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Geophysical Imaging of Archaeological Materials at Iyekere, Ile-Ife Southwestern Nigeria

K. D. Oyeyemi[1*], M. A. Oladunjoye[2], A. I. Olayinka[2] and A. P. Aizebeokhai[1]
1. Department of Physics, College of Science and Technology, Covenant University, Nigeria
2. Department of Geology, University of Ibadan, Nigeria
* E-mail of the corresponding author: kdoyeyemi@yahoo.com

Abstract

Non-invasive geophysical methods are increasingly being used in archaeological studies. In this study, magnetic and electrical resistivity tomography geophysical techniques were integrated to locate subsurface archaeological materials. The survey consists of four parallel and three perpendicular profiles with station interval of 0.5 m for both magnetic and electrical resistivity tomography. Wenner array with electrode spacing ranging from 0.5 – 3.0 m was used to collect the electrical resistivity data. The results show that high total magnetic intensity anomalies correspond to high inverse model resistivities. The regions with high magnetic and resistivity anomalies were thought to be locations of archaeological materials; the corresponding depths to these materials were inferred from the resulting geophysical images. Test units conducted at the regions of high total magnetic intensity and inverse model resistivity yield archaeological materials including burnt pipes (Tuyere), iron slag, iron smelting, and pottery fragments at approximate depths inferred from the geophysical images.

Keywords: Archaeogeophysics, Artefacts, ERT, Magnetic methods, 2D imaging

1. Introduction

Archaeological investigations and environmental impact assessments as part of development planning often require geophysical surveys. The geophysical surveys are often designed to detect and define archaeological structures and features that may be hidden beneath the subsurface. Environmental impact assessments normally take place in advance of projects such as road or pipe corridors, the building of single houses or estates and the development of industrial zones or mineral extraction sites. In the case of archaeological research projects and monument delimiting surveys where there are known or visible archaeological monuments, geophysical surveys can be used to assess their possible hidden sub-surface extension and preservation, preservation potential or to prospect for undiscovered monuments in the locality.

Geophysical methods provide fast, economical, efficient and non-destructive reconnaissance surveying techniques often required by archaeologists. Also, geophysical techniques offer rapid, uniform, reconnaissance for an entire site together with a synoptic view of the interrelationships within the site (Weymouth and Huggings 1985). Geophysical methods has been used to map archaeological materials such as healths, klins, buried bricks, building foundations, middens (trash heaps), burial tombs, ditches and soils compacted or excavated by previous human activities (e.g. Weymouth 1986; Witten 2006; Cardarelli 2009; Loperte *et al.* 2011). In this study, high resolution geophysical methods involving magnetic method and electrical resistivity tomography (ERT) have been used in the search for archaeological materials (iron slag pottery materials, burnt pipes or Tuyere) in the investigation site. The locations and approximate depths to these archaeological materials were inferred from the resulting geophysical images; pitting was carried out at these locations to verify the accuracy of the geophysical results.

2. Study Area

Historical Background

The study area is located within Iyekere in Ile-Ife with an area 1575 square-metres (Figure 2). Iyekere is an iron smelting archaeological site located near the disputed boundary between Ife and Modakeke communities in the ancient city of Ile-Ife, southwestern Nigeria. It is boarded by latitudes $4^0 30'$ N and $4^0 33'$ N and longitudes $7^0 22'$ E and $7^0 25'$ E (Figure 1). According to the oral tradition; Ile-Ife is regarded by all Yorubas as their immediate ancestral origin where their ancestors dispersed to establish towns in their present homeland in West Africa. It is considered to be the traditional birthplace of the Yoruba civilization, of the later part of the African Iron Age that span between the second and the tenth centuries AD. Ile- Ife was a centre of the iron manufacturing, most importantly of small wares, such as nails, horse-shoes, keys, locks, and common agricultural tools; and it was estimated that there were about 500 iron smelters, smiths and other workers in iron of various kinds living within a radius of about twenty kilometres (Adeniji 1977). Within the Yorubas, the knowledge of mining and metallurgy was prevalent among the royalty for iron mining and smelting majorly due to the need to acquire weapons to fight and conquer more lands and empires (Ige and Rehren 2003).

Archaeological finds relating to iron smelting including black sand (slags) and iron stones have been recorded within the study area by Ige and Rehren (2003). In their study, the chemical and mineralogical analysis revealed the slags to be tapped with rich level of titanium oxide. A very high level of vanadium of around 2000 ppm V_2O_5 was also reported. There are other archaeological sites in Ile-Ife that have been excavated by various researchers amongst which are Ita Yemoo site (Willett 1970), Odo-Ogbe site (Eyo 1974), Woye Asiri and Obalara site (Garlake 1977). The finds or archaeological deposits recovered from these sites were terracotta, bronze sculpture and potsherd pavements which formed part of the materials ensembles of cultural efflorescence and elaborate socio-political institutions in Ile-Ife between the 11th and 16th centuries (Eyo 1974).

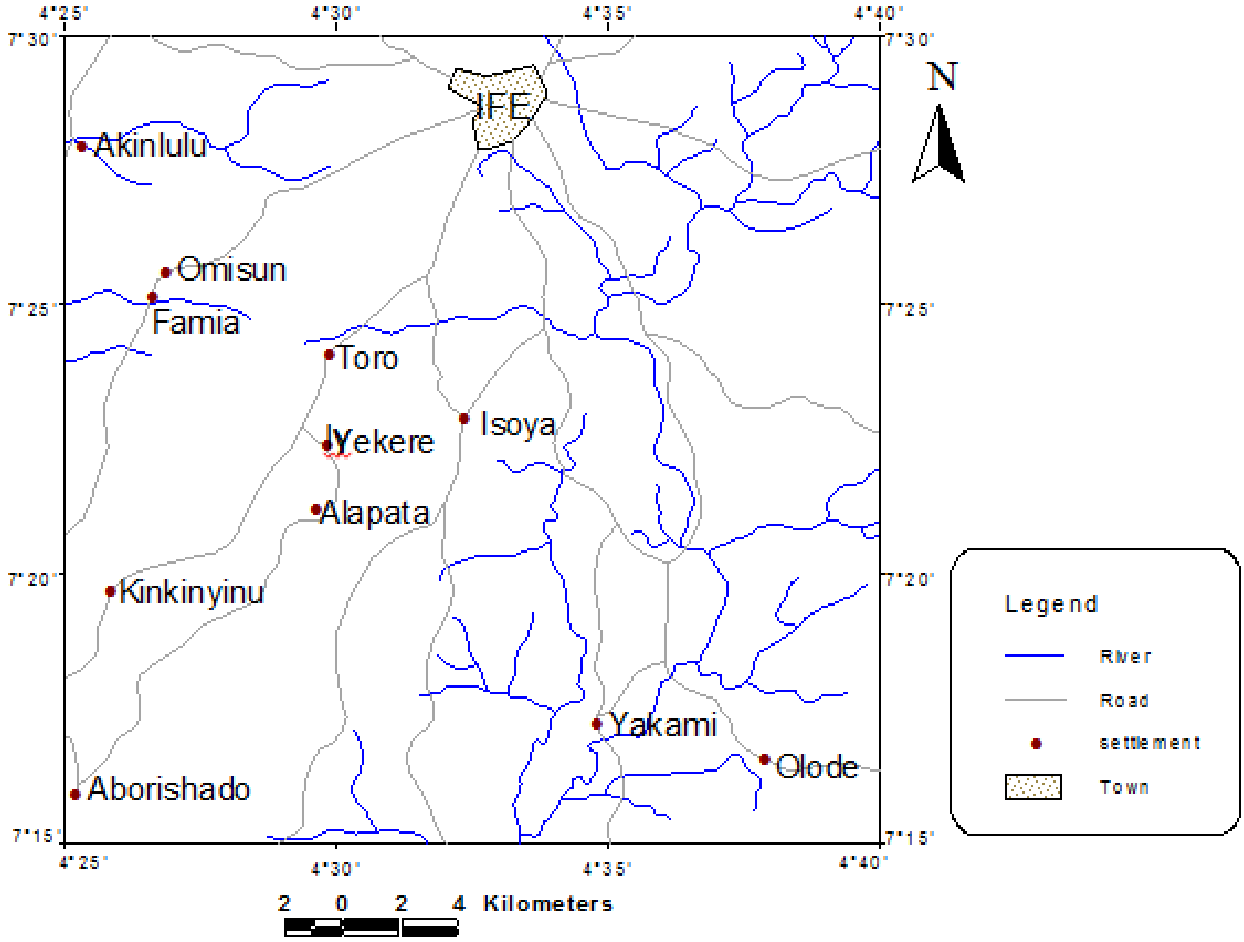

Figure 1: Location map of Iyekere, Ile-Ife and its environs

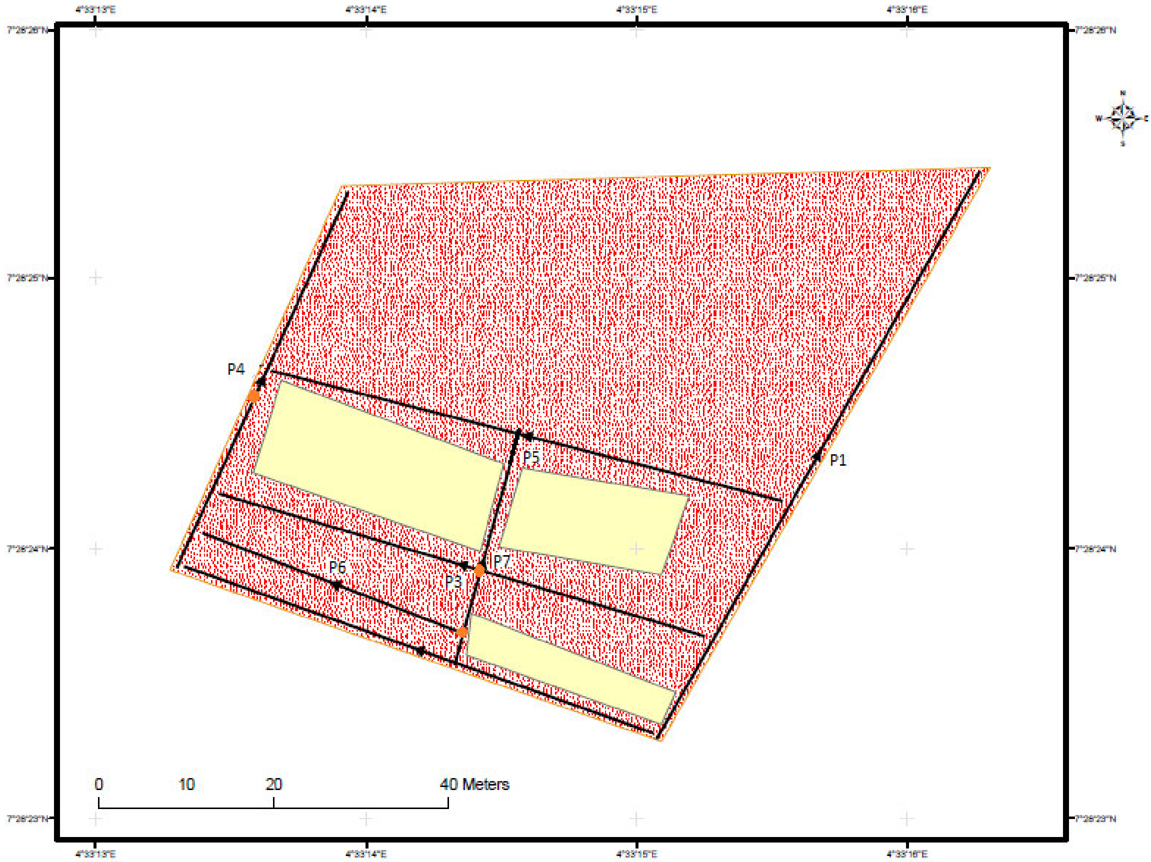

Figure 2: Survey base map showing profile lines and Pitting points.

Geological Setting

Geologically, the study area (Figure 3) is situated within the crystalline basement complex of Nigeria which consist of early Proterozoic (2200 My) granite-gneiss, gneisses and schists (Oyawoye 1972). The schists consist of mica-garnet bearing rocks intimately associated with mafic to ultramafic rocks. These rocks have been extensively studied and characterized by several authors (e.g. Ige and Asubiojo 1991; Ige et al. 1998). The greenstones which serve as the parent rocks for the lateritic ores occur as lenses within the polydeformed migmatite gneiss complex. Several outcrops reportedly occur along the 800 km-long greenstone belt of Nigeria. Their mineralogical composition consists mainly of iron-magnesium amphiboles and ore minerals such as spinel, pyrrhotite, and pyrite. The area is located within the tropical rain forest with high temperature and high humidity. Thick lateritic ironstones which are products of in situ weathering of some high Fe-Mg ultramafic rocks are uniquely abundant within the area.

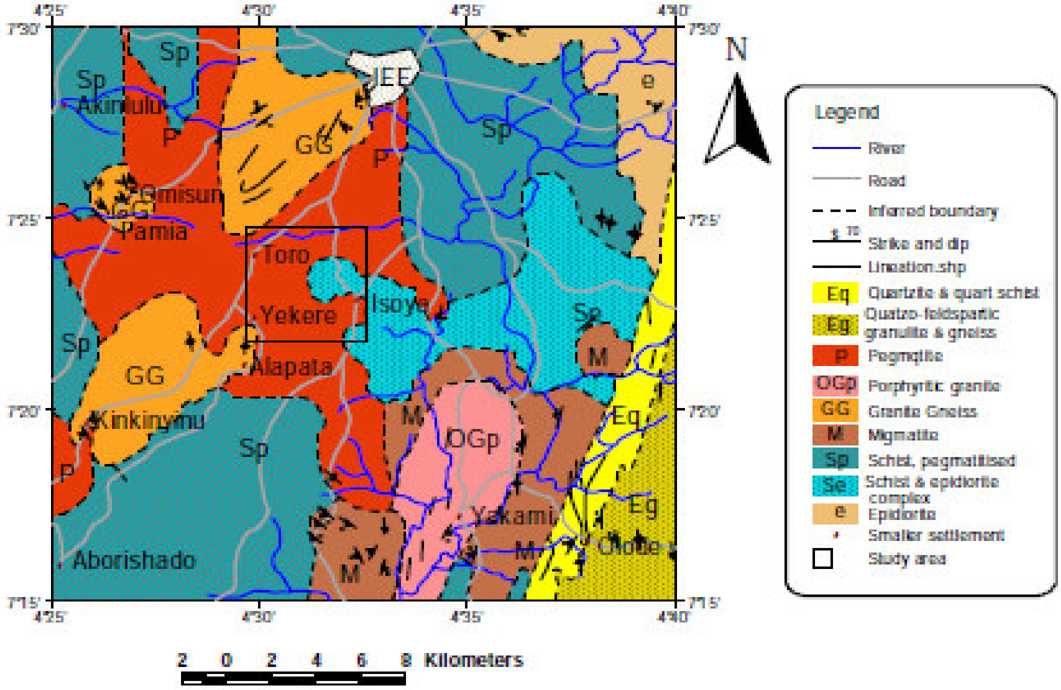

Figure 3: Geological map of Ile-Ife and its environs (after NGSA, 2004)

3. Methodology

Magnetic Method

The magnetic survey is a passive geophysical technique which depends on the contrasts in a magnetic property between the feature of interest and its surrounding environment (Schmidt 2007). The most significant magnetic properties for archaeological investigation are magnetic susceptibility and magnetization. As most archaeological materials contain magnetic substances, they possess magnetic properties that result to magnetic anomalies observed in magnetic surveys which can be applied in different ways (Tarling 1983). Magnetometry is one of the magnetic surveying 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 recorded using a proton magnetometer G-856AX that involves measuring the total magnetic intensity component at each data point along the survey line. Seven profiles involving four in-lines along NW-SE direction and three cross-lines (lines perpendicular to the in-lines) were established (Figure 3). Station interval of 0.5 m was maintained across each profiles making a data density of 770 points.

The magnetic sensor was oriented north during the survey, while the survey staff was maintained at 0.3 m above the ground surface. The coordinates of the beginning and end points of each line were recorded by Geographic Positioning System for applying in the Surfer software to create a plot of the survey area. A base station was set up around 200.0 m away from the survey area which a G-856 magnetometer recorded magnetic readings at time interval of one (1) minute in order to remove the diurnal variation effects of the earth's magnetic field from survey measurements. The magnetic data processing was carried out by inspecting raw data for spikes, gaps, instrument noise or any other irregularities in the data. The next step involved diurnal variation correction and International Geomagnetic Reference Field (IGRF) correction. Once the 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.

Electrical Resistivity Tomography (ERT) Method

Resistivity variations are generally known to correlate well with the lithological nature of the earth materials and have been used as a tool in subsurface stratigraphic characterization (e.g. Aizebeokhai and Oyeyemi 2014), thus providing important information in order to locate buried archaeological remains. The use of resistivity in identification of walls has long been a common practice in archaeological investigations (Sarris and Jones 2000;

Drahor et al. 2008; Tsokas et al. 2008; Tsokas et al. 2009; Berge and Drahor 2011). A total of seven multi-electrodes 2D geoelectrical resistivity imaging lines were measured using the Wenner-alpha array. The length of the 2D traverses ranges from a minimum of 30 m to a maximum of 75 m. The electrode spacing ranged from 0.5 to 3.0 m with an interval of 0.5 m. Line 2, 3, 5, and 6 were conducted the E-W direction whereas the other three 2D traverses (lines 1, 4, and 7) were conducted in the N-S direction (Figure 3).

RES2DINV computer code (Loke and Barker 1996) was used in the inversion of the 2D apparent resistivity data. Nonlinear optimization technique which automatically determines 2D resistivity model of the subsurface for the input apparent resistivity data (Griffiths and Barker 1993; Loke and Barker 1996) together with least square inversion and smoothness constraints were applied.

Excavations
Three test units of 1.0 m x 1.0 m x 1.0 m were excavated within the archaeological site, Iyekere, Ile-Ife. Units 1 and 2 coincide with areas of high total magnetic intensity and high inverse model resistivity from the results of magnetic method and the 2D resistivity tomography inversion modelling around the corresponding points of intersection of Lines 3 and 7, and Lines 6 and 7 respectively. Unit 3 however lies along Line 4 coinciding with the area of low total magnetic intensity and resistivity values. This serves as control (Figure 3) for the ground thruthing process.

4. Results and Discussion
The 2D resistivity tomography inversion model sections of the E-W and N-S traverses which are perpendicular to each other are presented alongside the total magnetic intensity profiles for proper integration to aid the general interpretation (Figures 4 – 7). Along the total magnetic profile plot for each traverse, regions of magnetic high correspond to those of high resistivity on the 2D tomography inversion model (Figures 6 and 7). The ERT result of Line 1 (Figure 4) appears relatively noisy due to near surface resistivity variations. A major sharp drop in magnetic signature was observed between 24.0 m and 40.0 m data points centring on 32.0 m point along Line 4 (Figure 5), which was about the lowest (-250 nT) in the entire study area. This is interpreted to be an evidence of a backfilled ditch or well (Weymouth, 1986; Herwanger et al. 2000). The total magnetic intensity contour map (Figure 4) and image map of the area (Figure 5) depicts region of very high magnetic intensity values to be localized almost towards the centre of the study area. These high magnetic intensity areas are thought to be the target areas for artefacts in archaeogeophysical studies (Mullins 1974; Weymouth 1986; Noel and Xu 1991; Kvamme 2001; Hammerstedt et al. 2010) and can be inferred to be the points of intersection of both the E-W Lines (lines 3 and 6) with the N-S Line 7 on the base map. These points coincide with the beginning of line 6 and within 25.0 m and 33.0 m data points on Line 3 as observed on 2D tomography inversion modelling results.

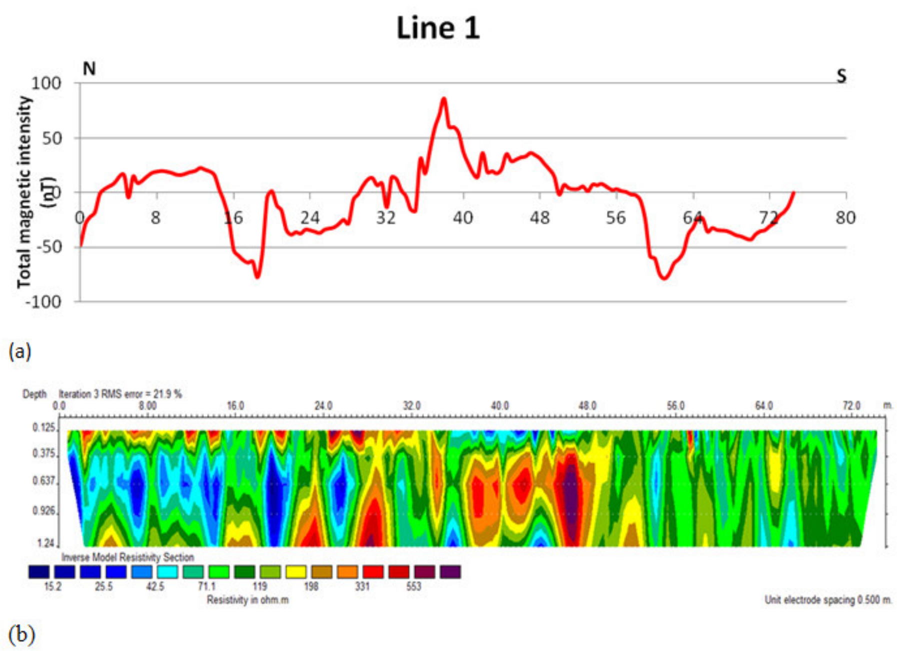

Figure 4: (a) Magnetic profiles and corresponding (b) 2D Electrical resistivity tomography imaging of Line 1

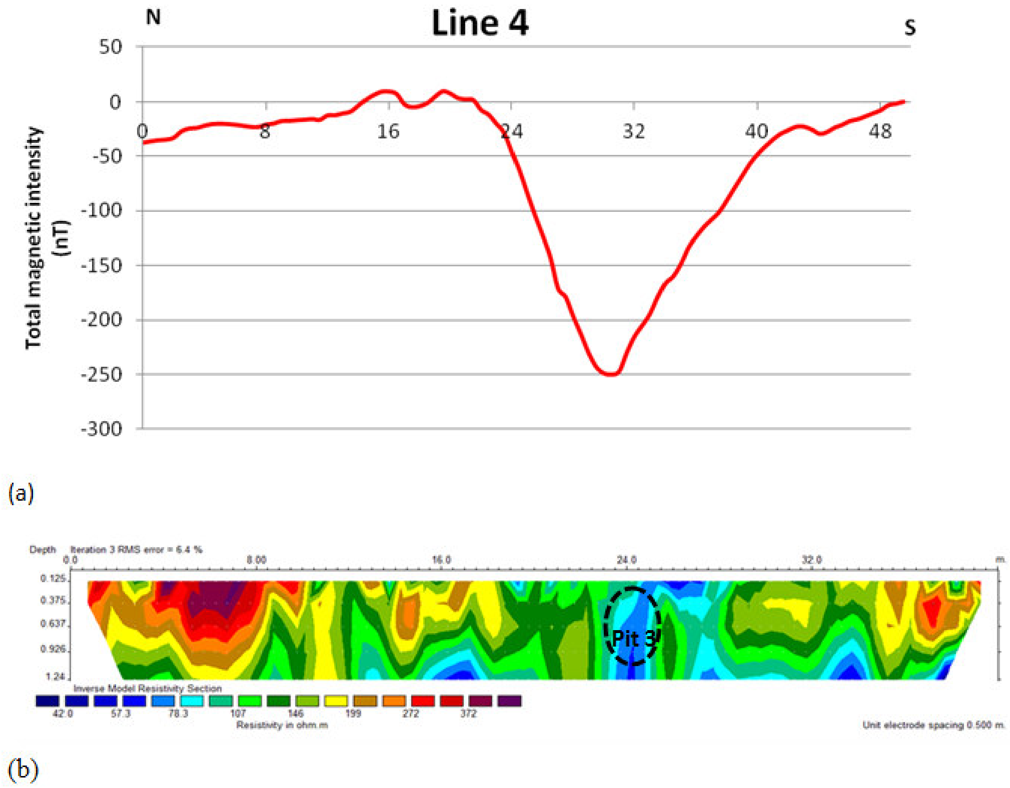

Figure 5: (a) Magnetic profiles and corresponding and (b) 2D electrical resistivity tomography imaging of Line 4

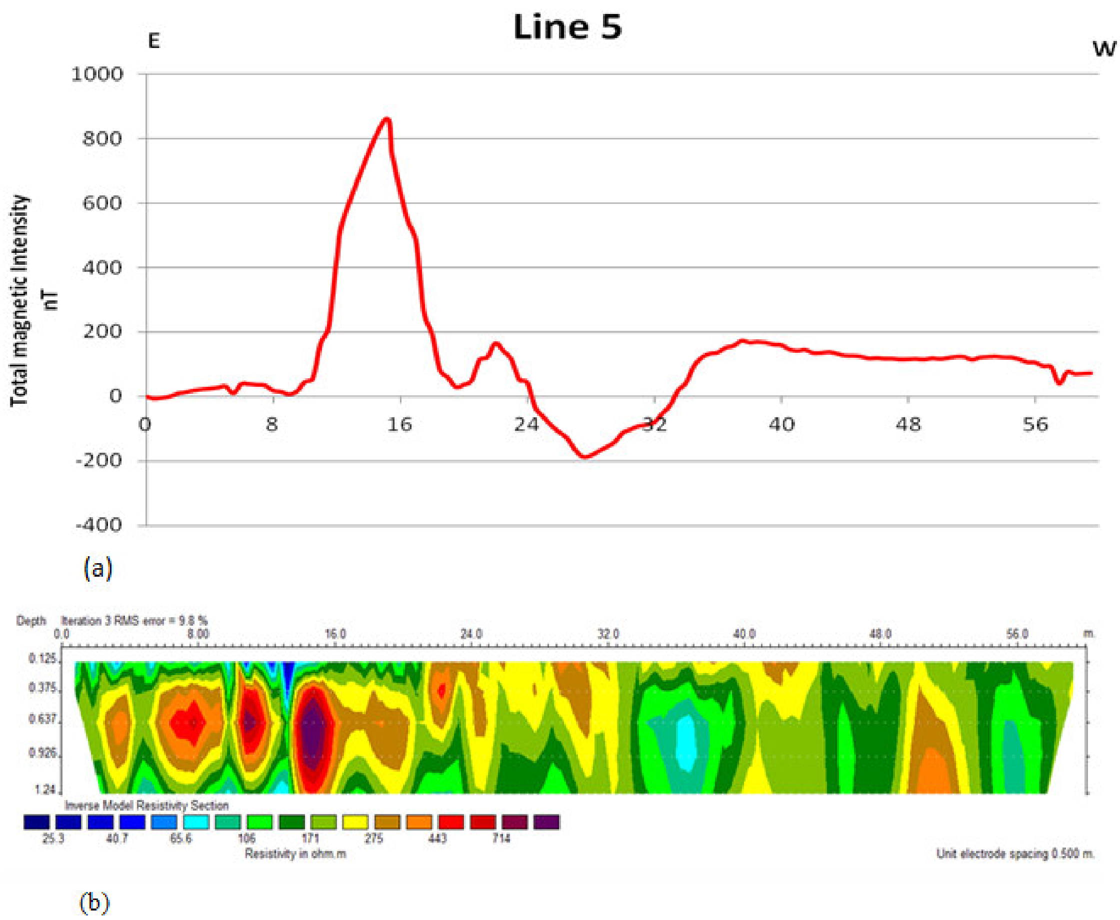

Figure 6: (a) Magnetic profiles and corresponding and (b) 2D electrical resistivity tomography imaging of Line 5

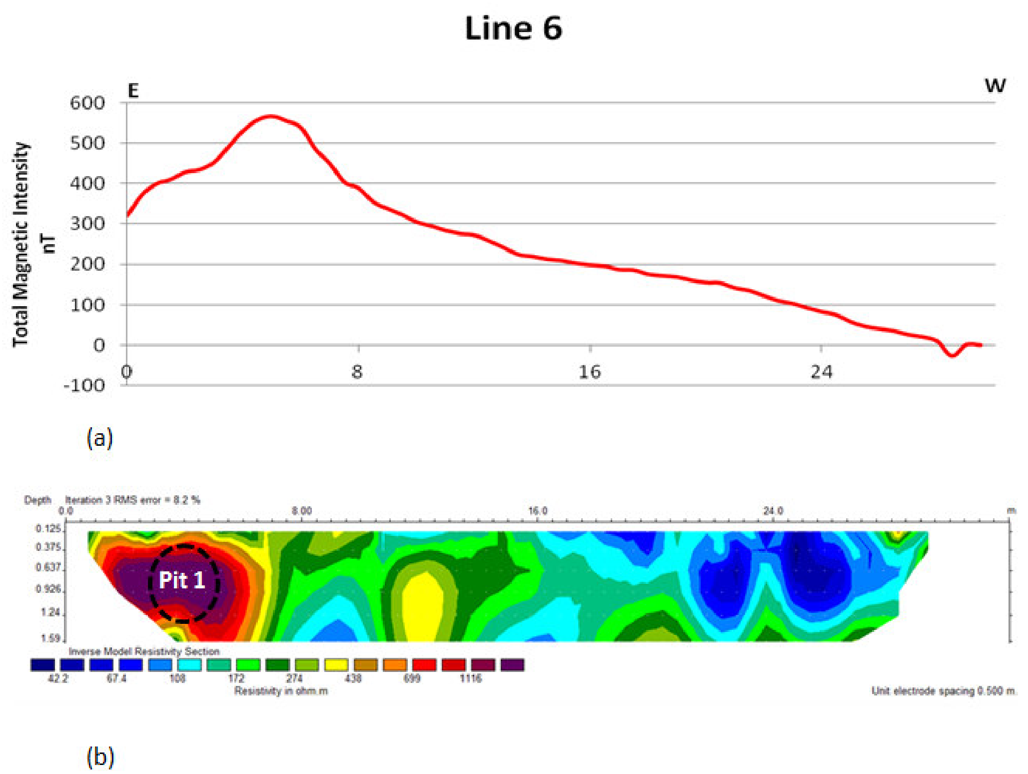

Figure 7: Magnetic profiles and corresponding 2-D electrical resistivity tomography imaging of Line 6

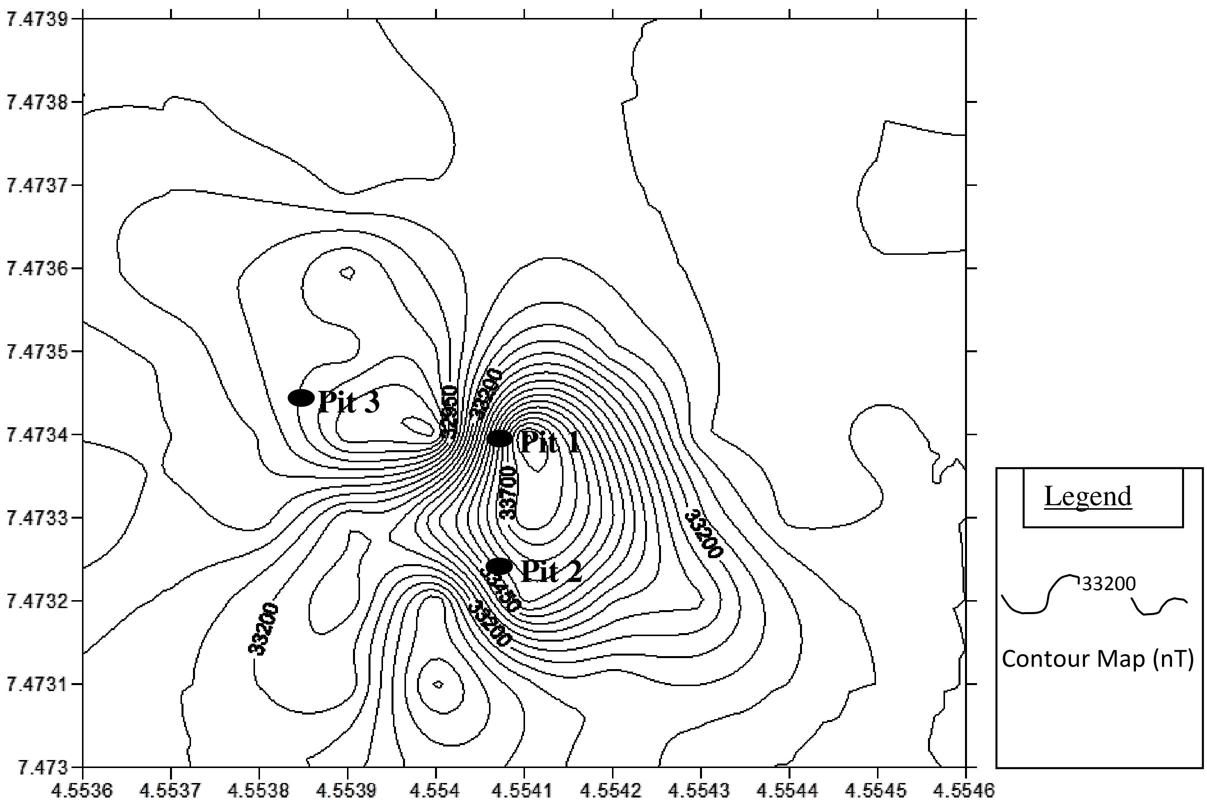

Fig. 8: Total magnetic intensity contour map showing test pits location

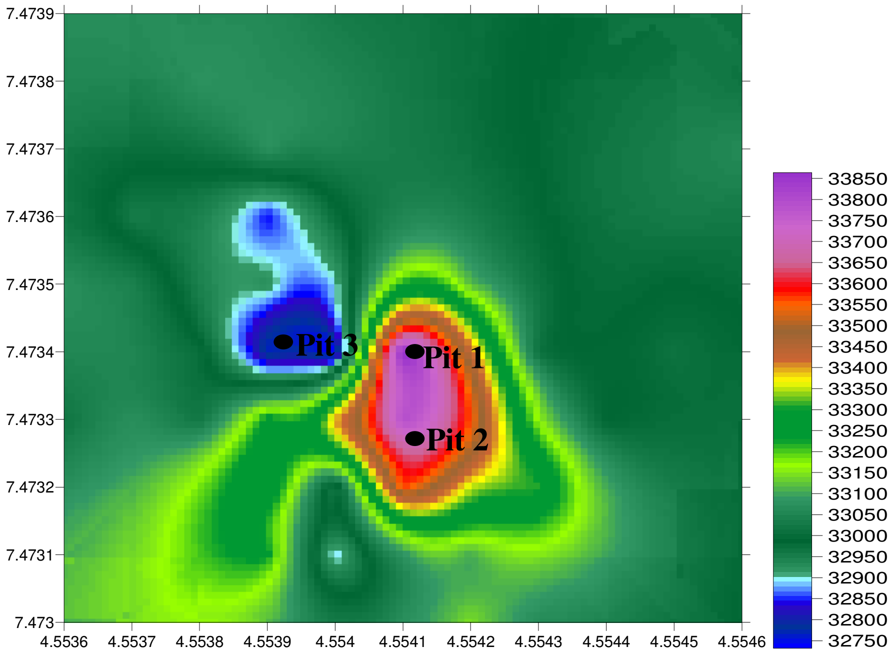

Figure 9: Total magnetic intensity colour image map showing the test pits location

The inventory of the findings from the excavated units (1 and 2) includes stone tools, Tuyere or burnt pipes, iron smelting, broken pottery, some of which were found in their in-situ position while many were recovered (Figures 10 and 11). Also found within these units are rimsherd pottery, decorated potsherds, plane-sherd body pottery and washed pottery. In Unit 2, a layer of charcoal was found in-situ (about 20 – 30 cm depth), iron slag, broken pottery, Tuyere or burnt pipes and broken calabash were recovered (about 10 - 40 cm depth) beneath the top soil. The charcoal within the study area was used for smelting and it was produced from special hard wood which are distinguished by their poisonous characteristics (Ige and Rehren 2003). However, within Unit 3 which serves as the control, sited along Line 4, no archaeological materials were recovered. The iron smelting and slags obtained from the pitting were found to be similar to that reported by Ige and Rehren (2003).

Figure 10: Cultural materials from Unit 1: stone tools, Tuyère or bunt pipes ,iron smelting , iron slag ,pottery lids and potsherds.

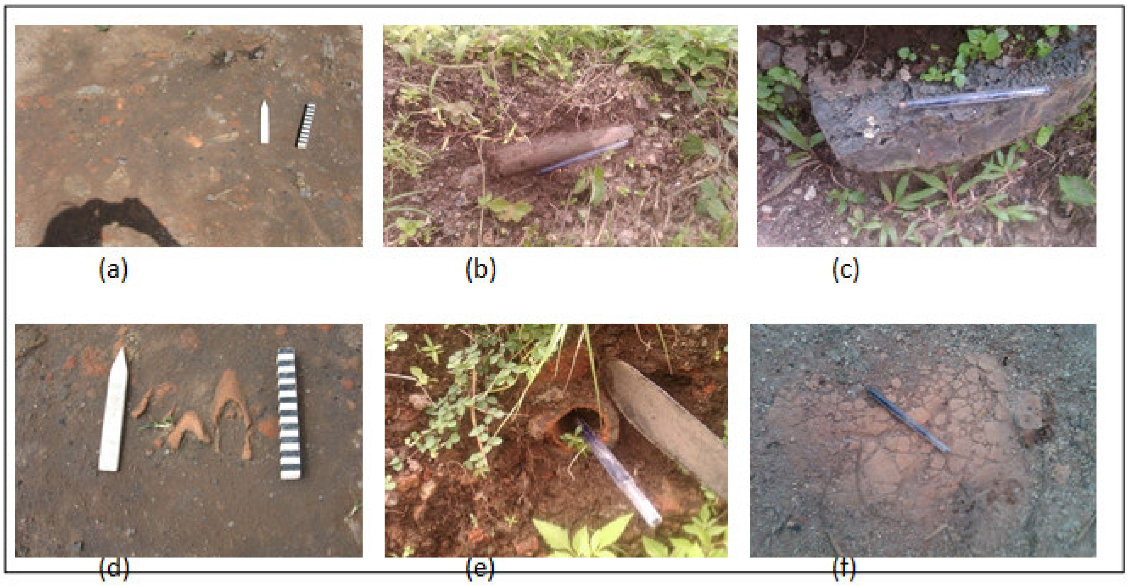

Figure 11: Archaeological objects in their in situ position after removing the top soil (a), (b) and (c) Unit 1, (d), (e) and (f) from Unit 2

5. Conclusions

The practical applications of geophysical techniques to delineate the locations and depths to archaeological materials have been demonstrated. It was observed that regions of high magnetic intensity coincide with that of high resistivity anomalies in most cases. Corroborative evidence from trial pitting shows that units located within these regions yielded high quantities of cultural materials, while that located at low magnetic intensity and resistivity anomaly was almost sterile of any archaeological deposit. Thus the study confirmed that geophysical techniques are non- destructive, and provide the capability to map and analyse subsurface archaeological materials and has been further proven to be an effective tool to expedite cultural preservation other than random pitting.

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