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EVALUATING THE STRATIGRAPHY AND SUB-SURFACE STRUCTURE OF QUATERNARY SEDIMENTS IN EASTERN DAHOMEY BASIN, SOUTHWESTERN NIGERIA USING ELECTRICAL RESISTIVITY TOMOGRAPHY

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ABSTRACT

This study investigated the stratigraphic and structural characteristics of Quaternary coastal deposits around Ilaje community, eastern Dahomey Basin, southwestern Nigeria, with the intent to provide valuable insights into the subsurface geology and depositional environment of the siliciclastic sediments round Ilaje community coastline. 2-D resistivity data were acquired along two 300m traverses using the dipole-dipole electrode array with electrode separation of "a=10" and the number of layers "N=5" were adopted. The resulting pseudo-sections revealed three to four geo-electric strata. The first profile showed quartz-rich sand (932Ωm – 3343Ωm) and silty sand strata (369Ωm – 470Ωm / 207Ωm - 354Ωm) with thickness ranges of 4m – 8m and infinity, respectively. The second profile depicted a descending resistivity trend with sand (800Ωm – 4640Ωm), silty sand (245Ωm – 350Ωm), sandy silt (119 Ωm - 204Ωm), and silt (48Ωm - 82Ωm) layers. Thickness ranges were 5m – 7m, 1m – 2m, 4m – infinity, and undeterminable. The 2-D resistivity structures indicated minor symmetrical folds and lateral variation in lithology from sandy to silty deposits, suggesting a fluvial meandering depositional mechanism. The study concludes that the probed section consists of simple, symmetrically folded siliciclastic deposits fining down the sequence, deposited in a fluvial environment. High-grade silica sand can be exploited with minimal processing to an average depth of 6m. It is hereby recommended that further surveys using Vertical Electrical Sounding and seismic refraction methods be adopted to improve accuracy.

Keywords: *Quaternary Deposits, Electrical Resistivity Tomography, Delineation*

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1. INTRODUCTION

The growth of sedimentary basins is usually controlled by the interplay of tectonics, sediment supply, sea level condition, erosion, and subsidence Schlische, (1991), (Lambiase and Bosworth, 1995), These can provide pointers to prevalent conditionsduring its evolution which may include the volume and amount of transported sediment, degree of deformation related to tectonics, character of transporting medium, proximity of sediment source area among others. This lithological and biological information derived from the rock will be valuable tools for effective basin analysis.

Researchers map the lithology and geometry of sand and gravel channel and valley fills due to their economical significant to groundwater and hydrocarbon reservoirs, sources of economic placer deposits (e.g. gold, tin, diamonds); sources of construction aggregate; and modern analogues of ancient deposits (Miall, 1996). Mapping these sediments is important based on their economic significance for construction aggregates, groundwater exploitation and information about depositional environments (Arjwech and Everett, 2015). However, the geological mapping of the Quaternary sediments by geomorphologists and surficial geologists has been hampered by inability to easily obtain information about the shallow subsurface (Ryan *et al.,* 2006; Castilho and Maia, 2008), hence a need for quick and effective tool subsurface imaging in geophysics.

Electrical Resistivity Tomography (ERT) is one of the most commonly used geophysical methods for imaging subsurface features (Dahlin 1996, 2001). The use of ERT profiles and additional data from the subsurface, such as drilling reports and borehole loggings, makes it possible to estimate the thickness, depth, and morphology of different units of the subsurface (Baines *et al*., 2002; Loke and Dahlin 2002; Loke *et al*., 2003; Loke, and Lane 2004; Crook *et al*., 2008; Martinez *et al*., 2009). (Moorman, 1990; Reynolds, 1997). Electrical resistivity imaging (ERI) works effectively in sand and gravel, as well as in fine sediments like silt and clay, since it measures the resistance of the material to electrical conduction and not the reflectance of electromagnetic waves.

While evaluating Salt-water Intrusion in the Coastal Area of Igbokoda, Southwestern, Nigeria, using ERT Talabi (2013) identified about five (5) major layers comprising. According to the study, the geoelectric parameter further indicated five different subsurface lithology sequences namely; silty sand, sand, sandy clay, clay, and sandy clay. The partly-salt water intruded zones and saltwater intruded zone was characterized by low resistivity while the high resistivity zones of the consolidated sand layer constitute fresh water bearing zone that could serve as boreholes in the study area. Faleye and Olorunfemi (2015) worked on Aquifer characterization and groundwater potential Assessment of the Sedimentary basin of Igbakoda, Ondo State using the vertical electrical sounding (VES), they concluded that the groundwater potential of the Coastal Alluvium and Coastal Plain Sands was high while the groundwater potential of the Imo Shale Group, the Upper Coal Measures and Nkporo Shale were adjudged low.

In a study to reconstruct the geological history of slope deposits exposure in some parts of the Eastern Dahomey basin, Ikhane *et al.* (2012) identified six (6) geo-electric facies from three locations; they include clay, resistive clay, sand, sandstone, compacted sandstone and conglomerate at Ijebu-Ife, while Akinmosin *et al.* (2012) successfully investigated the basin fills in some parts of Eastern Dahomey using electrical resistivity tomography which revealed three (3) geo-electric units characterized by resistivity value > 1000Ωm, > 1019Ωm and < 400Ωm for the conglomeratic sand, ferruginized sandstone, and the weathered layer respectively. Maciej *et al.* (2014) identified weak, low-strength soils like organic soils (peat, aggregated mud) and soft consistency cohesive soils using ERT as the main cause for unacceptable deformations appearing in the new road engineering structure in

Warsaw, Poland. Olayinka and Weller (1997) further applied ERT to characterize an engineering site along the Igarra-Auchi road, Edo State; they reported that pervasive underground geological structures are to blame for most of the observed road failures. The works of Alessandro *et al*., (2008) and Andres *et al*. (2016), reported that in quaternary sedimentary deposits, the apparent resistivity signature implies a high clay composition at the base and relatively low resistive clayey bedrock. Quaternary sediments are often complex due to the lateral changing commonly experienced over short distances, hence the need for more detailed information across an entire site. The purpose of this work is to integrate the delineated lithological (compositional) and structural pattern for paleo-environmental prediction of the explored Quaternary deposit along the Igbokoda coastline, Southwestern Nigeria using Electrical Resistivity Tomography method and to map the subsurface lithology present in relations to depth and thickness, at Ilaje community Ondo state, Nigeria. The study area lies within geographical coordinates 6° 21' 0" to 6° 38' 4" N and 4° 48' 0" to 4° 77' 0" E respectively. The study area is accessible via major and minor roads and footpaths (Fig 1).

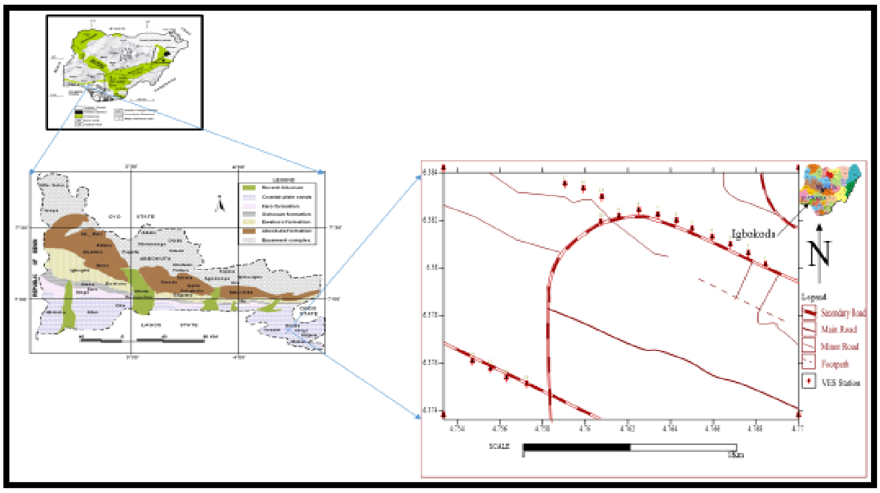

Fig 1: Map of the study area

2. REGIONALGEOLOGICAL SETTING

The study area lies within the Dahomey basin of Nigeria; this is a combination of inland/coastal/offshore basins that stretches from southeastern Ghana through Togo and the Republic of Benin to southwestern Nigeria. It is separated from the Niger Delta by a subsurface basement high referred to as the Okitipupa Ridge. Its offshore extent is poorly defined. Sediment deposition follows an east-west trend. In the Republic of Benin, geology is fairly well-known (De Klasz, 1977). In the onshore, Cretaceous strata are about 200 m thick (Okosun, 1990). A non-fossiliferous basal sequence rests on the Precambrian basement. This is succeeded by coal cycles, clays, and marls which contain fossiliferous horizons. Offshore, a 1,000 m thick sequence consisting of sandstones followed by black fossiliferous shales towards the top has been reported. This was dated by Billman (1992) as being pre-Albian to Maastrichtian. The Benin (Dahomey) basin forms one of a series of West African Atlantic Margin basins that are initiated during the period of rifting in the late Jurassic to early Cretaceous and also reported that the basin is made up of Tertiary to Recent sediments and Cretaceous sediments. The area is underlain by the Ilaro Formation coastal recent sediments overlie the formation. It is however observed that the basement complex is found within the sedimentary basins but deeply buried by the overlying Cretaceous and younger sediments about 2.5km thick.

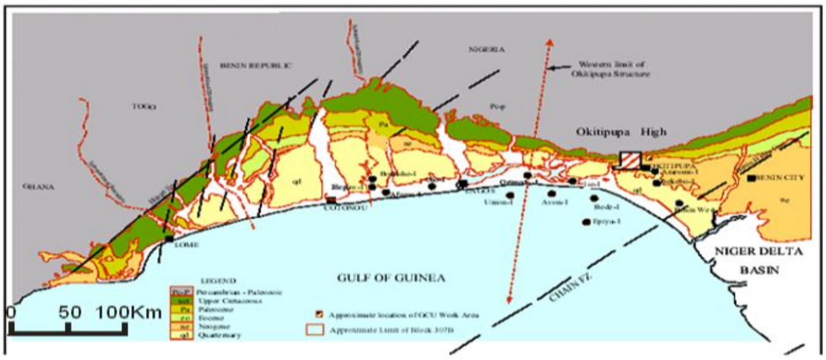

Fig 3: Generalized Geological Map of Eastern Dahomey Basin as modified (Billman, 1992)

2.1 Stratigraphy of Eastern Dahomey Basin

The stratigraphy of Dahomey basin has been extensively studied using both surface as well as sub-surface data by various workers (Table 1). Some of them include; Jones and Hockey (1964), Agagu (1985), and Omatsola and Adegoke (1981). Two lithostratigraphic units, the Abeokuta and Araromi Formations, have been recognized in the Cretaceous of the eastern Dahomey Embayment, with lithologic similarity to Ajali Sandstone and Nsukka Formation as reported by Reyment (1965). The southern Nigeria's sedimentary basin is partially divided into western and eastern portions by the Okitipupa ridge (Adegoke, 1969).The incompleteness of this separation is evidenced by similarity of lithologic units bearing identical marine faunas in both parts of the basin. In the western part of the basin, sedimentation did not begin until the terminal stages of the Cretaceous whereas the earliest transgression in the east was during the Albian. The thicker accumulation of the sediments in the east was attributed to the Tertiary deltaic build-up.

Sedimentation in the basin is similar to those in other Nigerian sedimentary basins.

Table 1: Stratigraphical Column of Dahomey Basin

[illegible]	Jones & Hockey (1964)		Adegoke&Omatsola (1981)		Agagu (1985)	
	Age	Formation	Age	Formation	Age	Formation
Quaternary	Recent	Alluvium			Recent	Alluvium
Tertiary	Pleistocene-Oligocene	Costal- Plain sands	Pleistocene-Oligocene	Coastal Plain Sands	Pleistocene-Oligocene	Coastal Plain Sands
	Eocene	Ilaro	Eocene	IlaroOshosun	Eocene	Ilaro Oshosun
	Paleocene	Ewekoro	Paleocene		Paleocene	AkinboEwekoro
Late Cretaceous	Late Senonian	Abeokuta	MaastrichtianNeocomian	AraromiAfowoIse	MaastrichtianNeocomian	Araromi member
						Afowo member
						Ise member

3. MATERIAL AND METHOD

3.1 Field Survey Procedure

The Electrical Resistivity method involving a dipole-dipole array was used to obtain a good two-dimensional (2-D) image of the subsurface. Two traverses of length 300m each were established. The inter-electrode spacing "a=10" and N=5, was used. Dipro - Win software was used to process the electrical resistivity (dipole-dipole) data. Conventionally for a system of 'n' electrodes, there are 'n-3' possible numbers of measurement. During this investigation, an electrode separation interval of 10,20,30,40 and 50m requiring 31, 28, 25, and 22 electrode systems along a 300m length profile were employed, with a corresponding 22, 25, 22 and12 possible measurements obtained at each cycle (level) movement in that order.

For the second measurement, electrodes number 1, 2, 3, and 4 were used for C1, P1, P2, and C2 respectively. This procedure (process) was repeated until the last measurement was taken at positions 270, 280, 290, and 300 with electrode numbers 26, 27, 28, and 29 was accomplished

Fig 4: Picture showing Terrameter and other field gadgets

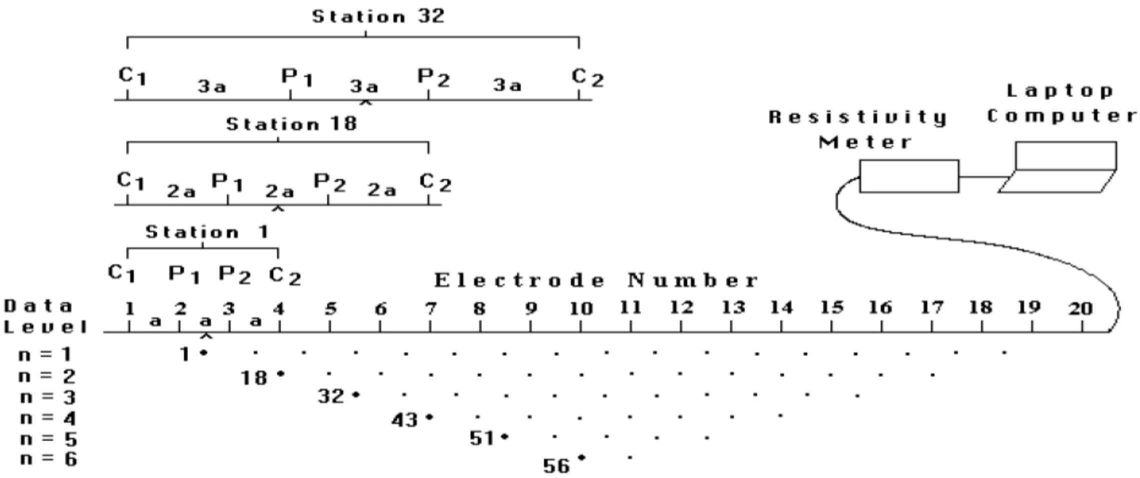

Fig 5: The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a Pseudo section.

3.2 Interpretation of 2-D Resistivity Data

3.2.1 Pseudo-section data plotting method The result of the 2D resistivity survey is presented as a pseudo-section (fig.). Along the two traverses, the point of investigation in the horizontal direction is placed at the mid-point of the set of electrodes used to make that measurement. The vertical location of the plotting point is placed at a distance that is proportional to the separation between the electrodes. The pseudo section presents a very approximate picture of the true subsurface resistivity distribution. However, the pseudo section gives a distorted picture of the subsurface because the shape of the contours depends on the type of array used as well as the true subsurface resistivity. The pseudo section is useful as a means to present the measured apparent resistivity values in a pictorial form, and as an initial guide for further quantitative interpretation. For the second measurement, electrodes number 1, 2, 3, and 4 were used for C1, P1, P2, and C2 respectively. This procedure (process) was repeated until the last measurement was taken at positions 270, 280, 290, and 300 with electrode numbers 26, 27, 28, and 29 was accomplished.

4. RESULTS AND DISCUSSION

4.1 Results

Inversion of the apparent pseudo sections acquired along the profile lines generated the 2-D resistivity structures used for the interpretation of the study area. The structural setting controlling the deposition of this coastal sequence is unraveled by these resistivity structures. A range of three to four geo-electric strata was distinctively delineated using resistivity contours decoded with unique coloration. With a maximum spacing interval of 50m, a targeted depth of 25m was probed. The upper silica sand channel ranges from 800 to 4640Ωm

4.1.1 Electrical Resistivity Tomography Profiles

The 2-D resistivity structure along profile one reveals three geo-electric strata. The first geo-electric stratum (coded red) ranges in resistivity value between 932Ωm – 3343Ωm, with a thickness range between 3m – 7m; aptly inferred as siliciclastic sand as displayed in Fig 4.1. The resistivity range of the second geo-electric stratum (coded green) is 369Ωm – 470Ωm corresponding to a folded silty sand stratum; thickness ranges from 2m anticlinorium to over 10m down the synclinorium.

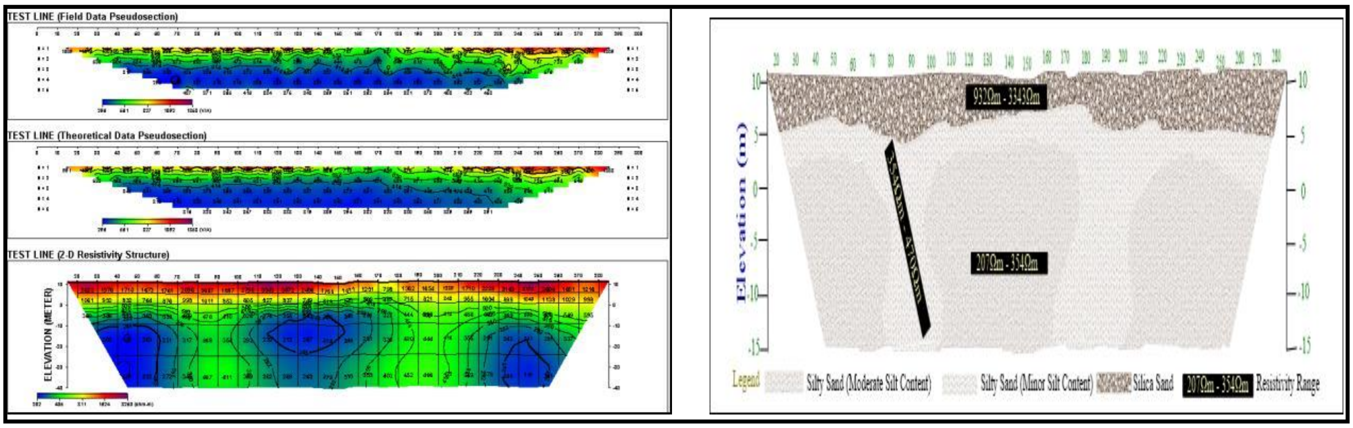

Figure 6: 2D Geo-electric and Lithological sections along profile 1

The basal blue-coded geo-electric stratum possesses a resistivity ranging between 207Ωm - 354Ωm inferred as silty sand

anticlinorium which is compositionally more silty than the overlying layer. The variability pattern of the probed subsurface sequence transits from an entirely sandy top (which gradually decreases with depth) to an increasing silty base. The silty proportion is markedly greater within the anticlinorium than in the synclinorium, as shown in Fig 7.

The resulting 2-D resistivity structure along traverse 2 also depicts a descending trend of resistivity variation from the top to the base of this sequence. The coloration code for the delineated geo-electric strata are 'red' for a resistivity range of 800Ωm – 4640Ωm inferred as sand, 'yellow' indicating a resistivity range between 245Ωm – 350Ωm corresponding to silty sand, 'green' for a range 119Ωm - 204Ωm and 'blue' between 48Ωm - 82Ωm as displayed in fig 7. Corresponding lithologic inference of these geo-electric units sand, silty sand, sandy silt, and silt. The thickness range of the sand stratum is 5m – 7m while the thin silty sand layer ranges in thickness between 1m – 2m. The silty sand layer has a uniform thickness of 4m on the southeastern half but becomes progressively thicker down the synclinorium of the northwestern part as shown in Fig 7.

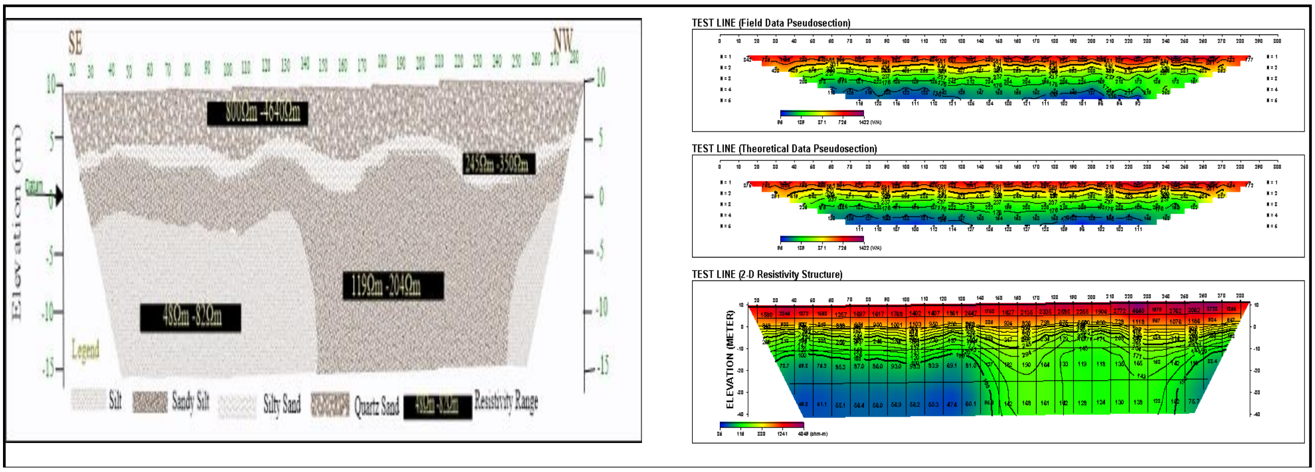

Fig 7: 2D Geoelectric and Lithological sections along profile 2

4.2 DISCUSSION

The 2-D resistivity structures can be logically discussed from both vertical and lateral (variation) perspectives for lithology and facies inferences. Vertically, the probed shallow sequence comprises three recognizable strata which from top to base are; quartz sand, the hybrid layer of folded silty sand and sandy silt, and silt. Generally, the investigation of the basin is a sand-dominated sequence that towards the regional river contains an appreciable increase in silt content at the base of the sequence. Facies analysis from lateral lithological contrast reveals a fluvial environment of deposition. Lateral interposition between the silty sand and sandy silt reflects the sediment transport mechanism along the concealed abandoned channel bar as the velocity of the meandering streams drops abruptly at its lower course.

This periodic compositional variation can be closely linked with the physical and chemical processes prevailing during the time of deposition. From an economic viewpoint, the upper quartz-rich sand deposit is the most commercially viable in the sequence as it serves as an essential raw material for a wide range of industrial uses.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

Subsurface stratification and reformative style of the studied siliciclastic deposits have been revealed through the Electrical Resistivity Tomography geophysical method. The depositional environment of this symmetrically folded stratum is inferentially believed to be a fluvial setting along the lower course of the buried meandering stream channel. Wenner configuration was adopted for the two (2) electrical resistivity imaging surveys using a profile length of 300m each, at an electrode separation interval of 10m for the first index. Repeated measurements were executed at a multiple electrode spacing interval of 20m, 30m, 40m, and 50m for the second, third, fourth, and fifth index respectively. Electrode spread movement was however kept fixed at 10m.

A range of three (3) to four (4) geo-electric strata was generated along the first and second profiles respectively. The resistivity range, from the top to the base of the sequence, along the first profile is 932Ωm – 3343Ωm and 369Ωm – 470Ωm / 207Ωm - 354Ωm inferred as quartz-rich sand and two-fold distinguishable silty sand strata (exhibiting a progressive increase in silt content with depth) respectively. The thickness range of quartz sand is 4m – 8m while that of the folded upper and lower silty sand extends to infinity. Along the second profile, the resulting 2-D resistivity structure also depicts a descending trend of resistivity variation which from top to base, delineated geo-electric strata with a resistivity range of 800Ωm – 4640Ωm inferred as sand, 245Ωm – 350Ωm corresponding to silty sand, 119Ωm - 204Ωm as sandy silt and between 48Ωm - 82Ωm for silt. In the aforementioned order, thickness ranges between 5m – 7m, 1m – 2m, 4m – infinity, and out rightly undeterminable for the last probed layer. The wavy undulations depicted on the 2-D resistivity structures are structurally interpreted as minor symmetrical folds. Facies analysis from lateral lithological contrast reveals a fluvial environment of deposition. Lateral interposition between the silty sand and sandy silt reflects the sediment transport mechanism along the concealed abandoned channel bar as the velocity of the meandering streams drops abruptly at its lower course. Concerning the aforementioned interpretations, the investigated sequence is wholly composed of siliciclastic strata deposited under fluvial conditions, symmetrically folded with an average silica thickness of 6m.

5.2 CONCLUSION

This study involves mapping the subsurface lithology and reformative style of the siliciclastic deposits lengthwise the Igbokoda coastal area, easten dahomey basin

Southwestern Nigeria, using the Electrical Resistivity Tomography geophysical method. The resulting two-dimensional (2-D) resistivity structure depicts a descending trend of resistivity variation which from top to base, delineated geo-electric strata with a resistivity range of 800m - 4640m inferred as sand, 245m-350m, corresponding to silt, 119m to 204m as sandy clay, and between 48m and 82m for sandy clay. The stratigraphic and structural styles of the siliclastic sequence provide a reliable template and control for the optimum mining of silica sand along the investigated section of the eastern Dahomey basin. Vertical and horizontal variations of strata and facies were imaged and interpreted. This revealed the effects of folding episodes within the strata, which could be a pointer for petroleum prospecting in future

5.3 RECOMMENDATION

A robust geological approach, integrating complementary geophysical techniques (Vertical Electrical Sounding and Seismic refraction) and geochemical analysis can be further employed for greater precision of estimation, quartz content determination, and facies analysis.Dredging of this highly-priced depositcould be done in line with best practices which include absolute compliance with constituted mining rules and regulations, reclamation of the exploited area, initiation and sustenance of environmental impact assessment program, and prompt tax disbursement among others.

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