GEOSEA '98 Proceedings, Geol. Soc. Malaysia Bull. 43, December 1999; pp. 481-489

Ninth Regional Congress on Geology, Mineral and Energy Resources of Southeast Asia — GEOSEA '98
17 – 19 August 1998 • Shangri-La Hotel, Kuala Lumpur, Malaysia

Geophysical measurements for archaeological investigation: case studies in Malaysia

ABDUL RAHIM SAMSUDIN AND UMAR HAMZAH

Department of Geology
Universiti Kebangsaan Malaysia
Bangi, 43600, Selangor D.E.
Malaysia

Abstract: Three archaeological sites containing different artifacts were investigated by geophysical methods. The first site is located at Sungai Mas village in Kuala Muda District of Kedah, north west of Malaysia. Since the beginning of the 1980 this site has produced a number of important and interesting archaeological finds relevant to the history of the Bujang Valley of Kedah. The archaeological teams from Universiti Kebangsaan Malaysia and the Museum Department of Malaysia revealed that there were several remains of low mounds of laterite block and brick foundation for structures in the village. A geoelectrical profiling method using dipole-dipole array was used to study the artifacts and the preliminary survey was designed to see whether the technique would be useful for identifying and locating anomalies of archaeological significance in the area. Result of the study indicates that the geoelectrical resistivity method can be successfully used in detecting archaeological anomalies of shallow buried artifacts in the studied area.

The second site is situated 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. The site is located approximately 7 kilometres from Alor Star, northern Kedah. It covers an area of about 3.5 hectares along the river side. Remains of partly buried nineteenth century fort which belong to the former sultan of Kedah was excavated by the Museum Department of Malaysia for future conservation plan. The area was gazetted as a museum reserve and planned to be developed as another historical tourist spot in Kedah. Geophysical measurements employing geoelectric profiling (Wenner array) and magnetic surveys were conducted to locate structures of partly buried foundation of the fort as a guide for future conservation work. Both the geoelectrical and magnetic surveys have produced results showing several anomalous areas which appear to coincide well with the locations of the uncovered artifacts.

The third archaeological site is located in the area of Pasir Salak historical complex in Kampong Gajah District, southern Perak. The site which covers an area of 80 x 60 square metres lies about 200 metres from the Perak River. It was identified to be a site of a former fort built by a Malay warrior to fight the British in the late nineteenth century. The site was developed into a football field for the school nearby before the land was gazetted as a museum reserve. The department of museum has conducted four phases of excavation in December 1990, April 1991, June 1993 and July 1996 but no significant major artifact was found. Detailed geophysical study (geoelectric and magnetic) was carried out to look for artifact. The geoelectrical profiling survey employing dipole-dipole array revealed eight different locations of high resistivity zones whereas the magnetic measurement indicated two anomalous areas. These anomalous areas could probably be associated with the artifact of archaeological significance and they need to be confirmed by excavation.

INTRODUCTION

Geophysical techniques have been successfully used to investigate archaeological sites in many parts of the world. Archaeologists using geophysical methods now routinely map hearths as well as soil materials magnetically altered by campfires. The use of geophysical techniques for this type of study is classified as 'nondestructive archaeology' because it provides three dimensional information about potential archaeological targets without disturbing them. Information on archaeological site location and content should be obtained in the least expensive and least destructive manner possible. Archaeologists are very well aware that excavation destroys the site being studied. The need for nondestructive methods increased lately for two reasons. First, our environmental legislation now

requires that historic places or structures need to be mitigated on land to be developed or altered. Secondly, there is an increasing movement to assess and preserve our archaeological heritage on public lands not in immediate danger of destruction.

The geophysical technique is very useful to archaeologist who wish to preserve the cultural heritage as well as to study it. The early history and development of the techniques for archaeological investigation are described by Weymouth and Huggins (1985), Aitken (1974) and Weymouth (1985). Archaeogeophysical investigation case studies discussed in this paper can be classified as 'intrasite mapping' because they were used to guide excavation programmes within already discovered sites. This paper will highlight results of geophysical investigation at three archaeological sites containing different artifacts in north west Malaysia. The first site (site 1) is located at Sungai Mas village in Kuala Muda District of Kedah and the second site (site 2) lies in the vicinity of the Kedah river side in the Kuala Kedah area. Whereas the third site (site 3) is situated in Pasir Salak district in Perak (Fig. 1).

GEOPHYSICAL METHODS

These case studies illustrate the applicability of geophysical methods in archaeological investigation in Malaysia. Geophysical methods that are widely used for this type of study are geoelectrical resistivity measurements, ground-penetrating radar and magnetometry. However for these case studies, only two of the above geophysical techniques (geoelectrical resistivity and magnetic) were used. Brief description of the techniques and their field procedures are discussed in the following sections.

i) Geoelectrical resistivity method

The resistivity method appears to be very useful in detecting building materials such as bricks and lateritic blocks because these objects are expected to have high resistivity and excavations may be resistivity highs or resistivity lows depending on the water content and degree of compaction of the materials compared to the surrounding medium (Umar Hamzah and Abdul Rahim Samsudin, 1995). However the success of the resistivity method in determining the archaeological features would depend on the resistivity contrast between the objects and the surrounding rocks or soils. Soils having similar resistivity would tend to hide the anomaly produced by the archaeological object within it. Resistivity contrasts can occur in some earthen features, such as storage pits, filled ditches and mounds. Besides the dependence on soil properties, soil resistivity contrast depends upon the recent weather history of the site. Historic architectural features such as foundations or house floors and walls usually provide good resistivity contrast.

For archaeological sites 1 and 3, a conventional resistivity profiling method employing dipole-dipole array was conducted using ABEM SAS300 terrameter with four- in-line metal electrodes. The meter reads resistance directly in ohm and values are converted to apparent resistivity by multiplying the resistance by the appropriate geometry factor for the array (Zohdy *et al.*, 1974). The resistivity meter was connected to two potential and two current electrodes. The electrode spacing of 1 m was used with transmitter-receiver separation (N) ranging from 1 to 6 m. Different electrode spacings (N) reflect different depths of investigation. The electrode configuration used is shown in Figure 2. For data plotting, each measured value was plotted at the intersection of two 45° lines through the centres of the dipoles. The measurements resulted in the resistivity pseudo section. Isoresistivity maps which indicates areal distribution of the resistivity were also prepared to determine which N or depth value would shows the best correspondence with known or suspected archaeological features.

Archeological site 2 was investigated using a new electrical imaging method (Griffiths and Barker, 1993) which is now frequently used for environmental studies. The electrical imaging survey was carried out with a multi-electrode resistivity meter system (Fig. 3). In this particular study, a total of fifty electrodes were laid out in a straight line with a constant spacing. Each of the electrode is connected to a multi-core cable and a switch box system which was used to manually select the active electrodes used for each measurement. The data collected was interpreted using a rapid 2-D resistivity inversion programme (RES2DINV) which automatically determines a two-dimensional (2-D) resistivity model for the subsurface using the data obtained from electrical imaging survey (Griffiths and Barker, 1993).

(ii) Magnetic method

Magnetic survey is the geophysical technique most frequently used by the archaeologist. It is routinely used to map buried stone foundations and to determine the locations of forges and kilns, hearths, and campfire sites (Gibson, 1986). Most burned features and bricks produce strong magnetic anomalies as a result of the conversion of iron oxides to a more magnetic state, and because of thermoremanent magnetisation. The response to

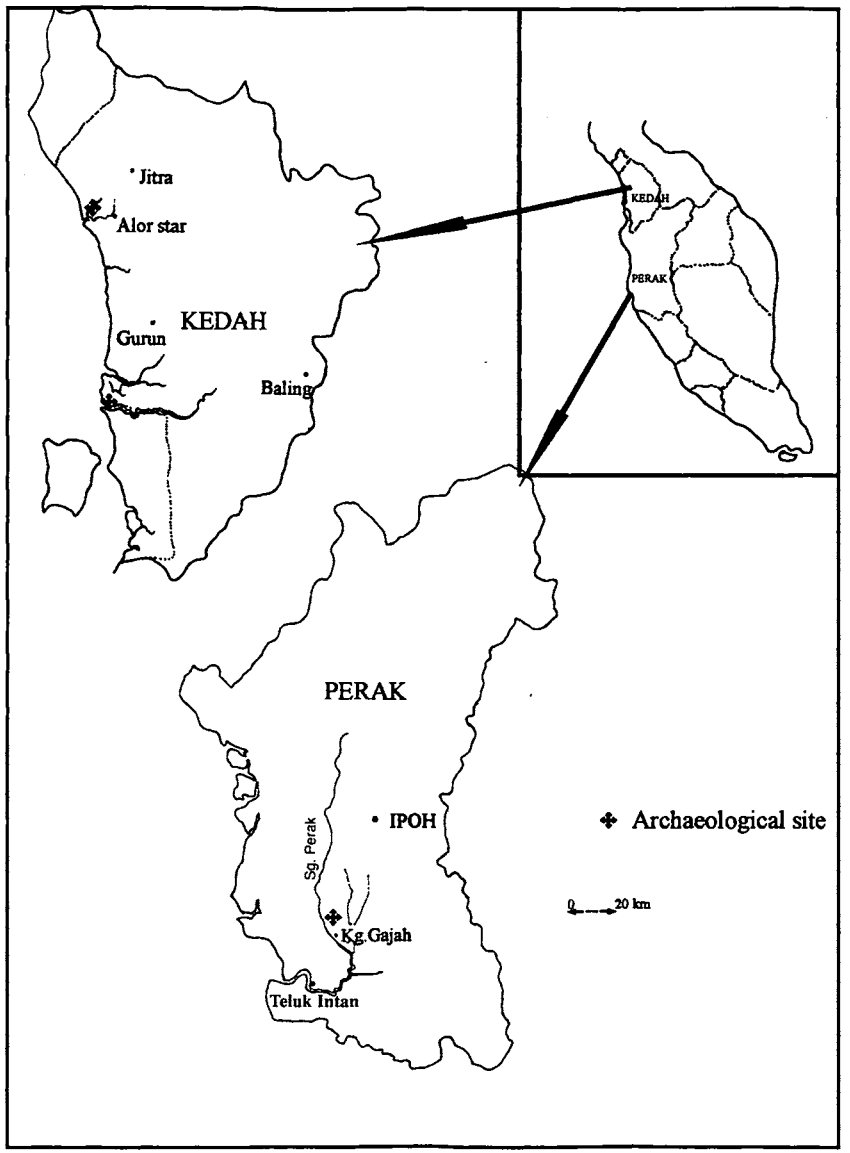

Figure 1. Map of Peninsular Malaysia showing location of archaeological sites.

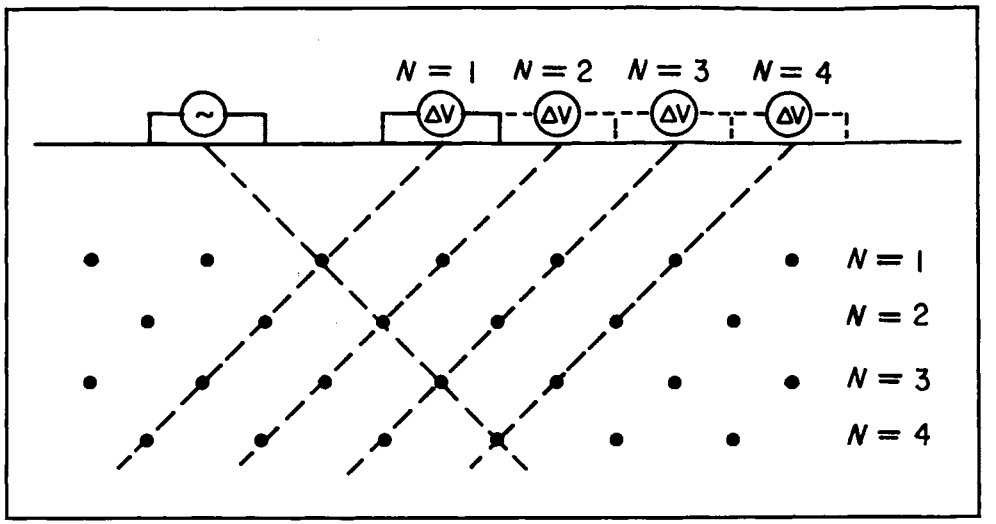

Figure 2. The presentation of dipole-dipole resistivity results on a pseudosection. 'N' represents the relative spacing between the current and potential electrode pairs.

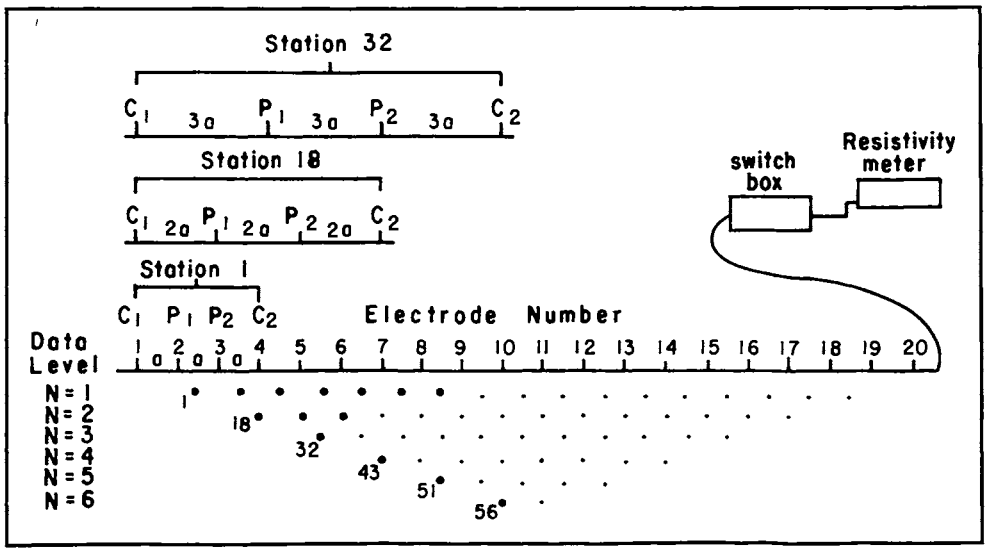

Figure 3. The arrangement of electrodes for 2-D electrical imaging survey and the sequence of measurements used to build up a pseudosection.

foundations and floors depends upon the magnetic contrast of the construction material with respect to the surrounding soils. Earthen features, such as storage pits with humic content, can produce observable anomalies because of the conversion of iron oxides (reduction of hematite to magnetite) that takes place in an organic environment. Concentrations of ferrous metal give good magnetic response. Low magnetic contrasts between objects and the surrounding soil, varying soil composition, and an increased depth of burial can obscure magnetic anomalies.

The magnetic survey was carried out using proton precession magnetometer for sites 2 and 3. The measurements were made at heights of 0.5 m and 1.0 m above ground, at 2 to 3 m interval along the same traverses used in the resistivity survey. At each position, three magnetometer readings were taken and averaged. The magnetic field gradient was found by subtracting the 1.5 m field strength from that found at 0.5 m. Contour map of the field gradient will shows the shallow sources which probably associated with the artifacts of archaeological significance and reduces regional gradients and removes drift.

CASE STUDIES

(i) Sungai Mas, Kuala Muda, Kedah

Since the beginning of the 1980 Sungai Mas area of Kuala Muda, Kedah has produced a number of important and interesting archaeological finds relevant to the history of the Bujang Valley of Kedah (Nik Hassan Nik Shuhaimi Bin Nik Abd. Rahman and Kamaruddin bin Zakaria, 1993. The archaeological teams from Universiti Kebangsaan Malaysia and the Museum Department of Malaysia revealed that there were several remains of low mounds of laterite block and brick foundation for structures in the village.

A geoelectrical profiling survey using dipole-dipole array was used to study the artifacts. The study was designed to see whether the geoelectrical technique would be useful for identifying and locating anomalies of archaeological significance in the studied area.

Site of investigation is located close to Sg. Muda and covers an area with dimension of approximately 100 m x 100 m. The area which has relatively flat topography consists of alluvium and coastal marine deposit. The resistivity of the soil is low and homogenous. The artifacts represented by old bricks and rocks were found buried by the soil at relatively shallow depth. The resistivity of these artifacts are expected to be high and therefore should be easily detected by the resistivity survey.

Based on results of geoelectrical sounding surveys, three categories of soil resistivities were observed for the study site:

i) soil with resistivity less than 20 ohm-m
ii) soil with resistivity ranges from 20 to 200 ohm-m
iii) soil with resistivity greater than 200 ohm-m

The first category of the low resistivity is interpreted to be related to marine sediment or sandy soil with salt water content. The second category of resistivity reading is referred to alluvium or sandy soil with brackish to fresh water contents. Whereas the third category of relatively high resistivity values could be related to the soil material associated with considerable amount of buried archaeological objects.

A total of six isoresistivity maps for different values of N and ten resistivity pseudo sections were obtained from the resistivity measurements. The isoresistivity maps for different value of N indicate the variation of resistivity at different horizon below surface. The plots of isoresistivity maps for N = 1, 2, 3 and 4 consistently reveal the presence of four distinct anomalies of high resistivity. These anomalies are relatively large in term of size area and illustrated as anomalies A, B, C and D in Figure 4. Location of these anomalies coincide well with the artifacts which were revealed from the earlier excavation programme in the study area. Depths of the artifacts interpreted from the resistivity pseudosection range from 0.1 to 2.5 m below surface.

Two or possibly five more anomalies were observed in the isoresistivity maps for N = 5 and 6. Their pseudosection plots suggest that these anomalies could be produced by the artifacts buried at much deeper level (greater than 3 metres). If this information is true, deep excavation is therefore necessary for this site and it would involves excavation work below water table. However these results need to be confirmed by conducting more detailed geoelectrical investigation or other geophysical methods such as magnetic or ground-penetrating radar. The magnetic method is not possible to be applied in this area due to the presence of many man made magnetic disturbances such as steel fences and houses.

(ii) Fort of Kuala Kedah, Kedah

The second site is situated 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. The site is located approximately 7 kilometres from Alor Star, northern Kedah. It covers an area of about 3.5 hectares in the vicinity of the Kedah River side. Remains of partly buried nineteenth century fort which belong to the former Sultan of Kedah was partially excavated by the

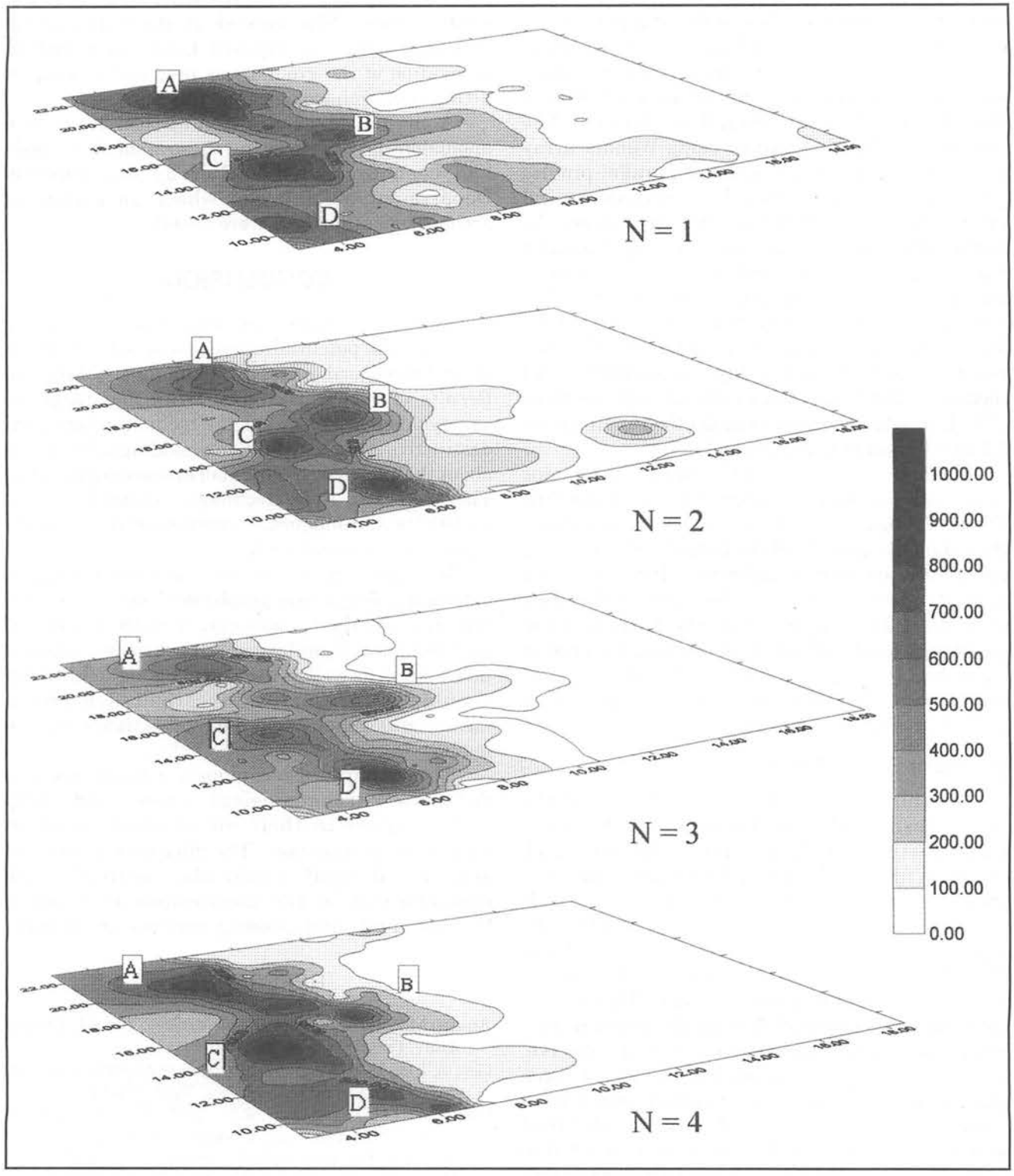

Figure 4. Resistivity map over buried remains of building at Sungai Mas archaeological site.

Museum Department of Malaysia since early 1996 for future conservation plan. The area has been gazetted as a museum reserve and would be developed as a historical tourist spot in Kedah. Geoelectrical imaging and magnetic surveys were conducted on selected sites of the studied area to locate structures of buried foundation of the fort.

Geoelectrical resistivity imaging and magnetic surveys were carried out only on selected areas of the site due to poor ground condition. The geoelectrical imaging survey using Wenner array was carried out along a series of parallel profiles about 6 metres apart to map the lateral and vertical extent of the fort foundation. Figure 5 shows the isoresistivity maps for horizons (N) = 1, 2, 3 and 4 indicating the locations and lateral distribution of the anomalies. Field evidence shows that the high resistivity anomalies corresponds to the wall of the fort foundation which was buried in the low resistivity soil of marine clay. Resistivity model sections of the survey lines indicate that the zones of high resistivity occurred at depths ranging from 0.1 to 5.0 metres below ground.

Magnetic survey was carried out at the remains of partially buried brick floor and wall of the fort. The main objective of the survey was to determine the magnetic anomaly of the buried structures and the associated buried artifacts. High magnetic gradient was obtained in the area of the floor structure which suggests that the anomaly could possibly be due to the bricks of the floor material or other highly magnetic objects of archaeological significance. However this would requires actual ground excavation for confirmation.

(iii) Pasir Salak, Perak

The third archaeological site is located in the area of Pasir Salak historical complex in Kampong Gajah District, south of Perak. The site which covers an area of about 80 x 60 square metres lies about 200 metres away from the Perak River. It was identified to be a site of a former fort built by a great Malay warrior (well known as Dato' Maharaja Lela) to fight the British Resident of Perak in the late nineteenth century. The site was developed into a football field for the school nearby before the land was gazetted as a museum reserve. The department of museum has conducted three phases of excavation in the studied area but no significant artifact was found. Both geoelectrical profiling and magnetic surveys were conducted to search for the possibility of buried artifacts within the identified site of the fort.

Geoelectrical resistivity profiling employing dipole-dipole array and magnetic measurements were carried out along a series of parallel lines of 5 metres apart to detect any possibility of buried artifact in the studied area. Plots of isoresistivity maps for N = 1 to N = 4 reveal the presence of several anomalies of high resistivity (Fig. 6) in the studied area. The ground at these anomalous locations were not exposed before and further excavation of the ground was proposed to look for artifacts of archaeological significance.

A magnetic gradient map indicates two anomalous areas. However, these anomalous zones had been excavated earlier by the Museum Department of Malaysia where no objects of archaeological interest were found.

CONCLUSION

The case studies presented in this paper illustrate the potential use of geophysical methods in archaeological intrasite mapping in Malaysia. Results of geoelectrical resistivity and magnetic surveys demonstrate that the techniques are non-destructive and very useful in providing information about the subsurface content of archaeological sites. The success of these techniques depends on the resistivity and magnetic contrasts of the artifacts with soils surrounding it.

It is also important to note that anomalies obtained through any geophysical method should not necessarily be associated with objects of archaeological significance. Subsurface geological information as well as geological history of the area should be thoroughly investigated before a meaningful geophysical interpretation could be made.

The geophysical techniques, if applicable, can delineate archaeological sites and help archaeologists in their initial planning of an excavation programme. The information from the geophysical study would also indirectly safe operating cost on site investigation by reducing number of pits and avoiding unnecessary digging.

REFERENCES

AITKEN, M.J., 1974. *Physics and archaeology*, 2nd ed. Oxford Univ. Press.

GIBSON, T.H., 1986. Magnetic prospection on prehistoric sites in western Canada, *Geophysics, 51(3)*, 553–560.

GRIFFITHS, D.H. AND BARKER, R.D., 1993. Two dimensional resistivity imaging and modelling in areas of complex geology. *Journal of applied Geophysics, 29*, 211–226.

NIK HASSAN SHUHAIMI BIN NIK ABD. RAHMAN AND KAMARUDDIN BIN ZAKARIA, 1993. Recent archaeological discoveries in Sungai Mas, Kuala Muda, Kedah. *JMBRAS, 66*, 73–80.

UMAR HAMZAH AND ABDUL RAHIM SAMSUDIN, 1995. Teknik

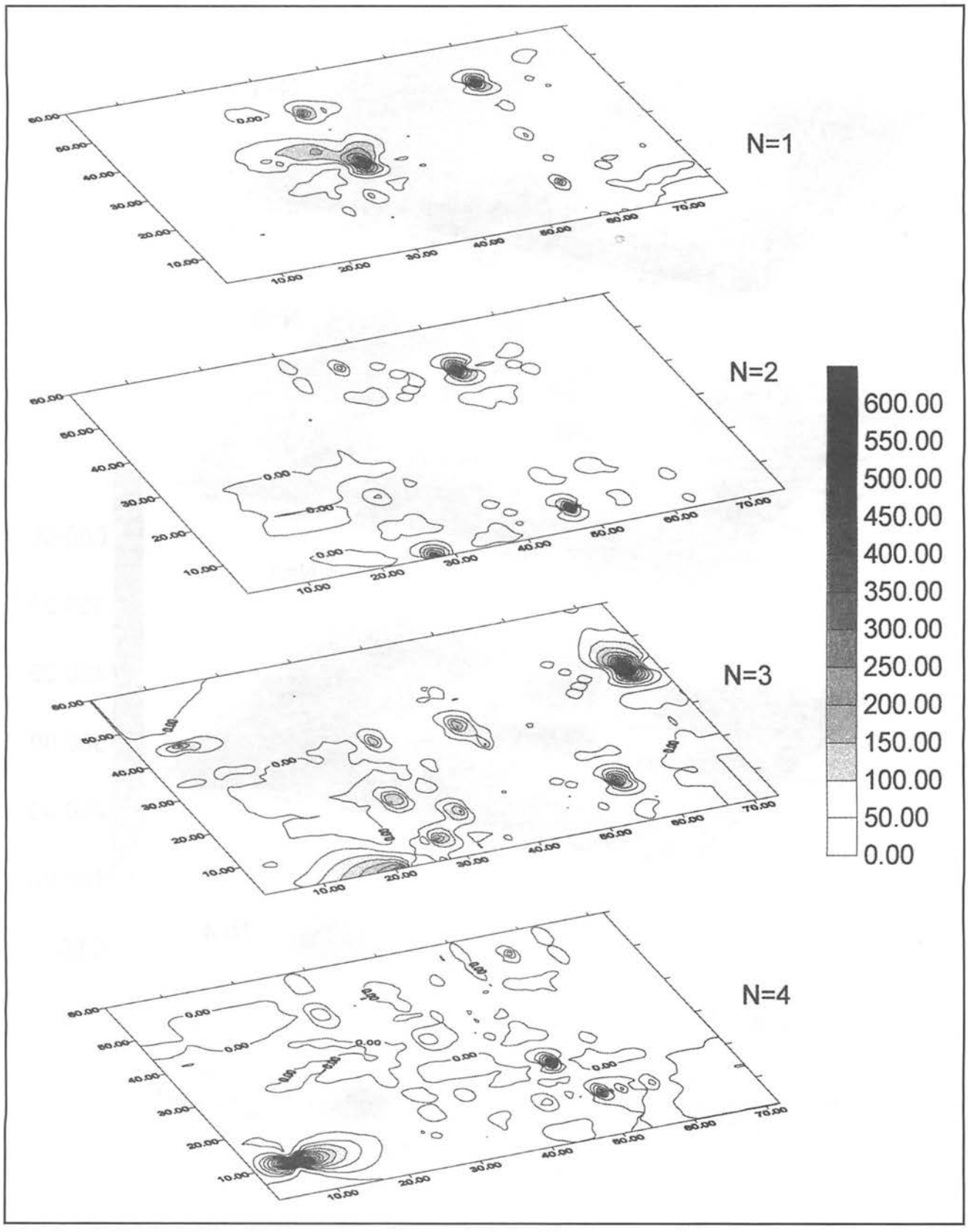

Figure 5. Resistivity anomalous areas of archaeological site in Kuala Kedah, Kedah.

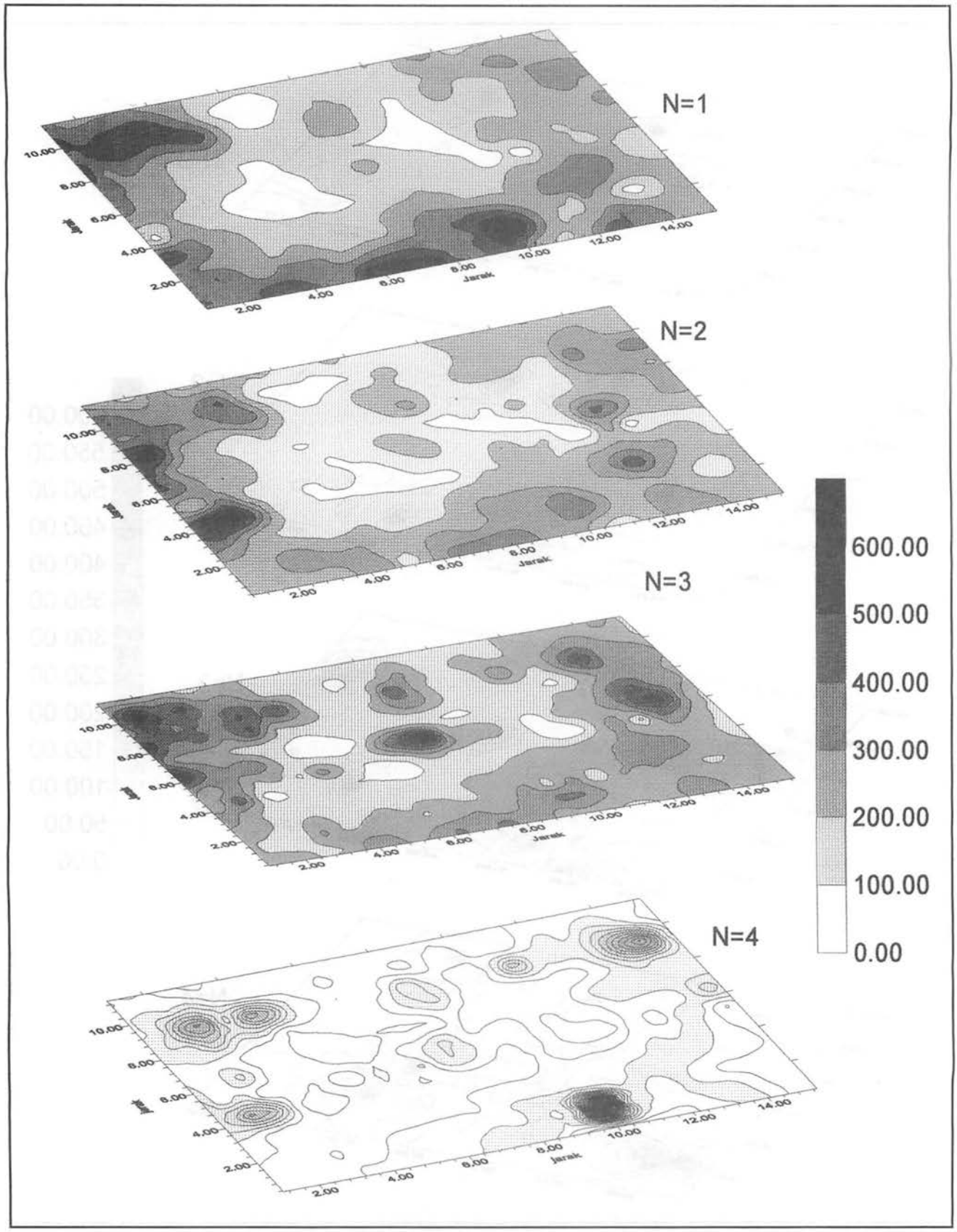

Figure 6. Pasir Salak archaeological site showing anomalous resistivity zones.

Pengprofilan geoelektrik dalam eksplorasi arkeologi di Sungai Mas, Kota Kuala Muda, Kedah. *Sains Malaysiana, 24(1)*, 29–44.

WEYMOUTH, J.W. AND HUGGINS, R., 1985. Geophysical surveying of archaeological sites. *In:* Rapp, G., and Gifford, J. (Eds.), *Archaeology geology*. Yale University Press.

WEYMOUTH, J.W., 1985. Geophysical Methods of archaeological site surveying. *In:* Schiffer, M. (Ed.), *Advances in archaeological method and theory, 9*. Academic Press.

ZOHDY, A.A.R., EATON, G.P. AND MABEY, D.R., 1974. *Application of surface geophysics to groundwater investigations*. U.S. Government printing Office, Washington, D.C.

Manuscript received 26 October 1998