

Mohamed Abdelwahab Mohamed Ali – Hans Burkhardt – Badr el Din Khalil

Integration of Magnetic and Resistivity Imaging Surveys for Archaeological Prospection in the Southern Part of Meroe City (Capital of Kush, Sudan)

Abstract: The current study was carried out in the southern part of the old Meroe city in Sudan. A magnetic gradient reconnaissance survey revealed the presence of fairly clear archaeological building structures, with small dipole anomalies in the magnetic image due to the presence of fired-brick buildings. 10 closely spaced (1 m) parallel resistivity imaging sections in profiles selected on the basis of magnetic results were used to confirm the magnetic anomalies and to provide complementary information about the variation of the sandstone anomalies in depth. Resistivity imaging profiles were also used to demonstrate the feasibility and reliability of combining 2D resistivity profiles in a 3D data set for inversion using a 3D resistivity inversion code. Inversion results of the 3D resistivity data set are displayed in form of horizontal slices, vertical slices and a 3D block diagram.

Introduction

Meroe City is one of the most important archaeological sites in Sudan. It is located east of the Nile about 214 km north of Khartoum (Fig. 1). It is bounded between 16°55"–16°56" N and 33°42"–33°43" E. It was hypothesised that the materials surrounding and concealing the archaeological features in the site show contrast in magnetic susceptibility and electrical resistivity. Therefore, a magnetic survey was

chosen to study the lateral extension of archaeological features, and an electrical resistivity imaging survey in profiles selected on the basis of magnetic results was used to confirm the magnetic anomalies and to provide complementary information about the variation of the archaeological features in depth. The results of both methods were used to produce an integrated interpretation of the geophysical anomalies related to the archaeological features of the site. A fluxgate gradiometer survey in the southern part of the excavated building M750 in Meroe City (Fig. 2.2) confirmed the basic correctness of Garstang's plan of this building while proving the usefulness and applicability of this particular geophysical technique for archaeological investigations in Meroe City (GRZYMSKI 2005).

Geological and Archaeological Conditions

Geological Background

Meroe City (Fig. 2.1) lies on the Shendi Formation, a term introduced by KHEIRALLA (1966) for the sediments near Shendi town which dominate the geology of the area. They consist predominantly of sandstone and sub-ordinate mudstone exposed as plateaus dissected by valleys or water courses and locally covered by recent superficial deposits. The Shendi Formation is recognised as continental sedi-



Fig. 1. Location of the study areas in the geographic map of the Sudan.

ments of a clayey-sand nature and the absence of conglomerate is a distinctive feature (OMER 1983). The palaeo-climate in the area when the Formation was deposited was tropical to subtropical with pronounced dry seasons (BUSSERT 1988). The Nile, which represents the most important drainage element in the area, is draining onto a sandstone lithological sequence. The latter was once referred to in the Sudanese geological literature as the Nubian Sandstone Formation (NSF). The area was subjected to several flooding periods which resulted in the sedimentation of nutrient-rich fertile soil, making not only the old site area but the whole area near the Nile attractive for agriculture. Successive flooding and human activities have led to a lot of damage with a severe impact on the archaeological site.

Archaeological Background

Sudan (*Fig. 1*) is a very large country with many different cultures and peoples in both ancient and recent times. Nubia was thus a corridor between Egypt and Sudan, where a kingdom arose in the 8th century B.C. The name of Kush was introduced for this kingdom and its capital established at Napata (*Fig. 1*) in the Jebel Barkal area near the fourth cataract of the River Nile. Meroe City became the capital of the Meroitic Kingdom, which was established by the Kushite kings when they had moved south along the Sudanese savannah. Meroitic kings had succeeded in occupying the Butana region in central Sudan by that date (HAKEM 1988). The archaeological site of Meroe City (*Fig. 2.2*) was first seen by James Bruce, who in 1772 passed through Meroe and described the red bricks and the ruined buildings generally (GRZYMSKI 2003). The most prominent among these ruins is a huge stone-walled enclosure containing the rubble remains of palaces, governmental buildings, several small temples and the so-called “Roman Bath”. Immediately behind it there is another walled compound enclosing the Amun Temple (*Fig. 2.2*), a near copy of the one at Jebel Barkal. Behind the city in the eastern desert lie its vast cemeteries. Those nearest to the town were reserved for the common people and further to the east, pyramids had been erected for the members of the royal family (KENDALL 1982). In Meroe, a mixture of various construction techniques was used, such as mud bricks and fired red-bricks along with stone slabs and rubble or combined with one or two-sided brick facing (HINKEL 1996).

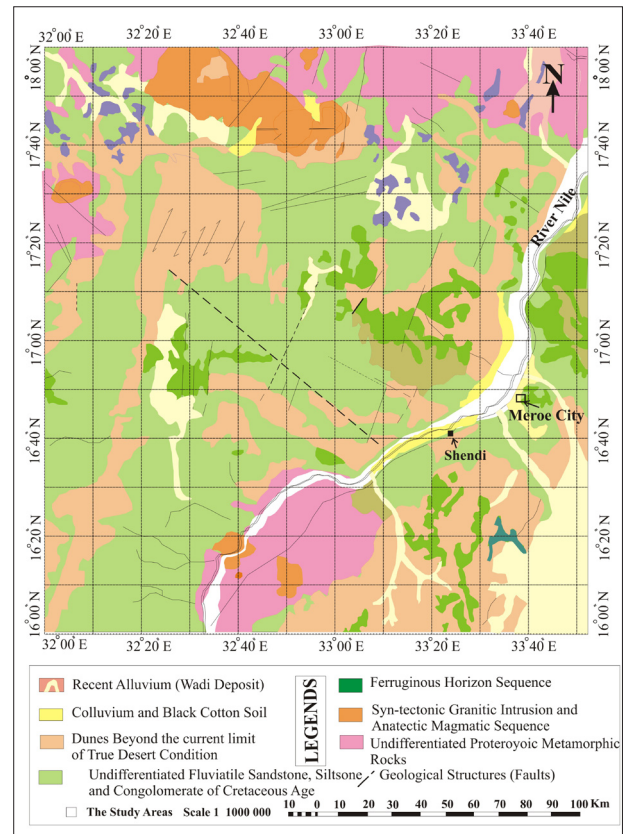


Fig. 2.1. The geological map of the study area and its surroundings (Modified after ROBERTSON 1988).

Field Methodology

A magnetic gradient survey (*Fig. 2.2*) was carried out to search for archaeological features using the Geoscan Fluxgate Gradiometer (FM36). The study area was partitioned into a number of grids, typically 20 m by 20 m. The measured independent grids were later combined to form a single master grid. The master grid provided a full magnetic map for easy display of the anomalies and allowed the data to be processed using Geoscan Geoplot software. Parallel traverses were preferred as a field procedure in order to collect data of high quality. The grids were sampled using meshes with squares of medium size (0.5 × 0.5 m) in the reconnaissance survey, whereas squares of small size (0.25 × 0.25 m) were used for resolving the smaller archaeological features.

A resistivity imaging survey (*Figs. 2.2, 5, 6*) was carried out using the SARIS resistivity system produced by Scintrex Ltd. The typical setup for a 2D resistivity imaging profile consisted of 25 electrodes along a straight line attached to a multi-core cable.

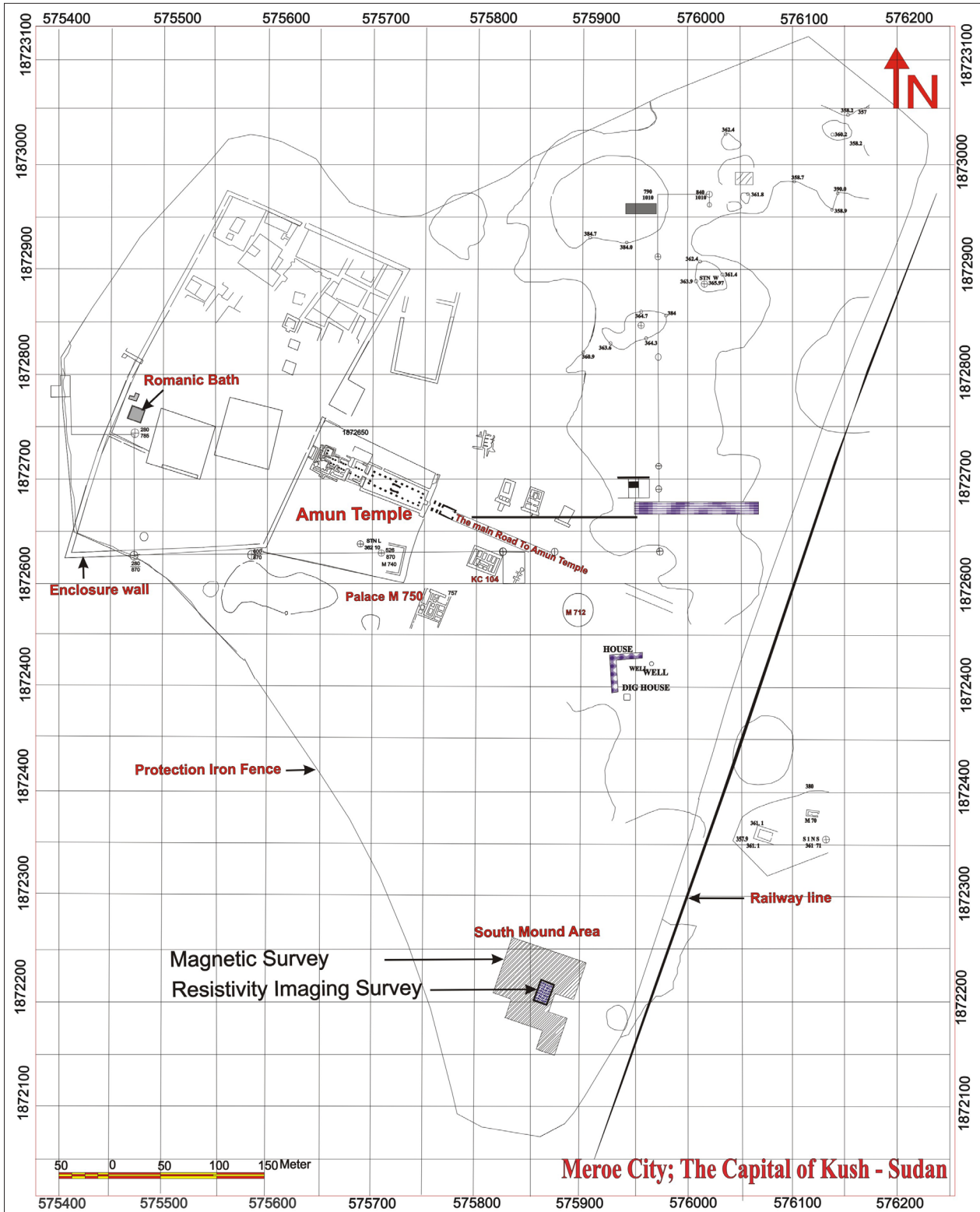


Fig. 2.2. The site map of Meroe City, Sudan, showing the locations of the geophysical surveys (modified after SHINNIE / ANDERSON 2004).

The cable was attached to an electronic switching unit which was connected to a laptop. 10 closely-spaced parallel resistivity imaging profiles (Fig. 6) were carried out in the same area as the magnet-

ic anomalies in grid 10 and grid 14 (Fig. 5). Each of these resistivity imaging profiles is 24 m long. Dipole-dipole array was used as electrode configuration with electrode spacing of 1m and the profiles

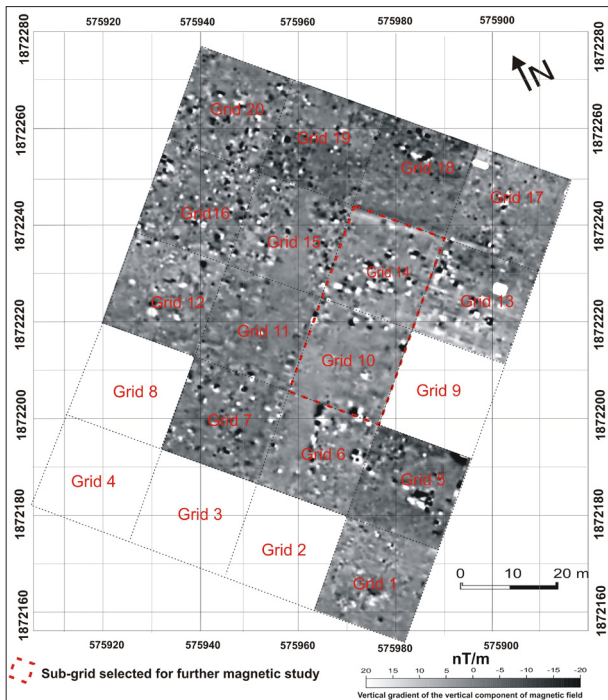


Fig. 3. Vertical gradient magnetic image of the South Mound area in Meroe City.

were spaced 1m apart. These profiles were used to confirm the magnetic anomalies and to provide estimates for the vertical extension of the archaeological building structures. Moreover, it is intended to demonstrate the applicability of combining 2D resistivity profiles to produce a 3D data set for inversion using a 3D inversion code (Res3div).

Discussion of Geophysical Results

Magnetic Results

The magnetic image of the surveyed part in Meroe city (Fig. 3) revealed the presence of many magnetic anomalies. Our interpretation of the most striking anomalies is as follows:

- A broad linear anomaly is encountered in the northern edge of grid 13 and grid 14, running east-west. This anomaly is similar to the enclosure wall signal in the western part of Meroe city, which appeared as a broad linear non-magnetic anomaly embedded in the magnetic background (MOHAMED ALI / BURKHARDT 2007). It is reasonable to interpret this anomaly as a remnant of a similar enclosure wall in this area.

- Fig. 4.1 shows the coarse-sampled (0.5 m) magnetic images of grid 10 and grid 14, whereas Fig. 4.2 shows the corresponding fine-sampled (0.25 m) magnetic images. The anomalies in all these images show some regularity and hint at the existence of building structures in this area. The scattered dipole anomalies along these buildings indicate that these buildings were probably partly constructed of fired bricks, whereas irregularly scattered dipole anomalies may be due to parts of the building having been destroyed.
- Fig. 4.1 shows the anomalies clearer than the magnetic images in Fig. 4.2. These examples indicate that in some cases the coarse-sampled pattern results may look better than the fine-sampled pattern. These results do not mean that the coarse-sampled pattern resolve the archaeological features better than the fine-sampled one; rather, the measurements in the former case were affected by signal from target features and undesired noises, which were sampled much more in the fine-sampled pattern (0.25 m) than the coarse one (0.5 m). Moreover, the assumed building structures in the coarse-sampled data (Fig. 4.1a) respond better to interpolation (Fig. 4.1b) than the fine-sampled data does (Fig. 4.2b). The features are even more clearly visible after high-pass filtering (HPF) of the coarse-sampled data (Fig. 4.1c) than in the filtered fine-sampling data (Fig. 4.2c).
- It was difficult to identify buildings with regular geometry in grid 16, but the magnetic image (Fig. 3) emphasises that the area was subjected to intensive construction work. Furthermore, remains of these building materials are still preserved in the subsurface. This interpretation is supported by the scattered regular and irregular boulders and blocks of sandstone in grid 16 and its surroundings.

Resistivity Imaging Results

The 2D parallel resistivity imaging profiles (Figs. 5, 6) were inverted using Res2Dinv and Res3Dinv. Of the 10 closely-spaced profiles, only three were selected to be discussed here to demonstrate some of the outcomes of using these complementary techniques in prospecting for archaeological features in Meroe City:

- The inverted geo-electric sections (Fig. 7) show the variation in electrical resistivity of the prospected zones horizontally and vertically. The variation

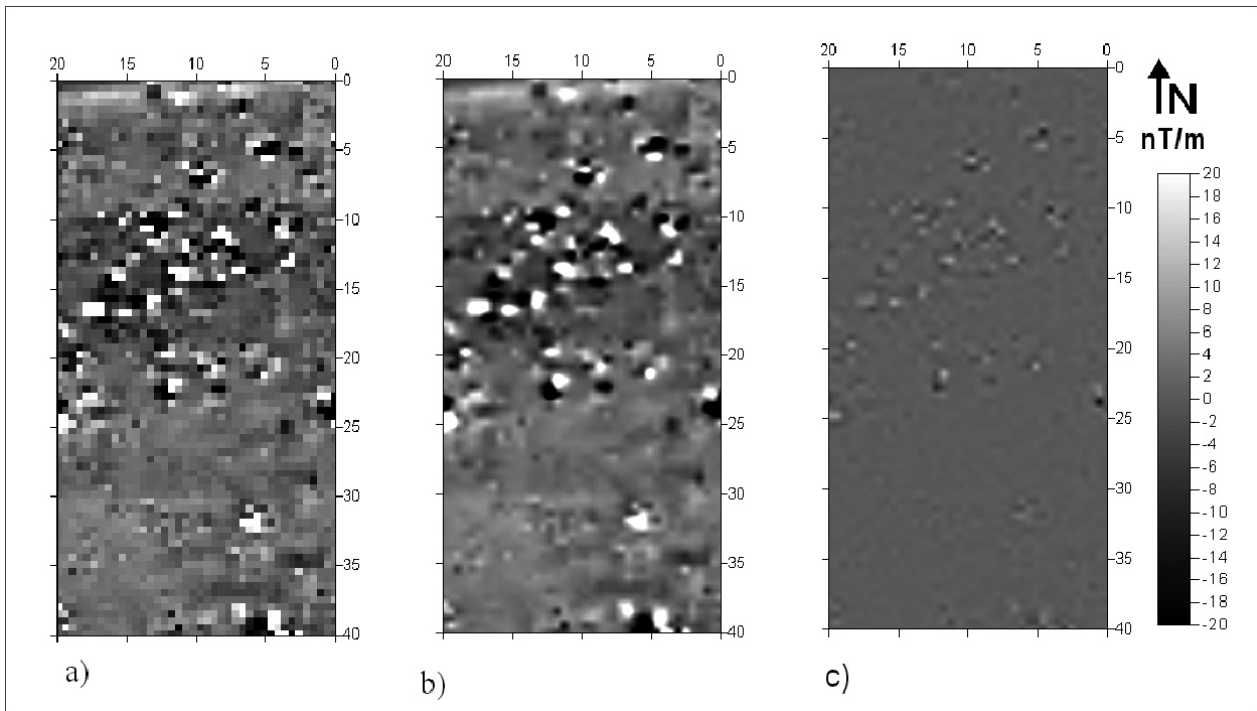


Fig. 4.1. The processing of magnetic data of grid10 and grid14, South Mound, Meroe City. The data was collected using a sampling interval of 0.5 m and a traverse interval of 0.5 m. (a) Raw data (b) Interpolated data (c) high-pass filtered data.

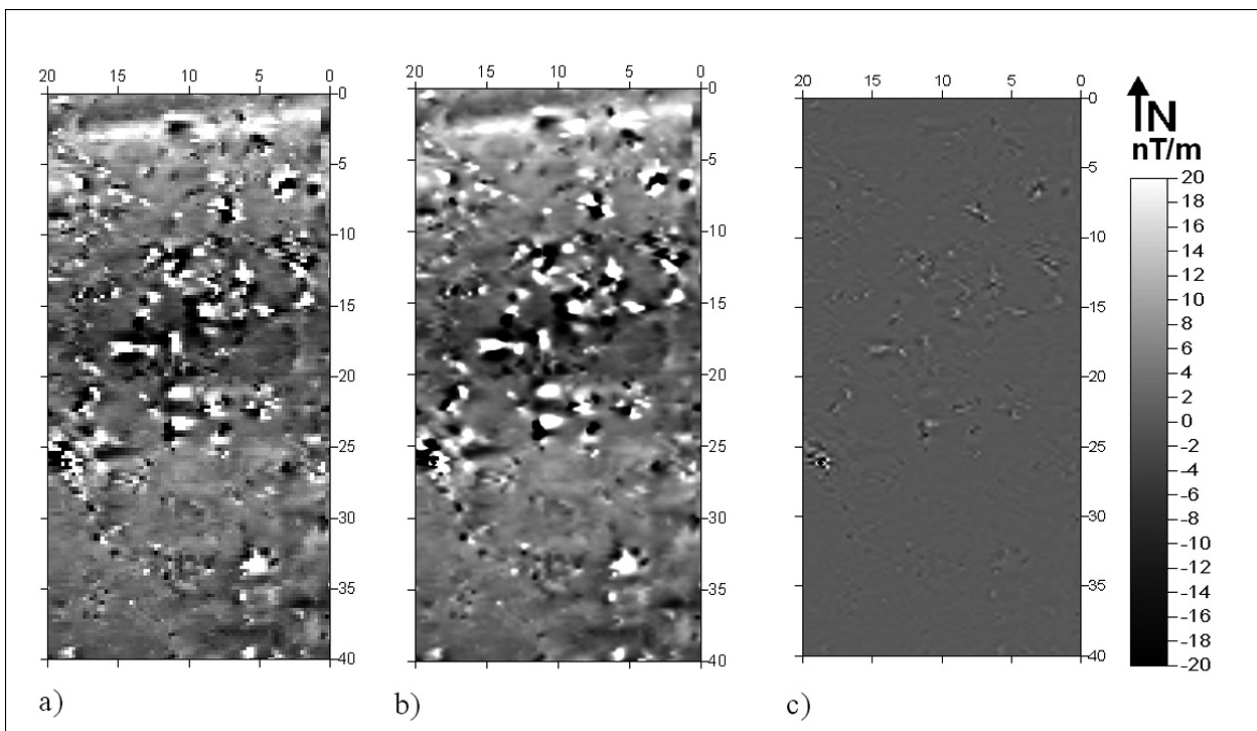


Fig. 4.2. The processing of magnetic data of grid10 and grid14, South Mound, Meroe City. The data was collected using a sampling interval of 0.25 m and a traverse interval of 0.25 m. (a) Raw data (b) Interpolated data (c) high-pass filtered data.

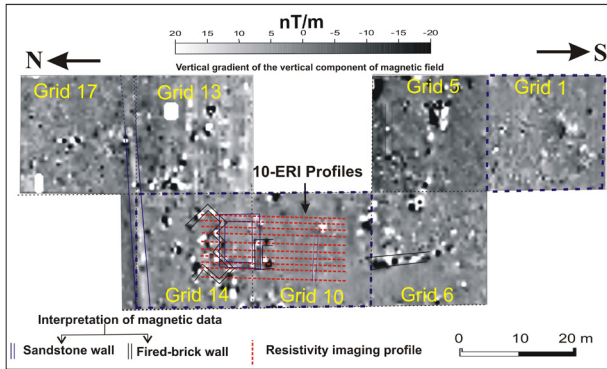


Fig. 5. Locations of resistivity imaging profiles on the magnetic image of the selected grids, which show the most interesting anomalies in the South Mound area, Meroe City. (a) Profile 4, Location – Y = 3 m. (b) Profile 5, Location – Y = 4. (c) Profile 6, Location – Y = 5 m.

is displayed in the form of separated anomalies with different resistivities. The estimated vertical extensions of the prominent anomalies, which are assumed to have link with the archaeological building structures, range between 0.5–1.5 m. This depth range is reasonable for buried sandstone structures and correlates well with the depths of similar features as revealed by previous excavations (GRZYMSKI 2005).

- Inversion results of the 3D resistivity data set are displayed in the form of horizontal and vertical slices. The horizontal slices (Fig. 8) show the layout of the sandstone buildings in the surveyed area in an easily understandable form, indicating that the southern part of grid 10 contains some regular building structures.
- The vertical slices in the y-direction located between 3 m and 5 m (Fig. 9) correlate well with the inversion results (Fig. 7) of the independent 2D imaging profiles (profile 4, profile 5 and profile 6) and confirm the reliability and feasibility of combining 2D resistivity profiles into a 3D data file for inversion using a 3D resistivity inversion code (Res3dinv).
- The vertical slices in the x-direction (Fig. 10) are not large enough to give a full image for the layout of the building in this direction, but some wide and highly resistive bodies with regular geometry are nevertheless encountered in most of the selected cuts.
- The 3D resistivity imaging data were exported to be displayed in a 3D block diagram (Fig. 11) using Slicer-Dicer software, which provides a better 3D presentation mode to visualise the surveyed features.

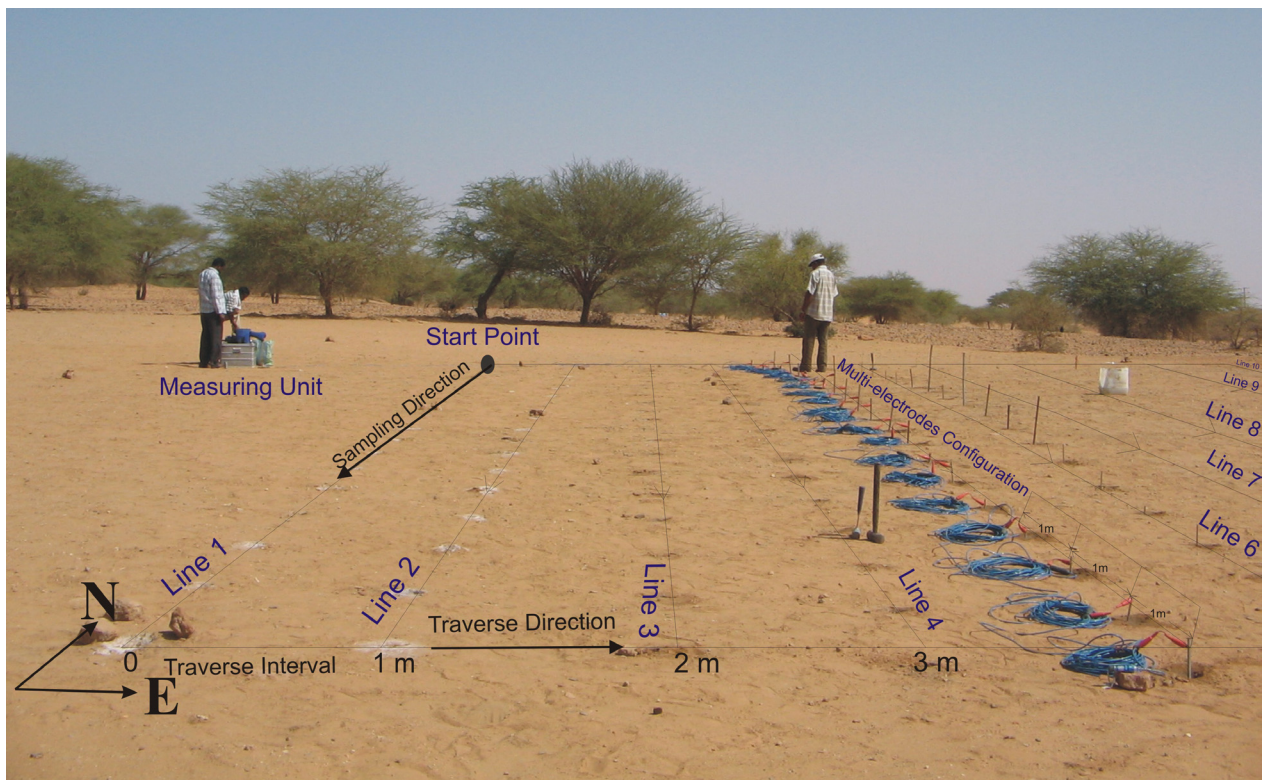


Fig. 6. The layout of the resistivity imaging profiles in the South Mound area, Meroe City.

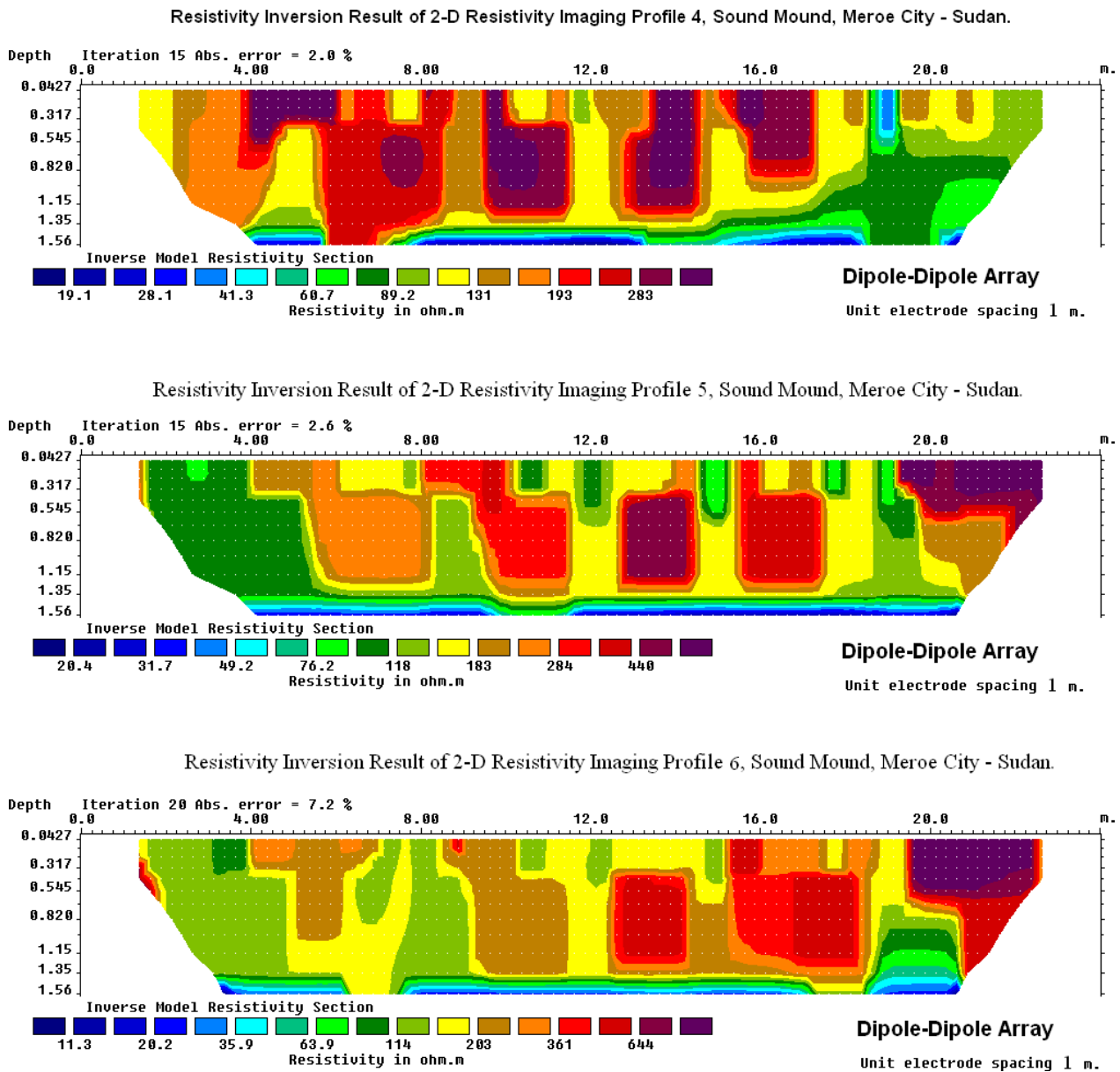


Fig. 7. The inverted resistivity imaging sections of the independent 2D resistivity sections of profiles 4, 5 and 6 using a dipole-dipole array.

Conclusions

- The integration of the magnetic and resistivity imaging surveys in the South Mound of Meroe City succeeded in discovering some new archaeological buildings in grid 10 and 14 (Fig. 4).
- The magnetic results indicate the presence of fired-brick buildings in grid 14, whereas the resistivity imaging results (Fig. 7) confirmed an extension for these buildings in grid 10. Therefore, this method helps in the interpretation of already-existing but hardly visible magnetic anomalies which refer to the same buildings in grid 10.
- The difficulty in identifying the magnetic anomalies can be attributed to the fact that the contrast in the magnetic susceptibility between the target features (e.g. the sandstone wall) and their surroundings was not large enough to successfully detect this material using a magnetic survey.
- The magnetic survey in the South Mound area in Meroe City reveals an extension of the enclosure wall in the surveyed area. It was difficult to define other building structures with regular geometries, but it is possible to conclude that the western part of the studied area was subjected to intensive construction work. The magnetic anomalies show

3-D Resistivity Imaging Profile - Dipole-dipole Array-South Mound, Meroe City.

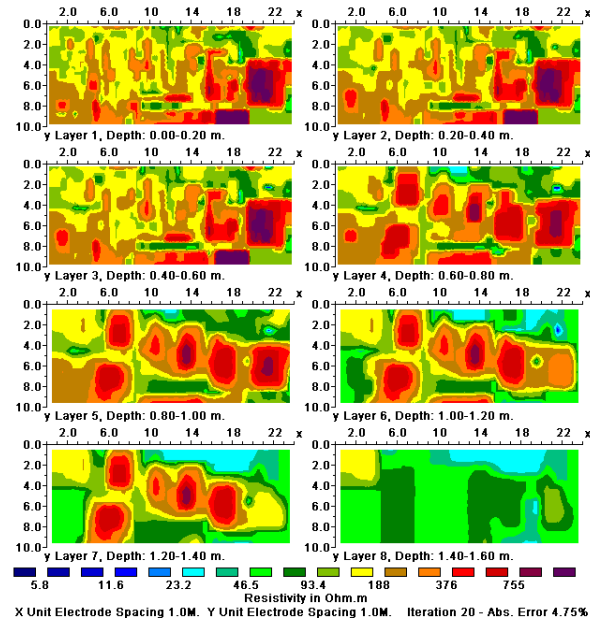


Fig. 8. Horizontal slices of the 3D dipole-dipole resistivity data.

that the interpreted and the assumed building structures were built using not only sandstone but also fired bricks.

- Depending on the size of the target features, measurements using the coarse-sampled pattern may in some cases produce more reliable results than fine-sampled pattern. Moreover, the archaeological structures, which are resolved with such a sampling pattern, may respond well to enhancing, smoothing or filtering of anomalies with various processing tools.
- Although the area was prepared for the magnetic survey by removing all the anticipated sources of noise (such as fired bricks, pottery fragments, iron objects, etc.), anomalies from buried noise sources in the shallow subsurface could be seen in magnetic images, making the interpretation of the sources more difficult.
- The 3D electrical resistivity imaging technique is a feasible approach for archaeological geophysics problems. It provides a high-resolution image of the subsurface electrical resistivity distribution. Consequently, it reduces the time and effort

3-D Resistivity Imaging Profile - Dipole-dipole Array-South Mound, Meroe City.

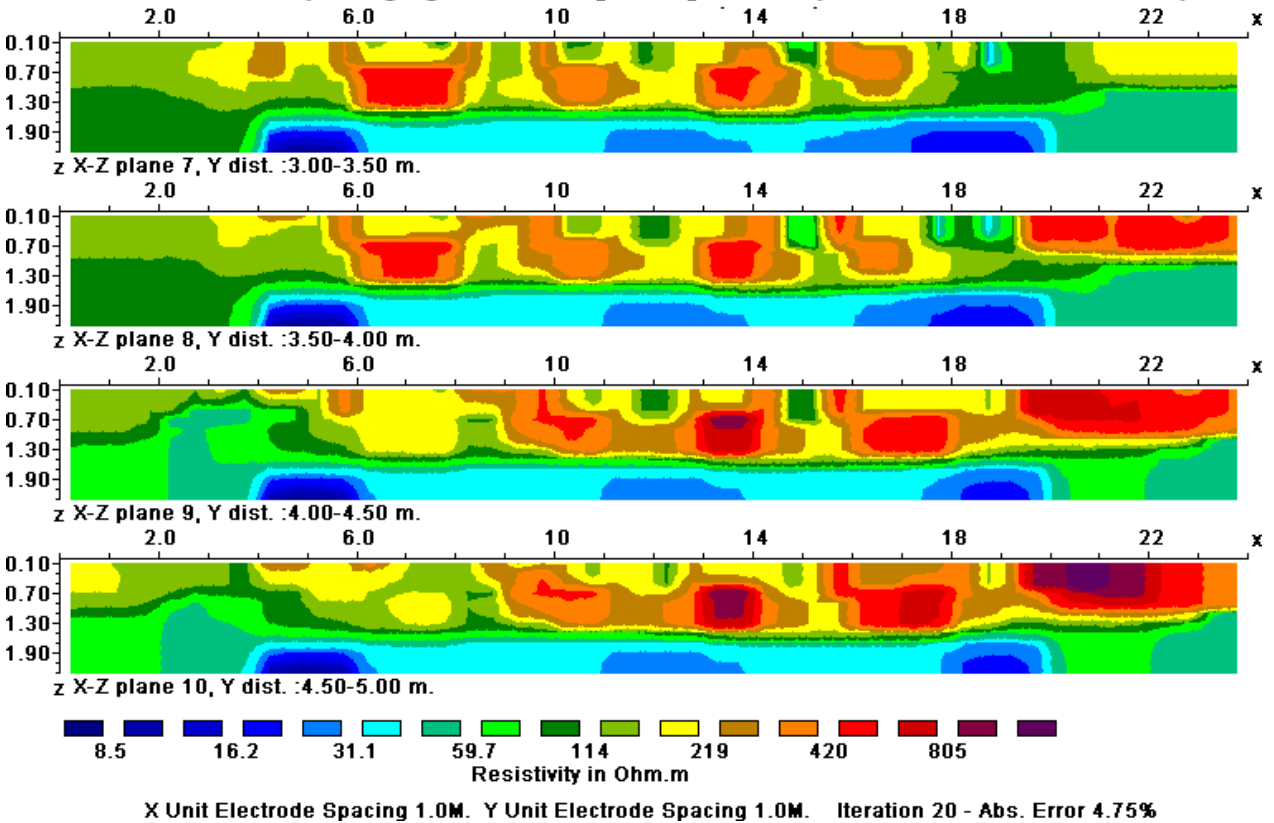


Fig. 9. Vertical slices (Y-cuts) of the 3D dipole-dipole resistivity data.

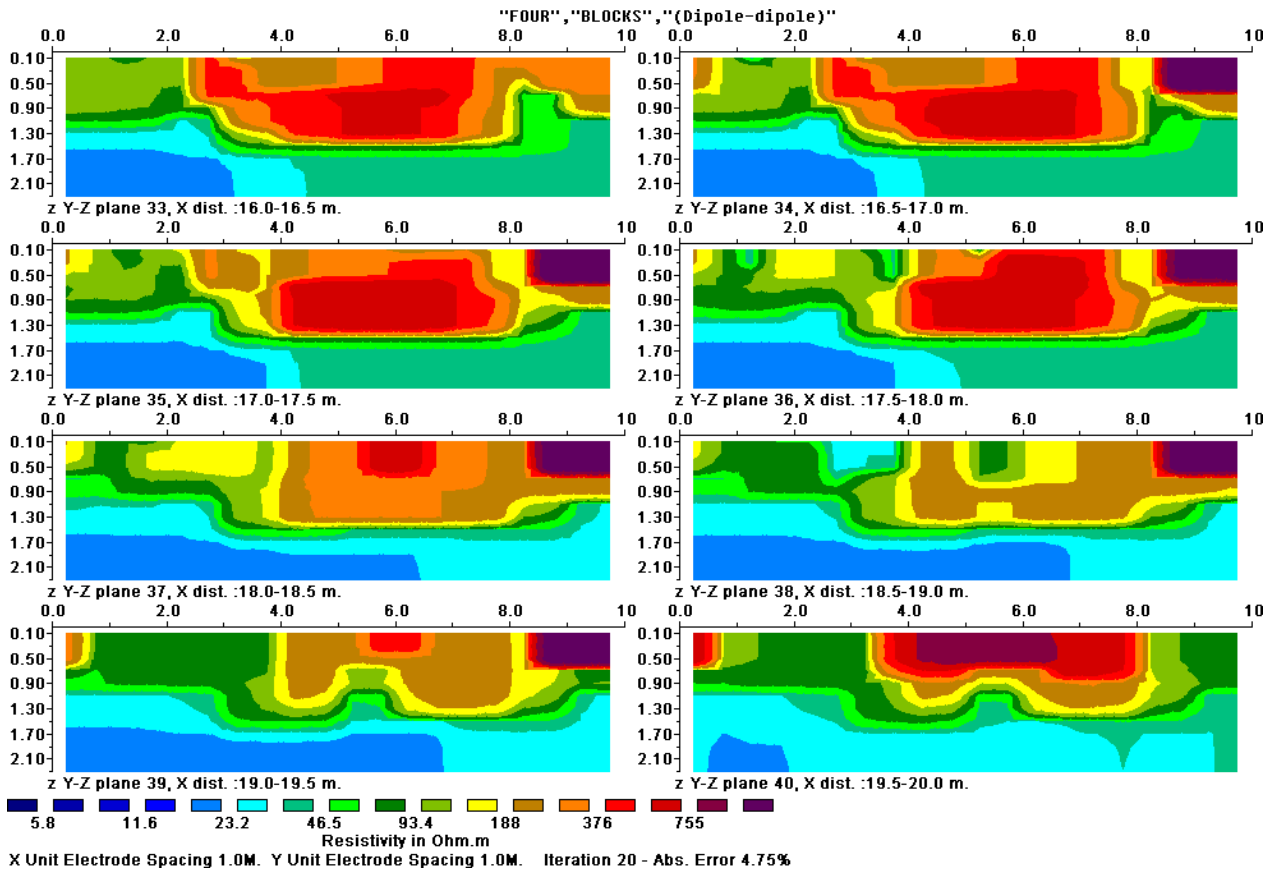


Fig. 10. X-cuts vertical slices of 3D model of the dipole-dipole resistivity data.

required to interpret and examine the reliability of anomalous features revealed by the 2D resistivity imaging data, but a full 3D ERI survey is time-consuming. The current study demonstrated the applicability of combining 2D resistivity imaging profiles in 3D data set for inversion using a 3D resistivity inversion code.

Acknowledgments

The authors would like to thank the DAAD Germany, which financed both the fieldwork in Sudan and the laboratorial work at the TU Berlin. Special thanks to Zickgraf and Posselt Company (Marburg, Germany) for providing the FM36 and to the Geological Research Authority of Sudan (GRAS) for providing the SARIS resistivity meter for carrying out the surveys. We are indebted and grateful to the team of the German Archaeological Institute (Dr. Simone Wolf and Dr. Hans-Ulrich Onasch) and to Mr. Zahir Ahmed for their help during the fieldwork in Sudan. Thanks to the National Corporation of Antiquities and Museums (NCAM) for providing access to the site. Thanks also to the staff of the Department of Archaeology at the University of Khartoum for their assistance in carrying out the magnetic survey in Meroe City.

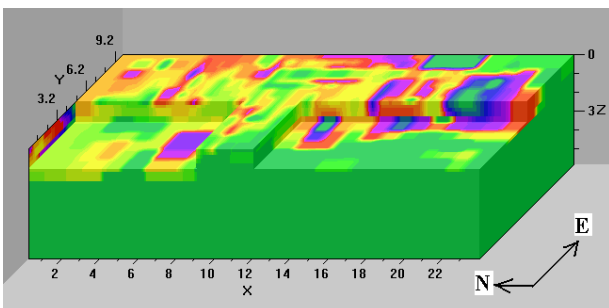


Fig. 11. 3D Block diagram of 3D resistivity imaging data using dipole-dipole array.

References

- BUSSERT 1988
R. BUSSERT, The Albian-Cenomanian Palaeo-Climates in Northern Sudan. In: U. THORWEIHE / H. SCHANDELEIMERE (eds.), *Geoscientific Research in Northeast Africa* (Rotterdam 1988) 407–414.
- GRZYMSKI 2003
K. GRZYMSKI, *Meroe Reports I*. SSEA Publications 17 (Mississauga 2003).
- GRZYMSKI 2005
K. GRZYMSKI, Meroe The Capital of Kush: Old Problems and new Discoveries. *Sudan & Nubia* 9, 2005, 44–55.
- HAKEM 1988
A. M. HAKEM, *Meroitic Architecture: A background of African Civilization* (Khartoum 1988).
- HINKEL 1996
F. HINKEL, Meroitische Architektur. In: D. WILDUNG (ed.), *Sudan: Antike Königreiche am Nil* (Tübingen 1996) 391–415.
- KENDALL 1982
T. KENDALL, *Kush: Lost Kingdom of the Nile* (Brockton 1982).
- KHEIRALLA 1966
M. K. KHEIRALLA, A Study of the Nubian Formation of the Nile Valley Between 14° N and 17°42" with Reference to the Groundwater Geology. Unpublished M.Sc. Thesis (Khartoum 1966).
- MOHAMED ALI / BURKHARDT 2007
M. A. MOHAMED ALI / H. BURKHARDT, 1D, 2D and 3D Inversion of Magnetic and Resistivity Data of the Royal Enclosure Wall in Meroe City, Sudan. 67th DGG Conference, Aachen, Germany, March 2007. Oral Presentation.
- OMER 1983
M. K. OMER, *The Geology of the Nubian Sandstone Formation in Sudan* (Khartoum 1983).
- ROBERTSON 1988
Robertson Research International, *Geological Atlas of Sudan* (Llandudno 1988).
- SHINNIE / ANDERSON 2004
P. L. SHINNIE / J. R. ANDERSON, *The Capital of Kush 2: Meroë Excavations 1973–1984*. *Meroitica* 20 (Wiesbaden 2004).

Mohamed Abdelwahab Mohamed Ali

*University of Dongola
Faculty of Earth Science & Mining
P.O. Box 47, Dongola
Sudan
mohdabdwahab@yahoo.com*

Hans Burkhardt

*TU Berlin
Department of Geophysics
Ackerstr. 76
ACK. SEK. 2
13355 Berlin
Germany*

Badr el Din Khalil

*Al Neelain University
Faculty of Science and Technology
School of Applied Geosciences
12702 Khartoum
Al Khartoum
Sudan*