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TECTONIC TRENDS DELINEATED FROM DRAINAGE LINEAMENT ANALYSIS AND AZIMUTHAL RESISTIVITY SURVEY: A CASE STUDY OF S. E. NIGERIA GULLY EROSION BELT.

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ABSTRACT

South Eastern Nigerian gully erosion belt lies in the Southern flank of the lower Benue Trough, The trough has its origin as a failed arm of the triple junction formed during the separation of South American plate from African plate in the Cretaceous time. It is therefore an extensive zone of weakness that is characterized by structural lineaments in the basement and overlying sediments. The belt has been ravaged by severe and chronic gully activities including other related mass movements. We intend to evaluate the tectonic trends in the belt using drainage lineament analysis and azimuthal resistivity survey. We will then correlate our results with trends of major gullies with a view of determining their structural relationship with known tectonic trends in the belt. Results of the drainage analysis and azimuthal survey reveal the presence of four prominent tectonic trends. These are the NE-SW, NW-SE, N-S and E-W trends which are consistent with the measured trend of major gullies – NE-SW, NW-SE and N-S. The gully trends cautiously follow the predominant tectonic trends of the localities where they occur and lie parallel to one another. This observation, however, confirms a structural control by such features as joints, faults, folliation axes, bedding trend, lithology and lithological variations in the belt.

KEYWORDS: Tectonic trends; Lineament; Rose diagram; Resultant Anisotropic Figure; Gully erosion.

INTRODUCTION

The South Eastern Nigeria gully erosion belt is situated a. the southern flank of the Lower Benue Trough, with an area of about 15, 600km^2, defined and enclosed by latitudes 5^0 20' to 6^0 30' N and longitudes 6^0 45' to 8^{o}00'E . It is mainly located in the water shade of major rivers and tributary streams with steep slopes, complex geological and tectonic settings. (Figs:1a,b).

The belt has suffered severe devastations in recent past due to gully erosion and landslide activities. The communities have been completely cut off from each other and most inhabitants have abandoned their farmlands and buildings to encroaching gullies. The most affected towns /communities are Agulu, Nanka, Uruala, Nimo-Neni, Ihiala, Nnewi, Ohafia, Bende, Afikpo, Umuahia and Enugu. The depth of the gullies ranges between 20 and 120m (Fig. 2).

These negative relief structures are parallel to one another and form characteristic linear valleys along their length of propagation. The striking parallel alignment suggests a probable structural relationship with linear structural elements in the basement and overlying sedimentary layer. Infact, their surface morphologies are reflections of the continuous interaction of tectonics and climate with the bedrock geology.

The mapping of tectonic trends (lineaments) has proved useful in tectonic studies especially where large areas are involved. Many lineaments are believed to be directly related to tectonic activity or tectonic features (Rowan and Lathran, 1980). Lineaments are naturally occurring alignments of soil, topography, stream channels, vegetation, or a combination of these that are visible on remotely sensed imagery and aerial photographs (Mabee and Hardcastle, 1994).

Tectonic lineament mapping and characterization of any scale requires a multi displinary approach for a more detailed and reliable result. A combination of geological and geophysical methods had been utilized to reveal the trends of Paleo- and Neo–tectonic trends in such belts (Skjernaa and Jorgensen ,1994 ; Hermann et al.,1999).

Drainage lineament analysis and azimuthal resistivity survey have been applied successfully in numerous tectonic studies (Vetel et al., 2004; Samir et al., 1999; Skjernaa and Joorgensen, 1994; Bradley and Weimer, 2002; and Gaylord and Çarlson, 2001). Flow path anomalies expressed by an unusually linear, dense drainage network or abrupt changes in drainage course, which is inferred to be a manifestation of structural control, form the basis of the drainage lineament analysis. These flow path anomalies are exceptionally developed over part of the earliest Cretaceous sediments and Tertiary sediments to the Northeast, Northwest and Southern part of the belt (Fig. 3).

Structural lineaments (rock joints and fractures) usually occur in sets with more or less well-preferred orientations. They are often filled with water containing dissolved clay particles and other hydrous minerals. In all cases of open and closed fractures, there is marked reduction in electrical resistivity. The resistivity values parallel to the fracture are smaller in all azimuthal direction and the resulting electric potential has highest magnitude in this direction and vice versa (Keller and Frischinecht, 1966; Dobrin, 1976). These structural inhomogeneities in the sediments make the resistivity anisotropic. Thus, the electric current flow has different magnitude in different direction, and so does the resulting electric potential measured at the surface, when a low frequency D. C. current is injected into the subsurface.

The analyses of these current and potential variations with azimuths give clue to the orientation and magnitude of the fracture and other structural anisotropies in the subsurface (Skjernaa and Jorgensen, 1994).

The principal aim of this study is to superimpose the results of both analyses on one another, correlating them to determine the extent of their match. We will use this analysis to develop the generalized axes of predominant trends and correlate the result with the trend of gullies. This will enable us establish a structural relationship between axes of known tectonic trends and trend of gullies, as well as infer the type of tectonic forces responsible for these instabilities.

GEOLOGY OF THE BELT

The gully erosion belt lies within the sedimentary basin of the lower Benue Trough. It is bordered by uplifted blocks of

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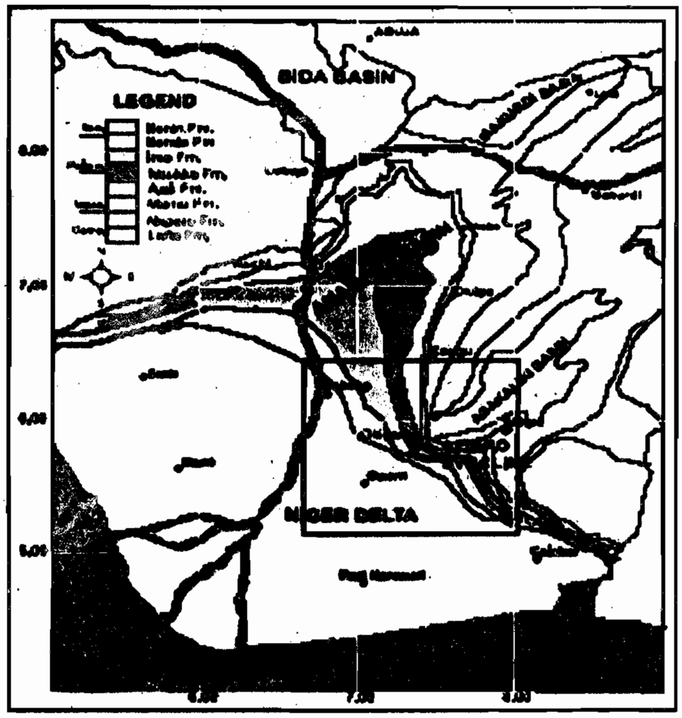

Fig. 1a: Geological map of southern Nigeria showing the study area (box, Fig. 1b).

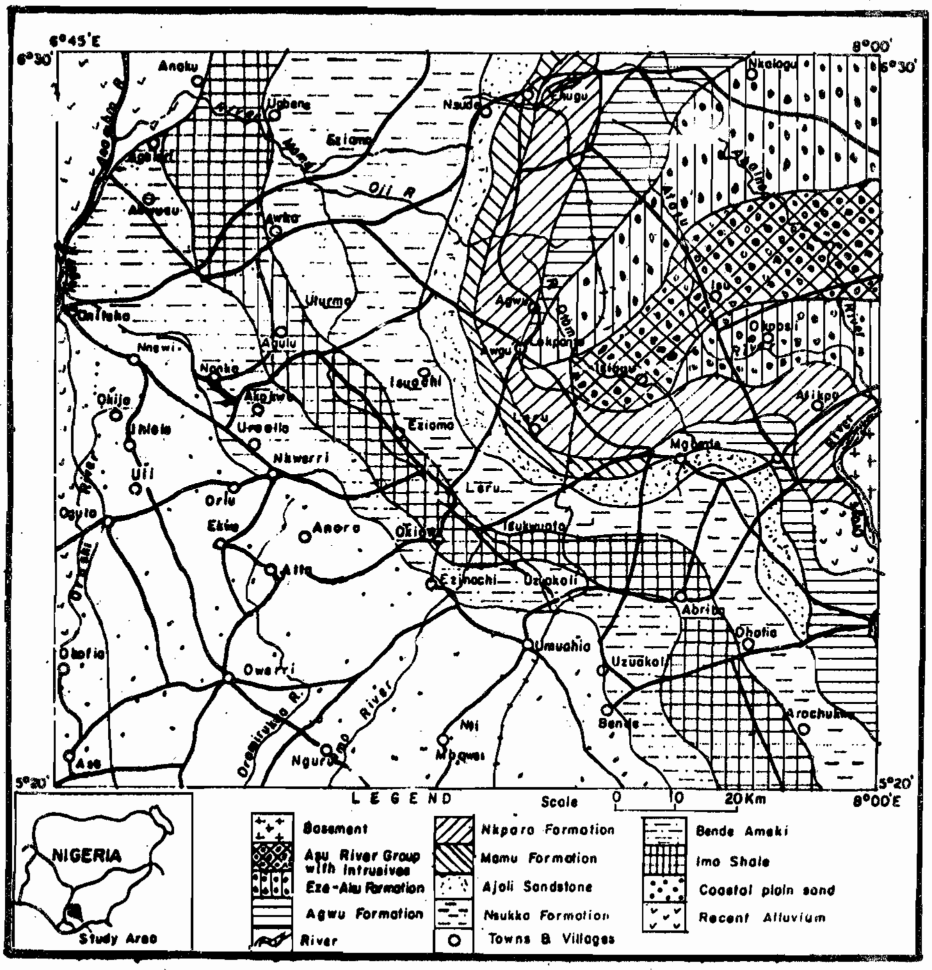

Figure 1b: Detailed geological map of the study area

Figure 2: A typical gully at Umuagu-Uruala Gully erosion site, pointing NW-SE

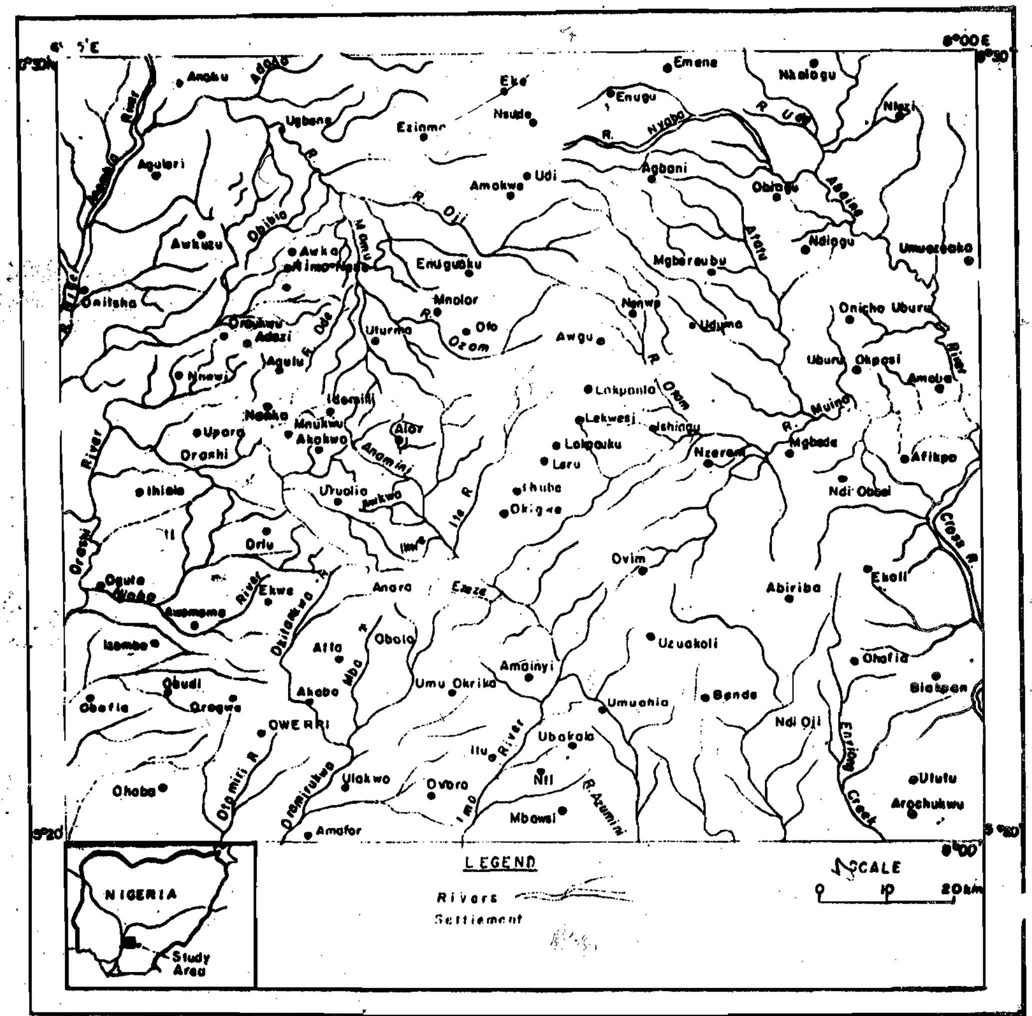

Figure 3: Drainage map of the study area

the crystalline rocks of the basement complex to the West and the Oban-Massif to the East. Between these complexes, sediments of the Cretaceous, Tertiary and Quatenary age occur. Precambrian Crystalline Basement rocks are predominantly gnesis, migmatites, and schists. These form the basement on which sediments were deposited and into which igneous rocks were emplaced. The sequence of events culminating in the formation of the Benue Trough, its component units and the adjacent Niger delta are now well documented (Burke and Whiteman, 1970, Burke et al., 1972, Nwachukwu, 1972).

The geologic formation within the belt varies predominantly between alternating thick beds of shale and thin beds of sandstones. Inter layer beds of limestone, coal, marls and lignite exist. The formations are characterized by lateral facie changes and the shaly associations tend to be sandy towards the top (Fig. 3)

Structurally, the belt is transversed by conjugate set of lineaments with minor associations, known to have formed tectonic boundaries between sedimentary and crystalline rocks of the Basement and cross cuts the Precambrian, Cretaceous and Tertiary rocks as numerous faults (Burke et al., 1972). The highest density of fractures are found in the stratas of the earliest marine sedimentary deposits of Abakaliki shales, Ezeaku shales and Late Creteceous to Tertiary continental clastic deposits of Nkporo shales (Afikpo sandstones), Bende Ameki shales (Nanka sands) and the coastal plain sands of the Benin Formation (Reyment, 1965).

METHODS

We have adopted an integrated approach of correlating the drainage lineament data (surface data) with the azimuthal resistivity data (subsurface data) acquired for this study to reveal tectonic lineaments. We also measured the trend of major gullies present in the belt and correlated their characteristics with our results.

(i) Drainage Lineament Analysis

Drainage lineament analysis involves the measurement and annotation of total field of lineation within the drainage basins by analysis of the drainage map. The main assumption inherent in performing any lineament analysis is that these alignments represent fracture zones or other discontinuities and the best lineaments are those that follow drainage courses (Mabee and Hardcastle, 1994).

The drainage map of the belt (Fig. 3) was carefully lineralized by tracing out the linear or almost straight segment of the drainage patterns. These acquired lineaments were then delineated on acetate paper placed over the drainage map. The resulting lineation map was further divided into grid cells of (10 x 10) km with a unit area of 100km^2

Quantitative analysis of linear features within each area of the grid cells were conducted by measuring the orientation of each linear feature using a protractor and grouped in 30^0 preferred orientation classes.

(ii) Azimuthal Resistivity Sounding

Azimuthal resistivity survey were performed with a digital readout ABEM Terremeter SAS (Signal Averaging System) 300B, using the Schlumberger electrode array with non-polarizable stainless steel electrodes in selected grid cells.

The Schlumberger array with AB/2 distances ranging between 20 – 100m and constant MN/2 distance of 10m were rotated about a central point on the earth surface and measurements were made at 45^0 increments to denote measurements in the N – S, NE – SW, E – W and NW - SE (Fig. 4). For some locations that were not easily accessible, measurements were either abandoned or slightly shifted.

(iii) Surface Measurements

Field measurements of the trends of the major gullies were conducted at the various gully sites. The trends were measured using a bruntum compass placed at the mouth of the gullies. The bruntum compass was balanced on the ground such that its North deflection aligns with the geographical north direction at the particular site from which measurement of the trend of the gully was determined. The gully paths were followed up to a distance of about 500-1000m, depending on accessibility to make a confirmatory measurement.

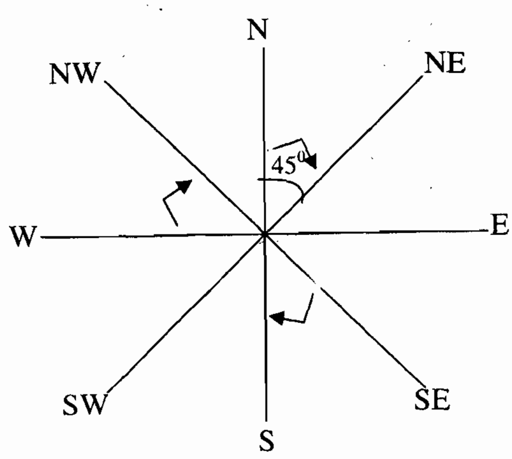

Figure 4: Plane view of the geoelectric azimuthal directions

RESULTS

The resulting data from drainage lineament analysis and azimuthal resistivity survey were used to produce Azimuth–Frequency Rose diagrams and resultant anisotropic figures (RAFs). The Azimuth–Frequency Rose diagrams were subsequently superimposed on the resultant anisotropic figures in each grid cell (Fig. 5), from which a generalized tectonic trend of the belt was delineated (Fig. 6). Tectonic trends were delineated by joining all grid cells having these features with similar peaks in a particular azimuth for the entire area.

The number of superimposed features totals thirty(30). The percentage match was calculated to be 93% leaving a mismatch accounting for the remaining 7%. The match includes such characteristics as orientation, geometric

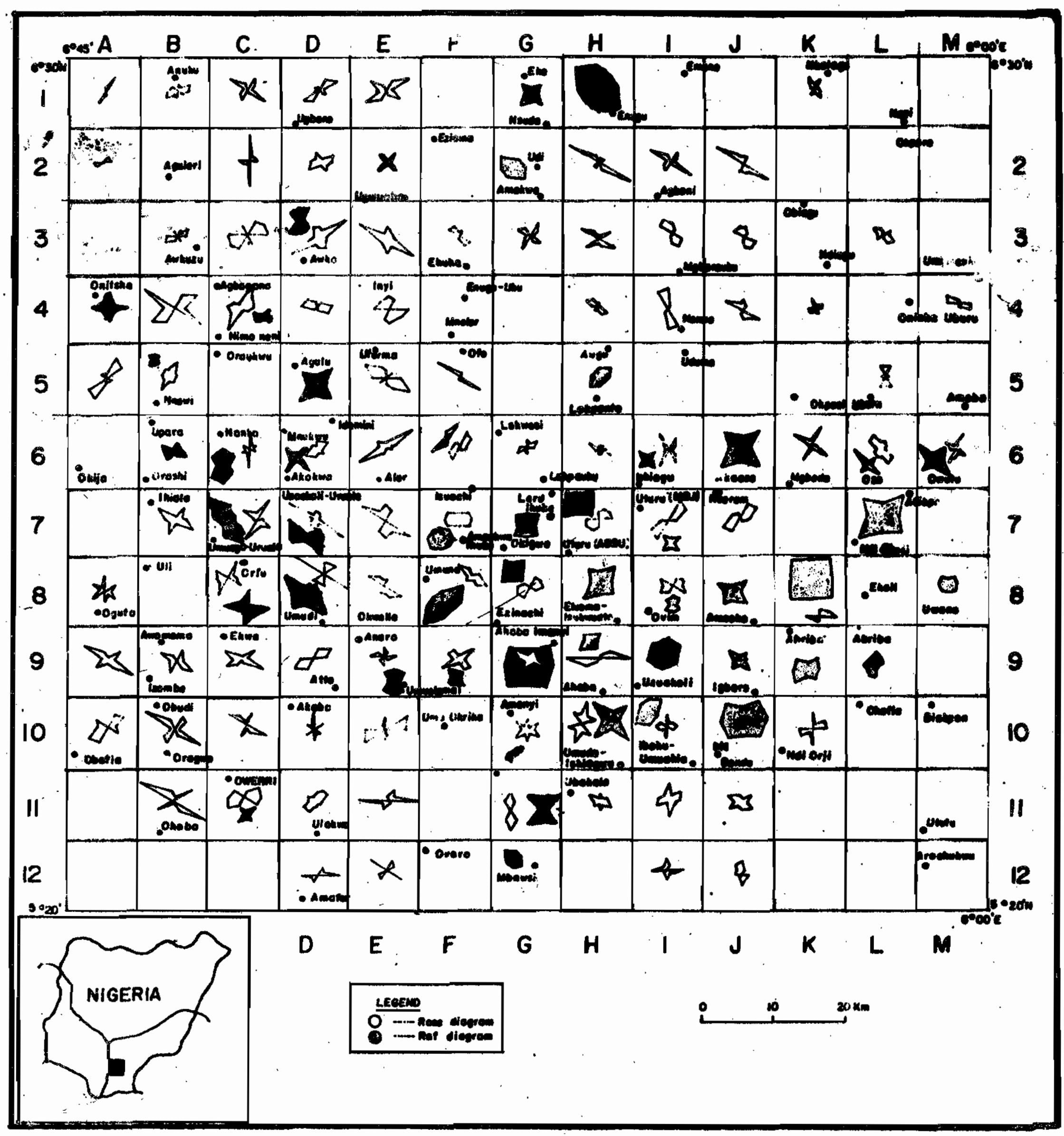

Figure 5: Superimposed RAFs and Rose diagrams

similarity or combination of these features. Results, however, indicate that the RAFs due quite precisely match the rose diagrams with minor exaggeration and suppression of trends in both diagrams in most grid cells.

The match reflects the presence of four tectonic trends. These are the NE-SW, NW-SE, N-S and E-W trends. The azimuth–frequency classes of combined rose and RAF azimuths of dominant trend (Fig. 7), reveals that the NE-SW trends are the dominant trends followed by the NW-SE trends, while the N-S and E-W trends are few and localised variable.

The surface measured trends of selected major gullies with locations are depicted in Table 1.

The gully trend-frequency classes also show that NE-SW trend is most frequent (Fig. 8). No E-W trend was practically measured in the field.

DISCUSSIONS

The superimposition of the results from the two analyses reveals the presence of four tectonic trends. These are the NE-SW, NW-SE, N-S and E-W trends. The dominant and widely pronounced trends are the NE-SW trend followed by the NW-SE trend, which form conjugate set of lineaments and are concentrated in the general area of the belt. The N-S and E-W trends are highly variable and localized mostly to the Southeastern flank of the belt. Chukwu – Ike (1978), Olujide (1997), Umeji (1977), Ananaba and Ajaikaye (1987) have all reported these styles of trend in the belt.

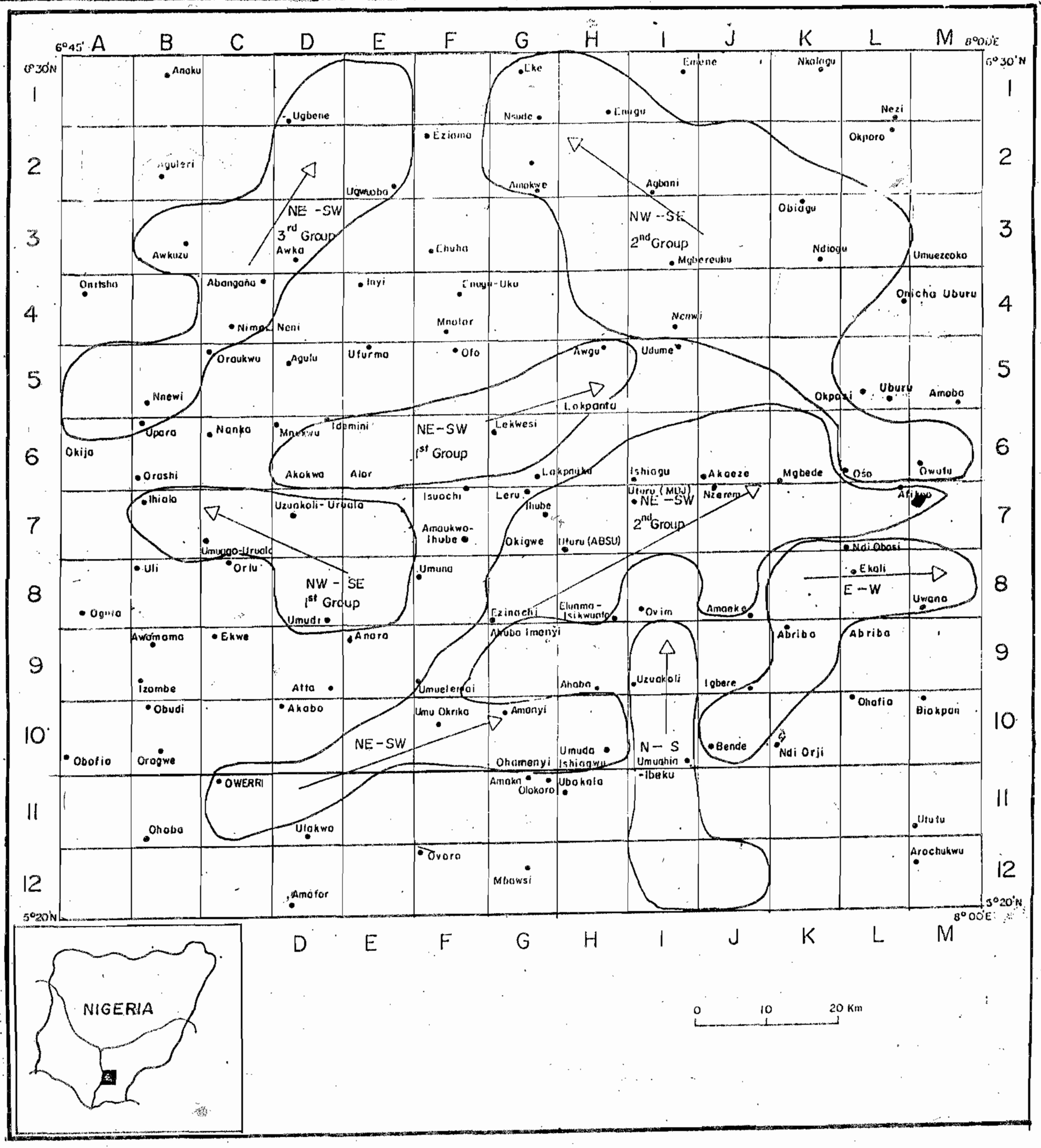

Figure 6 Generalized trend distribution in the study area (RAF and Rose) superimposed

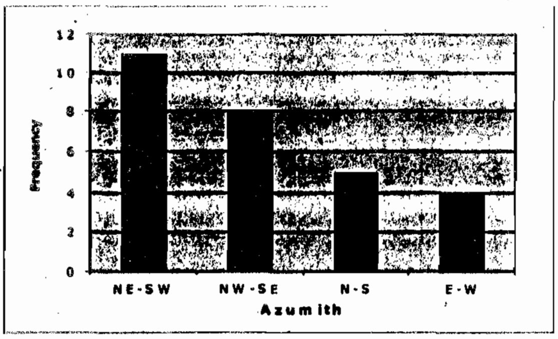

Fig. 7: Frequency classes of measured RAF and Rose

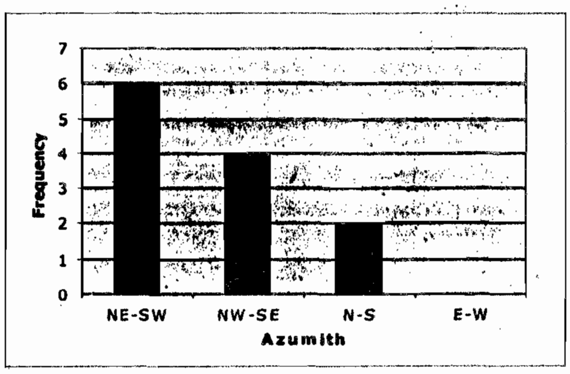

Fig. 8: Frequency classes of the gully trend

Table 1: Major Gullies of the belt showing the measured trends

S/N	LOCATION	TREND
1	Nanka	N – S, NW – SE
2.	Agulu	NW-SE, NE-SW
3.	Umuagu – Urualla	NW-SE
4.	Nimo – Neni	NE-SW
5.	Ihiala/Nnewi	NW-SE, NE-SW
6.	Afikpo	NE-SW
7.	Okigwe	NE-SW
8.	Umuahia	NE-SW, N-S

These tectonic trends are basement fractures resulting from the initiation of the Benue Trough as the failed arm of the triple junction in the early Cretaceous, forming block faults and drape folds over which lies the sediments (Wright, 1968). They were accentuated in the overlying Cretaceous to Recent sediments in part, probably by later vertical adjustment and reorganization along pre-existing fault planes in the basement. Although, subsequent Neotectonics influenced the structural features of these sediments, but the orientation of the principal structural elements are inherited in part from the tectonic trend of the Precambrian basement (Burke and Whiteman, 1970 and Benkhelhe, 1988).

The trend of major gullies measured in the field lies dominantly in the NE-SW, NW-SE and N-S (Table 1). The NE – SW gully trends are the most dominant followed by the NW – SE and finally, the N-S trend. The E-W trends were not observed in the field. This result is consistent with that of drainage analysis and azimuthal survey. The variation in trends within a particular gully body in each location (Nanka, Agulu, Ihiala /Nnewi and Umuahia) is a demonstration of structural incoherency in the subsurface formations, which may likely have a structural undertone, lithological variation or combination of them.

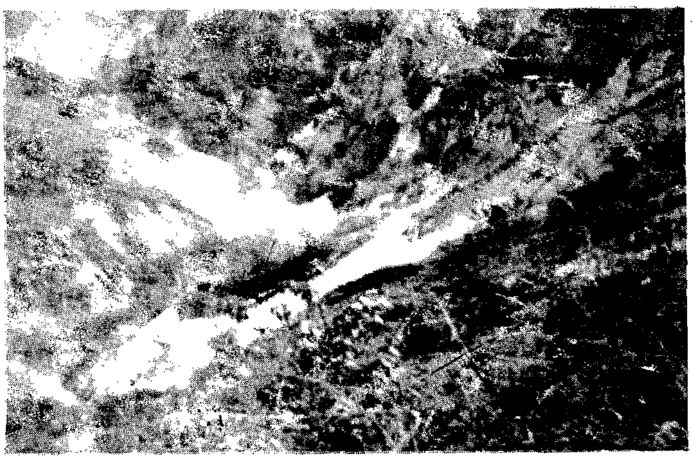

Figure 9: Agulu Gully erosion site (NE-SW and NW-SE).

Correlation of the gully trends and results of drainage analysis and azimuthal survey show that the gully trends cautiously follow the predominant trend of tectonic lineaments in the belt. The striking feature of these gullies is that they are parallel to one another and tend to align themselves in the direction of predominant tectonic trend of the area/locality where they occur, thereby conforming with the direction of NE-SW, NW-SE and N-S predominant tectonic trends (Figs. 2, 9, 10). This is a reflection of structural control by jointing, faulting, foliation axes, bedding trend, lithology and lithological variation.

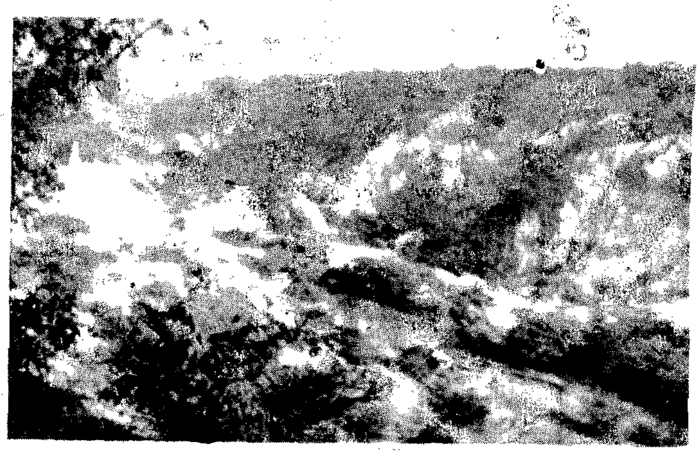

Figure 10: Nanka Gully erosion site (N-S and NW-SE)

CONCLUSION

The study identified four prominent tectonic trends. These are the NE-SW, NW-SE, N-S and E-W trends. The NE-SW trend is the most dominant followed by the NW-SE trend. These dual structural trends suggest that drainage lineament and electrical anisotropy lies in two principal directions. The N-S and E-W trends are variable and localized in the belt.

The gully trends measured in the field lies dominantly in the NE-SW, NW-SE and N-S, which is consistent with the result of the above study. The gully trends cautiously follow the predominant tectonic trend of the localities where they occur and lie parallel to one another.

This distribution pattern, however, reveals that gully activities and associated crustal instabilities are structurally control by such features as joints, faults, folliation axes, bedding trend, lithology and lithological variations or combinations of these in the belt.

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