Asian Journal of Information Technology 14 (7): 246-252, 2015
ISSN: 1682-3915

Integrated Geophysical Investigations for Imaging Archaeological Structures in Ancient Town of Ile-Ife, Nigeria

[1]K.D. Oyeyemi, [2]M.A. Oladunjoye, [1]A.P. Aizebeokhai,
[3]P.G. Ajekigbe and [4]B.A. Ogunfolakan
[1]Applied Geophysics Unit, College of Science and Technology, Covenant University, Ota, Nigeria
[2]Department of Geology, [3]Department of Archaeology and Anthropology,
University of Ibadan, Ibadan, Nigeria
[4]Natural History Museum, Obafemi Awolowo University, Ile-Ife, Nigeria

Abstract: Combined geophysical techniques have been used to delineate subsurface archaeological materials in Ile-Ife South-Western Nigeria. The magnetic survey comprises seven orthogonal profiles in N-S and E-W direction with station interval of 0.5 m. Orthogonal set of 2D electrical resistivity tomography data consisting of four parallel and three perpendicular profiles were collected using Wenner array with electrode spacing ranging from 0.5-3.0 m. The 3D inversion schemes applied on the collated 2D data set were based on non-linear least-square optimization technique. The results obtained show that regions of high magnetic intensities coincide with high model resistivity values. Trial pits carried out at these regions yield burnt pipes "TUYERE", iron slag, iron smelting, charcoal specks, stone tools and pottery fragments (e.g., decorative potsherds, pot-rims and pot-lids). These recovered archaeological materials have further proven the study area to be an ancient iron smelting site within Ile-Ife. The research has also demonstrated that integrated geophysical techniques provide fast and cost effective tools in pre-excavation investigation of archaeological materials.

Key words: Tomography, resistivity inversion, geophysical techniques, archaeological materials, Ile-Ife

INTRODUCTION

Applications of non-invasive geophysical investigations have demonstrated a vast potential in meeting environmental compliance obligations to avoid, minimize or mitigate the effects of transportation projects on archaeological resources. The geophysical investigation in archaeological prospecting is a growing and advancing field and surveys are designed to detect and define archaeological structures and features that may be hidden beneath the soil. In the case of 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 techniques have been used to map healths, klins, buried bricks, building foundations, middens (trash heaps), burial tombs, ditches and soils compacted or excavated by previous human (Weymouth, 1986; Loperte *et al*., 2011). They have proven to provide fast, efficient and non-destructive reconnaissance techniques often required by archaeologists. Also, geophysical investigations offer rapid, uniform, reconnaissance mapping of an entire site together with a synoptic view of the interrelationships among structures within the site (Weymouth and Huggins, 1985). In this study, high resolution geophysical methods involving magnetic method and Electrical Resistivity Tomography (ERT) imaging have been used in the search for archaeological materials (iron slag pottery materials, burnt pipes or tuyere). The locations and approximate depths of these archaeological materials were obtained from the resulting geophysical images; pitting was carried out at these locations to verify the accuracy of the geophysical results.

The study area, Iyekere is within the ancient city of Ile-Ife in Southwestern Nigeria. It is boarded by latitudes 4°30'N and 4°33'N and longitudes 7°22'E and 7°25'E (Fig. 1). Other settlements around the study area include Isoya, Alapata and Toro among others. The rock types are predominantly granite-gneiss and pegmatite of the older-granite complex. Schist and epidiorite complex belonging to gneiss-schist complex of the basement complex are the dominant rock type in North-Eastern part of the area as presented in Fig. 2 (Oyawoye, 1972).

Corresponding Author: K.D. Oyeyemi, Applied Geophysics Unit, College of Science and Technology, Covenant University, Ota, Nigeria

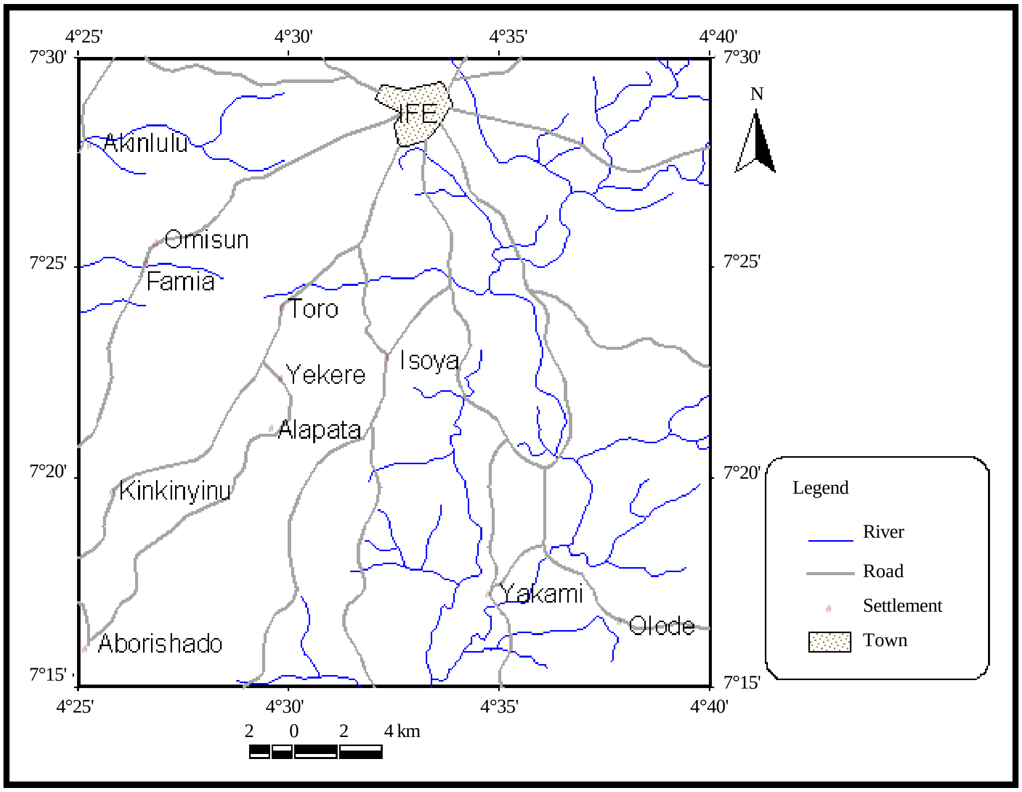

Fig. 1: Location and accessibility map of the study area

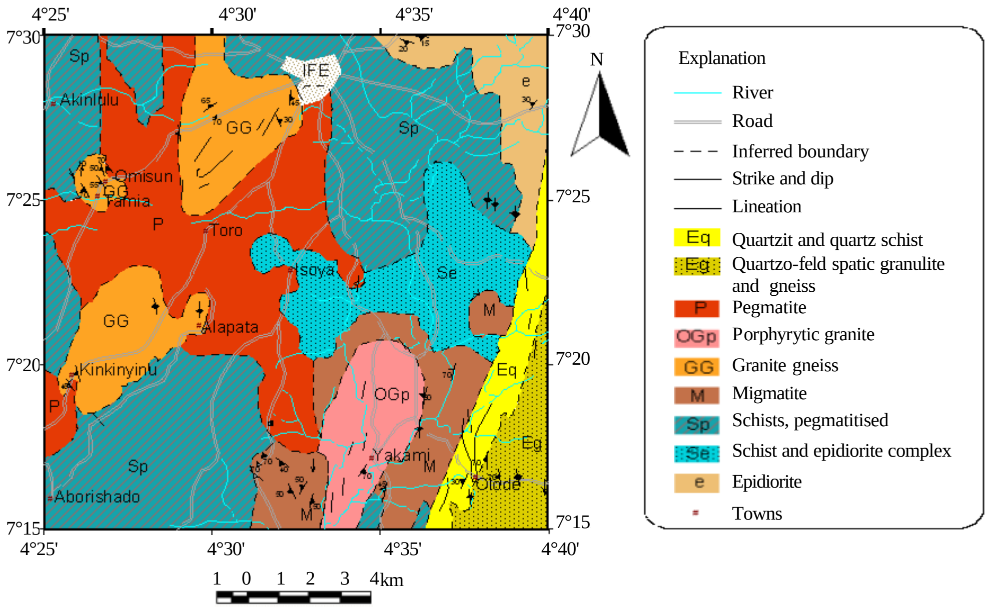

Fig. 2: The geological map of Ile-Ife and its environs (after NGSA, 2004)

MATERIALS AND METHODS

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 traverses. Seven profiles involving four in-lines and three cross-lines were established (Fig. 3).

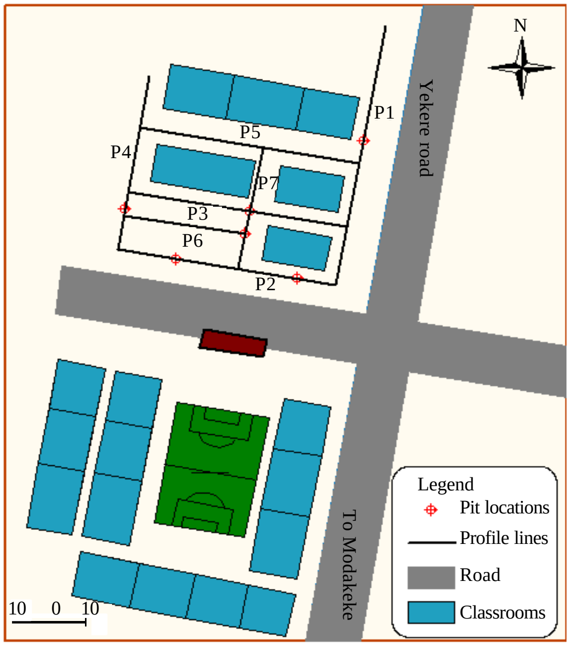

Fig. 3: The geophysical survey base map showing profile lines and pit locations

Station interval of 0.5 m was maintained across each profiles making a data density of 770 points. The sensor was oriented North during the survey while the survey staff was maintained at 0.3 m above the ground surface. The coordinate of each survey points were taking after magnetic measurements using the Geographic Positioning System (GPS) for applying in the surfer 8 software to create various magnetic plots in the study area.

The magnetic data collected in the study area were processed using MagMap 2000 so as to prepare the data set for further processing such as inspection of the raw data for spikes, gaps, instrumental noise and any other irregularities prior to interpretations. The drift correction was accounted for by setting a base station about 200 m away from the survey area whereby another G-856 magnetometer take readings at interval of 1 min. Other corrections made to the total magnetic intensity data include that of the diurnal variation and International Geomagnetic Reference Field (IGRF).

Similarly, a total of seven multi-electrodes 2D geoelectrical resistivity imaging lines were measured using the Wenner-alpha array. The maximum 2D traverse line was 75 m in length while the minimum was 30 m and they form an orthogonal set. The electrode spacing ranged from 0.5-3 m with an interval of 0.5 m. Line 2, 3, 5 and 6 were ran in E-W direction whereas the other three 2D traverses (lines 1, 4 and 7) were ran in N-S direction (Fig. 3).

RES2DINV computer code was used in the inversion of the 2D data. Nonlinear optimization technique which automatically determines 2D resistivity model of the subsurface for the input apparent resistivity data (Loke and Barker, 1996; Griffiths and Barker, 1993) were applied. The entire 2D data set were merged together to form a single 3D data set which were ten inverted using RES3DINV computer code. The inversion routine used by the program is based on the smoothness constrained least square (DeGroot-Hedlin and Constable, 1990; Sasaki, 1992) based on Eq. 1 f_x is the horizontal flatness, f_z is the vertical flatness, μ is the damping factor, J is the jacobian matrix of partial derivatives, d is the model perturbation vector, g is the discrepancy vector which contains the difference between the logarithms of the measured and calculated apparent resistivity values. Three trial pits of 1×1×1 m were excavated, two of which coincides with areas of total magnetic intensity and high resistivity from the results of magnetic method and the 2D resistivity tomography inversion modelling while the other which coincides with the area of low total magnetic intensity and resistivity serves as control:

$$\left\{J^T J+\mu\left(f_x f_x^T+f_z f_z^T\right)\right\}d = J^T g \quad (1)$$

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 (Fig. 4 and 5) alongside the total magnetic intensity profiles for proper integration to aid the general interpretation. The image colour map and 3D perspective map of the total magnetic intensity values within the site are shown in Fig. 6 and 7. The 3D tomographic inversion model resistivity data are presented as six horizontal depth slices (Fig. 8). Similarity between the image map, 3D perspective of the total magnetic data and the 3D resistivity inversion modelling is observed.

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 (Fig. 4 and 5). A major sharp drop in magnetic signature was observed between 24 and 40 m data points centring on 32 m point along line 4 which was about the lowest (-250 nT) in the entire study area. This is interpreted to be an evidence of a backfilled ditch or hand dug well (Weymouth, 1986; Herwanger *et al.*, 2000). The total magnetic intensity colour image map of the area (Fig. 6) depicts region of very high magnetic intensity values towards the centre constituting area of interest in this research.

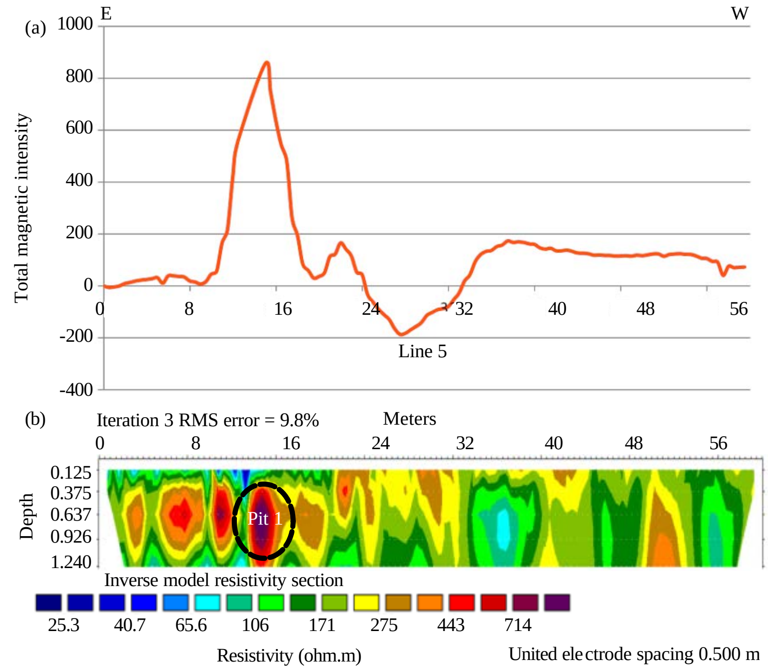

Fig. 4: Magnetic profiles and corresponding 2-D electrical resistivity tomography imaging of line 5

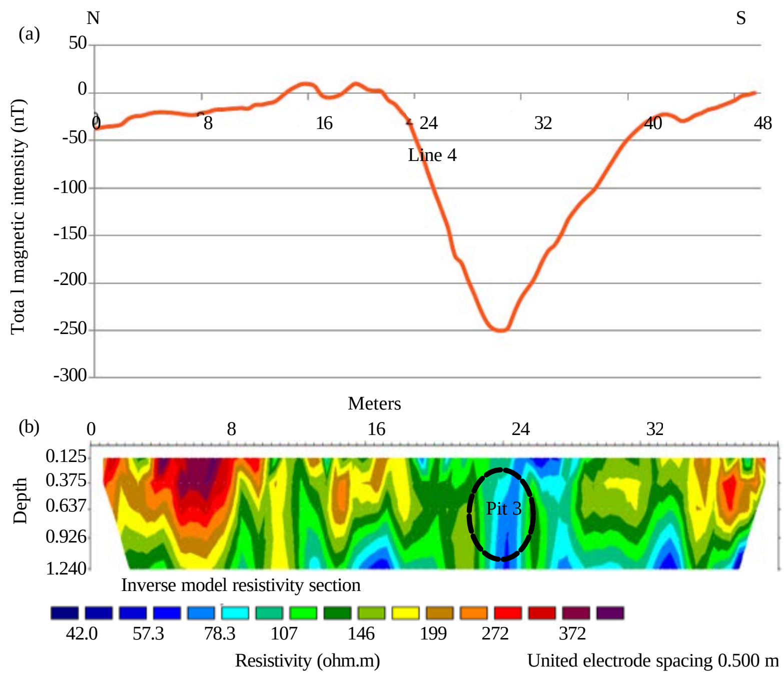

Fig. 5: Magnetic profiles and corresponding 2-D electrical resistivity tomography imaging of line 4

The area of very high resistivity values from the 3D inversion is within the electrodes 8 and 16 on y-axis; 25 and 30 on x-axis. These are interpreted to be points of intersection of lines 3 and 6 with line 7. The base map of the study area was posted on the 3D tomographic inversion (Fig. 9) for each layer slice within the subsurface in order to isolate the targets which correspond to high resistivity data points (Lockhart *et al*., 2001). The depth extent of the archaeological materials can be inferred from six layers in horizontal depth slices to range from 0.25-2.19 m.

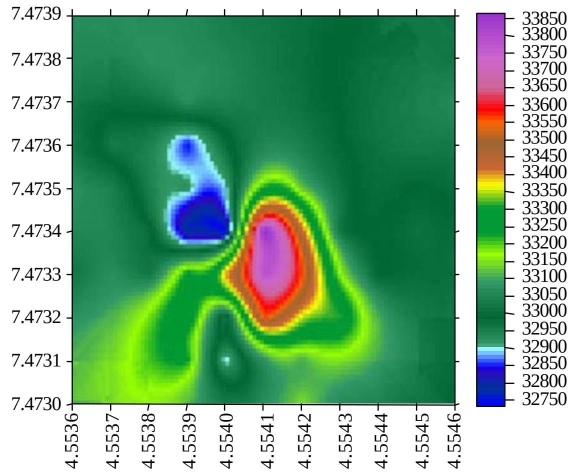

Fig. 6: Total magnetic intensity colour image map of the study area

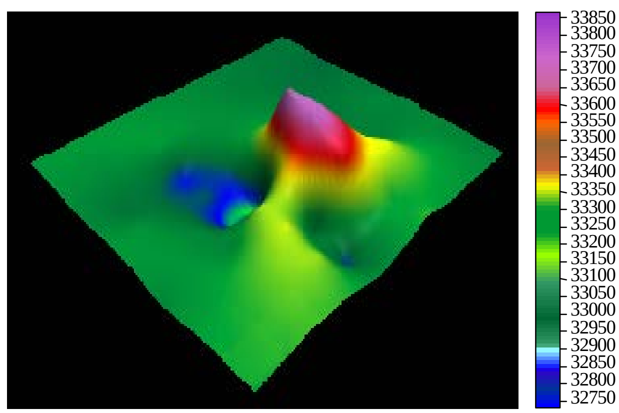

Fig. 7: The 3D perspective map of the total magnetic intensity of the study area

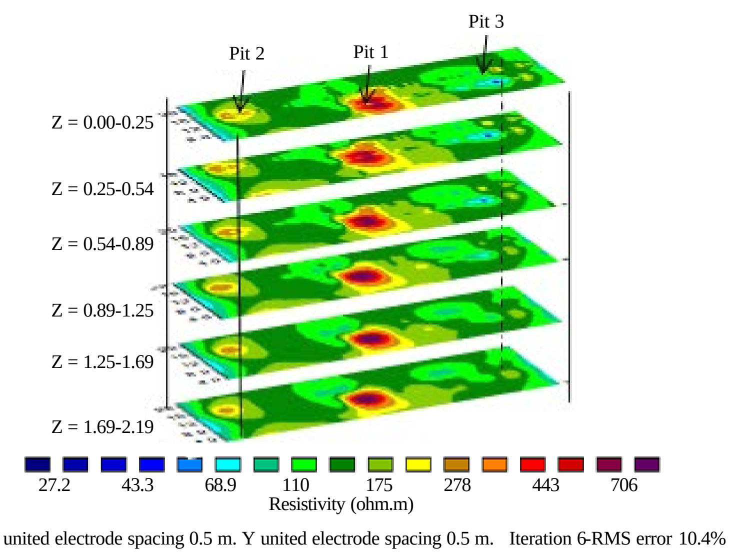

Fig. 8: The 3D electrical resistivity inversion modeling in horizontal depth slices

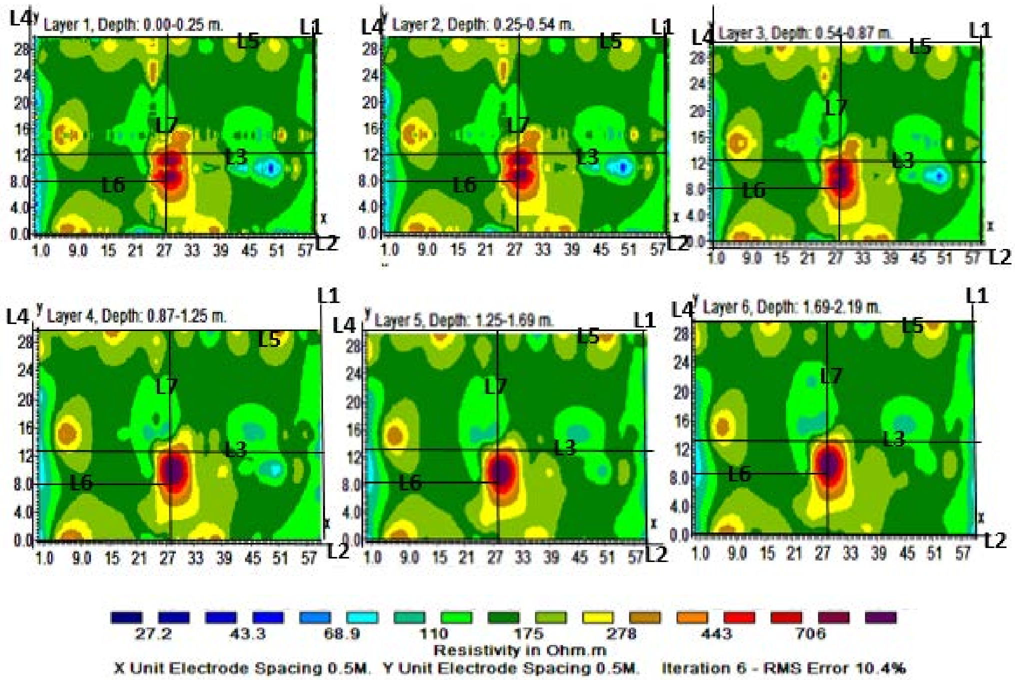

Fig. 9: The 3D geoelectrical resistivity inversion modeling overlaid by the basemap

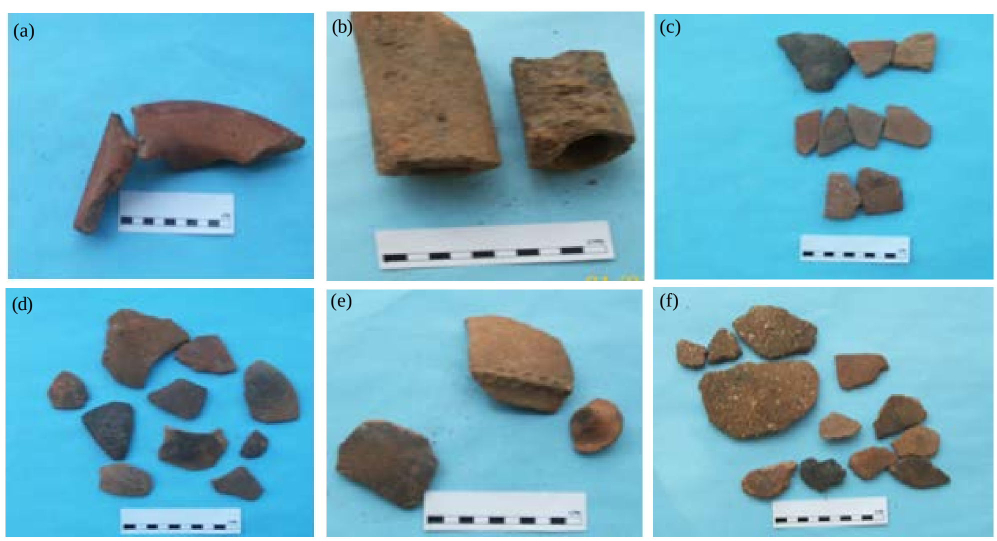

Fig. 10: Photographs showing materials recovered from test pits 1 and 2; a) Rimsherd; b) Tuyere or bunt pipes; c) Decorated potsherds; d) Plane potsherd; e) Decorated potsherds; f) Washed potsherd

After the removal of topsoil in test pits 1 and 2, some archaeological finds were found in their *in situ* position (20-30 cm) which include a layer of coal together with broken calabash. Within test pit 1 which was about 1 m deep at (1×1) m dimensions, stone tools like rolling stones, Tuyere or burnt pipes, iron smelting, broken pottery, decorated potsherds and washed pottery were recovered (Fig. 10). These archaeological finds further corroborated the report of Ige and Rehren (2003) indicating the area to be an ancient iron smelting site. Test pit 3 serves as a control sited along line 4 corresponding to region of very low resistivity and total magnetic intensity values, therefore relatively scanty materials were recovered from this pit during excavation.

CONCLUSION

Integrated geophysical techniques involving magnetic method and electrical resistivity tomography has been effectively used to delineate the locations and depths to archaeological materials at Iyekere, Ile-Ife South-Western Nigeria. The regions of high magnetic intensities correspond to those of anomalously high model resistivities. Inventory from trial pitting shows that pits located at regions of high total magnetic intensities and resistivities yield high quantities of archaeological materials while that located at low magnetic intensity and resistivity was almost sterile. The recovered archaeological materials have further proven the study area to be an ancient iron smelting site in Ile-Ife. The study has also confirmed that non-invasive geophysical techniques provide the capability to map and analyse subsurface archaeological features.

REFERENCES

DeGroot-Hedlin, C. and S. Constable, 1990. Occam's inversion to generate smooth two dimensional models from magnetotelluric data. Geophysics, 55: 1613-1624.

Griffiths, D.H. and R.D. Barker, 1993. Two-dimensional resistivity imaging and modelling in areas of complex geology. J. Applied Geophys., 29: 211-226.

Herwanger, J., H. Maurer, A.G. Green and J. Leckebusch, 2000. 3-D inversions of magnetic gradiometer data in archeological prospecting: Possibilities and limitations. Geophys., 65: 849-860.

Ige, A. and T. Rehren, 2003. Black sand and iron stone: Iron smelting in Modakeke, Ife, South Western Nigeria. Inst. Archaeo-Metall. Stud., 23: 15-20.

Loke, M.H. and R.D. Barker, 1996. Rapid least squares inversion of apparent resistivity pseudosection using a quasi-Newton method. Geophys. Prospec., 44: 131-152.

Loperte, A., A. Satriani, M. Bavusi, V. Lapenna and S. Del Lungo *et al*., 2011. Geophysical prospecting in archaeology: Investigations in Santa Venera, South suburb of Poseidonia-Paestum, Campania, Southern Italy. J. Geophys. Eng., 8: S03-S23.

Oyawoye, M.O., 1972. The Basement Complex of Nigeria. In: African Geology, Dessauvagie, T.F.J. and A.J. Whiteman (Eds.). University of Ibadan, Ibadan, Nigeria, pp: 67-99.

Sasaki, Y., 1992. Resolution of resistivity tomography inferred from numerical simulation. Geophys. Prospect., 40: 453-463.

Weymouth, J.W. and R. Huggins, 1985. Geophysics Surveying of Archaeological Sites. In: Archaeological Geology. Rapp, G. and D.A. Gifford (Eds.). Yale University Press, New Haven, pp: 191-235.

Weymouth, J.W., 1986. Archaeological site surveying program at the University of Nebraska. Geophys., 51: 538-552.