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SECOND VERTICAL DERIVATIVES AND TREND SURFACE ANALYSIS OF THE AEROMAGNETIC DATA OVER PART OF THE BENIN BASIN, NIGERIA

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ABSTRACT

The Benin basin has been interpreted as a rift basin bounded by two trans-oceanic fracture zones: the Romanche Fracture Zone to the west and Chain Fracture Zone to the east. These paleo-structures trend approximately in the NE-SW direction. Linear features identified in the study area have principal trend directions in the NE-SW and N-S, and to a lesser extent E-W and NW-SE directions. The E-W structures are localized in their occurrence and are revealed around Akure area while the N-S fractures which are revealed in part of the study area especially around the Ilesha – Ife axis are marked by considerable shearing and brecciations. The N-S fractures are gravity induced while the conjugate northeasterly and northwesterly sets which were products of transcurrent movements are characterized by wide zones of cataclastic deformation. The NE-SW is indeed well developed in the study area and has been interpreted as an important zone of tectonic activity which tends to suggest that they are deep seated. Finally, the distribution of mafic and felsic rock forming minerals were correlated to the positive and negative second vertical derivative anomalies around Ilesha area. These minerals are believed to be the by-products of the re-activation of the trans-oceanic fracture zones that also acted as conduits for the primary mineralization.

KEYWORDS: Second vertical derivatives, trend surface, aeromagnetic, lineaments, tectonics.

INTRODUCTION

The past two decades have seen a revolution in the application of aeromagnetic surveys from interpretation of solely basement structures to detailed examination of structure and lithologic variations in the sedimentary section. In many sedimentary basins, magnetic anomalies result from secondary mineralization along fault planes, which are often revealed on aeromagnetic maps as surface linear features. Most mineral deposits are related to some type of deformation of the lithosphere, and most theories of ore formation and concentration embody tectonic or deformational concepts (Ananaba, and Ajakaiye.,1987). Some lineament patterns have been defined to be the most favourable structural conditions in control of various mineral deposits. They include the traces of major regional lineaments, the intersection of major lineaments or both major (regional) and local lineaments, lineaments of tensional nature, local highest concentration (or density) of lineament between en echelon lineaments, and lineaments associated with circular features. Linear features are clearly discernible on aeromagnetic maps and often indicate the form and position of individual folds, faults, joints, veins, lithologic contacts, and other geologic features that may lead to the location of individual mineral deposits. They often indicate the general geometry of subsurface structures of an area thereby providing a regional structural pattern.

Several authors have applied aeromagnetic data in delineating the structural and tectonic trends, geodynamics and history of sedimentary basins(Onyedim, G.C., 2007; Liesa, et al.,2006; Jacques, et al.,2003 ;Guiraud, et al.,2000;Ako,et al.,2004;Akanbi and Udensi.,2006).The detail in total magnetic data supplemented by the range of enhanced maps and image products typically produced to display these data normally provides an excellent basis for qualitative interpretations in which geological boundaries, lithologies and structural features are virtually estimated(Gunn,1997).However, because of the weak and subtle nature of the majority of the intra – sedimentary responses, some form of data enhancement is therefore required to clearly delineate such features relative to strong regional gradients and the more intense anomalies due to basement features, igneous intrusive, etc. Typical techniques applied are computation of second vertical derivatives, trend surface analysis, etc. (Milligan and Gunn, 1997).

The purpose of this study is therefore to investigate the basement morphology, identify and delineate the trends patterns and of basement structures and to infer the effects of these structures on basin formation and geodynamics.

GEOLOGY OF THE STUDY AREA

Detailed study of the geology of the Benin Basin , Nigeria have been carried out by so many researchers(Coker and Ejedawe,1987;Elueze,1982;2000;Omatsola and Adegoke,1981; Mascle et al,1988).The study area lies at about longitude $4^0 30^1$ – $6^0 00^1$E and latitudes $6^0 00^1$ – $7^0 00^1$N.The Benin basin (Dahomey Embayment) is bounded in the west by the Ghana Ridge which is the extension of the Romanche Fracture Zone and the east by the Benin Hinge line, a basin escarpment which separates the Okitipupa structure from the Niger delta basin and marks the continental extension of the Chain

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Fracture Zone (Fig.1). The Benin basin is a sedimentary basin that was initiated during the Mesozoic in response to the separation of the African–South American landmasses and the subsequent opening of the Atlantic. The basin forms the onshore part of the West African miogeocline in eastern Ghana, Togo, Benin and western Nigerian. The Nigerian part of the basin forms part of a miogeoclinal wedge extending from the Volta delta area in Ghana to Okitipupa Ridge, east of Lagos. The distance from the volta mouth(Ghana) to the axis of the Okitipupa Ridge or Ilesha spur (Nigeria) being about 250miles(450km). Sediments encountered in the onshore part of the basin range in age from Late Cretaceous to Recent and exceed 7000ft at the coast in western Nigeria. They thicken into the offshore and then thin down to deep water (Whiteman, 1982; Coker and Ejedawe, 1987).The physiography of the basin can be described based on the structural elements in the entire basin. These include the Benin basin proper and the Okitipupa hinge which separates the former from the Anambra basin to the east and the Niger Delta basin to the southwest.

A study of the sediments in the Benin basin revealed that the oldest outcropping sediments of the basin are the Abeokuta Formation (Maastrichtian). It rest uncomformably on the highly weathered and fractured basement complex rocks. Paleocene- Eocene marine shales, limestones, sandy shales and clay stones comformably overlie the Maastrichtian sediments. The stratigraphy of the basin is presented in table1 below.

THEORY

The regional trend is represented by a straight line, or more generally by a smooth polynomial curve. The fitting of polynomials to observed geophysical data is used to compute the mathematical surface giving the closest fit to the data that can be obtained within a specified degree of details. This surface is considered to approximate the effect of deep seated or regional structures if the polynomial is of low degree. The function that generates this surface is called the trend for that specified degree and the consequent analysis of this

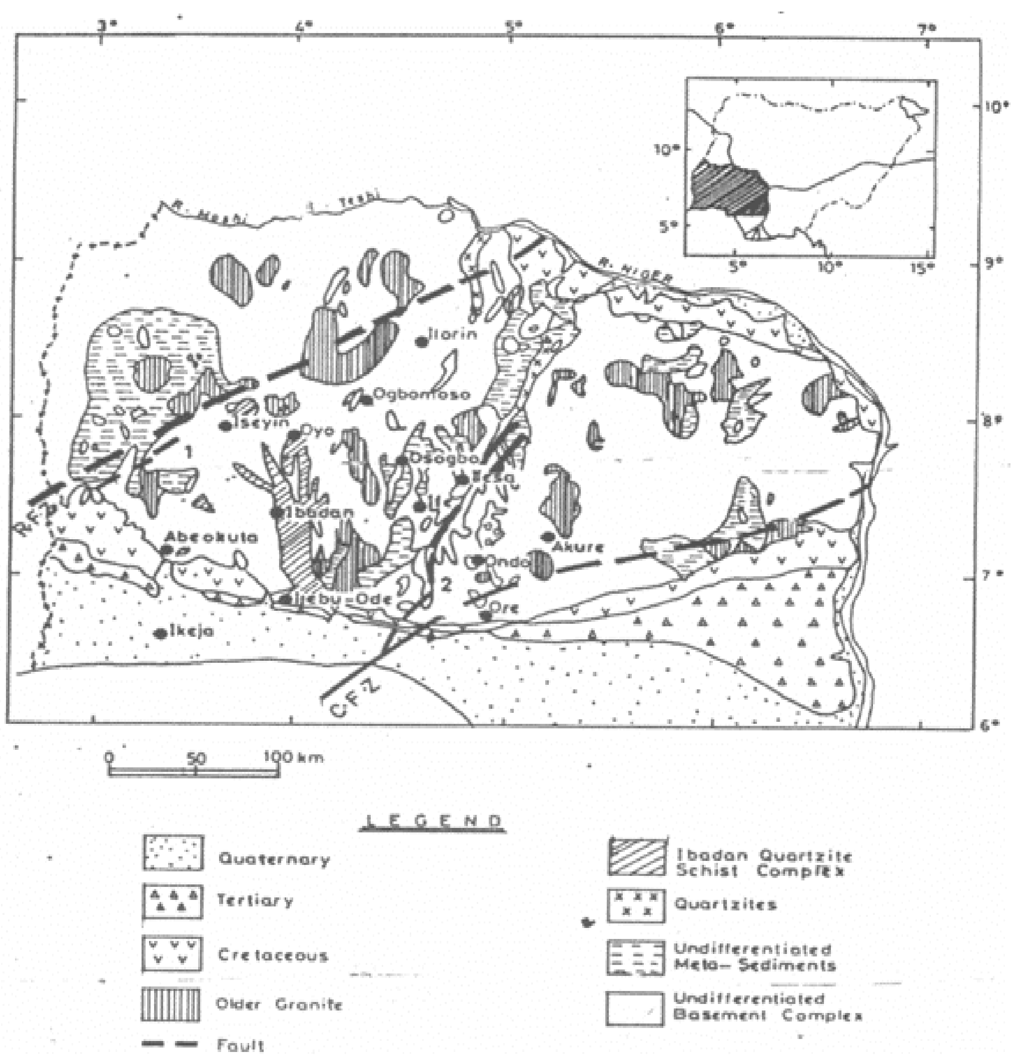


Fig.1: Simplified geological map of southwestern Nigeria showing assumed locations of major fracture zones (after Osazuwa and Ajakaiye, 1989)

constitutes the trend surface analysis. The fitting surface which represents the regional is a surface which will have both positive and negative deflections from the observed data points with the residuals balanced between positive and negative areas(Nettleton, 1976).

In trying to determine a geologic surface, the use of a polynomial expansion of the linear trend surface which introduces powers and cross products of the geographic coordinates is used. Trend functions are often defined by equations. Thus, for a surface of degree n, the trend function, F(Simpson, 1954) is given as:

$$F(x,y) = \sum_{i=0}^{n}\sum_{j=0}^{n-i} a_{ij}\, x^i y^j \quad \text{.................... (1)}$$

where a_{ij} are coefficients to be determined by adjustments using the least squares method, while x, y are coordinates of a point at which the function is evaluated. A typical trend surface program consists of three (3) parts: a routine to generate the matrix of sums of powers and cross products, a simultaneous equation solver or matrix inverter and a plot algorithm.

Similarly, second vertical derivative filters are used to enhance subtle anomalies while reducing regional trends. These filters are considered most useful for defining the edges of bodies and for amplifying fault trends. In mathematical terms, a vertical derivative can be shown to be a measure of the curvature of the potential field, while the zero second vertical derivative contours defines the edge of the causative body. Thus, the second vertical derivative is in effect a measure of the curvature, i.e., the rate of change of non- linear magnetic gradients. The zero magnetic contours of the second vertical derivative often coincide with the lithologic boundaries while positive and negative anomalies often match surface exposures of the mafic and felsic rocks respectively. The use of the second vertical derivatives can best be understood by noting that the magnetic field potential satisfies Laplace's equation given as:

$$\frac{\partial^2 s}{\partial x^2} + \frac{\partial^2 s}{\partial y^2} + \frac{\partial^2 s}{\partial z^2} \quad \text{.................................... (2)}$$

Table1: Stratigraphic setting of the Dahomey Basin SW Nigerian (after Idowu et al, 1993)

<table>
<tr><th colspan="2" rowspan="2">AGE</th><th colspan="3">FORMATION</th><th rowspan="2">LITHOLOGY</th></tr>
<tr><th>Ako et al,1980</th><th colspan="2">Omatsola and Adegoke,1981</th></tr>
<tr><td rowspan="3">TERTIARY</td><td rowspan="2">EOCENE</td><td>ILARO FM</td><td colspan="2">ILARO FM</td><td>SANDSTONE</td></tr>
<tr><td rowspan="2">OSHOSUN FM
EWEKORO FM</td><td colspan="2" rowspan="2">OSHOSUN FM
EWEKORO FM</td><td rowspan="2">SHALE
LIMESTONE</td></tr>
<tr><td>PALEOCENE</td></tr>
<tr><td rowspan="3">CRETACEOUS</td><td>MAASTRICHTIAN</td><td>ABEOKUTA FM</td><td rowspan="3">ABEOKUTA GROUP</td><td>ARAROMI</td><td>SHALE</td></tr>
<tr><td>TURONIAN</td><td rowspan="2"></td><td>AFOWO</td><td>SANDSTONE&SHALE</td></tr>
<tr><td>BARREMIAN</td><td>ISE</td><td>SANDSTONE</td></tr>
</table>

DATA REDUCTION AND ANALYSIS

Contoured aeromagnetic data over the Benin Basin have been compiled by the GSAN as a part of its country-wide geophysical survey data. The data were acquired along a series of NE-SW flight lines with a spacing of 2km and average flight elevation of 150m above terrain and a nominal tie line spacing of 20km. The geomagnetic gradient was removed using the International Geomagnetic Reference Field Formula (IGRF). The maps are published on a scale of 1:100,000.

After the reduction and analysis, prominent features and major tectonic trends were established which are believed to be landward extension of the trans-oceanic fracture zones. The regional gradients were removed by fitting a plane surface to the data by multi-regression least squares analysis. Figure 2 is the total field of the magnetic data presented as a contour map while the first to fourth degree regional and residual fields are shown in figures 3 and 4 respectively. Figures 5a and 5b are the zero contours and second vertical derivative maps of the study area.

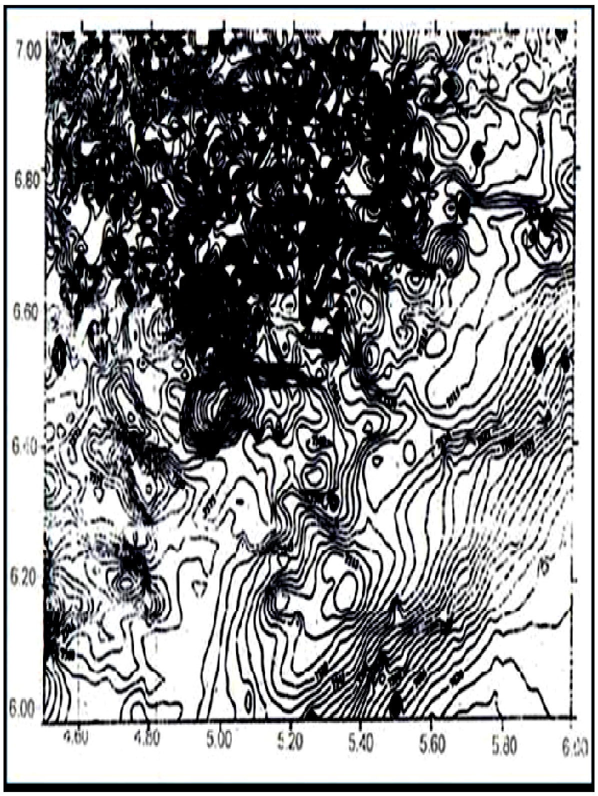


Figure2: Total field intensity map of the aeromagnetic data of the study area.

GEOLOGICAL INTERPRETATION OF RESULTS

Since the primary objective of this study is to identify structures expressed as lineaments and to classify them according to their spatial and directional attributes, it was necessary to process the aeromagnetic data in a manner that would both enhance trends and facilitate the computation of locations and depths to magnetic sources. Drainage pattern (linearity and parallelism of drainage networks), termination of potential field (gravity or magnetic) map anomalies on a linear trend, termination of drainage line on linear trends and straight stream segments were the basic hypothetical models used to map fractures. Lineaments can also be revealed on aeromagnetic maps by breaks in anomaly trends (lengthwise) and prominently narrow magnetic lows (broad wise) and sharp gradients of anomaly (Ajayi, etal, 1991).

Subsurface linear structures identified in the study area revealed features with dominant trend directions in the N-S and NE-SW, and to a lesser extent NW-SE and E-W directions. The N-S fractures in part of the study area especially around the Ilesha – Ife area are marked by considerable shearing and brecciations. The N-S fractures are gravity induced while the conjugate northeasterly and northwesterly sets which were products of transcurrent movements are characterized by wide zones of cataclastic deformation. The NE-SW and NW-SE conjugate sets are mostly strike- slip faults with the north easterly characterized by dextral sense of movement. The NE-SW is well developed in the study area. The E-W structures are localized in their occurrence and are revealed around Akure area. Similarly, drainage analysis revealed a predominance of parallel drainage pattern indicative of tectonic control of the basin and its drainage system. The trends of the drainage linears in the study area were correlated to the structural linears which revealed that drainage in the area are controlled by structures in the underlying Precambrian rocks of the Basement Complex (Onyedim, 1996).

Several clusters of circular anomaly closures with different amplitudes occur especially in the northwestern half of the area suggesting lithological variations of mafic –ultramafic inclusions within granodioritic batholiths. These anomalies are probably associated with banded iron ores and base metal sulphide bodies.In addition, the magnetic relief of the area is generally varied with regards to the types of the surface exposures of the basement rocks. This high magnetic relief is closely related to mafic-ultramafic rock masses in the area. These findings are in line with the second vertical derivatives of zero contours which indicated lithologic boundaries between the sedimentary formations and the basement. Similarly,the distribution of mafic and felsic rock forming

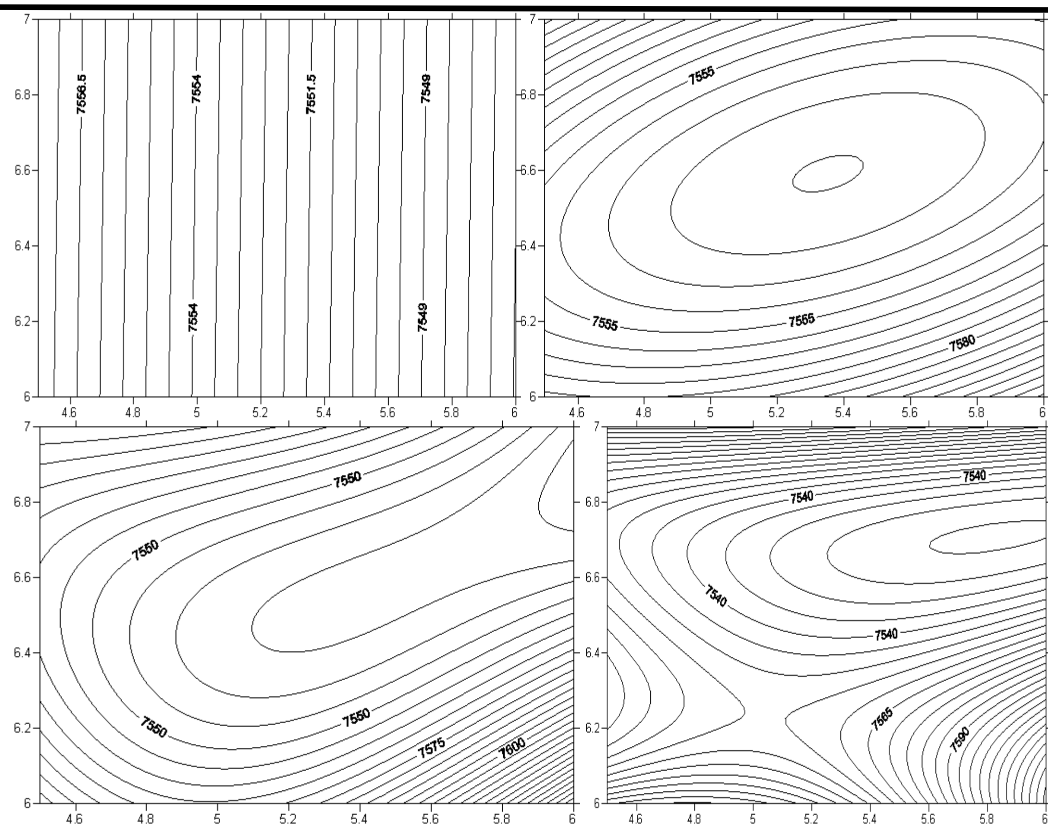


Fig.3: First to fourth degree regional fields of the aeromagnetic data of the study area.

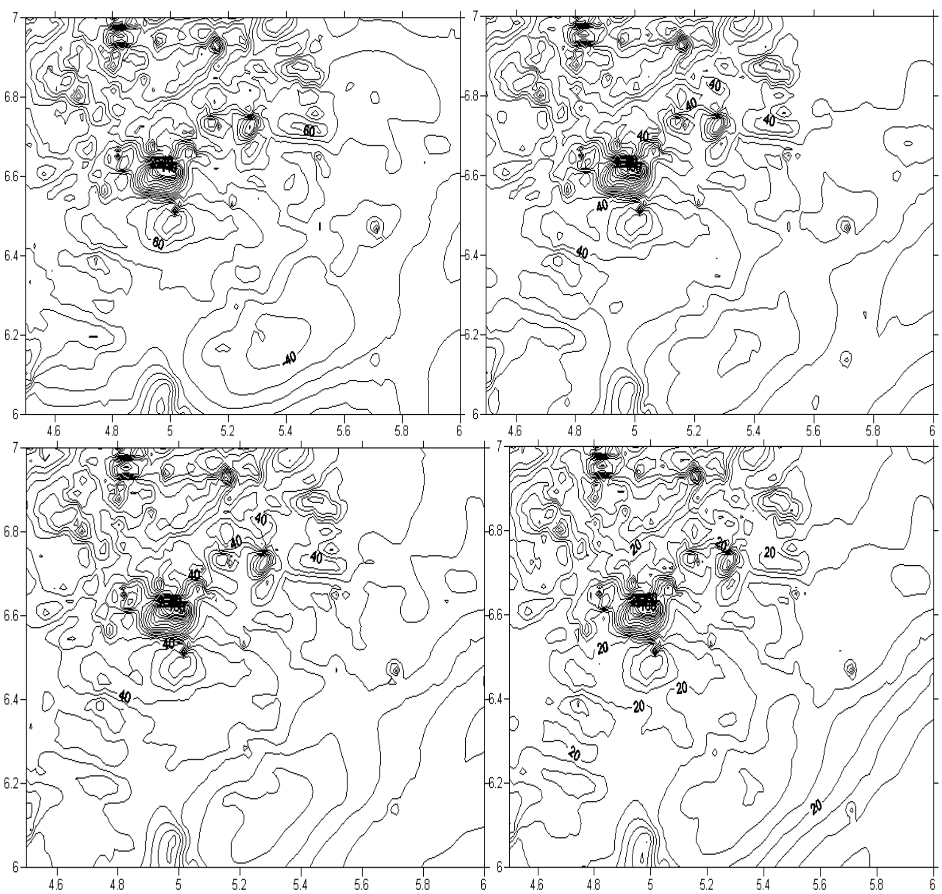
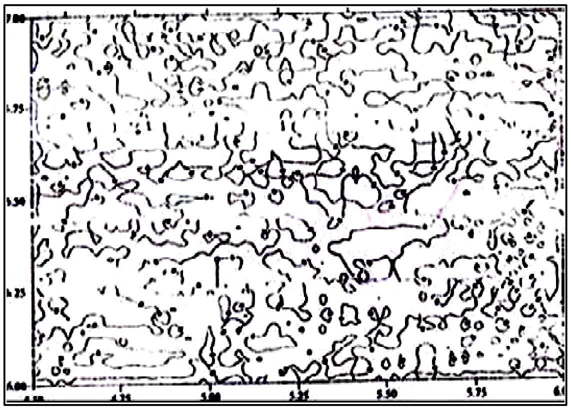
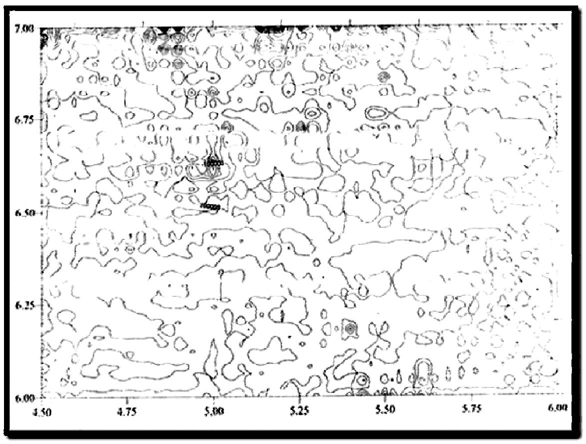


Fig.4. First to fourth degree residual fields of the aeromagnetic data of the study area



(a)



(b)

Fig.5 :(a) Zero contours of the second vertical derivatives (b) Second vertical derivative map of the aeromagnetic data of the study area.

minerals were correlated to the positive and negative second vertical derivative anomalies around Ilesha area (Figures5a&5b). These rocks are believed to be the by-products of the re-activation of the trans-oceanic fracture zones that also acted as conduits for primary mineralization. In the Ilesha district, the metasediments with the associated mafic –ultramafic rocks, are bordered by approximately N-S trending units of the gneiss-migmatite complex. The contacts may be tectonic, and marked by the development of cataclasites and mylonites (Elueze, 1982; 2000).Granites and pegmatites also intrude the migmatitic gneisses, the mafic – ultramafic bodies and the meta-sediments.(Olade and Elueze,1979).The mafic – ultramafic units include a variety of amphibolites and talc bearing bodies. Lithologies of the metasedimentary suite comprise quartzites and quartz, quartz-sericite/muscovite, quartz-chlorite/biotite and biotite – rich schists. Rocks with residual igneous textures are likewise encountered (Elueze, 2000).

The Benin basin has been interpreted as a divergent rift basin bounded by two trans-oceanic fracture zones: the Romanche Fracture Zone to the west and Chain Fracture Zone to the east. These paleo-structures trend approximately in the NE-SW direction .The western margin of the Benin Basin is widely believed to be formed by structures associated with the onshore extension of the Romanche fracture zone, the basin originating along the transform margin of the incipient Equatorial Atlantic Ocean(Omatsola and Adegoke,1981; Coker and Ejedawe,1987; Mascle et al,1988).At its eastern end a basement uplift, the Okitipupa ridge forms the boundary between the Benin Basin and the Niger Delta/Anambra Basin. The eastern margin of the ridge corresponds to the Benin Hinge Line of Murat (1972), which Omatsola and Adegoke (1981) regarded as the onshore extension of the Chain fracture zone.

DISCUSSION AND CONCLUSION

Four linear structures were revealed in the study area with the NE-SW and the N-S trending features been the dominant. However, the lesser developed and localized E-W and NW-SE features were mapped in some areas. The Benin basin has been interpreted as an embayment because the western boundary is fault – bounded by the Romanche fault and the eastern side by the Benin Hinge line (Okitipupa High).These paleo-structures trend approximately in the NE-SW direction. Infact, the Ilesha schist belt is divided into two distinct facies by a NE-SW trending Ifewara fault which outcrops in the extreme southeastern portion (Oluyide and Udoh, 1989). The NE-SW trending lineaments have been interpreted as an important zone of magmatic activity which tends to suggest that they are deep seated and may probably be related to the prolongation of the oceanic fracture system (Oluyide and Udoh, 1989). The possible triggering mechanisms of the Nigerian earth tremors are closely associated with the locations of the earth movements associated with NE-SW trending deep fractures and zones of weakness extending from the Atlantic Ocean into the country(Ajakaiye et-al, 1986). It is therefore believed that the re-activation of the Chain Fracture Zone may have induced some motion in the Ifewara fault within the Ife fault zone which in turn caused the earth tremors in Ijebu-Ode area in 1984. Along strike, the Benin Basin is subdivided into a number of horst and graben structures by N-S to NE-SW trending faults. Coker and Ejedawe (1987) recognized a western Benin Basin proper and an eastern Okitipupa structure. Ige et al inferred that N-S linear structures are dominant in part of the study area especially within the Lagos Graben.Onyedim,1996,mapped several linear structures in the study area which revealed three main systems of NNE-SSW, NE-SW and E-W and four minor systems in the ENE-WSW, WNW-ESE,NW-SE, and NNW-SSE directions. This variety of structural trends probably results from the interaction of two factors: pre-deformational anisotropies and external rotation and reactivation of the fractures. The presence of boundary faults in the Benin Basin and the correlation and alignment of the major intrusions into the basin with both the strike and trend of the basin makes it plausible that rifting and wrench faulting are possible origins of the basin. Furthermore, it is geologically plausible that the landward intersections of the transform zones may have influenced the formation of the river patterns and basin formation. Finally, the distribution of mafic and felsic rocks are believed to be the by-products of the re-activation of the trans-oceanic fracture zones that also acted as conduits for primary mineralization(which is very pronounced in the Ilesha district).

In conclusion, this present research is therefore in agreement with previous studies which suggested that

Nigeria has a complex network of fractures and lineaments with dominant trends of NW-SE, NE-SW, N-S and E-W directions. Similarly, the correlation of these lineaments with mineralization in the area has been ascertained by previous authors (Chukwu-Ike and Norman, 1997; Ananaba and Ajakaiye, 1987; Onyedim, 1996, 2007; Elueze, 1982; 2000; Udoh, 1988)

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