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Comparative Analysis of Fracture Lineaments in Oban and Obudu Areas, SE Nigeria

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Abstract

The Precambrian polycyclic basement terrains of Oban and Obudu in southeastern Nigeria contain a plethora of fractures, which on analysis fall into only four sets or trends. The most prominent fracture set in Oban Massif is the NNW-SSE, with a trend of 150^0-160^0 from the north. Others are NNE-SSW, E-W and NW-SE sets. The most prominent fracture set in Obudu is the NW-SE which trends 140-150^0 from north. Minor sets occur in the NNE-SSW, E-W and ESE-WNW directions. While E-W fractures are interpreted as 'ac' tensile or extension fractures, NE-SW and NW-SE fractures are shear fractures. The orientation difference of 10^0 between the major facture sets in Oban and Obudu is interpreted as the amount of fracture induced angular rotation between the two basement blocks, leading to the formation of the Ikom-Mamfe embayment. The most frequently occurring fracture length in both areas is ~ 2km, while the fracture frequency decreases exponentially as fracture length increases. This is depicted by the exponential relationship $n(l) = n_{oe}^{-kl}$. There appears to be compensation between fracture length and frequency, such that directions of long fractures have lower density and vice versa. Whenever fracture lineaments less than 5km are ignored in the Nigerian basement, it could represent over 60% loss of data in the analysis.

Keywords: fracture lineaments, fracture set, Oban massif, Obudu massif, lineament trend, remote sensing

1. Introduction

Satellite imagery, radar imagery and other airborne remote sensing techniques have been applied in the areas of mineral exploration (Chukwu-Ike & Norman, 1977; Norman et al., 1977; Ananaba & Ajakaiye, 1989), ground water studies and aquifer location (Edet et al., 1994) geologic and surface drainage studies (Okonny, 1984). Other applications are in air pollution studies (Shalimov, 1992), engineering geology and civil works (Alexander et al., 1974; Gelnett, 1975) and for an understanding of the structural geology and tectonic control on later geologic processes (Kowalik & Gold, 1976; Okonny, 1984).

In Nigeria, Chukwu-Ike and Norman (1977) used satellite imagery to establish a series of N-S trending lineaments, hundreds of kilometers in length, some of which pass through strong centers of mineralization. Some of those lineaments pass over basement, Cretaceous to Recent rocks, without change in orientation. That Okonny (1984) did not observe these N-S trending lineaments in Oban Massif and the eastern Niger Delta from radar imagery analysis may be for the simple reason that the lineaments were, in most cases, confined to the central part of the country. The lineament study of Nigeria done by Ananaba and Ajakaiye (1989) only covered parts of the country from latitude 8^0 northwards. The serious flaw in this study was that only lineaments greater than or equal to 5km were mapped from their satellite images. A lot of information, probably more than half of the structural data, was therefore lost in that study. The work of Ogunmola et al. (2008) over the Younger granite province of Nigeria, using Nigeriasat-1imagery, revealed abundant N-S, NW- SE and E-W- trending lineaments. These ranged in length from 0.8 to 13km. In eastern Nigeria Okonny (1984) studied the lineaments of Oban Massif and the adjoining Calabar Flank comparatively, using radar imagery. The work was technically flawed because all lineaments below 5km length were screened out, and by that well over 50% of the data was lost. This, however, did not prevent him from noticing a structural control of the basement lineaments on the sedimentary lineaments of the Calabar Flank. Iliya and Bassey (1993) used aeromagnetic data analysis over Oban and Obudu basement and adjoining sedimentary basins to locate fracture lineaments. Based on their anomaly trends, they concluded that there are no N-S-trending lineaments in Oban Massif, even though a thorough trend and dimensional analysis of all their inferred lineaments was not attempted. Edet et al. (1994) analysed the lineaments of Oban and Obudu basement areas with the aim of using lineament length density and lineament intersection density to delineate areas of aquifer potentials. Their rose diagrams showed the NW- SE as the strongest lineament trend, 2.5-5km as the most frequently occurring lineament lengths in both areas.

In this study the full range of fractures present is analysed in both Oban Massif and Obudu basement areas. The analysis is purely from a structural geological standpoint, while an attempt is made at inferring a causative stress, as well as the deformation that initiated the Ikom-Mamfe embayment.

2. Location and Geology of Study Areas

Both Oban Massif and Obudu basement area are located in Cross River State (Figure 1) in eastern Nigeria. They are both western extensions of the Adamawa plateau. Oban Massif is bounded between $8^0 02^1$ and $8^0 54^1$ E longitudes and Latitudes $5^0 00^1$ and $5^0 50^1$ N, while Obudu basement is located between $8^0 39^1$ and $9^0 29^1$E longitudes and $6^0 00^1$ to $6^0 45^1$N latitudes. While Oban hills are located in the former, Obudu plateau and cattle ranch are located in the latter area (Figure 1).

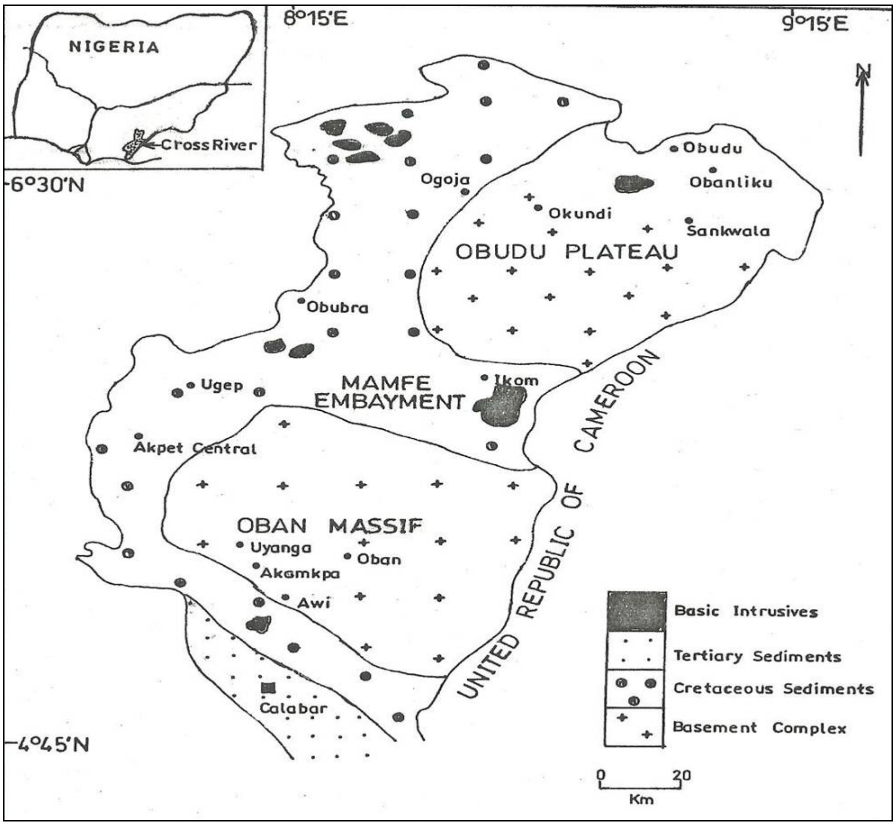

Figure 1. Map of Cross River State showing the basement complex areas, inset mep of Nigeria

Exposed in both basement areas are crystalline rocks from phyllites to amphibolites, charnockite and other igneous intrusives. While phillites and schist enclaves are more extensive in Oban Massif, especially in the western part, the eastern part is more dominantly migmatite gneiss and granite gneiss country (Ekwueme, 1990). Western Oban Massif is also dominated by a syntectonic granitoid-Uwet granodiorite (Ekwueme & Nganje, 2000; Rahman et al. 1981).

Obudu basement area is dominantly a gneissose terrain with several igneous intrusives. The dominant gneisses are migmatite gneiss, pyroxene gneiss, biotite granite gneiss, garnet hornblende gneiss and garnet sillimanite gneiss. The schist enclaves are very limited, while phyllites have not been reported in this environment yet. This, in association with the presence of extensive charnockites and granulites, give the impression that Obudu basement might have exposed rocks at a somewhat deeper crustal level than Oban Massif (Ekwueme, 2003, Ukwang et al., 2003).

3. Materials and Methods

3.1 Lineament Data Acquisition

The lineament map covering Oban and Obudu basement areas has been published by the Cross River Basin and Rural Development Authority (CRBRDA), Calabar, in Nigeria, on a scale of 1:250,000. This was complied by both Nigerian and German consultants using Landsat CCTS of 1972-1978, Radar mosaic data of Nigeria on a scale of 1:250,000, from the Federal Department of Forestry; geological Maps on 1:250,000 from the Nigerian Geological Survey Agency as well as topographic maps from the Federal Surveys Department of Nigeria. This map shows the detailed disposition of fracture lineaments in both sedimentary and basement complex terrains covering Cross River and Akwa Ibom States of Nigeria. It was prepared as an aid for groundwater exploration by CRBRDA, a statutory body of the Federal Government of Nigeria.

To evaluate the lineament Maps (Figures 2 and 3), black and white, aerial photographs of western Oban massif (Uyangha-Iwuru-Akwa Ibami area) and Obudu SE were studied using stereoscopes for fracture lineaments. The fractures obtained there from compared very well in length and orientation with those in Figures 2 and 3, which were published by CRBRDA.

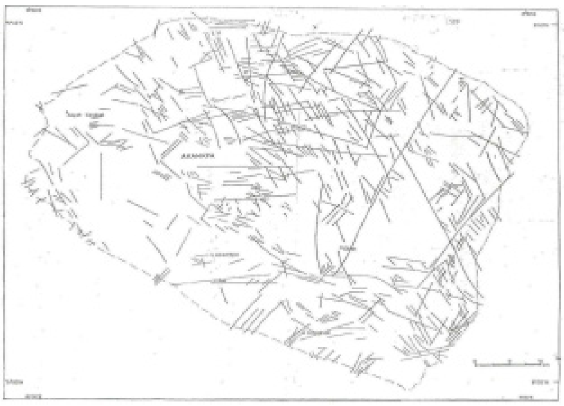

Figure 2. Fracture lineament map of Oban massif

Figure 3. Fracture lineament map of Obudu basement area

3.2 Fracture Trace Analysis

As shown in Figures 2 and 3, many of the fractures that are close to the border actually project over it into the adjoining sedimentary cover, without change in trajectory. That fracture orientation in the sedimentary Calabar flank south of Oban massif is similar to or follows that in the basement complex was demonstrated by Okonny (1984). There are generally two types of curved fractures in the two basement areas: those that appear smooth and to be part of a circle of large radius and those with a discernible kink. While the former may be related to the presence of intrusive bodies (Norman et al., 1977), the latter were treated as two distinct fractures meeting at the kink. It was very difficult to infer faults from the lineament maps, neither was it any easier during subsequent fieldwork on account of the thick forest canopy. This, notwithstanding, it is very likely that some of the lineaments are indeed faults. Altogether 688 fracture traces were analysed in Oban basement area, varying in length from 0.5 to 54km, while Obudu basement produced 581 traces ranging from 0.5 to 37km in length.

4. Results

4.1 Fracture Orientation

Figure 4 shows about four fracture sets in Oban massif, the most prominent of which is the NNW-SSE trend-150-160^0 from N. Minor sets occur in the NNE-SSW (20^0-40^0 from N), E-W (70^0-90^0), and NW-SE (120^0-130^0). Obudu basement area (Figure 5) also shows four fracture sets, with the NW-SE set (140^0- 150^0 from N) being the most prominent. Minor sets trend in the NNE-SSW (20^0-50^0 from N), E-W (70^0-90^0) and ESE-WNW (110^0-120^0 from N).

Four aspects of the fracture orientations of these basement areas are interesting and remarkable.

1) The strength of the NW-SE main fracture set.

2) The relative orientations of the main set in the two basement areas.

3) The presence of only four fracture sets in each basement complex area which is said to be polycyclic.

4) The presence of E-W trending fractures.

The presence of NE-SW, NW-SE and E-W fractures, joints, faults and dykes has been reported in the Pan-African basement by Ball (1980), Okonny (1984), Ike (1988), Oluyide (1988), Edet et al. (1994). Ananaba and Ajakaiye (1989) reported one major fracture trend in the NNE-SSW, mainly because they screened out all lineaments less than 5km in length.

The strength of the NW-SE trend compared to the other orientations was also reported by Ike (Op. cit.) and *Edet* et al. (op.cit.), without any explanation. In an analysis of preferred orientation of phenocrysts of a porphyritic granitoid in Oban Massif, Oden (in prep.) also noticed a high tendency for these megacrysts to align in the NW-SE direction. From all these indications, the NW-SE trend was a preferred shear direction during the Pan-African orogeny.

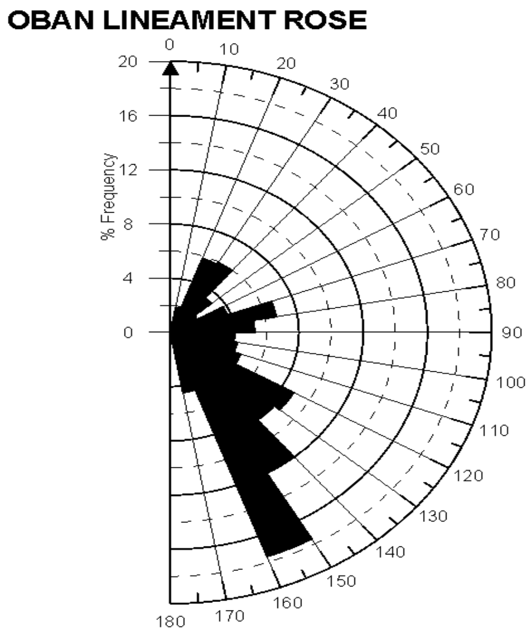

Figure 4. Rose diagram of fracture lineaments in Oban massif (688 data points)

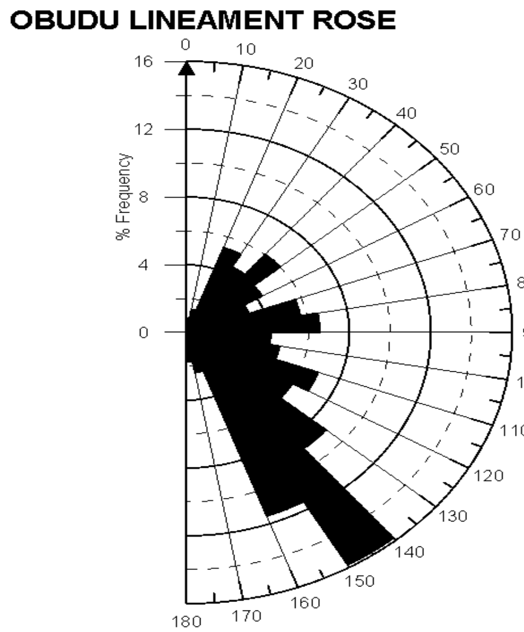

Figure 5. Rose diagram of fracture lineaments in Obudu basement area (581 data points)

The major lineament trend in Oban area is that between N150^0 to 160^0 (Figure 4). This same trend is between N140^0-150^0 in Obudu area (Figure 5). The orientation difference of 10^0 between the two trends is interpreted as probably the angle of block rotation between the two areas, leading to the formation of the Ikom -Mamfe embayment (Iliya and Bassey, 1993). The presence of only four fracture sets in each basement area, given that the Nigerian basement has been exposed to many deformation episodes, is another interesting result of this investigation. The Nigerian basement has been reworked at least four times in the Precambrian (Ajibade et al. 1988). These were the Liberian (~ 2,700my), the Eburnean (~ 2,000my), the Kibaran (~ 1,100my) and the Pan-African (600 ± 150my). Ekwueme (1988, 1990) obtained ages of 1,289 ± 153my and 1313 ± 37my from charnockites and homogeneous amphibolite, respectively, from Oban massif. He considered these as Kibaran ages. Other rock types like kyanite gneiss, kyanite -sillimanite schist and banded amphibolite from the same area, gave generally Pan-African ages. In response to Nur's (1982) question-"why are the directions and number of (fracture) sets so few?" one would imagine that either a lot of "healing" of older fractures takes place in subsequent deformations or they are simply closed as stress configurations change. The presence of E-W fractures is not surprising because in this configuration they are the trajectories of the maximum principal stress during the Pan-African deformation (Ball, 1980). These are therefore the "ac" tensile fractures or extension fractures (Muehlberger, 1961; Price, 1966; Engelder & Geiser, 1980; Ike, 1988). Oluyide (1988) commented that these fractures have a localized occurrence and he presumed that they are the oldest (?). Fractures of N-S orientation are weakly developed in Oban and Obudu basement areas. This was also noticed by Okonny (1984), Iliya and Bassey

(1993) and Edet et al. (1994), despite the fact that Oluyide (Op. cit.) as well as Chukwu-Ike and Norman (1977) reported the presence of spaced major N-S lineaments in the Nigerian basement complex. It is therefore possible that the N-S lineaments are restricted in occurrence to some parts of the country.

4.2 Sectorial Lineament Analysis

For a better understanding of the sectoral distribution of lineament numbers and lengths from the population of lineament data, Table 1 was compiled. Four sectors were considered, each of 40^0 Span, hence there are N-S, NE-SW E-W and NW- SE sectors. In both Oban massif and Obudu area, the N-S sector has the lowest number and lowest total sector length of lineaments, while the NW-SE sector has the highest number and the highest total sectoral length. The NE-SW and E-W sectoral data fall in between these two extremes. On the other hand average unit length of lineaments is highest for the N-S sector and lowest for the NW-SE sector, in both areas. This factor is obtained by dividing the total length of all lineaments in each sector by the number of lineaments in that sector. As usual the NE-SW and E-W sectors fall between the two extremes.

Table 1. sectorial distribution of lineament numbers or density and lengths

	N-S 0^0-20^0;160^0- 180^0	**NE-SW** 30^0- 60^0	**E-W** 70^0-110^0	**NW-SE** 120^0-160^0
	OBAN			
Number of lineaments (a)	53	103	138	322
% of total Number	7.70	14.97	20.06	46.80
Length of lineaments (km) (b)	272	398.5	641.25	1170.25
% of total length.	9.59	14.06	22.62	41.28
Average length (b/a)km lin.	5.13	3.87	4.65	3.63
	OBUDU			
Number of Lineaments (a)	37	105	122	246
% of total Number	6.37	18.07	20.10	42.34
Length of lineaments (km) (b)	369	729.75	844.75	1045.50
% of total length	10.42	20.62	23.86	29.54
Average length (b/a) Km/lin.	9.97	6.95	6.92	4.25

In both areas under consideration, there appears to be a compensating mechanism between fracture length and density or intensity. The sector with low fracture intensity is sort of compensated with higher fracture length, and vice versa. This inverse relationship is expressed graphically in Figure 6, where average sectoral length of lineaments is plotted against sectoral percentage of total number of lineaments (data from Table 1). The slopes of the two graphs are slightly different, that of Obudu area being steeper than that of Oban massif. Figures 7 and 8 show the variations of average length of fractures as a function of trend of lineaments. In both areas lineament average lengths are lowest for the NW-SE (120-150^0 from N), while the same parameter is highest for lineaments of approximately N-S trend.

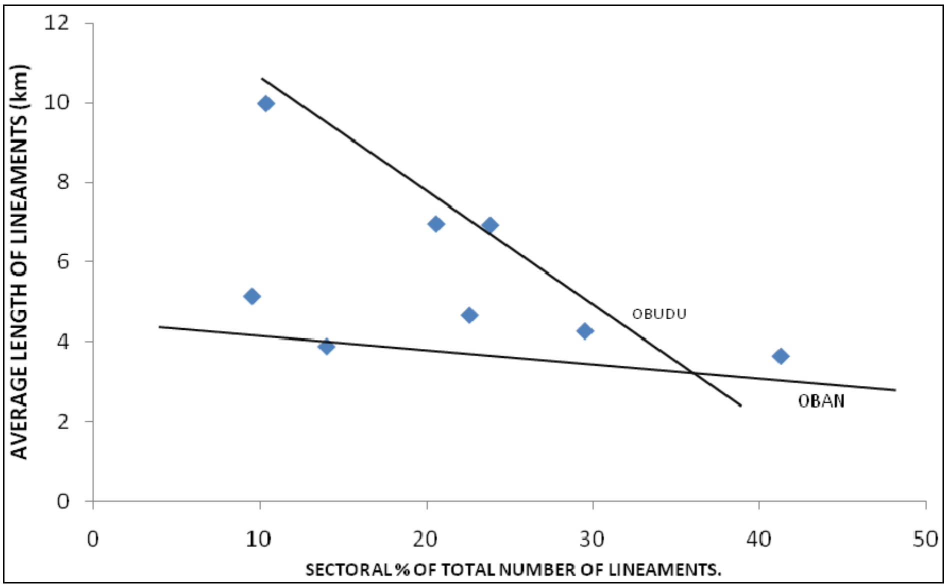

Figure 6. Graph of average length of lineaments against sectoral percentage of tatal number of lineaments (data from Table 1)

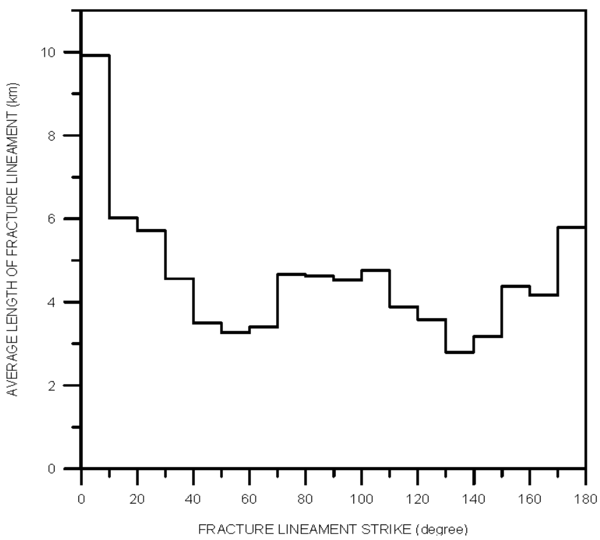

Figure 7. Histogram showing variation of average length of fracture lineament against fracture orientation in Oban massif

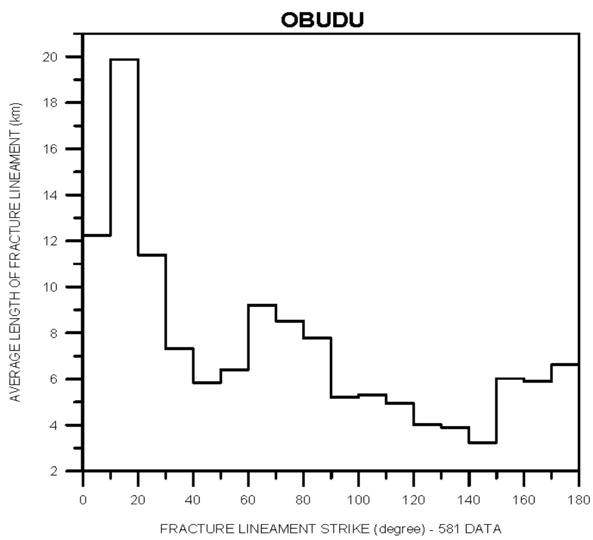

Figure 8. Histogram showing variation of average length of fracture lineament against fracture orientation in Obudu area

4.3 Lineament Length Frequency and Decay

The most frequently occurring lineament length (Figures 9 and 10) is between 1.50 and 2.50km (approximately 2km). This is common to both Oban massiff and Obudu area, and is interpreted as the fracture length that equilibrated with the regional stress during the deformation episode (Price, 1966). Percentage allocation of total lineament budget is leanest for the N-S sector and highest for the NW-SE sector in both areas, while average lineament length is higher in the N- S sector than the NW-SE sector. The NE-SW and E-W sectors fall in between the two extremes. Lineament average lengths are lowest for the NW-SE (120-150^0 from N), while the same parameter is highest for lineaments of approximately N-S trend).

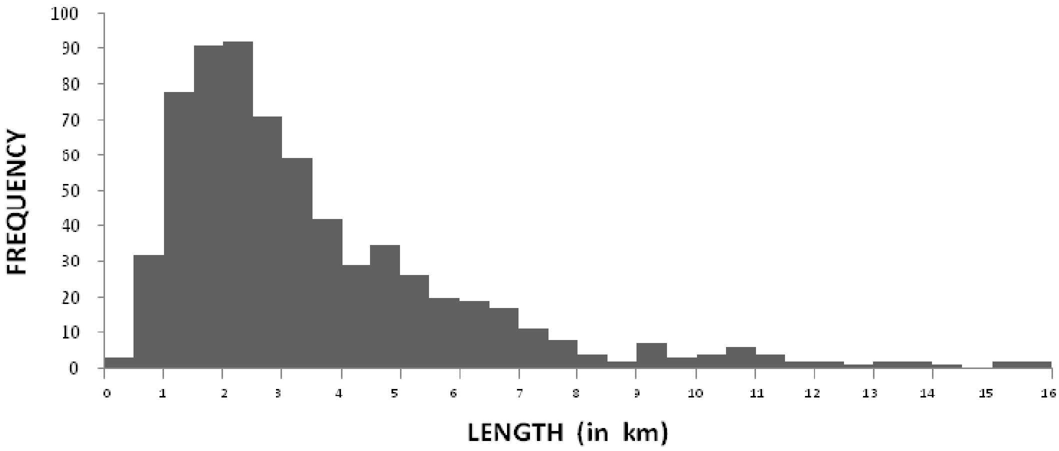

Figure 9. Histogram of lineament lengths (Oban massif). The most frequently occuring lineament lengths are 1.5-2.5 km, giving an average of 2.0 km

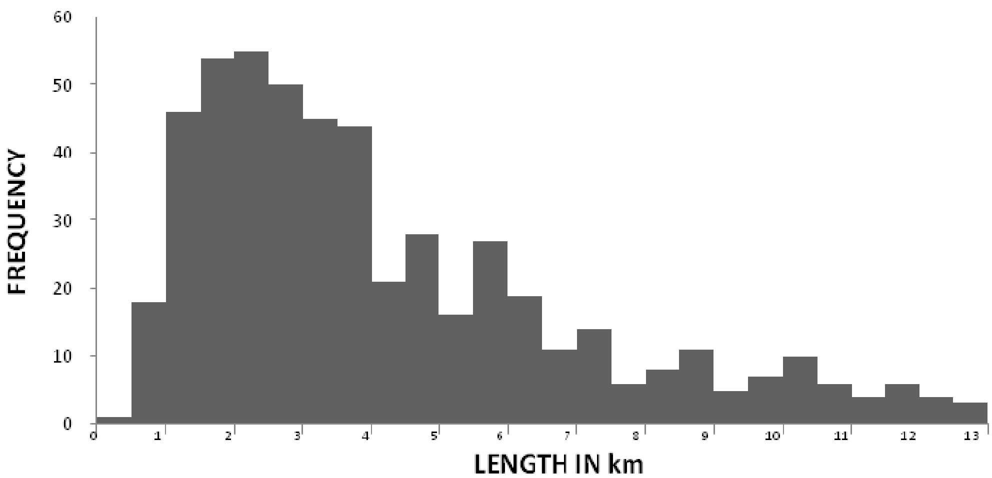

Figure 10. Histogram of lineament lengths (Obudu area). The most frequently occurring lineament lengths are 1.5-2.5 km, giving an average of 2.0 km

In Okonny's (1984) lineament study of Oban massif, all lineaments less than 5km in length were disregarded. This, as shown in Figure 9, represents a loss of about 77% and the most vital part of the data. In Obudu area, a 5km length cut-off would amount to a loss of 62% of the data, as well as the most vital aspect of the lineament distribution. In both basement areas, the lineament frequency decay is an exponential function of the length (Figures 11 and 12). The equations that best fit the data from Oban massif are of the form:

$$Y = 138.55e^{-0.1566x} \tag{1}$$

For the exponential model (Figure 11) or for the polynomial model:

$$Y = -0.0002x^4 + 0.0092x^3+0.1283x^2-9.9441x+113.78 \tag{2}$$

Similar relationships for Obudu area are of the form:

$$Y = 102.05_e^{-0.129x} \tag{3}$$

for the exponential model (Figure 12) or

$$y = -7E\text{-}05x^4 + 0.001x^3 + 0.2046x^2 - 7.9199x + 88.011 \tag{4}$$

for the polynomial model.

Equations 2 and 4 are polynomials of the 4th degree, which are also called quartic expressions (Stroud and Booth, 2001). The difference between these two equations has to do with difference in length distribution, of the maximum frequency as well as the range of fracture lengths on the decreasing side of the distribution. Equations 1 and 3 are of the form:

$$n(L) = noe^{-kl} \quad (5)$$

Which was proposed by Nur (1982), to fit the data set of Kowalik and Gold (1976) from the basement of Pennsylvania, USA. In equation 5 both no and k are constants within a given area, and they vary from 138.55 to 102.05 for no and-0.1566 to-0.129 for k, going from Oban massif to Obudu basement area. The constant k is similar in effect to the decay constant in radioactivity. Although small in value, the more negative it is the faster the representative curve approaches the x-axis. n(l) and l represents y and x variables respectively, of equations 1 and 3. It is possible that equation 5 is the best fit expression for fracture frequency/length distributions in the crystalline basement areas of the world, irrespective of tectonic regimes responsible for them.

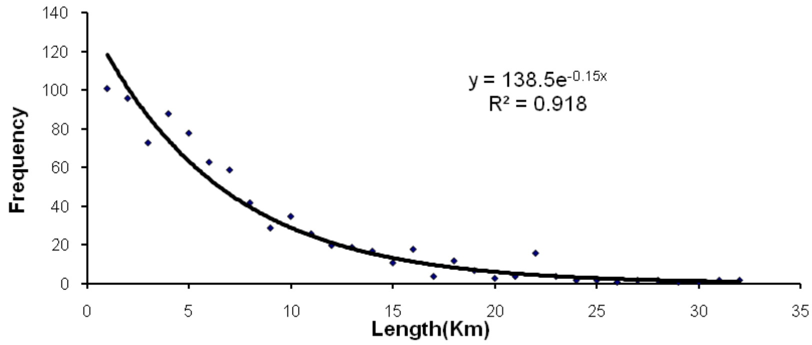

Figure 11. Graph of fracture length against frequency. Oban massif (from Figure 9). Note the negative exponential behaviour of frequency as fracture length increases

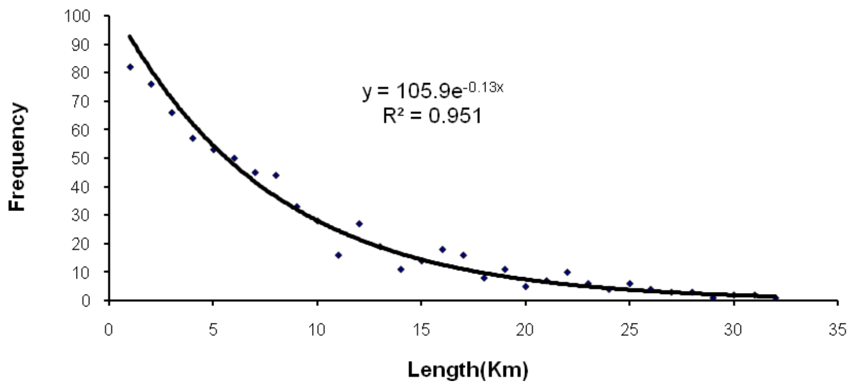

Figure 12. Graph of fracture length against frequency. Obudu basement area (from Figure 10). Note the negative exponential behaviour of frequency as fracture length increases

4.4 Joint Dips in Oban Massif

During subsequent field visits a number of structural measurements were made, including strike and dip of joints, in Oban massif and Obudu area. Figures 13(a), (b) and (c) show the variation of dip values of joints in schist, gneiss and granodiorite in Oban massif. Dip angles in schist are characteristically high, the most frequent values range from 70^0 to 90^0 (Figure 13a). The most frequently occurring joint dip values in gneiss range from 70^0 to 80^0 (Figure 13b), while those in granodiorite range from 60^0 to 80^0, but occur mostly around 60^0 to 70^0. The impression presented by these structures is that these discontinuities (fractures, joints and faults) do not maintain the same angle of dip from surface down to rock fusion depths. They are steeper close to the surface, and flatten gradually with depth. This could be due to the effect of increasing confining pressure which tends to increase the fracture angle (θ) (Wawersik & Fairhurst, 1970; Baidyuk, 1963; Paterson, 1978; Jaeger & cook, 1976). In the development of a model for spacing, opening and depth of tensile fractures, Nur (1982) showed that tensile fractures become fewer as they attain greater depths, but he assumed that such fractures maintain the same trajectories, without change in dip with depth. The latter assumption is not supported by our field observations.

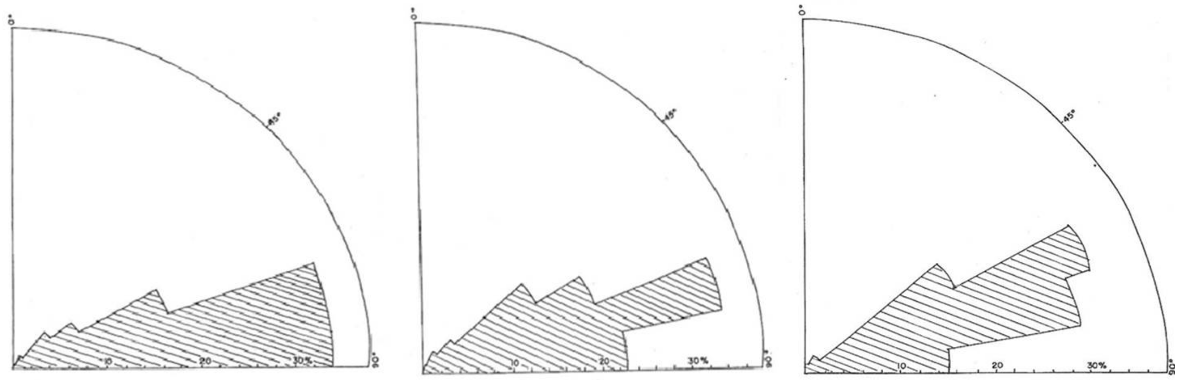

Figure 13. Showing joint dips in Oban Massif: A, in schist (373 data points);
B, in gneisses (230 data points); C, in granodiorite (191 data points)

4.5 Orientations of Barite Veins in Western Oban Massif

Barite mineralization occurs in the Cretaceous sandstones close to, as well as in the phyllites and schists of the basement complex around Akpet in western Oban massif (Figure 2). The mineral veins in both terrains are thought to be of the same age and were formed when the Cretaceous sediments covered much more of the basement area. The most preferred orientation of the veins is in the NW-SE, between 140^0 to 170^0 from N. These Cretaceous barite veins might have used some fractures of Precambrian age, reworked during one of the Cretaceous deformation episodes that affected the Benue Trough. The reworking processes which started from the basement complex also affected the Cretaceous sedimentary cover. It is interesting to note that although there were other fracture sets in the basement at that time (Figure 4), only part of the NW-SE set was probably reworked and then mineralized. The other sets remained passive or closed during the first Cretaceous deformation episode.

5. Discussion

Rock fracturing is not a random process; rather it is associated with the laws of mechanics and the prevailing environmental conditions (Aydan & Kawamoto, 1990). Consequently the spatial distributions of fractures in rock bodies are bound to be in sets and in relation to the stress configurations that produced them. Although much of the cover rocks of both Oban massif and Obudu area have been removed by weathering and erosion, it is obvious that the phyllites and schists were deformed dominantly by brittle fracturing, while the migmatite gneisses and granitic rocks were deformed dominantly by ductile processes, leading to ductile fracturing (Suppe, 1985). Under laboratory conditions, deforming rocks tend to exhibit one major shear plane at failure when low values of confining pressure are applied (Jaeger & Cook, 1976, Wawersik & Fairhurst, 1970). This type of shear failure is close to the one exhibited in Figures 4 and 5. The orientation difference between the main trend (NW-SE) in Figure 4 and that in Figure 5 is about 10^0. Because this is a major trend, it is interpreted that the Oban massif probably went through a 10^0, fracture induced clockwise, block rotation, with respect to the Obudu block. This must have lead to the development of the E-W-trending Ikom-Mamfe embayment, a Cretaceous sedimentary basin that straddles the Nigeria-Cameroun boarder (Figure 1). That such major fractures exist beneath the Cretaceous cover in the embayment is indicated by the presence of a large number of quite extensive igneous bodies, like Ikom basalt, Obubra dolerite, Ogurude gabbro, etc. (Ugbaja, 2007; Okpamu, 2008), on the Nigerian side, as well as the basalt of Bakwelle, and the granitic plutons north and south of Mamfe, etc; all in Cameroun (Wilson, 1928; Ndougsa-Mbarga et al., 2007).

Gudmundsson (1983) derived an inverse relationship between fracture length and the tensile stress that produced it. From this it could be inferred that the same stress magnitudes (regional compressive and tensile) affected both Oban and Obudu basement areas and equilibrated with the most frequently occurring fracture length of ~ 2km.This might also be the most frequently occurring fracture length in the entire Pan-African basement. Kowalik and Gold

(1976) used LANDSAT imagery to study fracture lineaments over the folded and fractured basement rocks of Pennsylvania (USA). They obtained a most frequently occurring fracture length of 7 to 8km (approx. 7.5km) and an exponential dependence of the fracture frequency on fracture length (see also Nur, 1982), similar to Figures 11 and 12. This leaves one with the question: Is fracture frequency decay always an exponential function of the fracture length or does this apply only to the crystalline basement?

The fluid-assisted reworking of Precambrian basement fractures during the Cretaceous period produced the barite veins around Akpet area. Only those fractures parallel to the new orientation of maximum compression were opened. That is the barite veins were trajectories of the maximum compressive stress at the time of opening (Engelder & Geiser, 1980). Large quantities of fluids must have been involved, given the very low solubility of barium sulphate in water (Price & Cosgrove, 1990) even to produce thin veins. While this preferential reworking affecting only NW-SE fractures was going on, the other fracture sets in the basement remained closed or passive.

6. Conclusion

The fracture lineaments of Oban massif and Obudu basement area fall naturally into four principal sets, with the NW- SE set being most dominant. Although the N-S trend is not a direction of preferred fracture orientation, the few fractures with this trend tend to be longer than others. In the same vein, fractures of the NW -SE (shear) set, although great in number, are relatively shorter. There is a 10^0 disorientation of the main fracture set (NW-SE) between Oban massif and Obudu basement area, which is interpreted as the amount of block rotation done by the former against the latter basement block. This rotation is thought to have created the Ikom-Mamfe basin, producing deep fractures along which magmatic fluids moved upwards during the Cretaceous period. The most frequently occurring fracture length in both basement areas is about 2km and the fracture frequency decrease is exponential as length increases. It is clear from this that rejecting or neglecting fractures less than 5km in any analysis in the Nigerian basement would create a very substantial loss of information, which might even render such an investigation a wasted effort.

Field studies in Oban massif show that joints do not maintain constant dip trajectories. They have higher angles of dip close to the surface than at depth. Also there was a period of fluid-assisted reworking of basement fractures in western Oban massif. Only fractures of NW-SE trend were reworked, resulting in the deposition of barite as veins in that orientation, during the Cretaceous period. From all indications Oban massif and Obudu basement formed one continuous land mass in the Precambrian and deformed as such during the Pan- African orogeny. They were only separated during the Cretaceous period with deposition of sediments in the Ikom-Mamfe embayment.

As a follow up to this investigation, it is suggested that three vertical seismic profiles should be run across the embayment: one near Manife in the Cameroun, and others near Ikom and Obubra in Nigeria. Such profiles should be run along north-south lines, and each should cover the entire width of the basin. This type of investigation would reveal the deep structure of the basin, the sediment load as well as give some information on its petroleum prospects.

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