

Geophysical Imaging of Channel-Fill Sandstones Within the Gombe Formation in The Gongola Basin, Northeast Nigeria: Implication for Groundwater Exploration in Kashere Town

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Abstract

Geophysical investigation using electrical resistivity method was conducted for groundwater exploration at Kashere town, with the objective of delineating channel-fill sand that may exist within the underlying Gombe Sandstone Formation in the study area. The survey utilizes the Vertical Electrical Sounding (VES) technique and the Schlumberger electrode array to acquire data at regular station intervals of 100 m along three E-W trending profiles (P1, P2, and P3) of 600 - 700 m in length. The investigation was able to delineate three channel-fills in the study area. One of the channel-fills is exposed along profile P2 and filled with clayey-sand and lateritic materials to the depth of about 10 m. The other two channel-fills occur as multi-storey channels with upper and lower channel that are centred at 200 m along profile P3. The upper channel occurs at the depth between 2 and 8 m and has a maximum thickness and lateral extent of about 7 and 200 m, respectively. This channel is filled with silty clay to very fine-grained sand that may not be of good reservoir quality. The second, lower channel is confined within fine-grained sediment and filled with medium- to coarse-grained sands that can serve as potential reservoir for groundwater storage and extraction. This channel-fill occurs at the depth between 8 and 22 m beneath profile P3 and has a maximum thickness and lateral extent of approximately 22 and 500 m, respectively.

Key Words: Channel-fill; Gombe Sandstones; Kashere; VES; Paleochannel.

INTRODUCTION

Channel-fills (or paleochannels) are erosional channels that cut into older rocks and are filled or buried by overlying younger sediment. The fluvial sediment that fills the channels are usually coarse-grained and well sorted, which makes them potential reservoirs for hydrocarbon and groundwater (Bello et al., 2023). The Gombe Sandstone within Kashere town, the study area, forms the focus of this study. Previous fieldwork (by undergraduate students of Geology Department of Ahmadu Bello University Zaria) has revealed the occurrence of several channel-fill sandstones within the lower and middle

part of the Gombe Sandstone Formation (Fig. 1). The channel-fill sandstones usually cut-through previously deposited Gombe Sandstone units – displaying sharp erosional base, and in some instances forming multi-storey channels (Fig. 1) that are of good reservoir quality. The individual storey can reach up to 13 m in thickness, with lateral extension of about 60 to 480 m (Bello et al., 2023). The channel-fill sands of the Gombe Formation are usually medium-coarse grained, light-grey colour with or without crossbedding and can be interpreted as reworked sands being derived from ‘rip-currents’ that developed as waves/tides cut-through previously

deposited litho-facies of the Gombe Sandstone (Sakar and Koner, 2020).

Kashere town, which is predominantly underlain by the Gombe Sandstone, is plagued with water scarcity. It has also been reported that water storage of Gombe Sandstone is generally poor with many dry boreholes (Kwami et al. 2019). However, the channel-fill sandstones within the middle to lower part of Gombe Formation are moderate to well-sorted and can serve as good aquifer for domestic water supply. Hence, proper delineation of these channel-fill sands can be of significant exploration target for groundwater which may help mitigate the problem of water scarcity in the study area. Non-invasive geophysical method, such as electrical resistivity method, has been successfully used to delineate paleochannels (e.g. Goldman and Neubauer, 1994; Kumar, 2011; Francke, 2016; Bhadra et al., 2021), based on the contrast in the resistivity that exist between the channel-fills and the surrounding host sediment. Therefore, this study is aimed at using the electrical resistivity method to explore for groundwater in the study area, with the objective of delineating buried channel-fill sandstones that may exist within the Gombe Formation in the area.

Location and Geology of the Study Area

The study area is located in Kashere town in Gombe State northeastern Nigeria and bounded by latitudes; 09° 54' 40.2" N, 09° 55' 19.50" N and longitudes; 10° 59' 51.12" E, 11° 00' 35.48" E, covering an area of about 1.22 sq. km (Fig. 2). Kashere falls within the Gongola Basin of the Upper Benue Trough of the northeastern Nigeria. The area is underlain by the Cretaceous sedimentary deposits of the Gombe

Sandstones, whose outcrops are expressed as ferruginous capping in most part of the study area, especially towards the east and the northeastern part. The oldest rocks in this basin are the Bima Sandstones which lie nonconformably on top of the crystalline basement complex (Fig. 3); and forms the thickest sedimentary succession in the upper Benue trough reaching up to 1500 m in thickness (Zaborski et al., 1998). The Bima sandstone represents an active rift stage of basin development comprising of pale-grey, trough cross bedded conglomeratic arkoses usually interbedded with purple-coloured mottled clays (Guiraud, 1990).

The formation overlying the Bima Sandstone is the Yolde Formation which is transitional in terms of environment of deposition from the dominantly continental early Cretaceous to the dominantly marine late Cretaceous (Zaborski, 2003). The Yolde Formation is made up of fine-grained, well bedded sandstones and braided-river sediments identical to those in the Bima Sandstone. The formation overlying the Yolde Formation is the Pindiga Formation which is a dominantly shaly unit that consists of gypsum-bearing, dark grey shales that become silty towards the top of the unit. There are horizons of yellow-grey impure calcareous nodules within the shales; which is an indication of true marine conditions that lasted from late-Cenomanian to mid-Santonian (Zaborski et al., 1998; see also Fig. 3).

The Gombe Sandstone was deposited between the mid-Santonian and end-Cretaceous (Maastrichtian) and is separated from the Pindiga Formation by a major angular unconformity (Fig. 3) that developed during the mid-Santonian

compression (Guiraud, 1993). Within the study area, the Gombe Formation and comprises three different lithological units: the reddish well bedded sandstones in the upper part, the micaceous silty sandstones in the middle part, and the intercalated sand-shale sequence that is characterized by erosional, concave channel filling structures in the lower part (Zaborski, 1998, 2003). A marked angular unconformity occurs between the Gombe sandstone and the post-Cretaceous Kerri-Kerri Formation (Fig. 3) which marks the end of deposition in the Gongola Basin.

METHODOLOGY

Geophysical method involving the electrical resistivity imaging was employed in this investigation. The principle of the electrical resistivity method is based on Ohm's Law and involves the injection of electric current into the ground through a pair of electrodes, while the resulting potential difference or voltage at the surface is measured through another pair of electrodes. The ratio of the potential difference measured at the potential electrodes to the input current at the current electrodes gives the resistance. The survey procedure utilizes the vertical electrical sounding (VES) technique, where the current and potential electrodes are maintained at the same relative spacing and the whole spread is progressively expanded about a fixed central point. The technique is extensively used in groundwater exploration to define horizontal zones of porous and permeable strata that may serve as reservoir for groundwater storage. Electrode configuration or arrays that are commonly employed in the VES survey include the Schlumberger array, Wenner

array, and the Dipole-dipole array, with individual array varying in depth of probe and lateral and temporal resolution. The Schlumberger electrode array was employed in this investigation because of its ability to resolve horizontal or near-horizontal interfaces, and to probe to greater depth as the electrodes are expanded about a fixed central point.

Data Acquisition

1D vertical electrical sounding (VES) data were acquired in the study area using the Schlumberger electrode configuration. The data were acquired with the aid of an Ohmega resistivity meter (Fig. 4) along three E-W trending profiles (P1, P2, and P3), with a profile length of 600-700 m (Fig. 2). In order to achieve an appreciable depth of investigation, as well as proper lateral correlation, the survey utilized maximum current electrodes separation of 200 m at stations that were spaced at regular intervals of 100 m along the profiles. Similarly, for the purpose of generating a subsurface 2D pseudo-section, the same E-W azimuth was maintained for the current flow direction at each station along the profile throughout the data acquisition. This is based on the assumption that subsurface vertical geological structures such as faults, folds, or fractures, which are usually characterized by lateral layer discontinuities, can cause anomalous distortions in current flow lines that may indicate their presence.

Data Processing

The Ipi2Win resistivity software package was used for the processing of the 1D VES

data acquired at each of the stations in the study area. The resistance obtained from the resistivity meter at each VES station was converted to apparent resistivity after multiplying by the corresponding geometric factor determined for each successive electrode spacing. This was followed by the generation of 1D VES curves from the plot of the apparent resistivity values against the electrode spacing, as well as the matching of the apparent resistivity curves with the calculated model. Subsequently, 1D inversion process aimed at minimizing the difference between the measured resistivities and the calculated response of the estimated model was carried out through a number of iteration steps, until a satisfactory agreement is reached between the calculated model and the field data. The resultant 1D inverted models obtained at all the stations along each profile were then concatenated to produce a 2D pseudo-section (Fig. 4-6). The final processing step was the correlation of all the 1D resistivity section and the generation of 2D geo-electrical model that best represents the subsurface geology below each profile (Fig. 4-6).

RESULTS AND INTERPRETATION

The 2D geo-electrical section obtained along profile P1 did not reveal any channel fill. However, the only striking feature observed in this section is a suspected fault or shear zone that occur in the middle of the profile (Fig. 4). As observed in the 2D model, the fault zone is about 200 m wide and has a near-vertical geometry with relatively high resistivity values ranging from about 900 - 3300 ohm-m. Outcrop exposure of this zone as observed during

the field campaign reveals the zone to be marked by highly ferruginized and silicified sediment that may not be of significance for groundwater exploration.

The geo-electrical section obtained along profile P2 shows a suspected channel-fill that cuts through the older sediment, and probably exposed and became lateritized by subsequent erosion and weathering processes (Fig. 5). This channel-fill is centred at about 100 m along the profile with a thickness and lateral extent of about 10 and 200 m, respectively. Similarly, the geo-electric section obtained along profile P3 shows a suspected 'multi-storey' channel comprising two channel-fills (Fig. 6). The upper channel-fill, which is younger, is centred at 200 m along the profile, and occurs at the depth between 2 and 8 m with a maximum thickness and lateral extent of about 7 and 200 m, respectively. This channel-fill is observed to be characterized by relatively low resistivity values that ranges from 21 to 77 ohm-m, and probably indicates silty-clay to very fine-grained sand that may not be of good reservoir quality.

However, the second, lower channel-fill that occurs at the depth between 8 and 22 m exhibits moderate to high resistivity values of about 416 - 2111 ohm-m (Fig. 6). This may indicate the channel is filled with medium- to coarse-grained sands that could be of significance exploration target for groundwater in the study area. The channel-fill is centred at 200 m along the profile with a maximum thickness and lateral extent of about 22 and 500 m, respectively, and appears to be confined within fine-grained sediment.

CONCLUSIONS

This investigation has revealed the existence of channel-fills that could be vital to groundwater exploration in the study area. The geophysical method using the electrical resistivity imaging has been able to delineate three channel-fills that exist in the study area. One of these channel-fills was observed along profile P2, while the other two channel-fills occur as multi-storey channel beneath profile P3. The channel-fill observed along profile P2 is exposed at the surface and filled with clayey-sand and lateritic materials, with a maximum thickness and lateral extent of about 10 and 200 m, respectively. Similarly, the two channel-fills observed beneath profile P3 are both centred at 200 m along

the profile with differences in thickness and sediment type. The upper channel is filled with silty clay to very fine-grained sand and occurs at the depth between 2 and 8 m, with a maximum thickness and lateral extent of about 7 and 200 m, respectively. The second, lower channel is confined within fine-grained sediment and probably filled with medium- to coarse-grained sands. It occurs at the depth between 8 and 22 m beneath profile P3 and has a maximum thickness and lateral extent of approximately 22 and 500 m, respectively. This channel-fill sand is suspected to be of good reservoir quality where groundwater can be stored and extracted based on its texture and confinement and could serve as target for future groundwater exploration and development in the study area.

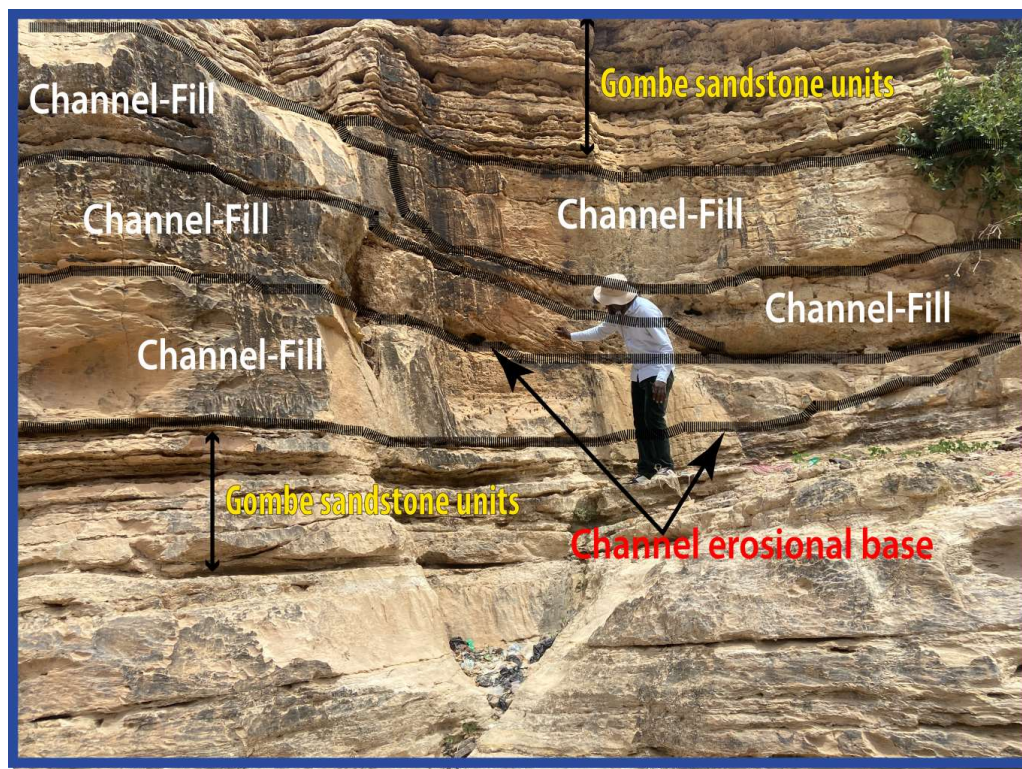


Figure 1: Multi-storey channel-fill sandstones within Gombe Sandstone Formation (Loc. N10° 18' 39", E11° 10' 4.5")

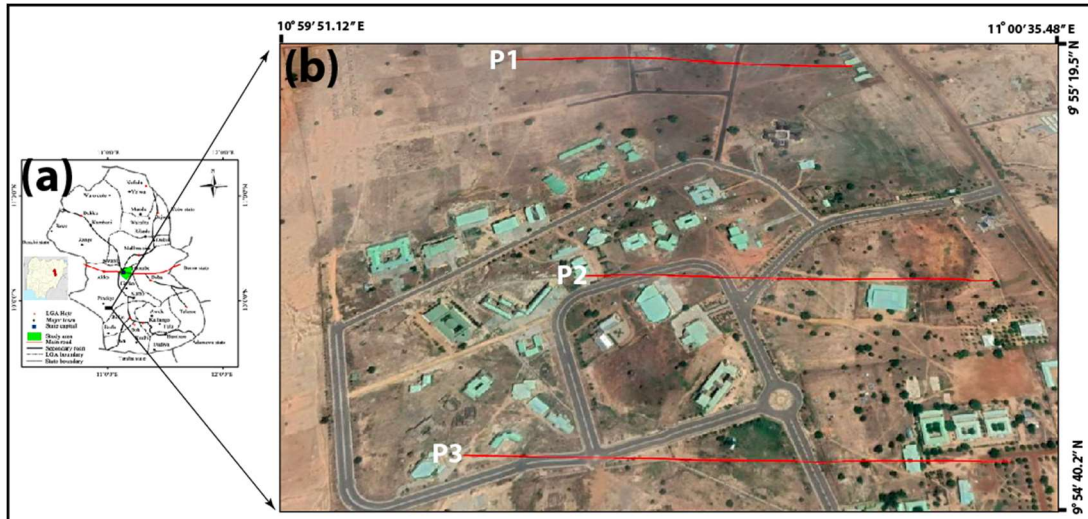


Figure 2: (a) Map of Gombe State in NE Nigeria showing the approximate location of the study area in Kashere; (b) Google image of the study area showing profile lines P1, P2 and P3.

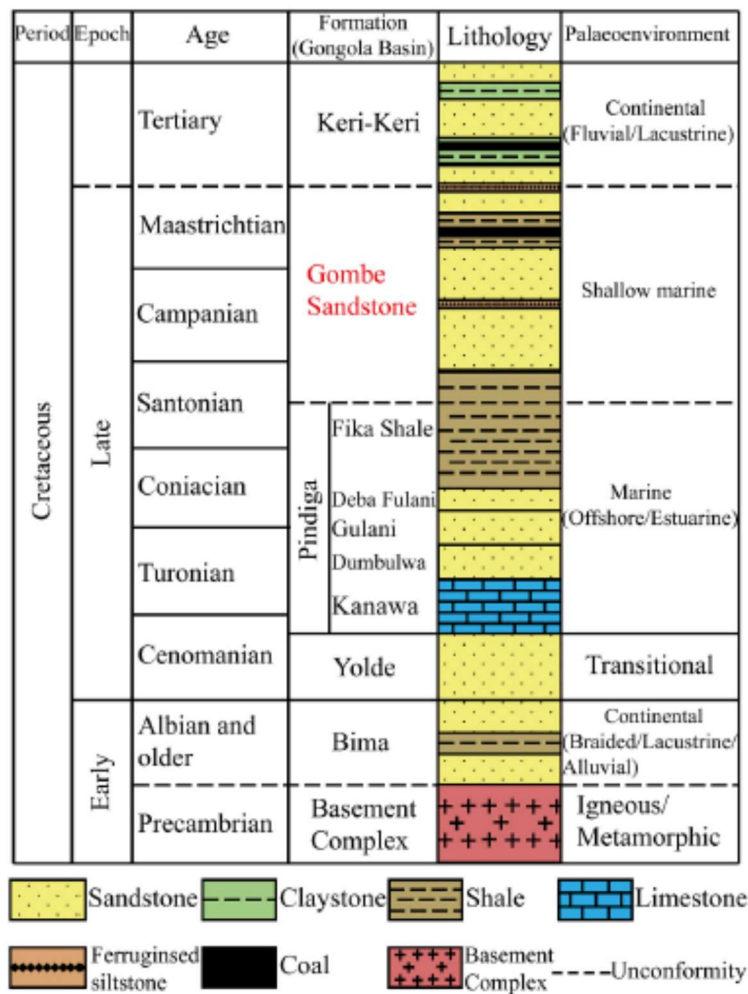


Figure. 3. The stratigraphic chart of the Cretaceous – Tertiary Gongola Basin (Adapted from Bello et al., 2023). Note the Gombe Sandstone which is the focus of this study is highlighted in red.

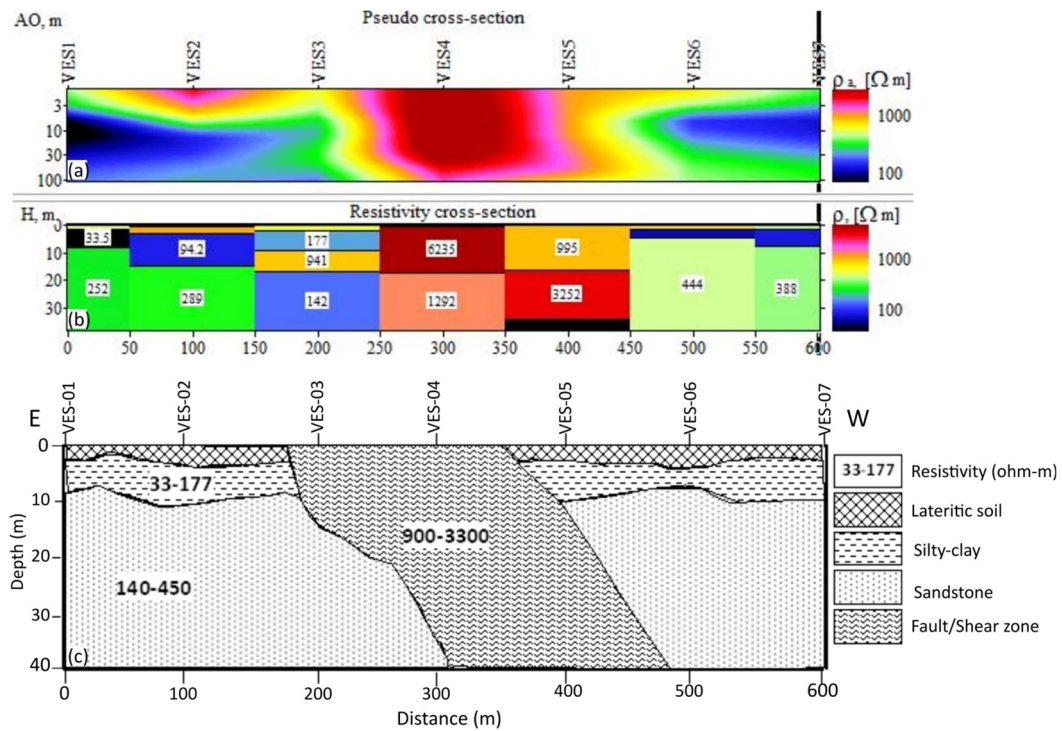


Figure 4: (a) The pseudo-section, (b) Resistivity cross-section, and (c) the 2D geo-electric model obtained along profile P1. Note the suspected fault/shear zone in the middle of the profile.

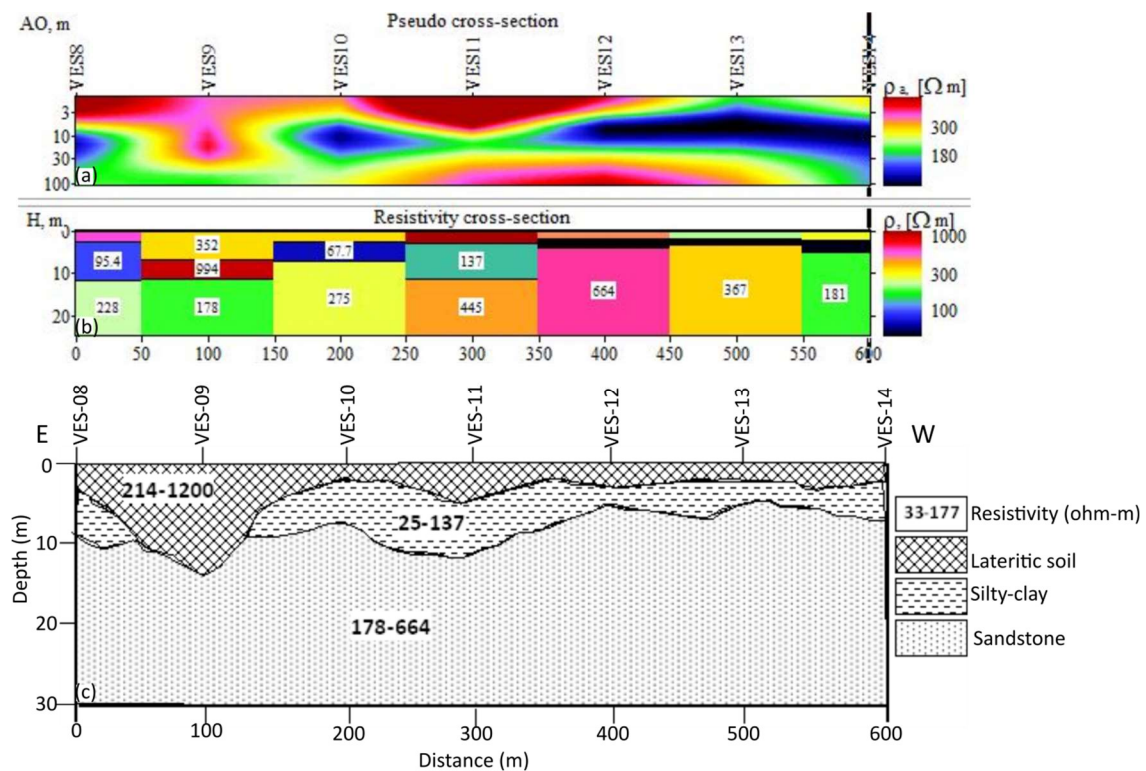


Figure 5: (a) The pseudo-section, (b) Resistivity cross-section, and (c) the 2D geo-electric model obtained along profile P2. Note the suspected channel-fill centered at 100 m along the profile.

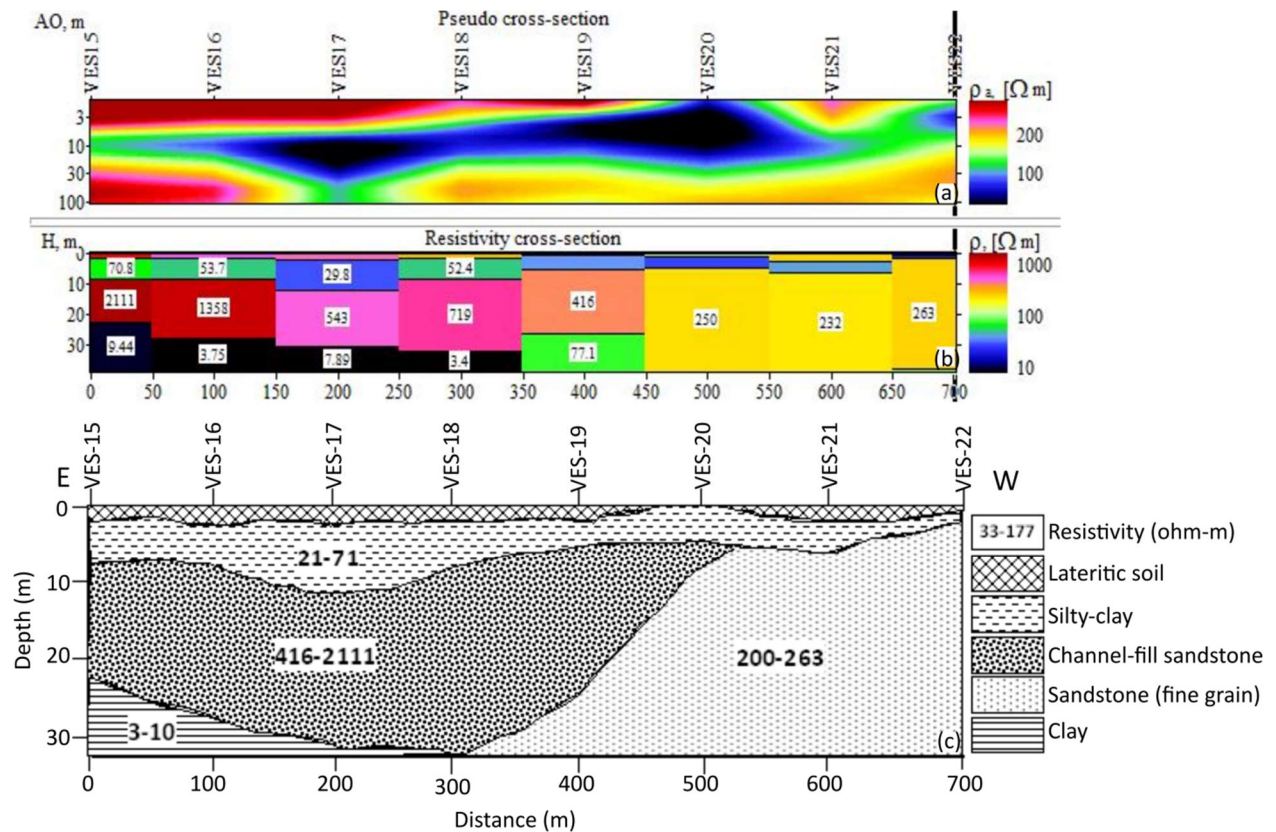


Figure 6; (a) The pseudo-section, (b) Resistivity cross-section, and (c) the 2D geo-electric model obtained along profile P3. Note the upper and lower channel-fill centered at 200 m along the profile and occur at the depth between 2 and 8 m and 8 and 22 m, respectively.

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