Geophysical Investigation for Marl Exploration Using Vertical Electrical Sounding in Akpokponke Ibii Afikpo Southeast Nigeria

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ABSTRACT

This study employs Vertical Electrical Sounding (VES) to investigate subsurface lithology with emphasis on identifying marl deposits in the study area. Resistivity profiles from five locations reveal diverse geological formations, including shallow weathered zones and deeper high-resistivity layers consistent with dense marl and sandstone. Results indicate that marl-rich formations occur at extractable depths. Overlying clay and shale horizons, identified as low-resistivity layers, may act as protective aquitards. These findings demonstrate the effectiveness of VES in delineating marl deposits and assessing their spatial distribution. The integration of recent advances in geophysical surveying and resistivity inversion enhances the accuracy of locating economically viable marl deposits, supporting sustainable extraction and land-use planning in sedimentary environments

Keywords: Vertical Electrical Sounding, Marl Exploration, Resistivity, Subsurface Lithology, Sedimentary Deposits, Geophysical Survey, Resource Assessment, Hydrogeology

INTRODUCTION

The exploration and characterization of sedimentary deposits such as marl are critical for construction, agriculture, and industry, particularly in regions with abundant sedimentary basins like Southeast Nigeria. Marl, a calcareous sedimentary rock composed of clay and carbonate minerals, is widely applied in cement production, soil stabilization, and as a building material (Akinluyi et al., 2020). Beyond its industrial value, marl plays an important role in agriculture by improving soil fertility and reducing acidity, making it a dual-purpose resource with economic and environmental benefits. Its local availability therefore presents a cost-effective alternative to imported raw materials for cement plants in Nigeria (Enesi et al,2023).

Within Nigeria, the Benue Trough is especially notable for its marl occurrences interbedded with shale, sandstone, and claystone (Ofoegbu, 1984; Nwankwo et al., 2019). Afikpo, located in the southeastern portion of the Benue Trough, contains a complex stratigraphy of marl, sandstone, and limestone. Despite the economic importance of these resources, the subsurface distribution of marl in Afikpo remains poorly mapped due to the heterogeneity of the formations and the limitations of conventional exploration techniques (Eze et al., 2018; Eze et al., 2022). The lack of detailed mapping limits the ability to evaluate the lateral continuity and thickness of marl beds, which are essential parameters for determining their long-term economic viability in quarrying and cement production. Traditional geological methods are often inadequate for delineating such heterogeneous deposits, creating the need for improved geophysical approaches.

Vertical Electrical Sounding (VES), based on the measurement of apparent resistivity variations with depth, has proven effective in distinguishing lithologies due to their contrasting electrical properties (Ajakaiye et al., 1994). The method has been successfully employed across Nigeria to delineate aquifers, locate mineral deposits, and map sedimentary layers (Oladipo et al., 2019). Recent advancements, including multi-electrode arrays, automated data acquisition, and robust inversion algorithms, have significantly improved the resolution and reliability of resistivity-based subsurface models (Olatunji et al., 2021).

Resistivity contrasts provide a useful framework for differentiating Afikpo's lithologies. Marl typically exhibits moderate resistivity values, generally ranging from 100 to 1000 Ωm, depending on moisture content, clay mineralogy, and cementation (Ojo et al., 2021). Limestone, by contrast, often exceeds 1000 Ωm when dry and well-cemented, though fractures and karst features may lower its resistivity (Akinluyi et al., 2021). Sandstone displays a broader range, from as low as 10 Ωm in saturated, clay-rich conditions to over 2000 Ωm in dry, cemented settings (Olatunji et al., 2022). These differences in resistivity reflect variations in porosity, cementation, and fluid content, which have important implications for both resource exploitation and groundwater flow.

To overcome the limitations of traditional exploration methods, this study applies VES to investigate the marl deposits of Afikpo. Specifically, it seeks to:

1. Delineate the depth, thickness and lateral extent of marl deposits.
2. Differentiate marl from adjacent sandstone and limestone formations using resistivity contrasts.
3. Assess the suitability of marl deposits for cement production and agricultural use by integrating geophysical results with geological and borehole data (Olatunji, et al., 2020).

The findings will provide a scientific basis for the sustainable quarrying and utilization of marl in the region, supporting both local economic development and infrastructure growth.

Complementing the scientific and technical efforts, the human kinetics expert plays a vital role in supporting the geophysical exploration team by optimizing physical performance, ensuring safety, and promoting well-being during field operations. This role enhances overall productivity and minimizes health risks, addressing the human element of exploration activities. Recent studies emphasize the importance of incorporating human performance optimization in fieldwork to improve efficiency and safety outcomes (Smith & Johnson, 2022).

Geology Of The Area

Akponkponsi Ibii is situated within the Ozara Shale/Amasiri Sandstone member of the Ezeaku Formation (Fig. 1). The geological setting of this area is characterized by a complex stratigraphy comprising various sedimentary lithologies indicative of shallow marine depositional environments during the Late Cretaceous period.

The Ezeaku Formation mainly consists of thick, calcareous and non-calcareous shales, interbedded with sandy and shelly limestones, as well as calcareous sandstones. Near Akponkponsi Ibii, the formation includes the Ozara Shale/Amasiri Sandstone member, notable for its massive sandstones exhibiting planar-tabular cross-bedding—an indicator of high-energy depositional processes such as river channels or deltaic systems (Adegoke et al., 2022). The shales and limestones often display lateral facies changes, reflecting a dynamic environment influenced by fluctuating energy levels and sediment supply.

The limestone horizons within the formation are fossiliferous, containing marine fossils such as pelecypods, gastropods, echinoids, brachiopods, and ammonites, primarily of Turonian age. These fossils suggest that the area was once a shallow marine habitat capable of supporting diverse marine life (Ojo et al., 2021). The presence of shelly limestones and calcareous sandstones further supports this interpretation.

Structurally, the formations in the area exhibit evidence of folding and faulting, indicating tectonic activity that has affected the stratigraphy and surface expression of the rocks (Eze et al., 2020). Lateral facies changes and the presence of cross-bedded sandstones highlight a depositional environment that ranged from quiet, deep marine settings to high-energy shoreline or deltaic environments.

Economically, the limestone horizons within the Ezeaku Formation are significant for cement manufacturing, while the sandstone units may serve as valuable construction materials. Archaeologically, the area contains rock shelters and artifacts, demonstrating its cultural importance and illustrating how geological features have influenced human activity (Nwachukwu & Okezie, 2022).

Overall, the geology of Akponkponsi Ibii reveals a rich and varied depositional history that provides valuable insights into paleoenvironmental conditions and the resource potential of the region.

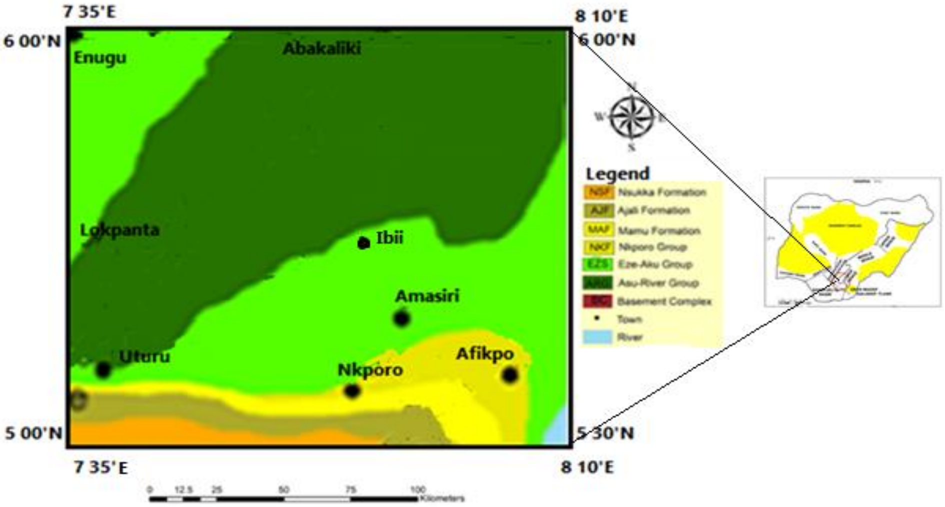


Figure 1: The Geological Map of the study Area

METHODOLOGY

The Research Area and Methodology

The study was conducted in Akponkponsi Ibii, within the Afikpo area of Southeast Nigeria. This environment is characterized by various sedimentary formations, including marl, limestone, and sandstone. Due to the geological complexity of the area, geophysical methods were employed to effectively map the subsurface lithologies. Vertical Electrical Sounding (VES) was used as the primary technique to investigate the subsurface resistivity distribution and delineate marl deposits.

Field Procedure

The fieldwork utilized the Schlumberger array, which comprises four electrodes arranged in a specific configuration. A controlled current and voltage were injected through the current and potential electrodes, respectively, and the resulting resistance of the rocks at various depths was measured. Multiple readings were taken with a maximum electrode spacing (AB/2) of 350 meters to improve data reliability. A total of five VES points were surveyed to ensure comprehensive coverage of the area.

Data Processing and Interpretation

The apparent resistivity data obtained from the field were processed through inversion and modelling using IPI2Win software, which generated true resistivity models of the subsurface layers and their corresponding depths. These models facilitated the identification of distinct lithological layers based on their resistivity characteristics.

Lithological Identification

Resistivity ranges associated with marl, limestone, and sandstone were established from existing literature and local geological data. The interpreted resistivity profiles enabled the mapping of marl deposits and other lithologies across the study area.

MATERIALS AND METHODS

Theory of Resistivity (DC) Method

Resistivity surveys are founded on the principle that different subsurface materials exhibit varying electrical resistivity levels, which measure a material's ability to resist the flow of electric current (Telford et al., 1990). The resistivity (ρ) of a material depends on factors such as lithology, porosity, moisture content, and mineral composition (Dahlin & Zhou, 2004).

In the direct current (DC) resistivity method, an electric current is introduced into the ground via a pair of electrodes, and the resulting potential difference is measured with another pair. The fundamental relationship relates the measured potential difference (ΔV) and the injected current (I) to the apparent resistivity (ρa) through the geometric factor (G):

$$\ell a=2\pi G\Delta V/I$$

where:

ℓa is the apparent resistivity in ohm-meters ($\Omega \cdot m$),

(G) depends on the electrode array configuration (Loke, 2013),

ΔV is the measured voltage difference,

(I) is the current injected into the ground.

The apparent resistivity reflects the average resistivity of the subsurface layers within the investigation zone. Varying the electrode spacing allows exploration at different depths, aiding in the interpretation of layered structures and lithologies (Dahlin & Zhou, 2004).

Electrode Arrays

Multiple electrode configurations exist; among these, the Schlumberger array is widely used due to its efficiency and depth penetration capabilities (Telford et al., 1990). In this array, the current electrodes (C1 and C2) are moved outward symmetrically, while the potential electrodes (P1 and P2) remain fixed near the center, enabling investigation of deeper layers as the electrode spacing increases.

Data Acquisition

Fieldwork Overview

A total of five VES points were surveyed within the study area to characterize the subsurface resistivity distribution. The site locations were strategically chosen to sample different geological features, with electrode spacing (AB/2) tailored to target specific depths (Figure 2):

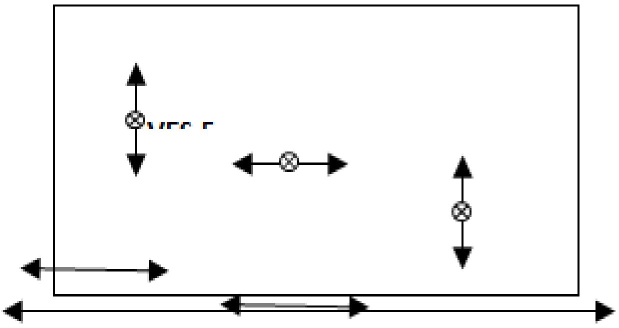


Figure 2: Location of The Study Area

The maximum electrode spacing was selected based on preliminary surveys and regional geological information to ensure comprehensive depth coverage.

Surface Mapping

Surface outcrops were mapped using GPS and measuring tapes, covering an area of approximately 69,284.96 m² (Figure 3). These surface features provided important geological context for interpreting the resistivity data.

Figure3: Showing an outcrop within the study Area

Equipment and Procedure

Data collection was performed using an ABEM Terrameter SAS 300B, which offers high precision and automation features (Loke, 2013). During measurements, electrodes were systematically moved following the Schlumberger array protocol—current electrodes (C1 and C2) moved outward symmetrically while potential electrodes (P1 and P2) remained fixed—allowing exploration at increasing depths (Telford et al., 1990).

Instrumentation

The ABEM SAS 300B Terrameter is equipped with features such as a digital liquid crystal display and microprocessors for automatic signal averaging, which reduce noise and improve data reliability (Loke, 2013). Additional modules, such as the SAS 2000 Booster and SAS Log, can be attached to enhance signal strength and facilitate data recording, respectively.

Figure 4: Showing Data acquisition by the prospecting Team

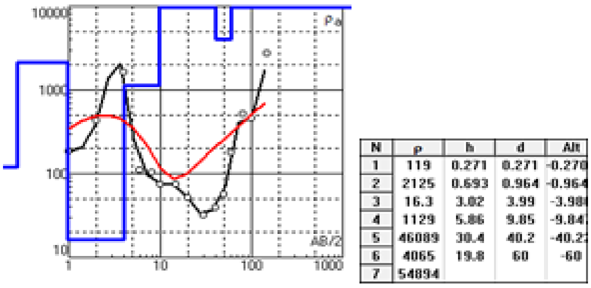
Data Processing

Data Handling and Analysis

Field data were first corrected for instrument and environmental factors. The corrected data were then processed using i2iwin software (Loke et al., 2015), which enables inversion modeling of resistivity data to generate detailed 2D and 3D subsurface resistivity images. These images facilitated the interpretation of geological structures and lithological distributions. The Surfer 12 software was employed to visualize the spatial distribution and resistivity models of the subsurface within the study area.

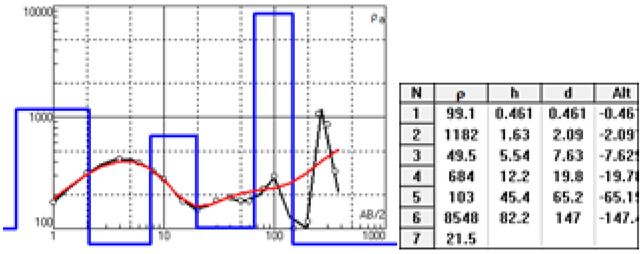
PRESENTATION OF RESULTS

The plotted sounding curves show apparent resistivity versus half-current electrode spacing on double logarithmic graphs, aiding in the identification of layered subsurface features (Telford et al., 1990), Figure 5.



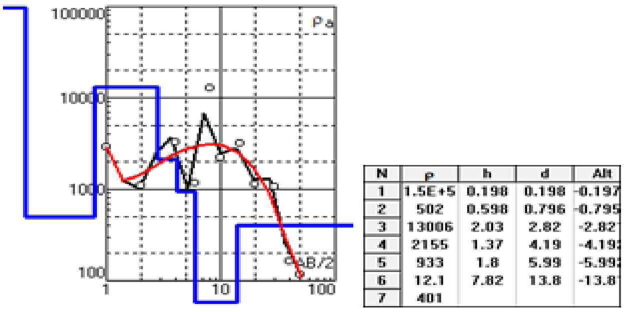
N	ρ	h	d	Alt
1	119	0.271	0.271	-0.270
2	2125	0.693	0.964	-0.964
3	16.3	3.02	3.99	-3.98
4	1129	5.86	9.85	-9.84
5	46089	30.4	40.2	-40.2
6	4065	19.8	60	-60
7	54894			

Figure 5a: The Modelled Curve of VES 1



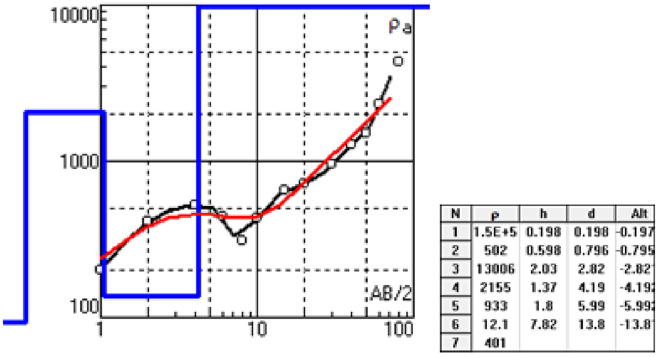
N	ρ	h	d	Alt
1	99.1	0.461	0.461	-0.46
2	1182	1.63	2.09	-2.09
3	49.5	5.54	7.63	-7.62
4	684	12.2	19.8	-19.7
5	103	45.4	65.2	-65.1
6	8548	82.2	147	-147.
7	21.5			

Figure 5b: The Modelled Curve of VES 2



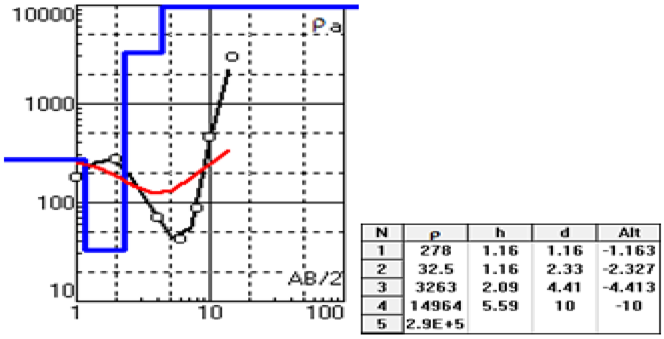
N	ρ	h	d	Alt
1	1.5E+5	0.198	0.198	-0.197
2	502	0.598	0.796	-0.795
3	13006	2.03	2.82	-2.82
4	2155	1.37	4.19	-4.19
5	933	1.8	5.99	-5.99
6	12.1	7.82	13.8	-13.8
7	401			

Figure 5c: The Modelled Curve of VES 3



N	ρ	h	d	Alt
1	1.5E+5	0.198	0.198	-0.197
2	502	0.598	0.796	-0.795
3	13006	2.03	2.82	-2.82
4	2155	1.37	4.19	-4.19
5	933	1.8	5.99	-5.99
6	12.1	7.82	13.8	-13.8
7	401			

Figure 5d: The Modelled Curve of VES 4



N	ρ	h	d	Alt
1	278	1.16	1.16	-1.163
2	32.5	1.16	2.33	-2.327
3	3263	2.09	4.41	-4.413
4	14964	5.59	10	-10
5	2.9E+5			

Figure 5f: The Modelled Curve of VES 5

Coordinates and elevation data of the outcrops were contoured to produce spatial distribution maps, enhancing geological interpretation. The outcrops are massive in clusters. The thicknesses are estimated to be from 4m (13ft) to greater than 20m (66ft) above ground surface, Figure 6a.

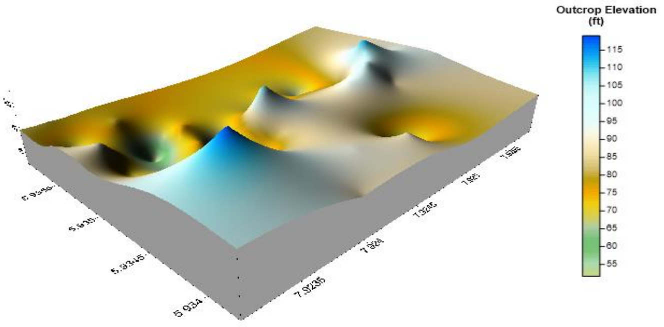


Figure 6: Model of Elevation of outcrops within the study area

Comparative Analysis and Interpretation of VES Data

The five VES profiles offer key insights into the subsurface lithology, resistivity variations, and depth distribution across different locations in the study area. The data indicate geological heterogeneity, reflecting variations in soil and rock types, which are crucial for geological, hydrogeological, and engineering evaluations (Table 1; Figures 7a, 7b and 7c).

Table 1: The Resistivity, thickness, Depth and Probable lithology of the modelled layers.

VES No	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Probable Lithology
1	1	119	0.271	0.271	Topsoil + Marl
	2	2125	0.693	0.964	Sand+ limestone
	3	16.3	3.02	3.99	Marl
	4	1129	5.86	9.85	Limestone
	5	46089	30.4	40.2	Dry Sandstone or Basement
	6	4065	19.8	60.0	Sandstone/ Fractured Basement
	7	54894		>60.0	Dry Sandstone or Basement
2	1	99.1	0.461	0.461	Topsoil + Marl
	2	1182	1.63	2.09	Limestone

	3	49.5	5.54	7.63	Marl
	4	684	12.2	19.8	Limestone
	5	103	45.2	65.2	Marl
	6	8548	82.2	147.2	Sandstone
	7	21.5		>147.2	Marl/ Shale
3	1	150000	0.198	0.198	Topsoil + Sandstone
	2	502	0.598	0.796	Limestone
	3	13006	2.03	2.82	Dry Sandstone or Basement
	4	2155	1.37	4.19	Sand+ limestone
	5	933	1.8	5.99	Limestone
	6	12.1	7.82	13.8	Marl
	7	401		>13.8	Limestone
4	1	93.5	0.333	0.333	Topsoil + Marl
	2	2040	0.707	1.04	Sand+ limestone
	3	136	3.19	4.23	Marl
	4	58781	13.2	17.40	Dry Sandstone or Basement
	5	85516		>17.40	Dry Sandstone or Basement
5	1	278	1.16	1.16	Topsoil + Marl
	2	32.5	1.16	2.33	Marl
	3	3263	2.09	4.41	Sand+ limestone
	4	14964	5.59	10.0	Dry Sandstone or Basement
	5	290000		>10.0	Dry Sandstone or Basement

Three profiles were drawn traversing VES 4 and VES 5 in the NE-SW, VES 4 and VES 2 AND VES 4 and VES 1 as shown in Figures 7a, 7b and 7c. A preliminary quantifications of rock types using thicknesses of the respective rock units, as illustrated in Figure 8.

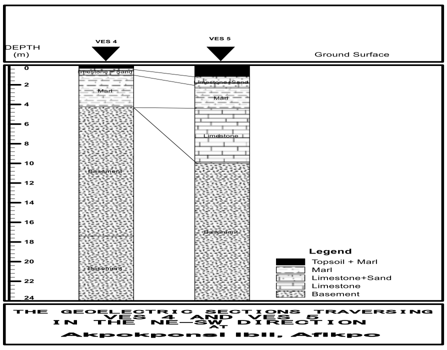


Figure 7a: Profile of Geo-Electric section across VES 4 and VES 5 in the NE-SW direction

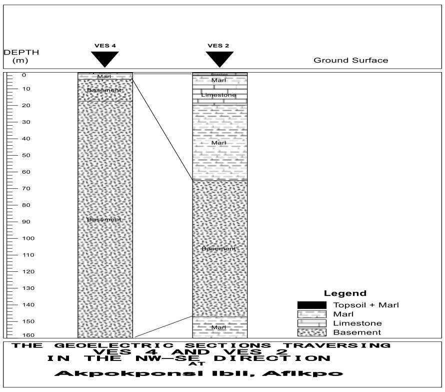


Figure 7b: Profile of Geo-Electric section across VES 4 and VES 2 in the NW-SE direction

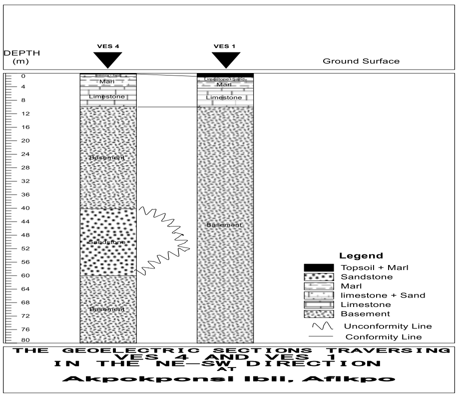


Figure 7c: Profile of Geo-Electric section across VES 4 and VES 1 in the NE-SW direction

DISCUSSION

The analysis of Vertical Electrical Sounding (VES) profiles across five locations in the study area reveals significant heterogeneity in subsurface lithology, resistivity distribution, and depth to various formations. Such variability is typical of sedimentary basins and has important implications for geotechnical engineering, hydrogeology, and resource management.

Lithological Variability and Geological Implications

Resistivity values in the profiles ranged from as low as 32.5 Ω·m in clay/shale horizons to as high as 290,000 Ω·m in dense sandstone or marl formations. These variations align with previous studies that highlight the usefulness of resistivity contrasts in delineating lithological boundaries (Smith et al., 2023; Zhang et al., 2024). Low-resistivity zones typically indicate clay-rich or weathered materials that are permeable and prone to water retention (Kumar & Patel, 2024). In contrast, high-resistivity values correspond to dense, unweathered rocks such as sandstone and marl, which are mechanically competent and less prone to deformation.

Depth profiles further reveal that the weathered overburden is relatively shallow, generally between 0.33 and 1.16 m. This agrees with findings by Lee et al. (2024), who observed similar shallow weathering profiles in sedimentary environments. More resistive layers at depths greater than 17 m represent consolidated formations that form stable geological horizons (Zhang et al., 2024).

Hydrogeological Significance

The resistivity data also point to potential aquifer zones within the high-resistivity sandstone and marl layers. These units are commonly associated with high porosity and permeability, making them favorable for groundwater storage and flow (Ojo & Adeyemi, 2024). Conversely, low-resistivity clay and shale layers at shallow depths may function as aquitards, restricting recharge and influencing groundwater distribution

(Zhang et al., 2024). Understanding the spatial extent of these lithologies is therefore critical for sustainable groundwater development, particularly in regions where groundwater is the main water supply (Kumar & Patel, 2024).

Engineering and Construction Considerations

From a geotechnical perspective, the dense, high-resistivity sandstone and marl formations represent competent and stable ground suitable for construction, as also observed by Lee et al. (2024). However, the presence of shallow weathered zones and clay/shale horizons introduces challenges such as differential settlement or slope instability. These issues necessitate careful site-specific assessment and, in some cases, ground improvement measures. The integration of VES data with geotechnical testing has been shown to enhance the reliability of construction site evaluations (Zhang et al., 2024).

Methodological Advances and Future Directions

Recent developments in geophysical techniques, including multi-electrode resistivity arrays and machine learning-assisted inversion, have significantly improved the resolution of subsurface models (Zhang et al., 2024; Kumar & Patel, 2024). Incorporating these methods into future studies will allow for more accurate characterization of subsurface heterogeneity. Furthermore, combining VES results with borehole logs, remote sensing, and geotechnical investigations provides a holistic framework for subsurface analysis, as recommended in recent studies (Ojo & Adeyemi, 2024; Zhang et al., 2024).

CONCLUSION

The VES data across the five locations demonstrate significant lithological variability that has direct implications for geotechnical, hydrogeological, and engineering applications within the study area. The presence of shallow weathered zones overlain by deeper, high-resistivity formations suggests suitable zones for foundation support and groundwater extraction, provided that detailed site investigations are carried out. The evolving geophysical techniques and integrative approaches documented in recent studies underscore the importance of comprehensive subsurface evaluation for sustainable development.

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