Application of azimuthal Schlumberger-resistivity survey in Southeastern Nigeria.

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ABSTRACT

Southeastern Nigeria was divided into four geologic basins namely: the Niger delta, Proto-delta, Anambra and the Abakaliki basins. These basins were subsequently divided into grids cells of 100km^2 areas and in each cell, azimuthal Schlumberger electrical survey was carried out to determine the degree of electrical anisotropy related to the structural texture and degree of tectonism. A maximum electrode expansion of AB/2 = 100m and MN/20m were employed and the maximum depth penetrated was 33m, which is appropriate for the investigation of geological and structural hazards related to electrical anisotropy in the basins. Results indicate that the basins are electrically anisotropic, probably due to bedding laminations, aligned mineral grains, grain boundary cracks and fractures in preferred directions. The Niger delta basin has the least mean coefficient of anisotropy of 1.05, percent anisotropy of 10.50%, and highest mean resistively of 4160.38Ωm; while the Abakaliki basin has the highest coefficient of anisotropy of 1.14, percent anisotropy of 24.66%, and least mean resistively of 55.50Ωm. The decrease in the coefficient of anisotropy and percent anisotropy with increased electrode expansion within each basin and the relatively low values of the coefficient of anisotropy in the basins imply that, these structures are less penetrative and as such, the basins are likely to be less intensely fractured and fairly homogeneous. The Niger delta basin is the most homogeneous, while the Abakaliki basin is the least homogeneous. The principal anisotropic axes lies in the NW-SE in the Niger delta and NE-SW in the other basins. These revelations will be of immense benefit to civil engineers, environmental and engineering geophysicists.

INTRODUCTION

Southeastern Nigeria encompasses the southern flank of the lower Benue valley comprising the Abakaliki, Anambra, and Proto-Delta basins, respectively, and the adjacent parts of the Niger Delta basin. It is a sedimentary basin sandwiched between the Precambrian crystalline basement complexes of Western Nigeria and the Cameroon-Oban Massif in the East. It is bordered by the Cross and Niger rivers drainage systems in the East and West, respectively, the Atlantic Ocean to the south, while the Anambra and Imo drainage systems with their tributary rivers drains it centrally (Fig. 1).

The region is characterized by geological hazards such as landslides, flooding, and gully erosion. Indiscriminate sitting of dump sites, scarcity of portable drinking water, outbreak of water borne diseases, poor road networks, cracks on the walls of private and public buildings, and in some cases, collapse of civil structures are evident in the region. These present environmental, economic and health problems that must be addressed by the relevant government agencies. This is to protect the life and property of its citizens and preserve the environment from total degradation.

Sedimentary rocks are generally weak. less competent, and highly susceptible to deformational stresses due to tectonics and the weight of the overlying sediments. They are characterized by stratified layers and beds, aligned mineral grains, rock constituents and fractures aligned in preferred direction. These structures are mechanical discontinuities which allow the propagation of stress and hence deformations parallel to their axes.

Recent investigation in petroleum and ore prospecting, geological and geotechnical studies in the region reveals that these sedimentary deposits exhibit directional dependence in their physical properties. This quality of variation of physical property in a body with direction is termed anisotropy (Nengi and Saraf, 1989). It is a common feature of sedimentary formations in the region This occur due to preferred orientation of mineral grains and fractures, compositional bedding laminations, micro cracks and weathering in accordance with the prevalent tectonic regime. These cause essential changes in the physical properties (resistivity, density, elasticity, porosity and water saturations) of component rocks. Other causes of anisotropy are dipping interfaces and gradational lateral variation in physical properties which are regarded as pseudoanisotropic lateral effects (Watson and Barker, 1999).

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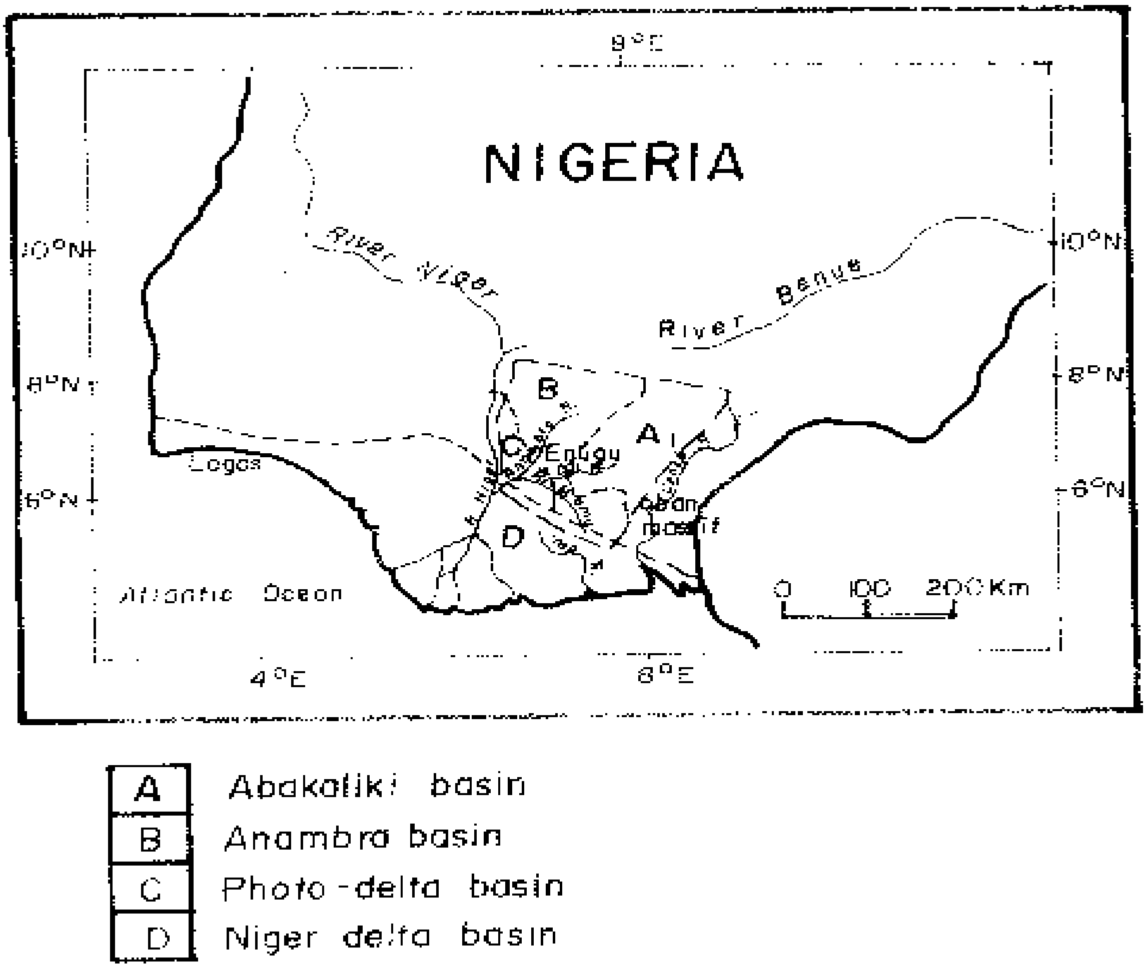

Fig.1. Location Map of Study Area (Southeastern Nigeria)

These are however, subordinate to the main causes of anisotropy in the region.

These sedimentary formations show endless variation in electrical resistivity within and across lithologic layers. The series and parallel connections due to these structures lead to change of resistivity with direction of current flow, that is, electrical anisotropy. Electrical anisotropy is not a constant quantity in nature, but depends upon the past and present state of stress of the rock mass which is a function of tectonism. it is a measure of the structural texture and strength of rocks. which undoubtedly varies in space. It is of interest to the Civil Engineers, Hydra geologists, Environmental and Engineering Geophysicists. This is because anisotropic parameters such as mean resistivities, strike of the principal anisotropic axes, and anisotropic coefficients are closely related to the stress levels and underground geological structures (Changchun and Greg, 2001). The determination of these parameters indirectly measures the magnitude and orientation of stresses, degree of deformations, and the strength of rocks in the investigated medium. Thus, the determination of electrical anisotropy provides structural information on the direction and strength of anisotropies in rocks. This could guide the choice of a site for a particular civil structure. It could also help to forecast geological hazards (gully erosion, landslides ete). leakage possibility, ground water flow pattern and the past and present degree of tectonism in the region.

Measurement of electrical anisotropy is carried out using azimuthal electrical Schlumberger survey. This provides a useful geological technique to map anisotropy in buried sedimentary formations. Rotating the linear array of electrodes allows the detection of possible directional variations of electrical resistance which could reflect an anisotropic response. Varying the measurement by azimuth constrains the symmetry of anisotropy and different current- potential separations explore various depths of investigation.

Azimuthal geoelectric survey have been employed by Bhattacharya and Patra (1968), Taylor and Fleming (1988), Skjernaa and Jorgensen (1993). Watson and Barker (1999). Busby (2000), Gaylord and Carlson (2001), Bradley and Weimer (2002), and Bragin et al (2005) in the determination and characterization of electrical anisotropic patterns in the subsurface.

This study is the first of its kind in the region aimed at determining the degree of tectonism, structural texture, and strength of Cretaceous to Recent sediments in the region. It could also be used in the determination of the direction of electrical anisotropies and hence ground water flow paths. These properties are characterized with respect to electrical anisotropic parameters viz:

Mean resistivities. orientation of the principal anisoiropic axis and the anisotropic coefficients.

Geology of the study area

Geologically, the study area is underlain by Precambrian crystalline basement rock which is predominantly gneisses, migmatites, and schist. These forms the basement on which the sediments of the trough and the adjacent parts of the Niger delta are deposited (Fig.2). Some igneous rocks are also emplaced in the earlier Cretaceous sediments of the trough. The origin and formation of the Benue valley and the adjacent Niger delta sedimentary basins have been discussed by numerous authors (Burke *et al*, 1970. Nwachukwu, 1972 and Hospers, 1965).

The sediments of the basins exhibit spatial variability in composition and texture. The formation types are predominantly thin beds of sandstones alternating with thick beds of shale in the entire geological column. Thin lenses of limestone, mudstones, lignite, coals. and granitic associations are prevalent (Murat, 1970).

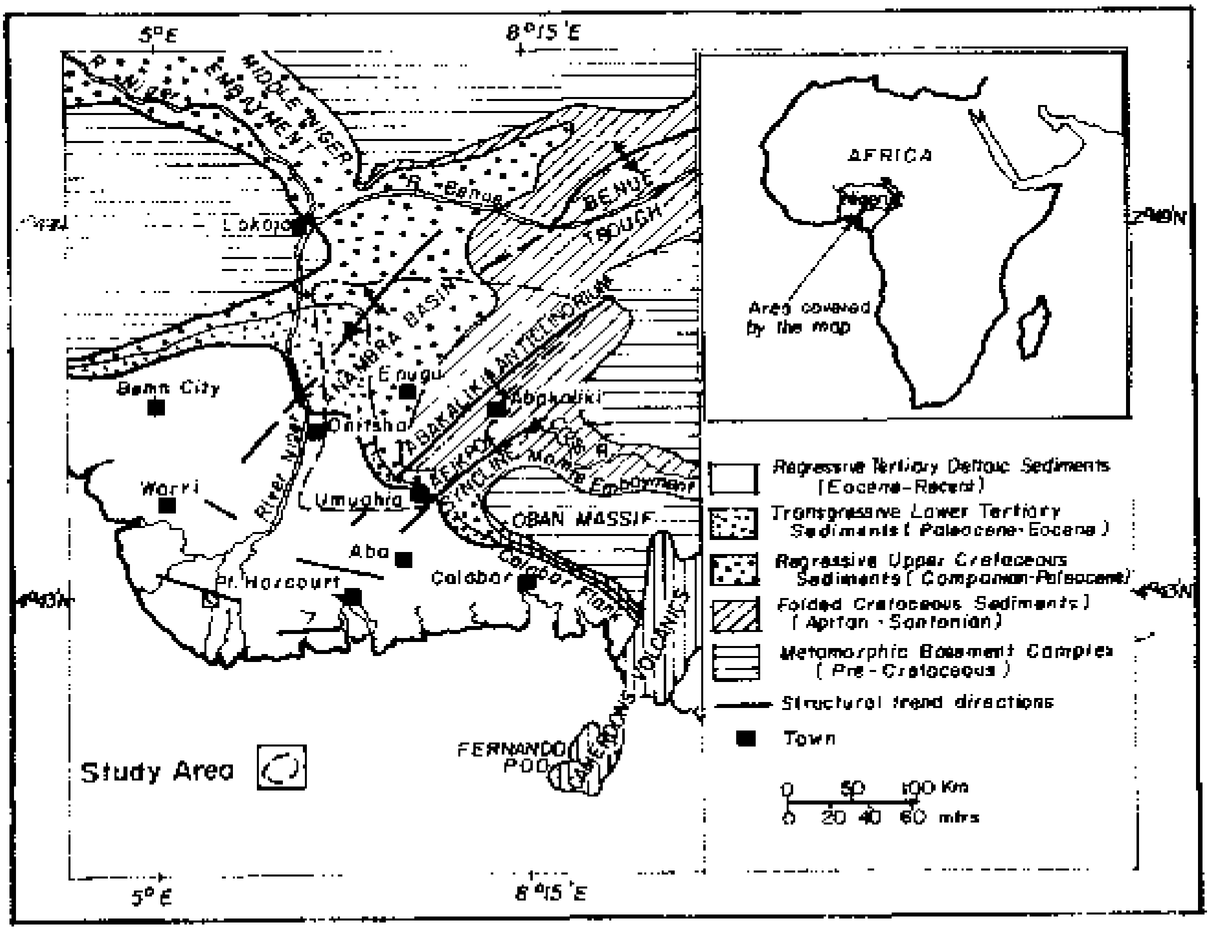

Fig.2. Geological Map of Southeastern Nigeria (adapted from Murat, 1970)

Structurally, the sediments are characterized by numerous faults which are consequences of the formation of the trough and reorganization of plate motions during the Santonian. These structures propagate through the connections established along the oceanic fracture zones and their continental counterpart that paved the way for the formation of the Niger delta. The sediments are disrupted by two principal fault systems, and their associations. These are echelons, high angle transform faults which strikes in the NE-SW and NW-SE axes, respectively, in the entire basins. These fracture systems form discontinuities and zones of weaknesses through which Stress are propagated. The presence of these structures undoubtedly, affects the integrity and hence the strength of subsurface rocks in these basins.

METHODOLOGY

The entire study area was divided into four geologic basins namely, the Niger delta, Proto-delta., Anambra and Abakaliki basins, respectively. Each belt was further divided into grid cells of 100km^2 area to facilitate the acquisition of data within each basin.

Azimuthal electrical surveys were conducted with a digital readout ABEM Teremeter SAS (signal average system) 300B, in each grid cells of the basins, using the Schlumberger electrode array with non-polarizable stainless steel electrodes. The array with AB/2 distances ranging between 20- l00m and MN/2 distances ranging between 3-20m, were rotated about a central point on the earth surface. Measurements were made with reference to the center of the array at *450* increments (0°, 45^0, 90°, 135°), denoting measurements in the N-S. NE-SW, E-W, and NW-SW azimuths, respectively. The maximum depth of penetration is 33m, which is appropriate for the investigation of geologic hazards, structural texture and strength of rocks related to electrical anisotropy.

To minimize the discrepancies that might arise in the relative values of the apparent resistivity data obtained from the basins during different seasons of the year, apparent resistivity data were acquired using the same electrode expansions at the same time of the year through out the basins. Topographic and other structural effects were avoided by either abandoning the survey or shifting measurements by about I0-30m from the main traverse lines. A total of fifty (50) sounding points were occupied and variations of apparent resistivity with azimuth were noted in each grid cells of the basins.

RESULTS

The apparent resistivity data from field measurements in each of the grid cells having the same electrode expansion and azimuth were stacked to determine the average apparent resistivity in each of the four geological basins. This singular act and the analytical equation adopted from Skjernaa and Jorgensen (1993) remove pseudo - anisotropies and other lateral effects from the observed data and improve data quality comparable to local geology.

The result shows a significant variation of ρa(Ω m) for different azimuthal directions and electrode expansions in each geological basin (Table 1).

These apparent resistivity data were analyzed analytically and plots of resultant anisotropic figures (RAFs) were obtained (Fig.3). The polar plots (RAFs) are elliptic, implying that the ground is anisotropic (Busby, 2000). The presence of more than one fractured strike is depicted by a multiple-peak pattern in the polar plots. The dominant or principal fracture direction is interpreted to be perpendicular to the direction of minimum resistivty (Skjemaa and Jorgensen, 1993). From the analysis of these RAFs. the anisotropic parameters were computed for each of the basin (Table 2).

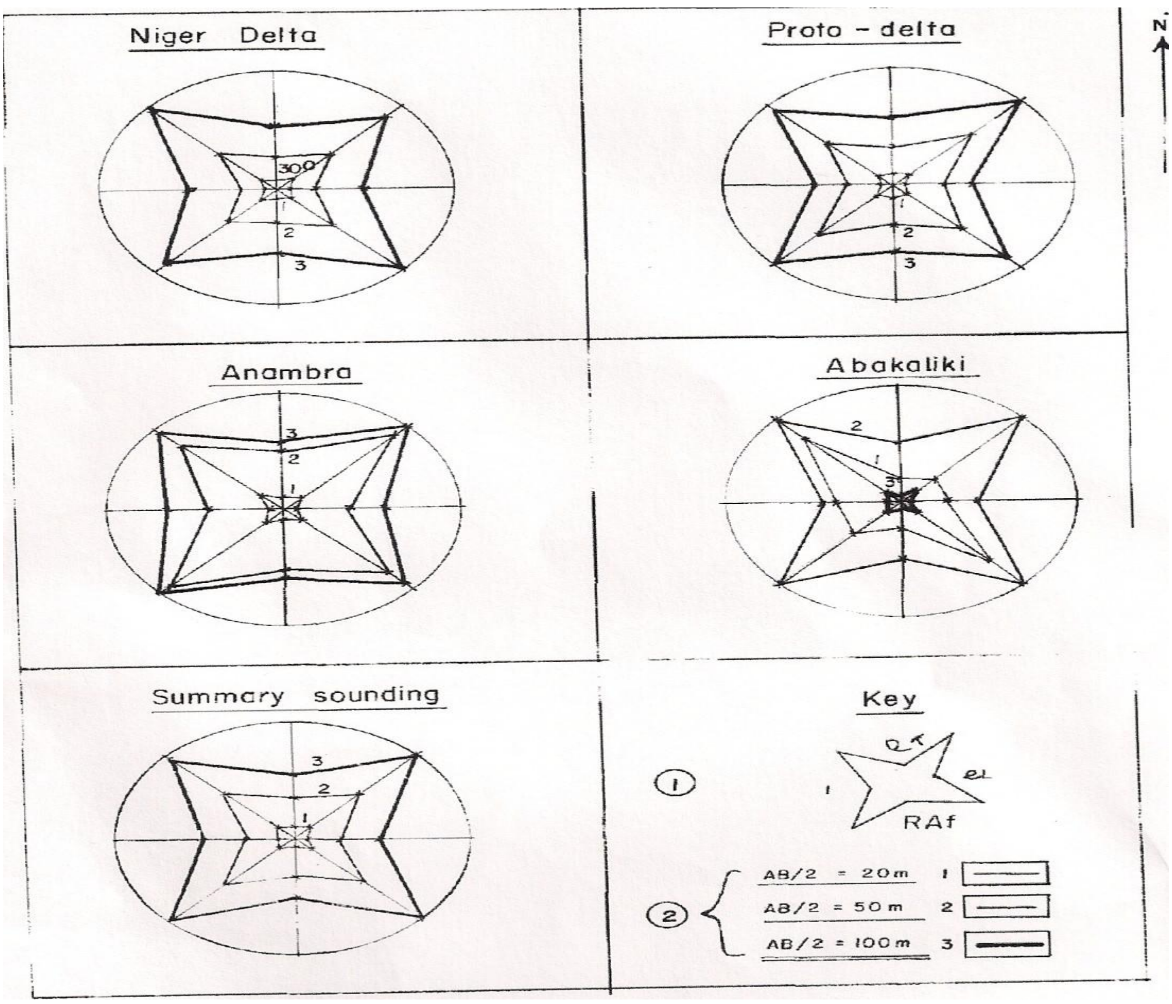

Fig.3. Representative RAF's of the Besin

Table 1. Numerical presentation of apparent resistivitydata (Ωm)

Geological basin	AB/2(m)	N-S	NE-SW	E-W	NW-SE
Niger Delta	20	101.98	124.27	91.18	110.78
	50	3595.18	3696.18	2683.30	4092.82
	100	6769.40	8038.27	5947.24	8934.13
Proto-delta	20	52.90	50.17	34.64	42.78
	50	2081.31	2643.64	1688.34	2090.00
	100	3495.55	4211.25	2666.67	3848.51
Anabra	20	60.78	64.17	49.94	79.43
	50	3467.21	4291.29	2791.10	3578.38
	2	3590.80	4866.92	4246.81	4366.88
Abakaliki	50	36.86	39.55	48.17	71.57
	50	72.45	100.28	61.47	95.00
	100	8.37	16.69	9.36	14.77
Summary sounding	20	63.13	69.54	55.98	76.14
	50	2304.04	2643.60	1806.05	2503.30
	100	3466.08	4291.55	3215.03	4282.80

Table 2. Numerical presentation of apparent resistivity data (Ωm)

Geological basin	AB/2	Longitudinal Resistivity ρ (Ωm)	Transverse Resistivity ρ (Ωm)	Coefficient of Anisotropy λ	Percent Anisotropy	Mean Resistivity ρ (Ωm)	λe	Percent average anisotropy	Principal anisotropic axes
Niger Delta	20	110.78	124.27	1.06	11	4160.38	1.05	10.50	NW-SE
	50	3696.18	4092.82	1.05	10				
	100	8038.27	8934.13	1.05	10.50				
Proto-delta	20	34.64	52.90	1.24	41	2139.73	1.13	24.33	NE-SW
	50	2090.00	2643.64	1.12	23				
	100	3848.51	4211.25	1.04	9				
Anambra	20	64.17	79.43	1.11	21	2866.73	1.08	16.66	NE-SW
	50	357838	4291.29	1.09	18				
	2	436688	4866.92	1.05	11				
Abakaliki	50	3955	71.57	1.34	57	55.50	1.14	24.66	NE-SW
	50	95.00	100.28	1.02	5				
	100	14.77	16.69	1.06	12				
Summary sounding	20	69.54	76.14	1.04	9	2310.81	1.02	4.73	NE-SW
	50	2503.30	2643.60	1.02	5				
	100	4282.80	4291.55	1.00	0.2				

The result of the analysis reveals that the anisotropic parameters vary from one geologic basin to the other. The decrease in the relative values of the anisotropic coefficient and percent anisotropy with increasing electrode expansions and the variations in the trends of the principal anisotropic axes in the respective basins are obvious from these results.

The mean coefficients of anisotropy, mean resistivities. and percent anisotropies varies from 1.05 - 1.14, (55.50 - 4160.38) Ωm, and (10.50-24.66) **%,** respectively, while the principal anisotropic axes predominantly lies in the NE - SW and NW - SW, respectively, in the entire basins.

The Niger delta basin has the least mean coefficient of anisotropy of 1.05 and a percent anisotropy value of *10.50%*. It has the highest mean resistivity of 4160.38 Ωm, with a NW - SE predominant principal axis. This is followed by the Anambra basin with a mean coefficient of anisotropy 1.08 and a percent anisotropy value of 16.66%. The mean resistivity of the Anambra basin is 2866.73 Ωm, with a NE - SW principal axis. The Proto -delta basin has a mean coefficient of anisotropy 1.13 and a percent anisotropy value of 24.33%. The mean resistivity value of this basin is 2139.73 Ωm, with a NE - SW principal axis. The Abakaliki basin has the highest mean coefficient of anisotropy of 1.14 and a percent anisotropy value of 24.66%. The Abakaliki basin has the least mean resistivity of 55.50Ω m, with a NE - SW principal axis. Finally, the summary soundings of Southeastern Nigeria depicts a mean coefficient of anisotropy, percent anisotropy and mean resistivity values of 1.02, 4.73% and 2310.81Ωm. respectively , while the principal anisotropic axis lies predominantly in the NE-SW directions. These results correlate to known structures and the local geology in the basins.

DISCUSSION

The relative values of the anisotropic parameters viz: Mean resistivity, Coefficient of anisotropy and Principal anisotropic axes obtained in each of the respective basins, reveal that the basins exhibit some degree of electrical anisotropy. The electrical anisotropy in the basins are probably due to compositional bedding laminations, aligned mineral grains and fractures in preferred directions, and grain boundary cracks. The extent of these structures is related in part to the origin, depth of burial and age of the sediments in the basins. They substantially alter the stress response and hence the strength and integrity of subsurface rocks. The stresses are due to the weight of the overlying column of rock and to the relative movement of the large rock mass in the crust and upper mantle. It propagates along the principal anisotropic axis and forms the locus of all deformation mechanism in subsurface rocks.

The most striking feature of the results in this study is the decrease in the coefficient of anisotropy and percent anisotropy with increase in electrode expansion. This is suggestive of the fact that these anisotropic structures are less penetrative, probably due to healing. This healing may be the result of the weight of the overlying sediments or tectonics associated with the basins at depth, which results in decreases in anisotropic coefficient with depth. The oldest and deeper beds of the Abakaliki basin have the highest mean coefficient of anisotropy and percent anisotropy values, with least resistivity. The Anambra basin has a low mean coefficient of anisotropy and percent anisotropy values, with a high resistivity, which probably is associated with facie changes in the sediments. Proto - delta basin has an abnormally high mean coefficient of anisotropy and percent anisotropy values, with a moderate resistivity. This abnormally high mean coefficient of anisotropy and percent anisotropy values are probably related to the variability in lithology and shale tectonics at depth. The most recent and shallower Niger delta basins exhibit the lowest mean coefficient of anisotropy and percent anisotropy values, and highest mean resistivity. The summary sounding has a low mean coefficient of anisotropy, percent anisotropy, and minimum resistivity. The relatively low values of coefficient of anisotropy in the basins suggest that the basins are likely to be less intensely fractured and fairly homogeneous.

It thus follows on the basis of the relative values of the anisotropic parameters that the Niger delta, Anambra, Proto-delta, and Abakaliki basins are less intensely fractured and fairly homogeneous in that order, in accordance with Habberjam's *(1965)* anisotropic classifications. The summary sounding results indicate a stable, homogenous and fairly tectonised sub region in Nigeria. This is in agreement with the local geology. The coefficient of anisotropy has been shown to have the same functional form as permeability anisotropy to a first order (Bespalov et al, 2002). Thus, a higher coefficient of anisotropy implies higher permeability anisotropy. This revelation has both environmental and engineering implications. The occurrence of geologic hazards, failure of civil structures, leakage possibility and contaminant transport, associated with these structures are concentrated within 33m depth of the subsurface. It thus follows from these results, that engineering and environmental considerations be adopted in the control of these hazards and design of civil structures in basins having high anisotropic coefficients.

These results are in agreement with the local geology and tectonic histories of the basins. The study area consists of predominantly alternating sequence of sandstones and shales deposited from the early Cretaceous to Recent Tertiary sediments in line with the prevailing tectonic regime in each basin. These regimes were accompanied by the proliferation of structural lineaments in the basement, which were subsequently accentuated in the overlying sediments (Wrights, 1981, Murat, 1970). The principal anisotropic axes lies in the NW-SE in the Niger delta and NE-SW in the other basins in accordance with the paradox of anisotropy (Bhattacharya and Patra, 1968, Keller and Frischinecht, 1988). The summary sounding result show a principal anisotropic axis oriented in the NE-SW. These results are related to the ground water flow paths (which controls leakage possibility and contaminant transport), and Neo- and Paleo-stress directions, respectively in the basins. These revelations however, could guide the Civil Engineer, Environmental and Engineering Geophysicist in the design and choice of any site for civil structures in each of the basins to avoid cracks and eventual collapse of such structures. It could also guide in ground water exploration, leakage possibilities, contaminant transport, and prevention of other geological hazards (landslides and gully erosion) in the basins.

CONCLUSION

Azimuthal Schlumberger electrical surveys were conducted in four geologic basins namely; The Niger delta, the Proto-delta, Anambra and Abakaliki basins, to determine the degree of electrical anisotropy related to the structural texture and degree of tectonism in each basin. Results indicate that the basins are electrically anisotropic. The electrical anisotropy in the basins are probably due to bedding laminations, aligned mineral grains and fractures in preferred directions, and grain boundary cracks. These substantially alters the stress response and hence the strength of subsurface rocks. The extent of these structures is related in part to the origin, age and depth of burial of the sediments in the basins. The magnitude of the anisotropic coefficients and percent anisotropy decreases with increase in electrode expansion. This is suggestive of the fact that these anisotropic structures are less penetrative and their effects decreases with depth, probably due to healing as a result of the weight of the overlying sediments, or tectonics associated with the basins at depth. These structures are concentrated within 33m depth of the subsurface which are related to the local tectonics of the basins.

The older and deeper beds of the Abakaliki basin has the highest anisotropic coefficient, percent anisotropy and least mean resistivity, the Anambra basin has moderate anisotropic parameters, the Proto-delta basin exhibits an abnormally high mean anisotropic coefficient, percent anisotropy and moderate mean resistivity relative to its age and depth of' burial. This is adduced to the variability in lithology, structure and shale tectonics, while the most recent and shallower Niger delta basin exhibit low anisotropic values and highest mean resistivity. The relatively low values of the anisotropic coefficients in the basins suggest that the basins are likely to be less intensely fractured and fairly homogeneous.

It thus follows on the basis of the relative values of the anisotropic parameters that the Niger delta, Anambra, Proto-delta, and Abakaliki basins are less intensely fractured and fairly homogeneous in that order, in accordance with Habbeilam's (1965) anisotropic classifications. The summary sounding results indicate a stable, homogenous and fairly tectonised sub region in Nigeria.

The principal anisotropic axes lies in the NW-SE in the Niger delta and NE-SW in the other basins. This determines ground water flow paths, which controls leakage possibilities from dump sites and contaminant transport. It is also related to Neo-and Paleo- stress directions. Finally, these revelations are of immense benefit to Civil Engineers, Environmental and Engineering Geophysicist, in the design and choice of any site for civil structures, ground water exploitation and production, sitting of waste dumps, control of contaminant transport and prevention of geological hazards in the basins.

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