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Delineation of Active Fractures in a Gully Erosion Area Using Geophysical Methods: Case study of the Okigwe - Umuahia Erosion Belt, Southeastern Nigeria.

ONU, N.N[1], OPARA, A. I[1], EHIRIM, C.N[2]
[1] Department of Geosciences, Federal University of Technology, Owerri, Nigeria
[2] Department of Physics, University of Port Harcourt, Nigeria

ABSTRACT

The Okigwe-Umuahia Erosion Belt, Southeastern Nigeria is characterized by severe gullies and occasional landslides. The present study was then designed to delineate the linear structures associated with the area and to evaluate the structural and tectonic trends in the study area using electrical anisotropy and drainage lineament analysis. The study area was divided into grid cells measuring 10 x $10km^2$ and within each grid cell, azimuthal resistivity soundings and drainage lineament analysis were carried out. Similarly, vertical electrical soundings were carried out using Schlumberger array to a maximum current electrode spacing of 1000m. The azimuth-frequency diagrams and the anisotropy figures revealed that, generally NE-SW and NW-SE trends are preponderant over other trends in the study area. Results revealed that the axes of maximum electrical anisotropy correlated well with the measured strikes of the geologic formations and the azimuth-frequency diagrams obtained from drainage lineament analysis. Similarly, there exists a relationship between the drainage density, depth to the water table and the coefficient of anisotropy. Higher coefficients of anisotropy (1.31-1.79) were obtained at locations where drainage density and depths to water table are high (0.27 – 0.47 and 160 – 194m respectively). The correlation of high coefficient of electrical anisotropy and drainage density values with deep gullies suggest that the network of fractures in the area serves mainly as channels for surface runoff, rather than zones of groundwater infiltration. This may also account for accelerated removal of surface materials leading to gully initiation.

Keywords: *Active fractures, Structural trend, Gully erosion, Nigeria, azimuthal resistivity, tectonic.*

1. INTRODUCTION

Many hypotheses have been proposed to account for gully initiation and propagation in southeastern Nigeria. Qualitative and semi-quantitative studies of the geomorphic processes [1], attributed gully initiation and propagation in the study area to mainly anthropogenic factors and this had a strong bias towards the control measures put in place to check gullying activities in the area. Several studies on gully erosion characterization [2-4] confirmed that while human activities such as pattern of land use, socio-economic pressure on land, poor engineering and agricultural practices have contributed to the initiation and growth of gullies, the geological, hydrogeological and geotechnical characteristics of the area, and the inherent properties of the soil are the main factors influencing gully genesis and rate of growth. A close study of the geologic map of southeastern Nigeria indicates that erosion gullies in this sub-region are concentrated within a broad area described in this study as the "gully erosion belt". This belt is situated at the southern flank of the lower Benue Trough (fig. 1) and runs from Onitsha through Awka (Ekwulobia, Agulu, Nanka, Mbaukwu) and Orlu (Njaba, Amucha, Okwudor and Umuagu Urualla) to Umuahia-Okigwe(Ishikwuato) axis.

The present study was carried out in Umuahia-Okigwe area which includes the area enclosed by latitudes $5^0 00^1$ to $6^0 00^1$N and longitude $7^0 00^1$ to $8^0 00^1$E (fig.1 & 2). The major towns and communities found within the study area include Afikpo, Okigwe, Abiriba, Bende, Arochukwu and Umuahia. The communities are connected by a network of motorable roads and track roads, which were used as traverses for the geophysical data acquisition.

The study area is characterized by severe gullies and sheet erosion, believed to be surface expressions of deep seated basement structures [3-4]. In hard rock terrain, weathering concentrates along a line of structural weakness such as faults, fracture zones and dykes which are mappable in the field and which often show up as linear features on satellite imagery, generally referred to as "lineaments". In a sedimentary setting, lineaments are concealed under thick sedimentary cover and are therefore not easy to map in the field. Lineaments interpreted from remote sensing data correspond to anything from minor drainage features or individual features to large valleys representing major fracture zones. Fracture zones in the subsurface are major conduits for water movement, especially in rocks with low porosity or lacking in primary porosity. Because of the analogy between Darcy's law of fluid flow and ohm's law for electric current flow, it is possible to determine the direction of the fracture plane from electrical resistivities measured as a function of azimuth [5-7] .

The objective of this study therefore was to evaluate the fracture system in Umuahia and its environs

using the azimuthal resistivity sounding techniques as well as lineament density analysis, and to deduce from it, the tectonic trends in the study area. Inference will then be made on the control of drainage, topography, groundwater

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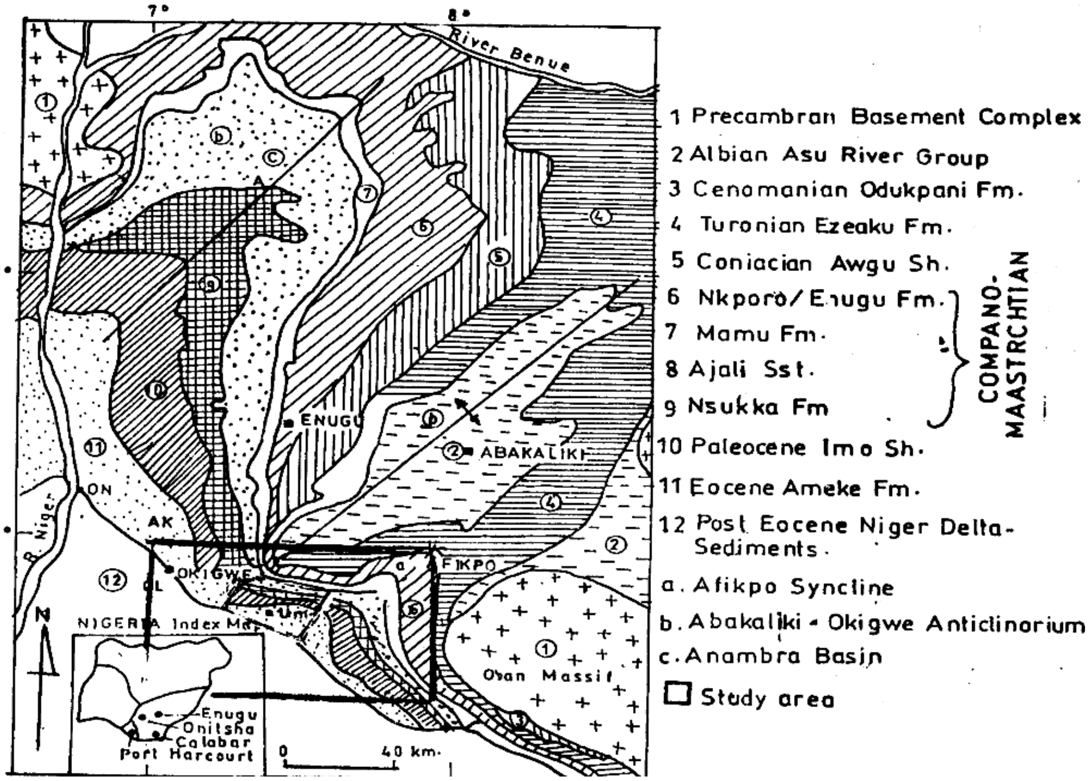

Fig.1: Geological map of southeastern Nigeria. The inset shows a sketch map of Nigeria. Locations and neighbourhoods mentioned in the text are also indicated as follows: (On) = Onitsha, (Ak) = Awka, (Ol) = Orlu, (Um) = Umuahia

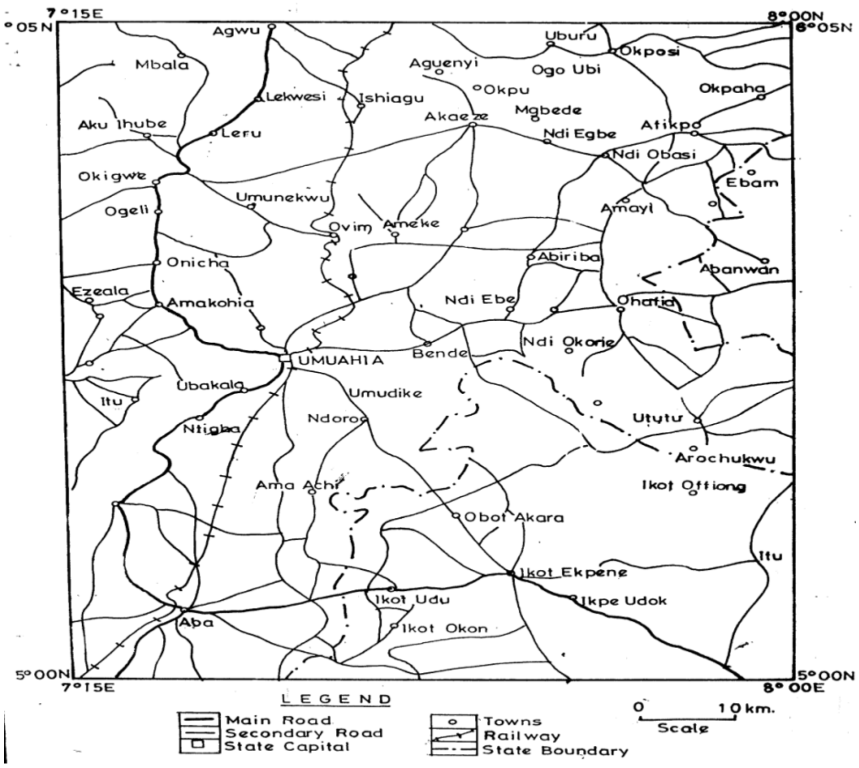

Fig. 2: Location map of the study area showing access roads and important communities where azimuthal soundings were carried out

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potentials, gully erosion and landslides in the area as a consequence of these tectonic features.

2. CLIMATE, PHYSIOGRAPHY AND GEOMORPHOLOGY

The topography of the study area is generally gently undulating and punctuated by a few low hills, some of which are relics of sandstone and siltstone deposits that are more resistant to denudation than the surrounding shales. The relief ranges from 75m on the hills to 30m on the adjoining lowlands and valleys. Major rivers in the area include Imo, Cross, Asu, Ivo Eze-Aku, and other smaller streams (fig.3). Most of the rivers and streams are ephemeral and dry up after the cessation of rainfall. The Imo and Cross rivers are perennial and have large discharges even in the dry season. The rivers rise generally in the southwest flowing northeast ward and finally join the Imo and Cross Rivers which discharge into the Atlantic Ocean. The drainage pattern is dendritic (fig.3), and defined by irregular branching of tributary streams. The study area lies in the rain forest and savannah vegetation zones typified by an almost continuous cover of thick forest and grasses with tall trees concentrated along stream valleys. Tilling, in most cases, for agriculture and road construction, has resulted in fine climax vegetation, an ecological situation where the normal development of vegetation is markedly retarded.

The climate of the area consists of dry and wet months. Rainfall regime is rather simple and runs intermittently from May to October and sometimes to November. The mean annual rainfall ranges from 1500 to 2800mm.This is followed by dry months characterized by the harmmattan which lasts from November to February.

2.1 Geology of the Area

The study area lies within the southern Nigeria sedimentary basin at the southern flanks of the lower Benue Trough. The sequence of events that led to the formation of the Benue Trough and its component units are now well documented [8-9]. The study area is underlain by thick sequence of sedimentary rocks ranging in age from Cretaceous to Recent. These include the Asu River group (Albian), Ezeaku Shale (Turonian), Agwu Shale (Campanian), Nkporo Shale (Campanian), Mamu Formation, Ajali Sandstones, Nsukka Formation (Maastrician), Imo Shale (Paleocene), Ameki Formation (Eocene), and the Benin Formation (Miocene to Recent). Fig.4 shows the geological map of the study area with the various formations numbered in an order that reflects their decreasing age.

The Benin formation is the youngest in the lithologic sequence of the area. The formation consists of over 90% sandstone with shale intercalation. It is coarse grained, gravely, poorly sorted, sub-angular to well rounded and bears lignite streaks and wood fragments. The thickness is variable but generally exceeds 1829m.The Ameki Formation was deposited during the Eocene. It consists of a series of highly fossilferous grayish green sandy-clays with calcareous shale and white clayey sandstones. The formation displays rapid lateral facies changes and may locally show shaly development or inclusions of white and mottled clay stone and sandstone [10].

The Imo Shale was deposited during the Paleocene and consists of thick blue grey shales with thin sandstones, marls and limestone with occasional admixture of clay iron stone. This formation shows lateral variation into sandstone in places. These arenaceous lateral equivalents are the Igbabu, Ebenebebe, and Umunna sandstones. Nsukka Formation was deposited during the Upper Maastrician. The Formation consists of alternating succession of sandstones, dark shales, and sandy shale, with thin coal seams at various horizons. The Ajali Formation was deposited during the Maastrician. This formation was previously known as the “False Bedded Sandstones” and consists of thick friable, poorly sorted sandstones, typically white in colour but sometimes iron stained with white thin bands of mudstone and shale occurring at intervals. The Ajali Formation is often overlain by a considerable thickness of red earth, which consists of red, earthy sands, formed by the weathering and ferruginization of the formation[11]. Mamu Formation was deposited during the Maasstrician and was previously known as the “Lower Coal Measures”. The formation consists of sandstones, shales, mudstone and sandy shales, with coal seams at several levels.

The Agwu - Ndeaboh Shale was deposited during the Coniacian and consists of bluish grey, well bedded with occasional intercalation of fine grained sandstone and thin often marly shalely limestones. The formation is folded and terminated by a discontinuity due to post tectonic regression. The Santonian tectonics was accompanied by igneous activity such as the intrusions and extrusions of basaltic magmas [10]. Nkporo Shale group was deposited during the Campanian. The group consists of blue-to-dark grey friable shales with occasional thin beds of limestone and sandstones. These formations rarely outcrop and information about them comes mainly from boreholes and they exhibit frequent sharp facies changes. The Owelle /Afikpo sandstone and Enugu-Asata Shales are lateral equivalent of Nkporo Formations and unconformably overlie older folded beds. It (Nkporo Shale) has a thickness of about 1000m [12].

The Eze-Aku Shales consists of hard grey and black calcareous shales, limestone and siltstones. Locally, the shale grade into sandstones (Amasiri sandstone near Afikpo, and Shalely limestone in Nkalagu area). The formation is strongly folded and distributed by faulting (Simpson, 1955). Asu River Group is the oldest in the lithologic sequence of the study area, and the oldest sediment in southern Nigeria. The sediments consist of rather poorly bedded sandy shales known as Abakiliki Shales with sandstones (Awe sandstone) and limestone lenses (Mfamosing limestone). The limestone beds can attain a thickness of 30m in some places. The sediments are associated with lead-zinc mineralization and intrusive bodies [10,13].

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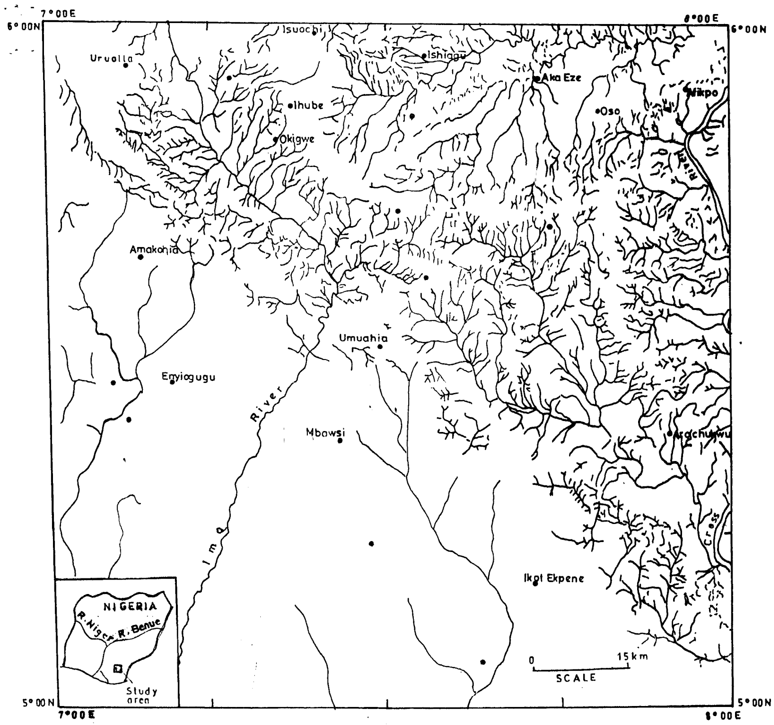

Fig 3 :

Fig.3: Drainage map of the study area. The drainage is defined by irregular branching of Tributary streams

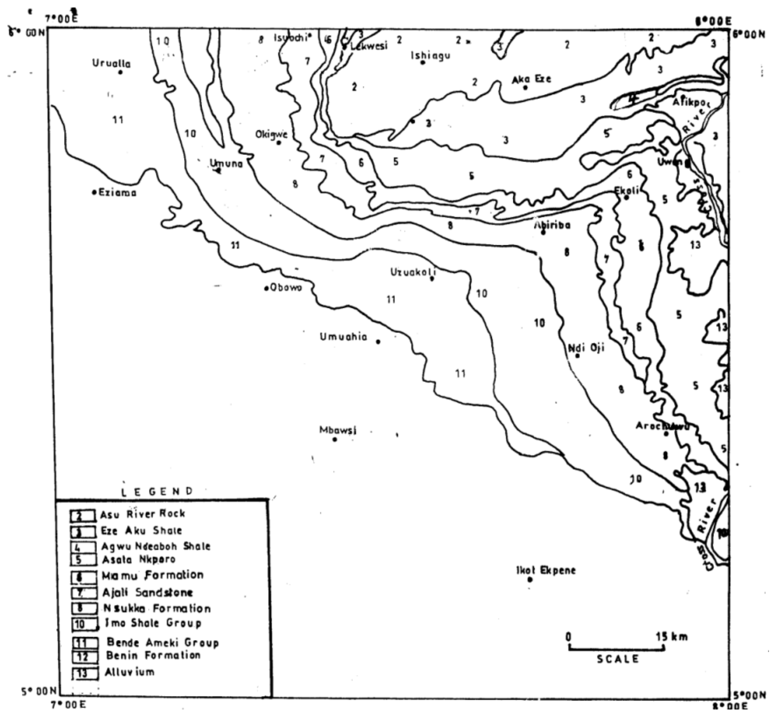

Fig.4: Geological map of the study area with the various formations numbered in an order that reflects their decreasing age

3. DATA ACQUISITION AND ANALYSIS

3.1 Lineament Density Analysis

The method adopted in this study is the multi-stage procedure for the detection of drainage lineation as suggested by [14]. The drainage lineament map of the study area (fig.5) was obtained by carefully tracing out drainage linears of almost straight segments of the drainage pattern, taking note of their lengths and orientations. The lineament map was then divided into grid cells, each of size 10 x 10km^2 for the annotation of the total field of lineation in the region. The total number of linear features and their total lengths were grouped into 30 preferred orientation classes and the resulting data used to produce azimuth-frequency diagrams for the entire area (fig.6). The lineament density was obtained for each grid cell from the relation:

$$LineamentDensity = \sum L_i / A \text{......................}(1)$$

Where, L_i represents the individual lengths of lineament, and A is the area of the grid cell. The data on lineament density and the azimuth-frequency diagrams as given by [15], were used in this study.

3.2 Azimuthal Resistivity Soundings (ARS)

The application of azimuthal resistivity soundings in mapping of local fracture zones is sufficiently understood [5-7, 16-17]. At a locality within the grid cell, azimuthal resistivity sounding measurements were performed, using ABEM Terrameter SAS 4000, using the Schlumberger electrode array. The Schlumberger array with constant AB/2 and MN/2 distances was rotated about a central point and measurements made at 45^{o} increments corresponding to the N-S, NE-SW, E-W and NW-SE directions. Several measurement series were carried out with different AB distances ranging between 30 and 400m depending on accessibility. Altogether a total of 42 azimuthal sounding locations were occupied. The values of apparent resistivity (ohm-m), were used to construct the anisotropy diagrams (fig.7) from which the trend of the fracture systems have been inferred. One anisotropy diagram from each locality is presented in fig.7.

4. RESULTS AND DISCUSSION

The azimuth-frequency diagrams (fig.6) and the anisotropy figures (fig.7) revealed that, generally NE-SW and NW-SE trends are preponderant over other trends in the study area. Of these, the NE-SW trend is dominant and greater in continuity than the NW-SE trends. Occasionally, N-S and E-W trends were exhibited.

The general orientations of the electrical anisotropy diagrams are in agreement with the measured or observed strikes of geologic formations recorded from geologic mapping. At Abiriba and Ahaba Imaiyi (cells E_4 and G_4 in fig.6) for instance, outcrops of the Abakiliki Anticlinorium occurring in contact with Ajali sandstones and Ameki Formation strike NW-SE direction and this coincided with the direction of maximum electrical anisotropy. The oldest structural trend in the area was the localized E-W trends followed by the N-S trends often attributable to brittle deformation. The two structures have been covered in most parts of the study area by sediment infillings, thus permitting only limited recognition in the field. They were observed in parts of Ovim, Abiriba, and Igbere in cells C_4, G_4 and E_3 respectively in fig.7.

The dominant and widely pronounced structural trends in the area, the NE-SW and NW-SE conjugate sets of fracture systems were produced by trans-current movements related to the formation of the Benue Trough [18].The NE-SW trend controlled the deposition of sediments in the Trough, the Cretaceous magmatism, orientation of fold belts, drainage, and mineralization in the area [19] . In contrast, the NW-SE, trend influenced distribution of facies, and discontinuities along which occurred synsedimentary faults [8]. The course of major rivers and their tributaries appears to be determined and controlled by these structural features. Such rivers are the Cross, Imo, Ezeaku, Asu and Ivo. They rise in the southwest and flow northeast wards (fig.3).

The coefficient of anisotropy for the electrical anisotropy diagrams were computed for each sounding location in the area. According to [20], the lengths of major axis of the anisotropy figures are numerically equivalent to the transverse resistivity ρ_t while the lengths of the minor axis are numerically equivalent to the longitudinal resistivity ρ_i. The coefficient of anisotropy λ is the square root of the ratio of ρ_t and ρ_i , that is:

$$\lambda = \sqrt{\left(\frac{\rho_t}{\rho_l}\right)} \text{..}(2)$$

For this study, λ ranges in value from 1.02 to 1.79 in the study area as shown in fig.7. Results indicate that around Afikpo, Oso, Owutu, Eda, Ahaba, Imaiyi, and Uwana, the coefficient of anisotropy varies from 1.31 to 1.79, whereas the values range from 1.02 to 1.26 around Ihube, Okigwe, Ezinachi, Amaeke, Uturu, and Umuda-Ishiagwu. The area where λ is high (1.31 – 1.79) all lie along the southern flank of the Benue Trough underlain by sediments of the Asu River group, Ezeaku Shales, and Nkporo Shales which are known to have jointed, faulted, and magmatised with igneous intrusions inter-bedding the sedimentary sequence. Electrical anisotropy and hence inhomogeneity exists in the formation, and is caused by structural features such as the intersection of joints, foliation axis and facies changes in the formation. Fig.6 also revealed that the drainage density is high (0.2– 0.6km^{-1}) around Uturu, Uzoakoli, Igbere and Abiriba in cells D_1, D_5, F_3 and G_4 whereas it is low around Umuna and Obowu in grid cells A_4 and B_4(0.06 – 0.1) respectively. Generally, the localities with high drainage densities are found to have high coefficients of electrical anisotropy. These areas also correspond to locations in the study area where gully erosion and landslides occur. This is particularly true of Uzoakoli, Abiriba and Igbere.

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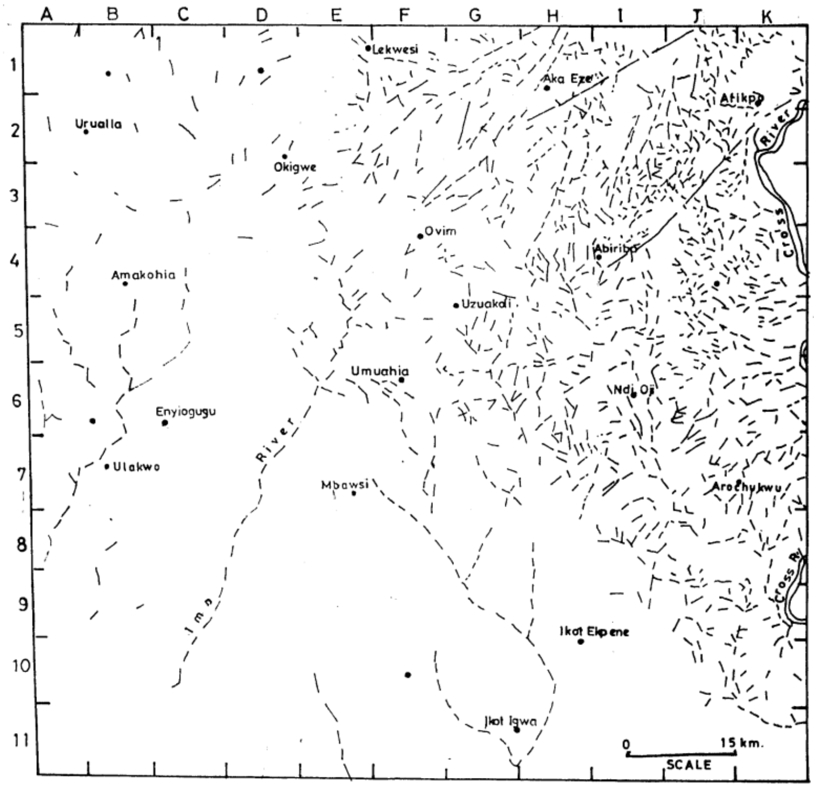

Fig.5: Drainage lineation map over Umuahia and environs (After Ufomadu, 1995)

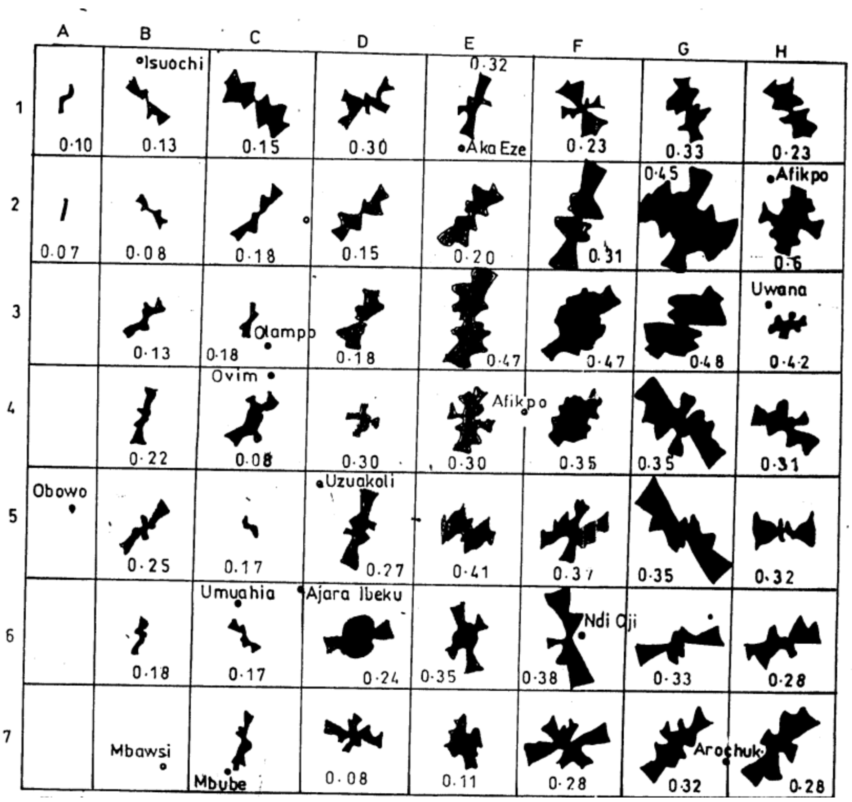

Fig.6: Azimuth-frequency map obtained for each grid cell of 10 x 10km^2 blocks. The drainage is indicated in each block [15]

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The structural trends obtained from electrical anisotropy diagrams correlated well with measured trends from drainage lineation analysis, and these seem quite precisely to reproduce the local fracture system. Field checks carried out during the geophysical survey confirm that linear features inferred from drainage pattern were found to correspond to geomorphic features such as large valleys and minor drainage features. In all**,** the match between the electrical anisotropy diagrams and the rosette diagrams from the drainage lineation were good except for minor mis-match in Umuda Isingwu, Ovim and Otampa in grid cells B_6, C_4 and D_1 respectively. The coefficient of electrical anisotropy computed for the study area shows that higher coefficients were obtained in the areas underlain by early Cretaceous sediments which are known to have undergone various episodes of tectonic activity and granites emplaced along lines of weakness.

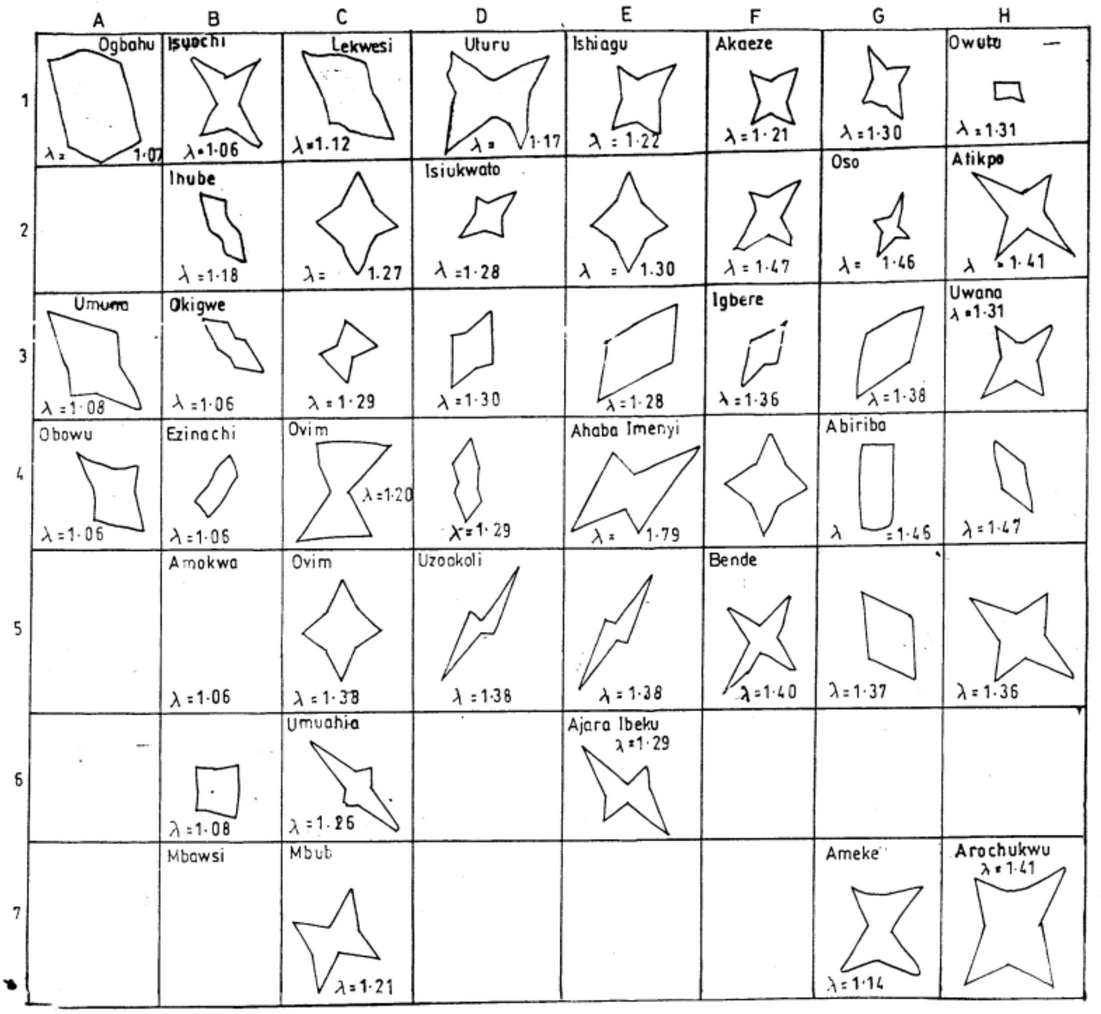

Fig.7: Electrical resistivity anisotropy diagrams obtained for each grid cell λ given the value for coefficient of anisotropy

5. CONCLUSIONS

This study has revealed that the tectonic trends in the study area are aligned in four directions. These are the NE-SW, NW-SE, E-W and N-S directions. The dominant trends are in NE-SW and NW-SE directions while the N-S and E-W trends are highly localized. These results are in agreement with results of earlier studies carried out in the Benue Trough[8-9, 19,21-25].There seems to be a correlation between coefficient of electrical anisotropy, lineament density and the occurrence of gully erosion in the study area. The interpretation of vertical electrical soundings revealed that the depth to the water table varies from 38.8 to 194.0m in the area. There exists a relationship between the drainage density, depth to the water and the coefficient of anisotropy. Higher coefficients of anisotropy (1.31-1.79) were obtained at locations where drainage and depths to water table are high (0.27 – 0.47 and 160 – 194m respectively). The high drainage densities obtained around Abiriba, Afikpo and Ahaba-Imenyi where exploration for groundwater resources have been difficult could suggest that the network of fractures serves mainly as conduits for

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surface runoff rather than zones of infiltration. This may also account for accelerated removal of surface materials leading to gully initiation. Taking into account the river divide of the major rivers and their tributaries, it can be seen that stream adjustment has followed abrupt changes in slope orientation. They are therefore believed to be controlled by local fractures.

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