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2D electrical resistivity imaging of tantalite-bearing veins in Kaiama, Nigeria

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ABSTRACT

The utility of the electrical resistivity (ER) method of geophysics for delineating tantalite-rich zones is demonstrated. To avoid negative environmental consequences, the local authority refused the use of trial-and-error method by the artisanal and small-scale miners. 2D ER method was applied to delineate the locations and dimensions of the tantalite-rich zones. Data were acquired along nine profiles in the study area at predetermined locations, after reconnaissance field mapping, using SuperSting R8/IP Earth Resistivity Metre, 84 electrodes, and the full accessories. Each profile was 249 m long with 84 electrodes coupled to the ground at 3 m intervals on a straight line following the dipole–dipole electrode array. Data acquired were processed to obtain tomographic images of the subsurface. The results revealed low resistivity anomalies (1–60 Ωm) corresponding to tantalite-rich quartz veins that intruded into the high-resistive migmatite-gneisses-schist complex. The tantalite-rich zones were located at depths ranging from near-surface to about 45 m, their lengths and thicknesses range from 40 to 220 m and 3 to 32 m, respectively. A pit dug along profile six confirmed the low resistivity structures to be tantalite-rich quartz veins. Findings from the study are useful for economic evaluation of similar deposits, determining the extent of excavation required for mining, and planning land reclamation.

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mineral exploration;
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tomography

1. Introduction

Artisanal and Small-scale Mining (ASM) activities have been going on in southern Kaiama for many years. The mineral commonly found in the areas include Gold, Cassiterite, Wolframite, and Tantalite hosted in weathered pegmatites and quartz veins at shallow depths up to about 6–7 m. In 2015, Tantalite mineralisation was discovered in the central part of Kaiama through a hand-dug well that was originally planned for groundwater exploitation near some incomplete buildings in the new residential area. The pits in the area revealed that the tantalite-rich veins are located at about 12 m depth. Because of the proximity of the site to the towncenter, ASMs were refused permission to explore and mine tantalite in the area. This is because the ASMs activities (trial-and-error exploration) are characterised by large-scale sand excavation, air and water pollution, land degradation, erosion, and other environmental concern. However, the local authority is interested in mining the mineral for economic reasons, with minimal negative environmental consequences.

To avoid indiscriminate soil and rock excavations and other environmental concerns that follow the trial-and-error exploration method used by ASMs, the Electrical Resistivity method was applied to explore the subsurface for Tantalite

minerals in the study area. This study aimed to delineate tantalite-rich zones in order to determine the average size and depth of tantalite ore bodies and recommend the appropriate mining method. Tantalite is a metallic mineral. Metallic minerals are electronic semi-conductor whose presence, even in small quantities, can influence the bulk resistivity of geologic materials hosting them. Their presence is usually indicated by a low resistivity anomaly compared to the country-rock. Therefore, Electrical Resistivity, ER, method of geophysics can be used to measure the inherent properties of tantalite ore hosted in a metamorphic basement rock provided the host rock has a contrasting resistivity property. ER is a non-invasive environmentally friendly technique that is suitable for subsurface exploration in built-up and undeveloped environments. The method is operationally simple, and cost-effective (Abubakar et al. 2014) compared to the labour-intensive environmentally degrading trial-and-error exploration practiced by ASMs. Two-dimensional (2D) ER survey is particularly suitable for mineral exploration because of its capacity to reveal the approximate dimension of the mineral deposit and the depth of the mineralised zones, thereby allowing pre-drill in-situ evaluation of mineral deposits. ER method has been successfully used for mineral

exploration in different parts of the world (Goh et al. 2006; Park et al. 2009; Arifin et al. 2019; Akanbi et al. 2017) and groundwater exploration in similar geological terrain (Raji 2014; Aromoye et al. 2019).

Park et al. (2009) applied electrical resistivity survey to identify gold-rich zones in Yongjang mine in South Korea. The results of the study showed that the gold-rich veins are associated with low resistivity regions and indicated that the veins have thicknesses ranging from 2 to 40 m and lengths that range from 100 to 260 m. Arifin et al. (2019) used ER and induced polarisation survey to delineate gold-rich veins in Kelantan, east coast of Malaysia. The study showed that gold-rich veins have resistivity values that are lower than the host rock. The study was used to propose forty (40) drilling locations for the exploitation of the gold deposit. Akanbi et al. (2017) used ER imaging to map cassiterite bearing faults in Jos, Nigeria. They found out that the cassiterite-rich zone is lying between 10 and 11.5 m. Arising from the success recorded in the above-cited studies among others, electrical resistivity method is applied for the exploration of tantalite-rich zones in Kaiama, Nigeria.

2. Geology of the study area

The study area falls with latitude $9^{\circ} 30'$ and $9^{\circ} 45'N$ and longitude $3^{\circ} 45'$ and $4^{\circ} 00'E$ in Kaiama, Kaiama local government area of Kwara State, Northcentral Nigeria. Kaiama lies within sheet 158 of the Federal Survey Map of Nigeria. Kaiama town is close to the international boundary between Nigeria and Benin Republic. The climate of the study area is divided into two major seasons: the rainy season which usually ranges from April to September and the dry season which usually ranges from October to March. The daily temperature ranges between 26° and 34° , while the mean annual rainfall ranges from 78 to 110 mm. Geologically, Kaiama falls within the basement complex terrain of southwestern Nigeria which is Pre-Cambrian to lower Palaeozoic in age. The four main lithological groups in the basement complex are the migmatite gneiss complex, the schist (meta-sedimentary or meta-volcanic); the older granite; and the undeformed acid to basic dykes (Oyawoye 1964; Rahaman 1976; Obaje 2009). The Nigeria basement complex is a polycyclic assemblage of heterogeneous migmatite-gneisses, metasediments, and granites that have undergone complex orogenic cycles of deformation, metamorphism, and remobilisation (Olade and Elueze 1979).

The meta-sediment and meta-volcanic schist belt intruded by igneous rocks are the mineral-bearing zones in the basement complex terrain of southwestern Nigeria. The schist belt lithologies consisting of fine-grained clastic, pelitic schist, marbles, banded

iron formation, tantalite, columbite, and amphibolites host most of the economic minerals in the basement complex terrain of Nigeria. The most prominent structural trend is approximately north-south direction. Kaiama is situated in the Nigerian schist belt between the Pharusian belt of northwest Africa and borborema province of Brazil (Dada 1982). The main rock types in Kaiama include granite, schist, migmatite, amphibolite, and quartzite. Pegmatites and quartz veins host metallic minerals, rare earth minerals, and gemstones in southwest Nigeria. The mineralisation control is the approximate north-south trending transcontinental fault that is related to the Pan African Orogeny which took place about 600 Ma. The orogeny was later followed by widespread intrusion of granitoid whose late phase is enriched in pegmatites. The pegmatites and quartz veins host the tantalite, columbite, cassiterite in Kaiama. Other metallic minerals in the area include gold, cassiterite, and columbite. A geological map of Nigeria showing the location of Kaiama is presented in Figure 1(a), while the topographic map of the study area is shown in Figure 1(b) with the 2D ER profiles.

3. Material and methods

3.1. Data acquisition

Geological field mapping and preliminary geophysical investigations were conducted to study the rocks in the area. Outcrops in the area were mapped, and the strike and dips of the planar features were measured. The pits enriched with tantalite mineralisation were examined to know the trend, depth, and approximate thickness of the mineralised veins in the area. From field observations and pit examinations, some geophysical survey parameters including electrode array, optimum electrode spacing, and the profile length required to penetrate the maximum depth of the mineralised veins were selected. Consequently, a preliminary geophysical survey was undertaken, and the results were used to adjust the acquisition parameter of the actual survey. Finally, nine (9) 2D ERS surveys were established at selected locations.

The equipment used for data acquisition is a SuperSting R8/IP multi-electrode earth resistivity meter comprising 84 metallic electrodes, a multi-channel switch box, a D.C. battery, 12-channel cables, hammers, and measurement tapes. Each channel cable is 70 m long and consists of seven metallic clips to connect seven electrodes. On each profile, eighty-four (84) electrodes were coupled to the ground on a straight line at intervals of 3 m. A group of the nearest seven electrodes was connected using the channel cables and the clips, and the whole electrode arrangements were connected to the resistivity meter using the multi-channel switch box. The resistivity

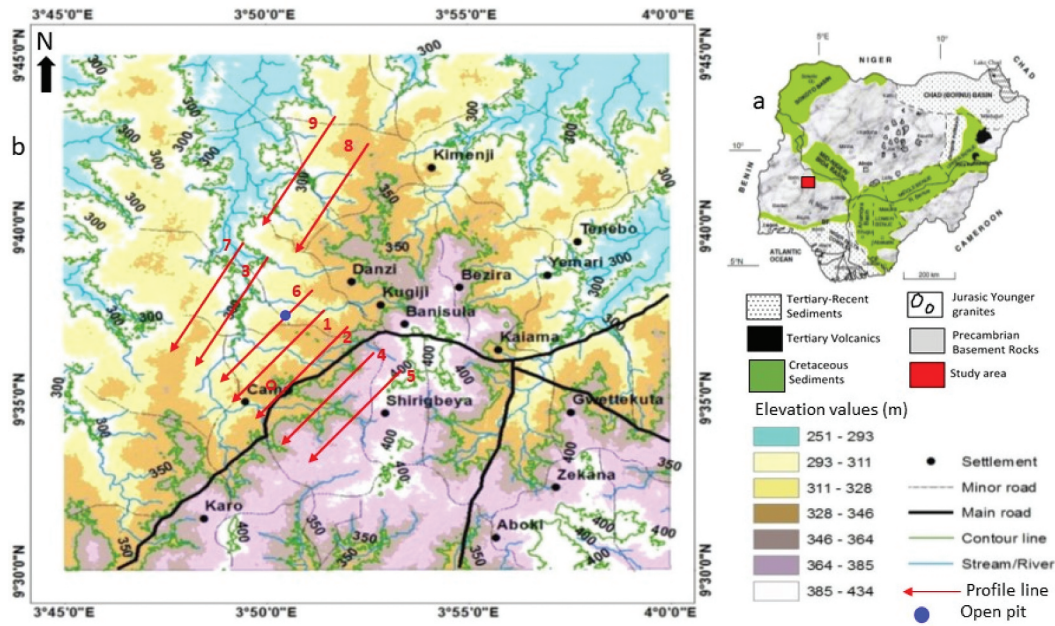


Figure 1. (a) Geological map of Nigeria showing the location of the study area (Obaje 2009). (b) Topographic map of Kaiama (modified after Alimi et al. 2019) showing the 2D ER Profiles.

meter was connected to a D.C. battery for power supply. Then the resistivity meter was initialised to take measurements following the dipole–dipole electrode array. Each profile was 249 m long. A topographic map showing the elevations and the arrangement of the 2D ER profiles is shown in Figure 1 (b). The measurement was serially automated such that electrodes 1, 2, 3, and 4; 2, 3, 4, and 5; 3, 4, 5, and 6, and so on, and finally, 81, 82, 83, and 84 were selected sequentially for resistivity measurement at the first level, $n = 1 * a$. This implies that there are 81 (i.e. $84 - 3$) measurements and potential points at level, $n = 1 * a$. Where n is the separation between the dipoles and a is the dipole separation. A description of the dipole–dipole electrode array, the spacing, and relationships between a and n are described in some geophysics literature including Raji et al. (2020). Measurements continue at dipole separation $n = 2, 3, 4, 5, 6$. The process is repeated at every profile until the 9th profile is completed.

3.2. Data Processing

Raw data were plotted graphically to allow visual inspection of the data for quality control purposes, and to properly identify data corrupted with noise and instrumental errors. The data were pre-processed to remove noise and attenuate spikes using a MATLAB-based script (Raji and Adeoye 2017). Then the pre-processed data were prepared for tomographic inversion. Apparent resistivity data were forward modelled using finite difference techniques and

the acquisition parameters. Resistivity model inversion was performed using the smoothness-constrained finite difference approach (Loke and Barker 1995). The inversion is based on the principle of geophysical tomography where the theoretically calculated data and the field data are compared iteratively until the minimum possible RMS error is obtained or the maximum iteration number is reached. At the end of every iteration, the misfit between the calculated and the observed (field) data is used to improve the field data, then the improved field data is input into the tomographic process for the next level of iteration (Loke and Barker 1996; Raji et al. 2018). The difference between the calculated and observed data is believed to be the error in the field measurements and noise in the data.

The inversion process can be mathematically defined (Loke and Barker 1996) as:

$$(J^T J + \mu F) \mathbf{d} = J^T \mathbf{g}.$$

J is the partial derivatives of apparent resistivity with respect to the model parameters and J^T is the transposed of the Jacobian matrix; μ is the damping factor constraining the range of values the model perturbation vector can take; F is an identity matrix, describing the geologic structure at subsurface; $\mathbf{d}$ is the discrepancy vector between the measured raw data and calculated data; and $\mathbf{g}$ contains the difference between the logarithms of the measured and the calculated apparent resistivity values. To improve the inversion results and optimise the convergence time, $\mathbf{d}$ was defined as a Marquardt-Levenberg modification that minimises a combination of the magnitude of the

discrepancy vector and the parameter change vector. The forward modelling and the inversion processes were performed using EarthImager2D software (AGI 2010). The final objective of apparent resistivity tomography is to obtain the best earth model that produced the apparent resistivity data acquired on the field. The earth model that produced the calculated data is known but the earth model that produced the measured data is not known. So, the earth model that produced the data that best-match the calculated data is believed to be the earth model that produced the field data, if instrumental errors and noise were not present. The resistivity models inverted from the data collected along the nine (9) profiles are shown in Figures 2 and 3.

4. Interpretations and discussion of results

Rocks, soils, and tantalite ores have different electrical properties that characterised the electrical conductivity of their constituent materials and the nature of the fluids in the rock. Rocks that are rich in metallic minerals usually have lower resistivity/higher conductivity than others. The difference in resistivity accounts for the presence of metallic ore. This

difference may constitute a local resistivity anomaly that may be detected through resistivity measurement. The tantalite ore is hosted in quartz veins and pegmatites that intruded the country rock in the study area; therefore, areas rich in tantalite are expected to have low resistivity (high conductivity) in contrast to the country-rock. Figures 2 and 3 show the tomographic resistivity images of the subsurface beneath the nine profile lines in the study area. Figure 2(a–d), show the resistivity tomograms beneath profile lines 1, 2, 4 and 5, respectively while Figure 3(a–e) showed the resistivity tomograms of profile lines 6, 3, 7, 8, and 9, respectively.

The tomographic images showed that the resistivity values of the subsurface materials, which comprised dry and saturated soil, rocks, quartz veins, pegmatites, and tantalite ore range from 1 to 100,000 Ωm . Three distinct resistivity features are recognised as follows (i) the low resistivity regions (1 to 60 Ωm , blue colour) which correspond to the tantalite-rich zones, (ii) the region with medium resistivity values (60 to 620 Ωm , green colour) which corresponds to the weathered basement rocks and (iii) the high resistivity region (>620 Ωm , yellow and red colours). At depths

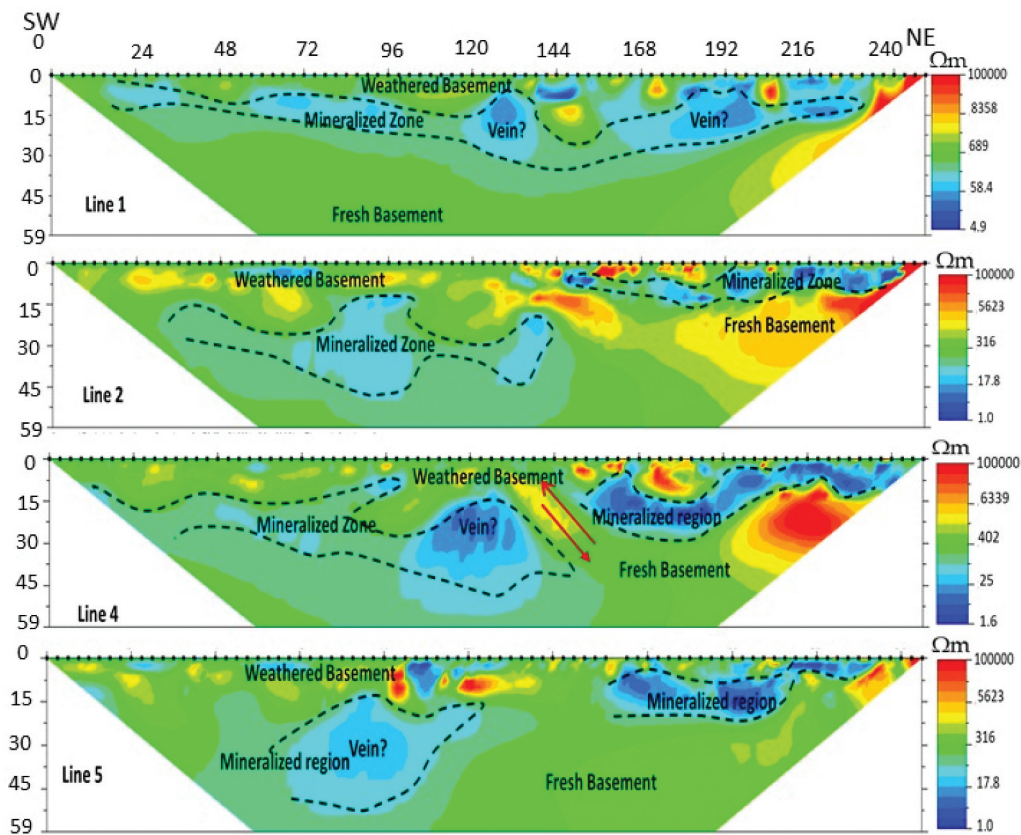


Figure 2. Electrical resistivity images (tomograms) for profiles lines 1, 2, 4, and 5.

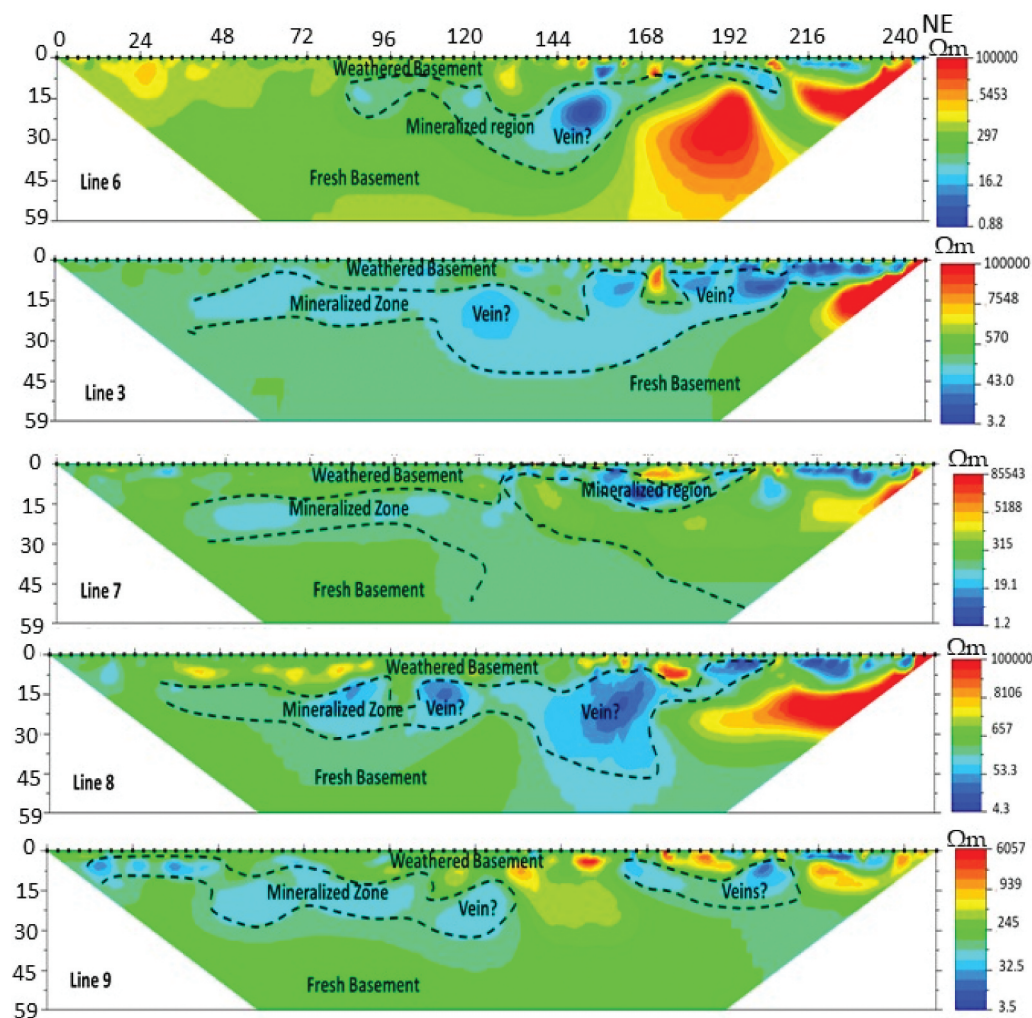


Figure 3. Electrical resistivity images (tomograms) for profiles lines 6, 3, 7, 8, and 9.

greater than 10 m, the high resistivity features were interpreted as un-weathered/fresh metamorphic and igneous rocks. At shallow depth, the high resistivity features are interpreted as dry, unsaturated sand and aggregates. The results in Figures 2 and 3 also show that the tantalite ore is concentrated within a depth interval of 2 to 45 m, and the mineralised vein is oriented in the NE-SW direction (Figure 2).

A comparison of the tomograms from the nine profiles shows that the tantalite-rich quartz veins and pegmatites have varying lengths and thicknesses. Some of the images suggest the possibility of a fault that post-dated the intrusion of the quartz veins. The fault is more apparent along profile 4 which corresponds to Figure 2(d), where possible breakages, up-thrown and down-thrown of the tantalite bearing veins were inferred. The tantalite-bearing veins appear to be continuous in some profiles. Generally, the width of the tantalite-rich zones ranges from 3 m to about 32 m while the length varies from 40 m (Figure 3(d)) to 219 m (Figure 2(a)). In Figure 3(d), the main mineralised vein at the top right corner is 4.5 – 16 m thick and

about 70 m long. Figure 4 is an open pit that was dug along profile 5, between 160 and 170 m horizontal distance after the survey. The pit confirmed the presence of tantalite-mineralised veins as predicted by the result of the ER survey. The augmented 3D view of the tomograms is shown in Figure 5. The consistency in the structures and similarities in the orientation of the tantalite-rich veins suggests the appropriateness of the geophysical method used for tantalite exploration in the environment, the data processing techniques, and the interpretation of results.

Findings from the study as shown in Figures 2 and 3 provided important information that makes mining and exploitation of tantalite mineral in the study area to be less laborious, more economical, and environmentally friendlier compared to the traditional trial-by-error indiscriminate excavation practiced by the ASMs. This is because the study was able to identify the approximate location, depth, length, and thickness of the tantalite-rich zones, thereby allowing the ASMs to know where to dig and excavate. Further, the study is useful for planning the mining site: to select the location for road, camps, and mineral washing point within the mine; to



Figure 4. The image of a pit dug to confirm the presence tantalite-mineralised vein detected by resistivity survey.

predict the optimum position and depth of pits or wells that will be used for mining; to do a rough estimation of the reserve for making business decision; and for planning land reclamation process after mineral exploitation.

5. Conclusion

The utility of the electrical resistivity method of geophysics for the exploration of a metallic mineral such as tantalite in a metamorphic basement complex area has been demonstrated through a carefully designed field survey in Kaiama, Nigeria as a case study. The goal of the study was to delineate and define the depth of the tantalite mineralised zones. The tomographic images of the subsurface obtained from 2D resistivity data acquired in the study area revealed low resistivity zones which correspond to tantalite mineralised zones. A pit dug along profile 6 confirmed that the low resistivity zones are tantalite-mineralised veins. The 2D resistivity tomograms revealed that the approximate length of the tantalite-rich veins ranges from 40 to 220 m while their thickness ranges 3 to 32 m. The mineralisation control and the orientation of the mineralised vein are consistent with the northeast-southwest trending fault that is related to the Pan African Orogeny. The method applied is non-invasive and environmentally friendly compared to the indiscriminate excavation trial-and-error method which has been the practice in Kaiama. This study is important for pre-investment economic evaluation of a mineral deposit, identifying the best mining method, and

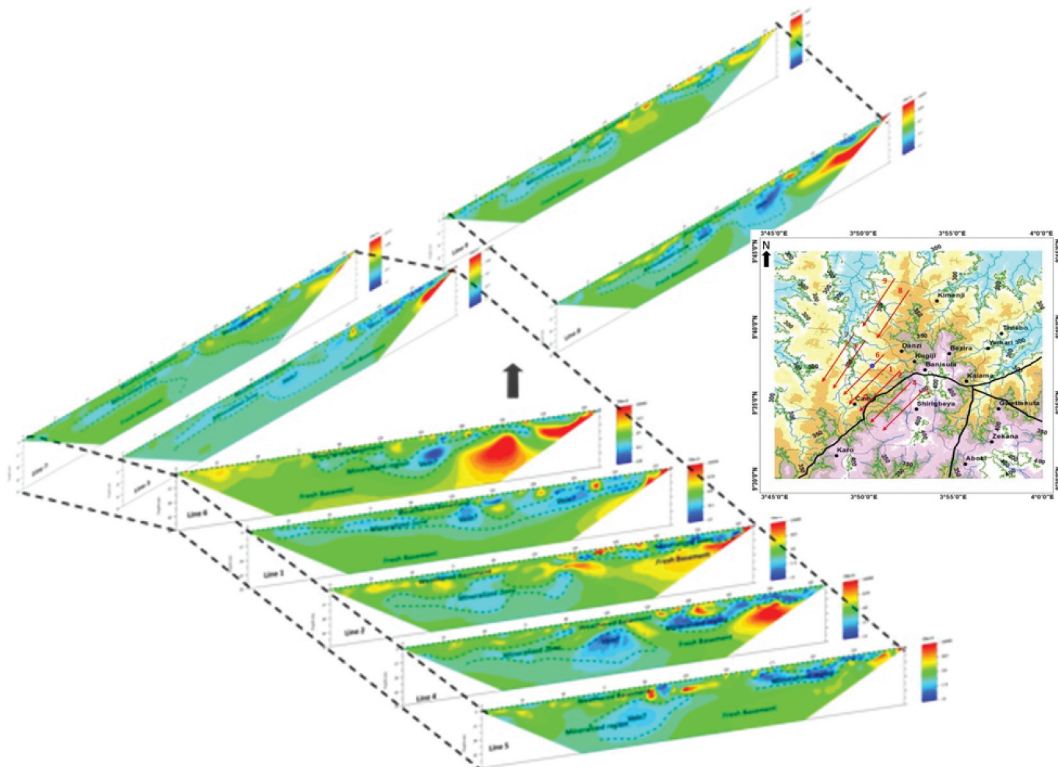


Figure 5. Augmented 3D of the electrical resistivity images across profiles 1–9.

planning land reclamation after exploitation. The study recommends open pit method for the exploitation of tantalite mineralisation in the study area.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

References

- Abubakar HO, Raji WO, Bayode S. 2014. Direct current resistivity and very low frequency electromagnetic studies for groundwater development in a basement complex area of Nigeria. *Sci Focus*. 19(1):1–10.
- AGI (2010). EarthImagerTM 2D and 3D, Resistivity and IP inversion software: advanced geosciences incorporated, www.Agiusa.com.
- Akanbi ES, Ugodulunwa FXO, Gyang BN. 2017. 2-D electrical resistivity survey for cassiterite potential mapping in Jos-Bukuru Area, North Central, Nigeria. *J Geogr EnvironEarth Sci Int*. 10(1):1–12. doi:10.9734/JGEESEI/2017/33350.
- Alimi SA, Bale RB, Alepa VC, Aromoye SA, Andongma TW, Bonde DS. 2019. Electrical resistivity imaging for metallic and sulphide deposits investigation in Kaiama area, North-Central Nigeria. *Sci Park J*. 5 (6):223–240.
- Arifin MH, Kayode JS, Izwan MK, Zaid HA, Hussin HA. 2019. Data for the potential gold mineralization mapping with the applications of electrical resistivity imaging and induced polarization geophysical surveys. *Data Brief*. 22:830–835. doi:10.1016/j.dib.2018.12.086.
- Aromoye SA, Alimi SA, Bello OS, Raji WO, Olawale LO, Bonde SD. 2019. 2-D electrical resistivity tomography for groundwater potential in basement terrain of a part of Ilorin Sheet 223 NW Nigeria. *Saudi J Eng Technol*. 4:357–362. doi:10.36348/SJET.2019.v04i09.004
- Dada SS. 1982. Central Nigerian mineral exploration project final report 33pp, 7 figures, 20 maps; Nigerian Mining Corporation, Jos.
- Goh SW, Teh GH, Hassan FW. 2006. Gold mineralization and zonation in the State of Kelantan. *Bull Geol Soc Malays*. 52:129–135.
- Loke MH, Barker RD. 1995. Least-squares deconvolution of apparent resistivity pseudo sections. *Geophysics*. 60:1682–1690. doi:10.1190/1.1443900.
- Loke MH, Barker RD. 1996. Rapid least-squares inversion of apparent resistivity pseudosections using a quasi-Newton method. *Geophys Prospect*. 44:131–152. doi:10.1111/j.1365-2478.1996.tb00142.x.
- Obaje NG. 2009. Geology and mineral resources of Nigeria. Berlin Heidelberg: Springer-Verlag, Springer.
- Olade MA, Elueze AA. 1979. Petrochemistry of the Ilesha amphibolite and Precambrian crustal evolution in the Pan-African domain of SW Nigeria. *Precambrian Res*. 8:303–318. doi:10.1016/0301-9268(79)90033-0.
- Oyawaye MO. 1964. The geology of Nigerian basement complex – a survey of our present knowledge of them. *J Nigerian Min Geol Metall Soc*. 1(2):87–102.
- Park JY, Kim YJ. (2009). Electrical resistivity surveys for gold-bearing veins in the Yongjang mine, Korea. *J Geophys Eng*. 6(1) 73. doi:10.1088/1742-2132/6/1/008
- Rahaman MA. 1976. Review of the basement geology of southwestern Nigeria. In: Kogbe CA, editor. *Geology of Nigeria*. 2nd ed. Lagos: Elizabethan publication; p. 41–58.
- Raji WO. 2014. Review of electrical and gravity method of near surface exploration for groundwater. *Niger J Technol Dev*. 11(2):31–38.
- Raji WO, Adeoye TO. 2017. Geophysical mapping of contaminant leachate around a reclaimed open dumpsite. *J King Saud Univ – Sci*. 29:348–359. doi:10.1016/j.jksus.2016.09.005.
- Raji WO, Harris JM, Lu S. 2018. Seismic velocity tomography for CO₂ monitor in subsurface geological structures. *J King Saud Univ-Sci*. 30(1):57–64. <http://www.sciencedirect.com/science/article/pii/S1018364716303044>.
- Raji WO, Ibitoye PE, Abiri OA, Adepoju JA, Abdulkadir KA. 2020. Comparison of six classical electrode arrays of 1D resistivity survey for subsurface delineation – field experiments. *Centre Point J*. 26(1):79–97.