Groundwater exploration in crystalline basement complex using seismic refraction and electrical resistivity tomography: case study of Olomore, Abeokuta, southwestern Nigeria

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Abstract

Groundwater occurrence in crystalline basement complex is mainly due to the development of secondary porosity and permeability arising from the weathering and fracturing of the low porosity igneous and metamorphic basement rocks. In this study, geophysical survey involving seismic refraction and 2D electrical resistivity tomography (ERT) was conducted to assess the hydrogeological characteristics of the weathering profile of the crystalline basement rocks in Olomore, Abeokuta, southwestern Nigeria. The 2D ERT survey was conducted along five Traverses using dipole-dipole array with a minimum electrode spacing of 5.0 m in Traverses 1, 2, 3 and 5, and 10.0 m in Traverse 4, and a dipole separation factor of 1 – 4 in all the traverses; the observed apparent resistivity data were inverted using RES2DINV. The seismic refraction survey was conducted along the same traverses using 10 Hz electromagnetic geophones; the refraction data were processed using SeisImager with the first arrival travel times picked using Pickwin module and inverted using Plotrefa to obtain velocity model of the subsurface. A good correlation exists between the 2D ERT images and the seismic refraction velocity models. The effective depth of investigation for both ERT and seismic refraction is approximately 43.0 m in all the traverses except for ERT of Traverse 4 which 66.0 m depth of investigation. Four lithologic layers may be inferred with varying model resistivity and P-wave velocity range of 546-974 m/s, 1456-1877 m/s, 2042-2944 m/s, and 3041-6894 m/s respectively. Both ERT and seismic refraction images indicate that the regolith (collapsed zone and saprolite) is relatively thin (< 10.0 m) and may be unable to support adequate drawdown for good yield. But the weathered and fractured basement is sufficiently thick to support adequate drawdown for high groundwater storativity and yield; depth-to-bedrock is greater than 20.0 m in most part of the study area. The study shows that the combination of ERT and seismic refraction is effective for near-surface characterisation for hydrogeological investigations in crystalline basement complex.

Groundwater Exploration in Crystalline Basement Complex Using Seismic Refraction and Electrical Resistivity Tomography: Case Study of Olomore, Abeokuta, southwestern Nigeria (360392)

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Introduction

Crystalline basement aquifers are important groundwater resources especially in rural settlements where alternative source of water is often not available or polluted. They are characterised with high spatial variability and low yield due to inherent low porosity and permeability of the basement rocks. Optimum and perennial yield requires adequate storativity, effective transmissivity and sufficient drawdown. Thus, wells or boreholes should penetrate appreciable thickness of regolith and/or saprock. In this study, seismic refraction and 2D electrical resistivity tomography (ERT) were conducted along five (5) traverses to assess the hydrogeologic characteristics of the weathered profile in Olomore, Abeokuta, southwestern Nigeria.

Study Area

The study area is within the crystalline basement complex of southwestern Nigeria. The topography is lowland with sparsely distributed hills and knolls; mean elevation is about 70 m above mean sea level. The climate is tropical humid marked by distinct dry and rainy seasons; mean rainfall is greater than 2300 mm per annum. The dominant rocks are biotite garnet gneiss, magmatic augen gneiss and migmatite which are essentially of migmatite-gneiss-granite complex (Fig. 1). Basement aquifers are developed within the weathered profile and fractured bedrock.

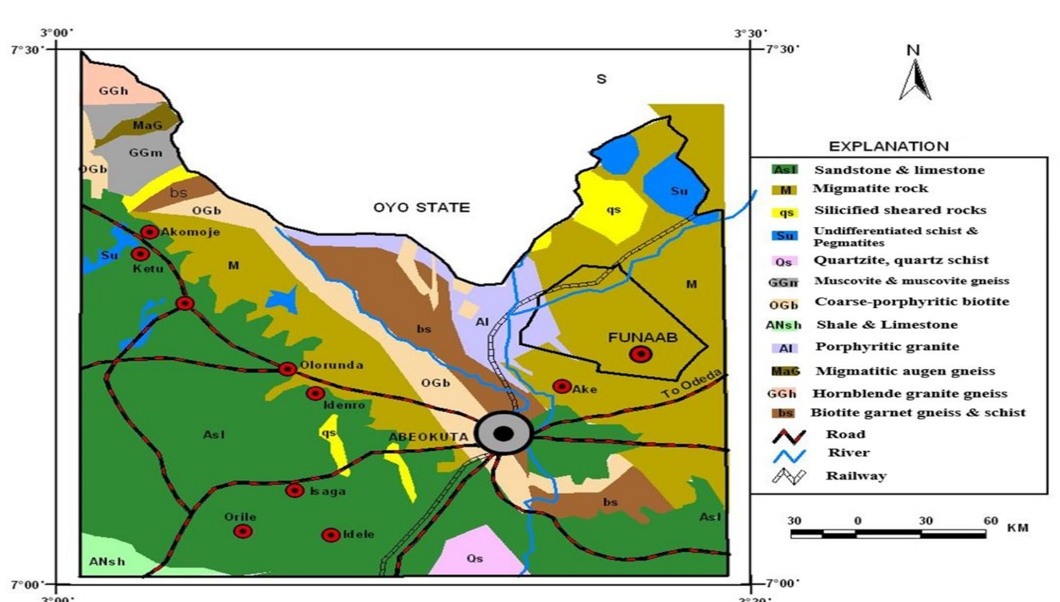
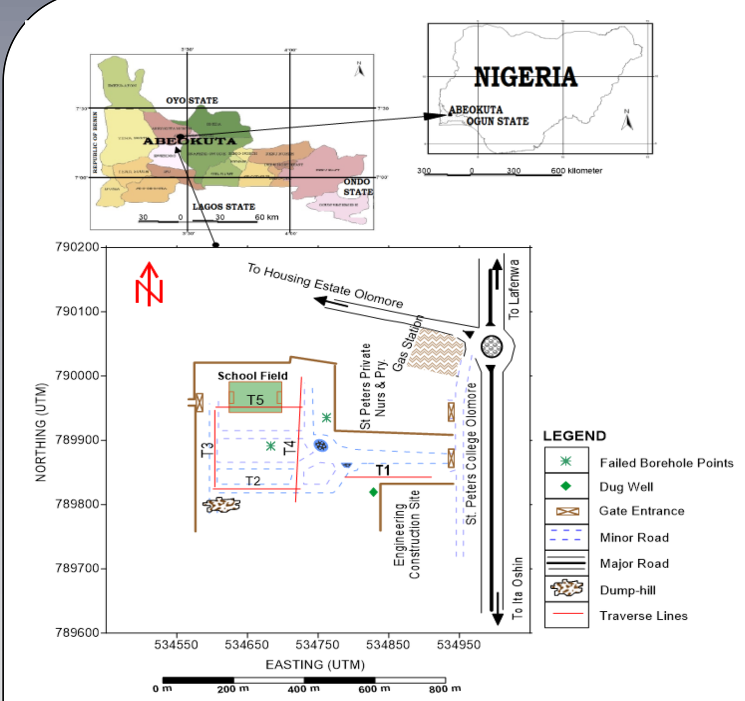


Fig. 1: Geological map of Abeokuta and its environs

Electrical Resistivity Tomography

2D ERT survey was conducted along five traverses (Fig. 2). Dipole-dipole array with minimum electrode spacing of 5.0 m in Traverses 1, 2, 3 & 5, and 10.0 m in Traverse 4 were used for the survey; the dipole separation factor ranges from 1 – 4. The observed apparent resistivity data sets have been presented in Aizebeokhai et al. (2018) data article.



The apparent resistivity data sets were inverted using RES2DINV inversion code. Smoothness constraint least-squares optimization (L_2-norm) was applied for the inversion.

Fig. 2: Base map of the study area.

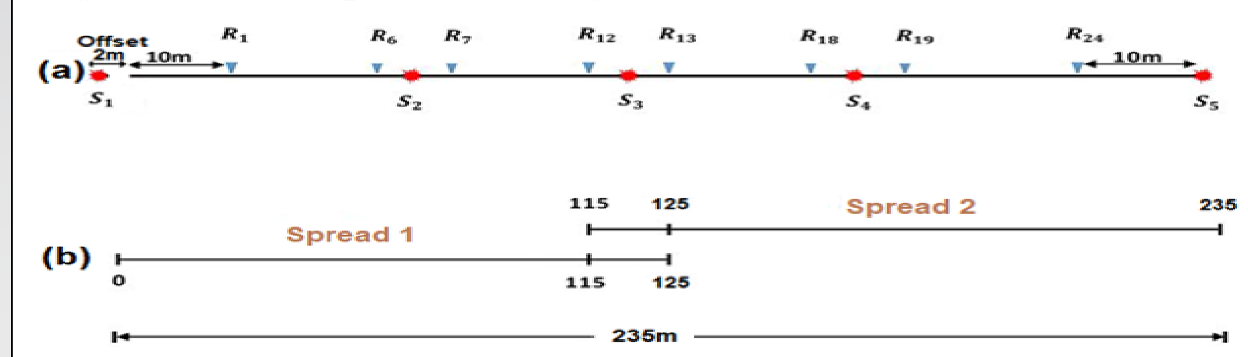


Fig. 3: Refraction survey design: (a) shot points S1-S5 and receiver positions, R1-R24; (b) two spreads on a profile line.

Seismic Refraction Survey

Seismic refraction survey was conducted along the same traverses for the 2D ERT. The seismic waves were generated by a 10.0 kg weight drop on a steel plate. Two spreads covering 235.0 m were used and five shot points were selected for each spread (Fig. 3). The data was processed using SeisImager/2D™; first arrival times were picked using Pickwin™ module. Arrival times were plotted against offset to determine the P-wave apparent velocity for each layer. The observed travel time data sets were inverted using Plotrefa™.

Results and Discussion

The inverse models for the ERT and seismic refraction tomography are shown in Figures 4 – 6. Electrical resistivity of crystalline basement rocks decreases with increasing degree of weathering and fracturing; this characteristic was used in detecting weathered and fractured zones. Low resistivity anomalies (vertical) were interpreted as fractures (*F*). other low resistivity anomalies were considered as weathered zones. Resistivity model of 1200 ohm-metre was used as the cut-off value to demarcate between the regolith (low resistivity) and bedrock (high resistivity). The regolith thickness ranges from about 10.0 – 23.0 m, depending on the degree of weathering and fracturing.

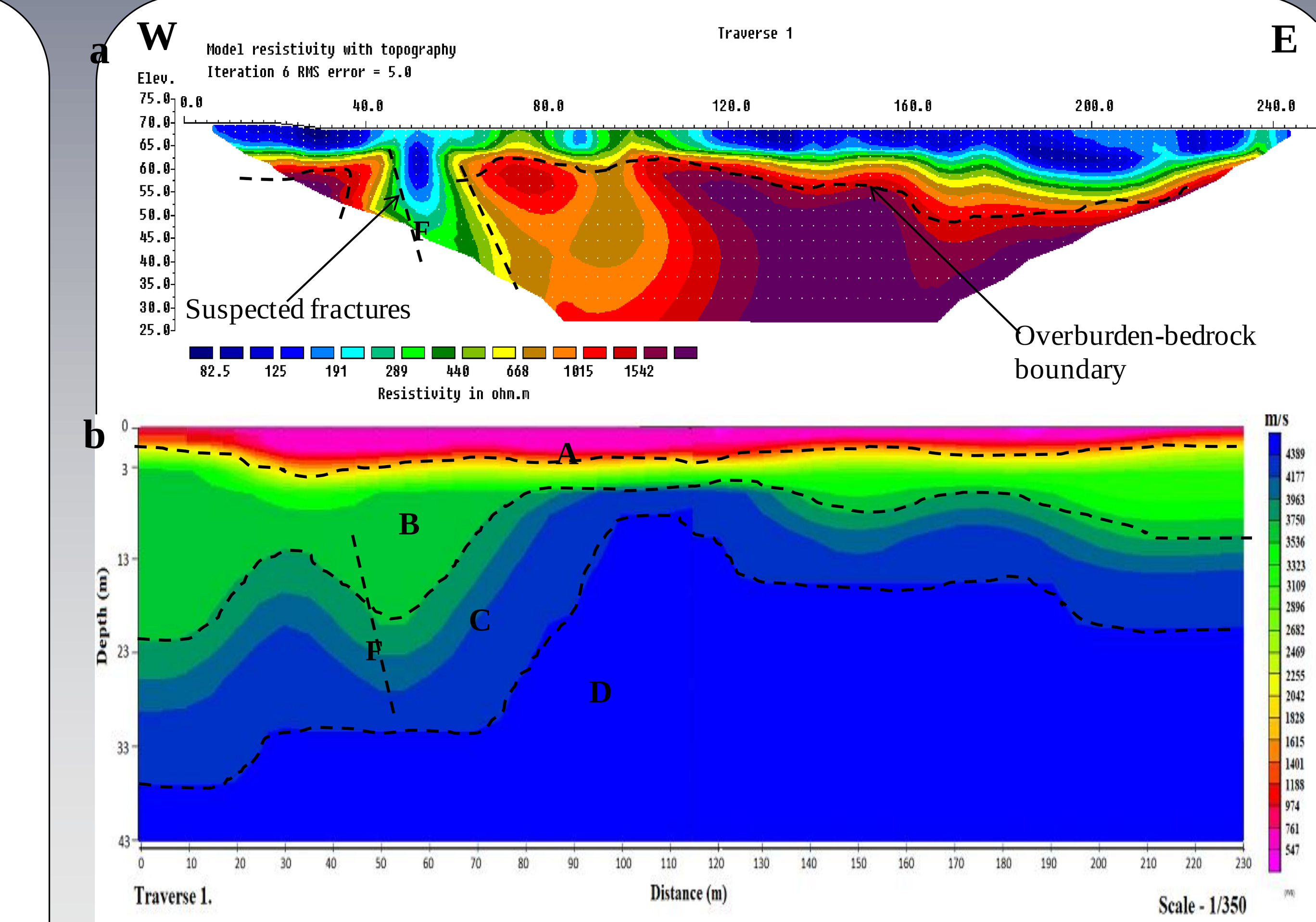


Fig. 4: Inverse model for Traverse 1: (a) ERT; and (b) P-wave velocity

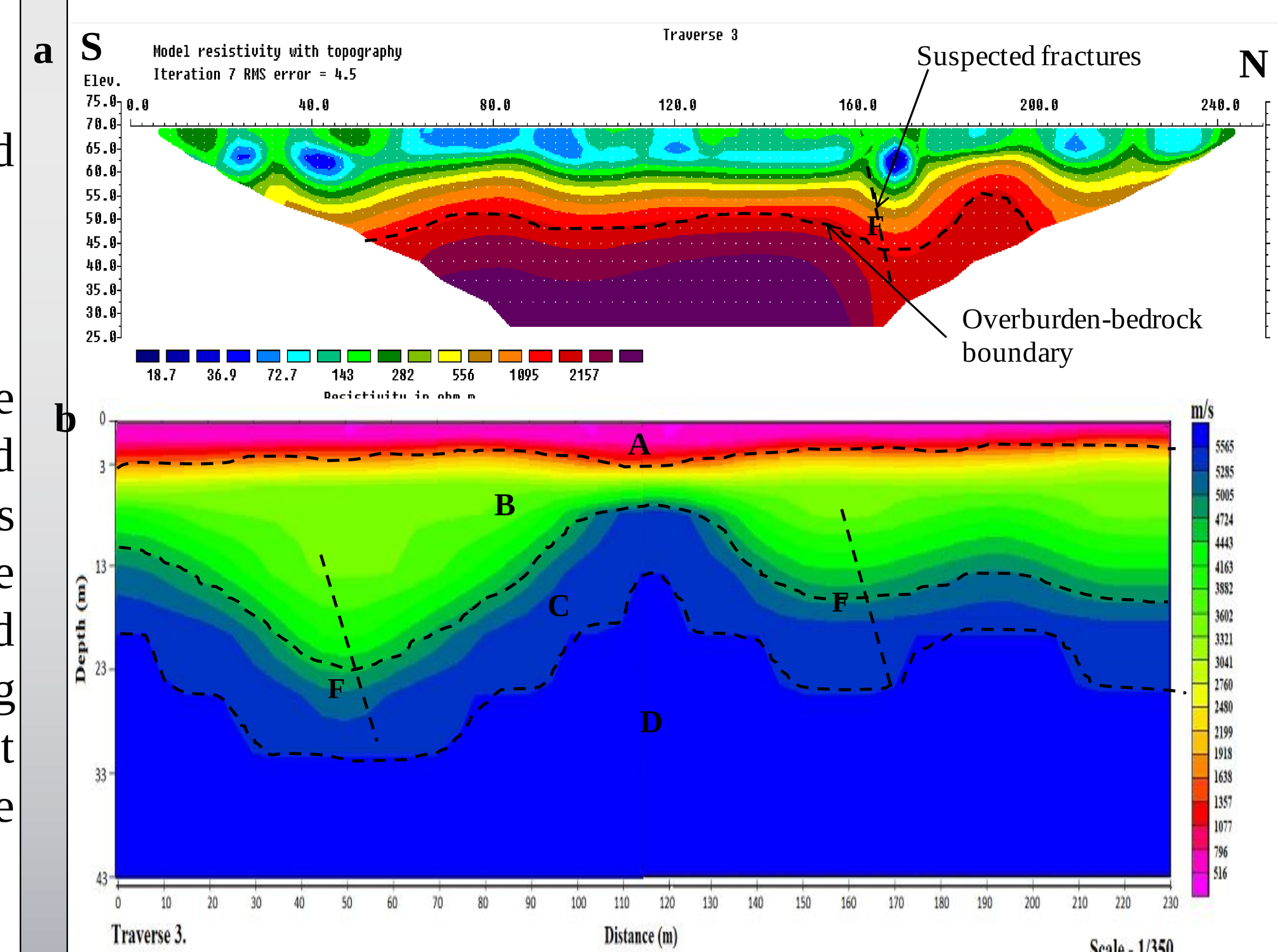


Fig. 5: Inverse model for Traverse 3: (a) ERT; and (b) P-wave velocity

Four main lithologic layers (denoted as A – D) are delineated in the seismic velocity models; their P-wave velocity ranges from 546-974 m/s, 1456-1877 m/s, 2042-2944 m/s, and 3041-6894 m/s, respectively. The layers correspond to the collapsed zone, saprolite, saprock and fresh bedrock respectively. The top soil is composed of hard lateritic clay (about 3.0 m thick); the saprolite consists of clayey sand with varying thickness characterised with low resistivity anomaly. The lower part of the saprolite forms shallow aquifer mainly developed by and dug wells. The P-wave velocity models also indicate the presence of weathered and fractured zones in the saprock overlying the fresh bedrock.

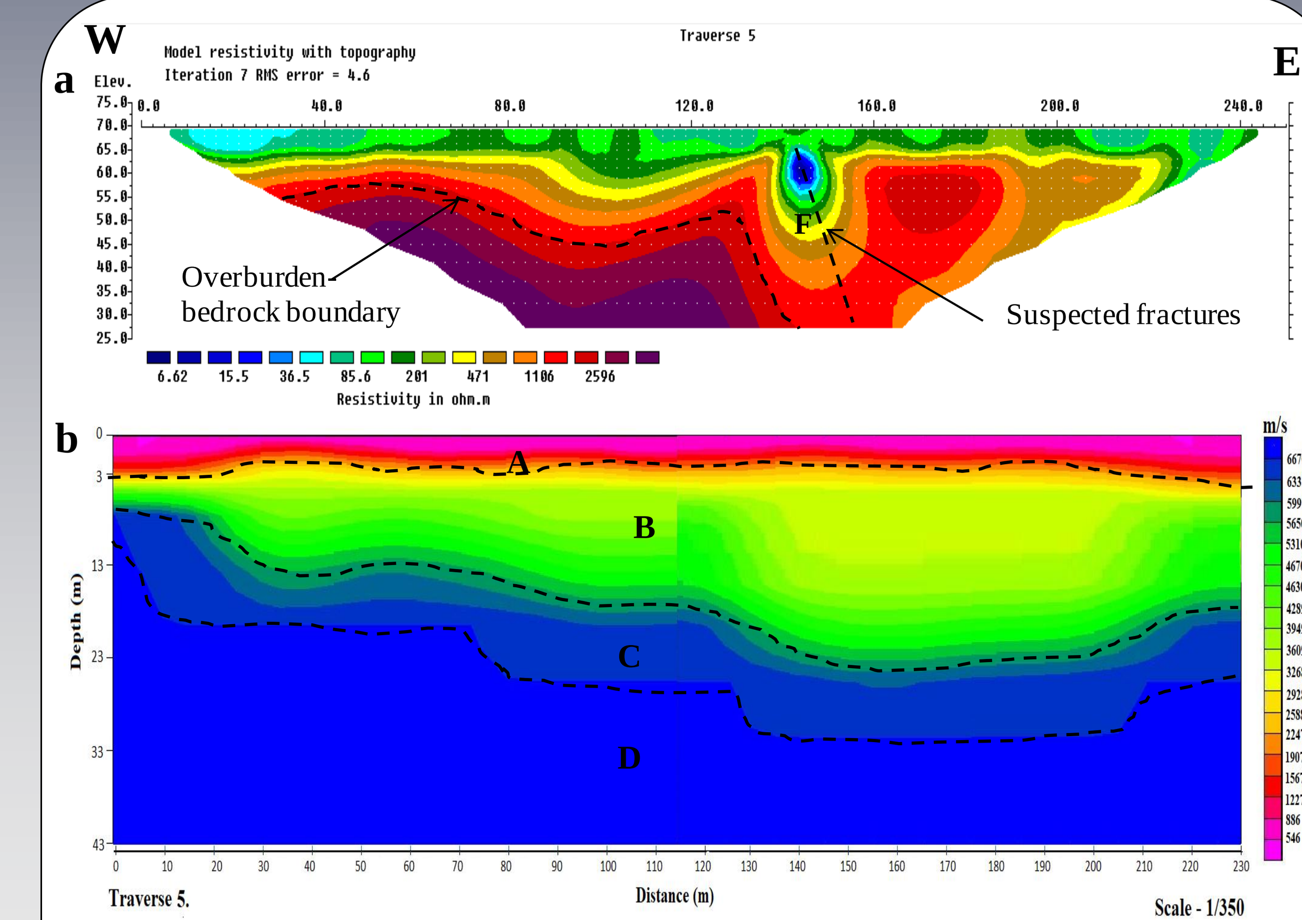


Fig.6: Inverse model for Traverse 5: (a) ERT; and (b) P-wave velocity

Both ERT and P-wave velocity models indicate that the overburden is relatively thin (10.0 – 23.0 m) in most part of the study area; potentially, this will be unable to support adequate drawdown for moderate-to-high storativity and yield. However, the weathered and fractured bedrock is moderately thick; depth to fresh bedrock is >20.0 m in most part of the study area. Thus, the saprock together with the regolith can potentially support adequate drawdown that can maintain moderate-to-high storativity and yield.

Conclusions

This study combines ERT with seismic refraction surveys to characterise the weathered profile in Olomore, Abeokuta, southwestern Nigeria. Both ERT and seismic velocity models indicate: (1) hard lateritic clay top soil (3.0 m thickness); (2) thin regolith (10.0 – 23.0 m) that may not support adequate drawdown for moderate-to-high yield; (3) moderately thick saprock which together with the regolith can support adequate drawdown for moderate-to-high storativity and yield; and (4) weathered and fractured zones that preferentially influence groundwater accumulation. The study shows that combining ERT with seismic refraction survey is effective for near-surface characterisation in crystalline basement complex.

Acknowledgements

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References

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