley at geographical coordinates 5° 41’ 46” N and 100° 27’ 5” E along the road from Sungai Petani to Merbok in northwestern Malaysia. Bujang Valley is believed to be the earliest entrepot and religious center. Its role can be confirmed by the discovery of archaeological evidence such as the discovery site of the Hindu-Buddhist temple, broken ceramics, statues, porcelain, beads and many other artifacts. The study area is part of Jerai formation in Kedah, and its elevation is about 12 m above the sea level. The drainage pattern on the Kedah Peak massif is truly radial. Away from the peak area, however, the pattern becomes more complicated. This area is covered by Jerai Formation which consists of two distinct facies, and mapped as a separate units. 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 [11]. The petrological evidence suggests that the sediments of the Jerai Formation were laid down in shallow water and derived from a largely granitic landmass not far away. Generally however the sediments are very poorly sorted, the sand and clay strata are frequently interbedded.

3. Data Acquisition

The geophysical surveys involved the application of seismic refraction and magnetic techniques. These techniques are characterized by fast data acquisition rate, high resolution, non-invasive and cost-effective. Furthermore, it is possible to provide efficient information for mapping shallow structures and planning guidelines for the future excavations and archaeological prospection. The present survey was performed in the following way, first a magnetic prospecting was carried out followed by seismic refraction survey.

3.1. Magnetic 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 [12]. The most significant magnetic properties for archaeological investigation are magnetic susceptibility and magnetization. As most archaeological materials contain magnetic particles, they will have magnetic properties and cause to magnetic anomalies that can be applied in different ways [13]. Magnetometry is one of the magnetic survey methods which record 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 this 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 applying 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 which 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 XY location.

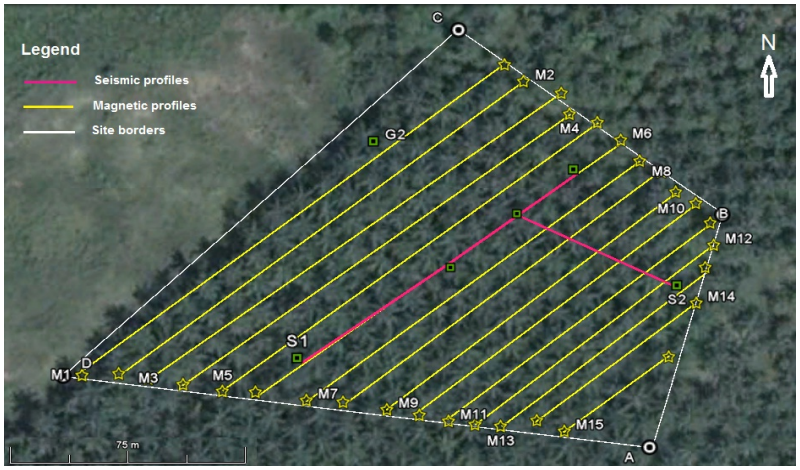

Fig. 2: Survey plan of magnetic and seismic investigations.

3.2. Seismic Refraction Survey

Seismic refraction is a quantitative method as it produces depths of different geological layers, as well as the seismic velocities of these different layers. This method utilizes the physics of wave propagation through the ground to determine subsurface characteristics, particularly the speed of a wave through the subsurface media.

Seismic refraction data were acquired in two profiles of S_1 and S_2 over a survey length of 115m and 57.5m, respectively (Figure 2). S_1 was conducted in two spreads, and S_2 was measured only in one spread using 24 channel ABEM Terraloc MK 8 seismograph with 28 Hz geophones. The P wave energy source of the survey was a 5.5 kg sledgehammer propagating seismic waves through the ground. Nine shot points were chosen for each spread that five shot points were located within the spread which between geophones 1-2, 6-7, 12-13, 18-19 and 23-24, also four off-set shots were recorded at 38m and 80m from the end geophones to give detailed shallow data and greater penetration depth, also facilitate the processing of data (Figure 3).

After ensuring that quality data were collected in the field, seismic refraction data were processed and interpreted utilizing the FIRSTPIX and GREMIX15 software. The analog data of the seismic wave propagation were transferred into the digital data by a seismograph. The significant part of the digital data for the seismic refraction technique was the first arrival time of P waves which travel to the geophones.

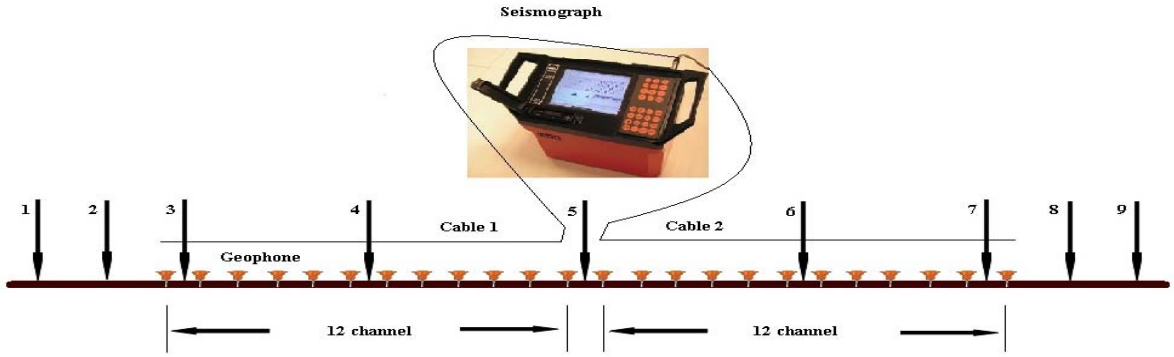

Fig. 3: The geophone spread of seismic survey with 2.5 m interval between geophones and 9 shot points.

The first arrival of the P wave was picked for all the recorded data using FIRSTPIX software, and then the first arrival times were plotted against the distance of geophones. If the first-arrival time for each of them was not matched, an arrival time correction was performed. After correction, these data were stored, and the Generalized Reciprocal Method (GRM) of GREMIX 15 software was used to interpret the first arrivals.

4. Results and Discussion

4.1. Magnetic Method

Magnetic method is a powerful tool for prospecting the archaeological sites. 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. Two versions of the same residual magnetic map can be seen in Figure 4 which magnetic survey lines are indicated by yellow symbols in the first one, and in other one the most distinct anomalies are rounded for further discussion and analysis.

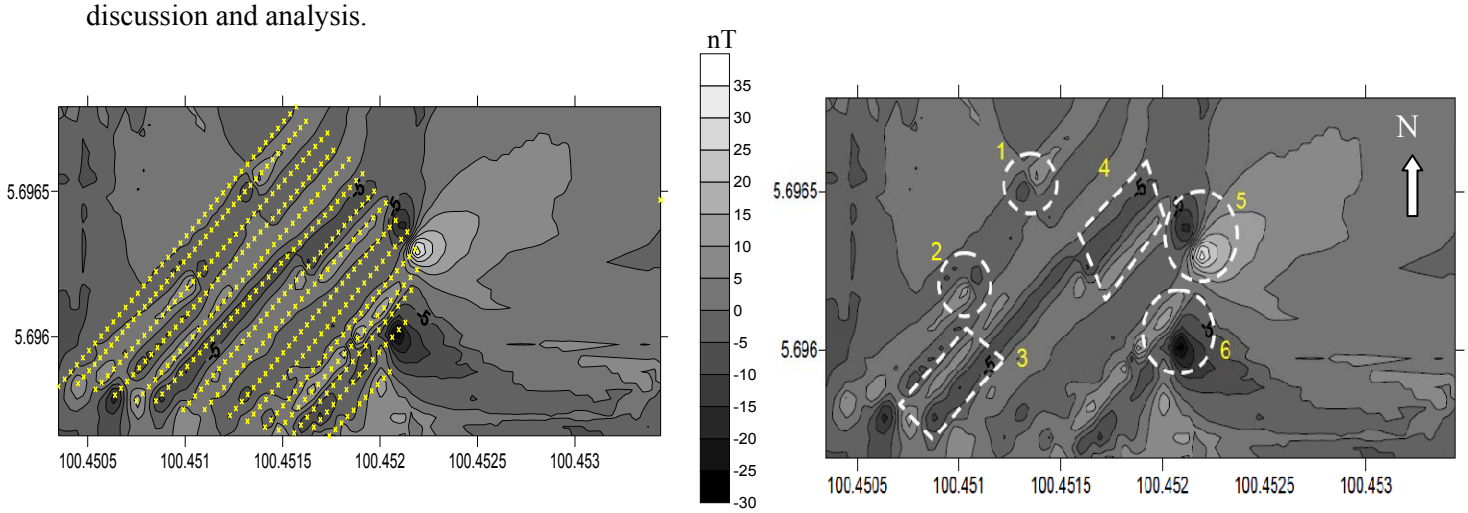

Fig. 4: Residual map with magnetic profiles. It is mapped at a 5 nT contour interval.

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, which were found in line 2 and 3, respectively, have a same magnetic value of about 20 nT in positive pole and -5 nT in negative pole. Magnetic anomaly 3 is a dipole anomaly which the positive pole with value of 15 nT is located along line 5, and the negative pole with value of -5 nT is placed along line 6. Another magnetic anomaly, which ia 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 magnetic value -15 nT is found in the northeast of the site within lines 9 to 11 which is 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 enough information to make any convincing conclusion about the archaeological remains. This can be confirmed by seismic results which no sudden change of wave velocity is observed in

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. Seismic Refraction Method

In order to determine the shallow geological stratigraphy and thickness of layers, two lines of seismic survey were measured. After data processing, the velocity of wave in the medium and the depth of layers were specified. The data of profile S_1 are plotted in Figure 5 and 6, also the profile S_2 is shown in Figure 7. Unconsolidated soil generally has velocity values of 100 to 500 m/s but may vary if saturated or compacted. The P-wave velocity in saturated or more compacted materials is from 1500 to 2000 m/s [14]. Seismic refraction study within the archaeological site shows similar velocity structures. The profile S_1 consists two layers with velocity 250 to 400 m/s in first layer and 1650 to 2000 m/s in second layer. Depth of first layer is changed from 2 to 3.2 m. 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 first layer is from 1.2 to 3.3 m (Figure 7). Overall, this area involves two main layers which upper layer is made up of soil consisting of alluvium and sandy clay, and the second layer is made up of mixed saturated soil with water. It can clearly be seen that there is no anomaly caused by archaeological structures over the seismic profiles.

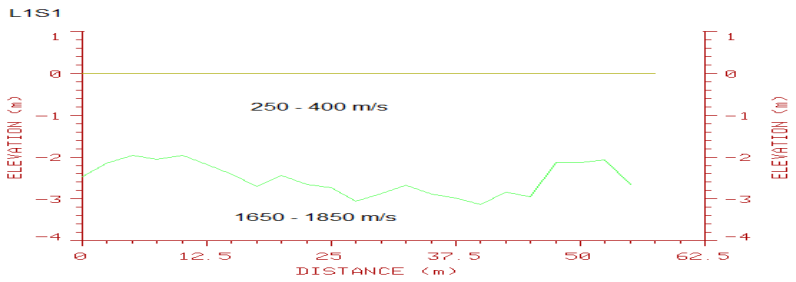

Fig. 5: Seismic refraction profile S_1, the first spread.

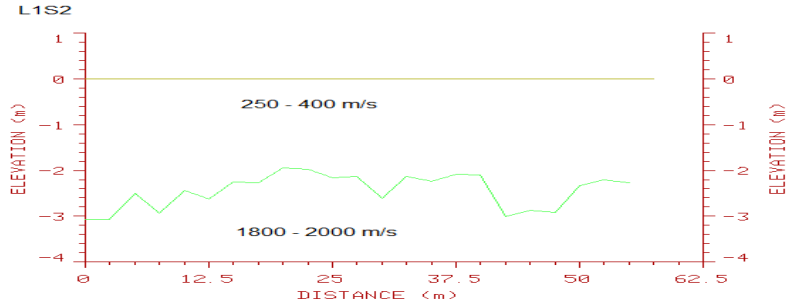

Fig. 6: Seismic refraction profile S_1, the second spread.

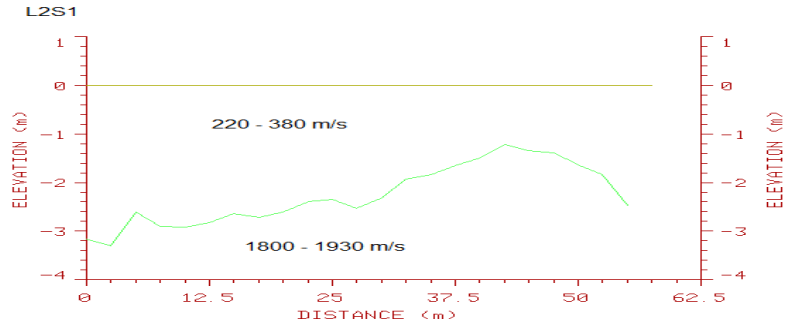

Fig. 7: Seismic refraction profile S_2.

5. Conclusions

Seismic refraction and magnetic methods were used in this study to locate buried artifacts, ruins of old buildings, shallow geological stratigraphy and thickness of layers at the Sungai Batu archaeological area. The results of seismic refraction survey revealed two main layers: first layer, made up of soil consisting of alluvium and sandy clay, and the second layer, made up of mixed saturated soil with water. Furthermore, 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.

Consequently, this study and its results confirmed, once more, that the utilizing of magnetic and seismic refraction techniques in archaeological prospection yields more information upon which archaeologists can base further investigations of the site.

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